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Appendix 1

HDR, Illinois Power Generating Company; Primary Ash Pond Construction Permit Application (July 28, 2022)

Electronic Filing: Received, Clerk's Office 07/01/2024

Luminant

Illinois Power Generating Company
1500 Eastport Plaza Dr.
Collinsville, IL 62234

July 28, 2022

Illinois Environmental Protection Agency
DWPC – Permits MC #15
Attn: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Re: Newton Power Plant Primary Ash Pond; IEPA ID # W0798070001-01

Dear Mr. LeCrone:

In accordance with 35 I.A.C. § 845.200, Illinois Power Generating Company (IPGC) is submitting a construction permit application for the Newton Power Plant Primary Ash Pond (IEPA ID # W0798070001-01). One hardcopy is provided with this submittal.

The permit application was prepared in accordance with 35 I.A.C. § 845.220 (a) and (d). This submittal includes the completed permit forms as required by § 845.210.

Sincerely,

Cynthia Vodopivec
SVP-Environmental Health and Safety

Enclosures

Form CCR 1	Illinois Environmental Protection Agency CCR Surface Impoundment Permit Application Form CCR 1 – General Provisions

Bureau of Water ID Number:
W0798070001
CCR Permit Number:
Initial Permit
Facility Name:
Newton Power Plant

For IEPA Use Only

SECTION 1: FACILITY, OPERATOR, AND OWNER INFORMATION (35 Ill. Adm. Code 845.210(b))

Facility, Operator, and Owner Information

1.1	Facility Name		
	Illinois Power Generating Company - Newton Power Plant		
1.2	Illinois EPA CCR Permit Number (if applicable)		
	Initial Permit		
1.3	Facility Contact Information		
	Name (first and last) Phil Morris	Title Senior Director - Environmental	Phone Number 618-343-7794
	Email address phil.morris@vistracorp.com		
1.4	Facility Mailing Address		
	Street or P.O. box 1500 Eastport Plaza Dr		
	City or town Collinsville	State IL	Zip Code 62234
1.5	Facility Location		
	Street, route number, or other specific identifier 6725 North 500th Street		
	County name Jasper	County code (if known)	
	City or town Newton	State IL	Zip Code 62448
1.6	Name of Owner/Operator		
	Illinois Power Generating Company		

Facility, Operator, and Owner Info

1.7 Owner/Operator Contact Information

Name (first and last)	Title	Phone Number
Phil Morris	Senior Director - Environmental	618-343-7794

Email address: phil.morris@vistracorp.com

1.8 Owner/Operator Mailing Address

Street or P.O. box: 1500 Eastport Plaza Dr

City or town	State	Zip Code
Collinsville	IL	62234

SECTION 2: LEGAL DESCRIPTION (35 Ill. Adm. Code 845.210(c))

Legal Description

2.1 Legal Description of the facility boundary

See Attachment A.

SECTION 3: PUBLICLY ACCESSIBLE INTERNET SITE REQUIREMENTS (35 Ill. Adm. Code 845.810)

Internet Site

3.1 Web Address(es) to publicly accessible internet site(s) (CCR website)

www.luminant.com/illinois-ccr

3.2 Is/are the website(s) titled "Illinois CCR Rule Compliance Data and Information"

☑ Yes ☐ No

SECTION 4: IMPOUNDMENT IDENTIFICATION

Impoundment Identification

4.1 List all the impoundment identification numbers for your facility and check the corresponding box to indicate that you have attached a written description for each impoundment.

W0798070001-01 (see Attachment A)	☑	Attached written description
	☐	Attached written description
	☐	Attached written description
	☐	Attached written description
	☐	Attached written description
	☐	Attached written description

			☐	Attached written description
			☐	Attached written description
			☐	Attached written description
			☐	Attached written description

SECTION 5: CHECKLIST AND CERTIFICATION STATEMENT

Checklist and Certification Statement

5.1 In Column 1 below, mark the sections of Form 1 that you have completed and are submitting with your application. For each section, specify in Column 2 any attachments that you are enclosing.

Column 1		Column 2	
Section 1: Facility, Operator, and Owner Information	☑	w/attachments	☐
Section 2: Legal Description	☑	w/attachments	☑
Section 3: Publicly Accessible Internet Site Requirement	☑	w/attachments	☐
Section 4: Impoundment Identification	☑	w/attachments	☑

5.2 **Certification Statement**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Name (print or type first and last name) of Owner/Operator	Official Title
Cynthia Vodopivec	SVP - Environmental
Signature: Cynthia S. Vodopivec	Date Signed: 7-18-2022

Form 2CC	Illinois Environmental Protection Agency CCR Surface Impoundment Permit Application Form CCR 2CC – Closure Construction

Bureau of Water ID Number:
W0798070001

CCR Permit Number:
N/A

Facility Name:
Newton Power Plant

For IEPA Use Only

SECTION 1: DESIGN AND CONSTRUCTION PLANS (35 Ill. Adm. Code 845.220)

Design and Construction Plans (Construction History)

1.1	CCR surface impoundment name.
	Primary Ash Pond
1.2	Identification number of the CCR surface impoundment (if one has been assigned by the Agency).
	N/A
1.3	Describe the boundaries of the CCR surface impoundment (35 Ill. Adm. Code 845.210 (c)).
	Attachment A and C
1.4	State the purpose for which the CCR surface impoundment is being used.
	Attachment C
1.5	How long has the CCR surface impoundment been in operation?
	Attachment C
1.6	List the types of CCR that have been placed in the CCR surface impoundment.
	Attachment D

Design and Construction Plans (Continued)

1.7	List the name of the watershed within which the CCR surface impoundment is located.	
	Attachment C	
1.8	What is the size in acres of the watershed within which the CCR surface impoundment is located?	
	Attachment C	
1.9	Check the corresponding boxes to indicate that you have attached the following:	
	☑	A description of the physical and engineering properties of the foundation and abutment materials on which the CCR surface impoundment is constructed.
	☑	A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR surface impoundment.
	☑	A statement of the method of site preparation and construction of each zone of the CCR surface impoundment.
	☑	A statement of the approximate dates of construction of each successive stage of construction of the CCR surface impoundment.
	☑	Drawings satisfying the requirements of 35 Ill. Adm. Code 845.220(a)(1)(F).
	☑	A description of the type, purpose, and location of existing instrumentation.
	☑	Area capacity curves for the CCR impoundment.
	☑	A description of each spillway and diversion design features and capacities and provide the calculations used in their determination.
	☑	The construction specifications and provisions for surveillance, maintenance, and repair of the CCR surface impoundment.
1.10.1	Is there any record or knowledge of structural instability of the CCR surface impoundment?	
	☐ Yes	☑ No
1.10.2	If you answered yes to Item 1.10.1, provide detailed explanation of the structural instability.	

SECTION 2: NARRATIVE DESCRIPTION OF THE FACILITY (35 Ill. Adm. Code 845.220)

Narrative Description

2.1	List the types of CCR expected in the CCR surface impoundments.			
	Attachment D			
2.2	Have you attached a chemical analysis of each type of expected CCR?			
	☑	Yes		
2.3	Estimate of the maximum capacity of the surface impoundment in gallons or cubic yards.			
	Section 2.2			
2.4	The rate at which CCR and non-CCR waste streams currently enter the CCR impoundment in gallons per day and dry tons.			
	Section 2.2	GPD	Section 2.2	dTn
2.5	Estimate length of time the CCR surface impoundment will receive CCR and non-CCR waste streams.			
	Section 2.2			
2.6	Have you attached an on-site transportation plan that includes all existing and planned roads in the facility that will be used during the operation of the CCR surface impoundment?			
	☑	Yes		

SECTION 3: MAPS (35 Ill. Adm. Code 845.220)

Maps

3.1	Check the corresponding boxes to indicate that you have attached the following maps:	
	☑	A site location map on the most recent United Sates Geological Survey (USGS) quadrangle of the area from the 7 ½ minute series (topographic) or on another map whose scale clearly shows the information required in 35 Ill. Adm. Code 845.220(a)(3).
	☑	Site plans maps satisfying the requirements of 35 Ill. Adm. Code 845.220(a)(4).

SECTION 4: ATTACHMENTS

Attachments

4.1	Check the corresponding boxes to indicate that you have attached the following:	
	☑	A narrative description of the proposed construction of, or modification to, a CCR surface impoundment and any projected changes in the volume or nature of the CCR or non-CCR waste streams.
	☑	Plans and specifications fully describing the design, nature, function, and interrelationship of each individual component of the facility.
	☑	The signature and seal of a qualified professional engineer.
	☑	Certification that the owner or operator of the CCR surface impoundment completed the public notification and public meetings required under 35 Ill. Adm. Code 845.240.

Attachments (Continued)		☑	A summary of the issues raised by the public during the public notification and public meetings.
		☑	A summary of any revisions, determinations, or other considerations made in response to those issues raised by the public during the public notification and public meetings.
		☑	A list of interested persons in attendance who would like to be added to the Agency's listserv for the facility.
		☑	Certification that all contractors, subcontractors, and installers utilized to construct, install, modify, or close a CCR surface impoundment are participants in a training program that is approved by and registered with the U.S. Department of Labor's Employment and Training Administration and that includes instruction in erosion control and environmental remediation.
		☑	Certification that all contractors, subcontractors, and installers utilized to construct, install, modify, or close a CCR surface impoundment are participants in a training program that is approved by and registered with the U.S. Department of Labor's Employment and Training Administration and that includes instruction in the operation of heavy equipment and excavation.
SECTION 5: GROUNDWATER MONITORING PROGRAM			
Groundwater Monitoring	5.1	Indicate that you have attached the following components of a new groundwater monitoring program or any modifications to an existing groundwater monitoring program by checking the corresponding boxes:	
		☑	A hydrogeologic site investigation meeting the requirements of 35 Ill. Adm. Code 845.620, if applicable.
		☑	Design and construction plans of a groundwater monitoring system meeting the requirements of 35 Ill. Adm. Code 845.630.
		☑	A proposed groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data as required by 35 Ill. Adm. Code 845.640 and 845.650.
SECTION 6: CLOSURE (35 Ill. Adm. Code 845.220(d))			
Closure	6.1	What is the closure prioritization category under 35 Ill. Adm. Code 845.700(g), if applicable?	
		Attachment I	
	6.2	Indicate that you have attached the following by checking the corresponding boxes:	
		☑	The final closure plan, as specified in 35 Ill. Adm. Code 845.720(b), which includes the closure alternatives analysis required by 35 Ill. Adm. Code 845.710.
		☑	Proposed schedule to complete closure.
		☑	Post-closure care plan as specified in 35 Ill. Adm. Code 845.780(d).
SECTION 7: GROUNDWATER MODELING (35 Ill. Adm. Code 845.220(d)(3))			
Groundwater	7.1	Indicate that you have attached the following by checking the corresponding boxes:	
		☑	The results of groundwater contaminant transport modeling and calculations showing how the closure will achieve compliance with the applicable groundwater standards.
		☑	All modeling inputs and assumptions.
		☑	Description of the fate and transport of contaminants with the selected corrective action over time.

		☑	Capture zone modeling, if applicable.
		☑	Any necessary licenses and software needed to review and access both the model and the data contained within the model.

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Illinois Power Generating Company

Primary Ash Pond CONSTRUCTION PERMIT APPLICATION

July 2022

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ATTACHMENTS

Attachment A	Legal Description (845.210(c))
Attachment B	Groundwater Information
Attachment C	History of Construction Report (845.220(a)(1))
Attachment D	Types of CCR and Chemical Constituents (845.220(a)(2)(A))
Attachment E	Site Location Maps (845.220(a)(3))
Attachment F	Site Plan Map and On-Site Transportation Plan ((845.220(a)(4) and 845.220(a)(2)(E))
Attachment G	Final Closure Plan and Proposed Closure Schedule (including Closure Alternatives Analysis, 845.210, 845.220(a)(5-6), 845.720(b), 845.220(d)(2))
Attachment H	Public Notification and Public Meeting Certification (845.220(a)(9))
Attachment I	Closure Prioritization Category Letter (845.220(d)(1))
Attachment J	Post-Closure Care Plan (845.220(d)(5))
Attachment K	Contractor Training Certification (45 ILCS 5/22.59(b)(4))

1. INTRODUCTION

Illinois Power Generating Company (IPGC) is the owner of the coal-fired Newton Power Plant (NPP), also referred to as Newton Power Station, in Jasper County, Illinois. The NPP will be active until 2027, after which electricity production and coal combustion residual (CCR) production will cease and the NPP will become inactive. According to the Illinois Environmental Protection Agency (IEPA), this power station has one CCR surface impoundment, the Primary Ash Pond, initially constructed in 1977. This construction permit application is for closure of the Primary Ash Pond (PAP).

This construction permit application was developed in accordance with 35 Ill. Admin. Code 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845).

1.1. Legal Description

Section 845.210(c): All permit applications must contain a legal description of the facility boundary and a description of the boundaries of all units included in the facility.

Legal description of the facility is provided in **Attachment A**.

1.2. Previous Assessments

Section 845.210(d): Previous Assessments, Investigations Plans, and Programs

The PAP was operating as of October 19, 2015 and the PAP was actively receiving CCR at that time. The PAP was therefore initially regulated by 40 C.F.R. Part 257, herein referred to as the CCR Rule [1] and subsequently regulated by Part 845. Multiple previous initial and periodic assessments, investigation plans, and programs were completed for the PAP to satisfy the requirements of both the CCR Rule and Part 845; some of which are referred to within this report.

Section 845.210(d)(1): The Agency may approve the use of any hydrogeologic site investigation or characterization, groundwater monitoring well or system, or groundwater monitoring plan, bearing the seal and signature of an Illinois Licensed Professional Geologist or Licensed Professional Engineer, completed before April 21, 2021 to satisfy the requirements of this Part.

The hydrogeologic site investigation and characterization, groundwater monitoring well system, and groundwater monitoring plan are provided for the PAP in **Attachment B**.

Section 845.210(d)(4): For inactive closed CCR surface impoundments, the owner or operator of the CCR surface impoundment may use a post-closure care plan previously approved by the Agency.

No post-closure care plan for the PAP was previously approved by the Agency.

2. CONSTRUCTION PERMIT

2.1. History of Construction

Section 845.220(a)(1): Design and Construction Plans (Construction History)

The History of Construction report for the PAP is provided in **Attachment C**.

2.2. Narrative Description of Facility

Section 845.220(a)(2): Narrative Description of the Facility. The permit application must contain a written description of the facility with supporting documentation describing the procedures and plans that will be used at the facility to comply with the requirements of this Part. The descriptions must include, but are not limited to, the following information:

The Facility Narrative Description details are described in the following sections.

Section 845.220(a)(2)(A): The types of CCR expected in the CCR surface impoundment, including a chemical analysis of each type of expected CCR;

The types of CCR expected in the PAP and analysis of the chemical constituents found within the CCR in the PAP are provided in **Attachment D.**

Section 845.220(a)(2)(B): An estimate of the maximum capacity of each surface impoundment in gallons or cubic yards;

The PAP currently contains approximately 5,000,000 cubic yards (CY) of CCR. Additional CCR will be generated at the NPP between now and the time of closure. Approximately 700,000 CY (950,000 tons) of additional waste material (ash, coal pile residuals, grading soils) that is currently existing at, and was previously generated by, the NPP will be placed in the PAP during closure (see **Section 2.4**), resulting in a maximum CCR capacity of approximately 5,700,000 CY.

Section 845.220(a)(2)(C): The rate at which CCR and non-CCR waste streams currently enter the CCR surface impoundment in gallons per day and dry tons;

CCR is entering the PAP at a rate of approximately the following rates, per the 2020 Alternative Closure Demonstration:

Bottom Ash Sluice	2.3-MGD
Dry Fly Ash	~27,500-tons/yr
Fly Ash Vacuum	1.4-MGD
Fly Ash Sluice	Discontinued

Section 845.220(a)(2)(D): The estimated length of time the CCR surface impoundment will receive CCR and non-CCR waste streams; and

The NPP will cease operation in September of 2027, and the PAP will cease receiving waste at that time.

Section 845.220(a)(2)(E): An on-site transportation plan that includes all existing and planned roads in the facility that will be used during the operation of the CCR surface impoundment.

The PAP is an active impoundment, currently receiving large waste streams via sluicing. The PAP has established site access roads for operations and management of solids. Existing site access roads will be used as necessary to support closure construction for the PAP. An On-Site Transportation Plan was developed as required by Section 845.220(a)(2)(E) and is provided for the PAP in **Attachment F** that includes all on-site access roads and the surrounding roadways.

2.3. Site Maps

Section 845.220(a)(3): Site Location Map. All permit applications must contain a site location map on the most recent United States Geological Survey (USGS) quadrangle of the area from the 7½ minute series (topographic), or on another map whose scale clearly shows the following information:

A. *The facility boundaries and all adjacent property, extending at least 1000 meters (3280 feet) beyond the boundary of the facility;*
B. *All surface waters;*

C. *The prevailing wind direction;*
D. *The limits of all 100-year floodplains;*
E. *All-natural areas designated as a Dedicated Illinois Nature Preserve under the Illinois Natural Areas Preservation Act [525 ILCS 30];*
F. *All historic and archaeological sites designated by the National Historic Preservation Act (16 USC 470 et seq.) and the Illinois Historic Sites Advisory Council Act [20 ILCS 3410]; and*
G. *All areas identified as critical habitat under the Endangered Species Act of 1973 (16 USC 1531 et seq.) and the Illinois Endangered Species Protection Act [520 ILCS 10].*

Site Location Maps showing the information required in Section 845.220(a)(3) are provided for the PAP in **Attachments E and F**. The Site Location Maps consist of the most recent USGS quadrangle map (2021) which contains the PAP and 1,000 meters of the surrounding area.

The data in the Site Location Map was collected by performing a comprehensive search of the Illinois Department of Natural Resources (IDNR) natural heritage database [2] for natural and protected areas within 1,000 meters of the PAP. Within Jasper County, a total of 5 sites were identified from the Illinois Natural Areas Inventory and 9 were identified from the Illinois Nature Preserves list. None of the natural areas of preserves fall within 1,000 meters of the PAP.

The IDNR natural heritage database also includes a list of Endangered Species by County [3] and notes that a total of 25 threatened and endangered species are located within Jasper County, including 18 endangered and 7 threatened species. A review of the U.S. Fish and Wildlife Service (USFWS) Threatened & Endangered Species Active Critical Habitat Report [4] identifies no critical habitat located within 1,000 meters of the PAP.

A search of the IDNR Historic and Architectural Resources Geographic Information System (HARGIS) database [5] for historical sites within the 1,000 meters of the Site located no results.

The 100-year flood plain limits were obtained from the Federal Emergency Management Area (FEMA) Flood Map Service Center [6], dated January 17, 1985. Portions of the NPP site are within the historic 100-year flood plain of Newton Lake. The PAP appears to be within the historic floodplain, but the perimeter berms constructed with the pond construction in 1977 altered the limits of the floodplain. It appears the map did not include the PAP in 1985 and has not been updated since that time.

Section 845.220(a)(4): Site Plan Map. The application must contain maps, including cross-sectional maps of the site boundaries, showing the location of the facility. The following information must be shown:

A. *The entire facility, including any proposed and all existing CCR surface impoundment locations;*
B. *The boundaries, both above and below ground level, of the facility and all CCR surface impoundments or landfills containing CCR included in the facility;*
C. *All existing and proposed groundwater monitoring wells; and*
D. *All main service corridors, transportation routes, and access roads to the facility.*

The Site Plan Map showing the information required in Section 845.220(a)(4) is provided for the PAP in **Attachment F**. See the drawings in **Attachment G** for more detailed information.

2.4. Narrative Description of Proposed Construction

Section 845.220(a)(5): A narrative description of the proposed construction of, or modification to, a CCR surface impoundment and any projected changes in the volume or nature of the CCR or non-CCR waste streams.

The proposed modification to the PAP will include closing the PAP by leaving CCR in-place and covering it with a final cover system. The PAP is an unlined CCR surface impoundment. There is not an engineered bottom liner system, rather, the underlying materials are primarily characterized as sandy or silty clays and clayey or silty sands, with a perimeter berm constructed of primarily clays.

Closure with a final cover system will include unwatering the PAP by removing impounded water, removing existing outfall structures, regrading existing CCR within the PAP, and constructing a final cover system including a geomembrane, geotextile, cover soil, topsoil, and vegetation. A post-closure stormwater management system including channels and riprap-lined downchutes will direct non-contact stormwater to the newly constructed stormwater pond.

A CCR volume increase of approximately 700,000 cubic yards (CY) will occur as part of consolidating material to the north at the time of closure. Closure will include excavating the estimated 1,917,700 CY of waste material on the south side of the PAP and coal pile residuals and placing it in the north side of the PAP as consolidated fill. No changes in waste streams are expected to occur.

All areas affected by releases of CCR from the CCR surface impoundment will be decontaminated in accordance with 845.740(a). All structures and conveyances used to manage CCR will be placed beneath the final cover system of the PAP, decontaminated, or removed and sent to a licensed landfill.

If the proposed closure-in-place system is approved, a new photovoltaic (PV) solar power facility will be installed on top of the closed ash pond as part of the closure effort. This facility is proposed to be installed in phases to take advantage of areas as they are closed. A total installed capacity of 106.4 megawatts DC and rated capacity of 81.9 megawatts AC is proposed with the closure-in-place project, with interconnection of the solar facility occurring at the existing Newton Power Plant substation.

Additional information on the proposed construction and modification to the PAP is included within the Closure Plan provided in **Attachment G**.

2.5. Plans and Specifications

Section 845.220(a)(6): Plans and specifications fully describing the design, nature, function and interrelationship of each individual component of the facility.

Permit-level design plans are included within the Closure Plan provided for the PAP in **Attachment G** and were prepared in accordance with Section 845.220(a)(6). The permit-level design plans are consistent with the narrative description provided in Section 845.220(A)(5).

2.6. Groundwater Monitoring Program

Section 845.220(a)(7): A new groundwater monitoring program or any modification to an existing groundwater monitoring program that includes but is not limited to the following information:

The Groundwater Monitoring Program details are described within this section and the referenced attachments.

Section 845.220(a)(7)(A): A hydrogeologic site investigation meeting the requirements of Section 845.620, if applicable;

Hydrogeologic site investigations for the PAP are provided in **Attachment B**.

Section 845.220(a)(7)(B): Design and construction plans of a groundwater monitoring system meeting the requirements of Section 845.630; and

Design and construction plans of a groundwater monitoring system as required by Section 845.630 are provided in **Attachment B**.

Section 845.220(a)(7)(C): A proposed groundwater sampling and analysis program that includes selection of the statistical procedures to be used for evaluating groundwater monitoring data (see Sections 845.640 and 845.650).

A groundwater sampling and analysis program that meets the requirements of Section 845.640 and 845.650 is provided in **Attachment B**.

2.7. Certification

Section 845.220(a)(8): The signature and seal of a qualified professional engineer.

I, Mark Roberts, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief, that the information contained in this construction permit application has been prepared in accordance with the accepted practice of engineering.

Printed Name: Mark Roberts, P.E.

7/28/2022

Signature *Date*

Registration Number: 062062011
Expiration Date: 11.30.2023

Seal applies to application and appendices prepared by HDR. This report relies upon data, analyses, and reports prepared by others.



Affix Seal

2.8. Public Meeting Information

Section 845.220(a)(9): Certification that the owner or operator of the CCR surface impoundment completed the public notification and public meetings required under Section 845.240, a summary of the issues raised by the public, a summary of any revisions, determinations, or other considerations made in response to those issues, and a list of interested persons in attendance who would like to be added to the Agency's listserv for the facility.

Certification that the public notification and public meetings have been completed as required by Section 845.240 is provided as **Attachment H**.

2.9. Closure Construction

Section 845.220(d): Closure Construction. In addition to the requirements in subsection (a), all construction permit applications for closure of the CCR surface impoundment under Subpart G must contain the following information and documents:

The Closure Construction details are described in the following sections.

Section 845.220(d)(1): Closure prioritization category, if applicable (see Section 845.700(g));

A CCR Surface Impoundment Category Designation and Justification letter was submitted to IEPA on May 19, 2021. The PAP was designated as Category 5 CCR surface impoundment. This letter is provided in **Attachment I**.

Section 845.220(d)(2): Final closure plan (see Section 845.720(b)), including the closure alternatives analysis required by Section 845.710;

The Final Closure Plan as required by Section 845.720(b) and the Alternatives Analysis as required by Section 845.210 are provided in **Attachment G**.

Section 845.220(d)(3): Groundwater modeling, including:

- *A. The results of groundwater contaminant transport modeling and calculations showing how the closure will achieve compliance with the applicable groundwater standards;*
- *B. All modeling inputs and assumptions;*
- *C. Description of the fate and transport of contaminants, with the selected closure over time;*
- *D. Capture zone modeling, if applicable; and*
- *E. Any necessary licenses and software needed to review and access*

both the model and the data contained within the model.

Groundwater modeling as required by Section 845.220(d)(3) is provided in **Attachment B**.

Section 845.220(d)(4): Proposed schedule to complete closure; and

The proposed schedule to completed closure is included within the Final Closure Plan, provided in **Attachment G.**

Section 845.220(d)(5): Post-closure care plan specified in Section 845.780(d), if applicable.

The Post Closure Care Plan required by Section 845.220(d)(5) is provided in **Attachment J**.

3. ADDITIONAL INFORMATION

Certification that IPGC will utilize contractors, subcontractors, and installers who are participants in an approved training program, in accordance with 415 Illinois Compiled Statutes (ILCS) 5/22.59(b)(4), is provided in **Attachment K**.

4. REFERENCES

[1] United Stated Environmental Protection Agency, "40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule, 2015," 2015.

[2] Illinois Department of Natural Resources, "IDNR Natural Heritage Database," [Online]. Available: https://www2.illinois.gov/sites/naturalheritage/DataResearch/Documents/INAICountyList_mar2022.pdf. [Accessed 31 March 2022].

[3] Illinois Department of Natural Resources, "Illinois Threatened and Endangered Species by County," March 2022. [Online]. Available: https://www2.illinois.gov/sites/naturalheritage/DataResearch/Documents/ETCountyList_mar2022.pdf. [Accessed 31 March 2022].

[4] U.S. Fish & Wildlife Service, "USFWS Threatened & Endangered Species Active Critical Habitat Report," [Online]. Available: https://fws.maps.arcgis.com/home/webmap/viewer.html?webmap=9d8de5e265ad4fe09893cf75b8dbfb77. [Accessed 31 March 2022].

[5] Illinois Department of Natural Resources, "IDNR Historic Preservation Division HARGIS," [Online]. Available: https://www2.illinois.gov/dnrhistoric/Preserve/Pages/HARGIS.aspx. [Accessed 31 March 2022].

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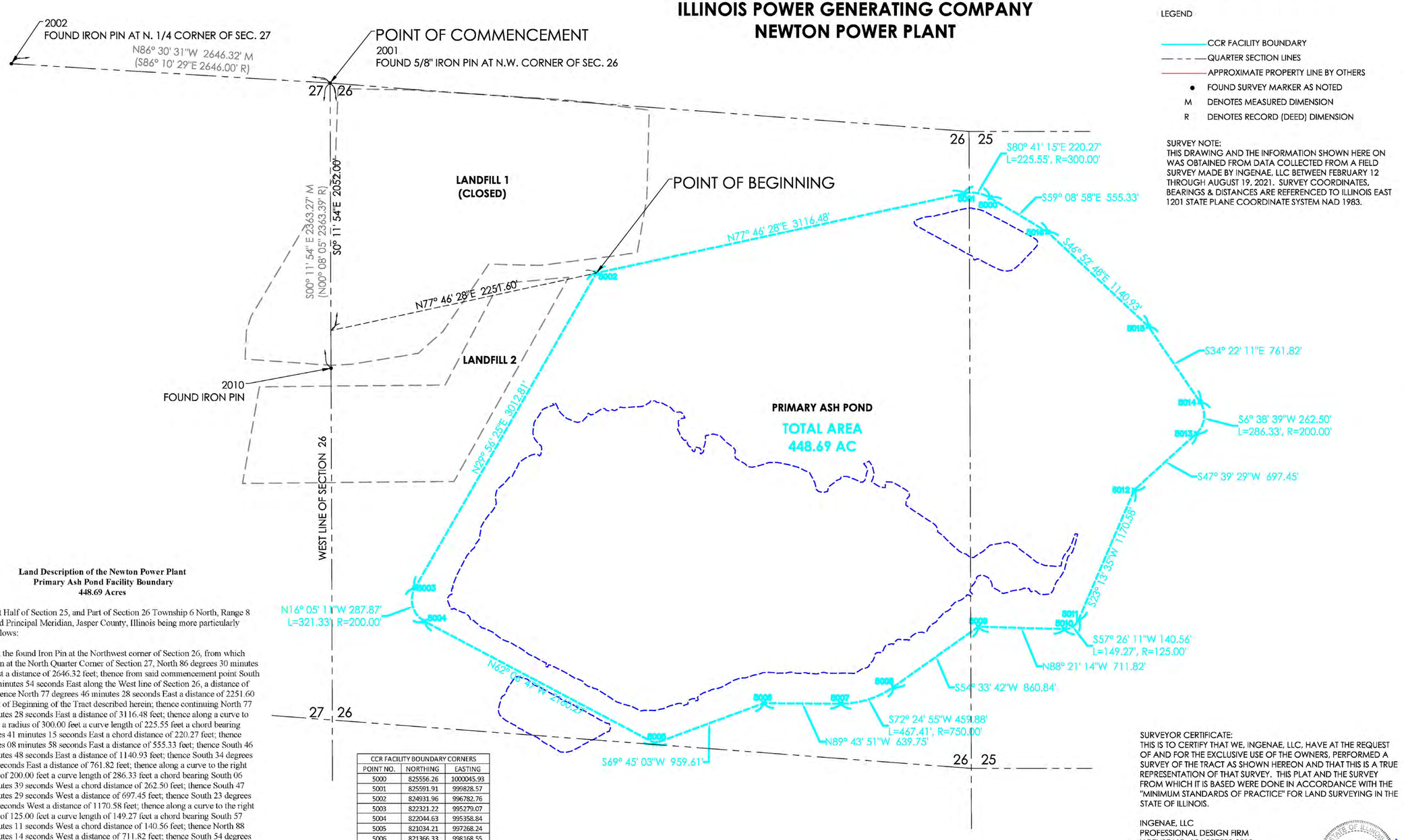
Attachment A

Legal Description

Luminant

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT



LEGEND

- CCR FACILITY BOUNDARY
- QUARTER SECTION LINES
- APPROXIMATE PROPERTY LINE BY OTHERS
- FOUND SURVEY MARKER AS NOTED
- M DENOTES MEASURED DIMENSION
- R DENOTES RECORD (DEED) DIMENSION

SURVEY NOTE:
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Land Description of the Newton Power Plant
Primary Ash Pond Facility Boundary
448.69 Acres

Part of the West Half of Section 25, and Part of Section 26 Township 6 North, Range 8 East of the Third Principal Meridian, Jasper County, Illinois being more particularly described as follows:

Commencing at the found Iron Pin at the Northwest corner of Section 26, from which bears an Iron Pin at the North Quarter Corner of Section 27, North 86 degrees 30 minutes 31 seconds West a distance of 2646.32 feet; thence from said commencement point South 00 degrees 11 minutes 54 seconds East along the West line of Section 26, a distance of 2052.00 feet; thence North 77 degrees 46 minutes 28 seconds East a distance of 2251.60 feet to the Point of Beginning of the Tract described herein; thence continuing North 77 degrees 46 minutes 28 seconds East a distance of 3116.48 feet; thence along a curve to the right having a radius of 300.00 feet a curve length of 225.55 feet a chord bearing South 80 degrees 41 minutes 15 seconds East a chord distance of 220.27 feet; thence South 59 degrees 08 minutes 58 seconds East a distance of 555.33 feet; thence South 46 degrees 52 minutes 48 seconds East a distance of 1140.93 feet; thence South 34 degrees 22 minutes 11 seconds East a distance of 761.82 feet; thence along a curve to the right having a radius of 200.00 feet a curve length of 286.33 feet a chord bearing South 06 degrees 38 minutes 39 seconds West a chord distance of 262.50 feet; thence South 47 degrees 39 minutes 29 seconds West a distance of 697.45 feet; thence South 23 degrees 13 minutes 35 seconds West a distance of 1170.58 feet; thence along a curve to the right having a radius of 125.00 feet a curve length of 149.27 feet a chord bearing South 57 degrees 26 minutes 11 seconds West a chord distance of 140.56 feet; thence North 88 degrees 21 minutes 14 seconds West a distance of 711.82 feet; thence South 54 degrees 33 minutes 42 seconds West a distance of 860.84 feet; thence along a curve to the right having a radius of 750.00 feet a curve length of 467.41 feet a chord bearing South 72 degrees 24 minutes 55 seconds West a chord distance of 459.88 feet; thence North 89 degrees 43 minutes 51 seconds West a distance of 639.75 feet; thence South 69 degrees 45 minutes 03 seconds West a distance of 959.61 feet; thence North 62 degrees 06 minutes 47 seconds West a distance of 2160.27 feet; thence along a curve to the right having a radius of 200.00 feet a curve length of 321.33 feet a chord bearing North 16 degrees 05 minutes 11 seconds West a chord distance of 287.87 feet; thence North 29 degrees 56 minutes 25 seconds East a distance of 3012.81 feet to the Point of Beginning and containing 448.69 Acres.

CCR FACILITY BOUNDARY CORNERS		
POINT NO.	NORTHING	EASTING
5000	825556.26	1000045.93
5001	825591.91	999828.57
5002	824931.96	996782.76
5003	822321.22	995279.07
5004	822044.63	995358.84
5005	821034.21	997268.24
5006	821366.33	998168.55
5007	821363.33	998808.29
5008	821502.27	999246.68
5009	822001.40	999948.04
5010	821980.96	1000659.57
5011	822056.61	1000778.03
5012	823132.32	1001239.67
5013	823602.09	1001755.18
5014	823862.82	1001785.55
5015	824491.64	1001355.48
5016	825271.49	1000522.69

CONTROL MONUMENTATION				
POINT NO.	NORTHING	EASTING	ELEVATION	DESCRIPTION
2001	826507.15	994575.12	539.73	FOUND IRON PIN - N. 1/4 CORNER SEC. 27
2002	826668.31	991933.71	538.32	FOUND 5/8" IRON PIN - N.W. CORNER OF SEC. 26
2010	824143.94	994583.30	-	FOUND IRON PIN

SURVEYOR CERTIFICATE:
THIS IS TO CERTIFY THAT WE, INGENAE, LLC, HAVE AT THE REQUEST OF AND FOR THE EXCLUSIVE USE OF THE OWNERS, PERFORMED A SURVEY OF THE TRACT AS SHOWN HEREON AND THAT THIS IS A TRUE REPRESENTATION OF THAT SURVEY. THIS PLAT AND THE SURVEY FROM WHICH IT IS BASED WERE DONE IN ACCORDANCE WITH THE "MINIMUM STANDARDS OF PRACTICE" FOR LAND SURVEYING IN THE STATE OF ILLINOIS.

INGENAE, LLC
PROFESSIONAL DESIGN FIRM
LICENSE NO. 184.007588-0010

STATE OF ILLINOIS · MICHAEL GRAMINSKI · 035-2901 · PROFESSIONAL LAND SURVEYOR

MICHAEL J. GRAMINSKI — DATE
I.P.L.S. NO. 035.002901
EXPIRES: 11/30/2022

IngenAE
502 Earth City Plaza, Suite 120
Earth City, MO 63045
www.ingenae.com

Submissions / Revisions:	Date:
1	
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8	
9	
10	
11	
12	
13	

Luminant

Project Name & Location:

NEWTON
POWER PLANT
6725 NORTH 500TH STREET
NEWTON, IL 62248

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CCR FACILITY BOUNDARY EXHIBIT

Date:	Project No.
09/09/2021	
Type: SITE	Drawing No. 1
Drawn By: CB	
Approved By: MG	
Scale: AS NOTED	

Luminant

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT



N

0' 400' 800'

LEGEND

- CCR FACILITY BOUNDARY
- QUARTER SECTION LINES
- APPROXIMATE PROPERTY LINE BY OTHERS
- ● FOUND SURVEY MARKER AS NOTED
- M DENOTES MEASURED DIMENSION
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IngenAE
502 Earth City Plaza, Suite 120
Earth City, MO 63045
www.ingenae.com

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Project Name & Location:

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Approved By: MG	
Scale: AS NOTED	

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Attachment B

Groundwater Information

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Intended for
Illinois Power Generating Company

Date
October 25, 2021

Project No.
1940100806-008

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT

PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT PRIMARY ASH POND

Project Name	**Newton Power Plant Primary Ash Pond**
Project No.	**1940100806-008**
Recipient	**Illinois Power Generating Company**
Document Type	**Hydrogeologic Site Characterization Report**
Revision	**FINAL**
Date	**October 25, 2021**

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com

Nicole M. Pagano
Senior Managing Engineer

Brian G. Hennings, PG
Managing Hydrogeologist

Scott S. Woods
Hydrogeologist

Nathaniel R. Keller
Senior Hydrogeologist

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Appendix D Geotechnical Laboratory Report
Appendix E Groundwater Contour Maps
Appendix F Hydraulic Conductivity Test Data
Appendix G FEMA Flood Hazard Map

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ACRONYMS AND ABBREVIATIONS

°F	degrees Fahrenheit
§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
40 C.F.R.	Title 40 of the Code of Federal Regulations
CCR	coal combustion residuals
cm/s	centimeters per second
CSM	conceptual site model
bgs	below ground surface
ESRI	Environmental Systems Research Institute
ft/day	feet/day
ft/ft	feet per feet
ft/mi	feet per mile
g	horizontal acceleration
GMP	Groundwater Monitoring Plan
GWPS	Groundwater Protection Standard
HCR	Hydrogeologic Site Characterization Report
HMP	Hydrogeologic Monitoring Plan
HUC	Hydraulic Unit Code
ID	identification
IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
ILWATER	ISGS Illinois Water and Related Wells
IPGC	Illinois Power Generating Company
ISGS	Illinois State Geological Survey
ISWS	Illinois State Water Survey
LCU	Lower Confining Unit
LF 1	Phase 1 Landfill
LF 2	Phase 2 Landfill
LVW	Low Volume Wastewater
mg/L	milligrams per liter
NAVD88	North American Vertical Datum of 1988
NID	National Inventory of Dams
No.	number
NPDES	National Pollutant Discharge Elimination System

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NPP	Newton Power Plant
NRT	Natural Resource Technology, Inc.
OBG	O'Brien and Gere Engineers, Inc.
PAP	Primary Ash Pond
Part 845	Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
pcf	pounds per cubic foot
pCi/L	picocuries per liter
PMP	Potential Migration Pathway
PWS	Public Water Supply
Ramboll	Ramboll Americas Engineering Solutions, Inc.
Rapps	Rapps Engineering and Applied Science
RCRA	Resource Conservation and Recovery Act of 1976
SI	surface impoundment
Site	Primary Ash Pond
SSURGO	Soil Survey Geographic
SU	standard units
TDS	total dissolved solids
UCU	upper confining unit
UD	upper drift
USEPA	United States Environmental Protection Agency
USCS	Unified Soil Classification System
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

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EXECUTIVE SUMMARY

This Hydrogeologic Site Characterization Report (HCR) for the Primary Ash Pond (PAP) at Newton Power Plant (NPP) expands upon the hydrogeology, groundwater quality data, and conceptual site model (CSM) presented in previous hydrogeologic investigation reports prepared for the PAP. This report has been assembled to satisfy the information and analysis requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.620 as summarized in **Table ES-1**. The CSM includes hydrogeologic and groundwater quality data specific to the PAP, which has been collected between 2015 and 2021. The PAP (Vistra identification [ID] number [No.] 501, Illinois Environmental Protection Agency [IEPA] ID No. W0798070001-01, and National Inventory of Dams [NID] No. IL50719) is located at the NPP which is located in Newton, Illinois (**Figure 1-1**).

The PAP is located south of the power plant and situated in a predominantly agricultural area. The PAP is surrounded by Newton Lake on the west, south, and east. Beyond the lake is additional agricultural land. Three coal combustion residuals (CCR) units are present on the NPP property, including the PAP and two landfills: the Phase 1 Landfill (LF 1) is located northwest and west of the PAP, and the Phase 2 Landfill (LF 2) is located west of the PAP. The PAP is located in Section 26 and the western half of Section 25, Township 6 North, Range 8 East.

In addition to the CCR present in the PAP, there are six layers of unlithified material present above the bedrock, these materials were categorized into four hydrostratigraphic units in this report, presented below in descending order:

- **Upper Drift (UD)/Potential Migration Pathway (PMP):** The UD is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.,* PMP).
  - **Hagarstown Member/PMP:** The Hagarstown Member consists of discontinuous sandier deposits of the UD, where present, and overlies the Vandalia Till.
- **Upper Confining Unit (UCU):** This unit consists of the low permeability clay and silt of the Vandalia Till.
- **Uppermost Aquifer:** This unit is composed of the Mulberry Grove Formation, which onsite has been classified as poorly graded sand, silty sand, clayey sand, and gravel.
- **Lower Confining Unit (LCU):** This unit is comprised of low permeability silt and clay of the Smithboro Till (Smithboro Till) and the Banner Formation.

Groundwater migrates downward through the UD and UCU into the uppermost aquifer. Groundwater in the uppermost aquifer flows from north to south/southwest and converges near a former drainage feature located west of the PAP. Groundwater elevations vary seasonally, although generally less than one foot per year. The surface water elevation at Newton Lake (at location SG02) measured between February 15 and March 9, 2021 ranged from 504.42 to 504.84 feet North American Vertical Datum of 1988 (NAVD88). Groundwater elevations in the uppermost aquifer at downgradient wells were observed around 491 feet NAVD88 (approximately 15 feet lower than the Lake elevation). The separation between measured groundwater elevations and Lake elevations (and observed downward vertical gradients) indicates groundwater does not flow into Newton Lake from the uppermost aquifer.

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Part 845 parameters were monitored in uppermost aquifer and PMP monitoring wells as part of groundwater quality evaluations performed between 2015 and present. These data were supplemented with installation and sampling of additional locations in 2021. The results indicate that the following parameters were detected at concentrations greater than the applicable 35 I.A.C. § 845.600 groundwater protection standards (GWPSs) and are considered potential exceedances:

- Arsenic at six uppermost aquifer wells, including downgradient wells APW08, APW09, APW15, and APW16 and background wells APW05 and APW06.
- Chloride at upgradient UD well APW05S and downgradient uppermost aquifer well APW15.
- Cobalt at PMP well APW12.
- Fluoride at downgradient uppermost aquifer well APW15 and APW18.
- Lead at downgradient uppermost aquifer wells APW08, APW11, and APW18.
- Lithium at three PMP wells APW02, APW04, and APW12; one upgradient UD well APW05S; and two downgradient uppermost aquifer wells APW13 and APW14.
- pH values below the lower range of the GWPS were observed at four PMP wells APW02, APW03, APW04, APW12; one background UA well APW06; and two downgradient uppermost aquifer wells APW11 and APW13.
- Radium 226 and 228 combined at downgradient uppermost aquifer well APW16.
- Sulfate at three PMP wells APW02, APW04, and APW12; one upgradient UD well APW05S; and one downgradient uppermost aquifer well APW10
- Thallium at one background well APW06, and two downgradient uppermost aquifer wells APW11 and APW18.
- Total dissolved solids (TDS) at four PMP wells APW02, APW03, APW04, and APW12; and one upgradient UD well APW05S.

Concentration results for the above parameters were compared directly to 35 I.A.C. § 845.600 GWPS to determine potential exceedances. Potential exceedances include results reported during the background groundwater monitoring or prior period that are greater than the GWPS. The results are considered potential exceedances because the results were compared directly to the standard and did not include an evaluation of background groundwater quality and the statistical methodologies proposed in the groundwater monitoring plan (GMP) provided in the Operating Permit application. Exceedances will be determined following IEPA approval of the GMP.

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in HCR
845.620(b)	**The hydrogeologic site characterization shall include but not be limited to the following:**	--
845.620(b)(1)	Geologic well logs/boring logs;	Table 3-1 Figure 3-1 Appendix C
845.620(b)(2)	Climatic aspects of the site, including seasonal and temporal fluctuations in groundwater flow;	Sections 3.2.4 & 3.3.1 Figures 3-3 to 3-4
845.620(b)(3)	Identification of nearby surface water bodies and drinking water intakes;	Sections 3.3.2 & 5.2 Appendix B
845.620(b)(4)	Identification of nearby pumping wells and associated uses of the groundwater;	Section 5.1 Appendix B
845.620(b)(5)	Identification of nearby dedicated nature preserves;	Section 5.3 Appendix B
845.620(b)(6)	Geologic setting;	Section 2 Figures 2-1 to 2-5
845.620(b)(7)	Structural characteristics;	Section 2.4.3 Figure 2-4
845.620(b)(8)	Geologic cross-sections;	Figures 2-6 through 2-8
845.620(b)(9)	Soil characteristics;	Section 2.3 Figure 2-2 Tables 2-1 & 2-4

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in HCR
845.620(b)(10)	Identification of confining layers;	Section 3.2.1
845.620(b)(11)	Identification of potential migration pathways;	Section 3.2.1
845.620(b)(12)	Groundwater quality data;	Section 4.2 Table 4-1
845.620(b)(13)	Vertical and horizontal extent of the geologic layers to a minimum depth of 100 feet below land surface, including lithology and stratigraphy;	Section 2.5 Figures 2-6 to 2-8
845.620(b)(14)	A map displaying any known underground mines beneath a CCR surface impoundment;	Section 2.4.5 Appendix B
845.620(b)(15)	Chemical and physical properties of the geologic layers to a minimum depth of 100 feet below land surface;	Section 2.5 Tables 2-1, 2-2, & 2-4 Appendix E
845.620(b)(16)	Hydraulic characteristics of the geologic layers identified as migration pathways and geologic layers that limit migration, including:	Sections 3.2.4.1, 3.2.5, & 3.2.6 Tables 3-2 to 3-4 Appendix F
845.620(b)(16)(A)	water table depth;	Section 3.2.4 Figures 3-3 & 3-4
845.620(b)(16)(B)	hydraulic conductivities;	Section 3.2.5 Table 3-3 Appendix F

TABLE ES-1. PART 845 REQUIREMENTS CHECKLIST
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in HCR
845.620(b)(16)(C)	effective and total porosities;	Section 2.5 Table 2-1
845.620(b)(16)(D)	direction and velocity of groundwater flow; and	Sections 3.2.4 & 3.2.6 Tables 3-2 & 3-4 Figures 3-3 & 3-4
845.620(b)(16)(E)	map of the potentiometric surface;	Figures 3-3 & 3-4
845.620(b)(17)	Groundwater classification pursuant to 35 I.A.C. § 620	Section 3.2.7

[O: EDP 08/23/21, U: SSW 9/1/21, C: LDC 09/21/21]

Notes:
35 I.A.C. § 620 = Title 35 of the Illinois Administrative Code, Part 620
HCR = Hydrogeologic Characterization Report
-- = reference to main regulation

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1. INTRODUCTION

1.1 Overview

In accordance with requirements of the Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (SIs): 35 I.A.C. § 845 (Part 845) (IEPA, April 15, 2021), Ramboll Americas Engineering Solutions, Inc. (Ramboll) has prepared this HCR on behalf of NPP (**Figure 1-1**), operated by Illinois Power Generating Company (IPGC). This report will apply specifically to the CCR Unit referred to as the PAP. However, information gathered to evaluate other CCR units at the NPP regarding geology, hydrogeology, and groundwater quality is included, where appropriate. The PAP is a 404-acre unlined CCR SI used to manage stormwater runoff, bottom ash, fly ash, low-volume wastewater (LVW) from the plant's two coal-fired boilers. The PAP discharges into the Secondary Pond, which is used to clarify process water prior to discharge in accordance with the plants National Pollutant Discharge Elimination System (NPDES) permit (No. IL0049191) at the NPP. This HCR includes Part 845 content requirements specific to 35 I.A.C. § 845.620(b) (Hydrogeologic Site Characterization) for the PAP at NPP.

1.2 Part 845 Description

CCR is commonly referred to as coal ash, and CCR SIs are commonly referred to as coal ash ponds. Part 845 contains comprehensive rules for the design, construction, operation, corrective action, closure, and post closure care of these SIs. This rule includes GWPSs applicable at the waste boundary at each CCR SI and requires each owner or operator to monitor groundwater. IEPA's rule includes a permitting program as well as all federal standards for CCR SIs promulgated by the United States Environmental Protection Agency (USEPA). In addition, IEPA's rule includes procedures for public participation, closure alternatives analyses, and closure prioritization, and provides access to records via public website. The rules also include financial assurance requirements for CCR SIs.

A checklist which identifies the specific requirements of 35 I.A.C. § 845.620 is included in **Table ES-1**. The table provides references to sections, tables, and figures included in this document to locate the information that meets specific requirements of 35 I.A.C. § 845.620.

1.3 Previous Investigations and Reports

Numerous hydrogeologic investigations have been performed concerning the CCR Units located at the NPP. The information presented in this HCR includes comprehensive data collection and evaluations from prior hydrogeologic investigation reports (most recent to oldest), including, but not limited to, the following:

- ***Hanson, 2019, Phase 1 Ash Landfill Annual Report, Newton Power Station, Jasper County, Illinois.*** An annual report to provide groundwater and leachate monitoring results for 2019 and proposed activities for 2020, pursuant to 35 I.A.C. § 813.504 and Permit Condition III. Report includes monitoring data, graphical results, and a summary of modifications or changes to the monitoring program.
- ***O'Brien & Gere Engineers, Inc. (OBG), 2017, Hydrogeologic Monitoring Plan, Newton Power Station, Canton, Illinois.*** Although the title refers to Canton, Illinois, the subject of the report is the NPP. The Hydrogeologic Monitoring Plan (HMP) was prepared to provide background information necessary to support the monitoring well network established for development of the Sampling and Analysis Plan requirements of the USEPA Final Rule to

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regulate the disposal of CCR as solid waste under Subtitle D of the Resource Conservation and Recovery Act of 1976 (RCRA) for the NPP. The HMP provides site geology and hydrogeology, aquifer properties, and monitoring network placement and rationale.

- ***AECOM, 2016, History of Construction, Newton Power Station, Newton, Illinois.*** This is a construction history compiled to fulfill Title 40 of the Code of Federal Regulations (40 C.F.R.) § 257.73(c)(1), which requires that the owner/operator of an existing CCR SI that either (1) has a height of five feet or more and a storage volume of 20 acre-feet or more, or (2) has a height of 20 feet or more, compile a history of construction that contains, to the extent feasible, the information specified in 40 C.F.R. § 257.73(c)(1)(i) through (xii). The history of construction was based on existing documentation; AECOM's document review included record drawings, geotechnical investigations, etc., for the PAP.
- ***Natural Resource Technology, Inc. (NRT), April 10, 2013, Hydrogeological Assessment Report, Revision 1, Newton Energy Center, Jasper County, Illinois.*** In 2009, Ameren (the former owner/operator) commissioned a hydrogeologic study, water well survey, development of a GMP, and an initial groundwater quality assessment. This report summarizes hydrogeologic information pertinent to the Site, evaluates groundwater quality data to determine if groundwater has been affected adversely, and determines the potential for off-site migration and for potential groundwater receptors in the event of such a migration.
- ***Geotechnology, Inc., February 8, 2011, Initiation of Monitoring Report, Ameren, Newton Power Station, Newton, Illinois.*** This report documents the results of the monitoring well installation and groundwater monitoring activities performed at the Site. Three wells were installed, developed, and sampled.
- ***Rapps Engineering and Applied Science (Rapps), November 2009, Site Characterization and Groundwater Monitoring Plan for CCP Impoundment, Ameren Energy Generating Company, Newton Power Station, Jasper County, Illinois.*** Hydrogeologic study and GMP to assess the potential for constituent migration from this impoundment. Includes an assessment of subsurface hydrogeologic conditions at the Site, identification of private, potable water wells and oil and gas wells within 2,500 feet of the facility, public water supply (PWS) wells within 10 miles of the facility, and plans for a groundwater monitoring well network designed to characterize and monitor groundwater quality.
- ***Rapps, 1997, Hydrogeologic Investigation and Groundwater Monitoring Program, Newton Power Station, Jasper County, Illinois.*** Investigation presents site-specific data obtained through the completion of approximately 40 borings, 20 monitoring wells, and review of regional information and an evaluation of subsurface data from nearby residential wells. Part of Application for Landfill Permit.

A GMP is being prepared for the PAP in conjunction with this report and is included in the Operating Permit to which this Report is attached.

1.4 Site Location and Background

The NPP is located in Jasper County in the southeastern part of central Illinois, approximately seven miles southwest of the town of Newton (**Figure 1-1**). The PAP is located in Section 26 and the western half of Section 25, Township 6 North, Range 8 East. The PAP is located south of the power plant and situated in a predominantly agricultural area. The PAP is surrounded by Newton Lake on the west, south, and east. Beyond the lake is additional agricultural land. LF 1 is located

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northwest and west of the PAP, and LF 2 is located west of the PAP (**Figure 1-2**). The PAP is the subject of this report and will hereafter be referred to as the Site in this document.

1.5 Site History and Unit Description

The PAP was constructed in 1977 and has a design capacity of approximately 9,715 acre-feet. There is also a non-CCR 83.6 acre-feet Secondary Pond located immediately south of the PAP. The PAP has a surface area of 404 acres and the Secondary Pond has an area of 9.3 acres. The PAP currently receives bottom ash, fly ash, and LVW from the plant's two coal-fired boilers. The SI is operated per NPDES Permit No. IL0049191, Outfall 001 (located at the Secondary Pond). Areas within the impoundment were excavated during construction for native materials used to build the containment berms. In 2014, three areas along the interior berm were re-graded and covered with riprap (AECOM, 2016).

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2. REGIONAL AND LOCAL GEOLOGY

2.1 Topography

The embankments surrounding the PAP are at an elevation of approximately 550 feet NAVD88 (**Figure 2-1**) with the surrounding areas, Newton Lake, generally at an elevation of around 504 to 505 feet NAVD88. Topographic maps drawn prior to construction indicate the area of the PAP was generally between 500 and 550 feet NAVD88, except for the drainage features in the south-central portion of the PAP. The contours in the area of the drainage feature in the south-central portion of the PAP illustrate lower elevations of approximately 475 to 485 feet NAVD88 (**Appendix A**). Prior to creation of Newton Lake, the elevation of the land surface east and southeast of the PAP was approximately 475 to 480 feet NAVD88.

2.2 Regional Geomorphology

The PAP, as well as all of Jasper County, is located within the Springfield Plain of the Till Plains Sections of the Central Lowlands Province. The Springfield Plain physiographic province is comprised largely of Illinoian glacial drift (Willman et al., 1975). The region is characterized by relatively flat to gently rolling topography. The uppermost geologic materials consist primarily of unconsolidated eolian, slopewash, and fluvial deposits underlain by superglacial and subglacial deposits associated with recent glaciations. The topography of these materials is a function of the underlying bedrock surface on which the material was deposited, and eolian and fluvial processes which have been in effect from their deposition to the present.

The Embarras River and its tributaries drain much of the county and eventually flow into the Wabash River. The southwestern portion of the county, including the NPP, lies within the Little Wabash River Basin. Therefore, all surface drainage from the property flows to the Little Wabash River, which then flows into the Wabash River.

The highest point in Jasper County is at Island Grove, at an elevation of 624 feet NAVD88. The lowest elevation, 440 feet NAVD88, is located at the point on the Crawford County line, which is intersected by the Embarras River. With a total relief of only 184 feet, the surface features of Jasper County are nominal and reflect the moderate amount of erosional modification to the post-glacial topographic surface.

2.3 Soils

Surficial soils at the PAP are shown on **Figure 2-2** and based on Jasper County soil survey data, available in the Soil Survey Geographic (SSURGO) by the United States Department of Agriculture's Natural Resources Conservation Service provided by Environmental Systems Research Institute (ESRI) web hosted layer. Soils surrounding the PAP, not including the Urban Land (#533) within the limits of the NPP, are identified as: Orthents (clayey, sloping) along the western, southern, and eastern boundaries of the PAP; Hickory silt loam (18 to 35 percent slopes) and Ava silt loam (2 to 5 percent slopes) adjacent to Newton Lake; Bluford silt loam, Wynoose silt loam (0 to 2 percent slopes), Racoon silt loam (0 to 2 percent slopes) and Atlas silt loam (5 to 10 percent slopes, eroded) west and northwest of the PAP within agricultural land.

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2.4 Regional Geology

2.4.1 Regional Unlithified Deposits

The unlithified geologic deposits in Jasper County, Illinois primarily consists of loess overlying glacial drift from the Illinoian and Pre-Illinoian glaciers. The unlithified deposits in the region are derived from recent river deposition (alluvium), glacial outwash, and glacial till deposits. The hydrogeologic investigation conducted by Rapps (1997) is the basis for much of the descriptions provided below. From the surficial deposits downward, there are eight primary unlithified geologic units in the region consisting of:

- **Cahokia Formation:** Holocene stage deposits in floodplains and channels of modern rivers and streams. Generally, consists of poorly sorted sand, silt, and clay with wood and shell fragments with local deposits of sandy gravel.
- **Peoria Silt:** Wisconsinan Age deposits that commonly occur in upland areas and along valley walls in Illinois. They generally grade from sandy silt in the bluffs of major source river valleys (like the Mississippi Valley) to clayey silt away from the bluffs, where it is commonly thinner and relatively weathered (Hansel and Johnson, 1996). They are typically massive and consist predominantly of windblown silt from the valley floor, with local lenses of well-sorted, fine- to medium-grained sand (Willman and Frye, 1970).
- **Sangamon Soil:** Silt and clay soils formed during the interglacial period between the Illinoian and Wisconsinan Stages as a result of weathering of the upper portion of the Illinoian drift.
- **Hagarstown Member of the Glasford Formation:** Gravel, sand, and gravelly diamicton occurring as ice-contact deposits that commonly occurs as ridged drift in a distinctive belt of linear to curved ridges and knolls. Outwash plains of poorly sorted to well-sorted sand and gravel may be present between the ridges in many places (Killey and Lineback, 1983).
- **Vandalia Till Member of the Glasford Formation:** Sandy/silty till with thin, discontinuous lenses of silt, sand, and gravel (Lineback, 1979; Willman and Frye, 1970).
- **Mulberry Grove Member of the Glasford Formation:** Typically consists of a thin, lenticular unit of gray sandy silt (Willman et al., 1975). It represents the interval between the retreat of the glacier that deposited the Smithboro Member and the advance of the glacier that deposited the Vandalia Till.
- **Smithboro Till Member of the Glasford Formation:** Gray, compact, silty clay diamicton that is less friable than the overlying Vandalia Till, and was deposited by ice sheets moving northwest to southeast across the region (Jacobs and Lineback, 1969).
- **Banner Formation:** Undifferentiated diamictons that rest directly on bedrock and consist mostly of glacial diamictons and intercalated sand and gravel outwash.

The surficial Quaternary geologic deposits in the vicinity of the Site that were mapped on a regional scale are shown on **Figure 2-3**.

2.4.2 Regional Bedrock Geology

The unlithified deposits are underlain by Pennsylvanian age bedrock belonging to the Mattoon Formation. The Mattoon Formation is the youngest formation in the Pennsylvanian System in Illinois. It is underlain by the Bond Formation. The Mattoon Formation has a maximum thickness of more than 600 feet in the central part of the Illinois Basin in Jasper County. It is characterized

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by a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well-developed sandstones. The lateral extent of many of the named units has not been determined due to widely scattered outcrops and scarce subsurface data. However, coals and limestone units are considered to be as persistent as those in the underlying Bond Formation (Rapps, 1997).

2.4.3 Structure

The major geologic structural features within Illinois are depicted on **Figure 2-4**. The PAP is situated within the Fairfield Basin, one of the major structural features of the encompassing Illinois Basin. The Fairfield Basin, characterized as a smooth floored inner central deep basin, is bound to the west and northwest by the DuQuoin-Louden Monoclinal Belt, to the north and northeast by the LaSalle Anticlinal Belt, and to the south by the Cottage Grove-Rough Creek-Shawneetown Fault Zone (Buschbach and Kolata, 1991). North of the Rouch Creek Fault System, the strata dip gently to the west at approximately 15 to 20 feet per mile (ft/mi), which parallels the general north-south, asymmetrical syncline structure of the Illinois Basin (Hatch and Affolter, 2002).

2.4.4 Seismic Setting

A review of the available data from the United States Geological Survey (USGS), Illinois State Geological Survey (ISGS), and other available regional structural information was completed by Haley & Aldrich, Inc. (2018) for the Location Restriction Demonstration to address the requirements of 40 C.F.R. § 257.62 (Fault Areas). The review found that the Wabash Valley Fault System is located approximately 40 miles southeast of the PAP (**Figure 2-4**). The Wabash Valley Fault system within Illinois extends laterally for approximately 60 miles in a general north-northeastward to south-southwestward trend. Haley & Aldrich, Inc. (2018) found that the timeframe of the most recent activity on the Wabash Fault System is not known. Based on available geologic data and information reviewed, there are no active faults or fault damage zones that have had displacement in the Quaternary period reported within 200 feet of the PAP.

As required by 35 I.A.C. § 845.330, existing and new CCR SIs and lateral expansions of existing SIs must not be located in seismic impact areas, unless owners or operators demonstrate that the SI is designed to resist the maximum horizontal acceleration (g) in lithified earth material. This requirement is identical to that in 40 C.F.R. § 257.63. The definition of a seismic impact zone is “areas having a 2 percent or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of the earth's gravitation pull, will exceed 0.10 g in 50 years.” Although the PAP is located within a seismic impact zone, it satisfies the demonstration requirements of 35 I.A.C. § 845.330. The AECOM report titled “CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Flow Design Control System Plan for the Primary Ash Pond at Newton Power Station”, dated October 2016, includes engineering analysis, calculations, and findings that support the requirements of 40 C.F.R. § 257.63 (Haley & Aldrich, Inc., 2018), and, by extension, 35 I.A.C. § 845.330.

2.4.5 Mining Activities

The areas immediately surrounding the facility have never been mined. Based on the directory of coal mines for Jasper County (ISGS, 2021), the nearest coal mines in the vicinity of the PAP are located approximately 6.7 miles to the northeast (**Appendix B**).

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2.5 Site Geology

A field investigation was performed in 2021 to collect additional data for the discussion of vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet below ground surface (bgs) as specified in 35 I.A.C. § 845.620(b). Field investigation locations are shown on **Figure 2-5**. Boring logs, monitoring well and piezometer construction forms obtained from investigations at the PAP are provided in **Appendix C**.

The Cahokia Formation, described in the regional geology above, occurs in modern river valleys and floodplains. If present, these deposits are expected to occur south of the PAP in areas that are currently beneath the surface water of Newton Lake. The principal types of unlithified materials present above the bedrock in the vicinity of the PAP consist of the following in descending order:

- **CCR and Fill Material:** CCR and reworked surface materials within and adjacent to the various CCR Units.
- **Peoria Silt and Sangamon Soil** (wind-blown deposits and weathered till)**:** Clays and silts, including the Peoria Silt (Loess Unit) in upland areas, underlain by the Sangamon Soil which is comprised of weathered glacial drift.
- **Hagarstown Member:** where present, consists of relatively thin sandy deposits between the clays and silts of the Sangamon Soil and the Vandalia Till.
- **Vandalia Till:** Compacted clay and silt glacial till with varying amounts of sand and gravel (diamicton).
- **Mulberry Grove Member:** Sand, silty sand, and sandy silt/clay units found between the Vandalia Till and the Smithboro Till. These sandy deposits are the first laterally continuous sands observed beneath the PAP.
- **Smithboro Till and Banner Formation:** Thick, gray, compacted silty clay diamicton of the Smithboro Till and the greenish-gray silty clay of the Banner Formation.

Cross-sections showing the subsurface materials encountered at the PAP are included in **Figures 2-6 through 2-8**.

2.5.1 CCR and Fill

CCR is present within most of the PAP at thicknesses between 17 to 19.5 feet thick as observed in XPW01 through XPW04 (**Appendix C**). The lowest bottom-of-ash elevation observed is approximately 486 feet in the center of a former drainage feature oriented north-south through the center of the PAP, whereas ash is potentially highest in elevation at approximately 550 feet along the outer edges of the PAP (**Figure 2-9**)[1]. Note, drawing S-69 (**Appendix A**) indicates the former drainage feature was filled to elevation 508 feet NAVD88 during construction. The bottom of ash surface appears to mirror the former drainage feature. Comparison of the bottom of ash contours and topographic contours indicate CCR fill may be 40 feet or greater within the former drainage feature.

Geotechnical analysis results from six samples collected from ash at soil borings XPW01, XPW03 and XPW04 yielded Unified Soil Classification System (USCS) soil classifications of silty sand and

[1] Base of ash surface is being further evaluated as the construction permit is being developed.

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poorly graded sand with silt. Sample locations are shown on **Figure 2-5,** the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from XPW01, XPW03 and XPW04 indicated the following:

- Average moisture content of 21.3 percent, with a range of 12.6 to 31.1 percent.
- Average total porosity (calculated) of 50 percent, with a range of 38 to 56 percent.
- Average dry density of 84.3 pounds per cubic foot (pcf), with a range of 73.9 to 103.6 pcf.
- Average specific gravity of 2.69, with a range of 2.650 to 2.741.
- Average grain size composition of 14 percent gravel, 60 percent sand, and 26 percent fines (silt and clay). The fines content ranged from 11.8 to 61.3 percent, with a median value of 18.9 percent.
- Geometric mean vertical hydraulic conductivity of 3.11 x 10^{-4} centimeters per second (cm/s) and ranged from 1.58 x 10^{-5} to 1.34 x 10^{-3} cm/s.

Solid samples were collected from XPW01, XPW02, XPW03 and XPW04 by Ramboll in 2021 for chemical analysis. The results of solid samples collected from within the PAP are summarized in **Table 2-2**.

Leachate wells were installed in XPW01, XPW02, XPW03 and XPW04 by Ramboll in 2021, and porewater samples were collected. The results of porewater samples collected from within the PAP are summarized in **Table 2-3**.

2.5.2 Peoria Silt and Sangamon Soil

The Peoria Silt and Sangamon Soil is present within the PAP at thicknesses up to approximately 46 feet as measured in APW15 and ranged from 3 to 46 feet thick as observed in APW05 and APW10 (**Appendix C**). The bottom of this geologic unit is at the lowest elevation of 469.5 feet NAVD88 (APW15) along the southern portion of the PAP while highest in elevation of 543.4 feet NAVD88 in the northwest corner of the PAP (**Figures 2-6 and 2-7**). Generally, the elevation of the bottom of this unit decreases from north to south across the PAP.

Geotechnical analysis results from two samples collected from the Peoria Silt and Sangamon Soil at soil borings APW11 and APW15 yielded USCS soil classifications of lean clay. Sample locations are shown on **Figure 2-5,** the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from these samples indicated the following:

- Average moisture content of 18.2 percent, with a range of 17.8 to 18.5 percent.
- Average porosity (calculated) of 33 percent, with a range of 32 to 34 percent.
- Average dry density of 110.8 pcf, with a range of from 109.8 to 111.7 pcf.
- Average specific gravity of 2.67 with a range of 2.65 to 2.69.
- Grain size composition of 0.6 percent gravel, 43 percent sand, and 56.5 percent fines (silt and clay).

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Soil samples collected from the Peoria Silt and Sangamon Soil (APW11, APW13 and APW15) were also analyzed for chemical parameters. The results of soil samples collected from the Peoria Silt and Sangamon Soil are summarized in **Table 2-4**.

2.5.3 Hagarstown Member

A discontinuous sandy unit, the Hagarstown Member of the Pearl Formation was encountered at elevations ranging from approximately 497 feet NAVD88 (APW08) to 533 feet NAVD88 (APW12). The unit was encountered at thicknesses up to approximately 6.9 feet at APW18, but generally the thickness is less than 2 feet, where present.

Geotechnical analysis results from three samples collected from the Hagarstown Member at soil borings APW12 and APW13 yielded a USCS soil classification of poorly graded sand with silt. Sample locations are shown on **Figure 2-5,** the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from these samples indicated the following:

- Average moisture content of 14.9 percent, with a range of 8.4 to 21.2 percent.
- Average porosity (calculated) of 36 percent, with a range of 30 to 47 percent.
- Average dry density of 106.1 pcf, with a range of 87.1 to 118.3 pcf.
- Average specific gravity of 2.70, with a range of 2.649 to 2.694.
- Grain size composition of 10.6 percent gravel, 68.4 percent sand, and 21.0 percent fines (silt and clay).

Soil samples collected from the Hagarstown Member (APW12, APW13 and APW15) were also analyzed for chemical parameters. The results of soil samples collected from the Hagarstown Member are summarized in **Table 2-4**.

2.5.4 Vandalia Till

Thick glacial deposits of the Vandalia Till, which are laterally continuous beneath the Site and NPP, were encountered at elevations ranging from 425 feet NAVD88 (APW15) to 530 feet NAVD88 (AWP05). The unit was encountered at thicknesses up to 59 feet at APW07, while the average thickness is 26 feet.

Geotechnical analysis results from five samples collected from the Vandalia Till at soil borings APW14, APW17, SB300/APW18, and SB301 yielded a USCS soil classification of lean clay and silty clay. Sample locations are shown on **Figure 2-5**, the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from these samples indicated the following:

- Average moisture content of 14 percent, with a range of 12.4 to 16.6 percent.
- Average porosity (calculated) of 31 percent, with a range of 27 to 36 percent.
- Average dry density of 117.1 pcf, with a range of 108.8 to 122.7 pcf.
- Average specific gravity of 2.70, with a range of 2.697 to 2.709.
- Grain size composition of 1.7 percent gravel, 29.1 percent sand, and 69.2 percent fines (silt and clay).

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Soil samples collected from the Vandalia Till (APW11, APW12, APW15 and APW17) were also analyzed for chemical parameters. The results of soil samples collected from the Vandalia Till are summarized in **Table 2-4**.

2.5.5 Mulberry Grove Member

Thin to moderately thick (3 to 17 feet), the Mulberry Grove member was encountered at elevations ranging from approximately 417 feet NAVD88 (APW15) to 483 feet NAVD88 (APW10). The unit generally slopes from approximately 483 feet NAVD88 in the northeast portion of the site near APW10 to 462 feet NAVD88 in the southwest portion of the site near APW08. The unit was encountered at thicknesses up to 30 feet at APW17, while the average thickness is approximately 10 feet. At APW12 (**Figure 2-8**) sand and gravel was not encountered at a similar elevation during drilling.

Geotechnical analysis results from five samples collected from the Mulberry Grove Member at soil borings APW13, APW15, APW17, and SB300/APW18 yielded USCS soil classifications of silty sand, poorly graded sand with silt and well graded sand with silt. Sample locations are shown on **Figure 2-5,** the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from these samples indicated the following:

- Average moisture content of 10.8 percent, with a range of 6.1 to 14.5 percent.
- Average porosity (calculated) of 32 percent, with a range of 30 to 35 percent.
- Average dry density of 113.5 pcf, with a range of 109.6 to 116.8 pcf.
- Average specific gravity of 2.67, with a range of 2.660 to 2.686.
- Grain size composition of 10.4 percent gravel, 69 percent sand, and 20.6 percent fines (silt and clay).

Soil samples collected from the Mulberry Grove Member (APW11, APW13 and APW14) were also analyzed for chemical parameters. The results of soil samples collected from the Mulberry Grove Member are summarized in **Table 2-4**.

2.5.6 Smithboro Till and Banner Formation

Thick glacial till of the Smithboro Till Member and Banner Formation, which are laterally continuous beneath the Site and NPP, was encountered at elevations ranging from approximately 412 feet NAVD88 (APW15) to 475 feet NAVD88 (APW10). The unit was encountered at thicknesses up to 36 feet (APW14), while the average thickness is 32 feet (based upon the two borings that encountered bedrock APW13 and APW14).

Geotechnical analysis results from eight samples collected from the Smithboro Till and Banner Formation at soil borings APW11, APW12, APW14, APW15, SB300/APW18, and SB301 yielded USCS soil classifications of lean clay and silty clay. Sample locations are shown on **Figure 2-5,** the geotechnical results from the most recent investigation are summarized in **Table 2-1**, and laboratory reports are included in **Appendix D**. Geotechnical results from these samples indicated the following:

- Average moisture content of 15.5 percent, with a range of 11.1 to 19.1 percent.
- Average porosity (calculated) of 32 percent, with a range of 29 to 38 percent.

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- Average dry density of 115.1 pcf, with a range of 104.6 to 121.3 pcf.
- Average specific gravity of 2.70, with a range of 2.686 to 2.723.
- Grain size composition of 0 percent gravel, 24.2 percent sand, and 75.8 percent fines (silt and clay).

Soil samples collected from the Smithboro Till and Banner Formation (APW11, APW12, APW13, APW14 and APW17) were also analyzed for chemical parameters. The results of soil samples collected from within the PAP are summarized in **Table 2-4**.

2.5.7 Bedrock

Bedrock underlying the PAP is the Pennsylvanian Age Mattoon Formation, which consists of a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well-developed sandstones. Bedrock was encountered in borings APW13 and APW14 (**Appendix C**). The elevation of the top of bedrock ranged from 445.5 feet NAVD88 (APW13) to 432.9 feet NAVD88 (APW14). The top of bedrock was described as shale in both borings advanced to bedrock.

No bedrock samples were collected for geotechnical testing or chemical analysis. Boring locations are shown on **Figure 2-5**.

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3. REGIONAL AND LOCAL HYDROGEOLOGY

3.1 Regional Hydrogeology

Aquifers in the area of the PAP generally fall into two broad categories: (1) unlithified sediments that are glacial or alluvial in origin and contain mostly sand and gravel deposits interbedded with clay and silt; and (2) bedrock aquifers consisting of sandstone and fractured limestone, which vary widely in permeability. To the east of the NPP, water-yielding sandstone formations occur at depths of 100 to 300 feet bgs (Selkregg et al., 1957). Groundwater available from bedrock units is mostly mineralized and rarely used as a source for potable water (Rapps, 2009).

Glacial deposits generally provide enough water for rural and residential water supplies. Sand and gravel deposits within the Glasford Formation and the Pearl Formation have been developed locally for domestic water supplies. Locally occurring discontinuous sand and gravel deposits exist along the bottomlands of Big Muddy Creek, which can sustain domestic and farm groundwater supplies. The water bearing zones at the PAP are the sandy horizons that occur within Mulberry Grove Member of the Glasford Formation and the intermittent sands of the Hagarstown Member of the Pearl Formation.

3.2 Site Hydrogeology

In 2015, a monitoring program consisting of six monitoring wells (APW05, APW06, APW07, APW08, APW09, and APW10) was established to comply with requirements of 40 C.F.R. § 257. In 2021, nine additional monitoring wells (APW05S, and APW11 through APW18) were installed to collect information to meet the requirements of Part 845. Construction details for monitoring wells and piezometers is provided in **Table 3-1** and locations are depicted in **Figure 3-1**. Boring logs, monitoring well and piezometer construction forms are provided in **Appendix C**.

3.2.1 Hydrostratigraphic Units

Materials have been categorized into six hydrostratigraphic units at the PAP based on stratigraphic relationships, geologic composition, and common hydrogeologic properties. The units, listed from surface downward, are summarized as follows:

- **CCR**: CCR consisting of fly and bottom ash within the PAP. CCR may be present from the surface (approximately 545 to 555 feet NAVD88) to a minimum elevation of approximately 475 feet NAVD88. Water elevations measured in piezometers screened within the PAP indicate the phreatic surface ranges from approximately 535 to 547 feet NAVD88, which is higher than surrounding monitoring wells.
- **UD/PMP:** The UD is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.,* PMP).
  - **Hagarstown Member/PMP**: The Hagarstown Member consists of the discontinuous, sandier deposits of the UD where present and overlies the Vandalia Till.
- **UCU:** The UCU consists of a thick package of the low permeability clay and silt of the Vandalia Till. This unit is a laterally continuous layer between the base of the CCR unit and the top of the uppermost aquifer.
- **Uppermost Aquifer**: The uppermost aquifer is composed of the Mulberry Grove Member, which has been classified as poorly graded sand, silty sand, clayey sand, and gravel.

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- **LCU**: The LCU is comprised of low permeability silt and clay of the Smithboro Till Member and the Banner Formation.
- **Bedrock Confining Unit**: Bedrock was classified as shale of the Mattoon Formation in locations it was encountered in soil borings during 2021 investigation activities (APW13 and APW14).

3.2.2 Uppermost Aquifer

The uppermost aquifer includes saturated portions of the Mulberry Grove Member in the vicinity of the PAP. Groundwater monitoring for the uppermost aquifer is focused on this zone because it is continuous, moderate permeability, and likely to indicate potential impacts from the PAP. The top of uppermost aquifer was evaluated with respect to the location restrictions in 2018 (Haley & Aldrich, Inc., 2018) and provided in **Figure 3-2**. The top of the uppermost aquifer is separated from overlying CCR material by the low permeability Vandalia Till which was encountered at thicknesses up to 59 feet and an average thickness of 26 feet (**Figures 2-6 to 2-8**). The base of the uppermost aquifer is the top of the LCU containing the low permeability Smithboro Till and the Banner Formation.

3.2.3 Potential Migration Pathways

The UD consists of low permeability clays and silts of the Peoria Silt, Sangamon Soil, and discontinuous sand lenses of the Hagarstown Member. Monitoring wells APW02, APW03, APW04, APW05S, and APW12 are screened within the sandier deposits of the UD and may be utilized for monitoring shallow PMPs adjacent to the PAP.

3.2.4 Water Table Elevation and Groundwater Flow Direction

The elevations of water within the PAP (as observed in XPW01 through XPW04 and XSG01) are greater than the surrounding areas. The phreatic surface within the PAP between February and August 2021 averaged 542 feet NAVD88, ranging from 546.69 feet NAVD88 in XPW02 (located along the northern portion of the PAP) to 535.40 feet NAVD88 in XSG01 (located along the southern portion of the PAP) (**Figures 3-3 and 3-4)**.

Groundwater flow in the uppermost aquifer is generally from north to south. However, uppermost aquifer wells also display flow converging towards a former surface drainage feature located west of the PAP (**Figure 3-3 and 3-4**) and an area where the uppermost aquifer is lowest in elevation. Groundwater elevations vary seasonally, generally less than one foot per year, while across the PAP they range from approximately 490 to 530 feet NAVD88, although flow directions are generally consistent (historic contour maps are included in **Appendix E**).

Groundwater elevations in PMP wells are above those in the uppermost aquifer and range from approximately 518 feet NAVD88 (APW05S) to 535 feet NAVD88 (APW05S). Groundwater elevations within the UCU, LCU, and bedrock confining unit were not contoured because no wells are screened within these units.

3.2.4.1 Vertical Hydraulic Gradients

Vertical hydraulic gradients were calculated using available groundwater elevation data from February to August 2021 at nested well locations within the UD (*i.e.,* PMP) and uppermost aquifer wells. Vertical hydraulic gradients are presented in **Table 3-2**. The results of the vertical hydraulic gradient calculations for these hydrostratigraphic units are summarized below:

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- UD (*i.e.,* PMP) to uppermost aquifer:
  - Gradients calculated between APW05 (uppermost aquifer) and APW05S (PMP) were downward for all events.
  - Gradients calculated between APW10 (uppermost aquifer) and APW04 (PMP) were downward for all events.
  - Gradients calculated between APW09 (uppermost aquifer) and APW03 (PMP) were downward for all events.

These results are consistent with previous vertical gradient calculations (OBG, 2017).

3.2.4.2 Impact of Existing Ponds and Ash Saturation

Water levels collected from XPW01 through XPW04 indicate the phreatic surface is above water levels observed in the uppermost aquifer; however, the groundwater elevation contours of the uppermost aquifer (**Figures 3-3 and 3-4)** illustrate flow towards the south and converges at the former drainage feature along the western edge of the PAP. The absence of a radial component of flow outward indicates the PAP does not significantly impact groundwater flow direction. Furthermore, there is a thick layer of UCU Vandalia Till separating the base of ash and top of uppermost aquifer.

Saturated ash has been observed within the PAP leachate wells (XPW01 through XPW04) located along the northern portion of the unit. The maximum thickness of saturated ash as measured at XPW03 ranged from 11.5 feet in June 2021 to 12.6 feet in February 2021. The minimum thickness of saturated ash as measured at XPW01 ranged from 7.7 feet in July 2021 to 8.2 feet in June 2021. Greater thicknesses of saturated ash are likely in the central portion of the PAP where the former drainage feature was present prior to filling (**Figure 2-9**).

3.2.4.3 Impact of Newton Lake on Groundwater Flow

The surface water elevation at Newton Lake measured from February 15 to March 9, 2021 ranged from 504.42 to 504.84 feet NAVD88 at location SG02 near the outfall from the Secondary Pond. Groundwater flow in the uppermost aquifer generally flows southwest across the PAP with potentiometric surface elevations at downgradient wells around 491 feet NAVD88 (approximately 15 feet lower than the Newton Lake elevation). This separation in groundwater and Lake elevations (and observed downward vertical gradients) indicates groundwater within the uppermost aquifer does not flow into Newton Lake.

Groundwater elevations observed at APW10 are approximately 2-feet higher than surface water in Newton Lake (506 feet NAVD88 versus 504 feet NAVD88). The uppermost aquifer also approaches the former land surface, now beneath Newton Lake, in this area. As illustrated in cross-section B-B' (**Figure 2-7**), the uppermost aquifer may intersect the base of Newton Lake and interact with groundwater upgradient of the PAP.

3.2.5 Hydraulic Conductivities

3.2.5.1 Field Hydraulic Conductivities

Field hydraulic conductivity tests were conducted by Ramboll during the 2021 investigation. The results are summarized in **Table 3-3**, provided in **Appendix F**, and discussed below:

- **CCR**: Results of field hydraulic tests in wells screened within the CCR (XPW01 through XPW04) ranged from 1.0 x 10^{-3} to 2.3 x 10^{-1} cm/s, with a geometric mean of 2.0 x 10^{-2} cm/s.
- **UD**: No field hydraulic conductivity tests were performed by Ramboll in 2021 in wells screened within the Sangamon Soil of the UD. Previous field hydraulic conductivity tests conducted by NRT in 2017 in wells screened within the Sangamon Soil of the UD (APW02, APW03, and APW04) ranged from 5.14 x 10^{-6} to 4.53 x 10^{-5} cm/s, with a geometric mean hydraulic conductivity of 1.5 x 10^{-5} cm/s (OBG, 2017).
- **PMP**: Results of field hydraulic tests in wells screened within the Hagarstown PMP (APW05S and APW12) ranged from 6.1 x 10^{-4} to 1.5 x 10^{-2} cm/s, with a geometric mean hydraulic conductivity of 3.1 x 10^{-3} cm/s.
- **UCU**: No field hydraulic conductivity tests were performed as there are no wells screened within the UCU.
- **Uppermost Aquifer**: Results of field hydraulic tests in wells screened within the uppermost aquifer (APW11, APW13, APW14, APW15, APW16, APW17, and APW18) ranged from 2.0 x 10^{-4} to 1.5 x 10^{-1} cm/s, with a geometric mean of 6.8 x 10^{-3} cm/s. Previous field hydraulic conductivity tests conducted by NRT in 2017 obtained similar results with a geometric mean hydraulic conductivity of 1.2 x 10^{-3} cm/s (OBG, 2017). The highest conductivities are measured in APW15, APW16, and APW17, which is consistent with groundwater flow toward these wells. In addition, the grain-size analyses of the uppermost aquifer materials from two samples collected at APW17 were amongst the highest observed at the Site, with sand and gravel contents of 91.1 and 93.3 percent.
- **LCU**: No field hydraulic conductivity tests were performed as there are no wells screened within the LCU.
- **Bedrock**: No field hydraulic conductivity tests were performed as there are no wells screened within the bedrock unit.

3.2.5.2 Laboratory Hydraulic Conductivities

Falling head permeability tests (ASTM D5084 Method F) were performed in the laboratory on samples collected during the 2021 investigations. Sample locations are shown in **Figure 2-5**. The geotechnical laboratory report is provided in **Appendix D**. The results are summarized in **Table 2-1** and discussed below.

- **CCR**: Eight samples were collected from CCR borings XPW01 through XPW04. However, the two samples collected from XPW02 (8 to 8.5 and 16.5 to 17 feet bgs) were not representative of the ash and are not included in summary of CCR characteristics. Laboratory falling head permeability test results for the six CCR samples indicated a geometric mean vertical hydraulic conductivity of 3.1 x 10^{-4} cm/s with a range of 1.6 x 10^{-5} to 1.3 x 10^{-3} cm/s.
- **UD**: One sample was collected from the Sangamon Soil at borings APW11 and APW15. Laboratory falling head permeability test results in the UD indicated a geometric mean vertical hydraulic conductivity of 5.9 x 10^{-8} cm/s and ranged from 3.1 x 10^{-8} to 8.6 x 10^{-8} cm/s. These values are lower than previous samples collected by NRT in 2017, with a geometric mean hydraulic conductivity of 1.3 x 10^{-5} cm/s (OBG, 2017).
- **PMP**: Three samples were collected from the Hagarstown Member, a PMP within the UD, at borings APW12 and APW13. Laboratory falling head permeability test results for the

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Hagarstown Member indicated a geometric mean vertical hydraulic conductivity of 3.5×10^{-5} cm/s and ranged from 1.1×10^{-7} to 9.6×10^{-5} cm/s.

- **UCU**: Four samples were collected from the Vandalia Till at borings APW14, APW17, SB300/APW18, and SB301. Laboratory falling head permeability test results for the UCU samples indicated a geometric mean vertical hydraulic conductivity of 6.7×10^{-8} cm/s and ranged from 3.3×10^{-8} to 9.7×10^{-8} cm/s. These values are similar to a previous investigation completed by Rapps (1997) with hydraulic conductivity values ranging from 6.3×10^{-9} to 2.1×10^{-8} cm/s with a geometric mean hydraulic conductivity of 1.1×10^{-8} cm/s (Rapps, 1997).
- **UA**: Five samples were collected from the Mulberry Grove Formation at borings APW13, APW15, APW17, and APW18. Laboratory falling head permeability test results for the Mulberry Grove Formation indicated a geometric mean vertical hydraulic conductivity of 3.2×10^{-4} cm/s and ranged from 3.5×10^{-6} to 7.2×10^{-4} cm/s.
- **LCU**: Eight samples were collected from the glacial tills of the Smithboro Till at borings APW11, APW12, APW14, APW15, APW18, and SB301. Laboratory falling head permeability test results for the Smithboro Till indicated a geometric mean vertical hydraulic conductivity of 9.3×10^{-8} cm/s and ranged from 2.4×10^{-8} to 2.7×10^{-7} cm/s. No samples were collected from the Banner Formation of the LCU.
- **Bedrock**: No bedrock samples were analyzed.

3.2.6 Horizontal Groundwater Gradients and Flow Velocity

In the vicinity of the PAP, groundwater generally flows from north to south/southwest in the uppermost aquifer. Groundwater elevations and flow directions near the PAP are illustrated in 2021 contour maps (**Figures 3-3 and 3-4**). There is little seasonal variation in groundwater flow direction in the unlithified materials regardless of the lake elevation, as illustrated in **Figures 3-3 and 3-4** (historic contour maps are included in **Appendix E**). Horizontal gradients determined in 2021 across the PAP between wells APW10 and APW17 were very stable around the average of 2.5×10^{-3} feet/feet (ft/ft) with an average groundwater velocity of 1.88 feet per day (ft/day) (**Table 3-4**).

Horizontal gradients determined in 2021 across the northeastern portion of the CCR unit were very stable around the average of 7.1×10^{-3} ft/ft with an average groundwater velocity of 0.04 ft/day (**Table 3-4**).

3.2.7 Groundwater Classification

Per 35 I.A.C. § 620.210, groundwater within the uppermost aquifer at the PAP meets the definition of Class I – Potable Resource Groundwater based on the following criteria:

- Groundwater is located more than 10 feet bgs and within an unconsolidated silty sand and gravel unit which is five feet or more in thickness.
- Hydraulic conductivity exceeds the 1×10^{-4} cm/s criterion (**Table 3-3**).
- Groundwater is not downgradient of or underlying previously mined out areas.

Testing of the unconsolidated materials of the Mulberry Grove Member averaged 21 percent fines, which is greater than the 12 percent fines criterion (Section 2.5.5); however, this was not deemed prohibitive of the Class I Classification.

3.3 Surface Water Hydrology

3.3.1 Climate

Jasper County has a humid and temperate climate with a normal annual total precipitation of approximately 40 inches. Approximately two-thirds of the precipitation falls from April through September and is produced primarily by thunderstorms, with May having the highest average monthly precipitation. The average annual snowfall for the area is approximately 15 inches.

Average climatic data was obtained from the Illinois State Water Survey (ISWS). The data was recorded between 1989 and 2020 from Olney, Illinois, which is located approximately 16.5 miles southeast of the NPP. The data includes monthly maximum and minimum temperatures (degrees Fahrenheit [°F]) and monthly average rainfall calculated from daily values collected over the 31-year period. The data is summarized in **Table A**.

Table A. Average Monthly Temperature Extremes and Precipitation for Olney, IL

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max Temperature (ºF)	38.8	43.5	54.0	65.6	74.9	83.8	86.4	85.2	79.8	67.9	54.1	42.4	64.7
Min Temperature (ºF)	23.2	26.4	35.0	44.7	54.8	63.4	66.6	64.3	56.4	45.2	35.2	26.9	45.2
Precipitation (inches)	3.10	2.39	3.37	4.23	4.64	3.82	4.04	2.73	2.97	3.66	3.81	3.25	42.0

https://www.isws.illinois.edu/warm/stationmeta.asp?site=OLN&from=wx

3.3.2 Surface Waters

The major surface water body in the vicinity of the PAP is Newton Lake, an elongated body of water that borders the PAP on three sides (south, east, and west). The southern boundary of the PAP runs parallel to the north shore of the lake and is located approximately 250 to 700 feet from the water's edge (**Figure 1-1**). The surface water elevation measured from February 15 to March 9, 2021 ranged from 504.42 to 504.84 feet NAVD88 at location SG02 near the outfall from the Secondary Pond. Surface water elevations in Newton Lake are not expected to fluctuate greatly as a result of the lake elevation being controlled by a dam to provide cooling water for the NPP.

The phreatic surface within the PAP as measured at XSG01 and XPW01 through XPW04 ranged from 535.4 to 546.69 feet NAVD88 between February and July in 2021. Other surface waters in the vicinity include small freshwater ponds.

Other primary drainage ways in the area are Big Muddy Creek and Wolf Creek, which lie approximately 2.3 miles west and 1.7 miles east of the Site, respectively. In addition, minor streams and drainage channels cut across the drift plain in the area.

4. GROUNDWATER QUALITY

4.1 Summary of Groundwater Monitoring Activities

4.1.1 IEPA Program Monitoring

In accordance with NPDES Permit No. IL0049191 (effective October 1, 2015), samples are collected quarterly from four monitoring wells (G116, APW02, APW03, and APW04) for laboratory and/or field parameters listed in Special Condition No. 19 of the NPDES Permit. Groundwater monitoring results from sampling of these four wells are reported to IEPA annually in accordance with the NPDES Permit. Of the four wells monitored as part of the NPDES Permit monitoring, two wells (APW03 and APW04) are located downgradient of the PAP. The results of NPDES Permit monitoring wells APW03 and APW04 are not included in the discussion in **Section 4.2** as the groundwater samples were not analyzed for total metals.

4.1.2 40 C.F.R. § 257 Program Monitoring and Well Network

The 40 C.F.R. § 257 monitoring well network consists of six groundwater monitoring wells screened in the uppermost aquifer, including two background monitoring wells (APW05 and APW06) and four compliance wells (APW07, APW08, APW09, and APW10). The boring logs, well construction forms, and other related monitoring well forms for the well network are included in **Appendix C** of this HCR. The well locations are shown on **Figure 3-1**.

Groundwater is being monitored at the PAP in accordance with the Detection Monitoring Program requirements specified in 40 C.F.R. § 257.95. Details of the procedures and techniques used to fulfill the groundwater sampling and analysis program requirements are found in the Sampling and Analysis Plan for the PAP (NRT, 2017). Results are discussed in Section 4.2.

Groundwater samples are collected semi-annually and analyzed for the field and laboratory parameters from Appendix III of 40 C.F.R. § 257, summarized in **Table B** below.

Table B. 40 C.F.R. § 257 Groundwater Monitoring Program Parameters

Field Parameters[1]		
Groundwater Elevation	pH	
Appendix III Parameters (Total, except TDS)		
Boron	Chloride	Sulfate
Calcium	Fluoride	TDS

[1]Dissolved oxygen, temperature, specific conductance, oxidation/reduction potential, and turbidity are recorded during sample collection.

4.1.3 Part 845 Well Installation and Monitoring

In 2021, nine additional monitoring wells (APW11, APW12, APW13, APW14, APW15, APW16, APW17, APW18, and APW5S) were installed along the perimeter of the PAP to assess the vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet bgs as specified in 35 I.A.C. § 845.620(b). Additionally, four leachate monitoring wells (XPW01, XPW02, XPW03, and XPW04) were installed within the PAP unit to characterize CCR materials and leachate. These locations and samples were discussed in **Section 2.5.1**. The boring logs, well construction forms, and other related monitoring well forms

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for the well network are included in **Appendix C** of this HCR. The well locations are shown on **Figure 3-1**.

Prospective monitoring wells (APW02, APW03, APW04, APW05, APW05S, APW06, APW11, APW12, APW13, APW14, APW15, APW16, APW17, and APW18) were sampled for eight rounds between February and August 2021 and the results were used to develop this HCR and assess well locations for inclusion in the PAP Part 845 monitoring well network.

Groundwater samples were analyzed for 35 I.A.C. § 845.600 parameters summarized in **Table C** below. Part 845 groundwater monitoring results are included below in **Section 4.2**. A summary of groundwater analytical results is presented in **Table 4-1**.

Table C. Part 845 Groundwater Monitoring Program Parameters

Field Parameters[1]			
pH	Turbidity	Groundwater Elevation	
Metals (Total)			
Antimony	Boron	Cobalt	Molybdenum
Arsenic	Cadmium	Lead	Selenium
Barium	Calcium	Lithium	Thallium
Beryllium	Chromium	Mercury	
Inorganics (Total)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1]Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential were recorded during sample collection.

4.2 Groundwater Monitoring Results and Analysis

Groundwater data collected from the 40 C.F.R. § 257 network monitoring wells between 2015 and 2021 and from the wells installed in 2021 were evaluated with respect to standards included in 35 I.A.C. § 845.600(a)(1). This data set was selected because it includes parameters (total metals) consistent with the parameter list in 35 I.A.C. § 845.600(a)(1). The groundwater analytical results are summarized in **Table 4-1** and discussed in the subsections below. Groundwater elevations and field parameters are included in **Table 4-2**. Results indicate that the parameters discussed in the following sections were detected at concentrations greater than the applicable 35 I.A.C. § 845.600(a)(1) standards and are considered potential exceedances[1].

[1] Potential exceedances include results reported during the eight rounds of baseline groundwater monitoring that are greater than the applicable 35 I.A.C. § 845.600(a)(1) standards. The results are considered potential exceedances because they were compared directly to the standard and did not include an evaluation of background groundwater quality or apply the statistical methodologies proposed in the Groundwater Monitoring Plan (GMP). For simplicity, “GWPS” will be used hereafter in discussing potential exceedances. Exceedances will be determined following IEPA approval of the GMP.

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4.2.1 Arsenic

Arsenic was detected at concentrations greater than the GWPS (0.01 milligrams per liter [mg/L]) at six uppermost aquifer wells: downgradient wells APW08, APW09, APW15, and APW16; and background wells APW05 and APW06. Arsenic concentrations in downgradient wells ranged from 0.0039 to 0.022 mg/L. Arsenic concentrations in background wells ranged from 0.003 to 0.022 mg/L.

4.2.2 Chloride

Chloride was detected at concentrations greater than the GWPS (200 mg/L) in upgradient UD well APW05S and downgradient uppermost aquifer well APW15. Chloride concentrations in APW05S ranged from 180 to 550 mg/L. Chloride concentrations in uppermost aquifer well APW15 ranged from 230 to 260 mg/L.

4.2.3 Cobalt

Cobalt was detected at concentrations greater than the GWPS (0.006 mg/L) at PMP well APW12 with concentrations ranging from 0.0032 to 0.0073 mg/L. Concentrations have been below the GWPS for the last four consecutive sampling events.

4.2.4 Fluoride

Fluoride was detected at concentrations greater than the GWPS (4.0 mg/L) at downgradient uppermost aquifer well APW15 during one event (8.16 mg/L) and at APW18 with concentrations ranging from 0.597 to 7.02 mg/L.

4.2.5 Lead

Lead was detected at concentrations greater than the GWPS (0.0075 mg/L) at downgradient uppermost aquifer wells APW08, APW11, and APW18 with concentrations ranging from less than the reporting limit to 0.014 mg/L. Concentrations are less than the GWPS for the last five consecutive events.

4.2.6 Lithium

Lithium was detected at concentrations greater than the GWPS (0.04 mg/L) at three PMP wells APW02, APW04, and APW12; one upgradient UD well APW05S; and two downgradient uppermost aquifer wells APW13 and APW14. Lithium concentrations in the PMP wells ranged from 0.02 to 0.3 mg/L. Lithium concentrations in the upgradient well APW05S ranged from 0.038 to 0.091 mg/L. Lithium concentrations in the downgradient uppermost aquifer wells ranged from 0.024 to 0.054 mg/L.

4.2.7 pH

Groundwater samples collected with pH measurements below the lower range of the GWPS (6.5 standard units [SU]) were observed at four PMP wells APW02, APW03, APW04, APW12, one background well APW06, and two downgradient uppermost aquifer wells APW11 and APW13. Observed pH measurements in these PMP wells ranged from 5.4 to 7.7 SU. Observed pH measurements in the background well ranged from 6.4 to 7.8 SU. Observed pH measurements in these downgradient uppermost aquifer wells ranged from 6.1 to 7.4 SU.

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4.2.8 Radium 226 and 228 Combined

Radium 226 and 228 combined was detected at concentrations greater than the GWPS (5 picocuries per liter [pCi/L]) at downgradient uppermost aquifer well APW16 with concentrations ranging from 0.946 to 5.85 pCi/L.

4.2.9 Sulfate

Sulfate can be a primary indicator parameter of CCR leachate impacts on groundwater quality. Sulfate was detected at concentrations greater than the GWPS (400 mg/L) at three PMP wells APW02, APW04, and APW12; upgradient UD well APW05S; and one downgradient uppermost aquifer well APW10. Concentrations of sulfate in these PMP wells ranged from 290 to 3,200 mg/L. Concentrations of sulfate in the upgradient well ranged from 200 to 2,100 mg/L. Concentrations of sulfate in the downgradient uppermost aquifer well (APW10) ranged from 390 to 540 mg/L.

4.2.10 Thallium

Thallium was detected at concentrations greater than the GWPS (0.002 mg/L) at one background well APW06, and two downgradient uppermost aquifer wells APW11 and APW18. Concentrations of thallium in the background well ranged from less than the reporting limit to 0.0025 mg/L. Concentrations of thallium in these downgradient uppermost aquifer wells ranged from less than the reporting limit to 0.0036 mg/L.

4.2.11 Total Dissolved Solids

TDS was detected at concentrations greater than the GWPS (1,200 mg/L) at four PMP wells APW02, APW03, APW04, and APW12; and one upgradient UD well APW05S. Concentrations of TDS at these PMP wells ranged from 540 to 5,300 mg/L. Concentrations at this upgradient well ranged from 3,200 to 3,800 mg/L.

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5. EVALUATION OF POTENTIAL RECEPTORS

5.1 Water Well Survey

A potable water well inventory was completed in 2021 utilizing state databases to assess nearby pumping wells, drinking water receptors, and other uses of water in the vicinity of the PAP. The following sources of information were queried to identify well locations, drinking water receptors, and other uses of water within 1,000 meters of the PAP boundary:

- ISGS Illinois Water and Related Wells (ILWATER) Map[2]

A search of the ILWATER Map identified two wells located within 1,000-meters of the PAP (Well Nos. 120790038600 and 120790043600). Both wells are located to the southeast, or side-gradient, of the PAP and are listed as dry and abandoned. The assessment concluded there are no existing off-site water wells, potable or non-potable, that could potentially be impacted by groundwater from the PAP. The water well potential receptors are detailed in **Appendix B**.

5.2 Surface Water

A search was performed utilizing the United States Fish and Wildlife Service (USFWS) Wetlands Mapper[3] and the USGS National Map[4] for surface water bodies within 1,000 meters of the PAP. The predominant surface water body nearest the PAP is Newton Lake. Newton Lake is an approximately 1,648-acre freshwater lake partially encircling the PAP along the east, west, and south sides and at its closest point is approximately 240 feet downgradient from the PAP.

Additional surface water features indicated in the USFWS Wetlands Mapper and USGS National Map include several freshwater ponds ranging from 0.27 acres to 6.16 acres located generally north, west, and south of the PAP, riverine wetlands located north and northwest of the PAP, and an approximately 13.7-acre lake located to the north of the PAP.

The USGS National Map places the PAP within the Weather Creek Watershed (Hydrologic Unit Code [HUC] 051201140504), which is part of the Big Muddy Creek Watershed (HUC 0512011405) and located within the larger Little Wabash subbasin (HUC 05120114). The HUC watershed location is presented in **Appendix B**.

A Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map for Jasper County (Map No. 1709900125B; Effective Date: January 17, 1985 is attached in **Appendix G** and can also be viewed online at: https://www.illinoisfloodmaps.org/dfirm.aspx?county=jasper. No base flood elevation has been established for this region.

5.3 Nature Preserves, Historic Sites, Endangered/Threatened Species

A search of the Illinois Department of Natural Resources (IDNR) Natural Heritage Database[5] for natural areas and protected areas within 1,000 meters of the PAP was performed. No natural or protected areas were identified within 1,000 meters of the PAP (**Appendix B**).

[2] ISGS ILWATER Map: https://prairieresearch.maps.arcgis.com/apps/webappviewer/index.html?id=e06b64ae0c814ef3a4e43a191cb57f87
[3] USFWS Wetlands Mapper: https://www.fws.gov/wetlands/data/mapper.html
[4] USGS National Map: https://apps.nationalmap.gov/viewer/
[5] IDNR Natural Heritage Database: https://www2.illinois.gov/dnr/conservation/NaturalHeritage/Pages/NaturalHeritageDatabase.aspx

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The IDNR Natural Heritage Database Threatened and Endangered Species by County[6] lists 25 threatened and endangered species as located within Jasper County, including 18 endangered and 7 threatened species. Habitats for endangered or threatened species are identified at the county level only (**Appendix B**).

Additionally, a search of the IDNR Historic Preservation Division[7] databases for historic sites in the vicinity of the PAP yielded no results within 1,000 meters of the PAP. The Illinois State Archaeological Survey (ISAS)[8] databases that do not require credentials to access were also searched and yielded no results within 1,000 meters of the PAP.

[6] Illinois Threatened and Endangered Species by County: https://www2.illinois.gov/dnr/ESPB/Documents/ET_by_County.pdf
[7] IDNR Historic Preservation Division: https://www2.illinois.gov/dnrhistoric/Pages/default.aspx
[8] ISAS: https://www.isas.illinois.edu/

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6. CONCLUSIONS

Hydrogeologic characterization of the PAP was originally developed as part of the *Hydrogeologic Investigation and Groundwater Monitoring Program, Newton Power Station, Jasper County, Illinois* (Rapps, 1997) and most recently updated for this HCR. Results of these hydrogeologic studies were reintroduced in this HCR and updated to include geologic, hydrogeologic, and groundwater quality data collected with a focus on the PAP (Part 845 regulated) CCR Unit and subject of this HCR.

The data were summarized and evaluated for changes in groundwater conditions since the previous investigations; available groundwater quality data for the PAP was compared to the to the Part 845 Standards.

The results of the hydrogeologic and groundwater quality evaluation are:

- There are six types of unlithified material present in the vicinity of the PAP, these include the following in descending order:
  - **CCR and Fill Material:** CCR and reworked surface materials within and adjacent to the various CCR Units.
  - **Peoria Silt and Sangamon Soil** (wind-blown deposits and weathered till)**:** Clays and silts, including the Peoria Silt (Loess Unit) in upland areas, underlain by the Sangamon Soil which is comprised of weathered glacial drift.
  - **Hagarstown Member:** Where present, consists of relatively thin sandy deposits between the clays and silts of the Sangamon Soil and the Vandalia Till.
  - **Vandalia Till Member:** Compacted clay and silt glacial till with varying amounts of sand and gravel (diamicton).
  - **Mulberry Grove Member:** Sand, silty sand, and sandy silt/clay units found between the Vandalia Till and the Smithboro Till. These sandy deposits are the first laterally continuous sands observed beneath the PAP.
  - **Smithboro Till Member and Banner Formation:** Thick, gray compacted silty clay diamicton of the Smithboro Till and the greenish-gray silty clay of the Banner Formation.
- Bedrock underlying the PAP is the Pennsylvanian Age Mattoon Formation, which consists of a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well-developed sandstones.
- Six hydrostratigraphic units have been identified at the PAP based on stratigraphic relationships and common hydrogeologic characteristics, these include the following in descending order:
  - **CCR**: CCR consisting of fly and bottom ash within the PAP.
  - **UD/PMP**: The UD is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.,* PMP).
    - **Hagarstown Member/PMP**: The Hagarstown Member consists of the discontinuous, sandier deposits of the UD where present and overlies the Vandalia Till.
  - **UCU**: This unit consists of the low permeability clay and silt of the Vandalia Till.

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  - **Uppermost Aquifer**: This unit is composed of the Mulberry Grove Formation, which onsite has been classified as poorly graded sand, silty sand, clayey sand, and gravel.
  - **LCU**: This unit is comprised of low permeability silt and clay of the Smithboro Till and the Banner Formation.
  - **Bedrock Confining Unit**: Bedrock was classified as shale of the Mattoon Formation in locations it was encountered during 2021 investigation activities (APW13 and APW14).

- Groundwater within the uppermost aquifer flows generally from north to south. However, uppermost aquifer wells also display flow converging towards a former surface drainage feature located west of the PAP (resulting in a southwest flow direction). Groundwater elevations vary seasonally, generally less than one foot per year, while across the PAP they range from approximately 490 to 530 feet NAVD88, although flow directions are generally consistent.
- The surface water elevation at Newton Lake measured from February 15 to March 9, 2021 ranged from 504.42 to 504.84 feet NAVD88 at location SG02. Groundwater flow in the uppermost aquifer generally flows southwest across the PAP with potentiometric surface elevations at downgradient wells around 491 feet (approximately 15 feet lower than the lake elevation). This separation in groundwater and Lake elevations (and observed downward vertical gradients) indicates groundwater does not flow into Newton Lake.
- Groundwater velocities in the uppermost aquifer range from 0.04 ft/day in the north and east portion of the site to 1.9 ft/day in the south and west portion of the PAP.
- The phreatic surface within the PAP is higher than groundwater elevations; however, there is a significant thickness of low permeability Vandalia Till (UCU) that separates the base of the unit from the uppermost aquifer. Groundwater flow within the uppermost aquifer does not appear to be influenced by the PAP.
- Based on the detailed geologic information provided, and the hydrogeologic and groundwater quality data, groundwater within the uppermost aquifer at the PAP is classified as Class I – Potable Resource Groundwater.
- Arsenic, chloride, fluoride, lead, lithium, pH, radium 226 and 228 combined, sulfate, and thallium were detected at concentrations/measurements greater than the GWPS in downgradient uppermost aquifer wells. Cobalt, lithium, pH, sulfate, and TDS were detected at concentrations/measurements greater than the GWPS at PMP wells. Arsenic, chloride, lithium, pH, sulfate, thallium, and TDS were detected at concentrations/measurements greater than the GWPS in background monitoring wells.

This HCR satisfies Part 845 content requirements specific to 35 I.A.C. § 845.620(b) (Hydrogeologic Site Characterization) for the PAP at the NPP.

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TABLES

TABLE 2-1. GEOTECHNICAL DATA SUMMARY
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample ID	Field Location ID	Top of Sample (ft bgs)	Bottom of Sample (ft bgs)	HSU	Moisture Content (%)	Dry Density (pcf)	Specific Gravity	Calculated Porosity [1] (%)	Vertical Hydraulic Conductivity (cm/s)	LL	PL	PI	Laboratory USCS	Gravel (%)	Sand (%)	Fines (%)
Sangamon Soil																
APW11	APW11	10	12	UD	17.8	111.7	2.645	32	8.57E-08	28	12	16	CL	1.1	45.1	53.8
APW15	APW15	20	22	UD	18.5	109.8	2.686	34	3.21E-08	33	10	23	CL	0.0	40.8	59.2
Hagarstown Member																
APW12	APW12	20	22	UD/PMP	15.1	118.3	2.694	30	1.07E-07	27	12	15	SC	7.4	46.8	45.8
APW12	APW12	25.5	26	UD/PMP	8.4	113.0	2.654	32	8.43E-06	10	13	NP	SP-SM	24.3	69.5	6.2
APW13	APW13	25	27	UD/PMP	21.2	87.1	2.649	47	9.63E-05	9	10	NP	SP-SM	0.0	88.9	11.1
Vandalia Till Member																
APW14	APW14	45	47	UCU	12.4	119.6	2.706	29	9.65E-08	26	14	12	CL	4.4	32.3	63.3
APW17	APW17	40	42	UCU	16.6	108.8	2.709	36	3.34E-08	26	13	13	CL	1.3	27.6	71.1
SB300	APW18	50	52	UCU	12.9	122.7	2.700	27	7.29E-08	32	12	20	CL	0.8	22.4	76.8
SB301	SB301	48	50	UCU	14.1	117.3	2.697	30	6.63E-08	27	14	13	CL	0.4	34.2	65.4
Mulberry Grove Member																
APW13	APW13	60.5	61	UA	14.5	114.3	2.661	31	2.18E-04	8	13	NP	SM	0.3	75.2	24.5
APW15	APW15	100.5	101	UA	12.1	116.4	2.665	30	3.50E-06	15	12	3	SM	4.4	49.8	45.8
APW17	APW17	71	71.5	UA	7.8	110.2	2.660	34	7.21E-04	5	9	NP	SW-SM	14.3	76.8	8.9
APW17	APW17	90.5	91	UA	6.1	116.8	2.672	30	6.39E-04	6	8	NP	SP-SM	28.2	65.1	6.7
SB300	APW18	61	61.5	UA	13.6	109.6	2.686	35	1.85E-05	5	9	NP	SM	4.7	78.2	17.1
Smithboro Till Member																
APW11	APW11	61	61.5	LCU	17.8	110.5	2.686	34	1.87E-07	27	18	9	CL	0.0	21.4	78.6
APW11	APW11	80	82	LCU	16.5	116.1	2.705	31	2.94E-08	32	14	18	CL	0.0	21	79
APW12	APW12	85	87	LCU	14.4	116.4	2.711	31	2.36E-08	29	14	15	CL	0.3	19.5	80.2
APW14	APW14	55.5	56	LCU	18.0	104.6	2.709	38	2.74E-07	25	15	10	CL	0.0	27.8	72.2
APW15	APW15	105	107	LCU	19.1	107.8	2.695	36	8.20E-08	29	13	16	CL	0.0	23.8	76.2
SB300	APW18	62.5	63	LCU	11.1	124.6	2.659	25	4.32E-06	20	14	6	CL-ML	0.0	42.4	57.6
SB300	APW18	105	107	LCU	14.1	116.4	2.710	31	4.28E-08	28	13	15	CL	0.0	30.7	69.3
SB301	SB301	68.5	69	LCU	13.1	121.3	2.723	29	4.05E-08	23	14	9	CL	0.0	31.3	68.7
SB301	SB301	98	100	LCU	15.7	118.2	2.720	30	6.13E-08	37	15	22	CL	0.0	17.8	82.2
CCR																
XPW01	XPW01	8.5	9	CCR	18.6	87.7	2.675	47	1.71E-04	47	57	NP	SP-SM	37.1	51.1	11.8
XPW01	XPW01	15.5	16	CCR	12.6	84.4	2.741	51	1.58E-05	35	17	18	CL	4.6	34.1	61.3
XPW03	XPW03	6	6.5	CCR	17.4	75.3	2.663	55	1.34E-03	33	27	6	SM	6.8	71.7	21.5
XPW03	XPW03	15.5	16	CCR	16.7	103.6	2.689	38	9.70E-05	12	19	NP	SM	16.4	67.3	16.3
XPW04	XPW04	6.5	7	CCR	31.1	73.9	2.697	56	1.61E-04	41	38	3	SM	1.6	84.5	13.9
XPW04	XPW04	15.5	16	CCR	31.1	80.8	2.650	51	7.83E-05	46	42	4	SM	15.7	51	33.3

TABLE 2-1. GEOTECHNICAL DATA SUMMARY
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample ID	Field Location ID	Top of Sample (ft bgs)	Bottom of Sample (ft bgs)	HSU	Moisture Content (%)	Dry Density (pcf)	Specific Gravity	Calculated Porosity [1] (%)	Vertical Hydraulic Conductivity (cm/s)	LL	PL	PI	Laboratory USCS	Gravel (%)	Sand (%)	Fines (%)
Fill																
XPW02	XPW02	8	8.5	CCR	29.1	92.9	2.691	45	6.07E-08	36	16	20	CL	0.3	44.8	54.9
XPW02	XPW02	16.5	17	CCR	21.8	103.7	2.694	38	7.38E-08	36	14	22	CL	0.0	19.8	80.2

[O: SSW 04/22/21, U:EDP 08/23/21, U: SSW 08/26/21, C: LDC 08/31/21; U: LDC 09/16/21, C: SSW 09/21/21]

Notes:
[1] Porosity calculated as relationship of bulk density to particle density (n = 100[1- (pb/pd)])
% = Percent
bgs = below ground surface
CCR = coal combustion residuals
cm/s = centimeters per second
ft = foot/feet
in = inch
LL = Liquid limit
NP = Non Plastic
pcf = pounds per cubic foot
PI = Plastic Index
PL = Plasticity Limit

HSU = Hydrostratigraphic Unit
LCU = lower confining unit
PMP = potential migration pathway
UA = uppermost aquifer
UCU = upper confining unit
UD = upper drift

USCS = Unified Soil Classification System
CL - Lean Clay
CL-ML = Silty Lean Clay
SC = Clayey Sand
SM = Silty Sand
SP-SM = Poorly Graded Sand with Silt
SW-SM = Well Graded Sand with Silt

TABLE 2-2. ASH ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Depth (ft BGS)	Sample Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Lead (mg/kg)	Lithium (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)
XPW01	6-8	01/20/2021	<4.1	7.5	1800	1.6	260	<1.4	27	12	21	15	0.53	3.3	5.8	<1.4
XPW01	13-15	01/20/2021	<4	12	2400	2	390	<1.3	33	18	24	21	0.74	4.5	8.1	<1.3
XPW02	9-10	01/19/2021	<3	2.6	1900	1.2	94	<1	13	6.7	5	10	<0.2	1.2	<1	<1
XPW02	11.5-13.5	01/19/2021	<4.6	19	570	<1.5	69	<1.5	14	5	6.9	<7.7	<0.31	21	2.1	<1.5
XPW03	7.5-9	01/19/2021	<4.4	7.4	3600	1.8	280	<1.5	31	15	21	16	<0.29	3.6	3	<1.5
XPW03	17-19	01/19/2021	<3.6	27	490	1.3	95	<1.2	22	3.1	6.3	6.7	<0.24	3.4	1.3	<1.2
XPW04	13-15	01/19/2021	<3.4	9.4	1100	1.9	310	<1.1	26	13	21	18	0.69	3.6	5.9	<1.1
XPW04	17-19	01/19/2021	<5.6	9	4100	2.2	320	<1.9	33	15	21	18	<0.37	3.7	3.4	<1.9

Notes:
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
BGS = below ground surface
ft = feet
mg/kg = milligrams per kilogram

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TABLE 2-3. POREWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)
XPW01	02/17/2021	<0.003	0.042	0.035	<0.001	9.5	<0.004	62	49	<0.004	<0.008	2.17	<0.001	0.11	0.015	0.66	12.3	0.0059	0.23	19000	<0.001
XPW01	03/09/2021	<0.003	0.049	0.14	<0.001	11	<0.001	63	38	<0.004	<0.002	2.37	<0.001	0.13	0.014	0.59	12.4	0.211	0.21	14000	<0.001
XPW01	03/30/2021	<0.003	0.049	0.064	<0.001	9.9	<0.001	54	32	<0.004	<0.002	2.7	<0.001	0.14	0.011	0.54	12.4	0	0.19	19000	<0.001
XPW01	04/28/2021	<0.003	0.054	0.46	<0.001	10	<0.001	61	33	0.008	0.003	2.61	0.0039	0.074	0.013	0.53	12.3	0.157	0.17	12000	<0.001
XPW01	06/30/2021	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.19	--	--	--
XPW01	07/14/2021	<0.003	0.052	0.039	<0.001	12	<0.001	31	27	<0.004	<0.002	1.92	<0.001	0.15	0.012	0.38	12.2	0.167	0.12	11000	<0.001
XPW02	02/17/2021	<0.003	0.092	0.017	<0.001	2.3	<0.001	15	10	<0.004	<0.002	0.762	<0.001	<0.02	<0.0002	0.093	8.6	0.096	<0.001	160	<0.001
XPW02	03/09/2021	<0.003	0.091	0.024	<0.001	2.5	<0.001	20	9.6	<0.004	<0.002	0.61	<0.001	<0.02	<0.0002	0.097	9.2	0.705	<0.001	150	<0.001
XPW02	03/30/2021	<0.003	0.085	0.05	<0.001	2.4	<0.001	22	9.9	<0.004	<0.002	0.575	<0.001	0.026	<0.0002	0.1	8.9	0.832	<0.001	160	<0.001
XPW02	04/28/2021	<0.003	0.082	0.042	<0.001	2.6	<0.001	25	9.7	<0.004	<0.002	0.637	<0.001	0.023	<0.0002	0.11	9.9	0.668	<0.001	190	<0.001
XPW02	06/30/2021	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.026	--	--	--
XPW02	07/14/2021	<0.003	0.077	0.025	<0.001	2.5	<0.001	21	10	<0.004	<0.002	0.508	<0.001	0.028	<0.0002	0.086	9.7	0.388	<0.001	160	<0.001
XPW03	02/17/2021	<0.003	0.036	0.069	<0.001	1.3	<0.001	42	14	<0.004	<0.002	0.466	<0.001	0.032	<0.0002	0.061	10.9	0.204	0.0023	92	<0.001
XPW03	03/09/2021	<0.003	0.031	0.11	<0.001	1.2	<0.001	47	9.2	<0.004	<0.002	0.569	<0.001	0.024	<0.0002	0.054	10.8	0.576	0.0038	93	<0.001
XPW03	03/30/2021	<0.003	0.014	0.088	<0.001	0.84	<0.001	44	13	<0.004	<0.002	0.384	<0.001	0.025	<0.0002	0.027	10.2	0.451	0.0019	94	<0.001
XPW03	04/28/2021	<0.003	0.035	0.37	<0.001	1.2	<0.001	55	11	0.0055	<0.002	0.598	0.0027	0.029	<0.0002	0.054	11.3	0.613	0.0017	96	<0.001
XPW03	06/30/2021	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.47	--	--	--
XPW03	07/14/2021	<0.003	0.032	0.44	<0.001	1.3	<0.001	72	11	0.0068	0.0021	0.372	0.0036	0.04	<0.0002	0.055	11.2	0.57	0.0019	120	<0.001
XPW04	02/17/2021	<0.003	0.0065	0.13	<0.001	2.5	<0.001	80	62	<0.004	<0.002	0.618	<0.001	0.021	0.00029	0.37	10.8	0.0723	0.055	2200	<0.001
XPW04	03/09/2021	<0.003	0.0067	0.15	<0.001	2.4	<0.001	65	34	<0.004	<0.002	0.602	<0.001	<0.02	<0.0002	0.19	10.0	0.374	0.028	1400	<0.001
XPW04	03/29/2021	<0.003	0.0062	0.3	<0.001	2.1	<0.001	53	31	0.005	<0.002	0.605	<0.001	<0.02	<0.0002	0.059	9.1	0.62	0.0074	600	<0.001
XPW04	04/28/2021	<0.003	0.0071	0.22	<0.001	2.8	<0.001	120	37	<0.004	<0.002	0.628	<0.001	0.02	0.00027	0.52	11.5	0.0889	0.083	3800	<0.001
XPW04	06/30/2021	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1.66	--	--	--
XPW04	07/14/2021	<0.003	0.0067	0.089	<0.001	2.3	<0.001	60	34	<0.004	<0.002	0.542	<0.001	<0.02	<0.0002	0.14	10.0	0.36	0.02	1600	<0.001

TABLE 2-3. POREWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)

Notes:
Field readings are reported with as many significant figures as provided by analytical laboratory.
-- = data not available
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
mg/L = milligrams per liter
pCi/L = picocuries per liter
SU = standard units

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TABLE 2-4. SOIL ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Geologic Unit	Sample Depth (ft BGS)	Sample Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Lead (mg/kg)	Lithium (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)
APW11	Peoria Silt/Sangamon Soil	8-10	01/23/2021	<3.6	4.3	45	<1.2	<12	<1.2	7.3	9.4	8.5	<6.1	<0.24	<1.2	<1.2	<1.2
APW11	Mulberry Grove Member	62-64	01/23/2021	<3.5	2.8	16	<1.2	<12	<1.2	7.1	4.3	5.7	7.3	<0.23	<1.2	<1.2	<1.2
APW11	Smithboro Till Member	94-96	01/23/2021	<3.6	8.9	86	<1.2	<12	<1.2	9.8	5.7	8.6	<6	<0.24	1.2	<1.2	<1.2
APW12	Hagarstown Member	22-23.5	01/21/2021	<3.6	2.4	46	<1.2	<12	<1.2	13	7.4	8.4	10	<0.24	<1.2	<1.2	<1.2
APW12	Hagarstown Member	23.5-25	01/21/2021	<3.8	1.4	9.7	<1.3	<13	<1.3	<5.1	<2.5	1.7	<6.3	<0.25	<1.3	<1.3	<1.3
APW12	Smithboro Till Member	83-85	01/21/2021	<3.2	22	65	<1.1	<11	<1.1	11	9.4	13	7.8	<0.21	1.3	<1.1	<1.1
APW13	Sangamon Soil	23-25	01/22/2021	<3.1	2.4	41	<1	<10	<1	11	5.5	8.6	10	<0.21	<1	<1	<1
APW13	Mulberry Grove Member	58-60	01/22/2021	<4	4.6	25	<1.3	<13	<1.3	10	6.7	8.6	<6.6	<0.26	2.3	<1.3	<1.3
APW13	Banner Formation	78-80	01/22/2021	<3.1	5.9	57	<1	<10	<1	16	9.7	12	20	<0.21	2.5	<1	<1
APW14	Mulberry Grove Member	48-50	01/23/2021	<3.2	3.7	11	<1.1	<11	<1.1	6.6	3.9	6	6.3	<0.21	1.4	<1.1	<1.1
APW14	Smithboro Till Member	88-90	01/23/2021	<3.2	4.1	83	<1.1	<11	<1.1	12	7.2	15	9.6	<0.21	<1.1	1.2	<1.1
APW15	Hagarstown Member	23-25	01/21/2021	<3	<1	42	<1	<10	<1	5.1	<2	7.5	<5.1	<0.2	<1	<1	<1
APW15	Vandalia Till Member	85-87	01/21/2021	<3	1.8	14	<1	<10	<1	<4	<2	3.2	<5	<0.2	<1	<1	<1
APW15	Smithboro Till Member	102-104	01/22/2021	<3.5	1.8	14	<1.2	<12	<1.2	<4.7	<2.3	3.5	<5.9	<0.23	<1.2	<1.2	<1.2
APW17	Vandalia Till Member	38-40	01/22/2021	<3.1	3.4	21	<1	<10	<1	7.5	5.7	7.7	7	<0.21	1.5	<1	<1
APW17	Mulberry Grove Member	68-70	01/22/2021	<3	1.8	12	<1	<10	<1	<4	<2	2.8	<5	<0.2	<1	<1	<1
APW17	Mulberry Grove Member	88-90	01/22/2021	<3	5.9	37	<1	<10	<1	7.8	10	6.9	<5	<0.2	1.4	<1	<1

TABLE 2-4. SOIL ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Geologic Unit	Sample Depth (ft BGS)	Sample Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Lead (mg/kg)	Lithium (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Selenium (mg/kg)	Thallium (mg/kg)
APW17	Smithboro Till Member	94-96	01/22/2021	<3.5	4.2	75	<1.2	<12	<1.2	8.6	4.6	7.4	7.6	<0.24	<1.2	<1.2	<1.2
XPW02	Fill	9-10	01/19/2021	<3	2.6	1900	1.2	94	<1	13	6.7	5	10	<0.2	1.2	<1	<1
XPW02	Fill	11.5-13.5	01/19/2021	<4.6	19	570	<1.5	69	<1.5	14	5	6.9	<7.7	<0.31	21	2.1	<1.5

Notes:
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method.
BGS = below ground surface
ft = foot or feet
mg/kg = milligrams per kilogram

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TABLE 3-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft BGS)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
APW02	UD	06/19/2010	533.61	533.61	Top of Riser	529.90	9.70	19.70	520.20	510.20	20.00	509.90	10	2	38.925918	-88.293907
APW03	UD	06/18/2010	532.41	532.41	Top of Riser	528.37	9.70	19.70	518.67	508.67	20.00	508.40	10	2	38.922322	-88.281567
APW04	UD	06/19/2010	525.06	525.06	Top of Riser	521.45	7.70	17.70	513.75	503.75	18.00	503.50	10	2	38.927444	-88.273113
APW05	UA	10/22/2015	544.07	544.07	Top of Riser	541.08	62.64	67.44	478.44	473.64	67.84	473.10	4.8	2	38.933958	-88.280983
APW05S	UD	01/19/2021	543.94	543.94	Top of PVC	541.05	10.00	20.00	531.05	521.05	20.00	518.10	10	2	38.933958	-88.281033
APW06	UA	10/21/2015	546.07	546.07	Top of Riser	542.89	67.67	72.48	475.22	470.41	72.88	468.90	4.8	2	38.933746	-88.286276
APW07	UA	11/05/2015	538.37	538.37	Top of Riser	535.72	77.89	82.70	457.83	453.02	83.10	452.60	4.8	2	38.928233	-88.292076
APW08	UA	10/28/2015	528.97	528.97	Top of Riser	526.26	71.40	81.06	454.86	445.20	81.53	444.30	9.7	2	38.923154	-88.292286
APW09	UA	11/03/2015	531.52	531.52	Top of Riser	528.33	56.66	61.46	471.67	466.87	61.85	466.30	4.8	2	38.922319	-88.281585
APW10	UA	11/06/2015	524.25	524.25	Top of Riser	521.49	40.74	45.54	480.75	475.95	45.94	475.60	4.8	2	38.927435	-88.273127
APW11	UA	01/23/2021	538.63	538.63	Top of PVC	536.05	60.00	65.00	476.05	471.05	65.00	436.10	5	2	38.932811	-88.27545
APW12	UD	02/21/2021	546.29	546.29	Top of PVC	543.33	20.00	30.00	523.33	513.33	30.00	456.30	10	2	38.92975	-88.272058
APW13	UA	01/22/2021	537.99	537.99	Top of PVC	535.16	58.50	63.50	476.66	471.66	63.50	445.20	5	2	38.92566	-88.274416
APW14	UA	01/23/2021	526.29	526.29	Top of PVC	523.85	50.00	55.00	473.85	468.85	55.00	428.90	5	2	38.924057	-88.277994
APW15	UA	01/22/2021	524.69	524.69	Top of PVC	522.06	98.00	103.00	424.06	419.06	103.00	412.10	5	2	38.921593	-88.285226
APW16	UA	01/20/2021	531.18	531.18	Top of PVC	529.16	80.50	85.50	448.66	443.66	85.50	419.20	5	2	38.920317	-88.291291
APW17	UA	01/22/2021	532.52	532.52	Top of PVC	529.84	87.00	92.00	442.84	437.84	92.00	429.80	5	2	38.925916	-88.293928
APW18	UA	01/21/2021	543.27	543.27	Top of PVC	540.55	75.00	80.00	465.55	460.55	80.00	433.60	5	2	38.930979	-88.290122
G48MG	UA	10/20/2015	545.53	545.53	Top of Riser	542.68	71.80	76.65	470.88	466.03	77.06	465.60	4.9	2	38.939248	-88.296012
G202	UA	10/16/1996	539.69	539.69	Top of Riser	536.85	64.00	74.00	472.85	462.85	74.00	462.90	10	2	38.930876	-88.290559
G203	UA	11/15/1996	533.13	533.13	Top of Riser	530.73	62.50	72.50	468.23	458.23	72.50	458.20	10	2	38.928597	-88.292217
G208	UA	10/13/2011	535.03	535.03	Top of Riser	533.19	74.93	94.71	458.26	438.48	94.80	438.20	19.8	2	38.929632	-88.298182
G217S	UD	08/26/1997	537.98	537.98	Top of Riser	535.54	9.00	19.00	526.54	516.54	19.00	510.50	10	2	38.932171	-88.290041

TABLE 3-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft BGS)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
G217D	UA	12/09/2014	537.92	537.92	Top of Riser	535.51	--	--	--	--	69.30	--	--	--	38.932174	-88.29008
G222	UA	10/25/2011	534.32	534.32	Top of Riser	532.38	64.57	79.24	467.81	453.14	79.30	452.40	14.7	2	38.927194	-88.299669
G223	UA	10/11/2011	533.60	533.60	Top of Riser	531.68	79.09	88.75	452.59	442.93	89.10	442.60	9.7	2	38.93016	-88.293451
G224	UA	10/05/2011	534.31	534.31	Top of Riser	532.31	63.51	73.17	468.80	459.14	73.50	458.30	9.7	2	38.931767	-88.292396
R202	UA	--	--	--	--	--	--	--	--	--	--	--	--	--	38.930879	-88.290581
R217D	UA	09/26/2017	538.18	538.18	Top of Riser	535.60	60.10	65.03	475.50	470.57	65.24	470.40	4.9	2	38.932191	-88.290118
XPW01	CCR	01/20/2021	551.76	551.76	Top of PVC	548.62	7.00	17.00	541.62	531.62	17.00	528.60	10	2	38.932212	-88.285525
XPW02	CCR	01/19/2021	554.43	554.43	Top of PVC	551.97	6.00	16.00	545.97	535.97	16.00	532.00	10	2	38.932343	-88.28289
XPW03	CCR	01/19/2021	553.65	553.65	Top of PVC	550.81	10.00	20.00	540.81	530.81	20.00	530.80	10	2	38.931062	-88.27641
XPW04	CCR	01/19/2021	554.51	554.51	Top of PVC	551.90	10.00	20.00	541.90	531.90	20.00	531.90	10	2	38.929888	-88.274073
XSG01	CCR	--	--	536.17	Staff gauge	--	--	--	--	--	--	--	--	--	38.923218	-88.29067
SG02	SW	--	--	506.89	Staff gauge	--	--	--	--	--	--	--	--	--	38.921234	-88.292057

Notes:
All elevation data are presented relative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
-- = data not available
BGS = below ground surface
CCR = Coal Combustion Residual
ft = foot or feet
HSU = Hydrostratigraphic Unit
PVC = polyvinyl chloride
SW = surface water
UA = uppermost aquifer
UD = upper drift

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TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, IL

Date	APW05S Groundwater Elevation (ft NAVD88)	APW05 Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	PMP	UA				
2/15/2021	533.90	529.83	4.07	50.01	0.081	down
3/9/2021	533.71	529.61	4.10	50.01	0.082	down
3/29/2021	533.91	529.68	4.23	50.01	0.085	down
4/27/2021	533.56	529.73	3.83	50.01	0.077	down
5/25/2021	533.23	529.51	3.72	50.01	0.074	down
6/15/2021	532.54	529.42	3.12	50.01	0.062	down
6/24/2021	531.93	529.38	2.55	50.01	0.051	down
7/14/2021	532.16	529.33	2.83	50.01	0.057	down
			Middle of screen elevation APW05S			526.05
			Middle of screen elevation APW05			476.04

Date	APW04 Groundwater Elevation (ft NAVD88)	APW10 Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	PMP	UA				
2/15/2021	518.19	506.65	11.54	30.40	0.38	down
3/9/2021	519.50	505.10	14.40	30.40	0.47	down
3/29/2021	520.34	506.94	13.40	30.40	0.44	down
4/27/2021	519.87	506.53	13.34	30.40	0.44	down
5/24/2021	519.73	506.35	13.38	30.40	0.44	down
6/15/2021	519.68	506.26	13.42	30.40	0.44	down
6/24/2021	529.51	506.12	23.39	30.40	0.77	down
7/14/2021	519.99	506.59	13.40	30.40	0.44	down
			Middle of screen elevation APW04			508.8
			Middle of screen elevation APW10			478.4

TABLE 3-2. VERTICAL HYDRAULIC GRADIENTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, IL

Date	APW03 Groundwater Elevation (ft NAVD88)	APW09 Groundwater Elevation (ft NAVD88)	Head Change (ft)	Distance Change [1] (ft)	Vertical Hydraulic Gradient [2] (dh/dl)	
	PMP	UA				
2/15/2021	523.58	504.93	18.65	47.00	0.40	down
3/9/2021	524.93	505.10	19.83	47.00	0.42	down
3/29/2021	526.00	505.23	20.77	47.00	0.44	down
4/27/2021	524.25	504.74	19.51	47.00	0.42	down
5/25/2021	523.85	- - -	- - -	- - -	- - -	- - -
6/15/2021	523.41	504.63	18.78	47.00	0.40	down
6/24/2021	523.18	504.48	18.70	47.00	0.40	down
7/14/2021	523.70	505.24	18.46	47.00	0.39	down
			Middle of screen elevation APW03			518.7
			Middle of screen elevation APW09			471.7

[O:SSW 09/09/21; U:SSW 08/31/21; C: LDC 08/31/21]

Notes:
[1] Distance change was calculated using the midpoint of the piezometer screen and water table surface. If the water table surface was above the top of the monitoring well screen, then distance change was calculated using the midpoint of both screens.
[2] Vertical gradients between ±0.0015 are considered flat, and typically have less than 0.02 foot difference in groundwater elevation between wells.
- - - = no data collected on date / no vertical gradient calculated
dh = head change
dl = distance change
ft = foot/feet
LCU = lower confining unit
NAVD88 = North American Vertical Datum of 1988
PMP = potential migration pathway
UA = uppermost aquifer

TABLE 3-3. FIELD HYDRAULIC CONDUCTIVITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, ILLINOIS

Well ID	Gradient Position	Bottom of Screen Elevation (ft NAVD88)	Screen Length [1] (ft)	Field Identified Screened Material	Slug Type	Analysis Method	Falling Head (Slug In) K (cm/s)			Rising Head (Slug Out) K (cm/s)			Minimum Hydraulic Conductivity (cm/s)	Maximum Hydraulic Conductivity (cm/s)	Hydraulic Conductivity Geometric Mean (cm/s)
							1	2	3	1	2	3			
Upper Drift Unit/Potential Migration Pathway															
APW5S	U	521.05	10	SP	Solid	C-B-P	8.9E-04	7.4E-04		6.1E-04	8.5E-04		6.1E-04	1.5E-02	3.1E-03
APW12	U	513.33	10	SP	Solid	C-B-P	1.3E-02	9.8E-03		1.3E-02	1.5E-02				
Uppermost Aquifer															
APW11	U	471.05	5	SP-SC/GP	Solid	KGS Model	6.8E-03	5.9E-03		3.5E-03	7.8E-03		2.0E-04	1.5E-01	6.8E-03
APW13	D	471.66	5	SM	Solid	C-B-P	1.6E-03	1.5E-03	3.3E-03	3.8E-03	3.4E-03				
APW14	D	468.85	5	SC	Solid	KGS Model	3.9E-03	4.3E-03		3.2E-04	3.2E-04	2.8E-03			
APW15	D	419.06	5	SP-SM	Solid	KGS Model	4.9E-04	2.0E-04	1.4E-01	1.5E-01	1.5E-01				
APW16	D	443.66	5	SP	Solid	B-Z	1.24E-01	1.41E-01		7.60E-02	7.96E-02				
APW17	D	437.84	5	(SW)g/(SP)g	Solid	C-B-P	1.13E-01	1.15E-02							
APW18	D	460.55	5	(SW)g/SC	Solid	C-B-P	2.67E-04								
Ash Pond															
XPW01	CCR	531.62	10	(SW)g	Solid	Bouwer-Rice	1.8E-01	1.3E-02		2.4E-02	1.4E-02		1.0E-03	2.3E-01	2.0E-02
XPW02	CCR	535.97	10	(SW)g	Solid	Bouwer-Rice	2.0E-03	2.6E-03							
XPW03	CCR	530.81	10	(SW)g/SP	Solid	Bouwer-Rice	5.7E-02	7.2E-02	2.3E-01	1.5E-01	1.2E-01	1.4E-01			
XPW04	CCR	531.90	10	(SW)g	Solid	KGS Model		2.1E-03		1.2E-03	1.0E-03				

[O: SSW 7/1/20; U:SSW 8/20/21; C:LDC 08/31/21]

Notes:
[1] All wells are constructed from 2 inch PVC with 0.01 inch slotted screens.
Test not analyzed/performed
B-Z = Butler-Zhan Test Solution
C-B-P = Cooper-Bredehoeft-Papadopulos Slug Test Solution
CCR = coal combustion residuals
cm/s = centimeters per second
D = downgradient
ft = foot/feet
K = hydraulic conductivity
KGS = Kansas Geological Survey
NAVD88 = North American Vertical Datum of 1988
U = upgradient

USCS = Unified Soil Classification System
GP = Poorly Graded Gravel
SC = Clayey Sand
SM = Silty Sand
SP = Poorly Graded Sand
SP-SC = Poorly Graded Sand to Clayey Sand
SP-SM = Poorly Graded Sand with Silt
(SW)g = Well Graded Sand with Gravel

TABLE 3-4. HORIZONTAL HYDRAULIC GRADIENTS AND GROUNDWATER FLOW VELOCITIES
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, IL

$V = K i / n_e$

V = Groundwater Velocity
K = Hydraulic Conductivity [1]
i = hydraulic gradient
n_e = Effective Porosity [2]

East-West Across CCR Unit (APW10 to APW17): Uppermost Aquifer

Distance between Wells (ft): 5941
Hydraulic Conductivity (ft/day): 181
Effective Porosity (%): 24% Assumes: sand and silt

Date	APW10 Groundwater Elevation (ft NAVD88)	APW17 Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity [3] (ft/day)
2/15/2021	506.65	492.02	14.63	0.0025	1.86
3/9/2021	506.84	491.74	15.10	0.0025	1.91
3/29/2021	506.94	491.95	14.99	0.0025	1.90
4/27/2021	506.53	491.87	14.66	0.0025	1.86
6/15/2021	506.26	491.57	14.69	0.0025	1.86
6/24/2021	506.12	491.52	14.60	0.0025	1.85
7/14/2021	506.59	491.58	15.01	0.0025	1.90
			Average	0.0025	1.88

North-South Across Northeastern Portion CCR Unit (APW05 to APW10): Uppermost Aquifer

Distance between Wells (ft): 3260
Hydraulic Conductivity (ft/day): 1.4
Effective Porosity (%): 24% Assumes: sand and silt

Date	APW05 Groundwater Elevation (ft NAVD88)	APW10 Groundwater Elevation (ft NAVD88)	Change in Elevation (ft)	Horizontal Gradient (ft/ft)	Velocity [3] (ft/day)
2/15/2021	529.83	506.65	23.18	0.0071	0.04
3/9/2021	529.61	506.84	22.77	0.0070	0.04
3/29/2021	529.68	506.94	22.74	0.0070	0.04
4/27/2021	529.73	506.53	23.20	0.0071	0.04
5/24/2021	529.51	506.35	23.16	0.0071	0.04
6/15/2021	529.42	506.26	23.16	0.0071	0.04
6/24/2021	529.38	506.12	23.26	0.0071	0.04
7/14/2021	529.33	506.59	22.74	0.0070	0.04
			Average	0.0071	0.04

[O:SSW 7/15/21; U:SSW 8/19/21; C:LDC 8/31/21]

TABLE 3-4. HORIZONTAL HYDRAULIC GRADIENTS AND GROUNDWATER FLOW VELOCITIES

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT

NEWTON POWER STATION

PRIMARY ASH POND

NEWTON, IL

Notes:

[1] Hydraulic conductivity values used above are average of the individual wells used in each velocity calculation as derived from slug tests completed in August 2015 and March and April 2021 by Ramboll.

[2] Effective porosity used in these calculations was derived from an average between estimated values of 0.20 for silt materials, 0.267 for gravel, 0.07 for clay, and 0.28 for sand from Morris, D.A. and A.I. Johnson, 1967. Summary of hydrologic and physical properties of rock and soil materials as analyzed by the Hydrologic Laboratory of the U.S. Geological Surve, U.S. Geological Survey Water-Supply Paper 1839-D, 42p. and Heath, R.C., 1983. Basic ground-water hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86p. Effective porosity may be as high as maximum total porosity (50%) calculated in Table 2-1.

% = percent

ft= foot/feet

ft/ft = feet per foot

ft/day = feet per day

NAVD88 = North American Vertical Datum of 1988

NM = not measured

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TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW02	01/13/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.9	--	--	--	--	4800
APW02	04/21/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.9	--	--	--	--	5300
APW02	07/15/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.0	--	--	--	--	5200
APW02	10/07/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.7	--	--	--	--	5000
APW02	02/17/2021	<0.003	<0.001	0.0084	<0.001	0.091	<0.001	430	84	<0.004	<0.002	<0.25	<0.001	0.079	<0.0002	<0.001	6.6	0.305	<0.001	2900	<0.001	4800
APW02	03/10/2021	<0.003	0.001	0.0091	<0.001	0.14	<0.001	530	120	<0.004	<0.002	<0.25	<0.001	0.11	<0.0002	0.0014	7.0	0.248	<0.001	3200	<0.001	5100
APW02	03/30/2021	<0.003	<0.001	0.0075	<0.001	0.24	<0.001	490	110	<0.004	<0.002	<0.25	<0.001	0.12	<0.0002	<0.001	6.6	0.193	<0.001	3100	<0.001	5200
APW02	04/29/2021	<0.003	<0.001	0.013	<0.001	0.12	<0.001	490	130	<0.004	<0.002	<0.25	<0.001	0.11	<0.0002	<0.001	6.7	0.924	<0.001	1500	<0.001	5100
APW02	05/25/2021	<0.003	<0.001	0.015	<0.001	0.14	<0.001	520	120	<0.004	<0.002	<0.25	<0.001	0.12	<0.0002	0.0011	6.7	1.01	<0.001	3200	<0.001	5200
APW02	06/16/2021	<0.003	<0.001	0.022	<0.001	0.16	<0.001	540	110	<0.004	<0.002	<0.25	<0.001	0.12	<0.0002	<0.001	6.6	0.34	<0.001	3100	<0.001	5000
APW02	06/30/2021	<0.003	<0.001	0.036	<0.001	0.49	<0.001	510	110	<0.004	<0.002	<0.25	<0.001	0.3	<0.0002	<0.001	6.6	0.618	<0.001	3200	<0.001	4900
APW02	07/15/2021	<0.003	<0.001	0.025	<0.001	0.14	<0.001	480	120	<0.004	<0.002	<0.25	<0.001	0.21	<0.0002	<0.001	6.6	0.33	<0.001	3100	<0.001	5400
APW03	01/13/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4	--	--	--	--	3000
APW03	04/20/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.0	--	--	--	--	580
APW03	07/15/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	6.9	--	--	--	--	580
APW03	10/07/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.3	--	--	--	--	680
APW03	02/18/2021	<0.003	<0.001	0.077	<0.001	0.42	<0.00089	120	8.1	<0.004	<0.002	0.276	0.0013	0.022	0.0006	0.0018	6.7	0.126	<0.001	180	<0.001	620
APW03	03/10/2021	<0.003	<0.001	0.073	<0.001	0.4	<0.001	110	8.7	<0.004	<0.002	<0.25	<0.001	0.024	<0.0002	0.0014	7.2	0.238	<0.001	180	<0.001	720
APW03	03/31/2021	<0.003	<0.001	0.07	<0.001	0.44	<0.001	110	8.6	<0.004	<0.002	<0.25	<0.001	<0.02	<0.0002	0.0012	6.3	0.246	<0.001	170	<0.001	720
APW03	04/29/2021	<0.003	<0.001	0.068	<0.001	0.4	<0.001	110	8.2	<0.004	<0.002	<0.25	<0.001	<0.02	<0.0002	0.0019	7.0	0.822	<0.001	170	<0.001	660
APW03	05/25/2021	<0.003	<0.001	0.063	<0.001	0.38	<0.001	110	8	<0.004	<0.002	<0.25	<0.001	0.023	<0.0002	0.0015	7.0	0.369	<0.001	170	<0.001	760
APW03	06/17/2021	<0.003	<0.001	0.081	<0.001	0.45	<0.001	120	8.3	<0.004	<0.002	<0.25	<0.001	0.02	<0.0002	0.0014	7.0	0.461	<0.001	170	<0.001	660

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TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW03	06/30/2021	<0.003	<0.001	0.059	<0.001	0.66	<0.001	110	11	<0.004	<0.002	<0.25	<0.001	0.035	<0.0002	0.0014	7.0	0.0646	<0.001	160	<0.001	600
APW03	07/15/2021	<0.003	<0.001	0.067	<0.001	0.49	<0.001	110	8.5	<0.004	<0.002	<0.25	<0.001	0.03	<0.0002	0.0013	6.9	1.03	<0.001	190	<0.001	710
APW04	01/13/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.2	--	--	--	--	2300
APW04	04/20/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.0	--	--	--	--	3100
APW04	07/15/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.0	--	--	--	--	2400
APW04	10/07/2015	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.0	--	--	--	--	2300
APW04	02/18/2021	<0.003	0.0012	0.021	<0.001	0.033	<0.00089	230	36	<0.004	<0.002	<0.25	0.0014	0.022	0.001	<0.001	6.5	0.391	<0.001	860	<0.001	1700
APW04	03/11/2021	<0.003	0.0012	0.022	<0.001	0.024	<0.001	220	33	<0.004	<0.002	<0.25	0.001	0.024	<0.0002	<0.001	6.9	0.104	<0.001	970	<0.001	1800
APW04	03/31/2021	<0.003	<0.001	0.018	<0.001	0.031	<0.001	210	37	<0.004	<0.002	<0.25	<0.001	0.021	<0.0002	<0.001	6.1	0.0836	<0.001	960	<0.001	2000
APW04	04/29/2021	<0.003	<0.001	0.013	<0.001	0.023	<0.001	220	29	<0.004	<0.002	<0.25	<0.001	<0.02	<0.0002	<0.001	6.9	0.0843	<0.001	990	<0.001	1800
APW04	05/25/2021	<0.003	0.0014	0.026	<0.001	0.027	<0.001	220	32	<0.004	<0.002	<0.25	0.0014	0.021	<0.0002	<0.001	6.9	0.0127	<0.001	900	<0.001	1800
APW04	06/17/2021	<0.003	0.0012	0.026	<0.001	0.025	<0.001	240	29	<0.004	<0.002	<0.25	<0.001	0.021	<0.0002	<0.001	6.8	0.488	<0.001	950	<0.001	1800
APW04	06/30/2021	<0.003	<0.001	0.032	<0.001	0.21	<0.001	220	27	<0.004	<0.002	<0.25	<0.001	0.045	<0.0002	<0.001	6.8	0.663	<0.001	910	<0.001	1700
APW04	07/15/2021	<0.003	0.0012	0.025	<0.001	0.033	<0.001	210	34	<0.004	<0.002	<0.25	<0.001	0.034	<0.0002	<0.001	6.8	1.29	<0.001	920	<0.001	1900
APW05	12/15/2015	<0.003	0.018	0.19	<0.001	0.099	<0.001	51	48	<0.004	<0.002	0.486	0.0017	0.023	<0.0002	0.023	7.5	0.311	<0.001	15	<0.001	560
APW05	01/20/2016	<0.003	0.017	0.19	<0.001	0.12	<0.001	52	50	<0.004	<0.002	0.409	0.0016	0.017	0.0002	0.023	7.5	0.235	<0.001	15	<0.001	510
APW05	04/27/2016	<0.003	0.021	0.24	<0.001	0.1	<0.001	71	58	<0.004	<0.002	0.494	0.0012	0.02	0.002	0.032	7.7	0.281	0.001	14	<0.001	520
APW05	08/01/2016	<0.003	0.014	0.21	<0.001	0.1	<0.001	49	52	<0.004	<0.002	0.54	<0.001	0.016	<0.0002	0.027	7.5	0.616	<0.001	1.8	<0.001	500
APW05	10/25/2016	<0.003	0.013	0.22	<0.001	0.12	<0.001	50	50	<0.004	<0.002	0.66	<0.001	0.015	<0.0002	0.027	7.6	0.654	<0.001	<1	<0.001	1000
APW05	01/23/2017	<0.003	0.015	0.21	<0.001	0.09	<0.001	45	50	<0.004	<0.002	0.418	<0.001	0.013	<0.0002	0.021	7.4	0.0999	<0.001	<1	<0.001	550
APW05	04/24/2017	<0.003	0.014	0.2	<0.001	0.079	<0.001	44	46	0.004	<0.002	0.437	0.0014	0.015	<0.0002	0.016	7.0	1.19	<0.001	1.2	<0.001	600
APW05	06/13/2017	<0.003	0.016	0.23	<0.001	0.082	<0.001	48	47	<0.004	<0.002	0.508	<0.001	0.014	<0.0002	0.018	7.1	1.32	<0.001	<1	<0.001	540

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW05	11/17/2017	--	--	--	--	0.099	--	51	43	--	--	0.634	--	--	--	--	6.9	--	--	<1	--	480
APW05	05/18/2018	--	--	--	--	0.1	--	48	48	--	--	0.525	--	--	--	--	7.1	--	--	2.1	--	480
APW05	08/17/2018	--	--	--	--	--	--	54	56	--	--	--	--	--	--	--	7.0	--	--	1.4	--	--
APW05	11/09/2018	--	--	--	--	0.098	--	50	51	--	--	0.427	--	--	--	--	7.0	--	--	5.1	--	500
APW05	02/22/2019	--	--	--	--	0.11	--	50	48	--	--	0.374	--	--	--	--	6.9	--	--	3.5	--	600
APW05	08/22/2019	--	--	--	--	0.12	--	49	50	--	--	<0.25	--	--	--	--	7.0	--	--	2.3	--	530
APW05	02/04/2020	--	--	--	--	0.091	--	51	54	--	--	0.48	--	--	--	--	7.5	--	--	2.3	--	600
APW05	06/11/2020	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4	--	--	--	--	--
APW05	07/28/2020	--	--	--	--	0.1	--	53	52	--	--	0.544	--	--	--	--	7.7	--	--	1.8	--	530
APW05	02/09/2021	--	--	--	--	0.13	--	54	50	--	--	0.543	--	--	--	--	7.6	--	--	1.3	--	560
APW05	02/17/2021	<0.003	0.003	0.22	<0.001	0.1	<0.001	49	52	<0.004	<0.002	0.479	<0.001	<0.02	<0.0002	0.019	7.2	0.356	<0.001	3.3	<0.001	510
APW05	03/10/2021	<0.003	0.022	0.24	<0.001	0.12	<0.001	55	48	<0.004	<0.002	0.365	<0.001	<0.02	<0.0002	0.011	7.7	0.872	<0.001	1.3	<0.001	530
APW05	03/30/2021	<0.003	0.022	0.27	<0.001	0.092	<0.001	54	49	<0.004	<0.002	0.342	<0.001	<0.02	<0.0002	0.011	7.2	1.31	<0.001	1.3	<0.001	560
APW05	04/28/2021	<0.003	0.018	0.24	<0.001	0.099	<0.001	52	51	<0.004	<0.002	0.514	<0.001	<0.02	<0.0002	0.012	7.5	0.932	<0.001	1.1	<0.001	570
APW05	05/25/2021	<0.003	0.019	0.24	<0.001	0.12	<0.001	54	48	<0.004	<0.002	0.532	<0.001	<0.02	<0.0002	0.012	7.5	1.04	<0.001	1	<0.001	570
APW05	06/17/2021	<0.003	0.022	0.25	<0.001	0.091	<0.001	58	50	<0.004	<0.002	0.516	<0.001	<0.02	<0.0002	0.011	7.7	1.08	<0.001	<1	<0.001	560
APW05	06/30/2021	<0.003	0.021	0.25	<0.001	0.26	<0.001	52	51	<0.004	<0.002	0.441	<0.001	<0.02	<0.0002	0.011	7.6	0.0954	<0.001	1	<0.001	470
APW05	07/15/2021	<0.003	0.022	0.25	<0.001	0.1	<0.001	51	52	<0.004	<0.002	0.386	<0.001	<0.02	<0.0002	0.011	7.8	0.305	<0.001	1.1	<0.001	560
APW05S	02/17/2021	<0.003	<0.001	0.048	<0.001	0.04	<0.001	390	550	<0.004	0.0058	0.345	<0.001	0.043	<0.0002	0.0027	6.6	0.191	<0.001	640	<0.001	3700
APW05S	03/10/2021	<0.003	<0.001	0.051	<0.001	0.13	<0.001	420	190	<0.004	0.0025	0.379	<0.001	0.042	<0.0002	0.0016	7.0	0.195	<0.001	200	<0.001	3600
APW05S	04/29/2021	<0.003	0.0018	0.048	<0.001	0.04	<0.001	420	200	<0.004	<0.002	0.373	<0.001	0.039	<0.0002	0.0014	6.8	0.146	<0.001	2000	<0.001	3800
APW05S	05/25/2021	<0.003	0.0016	0.053	<0.001	0.056	<0.001	420	210	<0.004	<0.002	0.391	<0.001	0.042	<0.0002	0.0014	6.9	0.386	<0.001	2100	<0.001	3500

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW05S	06/17/2021	<0.003	0.0022	0.051	<0.001	0.043	<0.001	410	190	<0.004	0.0022	0.364	<0.001	0.038	<0.0002	0.0013	6.8	1.58	<0.001	2100	<0.001	3600
APW05S	06/30/2021	<0.003	0.002	0.051	<0.001	0.046	<0.001	380	180	<0.004	0.0022	0.401	<0.001	0.091	<0.0002	0.0011	6.7	0.29	<0.001	1900	<0.001	3200
APW05S	07/15/2021	<0.003	0.0026	0.05	<0.001	0.039	<0.001	370	260	<0.004	0.0027	0.379	<0.001	0.067	<0.0002	0.0011	6.8	0.644	<0.001	2000	<0.001	3800
APW06	12/15/2015	<0.003	0.017	0.16	<0.001	0.073	<0.001	53	26	<0.004	<0.002	0.509	<0.001	0.019	0.00023	0.012	7.5	0.591	0.006	9.9	<0.001	480
APW06	01/20/2016	<0.003	0.0091	0.17	<0.001	0.082	<0.001	53	24	<0.004	<0.002	0.393	<0.001	0.012	<0.0002	0.013	7.4	0.236	<0.001	9.9	<0.001	500
APW06	04/27/2016	<0.003	0.019	0.21	<0.001	0.16	<0.001	64	29	<0.004	<0.002	0.564	0.0012	0.019	<0.0002	0.028	6.5	0.984	<0.001	7.4	<0.001	450
APW06	08/01/2016	<0.003	0.0045	0.2	<0.001	0.078	<0.001	50	27	<0.004	<0.002	0.65	<0.001	0.016	<0.0002	0.0066	7.4	0.69	<0.001	1.2	<0.001	520
APW06	10/25/2016	<0.003	0.0041	0.22	<0.001	0.093	<0.001	50	26	<0.004	<0.002	0.686	<0.001	0.015	<0.0002	0.0087	7.5	0.329	<0.001	<1	<0.001	560
APW06	01/23/2017	<0.003	0.0036	0.21	<0.001	0.076	<0.001	46	26	<0.004	<0.002	0.448	<0.001	0.014	<0.0002	0.0086	6.9	0.316	<0.001	<1	<0.001	530
APW06	04/24/2017	<0.003	0.0042	0.2	<0.001	0.074	0.0012	43	50	<0.004	<0.002	0.47	0.0012	0.015	<0.0002	0.011	7.2	0.859	<0.001	<1	0.0011	540
APW06	06/13/2017	<0.003	0.0057	0.22	0.0025	0.093	0.0017	51	25	<0.004	0.002	0.567	0.0025	0.014	<0.0002	0.014	7.1	0.932	0.0014	2.3	0.0025	460
APW06	11/17/2017	--	--	--	--	0.094	--	50	23	--	--	0.617	--	--	--	--	7.2	--	--	1.9	--	470
APW06	05/18/2018	--	--	--	--	0.087	--	51	25	--	--	0.564	--	--	--	--	7.3	--	--	1.7	--	420
APW06	08/17/2018	--	--	--	--	--	--	52	25	--	--	--	--	--	--	--	7.3	--	--	1.7	--	--
APW06	11/09/2018	--	--	--	--	0.083	--	51	24	--	--	0.459	--	--	--	--	7.2	--	--	2.1	--	440
APW06	02/22/2019	--	--	--	--	0.09	--	45	24	--	--	0.386	--	--	--	--	7.3	--	--	1.7	--	480
APW06	08/23/2019	--	--	--	--	0.11	--	55	26	--	--	0.314	--	--	--	--	7.3	--	--	5.8	--	500
APW06	02/04/2020	--	--	--	--	0.08	--	53	27	--	--	0.483	--	--	--	--	7.5	--	--	<1	--	640
APW06	06/11/2020	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.4	--	--	--	--	--
APW06	07/28/2020	--	--	--	--	0.091	--	55	24	--	--	0.564	--	--	--	--	7.8	--	--	3.2	--	510
APW06	02/09/2021	--	--	--	--	0.087	--	55	24	--	--	0.585	--	--	--	--	7.6	--	--	1.8	--	450
APW06	02/17/2021	<0.003	0.0045	0.24	<0.001	0.086	<0.001	54	23	<0.004	<0.002	0.504	<0.001	<0.02	<0.0002	0.0073	6.4	0.231	<0.001	3.6	<0.001	500

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW06	03/10/2021	<0.003	0.0052	0.25	<0.001	0.086	<0.001	58	22	<0.004	<0.002	0.427	<0.001	<0.02	<0.0002	0.0058	7.7	0.594	<0.001	9.2	<0.001	540
APW06	03/30/2021	<0.003	0.0052	0.22	<0.001	0.078	<0.001	56	26	<0.004	<0.002	0.368	<0.001	<0.02	<0.0002	0.0062	7.1	4.9	<0.001	7.7	<0.001	500
APW06	04/29/2021	<0.003	0.0073	0.25	<0.001	0.082	<0.001	62	23	0.0068	0.0027	0.496	0.0032	<0.02	<0.0002	0.0077	7.7	1.55	<0.001	8.5	<0.001	610
APW06	05/25/2021	<0.003	0.0088	0.28	<0.001	0.1	<0.001	68	23	0.011	0.0043	0.55	0.0074	<0.02	<0.0002	0.0085	7.7	0.474	<0.001	7.8	<0.001	490
APW06	06/16/2021	<0.003	0.0081	0.25	<0.001	0.11	<0.001	67	25	0.0076	0.0033	0.545	0.0066	<0.02	<0.0002	0.0083	7.7	1.35	<0.001	6.2	<0.001	520
APW06	06/30/2021	<0.003	0.0078	0.23	<0.001	0.085	<0.001	63	32	0.0058	0.0033	0.481	0.0063	0.03	<0.0002	0.0078	7.6	0.544	<0.001	6.3	<0.001	500
APW06	07/15/2021	<0.003	0.0067	0.23	<0.001	0.083	<0.001	55	27	<0.004	<0.002	0.442	0.0013	<0.02	<0.0002	0.0076	7.5	0.285	<0.001	7.8	<0.001	490
APW07	12/15/2015	<0.003	0.0039	0.35	<0.001	0.073	<0.001	74	69	<0.004	<0.002	0.467	<0.001	<0.01	<0.0002	0.014	7.4	1.16	<0.001	13	<0.001	520
APW07	01/21/2016	<0.003	0.0065	0.4	<0.001	0.052	<0.001	74	79	<0.004	<0.002	0.38	0.0015	<0.01	<0.0002	0.0083	7.4	1.06	<0.001	8.6	<0.001	440
APW07	05/03/2016	<0.003	0.004	0.41	<0.001	0.071	<0.001	85	72	<0.004	<0.002	0.545	<0.001	<0.01	<0.0002	0.0086	7.5	1.74	<0.001	7.5	<0.001	500
APW07	08/01/2016	<0.003	0.0049	0.45	<0.001	0.07	<0.001	86	77	<0.004	<0.002	0.462	<0.001	<0.01	<0.0002	0.006	7.3	1.32	<0.001	2.8	<0.001	490
APW07	10/26/2016	<0.003	0.0058	0.5	<0.001	0.096	<0.001	76	79	<0.004	<0.002	0.425	<0.001	<0.01	<0.0002	0.0054	7.2	2.02	<0.001	<1	<0.001	590
APW07	01/26/2017	<0.003	0.0062	0.45	<0.001	0.082	<0.001	87	77	<0.004	<0.002	0.352	<0.001	<0.01	<0.0002	0.0072	7.2	1.82	<0.001	<1	<0.001	520
APW07	04/24/2017	<0.003	0.0077	0.45	<0.001	0.069	<0.001	87	77	0.0049	<0.002	0.367	0.0022	<0.01	<0.0002	0.0029	7.3	1.26	<0.001	<1	<0.001	600
APW07	06/13/2017	<0.003	0.0087	0.48	<0.001	0.084	<0.001	93	77	<0.004	<0.002	0.425	0.0046	<0.01	<0.0002	0.0039	7.2	1.69	<0.001	<1	<0.001	560
APW07	11/17/2017	--	--	--	--	0.097	--	72	73	--	--	0.508	--	--	--	--	7.2	--	--	3.8	--	530
APW07	05/18/2018	--	--	--	--	0.082	--	97	75	--	--	0.435	--	--	--	--	7.1	--	--	4.9	--	500
APW07	08/18/2018	--	--	--	--	--	--	100	77	--	--	--	--	--	--	--	7.1	--	--	3.2	--	--
APW07	11/09/2018	--	--	--	--	0.08	--	92	71	--	--	0.343	--	--	--	--	7.0	--	--	4.5	--	500
APW07	02/22/2019	--	--	--	--	0.06	--	45	43	--	--	0.734	--	--	--	--	7.2	--	--	66	--	340
APW07	08/23/2019	--	--	--	--	0.075	--	58	46	--	--	0.632	--	--	--	--	7.1	--	--	62	--	350
APW07	02/05/2020	--	--	--	--	0.092	--	100	68	--	--	0.332	--	--	--	--	7.4	--	--	5.7	--	640

RAMBOLL

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW07	06/11/2020	--	--	--	--	--	--	--	68	--	--	--	--	--	--	--	7.3	--	--	--	--	--
APW07	07/28/2020	--	--	--	--	0.086	--	94	77	--	--	0.412	--	--	--	--	7.3	--	--	6.7	--	530
APW07	02/10/2021	--	--	--	--	0.11	--	110	69	--	--	0.372	--	--	--	--	7.0	--	--	6.3	--	540
APW08	12/15/2015	<0.003	0.0083	0.24	<0.001	0.083	<0.001	85	52	<0.004	<0.002	0.441	0.0016	0.013	<0.0002	0.0075	7.4	1.95	<0.001	35	<0.001	560
APW08	01/21/2016	<0.003	0.016	0.3	<0.001	0.06	<0.001	85	59	0.0049	<0.002	0.414	0.0023	0.012	<0.0002	0.0055	7.5	2.27	<0.001	34	<0.001	510
APW08	05/03/2016	<0.003	0.012	0.32	<0.001	0.083	<0.001	100	55	0.0045	<0.002	0.566	0.0021	<0.01	<0.0002	0.0063	7.4	1.88	0.0016	30	<0.001	560
APW08	08/02/2016	<0.003	0.013	0.32	<0.001	0.076	<0.001	94	56	<0.004	<0.002	0.504	<0.001	<0.01	<0.0002	0.0054	7.2	0.857	<0.001	35	<0.001	520
APW08	10/26/2016	<0.003	0.013	0.35	<0.001	0.091	<0.001	84	59	<0.004	<0.002	0.463	<0.001	<0.01	<0.0002	0.0055	7.4	0.812	<0.001	37	<0.001	600
APW08	01/25/2017	<0.003	0.017	0.37	<0.001	0.081	<0.001	100	57	<0.004	<0.002	0.404	<0.001	<0.01	<0.0002	0.0057	7.2	0.499	<0.001	36	<0.001	600
APW08	04/25/2017	<0.003	0.02	0.36	<0.001	0.073	<0.001	100	57	0.016	0.0056	0.418	0.0097	0.017	<0.0002	0.0074	7.5	1.8	<0.001	38	<0.001	590
APW08	06/13/2017	<0.003	0.017	0.39	<0.001	0.092	<0.001	110	57	0.01	0.0043	0.449	0.0075	0.012	<0.0002	0.0081	7.3	2.08	<0.001	38	<0.001	600
APW08	11/17/2017	--	--	--	--	0.11	--	83	50	--	--	0.474	--	--	--	--	7.1	--	--	39	--	490
APW08	05/18/2018	--	--	--	--	0.088	--	92	56	--	--	0.448	--	--	--	--	7.2	--	--	37	--	520
APW08	08/18/2018	--	--	--	--	--	--	82	57	--	--	--	--	--	--	--	7.2	--	--	43	--	--
APW08	11/09/2018	--	--	--	--	0.086	--	110	56	--	--	0.373	--	--	--	--	7.1	--	--	42	--	580
APW08	02/22/2019	--	--	--	--	0.1	--	80	56	--	--	0.393	--	--	--	--	7.2	--	--	46	--	600
APW08	08/23/2019	--	--	--	--	0.1	--	82	59	--	--	0.337	--	--	--	--	7.2	--	--	48	--	570
APW08	02/05/2020	--	--	--	--	0.1	--	120	55	--	--	0.331	--	--	--	--	7.4	--	--	45	--	700
APW08	06/11/2020	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.3	--	--	--	--	--
APW08	07/28/2020	--	--	--	--	0.087	--	110	62	--	--	0.441	--	--	--	--	7.3	--	--	47	--	620
APW08	10/28/2020	--	--	--	--	--	--	--	55	--	--	--	--	--	--	--	7.4	--	--	--	--	--
APW08	02/10/2021	--	--	--	--	0.11	--	110	57	--	--	<0.25	--	--	--	--	7.2	--	--	42	--	550

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW09	12/15/2015	<0.003	0.007	0.24	<0.001	0.062	<0.001	54	88	<0.004	<0.002	0.574	0.0011	<0.01	<0.0002	0.021	7.5	0.612	<0.001	25	<0.001	630
APW09	01/20/2016	<0.003	0.0067	0.24	<0.001	0.074	<0.001	57	95	<0.004	<0.002	0.468	0.0044	<0.01	<0.0002	0.023	7.6	0.743	<0.001	27	<0.001	540
APW09	05/03/2016	<0.003	0.008	0.32	<0.001	0.07	<0.001	70	110	<0.004	<0.002	0.746	0.0051	<0.01	<0.0002	0.021	7.6	1.54	<0.001	18	<0.001	590
APW09	08/02/2016	<0.003	0.014	0.41	<0.001	0.073	<0.001	74	130	<0.004	<0.002	0.532	<0.001	<0.01	<0.0002	0.011	7.2	1.137	<0.001	4.2	<0.001	640
APW09	10/26/2016	<0.003	0.016	0.47	<0.001	0.09	<0.001	77	130	<0.004	<0.002	0.528	<0.001	<0.01	<0.0002	0.01	7.6	1.18	<0.001	1.5	<0.001	770
APW09	01/25/2017	<0.003	0.018	0.44	<0.001	0.081	<0.001	79	130	<0.004	<0.002	0.468	<0.001	<0.01	<0.0002	0.0075	7.5	1.78	<0.001	<1	<0.001	740
APW09	04/25/2017	<0.003	0.017	0.38	<0.001	0.078	<0.001	67	120	<0.004	<0.002	0.515	<0.001	<0.01	0.00023	0.0053	7.5	1.07	<0.001	1.1	<0.001	840
APW09	06/13/2017	<0.003	0.0039	0.11	<0.001	0.053	<0.001	42	51	<0.004	<0.002	0.755	<0.001	<0.01	<0.0002	0.016	7.5	0.984	<0.001	48	<0.001	300
APW09	11/18/2017	--	--	--	--	0.08	--	68	84	--	--	0.655	--	--	--	--	7.4	--	--	4.5	--	720
APW09	05/18/2018	--	--	--	--	0.098	--	80	120	--	--	0.467	--	--	--	--	7.4	--	--	1	--	710
APW09	08/17/2018	--	--	--	--	--	--	81	130	--	--	--	--	--	--	--	7.5	--	--	2.4	--	--
APW09	11/09/2018	--	--	--	--	0.055	--	44	44	--	--	0.73	--	--	--	--	7.4	--	--	62	--	300
APW09	02/22/2019	--	--	--	--	0.054	--	38	47	--	--	0.714	--	--	--	--	7.5	--	--	61	--	320
APW09	08/23/2019	--	--	--	--	0.055	--	41	51	--	--	0.621	--	--	--	--	7.4	--	--	51	--	360
APW09	02/19/2020	--	--	--	--	0.1	--	88	130	--	--	0.453	--	--	--	--	7.5	--	--	7.5	--	790
APW09	06/11/2020	--	--	--	--	--	--	--	130	--	--	--	--	--	--	--	7.4	--	--	--	--	870
APW09	07/28/2020	--	--	--	--	0.1	--	84	140	--	--	0.537	--	--	--	--	7.4	--	--	3.2	--	810
APW09	02/11/2021	--	--	--	--	0.11	--	85	140	--	--	0.536	--	--	--	--	7.4	--	--	<10	--	840
APW10	12/16/2015	<0.003	0.0034	0.038	<0.001	0.066	<0.001	120	46	<0.004	<0.002	0.328	<0.001	0.03	<0.0002	0.0094	7.1	0.755	<0.001	430	<0.001	1000
APW10	01/20/2016	<0.003	0.0043	0.042	<0.001	0.077	<0.001	120	48	<0.004	<0.002	<0.25	<0.001	0.021	<0.0002	0.011	7.2	1.16	<0.001	410	<0.001	950
APW10	05/03/2016	<0.003	0.0083	0.04	<0.001	0.065	<0.001	140	46	<0.004	<0.002	0.448	<0.001	0.023	<0.0002	0.01	7.1	0.799	<0.001	410	<0.001	930
APW10	08/02/2016	<0.003	0.0092	0.037	<0.001	0.063	<0.001	140	45	<0.004	<0.002	0.367	<0.001	0.026	<0.0002	0.0091	7.1	0.6	<0.001	410	<0.001	840

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW10	10/26/2016	<0.003	0.009	0.04	<0.001	0.069	<0.001	120	48	<0.004	<0.002	0.371	<0.001	0.027	<0.0002	0.0093	7.1	0.556	<0.001	470	<0.001	960
APW10	01/25/2017	<0.003	0.01	0.035	<0.001	0.065	<0.001	160	46	<0.004	<0.002	0.258	<0.001	0.023	<0.0002	0.0085	7.1	0.43	<0.001	430	<0.001	1000
APW10	04/25/2017	<0.003	0.0084	0.031	<0.001	0.056	<0.001	120	44	<0.004	<0.002	0.289	<0.001	0.026	<0.0002	0.0071	7.0	0.604	<0.001	410	<0.001	1000
APW10	06/13/2017	<0.003	0.0035	0.027	<0.001	0.077	<0.001	110	46	<0.004	<0.002	0.344	<0.001	0.026	<0.0002	0.0091	6.9	0.897	<0.001	410	<0.001	920
APW10	11/18/2017	--	--	--	--	0.072	--	120	47	--	--	0.414	--	--	--	--	6.9	--	--	390	--	910
APW10	05/18/2018	--	--	--	--	0.08	--	130	51	--	--	0.335	--	--	--	--	7.2	--	--	440	--	900
APW10	08/17/2018	--	--	--	--	--	--	130	51	--	--	--	--	--	--	--	6.9	--	--	420	--	--
APW10	11/09/2018	--	--	--	--	0.078	--	140	47	--	--	0.281	--	--	--	--	7.0	--	--	410	--	900
APW10	02/22/2019	--	--	--	--	0.079	--	110	50	--	--	0.276	--	--	--	--	6.9	--	--	420	--	990
APW10	08/23/2019	--	--	--	--	0.096	--	130	50	--	--	0.359	--	--	--	--	7.0	--	--	390	--	1000
APW10	02/05/2020	--	--	--	--	0.094	--	140	44	--	--	<0.25	--	--	--	--	7.1	--	--	400	--	1200
APW10	06/11/2020	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.2	--	--	--	--	1000
APW10	07/28/2020	--	--	--	--	0.076	--	140	53	--	--	0.356	--	--	--	--	7.1	--	--	410	--	1000
APW10	02/11/2021	--	--	--	--	0.082	--	150	45	--	--	0.362	--	--	--	--	7.4	--	--	410	--	1100
APW10	06/17/2021	<0.003	0.008	0.026	<0.001	0.07	<0.001	150	47	<0.004	<0.002	0.436	<0.001	0.022	<0.0002	0.0074	7.3	0.617	<0.001	540	<0.001	1100
APW10	06/30/2021	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7.5	--	--	--	--	1000
APW10	07/29/2021	<0.003	0.0058	0.026	<0.001	0.075	<0.001	150	45	<0.004	<0.002	0.462	<0.001	0.022	<0.0002	0.0071	7.5	0.794	<0.001	410	<0.001	1000
APW11	02/18/2021	<0.003	0.002	0.16	<0.001	0.074	<0.00089	96	47	<0.004	<0.002	0.497	<0.001	0.021	0.00042	0.013	6.1	1.87	<0.001	280	<0.001	780
APW11	03/09/2021	<0.003	0.0046	0.077	<0.001	0.075	<0.001	120	26	0.0086	0.0029	<0.25	0.0076	0.024	<0.0002	0.0078	7.2	0.763	0.001	290	<0.001	940
APW11	03/29/2021	<0.003	0.005	0.071	<0.001	0.15	<0.001	130	26	0.012	0.0048	<0.25	0.014	0.028	<0.0002	0.0059	6.6	2.13	0.0032	270	<0.001	820
APW11	04/28/2021	<0.003	0.0021	0.048	<0.001	0.066	<0.001	120	26	<0.004	<0.002	<0.25	<0.001	0.021	<0.0002	0.0046	7.1	0.477	<0.001	280	<0.001	920
APW11	05/24/2021	<0.003	0.0015	0.05	<0.001	0.083	<0.001	130	27	<0.004	<0.002	<0.25	<0.001	0.024	0.00082	0.005	7.4	0.563	<0.001	300	0.0036	850

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW11	06/16/2021	<0.003	0.002	0.047	<0.001	0.078	<0.001	130	26	<0.004	<0.002	0.375	<0.001	0.024	<0.0002	0.0048	7.2	2.05	<0.001	290	<0.001	850
APW11	06/30/2021	<0.003	0.0018	0.042	<0.001	0.065	<0.001	120	33	<0.004	<0.002	0.409	<0.001	0.038	<0.0002	0.0044	7.1	0.382	<0.001	280	<0.001	860
APW11	07/15/2021	<0.003	0.0023	0.042	<0.001	0.062	<0.001	120	31	<0.004	<0.002	<0.25	<0.001	0.03	<0.0002	0.0043	7.2	0.474	<0.001	140	<0.001	810
APW12	02/17/2021	<0.003	0.0016	0.058	<0.001	0.27	<0.00089	230	27	<0.004	0.0073	<0.25	<0.001	0.033	0.0019	0.0037	6.2	0.682	<0.001	390	<0.001	1300
APW12	03/09/2021	<0.003	0.0017	0.05	<0.001	0.26	<0.001	230	27	<0.004	0.0073	<0.25	<0.001	0.028	<0.0002	0.0025	6.5	0.367	<0.001	480	<0.001	1300
APW12	03/29/2021	<0.003	0.002	0.046	<0.001	0.29	<0.001	220	28	<0.004	0.0065	<0.25	<0.001	0.029	<0.0002	0.0019	6.0	0.166	<0.001	440	<0.001	1400
APW12	04/28/2021	<0.003	0.0016	0.038	<0.001	0.21	<0.001	210	23	<0.004	0.005	<0.25	<0.001	0.026	<0.0002	0.0012	6.4	0.234	<0.001	390	<0.001	1300
APW12	05/25/2021	<0.003	0.0023	0.038	<0.001	0.29	<0.001	220	23	<0.004	0.0043	<0.25	<0.001	0.029	<0.0002	0.0038	6.5	0.319	<0.001	390	<0.001	1300
APW12	06/16/2021	<0.003	0.0027	0.039	<0.001	0.15	<0.001	210	20	<0.004	0.0034	<0.25	<0.001	0.026	<0.0002	<0.001	6.4	1.88	<0.001	290	<0.001	1100
APW12	06/30/2021	<0.003	0.0019	0.04	<0.001	0.11	<0.001	190	20	<0.004	0.0032	<0.25	<0.001	0.046	<0.0002	<0.001	6.3	0.466	<0.001	310	<0.001	990
APW12	07/15/2021	<0.003	0.0017	0.033	<0.001	0.28	<0.001	210	26	<0.004	0.0032	<0.25	<0.001	0.045	<0.0002	<0.001	6.5	0.667	<0.001	440	<0.001	1300
APW13	02/22/2021	<0.003	0.0043	0.055	<0.001	0.12	<0.001	110	57	<0.004	<0.002	0.503	<0.001	0.042	<0.0002	0.016	7.1	0.429	<0.001	220	<0.001	760
APW13	03/10/2021	<0.003	0.0046	0.054	<0.001	0.11	<0.001	120	71	<0.004	<0.002	0.326	<0.001	0.044	<0.0002	0.017	7.2	0.17	<0.001	210	<0.001	850
APW13	03/31/2021	<0.003	0.0047	0.057	<0.001	0.12	<0.001	110	46	<0.004	<0.002	0.43	<0.001	0.041	<0.0002	0.011	6.4	1.05	<0.001	210	<0.001	880
APW13	04/29/2021	<0.003	0.0046	0.05	<0.001	0.11	<0.001	110	48	<0.004	<0.002	0.327	<0.001	0.032	<0.0002	0.011	7.2	1.44	<0.001	210	<0.001	840
APW13	05/25/2021	<0.003	0.0031	0.051	<0.001	0.12	<0.001	120	64	<0.004	<0.002	0.402	<0.001	0.03	<0.0002	0.0096	7.3	0.966	<0.001	220	<0.001	880
APW13	06/17/2021	<0.003	0.0037	0.051	<0.001	0.1	<0.001	130	53	<0.004	<0.002	0.487	<0.001	0.027	<0.0002	0.0089	7.2	0.281	<0.001	220	<0.001	830
APW13	06/30/2021	<0.003	0.0039	0.051	<0.001	0.11	<0.001	120	45	<0.004	<0.002	0.447	<0.001	0.054	<0.0002	0.0088	7.3	0.546	<0.001	230	<0.001	790
APW13	07/15/2021	<0.003	0.006	0.05	<0.001	0.15	<0.001	110	55	<0.004	<0.002	<0.25	<0.001	0.036	<0.0002	0.0082	7.3	0.328	<0.001	210	<0.001	820
APW14	02/22/2021	<0.003	0.0074	0.14	<0.001	0.11	<0.001	120	55	0.0057	0.0023	0.489	0.0032	0.051	<0.0002	0.014	7.5	0.752	<0.001	320	<0.001	830
APW14	03/10/2021	<0.003	0.0095	0.099	<0.001	0.097	<0.001	130	65	<0.004	<0.002	0.313	0.002	0.044	<0.0002	0.0083	7.4	0.356	<0.001	340	<0.001	970
APW14	03/31/2021	<0.003	0.0098	0.092	<0.001	0.11	<0.001	130	46	<0.004	<0.002	0.363	<0.001	0.034	<0.0002	0.0068	6.5	0.594	<0.001	330	<0.001	1000

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW14	04/28/2021	<0.003	0.0053	0.1	<0.001	0.093	<0.001	130	44	<0.004	<0.002	<0.25	<0.001	0.03	<0.0002	0.0081	7.4	0.342	<0.001	320	<0.001	1000
APW14	05/25/2021	<0.003	0.0047	0.098	<0.001	0.11	<0.001	130	43	<0.004	<0.002	0.358	<0.001	0.029	<0.0002	0.0063	7.5	0.658	<0.001	320	<0.001	920
APW14	06/17/2021	<0.003	0.0054	0.086	<0.001	0.089	<0.001	140	45	<0.004	<0.002	0.436	<0.001	0.024	<0.0002	0.0053	7.4	1.26	<0.001	310	<0.001	940
APW14	06/30/2021	<0.003	0.0061	0.082	<0.001	0.097	<0.001	150	49	<0.004	<0.002	0.371	<0.001	0.047	<0.0002	0.0053	7.5	1.05	<0.001	330	<0.001	860
APW14	07/15/2021	<0.003	0.0055	0.07	<0.001	0.12	<0.001	130	53	<0.004	<0.002	<0.25	<0.001	0.032	<0.0002	0.0046	7.4	0.695	<0.001	330	<0.001	970
APW15	02/23/2021	<0.003	0.02	0.56	<0.001	0.14	<0.001	93	260	<0.004	<0.002	0.544	0.0011	<0.02	<0.0002	0.0089	7.0	1.43	<0.001	<1	<0.001	1100
APW15	03/10/2021	<0.003	0.022	0.61	<0.001	0.13	<0.001	100	250	<0.004	<0.002	1.65	0.0012	<0.02	<0.0002	0.016	7.2	2.88	<0.001	<1	<0.001	1100
APW15	03/31/2021	<0.003	0.016	0.63	<0.001	0.16	<0.001	100	240	0.005	0.0021	1.44	0.003	<0.02	<0.0002	0.013	6.5	1.76	<0.001	<1	<0.001	1100
APW15	04/28/2021	<0.003	0.021	0.6	<0.001	0.13	<0.001	96	230	<0.004	<0.002	1.81	<0.001	<0.02	<0.0002	0.015	7.2	1.17	<0.001	<1	<0.001	1200
APW15	05/24/2021	<0.003	0.017	0.57	<0.001	0.15	<0.001	98	230	<0.004	<0.002	1.68	<0.001	<0.02	<0.0002	0.012	7.3	1.87	<0.001	<1	<0.001	1000
APW15	06/17/2021	<0.003	0.017	0.6	<0.001	0.13	<0.001	95	240	<0.004	<0.002	3.18	<0.001	0.022	<0.0002	0.012	7.3	2.54	<0.001	<1	<0.001	1000
APW15	06/30/2021	<0.003	0.017	0.6	<0.001	0.13	<0.001	98	230	<0.004	<0.002	2.89	<0.001	0.022	<0.0002	0.0098	7.1	2.46	<0.001	<1	<0.001	1000
APW15	07/14/2021	<0.003	0.016	0.6	<0.001	0.16	<0.001	96	130	<0.004	<0.002	8.16	<0.001	<0.02	<0.0002	0.0094	7.2	2.23	<0.001	<1	<0.001	1200
APW16	02/23/2021	<0.003	0.014	0.62	<0.001	0.14	<0.001	92	71	<0.004	<0.002	0.629	<0.001	<0.02	<0.0002	0.0036	7.4	2.08	<0.001	1.9	<0.001	780
APW16	03/10/2021	<0.003	0.015	0.66	<0.001	0.15	<0.001	99	71	<0.004	<0.002	0.755	<0.001	<0.02	<0.0002	0.0044	7.5	2.17	<0.001	<1	<0.001	750
APW16	03/30/2021	<0.003	0.013	0.66	<0.001	0.17	<0.001	97	71	<0.004	<0.002	0.886	<0.001	<0.02	<0.0002	0.0033	7.0	0.946	<0.001	<1	<0.001	740
APW16	04/28/2021	<0.003	0.0083	0.62	<0.001	0.12	<0.001	96	75	<0.004	<0.002	0.742	<0.001	<0.02	<0.0002	0.0015	7.4	1.55	<0.001	<1	<0.001	750
APW16	05/24/2021	<0.003	0.0074	0.61	<0.001	0.15	<0.001	100	74	<0.004	<0.002	0.639	<0.001	<0.02	<0.0002	0.0012	7.6	1.19	<0.001	<1	<0.001	810
APW16	06/16/2021	<0.003	0.0077	0.57	<0.001	0.14	<0.001	100	73	<0.004	<0.002	0.735	<0.001	<0.02	<0.0002	<0.001	7.4	2.05	<0.001	<1	<0.001	720
APW16	06/30/2021	<0.003	0.0083	0.55	<0.001	0.13	<0.001	96	59	<0.004	<0.002	0.766	<0.001	<0.02	<0.0002	<0.001	7.0	5.85	<0.001	<1	<0.001	610
APW16	07/15/2021	<0.003	0.0088	0.56	<0.001	0.13	<0.001	95	77	<0.004	<0.002	0.55	<0.001	<0.02	<0.0002	<0.001	7.4	2.91	<0.001	<1	<0.001	690
APW17	02/23/2021	<0.003	0.0033	0.54	<0.001	0.091	<0.001	100	64	<0.004	<0.002	0.944	<0.001	<0.02	<0.0002	0.0085	7.4	0.821	<0.001	34	<0.001	680

TABLE 4-1. GROUNDWATER ANALYTICAL RESULTS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Location	Sample Date	Antimony, total (mg/L)	Arsenic, total (mg/L)	Barium, total (mg/L)	Beryllium, total (mg/L)	Boron, total (mg/L)	Cadmium, total (mg/L)	Calcium, total (mg/L)	Chloride, total (mg/L)	Chromium, total (mg/L)	Cobalt, total (mg/L)	Fluoride, total (mg/L)	Lead, total (mg/L)	Lithium, total (mg/L)	Mercury, total (mg/L)	Molybdenum, total (mg/L)	pH (field) (SU)	Radium 226 and 228 combined (pCi/L)	Selenium, total (mg/L)	Sulfate, total (mg/L)	Thallium, total (mg/L)	Total Dissolved Solids (mg/L)
35 I.A.C. 845.600	Lower	0	0	0	0	0	0	--	0	0	0	0	0	0	0	0	6.5	0	0	0	0	0
	Upper	0.006	0.010	2.0	0.004	2	0.005	--	200	0.1	0.006	4.0	0.0075	0.04	0.002	0.1	9.0	5	0.05	400	0.002	1200
APW17	03/10/2021	<0.003	0.0026	0.57	<0.001	0.083	<0.001	110	60	<0.004	<0.002	0.677	<0.001	<0.02	<0.0002	0.0066	7.7	0.849	<0.001	30	<0.001	650
APW17	03/30/2021	<0.003	0.0014	0.63	<0.001	0.086	<0.001	110	57	<0.004	<0.002	0.374	<0.001	<0.02	<0.0002	0.0052	7.1	0.259	<0.001	31	<0.001	620
APW17	04/29/2021	<0.003	0.003	0.6	<0.001	0.088	<0.001	120	55	<0.004	<0.002	0.468	<0.001	<0.02	<0.0002	0.0055	7.4	1.51	<0.001	36	<0.001	630
APW17	05/24/2021	<0.003	0.0035	0.59	<0.001	0.087	<0.001	110	88	<0.004	<0.002	0.474	<0.001	<0.02	<0.0002	0.005	7.4	1.36	<0.001	40	<0.001	670
APW17	06/16/2021	<0.003	0.0058	0.62	<0.001	0.088	<0.001	120	54	<0.004	<0.002	0.593	<0.001	<0.02	<0.0002	0.0048	7.4	3.11	<0.001	40	<0.001	640
APW17	06/30/2021	<0.003	0.0074	0.61	<0.001	0.084	<0.001	110	49	<0.004	<0.002	0.548	<0.001	<0.02	<0.0002	0.0048	7.4	2.6	<0.001	41	<0.001	630
APW17	07/15/2021	<0.003	0.0083	0.61	<0.001	0.091	<0.001	110	31	<0.004	<0.002	0.412	<0.001	<0.02	<0.0002	0.0049	7.4	1.55	<0.001	<25	<0.001	650
APW18	02/23/2021	<0.003	0.0043	0.18	<0.001	0.12	<0.001	49	79	0.0085	0.0034	1.43	0.0079	<0.02	<0.0002	0.033	7.9	2.72	<0.001	26	<0.001	560
APW18	03/10/2021	<0.003	0.0032	0.36	<0.001	0.11	<0.001	62	42	0.0066	0.0024	6.38	0.0048	<0.02	<0.0002	0.015	7.8	1.88	<0.001	12	<0.001	610
APW18	03/30/2021	<0.003	0.0025	0.34	<0.001	0.15	<0.001	60	35	<0.004	<0.002	7.02	0.0023	<0.02	<0.0002	0.012	7.3	0.912	<0.001	9.4	0.0016	580
APW18	04/29/2021	<0.003	0.0019	0.34	<0.001	0.14	<0.001	60	40	<0.004	<0.002	0.617	0.0018	<0.02	<0.0002	0.016	7.6	2.4	<0.001	<1	<0.001	490
APW18	05/24/2021	<0.003	0.0014	0.35	<0.001	0.11	<0.001	59	35	<0.004	<0.002	0.597	<0.001	<0.02	<0.0002	0.0095	7.6	1.91	<0.001	<1	<0.001	650
APW18	06/16/2021	0.0035	0.0043	0.36	0.0033	0.19	0.0034	64	29	0.0042	0.0036	6.67	0.0035	<0.02	0.00047	0.0096	7.6	2.12	0.0038	4.8	0.0022	550
APW18	06/30/2021	<0.003	<0.001	0.36	<0.001	0.11	<0.001	60	28	<0.004	<0.002	3.23	<0.001	<0.02	<0.0002	0.0048	7.6	1.73	<0.001	2.2	<0.001	450
APW18	07/15/2021	<0.003	0.0015	0.33	<0.001	0.12	<0.001	64	31	<0.004	<0.002	4.67	<0.001	<0.02	<0.0002	0.0051	7.6	2.2	<0.001	1.9	<0.001	520

Notes:
Detected at concentration greater than the GWPS
-- = data not available
GWPS = Groundwater Protection Standard
mg/L = milligrams per liter
pCi/L = picocuries per liter
SU = standard units
< = concentration is less than the concentration shown, which corresponds to the reporting limit for the method. Estimated concentrations below the reporting limit and associated qualifiers are not provided since they are not utilized in statistics to determine exceedances above Part 845 standards.
35 I.A.C. 845.600 = Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW02	01/13/2015	--	--	6.9	6190	--	--
APW02	04/21/2015	--	--	6.9	5320	--	--
APW02	07/15/2015	--	--	7.0	1653	--	--
APW02	10/07/2015	--	--	6.7	4290	--	--
APW02	02/17/2021	6.88	90.3	6.6	5409	5.9	22.1
APW02	03/10/2021	2.11	62.6	7.0	4714	12.4	57.5
APW02	03/30/2021	1.91	82	6.6	3158	13.6	20800
APW02	04/29/2021	1.10	164	6.7	5417	17.8	13.9
APW02	05/25/2021	1.10	116	6.7	5536	29.6	57
APW02	06/16/2021	0.57	52.9	6.6	5574	30.0	62.9
APW02	06/30/2021	0.86	82.3	6.6	5523	22.8	19
APW02	07/15/2021	0.51	57.6	6.5	5543	29.6	8.04
APW03	01/13/2015	--	--	7.4	1132	--	--
APW03	04/20/2015	--	--	7.0	988	--	--
APW03	07/15/2015	--	--	6.9	1212	--	--
APW03	10/07/2015	--	--	7.3	1047	--	--
APW03	02/18/2021	6.74	225	6.7	1132	7.9	140
APW03	03/10/2021	2.67	30.7	7.2	1041	12.6	55.8
APW03	03/31/2021	1.17	28.9	6.3	949.5	10.1	51.8
APW03	04/29/2021	0.92	114	7.0	1104	19.6	8.47
APW03	05/25/2021	1.10	132	7.0	1132	29.6	15.8
APW03	06/17/2021	0.81	166	7.0	1114	22.8	26.5
APW03	06/30/2021	0.85	37.8	7.0	1115	25.4	7.56
APW03	07/15/2021	0.78	-28.6	6.9	1121	35.0	124
APW04	01/13/2015	--	--	7.2	2980	--	--
APW04	04/20/2015	--	--	7.0	2880	--	--
APW04	07/15/2015	--	--	7.0	1431	--	--
APW04	10/07/2015	--	--	7.0	2510	--	--
APW04	02/18/2021	1.81	217	6.5	2396	6.9	293
APW04	03/11/2021	0.44	224	6.9	2387	10.6	62.9
APW04	03/31/2021	0.35	55	6.1	2005	10.8	63.4
APW04	04/29/2021	0.43	140	6.9	2297	19.0	8.29
APW04	05/25/2021	0.42	166	6.9	2313	22.7	56.7
APW04	06/17/2021	0.53	169	6.8	2330	27.0	31.4
APW04	06/30/2021	1.10	141	6.8	2339	26.4	25.9
APW04	07/15/2021	0.74	78.1	6.8	2333	33.9	227
APW05	12/15/2015	0	-57	7.5	1040	13.4	14.4
APW05	01/20/2016	0	-51	7.5	1030	12.6	44.6
APW05	04/27/2016	0	27	7.7	1120	14.3	15
APW05	08/01/2016	0	-64	7.5	1100	18.0	2.5
APW05	10/25/2016	0	-83	7.6	1070	16.8	0
APW05	01/23/2017	0	-143	7.4	1050	13.6	0
APW05	04/24/2017	0	-101	7.0	1060	17.3	0
APW05	06/13/2017	0	-88	7.1	1050	17.5	35.5

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW05	11/17/2017	0	-60	6.9	1080	12.7	24.2
APW05	05/18/2018	0	-61	7.1	1140	15.6	22.6
APW05	08/17/2018	0	-69	7.0	1025	15.2	22
APW05	11/09/2018	0	-56	7.0	1100	14.7	27.1
APW05	02/22/2019	0	-60	6.9	1071	11.4	34.6
APW05	08/22/2019	0	-60	7.0	1021	17.3	67.3
APW05	02/04/2020	0.83	-119	7.5	971.9	11.3	2.97
APW05	06/11/2020	1.20	-124	7.4	856	15.0	4.5
APW05	07/28/2020	1.20	-146	7.7	924.7	19.0	3.57
APW05	02/09/2021	0.19	-129	7.6	996	11.2	39.9
APW05	02/17/2021	1.33	192	7.2	1086	7.6	0
APW05	03/10/2021	0.15	-129	7.7	975.9	13.6	16.5
APW05	03/30/2021	0.69	-71.9	7.2	980.3	13.6	1.08
APW05	04/28/2021	0.60	-65	7.5	867	15.9	6.7
APW05	05/25/2021	0.95	61.8	7.5	976	17.9	1.89
APW05	06/17/2021	0.34	-150	7.7	946	18.8	0.81
APW05	06/30/2021	0.29	-160	7.5	977	19.0	1.02
APW05	07/15/2021	0.25	-140	7.8	995	16.7	3.96
APW05S	02/17/2021	0.69	202	6.6	4672	6.5	0
APW05S	03/10/2021	0.24	16.3	7.0	4186	12.5	0
APW05S	04/29/2021	0.45	4.7	6.8	4339	18.0	14.2
APW05S	05/25/2021	0.93	-37	6.9	4306	30.3	40.2
APW05S	06/17/2021	0.73	-8.8	6.8	3977	28.6	20.5
APW05S	06/30/2021	0.81	2.8	6.7	3967	27.6	32.6
APW05S	07/15/2021	0.73	-35.6	6.8	3933	32.6	9.27
APW06	12/15/2015	0	-5	7.5	915	13.2	1000
APW06	01/20/2016	0	58	7.4	990	11.9	77.4
APW06	04/27/2016	0	-61	6.5	896	14.4	0.3
APW06	08/01/2016	0	-80	7.4	1010	17.1	0
APW06	10/25/2016	0	-73	7.5	971	15.3	0
APW06	01/23/2017	0	-109	6.9	938	13.2	0
APW06	04/24/2017	0	-94	7.2	961	17.6	0
APW06	06/13/2017	0	-83	7.1	914	16.5	19.8
APW06	11/17/2017	0	-79	7.2	860	12.1	17.2
APW06	05/18/2018	0	-67	7.3	902	14.4	12.3
APW06	08/17/2018	0	-73	7.3	910	15.0	22.7
APW06	11/09/2018	0	-82	7.2	938	15.7	28.3
APW06	02/22/2019	0	-71	7.3	942	11.9	34.7
APW06	08/23/2019	0	-58	7.3	873	17.5	14.9
APW06	02/04/2020	2.20	-125	7.5	889.5	11.2	3.04
APW06	06/11/2020	1.30	-125	7.4	807	15.2	24.6
APW06	07/28/2020	0.66	-164	7.8	880.8	18.3	5.59
APW06	02/09/2021	1.40	-110	7.6	859.8	9.0	0.91
APW06	02/17/2021	0.19	-41	6.4	937.9	4.6	0

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW06	03/10/2021	0.23	-131	7.7	779.1	14.4	25.7
APW06	03/30/2021	0.31	-69.7	7.1	893.1	15.5	0
APW06	04/29/2021	0.36	-130	7.7	925	15.8	111
APW06	05/25/2021	0.29	-138	7.7	939	24.4	225
APW06	06/16/2021	0.47	-127	7.7	928	22.8	315
APW06	06/30/2021	0.78	-120	7.6	925	23.8	276
APW06	07/15/2021	0.75	-148	7.5	926	27.7	41.9
APW07	12/15/2015	1.71	-40	7.4	1060	12.0	55.1
APW07	01/21/2016	0	-110	7.4	1130	10.5	185
APW07	05/03/2016	0	-94	7.5	1210	13.5	179
APW07	08/01/2016	0	-114	7.3	1130	19.4	26
APW07	10/26/2016	0	-69	7.2	1110	17.9	5.7
APW07	01/26/2017	0	-136	7.2	1110	11.0	0
APW07	04/24/2017	0	-112	7.3	1130	17.2	0
APW07	06/13/2017	0	-94	7.2	1060	17.1	39.5
APW07	11/17/2017	0	-71	7.2	1120	12.5	47
APW07	05/18/2018	0	-88	7.1	1090	15.4	47.9
APW07	08/18/2018	0	-88	7.1	1000	15.0	41.1
APW07	11/09/2018	0	-92	7.0	993	13.9	33
APW07	02/22/2019	0	-92	7.2	1012	11.6	34
APW07	08/23/2019	0	-74	7.1	879	17.0	27.4
APW07	02/05/2020	0.39	-137	7.4	247.7	10.3	77.6
APW07	06/11/2020	0.16	-164	7.3	1112	15.1	51
APW07	07/28/2020	1.40	-104	7.3	1083	18.8	3.3
APW07	02/10/2021	2.30	-10.5	7.0	806.2	9.4	72.6
APW08	12/15/2015	0	38	7.4	1140	12.7	105
APW08	01/21/2016	0	-93	7.5	1150	11.0	83.3
APW08	05/03/2016	0	-93	7.4	1055	13.3	168
APW08	08/02/2016	0	-87	7.2	1160	17.9	5
APW08	10/26/2016	0	-76	7.4	1180	17.2	2.1
APW08	01/25/2017	0	-121	7.2	1140	14.2	0
APW08	04/25/2017	0	-103	7.5	1160	17.0	1000
APW08	06/13/2017	0	-108	7.3	1090	17.4	1000
APW08	11/17/2017	0	-102	7.1	1020	12.5	1000
APW08	05/18/2018	0	-96	7.2	940	16.2	890
APW08	08/18/2018	0	-101	7.2	993	15.0	100
APW08	11/09/2018	0	-109	7.1	857	13.8	1000
APW08	02/22/2019	0	-99	7.2	955	11.8	1000
APW08	08/23/2019	0	-98	7.2	1004	17.1	1000
APW08	02/05/2020	1.10	-130	7.4	1150	11.5	114
APW08	06/11/2020	0.54	-127	7.3	1163	15.1	30
APW08	07/28/2020	1.30	-101	7.3	1138	16.8	9.2
APW08	10/28/2020	1.00	-94.2	7.4	1148	14.2	17.9
APW08	02/10/2021	1.70	-103	7.2	1045	10.3	104

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW09	12/15/2015	0	11	7.5	1150	13.0	11.7
APW09	01/20/2016	0	72	7.6	1040	11.3	49.6
APW09	05/03/2016	0	56	7.6	988	13.9	67.7
APW09	08/02/2016	0	-106	7.2	1460	17.2	0
APW09	10/26/2016	0	-77	7.6	1450	15.9	0
APW09	01/25/2017	0	-140	7.5	1470	14.8	0
APW09	04/25/2017	0	-74	7.5	1420	18.4	0
APW09	06/13/2017	0	-67	7.5	1390	17.1	27.4
APW09	11/18/2017	0	-78	7.4	1420	13.0	34.1
APW09	05/18/2018	0	-71	7.4	1490	15.2	35.1
APW09	08/17/2018	0	-69	7.5	1265	15.0	40
APW09	11/09/2018	0	-72	7.4	1240	16.7	48.5
APW09	02/22/2019	0	-65	7.5	1285	11.7	50.3
APW09	08/23/2019	0	-60	7.4	1180	16.6	29
APW09	02/19/2020	0.86	-151	7.5	1456	13.5	10.1
APW09	06/11/2020	0.60	-152	7.4	1516	15.7	389
APW09	07/28/2020	0.47	-136	7.4	1467	18.9	19.9
APW09	02/11/2021	2.00	-28.1	7.4	1208	9.4	31.8
APW10	12/16/2015	1.93	-29	7.1	1610	13.3	1000
APW10	01/20/2016	0	-21	7.2	1430	12.5	1000
APW10	05/03/2016	0	-19	7.1	1326	13.4	33.3
APW10	08/02/2016	0	-18	7.1	1640	17.4	0
APW10	10/26/2016	0	38	7.1	1600	14.5	0
APW10	01/25/2017	0	-73	7.1	1570	13.6	0
APW10	04/25/2017	0	0	7.0	1610	15.6	0
APW10	06/13/2017	0	12	6.9	1620	15.8	36.5
APW10	11/18/2017	0	34	6.9	1480	12.4	43
APW10	05/18/2018	0	29	7.2	1600	14.7	48.5
APW10	08/17/2018	0	57	6.9	1468	15.1	41.2
APW10	11/09/2018	0	78	7.0	1340	14.9	46.8
APW10	02/22/2019	0	61	6.9	1510	11.9	41.1
APW10	08/23/2019	0	69	7.0	1520	17.2	30.7
APW10	02/05/2020	0.50	14.7	7.1	356	10.6	4.57
APW10	06/11/2020	1.10	-207	7.2	1563	16.1	1.4
APW10	07/28/2020	0.21	-153	7.1	1546	20.8	1.6
APW10	02/11/2021	3.00	46.7	7.4	1594	5.9	168
APW10	06/17/2021	1.70	79.6	7.3	1501	20.4	2.24
APW10	06/30/2021	1.50	140	7.5	1531	16.2	5.8
APW10	07/29/2021	2.80	132	7.5	4100	19.1	0
APW11	02/18/2021	0.14	125	6.1	1285	9.8	0
APW11	03/09/2021	0.37	-56.2	7.2	1460	15.0	174
APW11	03/29/2021	0.23	2.6	6.6	1130	14.4	1760
APW11	04/28/2021	2.00	-51.6	7.1	1297	16.7	96.4
APW11	05/24/2021	3.10	-82.4	7.4	1337	16.5	11.3

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW11	06/16/2021	2.60	-41.2	7.2	1320	19.9	14.8
APW11	06/30/2021	3.10	-37.2	7.1	381.5	17.4	3.65
APW11	07/15/2021	4.10	-24.4	7.2	1318	16.9	5.12
APW12	02/17/2021	0.16	27.2	6.2	1917	10.2	0
APW12	03/09/2021	0.15	45.5	6.5	2115	13.6	6.38
APW12	03/29/2021	0.20	117	6.0	1752	13.4	12.2
APW12	04/28/2021	0.92	11.2	6.4	1537	15.5	22.6
APW12	05/25/2021	0.84	49.5	6.5	1571	17.6	44.5
APW12	06/16/2021	2.40	9.9	6.4	268.4	22.4	10.7
APW12	06/30/2021	1.10	115	6.3	1546	17.6	3.59
APW12	07/15/2021	0.40	22.8	6.5	1870	17.1	3.16
APW13	02/22/2021	0.25	-102	7.1	1544	13.4	25.7
APW13	03/10/2021	0.31	-80.2	7.2	1336	13.8	28.7
APW13	03/31/2021	1.13	-9.4	6.4	1392	12.7	28.8
APW13	04/29/2021	1.40	-96.2	7.2	1399	15.9	8.6
APW13	05/25/2021	3.50	-95.6	7.3	1390	19.1	12.4
APW13	06/17/2021	1.90	-75.3	7.2	1399	18.9	1.69
APW13	06/30/2021	2.10	-78.8	7.3	1393	18.2	0
APW13	07/15/2021	1.50	-90	7.3	1237	16.9	3.97
APW14	02/22/2021	0.95	-113	7.5	1646	12.8	173
APW14	03/10/2021	0.29	-104	7.4	1251	13.7	57.1
APW14	03/31/2021	0.16	-46.7	6.5	1236	13.5	40.4
APW14	04/28/2021	0.99	-120	7.4	1504	17.0	51.6
APW14	05/25/2021	2.00	-145	7.5	1300	20.1	24.9
APW14	06/17/2021	2.60	-97.8	7.4	1313	17.3	19.3
APW14	06/30/2021	1.80	-123	7.5	1290	17.4	11.3
APW14	07/15/2021	0.73	-144	7.4	1533	19.5	4.81
APW15	02/23/2021	0.44	-98.5	7.0	2095	12.9	80.4
APW15	03/10/2021	1.03	-108	7.2	1648	14.9	134
APW15	03/31/2021	0.13	-61.8	6.5	184.7	13.3	126
APW15	04/28/2021	0.16	-122	7.2	2041	16.2	506
APW15	05/24/2021	1.70	-128	7.3	1955	18.8	23.5
APW15	06/17/2021	0.22	-136	7.3	2030	19.9	6.01
APW15	06/30/2021	0.90	-133	7.1	1926	18.2	7.5
APW15	07/14/2021	1.20	-142	7.2	1662	19.4	5.18
APW16	02/23/2021	3.16	-71.4	7.4	1162	12.1	9.52
APW16	03/10/2021	0.18	-132	7.5	1316	13.6	0
APW16	03/30/2021	0.22	-99.5	7.0	1318	13.5	0
APW16	04/28/2021	1.30	-129	7.4	1350	15.1	10.6
APW16	05/24/2021	2.40	-132	7.5	1375	16.2	38.9
APW16	06/16/2021	0.88	-123	7.4	1338	16.6	23.9
APW16	06/30/2021	0.88	-119	7.0	1331	16.8	7.06
APW16	07/15/2021	0.80	-143	7.4	1421	19.4	9.03
APW17	02/23/2021	2.55	-22.5	7.4	901.8	12.6	22.6

TABLE 4-2. GROUNDWATER FIELD PARAMETERS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Dissolved Oxygen (mg/L)	Oxidation Reduction Potential (mV)	pH (field) (SU)	Specific Conductance (micromhos/cm)	Temperature (deg. C)	Turbidity (NTU)
APW17	03/10/2021	1.60	-132	7.7	951.8	13.8	0
APW17	03/30/2021	0.29	-87.2	7.1	1202	14.1	0
APW17	04/29/2021	3.40	-126	7.4	1042	16.3	9.5
APW17	05/24/2021	2.30	197	7.4	1206	20.8	29.5
APW17	06/16/2021	1.80	-130	7.4	1122	21.3	1.13
APW17	06/30/2021	1.30	-138	7.4	1206	19.7	3.13
APW17	07/15/2021	1.50	-110	7.4	1210	18.5	1.81
APW18	02/23/2021	1.94	-141	7.9	941.7	13.6	430
APW18	03/10/2021	0.80	-150	7.8	930.2	13.8	241
APW18	03/30/2021	0.49	-110	7.3	626.2	13.8	247
APW18	04/29/2021	1.50	-154	7.6	920	16.0	61.3
APW18	05/24/2021	2.30	120	7.6	1029	19.3	208
APW18	06/16/2021	0.75	-171	7.5	995	22.2	4.58
APW18	06/30/2021	0.41	-182	7.6	1011	21.6	8.28
APW18	07/15/2021	0.42	-154	7.6	1010	19.6	27.7

Notes:
Field readings are reported with as many significant figures as provided by analytical laboratory.
-- = data not available
cm = centimeter
deg. C = degrees Celsius
mg/L = milligrams per liter
mV = millivolts
NTU = nephelometric turbidity units
SU = standard units

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FIGURES

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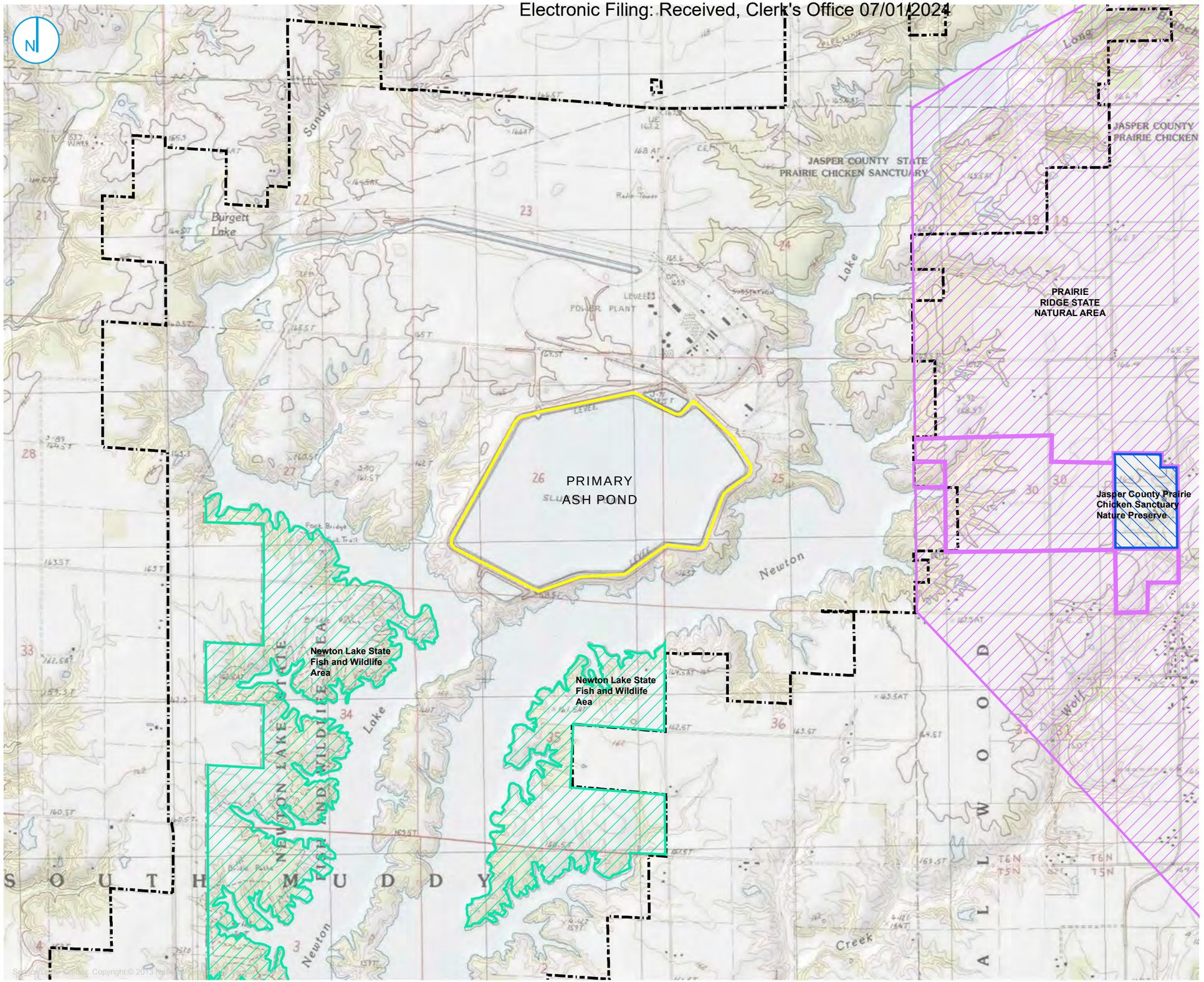

PART 845 REGULATED UNIT FACILITY BOUNDARY
JASPER COUNTY PRAIRIE CHICKEN SANCTUARY NATURE PRESERVE
NEWTON LAKE STATE FISH AND WILDLIFE AREA
PRAIRIE RIDGE STATE NATURAL AREA
PROPERTY BOUNDARY

0 1,000 2,000 Feet

SITE LOCATION MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-1

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Newton\Figure 1-1_Site Location Map.mxd

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PART 845 REGULATED UNIT FACILITY BOUNDARY
SITE FEATURE
PROPERTY BOUNDARY

0 500 1,000
Feet

SITE MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\Newton\Figure 1-2_Site Map.mxd

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10-FOOT ELEVATION CONTOUR
2-FOOT ELEVATION CONTOUR
PART 845 REGULATED UNIT FACILITY BOUNDARY
SITE FEATURE
PROPERTY BOUNDARY

NOTE

ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

SOURCE

INGENAE SURVEY, 2021

0 400 800 Feet

TOPOGRAPHIC MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2222285\MXD\845_Operating_Permit\Newton\Figure 2-1_Topo Map.mxd

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PART 845 REGULATED UNIT FACILITY BOUNDARY
SITE FEATURE
NRCS SOIL SURVEY MAP UNIT BOUNDARY

MAP UNIT SYMBOL	MAP UNIT NAME
533	Urban land
866	Dumps, slurry
109A	Racoon silt loam, 0 to 2 percent
12A	Wynoose silt loam, 0 to 2 percent
13A	Bluford silt loam, 0 to 2 percent
13B2	Bluford silt loam, 2 to 5 percent slopes, eroded
14B	Ava silt loam, 2 to 5 percent slopes
14C2	Ava silt loam, 5 to 10 percent slopes, eroded
2A	Cisne silt loam, 0 to 2 percent
3333A	Wakeland silt loam, 0 to 2 percent slopes, frequently flooded
48A	Ebbert silt loam, 0 to 2 percent
581B2	Tamalco silt loam, 2 to 5 percent slopes, eroded
7C2	Atlas silt loam, 5 to 10 percent slopes, eroded
7C3	Atlas silty clay loam, 5 to 10 percent slopes, severely eroded
805C	Orthents, clayey, sloping
8F	Hickory silt loam, 18 to 35 percent
912A	Hoyleton-Darmstadt silt loams, 0 to 2 percent slopes
M-W	Miscellaneous water
W	Water

SOURCE:
NATURAL RESOURCES CONSERVATION SERVICE (NRCS)

0 400 800
Feet

SOIL SURVEY MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 2-2_Soil Survey.mxd

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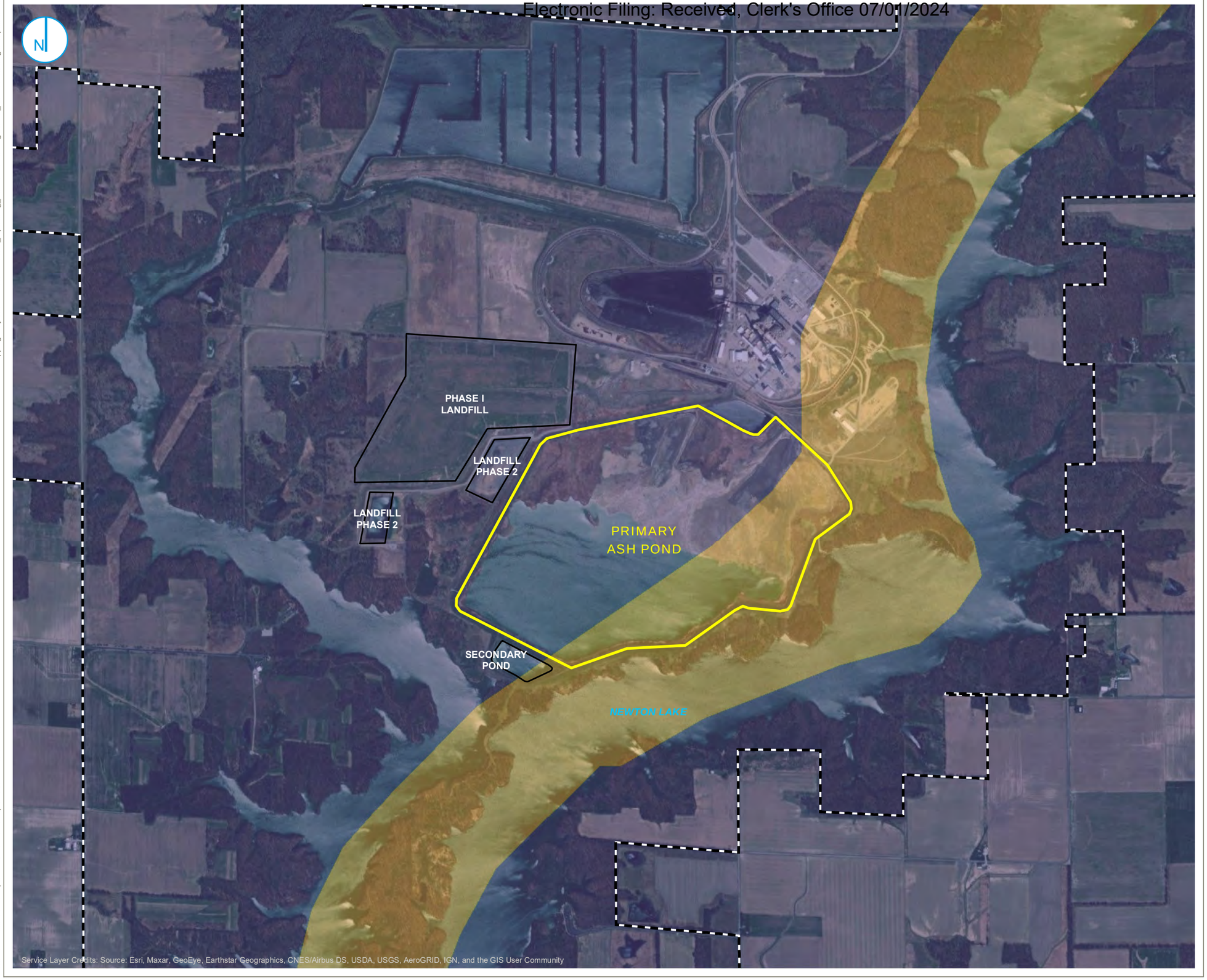

PART 845 REGULATED UNIT FACILITY BOUNDARY

SITE FEATURE

CAHOKIA ALLUVIUM (INCLUDES ALLUVIAL FAN FACIES)

VANDALIA TILL MEMBER

PROPERTY BOUNDARY

SOURCE
ILLINOIS STATE GEOLOGICAL SURVEY (ISGS)

0 750 1,500
Feet

SURFICIAL GEOLOGIC DEPOSITS

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 2-3_Surficial Geologic Deposits.mxd

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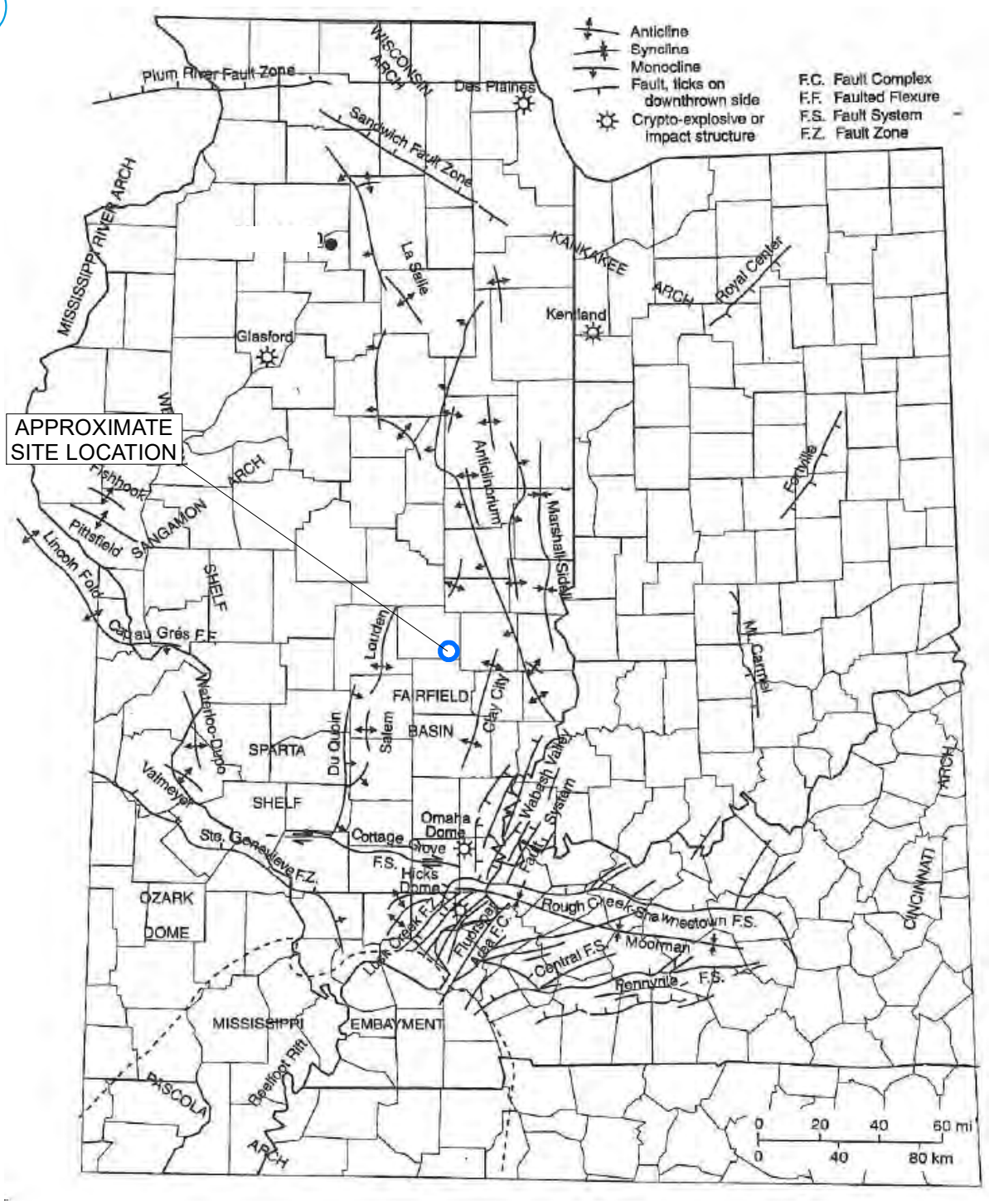

SOURCE NOTE: MODIFIED FROM "NELSON, W.J. 1995, STRUCTURAL FEATURES IN ILLINOIS, ILLINOIS STATE GEOLOGICAL SURVEY, BULLETIN 100, CHAMPAIGN, ILLINOIS."

Service Layer Credits:

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 2-4_Major Structural Features of Illinois.mxd

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MAJOR STRUCTURAL FEATURES OF ILLINOIS

DRAFT

FIGURE 2-4

PRIVILEGED AND CONFIDENTIAL
PREPARED AT THE REQUEST OF COUNSEL

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

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- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- SOIL BORING
- PART 845 REGULATED UNIT FACILITY BOUNDARY
- SITE FEATURE

0 400 800
Feet

FIELD INVESTIGATION LOCATIONS

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-5

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 2-5_Field Investigation Locations.mxd

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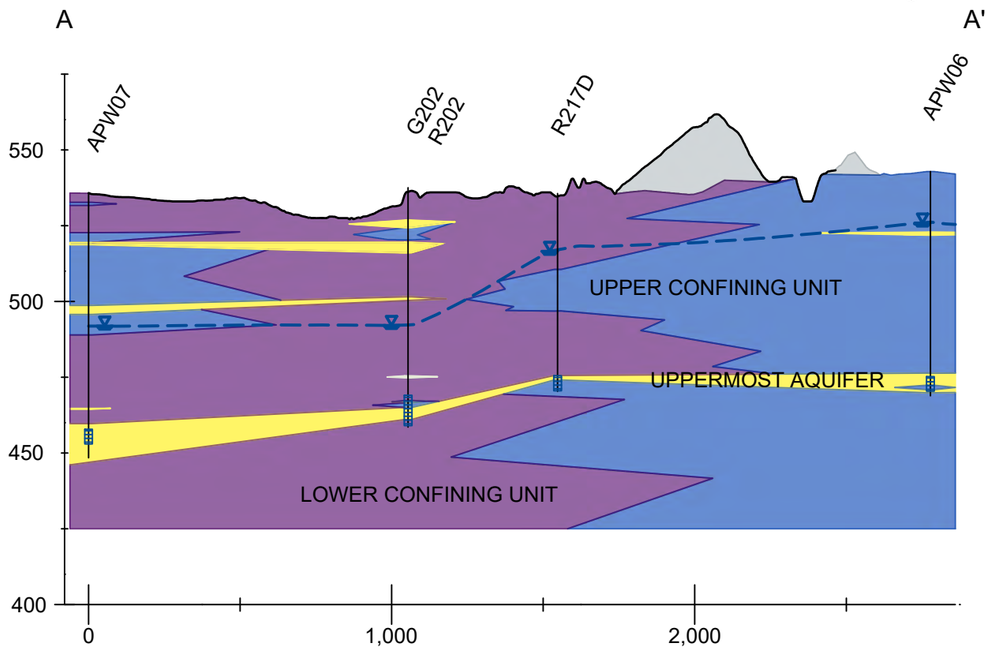
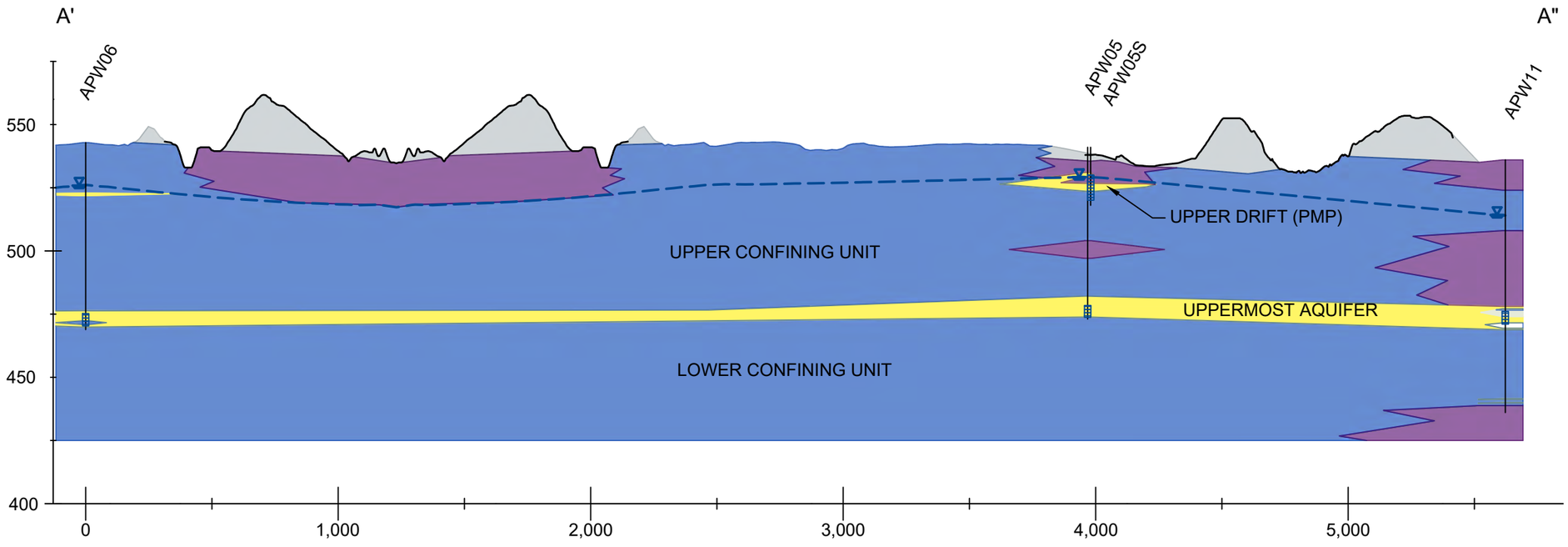




NOTES

1. This profile was developed by interpolation between widely spaced boreholes. Only at the borehole location should it be considered as an approximately accurate representation and then only to the degree implied by the notes on the borehole logs.
2. Scale is approximate.
3. Vertical scale is exaggerated 10X.
4. Groundwater elevations measured on June 24, 2021.
5. PMP = potential migration pathway



LEGEND

- FILL
- CLAY (CL/CH)
- SILT (ML)
- SAND (SP/SM/SW)
- GRAVEL (GP/GW)
- WELL SCREEN INTERVAL
- UPPERMOST AQUIFER POTENTIOMETRIC SURFACE
- UPPERMOST AQUIFER GROUNDWATER ELEVATION

50' 0 500'

GEOLOGIC CROSS SECTION
A-A' & A'-A"

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-6

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

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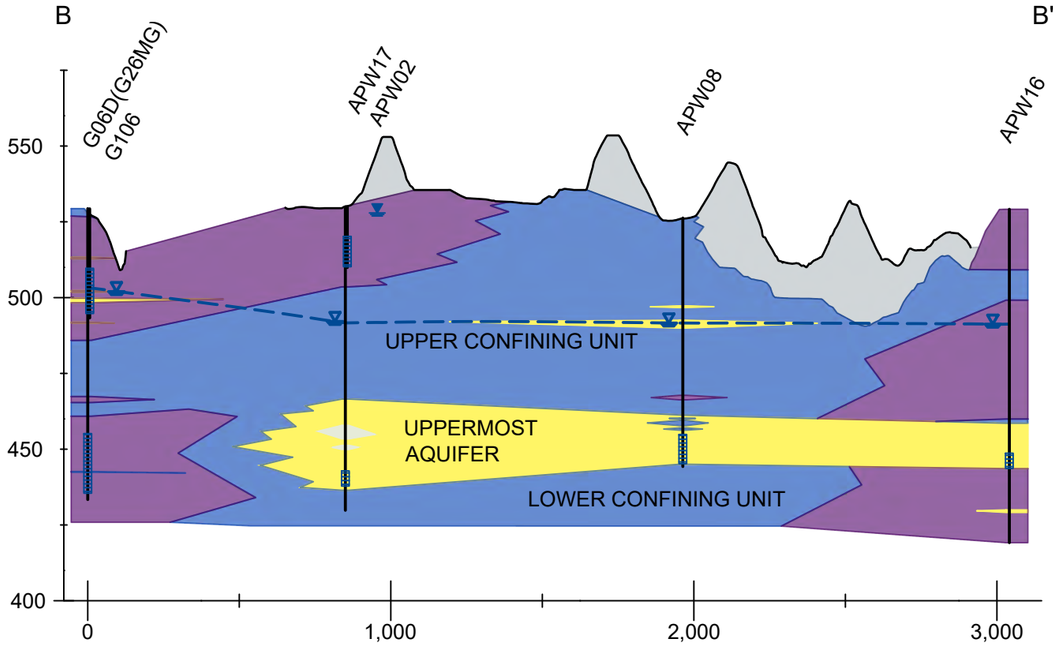


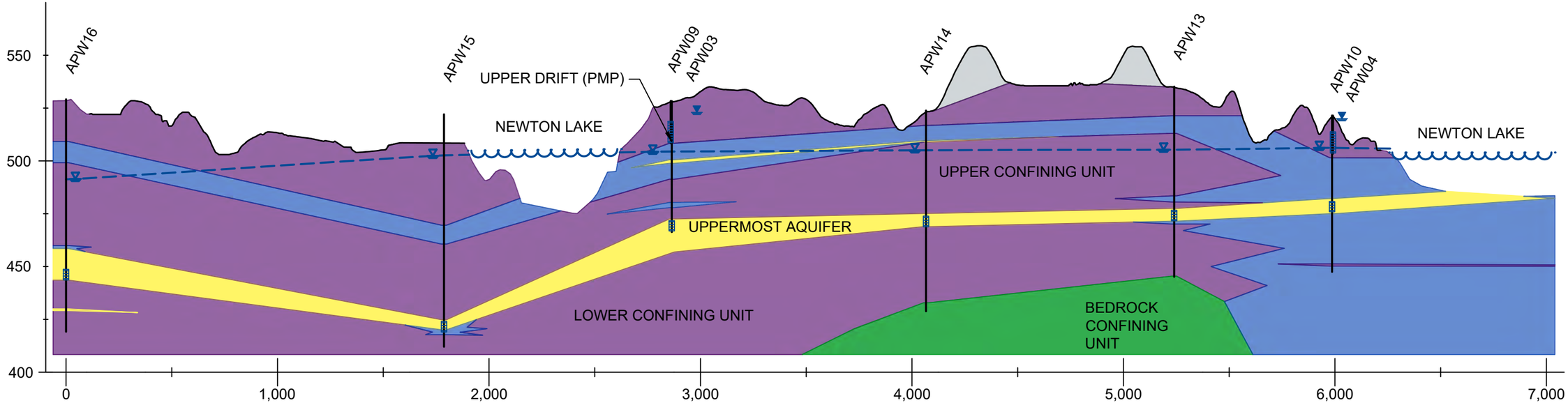


NOTES

1. This profile was developed by interpolation between widely spaced boreholes. Only at the borehole location should it be considered as an approximately accurate representation and then only to the degree implied by the notes on the borehole logs.
2. Scale is approximate.
3. Vertical scale is exaggerated 10X.
4. Groundwater elevations measured on June 24, 2021.
5. PMP = potential migration pathway

B'

B"



LEGEND

- FILL
- CLAY (CL/CH)
- SILT (ML)
- SAND (SP/SM/SW)
- GRAVEL (GP/GW)
- BEDROCK / WEATHERED BEDROCK (SHALE)
- WELL SCREEN INTERVAL
- UPPERMOST AQUIFER POTENTIOMETRIC SURFACE
- UPPERMOST AQUIFER GROUNDWATER ELEVATION
- BEDROCK GROUNDWATER / OTHER GROUNDWATER / SURFACE WATER ELEVATION(S)

50' 0 500'

GEOLOGIC CROSS SECTION
B-B' & B'-B"

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-7

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: ####
DATE: 10/8/2019
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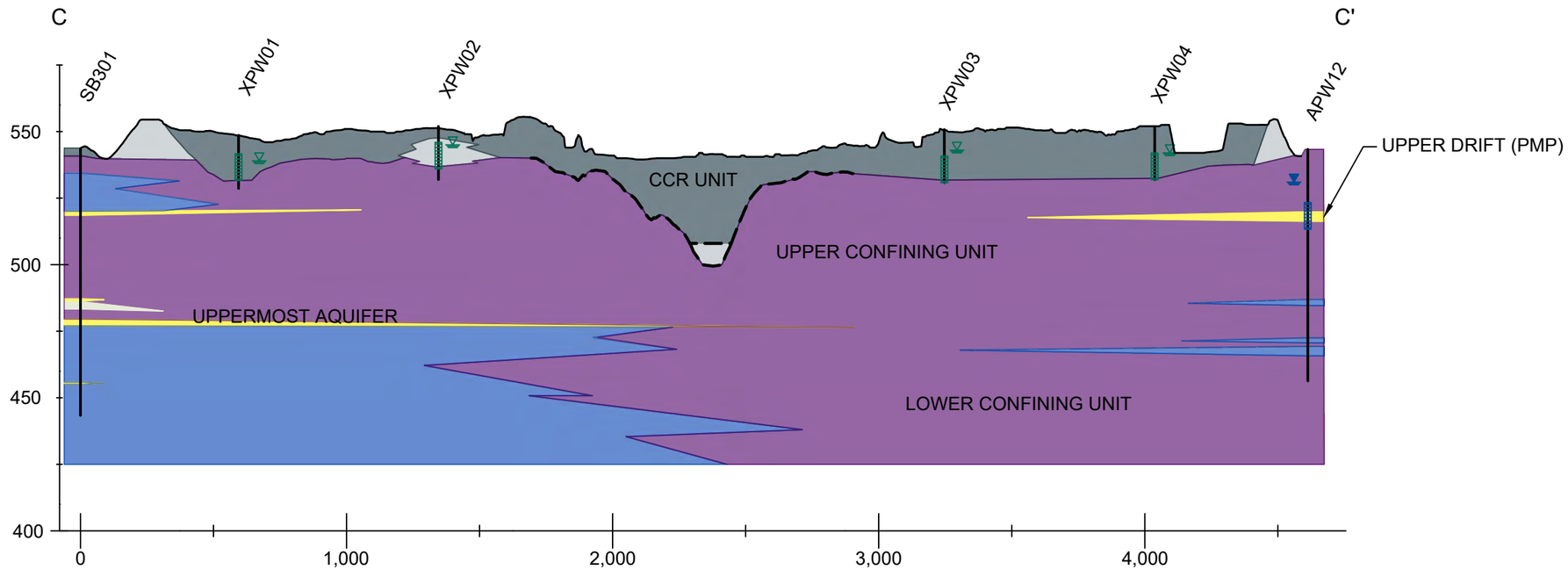
NOTES
1. This profile was developed by interpolation between widely spaced boreholes. Only at the borehole location should it be considered as an approximately accurate representation and then only to the degree implied by the notes on the borehole logs.
2. Scale is approximate.
3. Vertical scale is exaggerated 10X.
4. Base of CCR Unit is based on historic land surface contours. This surface is being further evaluated as the construction permit is being developed.
5. Groundwater elevations measured on June 24, 2021.
6. PMP = potential migration pathway



LEGEND
- COAL COMBUSTION RESIDUALS (CCR)
- FILL
- CLAY (CL/CH)
- SILT (ML)
- SAND (SP/SM/SW)
- GRAVEL (GP/GW)
- WELL SCREEN INTERVAL
- POREWATER ELEVATION
- BEDROCK GROUNDWATER / OTHER GROUNDWATER / SURFACE WATER ELEVATION(S)

50' 0 500'

GEOLOGIC CROSS SECTION
C-C'

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-8

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: #### DATE: 10/8/2024 DESIGNER: ENGELHARD \\ramboll.sharepoint.com@SSL\DavidWWRoot\sites\vista\Shared Documents\-CCR GW\Deliverables\Part 845 Operating Permits\Sites\Newton\Hydrogeo\EVS\working files\CAD\Cross Sections\Newton-Cross Sections.dwg

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SOIL BORING AND BOTTOM OF ASH ELEVATION

10 FOOT HISTORIC ELEVATION CONTOUR

2 FOOT HISTORIC ELEVATION CONTOUR

CONSTRUCTION DRAWING S-69 INDICATES DRAINAGE FEATURE WAS TO BE FILLED TO MAX ELEVATION 508 PRIOR TO OPERATION OF THE UNIT.

PART 845 REGULATED UNIT FACILITY BOUNDARY

SITE FEATURE

PROPERTY BOUNDARY

NOTES

1. CONTOUR LINES ARE A HISTORIC LAND SURFACE. THIS SURFACE IS BEING FURTHER EVALUATED AS THE CONSTRUCTION PERMIT IS BEING DEVELOPED.

0 400 800
Feet

BOTTOM OF ASH MAP

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-9

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\Newton\Figure 2-9_Bottom of Ash Map.mxd

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BACKGROUND WELL
MONITORING WELL
SOURCE SAMPLE LOCATION
STAFF GAGE
PART 845 REGULATED UNIT FACILITY BOUNDARY
SITE FEATURE

0 400 800
Feet

MONITORING WELL LOCATIONS

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 3-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\Newton\Figure 3-1_Monitoring Well Location Map.mxd

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MONITORING WELL

UPPERMOST AQUIFER ELEVATION (2-FOOT INTERVAL)

PART 845 REGULATED UNIT FACILITY BOUNDARY

SITE FEATURE

PROPERTY BOUNDARY

NOTES:
* = NOT USED FOR CONTOURING
ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88)

TOP OF AQUIFER CONTOURS GENERATED IN 2018 (HALEY & ALDRICH, INC., 2018) FOR 40 C.F.R. § 257; CONTOURS HAVE NOT BEEN MODIFIED USING BORING DATA COLLECTED IN 2021, ALTHOUGH THE SEPARATION DISTANCE BETWEEN THE TOP OF UPPERMOST AQUIFER AND BOTTOM OF ASH IS CONSISTENT.

0 400 800
Feet

TOP OF UPPERMOST AQUIFER

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 3-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 3-2_Top of Uppermost Aquifer.mxd

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Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\NewtonFigure 3-3_GWE_Contours_20210427.mxd

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: STOLZSD



- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

NOTES:

1.ELEVATIONS IN PARENTHESES WERE NOT USED FOR CONTOURING.

2. NM = NOT MEASURED

3. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

0 400 800 Feet

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS APRIL 27, 2021

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

FIGURE 3-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

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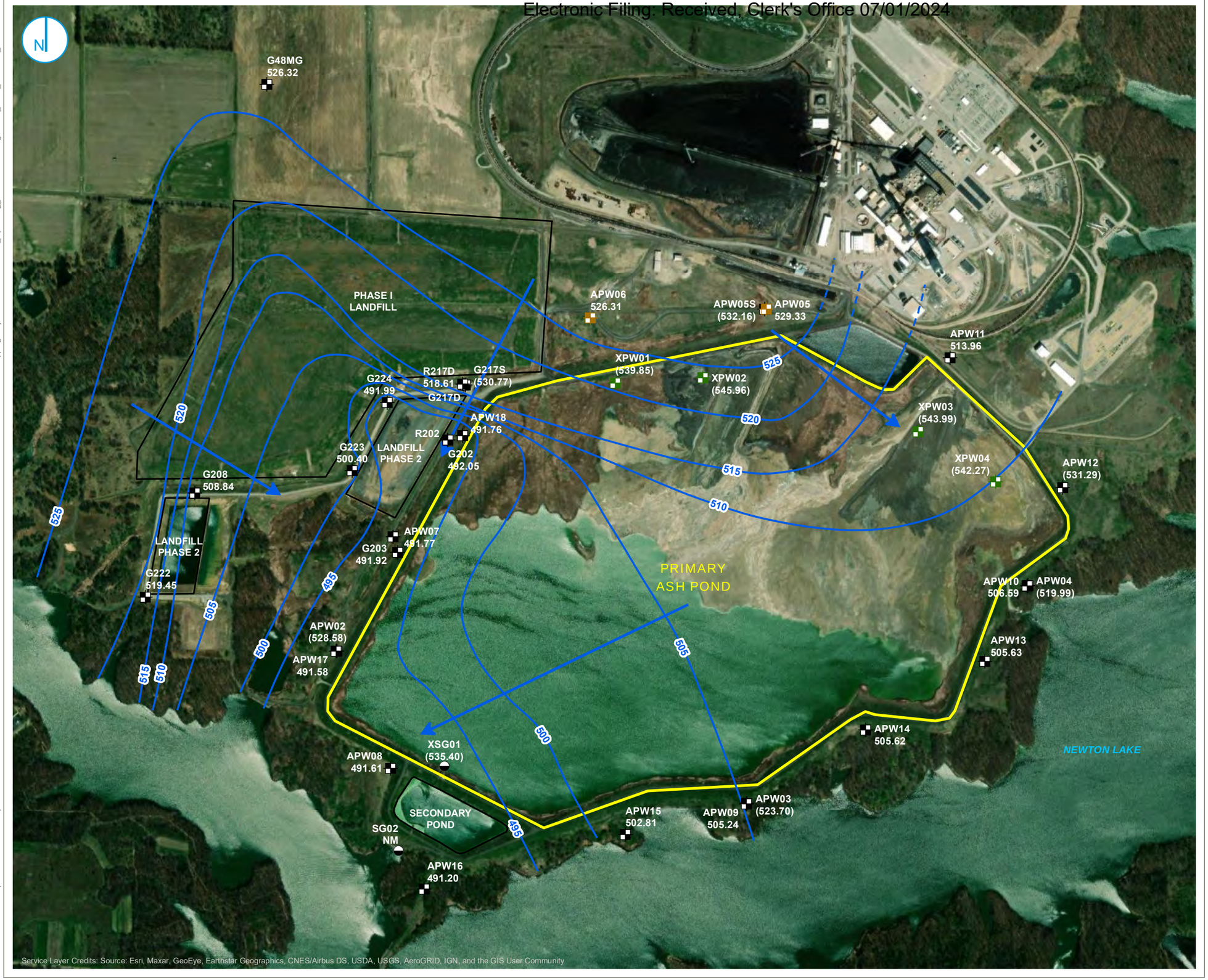

- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

NOTES:

1.ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.

2. NM = NOT MEASURED

3. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

0 400 800 Feet

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS JULY 14, 2021

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

FIGURE 3-4

RAMBOLL AMERICAS ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\Figure 3-4_GWE_Contours_20210714.mxd

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: STOLZSD

APPENDICES

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX A
HISTORIC TOPOGRAPHIC MAP S-69

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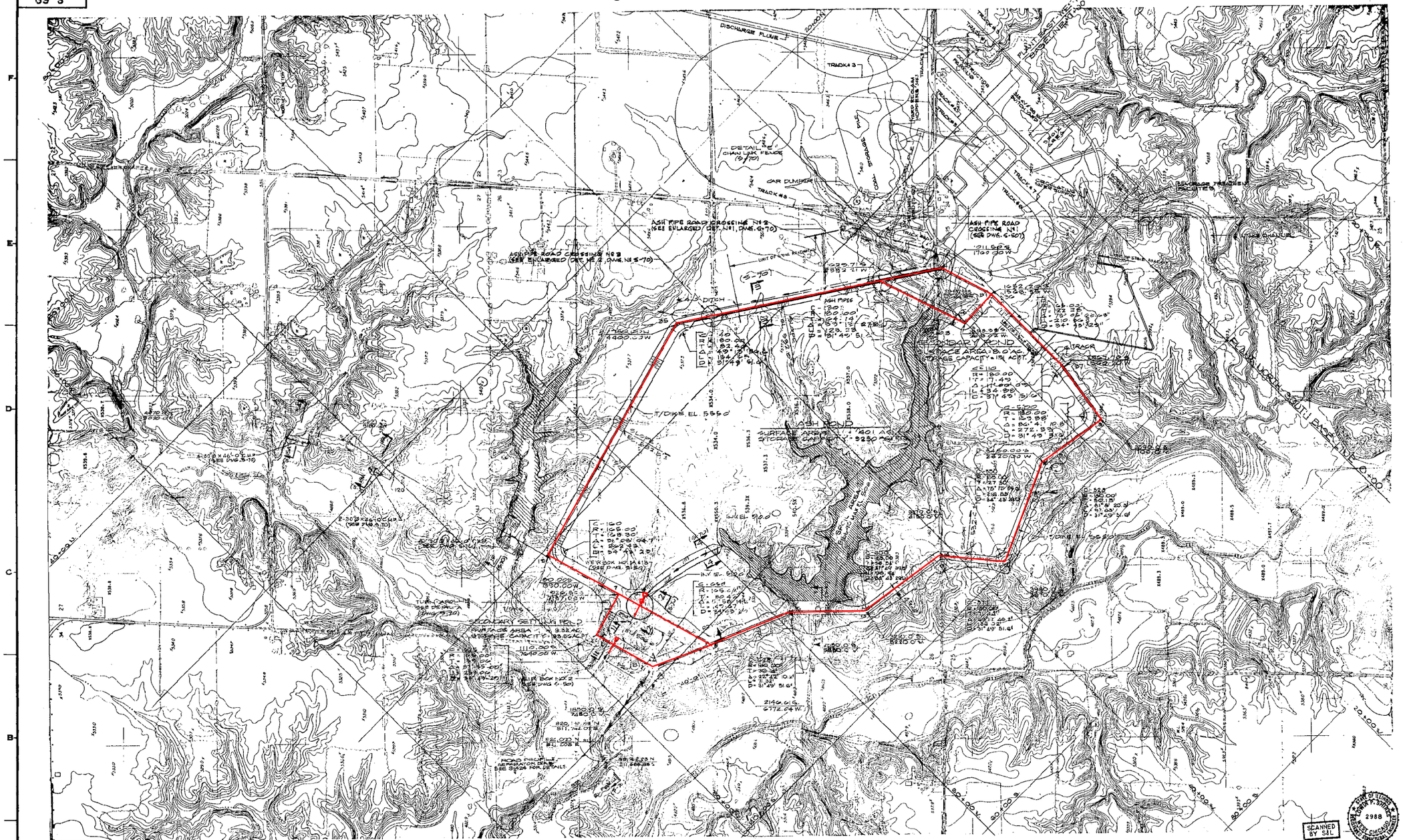
Electronic Filing: Received, Clerk's Office 07/01/2024

S-69



APPENDIX B
INFORMATION PERTINENT TO 35 I.A.C. § 845.220(A)(3)

SUMMARY OF POTENTIAL RECEPTORS WITHIN 1,000 METERS

DESKTOP STUDY

NEWTON POWER PLANT

PRIMARY ASH POND

NEWTON, IL

Category	Number of Receptors Identified Within 1,000 Meters	Number of Receptors Identified Downgradient of Unit	Notes
Wells	2	0	Sidegradient; Wells are listed as dry/abandoned.
Surface Water Features	12	2	
Historic Sites	0	0	
Natural Sites	0	0	
Threatened or Endangered Species	25	10	Data provided only at a county level.
Mines	0	0	Nearest mine is 6.7 miles northeast.
Oil Sites	0	0	

[O: CJC 06/02/21; C: LDC 09/15/21]

WATER WELL SURVEY

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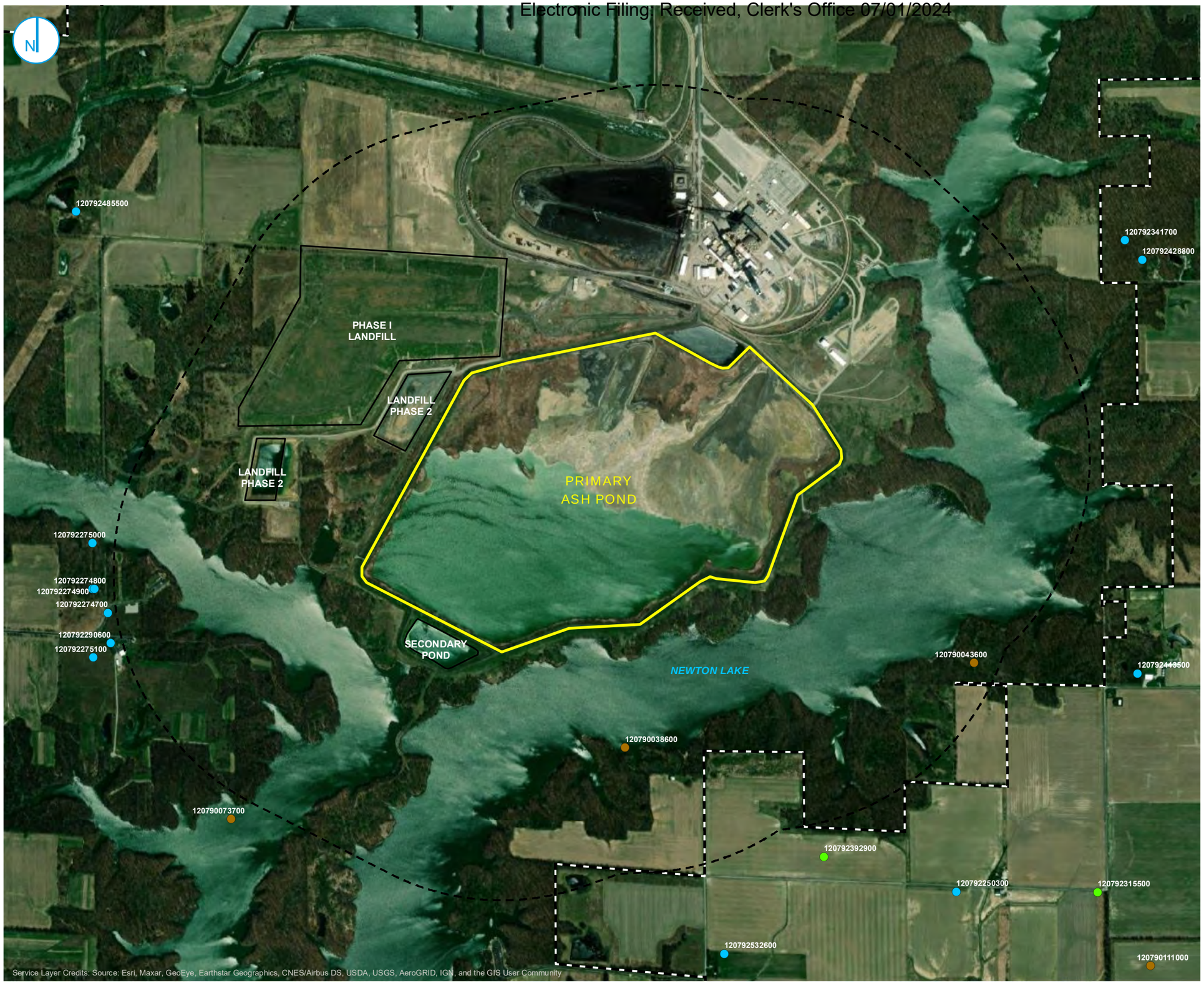

- DRY
- WATER
- N/A
- PART 845 REGULATED UNIT FACILITY BOUNDARY
- 1000 METER UNIT BUFFER
- SITE FEATURE
- PROPERTY BOUNDARY

SOURCE: IL WELLS

0 625 1,250
Feet

DRINKING WATER INTAKES, PUMPING WELLS, AND USES OF WATER

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE B-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2022285\MXD\845_Operating_Permit\Newton\Figure B-2_Drinking Water Intakes Uses of Water.mxd

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: STOLZSD

WELLS WITHIN 1,000 METERS
DESKTOP STUDY
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well Number	Date Constructed	Ground Elevation (ft NAVD88)	Screen Top Depth (FT BGS)	Screen Bottom Depth (ft BGS)	Screen Length (ft)	Screen Diameter (inches)	Well Depth (ft BGS)	Total Boring Depth (ft BGS)	Latitude (DD)	Longitude (DD)	Hydraulic Position Designation (B/Sd/U/D)	Notes
120790038600	5/27/1948	---	---	---	---	---	---	---	38.918277	-88.281956	Sd	
120790043600	7/13/1950	---	---	---	---	---	---	---	38.921356	-88.265738	Sd	

[O: CJC 06/02/21; C: LDC 09/15/21]

Notes:
--- = no data
B = background
BGS = below ground surface
D = downgradient
DD = decimal degrees
ft = foot/feet
LCU = lower confining unit
Sd= Sidegradient
U = upgradient
NAVD88 = North American Vertical Datum of 1988, GEOID 12A

SURFACE WATERS

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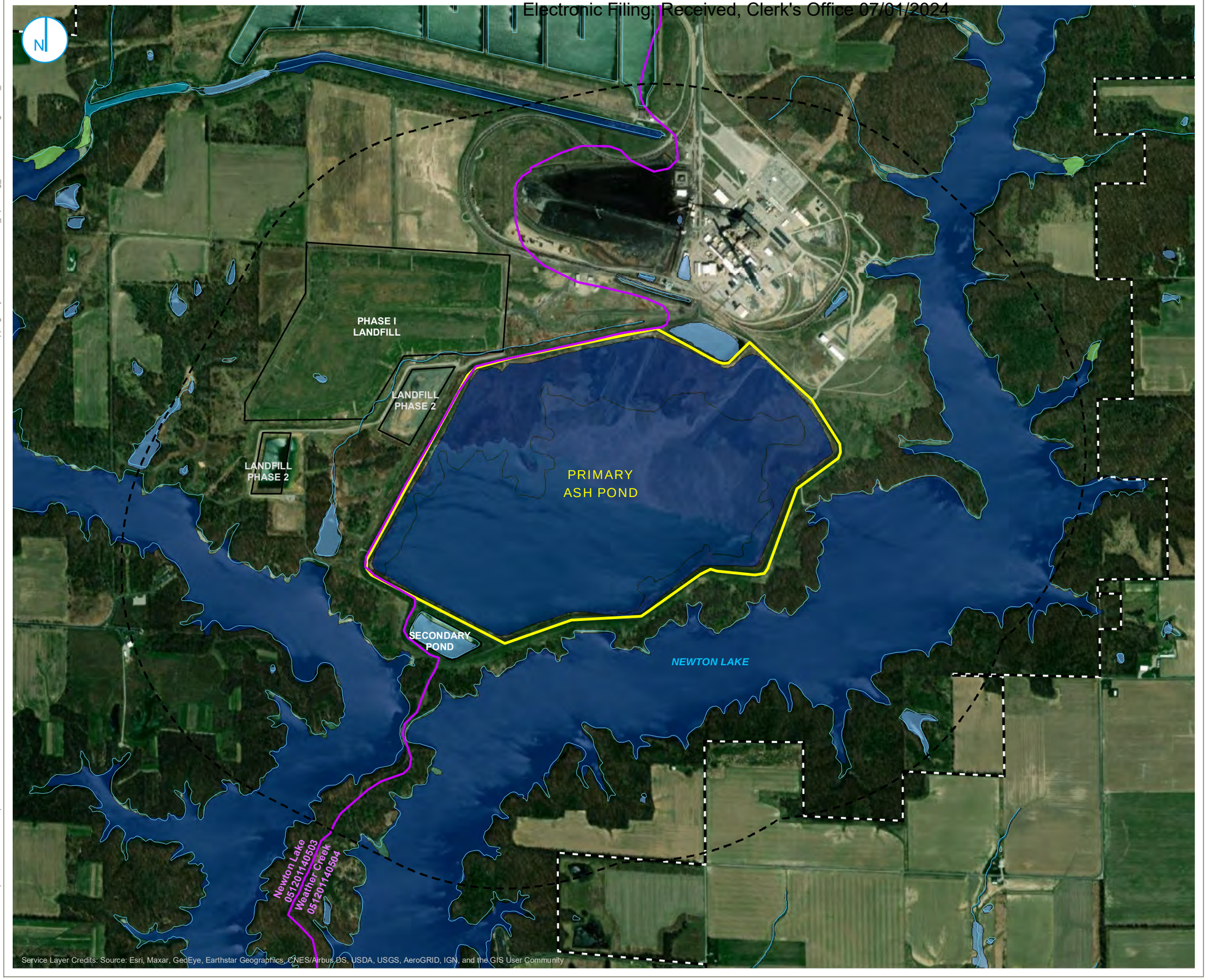


SURFACE WATERBODY
WATERSHED BOUNDARY (HUC 12)

NATIONAL WETLANDS INVENTORY

FRESHWATER EMERGENT WETLAND
FRESHWATER FORESTED/SHRUB WETLAND
FRESHWATER POND
LAKE
OTHER
RIVERINE

PART 845 REGULATED UNIT FACILITY BOUNDARY
1000 METER UNIT BUFFER
SITE FEATURE
PROPERTY BOUNDARY

SOURCES: USGS, USFWS

0 625 1,250
Feet

SURFACE WATERBODIES

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE B-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: STOLZSD

Y:\Mapping\Projects\22\2285\MXD\845_Operating_Permit\Newton\Figure B-3_Surface Waterbodies.mxd

SURFACE WATER FEATURES WITHIN 1,000 METERS

DESKTOP STUDY

NEWTON POWER PLANT

PRIMARY ASH POND

NEWTON, IL

HUC	Surface Water ID	Distance from Unit (ft)	Distance from Unit (meters)	Physical Orientation to Unit	Hydraulic Orientation to Unit	Classification Code	Size (acres)
--	Freshwater Pond	45	14	NE	Upgradient	PUBGh	6.16
--	Freshwater Pond	2610	795	SE	Sidegradient	PUBGh	2.28
--	Freshwater Pond	3250	991	NW	Upgradient	PUBGh	4.07
--	Freshwater Pond 2	153	47	SW	Downgradient	PUBGh	5.79
--	Freshwater Pond 3	958	292	NE	Upgradient	PUBGh	0.92
--	Freshwater Pond 4	720	219	N	Upgradient	PUBGx	0.99
--	Freshwater Pond 5	440	134	W	Upgradient	PUBGh	3.7
--	Freshwater Pond 6	1600	488	NW	Upgradient	PUBGh	0.27
--	Lake	2780	847	N	Upgradient	L1UBHx	13.72
--	Lake Newton	240	73	S	Downgradient	L1UBHh	1647.98
--	Riverine Wetland	123	37	N	Upgradient	R4SBC	2.26
--	Riverine Wetland 2	142	43	N/NW	Upgradient	R4SBC	2.26

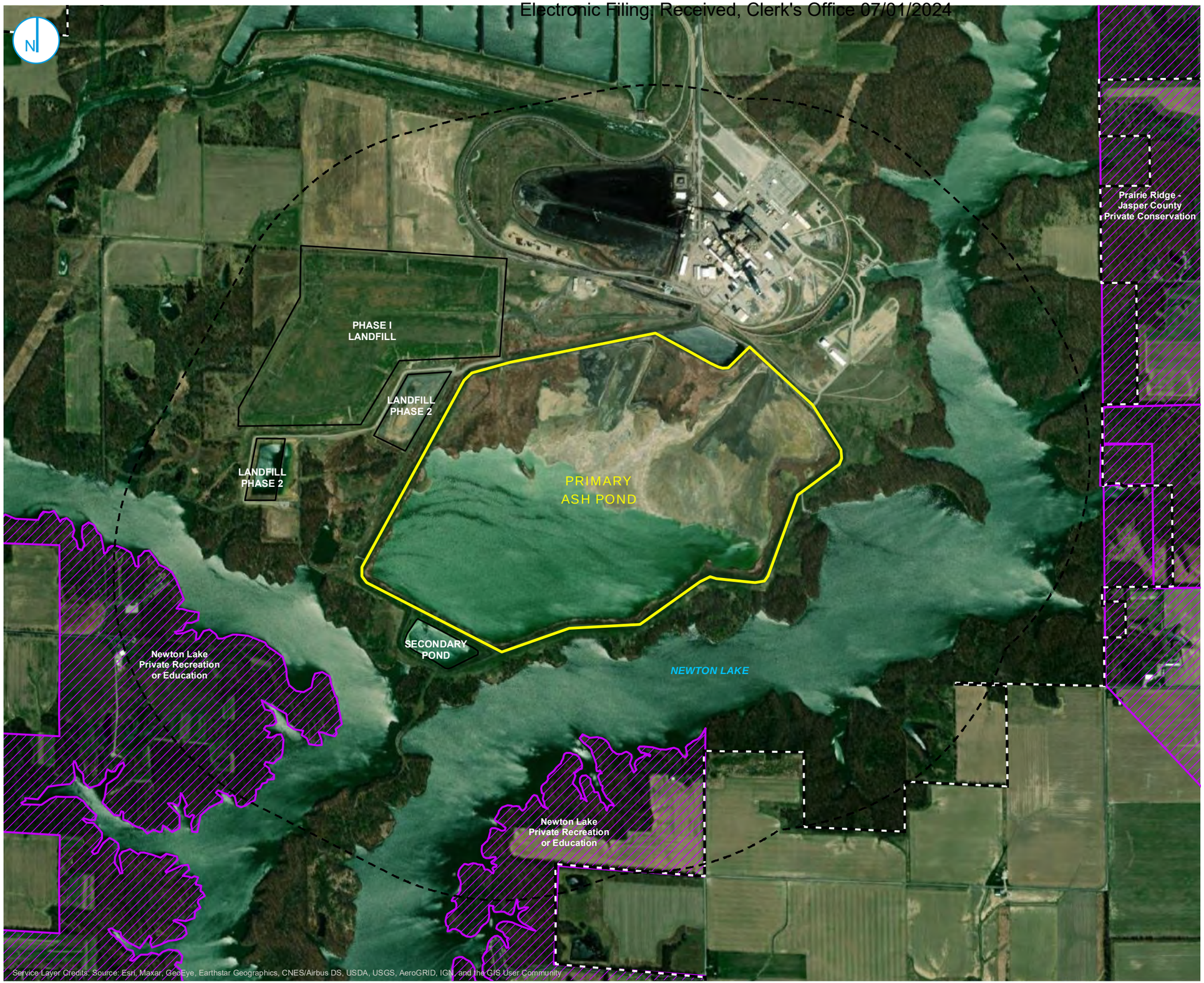
[O: CJC 06/02/21; C: LDC 09/15/21]

Notes:

-- = not applicable
ft = foot/feet
bgs = below ground surface
HUC = Hydrologic Unit Code
N = north
W = west
SE = southeast

NATURE PRESERVES, HISTORIC SITES, ENDANGERED / THREATENED SPECIES

Electronic Filing: Received, Clerk's Office 07/01/2024



PROTECTED
PART 845 REGULATED UNIT FACILITY BOUNDARY
1000 METER UNIT BUFFER
SITE FEATURE
PROPERTY BOUNDARY

SOURCES: USGS - PAD-US, USFWS

0 625 1,250
Feet

NATURE PRESERVES

HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE B-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22851\MXD\845_Operating_Permit\Newton\Figure B-4_Nature Preserves.mxd

PROJECT: 169000XXXX | DATED: 10/19/2021 | DESIGNER: STOLZSD

JASPER COUNTY THREATENED AND ENDANGERED SPECIES

DESKTOP STUDY

NEWTON POWER PLANT

PRIMARY ASH POND

NEWTON, IL

Scientific Name	Common Name	Status	Number of Occurances	Last Observed
Ammocrypta pellucida	Eastern Sand Darter	LT	9	8/5/2019
Apalone mutica	Smooth Softshell	LT	2	8/31/2017
Asio flammeus	Short-eared Owl	LE	2	12/23/2014
Bartramia longicauda	Upland Sandpiper	LE	1	5/22/2013
Botaurus lentiginosus	American Bittern	LE	1	6/3/2013
Circus hudsonius	Northern Harrier	LE	3	2/6/2016
Coccyzus erythropthalmus	Black-billed Cuckoo	LT	1	6/25/1998
Emydoidea blandingii	Blanding's Turtle	LE	1	5/18/1998
Etheostoma histrio	Harlequin Darter	LE	1	9/18/1967
Festuca paradoxa	Cluster Fescue	LT	1	6/30/1999
Ixobrychus exilis	Least Bittern	LT	2	5/26/2017
Lanius ludovicianus	Loggerhead Shrike	LE	3	6/7/2017
Laterallus jamaicensis	Black Rail	LE	1	6/20/2012
Nyctanassa violacea	Yellow-crowned Night-Heron	LE	1	5/24/1995
Papaipema eryngii	Eryngium Stem Borer	LT	1	7/8/2020
Penstemon tubaeflorus	Tube Beard Tongue	LE	3	5/27/2019
Rallus elegans	King Rail	LE	1	6/7/2016
Sabatia campestris	Prairie Rose Gentian	LE	1	7/30/2019
Schoenoplectus purshianus	Pursh's Bulrush	LE	1	2012
Silene regia	Royal Catchfly	LE	1	5/12/2015
Spiranthes vernalis	Spring Ladies' Tresses	LE	3	8/5/2019
Sternula antillarum	Least Tern	LE	1	6/13/2004
Terrapene ornata	Ornate Box Turtle	LT	2	4/6/2020
Tracaulon arifolium	Halberd-leaved Tearthumb	LE	1	8/14/1985
Tympanuchus cupido	Greater Prairie-Chicken	LE	2	7/10/1905

[O: CJC 06/02/21; C: LDC 09/15/21]

Notes:

-- = not provided/cannot be determined

LE = listed endangered

LT = listed threatened

RAMBOLL

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX C
BORING LOGS AND WELL CONSTRUCTION LOGS

BORING AND WELL LOCATION MAP

BORING LOGS

RAMBOLL

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW11

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Dave Gordon Cascade Drilling	1/23/2021	1/23/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW11	Feet (NAVD88)	536.05 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 825,195.28 N, 1,000,717.50 E Ⓔ/W

1/4 of 1/4 of Section 25, T 6 N, R 8 E

Lat 38° 55' 58.09"

Long -88° 16' 31.6"

Local Grid Location: Feet ☐N ☐S ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	120 113		0	0 - 0.4' **CLAYEY SILT** ML/CL, grayish brown (10YR 5/2) to brownish yellow (10YR 6/6), roots (5-15%), gravel (0-5%), no dilatancy, medium toughness, low plasticity, wet.	ML/CL									CS= Core Sample
			1	0.4 - 10' **LEAN CLAY:** CL, gray (10YR 6/1), strong brown (7.5YR 5/8) mottling (15-30%), brown (10YR 3/3), silt (15-30%), sand (0-5%), organic material (0-5%), no dilatancy, low toughness, medium plasticity, wet to moist.										
			2											
			3											
			4											
			5		CL									
			6											
			7											
			8											
			9											
			10											
2 SH	24 24			10 - 12' **LEAN CLAY:** CL.						17.8	28	16	53.8	SH= Shelby Tube
			11		CL									
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

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Boring Number APW11 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
3 CS	96 96		13	12 - 22.3' **SILT WITH SAND:** (ML)s, brown (10YR 5/3), clay (5-15%), gravel (0-5%), cohesive, low toughness, non-plastic to low plasticity, moist.										
			14											
			15	15' brown (10YR 4/3), clay (5-15%), gravel (5-15%), low to medium toughness.										
			16											
			17		(ML)s									
			18	18' sand seams (0-5%) 1/16" diameter.										
			19											
4 CS	120 120		20											
			21											
			22											
			23	22.3 - 28' **SILT:** ML, yellowish brown (10YR 5/4), grayish brown (10YR 5/2) mottling (0-5%), strong brown (7.5YR 5/6) mottling (0-5%), clay (15-30%), sand (0-5%), gravel (0-5%), no dilatancy, medium toughness, low plasticity.										
			24											
			25		ML									
			26											
			27											
			28	28 - 58' **LEAN CLAY:** CL, yellowish brown (10YR 5/4), grayish brown (10YR 5/2) mottling (0-5%), strong brown (7.5YR 5/6) mottling (0-5%), silt (15-30%), sand (0-5%), gravel (0-5%), no dilatancy, low toughness, medium to high plasticity.										
			29											
5 CS	120 120		30		CL									
			31											
			32											

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Boring Number APW11 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	28 - 58' **LEAN CLAY:** CL, yellowish brown (10YR 5/4), grayish brown (10YR 5/2) mottling (0-5%), strong brown (7.5YR 5/6) mottling (0-5%), silt (15-30%), sand (0-5%), gravel (0-5%), no dilatancy, low toughness, medium to high plasticity. *(continued)*										
			34	33.2' - 34.4' gray (10YR 5/1) mottling (5-15%), sand (5-15%).										
			35	34.4' - 40' sand (5-15%).										
			36											
			37											
			38											
			39											
6 CS	120 120		40											
			41											
			42		CL									
			43											
			44											
			45											
			46											
			47											
			48											
			49	48.6' dark grayish brown (10YR 4/2), olive gray (5Y 4/2) mottling (5-15%), dark grayish brown (2.5Y 4/2) mottling (5-15%), dark reddish brown (5YR 3/4) mottling (0-5%),.										
7 CS	120 120		50											
			51											
			52											

Boring Number APW11 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			53	28 - 58' **LEAN CLAY:** CL, yellowish brown (10YR 5/4), grayish brown (10YR 5/2) mottling (0-5%), strong brown (7.5YR 5/6) mottling (0-5%), silt (15-30%), sand (0-5%), gravel (0-5%), no dilatancy, low toughness, medium to high plasticity. *(continued)*										
			54											
			55		CL									
			56	55.7' - 56.9' dark gray (10YR 4/1) to (7.5YR 4/1).										
			57											
			58	58 - 58.9' **SILTY SAND:** SM, grayish brown (10YR 5/2), gravel (5-15%), dense, moist.	SM									
			59	58.9 - 59.5' **SILT WITH SAND:** (ML)s, grayish brown (10YR 5/2), dark yellowish brown (10YR 4/6) mottling (0-5%), clay (15-30%), gravel (0-5%), low toughness, low plasticity.	(ML)s									
8 MC	24 20		60	59.5 - 60' **POORLY-GRADED GRAVEL:** GP, grayish brown (10YR 5/2), subrounded to subangular, fine gravel, sand (30-45%), silt (15-30%), moist.	GP					17.8	27	9	78.6	MC= Modified California Sample
			61	60 - 62' **LEAN CLAY:** CL.	CL									
9 CS	96 96		62	62 - 64.5' **POORLY-GRADED SAND WITH CLAY:** SP-SC, dark gray (10YR 4/1), subrounded, fine sand, dense, wet.	SP-SC									
			63											
			64											
			65	64.5 - 66.6' **CLAYEY SILT** ML/CL, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), no dilatancy, medium toughness, low to medium plasticity, moist.	ML/CL									
			66											
			67	66.6 - 67.2' **POORLY-GRADED SAND WITH CLAY:** SP-SC, dark gray (10YR 4/1), subrounded, fine sand, gravel (5-15%), dense, wet.	SP-SC									
			68	67.2 - 80' **CLAYEY SILT** to **SILTY CLAY:** ML/CL, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, moist.										
			69											
			70		ML/CL									
10 CS	120 120		71											
			72											

Boring Number APW11 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			73	67.2 - 80' **CLAYEY SILT** to **SILTY CLAY:** ML/CL, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, moist. *(continued)*										
			74											
			75											
			76		ML/CL									
			77											
			78											
			79											
11 SH	24 24		80	80 - 82' **LEAN CLAY:** CL.	CL					16.5	32	18	79	
			81											
12 CS	96 96		82	82 - 93.5' **CLAYEY SILT** to **SILTY CLAY:** ML/CL, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, moist.										
			83											
			84											
			85											
			86	86' olive (5Y 4/4), dark yellowish brown (10YR 4/6) mottling (5-15%), dark gray (10YR 4/1) mottling (0-5%), black (10YR 2/1) mottling (0-5%).										
			87		ML/CL									
			88	87.4' olive gray (5Y 4/2), dark gray (10YR 4/1) mottling (15-30%), organic material (0-5%).										
			89	88.5' dark gray (10YR 4/1), olive gray (5Y 4/2) mottling (5-15%), olive brown (2.5Y 4/4) mottling (0-5%).										
			90	89.7' olive (5Y 4/4).										
13 CS	120 120			90.2' olive gray (5Y 4/2), organic material (0-5%).										
			91											
			92											

Boring Number APW11 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			93	82 - 93.5' **CLAYEY SILT** to **SILTY CLAY:** ML/CL, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, moist. *(continued)*	ML/CL									
				92' - 92.2' layer of organic material.										
			94	93.5 - 94' **SANDY SILT:** s(ML), dark gray (10YR 4/1), reddish brown (5YR 4/4) mottling (5-15%), clay (5-15%), gravel (0-5%), cohesive, non-plastic, moist.	s(ML)									
				94 - 94.5' **SILT:** ML, olive gray (5Y 4/2).	ML									
			95	94.5 - 94.7' **CLAYEY SAND:** SC, dark gray (10YR 4/1), wet.	SC									
				94.7 - 96' **SANDY SILT:** s(ML), dark gray (10YR 4/1), reddish brown (5YR 4/4) mottling (5-15%), clay (5-15%), gravel (0-5%), cohesive, non-plastic, moist.	s(ML)									
			96	96 - 96.2' **POORLY-GRADED SAND WITH CLAY:** SP-SC, dark gray (10YR 4/1), loose, moist.	SP-SC									
				96.2 - 97' **SILT:** ML, dark gray (10YR 4/1), clay (5-15%), sand (5-15%), no dilatancy to slow dilatancy, low toughness, medium plasticity.	ML									
			97	97 - 97.2' **SILT:** ML, very dark grayish brown (10YR 3/2), dry.	ML									
			98	97.2 - 100' **LEAN CLAY:** CL, dark gray (10R 4/1), silt (5-15%), organic material (0-5%), no dilatancy, high toughness, medium to high plasticity, moist.	CL									
			99											
			100	100' End of Boring.										

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW12

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/21/2021	2/21/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW12	Feet (NAVD88)	543.33 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 824,081.13 N, 1,001,683.34 E Ⓔ/W
1/4 of 1/4 of Section 25, T 6 N, R 8 E
Lat 38° 55' 47.07"
Long -88° 16' 19.39"
Local Grid Location Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 / 37		0	0 - 0.4' **LEAN CLAY:** CL, dark brown (10YR 3/3), sand (0-5%), roots (0-5%), moist.	CL									CS= Core Sample
			1	0.4 - 6.4' **SANDY LEAN CLAY:** s(CL), yellowish brown (10YR 5/6), gravel (0-5%), stiff, low plasticity, moist.					2					
			2											
			3		s(CL)				1.5					
			4											
2 CS	60 / 43		5											
			6						1.5					
				6.4 - 11.8' **LEAN CLAY:** CL, yellowish brown (10YR 5/6), gray and yellowish brown mottling (0-5%), sand (0-5%), stiff medium plasticity.									
			7						1.5					
			8						1.5					
			9		CL									
3 CS	60 / 60		10											
			11						1					
			12	11.8 - 20' **LEAN CLAY:** to **SILTY CLAY:** CL, yellowish brown (10YR 5/6), gray and yellowish brown mottling (0-5%), gravel (0-5%), sand (0-5%), very stiff, medium plasticity, moist.					2					
			13						2.5					
			14		CL				2					
			15	15' hard, gray and yellowish brown mottling (15-25%).					2.5					
4 CS	60 / 60		16											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature	Firm	Tel: (414) 837-3607
SA WL	Ramboll 234 W. Florida Street, Milwaukee, WI 53204	Fax: (414) 837-3608

Boring Number APW12 Page 2 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			17	11.8 - 20' **LEAN CLAY:** to **SILTY CLAY:** CL, yellowish brown (10YR 5/6), gray and yellowish brown mottling (0-5%), gravel (0-5%), sand (0-5%), very stiff, medium plasticity, moist. *(continued)*					4.5					
			18		CL				4.5					
			19						4.5					
5 SH	24 24		20	20 - 22' **CLAYEY SAND:** SC.						15.1	27	15	45.8	SH= Shelby Tube
			21		SC									
6 CS	36 36		22	22 - 23.5' **SANDY LEAN CLAY:** s(CL), yellowish brown (10YR 5/6), silt (15-25%), gravel (0-5%), hard, low plasticity, wet.	s(CL)				4.5					
			23											
			24	23.5 - 25' **POORLY-GRADED SAND:** SP, yellowish brown (10YR 5/6), fine to medium sand, gravel (0-5%), silt (0-5%), wet.	SP									
7 MC	24 24		25	25 - 27' **POORLY-GRADED SAND WITH SILT:** SP-SM.						8.4	10		6.2	MC= Modified California Sample
			26		SP-SM									
8 CS	36 36		27	27 - 29.2' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), sand (15-25%), gravel (15-25%), hard, low plasticity, dry.					4.5					
			28		CL/ML									
			29											
9 CS	60 60		30	29.2 - 35' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), gravel (15-25%), sand (0-5%), hard, low plasticity, dry.					4.5					
			31											
			32		CL/ML									
			33	32.6' - 34' sand (15-25%).										
			34											
10 CS	60 60		35	35 - 55' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), yellowish brown and gray mottling (0-5%), gravel (15-25%), sand (0-25%), hard, low plasticity, dry.					4.5					
			36											
			37						4.5					
			38											
			39		CL/ML									
			40						4.5					
11 CS	60 60		41											
			42	41.7' - 43.2' gravel (15-45%).					4.5					

Boring Number APW12 Page 3 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			43	35 - 55' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), yellowish brown and gray mottling (0-5%), gravel (15-25%), sand (0-25%), hard, low plasticity, dry. *(continued)*					4.5					
			44											
12 CS	60 60		45						4.5					
			46											
			47						4.5					
			48											
			49		CL/ML				4.5					
13 CS	60 60		50											
			51						4.5					
			52						4.5					
			53											
			54											
14 CS	60 60		55	55 - 56.4' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), yellowish brown mottling (0-5%), sand (0-5%), hard, medium plasticity, moist.	CL/ML										
			56	56.4 - 58.6' **SILT:** ML, dark gray (10YR 4/1), clay (15-25%), sand (0-5%), moist.					4.5					
			57		ML									
			58											
			59	58.4' - 58.6' layer of clayey sand. 58.6 - 70.8' **LEAN CLAY:** to **SILTY CLAY:** CL, dark gray (10YR 4/1), gravel (15-25%), sand (0-5%), hard, low plasticity, dry.					4.5					
15 CS	60 60		60											
			61						4.5					
			62											
			63						4.5					
			64		CL									
16 CS	60 60		65						4.5					
			66											
			67						4.5					
			68											
			69											

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Boring Number APW12 Page 4 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			70	58.6 - 70.8' **LEAN CLAY:** to **SILTY CLAY:** CL, dark gray (10YR 4/1), gravel (15-25%), sand (0-5%), hard, low plasticity, dry. *(continued)*	CL				4.5					
17 CS	60 60		71	70.8 - 72.6' **SILT:** ML, dark gray (10YR 4/1), sand (0-5%), dry to moist.	ML									
			72											
			73	72.6 - 74' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), sand (0-5%), gravel (0-5%), hard, low plasticity, dry.	CL/ML									
			74	74 - 77.5' **SILT:** ML, dark gray (10YR 4/1), sand (0-5%), dry.										
18 CS	60 60		75		ML									
			76											
			77											
			78	77.5 - 85' **SILTY CLAY:** CL/ML, gray (10YR 4/1), sand (0-5%), gravel (0-5%), dry.										
			79											
19 CS	60 60		80											
			81		CL/ML									
			82											
			83											
			84											
20 SH	24 24		85	85 - 87' **LEAN CLAY:** CL.						14.4	29	15	80.2	
			86		CL									
			87	87' End of Boring.										

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SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW13

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/22/2021	1/22/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW13	Feet (NAVD88)	535.16 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 822,591.02 N, 1,001,013.30 E Ⓔ/W

1/4 of 1/4 of Section 25, T 6 N, R 8 E

Lat 38° 55' 32.35"

Long -88° 16' 27.88"

Local Grid Location: ☐N ☐S Feet ☐E ☐W Feet

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 / 60		0–2	0 - 0.4' **SILTY SAND:** SM, dark brown (10YR 3/3), clay (15-25%), moist. 0.4 - 2.3' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), gray mottling (0-5%), sand (0-5%), gravel (0-5%), firm to stiff, medium plasticity, moist.	SM CL/ML				1					CS= Core Sample
			2–5	2.3 - 6.2' **SILTY CLAY:** to **LEAN CLAY:** CL/ML, yellowish brown (10YR 5/6), sand (0-5%), gravel (0-5%), stiff, low plasticity, moist.	CL/ML				2					
2 CS	60 / 60		5–7						2					
			6–8	6.2 - 8.7' **SANDY LEAN CLAY:** (CL)g, yellowish brown (10YR 5/6), gravel (0-5%), stiff, low plasticity, moist. 6.5' yellowish brown and gray mottling (15-25%).	(CL)g				1.5 1.5 1.5					
			8–10	8.7 - 10' **SILTY CLAY:** to **LEAN CLAY:** CL/ML, yellowish brown (10YR 5/6), sand (0-5%), gravel (0-5%), stiff, low plasticity, moist.	CL/ML				1.5					
3 CS	60 / 60		10–12	10 - 13.8' **SANDY LEAN CLAY:** (CL)g, yellowish brown (10YR 5/6), gravel (15-25%), hard, low plasticity, moist. 10.8' - 11.1' layer of clayey sand.	(CL)g				2 4.5					
			12–14											
			14–15	13.8 - 22.1' **SILT:** ML, dark gray (10YR 4/1), clay (0-25%), sand (0-5%), gravel (0-5%), hard, dry.	ML									
4 CS	60 / 60		15–16											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature SA WL

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

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Boring Number APW13 Page 2 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			17	13.8 - 22.1' **SILT:** ML, dark gray (10YR 4/1), clay (0-25%), sand (0-5%), gravel (0-5%), hard, dry. *(continued)*										
			18	17.8' clay (0-5%).										
			19		ML									
5 CS	60 60		20											
			21											
			22											
			23	22.1 - 25' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), gravel (0-5%), sand (0-5%), hard, low plasticity, dry.					4.5					
			24		CL/ML									
6 SH	24 24		25	25 - 27' **POORLY-GRADED SAND WITH SILT:** SP-SM.						21.2	9		11.1	SH= Shelby Tube
			26		SP-SM									
7 CS	36 36		27	27 - 31.2' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), gravel (0-5%), sand (0-5%), hard, low plasticity, dry.					4.5					
			28	27.8' - 28' layer of sand, moist.										
			29		CL/ML				4.5					
8 CS	60 60		30											
			31						4.5					
			32	31.2 - 35' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), yellowish brown and gray mottling (0-5%), gravel (15-25%), sand (0-5%), hard, low plasticity, dry.										
			33		CL/ML				4.5					
			34											
9 CS	60 60		35	35 - 51.7' **SILTY CLAY:** CL/ML, brown (10YR 5/3), gravel (0-5%), sand (0-5%), hard, low plasticity, dry.										
			36											
			37	37.2' - 38.3' gray mottling (15-25%).										
			38											
			39		CL/ML									
10 CS	60 60		40	40' very stiff to hard, medium plasticity.										
			41						3					
			42						3.5					

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Boring Number APW13 Page 3 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			43	35 - 51.7' **SILTY CLAY:** CL/ML, brown (10YR 5/3), gravel (0-5%), sand (0-5%), hard, low plasticity, dry. *(continued)*					4.5					
			44						3.5					
11 CS	60 60		45						4.5					
			46						4.5					
			47		CL/ML				3.5					
			48						3.5					
			49						4.5					
12 CS	60 60		50						4.5					
			51						4.5					
			52	51.7 - 54.6' **SILT:** ML, brown (10YR 5/3), gray mottling (15-25%), sand (0-5%), gravel (0-5%).										
			53		ML									
			54											
13 CS	60 60		55	54.6 - 57.6' **SILTY CLAY:** CL/ML, brown (10YR 5/3), sand (0-5%), gravel (0-5%), hard, low plasticity.					4.5					
			56		CL/ML									
			57											
			58	57.6 - 60' **SILTY SAND:** SM, brown (10YR 5/3), fine sand, clay (0-5%), wet.										
			59		SM									
14 MC	24 24		60	60 - 62' **SILTY SAND:** SM.						14.5	8		24.5	MC= Modified California Sample
			61		SM									
15 CS	96 96		62	62 - 63.7' **SILTY SAND:** SM, brown (10YR 5/3), fine sand, clay (0-5%), wet.										
			63	62.5' - 63.1' layer of silt.	SM									
			64	63.7 - 65' **SILT:** ML, brown (10YR 5/3), sand (0-5%), clay (0-5%), dry.	ML									
			65	65 - 67.6' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-5%), stiff to very stiff, medium plasticity, dry.					2					
			66		CL				2					
			67											
			68	67.6 - 89.7' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), gravel (15-25%), sand (15-25%), hard, low plasticity, dry.					4.5					
			69		CL/ML									

Boring Number APW13 Page 4 of 4

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
16 CS	120 120		70	67.6 - 89.7' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), gravel (15-25%), sand (15-25%), hard, low plasticity, dry. *(continued)*					4.5					
			71	70' dark green mottling, gravel (0-5%).					4.5					
			72											
			73						4.5					
			74											
			75						4.5					
			76											
			77						4.5					
			78											
			79						4.5					
17 CS	120 120		80		CL/ML									
			81											
			82											
			83											
			84											
			85											
			86											
			87											
			88											
			89											
			90	89.7 - 90' **SHALE:** BDX (SH), black (10YR 2/1). 90' End of Boring.	BDX (SH)									

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RAMBOLL

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW14

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Adam Jochimsen Cascade Drilling	1/23/2021	1/23/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW14	Feet (NAVD88)	523.85 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 822,006.47 N, 999,995.70 E Ⓔ/W

1/4 of 1/4 of Section 25, T 6 N, R 8 E

Lat 38° 55' 26.58"

Long -88° 16' 40.76"

Local Grid Location: ☐ N Feet ☐ S ☐ E Feet ☐ W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 / 51		0	0 - 7.1' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/4), yellowish brown (10YR 5/6) mottling (10-20%), gray (10YR 5/1) mottling (0-5%), sand (0-5%), gravel (0-5%), very stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL/ML				3					CS= Core Sample
			3						3.5					
2 CS	60 / 53		5						2.5					
			7	7.1 - 10.6' **SILTY SAND:** s(ML), yellowish brown (10YR 5/6), clay (5-10%), soft, slow dilatancy, low toughness, low plasticity, moist.	s(ML)				0.5					
3 CS	60 / 57		10											
			11	10.6 - 14.2' **CLAYEY SILT** ML/CL, brown (10YR 5/3), sand (5-10%), gravel (0-5%), hard, no dilatancy, medium toughness, low plasticity, dry.	ML/CL				4.5					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204

Tel: (414) 837-3607
Fax: (414) 837-3608

Template: RAMBOLL_IL_BORING LOG - Project: 845_NEWTON_2021 (1).GPJ

Boring Number APW14 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	10.6 - 14.2' **CLAYEY SILT** ML/CL, brown (10YR 5/3), sand (5-10%), gravel (0-5%), hard, no dilatancy, medium toughness, low plasticity, dry. *(continued)*	ML/CL				4					
			14											
				14.2 - 15' **SILTY SAND:** SM, yellowish brown (10YR 5/6), subrounded to rounded, medium to fine sand, loose, moist.	SM									
4 CS	60 57		15	15 - 45' **LEAN CLAY:** CL, gray (10YR 5/1), silt (15-25%), sand (5-10%), gravel (0-5%), hard, no dilatancy, medium toughness, medium plasticity, dry to moist.					4					
			16											
			17						4.5					
			18											
			19						4.5					
5 CS	120 104		20	20' yellowish brown (10YR 5/6) mottling (15-20%).										
			21						3.5					
			22											
			23						3					
					CL									
			24											
			25						3.5					
			26											
			27						4					
			28											
			29						4.5					
6 CS	60 60		30	30' silt stringers 1mm to 3mm diameter in fractures.										
			31						4.5					
			32											

Boring Number APW14 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	15 - 45' **LEAN CLAY:** CL, gray (10YR 5/1), silt (15-25%), sand (5-10%), gravel (0-5%), hard, no dilatancy, medium toughness, medium plasticity, dry to moist. *(continued)*					4.5					
			34											
7 CS	60 60		35						4.5					
			36											
			37						4.5					
			38											
			39		CL				4.5					
8 CS	60 60		40											
			41						4.5					
			42											
			43						4.5					
			44											
9 SH	24 24		45	45 - 47' **LEAN CLAY:** CL.	CL					12.4	26	12	63.3	SH= Shelby Tube
			46											
10 CS	96 94		47	47 - 48.7' **LEAN CLAY:** CL, gray (10YR 5/1), yellowish brown (10YR 5/6) mottling (15-20%), silt (15-25%), sand (5-10%), gravel (0-5%), hard, no dilatancy, medium toughness, medium plasticity, dry to moist.	CL				4.5					
			48											
			49	48.7 - 55' **CLAYEY SAND:** to **SANDY LEAN CLAY WITH GRAVEL:** SC, dark grayish brown (10YR 4/2), subrounded to rounded, medium sand, dense, moist.					4.5					
			50		SC									
			51						2.25					
			52											

Boring Number APW14 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			53	48.7 - 55' **CLAYEY SAND:** to **SANDY LEAN CLAY WITH GRAVEL:** SC, dark grayish brown (10YR 4/2), subrounded to rounded, medium sand, dense, moist. *(continued)*	SC									
			54											
11 MC	24 24		55	55 - 57' **LEAN CLAY:** CL.	CL					18	25	10	72.2	MC= Modified California Sample
			56											
12 CS	96 96		57	57 - 91' **LEAN CLAY:** CL, gray (10YR 5/1), yellowish brown (10YR 5/6) mottling (0-5%), silt (15-25%), sand (5-10%), gravel (0-5%), organic material (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry.					3.75					
			58											
			59						4.25					
			60											
			61						4.25					
			62											
			63						4.25					
			64											
13 CS	120 120		65		CL				4					
			66											
			67						2.25					
			68											
			69						4.5					
			70											
			71						4.5					
			72											

Boring Number APW14 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			73	57 - 91' **LEAN CLAY:** CL, gray (10YR 5/1), yellowish brown (10YR 5/6) mottling (0-5%), silt (15-25%), sand (5-10%), gravel (0-5%), organic material (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry. *(continued)*					4.5					
			74											
14 CS	120 120		75						4.5					
			76											
			77						4.5					
			78											
			79						4					
			80											
			81						4.25					
			82		CL									
			83						2.5					
			84	83.7' greenish gray (GLEY1 6/5GY) mottling (10-15%), yellowish brown (10YR 5/6) mottling (10-15%), stiff.										
15 CS	60 46		85						2.75					
			86											
			87						3					
			88											
			89						3.5					
16 CS	60 56		90											
			91	91 - 95' **Weathered SHALE Bedrock** BDX (SH), gray (10YR 6/1) to grayish brown (10YR 5/2).	BDX (SH)				4.5					
			92											

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Boring Number APW14 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			93	91 - 95' **Weathered SHALE Bedrock** BDX (SH), gray (10YR 6/1) to grayish brown (10YR 5/2). *(continued)*	BDX (SH)									
			94											
			95	95' End of Boring.										

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW15

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Adam Jochimsen Cascade Drilling	1/21/2021	1/22/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW15	Feet (NAVD88)	522.06 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 821,107.90 N, 997,938.87 E Ⓔ/W

1/4 of 1/4 of Section 26, T 6 N, R 8 E

Lat 38° 55' 17.71"

Long -88° 17' 6.79"

Local Grid Location: Feet ☐N ☐S, Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 54		1	0 - 6.3' **FILL, LEAN CLAY:** CL, brown (10YR 5/3), silt (15-25%) sand (0-5%), stiff, no dilatancy, low toughness, medium plasticity, moist.	(FILL) CL				1.75					CS= Core Sample
			2											
			3						1.75					
			4											
2 CS	60 40		5											
			6											
			7	6.3 - 20' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%) sand (0-5%), gravel (0-5%), organic material (0-5%), very stiff to stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL				2.25					
			8											
			9						4					
3 CS	60 50		10											
			11						1					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number APW15 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	6.3 - 20' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%) sand (0-5%), gravel (0-5%), organic material (0-5%), very stiff to stiff, no dilatancy, medium toughness, medium plasticity, moist. *(continued)*					2.5					
			14											
4 CS	60 54		15						1.5					
			16		CL									
			17						2.25					
			18											
			19	19.2' brown (10YR 4/3), yellowish brown (10YR 5/6) mottling (10-15%), stiff.					2.5					
5 SH	24 23		20	20 - 22' **LEAN CLAY:** CL.						18.5	33	23	59.2	SH= Shelby Tube
			21		CL									
6 CS	96 96		22	22 - 23.5' **LEAN CLAY:** CL, brown (10YR 4/3), yellowish brown (10YR 5/6) mottling (10-15%), stiff, no dilatancy, medium toughness, medium plasticity, moist.					1.25					
			23		CL				1					
			24	23.5 - 26.7' **SANDY LEAN CLAY:** s(CL), brown (10YR 5/3), gray (10YR 5/1) mottling (5-10%), stiff, slow dilatancy, low toughness, medium plasticity, moist.										
			25		s(CL)				3.75					
			26											
			27	26.7 - 39.2' **LEAN CLAY:** CL, brown (10YR 5/3), yellowish brown (10YR 5/6) mottling (10-15%), gray (10YR 5/1) mottling (5-10%), sand (5-10%), gravel (0-5%), cobbles (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry to moist.					4.5					
			28											
			29		CL				4.5					
6 CS	60 49		30	30' hard, dry.										
			31						4.5					
			32											

Boring Number APW15 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	26.7 - 39.2' **LEAN CLAY:** CL, brown (10YR 5/3), yellowish brown (10YR 5/6) mottling (10-15%), gray (10YR 5/1) mottling (5-10%), sand (5-10%), gravel (0-5%), cobbles (0-5%), very stiff to hard, no dilatancy, medium toughness, medium plasticity, dry to moist. *(continued)*					4.5					
			34											
7 CS	60 49		35		CL				4.5					
			36											
			37						4.5					
			38											
			39						4.5					
			40	39.2 - 52.5' **LEAN CLAY:** CL, dark gray (10YR 4/1), no mottling, organic material (0-5%), sand (5-10%), gravel (0-5%), cobbles (0-5%), hard, no dilatancy, medium toughness, medium plasticity, dry, silt stringers 1mm to 3mm diameter fracture planes.										
8 CS	60 60		41						4.5					
			42											
			43						4.5					
			44											
9 CS	60 60		45		CL				4.5					
			46											
			47						4.5					
			48											
			49						4.5					
			50											
10 CS	60 60		51						4.5					
			52											

Boring Number APW15 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			52											
			53	52.5 - 61.4' **SILT:** ML, dark gray (10YR 4/1), clay (15-25%), hard, no dilatancy, medium toughness, non-plastic, dry.					4.5					
			54											
11 CS	60 57		55						4.5					
			56											
			57		ML				4.5					
			58											
			59						4.5					
12 CS	60 52		60											
			61						4.5					
			62	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry.										
			63						2.75					
			64											
13 CS	60 60		65						2.75					
			66											
			67		CL				2.25					
			68											
			69						2					
14 CS	60 60		70											
			71						2.5					
			72											

Boring Number APW15 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			73	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry. *(continued)*					2.5					
			74											
15 CS	60 53		75						2					
			76											
			77						2.5					
			78											
			79						2.25					
16 CS	60 60		80											
			81						2.25					
			82		CL									
			83						4.5					
			84	83.8' - 83.9' layer of silty sand, moist.										
17 CS	60 60		85	85' - 85.4' later of silty sand, moist.					2.75					
			86											
			87						2.5					
			88											
			89						2.75					
18 CS	60 60		90											
			91						2.5					
			92											

Boring Number APW15 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			93	61.4 - 97.2' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-25%), sand (0-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist to dry. *(continued)*					2.75					
			94											
			95		CL									
19 CS	60 60		96											
			97											
			98	97.2 - 100' **POORLY-GRADED SAND WITH SILT:** SP-SM, dark gray (10YR 4/1), subrounded to rounded, medium to fine sand, loose, wet.	SP-SM									
			99											
20 SH	24 24		100	100 - 102' **SILTY SAND:** SM.	SM					12.1	15	3	45.8	
			101											
21 CS	36 36		102	102 - 104.3' **SANDY SILT:** s(ML), gray (10YR 5/1), firm, slow dilatancy, low toughness, non-plastic, wet.	s(ML)				1					
			103											
			104											
22 MC	24 24		105	104.3 - 105' **LEAN CLAY:** CL, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL					19.1	29	16	76.2	MC= Modified California Sample
			106	105 - 107' **LEAN CLAY:** CL.	CL									
23 CS	36 36		107	107 - 110' **LEAN CLAY:** CL, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), organic material (0-5%), stiff to very stiff, no dilatancy, medium toughness, medium plasticity, moist.	CL				2.25					
			108											
			109						2.5					
			110	110' End of Boring.										

Electronic Filing: Received, Clerk's Office 07/01/2024

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW16

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Adam Jochimsen Cascade Drilling	1/19/2021	1/20/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW16	Feet (NAVD88)	529.16 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 820,642.46 N, 996,213.53 E Ⓔ/W

1/4 of 1/4 of Section 35, T 6 N, R 8 E

Lat 38° 55' 13.12"

Long -88° 17' 28.63"

Local Grid Location ☐N ☐S Feet ☐E ☐W Feet

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 48		0	0 - 20' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/4), gray (10YR 5/1) mottling (0-5%), sand (0-5%), gravel (0-5%), firm to stiff, slow dilatancy, medium to low toughness, medium plasticity, moist.					0.75					CS= Core Sample
			1											
			2											
			3						1.75					
			4											
2 CS	60 60		5	5' very dark grayish brown (10YR 3/2) mottling (0-5%), yellowish brown (10YR 5/6) mottling (0-5%), silt stringers 1mm diameter (5-10%), very stiff, dry.	CL/ML				2					
			6											
			7						3.5					
			8											
			9						3.75					
3 CS	60 60		10	10' hard.										
			11						4.5					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number APW16 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	0 - 20' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/4), gray (10YR 5/1) mottling (0-5%), sand (0-5%), gravel (0-5%), firm to stiff, slow dilatancy, medium to low toughness, medium plasticity, moist. *(continued)*					4.5					
			14											
4 CS	60 60		15	15' grayish brown (10YR 5/2), yellowish brown (10YR 5/6) mottling (5-10%).					4.5					
			16		CL/ML									
			17						4.5					
			18											
			19						4.5					
5 CS	120 65		20	20 - 30' **SILT:** ML, brown (10YR 5/3), yellowish brown (10YR 5/6) mottling (5-10%), sand (5-10%), gravel (0-5%), hard, no dilatancy, high toughness, low plasticity, dry.										
			21						4.5					
			22											
			23						4.5					
			24											
			25		ML				4.5					
			26											
			27						4.5					
			28											
			29						4.5					
6 CS	60 57		30	30 - 69.2' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), cobbles (0-5%), hard to very stiff, no dilatancy, medium toughness, medium plasticity, dry to moist.										
			31		CL/ML				4.5					
			32											

Boring Number APW16 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	30 - 69.2' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), cobbles (0-5%), hard to very stiff, no dilatancy, medium toughness, medium plasticity, dry to moist. *(continued)*					4.25					
			34											
7 CS	60 60		35						4					
			36											
			37						4.5					
			38											
			39						4.5					
8 CS	60 60		40											
			41						4.5					
			42	41.5' organic material (0-5%), wood (0-5%).	CL/ML									
			43						4.5					
			44											
9 CS	60 60		45						4.5					
			46											
			47						4.25					
			48											
			49						4.25					
10 CS	60 60		50											
			51						4.5					
			52											

Boring Number APW16 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			53	30 - 69.2' **SILTY CLAY:** CL/ML, dark gray (10YR 4/1), sand (5-10%), gravel (0-5%), cobbles (0-5%), hard to very stiff, no dilatancy, medium toughness, medium plasticity, dry to moist. *(continued)*					4.5					
			54											
11 CS	60 60		55						4.5					
			56											
			57						3.75					
			58											
			59						3.75					
12 CS	60 60		60											
			61		CL/ML				4.5					
			62											
			63						3.75					
			64											
13 CS	180 45		65						2.25					
			66											
			67						1.25					
			68											
			69						0.25					
			70	69.2 - 70.6' **SILT WITH SAND:** (ML)s, gray (10YR 6/1), soft, rapid dilatancy, low toughness, non-plastic, wet.	(ML)s										
			71	70.6 - 85.6' **POORLY-GRADED SAND:** SP, gray (10YR 5/1), subrounded to rounded, medium to coarse sand, gravel (0-5%), loose, wet.	SP									
			72											

Boring Number APW16 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			73	70.6 - 85.6' **POORLY-GRADED SAND:** SP, gray (10YR 5/1), subrounded to rounded, medium to coarse sand, gravel (0-5%), loose, wet. *(continued)*										
			74											
			75											
			76											
			77											
			78											
			79		SP									
14 CS	60 60		80											
			81											
			82											
			83											
			84											
15 CS	120 120		85	85' gravel (10-15%).										
			86	85.6 - 99.2' **LEAN CLAY:** CL, gray (10YR 5/1), silt (5-15%), sand (5-10%), gravel (0-5%), very stiff, no dilatancy, medium toughness, medium plasticity, moist.										
			87						3.5					
			88											
			89		CL				2.75					
			90											
			91						3.25					
			92											

Boring Number APW16 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			93	85.6 - 99.2' **LEAN CLAY:** CL, gray (10YR 5/1), silt (5-15%), sand (5-10%), gravel (0-5%), very stiff, no dilatancy, medium toughness, medium plasticity, moist. *(continued)*					3.25					
			94											
16 CS	60 48		95						3.5					
			96		CL									
			97						2.5					
			98											
			99						2.25					
			100	99.2 - 100' **POORLY-GRADED SAND:** SP, dark gray (10YR 4/1), subrounded to rounded, coarse sand, loose, wet.	SP									
17 CS	120 120		101	100 - 110' **LEAN CLAY:** CL, gray (10YR 5/1), silt (5-15%), sand (5-10%), organic material (0-10%), gravel (0-5%), very stiff, no dilatancy, medium toughness, medium plasticity, moist.					2					
			102											
			103						1.75					
			104											
			105		CL				2					
			106											
			107						2					
			108											
			109						2					
			110	110' End of Boring.										

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW17

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Dave Gordon Cascade Drilling	1/22/2021	1/22/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW17	Feet (NAVD88)	529.84 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 822,681.14 N, 995,462.29 E Ⓔ/W

1/4 of 1/4 of Section 26, T 6 N, R 8 E

Lat 38° 55' 33.27"

Long -88° 17' 38.12"

Local Grid Location

Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	120 120		0–15	0 - 0.3' **POORLY-GRADED SAND WITH SILT:** SP, yellowish brown (10YR 5/8), subrounded, fine sand, roots (15-30%), clay (5-15%), gravel (5-15%), loose, wet. 0.3 - 4' **LEAN CLAY WITH SAND:** (CL)s, yellowish brown (10YR 5/8), grayish brown (10YR 5/2) mottling (15-30%), gravel (0-5%), roots (0-5%), rapid dilatancy, low toughness, low to medium plasticity, wet. 4 - 12.3' **LEAN CLAY:** CL, yellowish brown (10YR 5/6), dark yellowish brown (10R 4/4) mottling (0-5%), silt (15-30%), sand (5-15%), gravel (0-5%), roots (0-5%), organic material (0-5%), slow dilatancy, medium toughness, low plasticity, moist. 7.5' dry. 11.6' - 11.8' layer of gravel with clay, wet. 12.2' layer of sand for 1/8". 12.3 - 26.3' **SILTY CLAY:** CL/ML, dark grayish brown (10YR 4/2), strong brown (10YR 5/8) mottling (5-15%), sand (0-5%), no dilatancy, medium toughness, low plasticity, dry sand seams 1/16" (0-5%).	SP (CL)s CL CL/ML									CS= Core Sample
2 CS	120 108													

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204

Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number APW17 Page 2 of 5

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
3 CS	240 240		16	12.3 - 26.3' **SILTY CLAY:** CL/ML, dark grayish brown (10YR 4/2), strong brown (10YR 5/8) mottling (5-15%), sand (0-5%), no dilatancy, medium toughness, low plasticity, dry sand seams 1/16" (0-5%). *(continued)*	CL/ML									
			17	16.5' white (10YR 8/1) for 1/16".										
			18											
			19											
			20											
			21											
			22											
			23											
			24											
			25											
			26	26' - 26.3' layer of silt, yellowish brown (10YR 5/4) to (10YR 5/6), sand (5-15%), dry.										
			27	26.3 - 40' **CLAYEY SILT** ML/CL, dark grayish brown (10YR 4/2), yellowish brown (10YR 5/4) mottling (5-15%), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, non-plastic to low plasticity, dry to moist.	ML/CL									
			28											
			29											
			30											
			31											
			32											
			33											
			34											
			35											
			36											
			37											
			38											
			39											
			40											

Boring Number APW17 Page 3 of 5

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
4 SH	24 21		40	40 - 42' **LEAN CLAY:** CL.	CL					16.6	26	13	71.1	SH= Shelby Tube
5 CS	96 96		42	42 - 43' **CLAYEY SILT** ML/CL, dark grayish brown (10YR 4/2), yellowish brown (10YR 5/4) mottling (5-15%), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, non-plastic to low plasticity, dry to moist.	ML/CL									
			43	43 - 44.5' **CLAYEY SILT** ML/CL, dark grayish brown (10YR 4/2) to grayish brown (10YR 5/2), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, non-plastic to low plasticity, dry to moist.	ML/CL									
			44	44.5 - 46.3' **SILT WITH SAND:** (ML)s, gray (10YR 5/1) to grayish brown (10YR 5/2), clay (5-15%), moist.	(ML)s									
			46	46.3 - 58' **CLAYEY SILT** ML/CL, dark grayish brown (10YR 4/2) to grayish brown (10YR 5/2), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, non-plastic to low plasticity, dry to moist.	ML/CL									
6 CS	120 118		50											
			58	58 - 63.3' **SILT WITH SAND:** (ML)s, dark grayish brown (10YR 4/2) to grayish brown (10YR 5/2), clay (5-15%), gravel (0-5%), non-cohesive to cohesive, no dilatancy, medium to high toughness, non-plastic to low plasticity, moist.	(ML)s									
7 CS	120 120		60											
			63	63.3 - 64.7' **WELL-GRADED SAND:** SW, gray (10YR 5/1), subangular to subrounded, gravel (5-15%), clay (5-15%), wet.	SW									
			65											

Boring Number APW17 Page 4 of 5

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			66	64.7 - 65.5' **POORLY-GRADED SAND WITH SILT:** SP, gray (10YR 5/1) to grayish brown (10YR 5/2), subrounded, fine to medium sand, gravel (5-15%), wet. *(continued)*	SP									
			67	65.5 - 70' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, gray (10YR 5/1), subangular to subrounded, gravel (5-15%), clay (0-5%), cobbles (0-5%), moist to wet.	(SW)g									
			68											
			69	68.5' - 69' cobbles (5-15%).										
			70	69.6' very dark gray (10YR 3/1).										
8 MC	24 24		71	70 - 72' **WELL-GRADED SAND WITH SILT:** SW-SM.	SW-SM					7.8	3.8	9	8.9	MC= Modified California Sample
			72											
9 CS	216 216		73	72 - 76.4' **WELL-GRADED GRAVEL WITH SAND:** (GW)s, gray (10YR 5/1), subrounded to rounded gravel, cobbles (5-15%), clay (5-15%), dense, wet.	(GW)s									
			74											
			75											
			76											
			77	76.4 - 78.6' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, gray (10YR 5/1), cobbles (0-5%), dense, wet.	(SW)g									
			78											
			79	78.6 - 79.9' **WELL-GRADED GRAVEL WITH SAND:** (GW)s, gray (10YR 5/1) to grayish brown (10YR 5/2), subrounded to rounded gravel, cobbles (5-15%), clay (5-15%), dense, wet.	(GW)s									
			80	79.9 - 86.8' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, grayish brown (10YR 5/2), clay (0-5%), cobbles (0-5%), dense, wet to moist.										
			81											
			82											
			83		(SW)g									
			84											
			85											
			86											
			87	86.8 - 88' **POORLY-GRADED SAND WITH GRAVEL:** (SP)g, grayish brown (10YR 5/2), rounded to subrounded, medium to coarse sand, clay (0-5%), loose, wet.	(SP)g									
			88	88 - 90' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, silt (5-15%), loose, wet to moist.										
			89		(SW)g									
			90											

Boring Number APW17 Page 5 of 5

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
10 MC	24 24		90	90 - 92' **POORLY-GRADED SAND WITH SILT:** SP-SM.	SP-SM					6.1	6		6.7	
			91											
			92	92 - 93.4' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, silt (5-15%), loose, wet to moist.	(SW)g									
11 CS	72 72		93											
			94	93.4 - 98' **SILT:** ML, dark gray (10YR 4/1) to gray (10YR 5/1), very dark gray (10YR 3/1) mottling (0-5%), clay (15-30%), sand (5-15%), gravel (0-5%), organic material (0-5%), no dilatancy, high toughness, low plasticity, moist.	ML									
			95											
			96											
			97											
			98											
12 SH	24 24		99	98 - 100' **SILT:** ML, Not Analyzed.	ML									
			100	100' End of Boring.										

Electronic Filing: Received, Clerk's Office 07/01/2024

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW18

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Dave Gordon Cascade Drilling	1/20/2021	1/21/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW18	Feet (NAVD88)	540.55 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 824,525.91 N, 996,544.05 E Ⓔ/W
1/4 of 1/4 of Section 26, T 6 N, R 8 E
Lat 38° 55' 51.5"
Long -88° 17' 24.42"
Local Grid Location Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	120 113		0	0 - 0.3' **FILL, SILT:** ML, dark grayish brown (10R 4/2), roots (15-30%), sand (5-15%), wet.	(FILL) ML									CS= Core Sample
			1	0.3 - 3.4' **SILTY SAND:** SM, yellowish brown (10YR 5/6), dark grayish brown (10YR 4/2) mottling (15-30%), fine sand, gravel (0-5%), roots (0-5%), dense, moist.	SM									
			2											
			3											
			4	3.4 - 11' **LEAN CLAY WITH SAND:** (CL)s, yellowish brown (10YR 5/6), dark grayish brown (10YR 4/2) mottling (5-15%), strong brown (7.5YR 5/8) mottling (5-15%), slow dilatancy, low toughness, low to medium plasticity, moist.	(CL)s									
			5											
			6											
			7											
			8											
			9											
			10											
2 CS	120 113		11	11 - 12.5' **CLAYEY SAND:** SC, dark yellowish brown (10YR 4/6), rounded, fine sand, gravel (0-5%), wet.	SC									
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number APW18 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			12	11.6' medium sand.										
			13	12.5 - 13.9' **LEAN CLAY WITH SAND:** (CL)s, yellowish brown (10YR 5/6), slow dilatancy, low toughness, low to medium plasticity, wet.	(CL)s									
			14	13.9 - 16.8' **SILT:** ML, dark grayish brown (10YR 4/2), clay (15-30%), sand (5-15%), gravel (0-5%), no dilatancy, low to medium toughness, low plasticity, dry.	ML									
			15											
			16											
			17	16.8 - 17.6' **POORLY-GRADED SAND:** SP, yellowish brown (10YR 5/6), rounded, fine sand, clay (5-15%), moist.	SP									
			18	17.6 - 20' **SILT:** ML, dark grayish brown (10YR 4/2), yellowish brown (10YR 5/6) mottling (0-5%), very dark grayish brown (10YR 3/2) mottling (0-5%), clay (15-30%), sand (5-15%), gravel (0-5%), no dilatancy, low to medium toughness, low plasticity, dry.	ML									
			19											
3 CS	120 120		20	20 - 20.9' **WELL-GRADED SAND:** SW, yellowish brown (10YR 5/6), clay (5-15%), gravel (0-5%), wet.	SW									
			21	20.9 - 23.2' **CLAYEY SILT** ML/CL, dark grayish brown (10YR 4/2), yellowish brown (10YR 5/6) mottling (0-5%), very dark grayish brown (10YR 3/2) mottling (0-5%), clay (15-30%), sand (5-15%), gravel (0-5%), no dilatancy, low to medium toughness, low plasticity, moist.	ML/CL									
			22											
			23											
			24	23.2 - 23.7' **WELL-GRADED SAND:** SW, subrounded, fine sand, gravel (5-15%), silt (5-15%), moist.	SW									
			25	23.7 - 28.9' **LEAN CLAY:** CL, dark gray (10YR 4/1), sand (5-15%), gravel (0-5%), no dilatancy, medium toughness, high plasticity, moist.	CL									
			26											
			27											
			28	28.2' sand (0-5%).										
			29	28.9 - 50' **CLAYEY SILT** ML/CL, dark gray (10YR 4/1), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, dry.	ML/CL									
4 CS	120 120		30											
			31											
			32											

Boring Number APW18 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	28.9 - 50' **CLAYEY SILT** ML/CL, dark gray (10YR 4/1), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, dry. *(continued)*										
			34											
			35											
			36											
			37											
			38											
			39											
5 CS	120 120		40											
			41		ML/CL									
			42											
			43											
			44											
			45											
			46											
			47											
			48											
			49											
6 SH	24 24		50	50 - 52' **LEAN CLAY:** CL.						12.9	32	20	76.8	SH= Shelby Tube
			51		CL									
			52											

Boring Number APW18 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
7 CS	96 96		52	52 - 58.2' **CLAYEY SILT** ML/CL, dark gray (10YR 4/1), sand (5-15%), gravel (0-5%), no dilatancy, high toughness, medium plasticity, dry.	ML/CL									
			53											
			54											
			55											
			56											
			57											
			58											
			59	58.2 - 60' **POORLY-GRADED SAND:** SP, gray (10YR 6/1) to light gray (10YR 7/1), subrounded, fine to medium sand, gravel (0-5%), silt (0-5%), loose, dry to moist.	SP									
8 MC	24 12		60	60 - 62' **SILTY SAND:** SM.	SM					13.6	5		17.1	MC= Modified California Sample
			61											
			62											
9 MC	24 16		62	62 - 64' **SILTY CLAY:** CL/ML.	CL/ML					11.1	20	6	57.6	
			63											
			64											
10 CS	72 72		64	64 - 67.5' **SANDY SILT:** s(ML), dark grayish brown (10YR 4/2), clay (0-5%), non-cohesive, moist.	s(ML)									
			65											
			66											
			67											
			68	67.5 - 70' **SILT:** ML, dark gray (10YR 4/1), clay (15-30%), sand (5-15%), gravel (0-5%), medium to high toughness, low plasticity, moist to wet.	ML									
			69											
			70											
11 SH	24 11		70	70 - 72' **SILT:** ML, Not Analyzed.	ML									
			71											
			72											

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Boring Number APW18 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
12 CS	96 92		73	72 - 72.4' **SILT:** ML, dark grayish brown (10YR 4/2), clay (15-30%), sand (5-15%), gravel (0-5%), medium to high toughness, low plasticity, moist to wet.	ML									
			74	72.4 - 76.7' **CLAYEY SAND:** SC, rounded, fine sand, dense, wet.	SC									
			75											
			76											
			77	76.7 - 79.4' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, subrounded to subangular, silt (0-5%), moist.	(SW)g									
			78											
			79											
			80	79.4 - 80' **SILT:** ML, dark gray (10YR 4/1), clay (15-30%), sand (5-15%), gravel (0-5%), medium to high toughness, low plasticity, moist to wet.	ML									
13 CS	120 72		81	80 - 80.7' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, subrounded to subangular, silt (0-5%), wet.	(SW)g									
			82	80.7 - 94.2' **SILT:** ML, dark gray (10YR 4/1), clay (15-30%), sand (5-15%), gravel (0-5%), medium to high toughness, low plasticity, moist.										
			83											
			84											
			85											
			86											
			87		ML									
			88											
			89											
			90											
14 CS	180 180		91											
			92											

Boring Number APW18 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			93	80.7 - 94.2' **SILT:** ML, dark gray (10YR 4/1), clay (15-30%), sand (5-15%), gravel (0-5%), medium to high toughness, low plasticity, moist. *(continued)*	ML									
			94											
			95	94.2 - 105' **CLAYEY SILT** ML/CL, dark gray (10YR 4/1) to dark grayish brown (10YR 4/2), sand (5-15%), gravel (5-15%), slow dilatancy, medium toughness, low plasticity, moist.										
			96											
			97											
			98	97.4' grayish brown (10YR 5/2), reddish gray (5YR 5/2) mottling (0-5%), yellowish brown (10YR 5/6) mottling (0-5%).										
			99											
			100		ML/CL									
			101											
			102											
			103											
			104											
15 SH	24 24		105	105 - 107' **LEAN CLAY:** CL.						14.1	28	15	69.3	
			106		CL									
			107	107' End of Boring.										

RAMBOLL

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		APW5S

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Dave Gordon Cascade Drilling	1/19/2021	1/19/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
APW5S	Feet (NAVD88)	541.05 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 825,612.15 N, 999,129.20 E Ⓔ/W

1/4 of 1/4 of Section 26, T 6 N, R 8 E

Lat 38° 55' 2.22"

Long -88° 16' 51.7"

Local Grid Location: ☐ N ☐ S Feet ☐ E ☐ W Feet

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	120 115		0	0 - 0.7' **FILL, LEAN CLAY:** CL, very dark gray (10YR 3/1), yellowish brown (10YR 5/4) mottling (30-45%), roots (5-15%), sand (5-15%), gravel (0-5%), very stiff, no dilatancy, low to medium toughness, low plasticity, wet.	(FILL) CL				3.25					CS= Core Sample
			1											
			2	0.7 - 5.5' **FILL, LEAN CLAY:** CL, yellowish brown (10YR 5/4), gray (10YR 5/1) mottling (0-5%), sand (0-5%), gravel (0-5%), very stiff to stiff, no dilatancy , medium toughness, low plasticity, moist.										
			3	2.8' - 2.9' black (10YR 2/1), black (2.5Y 2.5/1) mottling (0-5%), coal (0-5%).	(FILL) CL				3.25					
			4	3.1' strong brown (7.5YR 5/6), gray (10YR 5/1) mottling (0-5%), black (10YR 2/1) mottling (0-5%), sand (5-15%), gravel (0-5%).										
			5						3.25					
			6	5.5 - 6.3' **LEAN CLAY:** CL, grayish brown (10YR 5/2) to brown (10YR 5/3), light olive brown (2.5Y 5/6) mottling (15-30%), stiff, no dilatancy, low toughness, medium plasticity, moist.	CL									
			7	5.9' no mottling.					2					
			8	6.3 - 14.3' **LEAN CLAY WITH SAND:** (CL)s, gray (10YR 5/1), organic material (0-5%), stiff to firm, no dilatancy, low toughness, medium plasticity, moist.	(CL)s									
			9						2.25					
2 CS	36 36		10											
			11						2					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204

Tel: (414) 837-3607
Fax: (414) 837-3608

Template: RAMBOLL_IL_BORING LOG - Project: 845_NEWTON_2021 (1).GPJ

Boring Number APW5S

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
3 CS	120 94		13	6.3 - 14.3' **LEAN CLAY WITH SAND:** (CL)s, gray (10YR 5/1), organic material (0-5%), stiff to firm, no dilatancy, low toughness, medium plasticity, moist. *(continued)* 12.4' yellowish brown (10YR 5/6), gravel (0-5%).	(CL)s				0.75						
			14											
			15	14.3 - 17.5' **POORLY-GRADED SAND:** SP, yellowish brown (10YR 5/6) , subrounded to rounded, fine sand, clay (5-15%), gravel (0-5%), moist.	SP									
			16											
			17											
			18	17.5 - 23' **SILT:** ML, yellowish brown (10YR 5/6) to dark gray (10YR 4/1), strong brown (7.5YR 4/6) mottling (5-15%), very dark gray (7.5YR 3/1) mottling (0-5%), clay (5-15%), sand (5-15%), gravel (0-5%), very stiff to hard, no dilatancy, medium to high toughness, low plasticity.	ML				4.5						
			19											
			20	19.4' yellowish brown (10YR 5/6), gray (10YR 5/1) mottling (0-5%).										
			21						4					
			22						3.5					
			23	23' End of Boring.										

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		SB301

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Dave Gordon Cascade Drilling	1/19/2021	1/20/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
	Feet (NAVD88)	543.39 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 825,067.09 N, 997,264.71 E Ⓔ/W
1/4 of 1/4 of Section 25, T 6 N, R 8 E
Lat ° ' "
Long ° ' "
Local Grid Location
Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	120 99		0	0 - 2.6' **FILL, POORLY-GRADED SAND WITH GRAVEL:** (SP)g, black (10YR 2/1), loose.	(FILL) (SP)g									CS= Core Sample
			1											
			2	1.8' - 2.2' layer of clay, dark grayish brown (10YR 4/2), silt (15-30%), sand (5-15%), low toughness, low plasticity, moist.										
			3	2.6 - 6.5' **SILTY CLAY:** CL/ML, brown (10YR 5/3) to light olive brown (2.5Y 5/3), olive (5Y 4/3) mottling (15-30%), dark olive gray (5Y 3/2) mottling (0-5%), sand (0-5%), gravel (0-5%), roots (0-5%), stiff to very stiff, no dilatancy, low toughness, low plasticity, moist.					1.75					
			4											
			5	4.5' medium toughness.	CL/ML				3.5					
			6											
			7	6.5 - 9' **LEAN CLAY:** CL, gray (10YR 5/1), dark yellowish brown (10YR 4/6) mottling (5-15%), silt (15-30%), sand (0-5%), gravel (0-5%), very stiff, no dilatancy, low to medium toughness, medium plasticity, moist.					3.25					
			8		CL									
			9	9 - 23.3' **SILT:** ML, grayish brown (10YR 5/2), gray (10YR 5/1) mottling (0-5%), dark gray (10YR 4/1) mottling (0-5%), hard, no dilatancy, high toughness, low plasticity, dry.					3.5					
2 CS	120 114		10		ML									
			11						4.5					
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Template: RAMBOLL_IL_BORING LOG - Project: 845_NEWTON_2021 (1).GPJ

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Boring Number SB301 Page 2 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	9 - 23.3' **SILT:** ML, grayish brown (10YR 5/2), gray (10YR 5/1) mottling (0-5%), dark gray (10YR 4/1) mottling (0-5%), hard, no dilatancy, high toughness, low plasticity, dry. *(continued)*	ML				4.5					
			14											
			15						4.5					
			16											
			17						4.5					
			18											
			19						4.5					
3 CS	120 120		20											
			21						4.5					
			22											
			23						4.5					
			24	23.3 - 24.8' **POORLY-GRADED SAND:** SP, yellowish brown (10YR 5/6), subrounded to rounded, fine sand, silt (0-5%), loose, moist to dry.	SP									
			25	24.8 - 48' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-30%), sand (0-5%), gravel (0-5%), hard, no dilatancy, high toughness, medium to high plasticity, dry to moist, gravel and sand increase to (5-15%) with depth.	CL				4.5					
			26											
			27						4.5					
			28											
			29						4.5					
4 CS	96 96		30											
			31						4.5					
			32											

Boring Number SB301 Page 3 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			33	24.8 - 48' **LEAN CLAY:** CL, dark gray (10YR 4/1), silt (15-30%), sand (0-5%), gravel (0-5%), hard, no dilatancy, high toughness, medium to high plasticity, dry to moist, gravel and sand increase to (5-15%) with depth. *(continued)*										
			34											
			35											
			36											
			37											
5 CS	120 120		38											
			39											
			40		CL									
			41											
			42											
			43											
			44											
			45											
			46											
			47											
6 SH	24 20		48	48 - 50.						14.1	27	13	65.4	SH= Shelby Tube
			49											
7 CS	96 60		50	50 - 56.2' **SILTY CLAY:** CL/ML, grayish brown (10YR 5/2) to light olive brown (2.5Y 5/4), sand (5-15%), gravel (5-15%), hard, no dilatancy, high toughness, medium to high plasticity, dry.	CL/ML									
			51											
			52											

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Boring Number SB301 Page 4 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			53	50 - 56.2' **SILTY CLAY:** CL/ML, grayish brown (10YR 5/2) to light olive brown (2.5Y 5/4), sand (5-15%), gravel (5-15%), hard, no dilatancy, high toughness, medium to high plasticity, dry. *(continued)*	CL/ML									
			54											
			55											
			56											
			57	56.2 - 57' **POORLY-GRADED SAND:** SP, gray (10YR 5/1), rounded to subrounded, fine to medium sand, gravel (0-5%), dense, moist.	SP									
8 MC	24 24		58	57 - 57.4' **SILTY CLAY:** CL/ML, grayish brown (10YR 5/2) to light olive brown (2.5Y 5/4), sand (5-15%), gravel (5-15%), hard, no dilatancy, high toughness, medium to high plasticity, moist.	CL/ML									MC= Modified California Sample
			59	57.4 - 58' **WELL-GRADED GRAVEL WITH CLAY AND SAND:** (GW-GC)s, subangular to subrounded gravel, dense, wet.	(GW-GC)s									
			60	58 - 60.										
9 CS	96 96		61	60 - 63.8' **SILTY CLAY:** CL/ML, grayish brown (10YR 5/2) to light olive brown (2.5Y 5/4), sand (5-15%), gravel (5-15%), hard, no dilatancy, high toughness, medium to high plasticity, dry.	CL/ML									
			62											
			63											
			64	63.8 - 66.4' **WELL-GRADED SAND WITH GRAVEL:** (SW)g, dark grayish brown (10YR 4/2), subrounded sand, clay (5-15%), clay nodules (0-5%), loose, wet.	(SW)g									
			65											
			66											
			67	66.4 - 68' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist.	ML									
10 MC	24 24		68	68 - 70.						13.1	23	9	68.7	
			69											
			70											
11 CS	60 60		71	70 - 87.5' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist.	ML									
			72											

Boring Number SB301 Page 5 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			73	70 - 87.5' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist. *(continued)*										
			74											
12 CS	60 43		75											
			76											
			77											
			78											
			79											
13 CS	120 120		80		ML									
			81											
			82											
			83											
			84											
			85											
			86											
			87											
			88	87.5 - 88.3' **SILTY SAND:** SM, dark grayish brown (10YR 4/2), dense.	SM									
			89	88.3 - 90' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist.	ML									
14 SH	24 0		90	90 - 92.										
			91											
			92											

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Boring Number SB301 Page 6 of 6

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
15 CS	96 96		93	92 - 95.3' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist.	ML									
			94											
			95											
			96	95.3 - 96.8' **SANDY SILT:** s(ML), gray (10YR 5/1) to grayish brown (10YR 5/2), cohesive, high to medium toughness, non-plastic, moist.	s(ML)									
			97	96.8 - 98' **SILT:** ML, dark grayish brown (10YR 4/2), gravel (0-5%), sand (0-5%), low toughness, non-plastic, moist.	ML									
16 SH	24 24		98	98 - 100.						15.7	37	22	82.2	
			99											
			100	100' End of Boring.										

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SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		XPW01

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/20/2021	1/20/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
XPW01	Feet (NAVD88)	548.62 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 824,975.39 N, 997,851.62 E Ⓔ/W
1/4 of 1/4 of Section 26, T 6 N, R 8 E
Lat 38° 55' 55.93"
Long -88° 17' 7.87"
Local Grid Location ☐N ☐S Feet ☐E ☐W Feet

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 60		0	0 - 6' ASH, gray (10YR 5/1), silt sized grains, fine sand (0-5%), gravel (0-5%), dry.	(FILL) ASH									CS= Core Sample
2 CS	36 36		5	5 - 6' cobbles.	(FILL)									
			6	6 - 8' ASH, gray (10YR 5/1), silt sized grains, fine sand (0-5%), gravel (0-5%), dry.	(FILL) ASH									
3 MC	24 24		8	8 - 10' ASH, sand and silt sized grains.	(FILL) ASH				87.7	18.6	47		11.8	MC= Modified California Sample
4 CS	60 60		10	10 - 15' ASH, gray (10YR 5/1), sand with gravel sized grains, slag-like material (0-5%), wet.	(FILL) ASH									
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature SAW

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

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Boring Number XPW01 Page 2 of 2

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	10 - 15' ASH, gray (10YR 5/1), sand with gravel sized grains, slag-like material (0-5%), wet. *(continued)*	(FILL) ASH									
			14											
5 MC	24 24		15	15 - 17' ASH, clay sized grains.	(FILL) ASH				84.4	12.6	35	18	61.3	
			16						0.5					
6 CS	36 36		17	17 - 18' **LEAN CLAY:** CL, gray (10YR 5/1), medium plasticity, orange mottling (0-5%), medium stiff, moist.	CL									
			18	18 - 20' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), subrounded fine gravel (0-5%), low plasticity, hard, moist.	CL/ML				4.5					
			19											
			20	20' End of Boring.										

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SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		XPW02

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/19/2021	1/19/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
XPW02	Feet (NAVD88)	551.97 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒

State Plane 825,023.53 N, 998,601.28 E Ⓔ/W

1/4 of 1/4 of Section 26, T 6 N, R 8 E

Lat 38° 55' 56.41"

Long -88° 16' 58.38"

Local Grid Location: Feet ☐N ☐S ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 60		0	0 - 4.4' ASH, brown (10YR 5/3), silt and sand sized grains , slag-like material (0-5%), fine to coarse gravel (0-5%), dry.	(FILL) ASH									CS= Core Sample
			1											
			2											
			3											
			4											
			5	4.4 - 5' **FILL, LEAN CLAY:** CL, very dark gray (10YR 3/1), gravel (0-5%), coal (0-5%), low plasticity, hard.	(FILL) CL				4					
2 MC	24 24		6	5 - 7' not analyzed.										MC= Modified California Sample
			7											
3 MC	24 24		8	7 - 9' **FILL, LEAN CLAY:** CL, very dark gray (10YR 3/1), gravel (0-5%), coal fragments (0-5%), low plasticity, hard.	(FILL) CL				92.9	29.1	36	20	54.9	
			9											
4 CS	12 12		10	9 - 13.5' **FILL, WELL-GRADED SAND WITH GRAVEL:** (SW)g, brown (10YR 5/3), fine to coarse sand, fine to coarse gravel (15-25%), coal (0-5%), wet.	(FILL) (SW)g									
5 CS	60 60		11											
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature SA WL

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number XPW02 Page 2 of 2

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	9 - 13.5' **FILL, WELL-GRADED SAND WITH GRAVEL:** (SW)g, brown (10YR 5/3), fine to coarse sand, fine to coarse gravel (15-25%), coal (0-5%), wet. *(continued)* 12.8 - 13.8' shale fragments (20-30%).	(FILL) (SW)g									
			14	13.5 - 15' **FILL, CLAYEY SILT** ML/CL, very dark gray (10YR 3/1), organic material (15-25%), very fine to fine sand (0-5%), wet.	(FILL) ML/CL									
6 MC	24 24		15	15 - 17' **FILL, LEAN CLAY:** CL, very dark gray (10YR 3/1).	(FILL) CL				103.7	21.8	36	22	80.2	
			16											
7 CS	36 36		17	17 - 19' **LEAN CLAY:** CL, very dark gray (10YR 3/1), medium plasticity, medium stiff, moist.	CL				0.5					
			18											
			19	19 - 20' **LEAN CLAY:** CL, grayish brown (10YR 5/2), fine to coarse gravel (0-5%), low plasticity, very stiff, moist.	CL				2.5					
			20	20' End of Boring.										

SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		XPW03

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/19/2021	1/19/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
XPW03	Feet (NAVD88)	550.81 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 824,558.16 N, 1,000,444.81 E Ⓔ/W
1/4 of 1/4 of Section 25, T 6 N, R 8 E
Lat 38° 55' 51.8"
Long -88° 16' 35.06"
Local Grid Location
Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 60		0	0 - 5' ASH, gray (10YR 5/1), silt sized grains, very fine to fine sand (5-15%), slag-like material (5-10%), dry.	(FILL) ASH									CS= Core Sample
			1											
			2											
			3											
			4	3.5' moist.										
2 MC	24 24		5	5 - 7' ASH, sand and silt sized grains. 5.5' moist to wet.	(FILL) ASH				75.3	17.4	33	6	21.5	MC= Modified California Sample
			6											
3 CS	36 36		7	7 - 9' ASH, gray (10YR 5/1), silt sized grains, wet.	(FILL) ASH									
			8											
			9	9 - 10' ASH, light gray (10YR 7/1), gravel sized grains, angular, fine to coarse gravel, coarse sand (0-5%), wet.	(FILL) ASH									
4 CS	60 60		10	10 - 13.6' ASH, grayish brown (10YR 5/2), sand to gravel sized grains, fine to coarse sand, fine to coarse gravel (15-25%), coal (0-5%), wet.	(FILL) ASH									
			11											
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature	Firm	Tel: (414) 837-3607
SAW	Ramboll 234 W. Florida Street, Milwaukee, WI 53204	Fax: (414) 837-3608

Boring Number XPW03 Page 2 of 2

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	10 - 13.6' ASH, grayish brown (10YR 5/2), sand to gravel sized grains, fine to coarse sand, fine to coarse gravel (15-25%), coal (0-5%), wet. *(continued)*	(FILL) ASH									
			14	13.6 - 14.7' ASH, gray (10YR 5/1), sand sized grains, fine to medium sand, fine to coarse gravel (0-5%), coal (0-5%), wet.	(FILL) ASH									
5 MC	24 18		15	14.7 - 15' ASH, gray (10YR 5/1), silt sized grains, very fine to fine sand (0-5%), wet.	(FILL) ASH				103.6	16.7	12		16.3	
			16	15 - 17' ASH, sand and silt sized grains.	(FILL) ASH									
6 CS	36 36		17											
			18	17 - 19' ASH, gray (10YR 5/1), silt sized grains, very fine to coarse sand (0-5%), fine gravel (0-5%) , wet.	(FILL) ASH									
			19	19 - 20' **SILTY CLAY:** CL/ML, yellowish brown (10YR 5/6), subrounded fine gravel (0-5%), low plasticity, very stiff, moist.	CL/ML				2					
			20	20' End of Boring.										

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SOIL BORING LOG INFORMATION

Facility/Project Name	License/Permit/Monitoring Number	Boring Number
Newton Power Station		XPW04

Boring Drilled By: Name of crew chief (first, last) and Firm	Date Drilling Started	Date Drilling Completed	Drilling Method
Russ Gordon Cascade Drilling	1/19/2021	1/19/2021	Mini Sonic

Common Well Name	Final Static Water Level	Surface Elevation	Borehole Diameter
XPW04	Feet (NAVD88)	551.90 Feet (NAVD88)	6.0 inches

Local Grid Origin ☐ (estimated: ☐) or Boring Location ☒
State Plane 824,130.99 N, 1,001,110.06 E Ⓔ/W
1/4 of 1/4 of Section 25, T 6 N, R 8 E
Lat 38° 55' 47.57"
Long -88° 16' 26.64"
Local Grid Location
Feet ☐N ☐S Feet ☐E ☐W

Facility ID	County	State	Civil Town/City/ or Village
	Jasper	IL	Newton

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
1 CS	60 60		0	0 - 5' ASH, gray (10YR 5/1), silt sized grains, very fine to fine sand (0-5%), fine to coarse gravel (0-5%), dry.	(FILL) ASH									CS= Core Sample
2 MC	12 4		5	5 - 6.										MC= Modified California Sample, 4" of concrete recovered in MC
3 MC	24 24		6	6 - 8' ASH, sand and silt sized grains. 7' moist.	(FILL) ASH				73.9	31.1	41	3	13.9	
4 CS	24 24		8	8 - 12' ASH, gray (10YR 5/1), silt sized grains, very fine to fine sand (0-5%), fine to coarse gravel (0-5%), moist.										
5 CS	60 60		10		(FILL) ASH									
			12											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature SAW

Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Boring Number XPW04 Page 2 of 2

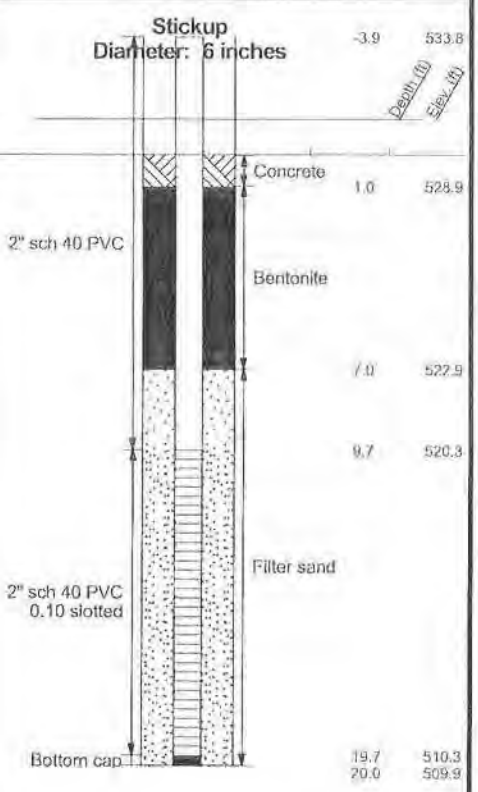
Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth In Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID 10.6 eV Lamp	Soil Properties: Compressive Strength (tsf)	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			13	12 - 15' ASH, gray (10YR 5/1), sand to gravel sized grains, very fine to fine sand (0-5%), fine to coarse gravel (0-5%), moist. 12.5' wet.	(FILL) ASH									
			14											
6 MC	24 24		15	15 - 17' ASH, sand and silt sized grains.					80.8	31.1	46	4	33.3	
			16		(FILL) ASH									
7 CS	36 36		17	17 - 19.5' ASH, gray (10YR 5/1), sand to gravel sized grains, very fine to fine sand (0-5%), fine to coarse gravel (0-5%), wet.										
			18		(FILL) ASH									
			19											
			20	19.5 - 20' **LEAN CLAY WITH SAND:** (CL)s, brown (10YR 5/3), fine to medium sand (15-25%), fine gravel (0-5%), wet. 20' End of Boring.	(CL)s									

Surface Elevation: 529.93
Datum msl
Completion Date: 6/19/10
Northing: 822688.04
Easting: 995465.25

DEPTH IN FEET	DESCRIPTION OF MATERIAL
	Soft, brown, silty CLAY - CL
5	Stiff, brown, sandy CLAY - CL
	Hard, brown, sandy CLAY with gravel - CL ▽
10	
	Hard, dark gray CLAY and glacial till - CH
15	
20	Boring terminated at 20 feet.
25	
30	
35	

GRAPHIC LOG | DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD | SAMPLES

WELL DIAGRAM



GROUNDWATER DATA

ENCOUNTERED AT 8.5 FEET ▽

DRILLING DATA

4 1/4" AUGER ___ HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RBF	App'vd. by: DTK
Date: 6/29/10	Date: 2-7-11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-2

Project No. J017150.01

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES
TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150 01ENV - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/22/10

Surface Elevation: 528.47

Datum msl

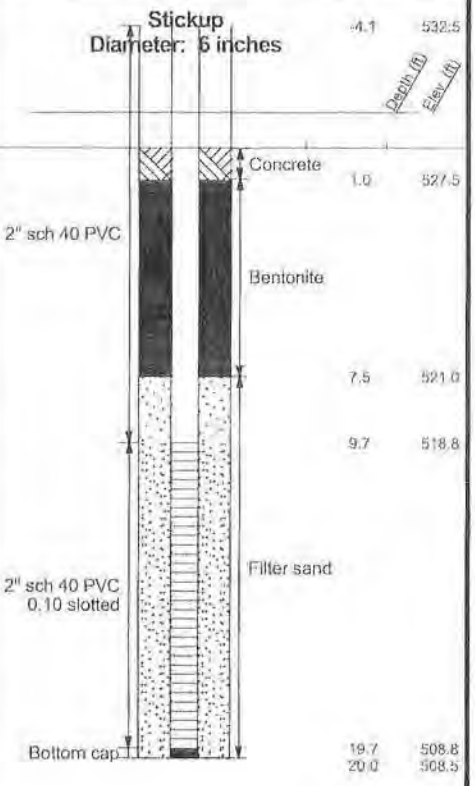
Completion Date: 6/18/10

Northing: 821379.76

Easting: 998975.74

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Soft, brown, silty CLAY - CL			
5				
	Soft, brown, sandy CLAY with gravel - CL			
10	Hard, brown, sandy CLAY with gravel - CL			
	Hard, brownish-gray, sandy CLAY with gravel - CL			
15				
20	Boring terminated at 20 feet.			
25				
30				
35				

WELL DIAGRAM



GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

4 1/4" AUGER __ HOLLOW STEM

WASHBORING FROM __ FEET

MVU DRILLER KCR LOGGER

CME 750X DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RSJ	App'vd. by: DTK
Date: 6/29/10	Date: 2/7/11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-3

Project No. J017150.01

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/22/10

Surface Elevation: 521.56

Datum msl

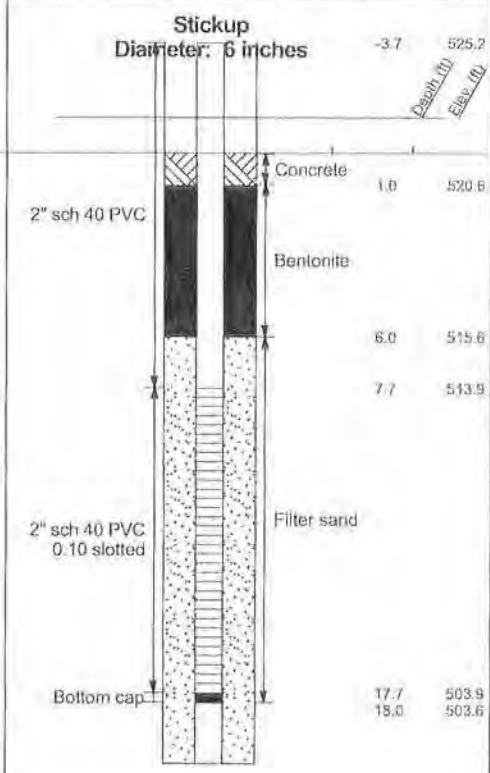
Completion Date: 6/19/10

Northing: 823246.45

Easting: 1001379.56

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Soft, brown, silty CLAY - CL			
5				
	Soft, brown, sandy CLAY - CL			
10				
	Stiff, brown, sandy CLAY with gravel - CL			
15				
	Boring terminated at 18 feet.			
20				
25				
30				
35				

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/22/11

GROUNDWATER DATA

ENCOUNTERED AT 8 FEET ∇

DRILLING DATA

4 1/4" AUGER __ HOLLOW STEM

WASHBORING FROM __ FEET

MVU DRILLER KCR LOGGER

CME 750X DRILL RIG

HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RJS	App'vd. by: DTK
Date: 6/29/10	Date: 2-7-11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-4

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/22/2015
Finish: 10/22/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW5
Well ID: APW5
Surface Elev: 541.57 ft. MSL
Completion: 68.00 ft. BGS
Station: 7,758.02N
9,318.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 58.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Very dark grayish brown (10YR3/2), dry, very stiff, SILT with little clay and trace very fine- to medium-grained sand, roots.			
1A	60/60 100%	DP		7		3.00	2	Yellowish brown (10YR5/6), dry, very stiff, SILT with little clay and few very fine- to medium-grained sand.		540	
1B				13		2.50	4	Yellowish brown (10YR5/6) with 10% gray (10YR6/1) mottles, moist, very stiff, silty CLAY with few very fine- to medium-grained sand and trace small gravel.		538	
							6			536	
2A	60/60 100%	DP		25		3.25	8	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, very stiff, CLAY with some silt, trace very fine- to fine-grained sand.		534	
2B				22		2.25	10	Dark grayish brown (10YR4/2), moist, stiff, CLAY with little silt and trace very fine- to fine-grained sand.		532	
3A				19		1.50	12	Gray (10YR6/1), moist, medium dense, very fine- to fine-grained SAND and SILT with little clay.		530	
3B	60/60 100%	DP		19		3.00	14	Gray (10YR5/1) with 5% yellowish brown (10YR5/6) mottles, moist, very stiff, silty CLAY with few fine- to coarse-grained sand and trace small gravel.		528	
							16			526	
4A	36/36 100%	DP		9		2.00	18	Yellowish brown (10YR5/6) with 15% grayish brown (10YR5/2) mottles, moist, stiff, SILT with little clay and trace fine- to coarse-grained sand and small gravel.		524	
5A	23/24 96%	SS	14-28 40-50 N=68	9		4.50	20	Brown (10YR5/3), moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel.		522	

NOTE(S): APW5 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/22/2015
Finish: 10/22/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW5
Well ID: APW5
Surface Elev: 541.57 ft. MSL
Completion: 68.00 ft. BGS
Station: 7,758.02N
9,318.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 58.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
6A	21/24 88%	ss	11-26 21-14 N=47	9		4.50		Brown (10YR5/3), moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel. *[Continued from previous page]*			
							22			520	
7A	24/24 100%	ss	5-5 8-13 N=13	16		4.25		Brown (10YR5/3) with 5% gray (10YR6/1) and 5% yellowish brown (10YR5/6) mottles, moist, hard, SILT with some clay and trace very fine- to fine-grained sand and small gravel.			
							24			518	
8A	22/24 92%	ss	18-31 43-27 N=74	9		4.50		Brown (10YR5/3), moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel.			
							26			516	
9A	21/24 88%	ss	4-5 11-11 N=16	14		2.75					
							28	Brown (10YR5/3) with 5% gray (10YR6/1) and 5% yellowish brown (10YR5/6) mottles, moist, hard, SILT with some clay and trace very fine- to fine-grained sand and small gravel.		514	
10A	22/24 92%	ss	3-6 9-12 N=15	15		3.75					
							30			512	
11A	24/24 100%	ss	4-7 13-16 N=20	14		4.50					
							32	Dark gray (10YR4/1), moist, hard, SILT with some clay, few very fine- to coarse-grained sand and trace small gravel.		510	
12A	24/24 100%	ss	4-7 11-17 N=18	16		4.50					
							34			508	
13A	24/24 100%	ss	5-9 12-15 N=21	18		4.50		Light olive brown (2.5Y5/3) with 5% gray (10YR5/1) mottles, moist, hard, SILT with little clay and trace very fine- to medium-grained sand.			
							36			506	
14A	24/24 100%	ss	4-8 11-14 N=19	16		4.50					
							38	Olive brown (2.5Y4/3) with 10% gray (N6/1) mottles, moist, hard, silty CLAY with little fine- to coarse-grained sand and trace small gravel.		504	
15A	24/24 100%	ss	5-13 16-23 N=29	12		4.50					
							40			502	

NOTE(S): APW5 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/22/2015
Finish: 10/22/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW5
Well ID: APW5
Surface Elev: 541.57 ft. MSL
Completion: 68.00 ft. BGS
Station: 7,758.02N
9,318.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 58.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
16A	24/24 100%	ss	6-13 16-30 N=29	12		4.50	42	Olive brown (2.5Y4/3) with 10% gray (N6/1) mottles, moist, hard, silty CLAY with little fine- to coarse-grained sand and trace small gravel. *[Continued from previous page]*		500	
17A	24/24 100%	ss	5-10 13-22 N=23	15		4.50	44			498	
18A	24/24 100%	ss	7-13 17-25 N=30	13		4.50	46			496	
19A	24/24 100%	ss	6-13 20-28 N=33	13		4.50	48			494	
20A	24/24 100%	ss	5-10 16-21 N=26	13		4.50	50	Olive brown (2.5Y4/3) with 10% gray (N6/1) mottles, moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		492	
21A	24/24 100%	ss	6-10 18-21 N=28	13		4.50	52			490	
22A	24/24 100%	ss	7-14 19-26 N=33	13		4.50	54			488	
23A	24/24 100%	ss	6-10 17-24 N=27	13		4.50	56			486	
24A	24/24 100%	ss	12-16 28-36 N=44	11		4.50	58 ▼	Olive gray (5Y5/2) with 40% olive brown (2.5Y4/4) mottles, moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		484	
25A	24/24 100%	ss	2-6 12-15 N=18	23				Greenish gray (10G5/1) with 40% olive gray (5Y4/2) mottles, moist, medium dense, SILT with few clay and trace very fine- to fine-grained sand.			
25B				15			60	Very dark gray (10YR3/1), wet, medium dense, very fine- to coarse-grained SAND with few silt.		482	

NOTE(S): APW5 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/22/2015
Finish: 10/22/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW5
Well ID: APW5
Surface Elev: 541.57 ft. MSL
Completion: 68.00 ft. BGS
Station: 7,758.02N
9,318.19E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 58.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) *% Recovery*	Type	TESTING *Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
26A	19/24 *79%*	ss	*3-19 34-48* N=53	13			62			480	
27A	20/24 *83%*	ss	*22-38 33-34* N=71	16			64	Very dark gray (10YR3/1), wet, very dense, very fine- to coarse-grained SAND with few silt.		478	
28A	22/24 *92%*	ss	*18-28 31-33* N=59	14			66			476	
29A	24/24 *100%*	ss	*21-27 24-23* N=51	16							
29B				14		*4.50*	68	Dark gray (10YR4/1), moist, hard, SILT with little clay and few very fine- to coarse-grained sand.		474	

End of boring = 68.0 feet

NOTE(S): APW5 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/20/2015
Finish: 10/21/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW6
Well ID: APW6
Surface Elev: 543.38 ft. MSL
Completion: 74.00 ft. BGS
Station: 7,688.54N
7,811.93E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Gray (10YR6/1), dry, very stiff, SILT with few clay and trace very fine- to coarse- grained sand, trace roots.			
1A	60/60 100%	DP		15		4.00	2	Brown (10YR5/3) with 5% dark yellowish brown (10YR4/6) and 5% gray (10YR6/1) mottles, dry, very stiff, SILT with few clay and very fine- to coarse-grained sand, trace small gravel, trace roots.		542	
1B				26		3.00	4	Gray (10YR5/1) with 35% dark yellowish brown (10YR4/6) mottles, moist, very stiff, CLAY with little silt and trace very fine- to fine-grained sand.		540	
2A	60/60 100%	DP		18		2.50	6	Gray (10YR5/1) with 40% dark yellowish brown (10YR3/6) mottles, moist, very stiff, SILT with little clay and trace very fine- to medium-grained sand.		538	
2B				18		1.00	8			536	
3A	60/60 100%	DP		27		1.50	10	Gray (10YR5/1) with 30% dark yellowish brown (10YR4/6) mottles, moist, stiff, SILT with some clay and few very fine- to medium-grained sand.		534	
3B	12/12 100%	DP		21		1.50	12	Dark yellowish brown (10YR4/6) with 25% gray (10YR5/1) mottles, moist, stiff, CLAY with some silt and few very fine- to medium-sand.		532	
4A				10			14 ▼	Dark yellowish brown (10YR3/4), wet, soft, fine- to coarse grained sandy CLAY with little silt.		530	
5A	22/24 92%	SS	15-29 41-50 N=70	8		4.50	16	Brown (10YR4/3), moist, stiff, SILT with little clay and few very fine- to coarse-grained sand.		528	
6A	21/24 88%	SS	14-30 40-50 N=70	8		4.50	18	Grayish brown (10YR5/2) with 15% dark gray (10YR4/1) mottles, dry, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		526	
							20			524	

NOTE(S): APW6 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/20/2015
Finish: 10/21/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW6
Well ID: APW6
Surface Elev: 543.38 ft. MSL
Completion: 74.00 ft. BGS
Station: 7,688.54N
7,811.93E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
7A	15/17 88%	ss	16-46 50/5"	9		4.50		Brown (10YR5/3), moist, very dense, silty, very fine- to medium-grained SAND with trace small gravel.		522	
8A	12/24 50%	ss	14-37 45-50 N=82	7		4.50	22	Brown (10YR5/3), dry, hard, SILT with little clay and few very fine- to coarse-grained sand.		520	
9A	24/24 100%	ss	8-17 23-32 N=40	10		4.50	24			518	
10A	24/24 100%	ss	10-22 26-36 N=48	11		4.50	26			516	
11A	24/24 100%	ss	10-18 23-26 N=41	10		4.50	28	Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		514	
12A	24/24 100%	ss	6-13 17-23 N=30	13		4.50	30			512	
13A	24/24 100%	ss	5-7 12-19 N=19	17		4.50	32			510	
14A	24/24 100%	ss	5-9 13-19 N=22	16		4.50	34	Dark gray (10YR4/1) with 30% dark greenish gray (10Y4/1) mottles, moist, hard, SILT with some clay, few very fine- to coarse-grained sand and trace small gravel.		508	
15A	24/24 100%	ss	5-10 15-22 N=25	15		4.50	36			506	
16A	24/24 100%	ss	5-9 15-22 N=24	15		4.50	38	Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small to large gravel.		504	
							40				

NOTE(S): APW6 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/20/2015
Finish: 10/21/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW6
Well ID: APW6
Surface Elev: 543.38 ft. MSL
Completion: 74.00 ft. BGS
Station: 7,688.54N
7,811.93E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
17A	21/24 88%	ss	4-14 18-25 N=32	12		4.25	42	Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small to large gravel. *[Continued from previous page]*		502	
18A	24/24 100%	ss	8-12 16-22 N=28	15		4.50	44			500	
19A	22/24 92%	ss	7-11 15-18 N=26	16		4.25	46			498	
20A	22/24 92%	ss	7-16 26-45 N=42	13		4.50	48			496	
21A	21/24 88%	ss	11-19 30-37 N=49	13		4.50	50	Olive gray (5Y4/2) with 20% dark gray (10YR4/1) mottles, moist, hard, SILT with little clay and trace very fine- to coarse- grained sand and small gravel.		494	
22A	19/24 79%	ss	5-13 26-38 N=39	14			52			492	
23A	24/24 100%	ss	12-18 29-40 N=47	13		4.50	54			490	
24A	24/24 100%	ss	7-18 30-37 N=48	13			56	Dark gray brown (2.5Y4/2) with 15% dark gray (10YR4/1) mottles, moist, hard, SILT with little clay and trace very fine- to coarse-grained sand.		488	
25A	24/24 100%	ss	11-18 27-38 N=45	14		4.50	58	Olive brown (2.5Y4/3) with 5% gray (N6/1) mottles, moist, hard, SILT with little clay and trace very fine- to medium-grained sand.		486	
26A	24/24 100%	ss	10-15 23-33 N=38	17		4.50	60	Olive brown (2.5Y4/3) with 5% gray (N6/1) mottles, moist, hard, SILT with little clay and trace very fine- to coarse-grained sand and small gravel.		484	

NOTE(S): APW6 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/20/2015
Finish: 10/21/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW6
Well ID: APW6
Surface Elev: 543.38 ft. MSL
Completion: 74.00 ft. BGS
Station: 7,688.54N
7,811.93E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 14.00 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
27A	24/24 100%	ss	5-4 21-32 N=25	13		4.50	62	Olive brown (2.5Y4/3) with 5% gray (N6/1) mottles, moist, hard, SILT with little clay and trace very fine- to coarse-grained sand and small gravel. *[Continued from previous page]*		482	
28A	24/24 100%	ss	7-18 23-31 N=41	12		4.50	64	Dark gray (10YR4/1) with 5% dark olive brown (2.5Y3/3) mottles, moist, hard, SILT with little clay and trace very fine- to coarse-grained sand and small gravel.		480	
29A	24/24 100%	ss	7-14 18-30 N=32	13		4.25	66	Dark gray (10YR4/1), moist, hard, SILT with little clay and trace very fine- to coarse-grained sand and small gravel.		478	
30A	24/24 100%	ss	13-21 33-33 N=54	14			68	Dark gray (10YR4/1), wet, very dense, silty, very fine- to coarse-grained SAND with trace small gravel.		476	
31A	16/23 70%	ss	3-27 49-50/5" N=76	13			70			474	
32A	20/23 87%	ss	6-29 38-50/5" N=67	22			72	Gray (10YR5/1), wet, very dense, SILT with few very fine- to fine-grained sand.		472	
33A	20/24 83%	ss	26-28 34-37 N=62	12		4.50	74	Dark gray (10YR4/1), wet, very dense, silty, very fine- to medium-grained SAND with trace small gravel. Dark gray (10YR4/1), moist, hard, SILT with little clay and few very fine- to coarse-grained sand.		470	

End of boring = 74.0 feet

NOTE(S): APW6 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/3/2015
Finish: 11/5/2015
WEATHER: Sunny, warm, lo-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW7a
Well ID: APW7
Surface Elev: 536.21 ft. MSL
Completion: 83.10 ft. BGS
Station: 5,688.85N
6,151.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % *Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Yellowish brown (10YR5/6), moist, medium, CLAY with some silt and trace very fine- to fine-grained sand, roots.		536	
							2	Light gray (10YR7/2), moist, medium, SILT with few very fine-grained sand and trace roots.		534	
							4	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, medium, CLAY with some silt, trace very fine-grained sand, and trace roots.		532	
							6			530	
							8	Gray (10YR5/1) with 30% yellowish brown (10YR5/8) mottles, moist, medium, CLAY with some silt and trace very fine- to medium-grained sand, trace small gravel, and trace roots.		528	
							10			526	
							12			524	
							14	Yellowish brown (10YR5/4), moist, hard, SILT with few clay, little very fine- to coarse-grained sand, and trace small to medium gravel.		522	
							16	Yellowish brown (10YR5/6), wet, dense, fine- to coarse-grained SAND with little silt.		520	
							18	Gray (10YR5/1), moist, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel.		518	
							20	Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, dry, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel.			

NOTE(S): APW7 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/3/2015
Finish: 11/5/2015
WEATHER: Sunny, warm, lo-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW7a
Well ID: APW7
Surface Elev: 536.21 ft. MSL
Completion: 83.10 ft. BGS
Station: 5,688.85N
6,151.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks

Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, dry, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel.
[Continued from previous page]

22 — 514

Yellowish brown (10YR5/6) with 20% gray (10YR5/1) mottles, dry, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel, horizontal and vertical fractures with dark brown (10YR3/3) oxidized faces.

24 — 512

26 — 510

Gray (10YR5/1), moist, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel, horizontal and vertical fractures with dark brown (10YR3/3) oxidized faces.

28 — 508

30 — 506

32 — 504

Gray (10YR5/1), moist, hard, SILT with few clay, little very fine- to very coarse-grained sand, and trace small to medium gravel.

34 — 502

36 — 500

Gray (10YR5/1), moist, dense, very fine- to fine-grained SAND with trace silt.

38 — 498

Gray (10YR5/1), moist, dense, very fine- to very coarse-grained SAND with trace silt and small gravel.

Gray (10YR5/1), moist, dense, very fine- to fine-grained SAND with trace silt.

40

NOTE(S): APW7 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/3/2015
Finish: 11/5/2015
WEATHER: Sunny, warm, lo-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW7a
Well ID: APW7
Surface Elev: 536.21 ft. MSL
Completion: 83.10 ft. BGS
Station: 5,688.85N
6,151.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail / Elevation ft. MSL / Remarks
							42	Gray (10YR5/1), moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, trace small gravel, and trace wood fragments.	496
							44		494
							46		492
							48		490
							50	Gray (10YR5/1), moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments.	488
							52		486
							54		484
							56		482
							58		480
							60		478

NOTE(S): APW7 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/3/2015
Finish: 11/5/2015
WEATHER: Sunny, warm, lo-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW7a
Well ID: APW7
Surface Elev: 536.21 ft. MSL
Completion: 83.10 ft. BGS
Station: 5,688.85N
6,151.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % *Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							62			476	
							64			474	
							66	Gray (10YR5/1), moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments. *[Continued from previous page]*		472	
							68			470	
							70			468	
							72	Gray (10YR5/1), moist, dense, very fine- to very coarse-grained SAND with some clay and silt.		466	
							74	Gray (10YR5/1), moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, trace small gravel, and trace wood fragments.		464	
							76			462	
							78	Gray (10YR5/1), wet, loose, very fine- to very coarse-grained SAND with trace small gravel.		460	
							80			458	

NOTE(S): APW7 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/3/2015
Finish: 11/5/2015
WEATHER: Sunny, warm, lo-70s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW7a
Well ID: APW7
Surface Elev: 536.21 ft. MSL
Completion: 83.10 ft. BGS
Station: 5,688.85N
6,151.60E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							82	Gray (10YR5/1), wet, loose, very fine- to very coarse-grained SAND with trace small gravel. *[Continued from previous page]*		456 / 454	
								Bluish black (10B2.5/1), wet dense, very fine- to very coarse-grained SAND with little silt and trace small gravel.			

End of boring = 83.1 feet

NOTE(S): APW7 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/28/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW8
Well ID: APW8
Surface Elev: 526.75 ft. MSL
Completion: 82.00 ft. BGS
Station: 3,839.59N
6,082.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 33.70 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							0	Black (10YR2/1), moist, very stiff, SILT with little clay and trace very fine- to medium-grained sand, roots.		526	
1A				13		4.50		Yellowish brown (10YR5/4) with 30% light gray (10YR7/2) mottles, dry, hard, SILT with little clay and trace very fine- to medium-grained sand.			
	60/60 100%	DP					2				
1B				21		3.00				524	
							4	Grayish brown (10YR5/2) with 15% dark yellowish brown (10YR4/6) and 10% black (10YR2/1) mottles, moist, very stiff, silty CLAY with few very fine- to coarse-grained sand and trace small gravel.			
							6			522	
2A				18		2.50					
	60/60 100%	DP					8				
								Grayish brown (10YR5/2) with 15% dark yellowish brown mottles, moist, stiff, silty CLAY with few very fine- to coarse-grained sand and trace small gravel.		520	
2B				28		2.00	10				
										518	
	20/24 83%	DP									
3A				8		2.00		Brown (10YR5/3) with 20% dark yellowish brown (10YR5/6) mottles, dry, stiff, SILT with little clay and trace very fine- to coarse-grained sand.			
							12			516	Rock in shoe of sampler.
	0/17 0%	SS	23-43 50/5"								
4A							14			514	
5A	21/24 88%	SS	13-20 24-28 N=44	10		4.50				512	
							16				
6A	24/24 100%	SS	7-14 20-48 N=34	11		4.50		Dark gray (10YR4/1), moist, hard, SILT with little clay, trace very fine- to coarse-grained sand and small gravel.		510	
							18				
7A	24/24 100%	SS	14-21 26-32 N=47	10						508	
							20				

NOTE(S): APW8 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/28/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW8
Well ID: APW8
Surface Elev: 526.75 ft. MSL
Completion: 82.00 ft. BGS
Station: 3,839.59N
6,082.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 33.70 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
8A	24/24 100%	ss	7-13 19-23 N=32	11		4.50					
9A	24/24 100%	ss	7-14 19-27 N=33	11		4.50	22			506	
10A	24/24 100%	ss	8-15 30-37 N=45	11		4.50	24	Dark gray (10YR4/1), moist, hard, SILT with little clay, trace very fine- to coarse-grained sand and small gravel. *[Continued from previous page]*		504	
11A	24/24 100%	ss	8-16 24-33 N=40	11		4.50	26			502	
12A	24/24 100%	ss	9-31 33-30 N=64	11			28			500	
12B				12		4.50		Gray (10YR5/1), moist, dense, silty, very fine- to medium-grained SAND.		498	
13A	24/24 100%	ss	10-23 40-35 N=63	11		4.50	30			496	
14A	21/24 88%	ss	16-16 29-50 N=45	10		4.50	32	Dark gray (10YR4/1), moist, hard SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel.		494	
15A	20/24 83%	ss	9-24 34-41 N=58	13			▼ 34			492	
16A	22/24 92%	ss	16-18 29-35 N=47	11		4.50	36	Dark gray (10YR4/1), wet, very dense, silty, very fine- to coarse-grained SAND with trace small gravel.		490	
17A	21/24 88%	ss	10-17 21-31 N=38	11		4.50	38	Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel.		488	
							40				

NOTE(S): APW8 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/28/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW8
Well ID: APW8
Surface Elev: 526.75 ft. MSL
Completion: 82.00 ft. BGS
Station: 3,839.59N
6,082.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 33.70 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
18A	24/24 100%	ss	9-16 26-32 N=42	11		4.50	42			486	
19A	24/24 100%	ss	10-16 23-34 N=39	12		4.50	44			484	
20A	24/24 100%	ss	10-15 26-44 N=41	13		4.50	46			482	
21A	24/24 100%	ss	12-21 32-48 N=53	12		4.50	48			480	
22A	24/24 100%	ss	11-17 22-31 N=39	13		4.50	50	Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel. *[Continued from previous page]*		478	
23A	24/24 100%	ss	10-13 21-32 N=34	13		4.50	52			476	
24A	24/24 100%	ss	8-13 50-26 N=63	13		4.50	54			474	
25A	24/24 100%	ss	8-11 19-28 N=30	14		4.25	56			472	
26A	24/24 100%	ss	10-12 18-26 N=30	13		4.50	58			470	
27A	22/24 92%	ss	7-10 15-22 N=25	21		4.50	60	Olive gray (5Y4/2), moist, hard, silty CLAY with few very fine- to coarse-grained sand and trace small gravel.		468	

NOTE(S): APW8 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/28/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW8
Well ID: APW8
Surface Elev: 526.75 ft. MSL
Completion: 82.00 ft. BGS
Station: 3,839.59N
6,082.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 33.70 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
28A	20/24 83%	ss	7-15 19-20 N=34	14		4.50		Dark gray (10YR4/1), moist, hard, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		466	
							62				
29A	21/24 88%	ss	7-8 11-16 N=19	11		3.75		Dark gray (10YR4/1), moist, very stiff, SILT with little clay, few very fine- to coarse-grained sand and trace small gravel.		464	
							64				
30A	21/24 88%	ss	6-13 14-11 N=27	14		4.00				462	
30B				10				Gray (10YR6/1), wet, medium dense, silty, very fine- to coarse-grained SAND with trace small to large gravel.			
							66	Dark gray (10YR4/1), moist, very stiff, SILT with little clay and few very fine- to coarse-grained sand.			
31A	18/24 75%	ss	4-3 4-3 N=7	28				Dark gray (10YR4/1), wet, loose, silty, very fine- to coarse-grained SAND with trace small gravel and trace wood fragments.		460	
31B				15		3.25					
							68	Dark gray (10YR4/1), moist, very stiff, SILT with little clay, few very fine- to coarse-grained sand, and trace small gravel, trace wood fragments.			
32A	20/24 83%	ss	1-3 3-2 N=6	17				Dark gray (10YR4/1), wet, loose, SILT with little very fine- to fine-grained sand.		458	
32B				28				Dark gray (10YR4/1), wet, loose, silty, very fine- to coarse-grained SAND.			
							70	Dark gray (10YR4/1), wet, loose, SILT with little very fine- to fine-grained sand, trace wood fragments.			
33A	15/24 63%	ss	woh-2 6-6 N=8	17				Dark gray (10YR4/1), wet, loose, silty, very fine- to coarse-grained SAND, trace wood fragments.		456	
							72				
34A	16/24 67%	ss	9-11 15-20 N=26	9				Dark gray (10YR4/1), wet, medium dense, silty, very fine- to coarse-grained SAND with trace small gravel.		454	
								Dark gray (10YR4/1), wet, medium dense, silty, very fine- to coarse-grained SAND with few small to large gravel.			
							74				
35A	15/24 63%	ss	16-21 23-24 N=44	9				Dark gray (10YR4/1), wet, dense, silty, very fine- to coarse-grained SAND with few small to large gravel.		452	
							76				
36A	14/24 58%	ss	11-20 25-24 N=45	11						450	
							78	Dark gray (10YR4/1), wet, dense, silty, very fine- to coarse-grained SAND with trace small gravel.			
37A	15/24 63%	ss	20-25 24-25 N=49	10						448	
							80				

NOTE(S): APW8 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/28/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, macro-core sampler, split spoon sampler
FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW8
Well ID: APW8
Surface Elev: 526.75 ft. MSL
Completion: 82.00 ft. BGS
Station: 3,839.59N
6,082.37E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 33.70 - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
38A	18/24 75%	ss	26-26 26-31 N=52	8				Dark gray (10YR4/1), wet, dense, silty, very fine- to coarse-grained SAND with trace small gravel. *[Continued from previous page]*		446	
38B				11		4.50	82	Dark gray (10YR4/1), moist, hard, SILT with little clay and few very fine- to coarse-grained sand.			

End of boring = 82.0 feet

NOTE(S): APW8 installed in borehole.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/2/2015
Finish: 11/3/2015
WEATHER: Foggy, mild, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler

FIELD STAFF: **Driller:** J. Gates
Helper: C. Lines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW9
Well ID: APW9
Surface Elev: 528.82 ft. MSL
Completion: 62.00 ft. BGS
Station: 3,519.59N
9,125.33E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 27.00 - During Drilling
▼ = 26.10 - 11/3/15
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) *% Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1	0/60 *0%*	BD					0			528	
							2				
							4			526	
2	0/60 *0%*	BD					6			524	
							8			522	
							10	Blind drill - see APW3 boring log for lithology, sample, and testing data		520	
3	0/60 *0%*	BD					12			518	
							14			516	
4	0/60 *0%*	BD					16			514	
							18			512	
							20			510	

NOTE(S): APW9 installed in borehole.
Lithology, sample, and testing data can be found on APW-3 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/2/2015
Finish: 11/3/2015
WEATHER: Foggy, mild, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW9
Well ID: APW9
Surface Elev: 528.82 ft. MSL
Completion: 62.00 ft. BGS
Station: 3,519.59N
9,125.33E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 27.00 - During Drilling
▼ = 26.10 - 11/3/15
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
5A	24/24 100%	ss	10-13 21-28 N=34	10		4.25	22	Gray (10YR5/1), moist, hard, SILT with some very fine-grained sand, little clay, and trace small to medium gravel. Vertical and horizontal fractures with yellowish brown (10YR5/8) faces.		508	
6A	24/24 100%	ss	13-15 21-29 N=36	10		4.50				506	
7A	2/24 8%	ss	15-28 33-39 N=61	11		4.50	24	Gray (10YR5/1), moist, hard, SILT with some very fine-grained sand, little clay, and trace small to medium gravel.		504	Rock in shoe of sampler.
8A	23/23 100%	ss	9-15 39-50/5" N=54	11			▼ 26 ▼			502	
8B				11			28	Gray (10YR5/1), wet, dense, very fine- to very coarse-grained SAND with some silt, few clay and trace small to medium gravel.		500	
9A	24/24 100%	ss	12-22 28-27 N=50	11							
9B				12		4.50	30			498	
10A	24/24 100%	ss	14-22 32-44 N=54	11		4.50					
11A	23/24 96%	ss	8-16 24-35 N=40	11		4.50	32	Gray (10YR5/1), moist, hard, SILT with little clay and very fine-grained sand and trace small gravel.		496	
12A	16/24 67%	ss	12-25 35-32 N=60	12		4.50	34			494	
13A	24/24 100%	ss	6-12 24-25 N=36	11		4.50	36			492	
14A	24/24 100%	ss	4-7 16-32 N=23	14		4.50	38	Gray (10YR5/1) moist, stiff, CLAY with some silt, little very fine-grained sand and trace small gravel.		490	
							40				

NOTE(S): APW9 installed in borehole.
Lithology, sample, and testing data can be found on APW-3 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/2/2015
Finish: 11/3/2015
WEATHER: Foggy, mild, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW9
Well ID: APW9
Surface Elev: 528.82 ft. MSL
Completion: 62.00 ft. BGS
Station: 3,519.59N
9,125.33E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 27.00 - During Drilling
▼ = 26.10 - 11/3/15
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
15A	24/24 100%	ss	5-11 19-23 N=30	14		4.50	42	Gray (10YR5/1) moist, stiff, CLAY with some silt, little very fine-grained sand and trace small gravel, trace wood fragments.		488	
16A	24/24 100%	ss	4-8 14-29 N=22	15		4.50				486	
16B				12			44	Light olive brown (2.5Y5/3), moist, stiff, CLAY with some silt, few very fine- to very coarse-grained sand, and trace small gravel.		484	
17A	24/24 100%	ss	8-17 24-34 N=41	11		4.50					
18A	24/24 100%	ss	7-13 20-29 N=33	12		4.50	46	Light olive brown (2.5Y5/3) with 30% yellowish brown (10YR5/8) mottles, moist, stiff, CLAY with some silt, few very fine- to very coarse-grained sand, and trace small gravel.		482	
19A	24/24 100%	ss	6-12 18-24 N=30	12		4.50	48	Grayish brown (2.5Y5/2) with 10% gray (2.5Y5/3) mottles, moist, hard, SILT with little very fine- to very coarse-grained sand, few clay and trace small to large gravel.		480	
20A	24/24 100%	ss	7-12 17-22 N=29	15		4.50	50			478	
21A	24/24 100%	ss	5-11 12-18 N=23	14		4.25	52	Yellowish brown (10YR5/6) with 25% gray (10YR6/1) mottles, moist, stiff, CLAY with some silt, little very fine-medium-grained sand, and trace small gravel.		476	
22A	23/23 100%	ss	6-14 24-50/5" N=38	13		4.50	54			474	
22B				13			56	Dark gray (10YR4/1), moist, dense, very fine- to fine-grained SAND with few silt.			
23A	24/24 100%	ss	7-15 21-30 N=36	13				Gray (10YR5/1), wet, loose, very fine- to very coarse-grained SAND with trace small gravel.		472	
24A	18/24 75%	ss	13-38 43-40 N=81	15			58	Gray (10YR5/1), wet, loose, very fine- to coarse-grained SAND.		470	
							60				

NOTE(S): APW9 installed in borehole.
Lithology, sample, and testing data can be found on APW-3 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/2/2015
Finish: 11/3/2015
WEATHER: Foggy, mild, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: APW9
Well ID: APW9
Surface Elev: 528.82 ft. MSL
Completion: 62.00 ft. BGS
Station: 3,519.59N
9,125.33E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 27.00 - During Drilling
▼ = 26.10 - 11/3/15
▽ =

SAMPLE Number	Recov / Total (in) *% Recovery*	Type	TESTING *Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
25A	24/24 *100%*	ss	*4-18* *25-30* N=43	21				Gray (10YR5/1), wet, loose, very fine- to coarse-grained SAND. *[Continued from previous page]*		468	
25B				16			62	Gray (10YR5/1), moist, stiff, CLAY with some silt and trace very fine-grained sand.			
								Gray (10YR5/1), wet, dense, SILT and very fine-grained SAND.			

End of boring = 62.0 feet

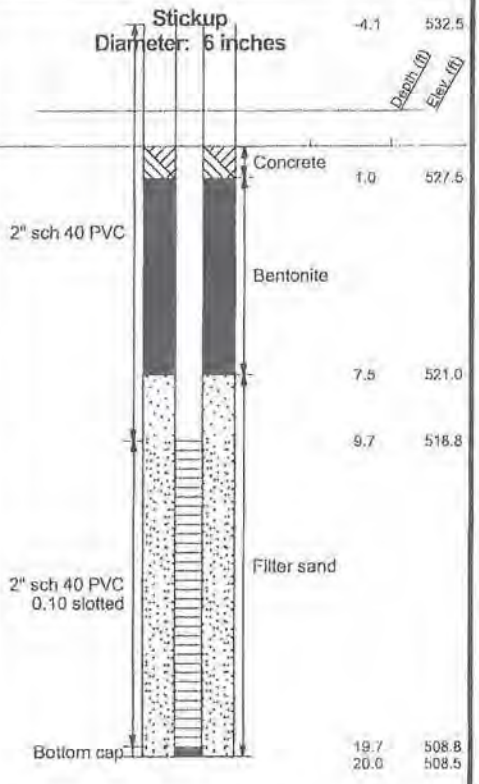
NOTE(S): APW9 installed in borehole.
Lithology, sample, and testing data can be found on APW-3 Field Boring Log.

Surface Elevation: 528.47
Datum msl
Completion Date: 6/18/10
Northing: 821379.76
Easting: 998975.74

DEPTH IN FEET	DESCRIPTION OF MATERIAL
	Soft, brown, silty CLAY - CL
5	Soft, brown, sandy CLAY with gravel - CL
10	Hard, brown, sandy CLAY with gravel - CL
	Hard, brownish-gray, sandy CLAY with gravel - CL
15	
20	Boring terminated at 20 feet.
25	
30	
35	

GRAPHIC LOG | DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD | SAMPLES

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 7/2/11

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

4 1/4" AUGER ___ HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: [illegible]	App'vd. by: DTK
Date: 6/29/10	Date: 2/7/11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-3

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/27/2015
WEATHER: Cool, rainy, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW10a
Well ID: APW10
Surface Elev: 521.98 ft. MSL
Completion: 45.94 ft. BGS
Station: 5,371.32N
11,541.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 25, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 36.00 - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft^3)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description
							0	
							2	
							4	
							6	
							8	
							10	Blind drill - see APW4 boring log for lithology, sample, and testing data
							12	
							14	
							16	
							18	
							20	

Borehole Detail

Elevation ft. MSL: 520, 518, 516, 514, 512, 510, 508, 506, 504, 502

Remarks

NOTE(S): APW10 installed in borehole.
Lithology, sample, and testing data can be found on APW-4 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/27/2015
WEATHER: Cool, rainy, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW10a
Well ID: APW10
Surface Elev: 521.98 ft. MSL
Completion: 45.94 ft. BGS
Station: 5,371.32N
11,541.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 25, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 36.00 - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % *Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22	Yellowish brown (10YR5/6) with 5% gray (N6/1) mottles, moist, hard, SILT with little clay, few very fine-grained sand, and trace small gravel.		500	
							24			498	
							26			496	
							28	Yellowish brown (10YR5/4) with 5% dark yellowish brown (10YR4/6) and 5% gray (N6/1) mottles, moist, hard, SILT with little clay, few very fine-grained sand, and trace small gravel.		494	
							30			492	
							32			490	
							34			488	
							▼ 36	Brown (10YR5/3) with 5% gray (N6/1) mottles, moist, hard, SILT with little clay, few very fine-grained sand, and trace small gravel.		486	
							38			484	
							40	Brown (10YR5/3), wet, very dense, silty, very fine- to medium-grained SAND with trace small gravel.		482	

NOTE(S): APW10 installed in borehole.
Lithology, sample, and testing data can be found on APW-4 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/27/2015
Finish: 10/27/2015
WEATHER: Cool, rainy, lo-50s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: APW10a
Well ID: APW10
Surface Elev: 521.98 ft. MSL
Completion: 45.94 ft. BGS
Station: 5,371.32N
11,541.23E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 25, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 36.00 - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							42	Brown (10YR5/3), wet, very dense, silty, very fine- to medium-grained SAND with trace small gravel. *[Continued from previous page]*		480	
							44			478	

End of boring = 45.94 feet

NOTE(S): APW10 installed in borehole.
Lithology, sample, and testing data can be found on APW-4 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/9/2015
Finish: 11/10/2015
WEATHER: Sunny, mild, lo-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G06D
Well ID: G06D
Surface Elev: 529.69 ft. MSL
Completion: 96.00 ft. BGS
Station: 5,328.80N
4,925.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % Recovery	SAMPLE Type	TESTING Blows / 6 in N - Value RQD	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
1	0/60 0%	BD					2	Blind drill - see G106 boring log for lithology, sample, and testing data		528	
							4			526	
							6			524	
2	0/60 0%	BD					8			522	
							10			520	
							12			518	
3	0/60 0%	BD					14			516	
							16			514	
							18			512	
4	0/60 0%	BD					20			510	

NOTE(S): G06D installed in borehole.
Lithology, sample, and testing data can be found on G106 Field Boring Log.

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/9/2015
Finish: 11/10/2015
WEATHER: Sunny, mild, lo-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G06D
Well ID: G06D
Surface Elev: 529.69 ft. MSL
Completion: 96.00 ft. BGS
Station: 5,328.80N
4,925.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) *% Recovery*	Type	TESTING *Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
	0/60 *0%*	BD					22			508	
							24			506	
5											
							26			504	
	0/60 *0%*	BD					28	Blind drill - see G106 boring log for lithology, sample, and testing data *[Continued from previous page]*		502	
6											
							30			500	
	0/60 *0%*	BD					32			498	
							34			496	
7											
	0/12 *0%*	BD									
8							36	Gray (10YR5/1), moist, stiff, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel.		494	
9A	24/24 *100%*	SS	*3-8* *12-15* N=20	13		*3.75*					
							38	Gray (10YR5/1), wet, loose, very fine- to medium-grained SAND.		492	
10A	14/24 *58%*	SS	*6-11* *19-22* N=30	14		*4.00*		Gray (10YR5/1), moist, stiff, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel.			
							40			490	

NOTE(S): G06D installed in borehole.
Lithology, sample, and testing data can be found on G106 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/9/2015
Finish: 11/10/2015
WEATHER: Sunny, mild, lo-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G06D
Well ID: G06D
Surface Elev: 529.69 ft. MSL
Completion: 96.00 ft. BGS
Station: 5,328.80N
4,925.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
11A	24/24 100%	ss	3-7 13-16 N=20	12		4.50	42	Gray (10YR5/1), moist, hard, CLAY with some silt, few very fine- to medium-grained sand, and trace small gravel.		488	
12A	24/24 100%	ss	3-7 11-12 N=18	13		4.50	44			486	
13A	24/24 100%	ss	6-8 12-14 N=20	14		4.50	46			484	
14A	3/24 13%	ss	13-14 16-20 N=30	13			48	Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments.		482	
15A	23/24 96%	ss	3-7 11-14 N=18	13		4.50	50			480	
16A	24/24 100%	ss	5-9 11-15 N=20	15		4.00	52			478	
17A	21/24 88%	ss	10-14 12-15 N=26	13		3.75	54			476	
18A	23/24 96%	ss	4-7 10-14 N=17	14		3.25	56	Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small to medium gravel, trace wood fragments.		474	
19A	24/24 100%	ss	2-4 9-12 N=13	15		3.25	58			472	
20A	24/24 100%	ss	3-7 10-14 N=17	13		3.50	60			470	

NOTE(S): G06D installed in borehole.
Lithology, sample, and testing data can be found on G106 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/9/2015
Finish: 11/10/2015
WEATHER: Sunny, mild, lo-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G06D
Well ID: G06D
Surface Elev: 529.69 ft. MSL
Completion: 96.00 ft. BGS
Station: 5,328.80N
4,925.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
21A	24/24 100%	ss	4-8 11-16 N=19	13		4.25		Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small to medium gravel, trace wood fragments. *[Continued from previous page]*			
							62			468	
22A	24/24 100%	ss	2-6 10-14 N=16	14		3.75		Gray (10YR5/1), moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small to medium gravel, trace wood fragments.			
							64			466	
23A	24/24 100%	ss	6-10 16-21 N=26	13		4.50		Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small to medium gravel, trace wood fragments.			
							66			464	
24A	24/24 100%	ss	4-8 11-14 N=19	13		4.50					
							68			462	
25A	24/24 100%	ss	2-6 8-9 N=14	15		3.60		Gray (10YR5/1), moist, stiff, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments.			
							70			460	
26A	24/24 100%	ss	1-4 8-9 N=12	17		2.75					
							72			458	
27A	24/24 100%	ss	woh-4 5-8 N=9	18		2.25					
							74			456	
28A	24/24 100%	ss	woh-3 5-8 N=8	17		1.50		Gray (10YR5/1), moist, medium, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments.			
							76			454	
29A	24/24 100%	ss	wor-1 5-7 N=6	18		1.50					
							78			452	
30A	24/24 100%	ss	1-4 5-8 N=9	19		1.00		Gray (10YR5/1), moist, soft, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments.			
							80			450	

NOTE(S): G06D installed in borehole.
Lithology, sample, and testing data can be found on G106 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 11/9/2015
Finish: 11/10/2015
WEATHER: Sunny, mild, lo-60s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" HSA, split spoon sampler
FIELD STAFF: **Driller:** J. Gates
Helper: C. Clines
Eng/Geo: R. Hasenyager

BOREHOLE ID: G06D
Well ID: G06D
Surface Elev: 529.69 ft. MSL
Completion: 96.00 ft. BGS
Station: 5,328.80N
4,925.99E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows / 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
31A	24/24 100%	ss	woh-3 5-8 N=8	19		0.75	82	Gray (10YR5/1), moist, soft, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small gravel, trace wood fragments. *[Continued from previous page]*		448	
32A	24/24 100%	ss	1-4 6-8 N=10	18		1.25	84			446	
33A	24/24 100%	ss	woh-4 6-8 N=10	19		1.00	86			444	
34A	24/24 100%	ss	woh-4 9-10 N=13	16		1.00		Gray (10YR5/1), moist, dense, SILT and very fine-grained SAND with trace very coarse-grained sand.			
34B				18			88	Gray (10YR5/1), moist, soft, CLAY with some silt, little very fine- to coarse-grained sand, and trace small gravel, trace wood fragments.		442	
35A	24/24 100%	ss	4-9 7-8 N=16	19		1.25	90			440	
36A	24/24 100%	ss	woh-2 5-6 N=7	20		0.75	92			438	
37A	24/24 100%	ss	woh-2 5-7 N=7	19		0.75	94	Gray (10YR5/1), moist, soft, CLAY with some silt, trace very fine- to coarse-grained sand, and trace small gravel, trace wood fragments.		436	
38A	24/24 100%	ss	woh-3 5-8 N=8	19		0.75	96			434	

End of boring = 96.0 feet

NOTE(S): G06D installed in borehole.
Lithology, sample, and testing data can be found on G106 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

CIPS NEWTON POWER STATION	BORING G-106	SHEET 1 of 1
DATE STARTED 8/1/90	DATE COMPLETED 8/1/90	LOGGED BY RAB	SURFACE EL. 529.0
DRILLING CONTRACTOR: BROTCKE ENG.	DRILL METHOD: H.S. AUGER	

Depth (ft)	Graphic Log	N-Value	SOIL/ROCK DESCRIPTION
0		22	Brn. clayey SILT, tr. roots, blocky, dry.
		20	Brn. sandy silty CLAY, tr. pebbles, sl. moist, blocky.
		18	
		33	Mottled gray & brn. silty sandy CLAY, tr. pebbles, moist.
10		50	Brn. sandy CLAY, tr. pebbles, vert. med. sand filled fract., so. mn & iron oxid., moist.
		72	
		50	Brn. coarse SAND.
		80	
		43	Gray brn. sandy silty CLAY, tr. pebbles, coal frag., oxid. vert. fract., hard.
20		59	
		45	
		9	Gray coarse – v. coarse SAND.
			Gray sandy silty CLAY, tr. pebbles, moist.
		63	
30			Coarse – v. coarse SAND grading downward to gravel.
		39	
		33	Gray sandy silty CLAY, tr. pebbles, unweathered.
			End of Boring = 36.0'
40			

VAPOR CONCENTRATION (ppm): 10^0 10^1 10^2 10^3

COMMENTS: ▽

Depth (ft): 0, 10, 20, 30, 40

SOIL/ROCK BORING DATA

HANSON ENGINEERS INCORPORATED

PAC REVIEWED 11-19-90 DATE

RKC APPROVED 11-19-90 DATE

CIPS
NEWTON POWER STATION
NEWTON, ILLINOIS

JOB NO. 89S5008A

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description
							0	Grayish brown (10YR5/2), moist, very soft, silty CLAY, trace roots.
							2	Grayish brown (10YR5/2) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY, slight trace roots.
							4	Brown (10YR5/3) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.
							6	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.
							8	Gray (10YR5/1) with 40% dark yellowish brown (10YR4/6) mottles, very moist, soft, silty CLAY with trace sand and slight trace gravel.
							10	Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, soft, wet, sandy CLAY with slight trace gravel.
							11	Yellowish brown (10YR5/4) with 10% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.
							12	Dark gray (10YR4/1) with 30% brown (10YR4/3) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							14	Dark gray (10YR4/1) with 20% dark grayish brown (10YR4/2) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							16	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							18	
							20	

Borehole Detail	Elevation ft. MSL	Remarks
	542	
	540	
	538	
	536	
	534	
	532	
	530	
	528	
	526	
	524	

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description

[Continued from previous page]

Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.

Dark gray (10YR4/1), moist, firm, silty CLAY with slight trace sand and gravel.

Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.

Dark gray (10YR4/1), slightly moist, firm, clayey SILT with trace sand and slight trace gravel.

Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.

Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.

Borehole Detail

Elevation ft. MSL: 522, 520, 518, 516, 514, 512, 510, 508, 506, 504

Remarks

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							42	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*		502	
							44	Dark gray (10YR4/1), slightly moist, firm, SILT with slight trace sand.		500	
							46			498	
							48	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		496	
							50			494	
							52	Olive gray (5Y4/2), slightly moist, firm, silty CLAY with slight trace sand and gravel.		492	
							54	Dark greenish gray (10Y4/1) with 20% greenish gray (10Y6/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.		490	
							56	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, hard, silty CLAY with slight trace sand and gravel.		488	
							58	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		486	
							60			484	

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N-Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
13A	24/24 100%	SS	8-13 17-17 N=30	10.1		12.36 Sh	22	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel. *[Continued from previous page]*		522	
14A	18/18 100%	SS	7-11 14 N=25	10.1		10.47 Sh				520	
15A	18/18 100%	SS	7-11 13 N=24	9.9		9.31 Sh	24			518	
16A	24/24 100%	SS	5-7 12-14 N=19	11.4		11.06 Sh	26	Dark gray (10YR4/1), moist, firm, silty CLAY with slight trace sand and gravel.			
16B				16.3		2.13 BSh		Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		516	
17A	18/18 100%	SS	4-6 11 N=17	11.2		6.79 Sh	28	Dark gray (10YR4/1), slightly moist, firm, clayey SILT with trace sand and slight trace gravel.		514	
18A	18/18 100%	SS	5-9 16 N=25	11.4		9.70 Sh	30				
19A	24/24 100%	SS	4-8 14-19 N=22	10.4		10.47 Sh				512	
20A	18/18 100%	SS	6-13 17 N=30	11.4			32			510	
21A	18/18 100%	SS	7-13 19 N=32	11.3		10.28 Sh	34	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		508	
22A	24/24 100%	SS	7-12 19-22 N=31	10.3		11.44 Sh	36			506	
23A	18/18 100%	SS	6-12 19 N=31	11.5		10.86 Sh	38	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		504	
24A	18/18 100%	SS	7-11 19 N=30	12.7		5.24 Sh	40				

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description

Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.
[Continued from previous page]
Light olive gray (5Y5/2), very moist, very soft, sandy CLAY with slight trace gravel.

62
Light olive gray (5Y5/2) with 10% greenish gray (5GY5/1) mottles, slightly moist, firm, silty CLAY with trace sand and slight trace gravel.

64
66
Greenish gray (10Y5/1) with 10% olive gray (5Y4/2) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.

68
Greenish gray (10G5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, dense, SILT with slight trace sand.

70
Dark greenish gray (10GY4/1), slightly moist, very hard, clayey SILT with trace sand and slight trace gravel.

72
Dark greenish gray (10GY4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.

74
Dark greenish gray (10GY4/1), wet, very dense, silty, coarse-grained SAND and gravel.

76
Dark gray (10YR4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.

Borehole Detail	Elevation ft. MSL	Remarks
	482	
	480	
	478	
	476	
	474	
	472	
	470	
	468	

End of boring = 77.06 feet

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

Number	Recov / Total (in) % Recovery	Type	Blows/ 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL
								Grayish brown (10YR5/2), moist, very soft, silty CLAY, trace roots.	
1A	13/18 72%	SS	woh-2 3 N=5	25.8					542
								Grayish brown (10YR5/2) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY, slight trace roots.	
2A	17/18 94%	SS	2-3 4 N=7	22.0		3.88 Sh	2		540
3A	17/18 94%	SS	2-4 4 N=8	15.7		1.90 Sh	4	Brown (10YR5/3) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.	538
4A	24/24 100%	SS	woh-1 2-3 N=3	20.5		1.78 BSh	6		536
5A	18/18 100%	SS	1-1 2 N=3	22.7		1.40 Sh	8	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.	534
6A	24/24 100%	SS	1-2 3-3 N=5	18.3		1.27 Sh		Gray (10YR5/1) with 40% dark yellowish brown (10YR4/6) mottles, very moist, soft, silty CLAY with trace sand and slight trace gravel.	
7-1							▼ 10		
7-2	23/24 96%	SH		19.9				Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, soft, wet, sandy CLAY with slight trace gravel.	532
7-3				15.0				Yellowish brown (10YR5/4) with 10% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.	
7-4				19.5			12		
8A	18/18 100%	SS	8-13 17 N=30	10.2		8.92 Sh		Dark gray (10YR4/1) with 30% brown (10YR4/3) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.	530
9A	18/18 100%	SS	6-12 17 N=29	9.7		5.62 Sh	14	Dark gray (10YR4/1) with 20% dark grayish brown (10YR4/2) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.	528
10A	24/24 100%	SS	7-14 20-20 N=34	9.0		7.18 Sh	16		526
11A	18/18 100%	SS	6-14 15 N=29	8.5		9.89 Sh	18	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.	524
12A	18/18 100%	SS	5-12 14 N=26	10.2		11.25 Sh	20		

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
25A	24/24 100%	SS	8-12 22-26 N=34	11.5		10.47 Sh	42	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*		502	
26A	18/18 100%	SS	7-12 18 N=30	11.7		7.76 Sh				500	
27A	18/18	SS	7-15 18 N=33	13.1			44	Dark gray (10YR4/1), slightly moist, firm, SILT with slight trace sand.			
27B	100%			10.9		11.64 Sh				498	
28A	24/24 100%	SS	8-10 16-21 N=26	13.7			46			496	
29A	18/18 100%	SS	7-10 16 N=26	14.5		5.82 Sh	48	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		494	
30A	18/18 100%	SS	4-9 13 N=22	14.1		2.52 B					
31-1							50				
31-2	19/24 79%	SH		14.0						492	
31-3											
31-4							52	Olive gray (5Y4/2), slightly moist, firm, silty CLAY with slight trace sand and gravel.			
32A	18/18	SS	7-13 19 N=32	12.9		10.28 Sh					
32B	100%			12.5		8.92 Sh		Dark greenish gray (10Y4/1) with 20% greenish gray (10Y6/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.		490	
33A	18/18 100%	SS	5-10 16 N=26	14.9		2.13 BSh	54				
33B				14.6		6.59 Sh				488	
34A	24/24 100%	SS	6-10 16-19 N=26	15.5		3.88 Sh	56	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, hard, silty CLAY with slight trace sand and gravel.			
35A	18/18 100%	SS	2-7 14 N=21	18.2		1.94 BSh				486	
36A	18/18 100%	SS	3-7 14 N=21	13.8		5.04 BSh	58	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		484	
							60				

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
37-1				16.5		1.75 BSh		Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.			
37-2	19/24 79%	SH		12.7		3.50 None		*[Continued from previous page]* Light olive gray (5Y5/2), very moist, very soft, sandy CLAY with slight trace gravel.		482	
37-3				15.0							
37-4							62				
38A	18/18 100%	SS	8-13 15 N=28	14.5		3.10 B		Light olive gray (5Y5/2) with 10% greenish gray (5GY5/1) mottles, slightly moist, firm, silty CLAY with trace sand and slight trace gravel.		480	
39A	18/18 100%	SS	6-9 15 N=24	12.8		5.04 BSh	64			478	
40A	24/24 100%	SS	4-9 13-15 N=22	13.6		5.43 Sh	66	Greenish gray (10Y5/1) with 10% olive gray (5Y4/2) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		476	
41A	18/18 100%	SS	12-13 14 N=27	13.2		4.07 BSh	68			474	
42A	16/17 94%	SS	6-32 28/5"	15.2				Greenish gray (10G5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, dense, SILT with slight trace sand.			
43A	3/3 100%	SS	60/3"	15.4			70	Dark greenish gray (10GY4/1), slightly moist, very hard, clayey SILT with trace sand and slight trace gravel.		472	
44A	13/14 93%	SS	28-47 15/2"	16.7			72	Dark greenish gray (10GY4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.		470	
45A	16/17 94%	SS	31-33 27/5"	13.6			74	Dark greenish gray (10GY4/1), wet, very dense, silty, coarse-grained SAND and gravel.		468	
46A	12/15 80%	SS	20-38 22/3"	15.3			76	Dark gray (10YR4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.		466	
47A	18/18 100%	SS	3-11 17 N=28	13.9		5.62 B	78	Dark gray (N4/1), moist, firm, silty CLAY with slight trace sand and gravel.		464	
48A	17/18 94%	SS	5-10 14 N=24	14.9		5.24 BSh	80	Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.			

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
49A	24/24 100%	SS	5-7 12-14 N=19	15.5		5.04 BSh	82			462	
50A	18/18 100%	SS	4-8 10 N=18	15.4		5.24 BSh		Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*		460	
51A	18/18 100%	SS	4-9 10 N=19	15.7		5.04 B	84			458	
52-1 52-2 52-3	18/18 100%	SH		14.3			86			456	
53A	24/24 100%	SS	9-12 21-26 N=33	13.9		6.21 B	88	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		454	
54A	18/18 100%	SS	6-11 17 N=28	13.8		6.79 Sh	90			452	
55A	24/24 100%	SS	6-12 15-24 N=27	13.6		7.37 Sh	92	Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.		450	
56A	18/18 100%	SS	5-8 12 N=20	13.9		3.88 Sh	94			448	
57A	18/18 100%	SS	5-12 19 N=31	13.4		6.21 Sh	96	Dark gray (N4/1), very moist, dense, silty, fine- to coarse-grained SAND with slight trace gravel.		446	
58A 58B	24/24 100%	SS	4-18 20-22 N=38	12.5 13.4		5.82 BSh		Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			
59A 59B	16/16 100%	SS	16-33 27/4"	16.0 15.7		3.69 Sh	98	Dark gray (N4/1), wet, dense, silty, fine- to medium-grained SAND with slight trace gravel. Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel. Dark gray (N4/1), wet, dense, silty, very fine- to medium-grained SAND with slight trace gravel.		444	
60A 60B	18/18 100%	SS	16-21 15 N=36	12.6			100	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
61A	24/24 100%	SS	7-12 18-25 N=30	13.4		6.59 Sh		Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.		442	
							102	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			
62A	17/18 94%	SS	12-18 22 N=40	15.3		3.88 BSh				440	

EOB = 103.5 feet bgs

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

CIPS NEWTON POWER STATION	BORING G-106	SHEET 1 of 1
DATE STARTED 8/1/90	DATE COMPLETED 8/1/90	LOGGED BY RAB	SURFACE EL. 529.0
DRILLING CONTRACTOR: BROTCKE ENG.	DRILL METHOD: H.S. AUGER

Depth (ft)	Graphic Log	N-Value	SOIL/ROCK DESCRIPTION
0		22	Brn. clayey SILT, tr. roots, blocky, dry.
		20	Brn. sandy silty CLAY, tr. pebbles, sl. moist, blocky.
		18	
		33	Mottled gray & brn. silty sandy CLAY, tr. pebbles, moist.
10		50	Brn. sandy CLAY, tr. pebbles, vert. med. sand filled fract., so. mn & iron oxid., moist.
		72	
		50	Brn. coarse SAND.
		80	
		43	Gray brn. sandy silty CLAY, tr. pebbles, coal frag., oxid. vert. fract., hard.
20		59	
		45	
		9	Gray coarse – v. coarse SAND.
			Gray sandy silty CLAY, tr. pebbles, moist.
		63	
30			Coarse – v. coarse SAND grading downward to gravel.
		38	
		33	Gray sandy silty CLAY, tr. pebbles, unweathered.
			End of Boring = 36.0'
40			

VAPOR CONCENTRATION (ppm): 10^0 10^1 10^2 10^3

COMMENTS: ▽

Depth (ft): 0, 10, 20, 30, 40

SOIL/ROCK BORING DATA

HANSON ENGINEERS INCORPORATED

PAC REVIEWED 11-19-90 DATE

RC APPROVED 11-19-90 DATE

CIPS
NEWTON POWER STATION
NEWTON, ILLINOIS

JOB NO. 89S5008A

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: _____ Date Started: 10–16–96 Completed: 10–16–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	DVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Fill Material: Drilled through built drilling pad	1	5.0' CME continuous sampler	0		NA	NA			0
5		2		0		NA	NA			5
10	10.0									10
	Brown–gray silty SAND (SM) w/clay & trace pebbles	3		30		NA	moist			
	12.5					0.25				
	Brown–clayey SILT (ML) w/ sand & pebbles					NA	wet			
15	16.5									15
	Gray silty CLAY (ML–CL) w/pebbles	4		30		NA	moist	Very weathered		
	18.0									
	Brown coarse SAND (SM) w/silt					NA	moist			
20	20.8									20
	Gray silty CLAY (ML–CL) w/pebbles	5		60		4.5+	dry			
						4.5+				
25						4.5+				25
		6		100		4.5+	moist			
						4.5+				
30						4.5+	moist			30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: Date Started: 10–8–96 Completed: 10–8–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	Gray silty CLAY (ML–CL) w/pebbles 31.3					4.5+				30
	Brownish Gray CLAY (CH) w/silt 32.3					4.5+	moist			
	Gray silty CLAY (ML–CL) w/pebbles	7	5.0' CME continuous sampler	100		3.0	wet			
						4.5+	moist			
35	36.0					4.5+				35
	Gray silty SAND (SM) 36.5					NA	wet			
		8		100		4.5+				
						4.5+	moist			
40	Gray silty CLAY (ML–CL) w/pebbles					4.5+				40
		9		90		4.5+	moist			
						4.5+				
						4.5+	moist			
45						4.5+				45
		10		100		3.75	moist			
						4.5+				
						4.5+	moist			
50						4.5+				50
		11		100		4.5+	moist			
						4.5+				
						4.5+	moist			
55						4.5+				55
		12		100		4.5+	moist			
						4.5+				
60						4.5+	moist			60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

Sheet 2 of 3

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2718

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: _____ Date Started: 10–16–96 Completed: 10–16–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles 61.4					4.5+				60
	Gray GRAVEL (GM) w/silt 62.0					4.5+	wet			
		13	5.0' CME continuous sampler	100		4.5+				
	Gray silty CLAY (ML–CL) w/pebbles					4.5+	wet			
65						4.5+				65
						4.5+	wet			
		14		100		4.5+				
						4.5+	wet			
	Gray fine sandy SILT (SM) 69.5					NA		Blind drill: Augers plugged w/SILT–SAND		
70	End Of Boring @70.0'									70
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

Sheet 3 of 3

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: _____ Date Started: 10-15-96 Completed: 10-15-96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Tan, mottled reddish clayey SILT (MH)	1	5.0' CME continuous sampler	75		4.5+ 4.5+ 4.0 2.75	dry moist	Very soft		0
3.5										
5	Gray, mottled brown silty CLAY (MH-CH) w/trace coarse sand & pebbles	2		100		1.75 1.0 0.75 1.75 2.5	moist moist			5
10		3		60		NA NA 2.5 2.75	dry dry			10
11.5										
15	Brown silty clay (CL-ML) w/coarse sand & pebbles	4		70		NA NA NA NA	dry dry			15
20		5		70		4.0 4.0 NA 4.5+	dry dry			20
21.5										
23.0	Brown SAND (SM) w/silt, poorly sorted									
25	Gray, mottled brown silty CLAY (CL) w/pebbles	6		95		4.5+ 4.5+ 4.25 4.5 4.5+	moist dry			25
28.0										
30	Gray silty CLAY (CL-ML) w/pebbles									30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

Sheet 1 of 3

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: Date Started: 10–15–96 Completed: 10–15–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	Gray silty CLAY (ML–CL) w/pebbles	7	5.0' CME continuous sampler	100		4.5+ 4.5+ 4.5+ 4.5	dry dry			30
	33.2 Gray fine grain SAND (SM) w/silt 34.5									
35	Brownish gray silty CLAY (CL) w/pebbles 36.5	8		100		4.0 4.5 4.5+ 4.5	dry dry			35
40	Gray silty CLAY (ML–CL) w/pebbles	9		100		4.5+ 4.5+ 4.5+ 4.5+	dry dry			40
45		10		100		4.5+ 4.5+ 4.5+ 4.5+	dry dry			45
50		11		100		4.5+ 4.5+ 4.5+ 4.5+	moist moist			50
55	57.5 Gray fine SAND (SM) w/silt 58.0	12		100		4.5+ 4.5+ 4.5+ 4.5+	moist moist			55
60	Gray silty CLAY (ML–CL) w/pebbles									60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: _____ Date Started: 10–15–96 Completed: 10–15–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles	13	5.0' CME continuous sampler	100		4.5+ 4.5+ 4.0 4.5 4.5+	moist moist			60
65	65.6									65
	Gray fine SAND (SM) w/silt 66.4	14		80		3.0 4.0 NA	wet wet			
	Gray fine SAND–SILT (SM) w/trace gravel									
70	70.0									70
	Blind Drill: Auger plugged & redrilled to 73.0'									
	End Of Boring @73.0'									
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

Sheet 3 of 3

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Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 27 T. 6N R. 8E

~~UTM (or State~~ Plant ~~Plane)~~ Coord. N. (X) 6208.18 E. (Y) 4417.18

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: CME 550

County: Jasper

Boring No. B208 Monitoring Well No. G208

Surface Elevation: 533.06 Completion Depth: 95'

Auger Depth: 95' Rotary Depth: NA

Date: Start: 10/11/11 Finish: 10/13/11

Personnel: G - Ken Miller; D - Todd Skinner; H - Justin Lance; H - Scott Walsh

Elev.	Description of Material	Graphic Log	Depth In Feet	Sample No.	Sample Type	Sample Recovery (X)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	REMARKS
	Clayey fill									
	Brown mottled gray silty clay (ML-CL); Trace sand & gravel; Moist; Firm			1	5' CS	100 %				
528.06			5	2	5' CS	100 %				
523.06			10	3	5' CS	100 %				
	Gray silty clay (ML-CL); Trace sand & gravel; Dry; Very firm to hard		15	4	5' CS	100 %				
518.06										
513.06	Brown silty sand (SM) to sand (SW); Some gravel; Moist		20	5	5' CS	100 %				
	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Moist; Very firm to hard		25	6	5' CS	100 %				
508.06										
503.06			30	7	5' CS	60 %				
			35	8	5' CS	80 %				Fe staining
498.06										
493.06			40	9	2' SS	100 %				Drove split spoon to remove obstruction
	Gray fine sand (SP); Wet			10	5' CS	30 %				
488.06			45	11	5' CS	100 %				

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Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 27 T. 6N R. 8E

~~UTM (or State~~ Plant ~~Plane)~~ Coord. N. (X) 6208.18 E. (Y) 4417.18

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: CME 550

County: Jasper

Boring No. B208 Monitoring Well No. G208

Surface Elevation: 533.06 Completion Depth: 95'

Auger Depth: 95' Rotary Depth: NA

Date: Start: 10/11/11 Finish: 10/13/11

Personnel

G - Ken Miller
D - Todd Skinner
H - Justin Lance
H - Scott Walsh

Elev.	Description of Material	Graphic Log	Depth In Feet	SAMPLES: Sample No.	Sample Type	Sample Recovery (%)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	REMARKS
	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Moist; Very firm to hard			12	5' CS	100 %				
478.06			55	13	5' CS	100 %				
473.06			60	14	5' CS	60 %				
468.06			65	15	5' CS	100 %				
463.06	*Softer		70	16	2' SS	100 %				Drove split spoon to remove obstruction
				17	5' CS	100 %				
458.06			75	18	5' CS	100 %				
453.06			80	19	5' CS	100 %				
448.06	Large wood pieces & plant debris		85	20	5' CS	100 %				
443.06			90	21	5' CS	100 %				
438.06	EOB @ 95' BGS		95							

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RAPPS

BORING LOG

ENGINEERING&APPLIED SCIENCE
821 S. DURKIN DRIVE-SPRINGFIELD IL 62704 - (217) 787-2118

Client: CIPS Project: Newton LF Monitoring Wells Boring No: G217
Drilling Firm: PSI Drilling Method: 4¼ HSA Surface Elev: 535.67
Logged By: MSS Checked By: --- Date Started: 8/26/97 Completed: 8/26/97

DEPTH	Material Description (Unified)	Tube No.	Type	% Rec.	Pocket Pen Qu tsf	% Moist	Comments	DEPTH
	Brown silty CLAY (CL): Fill Material 3.0	1	5 Foot Continuous Sampler	100	4.0 2.0	dry		
-5-	Gray-Brown silty CLAY (CL) w/coarse sand 8.2	2		100	3.0 2.5 2.0 2.0	mst	Gray, medium SAND (SM) w/silt from 8.2 to 8.6	-5-
	see comments 8.6				1.75			-10-
-10-	Gray, mottled brown CLAY (CH-CL) w/silt 14.0	3		100	2.5 3.0 4.5+ 4.5+	mst		
-15-	Brown silty CLAY (CL) w/pebbles 15.0	4		100	4.0 4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry	very weathered	-15-
-20-	Gray, mottled Brown silty CLAY (CL) w/ pebbles	5		100	4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry	End Boring at 25.0	-20-
-25-								-25-

Water Level NA at NA Hrs.
Water Level NA at NA Hrs.

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Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 27 T. 6N R. 8E

~~UTM (or State~~ Plant ~~Plane)~~ Coord. N. (X) 5322.24 E. (Y) 3989.08

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: CME 550

County: Jasper

Boring No. B222 Monitoring Well No. G222

Surface Elevation: 532.12 Completion Depth: 80'

Auger Depth: 80' Rotary Depth: NA

Date: Start: 10/24/11 Finish: 10/25/11

Elev.	Description of Material	Graphic Log	Depth In Feet	SAMPLES: Sample No.	Sample Type	Sample Recovery (X)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	Personnel / REMARKS
										G - Ken Miller D - Todd Skinner H - Justin Lance H - Tim Skinner
527.12	Blind drill to 50'		5							
522.12			10							
517.12			15							
512.12			20							
507.12			25							
502.12			30							
497.12			35							
492.12			40							
487.12			45							

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 27 T. 6N R. 8E

~~UTM (or State~~ Plant ~~Plane)~~ Coord. N. (X) 5322.24 E. (Y) 3989.08

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: CME 550

County: Jasper

Boring No. B222 Monitoring Well No. G222

Surface Elevation: 532.12 Completion Depth: 80'

Auger Depth: 80' Rotary Depth: NA

Date: Start: 10/24/11 Finish: 10/25/11

Personnel

G - Ken Miller
D - Todd Skinner
H - Justin Lance
H - Tim Skinner

Elev.	Description of Material	Graphic Log	Depth In Feet	SAMPLES: Sample No.	Sample Type	Sample Recovery (X)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	REMARKS
	Dk. gray to black silt (ML); Thinly laminated; Fissile; Hard			1	5' CS	100 %				
477.12	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Moist; Firm to hard		55	2	5' CS	100 %				
472.12			60	3	5' CS	100 %				
467.12	Coarse sand (SP) w/ gravel; Wet		65	4	5' CS	30 %				Poor recovery
462.12	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Moist; Firm to hard		70	5	2' SS	100 %				Drove split spoon to remove obstruction
				6	5' CS	100 %				
457.12			75	7	5' CS	100 %				
452.12	EOB @ 80' BGS		80							

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Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 26 T. 6N R. 8E

~~UTM (or State~~ Plant ~~Plane)~~ Coord. N. (X) 6976.66 E. (Y) 6067.30

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: Diedrich D-50

County: Jasper

Boring No. B224 Monitoring Well No. G224

Surface Elevation: 532.26 Completion Depth: 74'

Auger Depth: 74' Rotary Depth: NA

Date: Start: 10/04/11 Finish: 10/04/11

Personnel: G - Ken Miller; D - Tim Fuhl; H - Eric Sievers; H - Clifford Ohman

Elev.	Description of Material	Graphic Log	Depth In Feet	Sample No.	Sample Type	Sample Recovery (%)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	REMARKS
	Brown silty clay (ML-CL); Moist; Firm			1	5' CS	10 %				
527.26			5							
	Reddish brown mottled gray silty clay (ML-CL); Trace sand & gravel; Moist; Firm			2	5' CS	90 %				
522.26			10							
	*Softer, less mottling			3	5' CS	10 %				
517.26			15							
	Dark gray silty clay (ML-CL) w/ sand; Moist to wet; Soft			4	5' CS	60 %				
	Medium to coarse sand (SP); Wet									Plant debris
512.26	Brown mottled gray silty clay (ML-CL) w/ sand & gravel; Dry; Hard		20	5	5' CS	100 %				
	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Dry to moist; Hard									
507.26			25	6	5' CS	60 %				
502.26			30							
				7	5' CS	0 %				
497.26			35							
				8	5' CS	0 %				
492.26	No recovery		40							Hard drilling
				9	5' CS	0 %				
487.26			45							
				10	2' SS	0 %				Drove split spoons to remove possible obstruction
				11	2' SS	0 %				
				12	2' SS	100 %				

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Illinois Environmental Protection Agency

Field Boring Log

Site ID No. 0798085001 Federal ID No. _____

Site Name: Newton Power Station Landfill Phase II

Quadrangle: Latona Sec. 26 T. 6N R. 8E

~~UTM (or State Plane)~~ Plant Coord. N. (X) 6976.66 E. (Y) 6067.30

Latitude: ____ ____ ____ Longitude: ____ ____ ____

Boring Location: South side of Area 3

Drilling Equipment: CME 550

County: Jasper

Boring No. B224 Monitoring Well No. G224

Surface Elevation: 532.26 Completion Depth: 74'

Auger Depth: 74' Rotary Depth: NA

Date: Start: 10/04/11 Finish: 10/04/11

Personnel

G - Ken Miller
D - Tim Fuhl
H - Eric Sievers
H - Clifford Ohman

Elev.	Description of Material	Graphic Log	Depth In Feet	SAMPLES: Sample No.	Sample Type	Sample Recovery (X)	Penetrometer	N Values (Blow Counts)	OVA or HNU Readings	REMARKS
	Med. gray silty clay (ML-CL) w/ gravel; Trace sand; Moist; Very firm to hard		55	13	5' CS	100 %				
477.26				14	5' CS	100 %				
472.26			60	15	5' CS	100 %				
467.26	Gray silt (ML), silty sand (SM) and sand (SP); Wet		65	16	5' CS	60 %				Large wood pieces
	*w/ gravel		70	17	5' CS	0 %				Trace sand & gravel in tube; Harder drilling @ 72.5'
462.26	No recovery									
457.26	EOB @ 74' BGS		75							

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HALEY ALDRICH

TEST BORING REPORT

Boring No. HAB-N-1

Project Ash Pond, Newton, Illinois
Client Dynegy
Contractor CEC & Strata

File No. 129673-005
Sheet No. 1 of 1
Start 25 April 2017
Finish 26 April 2017
Driller J. Cooley
H&A Rep. J. Gerger
Elevation 535.0
Datum
Location See Plan

	Casing	Sampler	Barrel	Drilling Equipment and Procedures
Type		SS	--	Rig Make & Model: Diedrich D-25
Inside Diameter (in.)		1.375	--	Bit Type: Cutting Head
Hammer Weight (lb)		140	-	Drill Mud:
Hammer Fall (in.)		30	-	Casing:
				Hoist/Hammer: /
				PID Make & Model: N/A

Depth (ft)	Sampler Blows per 6 in.	Sample No. & Rec. (in.)	Sample Depth (ft)	Stratum Change Elev/Depth (ft)	USCS Symbol	VISUAL-MANUAL IDENTIFICATION AND DESCRIPTION (Density/consistency, color, GROUP NAME, max. particle size†, structure, odor, moisture, optional descriptions GEOLOGIC INTERPRETATION)
40						Water from 0 to 41.5 ft (El. 535)
				493.5		
	WOR WOR WOR WOR	SS1 6	41.5 43.5	41.5		Very loose gray SILT/FLYASH -FILL-
	WOR WOR WOR WOR	SS2 10	43.5 45.5			
45				490.0 45.0	CL	Very soft black CLAY (CL)
	WOR WOR 2 2	SS3 24	45.5 47.5	488.5 46.5	CL	Very soft gray CLAY (CL), with trace roots (very fine small roots)
	2 1 2 3	SS4 24	47.5 49.5	486.7 48.3	CL	Very soft gray and brown mottled silty CLAY (CL), trace sand, moist
50	WOH WOH 1 3	SS5 22	49.5 51.5			
	1 3 3 2	SS6 20	51.5 53.5			Similar to above, except not as soft, trace fine gravel
	2 5 5 8	SS7 21	53.5 55.5			
55				480.0 55.0	SP-SC	Medium dense brown coarse SAND (SP-SC), moist
	2 1 1 1	SS8 21	55.5 57.5			
				477.5		Similar to above, except gray
				57.5		BOTTOM OF EXPLORATION 57.5 FT
60						

Water Level Data

Date	Time	Elapsed Time (hr.)	Depth (ft) to: Bottom of Casing	Bottom of Hole	Water

Sample ID
O - Open End Rod
T - Thin Wall Tube
U - Undisturbed Sample
S - Split Spoon Sample

Well Diagram
Riser Pipe
Screen
Filter Sand
Cuttings
Grout
Concrete
Bentonite Seal

Summary
Overburden (ft) 16.0
Rock Cored (ft) 0.0
Samples 8SS

Boring No. HAB-N-1

Field Tests: **Dilatancy**: R - Rapid S - Slow N - None **Toughness**: L - Low M - Medium H - High **Plasticity**: N - Nonplastic L - Low M - Medium H - High **Dry Strength**: N - None L - Low M - Medium H - High V - Very High

†Note: Maximum particle size is determined by direct observation within the limitations of sampler size.

Note: Soil identification based on visual-manual methods of the USCS as practiced by Haley & Aldrich, Inc.

H&A-TEST BORING-07-1 WATER 129673-005_HA-LIB07-1-CLE2.GLB HA-TB+CORE+WELL-07-1.GDT \\HALEYALDRICH.COM\SHARE\POR_COMMON\GINT\OHIO OFFICES\129673-005\129673-005_TB.GPJ 10 May 17

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HALEY ALDRICH

TEST BORING REPORT

Boring No. HAB-N-2

Project Ash Pond, Newton, Illinois
Client Dynegy
Contractor CEC & Strata

File No. 129673-005
Sheet No. 1 of 1
Start 27 April 2017
Finish 27 April 2017
Driller J. Cooley
H&A Rep. J. Gerger
Elevation 535.2 Datum
Location See Plan

	Casing	Sampler	Barrel	Drilling Equipment and Procedures
Type		SS	--	Rig Make & Model: Diedrich D-25
Inside Diameter (in.)		1.375	--	Bit Type: Roller Bit
Hammer Weight (lb)		140	-	Drill Mud:
Hammer Fall (in.)		30	-	Casing:
				Hoist/Hammer: /
				PID Make & Model: N/A

Depth (ft)	Sampler Blows per 6 in.	Sample No. & Rec. (in.)	Sample Depth (ft)	Stratum Change Elev/Depth (ft)	USCS Symbol	VISUAL-MANUAL IDENTIFICATION AND DESCRIPTION (Density/consistency, color, GROUP NAME, max. particle size†, structure, odor, moisture, optional descriptions GEOLOGIC INTERPRETATION)
40						Water from 0 to 41.0 ft (El. 535.2) [2.2 ft on Dynegy water level gauge]
				494.2 41.0		
	WOR WOR WOR WOR	SS1 4	41.0 43.0			Dark gray SILT/ASH, wet -FILL-
	WOR WOR WOR WOR	SS2 4	43.0 45.0			
45	WOR WOR WOR WOR	SS3 12	45.0 47.0			
				488.9 46.3	CL	Very soft black CLAY (CL)
				488.5 46.7	CL	Similar to above, except gray/light gray
	WOR WOR WOR WOR	SS4 15	47.0 49.0	488.2 47.0	CL	Very soft dark gray CLAY (CL), trace sand, moist, organics present
	WOR WOR 1 1	SS5 12	49.0 51.0			
50				485.2 50.0	CL	Dark brown sandy CLAY (CL), trace organics
	WOH 2 3 2	SS6 16	51.0 53.0	484.2 51.0	SP-SC	Brown medium clayey SAND (SP-SC)
				483.2 52.0	SC	Brown clayey SAND (SC)
				482.2 53.0		BOTTOM OF EXPLORATION 53.0 FT
55						
60						

Water Level Data

Date	Time	Elapsed Time (hr.)	Depth (ft) to: Bottom of Casing	Bottom of Hole	Water

Sample ID
O - Open End Rod
T - Thin Wall Tube
U - Undisturbed Sample
S - Split Spoon Sample

Well Diagram
Riser Pipe
Screen
Filter Sand
Cuttings
Grout
Concrete
Bentonite Seal

Summary
Overburden (ft) 12.0
Rock Cored (ft) 0.0
Samples 6SS

Boring No. HAB-N-2

Field Tests: **Dilatancy**: R - Rapid S - Slow N - None **Toughness**: L - Low M - Medium H - High **Plasticity**: N - Nonplastic L - Low M - Medium H - High **Dry Strength**: N - None L - Low M - Medium H - High V - Very High

†Note: Maximum particle size is determined by direct observation within the limitations of sampler size.

Note: Soil identification based on visual-manual methods of the USCS as practiced by Haley & Aldrich, Inc.

H&A-TEST BORING-07-1 WATER 129673-005_HA-LIB07-1-CLE2.GLB HA-TB+CORE+WELL-07-1.GDT \\HALEYALDRICH.COM\SHARE\POR_COMMON\GINT\OHIO OFFICES\129673-005\129673-005_TB.GPJ 10 May 17

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HALEY ALDRICH

TEST BORING REPORT

Boring No. HAB-N-4

Project Ash Pond, Newton, Illinois
Client Dynegy
Contractor CEC & Strata

File No. 129673-005
Sheet No. 1 of 1
Start 27 April 2017
Finish 27 April 2017
Driller J. Cooley
H&A Rep. J. Gerger
Elevation 535.2 Datum
Location See Plan

	Casing	Sampler	Barrel	Drilling Equipment and Procedures
Type		SS	--	Rig Make & Model: Diedrich D-25
Inside Diameter (in.)		1.375	--	Bit Type:
Hammer Weight (lb)		140	-	Drill Mud:
Hammer Fall (in.)		30	-	Casing:
				Hoist/Hammer: /
				PID Make & Model: N/A

Depth (ft)	Sampler Blows per 6 in.	Sample No. & Rec. (in.)	Sample Depth (ft)	Stratum Change Elev/Depth (ft)	USCS Symbol	VISUAL-MANUAL IDENTIFICATION AND DESCRIPTION (Density/consistency, color, GROUP NAME, max. particle size†, structure, odor, moisture, optional descriptions GEOLOGIC INTERPRETATION)
						Water from 0 to 40.5 ft (El. 535.2) [2.2 ft on Dynegy water level gauge]
40				494.7 40.5		
	WOR WOR WOR WOR	SS1 4	40.5 42.5			Dark gray ASH -FILL-
	WOR WOR WOR WOR	SS2 8	42.5 44.5			Similar to above
45	WOR WOR WOR WOR	SS3 19	44.5 46.5			Similar to above, except darker black in color
				488.7		
	WOR WOR WOR WOR	SS4 4	46.5 48.5	46.5 488.2	CL	Soft black CLAY (CL)
				47.0	ML	Gray clayey SILT (ML)
				486.7		
	WOR WOR WOR WOR	SS5 24	48.5 50.5	48.5	SM	Gray silty SAND (SM), trace organics and very fine gravel
				485.7		
50				49.5	CL	Medium dense grayish-brown mottled sandy CLAY (CL), moist
	2 2 3 3	SS6 10	50.5 52.5			
	2 3 2 3	SS7 24	52.5 54.5	482.0		
				53.3	SP	Gray-brown SAND (SP)
				481.7 53.5	CL	Dense grayish-brown silty CLAY (CL), trace organics
				480.7 54.5		BOTTOM OF EXPLORATION 54.5 FT
55						

Water Level Data

Date	Time	Elapsed Time (hr.)	Depth (ft) to: Bottom of Casing	Bottom of Hole	Water

Sample ID
O - Open End Rod
T - Thin Wall Tube
U - Undisturbed Sample
S - Split Spoon Sample

Well Diagram
Riser Pipe
Screen
Filter Sand
Cuttings
Grout
Concrete
Bentonite Seal

Summary
Overburden (ft) 14.0
Rock Cored (ft) 0.0
Samples 7SS

Boring No. HAB-N-4

Field Tests: **Dilatancy**: R - Rapid S - Slow N - None **Toughness**: L - Low M - Medium H - High **Plasticity**: N - Nonplastic L - Low M - Medium H - High **Dry Strength**: N - None L - Low M - Medium H - High V - Very High

†Note: Maximum particle size is determined by direct observation within the limitations of sampler size.

Note: Soil identification based on visual-manual methods of the USCS as practiced by Haley & Aldrich, Inc.

H&A-TEST BORING-07-1 WATER 129673-005_HA-LIB07-1-CLE2.GLB HA-TB+CORE+WELL-07-1.GDT \\HALEYALDRICH.COM\SHARE\POR_COMMON\GINT\OHIO OFFICES\129673-005\129673-005_TB.GPJ 10 May 17

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HALEY ALDRICH

TEST BORING REPORT

Boring No. HAB-N-5

Project Ash Pond, Newton, Illinois
Client Dynegy
Contractor CEC & Strata

File No. 129673-005
Sheet No. 1 of 1
Start 27 April 2017
Finish 27 April 2017
Driller J. Cooley
H&A Rep. J. Gerger
Elevation 535.2 Datum
Location See Plan

	Casing	Sampler	Barrel	Drilling Equipment and Procedures
Type		SS	--	Rig Make & Model: Diedrich D-25
Inside Diameter (in.)		1.375	--	Bit Type: Roller Bit
Hammer Weight (lb)		140	-	Drill Mud:
Hammer Fall (in.)		30	-	Casing:
				Hoist/Hammer: /
				PID Make & Model: N/A

Depth (ft)	Sampler Blows per 6 in.	Sample No. & Rec. (in.)	Sample Depth (ft)	Stratum Change Elev/Depth (ft)	USCS Symbol	VISUAL-MANUAL IDENTIFICATION AND DESCRIPTION (Density/consistency, color, GROUP NAME, max. particle size†, structure, odor, moisture, optional descriptions GEOLOGIC INTERPRETATION)
						Water from 0 to 34.5 ft (El. 535.2) [2.2 ft on Dynegy water level gauge]
				500.7 34.5		
35	WOR WOR WOR WOR	SS1 11	34.5 36.5			Gray SILT/ASH -FILL-
	WOR WOR WOR 1	SS2 22	36.5 38.5	497.7 37.5		
				497.2 38.0	CL	Black CLAY (CL)
	2 4 3 2	SS3 13	38.5 40.5	496.2 39.0	CL	Medium stiff grayish-brown sandy CLAY (CL), trace gravel, moist
40				495.2 40.0	CL	Stiff gray sandy CLAY (CL), trace gravel, moist
	1 3 3 4	SS4 16	40.5 42.5		CL	Hard brown sandy CLAY (CL), trace gravel, moist
	2 2 4 6	SS5 21	42.5 44.5	492.2 43.0	SP	Well graded coarse brown SAND (SP)
				491.7 43.5	CL	Stiff brown sandy CLAY (CL), trace gravel, moist
45				490.7 44.5		BOTTOM OF EXPLORATION 44.5 FT
50						

Water Level Data

Date	Time	Elapsed Time (hr.)	Depth (ft) to: Bottom of Casing	Bottom of Hole	Water

Sample ID
O - Open End Rod
T - Thin Wall Tube
U - Undisturbed Sample
S - Split Spoon Sample

Well Diagram
Riser Pipe
Screen
Filter Sand
Cuttings
Grout
Concrete
Bentonite Seal

Summary

Overburden (ft)	10.0
Rock Cored (ft)	0.0
Samples	5SS

Boring No. HAB-N-5

Field Tests: **Dilatancy**: R - Rapid S - Slow N - None **Toughness**: L - Low M - Medium H - High **Plasticity**: N - Nonplastic L - Low M - Medium H - High **Dry Strength**: N - None L - Low M - Medium H - High V - Very High

†Note: Maximum particle size is determined by direct observation within the limitations of sampler size.

Note: Soil identification based on visual-manual methods of the USCS as practiced by Haley & Aldrich, Inc.

H&A-TEST BORING-07-1 WATER 129673-005_HA-LIB07-1-CLE2.GLB HA-TB+CORE+WELL-07-1.GDT \\HALEYALDRICH.COM\SHARE\POR_COMMON\GINT\OHIO OFFICES\129673-005\129673-005_TB.GPJ 10 May 17

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FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Co.
Site: Newton Power Station
Location: 6725 N 500th St, Newton, IL 62448
Project: 16E0044A
DATES: **Start:** 9/25/2017
Finish: 9/26/2017
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Bulldog Drilling
Rig mfg/model: CME-750 ATV Drill
Drilling Method: Mud Rotary w/split spoon
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: R217D
Well ID: R217D
Surface Elev: 535.91 ft. MSL
Completion: 65.24 ft. BGS
Station: 7,126.90N
6,712.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft^3)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL
1	0/60 *0%*	BD					0	FILL - Brown, silty CLAY.	534
							4		532
							6	Gray-brown, silty CLAY with coarse sand.	530
2	0/60 *0%*	BD					8		528
								Gray, medium SAND with silt.	
							10		526
								Gray, mottled brown, CLAY with silt.	
3	0/60 *0%*	BD					12		524
							14		522
								Brown, silty CLAY with pebbles.	
							16		520
4	0/60 *0%*	BD						Gray, mottles brown, silty CLAY with pebbles.	
							18		518
							20		516

Borehole Detail: 6"Ø permanent, PVC casing set to 20'

NOTE(S): R217D drilled 15.5 feet west of G217D.
Borehole reamed to 6" diameter to set well.
Lithology description to 25 ft. taken from G217 boring log as prepared by Rapps Engineering & Applied Science (1997).

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FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Co.
Site: Newton Power Station
Location: 6725 N 500th St, Newton, IL 62448
Project: 16E0044A
DATES: **Start:** 9/25/2017
Finish: 9/26/2017
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Bulldog Drilling
Rig mfg/model: CME-750 ATV Drill
Drilling Method: Mud Rotary w/split spoon
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: R217D
Well ID: R217D
Surface Elev: 535.91 ft. MSL
Completion: 65.24 ft. BGS
Station: 7,126.90N
6,712.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

SAMPLE Number	Recov / Total (in) *% Recovery*	Type	TESTING *Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
5	0/60 *0%*	BD					22	Gray, mottles brown, silty CLAY with pebbles. *[Continued from previous page]*		514	
							24			512	
6A	24/24 *100%*	SS	*12-19 27-34* N=46	11.2			26			510	
7A	22/24 *92%*	SS	*10-24 31-35* N=55	9.8			28	Gray (10YR5/1), moist, hard, SILT with some clay, few very fine- to very coarse-grained sand, and trace small gravel.		508	
8A	24/24 *100%*	SS	*9-16 24-25* N=40	11.2			30			506	
9A	24/24 *100%*	SS	*11-16 28-28* N=44	11.0			32			504	
10A	24/24 *100%*	SS	*11-16 24-32* N=40	11.5			34			502	
11A	24/24 *100%*	SS	*11-17 26-34* N=43	15.0			36	Gray (10YR5/1), moist, hard, SILT with some clay, few very fine- to very coarse-grained sand, and trace small to medium gravel.		500	
12A	24/24 *100%*	SS	*10-17 27-34* N=44	11.8			38			498	
	24/24		*9-23*				40	Gray (10YR5/1), moist, hard, CLAY, with some silt, few very fine- to very coarse-grained sand, and trace small to medium gravel.		496	

NOTE(S): R217D drilled 15.5 feet west of G217D.
Borehole reamed to 6" diameter to set well.
Lithology description to 25 ft. taken from G217 boring log as prepared by Rapps Engineering & Applied Science (1997).

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Co.
Site: Newton Power Station
Location: 6725 N 500th St, Newton, IL 62448
Project: 16E0044A
DATES: **Start:** 9/25/2017
Finish: 9/26/2017
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Bulldog Drilling
Rig mfg/model: CME-750 ATV Drill
Drilling Method: Mud Rotary w/split spoon
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: R217D
Well ID: R217D
Surface Elev: 535.91 ft. MSL
Completion: 65.24 ft. BGS
Station: 7,126.90N
6,712.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

SAMPLE Number	Recov / Total (in) / % Recovery	Type	TESTING Blows / 6 in; N - Value; RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
13A	100%	SS	33-35 N=56	10.9			42			494	
14A	24/24 100%	SS	8-18 22-29 N=40	13.1			44	Gray (10YR5/1), moist, hard, CLAY, with some silt, few very fine- to very coarse-grained sand, and trace small to medium gravel. *[Continued from previous page]*		492	
15A	24/24 100%	SS	9-15 17-22 N=32	14.1			46			490	
16A	24/24 100%	SS	6-15 20-30 N=35	13.2			48			488	
17A	24/24 100%	SS	8-14 20-25 N=34	14.8			50			486	
18A	24/24 100%	SS	5-12 17-20 N=29	14.9			52	Gray (10YR5/1), moist, hard, CLAY, with some silt, few very fine- to very coarse-grained sand, and trace small to medium gravel, trace wood fragments.		484	
19A	6/24 25%	SS	9-14 19-24 N=33	23.3			54			482	
20A	24/24 100%	SS	5-11 15-20 N=26	16.6			56	Olive gray (5Y4/2) with 10% gray (10YR5/1) mottles, moist, hard, CLAY with some silt, little very fine- to very coarse-grained sand, and trace small to medium gravel.		480	
21A	24/24 100%	SS	6-10 14-20 N=24	19.7			58			478	
22A	24/24 100%	SS	7-10 12-14 N=22	19.3			60			476	
23A	24/24		5-8	22.1							

NOTE(S): R217D drilled 15.5 feet west of G217D.
Borehole reamed to 6" diameter to set well.
Lithology description to 25 ft. taken from G217 boring log as prepared by Rapps Engineering & Applied Science (1997).

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FIELD BORING LOG

HANSON

CLIENT: Illinois Power Generating Co.
Site: Newton Power Station
Location: 6725 N 500th St, Newton, IL 62448
Project: 16E0044A
DATES: **Start:** 9/25/2017
Finish: 9/26/2017
WEATHER: Sunny, warm (lo-80's)

CONTRACTOR: Bulldog Drilling
Rig mfg/model: CME-750 ATV Drill
Drilling Method: Mud Rotary w/split spoon
FIELD STAFF: **Driller:** J. Dittmaier
Helper: M. Hill
Eng/Geo: R. Hasenyager

BOREHOLE ID: R217D
Well ID: R217D
Surface Elev: 535.91 ft. MSL
Completion: 65.24 ft. BGS
Station: 7,126.90N
6,712.16E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 26, **Tier** 6N; **Range** 8E

SAMPLE Number	Recov / Total (in) *% Recovery*	Type	TESTING *Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft^3)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
23B	*100%*	SS	*16-20* N=24	18.8				Gray (10YR5/1), wet, dense, very fine- to very coarse-grained SAND, with little silt and trace small gravel.			
24A				19.5							
24B	24/24 *100%*	SS	*8-9* *22-27* N=31	14.6			62	Yellowish brown (10YR5/6), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small gravel.		474	
25A	24/24 *100%*	SS	*13-19* *27-35* N=46	13.2			64	Gray (10YR5/1), moist, hard, SILT with some clay, little very fine- to very coarse-grained sand, and trace small gravel.		472	
	0/3 *0%*	BD									

End of Boring = 65.24 feet

NOTE(S): R217D drilled 15.5 feet west of G217D.
Borehole reamed to 6" diameter to set well.
Lithology description to 25 ft. taken from G217 boring log as prepared by Rapps Engineering & Applied Science (1997).

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RAPPS

ENGINEERING&APPLIED SCIENCE

BORING LOG

821 S. DURKIN DRIVE-SPRINGFIELD IL 62704 - (217) 787-2118

Client: CIPS Project: Newton LF Monitoring Wells Boring No: G217

Drilling Firm: PSI Drilling Method: 4¼ HSA Surface Elev: 535.67

Logged By: MSS Checked By: --- Date Started: 8/26/97 Completed: 8/26/97

DEPTH	Material Description (Unified)	Tube No.	Type	% Rec.	Pocket Pen Qu tsf	% Moist	Comments	DEPTH
	Brown silty CLAY (CL): Fill Material 3.0	1	5 Foot Continuous Sampler	100	4.0 2.0	dry		
-5-	Gray-Brown silty CLAY (CL) w/coarse sand 8.2	2		100	3.0 2.5 2.0 2.0 1.75	mst	Gray, medium SAND (SM) w/silt from 8.2 to 8.6	-5-
	see comments 8.6							
-10-	Gray, mottled brown CLAY (CH-CL) w/silt 14.0	3		100	2.5 3.0 4.5+ 4.5+	mst		-10-
-15-	Brown silty CLAY (CL) w/pebbles 15.0	4		100	4.0 4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry	very weathered	-15-
-20-	Gray, mottled Brown silty CLAY (CL) w/ pebbles	5		100	4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry	End Boring at 25.0	-20-
-25-								-25-

Water Level NA at NA Hrs.
Water Level NA at NA Hrs.

WELL CONSTRUCTION LOGS

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MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW11
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 58.1" Long. -88° 16' 31.6" or	
Facility ID	St. Plane 825,195 ft. N, 1,000,718 ft. E. Ⓔ/W	Date Well Installed: 01/23/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Dave Gordon
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ Cascade Drilling

A. Protective pipe, top elevation 539.11 ft. (NAVD88)

B. Well casing, top elevation 538.63 ft. (NAVD88)

C. Land surface elevation 536.0 ft. (NAVD88)

D. Surface seal, bottom 534.0 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☒ GM ☐ GC ☐ GW ☐ SW ☐ SP ☒
SM ☒ SC ☒ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 481.0 ft. (NAVD88) or 55.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 478.0 ft. (NAVD88) or 58.0 ft.

H. Screen joint, top 476.0 ft. (NAVD88) or 60.0 ft.

I. Well bottom 471.0 ft. (NAVD88) or 65.0 ft.

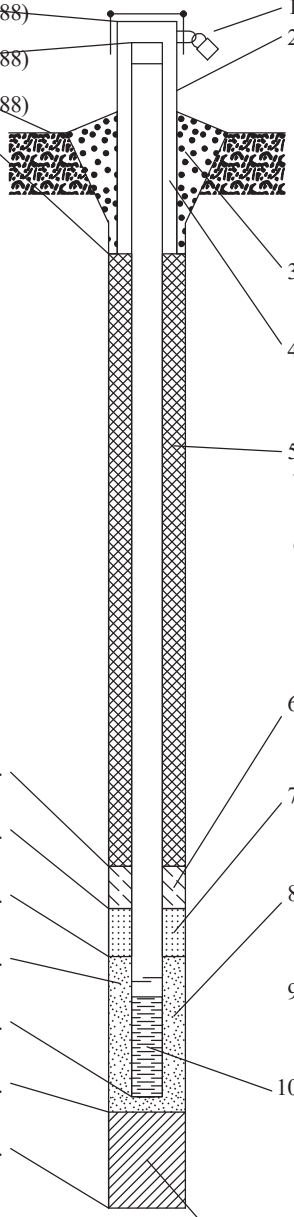
J. Filter pack, bottom 469.0 ft. (NAVD88) or 67.0 ft.

K. Borehole, bottom 436.0 ft. (NAVD88) or 100.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.6 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 9.250 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.614 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☐ Benoite Slurry Grout Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature ____ Firm Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW12
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 47.1" Long. -88° 16' 19.4" or	
Facility ID	St. Plane 824,081 ft. N, 1,001,683 ft. E. Ⓔ/W	Date Well Installed: 01/21/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon
Distance from Waste/Source ____ ft. State: IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ Cascade Drilling

A. Protective pipe, top elevation 546.68 ft. (NAVD88)

B. Well casing, top elevation 546.29 ft. (NAVD88)

C. Land surface elevation 543.3 ft. (NAVD88)

D. Surface seal, bottom 541.3 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☒
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required):
Potable Plant Water

E. Bentonite seal, top 541.3 ft. (NAVD88) or 2.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 525.3 ft. (NAVD88) or 18.0 ft.

H. Screen joint, top 523.3 ft. (NAVD88) or 20.0 ft.

I. Well bottom 513.3 ft. (NAVD88) or 30.0 ft.

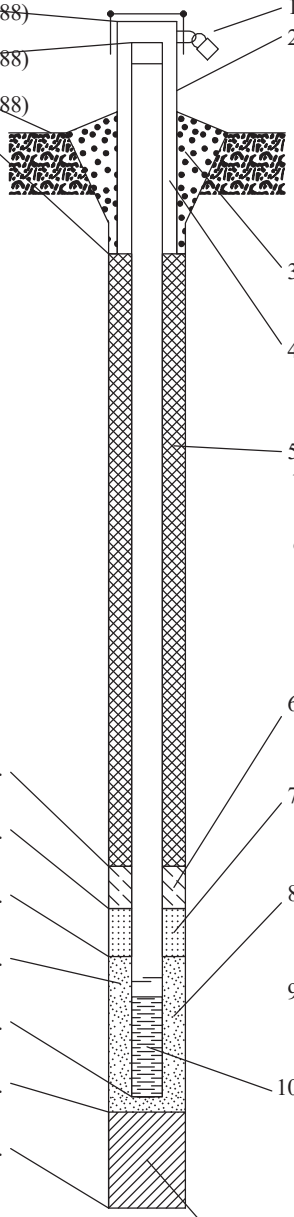
J. Filter pack, bottom 511.3 ft. (NAVD88) or 32.0 ft.

K. Borehole, bottom 456.3 ft. (NAVD88) or 87.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☒
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 0.000 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 2.487 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 10.0 ft.

11. Backfill material (below filter pack): None ☐ Benoite Slurry Grout Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature: SA WL

Firm: Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW13
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 32.4" Long. -88° 16' 27.9" or	
Facility ID	St. Plane 822,591 ft. N, 1,001,013 ft. E. Ⓔ/W	Date Well Installed: 01/23/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon
Distance from Waste/Source ____ ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ / Cascade Drilling

A. Protective pipe, top elevation 538.33 ft. (NAVD88)

B. Well casing, top elevation 537.99 ft. (NAVD88)

C. Land surface elevation 535.2 ft. (NAVD88)

D. Surface seal, bottom 533.2 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☒ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 481.2 ft. (NAVD88) or 54.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 479.2 ft. (NAVD88) or 56.0 ft.

H. Screen joint, top 476.7 ft. (NAVD88) or 58.5 ft.

I. Well bottom 471.7 ft. (NAVD88) or 63.5 ft.

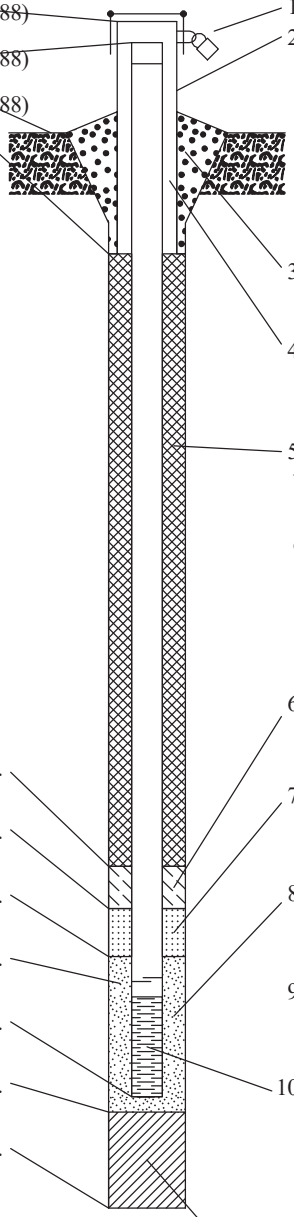
J. Filter pack, bottom 470.2 ft. (NAVD88) or 65.0 ft.

K. Borehole, bottom 445.2 ft. (NAVD88) or 90.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 5.0 ft.
   c. Material: Steel ☒ Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☐
   b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
   c. 9.6 Lbs/gal mud weight . . . Bentonite slurry ☒
   d. ____ % Bentonite . . . Bentonite-cement grout ☐
   e. 9.076 Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐
6. Bentonite seal: a. Bentonite granules ☐
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
   c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. Not Applicable
   b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
   a. Filter Sil, Industrial Quartz
   b. Volume added 1.604 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
    a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
    b. Manufacturer Johnson Screens
    c. Slot size: 0.010 in.
    d. Slotted length: 5.0 ft.
11. Backfill material (below filter pack): None ☐ Formation Materials Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature: SA WL

Firm: Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW14
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 26.6" Long. -88° 16' 40.8" or	
Facility ID	St. Plane 822,006 ft. N, 999,996 ft. E. Ⓔ/W	Date Well Installed: 01/23/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm): Adam Jochimsen; Cascade Drilling
Distance from Waste/Source ____ ft. State: IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____

A. Protective pipe, top elevation: 526.63 ft. (NAVD88)

B. Well casing, top elevation: 526.29 ft. (NAVD88)

C. Land surface elevation: 523.9 ft. (NAVD88)

D. Surface seal, bottom: 521.9 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☒ ML ☐ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top: 478.9 ft. (NAVD88) or 45.0 ft.

F. Fine sand, top: ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top: 475.9 ft. (NAVD88) or 48.0 ft.

H. Screen joint, top: 473.9 ft. (NAVD88) or 50.0 ft.

I. Well bottom: 468.9 ft. (NAVD88) or 55.0 ft.

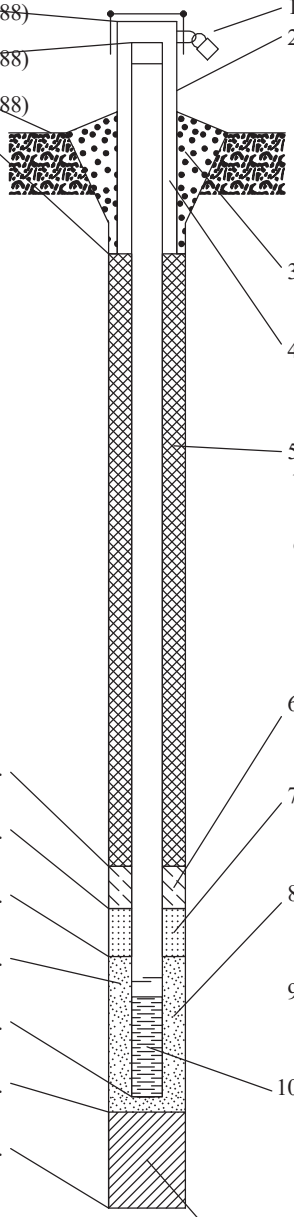
J. Filter pack, bottom: 466.9 ft. (NAVD88) or 57.0 ft.

K. Borehole, bottom: 428.9 ft. (NAVD88) or 95.0 ft.

L. Borehole, diameter: 6.0 in.

M. O.D. well casing: 2.38 in.

N. I.D. well casing: 2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.1 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 7.505 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.614 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☐ Benoite Slurry Grout Other ☒

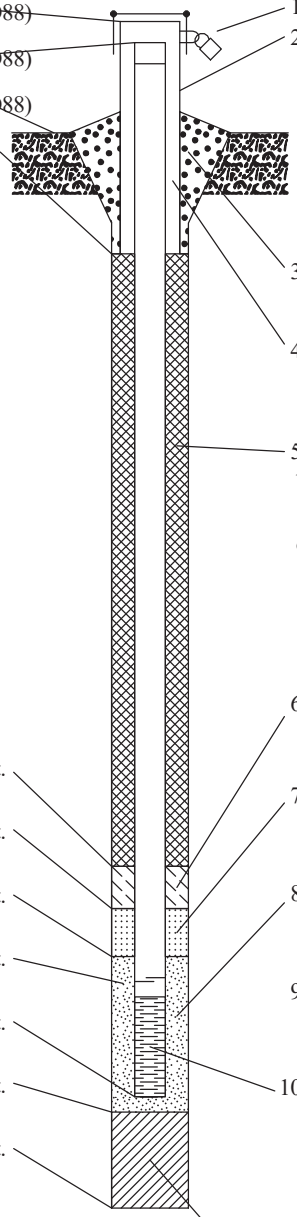
I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature: ____ Firm: Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW15
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 17.7" Long. -88° 17' 6.8" or	
Facility ID	St. Plane 821,108 ft. N, 997,939 ft. E. Ⓔ/W	Date Well Installed: 01/22/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm): Adam Jochimsen
Distance from Waste/Source ____ ft. State: IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ Cascade Drilling



A. Protective pipe, top elevation 525.07 ft. (NAVD88)

B. Well casing, top elevation 524.69 ft. (NAVD88)

C. Land surface elevation 522.1 ft. (NAVD88)

D. Surface seal, bottom 520.1 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☒
SM ☒ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 429.1 ft. (NAVD88) or 93.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 426.6 ft. (NAVD88) or 95.5 ft.

H. Screen joint, top 424.1 ft. (NAVD88) or 98.0 ft.

I. Well bottom 419.1 ft. (NAVD88) or 103.0 ft.

J. Filter pack, bottom 417.1 ft. (NAVD88) or 105.0 ft.

K. Borehole, bottom 412.1 ft. (NAVD88) or 110.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.1 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 15.882 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.702 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☐ Benoite Slurry Grout Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature ____ Firm Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station

Facility License, Permit or Monitoring No.:

Facility ID:

Type of Well: Well Code 72/dp

Distance from Waste/Source: ft. | State: IL

Local Grid Location of Well: ☐ N. ☐ S. ____ ft. ☐ E. ☐ W. ____ ft.

Local Grid Origin ☐ (estimated: ☐) or Well Location ☒

Lat. 38° 55' 13.1" Long. -88° 17' 28.6" or

St. Plane 820,642 ft. N, 996,214 ft. E. Ⓔ/W

Section Location of Waste/Source: ☒ E ☐ W

____ 1/4 of ____ 1/4 of Sec. 35, T. 6 N, R. 8

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known

Gov. Lot Number:

Well Name: APW16

Date Well Installed: 01/20/2021

Well Installed By: (Person's Name and Firm): Adam Jochimsen, Cascade Drilling

A. Protective pipe, top elevation 531.82 ft. (NAVD88)

B. Well casing, top elevation 531.18 ft. (NAVD88)

C. Land surface elevation 529.2 ft. (NAVD88)

D. Surface seal, bottom 527.2 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☒
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 453.7 ft. (NAVD88) or 75.5 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 450.7 ft. (NAVD88) or 78.5 ft.

H. Screen joint, top 448.7 ft. (NAVD88) or 80.5 ft.

I. Well bottom 443.7 ft. (NAVD88) or 85.5 ft.

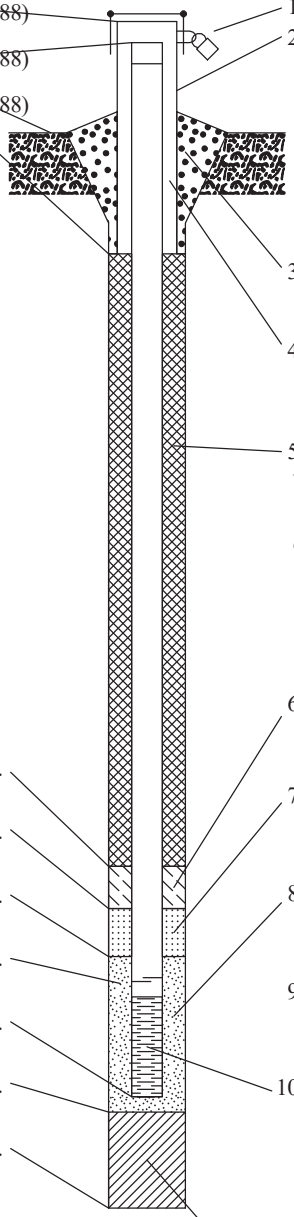
J. Filter pack, bottom 441.7 ft. (NAVD88) or 87.5 ft.

K. Borehole, bottom 419.2 ft. (NAVD88) or 110.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.1 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 12.828 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.614 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☐ Benoite Slurry Grout Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature: [signature] Firm: Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW17
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 33.3" Long. -88° 17' 38.1" or	
Facility ID	St. Plane 822,681 ft. N, 995,462 ft. E. Ⓔ/W	Date Well Installed: 01/22/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Dave Gordon
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ Cascade Drilling

A. Protective pipe, top elevation 533.02 ft. (NAVD88)

B. Well casing, top elevation 532.52 ft. (NAVD88)

C. Land surface elevation 529.8 ft. (NAVD88)

D. Surface seal, bottom 527.8 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☒
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required):
Potable Plant Water

E. Bentonite seal, top 446.8 ft. (NAVD88) or 83.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 444.8 ft. (NAVD88) or 85.0 ft.

H. Screen joint, top 442.8 ft. (NAVD88) or 87.0 ft.

I. Well bottom 437.8 ft. (NAVD88) or 92.0 ft.

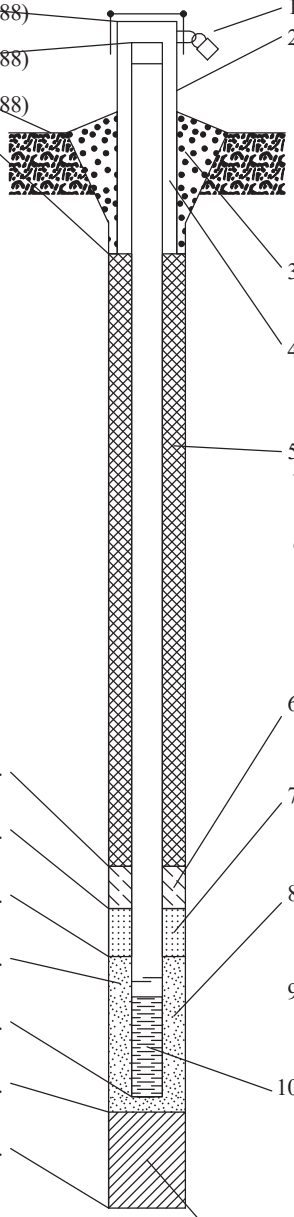
J. Filter pack, bottom 435.8 ft. (NAVD88) or 94.0 ft.

K. Borehole, bottom 429.8 ft. (NAVD88) or 100.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.6 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 14.137 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐
6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.614 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.
11. Backfill material (below filter pack): None ☐ Bentonite Chips Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature ____ Firm Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW18
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 51.5" Long. -88° 17' 24.4" or	
Facility ID	St. Plane 824,526 ft. N, 996,544 ft. E. Ⓔ/W	Date Well Installed: 01/21/2021
Type of Well: Well Code 72/dp	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Dave Gordon
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ / Cascade Drilling

A. Protective pipe, top elevation 543.81 ft. (NAVD88)

B. Well casing, top elevation 543.27 ft. (NAVD88)

C. Land surface elevation 540.6 ft. (NAVD88)

D. Surface seal, bottom 538.6 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☐
SM ☐ SC ☒ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required):
Potable Plant Water

E. Bentonite seal, top 469.6 ft. (NAVD88) or 71.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 467.6 ft. (NAVD88) or 73.0 ft.

H. Screen joint, top 465.6 ft. (NAVD88) or 75.0 ft.

I. Well bottom 460.6 ft. (NAVD88) or 80.0 ft.

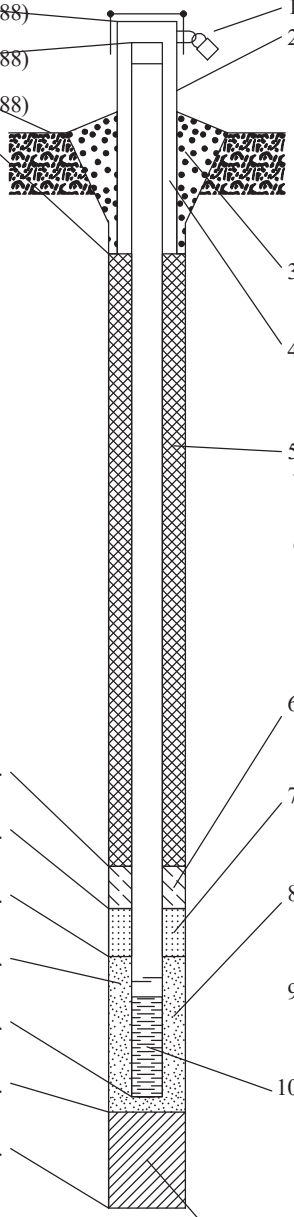
J. Filter pack, bottom 458.6 ft. (NAVD88) or 82.0 ft.

K. Borehole, bottom 433.6 ft. (NAVD88) or 107.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☐
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. 9.6 Lbs/gal mud weight . . . Bentonite slurry ☒
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 12.043 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☒ Gravity ☐
6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 1.614 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.
11. Backfill material (below filter pack): None ☐ Bentonite Chips Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature ____ Firm Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: APW5S
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 2.2" Long. -88° 16' 51.7" or	
Facility ID	St. Plane 825,612 ft. N, 999,129 ft. E. Ⓔ/W	Date Well Installed: 01/19/2021
Type of Well: Well Code 71/dw	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Dave Gordon
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ / Cascade Drilling

A. Protective pipe, top elevation 544.41 ft. (NAVD88)

B. Well casing, top elevation 543.94 ft. (NAVD88)

C. Land surface elevation 541.0 ft. (NAVD88)

D. Surface seal, bottom 540.0 ft. (NAVD88) or 1.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☒
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required):
Potable Plant Water

E. Bentonite seal, top 540.0 ft. (NAVD88) or 1.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 533.0 ft. (NAVD88) or 8.0 ft.

H. Screen joint, top 531.0 ft. (NAVD88) or 10.0 ft.

I. Well bottom 521.0 ft. (NAVD88) or 20.0 ft.

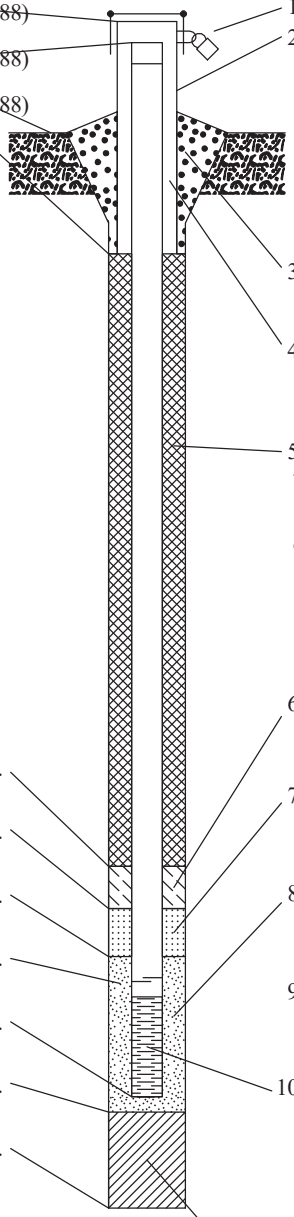
J. Filter pack, bottom 518.0 ft. (NAVD88) or 23.0 ft.

K. Borehole, bottom 518.0 ft. (NAVD88) or 23.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☒
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 1.222 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒
6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 2.683 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☒ Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature ____ Firm Ramboll, 234 W. Florida Street, Milwaukee, WI 53204 Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: XPW01
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 55.9" Long. -88° 17' 7.9" or	
Facility ID	St. Plane 824,975 ft. N, 997,852 ft. E. Ⓔ/W	Date Well Installed: 01/20/2021
Type of Well: Well Code 99/ot	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon, Cascade Drilling
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known / Gov. Lot Number	

A. Protective pipe, top elevation 552.11 ft. (NAVD88)

B. Well casing, top elevation 551.76 ft. (NAVD88)

C. Land surface elevation 548.6 ft. (NAVD88)

D. Surface seal, bottom 547.6 ft. (NAVD88) or 1.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 547.6 ft. (NAVD88) or 1.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 543.6 ft. (NAVD88) or 5.0 ft.

H. Screen joint, top 541.6 ft. (NAVD88) or 7.0 ft.

I. Well bottom 531.6 ft. (NAVD88) or 17.0 ft.

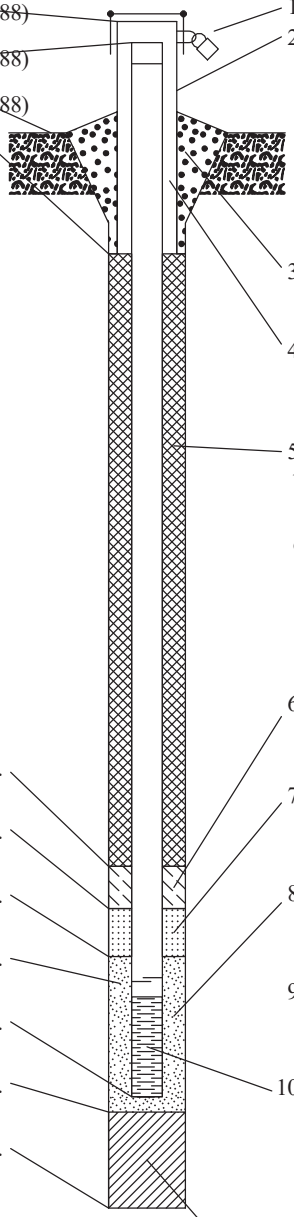
J. Filter pack, bottom 530.6 ft. (NAVD88) or 18.0 ft.

K. Borehole, bottom 528.6 ft. (NAVD88) or 20.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 5.0 ft.
   c. Material: Steel ☒ Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☒
   b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
   c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
   d. ____ % Bentonite . . . Bentonite-cement grout ☐
   e. 0.698 Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒
6. Bentonite seal: a. Bentonite granules ☐
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
   c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. Not Applicable
   b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
   a. Filter Sil, Industrial Quartz
   b. Volume added 2.291 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
    a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
    b. Manufacturer Johnson Screens
    c. Slot size: 0.010 in.
    d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☐ Bentonite Chips Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Date Modified: 5/3/2021

Signature	Firm	
[signature]	Ramboll 234 W. Florida Street, Milwaukee, WI 53204	Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: XPW02
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 56.4" Long. -88° 16' 58.4" or	
Facility ID	St. Plane 825,024 ft. N, 998,601 ft. E. Ⓔ/W	Date Well Installed: 01/19/2021
Type of Well: Well Code 99/ot	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 26, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon, Cascade Drilling
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known / Gov. Lot Number ____	

A. Protective pipe, top elevation 554.83 ft. (NAVD88)

B. Well casing, top elevation 554.43 ft. (NAVD88)

C. Land surface elevation 552.0 ft. (NAVD88)

D. Surface seal, bottom 550.0 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 550.0 ft. (NAVD88) or 2.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 548.0 ft. (NAVD88) or 4.0 ft.

H. Screen joint, top 546.0 ft. (NAVD88) or 6.0 ft.

I. Well bottom 536.0 ft. (NAVD88) or 16.0 ft.

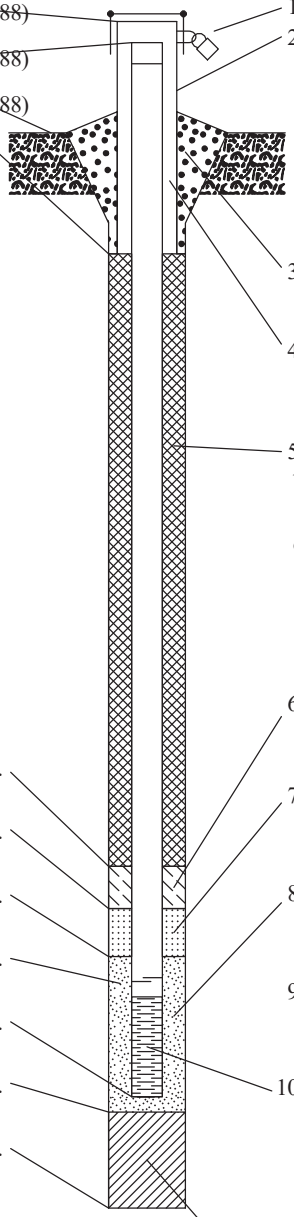
J. Filter pack, bottom 535.0 ft. (NAVD88) or 17.0 ft.

K. Borehole, bottom 532.0 ft. (NAVD88) or 20.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 5.0 ft.
   c. Material: Steel ☒ Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☒
   b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
   c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
   d. ____ % Bentonite . . . Bentonite-cement grout ☐
   e. 0.349 Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒
6. Bentonite seal: a. Bentonite granules ☐
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
   c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. Not Applicable
   b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
   a. Filter Sil, Industrial Quartz
   b. Volume added 2.291 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
    a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
    b. Manufacturer Johnson Screens
    c. Slot size: 0.010 in.
    d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☐ Bentonite Chips Other ☒

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Date Modified: 5/3/2021

Signature	Firm	
SA Wh	Ramboll 234 W. Florida Street, Milwaukee, WI 53204	Tel: (414) 837-3607 Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: XPW03
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 51.8" Long. -88° 16' 35.1" or	
Facility ID	St. Plane 824,558 ft. N, 1,000,445 ft. E. Ⓔ/W	Date Well Installed: 01/19/2021
Type of Well: Well Code 99/ot	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon
Distance from Waste/Source ft. / State: IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number: ____ / Cascade Drilling

A. Protective pipe, top elevation 553.95 ft. (NAVD88)

B. Well casing, top elevation 553.65 ft. (NAVD88)

C. Land surface elevation 550.8 ft. (NAVD88)

D. Surface seal, bottom 548.8 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☒
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required):
Potable Plant Water

E. Bentonite seal, top 548.8 ft. (NAVD88) or 2.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 542.8 ft. (NAVD88) or 8.0 ft.

H. Screen joint, top 540.8 ft. (NAVD88) or 10.0 ft.

I. Well bottom 530.8 ft. (NAVD88) or 20.0 ft.

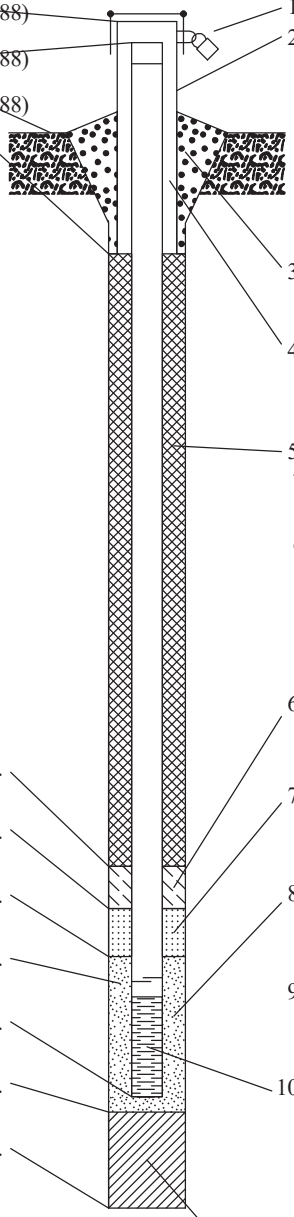
J. Filter pack, bottom 530.8 ft. (NAVD88) or 20.0 ft.

K. Borehole, bottom 530.8 ft. (NAVD88) or 20.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: Bollards

3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐

4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒

5. Annular space seal: a. Granular/Chipped Bentonite ☒
b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
d. ____ % Bentonite . . . Bentonite-cement grout ☐
e. 1.047 Ft^3 volume added for any of the above
f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒

6. Bentonite seal: a. Bentonite granules ☐
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
c. ____ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. Not Applicable
b. Volume added 0 ft^3

8. Filter pack material: Manufacturer, product name & mesh size
a. Filter Sil, Industrial Quartz
b. Volume added 2.094 ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐

10. Screen material: Schedule 40 PVC
a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
b. Manufacturer Johnson Screens
c. Slot size: 0.010 in.
d. Slotted length: 10.0 ft.

11. Backfill material (below filter pack): None ☒ Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge. Date Modified: 5/3/2021

Signature SH WL
Firm Ramboll
234 W. Florida Street, Milwaukee, WI 53204
Tel: (414) 837-3607
Fax: (414) 837-3608

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION

Facility/Project Name: Newton Power Station	Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.	Well Name: XPW04
Facility License, Permit or Monitoring No.	Local Grid Origin ☐ (estimated: ☐) or Well Location ☒ Lat. 38° 55' 47.6" Long. -88° 16' 26.6" or	
Facility ID	St. Plane 824,131 ft. N, 1,001,110 ft. E. Ⓔ/W	Date Well Installed: 01/19/2021
Type of Well: Well Code 99/ot	Section Location of Waste/Source: ____ 1/4 of ____ 1/4 of Sec. 25, T. 6 N, R. 8 ☒ E ☐ W	Well Installed By: (Person's Name and Firm) Russ Gordon, Cascade Drilling
Distance from Waste/Source ft. / State IL	Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☐ Not Known	Gov. Lot Number

A. Protective pipe, top elevation 554.74 ft. (NAVD88)

B. Well casing, top elevation 554.51 ft. (NAVD88)

C. Land surface elevation 551.9 ft. (NAVD88)

D. Surface seal, bottom 549.9 ft. (NAVD88) or 2.0 ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☒ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ Hollow Stem Auger ☐ Mini-Sonic Other ☒

15. Drilling fluid used: Water ☒ 0 2 Air ☐ Drilling Mud ☐ 0 3 None ☐

16. Drilling additives used? ☐ Yes ☒ No

Describe ____

17. Source of water (attach analysis, if required): Potable Plant Water

E. Bentonite seal, top 549.9 ft. (NAVD88) or 2.0 ft.

F. Fine sand, top ____ ft. (NAVD88) or ____ ft.

G. Filter pack, top 543.9 ft. (NAVD88) or 8.0 ft.

H. Screen joint, top 541.9 ft. (NAVD88) or 10.0 ft.

I. Well bottom 531.9 ft. (NAVD88) or 20.0 ft.

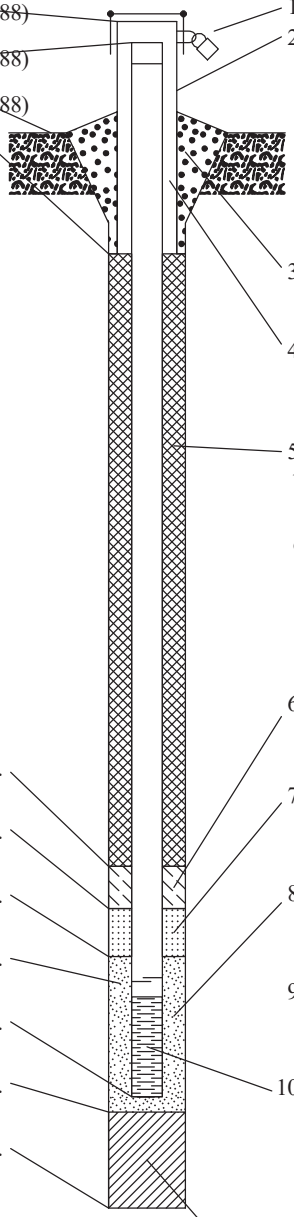
J. Filter pack, bottom 531.9 ft. (NAVD88) or 20.0 ft.

K. Borehole, bottom 531.9 ft. (NAVD88) or 20.0 ft.

L. Borehole, diameter 6.0 in.

M. O.D. well casing 2.38 in.

N. I.D. well casing 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 5.0 ft.
   c. Material: Steel ☒ Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: Bollards
3. Surface seal: Bentonite ☐ Concrete ☒ Other ☐
4. Material between well casing and protective pipe: Bentonite ☐ Sand Other ☒
5. Annular space seal: a. Granular/Chipped Bentonite ☒
   b. ____ Lbs/gal mud weight . . . Bentonite-sand slurry ☐
   c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐
   d. ____ % Bentonite . . . Bentonite-cement grout ☐
   e. 1.047 Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ Tremie pumped ☐ Gravity ☒
6. Bentonite seal: a. Bentonite granules ☐
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite chips ☒
   c. ____ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. Not Applicable
   b. Volume added 0 ft^3
8. Filter pack material: Manufacturer, product name & mesh size
   a. Filter Sil, Industrial Quartz
   b. Volume added 2.094 ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ Flush threaded PVC schedule 80 ☐ Other ☐
10. Screen material: Schedule 40 PVC
    a. Screen Type: Factory cut ☒ Continuous slot ☐ Other ☐
    b. Manufacturer Johnson Screens
    c. Slot size: 0.010 in.
    d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☒ Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Date Modified: 5/3/2021

Signature	Firm	
[signature]	Ramboll 234 W. Florida Street, Milwaukee, WI 53204	Tel: (414) 837-3607 Fax: (414) 837-3608

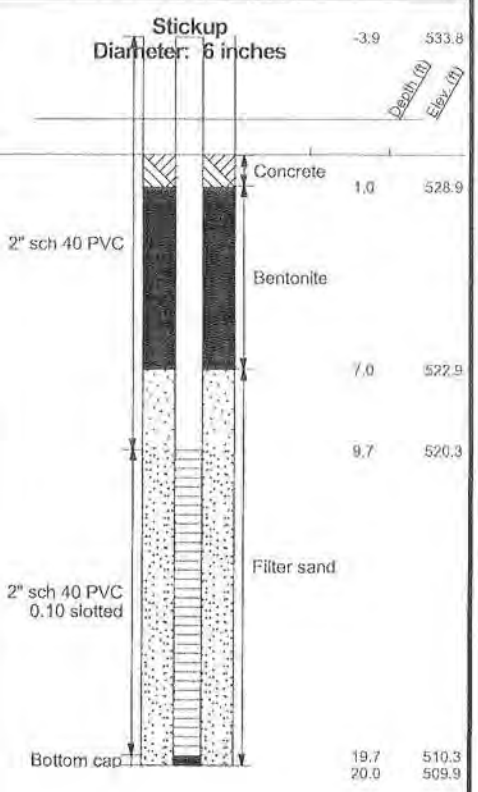
Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 529.93 | Completion Date: 6/19/10
Datum msl | Northing: 822688.04 | Easting: 995465.25

DEPTH IN FEET	DESCRIPTION OF MATERIAL
	Soft, brown, silty CLAY - CL
5	Stiff, brown, sandy CLAY - CL
	Hard, brown, sandy CLAY with gravel - CL ▽
10	
	Hard, dark gray CLAY and glacial till - CH
15	
20	Boring terminated at 20 feet.
25	
30	
35	

GRAPHIC LOG | DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD | SAMPLES

WELL DIAGRAM



GROUNDWATER DATA

ENCOUNTERED AT 8.5 FEET ▽

DRILLING DATA

4 1/4" AUGER ___ HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RBS	App'vd. by: DTK
Date: 6/29/10	Date: 2-7-11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-2

Project No. J017150.01

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES
IN-SITU, THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

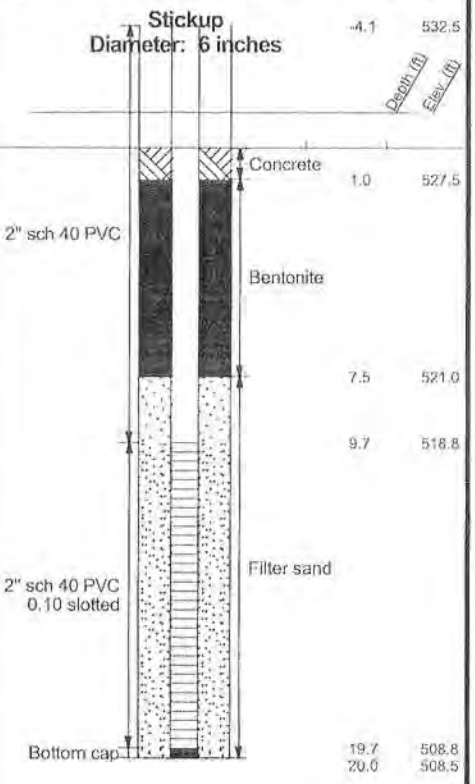
LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC.0638301.GPJ 12/22/10

Surface Elevation: 528.47 | Completion Date: 6/18/10
Datum msl | Northing: 821379.76 | Easting: 998975.74

DEPTH IN FEET	DESCRIPTION OF MATERIAL
	Soft, brown, silty CLAY - CL
5	Soft, brown, sandy CLAY with gravel - CL
10	Hard, brown, sandy CLAY with gravel - CL
15	Hard, brownish-gray, sandy CLAY with gravel - CL
20	Boring terminated at 20 feet.
25	
30	
35	

GRAPHIC LOG | DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD | SAMPLES

WELL DIAGRAM



NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES
THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC 0638301 GPJ 7/2/14

GROUNDWATER DATA

X FREE WATER NOT ENCOUNTERED DURING DRILLING

DRILLING DATA

4 1/4" AUGER __ HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: KCR	App'vd. by: DTK
Date: 6/29/10	Date: 2/7/14	Date: 2-7-14

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

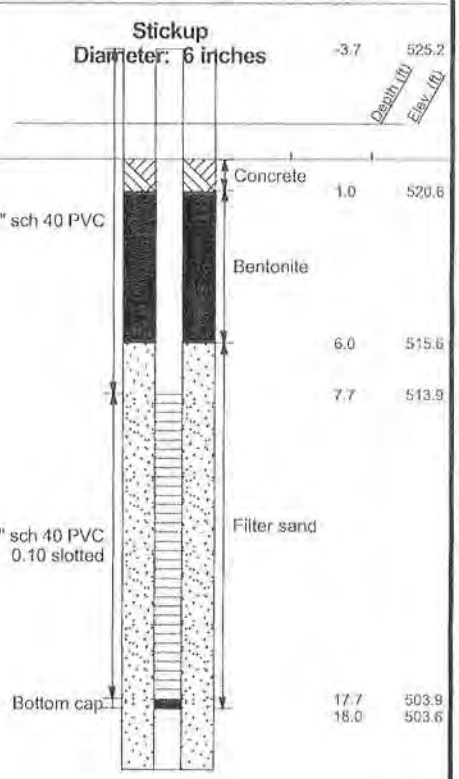
LOG OF BORING: APW-3

Project No. J017150.01

Surface Elevation: 521.56 | Completion Date: 6/19/10
Datum msl | Northing: 823246.45 | Easting: 1001379.56

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Soft, brown, silty CLAY - CL			
5				
	Soft, brown, sandy CLAY - CL ▽			
10				
	Stiff, brown, sandy CLAY with gravel - CL			
15				
	Boring terminated at 18 feet.			
20				
25				
30				
35				

WELL DIAGRAM



GROUNDWATER DATA

ENCOUNTERED AT 8 FEET ▽

DRILLING DATA

4 1/4" AUGER __ HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS:

Drawn by: KA	Checked by: RJS	App'vd. by: DTK
Date: 6/29/10	Date: 2-7-11	Date: 2-7-11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Ameren Power Plant
Newton, Illinois

LOG OF BORING: APW-4

Project No. J017150.01

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01ENV - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 7/25/11

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW5

Site Name: Newton Energy Center Borehole #: APW5

~~State~~ Plant ~~Plane~~ Coordinate: X 9,318.2 Y 7,758.0 (or) Latitude: 38° 56' 2.270" Longitude: -88° 16' 51.560"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: C. Dutton

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Suzanna L. Keim Date Started: 10/22/2015 Date Finished: 10/22/2015

Report Form Completed By: Suzanna L. Keim Date: 11/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 45 minutes

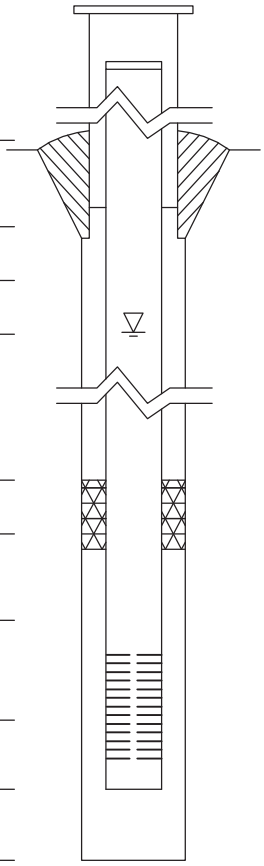
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
545.00	-3.43	Top of Protective Casing
544.56	-2.99	Top of Riser Pipe
541.57	0.00	Ground Surface
539.57	2.00	Top of Annular Sealant
527.06	14.51	Static Water Level (After Completion) 12/15/2015
484.39	57.18	Top of Seal
480.62	60.95	Top of Sand Pack
478.93	62.64	Top of Screen
474.13	67.44	Bottom of Screen
473.73	67.84	Bottom of Well
473.57	68.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	65.63
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	70.83
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW6

Site Name: Newton Energy Center Borehole #: APW6

~~State~~ Plant ~~Plane~~ Coordinate: X 7,811.9 Y 7,688.5 (or) Latitude: 38° 56' 1.510" Longitude: -88° 17' 10.610"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: C. Dutton

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Suzanna L. Keim Date Started: 10/20/2015 Date Finished: 10/21/2015

Report Form Completed By: Suzanna L. Keim Date: 11/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 30 minutes

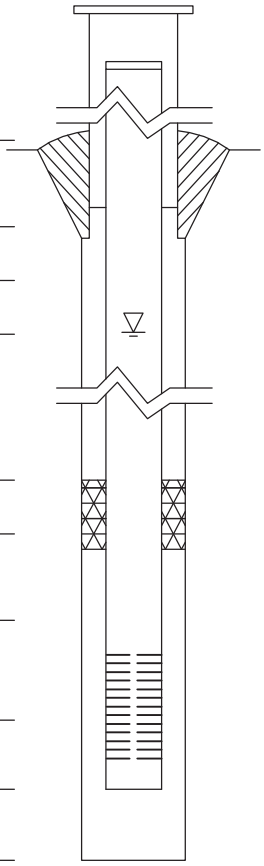
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand (if applicable)

Installation Method: gravity



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
546.88	-3.50	Top of Protective Casing
546.56	-3.18	Top of Riser Pipe
543.38	0.00	Ground Surface
541.38	2.00	Top of Annular Sealant
523.45	19.93	Static Water Level (After Completion) 12/15/2015
478.48	64.90	Top of Seal
477.28	66.10	Top of Sand Pack
475.71	67.67	Top of Screen
470.90	72.48	Bottom of Screen
470.50	72.88	Bottom of Well
469.38	74.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	70.85
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.81
Total Length of Casing	(feet)	76.06
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW7

Site Name: Newton Energy Center Borehole #: APW7a

~~State~~ Plant
~~Plane~~ Coordinate: X 6,151.6 Y 5,688.8 (or) Latitude: 38° 55' 41.660" Longitude: -88° 17' 31.490"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Gates

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Rhonald W. Hasenyager Date Started: 11/3/2015 Date Finished: 11/5/2015

Report Form Completed By: Suzanna L. Keim Date: 11/9/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry
(choose one)

Installation Method: Gravity

Setting Time: 120 minutes

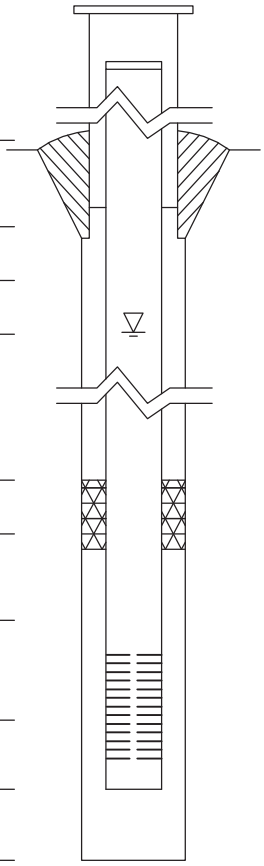
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand
(if applicable)

Installation Method: gravity



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
539.24	-3.03	Top of Protective Casing
538.86	-2.65	Top of Riser Pipe
536.21	0.00	Ground Surface
534.21	2.00	Top of Annular Sealant
490.68	45.53	Static Water Level (After Completion) 12/15/2015
462.06	74.15	Top of Seal
460.21	76.00	Top of Sand Pack
458.32	77.89	Top of Screen
453.51	82.70	Bottom of Screen
453.11	83.10	Bottom of Well
453.11	83.10	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	80.54
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.81
Total Length of Casing	(feet)	85.75
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW8

Site Name: Newton Energy Center Borehole #: APW8

~~State~~ Plant
~~Plane~~ Coordinate: X 6,082.4 Y 3,839.6 (or) Latitude: 38° 55' 23.380" Longitude: -88° 17' 32.250"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: C. Dutton

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Suzanna L. Keim Date Started: 10/27/2015 Date Finished: 10/28/2015

Report Form Completed By: Suzanna L. Keim Date: 11/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry
(choose one)

Installation Method: Gravity

Setting Time: 55 minutes

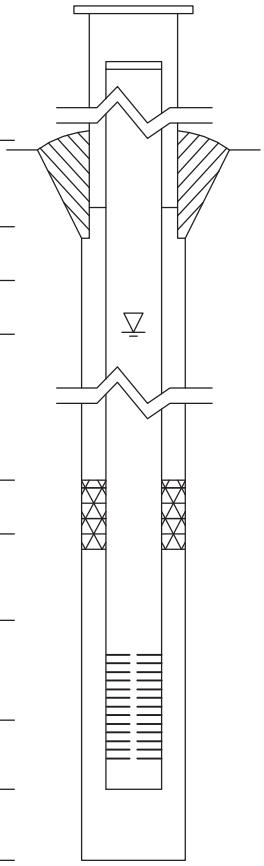
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
529.86	-3.11	Top of Protective Casing
529.46	-2.71	Top of Riser Pipe
526.75	0.00	Ground Surface
524.75	2.00	Top of Annular Sealant
490.50	36.25	Static Water Level (After Completion) 12/15/2015
462.45	64.30	Top of Seal
458.70	68.05	Top of Sand Pack
455.35	71.40	Top of Screen
445.69	81.06	Bottom of Screen
445.22	81.53	Bottom of Well
444.75	82.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	74.11
Bottom of Screen to End Cap	(feet)	0.47
Screen Length (1st slot to last slot)	(feet)	9.66
Total Length of Casing	(feet)	84.24
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW9

Site Name: Newton Energy Center Borehole #: APW9

~~State~~ Plant ~~Plane~~ Coordinate: X 9,125.3 Y 3,519.6 (or) Latitude: 38° 55' 20.370" Longitude: -88° 16' 53.730"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Gates

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Rhonald W. Hasenyager Date Started: 11/2/2015 Date Finished: 11/3/2015

Report Form Completed By: Suzanna L. Keim Date: 11/9/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry (choose one)

Installation Method: Gravity

Setting Time: 65 minutes

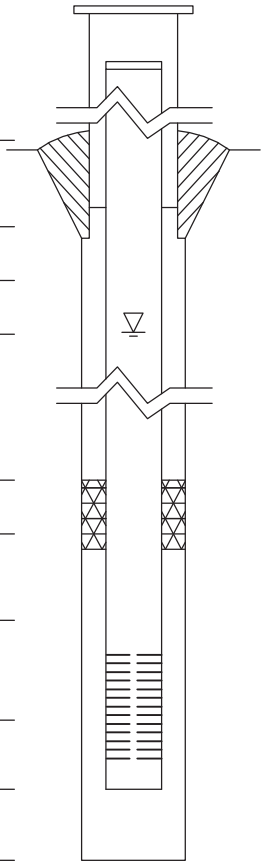
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a (if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
532.43	-3.61	Top of Protective Casing
532.01	-3.19	Top of Riser Pipe
528.82	0.00	Ground Surface
526.82	2.00	Top of Annular Sealant
502.18	26.64	Static Water Level (After Completion) 12/15/2015
475.91	52.91	Top of Seal
474.20	54.62	Top of Sand Pack
472.16	56.66	Top of Screen
467.36	61.46	Bottom of Screen
466.97	61.85	Bottom of Well
466.82	62.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: Steel
Riser Pipe Above W.T.	SS304	SS316	PTFE	PVC	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	PVC	OTHER:
Screen	SS304	SS316	PTFE	PVC	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	59.85
Bottom of Screen to End Cap	(feet)	0.39
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	65.04
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: APW10

Site Name: Newton Energy Center Borehole #: APW10a

~~State~~ Plant
~~Plane~~ Coordinate: X 11,541.2 Y 5,371.3 (or) Latitude: 38° 55' 38.790" Longitude: -88° 16' 23.280"

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: C. Dutton

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Suzanna L. Keim Date Started: 10/27/2015 Date Finished: 10/27/2015

Report Form Completed By: Suzanna L. Keim Date: 11/6/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry
(choose one)

Installation Method: Gravity

Setting Time: 50 minutes

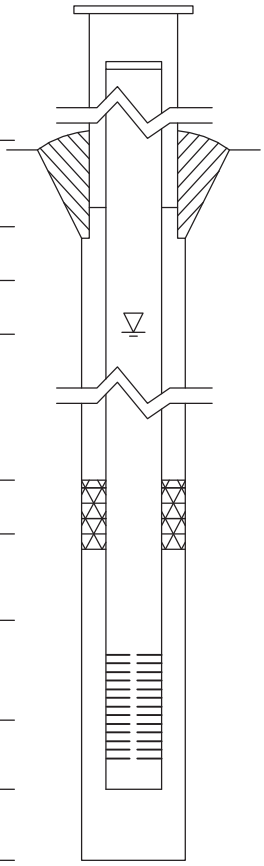
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: n/a
(if applicable)

Installation Method: _____



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
525.12	-3.14	Top of Protective Casing
524.74	-2.76	Top of Riser Pipe
521.98	0.00	Ground Surface
519.98	2.00	Top of Annular Sealant
504.12	17.86	Static Water Level (After Completion) 12/15/2015
484.66	37.32	Top of Seal
483.22	38.76	Top of Sand Pack
481.24	40.74	Top of Screen
476.44	45.54	Bottom of Screen
476.04	45.94	Bottom of Well
476.04	45.94	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	43.50
Bottom of Screen to End Cap	(feet)	0.40
Screen Length (1st slot to last slot)	(feet)	4.80
Total Length of Casing	(feet)	48.70
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper County Well #: G06D

Site Name: Newton Energy Center Borehole #: G06D

~~State~~ Plant
~~Plane~~ Coordinate: X 4,926.0 Y 5,328.8 (or) Latitude: 38 55! 38.040Ä Longitude: -88 17! 46.980Ä

Surveyed By: Michael J. Graminski IL Registration #: 035-002901

Drilling Contractor: Bulldog Drilling, Inc. Driller: J. Gates

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Hollow Stem Auger Drilling Fluid (Type): Water

Logged By: Rhonald W. Hasenyager Date Started: 11/9/2015 Date Finished: 11/10/2015

Report Form Completed By: Suzanna L. Keim Date: 11/16/2015

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: High-solids bentonite

Installation Method: Tremie

Setting Time: >48 hours

Type of Bentonite Seal -- Granular (Pellet) Slurry
(choose one)

Installation Method: Gravity

Setting Time: 45 minutes

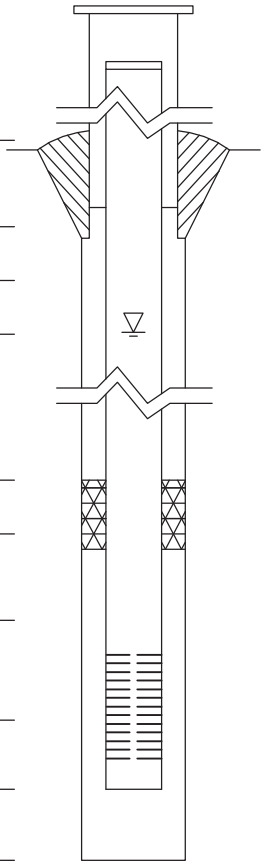
Type of Sand Pack: Quartz Sand

Grain Size: 10-20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: Quartz Sand
(if applicable)

Installation Method: gravity



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
532.59	-2.90	Top of Protective Casing
532.18	-2.49	Top of Riser Pipe
529.69	0.00	Ground Surface
527.69	2.00	Top of Annular Sealant
439.57	90.12	Static Water Level (After Completion) 12/16/2016
459.39	70.30	Top of Seal
457.58	72.11	Top of Sand Pack
455.46	74.23	Top of Screen
435.80	93.89	Bottom of Screen
435.36	94.33	Bottom of Well
433.69	96.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS
(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	76.72
Bottom of Screen to End Cap	(feet)	0.44
Screen Length (1st slot to last slot)	(feet)	19.66
Total Length of Casing	(feet)	96.82
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description
							0	Grayish brown (10YR5/2), moist, very soft, silty CLAY, trace roots.
							2	Grayish brown (10YR5/2) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY, slight trace roots.
							4	Brown (10YR5/3) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.
							6	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.
							8	Gray (10YR5/1) with 40% dark yellowish brown (10YR4/6) mottles, very moist, soft, silty CLAY with trace sand and slight trace gravel.
							10	Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, soft, wet, sandy CLAY with slight trace gravel.
							11	Yellowish brown (10YR5/4) with 10% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.
							12	Dark gray (10YR4/1) with 30% brown (10YR4/3) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							14	Dark gray (10YR4/1) with 20% dark grayish brown (10YR4/2) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							16	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.
							18	
							20	

Borehole Detail	Elevation ft. MSL	Remarks
	542	
	540	
	538	
	536	
	534	
	532	
	530	
	528	
	526	
	524	

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE Number	SAMPLE Recov / Total (in) % *Recovery*	SAMPLE Type	TESTING *Blows / 6 in* N - Value **RQD**	TESTING Moisture (%)	TESTING Dry Den. (lb/ft³)	TESTING Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
							22	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel. *[Continued from previous page]*		522	
							24			520	
							26	Dark gray (10YR4/1), moist, firm, silty CLAY with slight trace sand and gravel.		518	
								Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		516	
							28	Dark gray (10YR4/1), slightly moist, firm, clayey SILT with trace sand and slight trace gravel.		514	
							30			512	
							32			510	
							34	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		508	
							36			506	
							38	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		504	
							40				

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING						
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail / Elevation ft. MSL / Remarks
							42	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*	502
							44	Dark gray (10YR4/1), slightly moist, firm, SILT with slight trace sand.	500
							46		498
							48	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.	496
							50		494
							52	Olive gray (5Y4/2), slightly moist, firm, silty CLAY with slight trace sand and gravel.	492
							54	Dark greenish gray (10Y4/1) with 20% greenish gray (10Y6/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.	490
							56	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, hard, silty CLAY with slight trace sand and gravel.	488
							58	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.	486
							60		484

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: Natural Resource Technology, Inc.
Site: Newton Energy Center
Location: Newton, Illinois
Project: 15E0030
DATES: **Start:** 10/19/2015
Finish: 10/20/2015
WEATHER: Sunny, breezy, warm, lo-80s

CONTRACTOR: Bulldog Drilling, Inc.
Rig mfg/model: CME-550X ATV Drill
Drilling Method: 4¼" HSA

FIELD STAFF: **Driller:** C. Dutton
Helper: C. Jones
Eng/Geo: S. Keim

BOREHOLE ID: G48MG
Well ID: G48MG
Surface Elev: 543.17 ft. MSL
Completion: 77.06 ft. BGS
Station: 9,706.71N
5,052.58E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = Dry - During Drilling
▼ =
▽ =

SAMPLE			TESTING					
Number	Recov / Total (in) *% Recovery*	Type	*Blows / 6 in* N - Value **RQD**	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) *Qp* (tsf) Failure Type	Depth ft. BGS	Lithologic Description

Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.

[Continued from previous page]

Light olive gray (5Y5/2), very moist, very soft, sandy CLAY with slight trace gravel.

62

Light olive gray (5Y5/2) with 10% greenish gray (5GY5/1) mottles, slightly moist, firm, silty CLAY with trace sand and slight trace gravel.

64

66

Greenish gray (10Y5/1) with 10% olive gray (5Y4/2) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.

68

Greenish gray (10G5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, dense, SILT with slight trace sand.

70

Dark greenish gray (10GY4/1), slightly moist, very hard, clayey SILT with trace sand and slight trace gravel.

72

Dark greenish gray (10GY4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.

74

Dark greenish gray (10GY4/1), wet, very dense, silty, coarse-grained SAND and gravel.

76

Dark gray (10YR4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.

Borehole Detail	Elevation ft. MSL	Remarks
	482	
	480	
	478	
	476	
	474	
	472	
	470	
	468	

End of boring = 77.06 feet

NOTE(S): G48MG installed in borehole.
Sample and testing data can be found on B-48 Field Boring Log.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

Number	Recov / Total (in) % Recovery	Type	Blows/ 6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Elevation ft. MSL	Remarks
								Grayish brown (10YR5/2), moist, very soft, silty CLAY, trace roots.		
1A	13/18 72%	SS	woh-2 3 N=5	25.8					542	
								Grayish brown (10YR5/2) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY, slight trace roots.		
2A	17/18 94%	SS	2-3 4 N=7	22.0		3.88 Sh	2		540	
3A	17/18 94%	SS	2-4 4 N=8	15.7		1.90 Sh	4	Brown (10YR5/3) with 30% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.	538	
4A	24/24 100%	SS	woh-1 2-3 N=3	20.5		1.78 BSh	6		536	
5A	18/18 100%	SS	1-1 2 N=3	22.7		1.40 Sh	8	Gray (10YR5/1) with 20% dark yellowish brown (10YR4/6) mottles, moist, soft, silty CLAY with trace sand and slight trace gravel.	534	
6A	24/24 100%	SS	1-2 3-3 N=5	18.3		1.27 Sh		Gray (10YR5/1) with 40% dark yellowish brown (10YR4/6) mottles, very moist, soft, silty CLAY with trace sand and slight trace gravel.		
7-1							▼ 10	Yellowish brown (10YR5/4) with 10% gray (10YR6/1) mottles, soft, wet, sandy CLAY with slight trace gravel.	532	
7-2	23/24 96%	SH		19.9						
7-3				15.0				Yellowish brown (10YR5/4) with 10% gray (10YR5/1) mottles, moist, firm, silty CLAY with trace sand and slight trace gravel.		
7-4				19.5			12		530	
8A	18/18 100%	SS	8-13 17 N=30	10.2		8.92 Sh		Dark gray (10YR4/1) with 30% brown (10YR4/3) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		
9A	18/18 100%	SS	6-12 17 N=29	9.7		5.62 Sh	14	Dark gray (10YR4/1) with 20% dark grayish brown (10YR4/2) mottles, slightly moist, hard, clayey SILT with trace sand and slight trace gravel.	528	
10A	24/24 100%	SS	7-14 20-20 N=34	9.0		7.18 Sh	16		526	
11A	18/18 100%	SS	6-14 15 N=29	8.5		9.89 Sh	18	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.	524	
12A	18/18 100%	SS	5-12 14 N=26	10.2		11.25 Sh	20			

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
13A	24/24 100%	SS	8-13 17-17 N=30	10.1		12.36 Sh	22	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel. *[Continued from previous page]*		522	
14A	18/18 100%	SS	7-11 14 N=25	10.1		10.47 Sh				520	
15A	18/18 100%	SS	7-11 13 N=24	9.9		9.31 Sh	24			518	
16A				11.4		11.06 Sh					
16B	24/24 100%	SS	5-7 12-14 N=19	16.3		2.13 BSh	26	Dark gray (10YR4/1), moist, firm, silty CLAY with slight trace sand and gravel. Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		516	
17A	18/18 100%	SS	4-6 11 N=17	11.2		6.79 Sh	28	Dark gray (10YR4/1), slightly moist, firm, clayey SILT with trace sand and slight trace gravel.		514	
18A	18/18 100%	SS	5-9 16 N=25	11.4		9.70 Sh					
19A	24/24 100%	SS	4-8 14-19 N=22	10.4		10.47 Sh	30			512	
20A	18/18 100%	SS	6-13 17 N=30	11.4			32			510	
21A	18/18 100%	SS	7-13 19 N=32	11.3		10.28 Sh	34	Dark gray (10YR4/1), slightly moist, hard, clayey SILT with trace sand and slight trace gravel.		508	
22A	24/24 100%	SS	7-12 19-22 N=31	10.3		11.44 Sh	36			506	
23A	18/18 100%	SS	6-12 19 N=31	11.5		10.86 Sh	38	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		504	
24A	18/18 100%	SS	7-11 19 N=30	12.7		5.24 Sh	40				

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
25A	24/24 100%	SS	8-12 22-26 N=34	11.5		10.47 Sh	42	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*		502	
26A	18/18 100%	SS	7-12 18 N=30	11.7		7.76 Sh				500	
27A	18/18	SS	7-15 18 N=33	13.1			44	Dark gray (10YR4/1), slightly moist, firm, SILT with slight trace sand.			
27B	100%			10.9		11.64 Sh				498	
28A	24/24 100%	SS	8-10 16-21 N=26	13.7			46			496	
29A	18/18 100%	SS	7-10 16 N=26	14.5		5.82 Sh	48	Dark gray (10YR4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		494	
30A	18/18 100%	SS	4-9 13 N=22	14.1		2.52 B					
31-1							50				
31-2	19/24 79%	SH		14.0						492	
31-3											
31-4							52	Olive gray (5Y4/2), slightly moist, firm, silty CLAY with slight trace sand and gravel.			
32A	18/18	SS	7-13 19 N=32	12.9		10.28 Sh					
32B	100%			12.5		8.92 Sh		Dark greenish gray (10Y4/1) with 20% greenish gray (10Y6/1) mottles, slightly moist, hard, silty CLAY with trace sand and slight trace gravel.		490	
33A	18/18 100%	SS	5-10 16 N=26	14.9		2.13 BSh	54				
33B				14.6		6.59 Sh				488	
34A	24/24 100%	SS	6-10 16-19 N=26	15.5		3.88 Sh	56	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, hard, silty CLAY with slight trace sand and gravel.			
35A	18/18 100%	SS	2-7 14 N=21	18.2		1.94 BSh				486	
36A	18/18 100%	SS	3-7 14 N=21	13.8		5.04 BSh	58	Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		484	
							60				

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
37-1				16.5		1.75 BSh		Olive gray (5Y4/2) with 15% dark gray (N4/1) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.			
37-2	19/24 79%	SH		12.7		3.50 None		*[Continued from previous page]* Light olive gray (5Y5/2), very moist, very soft, sandy CLAY with slight trace gravel.		482	
37-3				15.0							
37-4							62				
38A	18/18 100%	SS	8-13 15 N=28	14.5		3.10 B		Light olive gray (5Y5/2) with 10% greenish gray (5GY5/1) mottles, slightly moist, firm, silty CLAY with trace sand and slight trace gravel.		480	
39A	18/18 100%	SS	6-9 15 N=24	12.8		5.04 BSh	64			478	
40A	24/24 100%	SS	4-9 13-15 N=22	13.6		5.43 Sh	66	Greenish gray (10Y5/1) with 10% olive gray (5Y4/2) mottles, slightly moist, firm, silty CLAY with slight trace sand and gravel.		476	
41A	18/18 100%	SS	12-13 14 N=27	13.2		4.07 BSh	68			474	
42A	16/17 94%	SS	6-32 28/5"	15.2				Greenish gray (10G5/1) with 5% dark yellowish brown (10YR4/6) mottles, moist, dense, SILT with slight trace sand.			
43A	3/3 100%	SS	60/3"	15.4			70	Dark greenish gray (10GY4/1), slightly moist, very hard, clayey SILT with trace sand and slight trace gravel.		472	
44A	13/14 93%	SS	28-47 15/2"	16.7			72	Dark greenish gray (10GY4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.		470	
45A	16/17 94%	SS	31-33 27/5"	13.6			74	Dark greenish gray (10GY4/1), wet, very dense, silty, coarse-grained SAND and gravel.		468	
46A	12/15 80%	SS	20-38 22/3"	15.3			76	Dark gray (10YR4/1), wet, very dense, silty, medium- to coarse-grained SAND with slight trace gravel.		466	
47A	18/18 100%	SS	3-11 17 N=28	13.9		5.62 B	78	Dark gray (N4/1), moist, firm, silty CLAY with slight trace sand and gravel.		464	
48A	17/18 94%	SS	5-10 14 N=24	14.9		5.24 BSh	80	Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.			

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
49A	24/24 100%	SS	5-7 12-14 N=19	15.5		5.04 BSh					
50A	18/18 100%	SS	4-8 10 N=18	15.4		5.24 BSh	82	Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel. *[Continued from previous page]*		462	
51A	18/18 100%	SS	4-9 10 N=19	15.7		5.04 B	84			460	
52-1	18/18 100%	SH								458	
52-2				14.3			86				
52-3										456	
53A	24/24 100%	SS	9-12 21-26 N=33	13.9		6.21 B	88	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			
54A	18/18 100%	SS	6-11 17 N=28	13.8		6.79 Sh				454	
55A	24/24 100%	SS	6-12 15-24 N=27	13.6		7.37 Sh	90			452	
56A	18/18 100%	SS	5-8 12 N=20	13.9		3.88 Sh	92	Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.		450	
57A	18/18 100%	SS	5-12 19 N=31	13.4		6.21 Sh	94			448	
58A	24/24 100%	SS	4-18 20-22 N=38	12.5			96	Dark gray (N4/1), very moist, dense, silty, fine- to coarse-grained SAND with slight trace gravel.			
58B				13.4		5.82 BSh		Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.		446	
59A	16/16 100%	SS	16-33 27/4"	16.0				Dark gray (N4/1), wet, dense, silty, fine- to medium-grained SAND with slight trace gravel.			
59B				15.7		3.69 Sh	98	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			
60A	18/18 100%	SS	16-21 15 N=36	12.6				Dark gray (N4/1), wet, dense, silty, very fine- to medium-grained SAND with slight trace gravel.		444	
60B							100	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

FIELD BORING LOG

HANSON

CLIENT: AEG Newton Power Station
Site: Gypsum Management Facility
Location: Newton, Jasper Co., IL
Project: 07E0150A 3000
DATES: Start: 5/12/2009
Finish: 5/14/2009
WEATHER: Sunny, warm, windy, (mid-60's)

CONTRACTOR: Skinner Limited
Rig mfg/model: CME-550 ATV Drill
Drilling Method: 4¼" hollow stem auger w/split spoon sampler
FIELD STAFF: Driller: T. Skinner
Helper: T. Skinner/J. Austin
Eng/Geo: S. Suzanna Simpson

BOREHOLE ID: B48
Well ID: n/a
Surface Elev: 542.9 ft. MSL
Completion: 103.5 ft. BGS
Station: 9,703.88N
5,042.40E

TOPOGRAPHIC MAP INFORMATION:
Quadrangle: Latona
Township: North Muddy
Section 23, **Tier** 6N; **Range** 8E

WATER LEVEL INFORMATION:
▼ = 10.00 - during drilling
▼ =
▽ =

SAMPLE Number	Recov / Total (in) % Recovery	Type	TESTING Blows/6 in N - Value RQD	Moisture (%)	Dry Den. (lb/ft³)	Qu (tsf) Qp (tsf) Failure Type	Depth ft. BGS	Lithologic Description	Borehole Detail	Elevation ft. MSL	Remarks
61A	24/24 100%	SS	7-12 18-25 N=30	13.4		6.59 Sh		Dark gray (N4/1), slightly moist, firm, silty CLAY with slight trace sand and gravel.		442	
							102	Dark gray (N4/1), slightly moist, hard, silty CLAY with slight trace sand and gravel.			
62A	17/18 94%	SS	12-18 22 N=40	15.3		3.88 BSh				440	

EOB = 103.5 feet bgs

NOTE(S): Borehole abandoned using bentonite grout.

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # ILD [illegible] County: Gallatin Well # G106

Site Name: Scrubber Sludge Landfill — PLANT Grid Coordinate Northing 983.42N Easting 7065.61W

Drilling Contractor Braecke Engineering — Date Drilled Start 8/1/90

Driller Mike Fappy — Geologist Rich Boyer CHEI — Date Completed 8/1/90

Drilling Method 4¼" ID, 8" OD Hollow Stem Augers — Drilling Fluids - type: None

Annular Space Details

Type of Surface Seal: Cement/Bentonite Grout

Type of Annular Sealant: Cement/Bentonite Grout

Amount of cement - # of bags 3 lbs. per bag 94

Amount of bentonite - # of bags 0.28 lbs. per bag 50

Type of Bentonite Seal - Granular, Pellets: ¼" pellets

Amount of bentonite - # of Bags 2 lbs. per bag 50

Type of Sand Pack: Silica Sand

Source of Sand: Meramec WA-95

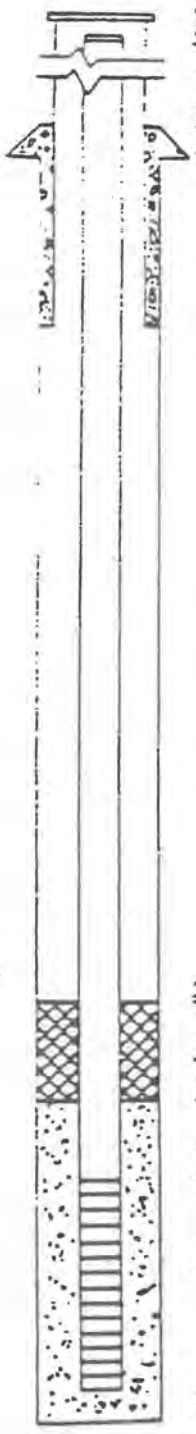
Amount of Sand - # of bags 3 lbs. per bag 94

Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type Schedule 40	Other Specify Type
Riser coupling joint			X	
Riser pipe above w.t.			2" ID	
Riser pipe below w.t.			2" ID	
Screen			0.01"	
Coupling joint screen to riser			X	
Protective casing				Steel

Measurements to .01 ft. (where applicable)

Riser pipe length	21.5
Protective casing length	5.0
Screen length	14.9
Bottom of screen to end cap	0
Top of screen to first joint	10
Total length of casing	36.4
Screen slot size	0.01"
# of openings in screen	0.125" spacing
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

530.87 MSL Top of Protective Casing
530.86 MSL Top of Riser Pipe
1.86 ft. Casing Stickup
529.00 MSL Ground Surface
529.00 ft. Top of annular sealant

515.76 ft. Top of Seal
3.20 ft. Total Seal Interval
512.56 ft. Top of Sand
509.36 ft. Top of Screen
14.90 ft. Total Screen Interval
494.46 ft. Bottom of Screen
492.56 ft. Bottom of Borehole

Completed by Robert Cowles (CHEI) Surveyed by Herb Williams (CHEI) Ill. registration # 035-00238

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: _____ County Jasper Well # G202

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6649.68 Easting 6587.20

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/16/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/16/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 14 lbs. per bag 94

Amount of bentonite: # of bags 1.5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 12.5 lbs. per bag 100

Well Construction Materials

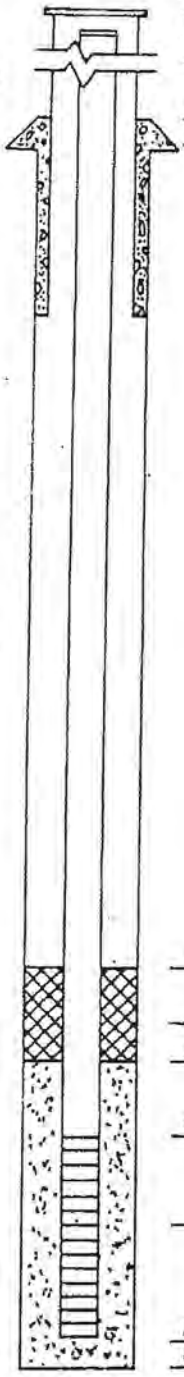
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.				
Riser pipe below w.t.				
Screen				
Coupling joint screen to riser				
Protective casing				

Measurements

to .01 ft. (where applicable)

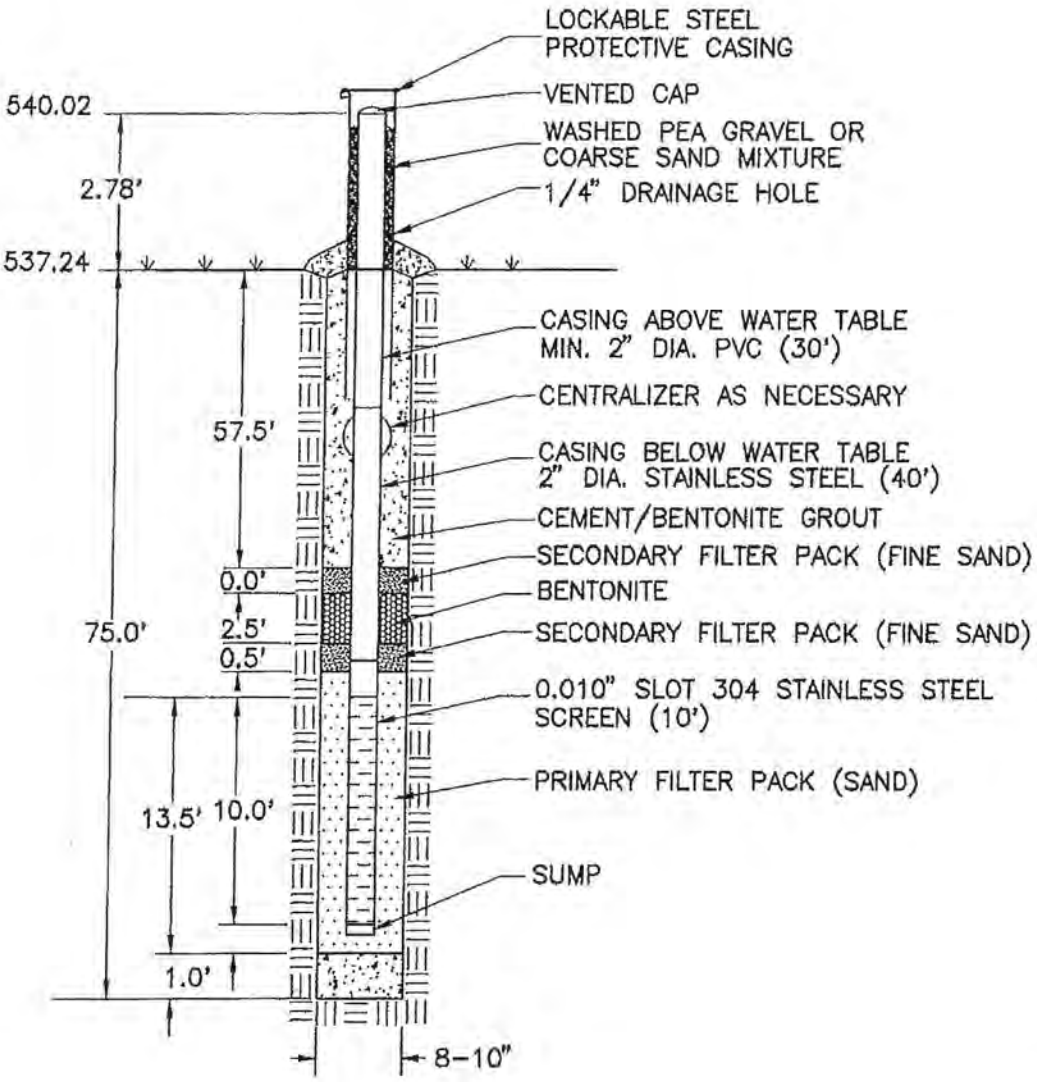
Riser pipe length	66.78 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



540	02	MSL Top of Protective Casing
2	78	MSL Top of Riser Pipe
		ft. Casing Stickup
537	24	MSL Ground Surface
___	___	ft. Top of annular sealant
479	24	ft. Top of Seal
2	50	ft. Total Seal Interval
476	74	ft. Top of Sand
473	24	ft. Top of Screen
10	00	ft. Total Screen Interval
463	24	ft. Bottom of Screen
463	24	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____



N: 6649.68 / E: 6587.20

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G202
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: _____ County Jasper Well # G203

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 5821.29 Easting 6113.10

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/15/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/15/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 10 lbs. per bag 94

Amount of bentonite: # of bags 1 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 8 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 13.5 lbs. per bag 100

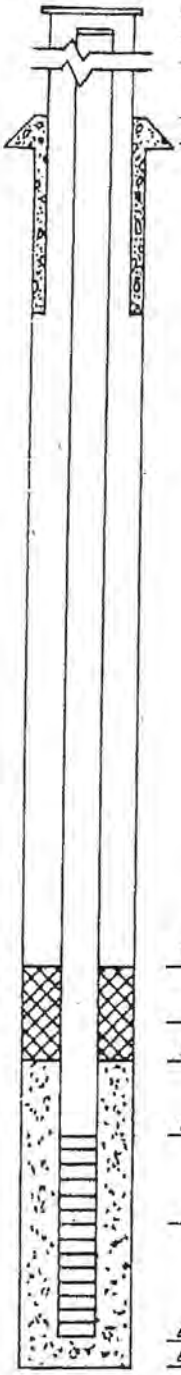
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

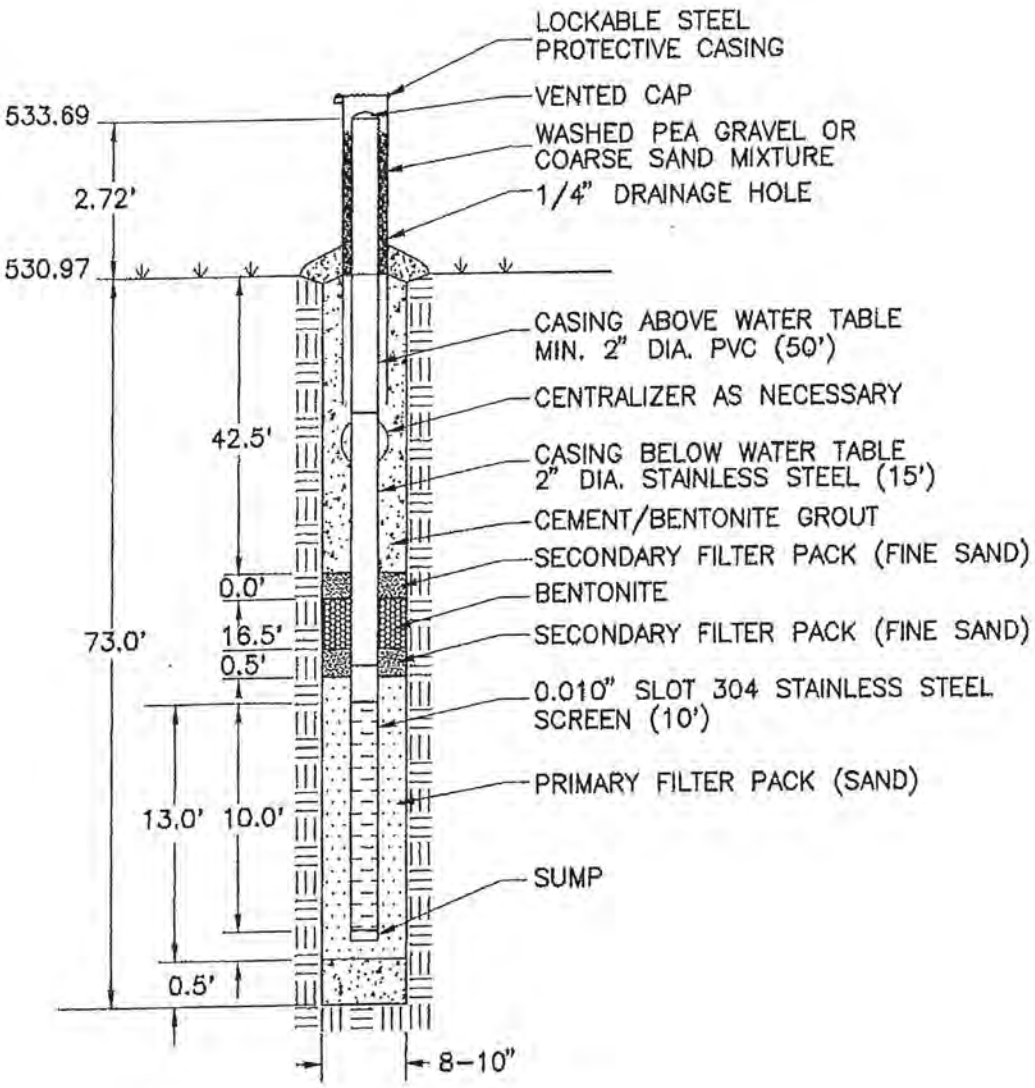
Riser pipe length	65.22 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

___	___	MSL Top of Protective Casing
533	69	MSL Top of Riser Pipe
2	72	ft. Casing Stickup
530	97	MSL Ground Surface
___	___	ft. Top of annular sealant
487	97	ft. Top of Seal
16	50	ft. Total Seal Interval
471	47	ft. Top of Sand
468	47	ft. Top of Screen
10	00	ft. Total Screen Interval
458	47	ft. Bottom of Screen
458	47	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____



N: 5821.29 / E: 6113.10

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G203
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, LANDFILL

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site Number: 0798085001 County: Jasper

Site Name: Newton Power Station Landfill Phase II Well #: G208

State Plane Coordinate: X ____ Y ____ (or) Latitude: ____ ____ ____ Longitude: ____ ____ ____ Borehole #: B208

Plant Coordinates: Northing 6208.18 Easting 4417.18

Surveyed by: Ken Miller IL Registration #: 196-001263

Drilling Contractor: Skinner Ltd. Driller: Todd Skinner

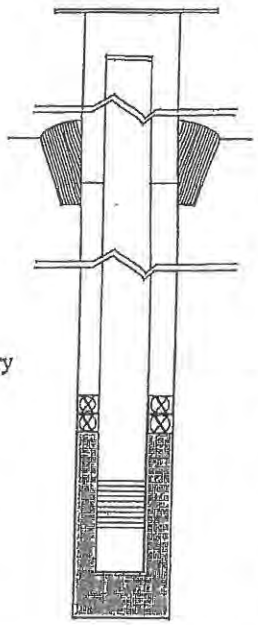
Consulting Firm: Rapps Engineering Geologist: Ken Miller

Drilling Method: HSA Drilling Fluid (Type): None

Logged By: Ken Miller Date Started: 10/11/11 Date Finished: 10/13/11

Report Form Completed By: Ken Miller Date: 11/30/11

ANNULAR SPACE DETAILS



Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Slurry

Installation Method: Tremi

Setting Time: ____

Type of Bentonite Seal - - Granular, (Pellet), Slurry (Choose One)

Installation Method: Poured

Setting Time: ____

Type of Sand Pack: Silica Sand

Grain Size: 20/40 (Sieve Size)

Installation Method: Poured

Type of Backfill Material: NA (if applicable)

Installation Method: ____

Elevations (MSL)*	Depths (BGS)	(.01ft.)
535.89	-2.83	Top of Protective Casing
535.52	-2.46	Top of Riser Pipe
533.06	0.00	Ground Surface
530.06	3.00	Top of Annular Sealant
____	____	Static Water Level (After Completion)
463.13	69.93	Top of Seal
460.13	72.93	Top of Sand Pack
458.13	74.93	Top of Screen
438.35	94.71	Bottom of Screen
438.29	94.77	Bottom of Well
438.06	95.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIAL

(Choose one type of material for each area)

Protective Casing	SS304, SS316, PTFE, PVC, or (Other)
Riser Pipe Above W.T.	SS304, SS316, PTFE, (PVC), or Other
Riser Pipe Below W.T.	(SS304) SS316, PTFE, PVC, or Other
Screen	(SS304) SS316, PTFE, PVC, or Other

CASING MEASURMENTS

Diameter of Borehole (inches)	9
ID of Riser Pipe (inches)	2
Protective Casing Length (feet)	5
Riser Pipe Length (feet)	77.39
Bottom of Screen to End Cap (feet)	0.06
Screen Length (1st slot to last slot) (feet)	19.78
Total Length of Casing (feet)	97.23
Screen Slot Size **	0.010

**Hand-Slotted Well Screens are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: 0798085001 County Jasper Well # G217

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 7121.09 Easting 6736.33

Drilling Contractor: PSI Environmental Services Date Drilled Start: 8/26/97

Driller: A. Shawgo Geologist: M. Summers Date Completed: 8/26/97

Drilling Method: 4¼ ID HSA Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Concrete

Type of Annular Sealant: 5% Bentonite in Cement

Amount of cement: # of bags ____ lbs. per bag ____

Amount of bentonite: # of bags ____ lbs. per bag ____

Type of Bentonite Seal (Granular, Pellet): Slurry

Amount of bentonite: # of Bags ____ lbs. per bag ____

Type of Sand Pack: Silica Sand #7

Source of Sand: Moble Drilling Supply

Amount of Sand: # of bags ____ lbs. per bag ____

Well Construction Materials

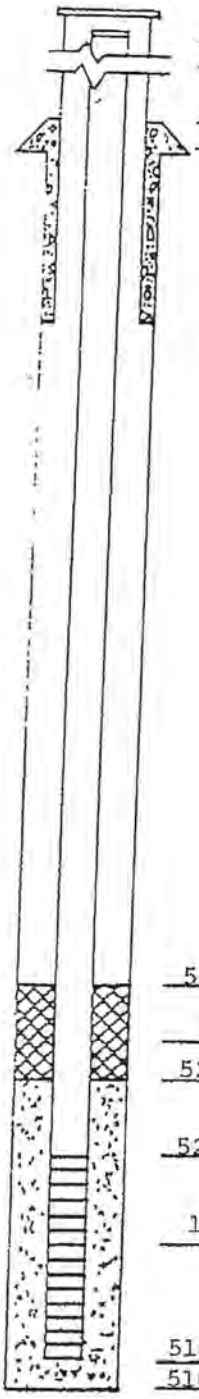
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint			Sch 40	
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	304			
Screen	304			
Coupling joint screen to riser	304			
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	10.0
Protective casing length	
Screen length	10.0
Bottom of screen to end cap	0.1
Top of screen to first joint	0.1
Total length of casing	5.0
Screen slot size	10 slot (0.01")
# of openings in screen	Continuous
Diameter of borehole (in)	8½"
ID of riser pipe (in)	2.0

Elevations — .01 ft.

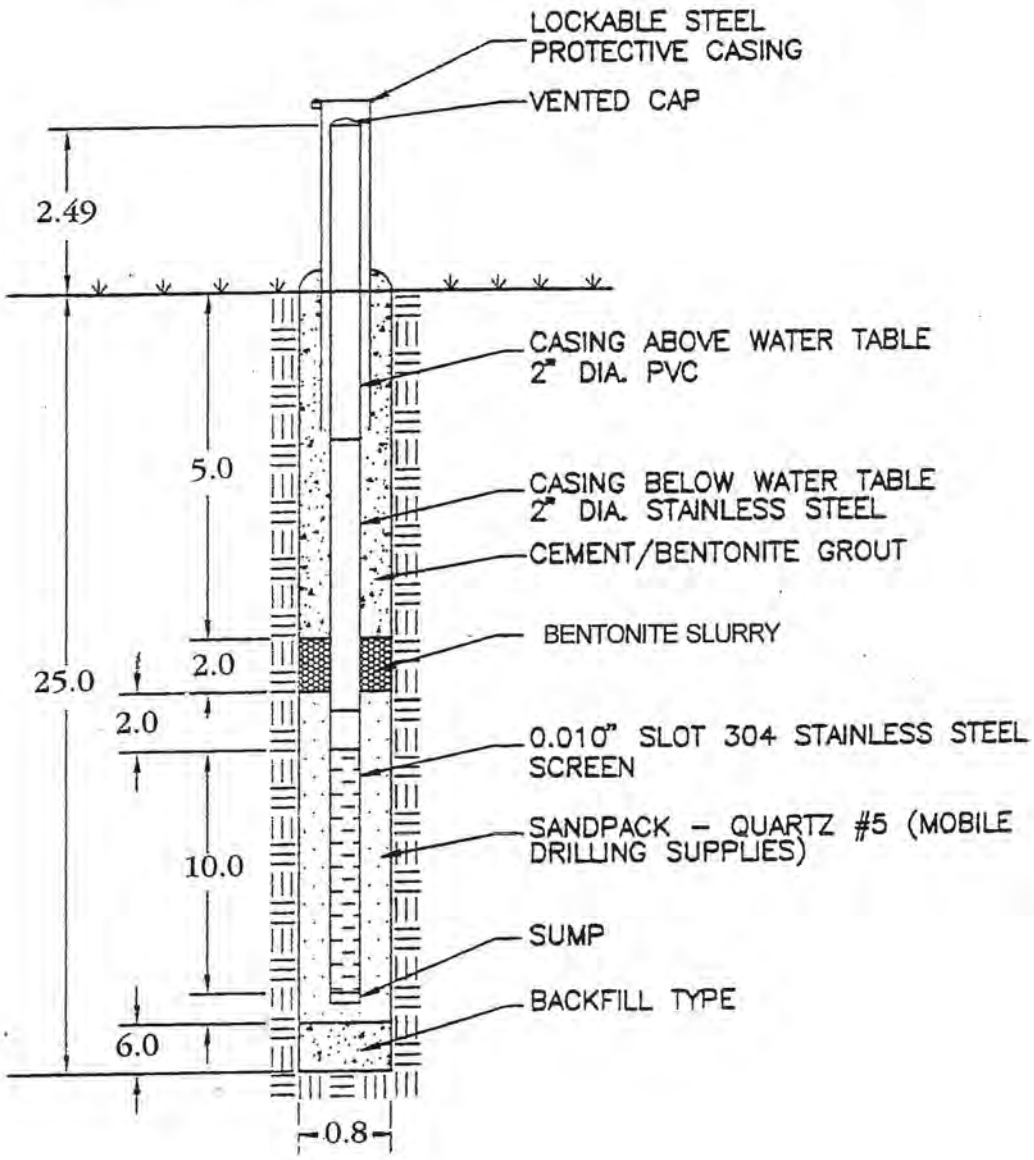


____ ____	MSL Top of Protective Casing
538. 16	MSL Top of Riser Pipe
____ ____	ft. Casing Stickup
535. 67	MSL Ground Surface
____ ____	ft. Top of annular sealant
530. 67	ft. Top of Seal
2. 0	ft. Total Seal Interval
528. 67	ft. Top of Sand
526. 67	ft. Top of Screen
10. 0	ft. Total Screen Interval
516. 67	ft. Bottom of Screen
510. 67	ft. Bottom of Borehole

Completed by: M. Summers Surveyed by: R. Whaley Ill. registration #: ____

Electronic Filing: Received, Clerk's Office 07/01/2024

MONITORING WELL CONSTRUCTION DIAGRAM



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G217
MONITORING WELL CONSTRUCTION DETAIL
Newton Power Station Landfill
Jasper County

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site Number: 0798085001 County: Jasper

Site Name: Newton Power Station Landfill Phase II Well #: G222

State Plane Coordinate: X ____ Y ____ (or) Latitude: ____ ____ ____ Longitude: ____ ____ ____ Borehole #: B222

Plant Coordinates: Northing 5322.24 Easting 3989.08

Surveyed by: Ken Miller IL Registration #: 196-001263

Drilling Contractor: Skinner Ltd. Driller: Todd Skinner

Consulting Firm: Rapps Engineering Geologist: Ken Miller

Drilling Method: HSA Drilling Fluid (Type): None

Logged By: Ken Miller Date Started: 10/24/11 Date Finished: 10/25/11

Report Form Completed By: Ken Miller Date: 11/30/11

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Slurry

Installation Method: Tremi

Setting Time: ____

Type of Bentonite Seal - - Granular, (Pellet), Slurry (Choose One)

Installation Method: Poured

Setting Time: ____

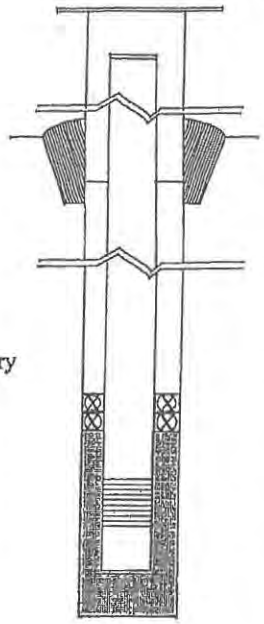
Type of Sand Pack: Silica Sand

Grain Size: 20/40 (Sieve Size)

Installation Method: Poured

Type of Backfill Material: NA (If applicable)

Installation Method: ____



Elevations (MSL)*	Depths (BGS)	(.01ft.)
535.16	-3.04	Top of Protective Casing
534.78	-2.66	Top of Riser Pipe
532.12	0.00	Ground Surface
529.12	3.00	Top of Annular Sealant
____	____	Static Water Level (After Completion)
472.55	59.57	Top of Seal
469.55	62.57	Top of Sand Pack
467.55	64.57	Top of Screen
452.88	79.24	Bottom of Screen
452.81	79.31	Bottom of Well
452.12	80.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIAL

(Choose one type of material for each area)

Protective Casing	SS304, SS316, PTFE, PVC, or (Other)
Riser Pipe Above W.T.	SS304, SS316, PTFE, (PVC), or Other
Riser Pipe Below W.T.	(SS304), SS316, PTFE, PVC, or Other
Screen	(SS304), SS316, PTFE, PVC, or Other

CASING MEASURMENTS

Diameter of Borehole (inches)	9
ID of Riser Pipe (inches)	2
Protective Casing Length (feet)	5
Riser Pipe Length (feet)	67.27
Bottom of Screen to End Cap (feet)	0.07
Screen Length (1st slot to last slot) (feet)	14.63
Total Length of Casing (feet)	81.97
Screen Slot Size **	0.010

**Hand-Slotted Well Screens are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site Number: 0798085001 County: Jasper

Site Name: Newton Power Station Landfill Phase II Well #: G224

State Plane Coordinate: X ____ Y ____ (or) Latitude: ____ ____ ____ Longitude: ____ ____ ____ Borehole #: B224

Plant Coordinates: Northing 6976.66 Easting 6067.30

Surveyed by: Ken Miller IL Registration #: 196-001263

Drilling Contractor: Whitney & Associates Driller: Tim Fuhl

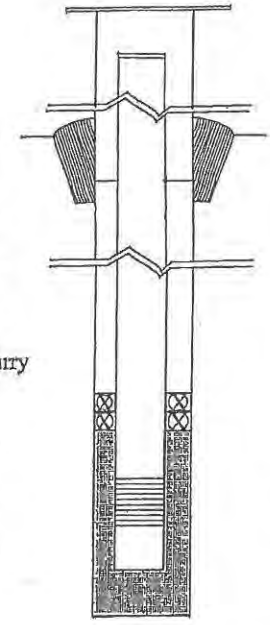
Consulting Firm: Rapps Engineering Geologist: Ken Miller

Drilling Method: HSA Drilling Fluid (Type): None

Logged By: Ken Miller Date Started: 10/4/11 Date Finished: 10/5/11

Report Form Completed By: Ken Miller Date: 11/30/11

ANNULAR SPACE DETAILS



Elevations (MSL)*	Depths (BGS)	(.01ft.)
535.19	-2.93	Top of Protective Casing
534.78	-2.52	Top of Riser Pipe
532.26	0.00	Ground Surface
529.26	3.00	Top of Annular Sealant
____	____	Static Water Level (After Completion)
473.75	58.51	Top of Seal
470.75	61.51	Top of Sand Pack
468.75	63.51	Top of Screen
459.09	73.17	Bottom of Screen
458.75	73.51	Bottom of Well
458.26	74.00	Bottom of Borehole

* Referenced to a National Geodetic Datum

Type of Surface Seal: Concrete

Type of Annular Sealant: Bentonite Chips

Installation Method: Poured

Setting Time: ____

Type of Bentonite Seal - - Granular, (Pellet), Slurry (Choose One)

Installation Method: Poured

Setting Time: ____

Type of Sand Pack: Silica Sand

Grain Size: 50 (Sieve Size)

Installation Method: Poured

Type of Backfill Material: NA (if applicable)

Installation Method: ____

WELL CONSTRUCTION MATERIAL

(Choose one type of material for each area)

Protective Casing	SS304, SS316, PTFE, PVC, or (Other)
Riser Pipe Above W.T.	SS304, SS316, PTFE, (PVC), or Other
Riser Pipe Below W.T.	(SS304), SS316, PTFE, PVC, or Other
Screen	(SS304), SS316, PTFE, PVC, or Other

CASING MEASURMENTS

Diameter of Borehole (inches)	9
ID of Riser Pipe (inches)	2
Protective Casing Length (feet)	5
Riser Pipe Length (feet)	66.03
Bottom of Screen to End Cap (feet)	0.34
Screen Length (1st slot to last slot) (feet)	9.66
Total Length of Casing (feet)	76.03
Screen Slot Size **	0.010

**Hand-Slotted Well Screens are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798085001 County: Jasper Well #: R217D

Site Name: Newton Power Station Borehole #: R217D

~~State~~ Plant ~~Plane~~ Coordinate: X 6,712.2 Y 7,126.9 (or) Latitude: 38° 55' 55.889" Longitude: -88° 17' 24.426"

Surveyed By: Matthew H. Schrader IL Registration #: 035-003487

Drilling Contractor: Bulldog Drilling Driller: J. Dittmaier

Consulting Firm: Hanson Professional Services Inc. Geologist: Rhonald W. Hasenyager, LPG #196-000246

Drilling Method: Mud Rotary Drilling Fluid (Type): Bentonite mud

Logged By: Rhonald W. Hasenyager Date Started: 9/25/2017 Date Finished: 9/26/2017

Report Form Completed By: Suzanna L. Keim Date: 10/16/2017

ANNULAR SPACE DETAILS

Type of Surface Seal: Concrete

Type of Annular Sealant: high-solids bentonite

Installation Method: Tremie

Setting Time: +24 hours

Type of Bentonite Seal -- (Granular) Pellet Slurry (choose one)

Installation Method: Gravity

Setting Time: 10 minutes

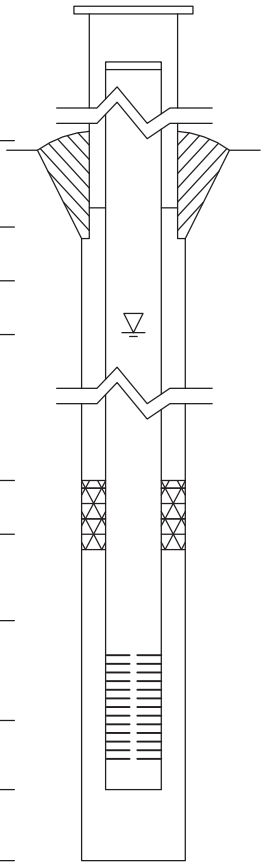
Type of Sand Pack: Quartz sand

Grain Size: 10/20 (sieve size)

Installation Method: Gravity

Type of Backfill Material: none (if applicable)

Installation Method:



Elevations (MSL)*	Depths (BGS) (0.01 ft.)	
538.85	-2.94	Top of Protective Casing
538.55	-2.64	Top of Riser Pipe
535.91	0.00	Ground Surface
533.41	2.50	Top of Annular Sealant
		Static Water Level (After Completion)
479.39	56.52	Top of Seal
478.01	57.90	Top of Sand Pack
475.81	60.10	Top of Screen
470.88	65.03	Bottom of Screen
470.67	65.24	Bottom of Well
470.67	65.24	Bottom of Borehole

* Referenced to a National Geodetic Datum

WELL CONSTRUCTION MATERIALS

(Choose one type of material for each area)

Protective Casing	SS304	SS316	PTFE	PVC	OTHER: (Steel)
Riser Pipe Above W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Riser Pipe Below W.T.	SS304	SS316	PTFE	(PVC)	OTHER:
Screen	SS304	SS316	PTFE	(PVC)	OTHER:

CASING MEASUREMENTS

Diameter of Borehole	(inches)	8.0
ID of Riser Pipe	(inches)	2.0
Protective Casing Length	(feet)	5.0
Riser Pipe Length	(feet)	62.64
Bottom of Screen to End Cap	(feet)	0.31
Screen Length (1st slot to last slot)	(feet)	4.93
Total Length of Casing	(feet)	67.88
Screen Slot Size **	(inches)	0.010

**Hand-Slotted Well Screens Are Unacceptable

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX D
GEOTECHNICAL LABORATORY REPORT

Electronic Filing: Received, Clerk's Office 07/01/2024

April 13, 2021
Revised: May 10, 2021

Mr. Scott Woods
Ramboll Environ U.S. Corporation
333 West Wacker Drive, Ste 2700
Chicago, IL 60606-2872

RE: Laboratory Testing Program for the Newton Power Station Project – Terracon Project No. 11215019

Dear Mr. Woods,

We are pleased to submit our report pertaining to geotechnical laboratory testing of thirty-one (31) soil samples in reference to the Newton Power Station Project. Per your instructions, Terracon performed the following tests on each of the samples:

- Specific Gravity of Soils – ASTM D854
- Water Content of Soil and Rock – ASTM D2216
- Liquid Limit, Plastic Limit and Plasticity Index of Soils – ASTM D4318
- Permeability of Granular Soils (Constant Head) – ASTM D 2434 *
- Hydraulic Conductivity of Saturated Porous Materials Using a Flexible-Wall Permeameter – ASTM D5084
- Laboratory Determination of Density (Unit Weight) of Soil Specimens – ASTM D7263
- Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis – ASTM D6913
- Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis – ASTM D7928

Three samples originally scheduled for hydraulic conductivity tests following ASTM D5084 did not meet the flow criteria for the standard because of the granular matrix of the samples. Instead the tests were run following ASTM D 2434 which allows for greater permeant flow through the specimen.

The test data included in this report, only represent the samples tested and may not reflect actual site materials and/or conditions. The scope of services provided by Terracon did not include interpretation of the laboratory test data, and therefore, we are not liable for any interpretation performed by others. If you wish us to provide you with this service, we would be happy to discuss this matter with you at your convenience. Any reproduction of this report must be done in its entirety.

We are pleased to have the opportunity to provide you with our testing services. Should you have any questions, or require additional assistance, please feel free to contact us at any time.

Sincerely,
Terracon Consultants, Inc.



William P. Quinn
Department Manager – Laboratory Services

Attachments:

Electronic Filing: Received, Clerk's Office 07/01/2024

LABORATORY TESTING SUMMARY

PROJECT NAME: Newton Power Station | PROJECT NUMBER: 11215019 | CLIENT: Ramboll

Boring Number	Sample Number	Depth	Description	USCS	WC %	Dry Density (pcf)	% Gravel	% Sand	% Silt	% Clay	LL	PL	PI	Permeability k (cm/sec)	Specific Gravity
APW-11	0805	10.0'-12.0'	BROWN SANDY LEAN CLAY	CL	17.8	111.7	1.1	45.1	25.2	28.6	28	12	16	8.57E-08	2.645
APW-11	1050	61.0'-61.5'	GRAYISH BROWN LEAN CLAY WITH SAND	CL	17.8	110.5	0.0	21.4	48.4	30.2	27	18	9	1.87E-07	2.686
APW-11	1115	80.0'-82.0'	DARK GRAY LEAN CLAY WITH SAND	CL	16.5	116.1	0.0	21.0	44.4	34.6	32	14	18	2.94E-08	2.705
APW-12	0825	20.0'-22.0'	BROWN AND RUST BROWN CLAYEY SAND - ROOTS NOTED	SC	15.1	118.3	7.4	46.8	24.3	21.5	27	12	15	1.07E-07	2.694
APW-12	0845	25.5'-26.0'	BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	SP-SM	8.4	113.0	24.3	69.5	2.9	3.3	10	13	NP	8.43E-06	2.654
APW-12	1245	85.0'-87.0'	DARK GRAY LEAN CLAY WITH SAND - SILT POCKETS NOTED	CL	14.4	116.4	0.3	19.5	44.4	35.8	29	14	15	2.36E-08	2.711
APW-13	0845	25.0'-27.0'	DARK BROWN AND GRAY POORLY GRADED SAND WITH SILT	SP-SM	21.2	87.1	0.0	88.9	6.8	4.3	9	10	NP	9.63E-05	2.649
APW-13	1345	60.5'-61.0'	BROWN SILTY SAND	SM	14.5	114.3	0.3	75.2	19.4	5.1	8	13	NP	2.18E-04	2.661
APW-14	0955	45.0'-47.0'	BROWN SANDY LEAN CLAY	CL	12.4	119.6	4.4	32.3	36.5	26.8	26	14	12	9.65E-08	2.706
APW-14	1045	55.5'-56.0'	GRAY AND BROWNISH GRAY LEAN CLAY WITH SAND	CL	18.0	104.6	0.0	27.8	44.4	27.8	25	15	10	2.74E-07	2.709
APW-15	1005	20.0'-22.0'	BROWN SANDY LEAN CLAY	CL	18.5	109.8	0.0	40.8	27.4	31.8	33	10	23	3.21E-08	2.686
APW-15	0755	100.5'-101.0'	GRAY SILTY SAND	SM	12.1	116.4	4.4	49.8	39.0	6.8	15	12	3	3.50E-06	2.665
APW-15	0905	105.0'-107.0'	DARK GRAY LEAN CLAY WITH SAND	CL	19.1	107.8	0.0	23.8	47.1	29.1	29	13	16	8.20E-08	2.695
APW-17	0945	40.0'-42.0'	GRAY LEAN CLAY WITH SAND	CL	16.6	108.8	1.3	27.6	44.1	27.0	26	13	13	3.34E-08	2.709
APW-17	1045	71.0'-71.5'	GRAY WELL GRADED SAND WITH SILT	SW-SM	7.8	110.2	14.3	76.8	5.1	3.8	5	9	NP	7.21E-04	2.660
APW-17	1200	90.5'-91.0'	GRAYISH BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	SP-SM	6.1	116.8	28.2	65.1	4.2	2.5	6	8	NP	6.39E-04	2.672
SB-300	0825	50.0'-52.0'	DARK GRAY LEAN CLAY WITH SAND	CL	12.9	122.7	0.8	22.4	44.5	32.3	32	12	20	7.29E-08	2.700
SB-300	0905	61.0'-61.5'	GRAYISH BROWN SILTY SAND	SM	13.6	109.6	4.7	78.2	12.5	4.6	5	9	NP	1.85E-05	2.686
SB-300	0920	62.5'-63.0'	GRAY AND BROWN SANDY SILTY CLAY	CL-ML	11.1	124.6	0.0	42.4	40.8	16.8	20	14	6	4.32E-06	2.659
SB-300	1350	105.0'-107.0'	DARK GRAY SANDY LEAN CLAY	CL	14.1	116.4	0.0	30.7	37.7	31.6	28	13	15	4.28E-08	2.710
SB-301	1330	48.0'-50.0'	BROWN AND GRAY SANDY LEAN CLAY	CL	14.1	117.3	0.4	34.2	35.5	29.9	27	14	13	6.63E-08	2.697
SB-301	1600	68.5'-69.0'	GRAY SANDY LEAN CLAY	CL	13.1	121.3	0.0	31.3	43.2	25.5	23	14	9	4.05E-08	2.723
SB-301	0946	98.0'-100.0'	DARK BROWN TO DARK GRAY LEAN CLAY WITH SAND	CL	15.7	118.2	0.0	17.8	47.0	35.2	37	15	22	6.13E-08	2.720
XPW-01	0820	8.5'-9.0'	DARK GRAY AND BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	SP-SM	18.6	87.7	37.1	51.1	8.2	3.6	47	57	NP	1.71E-04	2.675
XPW-01	0840	15.5'-16.0'	GRAY AND BROWN SANDY LEAN CLAY	CL	12.6	84.4	4.6	34.1	35.1	26.2	35	17	18	1.58E-05	2.741

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LABORATORY TESTING SUMMARY

PROJECT NAME: Newton Power Station

PROJECT NUMBER: 11215019

CLIENT: Ramboll

Boring Number	Sample Number	Depth	Description	USCS	WC %	Dry Density (pcf)	% Gravel	% Sand	% Silt	% Clay	LL	PL	PI	Permeability k (cm/sec)	Specific Gravity
XPW-02	1530	8.0'-8.5'	VERY DARK GRAY, GRAY AND BROWN SANDY LEAN CLAY	CL	29.1	92.9	0.3	44.8	28.9	26.0	36	16	20	6.07E-08	2.691
XPW-02	1545	16.5'-17.0'	GRAY AND DARK BROWN LEAN CLAY WITH SAND	CL	21.8	103.7	0.0	19.8	42.5	37.7	36	14	22	7.38E-08	2.694
XPW-03	1255	6.0'-6.5'	DARK BROWNISH GRAY SILTY SAND	SM	17.4	75.3	6.8	71.7	16.0	5.5	33	27	6	1.34E-03	2.663
XPW-03	1315	15.5'-16.0'	BROWNISH GRAY SILTY SAND WITH GRAVEL	SM	16.7	103.6	16.4	67.3	12.3	4.0	12	19	NP	9.70E-05	2.689
XPW-04	1000	6.5'-7.0'	GRAY SILTY SAND	SM	31.1	73.9	1.6	84.5	10.9	3.0	41	38	3	1.61E-04	2.697
XPW-04	1020	15.5'-16.0'	DARK BROWNISH GRAY SILTY SAND WITH GRAVEL	SM	31.1	80.8	15.7	51.0	24.7	8.6	46	42	4	7.83E-05	2.650

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Specific Gravity of Soils
ASTM D854

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Terracon
Consulting Engineers & Scientists

SPECIFIC GRAVITY OF SOIL SOLIDS
ASTM D-854

Laboratory Services Group 192 Exchange Blvd. Glendale Heights, Illinois 60139 Ph. (630) 717-4263

Project Number: 11215019
Project Name: Newton Power Station
Test Date: 3/1/2021

Results Summary

Boring / Sample	Sample Number	Depth (ft)		Specific Gravity (Gs)
APW-11	0805	10.0'-12.0'		2.645
APW-11	1050	61.0'-61.5'		2.686
APW-11	1115	80.0'-82.0'		2.705
APW-12	0825	20.0'-22.0'		2.694
APW-12	0845	25.5'-26.0'		2.654
APW-12	1245	85.0'-87.0'		2.711
APW-13	0845	25.0'-27.0'		2.649
APW-13	1345	60.5'-61.0'		2.661
APW-14	0955	45.0'-47.0'		2.706
APW-14	1045	55.5'-56.0'		2.709
APW-15	1005	20.0'-22.0'		2.686
APW-15	0755	100.5'-101.0'		2.665
APW-15	0905	105.0'-107.0'		2.692
APW-17	0945	40.0'-42.0'		2.709
APW-17	1045	71.0'-71.5'		2.660
APW-17	1200	90.5'-91.0'		2.672

Tested By: SJH Checked By: WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Terracon
Consulting Engineers & Scientists

SPECIFIC GRAVITY OF SOIL SOLIDS
ASTM D-854

Laboratory Services Group 192 Exchange Blvd. Glendale Heights, Illinois 60139 Ph. (630) 717-4263

Project Number: 11215019
Project Name: Newton Power Station
Test Date: 3/1/2021

Results Summary

Boring / Sample	Sample Number	Depth (ft)		Specific Gravity (Gs)
SB-300	0825	50.0'-52.0'		2.700
SB-300	0905	61.0'-61.5'		2.686
SB-300	0920	62.5'-63.0'		2.659
SB-300	1350	105.0'-107.0'		2.710
SB-301	1330	48.0'-50.0'		2.697
SB-301	1600	68.5'-69.0'		2.723
SB-301	0946	98.0'-100.0'		2.720
XPW-01	0820	8.5'-9.5'		2.675
XPW-01	0840	15.5'-16.0'		2.741
XPW-02	1530	8.0'-8.5'		2.691
XPW-02	1545	16.5'-17.0'		2.694
XPW-03	1355	6.0'-6.5'		2.663
XPW-03	1315	15.5'-16.0'		2.689
XPW-04	1000	6.5'-7.0'		2.697
XPW-04	1020	15.5'-16.0'		2.650

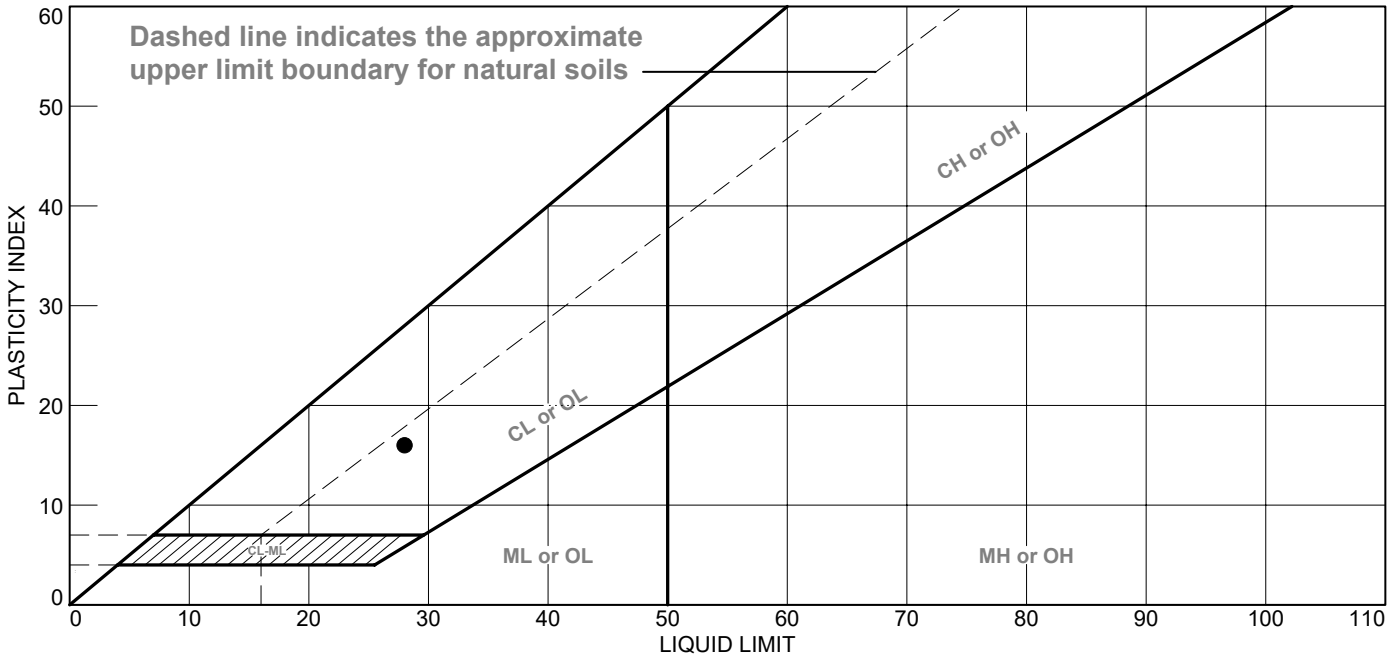
Tested By: SJH Checked By: WPQ

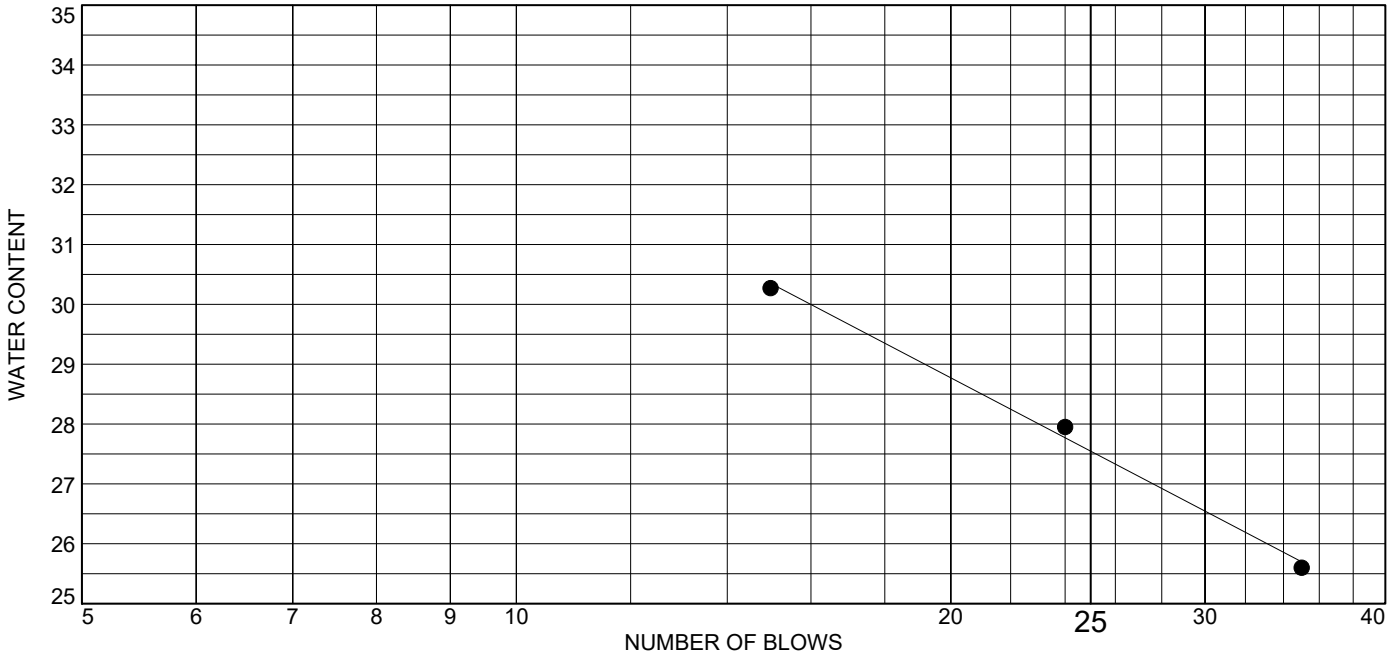
Electronic Filing: Received, Clerk's Office 07/01/2024

Liquid Limit, Plastic Limit and Plasticity Index of Soils
ASTM D4318

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SANDY LEAN CLAY	28	12	16	88.7	53.8	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-11 **Depth:** 10.0'-12.0'
Sample Number: 0805

Remarks:

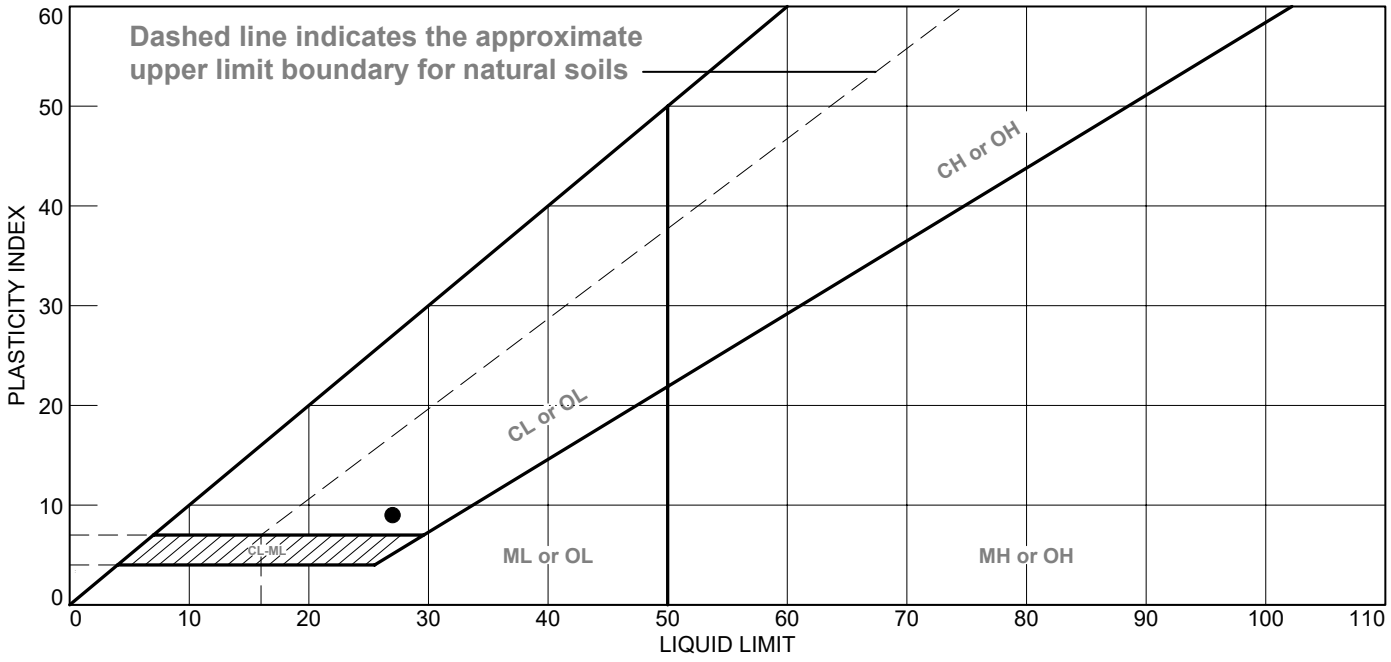
Terracon

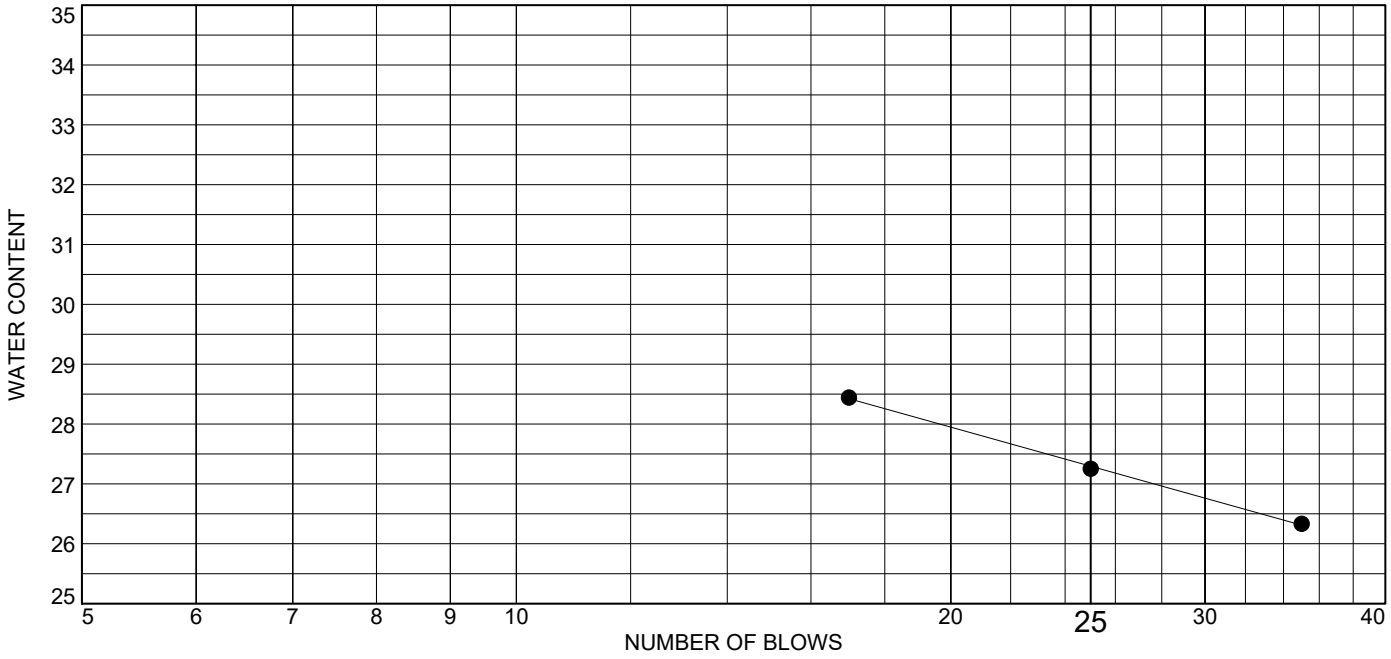
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAYISH BROWN LEAN CLAY WITH SAND	27	18	9	91.9	78.6	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-11 **Depth:** 61.0'-61.5'
Sample Number: 1050

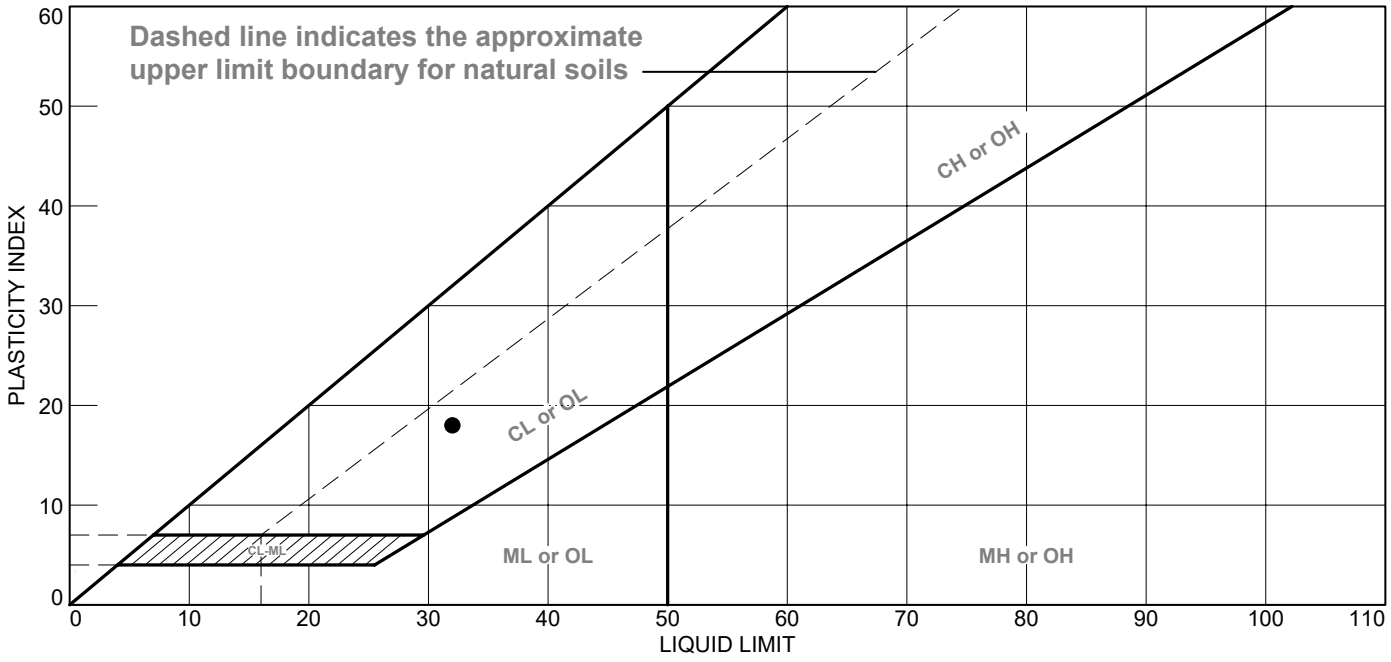
Remarks:

Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND	32	14	18	95.4	79.0	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-11 **Depth:** 80.0'-82.0'
Sample Number: 1115

Remarks:

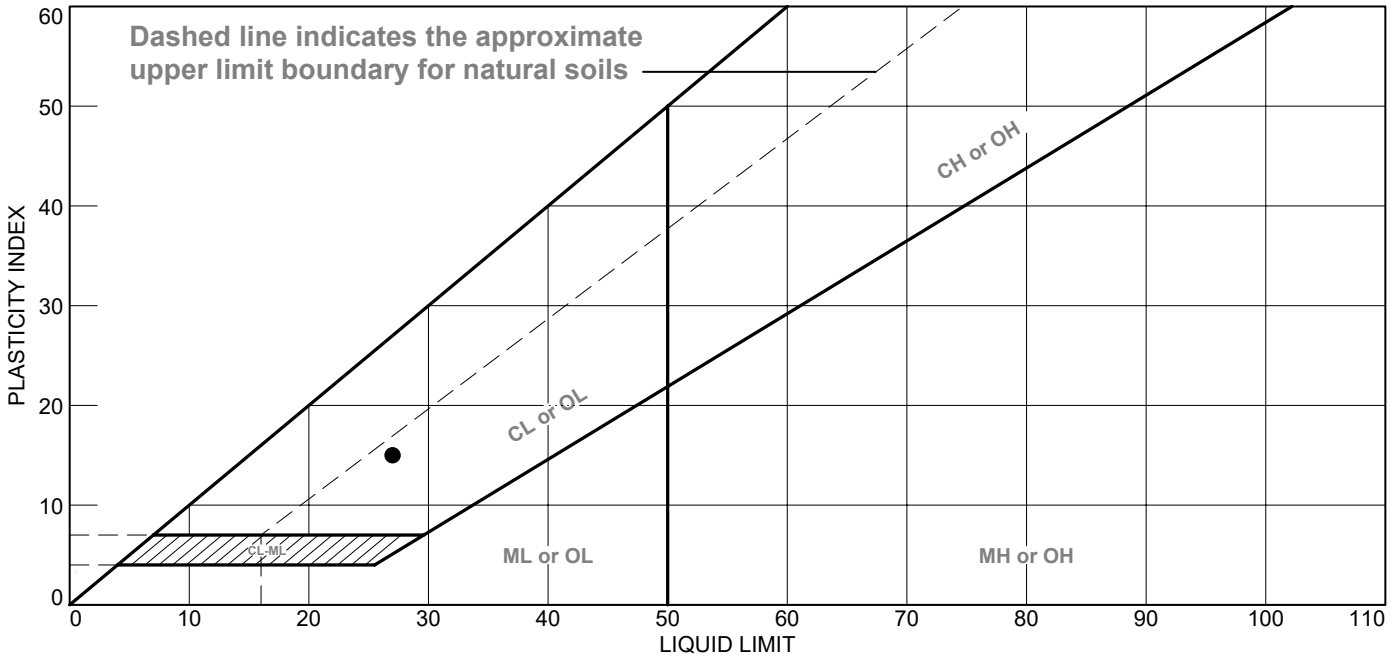
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND RUST BROWN CLAYEY SAND - ROOTS NOTED	27	12	15	82.3	45.8	SC

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-12 **Depth:** 20.0'-22.0'
Sample Number: 0825

Remarks:

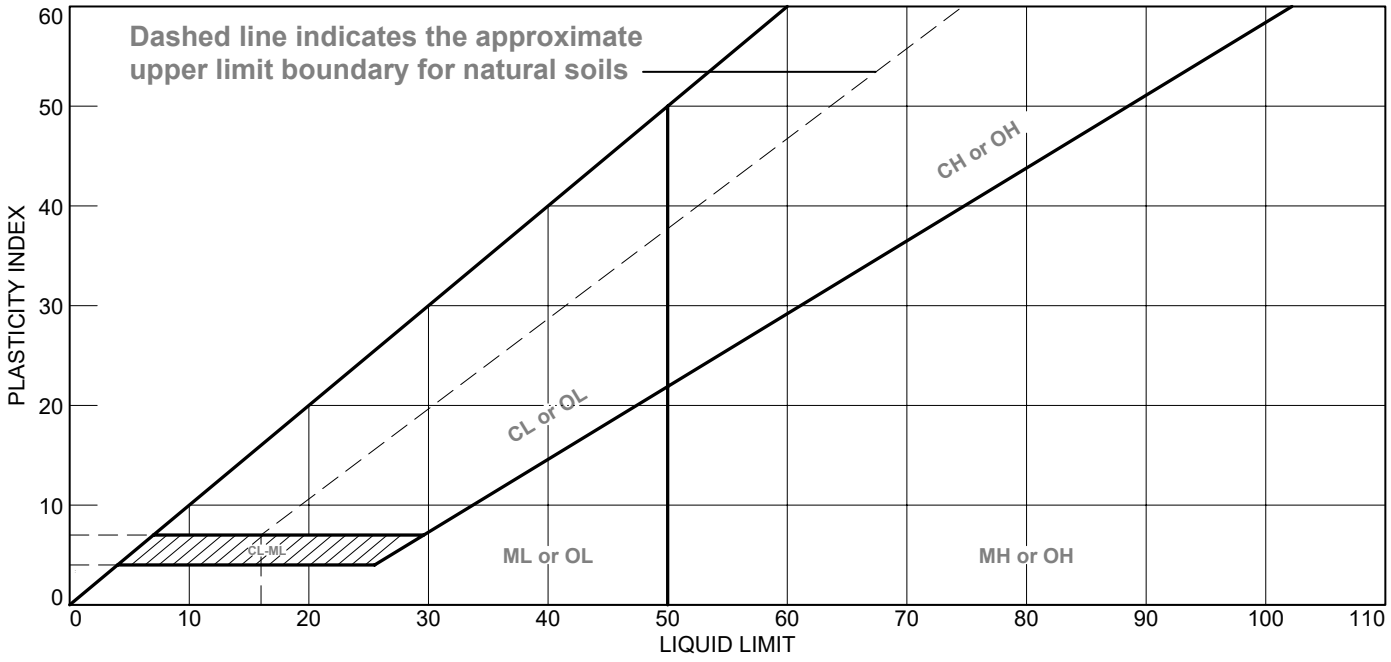
Terracon

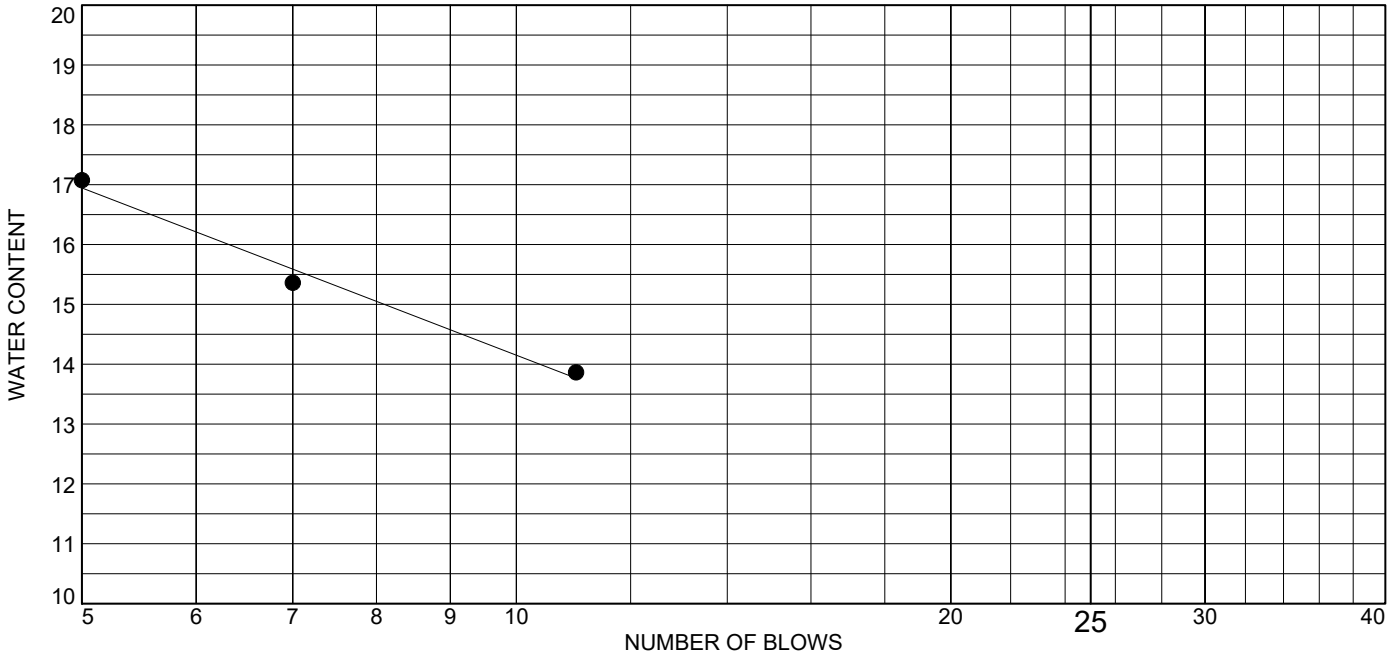
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	10	13	NP	21.4	6.2	SP-SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-12 **Depth:** 25.5'-26.0'
Sample Number: 0845

Remarks:

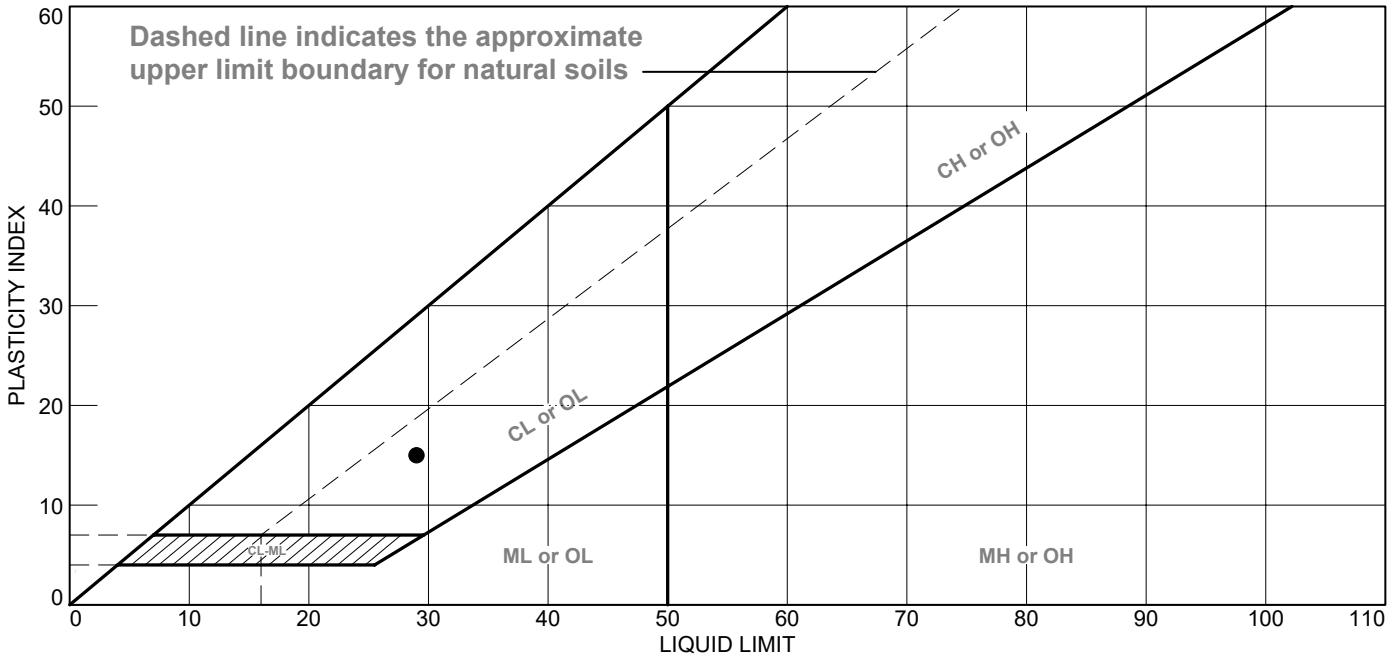
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND - SILT POCKETS NOTED	29	14	15	96.1	80.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-12 **Depth:** 85.0'-87.0'
Sample Number: 1245

Remarks:

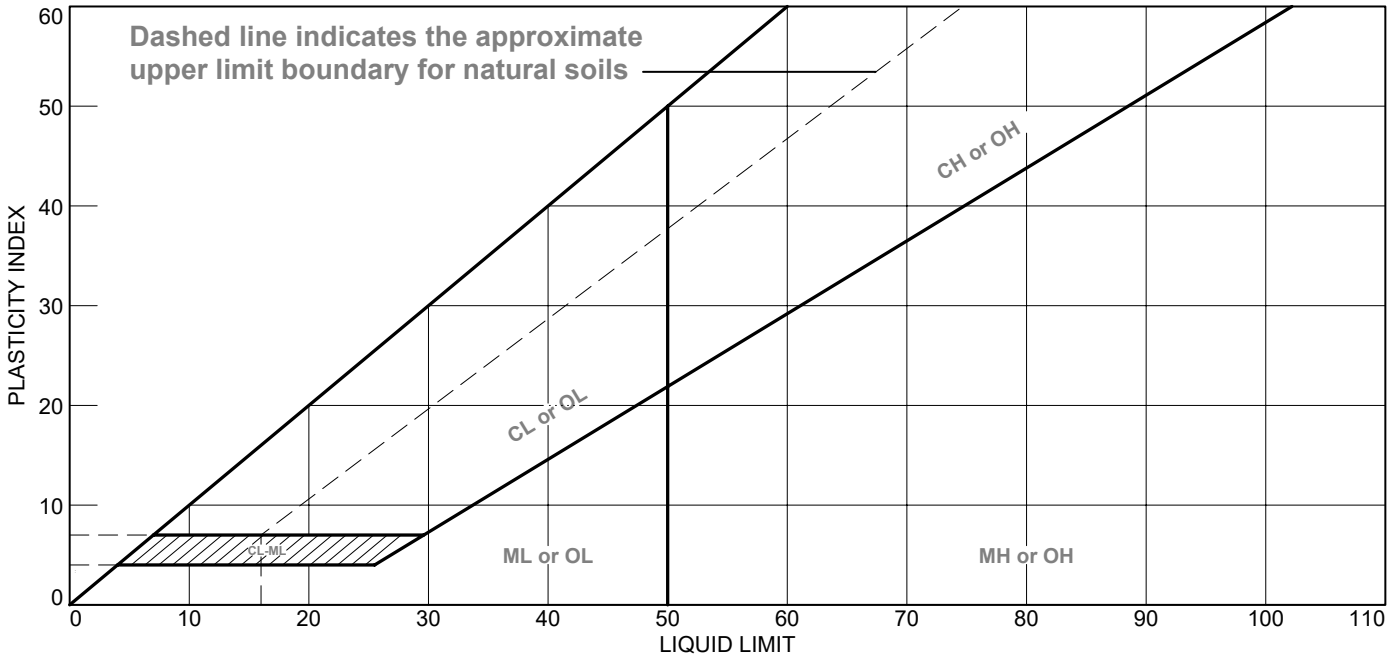
Terracon

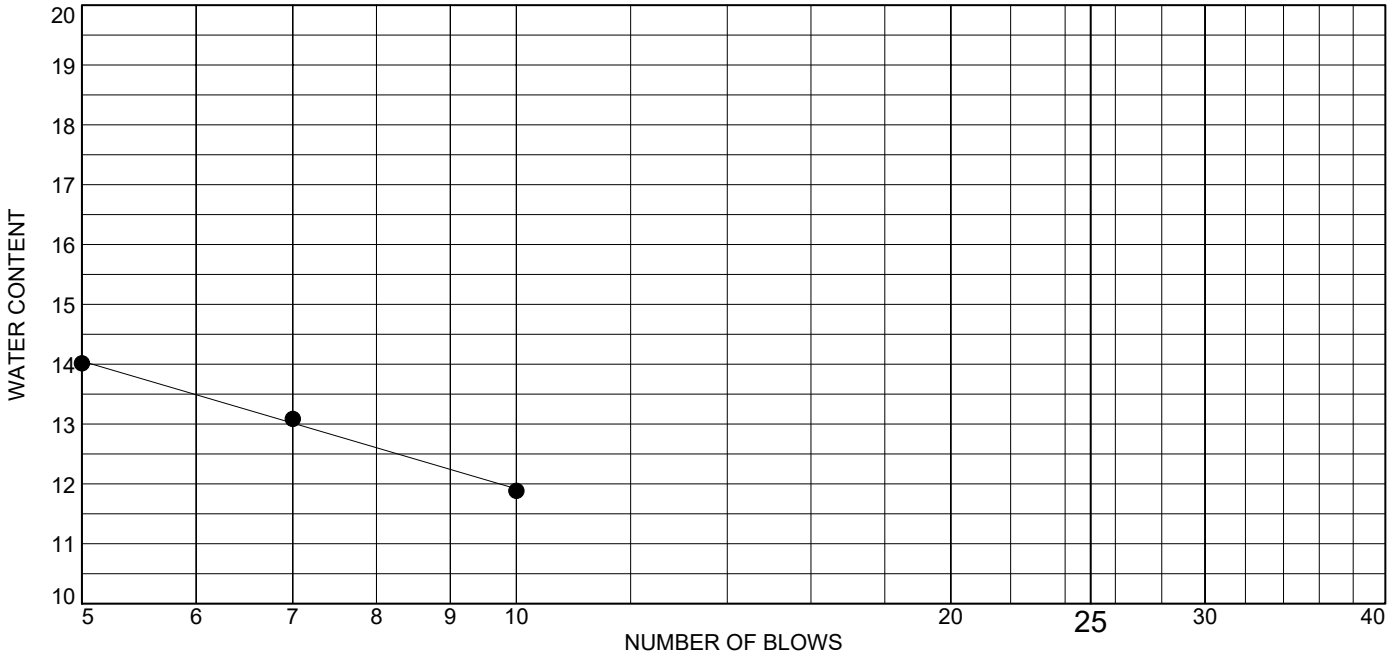
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN AND GRAY POORLY GRADED SAND WITH SILT	9	10	NP	30.5	11.1	SP-SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-13 **Depth:** 25.0'-27.0'
Sample Number: 0845

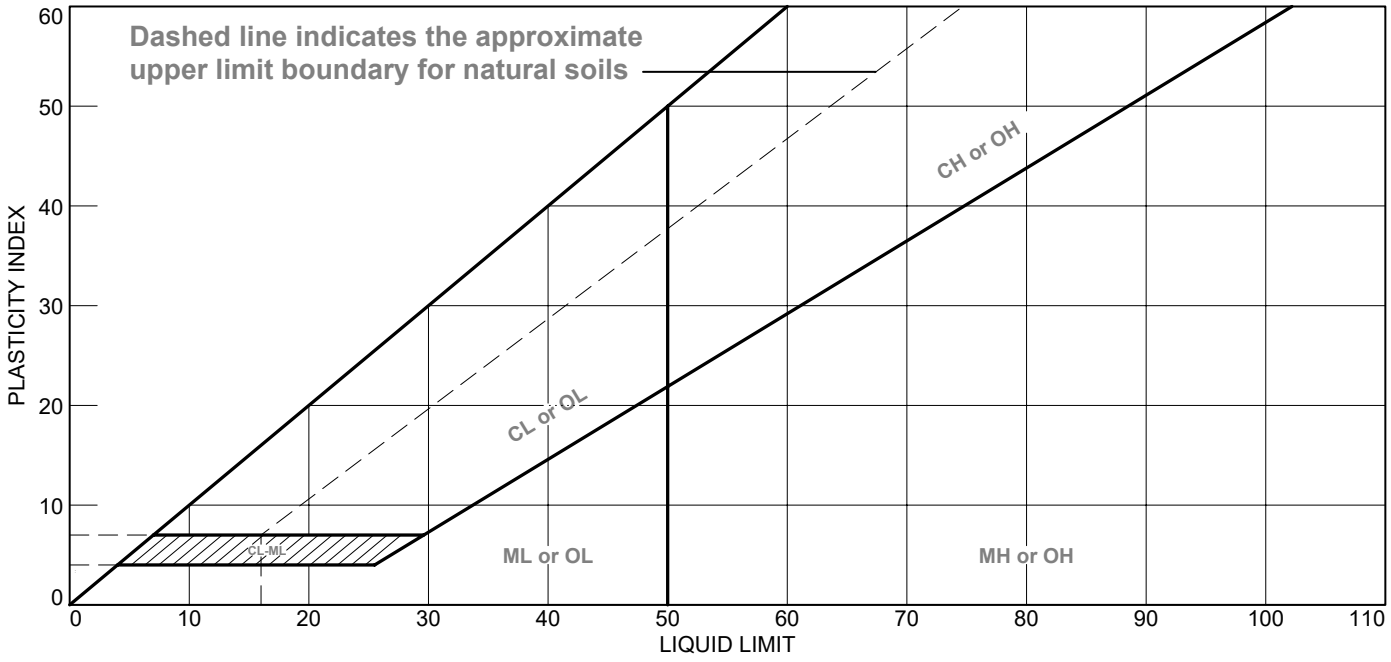
Remarks:

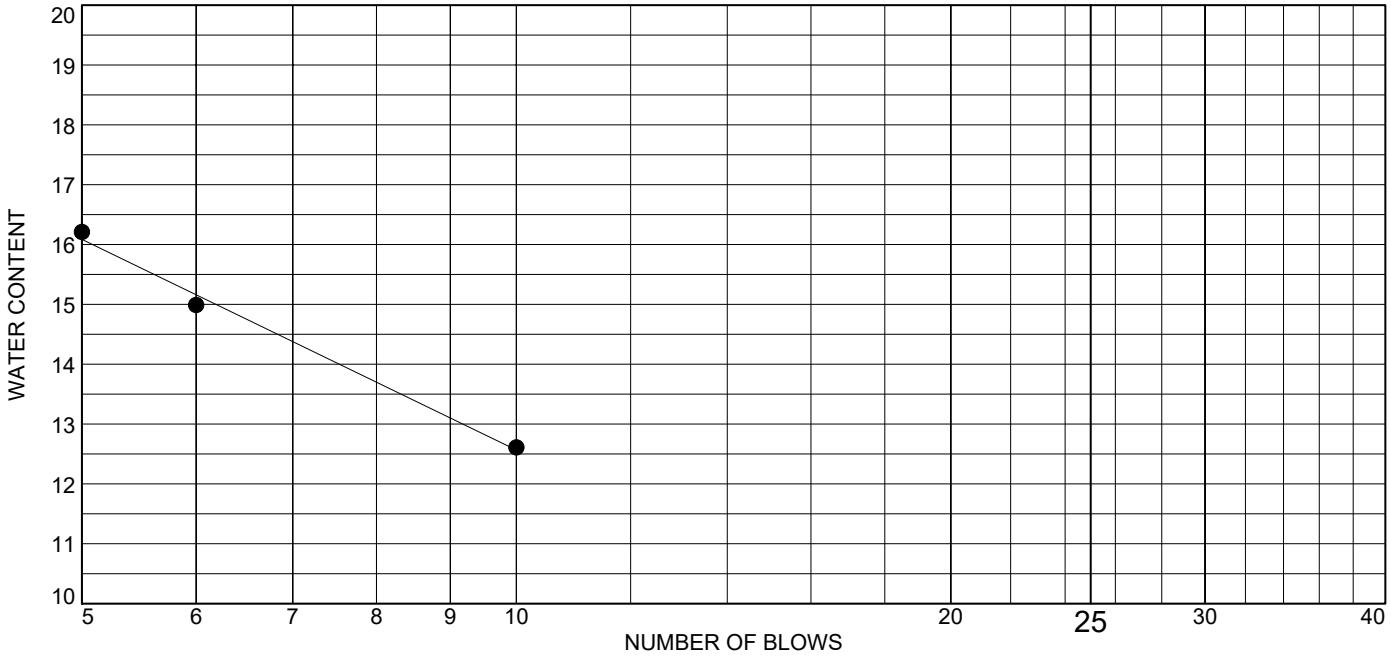
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SILTY SAND	8	13	NP	86.6	24.5	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-13 **Depth:** 60.5'-61.0'
Sample Number: 1345

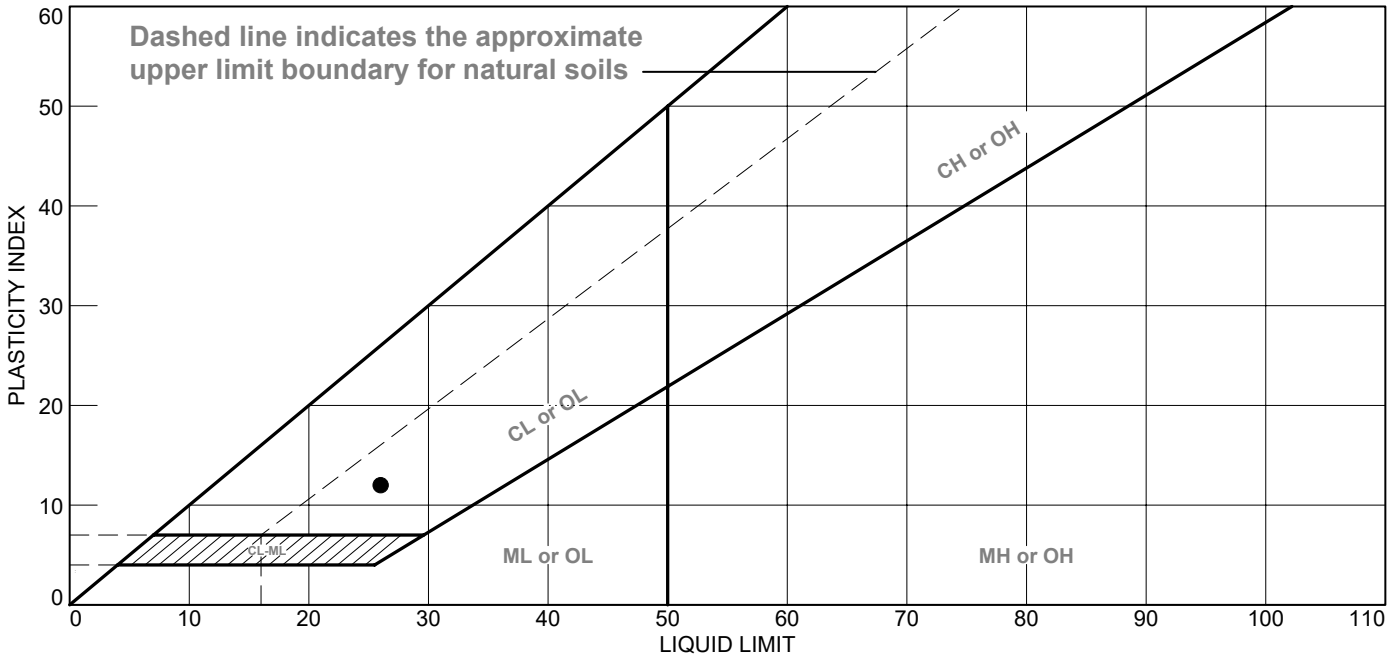
Remarks:

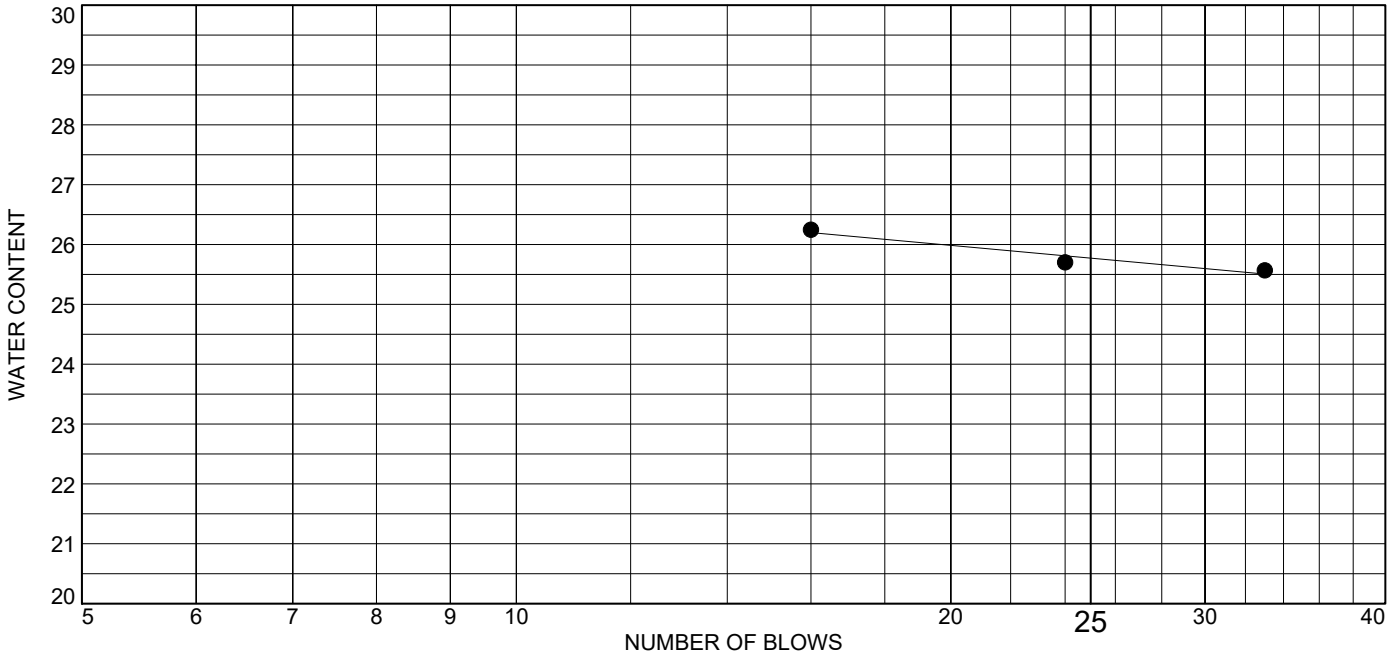
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SANDY LEAN CLAY	26	14	12	84.5	63.3	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-14 **Depth:** 45.0'-47.0'
Sample Number: 0955

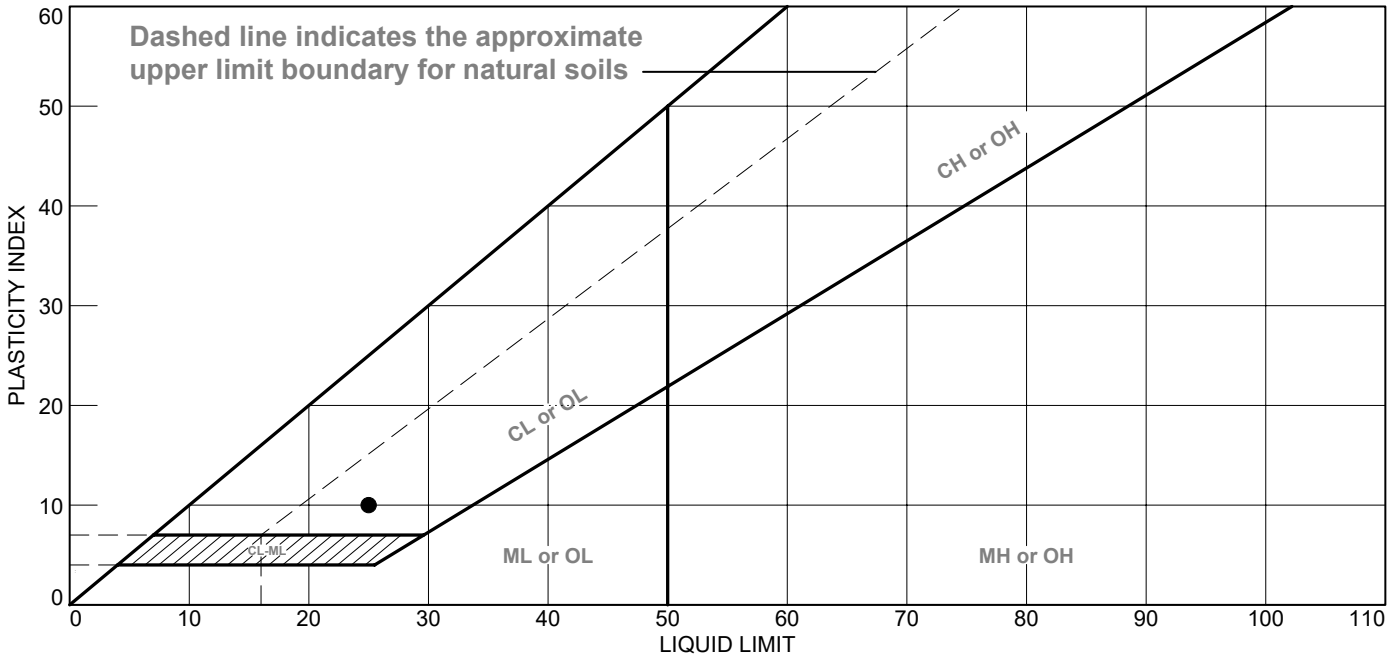
Remarks:

Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY AND BROWNISH GRAY LEAN CLAY WITH SAND	25	15	10	91.1	72.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-14 **Depth:** 55.5'-56.0'
Sample Number: 1045

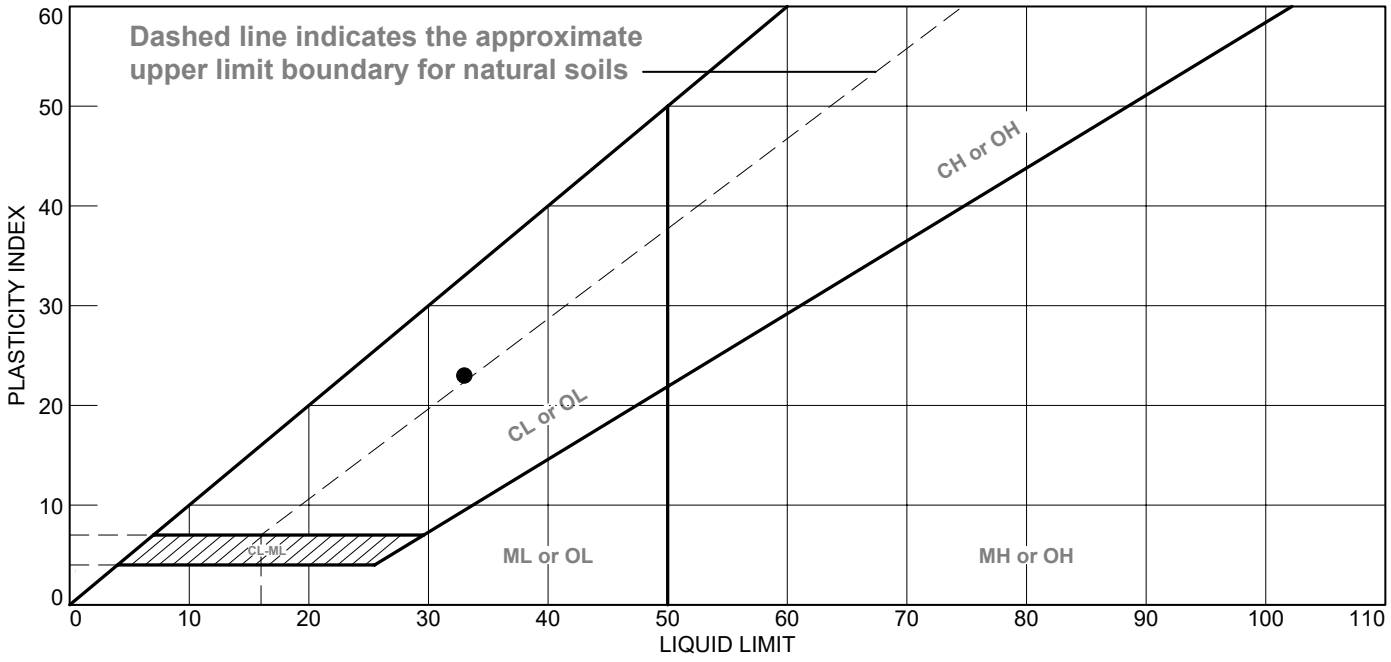
Remarks:

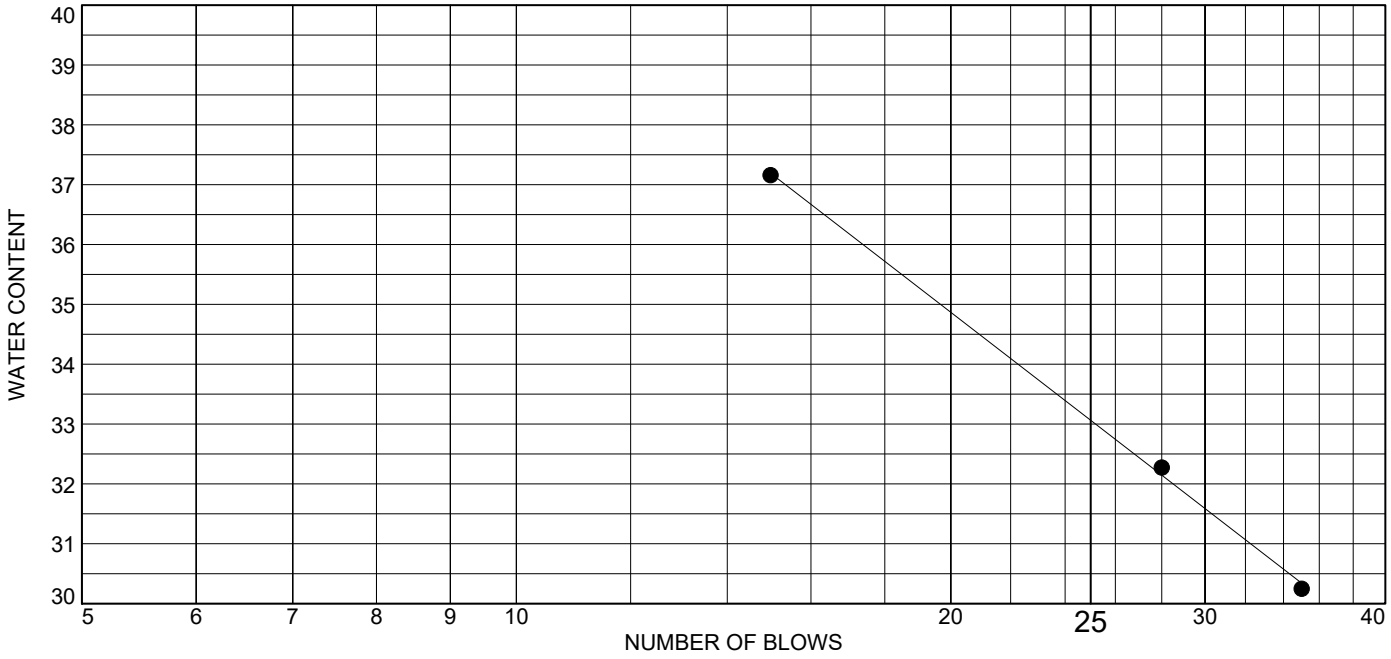
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN SANDY LEAN CLAY	33	10	23	95.1	59.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-15 **Depth:** 20.0'-22.0'
Sample Number: 1005

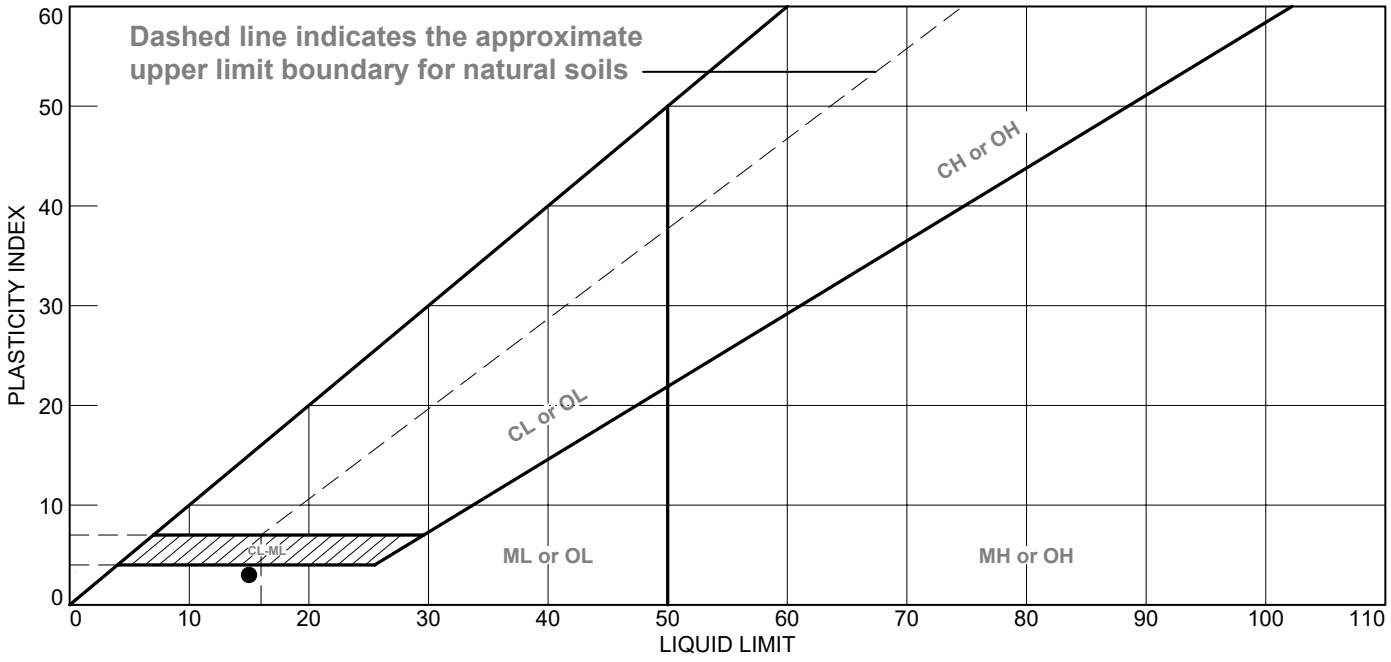
Remarks:

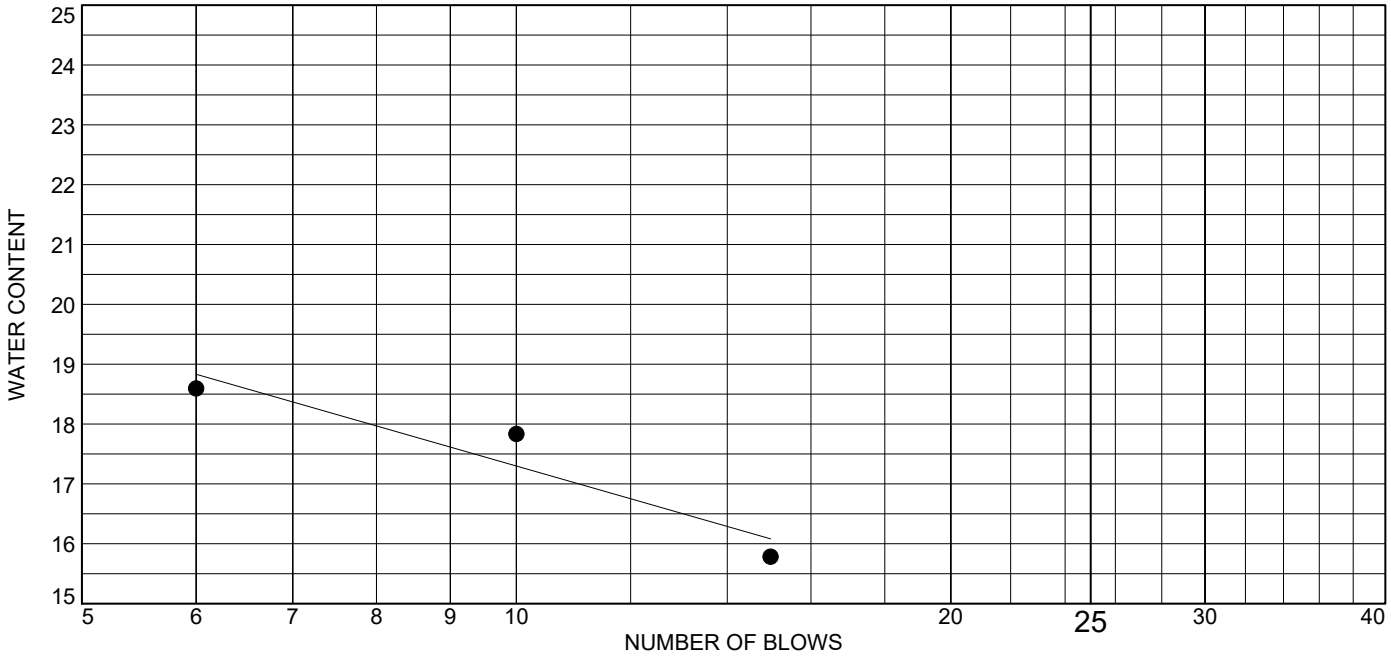
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY SILTY SAND	15	12	3	75.0	45.8	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-15 **Depth:** 100.5'-101.0'
Sample Number: 0755

Remarks:

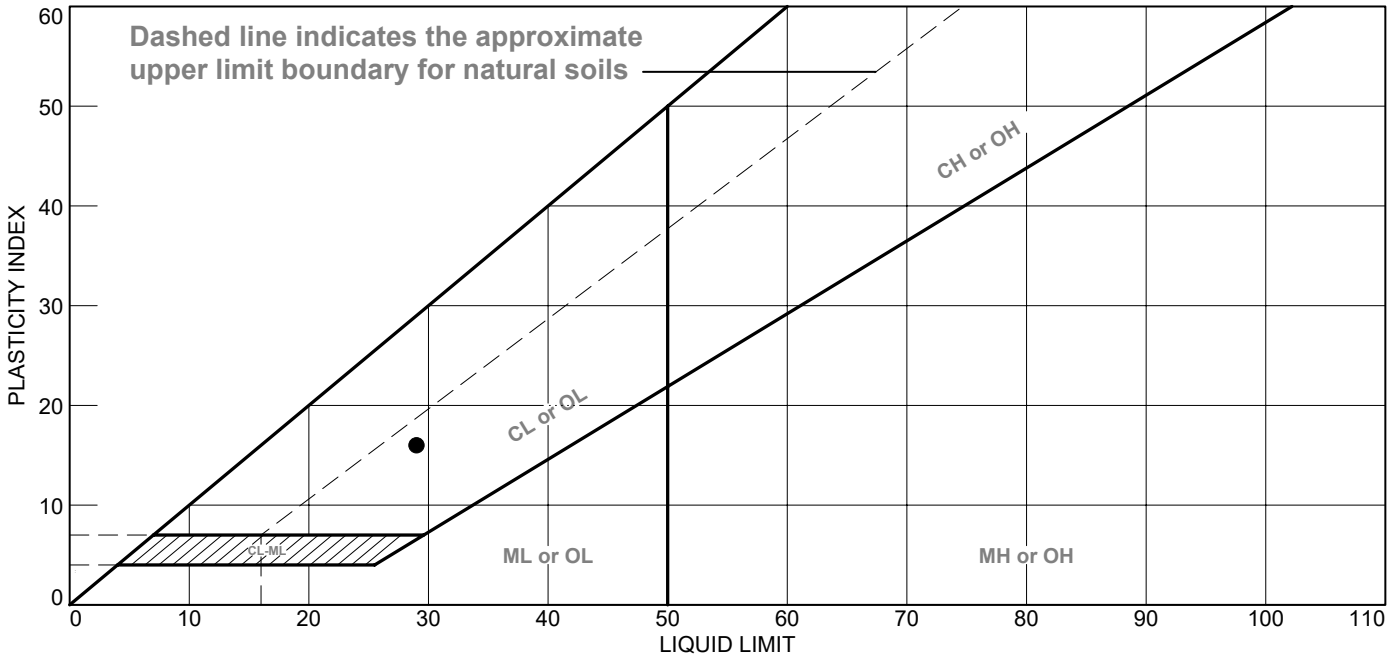
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND	29	13	16	94.1	76.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-15 **Depth:** 105.0'-107.0'
Sample Number: 0905

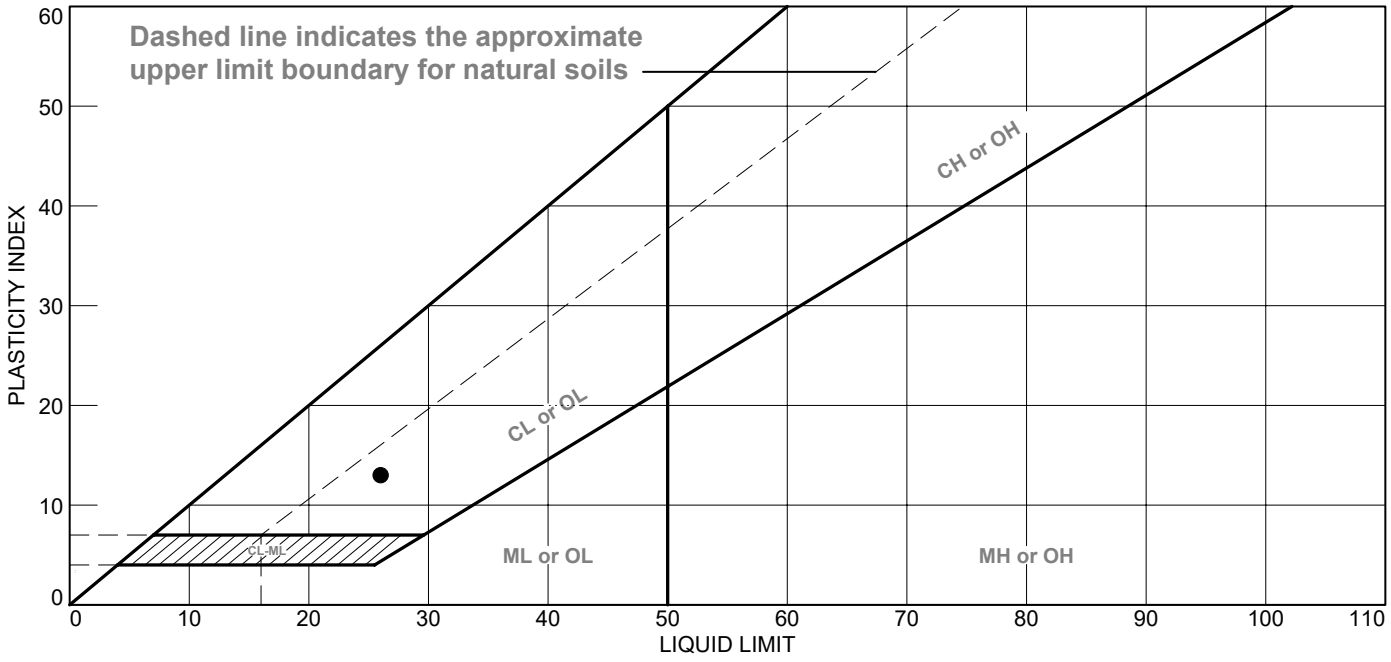
Remarks:

Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY LEAN CLAY WITH SAND	26	13	13	90.4	71.1	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-17 **Depth:** 40.0'-42.0'
Sample Number: 0945

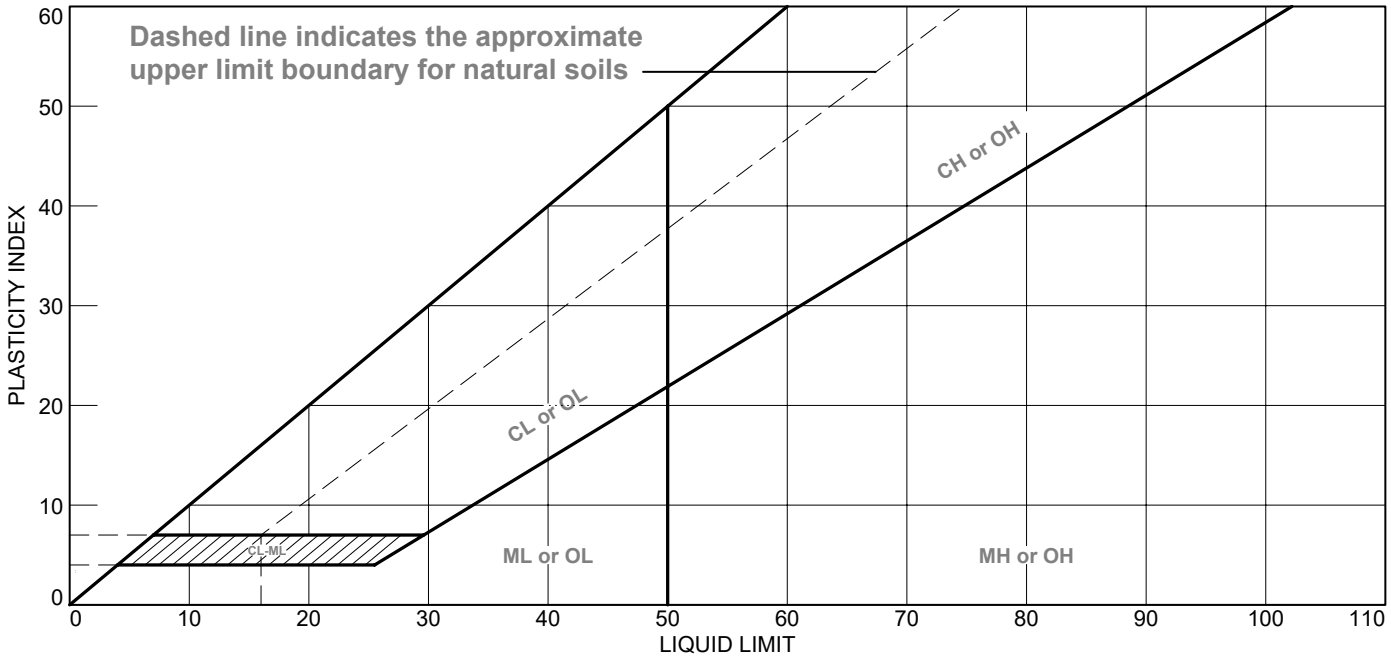
Remarks:

Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY WELL GRADED SAND WITH SILT	5	9	NP	47.7	8.9	SW-SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-17 **Depth:** 71.0'-71.5'
Sample Number: 1045

Remarks:

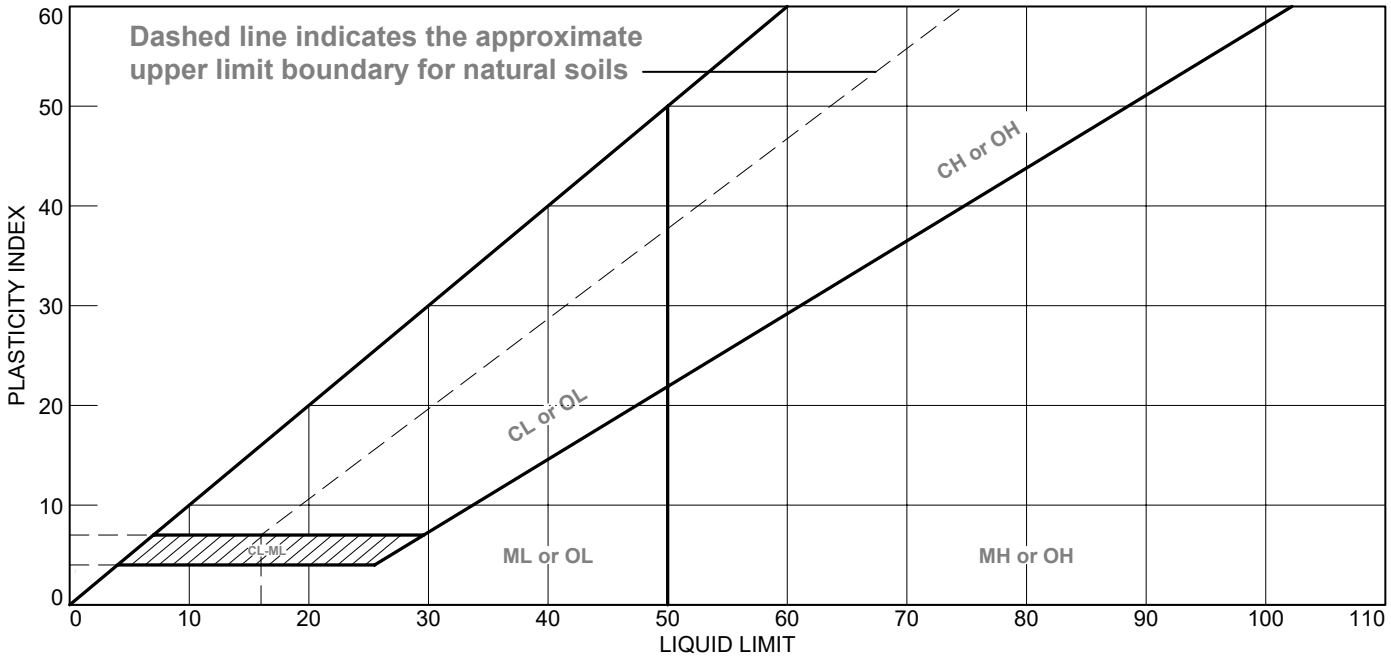
Terracon

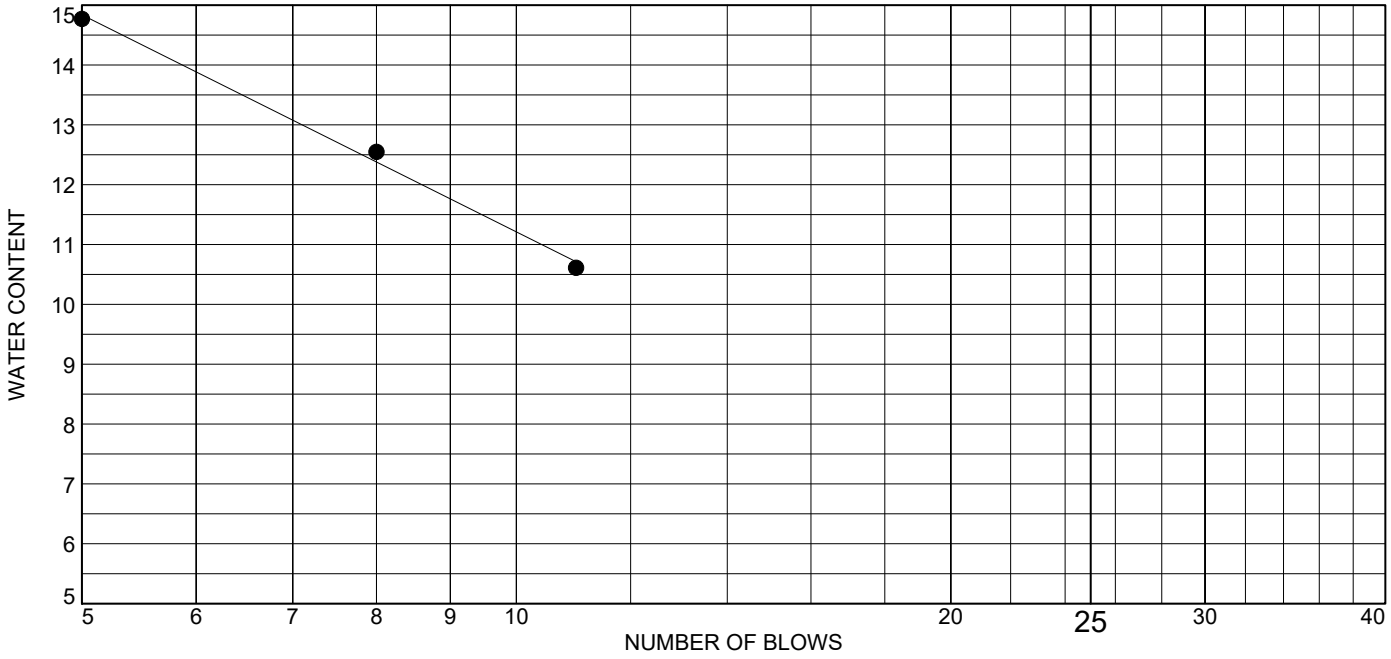
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAYISH BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	6	8	NP	23.8	6.7	SP-SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: APW-17 **Depth:** 90.5'-91.0'
Sample Number: 1200

Remarks:

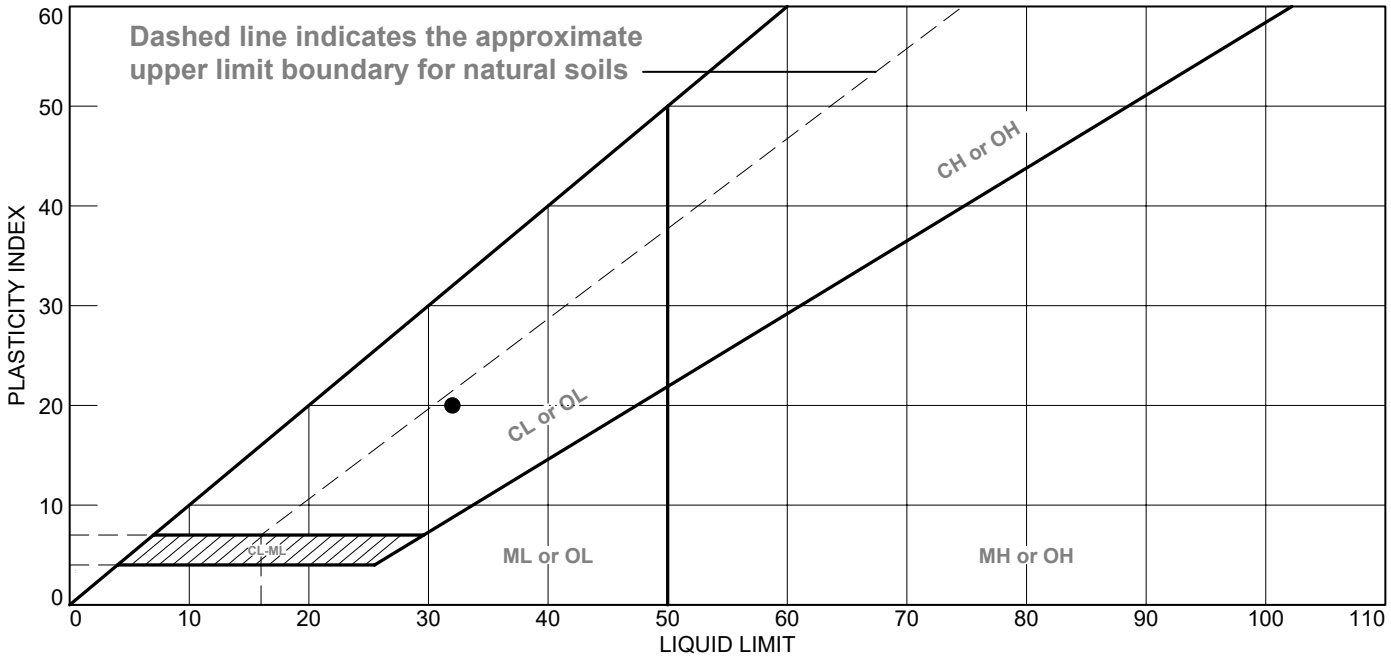
Terracon

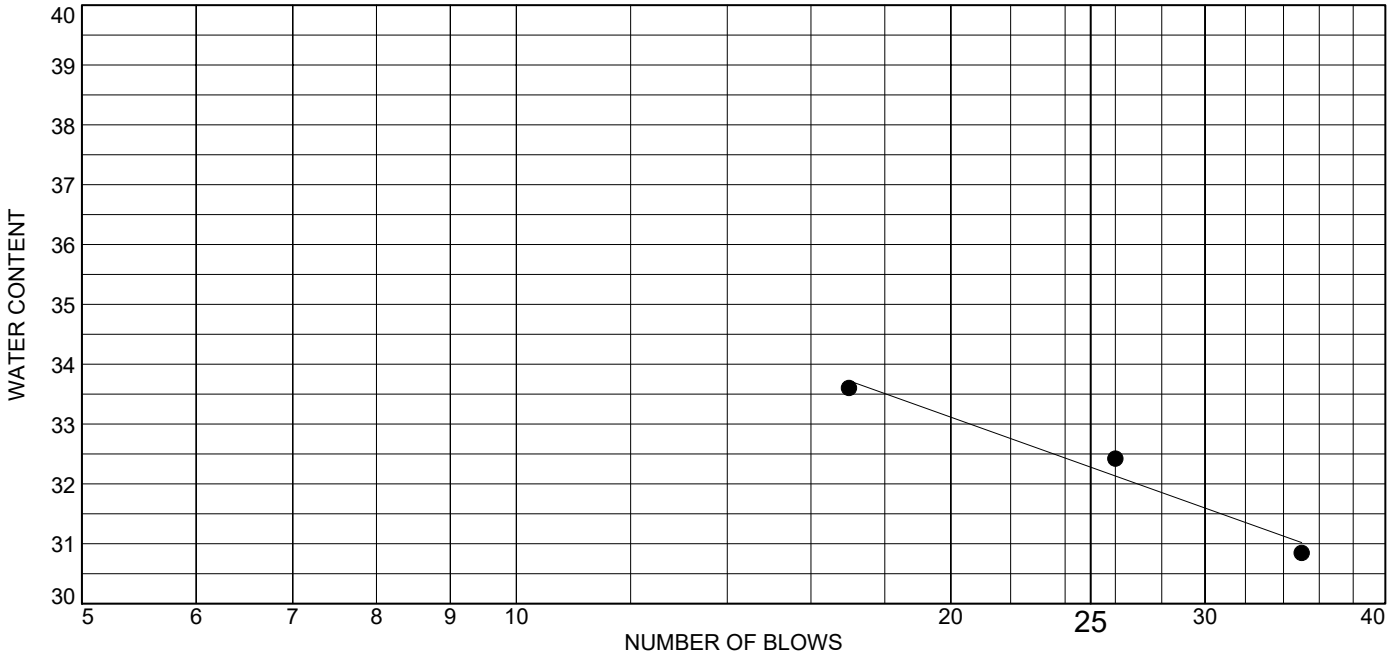
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY LEAN CLAY WITH SAND	32	12	20	93.5	76.8	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-300 **Depth:** 50.0'-52.0'
Sample Number: 0825

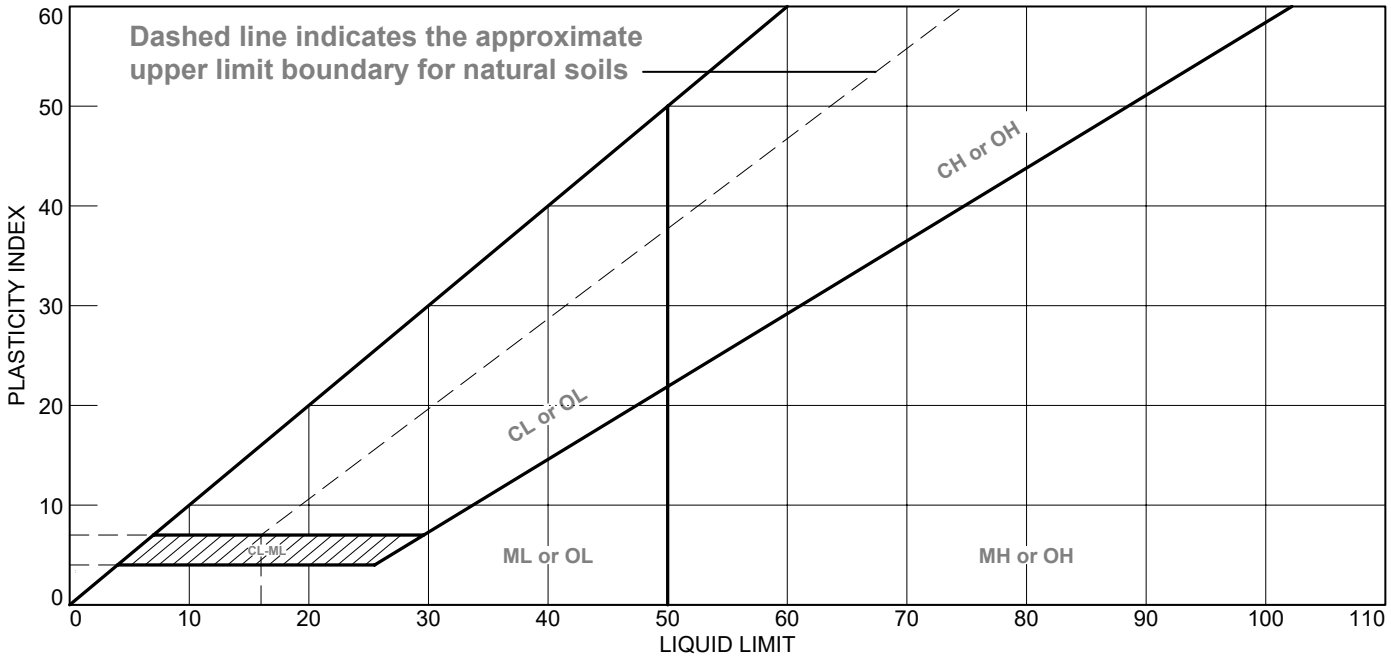
Remarks:

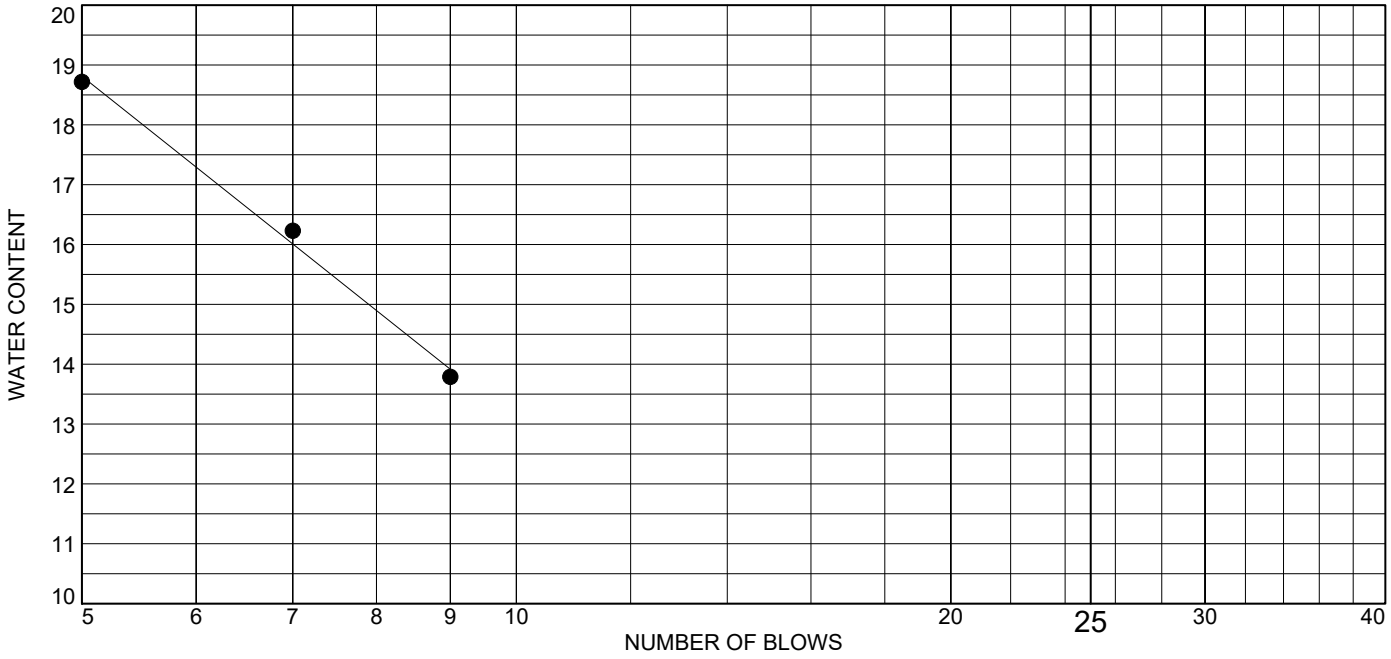
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAYISH BROWN SILTY SAND	5	9	NP	63.4	17.1	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-300 **Depth:** 61.0'-61.5'
Sample Number: 0905

Remarks:

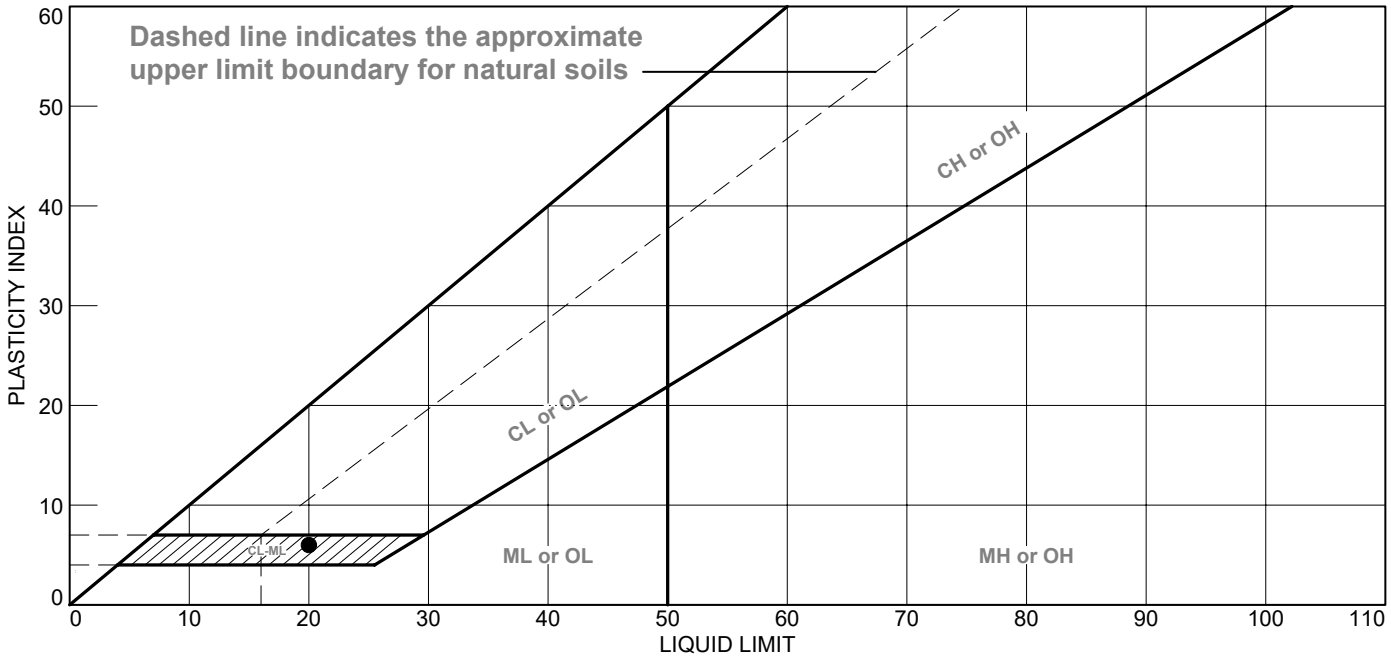
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY AND BROWN SANDY SILTY CLAY	20	14	6	96.1	57.6	CL-ML

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-300 **Depth:** 62.5'-63.0'
Sample Number: 0920

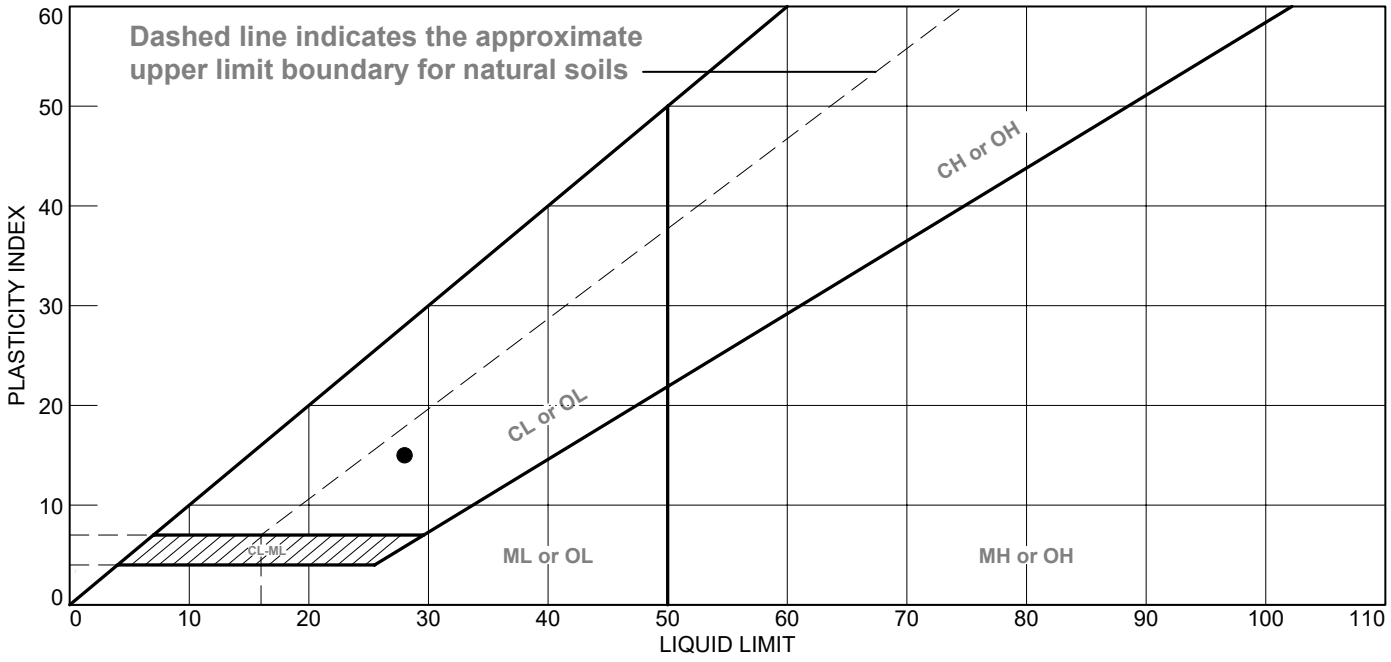
Remarks:

Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY SANDY LEAN CLAY	28	13	15	91.6	69.3	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-300 **Depth:** 105.0'-107.0'
Sample Number: 1350

Remarks:

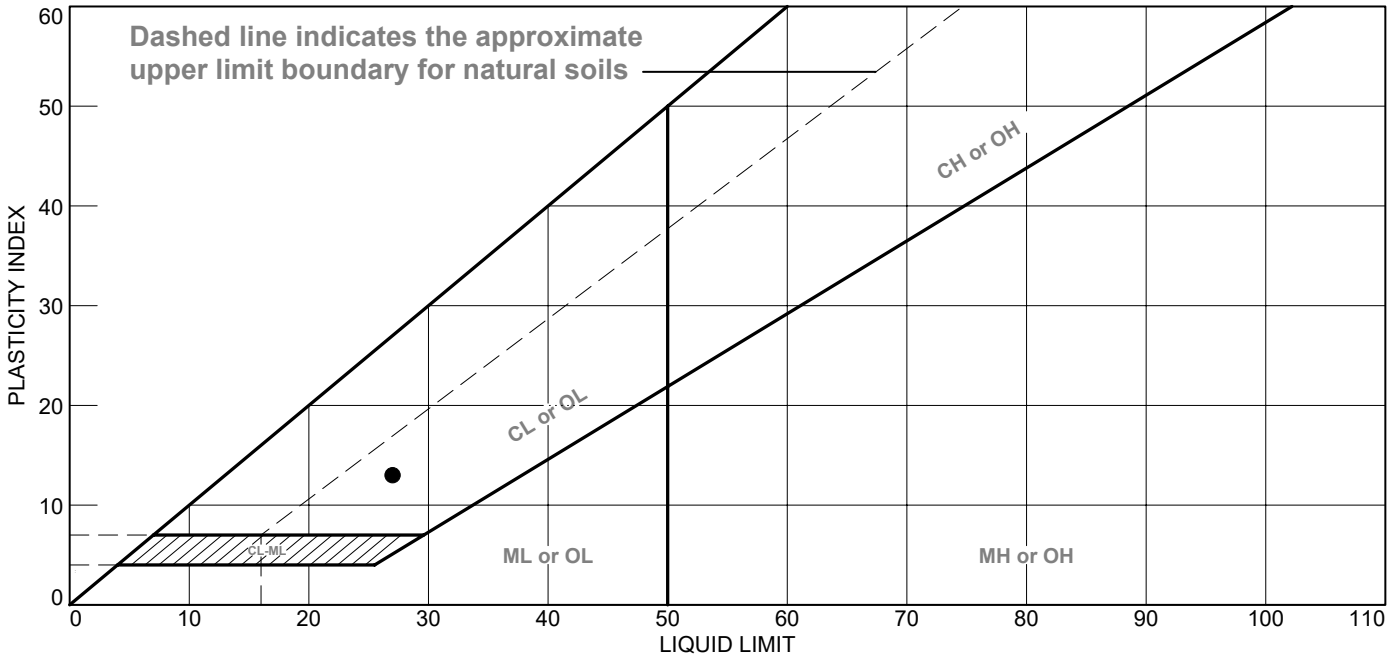
Terracon

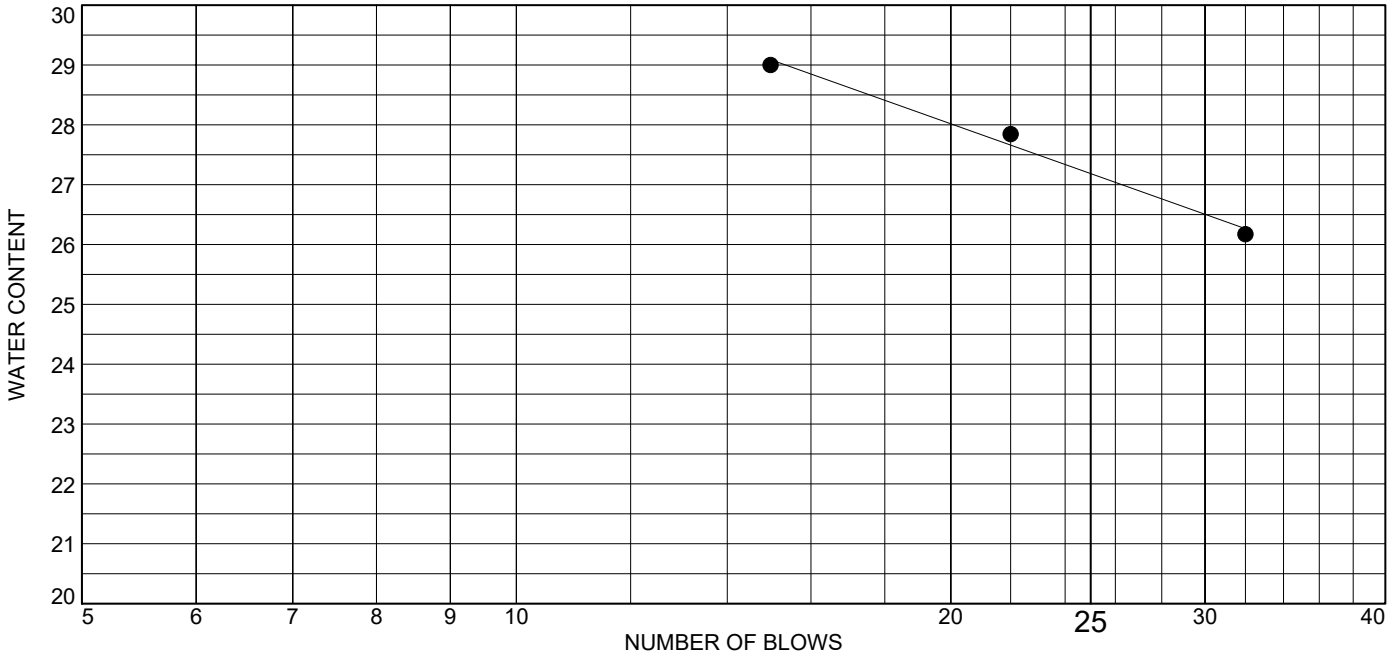
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWN AND GRAY SANDY LEAN CLAY	27	14	13	86.0	65.4	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-301 **Depth:** 48.0'-50.0'
Sample Number: 1330

Remarks:

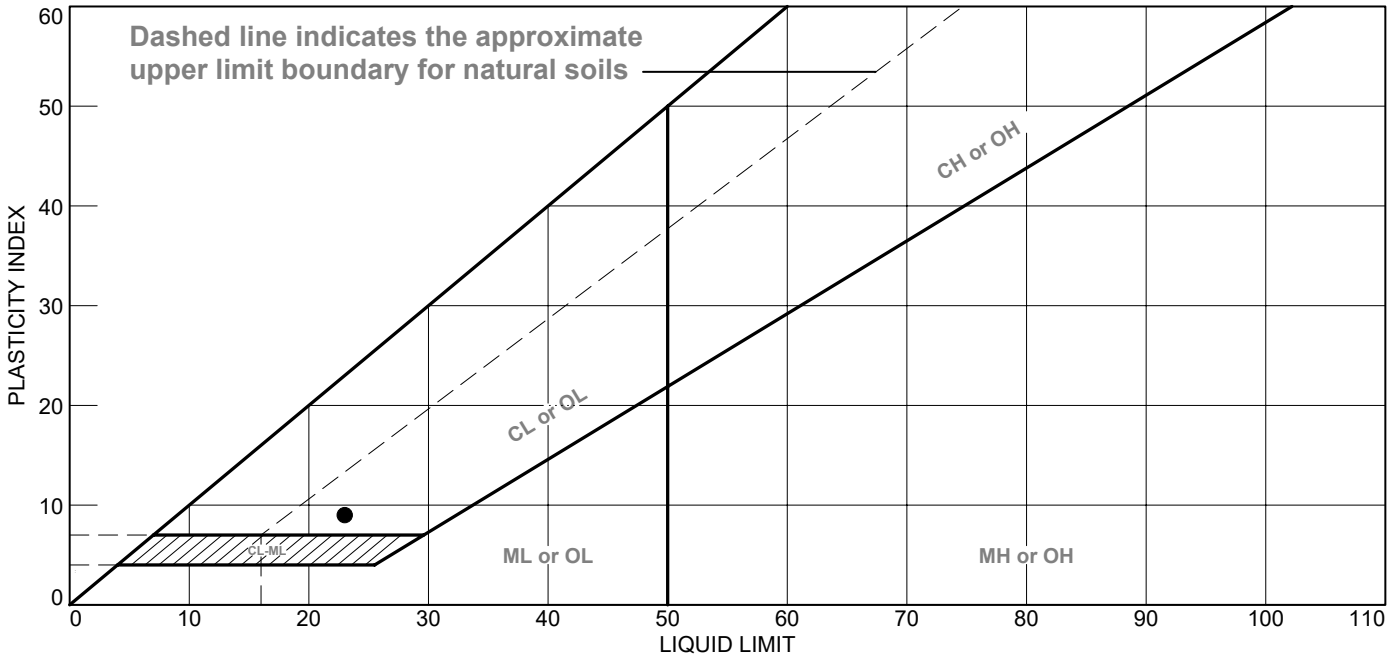
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY SANDY LEAN CLAY	23	14	9	92.5	68.7	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-301 **Depth:** 68.5'-69.0'
Sample Number: 1600

Remarks:

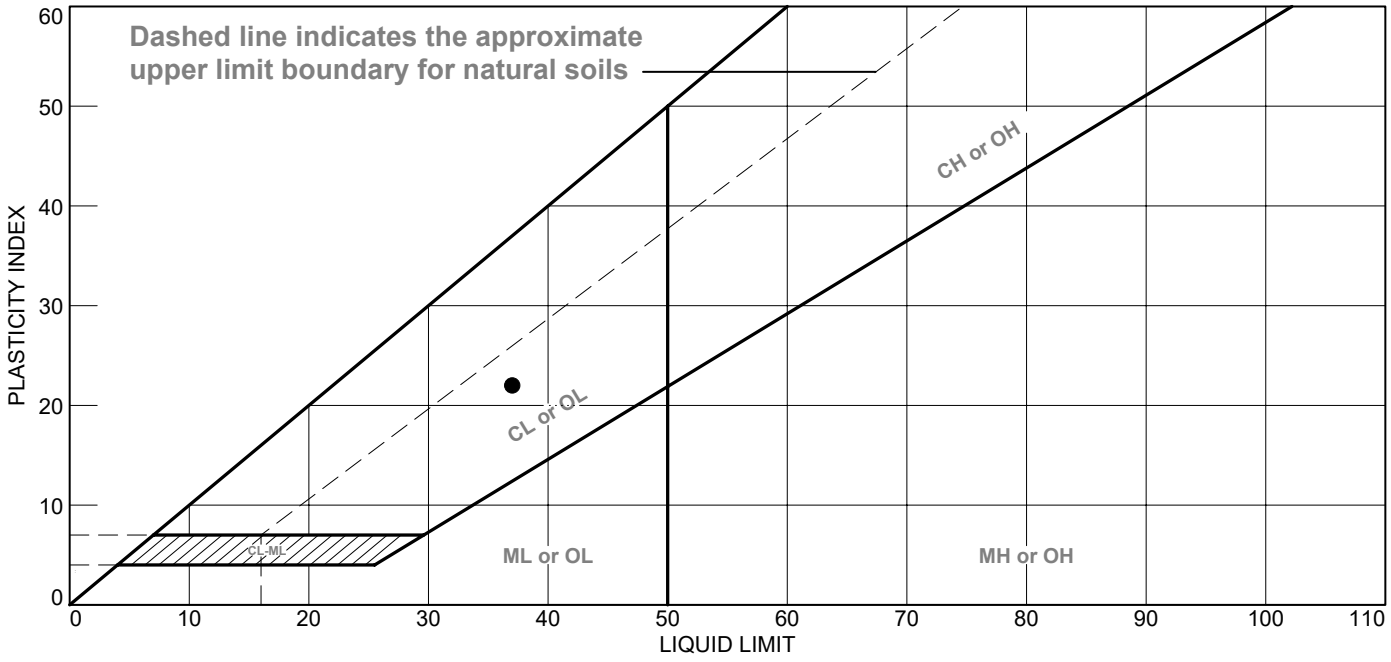
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWN TO DARK GRAY LEAN CLAY WITH SAND	37	15	22	97.0	82.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: SB-301 **Depth:** 98.0'-100.0'
Sample Number: 0946

Remarks:

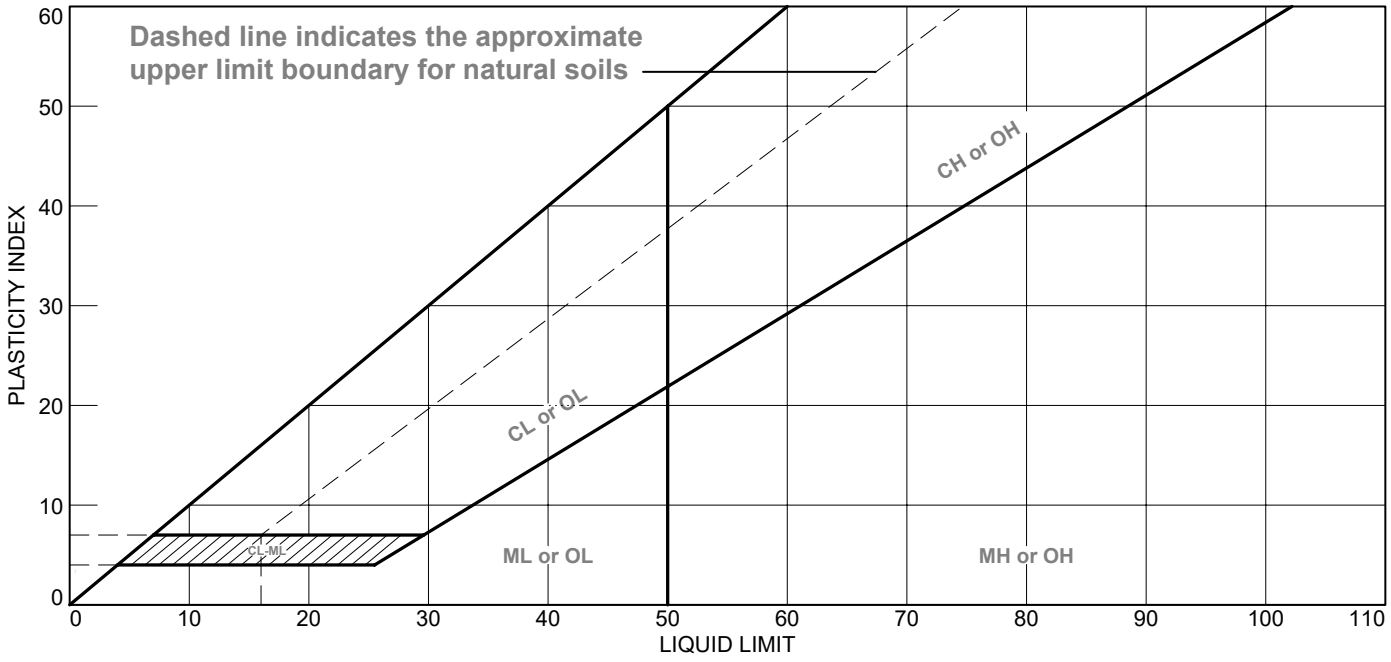
Terracon

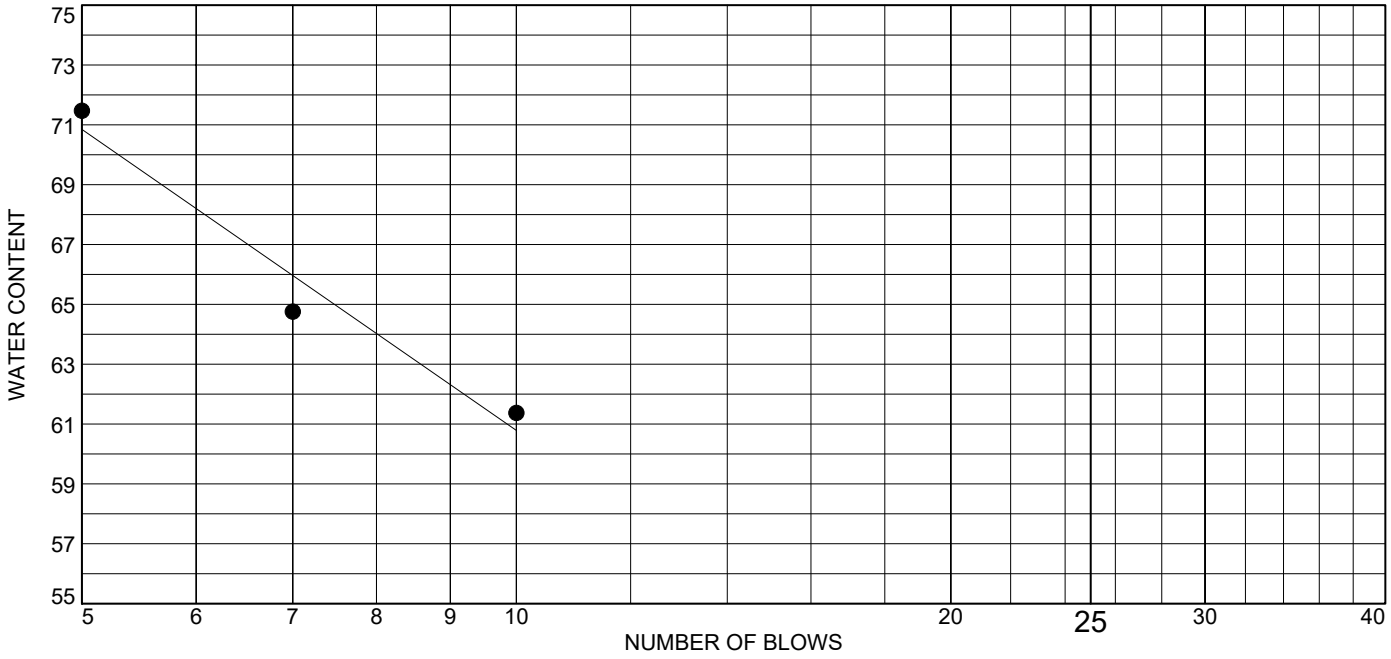
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK GRAY AND BROWN POORLY GRADED SAND WITH SILT AND GRAVEL	47	57	NP	22.3	11.8	SP-SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-01 **Depth:** 8.5'-9.0'
Sample Number: 0820

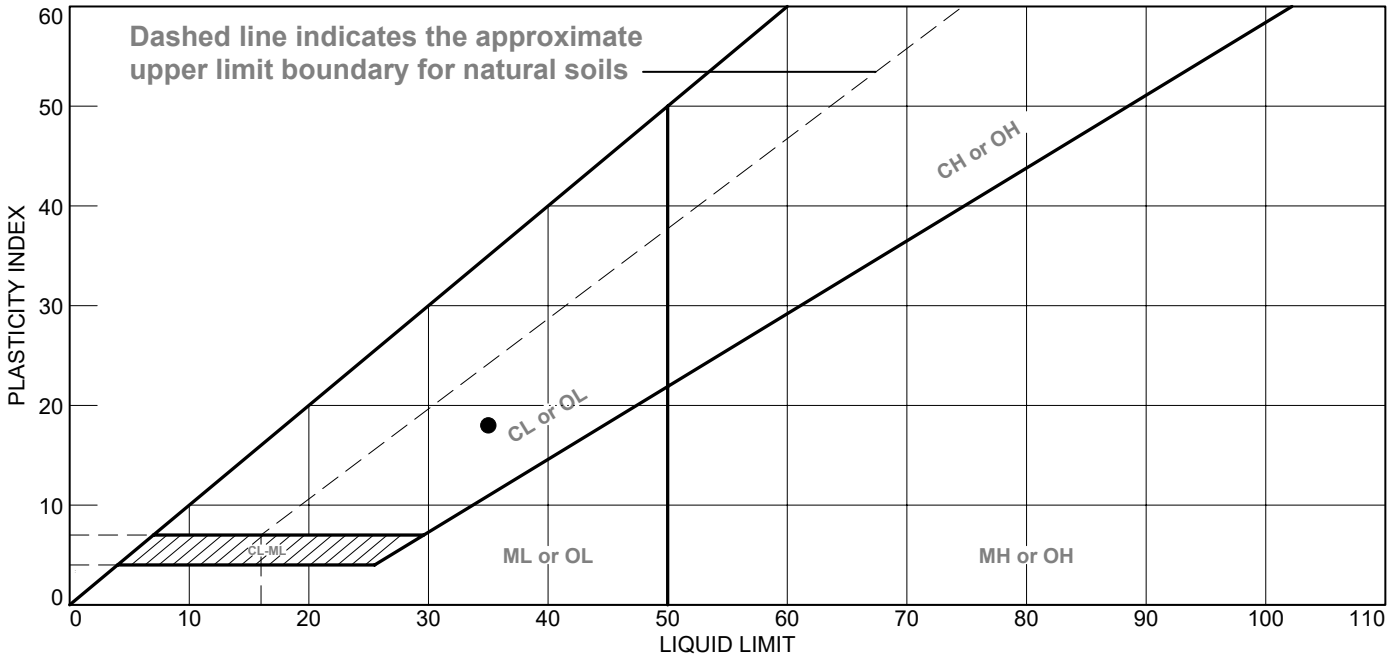
Remarks:

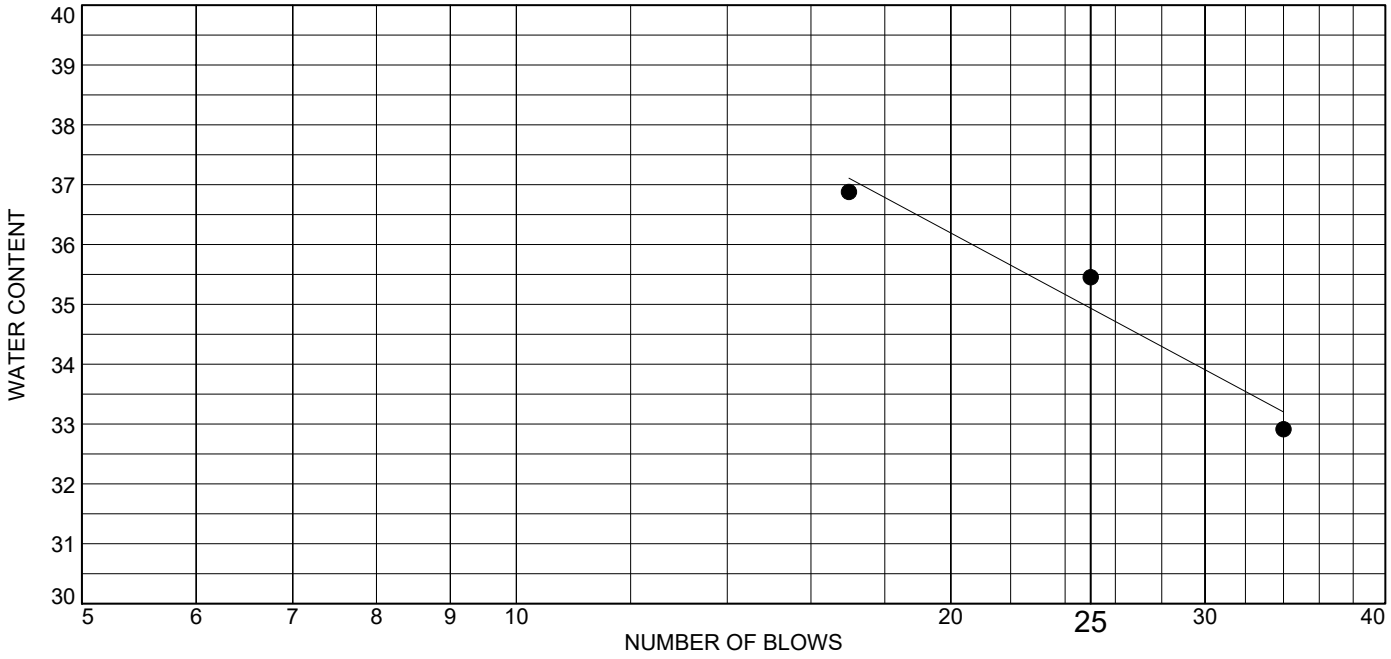
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY AND BROWN SANDY LEAN CLAY	35	17	18	81.1	61.3	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-01 **Depth:** 15.5'-16.0'
Sample Number: 0840

Remarks:

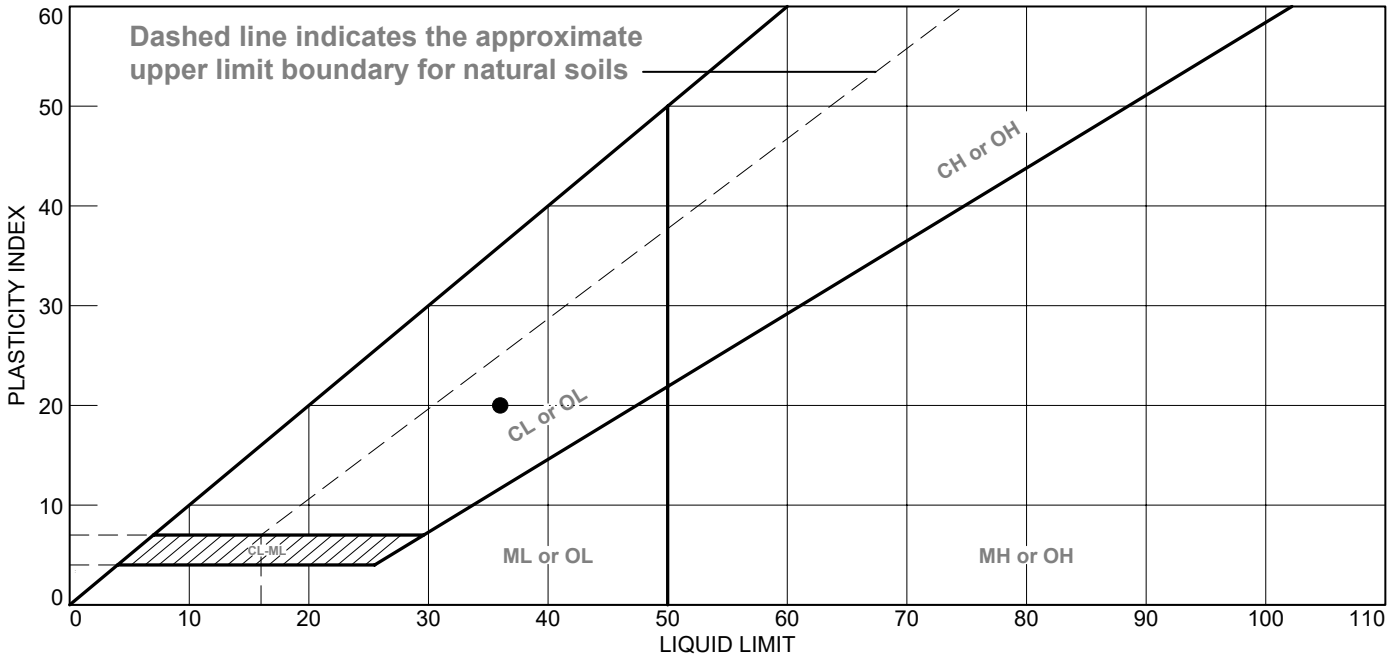
Terracon

Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	VERY DARK GRAY, GRAY AND BROWN SANDY LEAN CLAY	36	16	20	81.8	54.9	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-02 **Depth:** 8.0'-8.5'
Sample Number: 1530

Remarks:

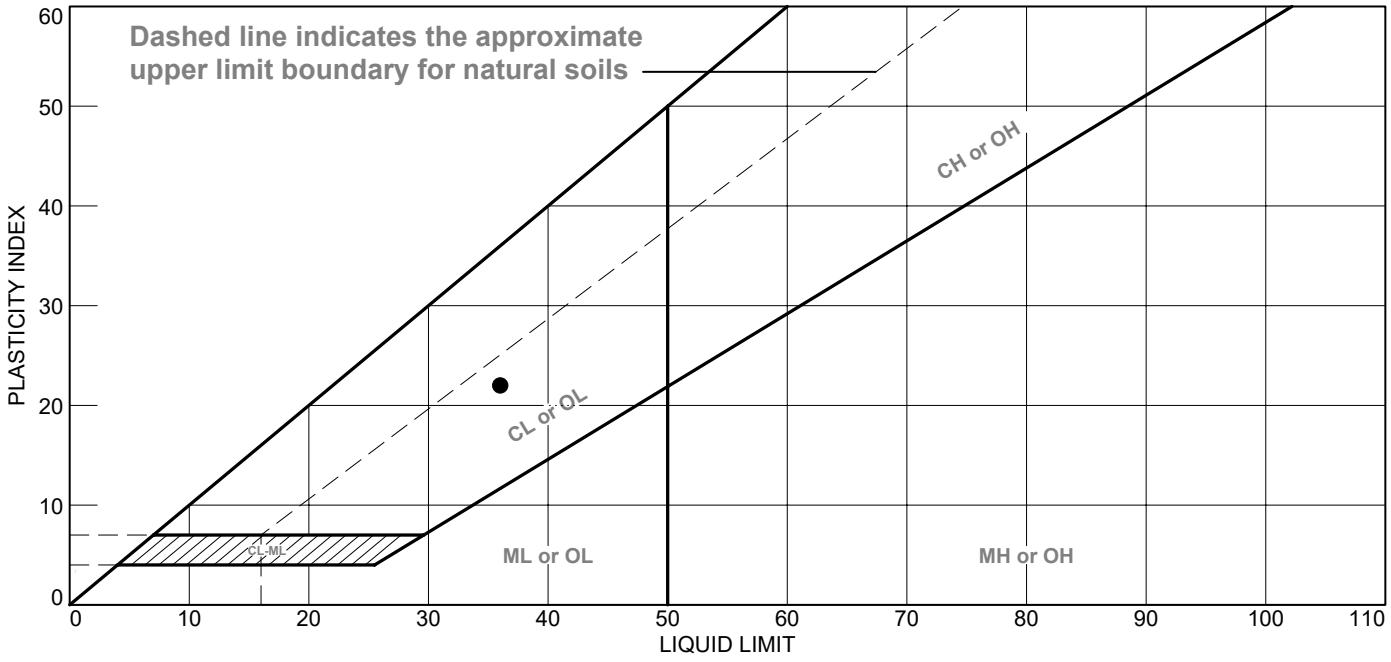
Terracon

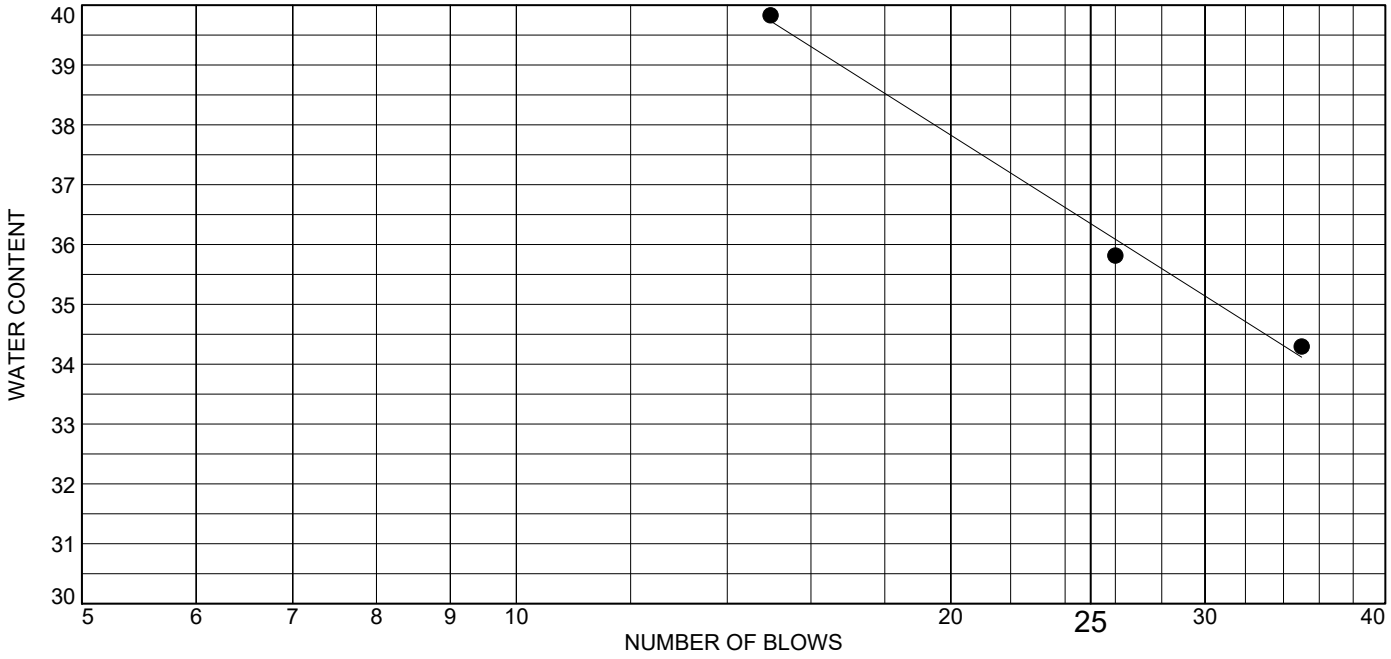
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY AND DARK BROWN LEAN CLAY WITH SAND	36	14	22	96.3	80.2	CL

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-02 **Depth:** 16.5'-17.0'
Sample Number: 1545

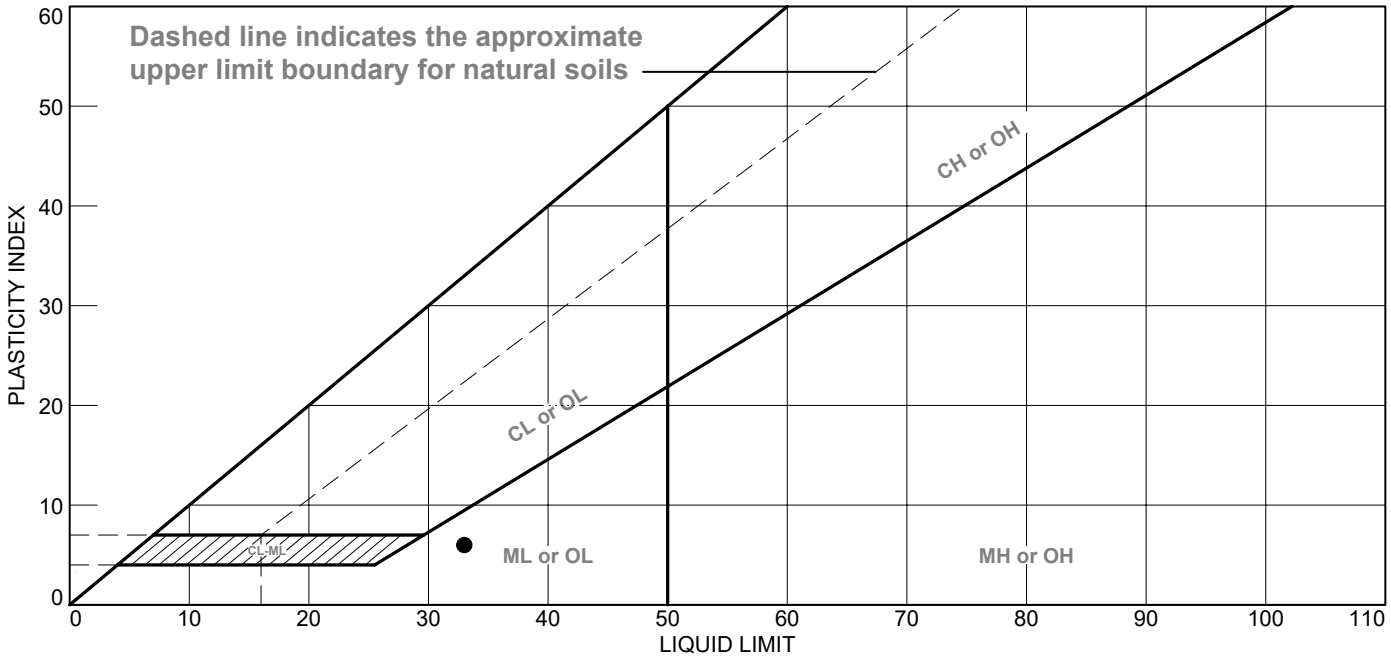
Remarks:

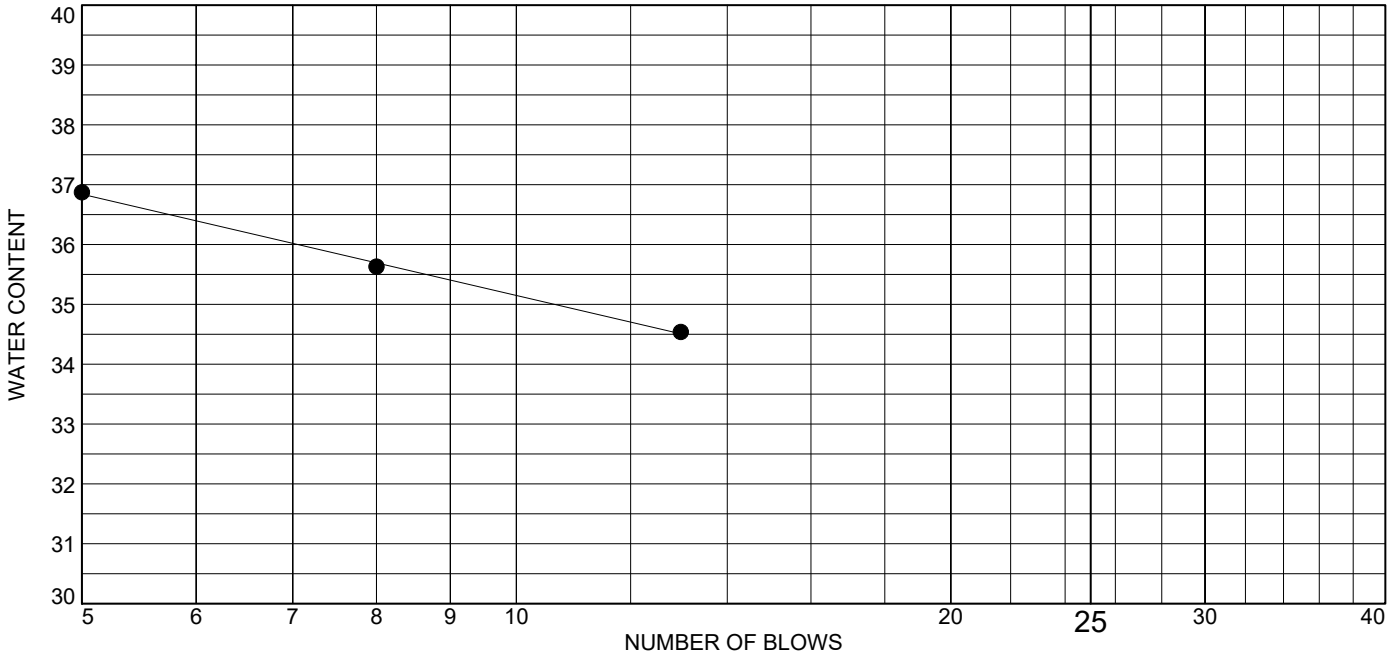
Terracon

Figure

Tested By: DT **Checked By:** WPQ

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWNISH GRAY SILTY SAND	33	27	6	46.6	21.5	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-03 **Depth:** 6.0'-6.5'
Sample Number: 1355

Remarks:

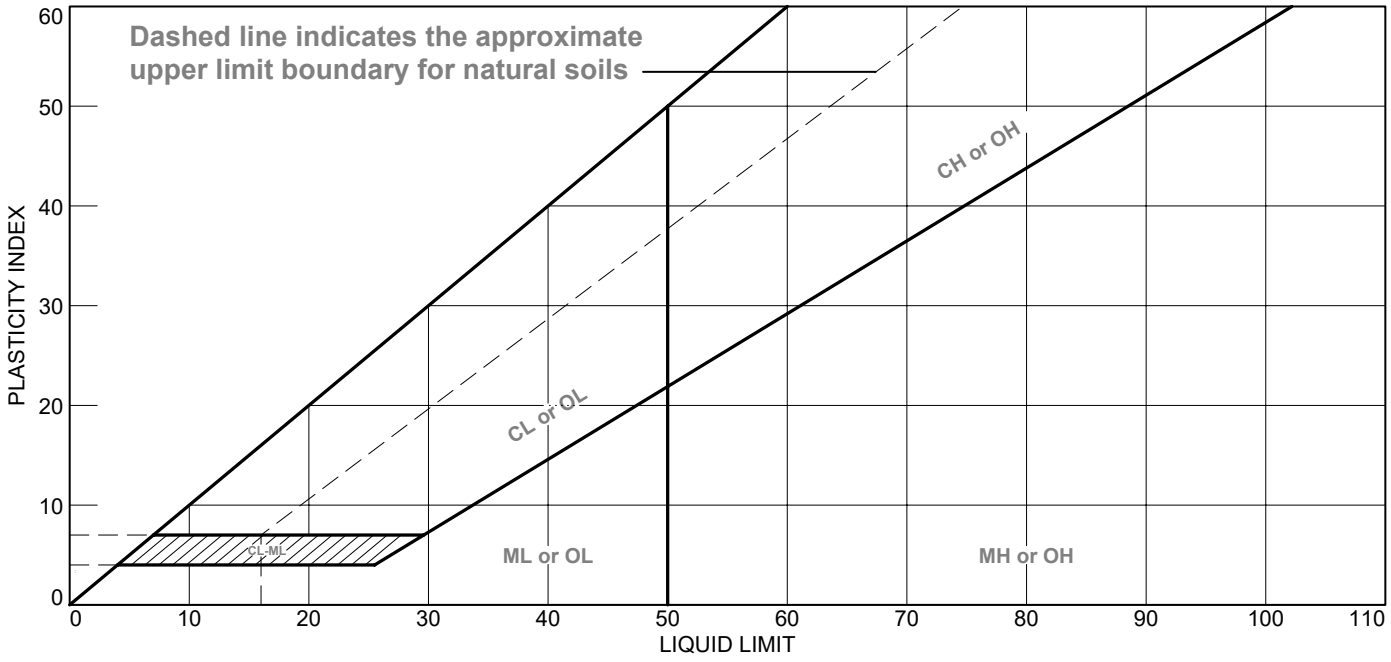
Terracon

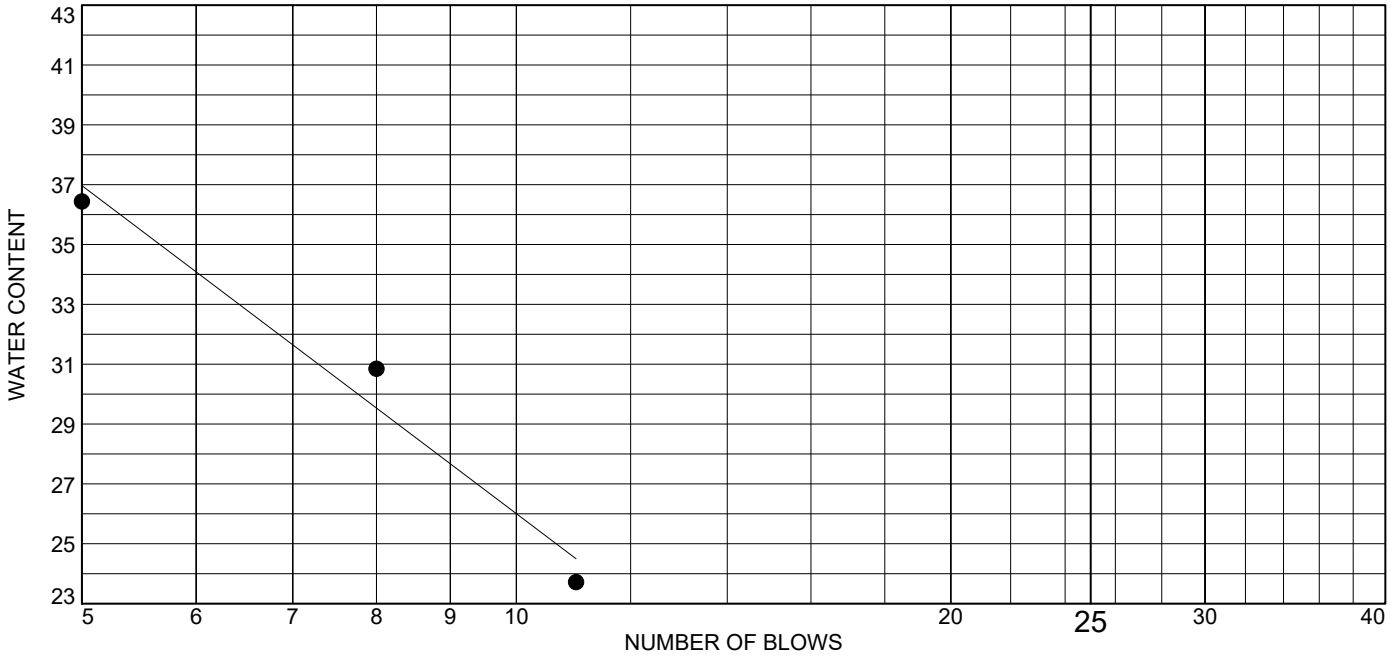
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	BROWNISH GRAY SILTY SAND WITH GRAVEL	12	19	NP	46.1	16.3	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-03 **Depth:** 15.5'-16.0'
Sample Number: 1315

Remarks:

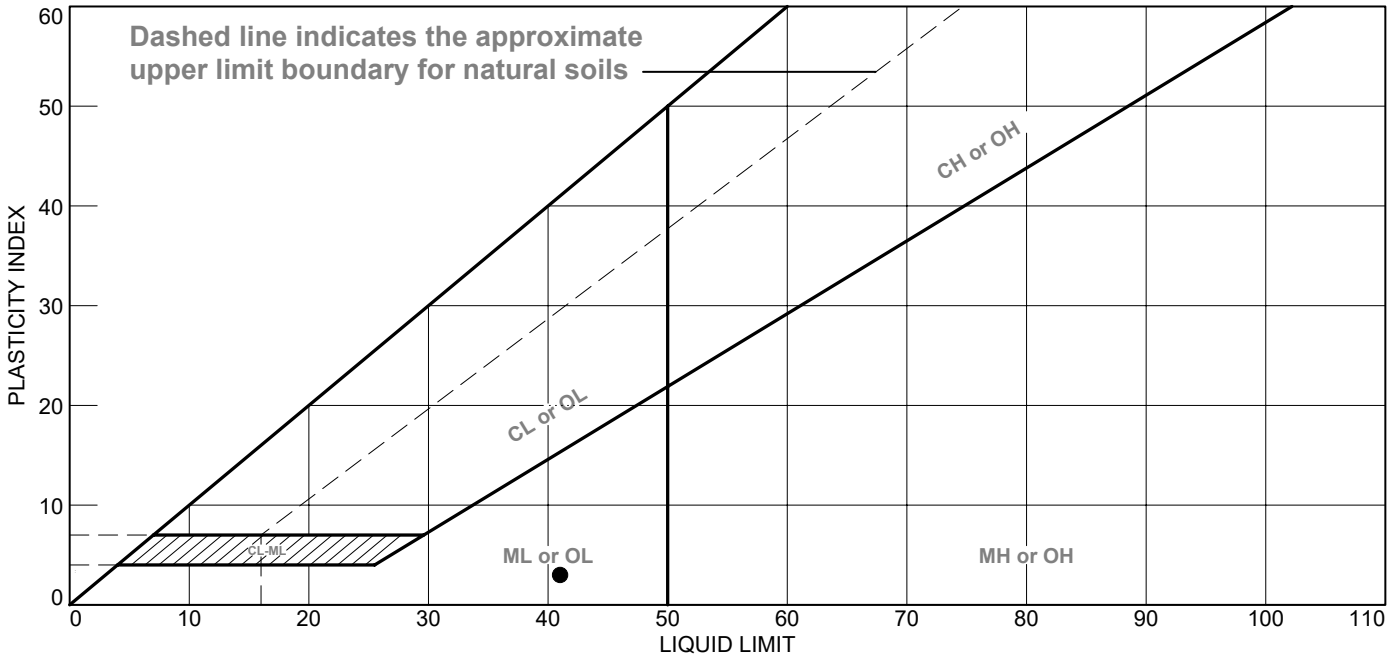
Terracon

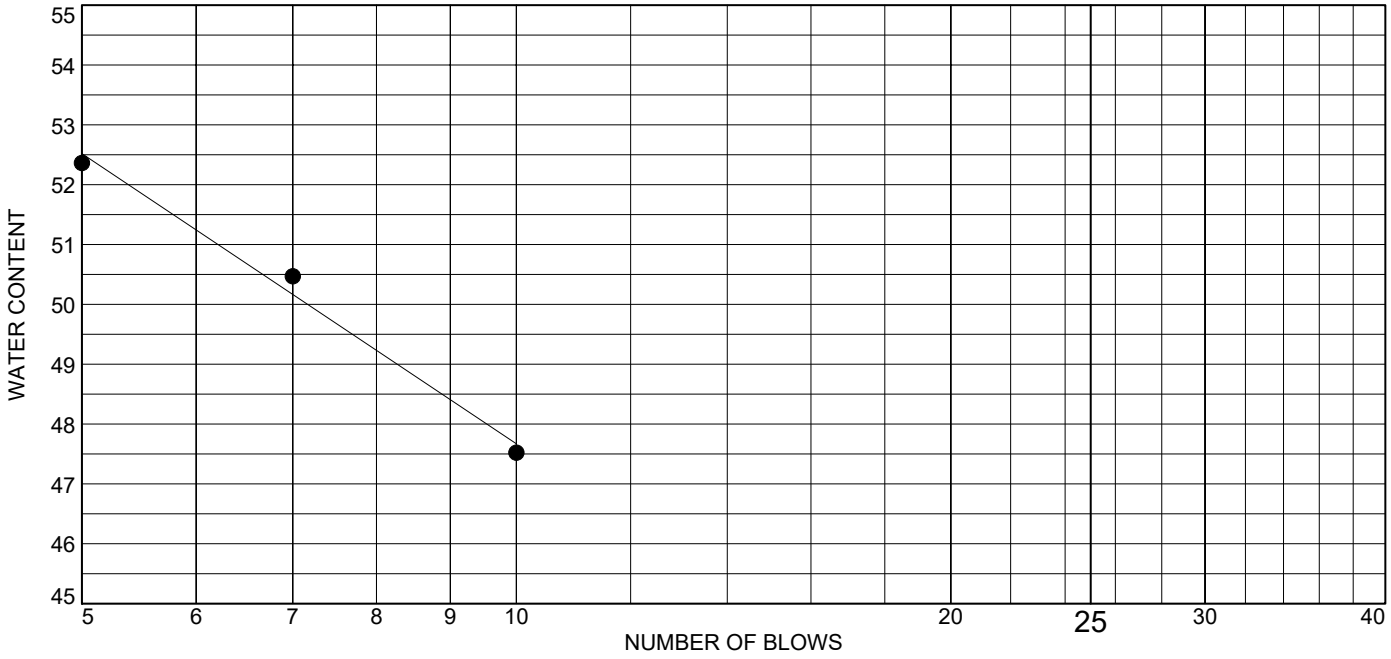
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	GRAY SILTY SAND	41	38	3	28.5	13.9	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-04 **Depth:** 6.5'-7.0'
Sample Number: 1000

Remarks:

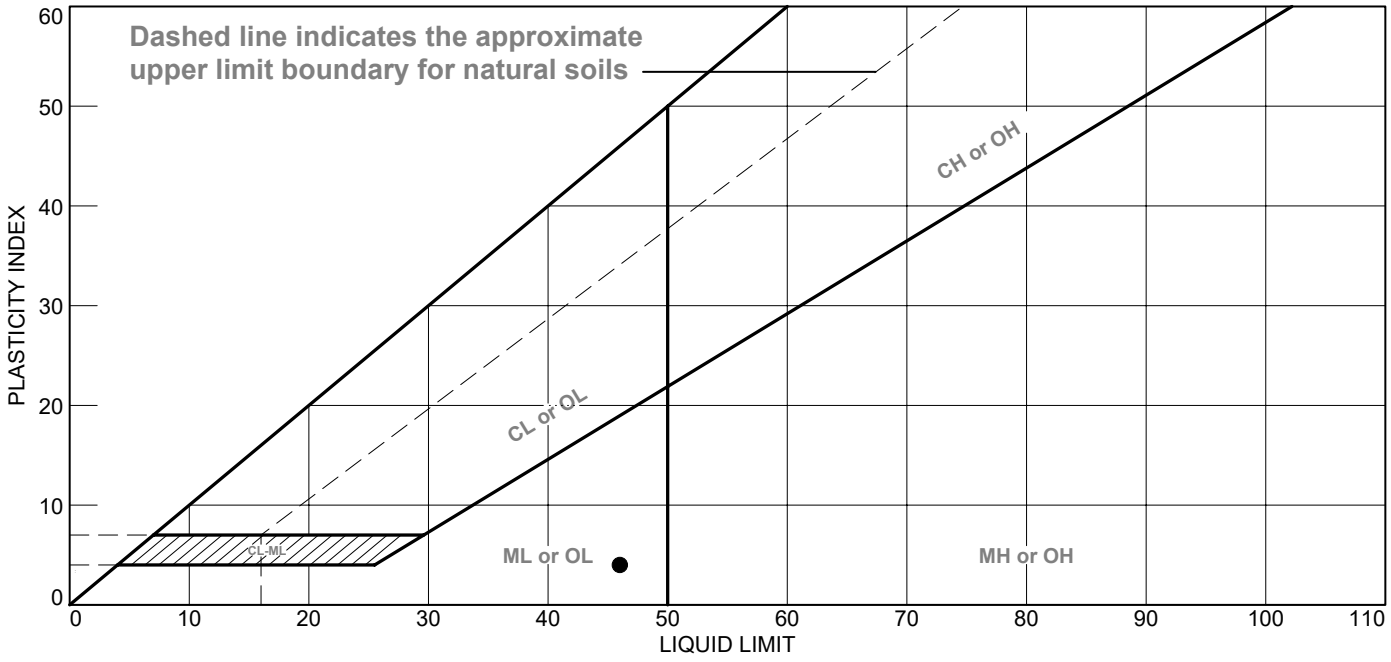
Terracon

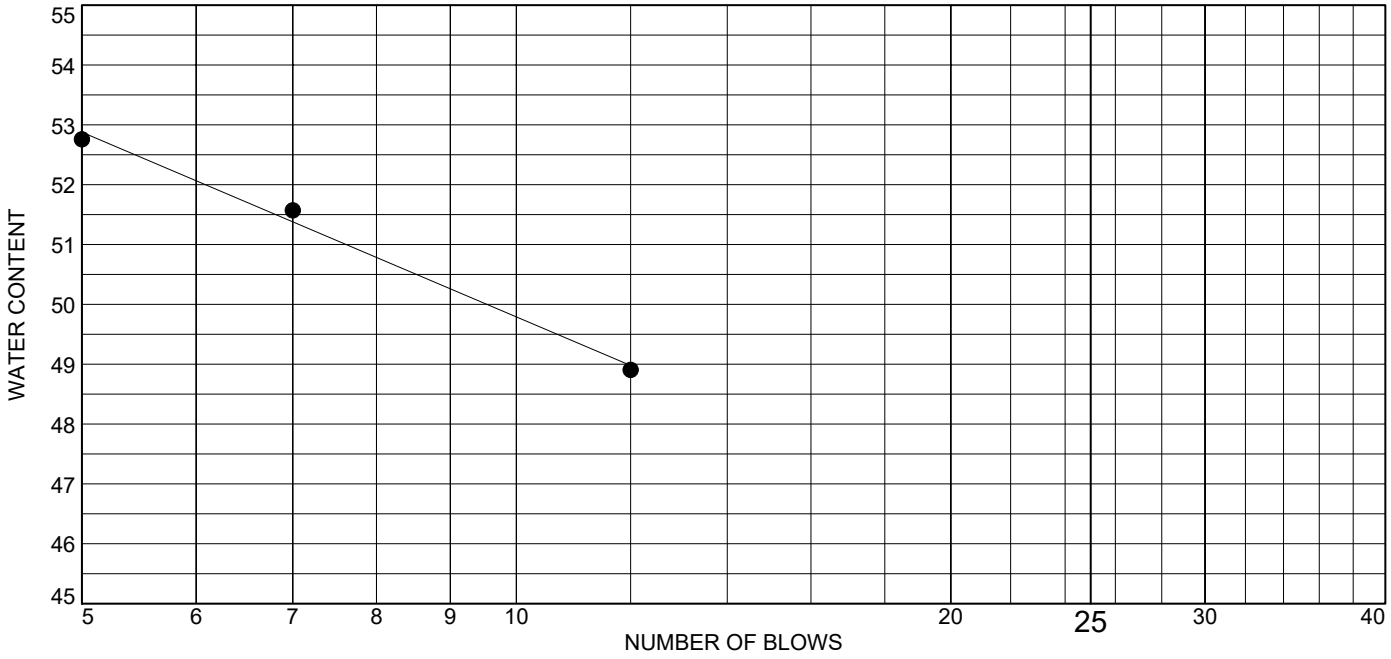
Figure

Tested By: DT **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

LIQUID AND PLASTIC LIMITS ASTM D4318





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	DARK BROWNISH GRAY SILTY SAND WITH GRAVEL	46	42	4	45.5	33.3	SM

Project No. 11215019 **Client:** RAMBOLL ENVIRON US CORP.

Project: NEWTON POWER STATION

Source of Sample: XPW-04 **Depth:** 15.5'-16.0'
Sample Number: 1020

Remarks:

Terracon

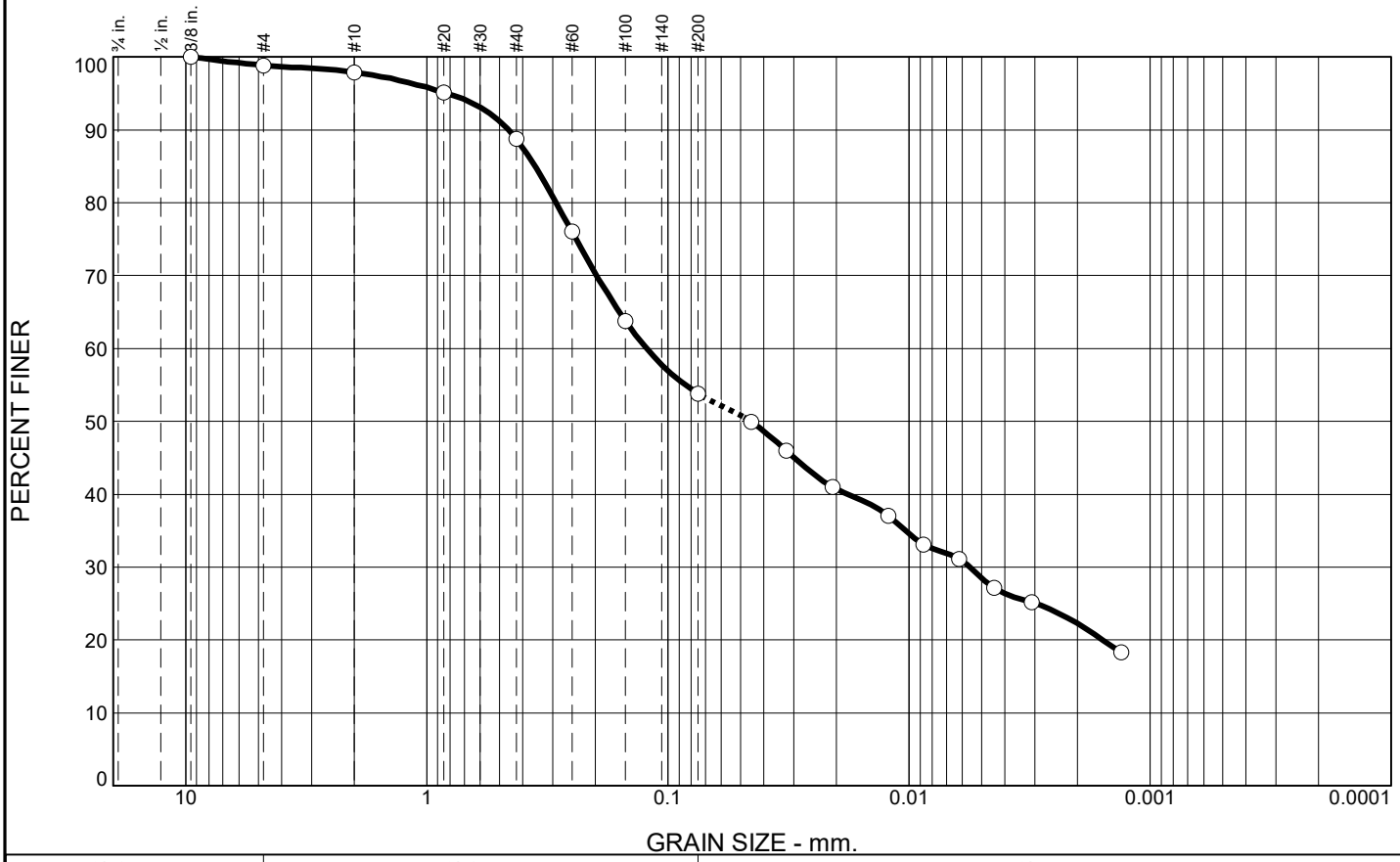
Figure

Tested By: DT **Checked By:** WPQ

Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis
ASTM D6913

Particle-Size Distribution (Gradation) of Fine-Grained Soils
Using the Sedimentation (Hydrometer) Analysis
ASTM D7928

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	1.1	1.0	9.2	34.9	25.2	28.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.9		
#10	97.9		
#20	95.1		
#40	88.7		
#60	76.0		
#100	63.8		
#200	53.8		
0.0450 mm.	49.9		
0.0323 mm.	46.0		
0.0208 mm.	41.0		
0.0122 mm.	37.1		
0.0087 mm.	33.1		
0.0062 mm.	31.1		
0.0044 mm.	27.2		
0.0031 mm.	25.2		
0.0013 mm.	18.3		

* (no specification provided)

Soil Description

BROWN SANDY LEAN CLAY

Atterberg Limits

PL= 12 LL= 28 PI= 16

Coefficients

D_{90}= 0.4588 D_{85}= 0.3552 D_{60}= 0.1224
D_{50}= 0.0454 D_{30}= 0.0056 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(5)

Remarks

F.M.=0.69

Source of Sample: APW-11 **Depth:** 10.0'-12.0'
Sample Number: 0805 **Date:** 3-30-21

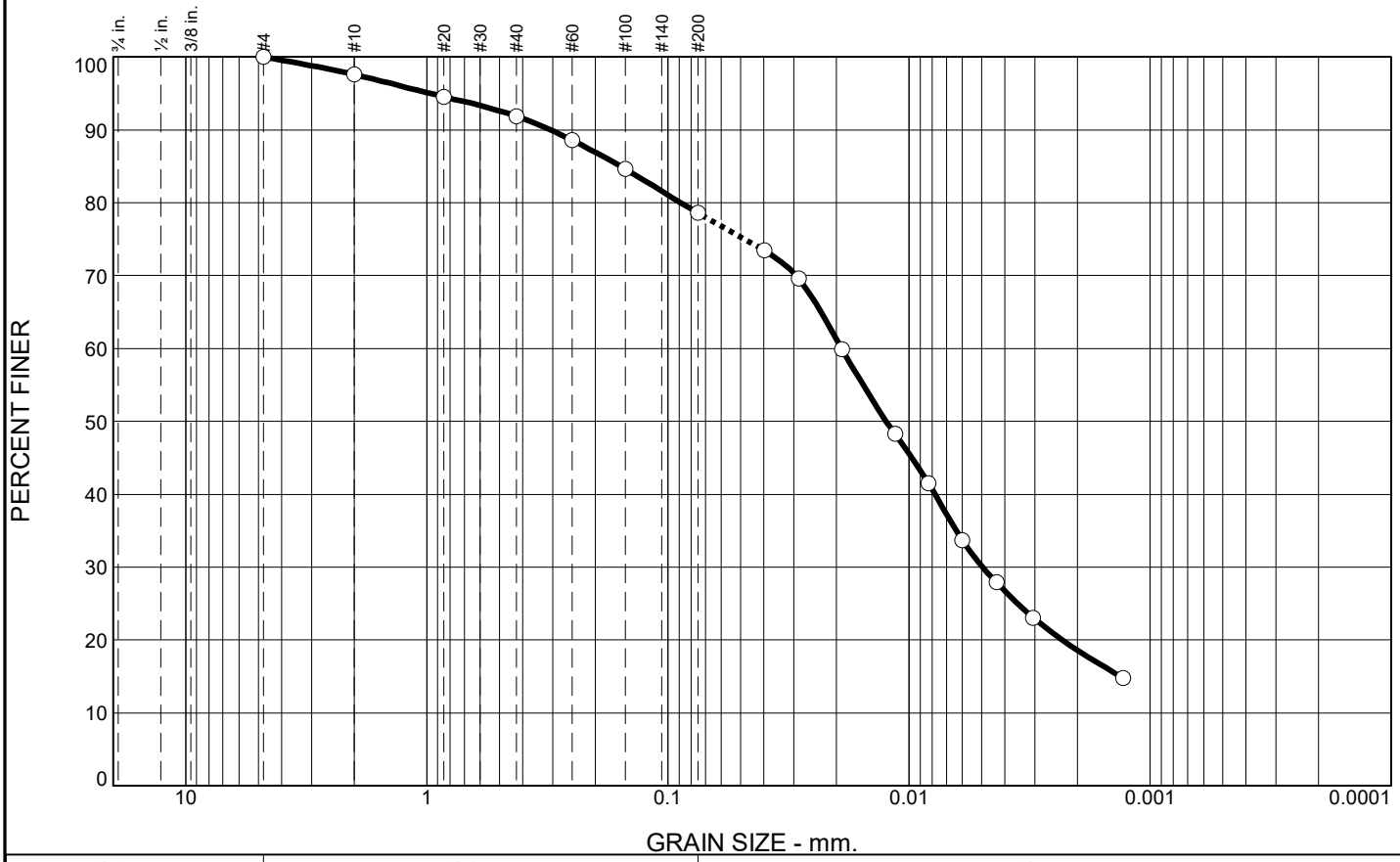
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	2.4	5.7	13.3	48.4	30.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	97.6		
#20	94.5		
#40	91.9		
#60	88.6		
#100	84.6		
#200	78.6		
0.0399 mm.	73.4		
0.0287 mm.	69.6		
0.0189 mm.	59.9		
0.0114 mm.	48.2		
0.0083 mm.	41.5		
0.0060 mm.	33.7		
0.0043 mm.	27.9		
0.0031 mm.	23.1		
0.0013 mm.	14.8		

* (no specification provided)

Soil Description

GRAYISH BROWN LEAN CLAY WITH SAND

Atterberg Limits

PL= 18 LL= 27 PI= 9

Coefficients

D_{90}= 0.3070 D_{85}= 0.1573 D_{60}= 0.0190
D_{50}= 0.0124 D_{30}= 0.0050 D_{15}= 0.0013
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-4(5)

Remarks

F.M.=0.38

Source of Sample: APW-11 **Depth:** 61.0'-61.5'
Sample Number: 1050 **Date:** 3-16-21

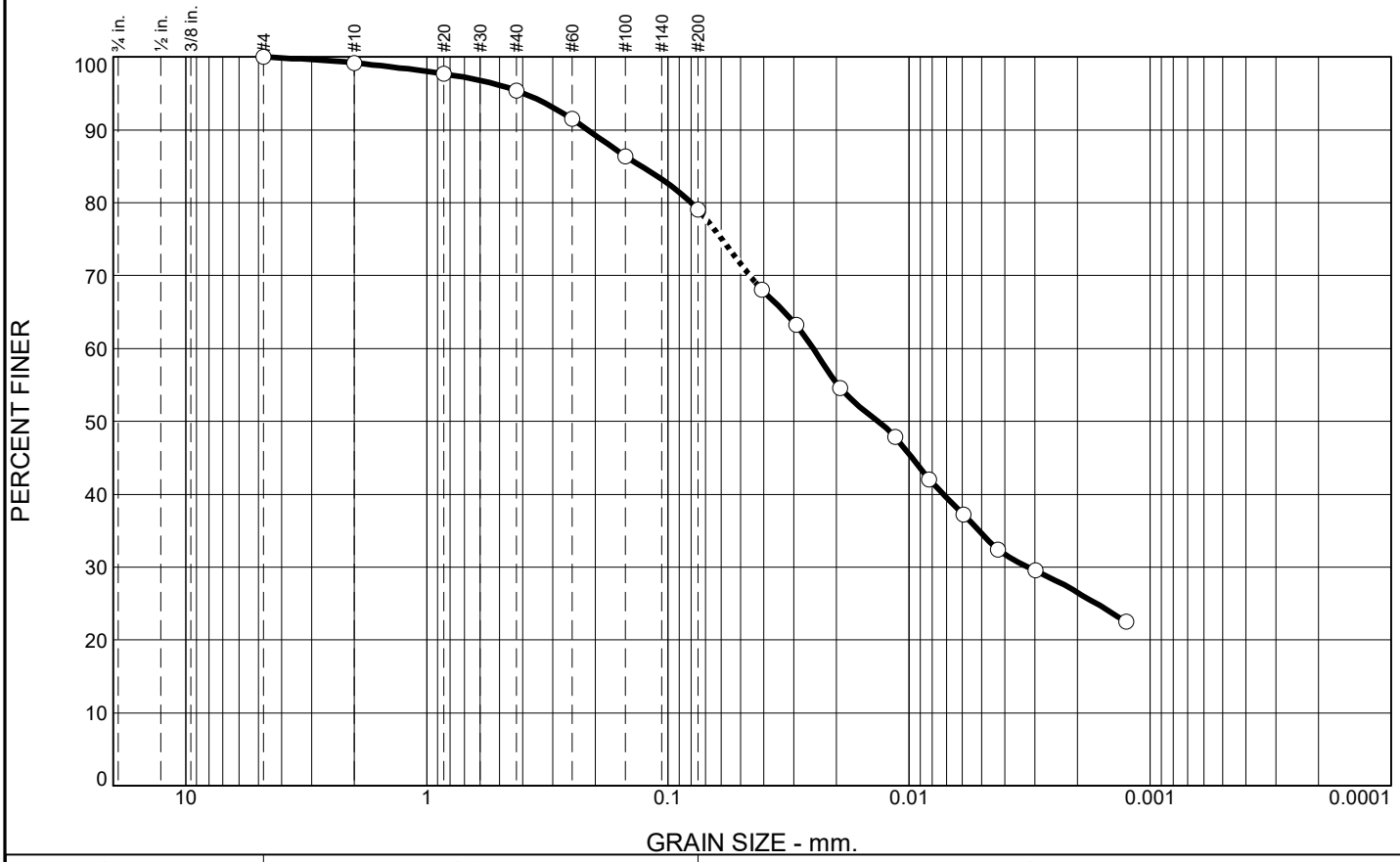
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.8	3.8	16.4	44.4	34.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.2		
#20	97.7		
#40	95.4		
#60	91.5		
#100	86.4		
#200	79.0		
0.0407 mm.	68.1		
0.0294 mm.	63.3		
0.0193 mm.	54.6		
0.0114 mm.	47.8		
0.0082 mm.	42.1		
0.0059 mm.	37.2		
0.0043 mm.	32.4		
0.0030 mm.	29.5		
0.0013 mm.	22.5		

* (no specification provided)

Soil Description

DARK GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 14 LL= 32 PI= 18

Coefficients

D_{90}= 0.2146 D_{85}= 0.1293 D_{60}= 0.0250
D_{50}= 0.0135 D_{30}= 0.0032 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(12)

Remarks

F.M.=0.26

Source of Sample: APW-11 **Depth:** 80.0'-82.0'
Sample Number: 1115 **Date:** 3-2-21

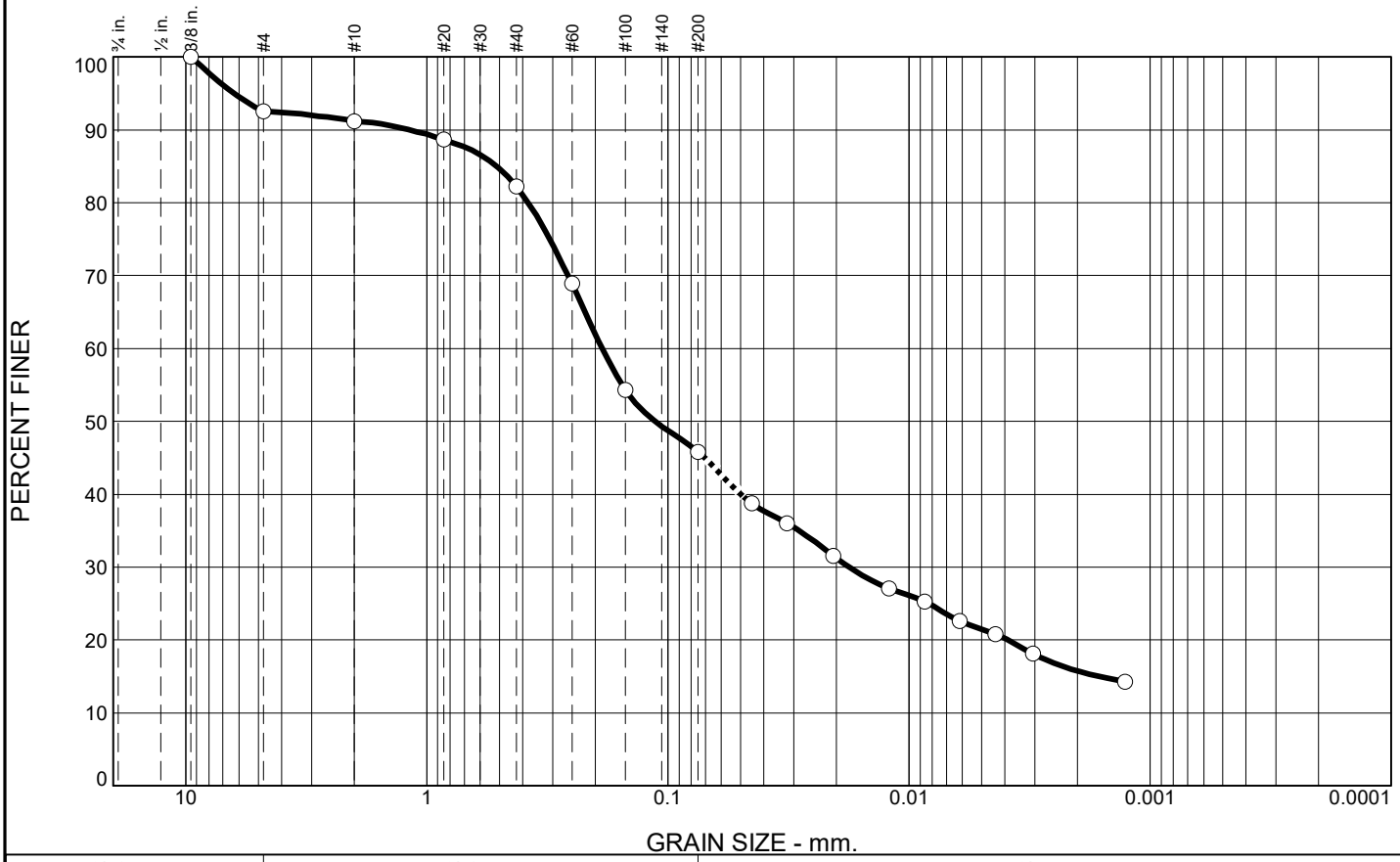
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	7.4	1.4	8.9	36.5	24.3	21.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	92.6		
#10	91.2		
#20	88.7		
#40	82.3		
#60	68.9		
#100	54.3		
#200	45.8		
0.0449 mm.	38.7		
0.0321 mm.	36.0		
0.0206 mm.	31.5		
0.0121 mm.	27.1		
0.0086 mm.	25.3		
0.0061 mm.	22.6		
0.0044 mm.	20.8		
0.0031 mm.	18.1		
0.0013 mm.	14.3		

* (no specification provided)

Soil Description

BROWN AND RUST BROWN CLAYEY SAND - ROOTS NOTED

Atterberg Limits

PL= 12 LL= 27 PI= 15

Coefficients

D_{90}= 1.1757 D_{85}= 0.5121 D_{60}= 0.1872
D_{50}= 0.1131 D_{30}= 0.0177 D_{15}= 0.0016
D_{10}= C_u= C_c=

Classification

USCS= SC AASHTO= A-6(3)

Remarks

F.M.=1.11

Source of Sample: APW-12 **Depth:** 20.0'-22.0'
Sample Number: 0825 **Date:** 2-26-21

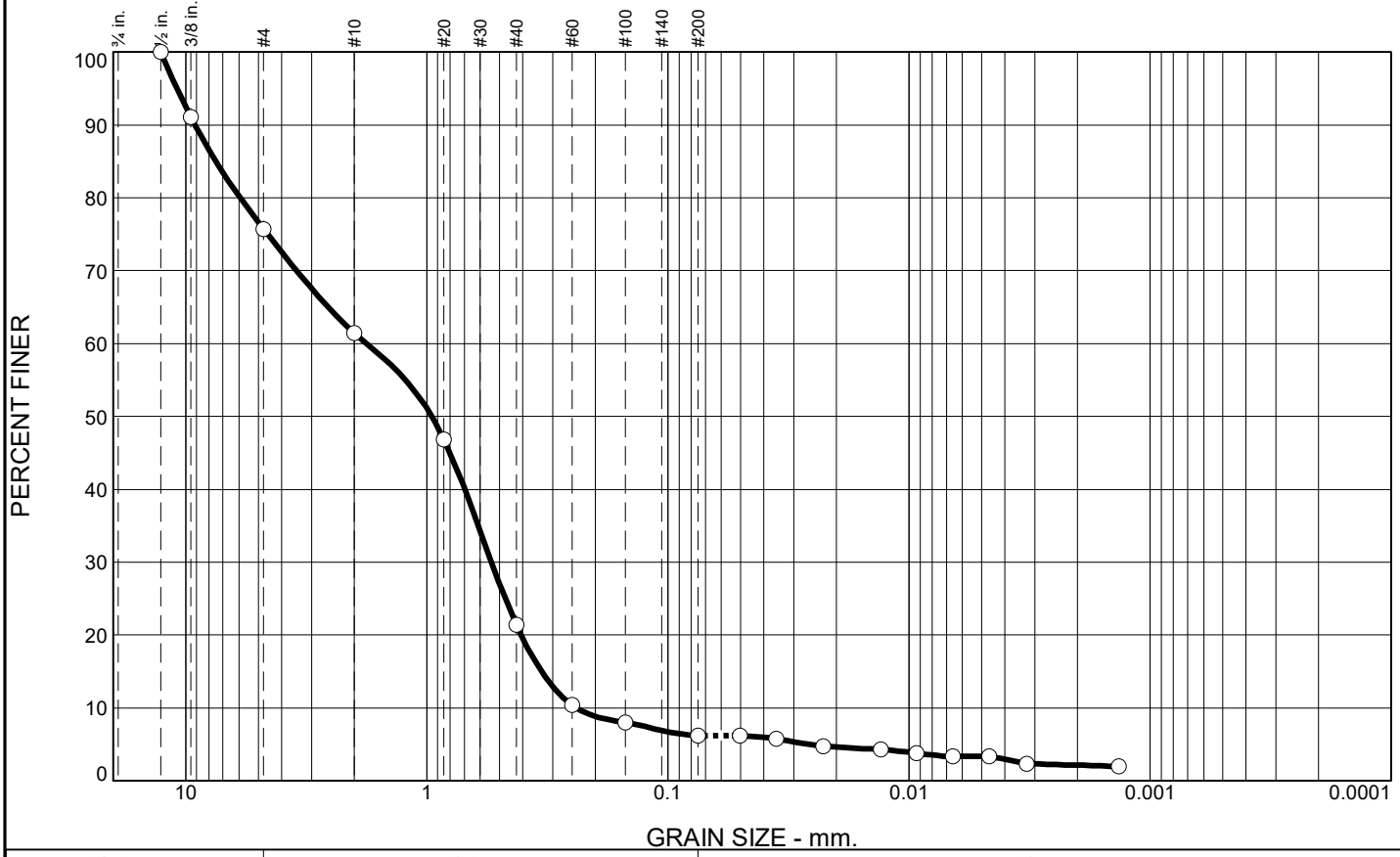
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	24.3	14.3	40.0	15.2	2.9	3.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	91.1		
#4	75.7		
#10	61.4		
#20	46.8		
#40	21.4		
#60	10.4		
#100	8.0		
#200	6.2		
0.0502 mm.	6.2		
0.0356 mm.	5.7		
0.0226 mm.	4.8		
0.0131 mm.	4.3		
0.0093 mm.	3.8		
0.0066 mm.	3.3		
0.0047 mm.	3.3		
0.0032 mm.	2.4		
0.0014 mm.	2.0		

* (no specification provided)

Soil Description

BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= 13 LL= 10 PI= NP

Coefficients

D_{90}= 9.1597 D_{85}= 7.5109 D_{60}= 1.7814
D_{50}= 0.9547 D_{30}= 0.5391 D_{15}= 0.3343
D_{10}= 0.2395 C_u= 7.44 C_c= 0.68

Classification

USCS= SP-SM AASHTO= A-1-b

Remarks

F.M.=3.60

Source of Sample: APW-12 **Depth:** 25.5'-26.0'
Sample Number: 0845 **Date:** 3-11-21

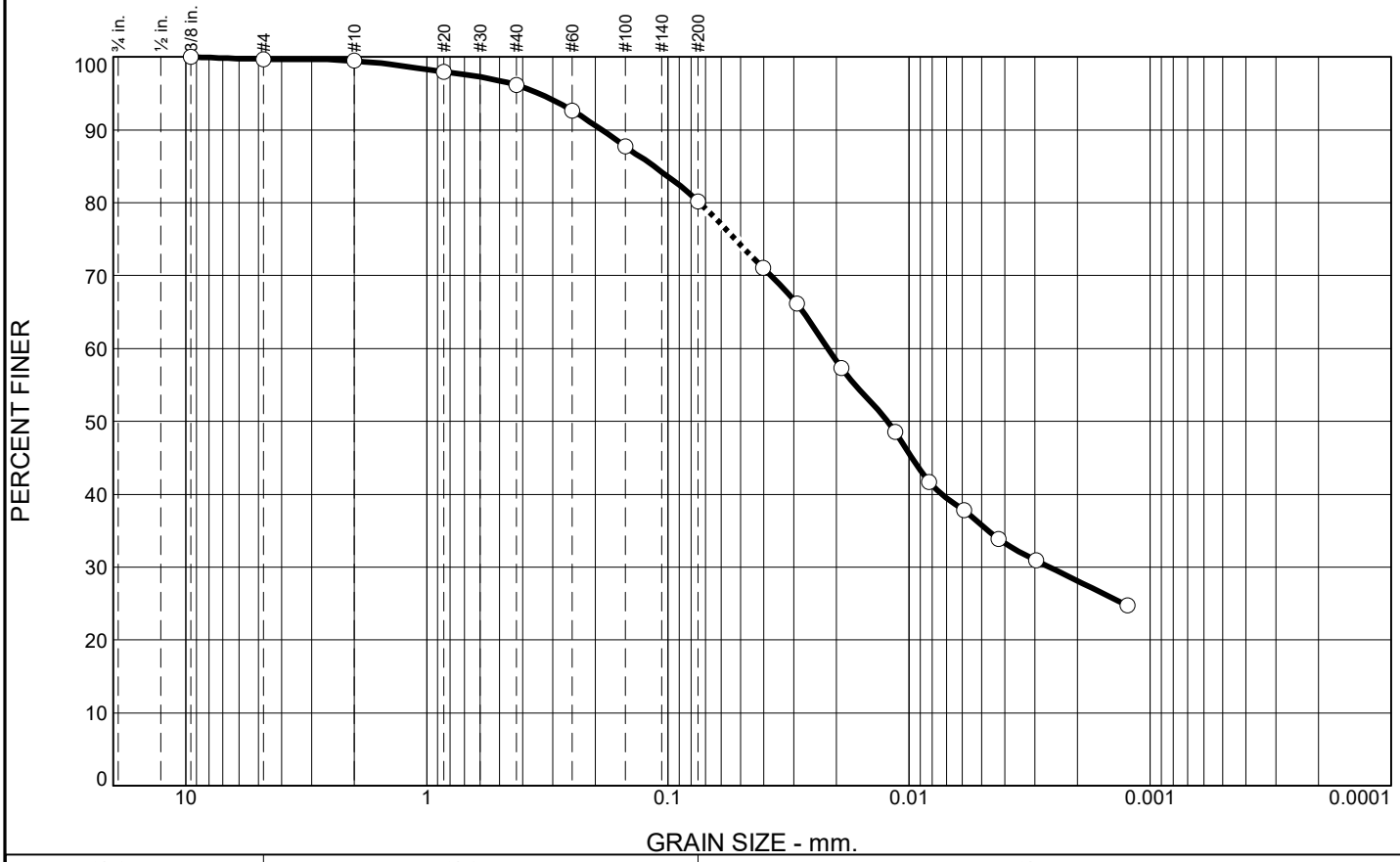
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.3	0.2	3.4	15.9	44.4	35.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.7		
#10	99.5		
#20	98.0		
#40	96.1		
#60	92.7		
#100	87.7		
#200	80.2		
0.0403 mm.	71.0		
0.0291 mm.	66.1		
0.0191 mm.	57.3		
0.0114 mm.	48.5		
0.0083 mm.	41.7		
0.0059 mm.	37.8		
0.0042 mm.	33.9		
0.0030 mm.	30.9		
0.0012 mm.	24.8		

* (no specification provided)

Soil Description

DARK GRAY LEAN CLAY WITH SAND - SILT POCKETS NOTED

Atterberg Limits

PL= 14 LL= 29 PI= 15

Coefficients

D_{90}= 0.1885 D_{85}= 0.1144 D_{60}= 0.0217
D_{50}= 0.0123 D_{30}= 0.0026 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(10)

Remarks

F.M.=0.23

Source of Sample: APW-12 **Depth:** 85.0'-87.0'
Sample Number: 1245 **Date:** 3-2-21

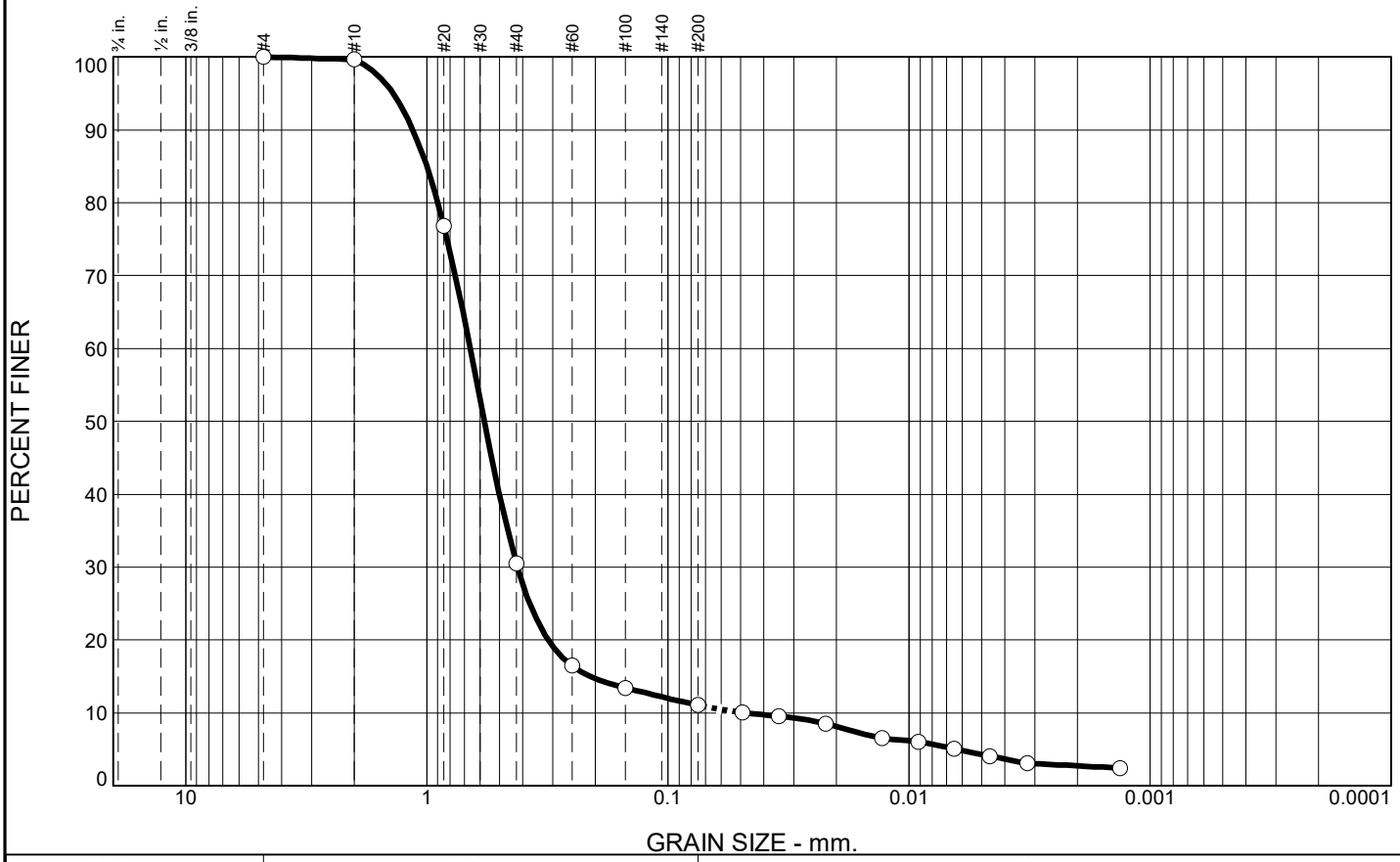
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.3	69.2	19.4	6.8	4.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.7		
#20	76.8		
#40	30.5		
#60	16.5		
#100	13.4		
#200	11.1		
0.0490 mm.	10.0		
0.0347 mm.	9.5		
0.0221 mm.	8.5		
0.0129 mm.	6.6		
0.0092 mm.	6.1		
0.0065 mm.	5.1		
0.0046 mm.	4.1		
0.0032 mm.	3.1		
0.0013 mm.	2.4		

* (no specification provided)

Soil Description

DARK BROWN AND GRAY POORLY GRADED SAND WITH SILT

Atterberg Limits

PL= 10 LL= 9 PI= NP

Coefficients

D_{90}= 1.1425 D_{85}= 1.0006 D_{60}= 0.6613
D_{50}= 0.5767 D_{30}= 0.4204 D_{15}= 0.2099
D_{10}= 0.0479 C_u= 13.80 C_c= 5.58

Classification

USCS= SP-SM AASHTO= A-1-b

Remarks

F.M.=2.24

Source of Sample: APW-13 **Depth:** 25.0'-27.0'
Sample Number: 0845

Date: 2-26-21

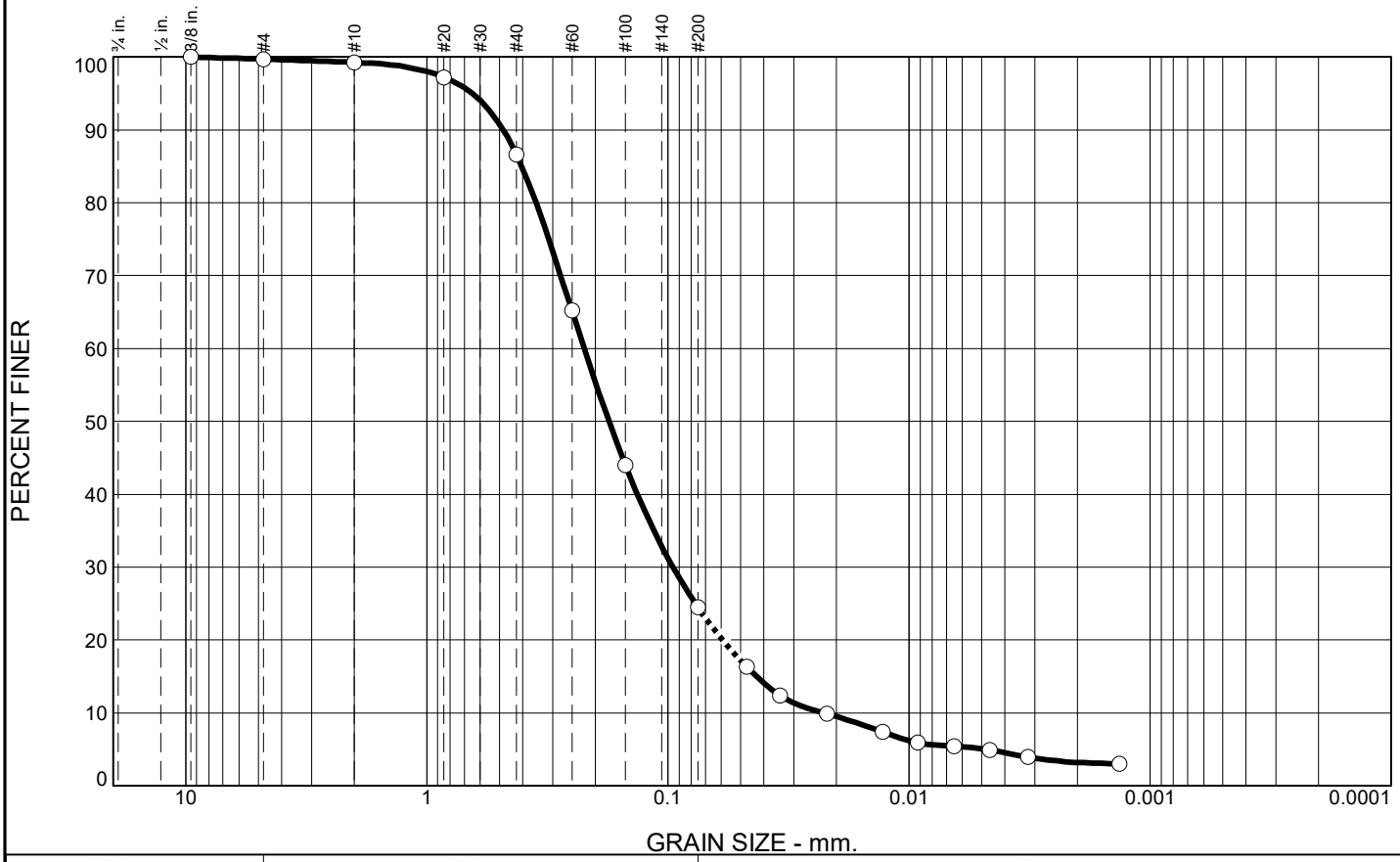
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.3	0.4	12.7	62.1	19.4	5.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.7		
#10	99.3		
#20	97.2		
#40	86.6		
#60	65.2		
#100	44.0		
#200	24.5		
0.0471 mm.	16.3		
0.0342 mm.	12.4		
0.0220 mm.	9.9		
0.0129 mm.	7.4		
0.0092 mm.	5.9		
0.0065 mm.	5.4		
0.0046 mm.	4.9		
0.0032 mm.	3.9		
0.0013 mm.	3.0		

* (no specification provided)

Soil Description

BROWN SILTY SAND

Atterberg Limits

PL= 13 LL= 8 PI= NP

Coefficients

D_{90}= 0.4819 D_{85}= 0.4036 D_{60}= 0.2222
D_{50}= 0.1755 D_{30}= 0.0953 D_{15}= 0.0429
D_{10}= 0.0226 C_u= 9.84 C_c= 1.81

Classification

USCS= SM AASHTO= A-2-4(0)

Remarks

F.M.=0.91

Source of Sample: APW-13 **Depth:** 60.5'-61.0'
Sample Number: 1345

Date: 3-11-21

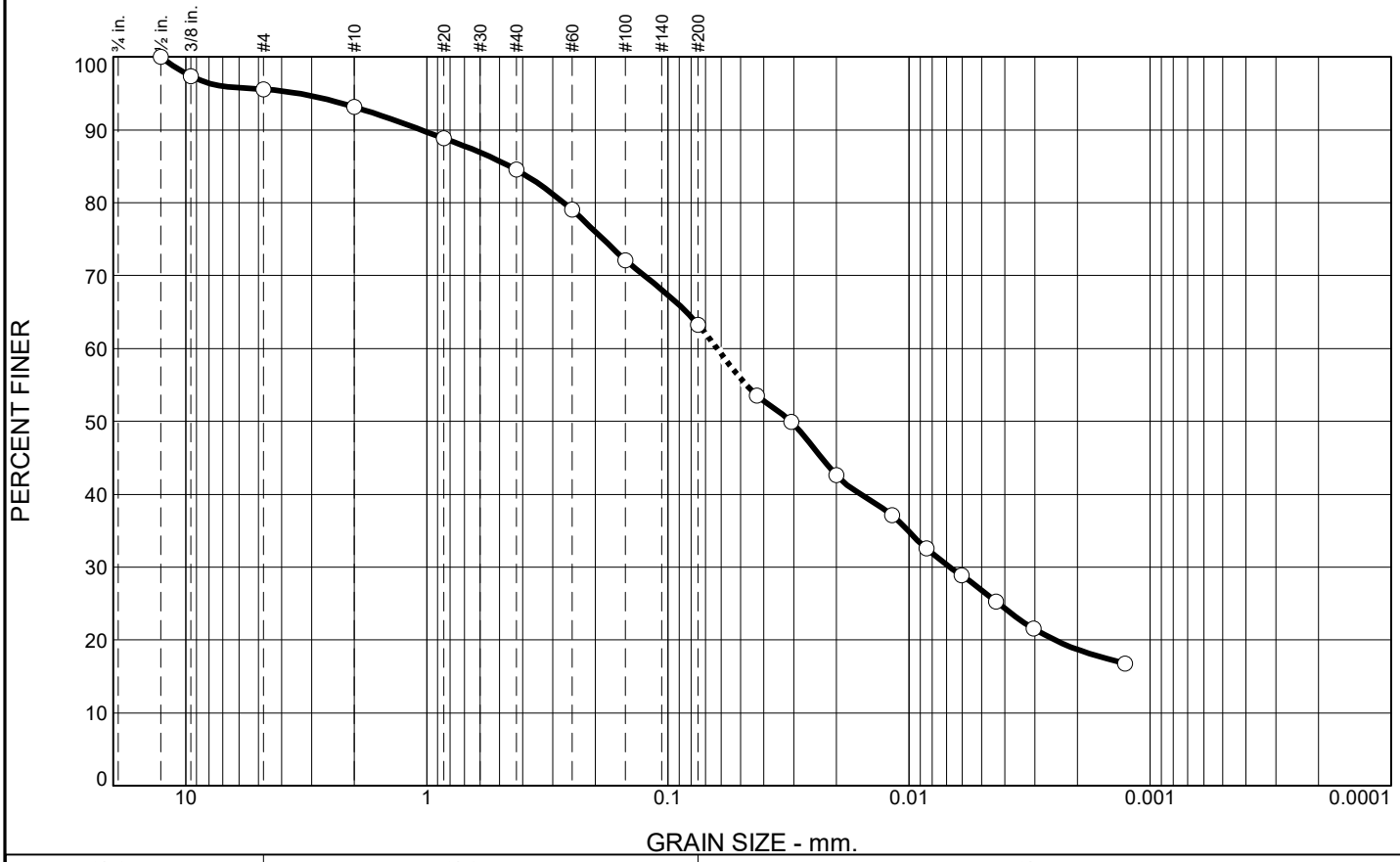
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.4	2.5	8.6	21.2	36.5	26.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	97.3		
#4	95.6		
#10	93.1		
#20	88.8		
#40	84.5		
#60	79.0		
#100	72.1		
#200	63.3		
0.0427 mm.	53.6		
0.0307 mm.	49.9		
0.0200 mm.	42.6		
0.0118 mm.	37.1		
0.0085 mm.	32.6		
0.0061 mm.	28.9		
0.0043 mm.	25.2		
0.0030 mm.	21.6		
0.0013 mm.	16.7		

* (no specification provided)

Soil Description

BROWN SANDY LEAN CLAY

Atterberg Limits

PL= 14 LL= 26 PI= 12

Coefficients

D_{90}= 1.0607 D_{85}= 0.4525 D_{60}= 0.0625
D_{50}= 0.0309 D_{30}= 0.0068 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(5)

Remarks

F.M.=0.83

Source of Sample: APW-14 **Depth:** 45.0'-47.0'
Sample Number: 0955 **Date:** 3-2-21

Terracon

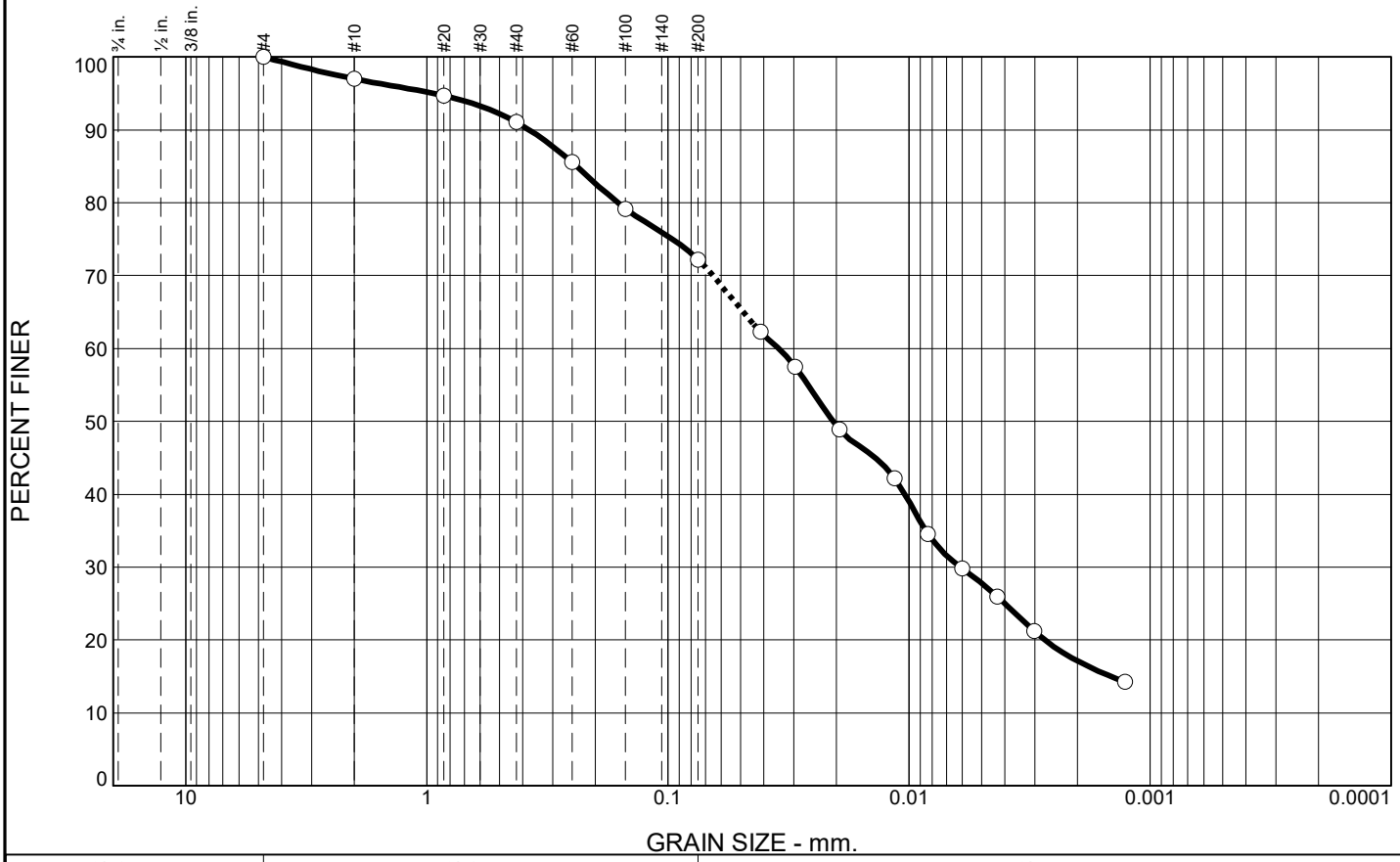
Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	3.0	5.9	18.9	44.4	27.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	97.0		
#20	94.7		
#40	91.1		
#60	85.6		
#100	79.2		
#200	72.2		
0.0411 mm.	62.3		
0.0297 mm.	57.5		
0.0194 mm.	48.9		
0.0115 mm.	42.2		
0.0084 mm.	34.6		
0.0060 mm.	29.8		
0.0043 mm.	26.0		
0.0030 mm.	21.2		
0.0013 mm.	14.2		

* (no specification provided)

Soil Description

GRAY AND BROWNISH GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 15 LL= 25 PI= 10

Coefficients

D_{90}= 0.3753 D_{85}= 0.2390 D_{60}= 0.0348
D_{50}= 0.0207 D_{30}= 0.0061 D_{15}= 0.0014
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-4(5)

Remarks

F.M.=0.47

Source of Sample: APW-14 **Depth:** 55.5'-56.0'
Sample Number: 1045 **Date:** 2-26-21

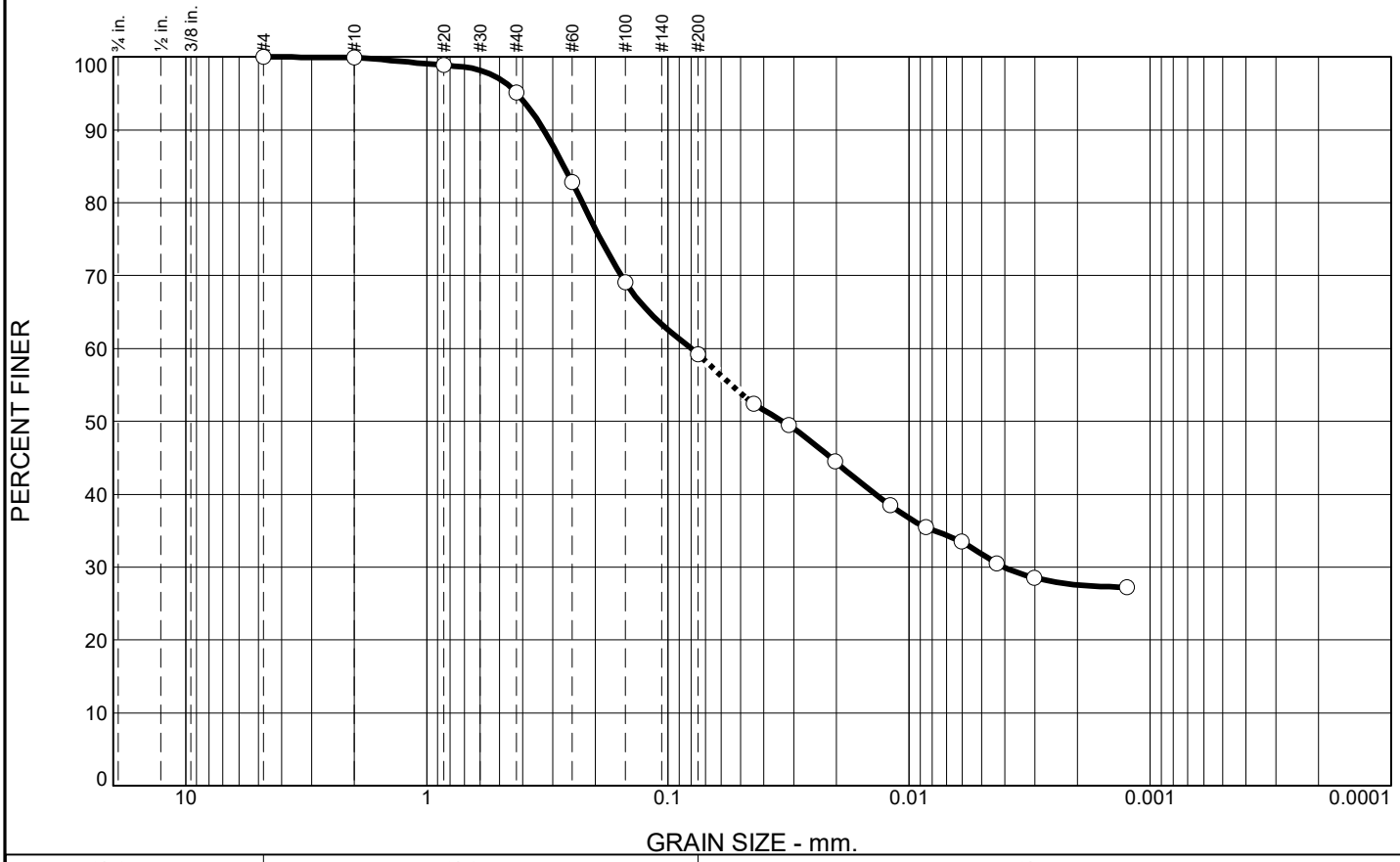
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.1	4.8	35.9	27.4	31.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.9		
#20	98.9		
#40	95.1		
#60	82.9		
#100	69.1		
#200	59.2		
0.0440 mm.	52.4		
0.0314 mm.	49.5		
0.0202 mm.	44.5		
0.0119 mm.	38.5		
0.0085 mm.	35.5		
0.0061 mm.	33.5		
0.0043 mm.	30.5		
0.0030 mm.	28.5		
0.0012 mm.	27.2		

* (no specification provided)

Soil Description

BROWN SANDY LEAN CLAY

Atterberg Limits

PL= 10 LL= 33 PI= 23

Coefficients

D_{90}= 0.3277 D_{85}= 0.2698 D_{60}= 0.0802
D_{50}= 0.0334 D_{30}= 0.0040 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(10)

Remarks

F.M.=0.46

Source of Sample: APW-15 **Depth:** 20.0'-22.0'
Sample Number: 1005 **Date:** 3-2-21

Terracon

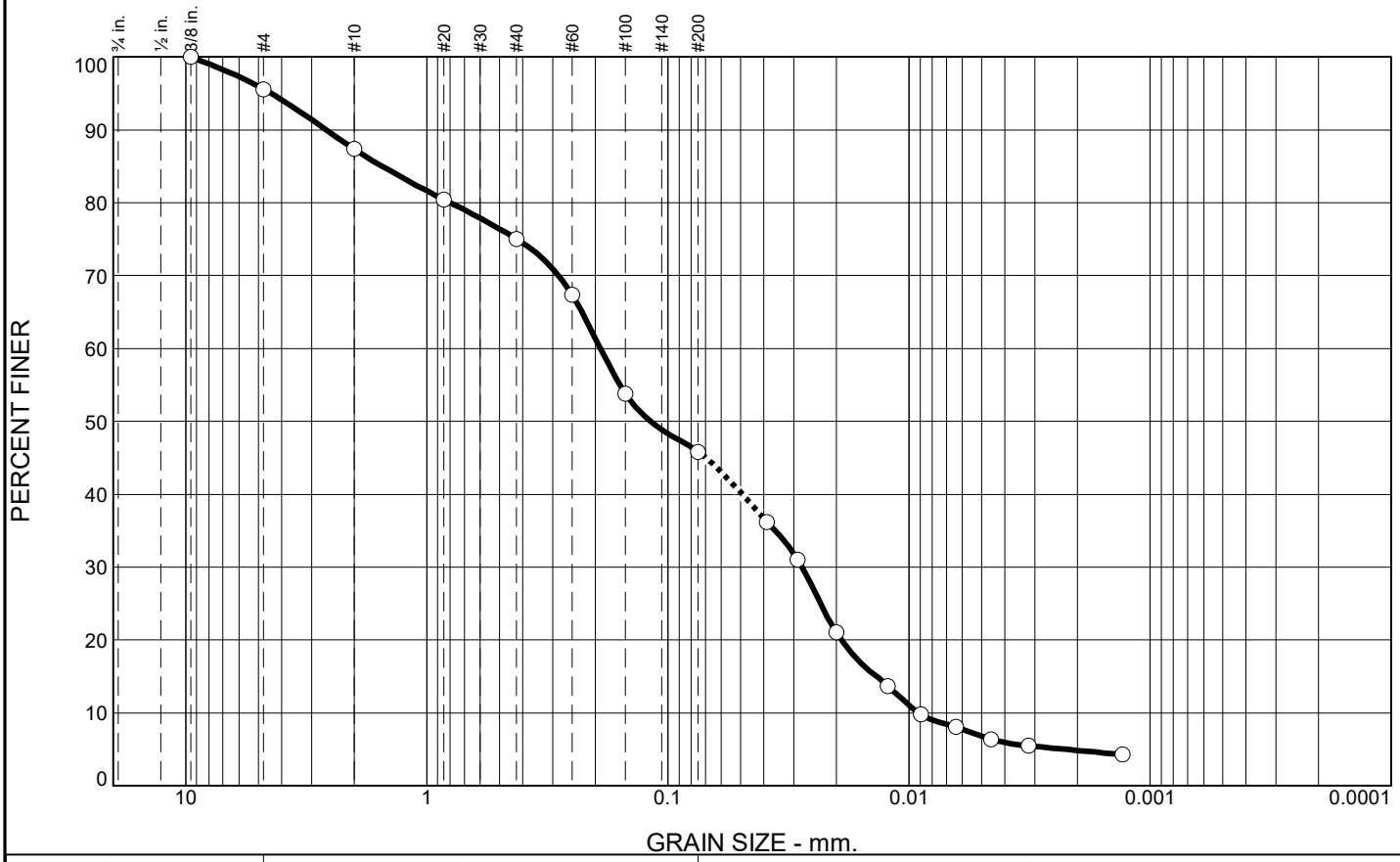
Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.4	8.2	12.4	29.2	39.0	6.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	95.6		
#10	87.4		
#20	80.4		
#40	75.0		
#60	67.4		
#100	53.8		
#200	45.8		
0.0388 mm.	36.2		
0.0290 mm.	31.0		
0.0201 mm.	21.1		
0.0123 mm.	13.7		
0.0089 mm.	9.8		
0.0064 mm.	8.1		
0.0046 mm.	6.3		
0.0032 mm.	5.5		
0.0013 mm.	4.3		

* (no specification provided)

Soil Description

GRAY SILTY SAND

Atterberg Limits

PL= 12 LL= 15 PI= 3

Coefficients

D_{90}= 2.6175 D_{85}= 1.5318 D_{60}= 0.1904
D_{50}= 0.1183 D_{30}= 0.0278 D_{15}= 0.0137
D_{10}= 0.0091 C_u= 20.90 C_c= 0.45

Classification

USCS= SM AASHTO= A-4(0)

Remarks

F.M.=1.30

Source of Sample: APW-15 **Depth:** 100.5'-101.0'
Sample Number: 0755 **Date:** 2-26-21

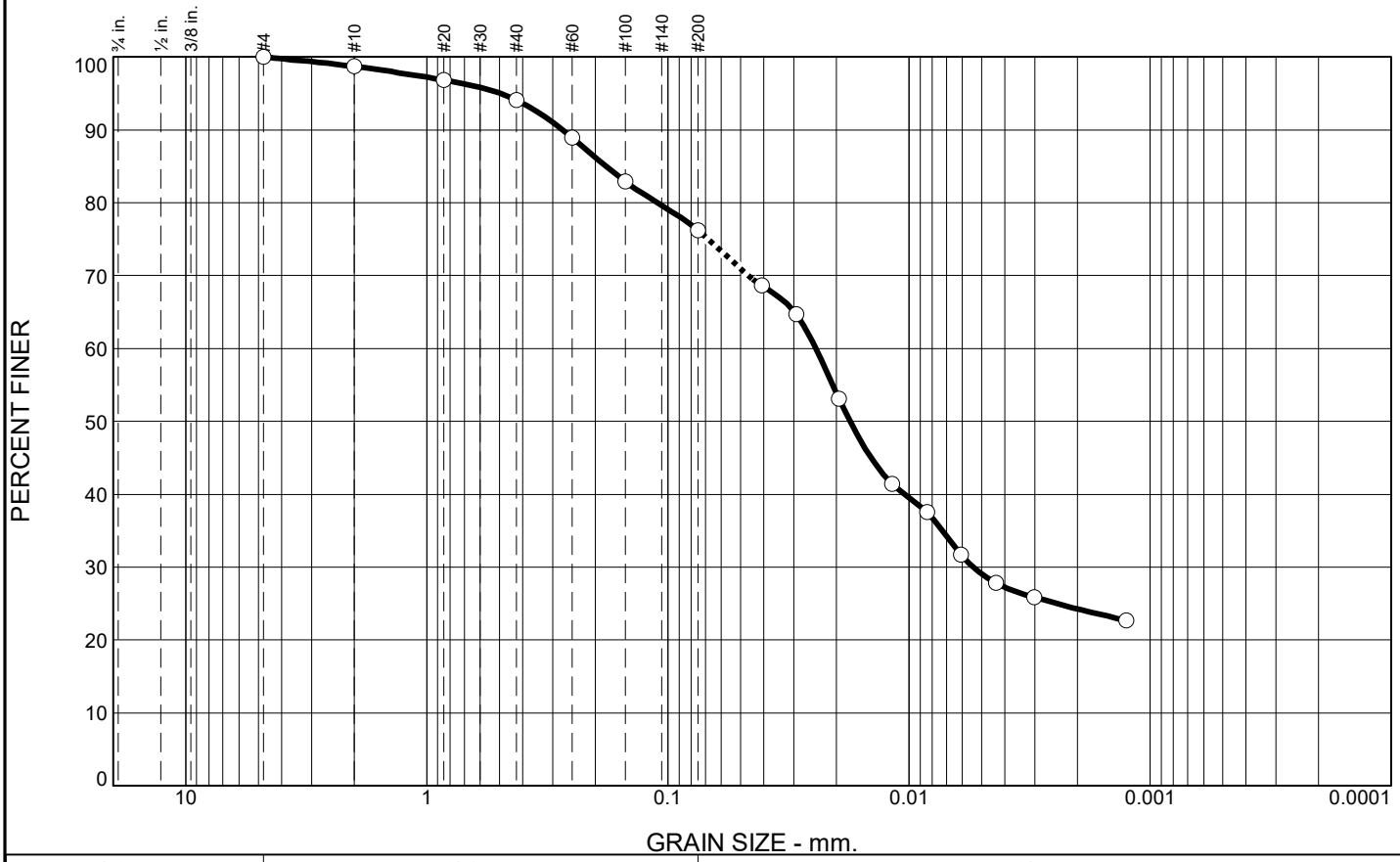
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.3	4.6	17.9	47.1	29.1

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	98.7		
#20	96.8		
#40	94.1		
#60	89.0		
#100	82.9		
#200	76.2		
0.0409 mm.	68.6		
0.0294 mm.	64.7		
0.0195 mm.	53.1		
0.0118 mm.	41.4		
0.0084 mm.	37.5		
0.0061 mm.	31.7		
0.0044 mm.	27.8		
0.0030 mm.	25.9		
0.0013 mm.	22.7		

* (no specification provided)

Soil Description

DARK GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 13 LL= 29 PI= 16

Coefficients

D_{90}= 0.2737 D_{85}= 0.1806 D_{60}= 0.0244
D_{50}= 0.0175 D_{30}= 0.0054 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(10)

Remarks

F.M.=0.34

Source of Sample: APW-15 **Depth:** 105.0'-107.0'
Sample Number: 0905 **Date:** 3-2-21

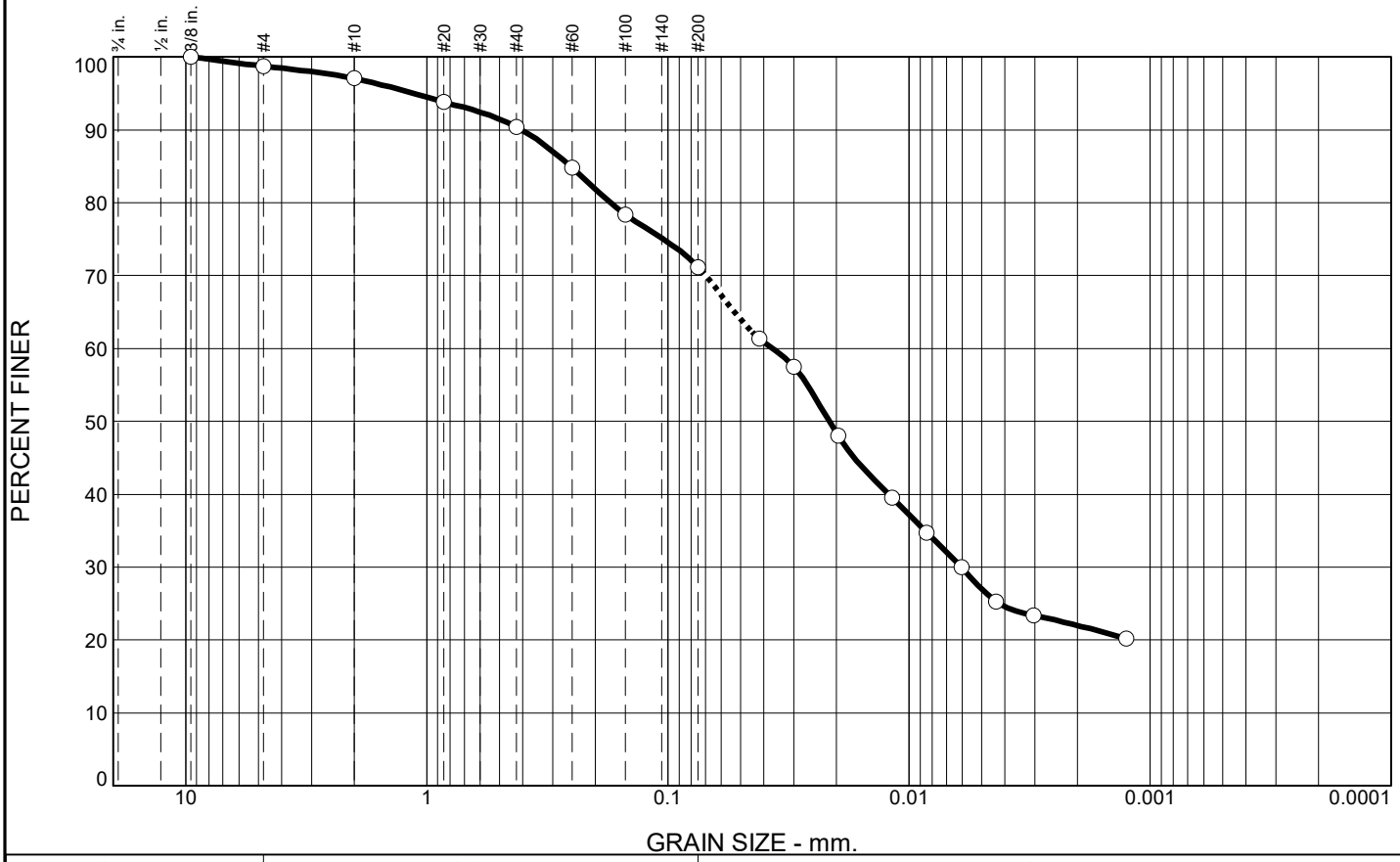
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	1.3	1.6	6.7	19.3	44.1	27.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.7		
#10	97.1		
#20	93.8		
#40	90.4		
#60	84.8		
#100	78.4		
#200	71.1		
0.0417 mm.	61.3		
0.0300 mm.	57.5		
0.0197 mm.	48.0		
0.0117 mm.	39.5		
0.0084 mm.	34.8		
0.0061 mm.	30.0		
0.0044 mm.	25.3		
0.0030 mm.	23.4		
0.0013 mm.	20.2		

* (no specification provided)

Soil Description

GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 13 LL= 26 PI= 13

Coefficients

D_{90}= 0.4047 D_{85}= 0.2534 D_{60}= 0.0368
D_{50}= 0.0214 D_{30}= 0.0061 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(6)

Remarks

F.M.=0.51

Source of Sample: APW-17 **Depth:** 40.0'-42.0'
Sample Number: 0945 **Date:** 3-2-21

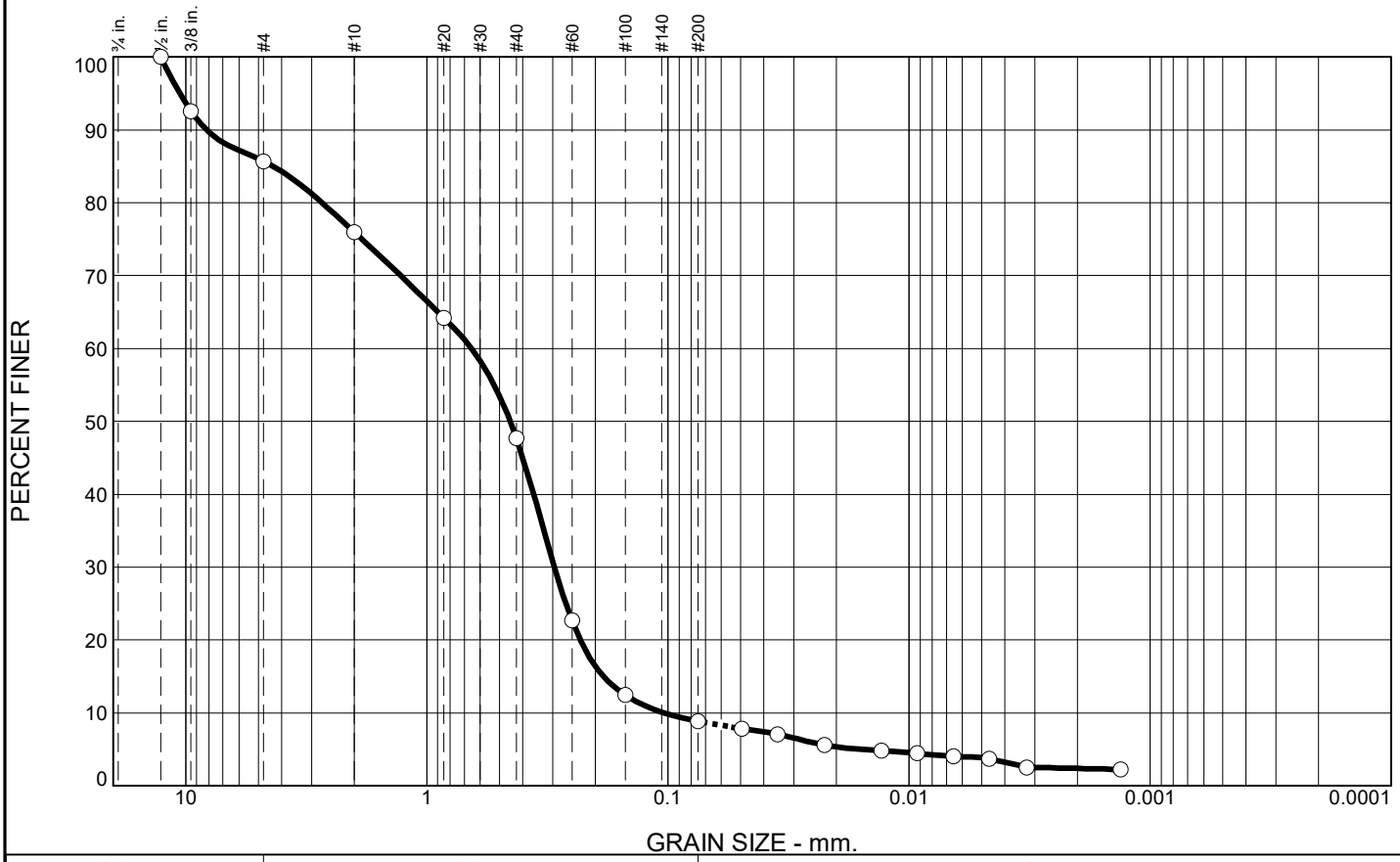
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	14.3	9.7	28.3	38.8	5.1	3.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	92.6		
#4	85.7		
#10	76.0		
#20	64.2		
#40	47.7		
#60	22.7		
#100	12.5		
#200	8.9		
0.0493 mm.	7.9		
0.0350 mm.	7.1		
0.0224 mm.	5.6		
0.0130 mm.	4.8		
0.0092 mm.	4.4		
0.0065 mm.	4.1		
0.0046 mm.	3.7		
0.0032 mm.	2.5		
0.0013 mm.	2.2		

* (no specification provided)

Soil Description

GRAY WELL GRADED SAND WITH SILT

Atterberg Limits

PL= 9 LL= 5 PI= NP

Coefficients

D_{90}= 8.1927 D_{85}= 4.3406 D_{60}= 0.6532
D_{50}= 0.4503 D_{30}= 0.2954 D_{15}= 0.1851
D_{10}= 0.1038 C_u= 6.29 C_c= 1.29

Classification

USCS= SW-SM AASHTO= A-1-b

Remarks

F.M.=2.73

Source of Sample: APW-17 **Depth:** 71.0'-71.5'
Sample Number: 1045 **Date:** 2-26-21

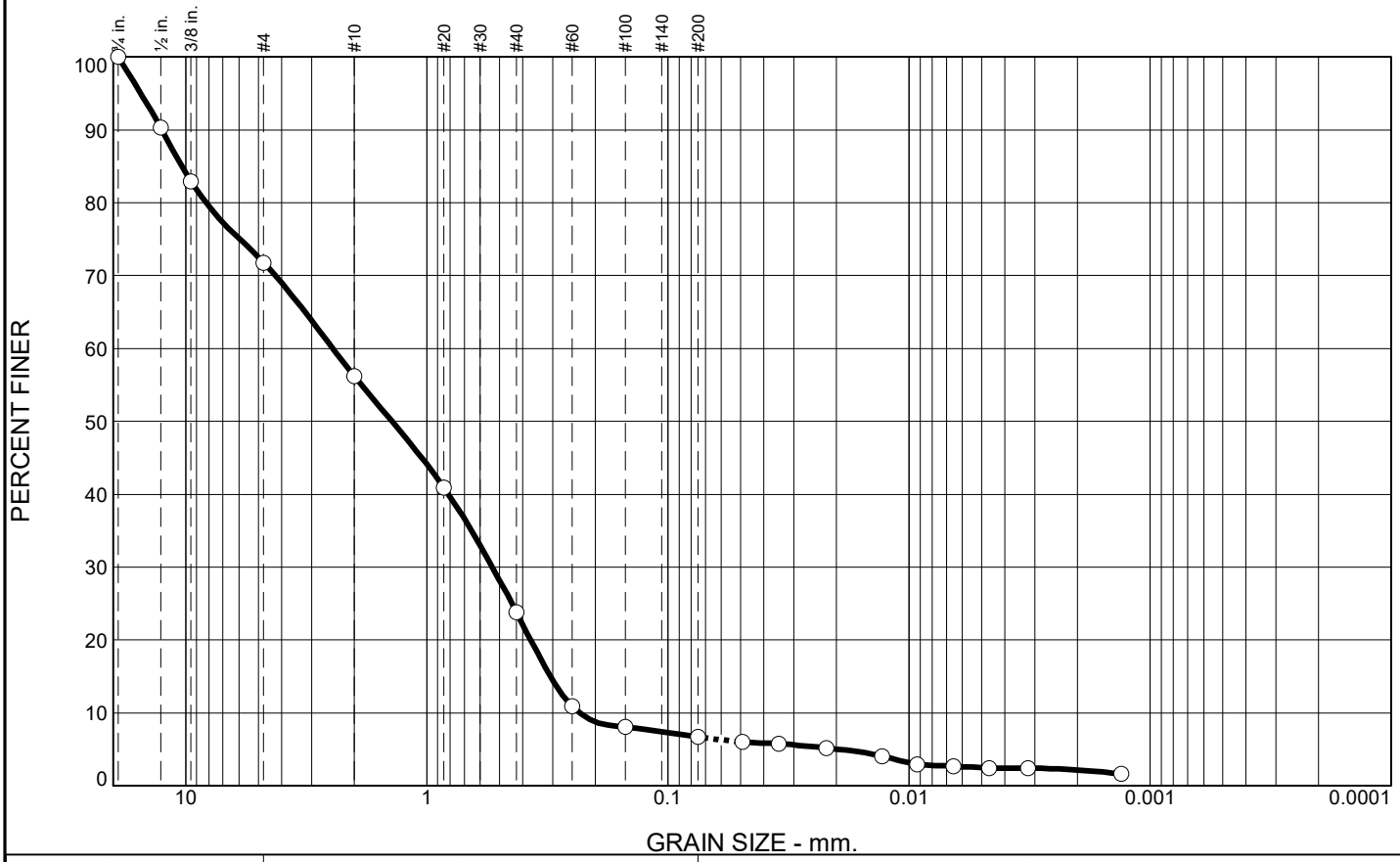
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	28.2	15.6	32.4	17.1	4.2	2.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.75	100.0		
.5	90.3		
.375	83.0		
#4	71.8		
#10	56.2		
#20	40.9		
#40	23.8		
#60	10.9		
#100	8.0		
#200	6.7		
0.0489 mm.	6.0		
0.0347 mm.	5.7		
0.0221 mm.	5.2		
0.0129 mm.	4.1		
0.0092 mm.	3.0		
0.0065 mm.	2.7		
0.0046 mm.	2.4		
0.0032 mm.	2.4		
0.0013 mm.	1.6		

* (no specification provided)

Soil Description

GRAYISH BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= 8 LL= 6 PI= NP

Coefficients

D_{90}= 12.5520 D_{85}= 10.3682 D_{60}= 2.4528
D_{50}= 1.3942 D_{30}= 0.5340 D_{15}= 0.3065
D_{10}= 0.2326 C_u= 10.54 C_c= 0.50

Classification

USCS= SP-SM AASHTO= A-1-b

Remarks

F.M.=3.83

Source of Sample: APW-17 **Depth:** 90.5'-91.0'
Sample Number: 1200 **Date:** 2-26-21

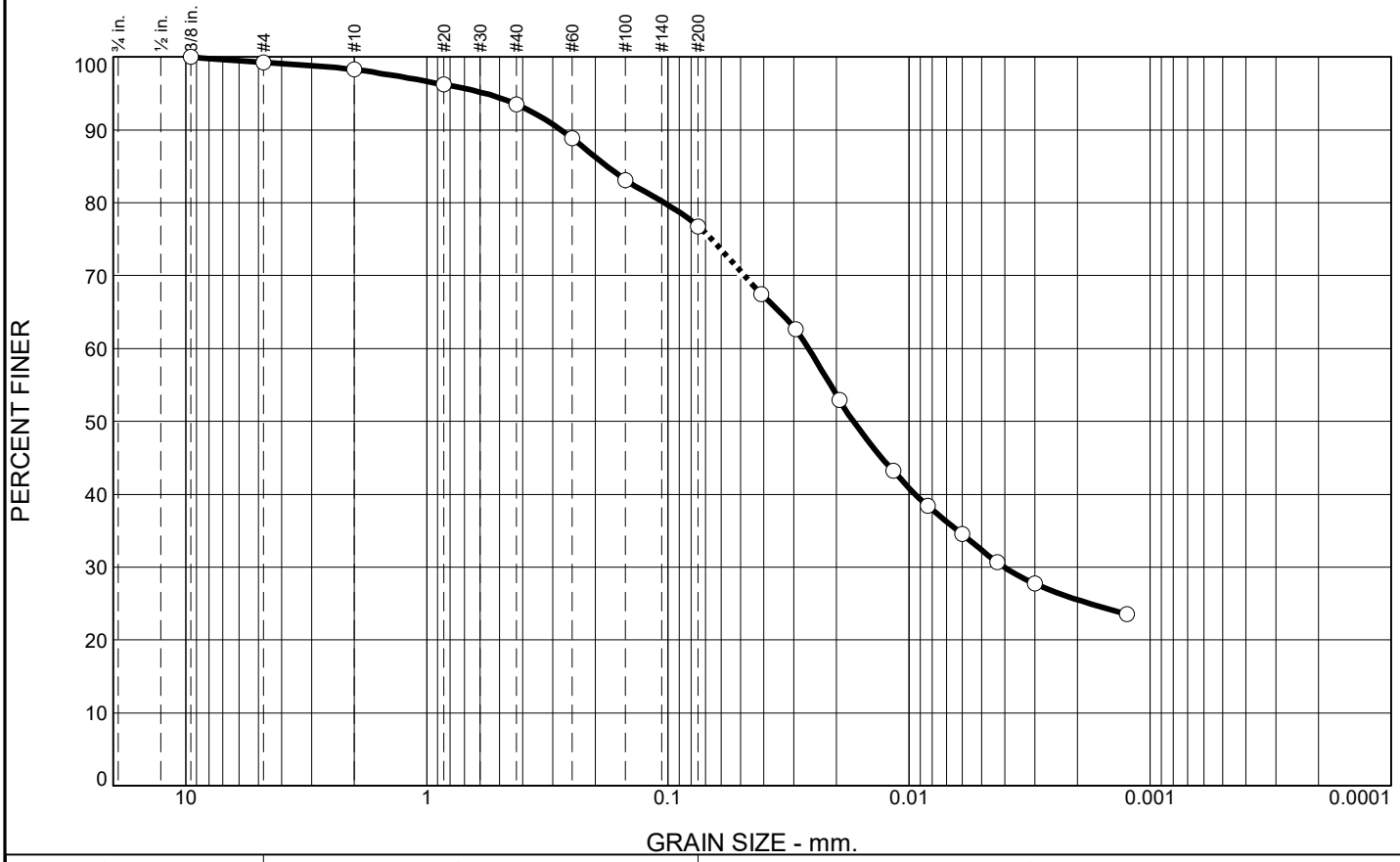
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.8	0.9	4.8	16.7	44.5	32.3

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.2		
#10	98.3		
#20	96.2		
#40	93.5		
#60	88.9		
#100	83.1		
#200	76.8		
0.0410 mm.	67.5		
0.0296 mm.	62.6		
0.0194 mm.	52.9		
0.0116 mm.	43.2		
0.0084 mm.	38.4		
0.0060 mm.	34.5		
0.0043 mm.	30.6		
0.0030 mm.	27.7		
0.0013 mm.	23.6		

* (no specification provided)

Soil Description

DARK GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 12 LL= 32 PI= 20

Coefficients

D_{90}= 0.2782 D_{85}= 0.1790 D_{60}= 0.0261
D_{50}= 0.0170 D_{30}= 0.0040 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(13)

Remarks

F.M.=0.36

Source of Sample: SB-300 **Depth:** 50.0'-52.0'
Sample Number: 0825

Date: 3-2-21

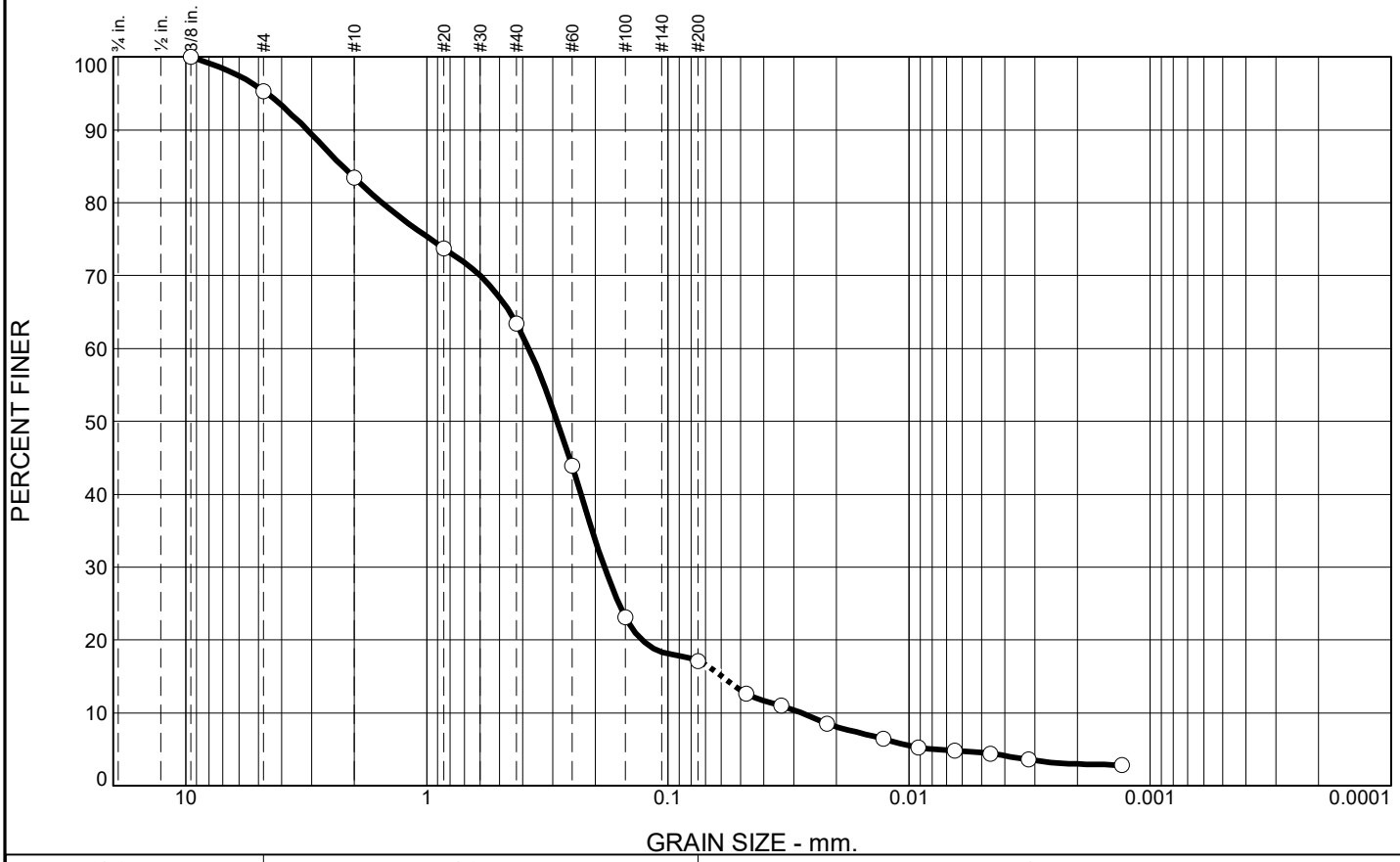
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.7	11.9	20.0	46.3	12.5	4.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	95.3		
#10	83.4		
#20	73.7		
#40	63.4		
#60	43.9		
#100	23.1		
#200	17.1		
0.0474 mm.	12.7		
0.0339 mm.	11.0		
0.0219 mm.	8.5		
0.0128 mm.	6.5		
0.0091 mm.	5.2		
0.0065 mm.	4.8		
0.0046 mm.	4.4		
0.0032 mm.	3.6		
0.0013 mm.	2.9		

* (no specification provided)

Soil Description

GRAYISH BROWN SILTY SAND

Atterberg Limits

PL= 9 LL= 5 PI= NP

Coefficients

D_{90}= 3.1361 D_{85}= 2.2352 D_{60}= 0.3777
D_{50}= 0.2877 D_{30}= 0.1834 D_{15}= 0.0597
D_{10}= 0.0281 C_u= 13.44 C_c= 3.17

Classification

USCS= SM AASHTO= A-2-4(0)

Remarks

F.M.=1.97

Source of Sample: SB-300 **Depth:** 61.0'-61.5'
Sample Number: 0905

Date: 2-26-21

Terracon

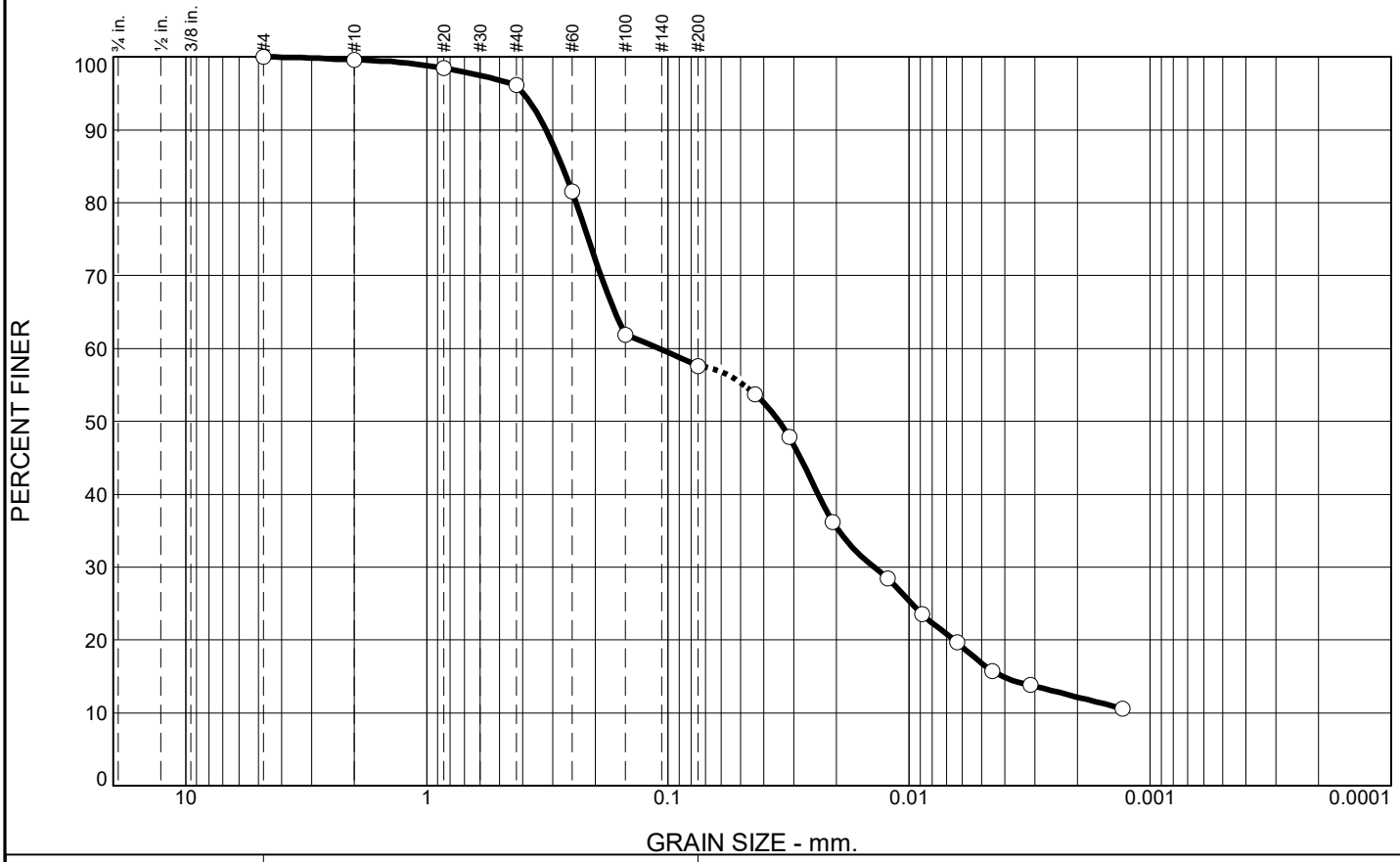
Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.4	3.5	38.5	40.8	16.8

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.6		
#20	98.5		
#40	96.1		
#60	81.6		
#100	61.9		
#200	57.6		
0.0434 mm.	53.7		
0.0314 mm.	47.9		
0.0207 mm.	36.2		
0.0123 mm.	28.4		
0.0088 mm.	23.5		
0.0063 mm.	19.6		
0.0045 mm.	15.7		
0.0031 mm.	13.8		
0.0013 mm.	10.6		

* (no specification provided)

Soil Description

GRAY AND BROWN SANDY SILTY CLAY

Atterberg Limits

PL= 14 LL= 20 PI= 6

Coefficients

D_{90}= 0.3201 D_{85}= 0.2739 D_{60}= 0.1090
D_{50}= 0.0345 D_{30}= 0.0139 D_{15}= 0.0041
D_{10}= C_u= C_c=

Classification

USCS= CL-ML AASHTO= A-4(1)

Remarks

F.M.=0.54

Source of Sample: SB-300 **Depth:** 62.5'-63.0'
Sample Number: 0920

Date: 2-26-21

Terracon

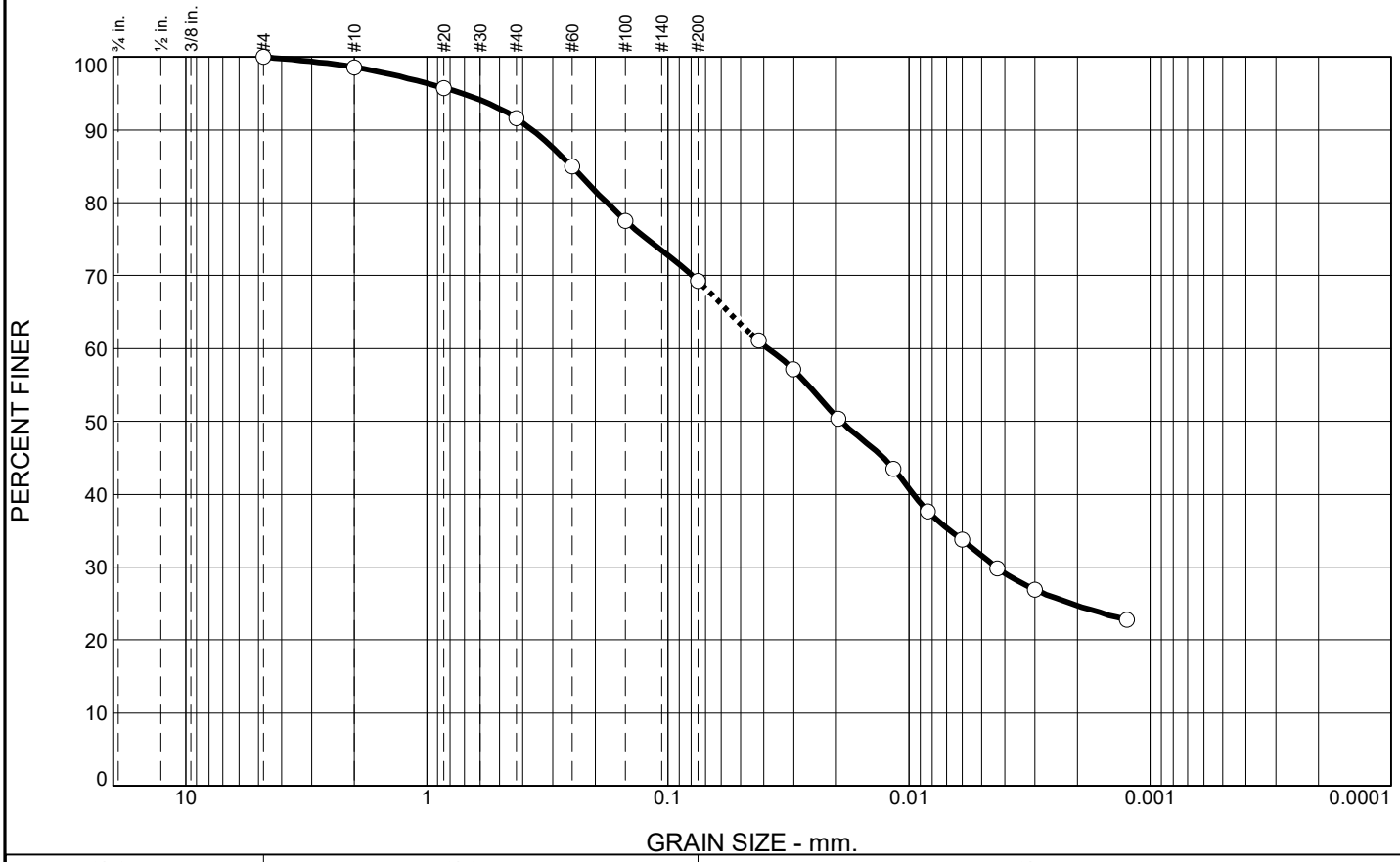
Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.4	7.0	22.3	37.7	31.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	98.6		
#20	95.7		
#40	91.6		
#60	84.9		
#100	77.5		
#200	69.3		
0.0420 mm.	61.1		
0.0302 mm.	57.2		
0.0196 mm.	50.3		
0.0116 mm.	43.5		
0.0084 mm.	37.7		
0.0060 mm.	33.8		
0.0043 mm.	29.9		
0.0030 mm.	26.9		
0.0013 mm.	22.7		

* (no specification provided)

Soil Description

DARK GRAY SANDY LEAN CLAY

Atterberg Limits

PL= 13 LL= 28 PI= 15

Coefficients

D_{90}= 0.3661 D_{85}= 0.2511 D_{60}= 0.0384
D_{50}= 0.0191 D_{30}= 0.0044 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(7)

Remarks

F.M.=0.45

Source of Sample: SB-300 **Depth:** 105.0'-107.0'
Sample Number: 1350

Date: 3-2-21

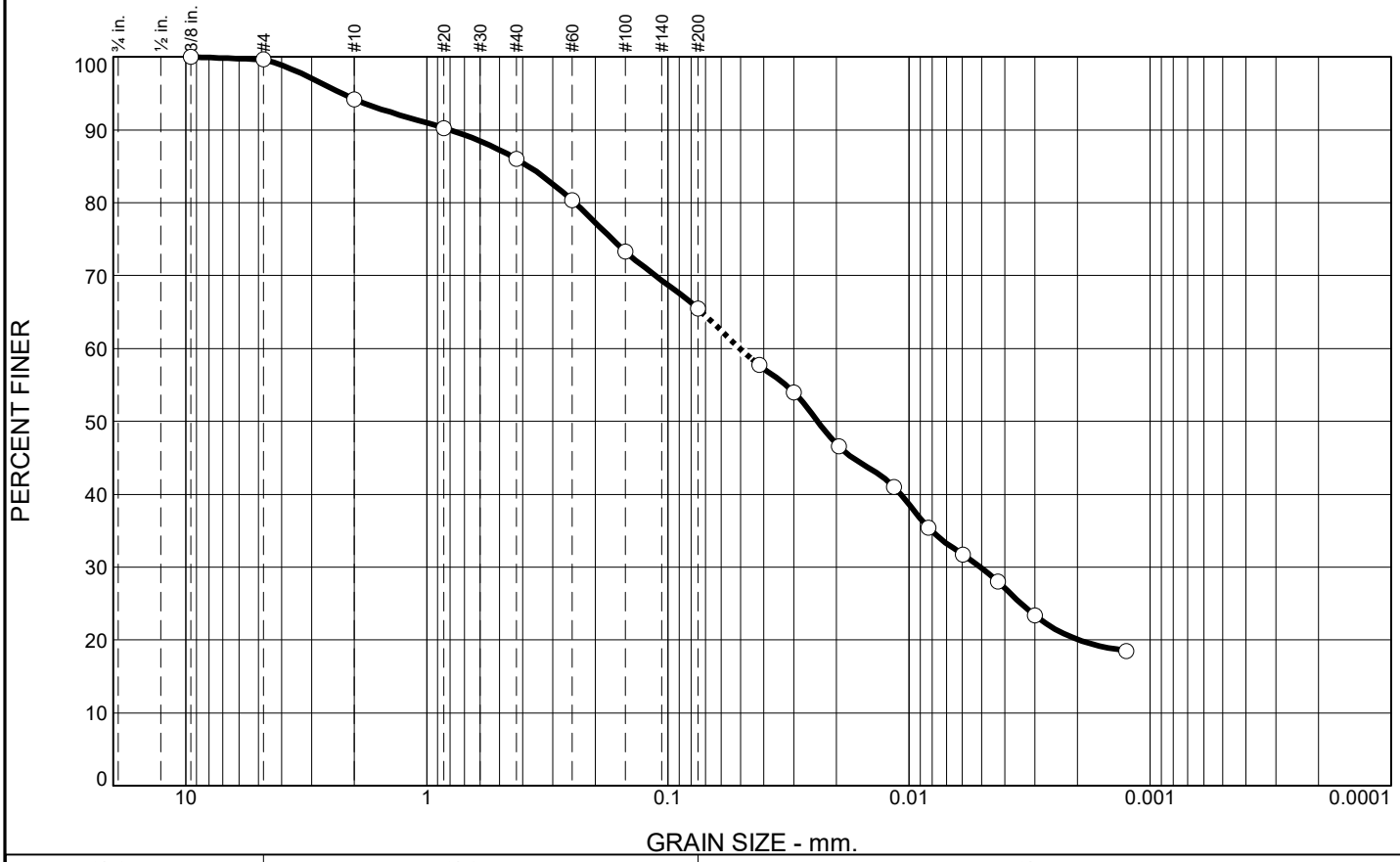
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.4	5.4	8.2	20.6	35.5	29.9

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.6		
#10	94.2		
#20	90.2		
#40	86.0		
#60	80.3		
#100	73.3		
#200	65.4		
0.0418 mm.	57.7		
0.0300 mm.	54.0		
0.0196 mm.	46.6		
0.0115 mm.	41.0		
0.0083 mm.	35.4		
0.0060 mm.	31.7		
0.0043 mm.	28.0		
0.0030 mm.	23.4		
0.0013 mm.	18.5		

* (no specification provided)

Soil Description

BROWN AND GRAY SANDY LEAN CLAY

Atterberg Limits

PL= 14 LL= 27 PI= 13

Coefficients

D_{90}= 0.8050 D_{85}= 0.3797 D_{60}= 0.0504
D_{50}= 0.0239 D_{30}= 0.0051 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(6)

Remarks

F.M.=0.69

Source of Sample: SB-301 **Depth:** 48.0'-50.0'
Sample Number: 1330

Date: 2-26-21

Terracon

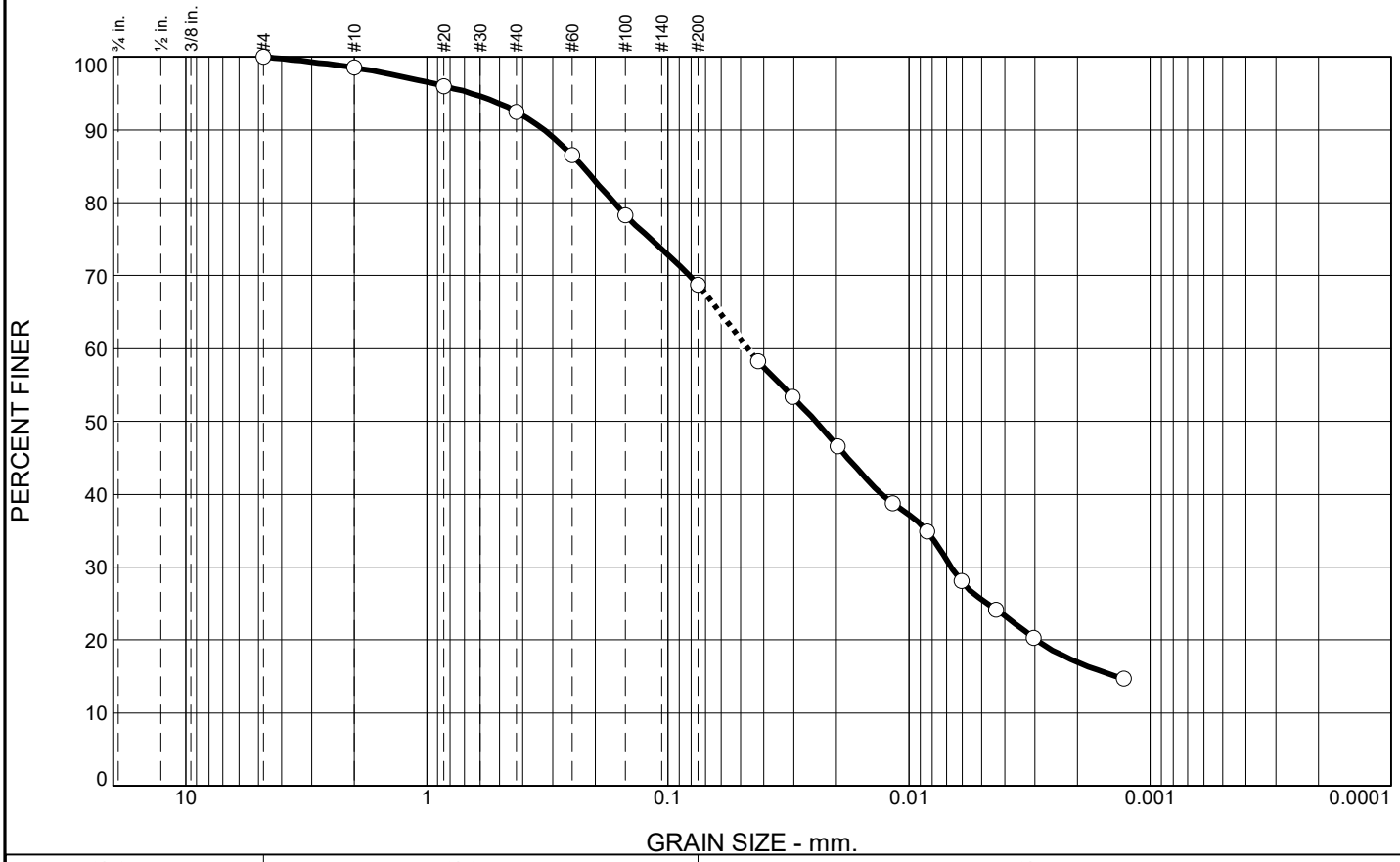
Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.5	6.0	23.8	43.2	25.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	98.5		
#20	96.0		
#40	92.5		
#60	86.5		
#100	78.3		
#200	68.7		
0.0422 mm.	58.3		
0.0304 mm.	53.4		
0.0197 mm.	46.6		
0.0117 mm.	38.8		
0.0084 mm.	34.9		
0.0061 mm.	28.1		
0.0043 mm.	24.2		
0.0030 mm.	20.3		
0.0013 mm.	14.7		

* (no specification provided)

Soil Description

GRAY SANDY LEAN CLAY

Atterberg Limits

PL= 14 LL= 23 PI= 9

Coefficients

D_{90}= 0.3271 D_{85}= 0.2265 D_{60}= 0.0466
D_{50}= 0.0243 D_{30}= 0.0067 D_{15}= 0.0014
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-4(3)

Remarks

F.M.=0.42

Source of Sample: SB-301 **Depth:** 68.5'-69.0'
Sample Number: 1600 **Date:** 3-31-21

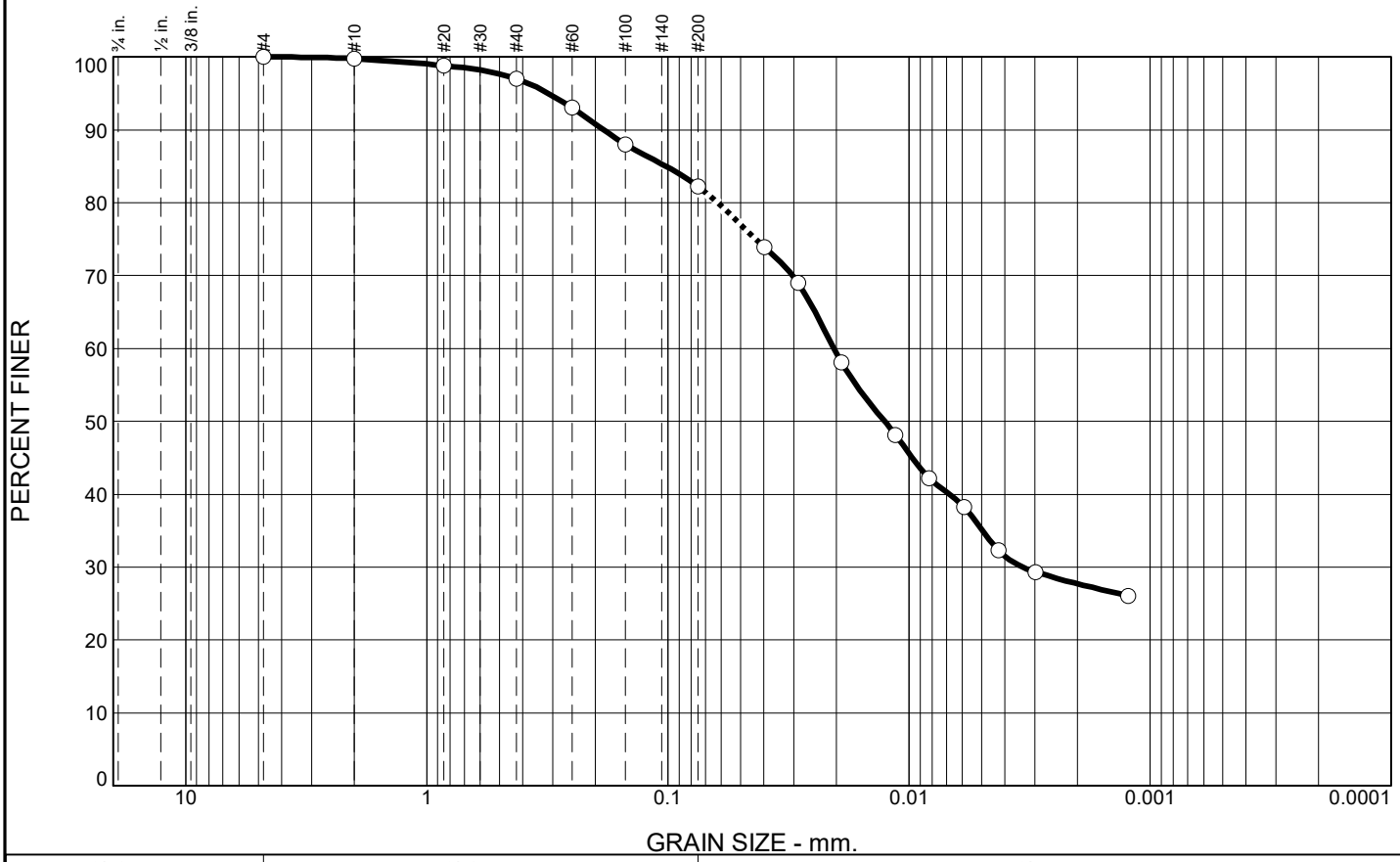
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.2	2.8	14.8	47.0	35.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	99.8		
#20	98.8		
#40	97.0		
#60	93.0		
#100	88.0		
#200	82.2		
0.0398 mm.	73.9		
0.0288 mm.	69.0		
0.0190 mm.	58.1		
0.0114 mm.	48.2		
0.0082 mm.	42.2		
0.0059 mm.	38.3		
0.0043 mm.	32.3		
0.0030 mm.	29.3		
0.0012 mm.	26.1		

* (no specification provided)

Soil Description

DARK BROWN TO DARK GRAY LEAN CLAY WITH SAND

Atterberg Limits

PL= 15 LL= 37 PI= 22

Coefficients

D_{90}= 0.1848 D_{85}= 0.1019 D_{60}= 0.0205
D_{50}= 0.0126 D_{30}= 0.0034 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(17)

Remarks

F.M.=0.20

Source of Sample: SB-301 **Depth:** 98.0'-100.0'
Sample Number: 0946

Date: 3-2-21

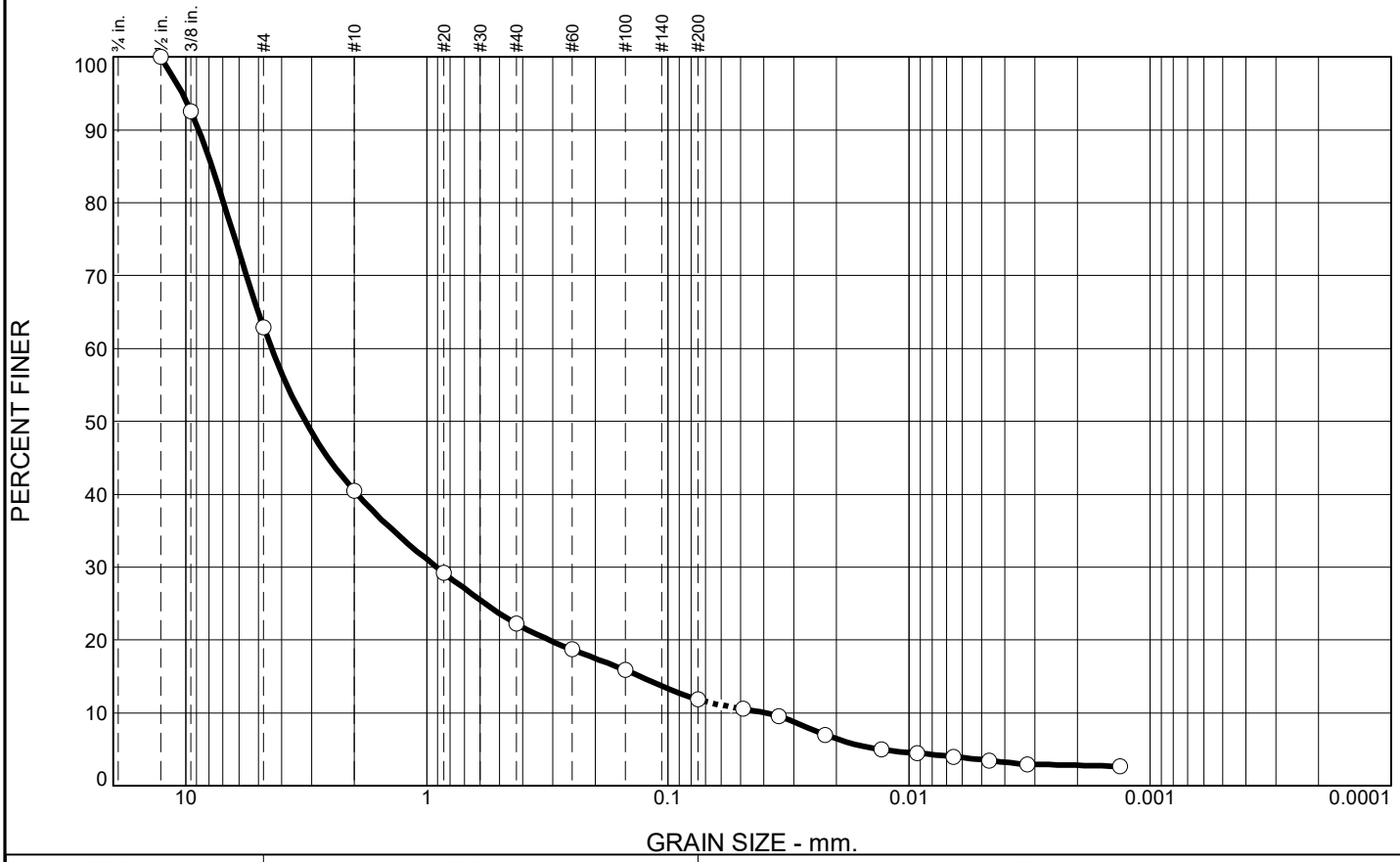
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	37.1	22.4	18.2	10.5	8.2	3.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	92.6		
#4	62.9		
#10	40.5		
#20	29.2		
#40	22.3		
#60	18.7		
#100	15.9		
#200	11.8		
0.0489 mm.	10.5		
0.0348 mm.	9.5		
0.0223 mm.	7.0		
0.0130 mm.	5.0		
0.0092 mm.	4.5		
0.0065 mm.	4.0		
0.0046 mm.	3.5		
0.0032 mm.	2.9		
0.0013 mm.	2.7		

* (no specification provided)

Soil Description

DARK GRAY AND BROWN POORLY GRADED SAND WITH SILT AND GRAVEL

Atterberg Limits

PL= 57 LL= 47 PI= NP

Coefficients

D_{90}= 8.8427 D_{85}= 7.7995 D_{60}= 4.4077
D_{50}= 3.1925 D_{30}= 0.9113 D_{15}= 0.1303
D_{10}= 0.0394 C_u= 111.78 C_c= 4.78

Classification

USCS= SP-SM AASHTO= A-1-a

Remarks

F.M.=4.07

Source of Sample: XPW-01 **Depth:** 8.5'-9.0'
Sample Number: 0820 **Date:** 3-16-21

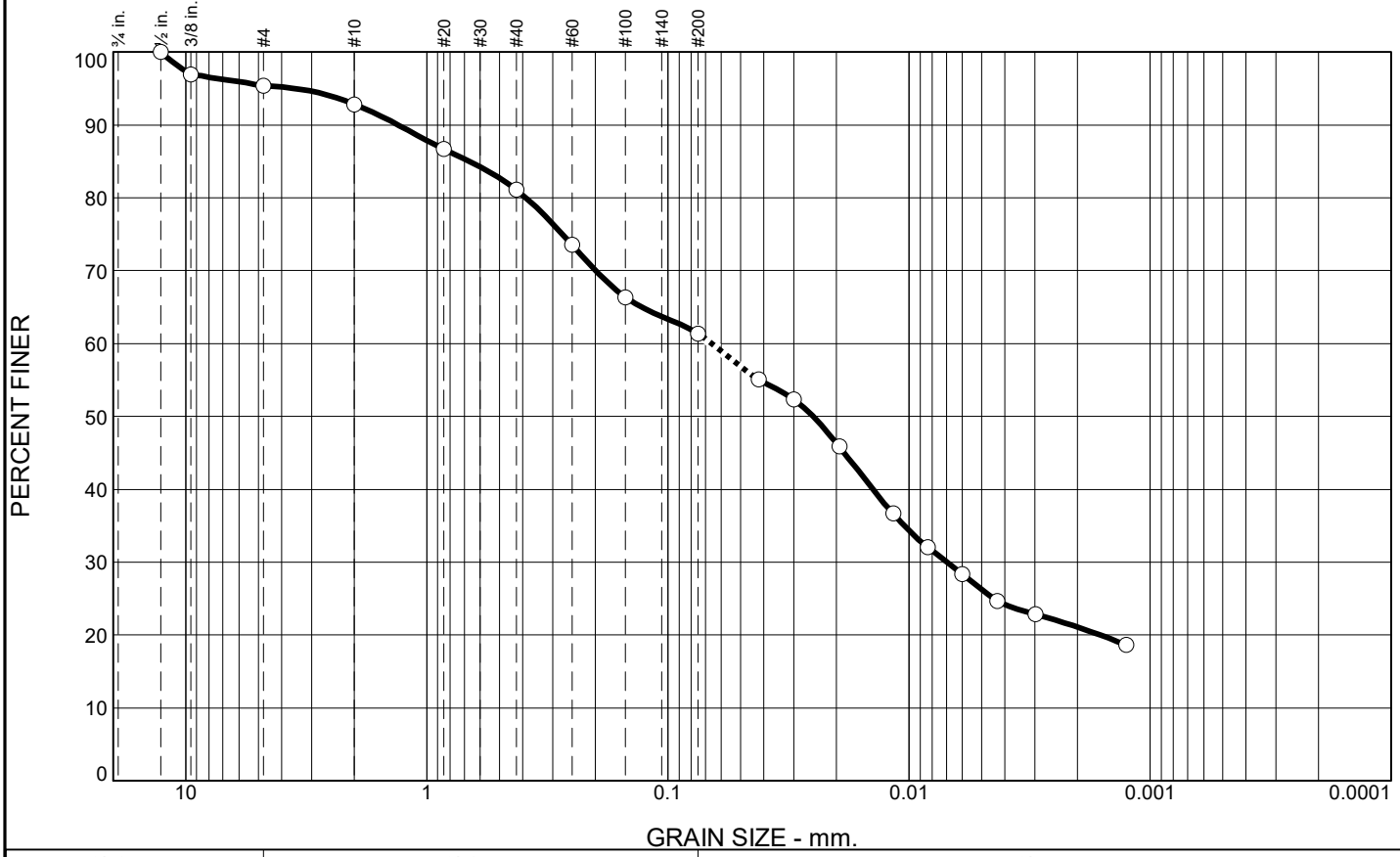
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.6	2.6	11.7	19.8	35.1	26.2

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	96.9		
#4	95.4		
#10	92.8		
#20	86.7		
#40	81.1		
#60	73.5		
#100	66.3		
#200	61.3		
0.0419 mm.	55.1		
0.0300 mm.	52.3		
0.0195 mm.	45.9		
0.0116 mm.	36.7		
0.0084 mm.	32.1		
0.0060 mm.	28.4		
0.0043 mm.	24.7		
0.0030 mm.	22.9		
0.0013 mm.	18.7		

* (no specification provided)

Soil Description

GRAY AND BROWN SANDY LEAN CLAY

Atterberg Limits

PL= 17 LL= 35 PI= 18

Coefficients

D_{90}= 1.3206 D_{85}= 0.6662 D_{60}= 0.0657
D_{50}= 0.0250 D_{30}= 0.0070 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(8)

Remarks

F.M.=0.98

Source of Sample: XPW-01 **Depth:** 15.5'-16.0'
Sample Number: 0840 **Date:** 3-16-21

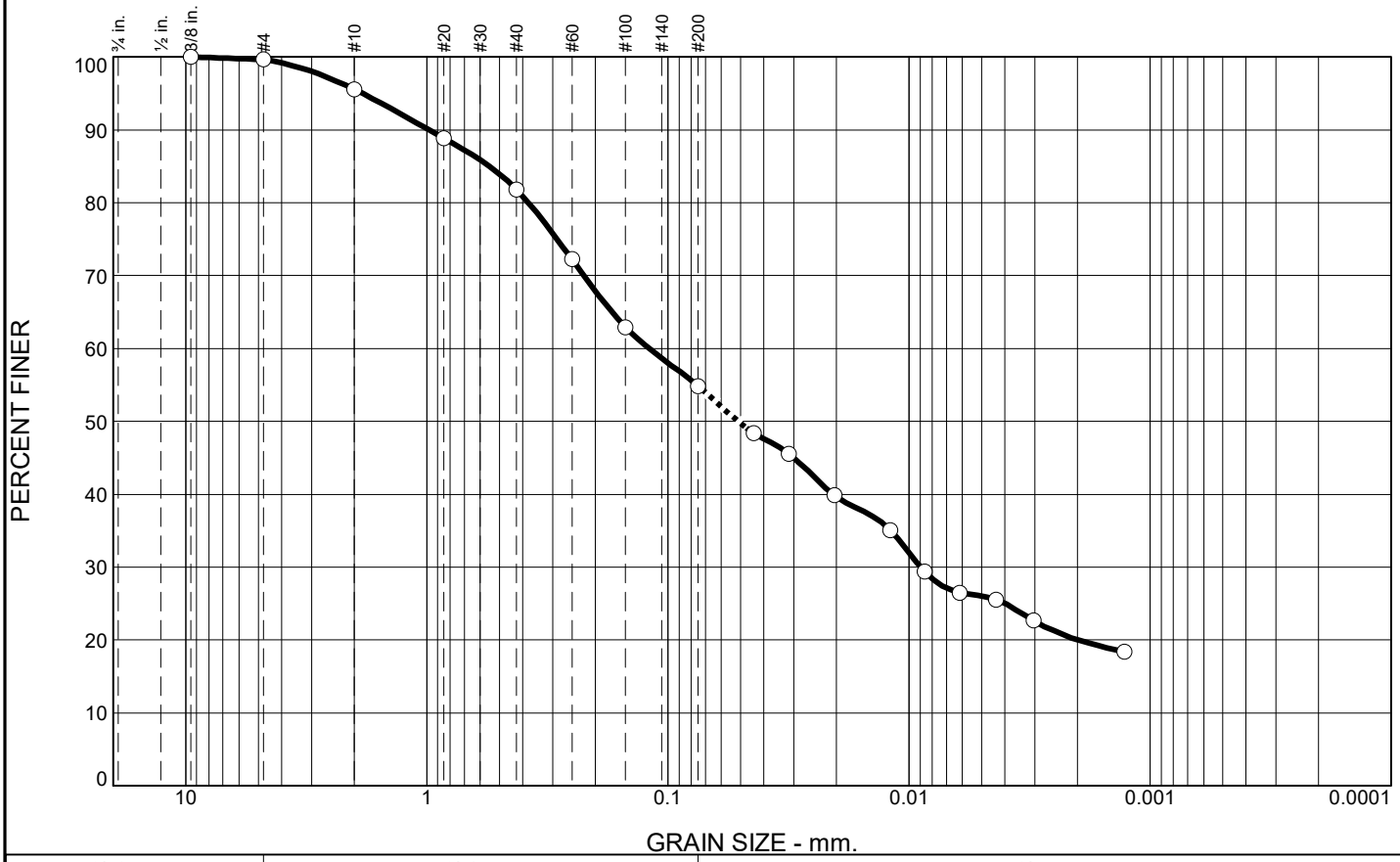
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.3	4.1	13.8	26.9	28.9	26.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	99.7		
#10	95.6		
#20	88.8		
#40	81.8		
#60	72.2		
#100	62.9		
#200	54.9		
0.0440 mm.	48.4		
0.0315 mm.	45.5		
0.0203 mm.	39.8		
0.0119 mm.	35.1		
0.0086 mm.	29.4		
0.0061 mm.	26.5		
0.0044 mm.	25.5		
0.0030 mm.	22.7		
0.0013 mm.	18.4		

* (no specification provided)

Soil Description

VERY DARK GRAY, GRAY AND BROWN SANDY LEAN CLAY

Atterberg Limits

PL= 16 LL= 36 PI= 20

Coefficients

D_{90}= 0.9818 D_{85}= 0.5511 D_{60}= 0.1197
D_{50}= 0.0512 D_{30}= 0.0090 D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(8)

Remarks

F.M.=0.88

Source of Sample: XPW-02 **Depth:** 8.0'-8.5'
Sample Number: 1530 **Date:** 3-16-21

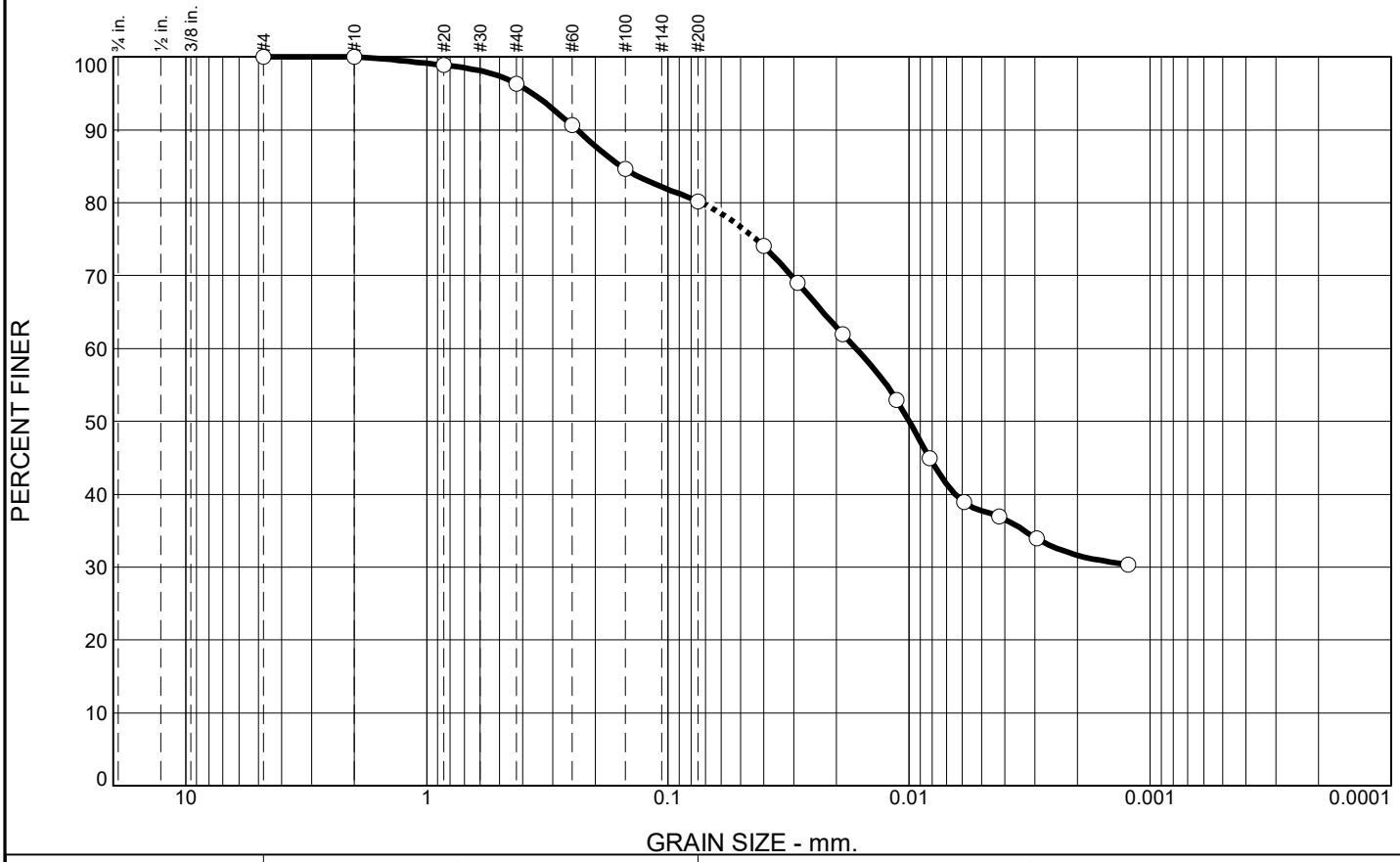
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	3.7	16.1	42.5	37.7

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
#4	100.0		
#10	100.0		
#20	98.9		
#40	96.3		
#60	90.6		
#100	84.6		
#200	80.2		
0.0401 mm.	74.0		
0.0290 mm.	69.0		
0.0189 mm.	62.0		
0.0113 mm.	53.0		
0.0082 mm.	44.9		
0.0059 mm.	38.9		
0.0042 mm.	36.9		
0.0030 mm.	33.9		
0.0012 mm.	30.4		

* (no specification provided)

Soil Description

GRAY AND DARK BROWN LEAN CLAY WITH SAND

Atterberg Limits

PL= 14 LL= 36 PI= 22

Coefficients

D_{90}= 0.2379 D_{85}= 0.1563 D_{60}= 0.0166
D_{50}= 0.0100 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Classification

USCS= CL AASHTO= A-6(16)

Remarks

F.M.=0.25

Source of Sample: XPW-02 **Depth:** 16.5'-17.0'
Sample Number: 1545 **Date:** 3-16-21

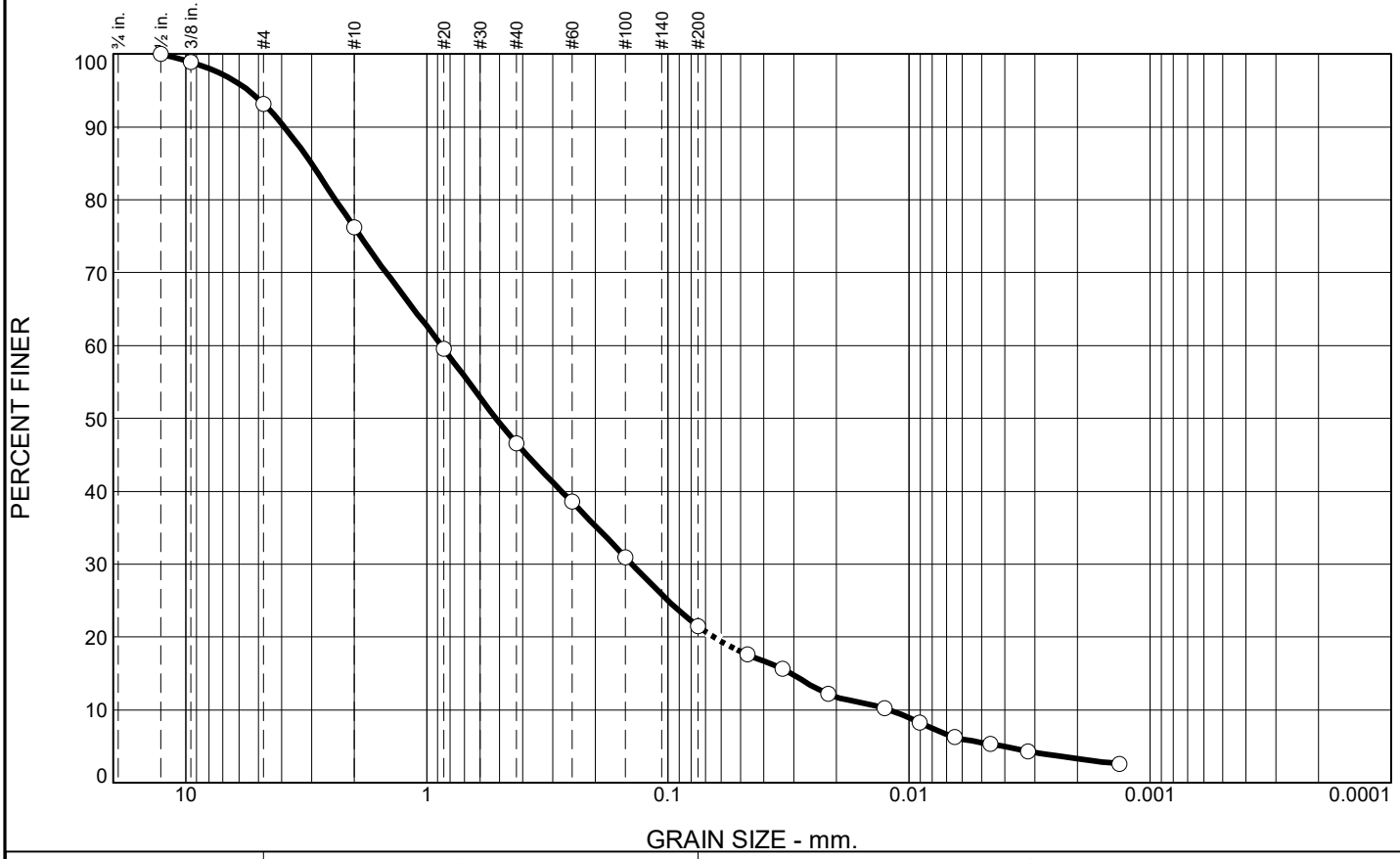
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	6.8	17.0	29.6	25.1	16.0	5.5

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	98.9		
#4	93.2		
#10	76.2		
#20	59.5		
#40	46.6		
#60	38.6		
#100	30.9		
#200	21.5		
0.0468 mm.	17.6		
0.0335 mm.	15.6		
0.0217 mm.	12.2		
0.0127 mm.	10.2		
0.0091 mm.	8.3		
0.0065 mm.	6.3		
0.0046 mm.	5.3		
0.0032 mm.	4.3		
0.0013 mm.	2.6		

* (no specification provided)

Soil Description

DARK BROWNISH GRAY SILTY SAND

Atterberg Limits

PL= 27 LL= 33 PI= 6

Coefficients

D_{90}= 3.8998 D_{85}= 3.0199 D_{60}= 0.8711
D_{50}= 0.5157 D_{30}= 0.1410 D_{15}= 0.0309
D_{10}= 0.0121 C_u= 72.20 C_c= 1.89

Classification

USCS= SM AASHTO= A-1-b

Remarks

F.M.=2.37

Source of Sample: XPW-03 **Depth:** 6.0'-6.5'
Sample Number: 1355 **Date:** 3-16-21

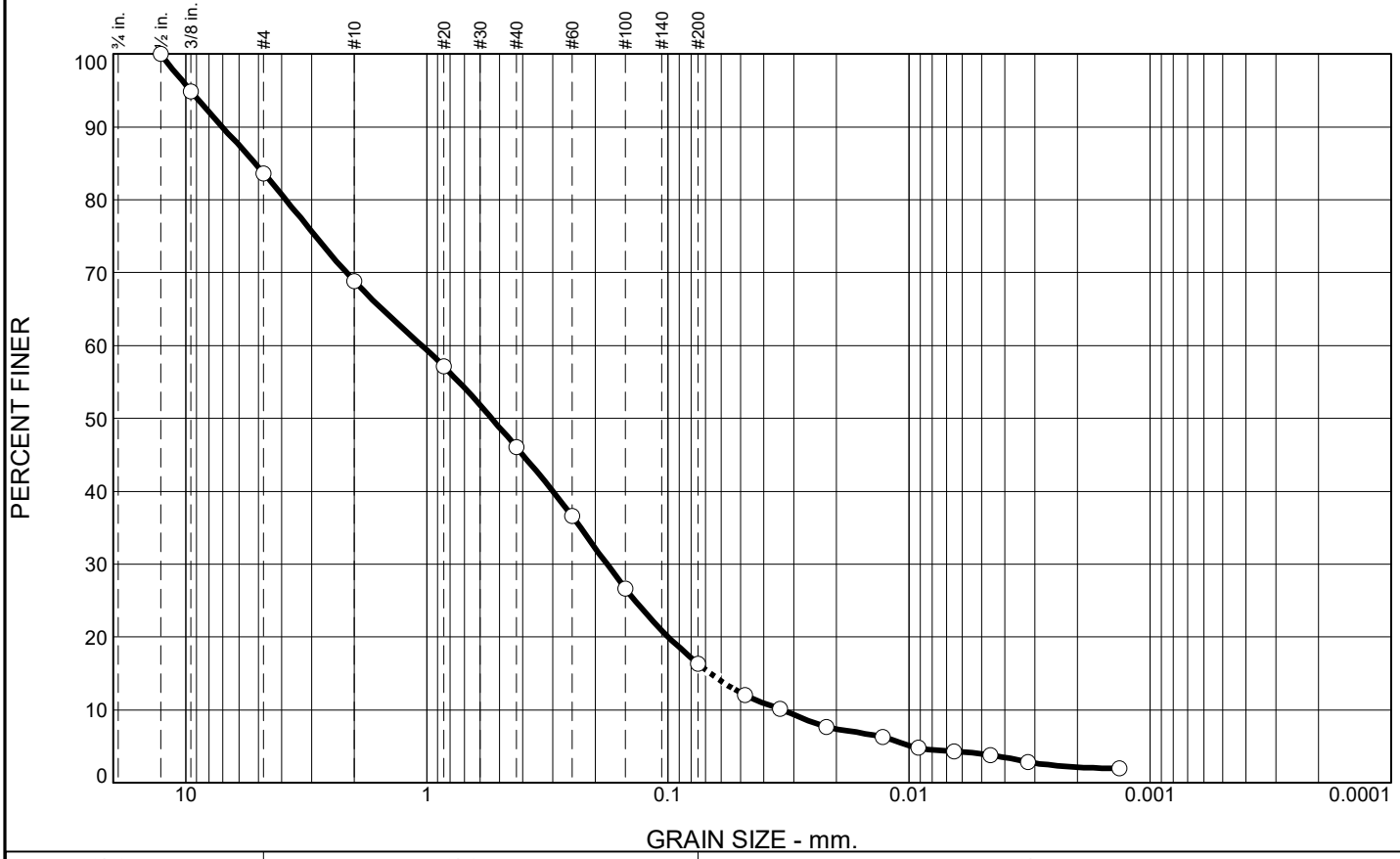
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	16.4	14.8	22.7	29.8	12.3	4.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	94.9		
#4	83.6		
#10	68.8		
#20	57.1		
#40	46.1		
#60	36.6		
#100	26.6		
#200	16.3		
0.0480 mm.	12.0		
0.0343 mm.	10.1		
0.0220 mm.	7.7		
0.0128 mm.	6.2		
0.0091 mm.	4.8		
0.0065 mm.	4.3		
0.0046 mm.	3.8		
0.0032 mm.	2.9		
0.0013 mm.	2.0		

* (no specification provided)

Soil Description

BROWNISH GRAY SILTY SAND WITH GRAVEL

Atterberg Limits

PL= 19 LL= 12 PI= NP

Coefficients

D_{90}= 7.0585 D_{85}= 5.1581 D_{60}= 1.0482
D_{50}= 0.5380 D_{30}= 0.1789 D_{15}= 0.0667
D_{10}= 0.0337 C_u= 31.15 C_c= 0.91

Classification

USCS= SM AASHTO= A-1-b

Remarks

F.M.=2.70

Source of Sample: XPW-03 **Depth:** 15.5'-16.0'
Sample Number: 1315 **Date:** 3-11-21

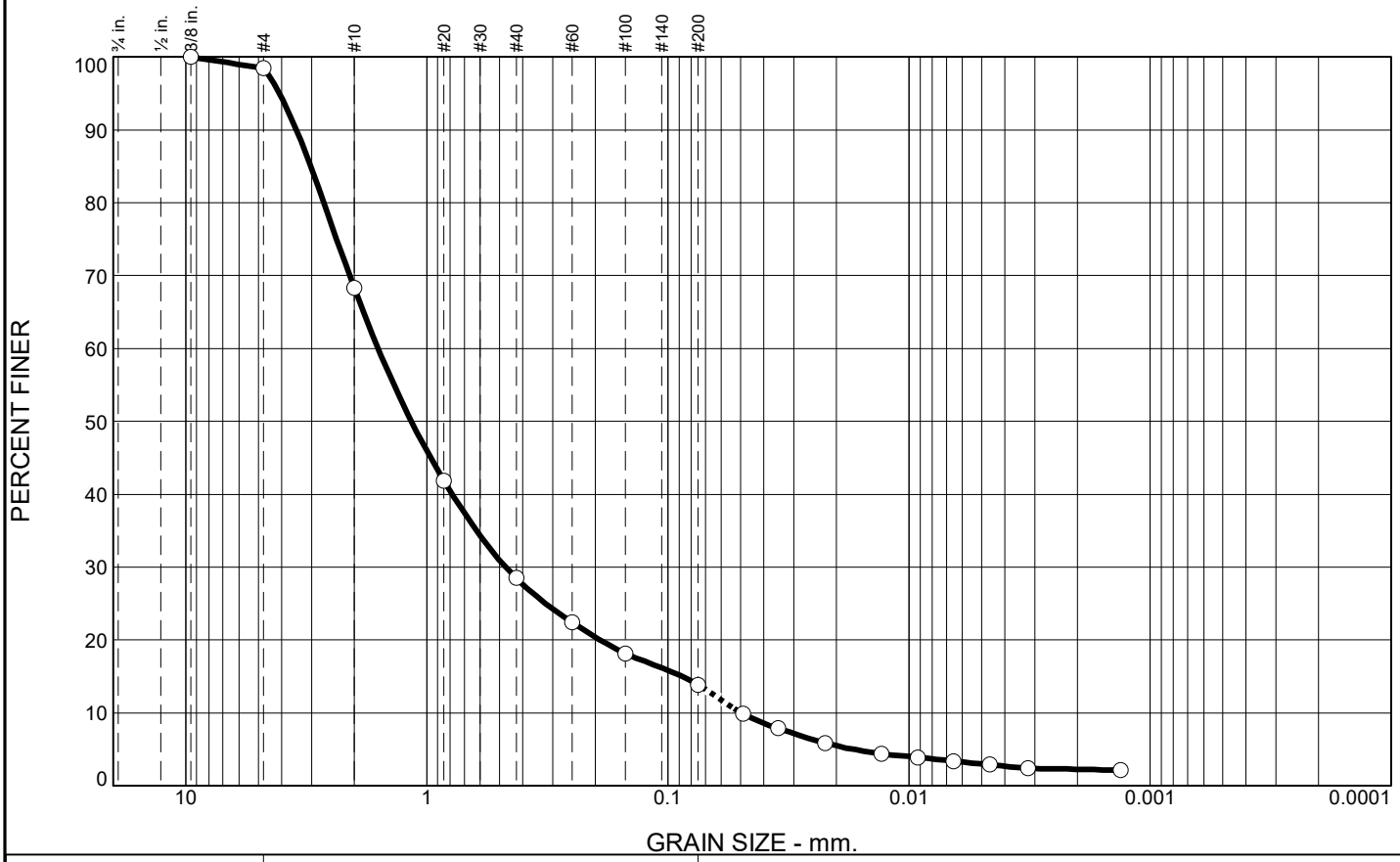
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	1.6	30.1	39.8	14.6	10.9	3.0

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.375	100.0		
#4	98.4		
#10	68.3		
#20	41.9		
#40	28.5		
#60	22.4		
#100	18.2		
#200	13.9		
0.0487 mm.	9.9		
0.0348 mm.	7.9		
0.0223 mm.	5.9		
0.0130 mm.	4.4		
0.0092 mm.	3.9		
0.0065 mm.	3.4		
0.0046 mm.	2.9		
0.0032 mm.	2.4		
0.0013 mm.	2.1		

* (no specification provided)

Soil Description

GRAY SILTY SAND

Atterberg Limits

PL= 38 LL= 41 PI= 3

Coefficients

D_{90}= 3.4781 D_{85}= 3.0339 D_{60}= 1.5927
D_{50}= 1.1581 D_{30}= 0.4698 D_{15}= 0.0872
D_{10}= 0.0496 C_u= 32.14 C_c= 2.80

Classification

USCS= SM AASHTO= A-1-b

Remarks

F.M.=2.99

Source of Sample: XPW-04 **Depth:** 6.5'-7.0'
Sample Number: 1000 **Date:** 3-16-21

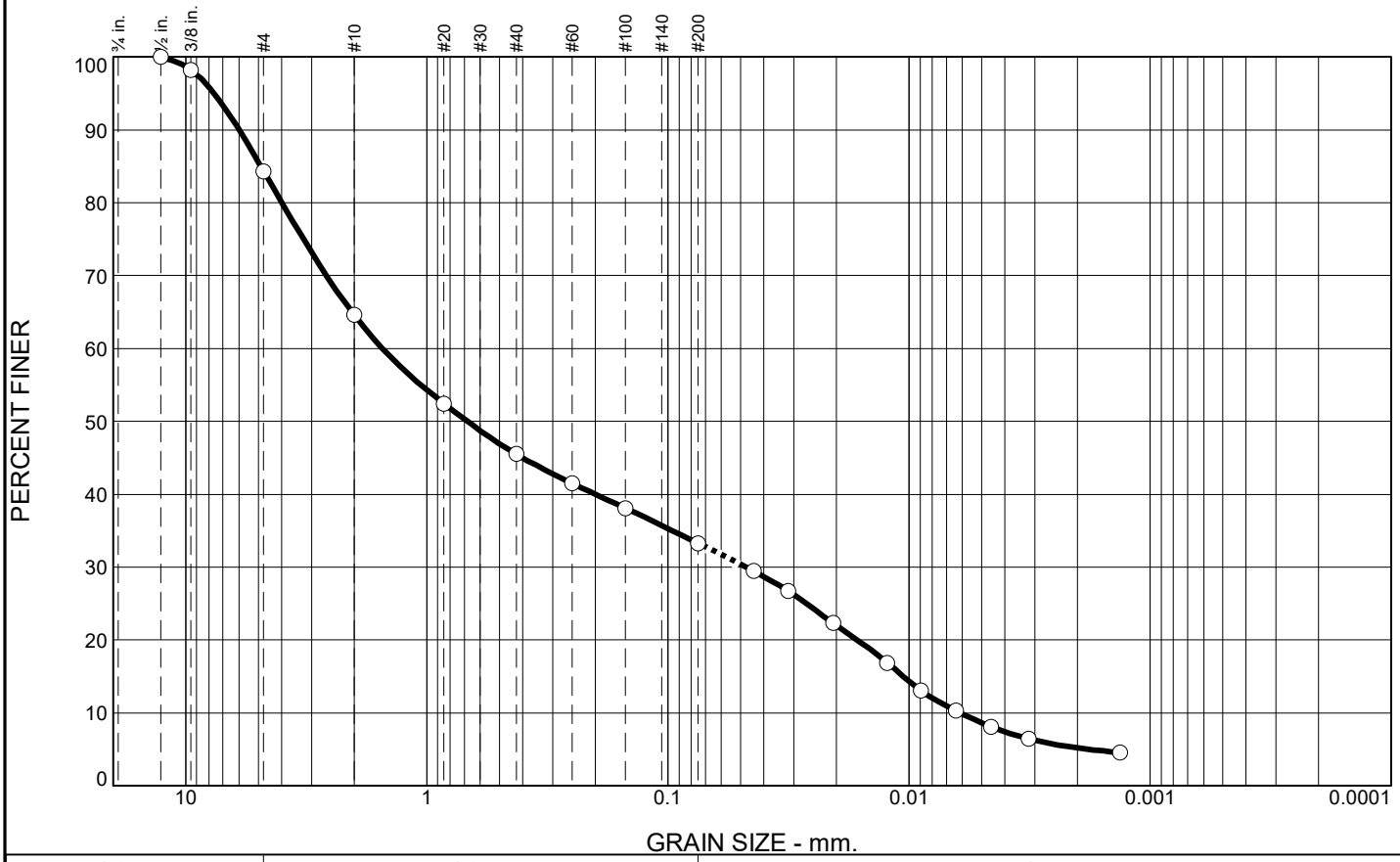
Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Particle Size Analysis of Soils ASTM D6913 and D7928



% Gravel		% Sand			% Fines	
Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	15.7	19.7	19.1	12.2	24.7	8.6

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
.5	100.0		
.375	98.2		
#4	84.3		
#10	64.6		
#20	52.4		
#40	45.5		
#60	41.5		
#100	38.1		
#200	33.3		
0.0441 mm.	29.5		
0.0318 mm.	26.7		
0.0207 mm.	22.3		
0.0123 mm.	16.9		
0.0089 mm.	13.0		
0.0064 mm.	10.3		
0.0046 mm.	8.1		
0.0032 mm.	6.5		
0.0013 mm.	4.5		

* (no specification provided)

Soil Description

DARK BROWNISH GRAY SILTY SAND WITH GRAVEL

Atterberg Limits

PL= 42 LL= 46 PI= 4

Coefficients

D_{90}= 6.0007 D_{85}= 4.8822 D_{60}= 1.5250
D_{50}= 0.6794 D_{30}= 0.0473 D_{15}= 0.0106
D_{10}= 0.0061 C_u= 248.95 C_c= 0.24

Classification

USCS= SM AASHTO= A-2-5(0)

Remarks

F.M.=2.64

Source of Sample: XPW-04 **Depth:** 15.5'-16.0'
Sample Number: 1020 **Date:** 3-16-21

Terracon

Client: RAMBOLL ENVIRON US CORP.
Project: NEWTON POWER STATION

Project No: 11215019 **Figure**

Tested By: SJH **Checked By:** WPQ

Electronic Filing: Received, Clerk's Office 07/01/2024

Hydraulic Conductivity of Saturated Porous Materials Using a Flexible-Wall Permeameter ASTM D5084

Electronic Filing: Received, Clerk's Office 07/01/2024

Terracon Consulting Engineers & Scientists

Laboratory Services Group 192 Exchange Blvd Glendale Heights, Illinois 60139 Ph. (630) 717-4263

HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP.**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-11
TIME SAMPLED:	8:05
DEPTH:	10.0'-12.0'
CLASSIFICATION	BROWN SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	111.7	112.0
WATER CONTENT (%)	17.8	17.7
DIAMETER (cm)	7.131	7.163
LENGTH (cm)	10.248	10.130
B VALUE PARAMETER:	0.99	
HYDRAULIC GRADIENT (MAXIMUM)	19.49	
PERCENT SATURATION	99.5	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 8.57E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP.**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-11
TIME SAMPLED:	10:50
DEPTH:	60.5'-61.0'
CLASSIFICATION	GRAYISH BROWN LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	110.5	117.8
WATER CONTENT (%)	17.8	15.6
DIAMETER (cm)	6.070	5.968
LENGTH (cm)	14.172	13.755
B VALUE PARAMETER:	0.99	
HYDRAULIC GRADIENT (MAXIMUM)	16.57	
PERCENT SATURATION	99.5	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 1.87E-07

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP.**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-11
TIME SAMPLED:	11:15
DEPTH:	80.0'-82.0'
CLASSIFICATION	DARK GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	116.1	117.2
WATER CONTENT (%)	16.5	16.0
DIAMETER (cm)	7.258	7.230
LENGTH (cm)	10.762	10.739

SPECIMEN PHOTO



B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	18.56	
PERCENT SATURATION	99.2	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	2.94E-08	

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO. APW-12

TIME SAMPLED: 8:20

DEPTH: 20.0'-22.0'

CLASSIFICATION BROWN AND RUST BROWN CLAYEY SAND - ROOTS NOTED

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	118.3	120.4
WATER CONTENT (%)	15.1	14.5
DIAMETER (cm)	7.256	7.229
LENGTH (cm)	8.539	8.448
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	23.39	
PERCENT SATURATION	99.6	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 1.07E-07

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-12
TIME SAMPLED:	8:45
DEPTH:	26.0'-26.5'
CLASSIFICATION	BROWN SILTY SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	113.0	114.8
WATER CONTENT (%)	8.4	16.3
DIAMETER (cm)	6.163	6.121
LENGTH (cm)	15.243	15.219
B VALUE PARAMETER:	0.95	
HYDRAULIC GRADIENT (MAXIMUM)	3.88	
PERCENT SATURATION	98.4	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 8.43E-06

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-12
TIME SAMPLED:	12:45
DEPTH:	85.0'-87.0'
CLASSIFICATION	DARK GRAY LEAN CLAY WITH SAND - SILT POCKETS NOTED

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	116.4	118.0
WATER CONTENT (%)	14.4	15.9
DIAMETER (cm)	7.234	7.202
LENGTH (cm)	7.464	7.431
B VALUE PARAMETER:	0.95	
HYDRAULIC GRADIENT (MAXIMUM)	22.05	
PERCENT SATURATION	99.8	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): **2.36E-08**

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAN=MBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO. APW-13

TIME SAMPLED: 8:45

DEPTH: 85.0'-87.0'

CLASSIFICATION DARK GRAY AND GRAY POORLY GRADED SAND WITH SILT

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	87.1	89.2
WATER CONTENT (%)	21.2	32.0
DIAMETER (cm)	7.090	7.039
LENGTH (cm)	9.808	9.718
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	6.03	
PERCENT SATURATION	99.7	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 9.63E-05

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-13
TIME SAMPLED:	13:45
DEPTH:	61.0'-61.5'
CLASSIFICATION	BROWN SILTY SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	114.3	117.3
WATER CONTENT (%)	14.5	15.4
DIAMETER (cm)	6.038	6.126
LENGTH (cm)	10.971	10.386
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	5.39	
PERCENT SATURATION	99.5	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 2.18E-04

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-14
TIME SAMPLED:	9:55
DEPTH:	45.0'-47.0'
CLASSIFICATION	BROWN SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	119.6	120.3
WATER CONTENT (%)	12.4	14.2
DIAMETER (cm)	7.380	7.372
LENGTH (cm)	10.775	10.736
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	18.54	
PERCENT SATURATION	100.5	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 9.65E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-14
TIME SAMPLED:	10:35
DEPTH:	56.0'-56.5'
CLASSIFICATION	GRAY AND BROWNISH GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	104.6	107.9
WATER CONTENT (%)	18.0	20.7
DIAMETER (cm)	6.049	6.023
LENGTH (cm)	9.965	9.749
B VALUE PARAMETER:	0.97	
HYDRAULIC GRADIENT (MAXIMUM)	20.05	
PERCENT SATURATION	99.6	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	2.74E-07	

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Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-15
TIME SAMPLED:	10:05
DEPTH:	20.0'-22.0'
CLASSIFICATION	BROWN SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	109.8	109.9
WATER CONTENT (%)	18.5	19.0
DIAMETER (cm)	7.189	7.201
LENGTH (cm)	8.227	8.190
B VALUE PARAMETER:	0.95	
HYDRAULIC GRADIENT (MAXIMUM)	24.28	
PERCENT SATURATION	97.7	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 3.21E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-15
TIME SAMPLED:	7:55
DEPTH:	101.0'-101.5'
CLASSIFICATION	GRAY SILTY SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	116.4	122.2
WATER CONTENT (%)	12.1	13.4
DIAMETER (cm)	5.990	5.964
LENGTH (cm)	10.539	10.126
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	8.95	
PERCENT SATURATION	97.6	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 3.50E-06

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-15
TIME SAMPLED:	9:05
DEPTH:	105.0'-107.0'
CLASSIFICATION	DARK GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	107.8	109.3
WATER CONTENT (%)	19.1	19.6
DIAMETER (cm)	7.178	7.136
LENGTH (cm)	5.565	5.551
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	29.58	
PERCENT SATURATION	99.5	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 8.20E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	APW-17
TIME SAMPLED:	9:45
DEPTH:	40.0'-42.0'
CLASSIFICATION	GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	108.8	109.5
WATER CONTENT (%)	16.6	19.6
DIAMETER (cm)	7.262	7.262
LENGTH (cm)	9.605	9.545
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	28.12	
PERCENT SATURATION	98.4	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	3.34E-08	

SPECIMEN PHOTO



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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRN US CORP**
LOCATION : **NEWTON , IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-300
TIME SAMPLED:	8:25
DEPTH:	50.0'-52.0'
CLASSIFICATION	GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	122.7	123.5
WATER CONTENT (%)	12.9	13.3
DIAMETER (cm)	7.242	7.217
LENGTH (cm)	10.288	10.288
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	19.42	
PERCENT SATURATION	99.1	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	7.29E-08	

SPECIMEN PHOTO



Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON , IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-300
TIME SAMPLED:	9:05
DEPTH:	61.5'-62.0'
CLASSIFICATION	GRAYISH BROWN SILTY SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	109.6	113.2
WATER CONTENT (%)	13.6	17.7
DIAMETER (cm)	5.903	5.916
LENGTH (cm)	7.615	7.338
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	26.23	
PERCENT SATURATION	99.7	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	1.85E-05	

SPECIMEN PHOTO



Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-300
TIME SAMPLED:	9:20
DEPTH:	62.0'-62.5'
CLASSIFICATION	GRAYISH BROWN SANDY SILTY CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	124.6	128.9
WATER CONTENT (%)	11.1	13.3
DIAMETER (cm)	6.067	6.043
LENGTH (cm)	13.366	13.026
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	7.06	
PERCENT SATURATION	119.5	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 4.32E-06

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-300
TIME SAMPLED:	13:50
DEPTH:	105.0'-107.0'
CLASSIFICATION	DARK GRAY SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	116.4	116.5
WATER CONTENT (%)	14.1	16.4
DIAMETER (cm)	7.328	7.336
LENGTH (cm)	7.558	7.534
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	26.43	
PERCENT SATURATION	98.8	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 4.28E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-301
TIME SAMPLED:	13:30
DEPTH:	48.0'-50.0'
CLASSIFICATION	BROWN AND GRAY SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	117.3	117.7
WATER CONTENT (%)	14.1	15.8
DIAMETER (cm)	7.204	7.230
LENGTH (cm)	10.348	10.239
B VALUE PARAMETER:	0.99	
HYDRAULIC GRADIENT (MAXIMUM)	19.30	
PERCENT SATURATION	99.6	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 6.63E-08

Deaired water was used as the liquid permeant.

Electronic Filing: Received, Clerk's Office 07/01/2024

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-301
TIME SAMPLED:	16:00
DEPTH:	68.5'-69.0'
CLASSIFICATION	GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	121.3	124.0
WATER CONTENT (%)	13.1	13.4
DIAMETER (cm)	6.062	6.049
LENGTH (cm)	8.581	8.434
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	23.28	
PERCENT SATURATION	99.2	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 4.05E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-301
TIME SAMPLED:	9:46
DEPTH:	98.0'-100.0'
CLASSIFICATION	DARK BROWN TO DARK GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	118.2	119.1
WATER CONTENT (%)	15.7	15.9
DIAMETER (cm)	7.200	7.196
LENGTH (cm)	9.694	9.629
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	16.98	
PERCENT SATURATION	102.5	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 6.13E-08

Deaired water was used as the liquid permeant.

Electronic Filing: Received, Clerk's Office 07/01/2024

Terracon Consulting Engineers & Scientists

Laboratory Services Group 192 Exchange Blvd Glendale Heights, Illinois 60139 Ph. (630) 717-4263

HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	SB-301
TIME SAMPLED:	9:46
DEPTH:	98.0'-100.0'
CLASSIFICATION	DARK BROWN TO DARK GRAY LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	118.2	119.1
WATER CONTENT (%)	15.7	15.9
DIAMETER (cm)	7.200	7.196
LENGTH (cm)	9.694	9.629
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	16.98	
PERCENT SATURATION	102.5	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	6.13E-08	

SPECIMEN PHOTO



Deaired water was used as the liquid permeant.

Electronic Filing: Received, Clerk's Office 07/01/2024

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-01
TIME SAMPLED:	8:40
DEPTH:	15.0'-15.5'
CLASSIFICATION	GRAY AND BROWN SANDY LEAN CLAY
NOTE:	SAMPLE DISTURBED, SAND LAYERS NOTED

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	84.4	85.6
WATER CONTENT (%)	12.6	31.3
DIAMETER (cm)	6.152	6.120
LENGTH (cm)	15.217	15.168
B VALUE PARAMETER:	0.96	
HYDRAULIC GRADIENT (MAXIMUM)	13.13	
PERCENT SATURATION	86.1	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 1.58E-05

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-02
TIME SAMPLED:	15:30
DEPTH:	7.5'-8.0'
CLASSIFICATION	VERY DARK GRAY TO GRAY AND BROWN SANDY LEAN CLAY

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	92.9	98.3
WATER CONTENT (%)	29.1	26.1
DIAMETER (cm)	6.069	6.042
LENGTH (cm)	12.025	11.469
B VALUE PARAMETER:	0.98	
HYDRAULIC GRADIENT (MAXIMUM)	13.69	
PERCENT SATURATION	99.5	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 6.07E-08

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-02
TIME SAMPLED:	15:45
DEPTH:	16.0'-16.5'
CLASSIFICATION	GRAY AND DARK BROWN LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	103.7	106.6
WATER CONTENT (%)	21.8	20.9
DIAMETER (cm)	6.002	5.979
LENGTH (cm)	11.395	11.179
B VALUE PARAMETER:	0.97	
HYDRAULIC GRADIENT (MAXIMUM)	17.53	
PERCENT SATURATION	98.2	(Percent saturation calculation is based on final measurements and a measured specific gravity.)
HYDRAULIC CONDUCTIVITY k (cm/sec)	7.38E-08	

SPECIMEN PHOTO



Deaired water was used as the liquid permeant.

Electronic Filing: Received, Clerk's Office 07/01/2024

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON , IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-02
TIME SAMPLED:	15:45
DEPTH:	16.0'-16.5'
CLASSIFICATION	GRAY AND DARK BROWN LEAN CLAY WITH SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	103.7	106.6
WATER CONTENT (%)	21.8	20.9
DIAMETER (cm)	6.002	5.979
LENGTH (cm)	11.395	11.179
B VALUE PARAMETER:	0.97	
HYDRAULIC GRADIENT (MAXIMUM)	17.53	
PERCENT SATURATION	98.2	

SPECIMEN PHOTO



(Percent saturation calculation is based on final measurements and a measured specific gravity.)

HYDRAULIC CONDUCTIVITY k (cm/sec): 7.38E-08

Deaired water was used as the liquid permeant.

Electronic Filing: Received, Clerk's Office 07/01/2024

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-04
TIME SAMPLED:	10:00
DEPTH:	7.0'-7.5'
CLASSIFICATION	GRAY SILTY SAND

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	73.9	75.6
WATER CONTENT (%)	31.1	45.1
DIAMETER (cm)	6.133	6.116
LENGTH (cm)	15.283	15.019
B VALUE PARAMETER:	0.95	
HYDRAULIC GRADIENT (MAXIMUM)	6.17	
PERCENT SATURATION	99.7	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): 1.61E-04

Deaired water was used as the liquid permeant.

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HYDRAULIC CONDUCTIVITY DETERMINATION
ASTM D 5084, METHOD C
RISING TAILWATER LEVEL

TERRACON PROJECT NO. **11215019** **4/9/2021**
PROJECT NAME: **NEWTON POWER STATION**
CLIENT: **RAMBOLL ENVIRON US CORP**
LOCATION : **NEWTON, IL**

SUMMARY OF TEST RESULTS

BORING NO.	XPW-04
TIME SAMPLED:	10:20
DEPTH:	16.0'-16.5'
CLASSIFICATION	DARK BROWN GRAY SILTY SAND WITH GRAVEL

	INITIAL	FINAL
DRY UNIT WEIGHT (pcf)	80.8	84.8
WATER CONTENT (%)	31.1	35.6
DIAMETER (cm)	6.118	6.068
LENGTH (cm)	14.041	13.607
B VALUE PARAMETER:	0.95	
HYDRAULIC GRADIENT (MAXIMUM)	6.72	
PERCENT SATURATION	97.9	

(Percent saturation calculation is based on final measurements and a measured specific gravity.)

SPECIMEN PHOTO



HYDRAULIC CONDUCTIVITY k (cm/sec): **7.83E-05**

Deaired water was used as the liquid permeant.

Permeability of Granular Soils (Constant Head)
ASTM D2434

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PERMEABILITY OF GRANULAR SOILS
CONSTANT HEAD METHOD IN RIGID WALL PERMEAMETER
ASTM D 2434

Laboratory Services Group **192 Exchange Blvd** **Glendale Heights, Illinois 60139** **Ph. (630) 717-4263**

PROJECT NO.: 11215019

PROJECT: NEWTON POWER STATION

DATE: 3/18/2021

SAMPLE INFORMATION

BORING NO. APW-17

TIME SAMPLED: 10:45

DEPTH: 70.5'-71.0'

CLASSIFICATION GRAY WELL GRADED SAND WITH SILT

	INITIAL
DRY UNIT WEIGHT (pcf)	110.2
WATER CONTENT (%)	7.8
DIAMETER (cm)	2.57
LENGTH (cm)	11.85

SPECIMEN PHOTO



SUMMARY OF TEST RESULTS

HYDRAULIC GRADIENT	1.3
HEAD HEIGHT (cm)	15.00
VOID RATIO	0.577
HYDRAULIC CONDUCTIVITY k (cm/sec)	**7.21E-04**

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PERMEABILITY OF GRANULAR SOILS
CONSTANT HEAD METHOD IN RIGID WALL PERMEAMETER
ASTM D 2434

Laboratory Services Group **192 Exchange Blvd** **Glendale Heights, Illinois 60139** **Ph. (630) 717-4263**

PROJECT NO.: 11215019

PROJECT: NEWTON POWER STATION

DATE: 3/18/2021

SAMPLE INFORMATION

BORING NO. APW-17

TIME SAMPLED: 12:00

DEPTH: 91.0'-91.5'

CLASSIFICATION GRAY WELL GRADED SAND WITH SILT

	INITIAL
DRY UNIT WEIGHT (pcf)	116.8
WATER CONTENT (%)	6.1
DIAMETER (cm)	2.57
LENGTH (cm)	11.85

SPECIMEN PHOTO



SUMMARY OF TEST RESULTS

HYDRAULIC GRADIENT	1.3
HEAD HEIGHT (cm)	15.00
VOID RATIO	0.488
HYDRAULIC CONDUCTIVITY k (cm/sec)	**6.39E-04**

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PERMEABILITY OF GRANULAR SOILS
CONSTANT HEAD METHOD IN RIGID WALL PERMEAMETER
ASTM D 2434

Laboratory Services Group **192 Exchange Blvd** **Glendale Heights, Illinois 60139** **Ph. (630) 717-4263**

PROJECT NO.: 11215019

PROJECT: NEWTON POWER STATION

DATE: 3/18/2021

SAMPLE INFORMATION

BORING NO. XPW-03

TIME SAMPLED: 12:55

DEPTH: 5.5'-6.0'

CLASSIFICATION DARK BROWNISH GRAY SILTY SAND

	INITIAL
DRY UNIT WEIGHT (pcf)	75.3
WATER CONTENT (%)	17.4
DIAMETER (cm)	2.57
LENGTH (cm)	11.85

SPECIMEN PHOTO



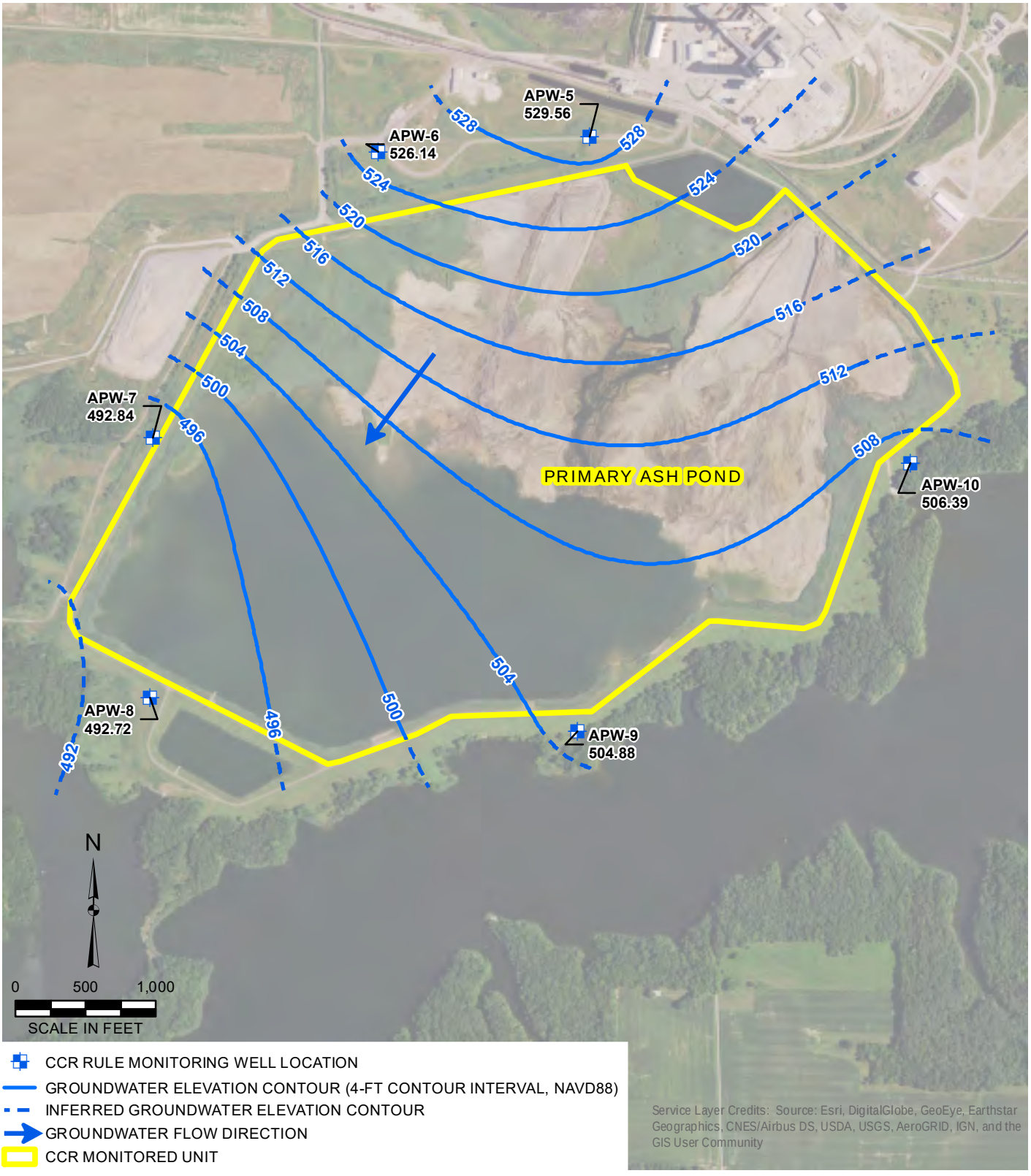
SUMMARY OF TEST RESULTS

HYDRAULIC GRADIENT	1.3
HEAD HEIGHT (cm)	15.00
VOID RATIO	1.202
HYDRAULIC CONDUCTIVITY k (cm/sec)	**1.34E-03**

APPENDIX E
GROUNDWATER CONTOUR MAPS AND ELEVATIONS

GROUNDWATER CONTOUR MAPS

Electronic Filing: Received, Clerk's Office 07/01/2024



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REVIEWED BY/DATE:
TBN 1/25/17
APPROVED BY/DATE:
JJW 2/7/17

NEWTON PRIMARY ASH POND (UNIT ID: 501)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 1: DECEMBER 14, 2015

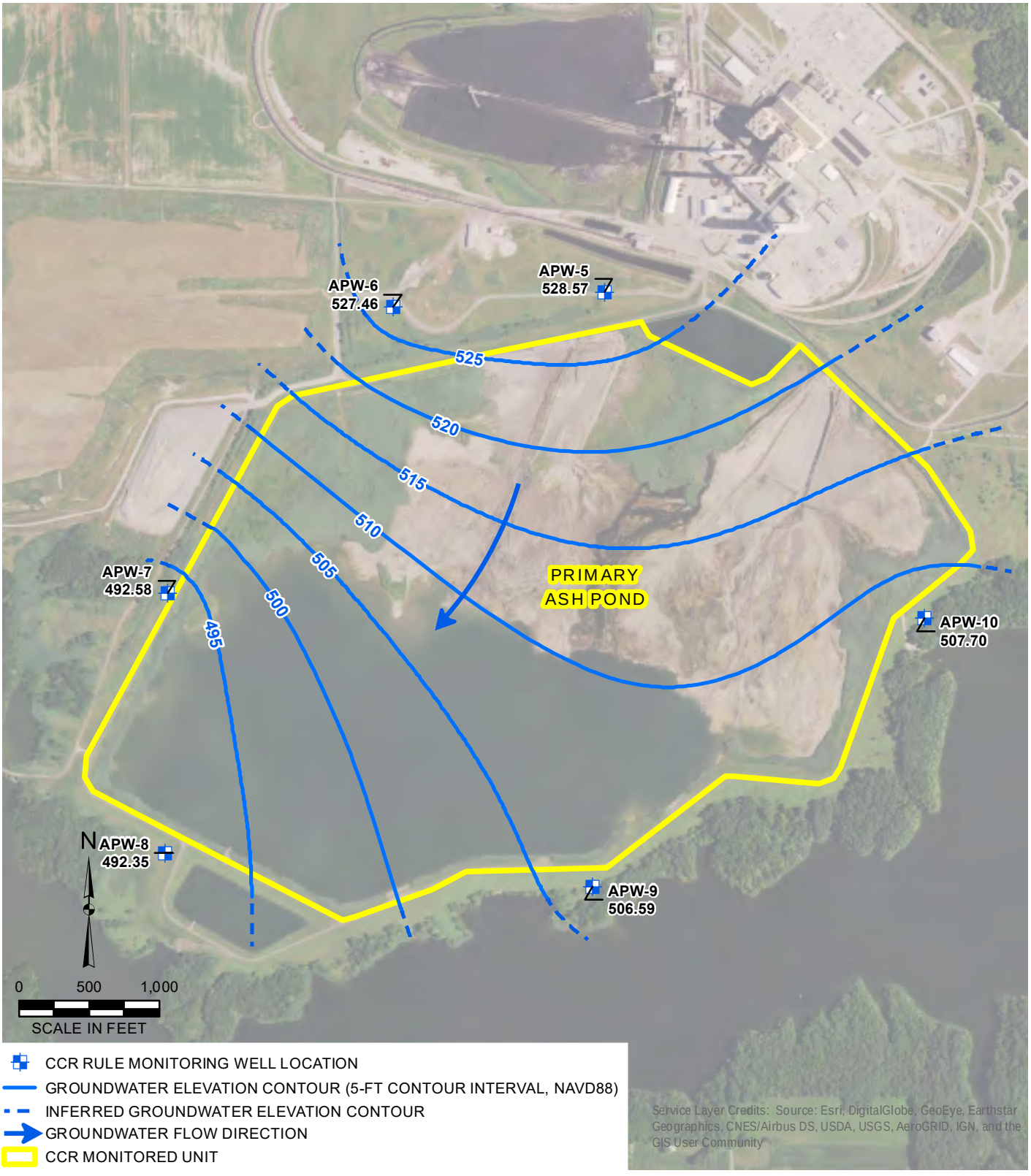
DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Electronic Filing: Received, Clerk's Office 07/01/2024



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DRAWN BY/DATE:
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REVIEWED BY/DATE:
TBN 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

NEWTON PRIMARY ASH POND (UNIT ID: 501)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 2: JANUARY 18, 2016

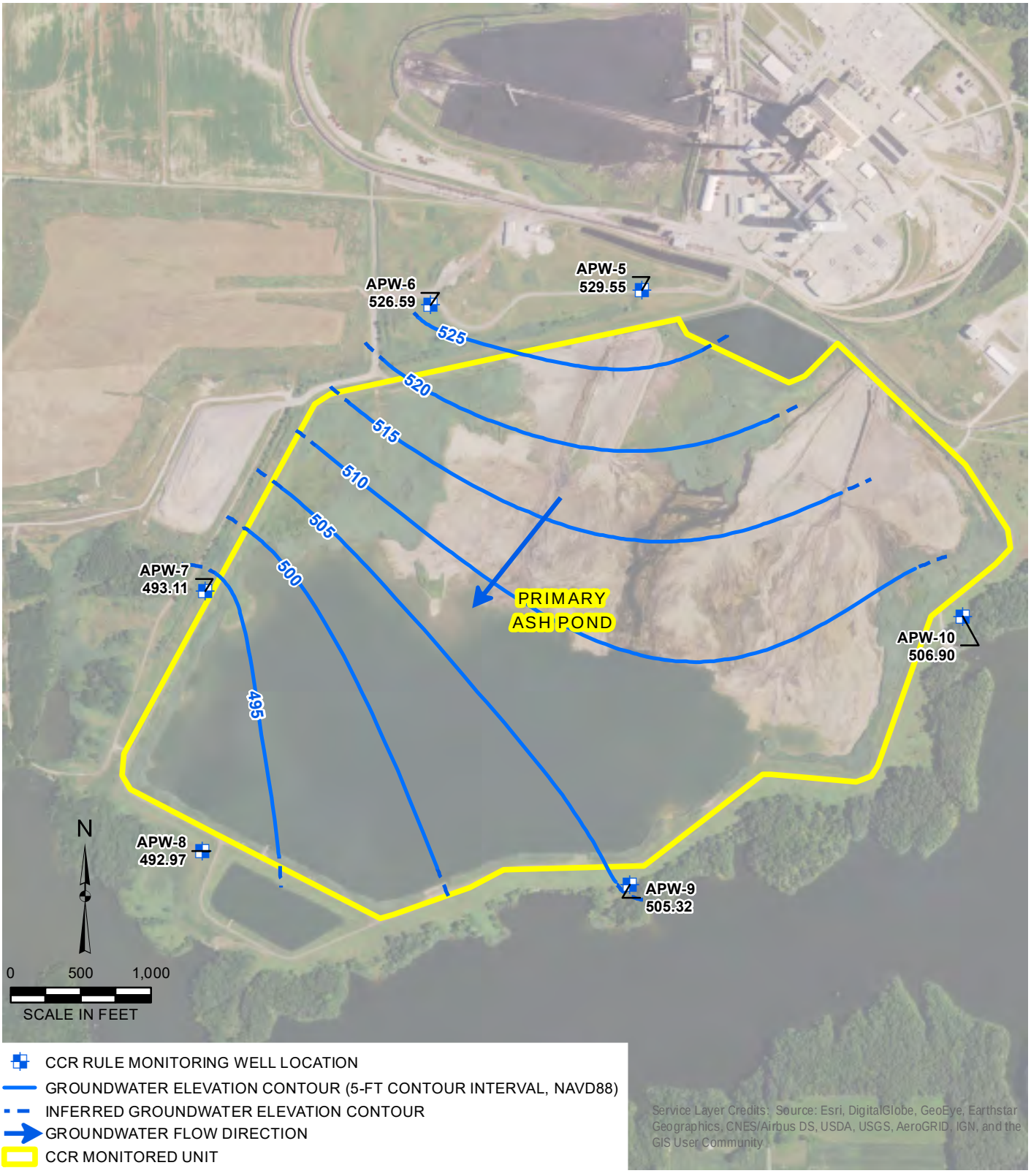
DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

Electronic Filing: Received, Clerk's Office 07/01/2024



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REVIEWED BY/DATE:
TBN 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

NEWTON PRIMARY ASH POND (UNIT ID: 501)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 3: APRIL 25, 2016

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

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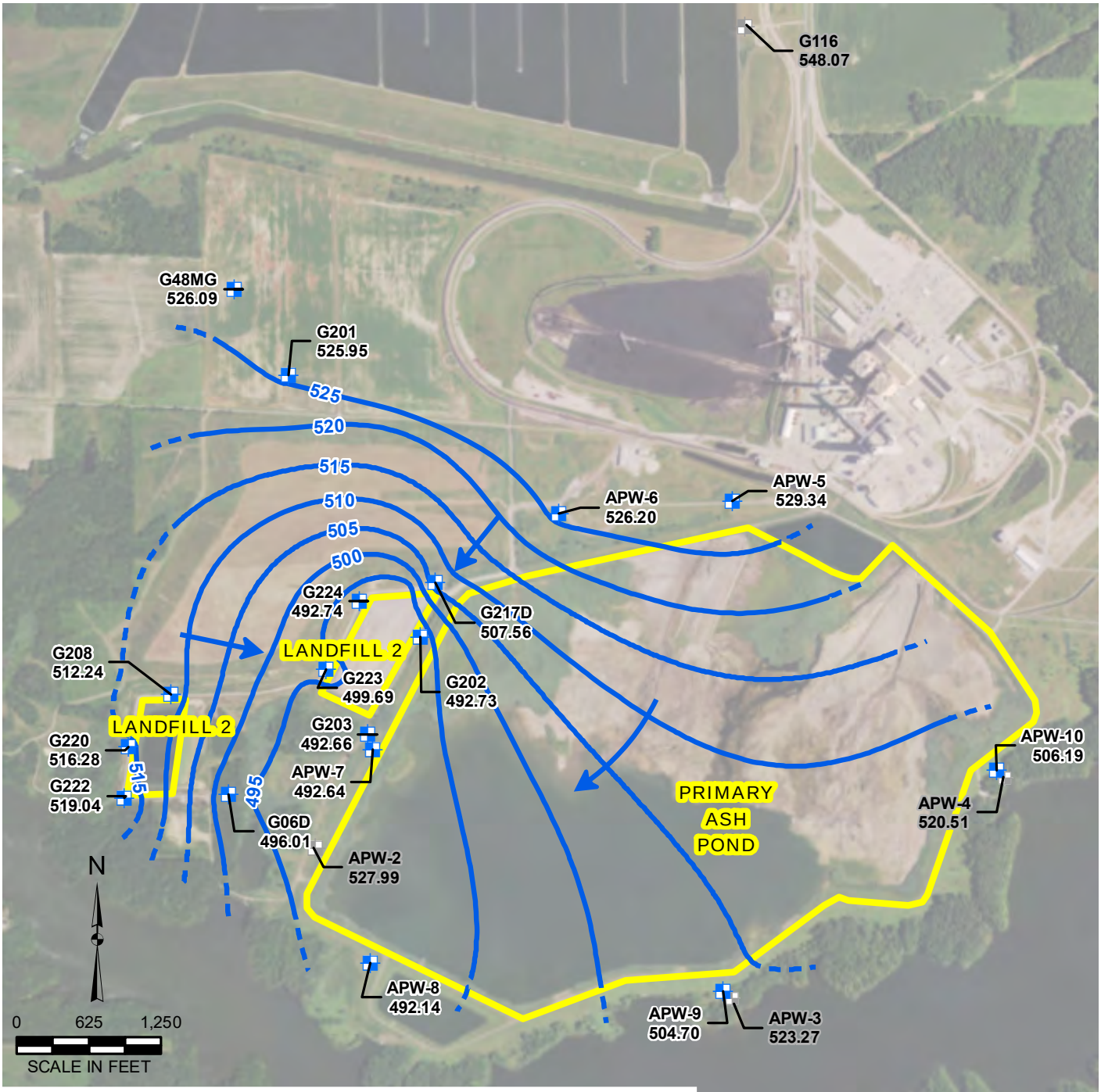

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SDS 1/23/17
REVIEWED BY/DATE:
TBN 1/25/17
APPROVED BY/DATE:
JJW 2/8/17

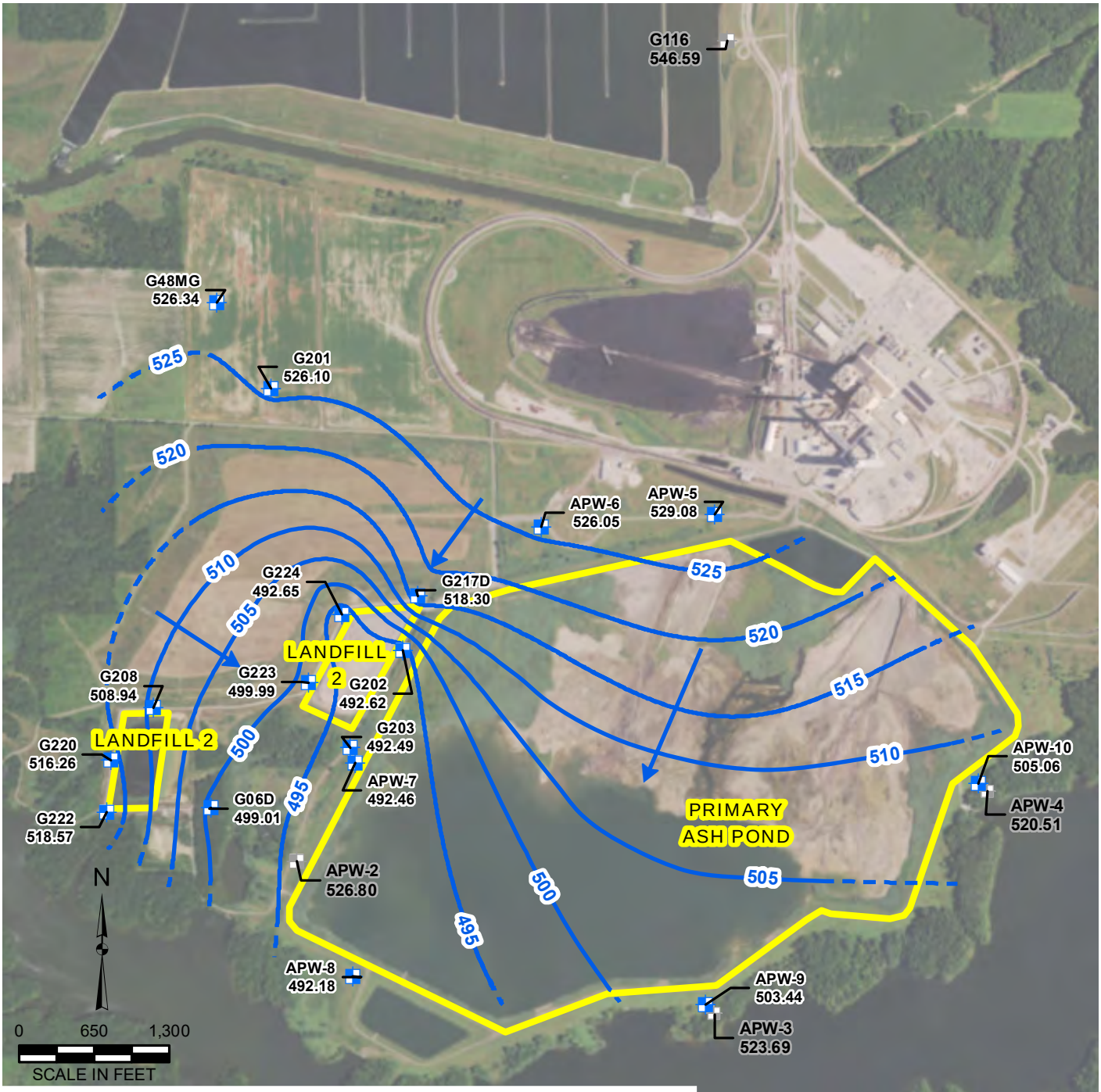
NEWTON PRIMARY ASH POND (UNIT ID: 501) AND NEWTON LANDFILL 2 (UNIT ID: 502) UPPERMOST AQUIFER UNIT GROUNDWATER ELEVATION CONTOUR MAP ROUND 4: JULY 25, 2016

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



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REVIEWED BY/DATE:
TBN 3/6/17
APPROVED BY/DATE:
JJW 8/30/17

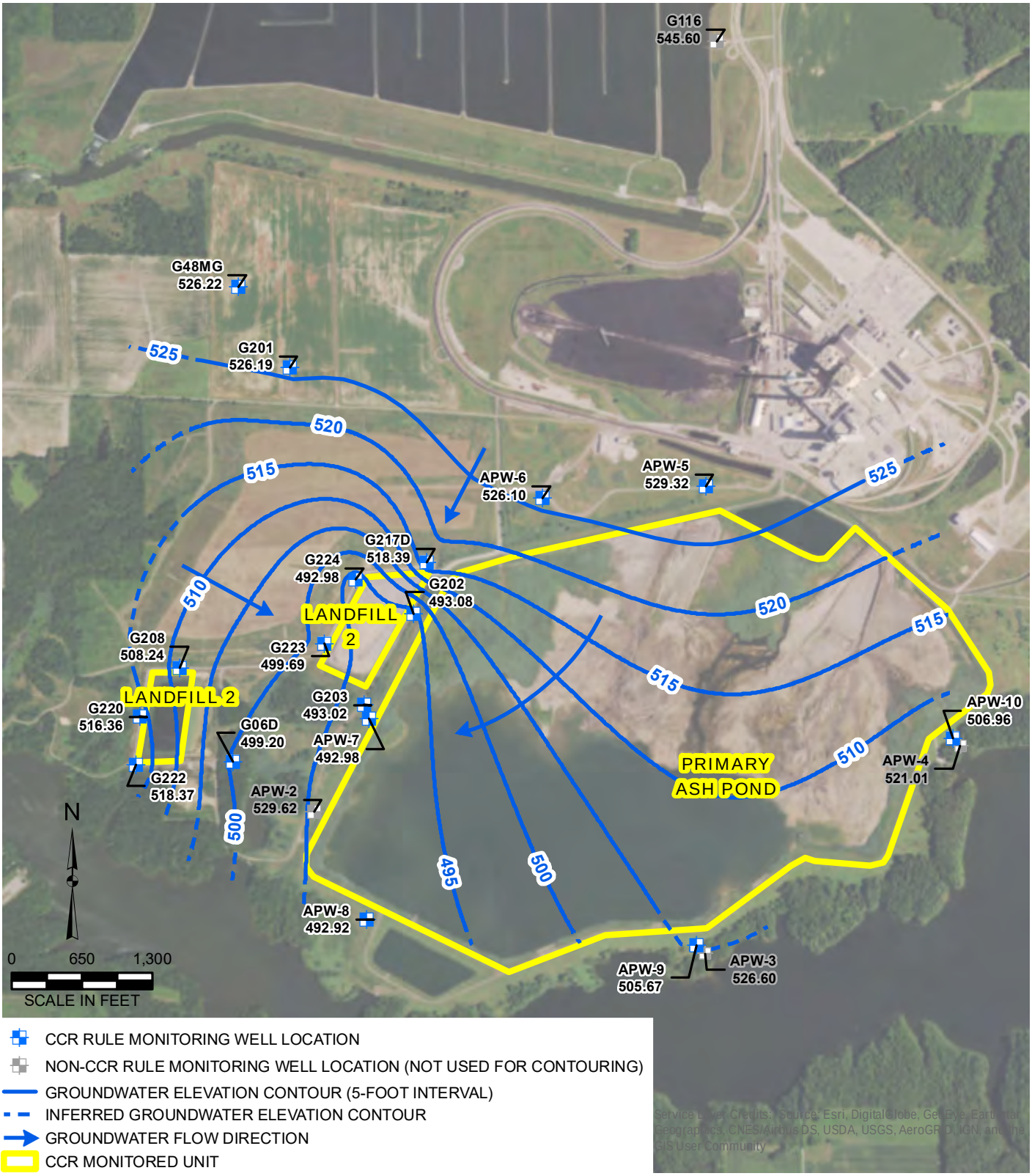
NEWTON PRIMARY ASH POND (UNIT ID: 501) AND LANDFILL 2 (UNIT ID: 502) UPPERMOST AQUIFER UNIT GROUNDWATER ELEVATION CONTOUR MAP ROUND 5: OCTOBER 17, 2016

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY



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SDS 3/6/17
REVIEWED BY/DATE:
TBN 3/6/17
APPROVED BY/DATE:
JJW 8/30/17

NEWTON PRIMARY ASH POND (UNIT ID: 501) AND LANDFILL 2 (UNIT ID: 502)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 6: JANUARY 16, 2017

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
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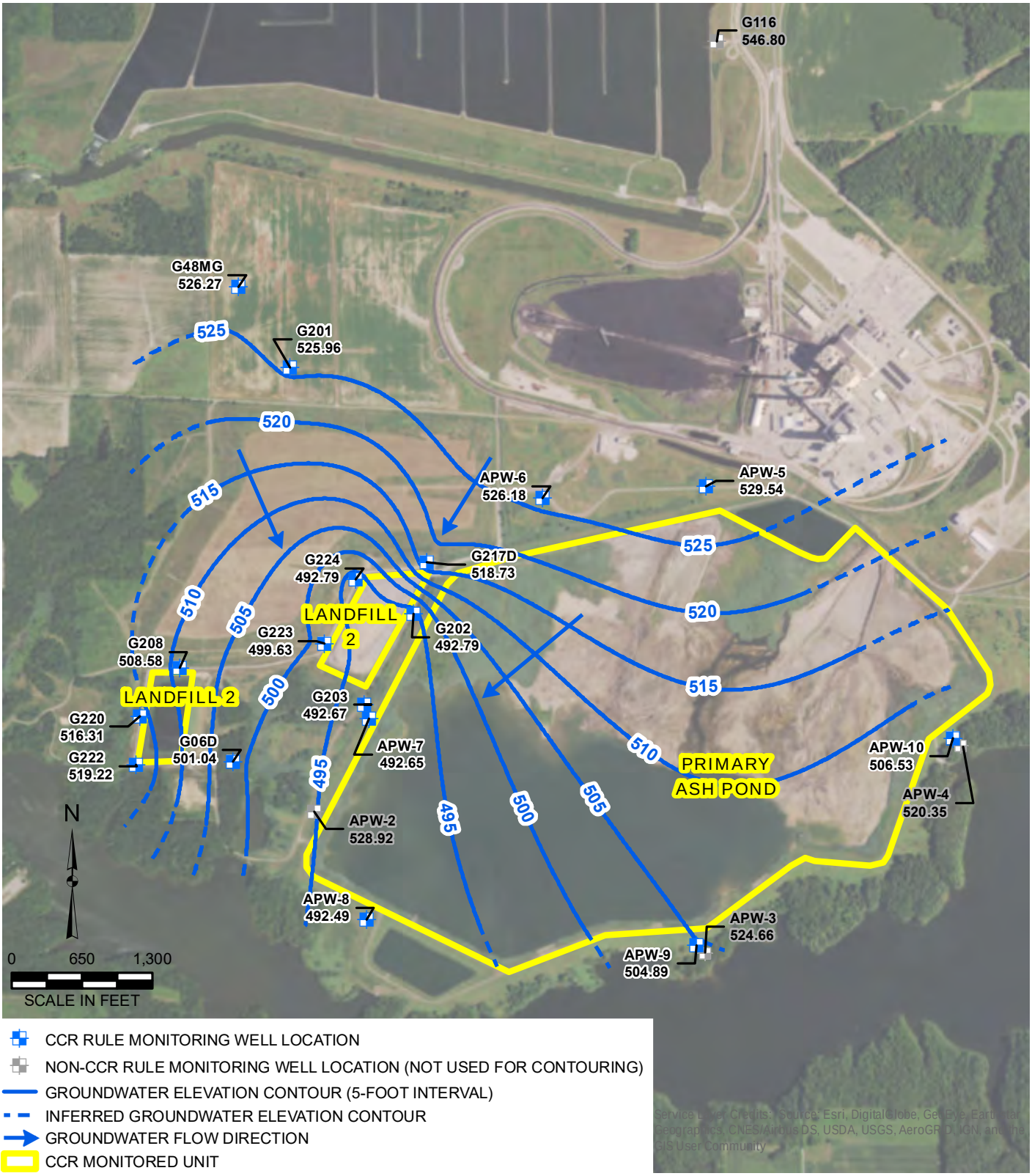

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REVIEWED BY/DATE:
TBN 7/10/17
APPROVED BY/DATE:
JJW 8/30/17

NEWTON PRIMARY ASH POND (UNIT ID: 501) AND LANDFILL 2 (UNIT ID: 502)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 7: APRIL 17, 2017

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
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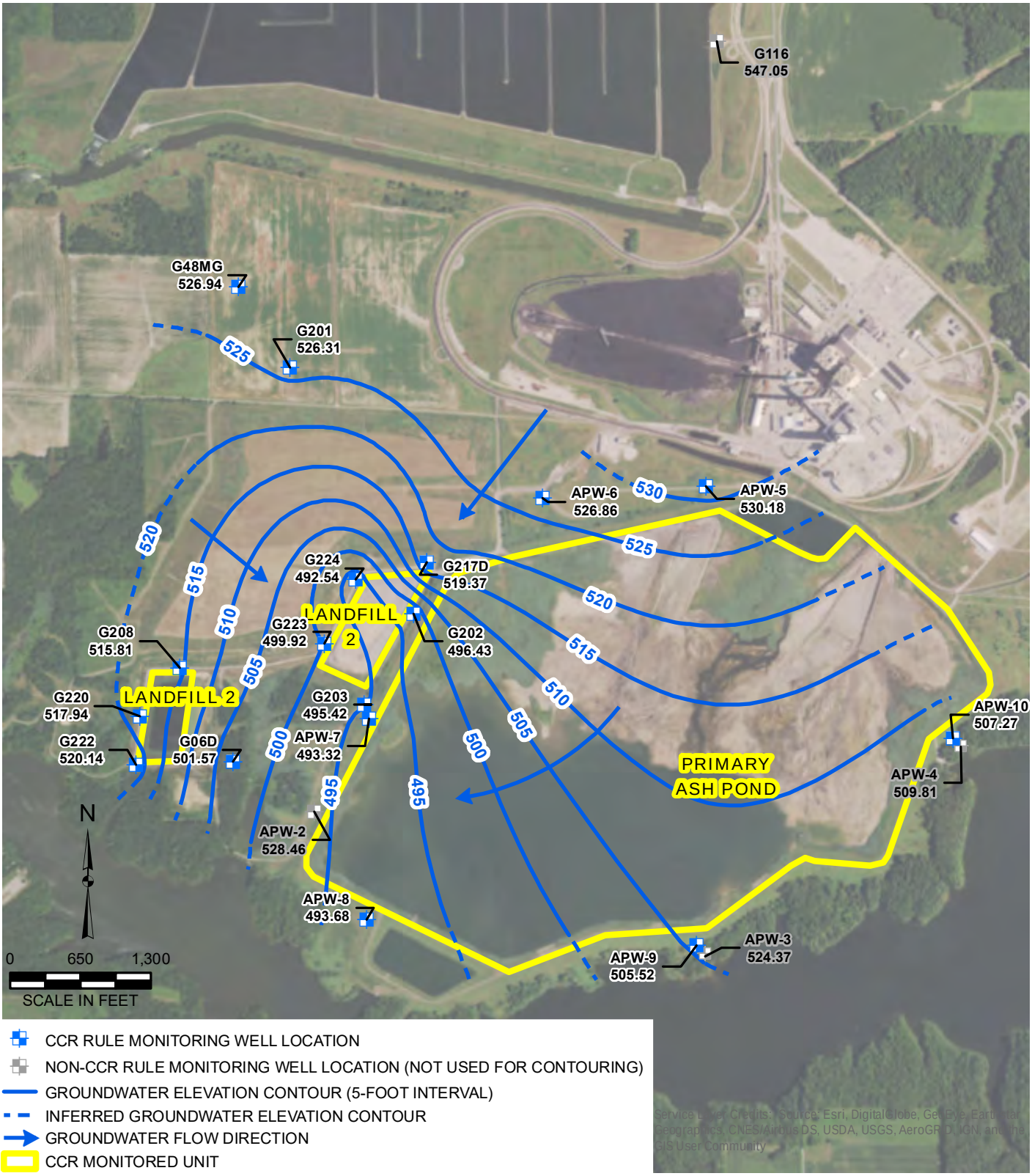

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SDS 8/12/17
REVIEWED BY/DATE:
TBN 8/12/17
APPROVED BY/DATE:
JJW 8/30/17

NEWTON PRIMARY ASH POND (UNIT ID: 501) AND LANDFILL 2 (UNIT ID: 502)
UPPERMOST AQUIFER UNIT
GROUNDWATER ELEVATION CONTOUR MAP
ROUND 8: JUNE 12, 2017

DYNEGY CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

Natural Resource Technology
AN OBG COMPANY

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8/14/2020 12:15:02 AM



CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
NOVEMBER 14, 2017

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

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CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
MAY 17, 2018

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

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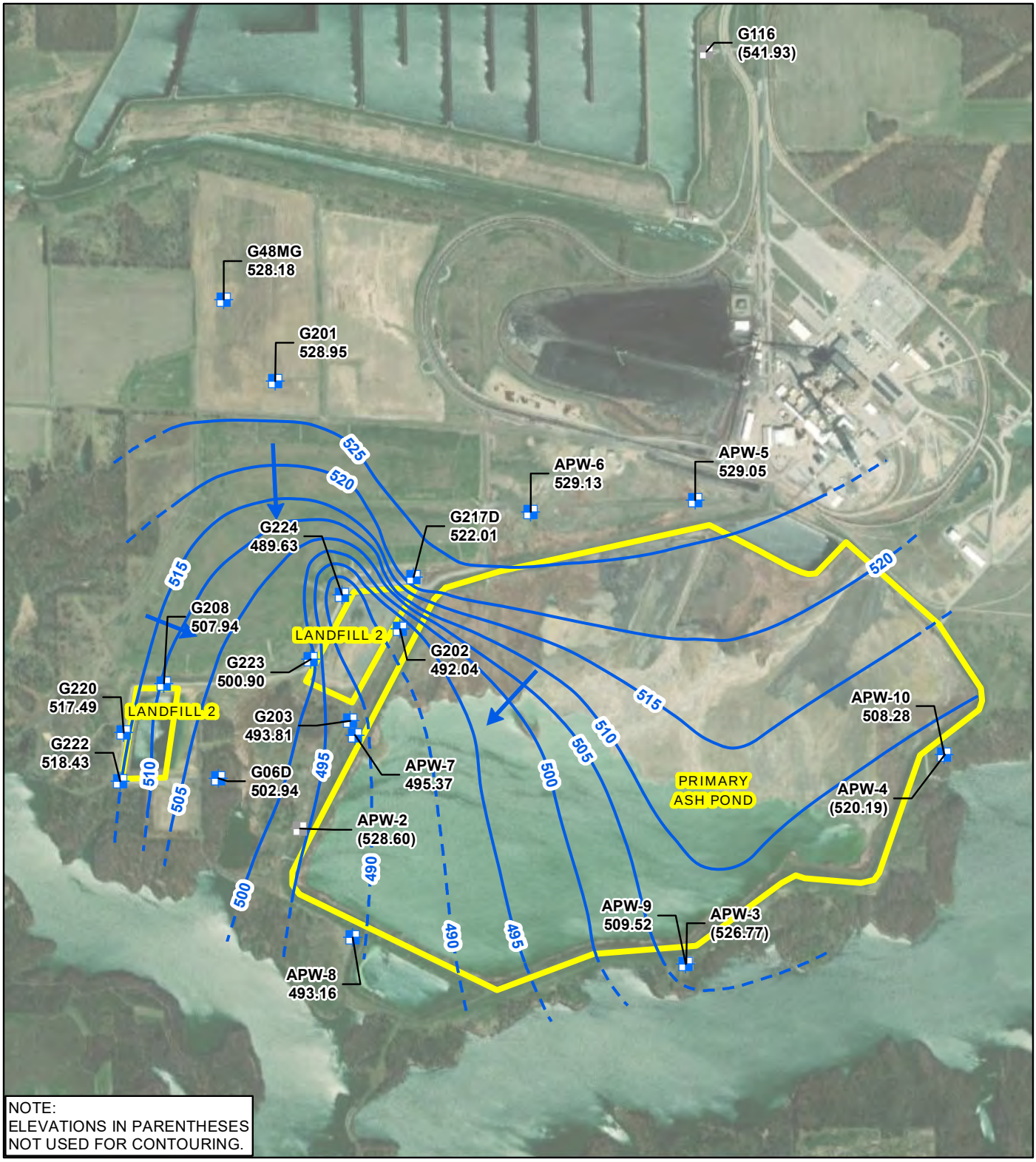

CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
AUGUST 14, 2018

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

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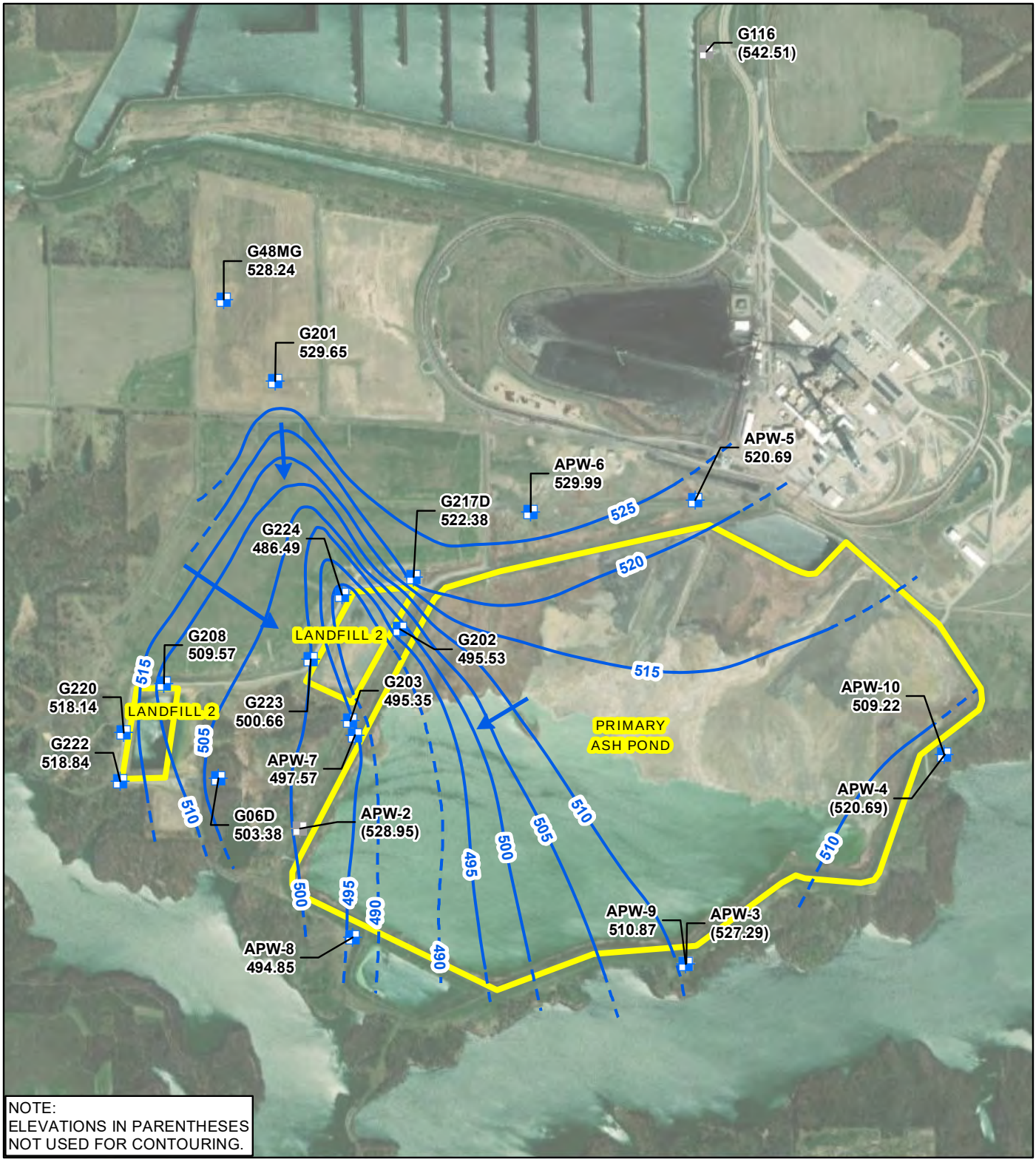

CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
NOVEMBER 8, 2018

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

Y:\Mapping\Projects\22\2285\MXD\GW_Contours\Round_2018_4Q\R2018_4Q_Newton_GW_Contours.mxd

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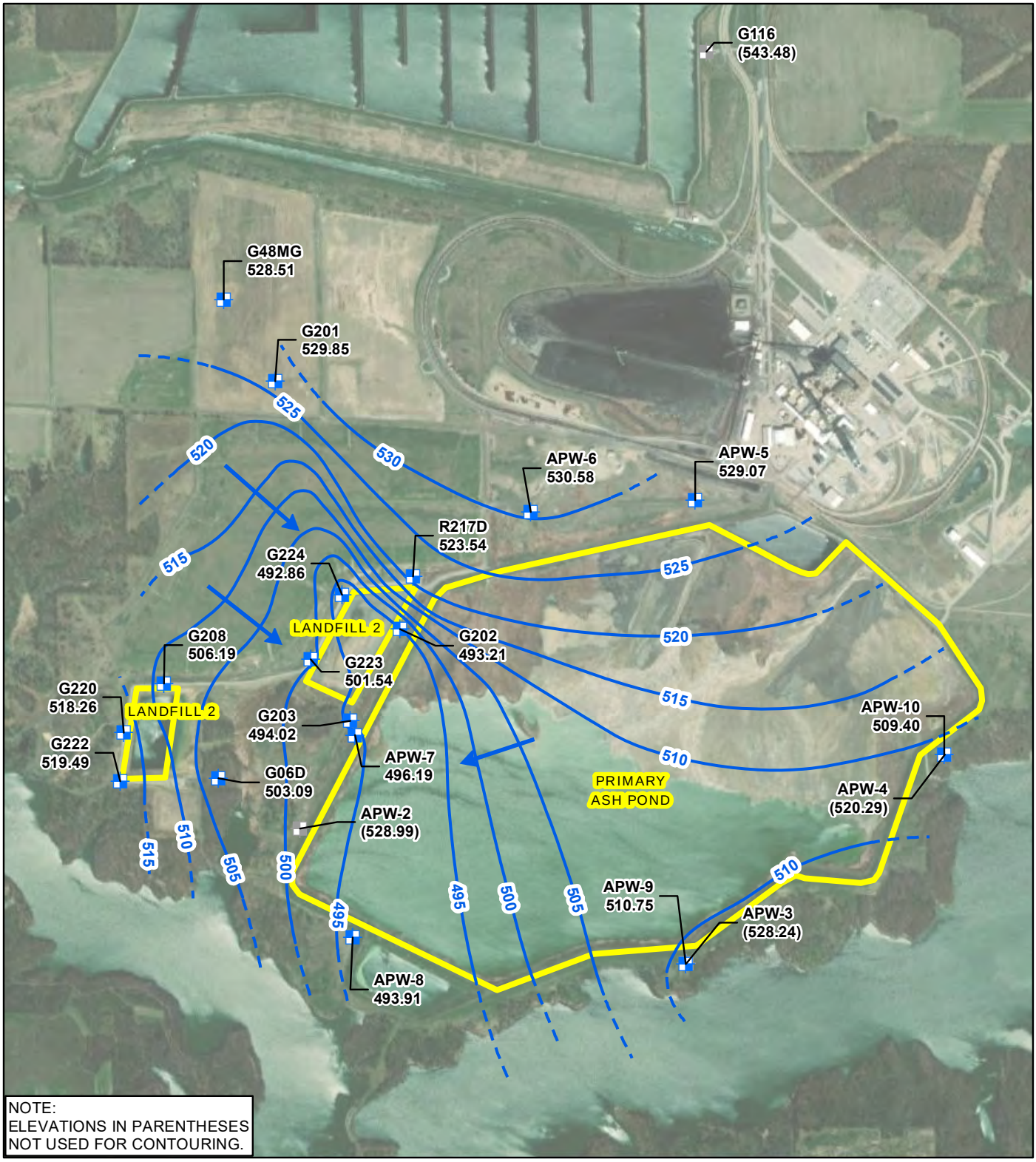

CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
FEBRUARY 18, 2019

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

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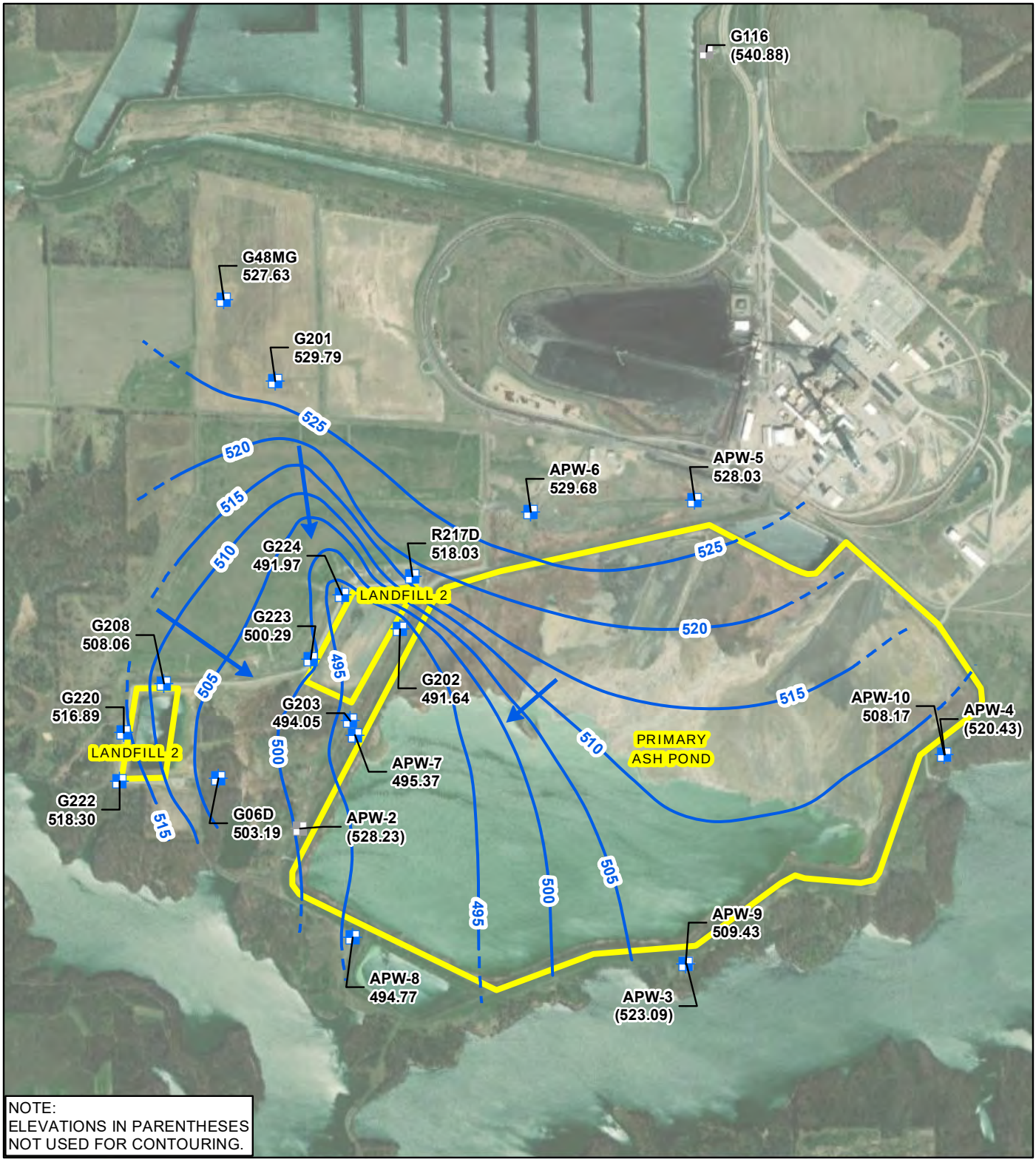

CCR RULE MONITORING WELL LOCATION

NON-CCR RULE MONITORING WELL LOCATION

GROUNDWATER ELEVATION CONTOUR (5-FOOT CONTOUR INTERVAL, NAVD88)

INFERRED GROUNDWATER ELEVATION CONTOUR

GROUNDWATER FLOW DIRECTION

CCR MONITORED UNIT

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
GROUNDWATER ELEVATION CONTOUR MAP
AUGUST 21, 2019

CCR RULE GROUNDWATER MONITORING
NEWTON POWER STATION
NEWTON, ILLINOIS

0 325 650 1,300
Feet

N

O'BRIEN & GERE ENGINEERS, INC.

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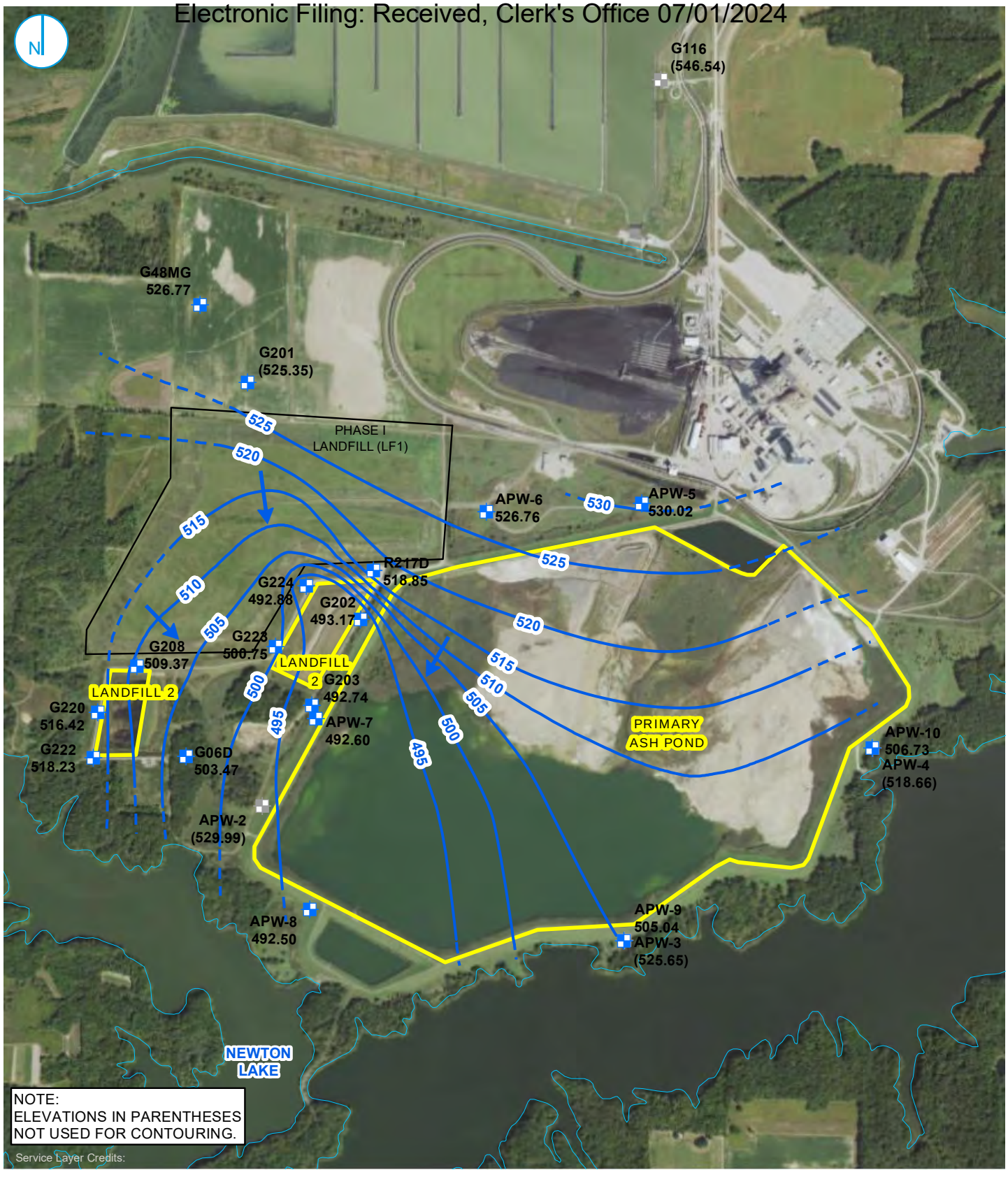


- CCR RULE MONITORING WELL
- NON-CCR RULE MONITORING WELL
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- SURFACE WATER FEATURE
- CCR MONITORED UNIT
- NON-CCR UNIT

0 650 1,300 Feet

GROUNDWATER ELEVATION CONTOUR MAP FEBRUARY 3, 2020

NEWTON PRIMARY ASH POND (UNIT ID: 501)
AND LANDFILL 2 (UNIT ID: 502)
NEWTON POWER STATION
NEWTON, ILLINOIS

RAMBOLL US CORPORATION
A RAMBOLL COMPANY

RAMBOLL

TABLE E-1. GROUNDWATER ELEVATION RESULTS

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW02	10/07/2015	524.93
APW02	12/14/2015	528.13
APW02	07/25/2016	527.99
APW02	10/17/2016	526.80
APW02	01/16/2017	529.62
APW02	04/17/2017	528.92
APW02	06/12/2017	528.46
APW02	11/14/2017	528.98
APW02	05/17/2018	529.03
APW02	08/14/2018	528.60
APW02	11/08/2018	528.95
APW02	02/18/2019	528.99
APW02	08/21/2019	528.23
APW02	02/03/2020	529.99
APW02	07/27/2020	529.01
APW02	10/22/2020	528.20
APW02	02/04/2021	530.41
APW02	02/15/2021	529.17
APW02	02/17/2021	529.17
APW02	03/09/2021	529.13
APW02	03/10/2021	529.13
APW02	03/29/2021	529.99
APW02	03/30/2021	529.99
APW02	04/27/2021	528.63
APW02	04/29/2021	529.37
APW02	05/24/2021	528.50
APW02	05/25/2021	528.49
APW02	06/15/2021	528.15
APW02	06/16/2021	528.15
APW02	06/24/2021	527.93
APW02	06/30/2021	526.56
APW02	07/14/2021	528.58
APW02	07/15/2021	528.53
APW02	08/02/2021	528.44
APW03	10/07/2015	520.82
APW03	12/14/2015	525.99
APW03	10/17/2016	523.69
APW03	01/16/2017	526.60
APW03	04/17/2017	524.66
APW03	06/12/2017	524.37
APW03	07/25/2017	523.27
APW03	11/14/2017	526.05
APW03	05/17/2018	526.06
APW03	08/14/2018	526.77
APW03	11/08/2018	527.29

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW03	02/18/2019	528.24
APW03	08/21/2019	523.09
APW03	02/03/2020	525.65
APW03	07/27/2020	525.19
APW03	10/22/2020	523.49
APW03	02/04/2021	526.54
APW03	02/15/2021	523.58
APW03	02/18/2021	523.58
APW03	03/09/2021	524.93
APW03	03/10/2021	524.93
APW03	03/29/2021	526.00
APW03	03/31/2021	526.00
APW03	04/27/2021	524.25
APW03	04/29/2021	524.93
APW03	05/25/2021	523.85
APW03	06/15/2021	523.41
APW03	06/17/2021	523.41
APW03	06/24/2021	523.18
APW03	06/30/2021	523.07
APW03	07/14/2021	523.70
APW03	07/15/2021	523.71
APW03	08/02/2021	523.92
APW04	10/07/2015	518.82
APW04	12/14/2015	521.12
APW04	10/17/2016	520.51
APW04	01/16/2017	521.01
APW04	04/17/2017	520.35
APW04	06/12/2017	509.81
APW04	07/25/2017	520.51
APW04	11/14/2017	520.31
APW04	05/17/2018	520.07
APW04	08/14/2018	520.19
APW04	11/08/2018	520.69
APW04	02/18/2019	520.29
APW04	08/21/2019	520.43
APW04	02/03/2020	518.66
APW04	07/27/2020	520.41
APW04	10/22/2020	520.08
APW04	02/04/2021	520.64
APW04	02/15/2021	518.19
APW04	02/18/2021	518.19
APW04	03/09/2021	519.50
APW04	03/11/2021	519.50
APW04	03/29/2021	520.34
APW04	03/31/2021	520.34

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW04	04/27/2021	519.87
APW04	04/29/2021	520.51
APW04	05/24/2021	519.72
APW04	05/25/2021	519.73
APW04	06/15/2021	519.68
APW04	06/17/2021	519.71
APW04	06/24/2021	519.64
APW04	06/30/2021	519.69
APW04	07/14/2021	519.99
APW04	07/15/2021	520.02
APW04	08/02/2021	520.00
APW05	12/14/2015	529.56
APW05	01/18/2016	528.57
APW05	04/25/2016	529.55
APW05	07/25/2016	529.34
APW05	10/17/2016	529.08
APW05	01/16/2017	529.32
APW05	04/17/2017	529.54
APW05	06/12/2017	530.18
APW05	11/14/2017	528.57
APW05	05/17/2018	529.06
APW05	08/14/2018	529.05
APW05	11/08/2018	530.19
APW05	02/18/2019	529.07
APW05	08/21/2019	528.03
APW05	02/03/2020	530.02
APW05	06/11/2020	529.71
APW05	07/27/2020	529.77
APW05	10/22/2020	529.54
APW05	02/04/2021	530.11
APW05	02/09/2021	530.11
APW05	02/15/2021	529.83
APW05	02/17/2021	529.83
APW05	03/09/2021	529.61
APW05	03/10/2021	529.61
APW05	03/29/2021	529.68
APW05	03/30/2021	529.68
APW05	04/27/2021	529.73
APW05	04/28/2021	529.72
APW05	05/24/2021	530.82
APW05	05/25/2021	529.51
APW05	06/15/2021	529.42
APW05	06/17/2021	529.43
APW05	06/24/2021	529.38
APW05	06/30/2021	529.38

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW05	07/14/2021	529.33
APW05	07/15/2021	529.40
APW05	08/02/2021	529.28
APW05S	02/04/2021	534.37
APW05S	02/15/2021	533.90
APW05S	02/17/2021	533.90
APW05S	03/09/2021	533.71
APW05S	03/10/2021	533.71
APW05S	03/29/2021	533.91
APW05S	04/27/2021	533.56
APW05S	04/29/2021	533.74
APW05S	05/25/2021	533.23
APW05S	06/15/2021	532.54
APW05S	06/17/2021	532.53
APW05S	06/24/2021	531.93
APW05S	06/30/2021	531.68
APW05S	07/14/2021	532.16
APW05S	07/15/2021	532.31
APW06	12/14/2015	526.14
APW06	01/18/2016	527.46
APW06	04/25/2016	526.59
APW06	07/25/2016	526.20
APW06	10/17/2016	526.05
APW06	01/16/2017	526.10
APW06	04/17/2017	526.18
APW06	06/12/2017	526.86
APW06	11/14/2017	525.40
APW06	05/17/2018	526.39
APW06	08/14/2018	529.13
APW06	11/08/2018	529.99
APW06	02/18/2019	530.58
APW06	08/21/2019	529.68
APW06	02/03/2020	526.76
APW06	06/11/2020	526.74
APW06	07/27/2020	526.78
APW06	10/22/2020	526.37
APW06	02/04/2021	526.82
APW06	02/09/2021	526.82
APW06	02/15/2021	526.48
APW06	02/17/2021	526.48
APW06	03/09/2021	526.46
APW06	03/10/2021	526.46
APW06	03/29/2021	526.49
APW06	03/30/2021	526.49
APW06	04/27/2021	526.68

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW06	04/29/2021	526.90
APW06	05/24/2021	537.51
APW06	05/25/2021	526.54
APW06	06/15/2021	526.45
APW06	06/16/2021	526.45
APW06	06/24/2021	526.42
APW06	06/30/2021	526.38
APW06	07/14/2021	526.31
APW06	07/15/2021	526.41
APW06	08/02/2021	526.31
APW07	12/14/2015	492.84
APW07	01/18/2016	492.58
APW07	04/25/2016	493.11
APW07	07/25/2016	492.64
APW07	10/17/2016	492.46
APW07	01/16/2017	492.98
APW07	04/17/2017	492.65
APW07	06/12/2017	493.32
APW07	11/14/2017	491.34
APW07	05/17/2018	491.73
APW07	08/14/2018	495.37
APW07	11/08/2018	497.57
APW07	02/18/2019	496.19
APW07	08/21/2019	495.37
APW07	02/03/2020	492.60
APW07	06/11/2020	491.90
APW07	07/27/2020	491.97
APW07	10/22/2020	491.50
APW07	02/04/2021	492.72
APW07	02/10/2021	492.72
APW07	02/15/2021	492.16
APW07	03/09/2021	491.93
APW07	03/29/2021	492.17
APW07	04/27/2021	492.19
APW07	05/24/2021	491.88
APW07	06/15/2021	491.85
APW07	06/24/2021	491.75
APW07	07/14/2021	491.77
APW07	08/02/2021	492.27
APW08	12/14/2015	492.72
APW08	01/18/2016	492.35
APW08	04/25/2016	492.97
APW08	07/25/2016	492.14
APW08	10/17/2016	492.18
APW08	01/16/2017	492.92

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW08	04/17/2017	492.49
APW08	06/12/2017	493.68
APW08	11/14/2017	491.77
APW08	05/17/2018	492.22
APW08	08/14/2018	493.16
APW08	11/08/2018	494.85
APW08	02/18/2019	493.91
APW08	08/21/2019	494.77
APW08	02/03/2020	492.50
APW08	06/11/2020	491.65
APW08	07/27/2020	491.82
APW08	10/22/2020	491.28
APW08	02/04/2021	492.46
APW08	02/10/2021	492.46
APW08	02/15/2021	491.90
APW08	03/09/2021	491.72
APW08	03/29/2021	491.93
APW08	04/27/2021	491.98
APW08	05/24/2021	491.68
APW08	06/15/2021	491.64
APW08	06/24/2021	491.56
APW08	07/14/2021	491.61
APW08	08/02/2021	491.59
APW09	12/14/2015	504.88
APW09	01/18/2016	506.59
APW09	04/25/2016	505.32
APW09	07/25/2016	504.70
APW09	10/17/2016	503.44
APW09	01/16/2017	505.67
APW09	04/17/2017	504.89
APW09	06/12/2017	505.52
APW09	11/14/2017	504.77
APW09	05/17/2018	505.34
APW09	08/14/2018	509.52
APW09	11/08/2018	510.87
APW09	02/18/2019	510.75
APW09	08/21/2019	509.43
APW09	02/03/2020	505.04
APW09	06/11/2020	504.64
APW09	07/27/2020	505.31
APW09	10/22/2020	503.83
APW09	02/04/2021	505.69
APW09	02/11/2021	505.69
APW09	02/15/2021	504.93
APW09	03/09/2021	505.10

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW09	03/29/2021	505.23
APW09	04/27/2021	504.74
APW09	05/24/2021	504.72
APW09	06/15/2021	504.63
APW09	06/24/2021	504.48
APW09	07/14/2021	505.24
APW09	08/02/2021	504.77
APW10	12/14/2015	506.39
APW10	01/18/2016	507.70
APW10	04/25/2016	506.90
APW10	07/25/2016	506.19
APW10	10/17/2016	505.06
APW10	01/16/2017	506.96
APW10	04/17/2017	506.53
APW10	06/12/2017	507.27
APW10	11/14/2017	506.18
APW10	05/17/2018	506.25
APW10	08/14/2018	508.28
APW10	11/08/2018	509.22
APW10	02/18/2019	509.40
APW10	08/21/2019	508.17
APW10	02/03/2020	506.73
APW10	06/11/2020	506.31
APW10	07/27/2020	506.76
APW10	10/22/2020	505.44
APW10	02/04/2021	507.12
APW10	02/11/2021	507.12
APW10	02/15/2021	506.65
APW10	03/09/2021	506.84
APW10	03/29/2021	506.94
APW10	04/27/2021	506.53
APW10	05/24/2021	506.35
APW10	06/15/2021	506.26
APW10	06/17/2021	506.31
APW10	06/24/2021	506.12
APW10	06/30/2021	506.05
APW10	07/14/2021	506.59
APW10	07/29/2021	506.48
APW10	08/02/2021	506.37
APW11	02/04/2021	514.71
APW11	02/15/2021	514.13
APW11	02/18/2021	514.13
APW11	03/09/2021	514.49
APW11	03/29/2021	514.55
APW11	04/27/2021	487.33

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW11	04/28/2021	514.50
APW11	05/24/2021	514.16
APW11	06/15/2021	514.02
APW11	06/16/2021	514.02
APW11	06/24/2021	513.90
APW11	06/30/2021	513.86
APW11	07/14/2021	513.96
APW11	07/15/2021	514.00
APW12	02/04/2021	533.12
APW12	02/15/2021	532.41
APW12	02/17/2021	532.41
APW12	03/09/2021	532.48
APW12	03/29/2021	532.91
APW12	04/27/2021	532.12
APW12	04/28/2021	532.31
APW12	05/24/2021	531.87
APW12	05/25/2021	531.82
APW12	06/15/2021	531.53
APW12	06/16/2021	528.83
APW12	06/24/2021	531.37
APW12	06/30/2021	531.28
APW12	07/14/2021	531.29
APW12	07/15/2021	531.34
APW13	02/04/2021	506.52
APW13	02/15/2021	505.94
APW13	02/22/2021	505.94
APW13	03/09/2021	506.06
APW13	03/10/2021	506.06
APW13	03/29/2021	506.10
APW13	03/31/2021	506.10
APW13	04/27/2021	505.69
APW13	04/29/2021	505.97
APW13	05/24/2021	505.62
APW13	05/25/2021	505.78
APW13	06/15/2021	505.44
APW13	06/17/2021	505.44
APW13	06/24/2021	505.27
APW13	06/30/2021	505.20
APW13	07/14/2021	505.63
APW13	07/15/2021	505.73
APW14	02/04/2021	506.29
APW14	02/15/2021	505.55
APW14	02/22/2021	505.55
APW14	03/09/2021	505.69
APW14	03/10/2021	505.69

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW14	03/29/2021	505.76
APW14	03/31/2021	505.76
APW14	04/27/2021	505.29
APW14	04/28/2021	505.37
APW14	05/24/2021	505.30
APW14	05/25/2021	505.41
APW14	06/15/2021	514.14
APW14	06/17/2021	505.16
APW14	06/24/2021	505.00
APW14	06/30/2021	504.93
APW14	07/14/2021	505.62
APW14	07/15/2021	505.63
APW15	02/04/2021	500.60
APW15	02/15/2021	500.54
APW15	02/23/2021	500.54
APW15	03/09/2021	501.19
APW15	03/10/2021	501.19
APW15	03/29/2021	501.88
APW15	03/31/2021	501.88
APW15	04/27/2021	502.40
APW15	04/28/2021	502.44
APW15	05/24/2021	502.69
APW15	06/15/2021	502.71
APW15	06/17/2021	502.77
APW15	06/24/2021	502.75
APW15	06/30/2021	502.76
APW15	07/14/2021	502.81
APW16	02/04/2021	492.13
APW16	02/15/2021	491.48
APW16	02/23/2021	491.48
APW16	03/09/2021	491.41
APW16	03/10/2021	491.41
APW16	03/29/2021	491.62
APW16	03/30/2021	491.62
APW16	04/27/2021	491.49
APW16	04/28/2021	491.49
APW16	05/24/2021	491.29
APW16	06/15/2021	491.23
APW16	06/16/2021	491.23
APW16	06/24/2021	491.17
APW16	06/30/2021	491.06
APW16	07/14/2021	491.20
APW16	07/15/2021	491.21
APW17	02/04/2021	492.56
APW17	02/15/2021	492.02

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
APW17	02/23/2021	492.02
APW17	03/09/2021	491.74
APW17	03/10/2021	491.74
APW17	03/29/2021	491.95
APW17	03/30/2021	491.95
APW17	04/27/2021	491.87
APW17	04/29/2021	492.19
APW17	05/24/2021	491.69
APW17	06/15/2021	491.57
APW17	06/16/2021	491.57
APW17	06/24/2021	491.52
APW17	06/30/2021	491.42
APW17	07/14/2021	491.58
APW17	07/15/2021	491.59
APW18	02/04/2021	492.73
APW18	02/15/2021	492.20
APW18	02/23/2021	492.20
APW18	03/09/2021	491.92
APW18	03/10/2021	491.92
APW18	03/29/2021	492.14
APW18	03/30/2021	492.14
APW18	04/27/2021	492.06
APW18	04/29/2021	492.37
APW18	05/24/2021	491.97
APW18	06/15/2021	491.82
APW18	06/16/2021	491.84
APW18	06/24/2021	491.76
APW18	06/30/2021	491.67
APW18	07/14/2021	491.76
APW18	07/15/2021	491.85
G48MG	12/14/2015	526.29
G48MG	01/18/2016	525.50
G48MG	04/25/2016	526.21
G48MG	07/25/2016	526.09
G48MG	10/17/2016	526.34
G48MG	01/16/2017	526.22
G48MG	04/17/2017	526.27
G48MG	06/12/2017	526.94
G48MG	11/14/2017	525.55
G48MG	05/17/2018	527.32
G48MG	08/14/2018	528.18
G48MG	11/08/2018	528.24
G48MG	02/18/2019	528.51
G48MG	08/21/2019	527.63
G48MG	02/03/2020	526.77

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G48MG	06/11/2020	526.32
G48MG	07/27/2020	526.54
G48MG	10/22/2020	526.31
G48MG	02/04/2021	526.83
G48MG	02/10/2021	526.83
G48MG	02/15/2021	526.30
G48MG	03/09/2021	526.15
G48MG	03/29/2021	526.35
G48MG	04/27/2021	526.56
G48MG	05/24/2021	526.40
G48MG	06/15/2021	526.42
G48MG	06/24/2021	539.15
G48MG	07/14/2021	526.32
G48MG	08/02/2021	526.35
G202	01/14/2015	492.88
G202	04/21/2015	493.71
G202	07/15/2015	494.53
G202	10/06/2015	492.29
G202	12/14/2015	492.94
G202	01/18/2016	496.48
G202	01/20/2016	492.80
G202	04/25/2016	493.23
G202	04/28/2016	493.46
G202	07/25/2016	492.73
G202	07/27/2016	493.28
G202	10/17/2016	492.62
G202	10/19/2016	492.72
G202	01/16/2017	493.08
G202	01/18/2017	493.42
G202	04/17/2017	492.79
G202	04/20/2017	493.45
G202	06/12/2017	496.43
G202	08/02/2017	493.09
G202	11/14/2017	491.83
G202	11/15/2017	492.29
G202	02/22/2018	494.31
G202	05/17/2018	492.39
G202	05/23/2018	492.87
G202	08/14/2018	492.04
G202	08/21/2018	492.55
G202	11/08/2018	495.53
G202	11/14/2018	496.05
G202	02/18/2019	493.21
G202	02/21/2019	496.68
G202	05/21/2019	492.70

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G202	08/21/2019	491.64
G202	08/22/2019	492.13
G202	02/03/2020	493.17
G202	07/28/2020	492.09
G202	10/22/2020	491.67
G202	02/04/2021	492.90
G202	02/08/2021	492.85
G202	03/09/2021	492.08
G202	03/29/2021	492.47
G202	04/27/2021	492.30
G202	05/24/2021	502.48
G202	06/15/2021	492.01
G202	06/24/2021	491.99
G202	07/14/2021	492.05
G203	01/14/2015	492.91
G203	04/21/2015	493.70
G203	07/15/2015	494.18
G203	10/06/2015	506.02
G203	12/16/2015	492.72
G203	01/18/2016	495.02
G203	01/20/2016	492.74
G203	04/25/2016	493.16
G203	04/28/2016	493.44
G203	07/25/2016	492.66
G203	07/27/2016	493.17
G203	10/17/2016	492.49
G203	10/19/2016	492.64
G203	01/16/2017	493.02
G203	01/19/2017	493.56
G203	04/17/2017	492.67
G203	04/20/2017	493.31
G203	06/12/2017	495.42
G203	08/02/2017	492.96
G203	11/14/2017	490.99
G203	11/15/2017	491.46
G203	02/22/2018	496.37
G203	05/17/2018	492.26
G203	05/23/2018	492.73
G203	08/14/2018	493.81
G203	08/21/2018	494.30
G203	11/08/2018	495.35
G203	11/14/2018	496.00
G203	02/18/2019	494.02
G203	02/21/2019	494.50
G203	05/21/2019	493.10

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G203	08/21/2019	494.05
G203	08/22/2019	494.54
G203	02/03/2020	492.74
G203	05/21/2020	491.49
G203	07/27/2020	491.99
G203	10/22/2020	491.63
G203	02/04/2021	492.84
G203	02/08/2021	492.73
G203	03/09/2021	492.10
G203	03/29/2021	492.33
G203	05/24/2021	501.18
G203	06/15/2021	491.99
G203	06/24/2021	491.93
G203	07/14/2021	491.92
G203	08/02/2021	491.95
G208	01/14/2015	513.98
G208	04/21/2015	514.82
G208	07/15/2015	514.55
G208	10/06/2015	513.51
G208	12/14/2015	513.41
G208	01/18/2016	514.11
G208	01/19/2016	515.99
G208	04/25/2016	507.69
G208	04/28/2016	508.77
G208	07/25/2016	512.24
G208	07/29/2016	513.14
G208	10/17/2016	508.94
G208	10/25/2016	509.54
G208	01/16/2017	508.24
G208	01/24/2017	509.27
G208	04/17/2017	508.58
G208	04/20/2017	509.15
G208	06/12/2017	515.81
G208	08/03/2017	511.82
G208	11/14/2017	512.07
G208	11/17/2017	512.48
G208	02/22/2018	509.43
G208	05/17/2018	507.59
G208	05/23/2018	508.02
G208	08/14/2018	507.94
G208	08/20/2018	508.43
G208	11/08/2018	509.57
G208	11/13/2018	510.19
G208	02/18/2019	508.19
G208	02/20/2019	508.68

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G208	05/22/2019	509.50
G208	08/21/2019	508.06
G208	08/22/2019	508.55
G208	02/03/2020	509.37
G208	05/20/2020	510.57
G208	07/27/2020	508.69
G208	10/22/2020	509.96
G208	02/04/2021	509.91
G208	02/09/2021	509.82
G208	02/15/2021	504.88
G208	03/09/2021	528.57
G208	03/29/2021	509.53
G208	04/27/2021	510.25
G208	05/24/2021	510.44
G208	06/15/2021	506.19
G208	06/24/2021	507.44
G208	07/14/2021	508.84
G208	08/02/2021	509.68
G217S	01/14/2015	531.59
G217S	04/21/2015	532.93
G217S	07/14/2015	528.58
G217S	10/07/2015	530.44
G217S	01/20/2016	531.63
G217S	04/26/2016	532.84
G217S	07/26/2016	531.14
G217S	10/19/2016	530.90
G217S	01/18/2017	531.47
G217S	04/18/2017	532.00
G217S	08/02/2017	531.46
G217S	11/28/2017	530.70
G217S	02/21/2018	533.36
G217S	05/23/2018	530.75
G217S	08/22/2018	533.49
G217S	11/16/2018	533.75
G217S	02/21/2019	535.19
G217S	05/23/2019	535.44
G217S	08/23/2019	530.94
G217S	07/27/2020	530.95
G217S	10/22/2020	530.14
G217S	02/04/2021	532.08
G217S	02/15/2021	531.41
G217S	03/09/2021	531.50
G217S	03/29/2021	532.14
G217S	04/27/2021	531.48
G217S	05/24/2021	531.26

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G217S	06/15/2021	531.16
G217S	06/24/2021	531.48
G217S	07/14/2021	530.77
G217S	08/02/2021	531.18
G217D	12/14/2015	518.26
G217D	01/18/2016	518.86
G217D	04/25/2016	518.70
G217D	07/25/2016	507.56
G217D	10/17/2016	518.30
G217D	01/16/2017	518.39
G217D	04/17/2017	518.73
G217D	06/12/2017	519.37
G222	01/14/2015	518.19
G222	04/21/2015	519.68
G222	07/15/2015	520.13
G222	10/06/2015	518.71
G222	12/14/2015	516.93
G222	01/18/2016	516.75
G222	01/19/2016	520.02
G222	04/25/2016	517.61
G222	04/28/2016	518.78
G222	07/25/2016	519.04
G222	07/28/2016	519.51
G222	10/17/2016	518.57
G222	10/25/2016	518.61
G222	01/16/2017	518.37
G222	01/24/2017	519.07
G222	04/17/2017	519.22
G222	04/25/2017	520.00
G222	06/12/2017	520.14
G222	08/02/2017	519.66
G222	11/14/2017	517.84
G222	11/15/2017	518.18
G222	02/20/2018	519.16
G222	05/17/2018	517.88
G222	05/22/2018	518.34
G222	08/14/2018	518.43
G222	08/16/2018	518.93
G222	11/08/2018	518.84
G222	11/12/2018	519.42
G222	02/18/2019	519.49
G222	02/20/2019	519.98
G222	05/22/2019	520.72
G222	08/21/2019	518.30
G222	02/03/2020	518.23

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G222	05/20/2020	520.24
G222	07/27/2020	519.20
G222	10/22/2020	518.18
G222	02/04/2021	518.42
G222	02/09/2021	518.33
G222	02/15/2021	517.25
G222	03/09/2021	518.78
G222	03/29/2021	519.17
G222	04/27/2021	519.73
G222	05/24/2021	519.66
G222	06/15/2021	519.44
G222	06/24/2021	519.57
G222	07/14/2021	519.45
G222	08/02/2021	519.09
G223	01/14/2015	499.35
G223	04/21/2015	500.45
G223	07/15/2015	499.77
G223	10/06/2015	500.15
G223	12/14/2015	500.21
G223	01/18/2016	498.87
G223	01/20/2016	499.89
G223	04/25/2016	499.88
G223	04/28/2016	500.33
G223	07/25/2016	499.69
G223	07/28/2016	500.65
G223	10/17/2016	499.99
G223	10/20/2016	500.21
G223	01/16/2017	499.69
G223	01/24/2017	500.40
G223	04/17/2017	499.63
G223	04/26/2017	500.80
G223	06/12/2017	499.92
G223	08/03/2017	500.40
G223	11/14/2017	498.51
G223	11/28/2017	498.95
G223	02/20/2018	502.87
G223	05/17/2018	499.01
G223	05/23/2018	495.64
G223	08/14/2018	500.90
G223	08/21/2018	501.42
G223	11/08/2018	500.66
G223	11/13/2018	501.54
G223	02/18/2019	501.54
G223	02/21/2019	502.05
G223	05/22/2019	504.22

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G223	08/21/2019	500.29
G223	08/22/2019	500.80
G223	02/03/2020	500.75
G223	05/20/2020	500.97
G223	07/27/2020	500.50
G223	10/22/2020	500.55
G223	02/04/2021	500.95
G223	02/08/2021	500.91
G223	02/15/2021	500.22
G223	03/09/2021	500.22
G223	03/29/2021	500.40
G223	04/27/2021	500.70
G223	05/24/2021	500.60
G223	06/15/2021	500.44
G223	06/24/2021	500.51
G223	07/14/2021	500.40
G223	08/02/2021	500.53
G224	01/14/2015	493.02
G224	04/21/2015	493.99
G224	07/14/2015	492.79
G224	10/06/2015	492.68
G224	12/14/2015	492.96
G224	01/18/2016	492.12
G224	01/21/2016	492.70
G224	04/25/2016	493.24
G224	04/28/2016	493.70
G224	07/25/2016	492.74
G224	07/28/2016	492.41
G224	10/17/2016	492.65
G224	10/20/2016	492.15
G224	01/16/2017	492.98
G224	01/24/2017	493.71
G224	04/17/2017	492.79
G224	04/20/2017	493.55
G224	06/12/2017	492.54
G224	08/02/2017	493.10
G224	11/14/2017	491.90
G224	11/15/2017	492.41
G224	02/20/2018	495.01
G224	05/17/2018	492.11
G224	05/23/2018	492.66
G224	08/14/2018	489.63
G224	08/21/2018	493.21
G224	11/08/2018	486.49
G224	11/15/2018	486.96

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
G224	02/18/2019	492.86
G224	02/21/2019	493.43
G224	05/22/2019	493.43
G224	08/21/2019	491.97
G224	08/22/2019	492.46
G224	02/03/2020	492.88
G224	05/21/2020	492.78
G224	07/27/2020	492.11
G224	10/22/2020	491.63
G224	02/04/2021	492.84
G224	02/09/2021	492.80
G224	02/15/2021	492.16
G224	03/09/2021	492.07
G224	03/29/2021	492.33
G224	04/27/2021	492.31
G224	05/24/2021	492.04
G224	06/15/2021	492.04
G224	06/24/2021	491.99
G224	07/14/2021	491.99
G224	08/02/2021	491.95
R202	05/21/2020	492.85
R202	02/08/2021	493.31
R217D	11/14/2017	517.88
R217D	11/28/2017	518.07
R217D	02/21/2018	521.40
R217D	05/17/2018	517.74
R217D	05/23/2018	517.82
R217D	08/14/2018	522.01
R217D	08/22/2018	522.14
R217D	11/08/2018	522.38
R217D	11/16/2018	522.14
R217D	02/18/2019	523.54
R217D	02/21/2019	523.68
R217D	05/23/2019	527.35
R217D	08/21/2019	518.03
R217D	02/03/2020	518.85
R217D	05/20/2020	519.36
R217D	07/27/2020	518.82
R217D	10/22/2020	518.53
R217D	02/04/2021	518.79
R217D	02/08/2021	518.79
R217D	02/15/2021	518.70
R217D	03/09/2021	518.63
R217D	03/29/2021	518.82
R217D	04/27/2021	518.82

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
R217D	05/24/2021	518.68
R217D	06/15/2021	518.63
R217D	06/24/2021	518.61
R217D	07/14/2021	518.61
R217D	08/02/2021	518.56
XPW01	02/04/2021	546.73
XPW01	02/15/2021	539.56
XPW01	02/17/2021	539.56
XPW01	03/09/2021	539.75
XPW01	03/29/2021	539.85
XPW01	03/30/2021	539.85
XPW01	04/27/2021	539.38
XPW01	04/28/2021	539.31
XPW01	05/24/2021	539.26
XPW01	06/15/2021	539.65
XPW01	06/24/2021	539.35
XPW01	07/14/2021	539.85
XPW02	02/04/2021	546.49
XPW02	02/15/2021	546.49
XPW02	02/17/2021	546.49
XPW02	03/09/2021	545.83
XPW02	03/29/2021	546.69
XPW02	03/30/2021	546.69
XPW02	04/27/2021	545.15
XPW02	04/28/2021	545.14
XPW02	05/24/2021	545.92
XPW02	06/15/2021	545.31
XPW02	06/24/2021	544.91
XPW02	07/14/2021	545.96
XPW03	02/04/2021	544.43
XPW03	02/15/2021	544.13
XPW03	02/17/2021	544.13
XPW03	03/09/2021	544.28
XPW03	03/29/2021	544.16
XPW03	03/30/2021	544.16
XPW03	04/27/2021	543.39
XPW03	04/28/2021	543.43
XPW03	05/24/2021	543.77
XPW03	06/15/2021	543.43
XPW03	06/24/2021	543.31
XPW03	07/14/2021	543.99
XPW04	02/04/2021	542.52
XPW04	02/15/2021	542.21
XPW04	02/17/2021	542.21
XPW04	03/09/2021	542.30

TABLE E-1. GROUNDWATER ELEVATIONS
HYDROGEOLOGIC SITE CHARACTERIZATION REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Sample Location	Sample Date	Groundwater Elevation (ft NAVD88)
XPW04	03/29/2021	542.33
XPW04	04/27/2021	541.98
XPW04	04/28/2021	542.03
XPW04	05/24/2021	542.03
XPW04	06/15/2021	541.91
XPW04	06/24/2021	541.80
XPW04	07/14/2021	542.27
XSG01	02/15/2021	536.17
XSG01	03/09/2021	536.17
XSG01	03/29/2021	536.17
XSG01	07/14/2021	535.40
SG02	02/15/2021	504.42
SG02	03/09/2021	504.84
SG02	03/29/2021	504.72

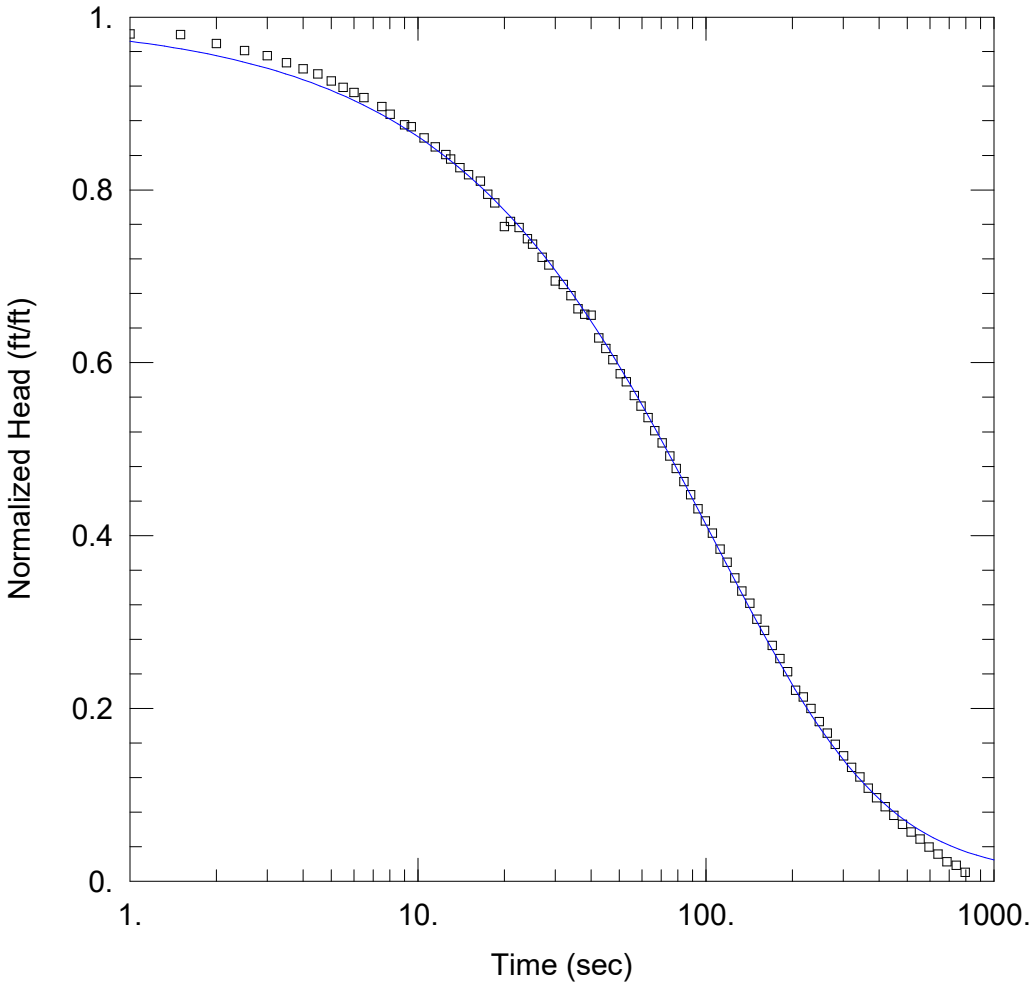
Notes:
ft NAVD88 = feet relative to the North American Vertical Datum 1988, GEOID 12A

generated 10/05/2021, 4:09:16 PM CDT

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX F
HYDRAULIC CONDUCTIVITY TEST DATA

2021 HYDRAULIC CONDUCTIVITY TEST DATA



APW-5S FH1

Data Set: \...\NEW_APW-5S FH1_07202021.aqt
Date: 10/21/21 Time: 14:56:12

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-5S
Test Date: 2/16/2021

AQUIFER DATA

Saturated Thickness: 3.2 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-5S)

Initial Displacement: 0.986 ft
Total Well Penetration Depth: 3.2 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 12.6 ft
Screen Length: 3.2 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.087 cm^2/sec
S = 0.000403

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.087	cm^2/sec
S	0.000403	

K = T/b = 0.000892 cm/sec
Ss = S/b = 0.0001259 1/ft

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
T	0.08962	0.02397	+/- 0.04765	3.739	cm^2/sec

S	0.0003389	0.000496	+/- 0.0009861	0.6832

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

K = T/b = 0.0009188 cm/sec
Ss = S/b = 0.0001059 1/ft

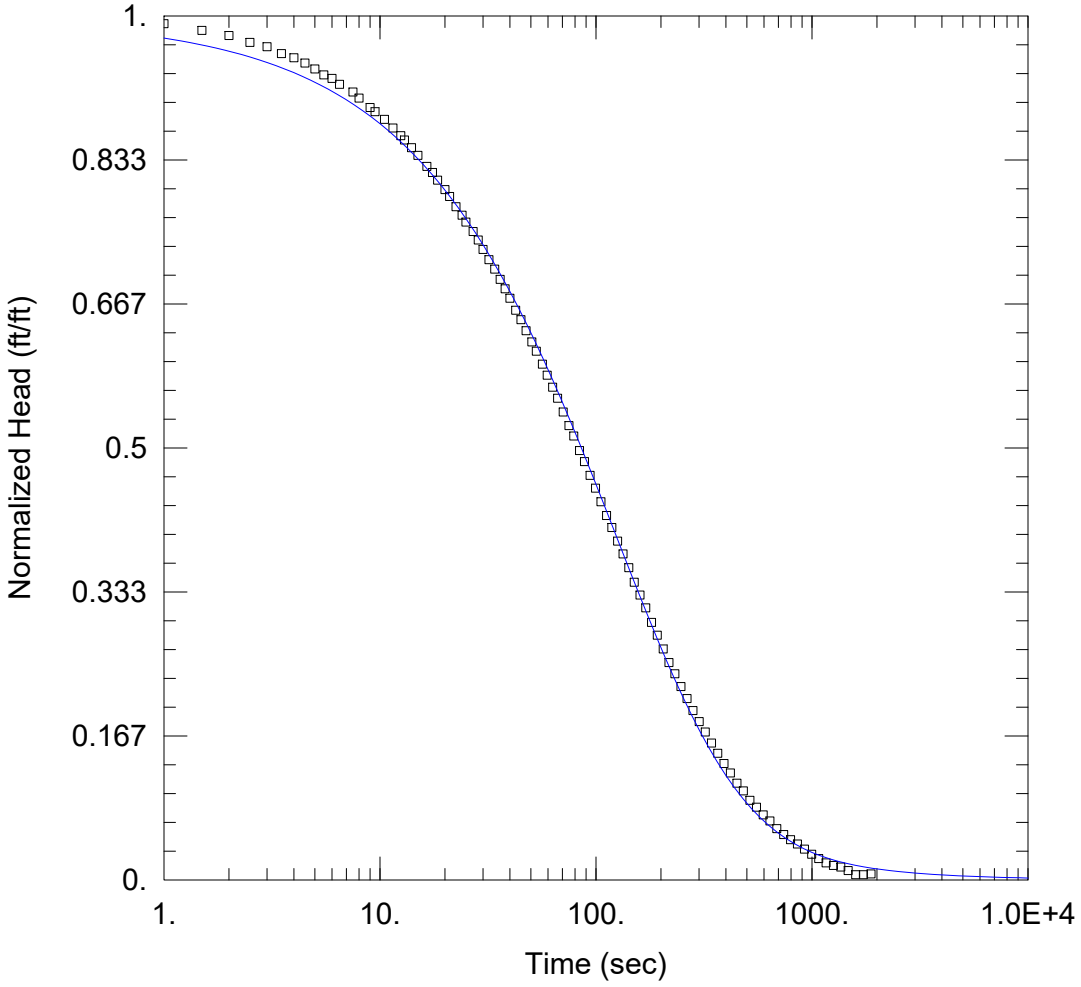
Parameter Correlations

	T	S
T	1.00	-0.97
S	-0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares ..... 0.9777 ft^2
Variance ..... 0.01124 ft^2
Std. Deviation ..... 0.106 ft
Mean ..... 0.01073 ft
No. of Residuals..... 89
No. of Estimates..... 2



APW-5S FH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-5S
Test Date: 2/16/2021

AQUIFER DATA

Saturated Thickness: 3.2 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-5S)

Initial Displacement: 1.01 ft
Total Well Penetration Depth: 3.2 ft
Casing Radius: 0.086 ft
Static Water Column Height: 12.6 ft
Screen Length: 3.2 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.0718 cm^2/sec
S = 0.000454

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
21.	0.799	419.5	0.125
22.5	0.787	449.5	0.113
24.	0.777	481.5	0.104
25.	0.769	516.5	0.093
27.	0.758	554.	0.085
28.5	0.748	595.	0.076
30.	0.737	639.5	0.069
32.	0.725	687.5	0.06
34.	0.714	739.5	0.053
36.	0.702	796.	0.047
38.	0.691	857.5	0.042
40.	0.68	924.	0.036
42.5	0.666	997.	0.03
45.	0.655	1076.	0.025
47.5	0.642	1162.5	0.02
50.5	0.629	1257.	0.017
53.	0.618	1360.	0.015
56.5	0.603	1472.5	0.011
59.5	0.59	1595.5	0.006
63.	0.576	1730.	0.006
66.5	0.563	1877.5	0.007

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.0718	cm^2/sec
S	0.000454	

K = T/b = 0.0007361 cm/sec
Ss = S/b = 0.0001419 1/ft

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
T	0.07177	0.01724	+/- 0.03421	4.163	cm^2/sec
S	0.0004536	0.0005595	+/- 0.00111	0.8107	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

K = T/b = 0.0007359 cm/sec
Ss = S/b = 0.0001418 1/ft

Parameter Correlations

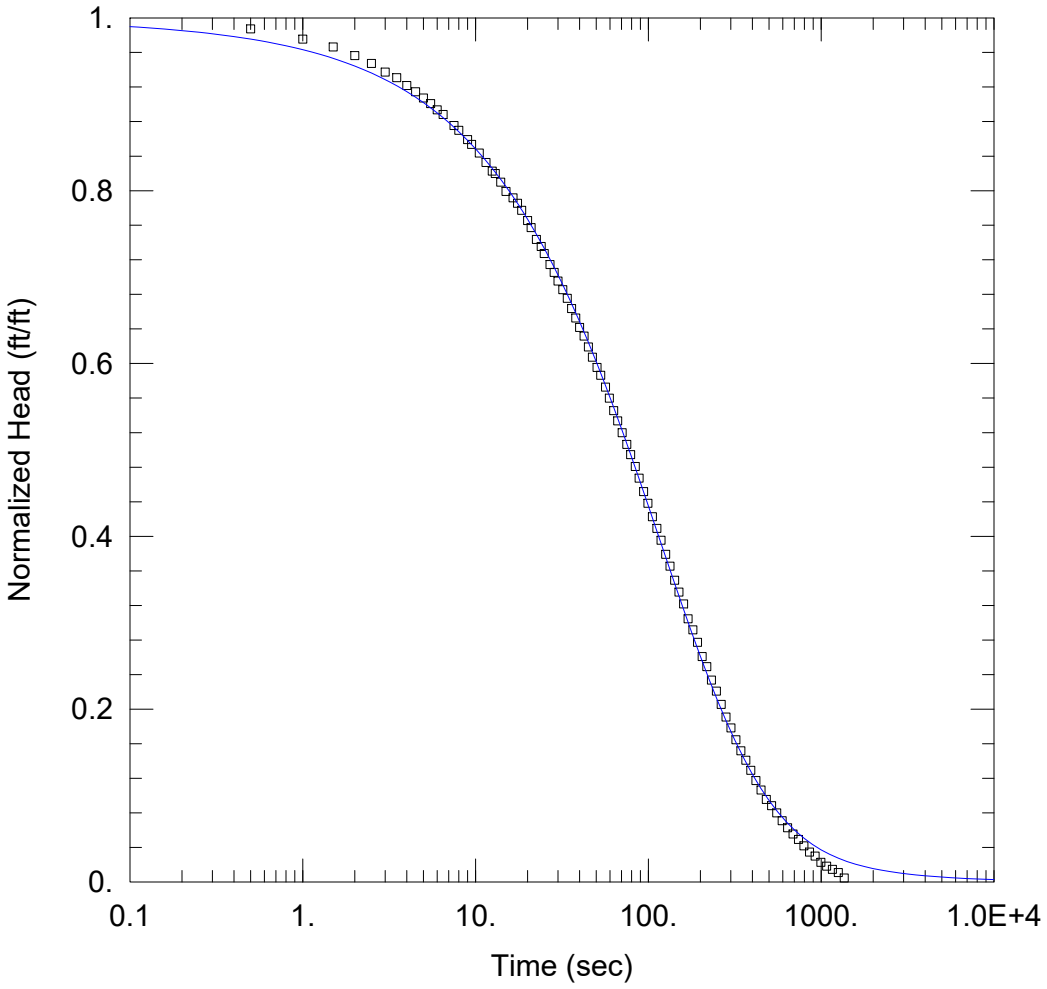
	T	S
T	1.00	-0.97
S	-0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 1.028 ft^2
Variance . . . . . 0.01049 ft^2

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-5S RH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-5S
Test Date: 2/16/2021

AQUIFER DATA

Saturated Thickness: 3.2 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-5S)

Initial Displacement: 1.1 ft
Total Well Penetration Depth: 3.2 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 12.6 ft
Screen Length: 3.2 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.0591 cm^2/sec
S = 0.00178

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
20.	0.842	366.5	0.155
21.	0.833	392.	0.142
22.5	0.818	419.5	0.129
24.	0.809	449.5	0.117
25.	0.8	481.5	0.105
27.	0.786	516.5	0.097
28.5	0.776	554.	0.088
30.	0.765	595.	0.078
32.	0.754	639.5	0.069
34.	0.743	687.5	0.061
36.	0.73	739.5	0.054
38.	0.718	796.	0.046
40.	0.706	857.5	0.038
42.5	0.695	924.	0.033
45.	0.681	997.	0.025
47.5	0.668	1076.	0.02
50.5	0.655	1162.5	0.016
53.	0.645	1257.	0.012
56.5	0.63	1360.	0.005
59.5	0.616		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.0591	cm^2/sec
S	0.00178	

K = T/b = 0.0006059 cm/sec
Ss = S/b = 0.0005562 1/ft

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
T	0.05907	0.01974	+/- 0.03919	2.992	cm^2/sec
S	0.001784	0.002265	+/- 0.004496	0.7877	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

K = T/b = 0.0006056 cm/sec
Ss = S/b = 0.0005575 1/ft

Parameter Correlations

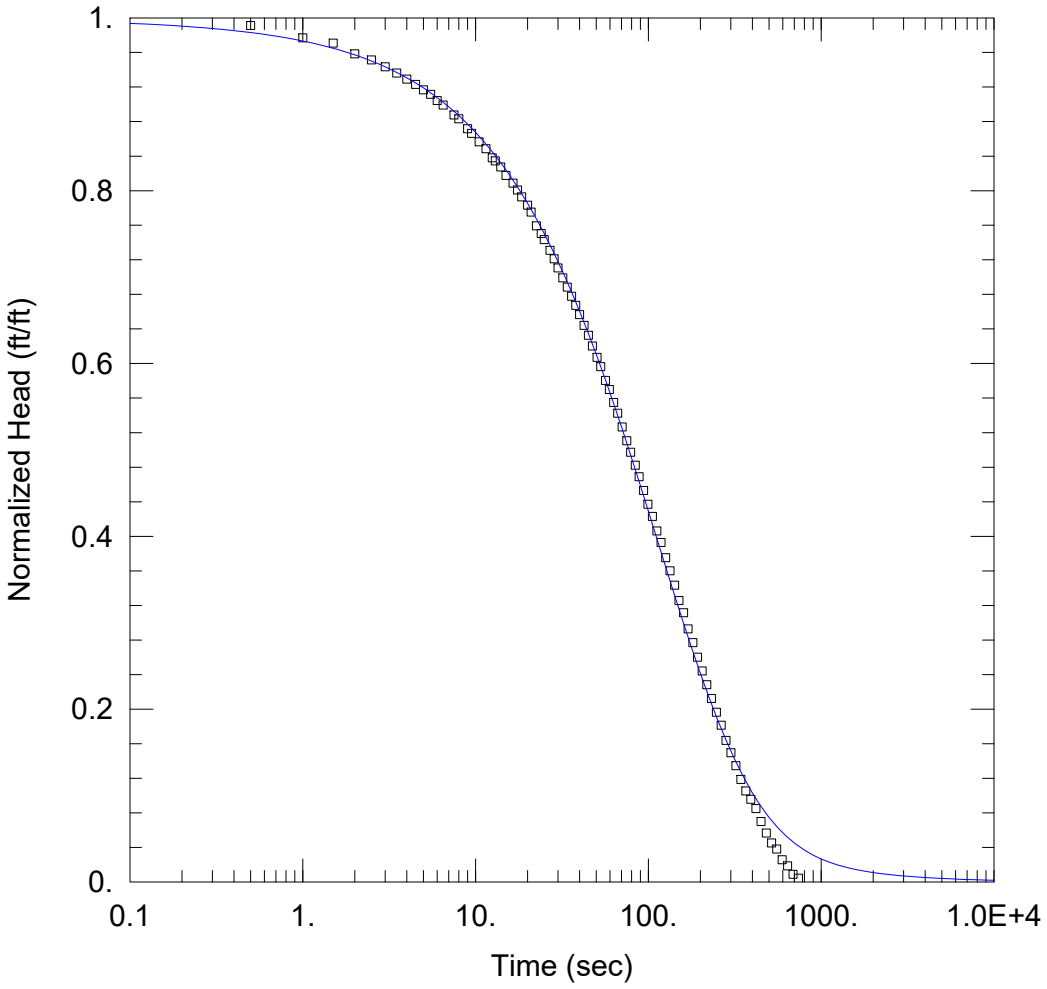
	T	S
T	1.00	-0.96
S	-0.96	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 2.725 ft^2
Variance . . . . . 0.02869 ft^2
Std. Deviation . . . . . 0.1694 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-5S RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-5S
Test Date: 2/16/2021

AQUIFER DATA

Saturated Thickness: 3.2 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-5S)

Initial Displacement: 1.13 ft
Total Well Penetration Depth: 3.2 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 12.6 ft
Screen Length: 3.2 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.0825 cm^2/sec
S = 0.000391

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
20.	0.885	281.5	0.185
21.	0.876	300.5	0.169
22.5	0.858	321.	0.152
24.	0.848	343.	0.134
25.	0.84	366.5	0.119
27.	0.826	392.	0.108
28.5	0.815	419.5	0.096
30.	0.803	449.5	0.079
32.	0.79	481.5	0.064
34.	0.778	516.5	0.051
36.	0.766	554.	0.043
38.	0.754	595.	0.029
40.	0.742	639.5	0.021
42.5	0.728	687.5	0.01
45.	0.715	739.5	0.005
47.5	0.701		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.0825	cm^2/sec
S	0.000391	

K = T/b = 0.0008458 cm/sec
Ss = S/b = 0.0001222 1/ft

AUTOMATIC ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	Std. Error	Approx. C.I.	t-Ratio	
T	0.08245	0.03155	+/- 0.06271	2.614	cm^2/sec
S	0.0003915	0.0007946	+/- 0.00158	0.4927	

C.I. is approximate 95% confidence interval for parameter
t-ratio = estimate/std. error
No estimation window

K = T/b = 0.0008454 cm/sec
Ss = S/b = 0.0001223 1/ft

Parameter Correlations

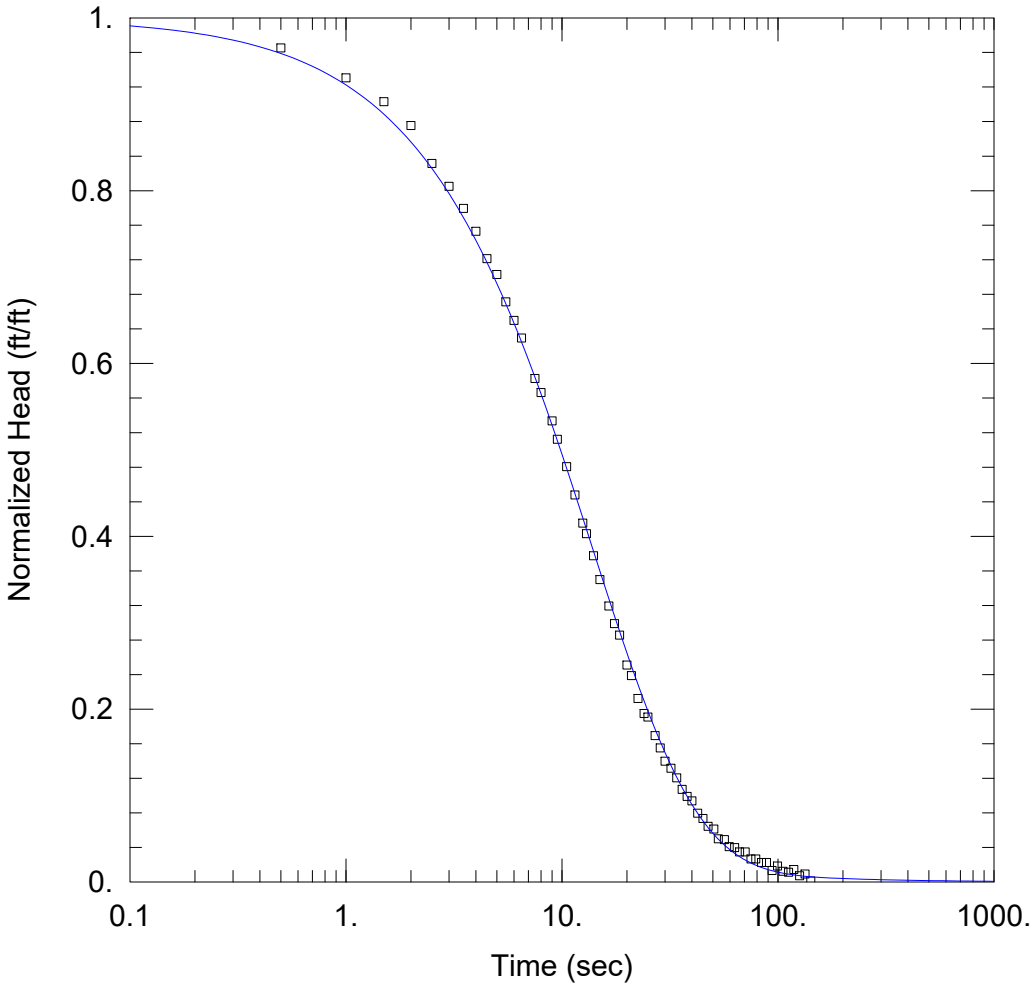
	T	S
T	1.00	-0.97
S	-0.97	1.00

Residual Statistics

for weighted residuals

Sum of Squares . . . . . 2.682 ft^2
Variance . . . . . 0.03083 ft^2
Std. Deviation . . . . . 0.1756 ft
Mean . . . . . -0.02888 ft
No. of Residuals 89
No. of Estimates 2

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-11 FH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-11
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 9.2 ft

WELL DATA (APW-11)

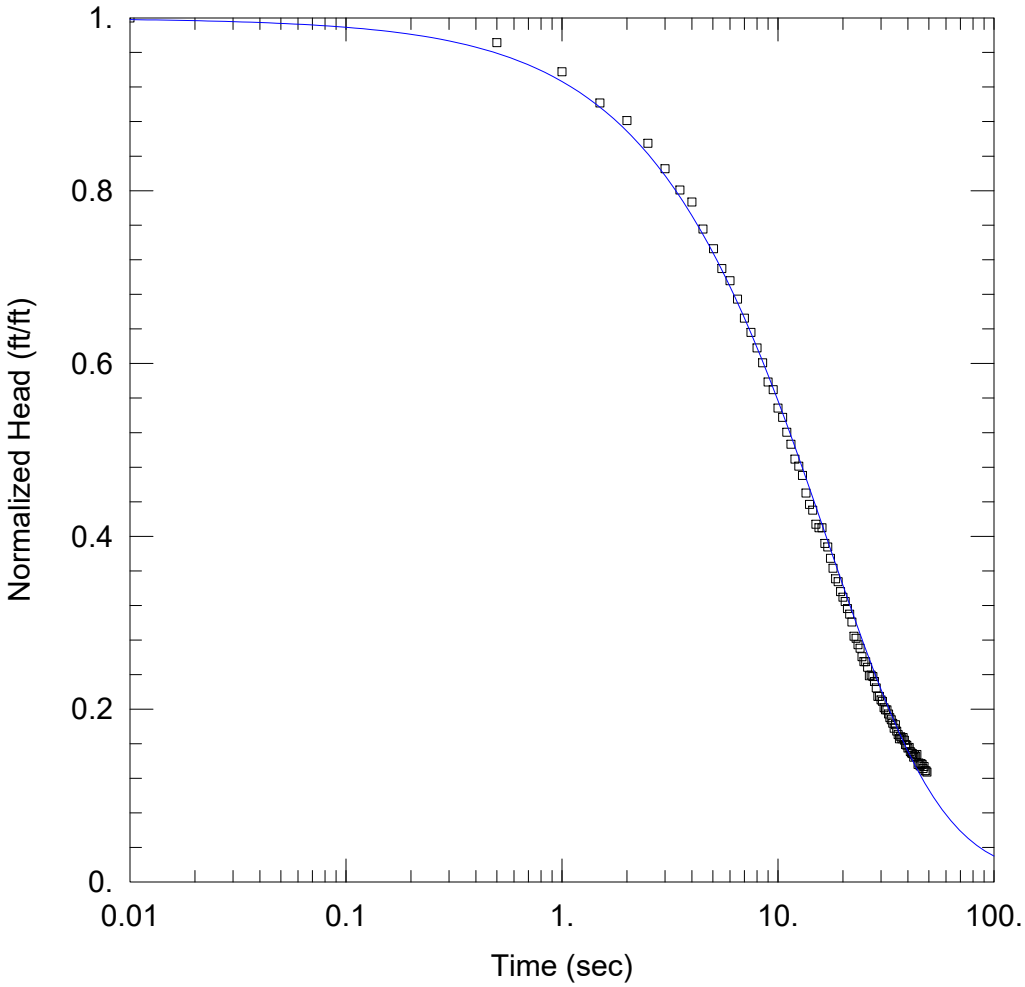
Initial Displacement: 0.98 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.086 ft
Static Water Column Height: 43.37 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.0078 cm/sec
Kz/Kr = 1.
Ss = 1.09E-9 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-11 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-11
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 9.2 ft

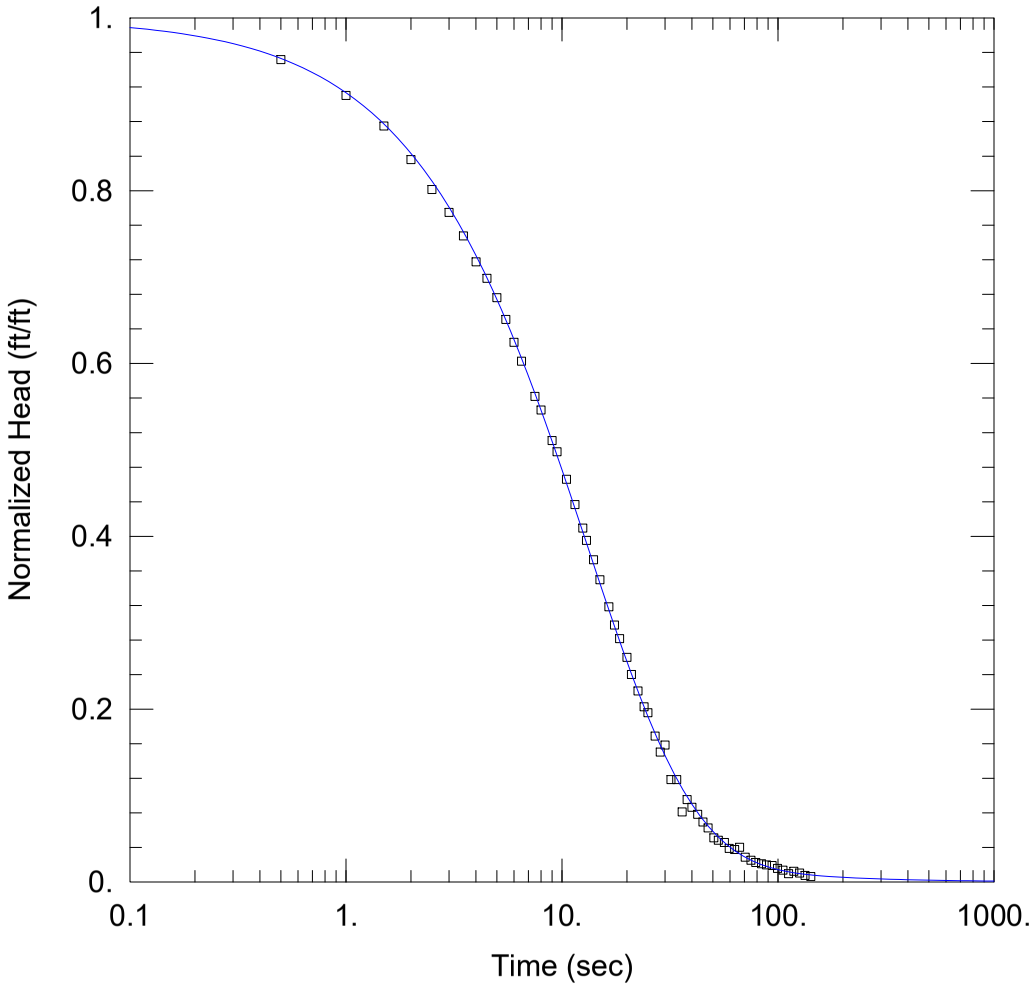
WELL DATA (APW-11)

Initial Displacement: 1.22 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.086 ft
Static Water Column Height: 43.53 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00351 cm/sec
Kz/Kr = 1.
Ss = 6.23E-6 ft^{-1}



APW-11 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-11
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 9.2 ft

WELL DATA (APW-11)

Initial Displacement: 1.47 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.086 ft

Static Water Column Height: 43.48 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

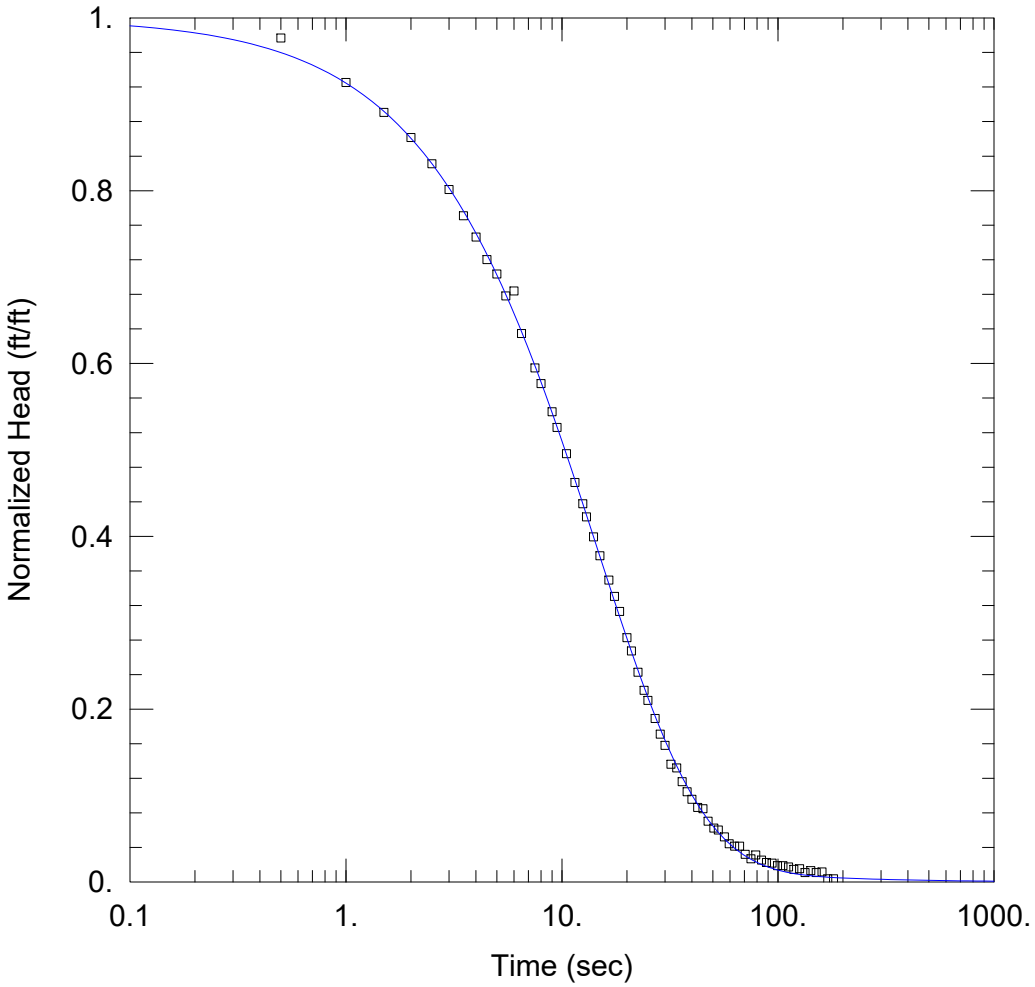
Aquifer Model: Confined

Kr = 0.00588 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 3.02E-7 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-11 RH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-11
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 9.2 ft

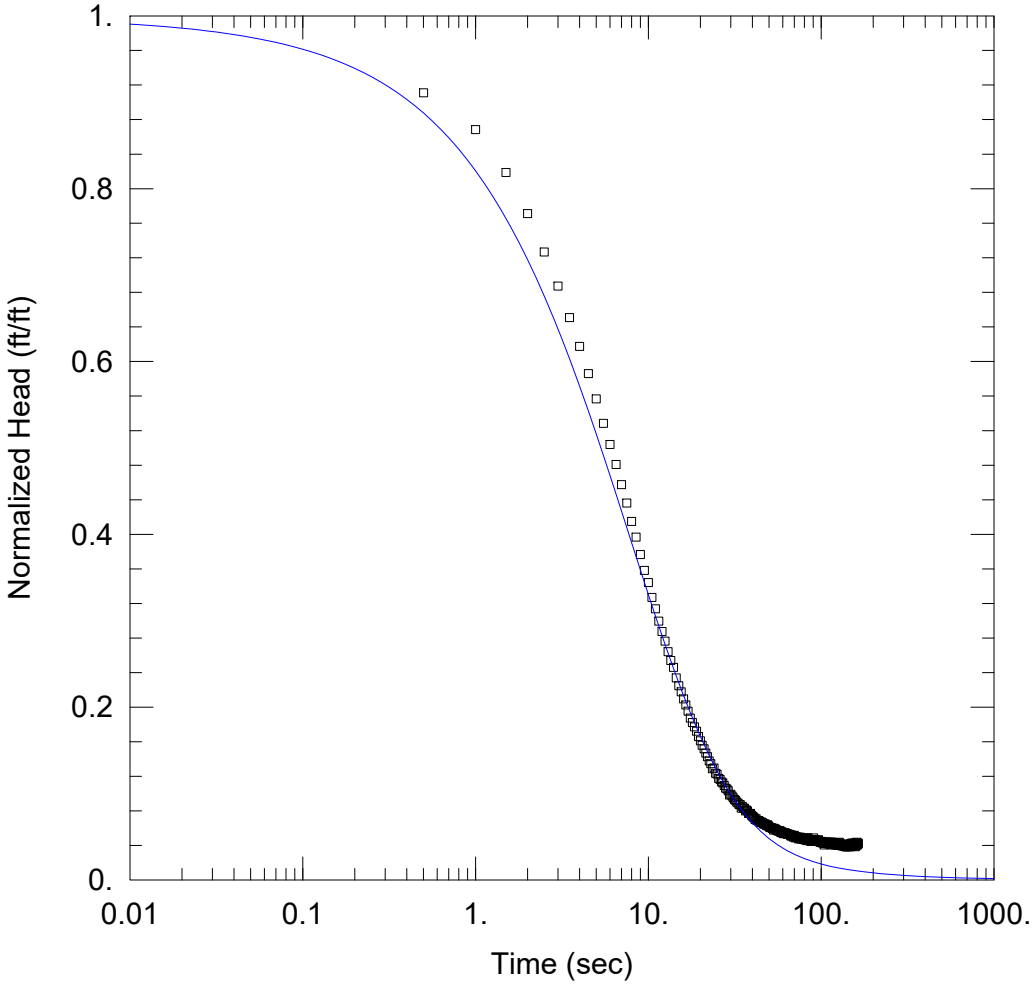
WELL DATA (APW-11 RH02)

Initial Displacement: 1.38 ft
Total Well Penetration Depth: 7. ft
Casing Radius: 0.086 ft
Static Water Column Height: 43.53 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00676 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 6.55E-9 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-12 FH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-12
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 3.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-12)

Initial Displacement: 0.988 ft
Total Well Penetration Depth: 3.5 ft
Casing Radius: 0.086 ft
Static Water Column Height: 19.03 ft
Screen Length: 3.5 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 1.05 cm^2/sec
S = 0.000733

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
75.5	0.049	160.5	0.041
76.	0.047	161.	0.04
76.5	0.047	161.5	0.043
77.	0.047	162.	0.04
77.5	0.048	162.5	0.041
78.	0.047	163.	0.041
78.5	0.047	163.5	0.041
79.	0.047	164.	0.042
79.5	0.046		

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

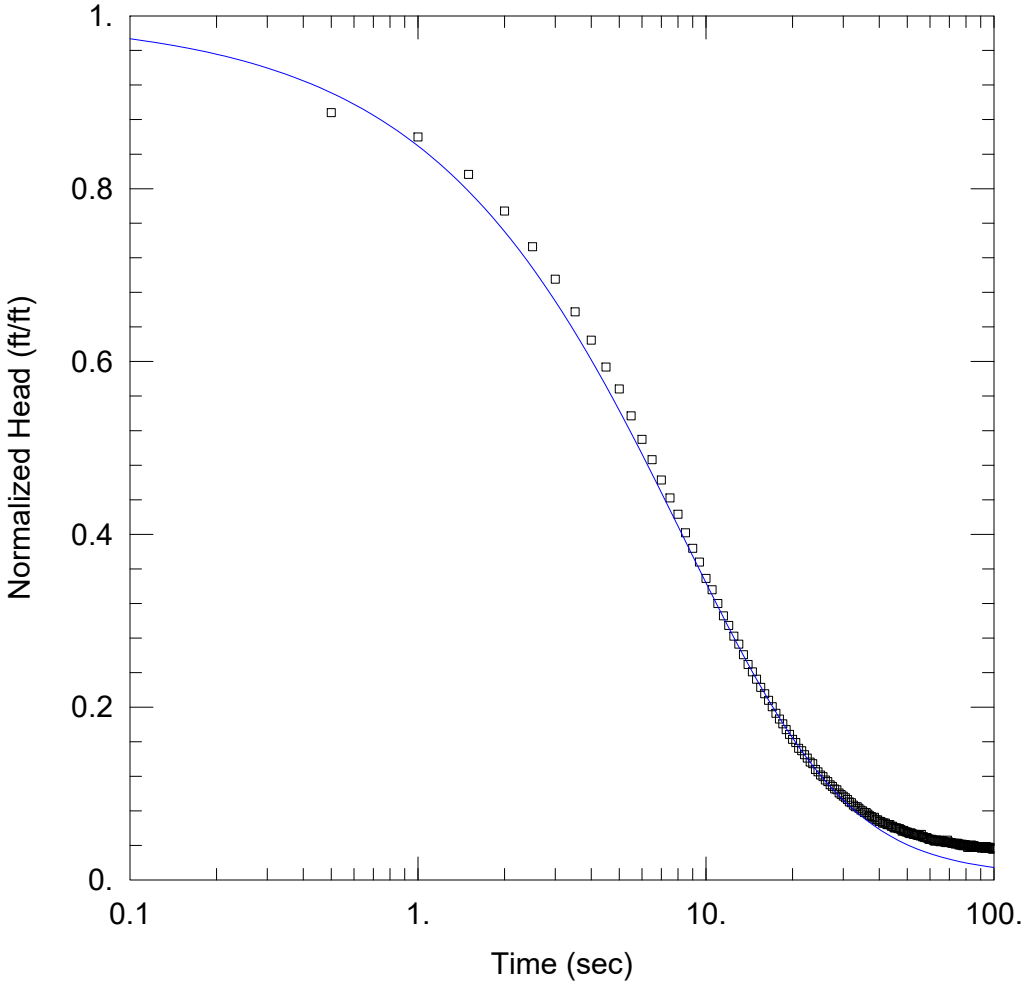
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	1.05	cm^2/sec
S	0.000733	

K = T/b = 0.009843 cm/sec
Ss = S/b = 0.0002094 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-12 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-12
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 3.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-12)

Initial Displacement: 1.063 ft
Total Well Penetration Depth: 3.5 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 19.06 ft
Screen Length: 3.5 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 1.35 cm^2/sec
S = 0.000108

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
40.	0.072	94.5	0.04
40.5	0.072	95.	0.04
41.	0.07	95.5	0.04
41.5	0.07	96.	0.04
42.	0.07	96.5	0.039
42.5	0.068	97.	0.039
43.	0.068	97.5	0.039
43.5	0.068	98.	0.04
44.	0.066	98.5	0.038
44.5	0.066	99.	0.038
45.	0.064	99.5	0.038
45.5	0.064	100.	0.039
46.	0.064	100.5	0.036
46.5	0.063	101.	0.038

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

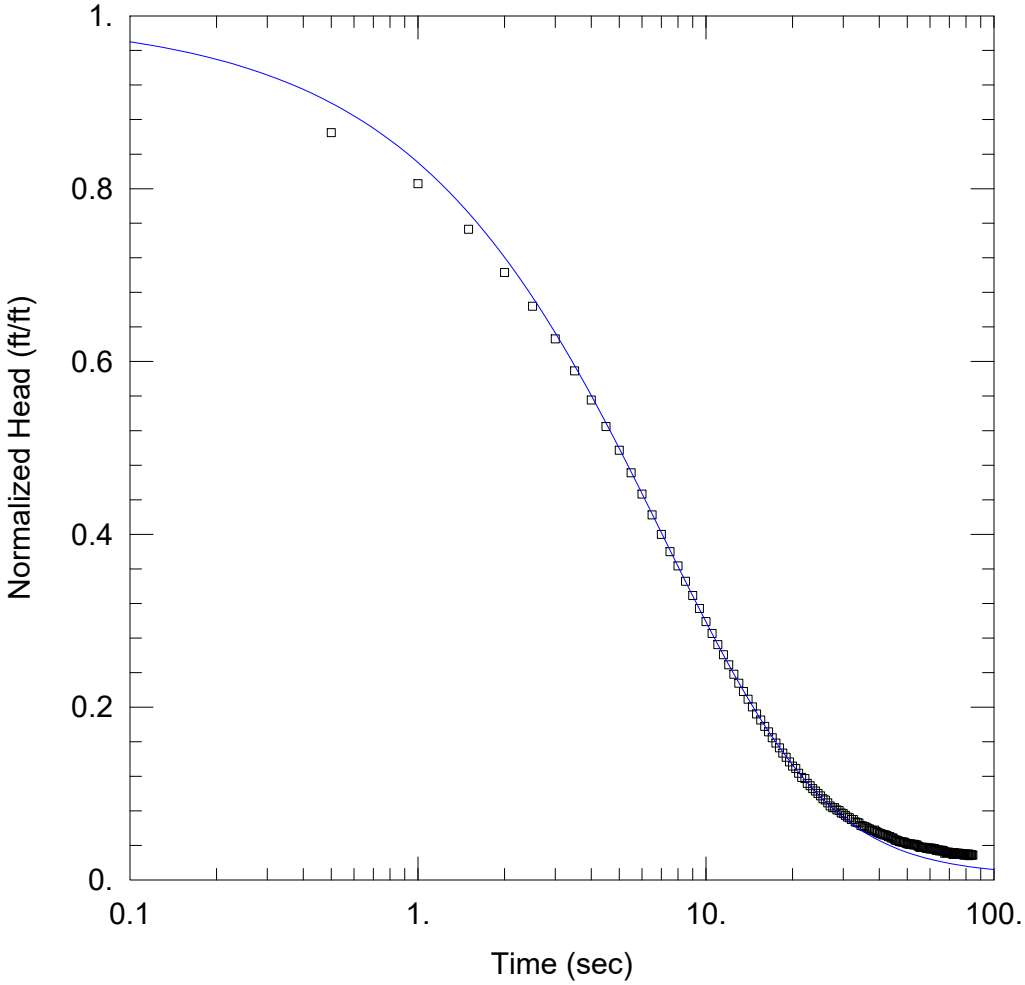
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	1.35	cm^2/sec
S	0.000108	

K = T/b = 0.01265 cm/sec
Ss = S/b = 3.086E-5 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-12 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-12
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 3.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-12)

Initial Displacement: -1.458 ft
Total Well Penetration Depth: 3.5 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 19.06 ft
Screen Length: 3.5 ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
T = 1.57 cm^2/sec
Solution Method: Cooper-Bredehoeft-Papadopulos
S = 0.000114

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

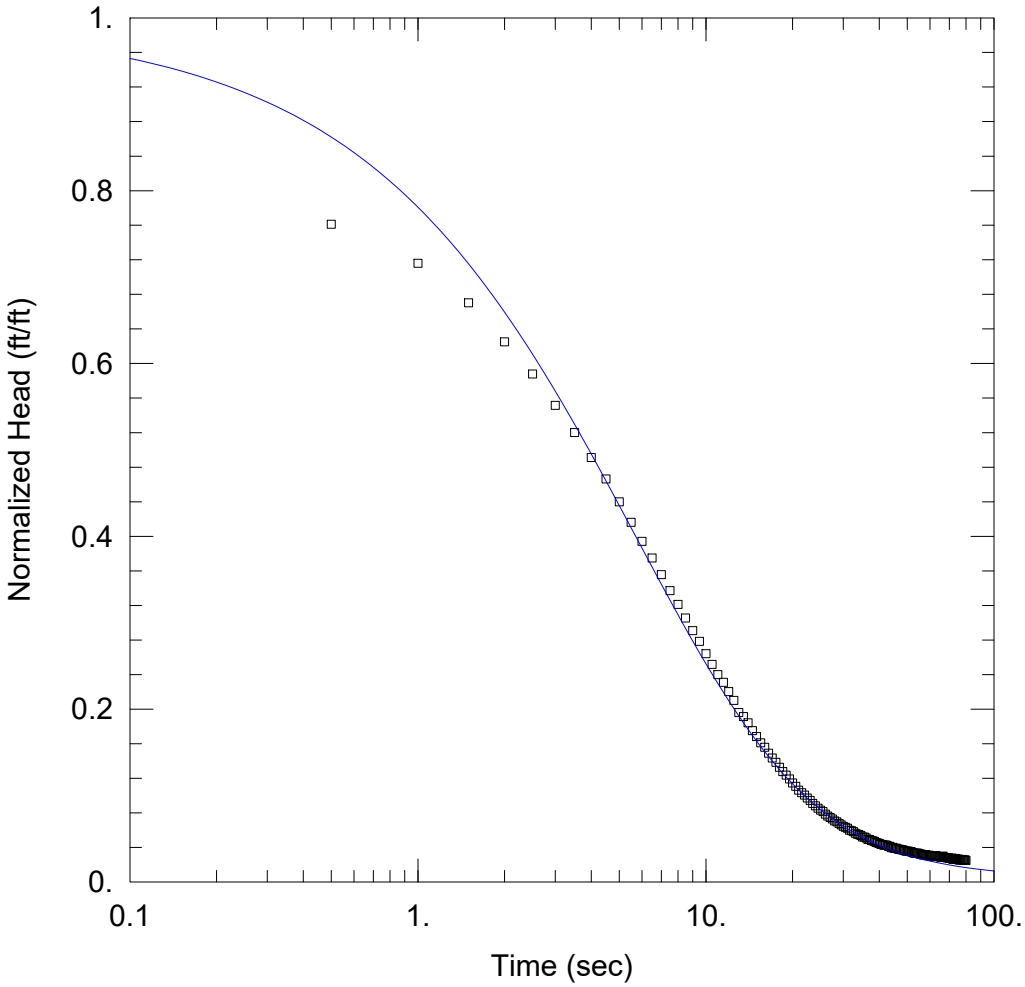
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	1.57	cm^2/sec
S	0.000114	

K = T/b = 0.01472 cm/sec
Ss = S/b = 3.257E-5 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-12 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-12
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 3.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-12)

Initial Displacement: -1.771 ft
Total Well Penetration Depth: 3.5 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 19.06 ft
Screen Length: 3.5 ft
Well Radius: 0.25 ft

SOLUTION

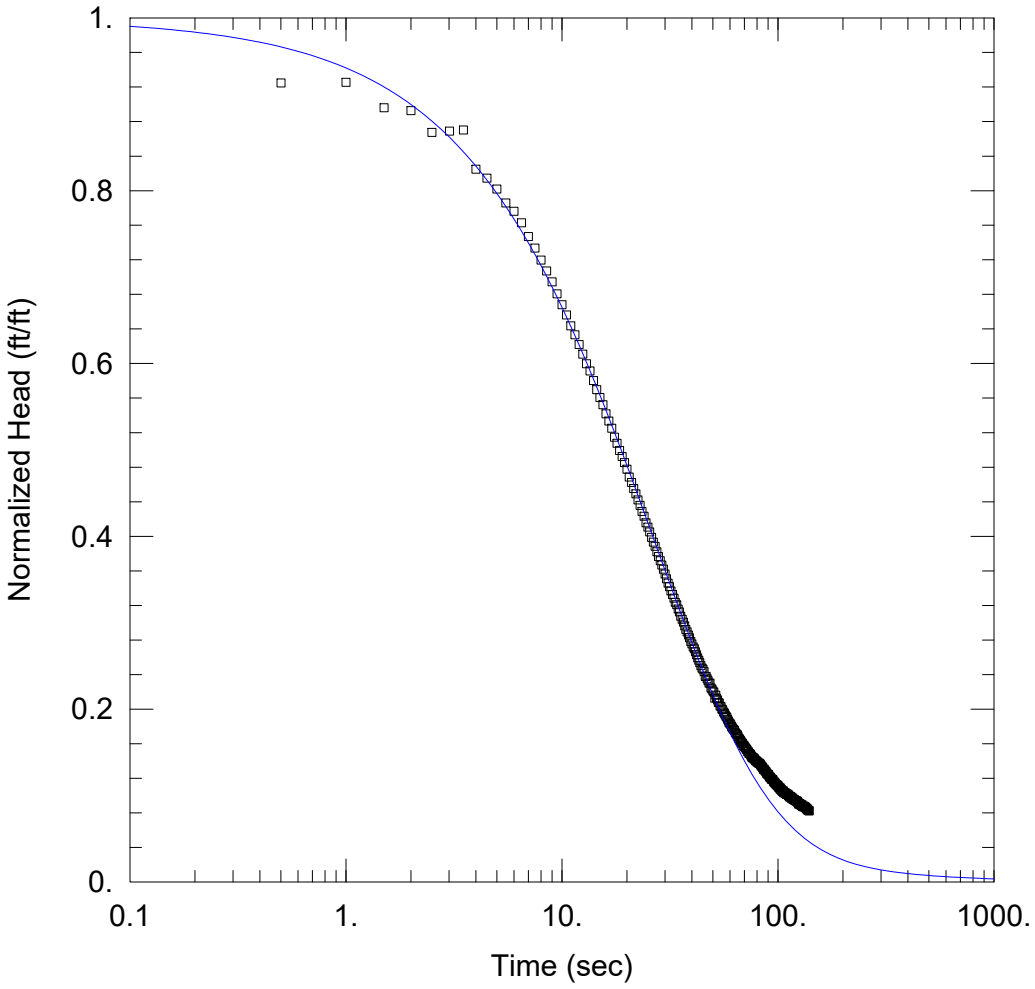
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 1.433 cm^2/sec
S = 0.000733

Estimated Parameters

Parameter	Estimate	
T	1.433	cm^2/sec
S	0.000733	

K = T/b = 0.01343 cm/sec
Ss = S/b = 0.0002094 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-13 FH-01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-13
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 7.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-13)

Initial Displacement: 1.434 ft
Total Well Penetration Depth: 5.9 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 34.23 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

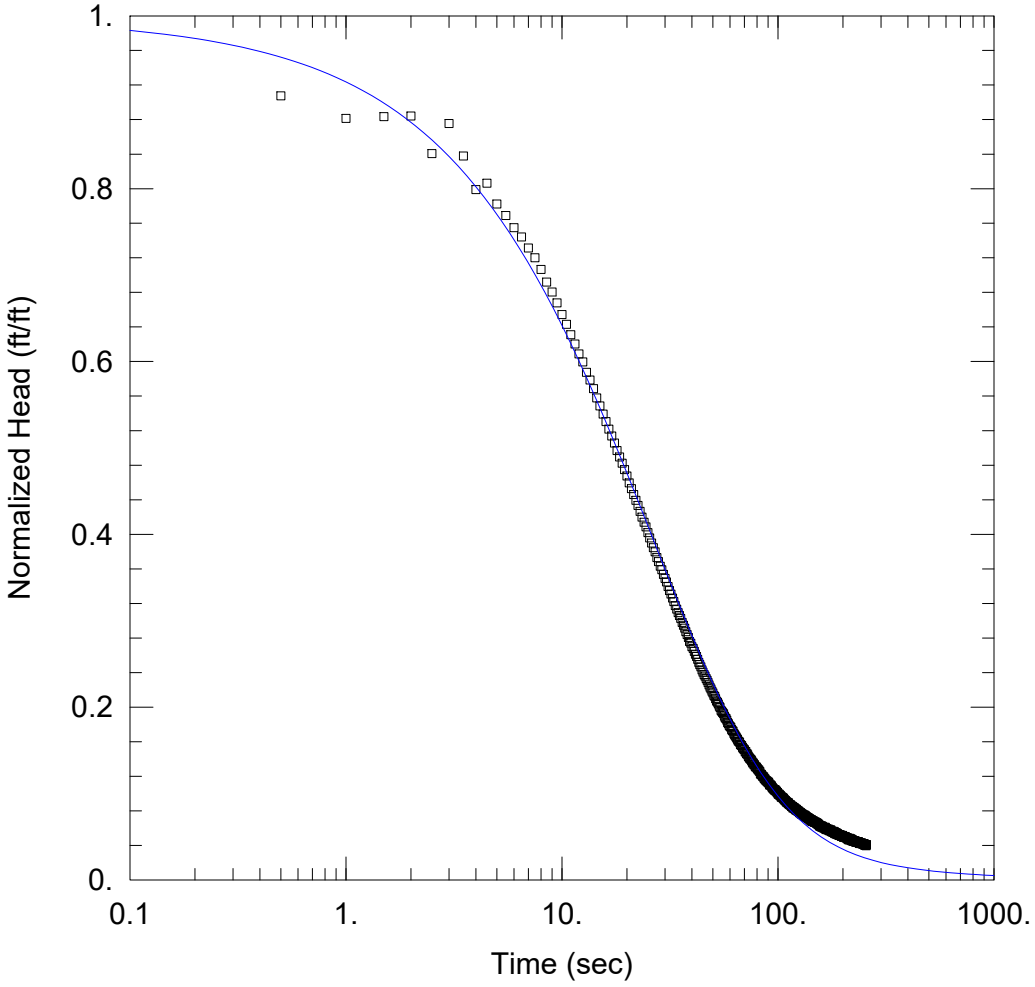
SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.475 cm^2/sec
S = 4.47E-5

S 4.47E-5

K = T/b = 0.002106 cm/sec
Ss = S/b = 6.041E-6 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-13 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-13
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 7.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-13)

Initial Displacement: 1.493 ft
Total Well Penetration Depth: 5.9 ft
Casing Radius: 0.086 ft
Static Water Column Height: 34.26 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
$T = 0.329\ cm^2/sec$
Solution Method: Cooper-Bredehoeft-Papadopulos
S = 0.000562

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
106.	0.141	238.5	0.064
106.5	0.14	239.	0.063
107.	0.139	239.5	0.064
107.5	0.138	240.	0.063
108.	0.137	240.5	0.064
108.5	0.137	241.	0.063
109.	0.136	241.5	0.063
109.5	0.135	242.	0.063
110.	0.134	242.5	0.064
110.5	0.134	243.	0.063
111.	0.134	243.5	0.063
111.5	0.132	244.	0.064
112.	0.133	244.5	0.063
112.5	0.131	245.	0.063
113.	0.13	245.5	0.063
113.5	0.13	246.	0.062
114.	0.13	246.5	0.063
114.5	0.129	247.	0.063
115.	0.129	247.5	0.063
115.5	0.127	248.	0.062
116.	0.127	248.5	0.062
116.5	0.126	249.	0.063
117.	0.127	249.5	0.062
117.5	0.124	250.	0.062
118.	0.125	250.5	0.061
118.5	0.125	251.	0.062
119.	0.125	251.5	0.062
119.5	0.123	252.	0.06
120.	0.123	252.5	0.061
120.5	0.123	253.	0.061
121.	0.121	253.5	0.06
121.5	0.121	254.	0.061
122.	0.122	254.5	0.061
122.5	0.12	255.	0.061
123.	0.12	255.5	0.06
123.5	0.119	256.	0.059
124.	0.119	256.5	0.061
124.5	0.119	257.	0.061

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

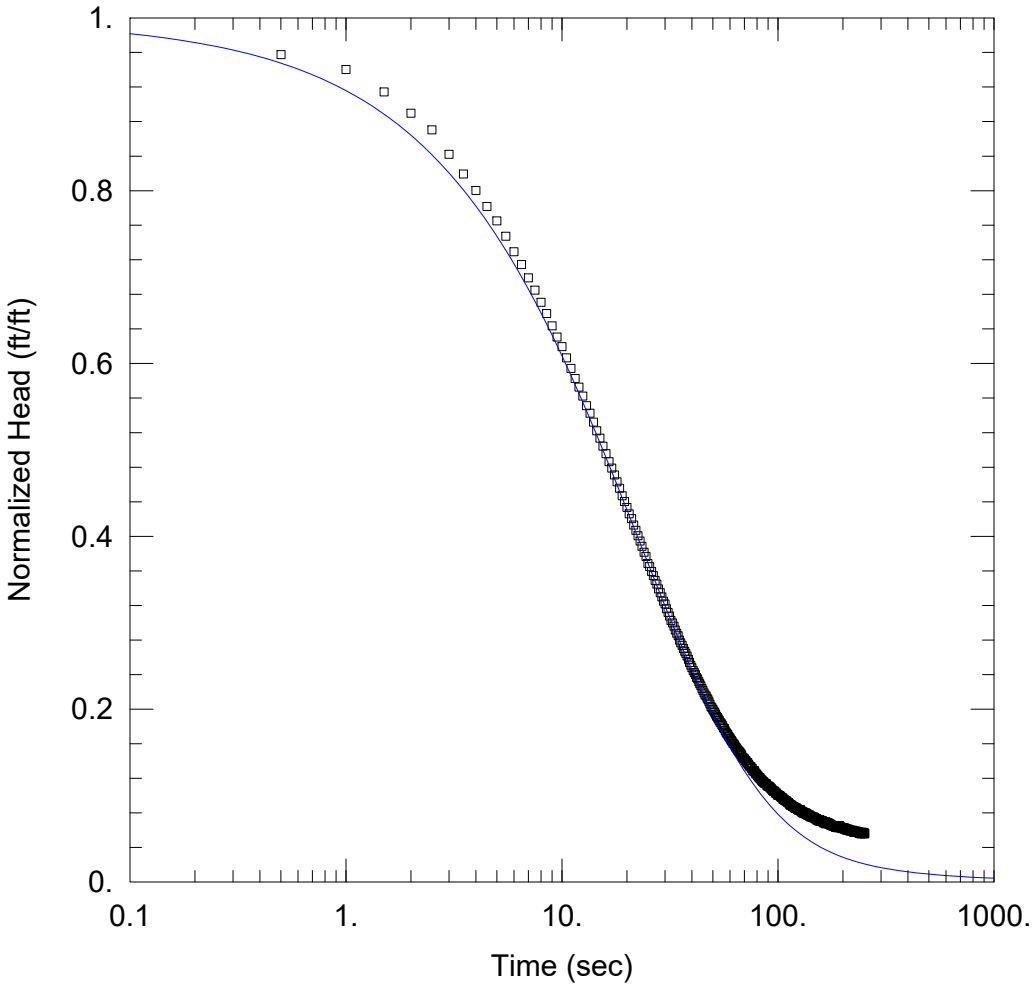
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.329	cm^2/sec
S	0.000562	

K = T/b = 0.001459 cm/sec
Ss = S/b = 7.595E-5 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-13 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-13
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 7.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-13)

Initial Displacement: -1.622 ft
Total Well Penetration Depth: 5.9 ft
Casing Radius: 0.086 ft
Static Water Column Height: 34.22 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos
T = 0.384 cm^2/sec
S = 0.000541

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
106.5	-0.155	236.5	-0.093
107.	-0.155	237.	-0.094
107.5	-0.153	237.5	-0.093
108.	-0.153	238.	-0.092
108.5	-0.152	238.5	-0.091
109.	-0.153	239.	-0.092
109.5	-0.152	239.5	-0.092
110.	-0.151	240.	-0.091
110.5	-0.15	240.5	-0.092
111.	-0.149	241.	-0.092
111.5	-0.149	241.5	-0.093
112.	-0.149	242.	-0.092
112.5	-0.147	242.5	-0.09
113.	-0.146	243.	-0.092
113.5	-0.146	243.5	-0.092
114.	-0.144	244.	-0.091
114.5	-0.145	244.5	-0.093
115.	-0.145	245.	-0.091
115.5	-0.144	245.5	-0.093
116.	-0.143	246.	-0.093
116.5	-0.142	246.5	-0.092
117.	-0.142	247.	-0.092
117.5	-0.142	247.5	-0.093
118.	-0.141	248.	-0.092
118.5	-0.141	248.5	-0.092
119.	-0.14	249.	-0.092
119.5	-0.14	249.5	-0.093
120.	-0.138	250.	-0.092
120.5	-0.139	250.5	-0.092
121.	-0.139	251.	-0.091
121.5	-0.139	251.5	-0.09
122.	-0.138	252.	-0.091
122.5	-0.138	252.5	-0.091

SOLUTION

Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

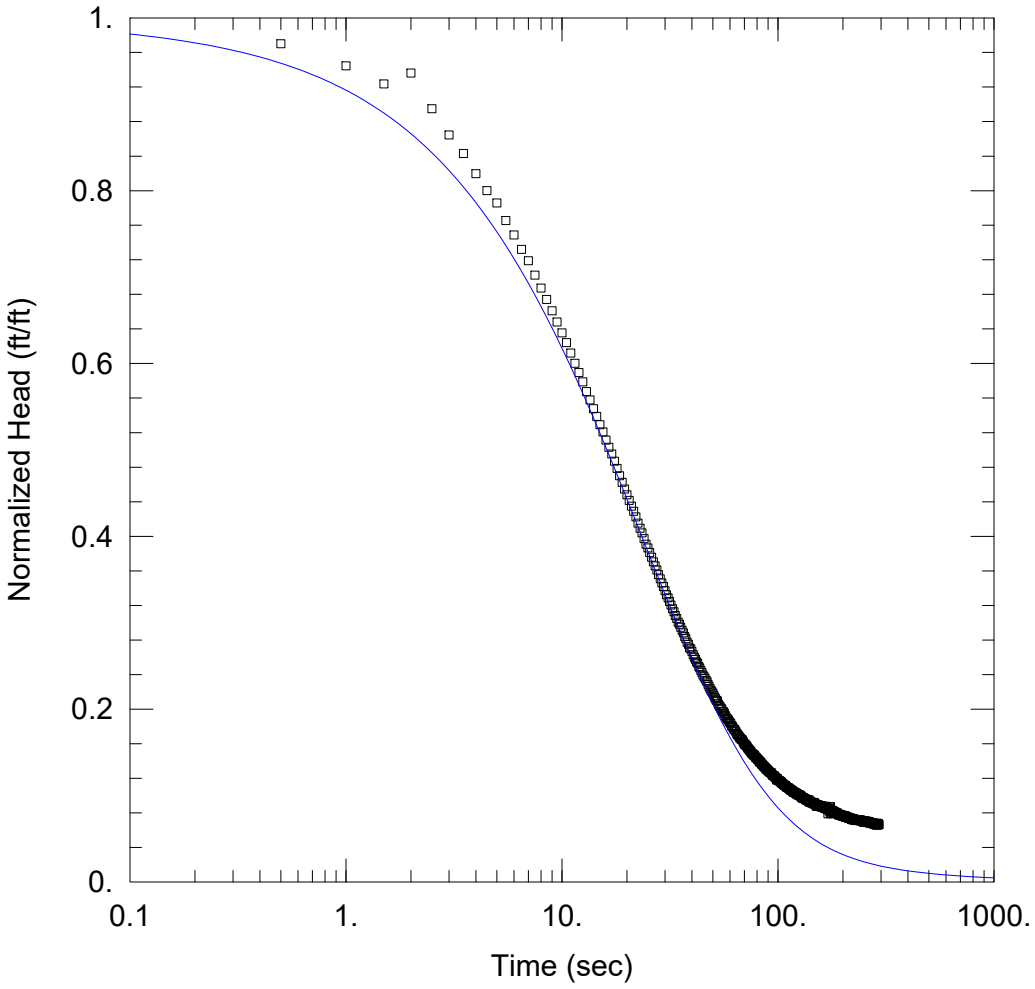
VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.384	cm^2/sec
S	0.000541	

K = T/b = 0.001702 cm/sec
Ss = S/b = 7.311E-5 1/ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-13 RH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-13
Test Date: 3/12/2021

AQUIFER DATA

Saturated Thickness: 7.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-13)

Initial Displacement: -1.676 ft
Total Well Penetration Depth: 5.9 ft
Casing Radius: 0.086 ft
Static Water Column Height: 34.26 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
T = 0.353 cm^2/sec
Solution Method: Cooper-Bredehoeft-Papadopulos
S = 0.000661

Time (sec)	Displacement (ft)	Time (sec)	Displacement (ft)
140.	-0.157	290.5	-0.111
140.5	-0.156	291.	-0.112
141.	-0.155	291.5	-0.113
141.5	-0.155	292.	-0.112
142.	-0.155	292.5	-0.111
142.5	-0.155	293.	-0.112
143.	-0.154	293.5	-0.111
143.5	-0.153		

SOLUTION

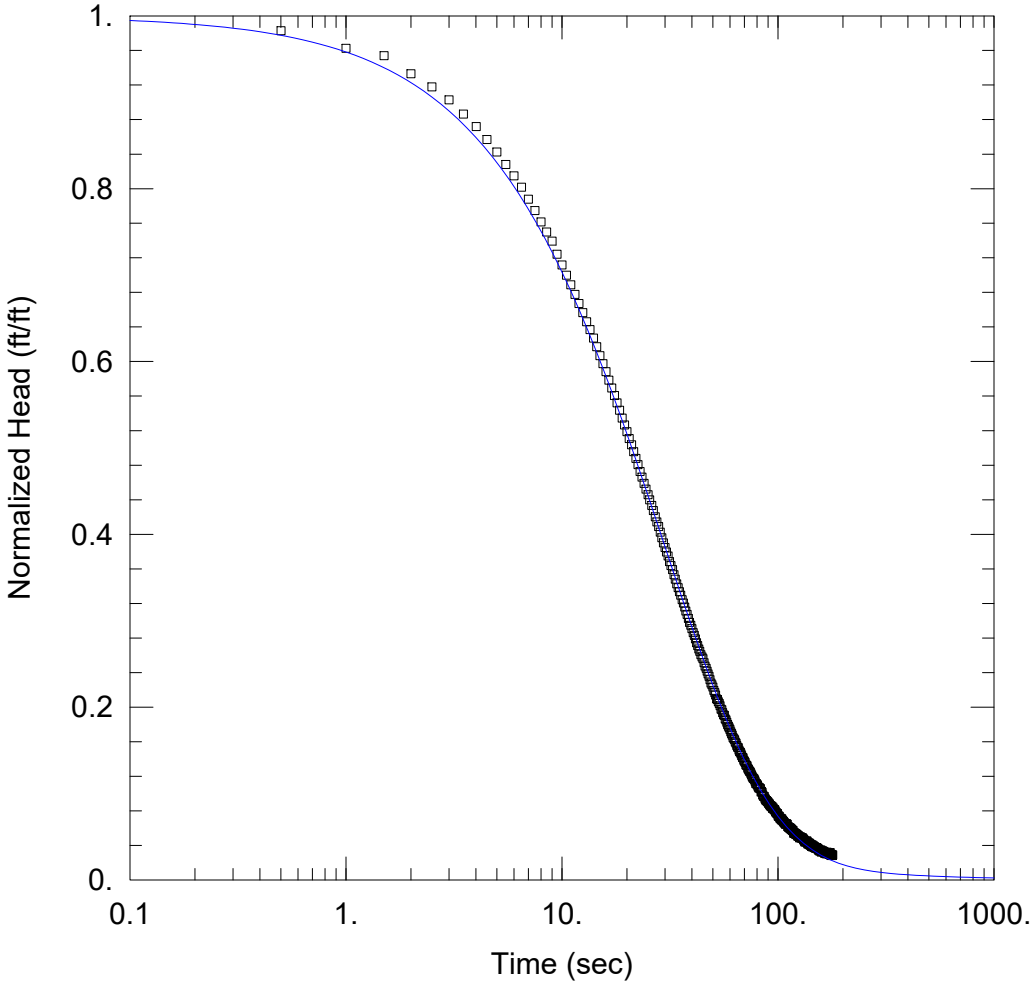
Slug Test
Aquifer Model: Confined
Solution Method: Cooper-Bredehoeft-Papadopulos

VISUAL ESTIMATION RESULTS

Estimated Parameters

Parameter	Estimate	
T	0.353	cm^2/sec
S	0.000661	

K = T/b = 0.001565 cm/sec
Ss = S/b = 8.932E-5 1/ft



APW-14 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

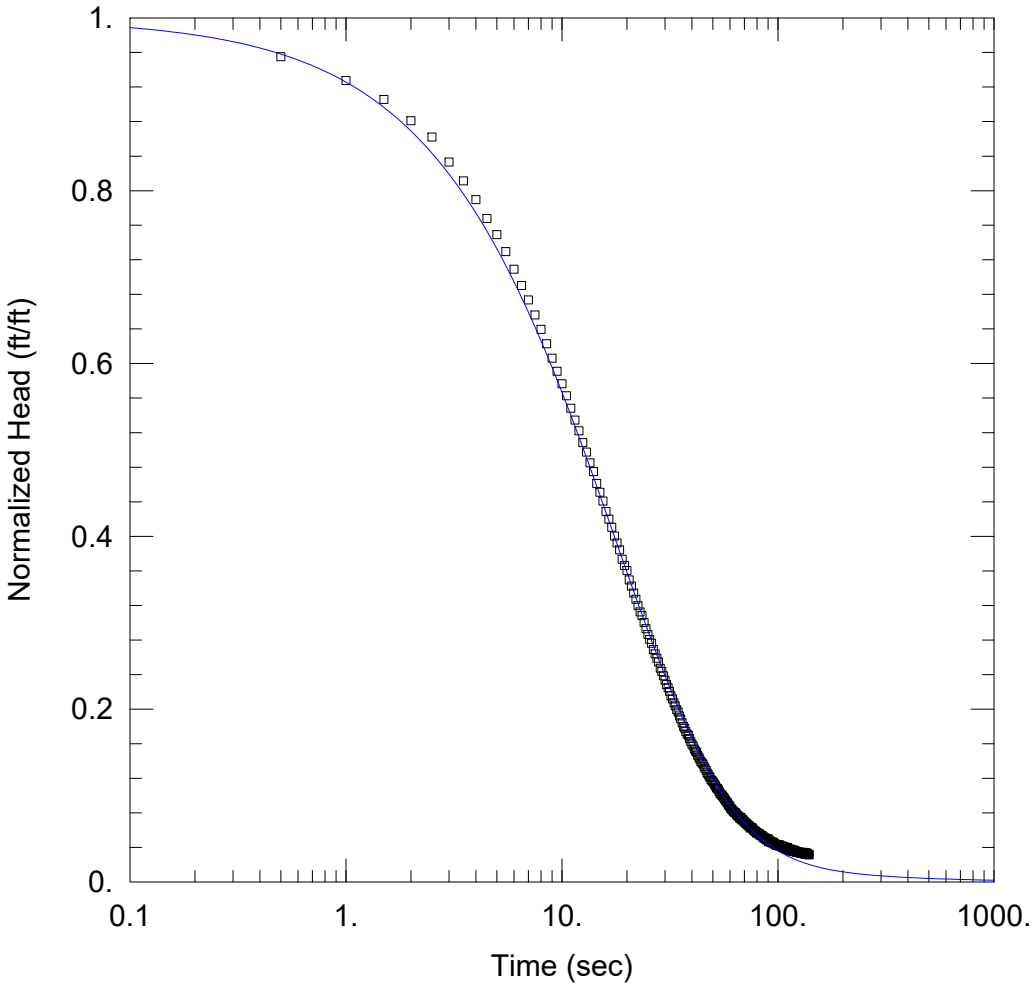
Saturated Thickness: 6.3 ft

WELL DATA (APW-14)

Initial Displacement: 1.523 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.086 ft
Static Water Column Height: 36.72 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00388 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 4.23E-8 ft^{-1}



APW-14 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 6.3 ft

WELL DATA (APW-14)

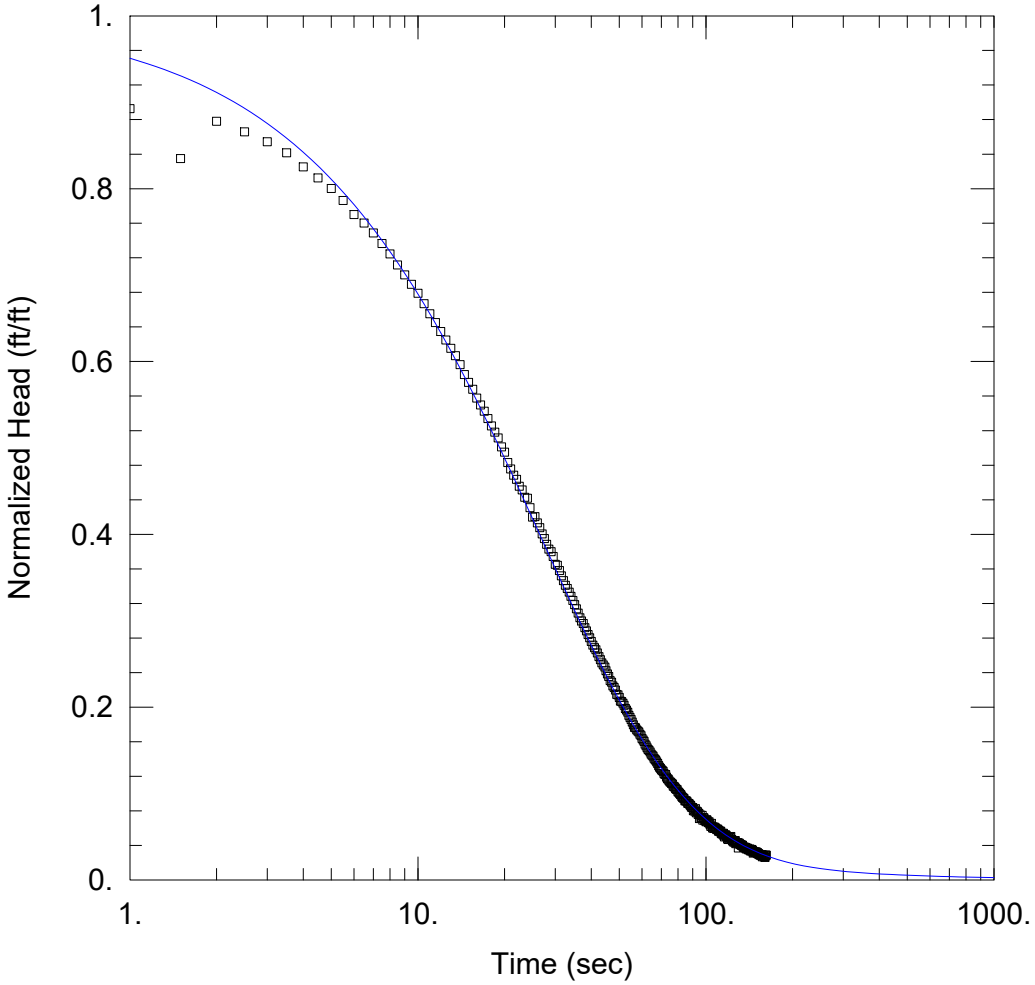
Initial Displacement: 1.379 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.086 ft
Static Water Column Height: 36.73 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.00433 cm/sec
Kz/Kr = 1.
Ss = 4.29E-6 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-14 FH3

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

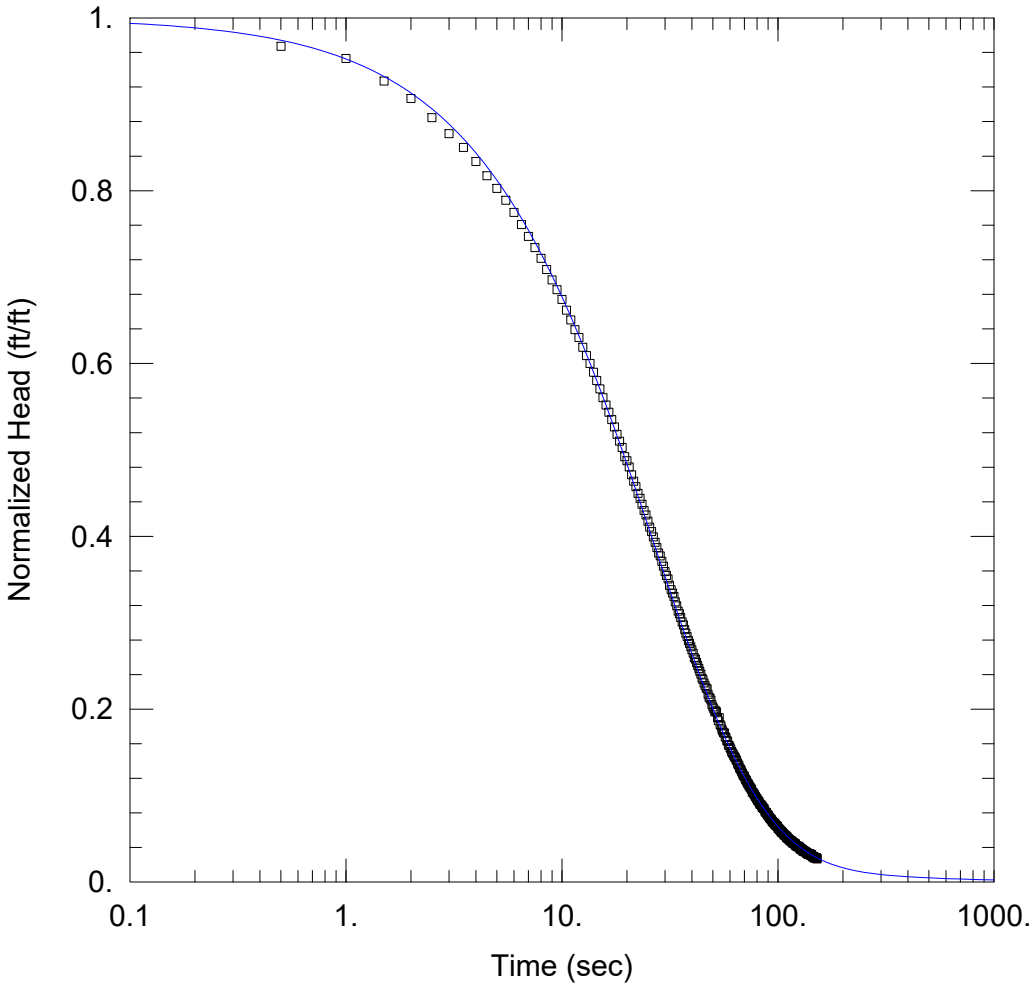
Saturated Thickness: 6.3 ft

WELL DATA (APW-14)

Initial Displacement: 1.648 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.086 ft
Static Water Column Height: 36.72 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00332 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 8.98E-7 ft^{-1}



APW-14 RH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 6.3 ft

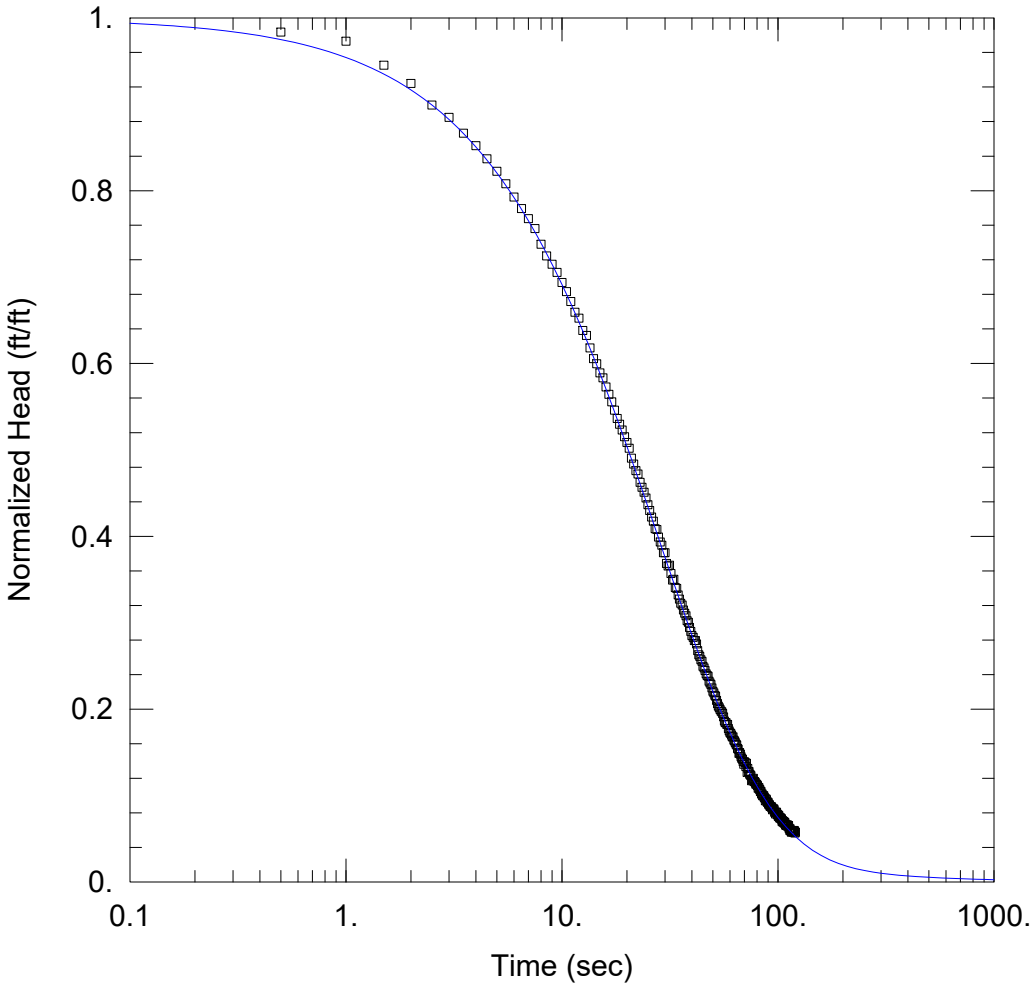
WELL DATA (APW-14)

Initial Displacement: -1.768 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.086 ft
Static Water Column Height: 36.76 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00381 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 2.12E-7 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-14 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

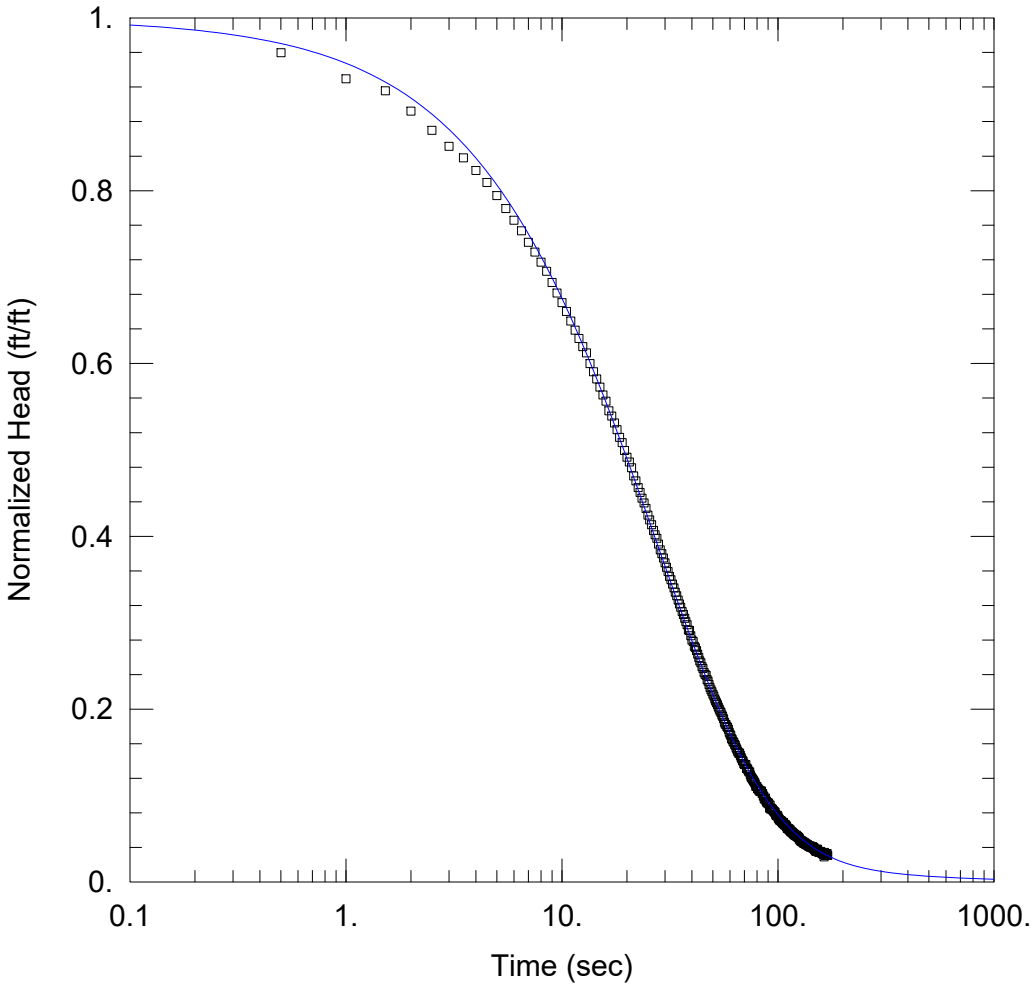
Saturated Thickness: 6.3 ft

WELL DATA (APW-14)

Initial Displacement: -1.042 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.086 ft
Static Water Column Height: 36.72 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00336 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 4.36E-7 ft^{-1}



APW-14 RH3

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-14
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 6.3 ft

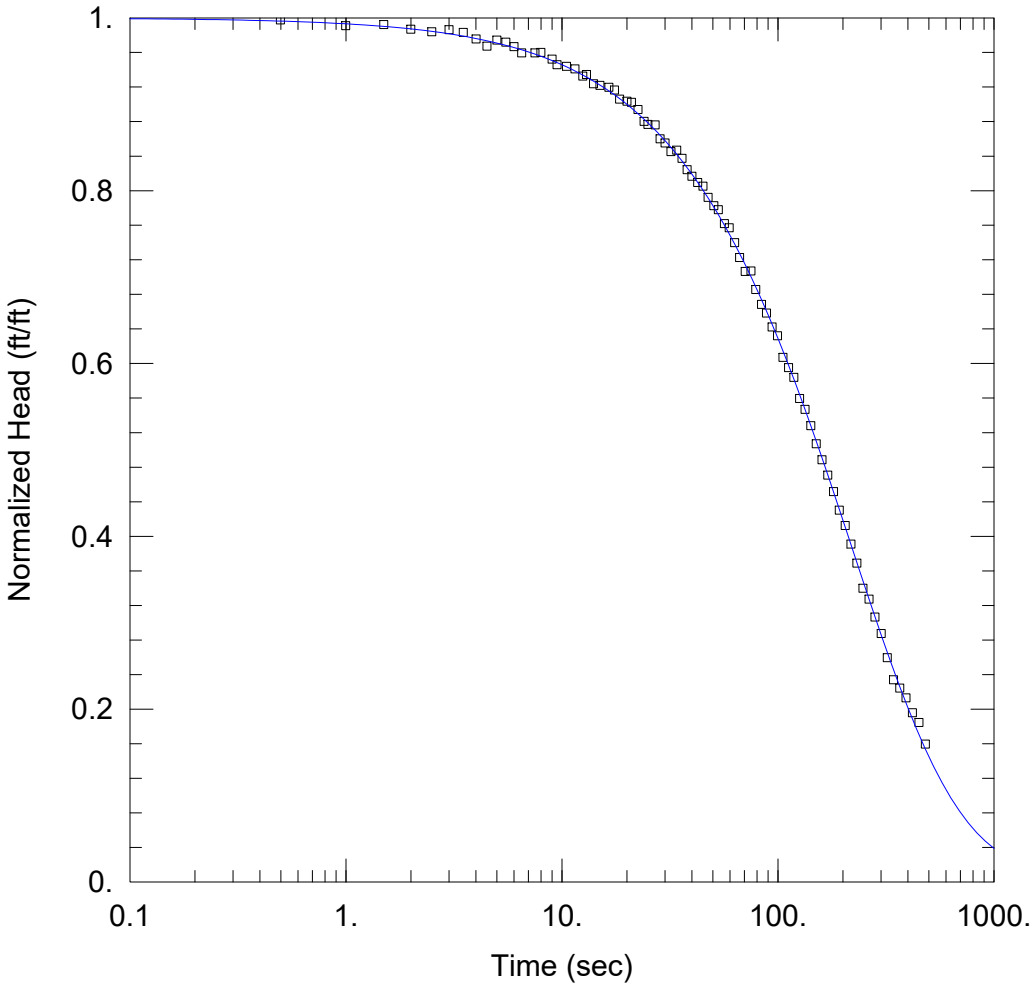
WELL DATA (APW-14)

Initial Displacement: -1.79 ft
Total Well Penetration Depth: 5. ft
Casing Radius: 0.08625 ft
Static Water Column Height: 36.75 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.0028 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 4.94E-6 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-15 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-15
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 7.1 ft

WELL DATA (APW-15)

Initial Displacement: 1.68 ft
Total Well Penetration Depth: 50.5 ft
Casing Radius: 0.086 ft

Static Water Column Height: 82.47 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

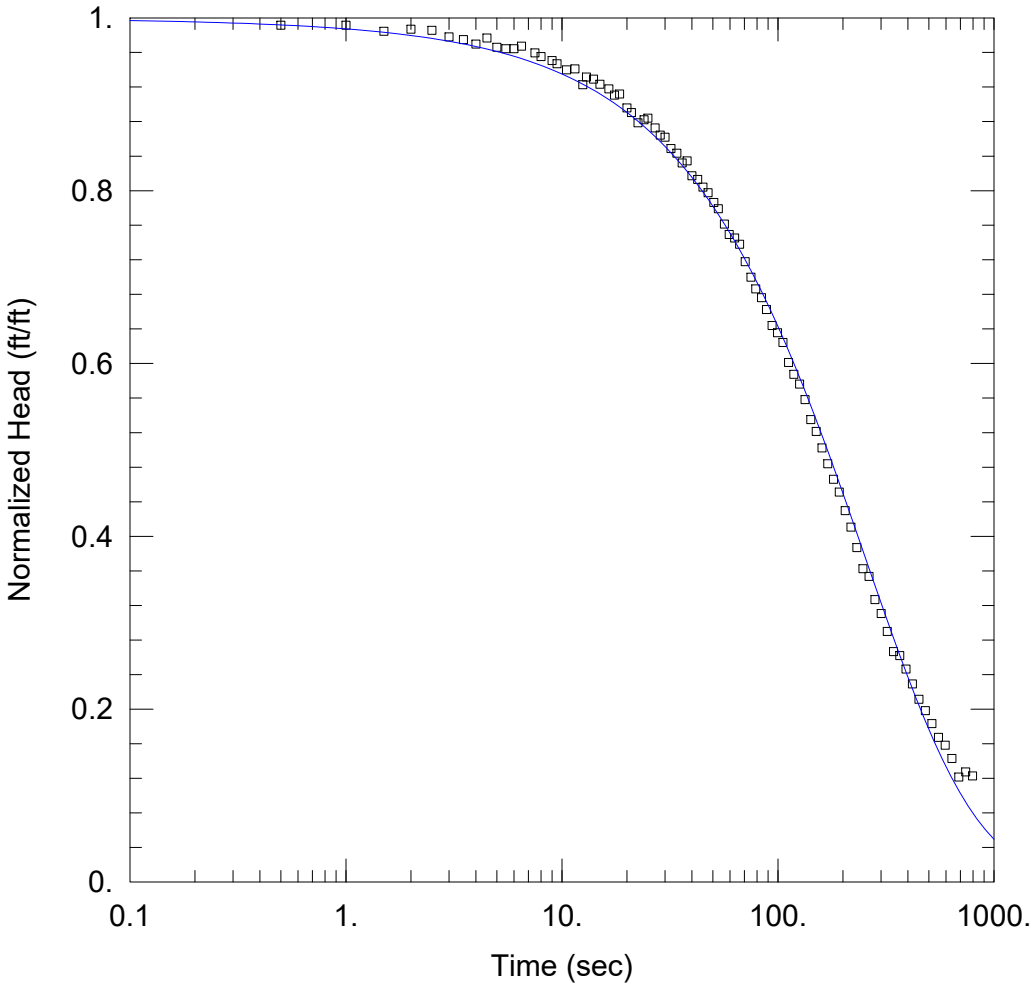
SOLUTION

Aquifer Model: Confined

Kr = 0.000485 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 3.29E-7 ft^{-1}



APW-15 FH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-15
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 51.8 ft

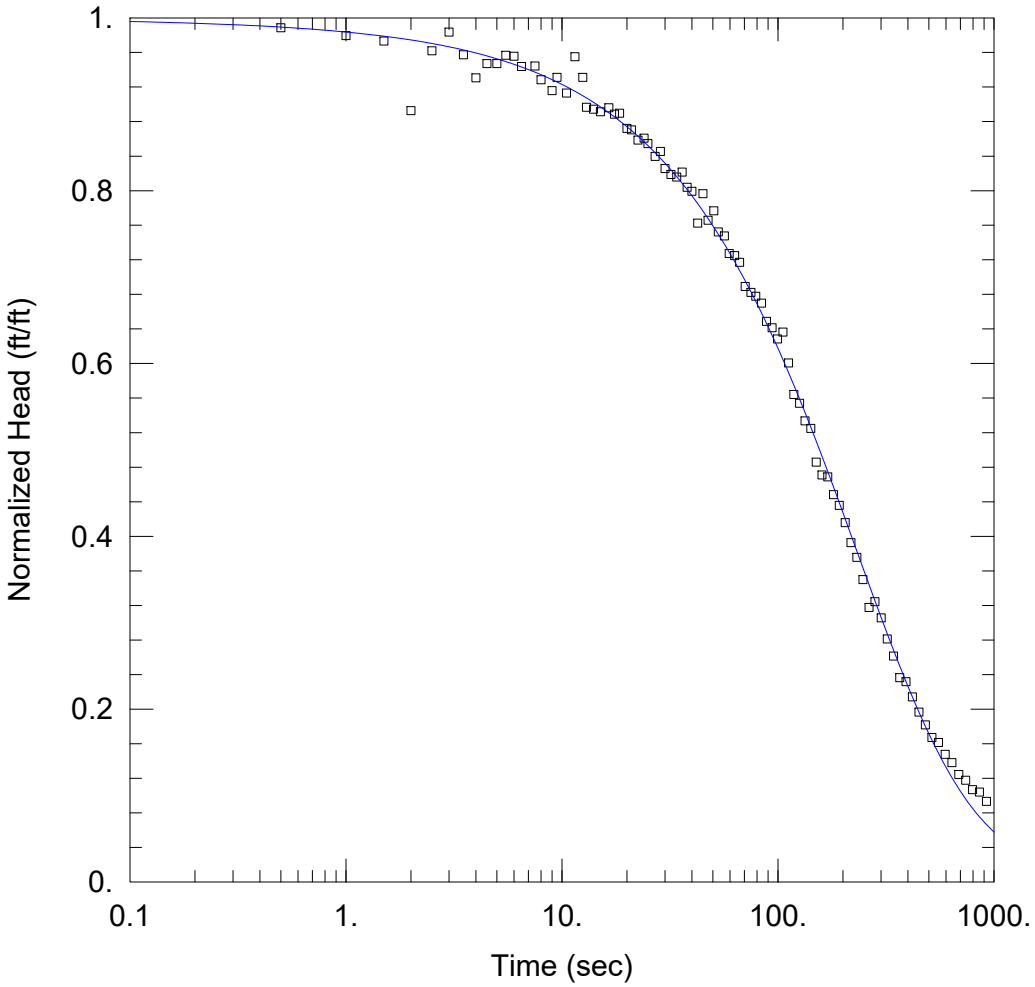
WELL DATA (APW-15)

Initial Displacement: 1.68 ft
Total Well Penetration Depth: 50.5 ft
Casing Radius: 0.086 ft
Static Water Column Height: 82.32 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.0002 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 5.25E-5 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-15 RH-01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-15
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 7.1 ft

WELL DATA (APW-15)

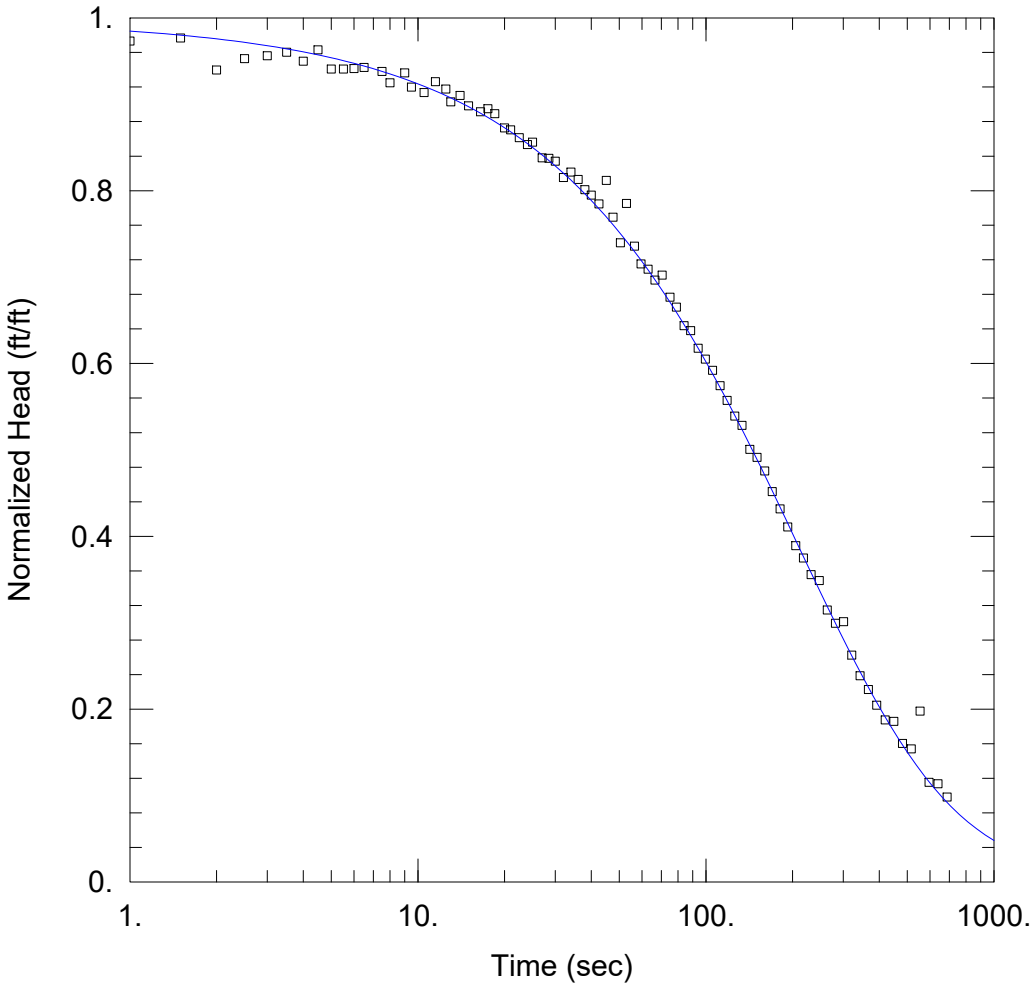
Initial Displacement: 1.76 ft
Total Well Penetration Depth: 50.5 ft
Casing Radius: 0.086 ft
Static Water Column Height: 82.59 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: KGS Model

Kr = 0.000281 cm/sec
Kz/Kr = 1.
Ss = 0.000132 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-15 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-15
Test Date: 3/31/2021

AQUIFER DATA

Saturated Thickness: 7.1 ft

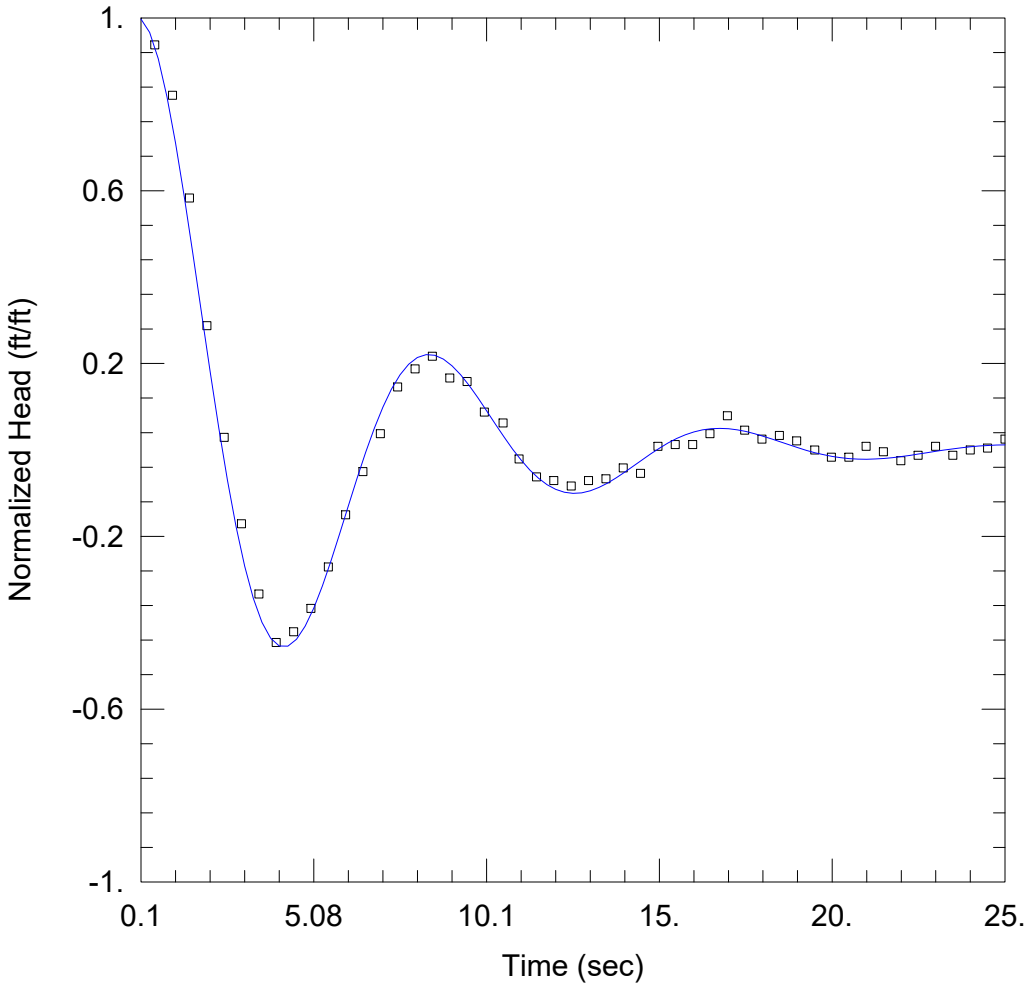
WELL DATA (APW-15)

Initial Displacement: 1.76 ft
Total Well Penetration Depth: 50.5 ft
Casing Radius: 0.086 ft
Static Water Column Height: 82.52 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Kr = 0.00032 cm/sec
Kz/Kr = 1.
Solution Method: KGS Model
Ss = 8.48E-5 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-16 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-16
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 16.4 ft
Anisotropy Ratio (Kz/Kr): 1.

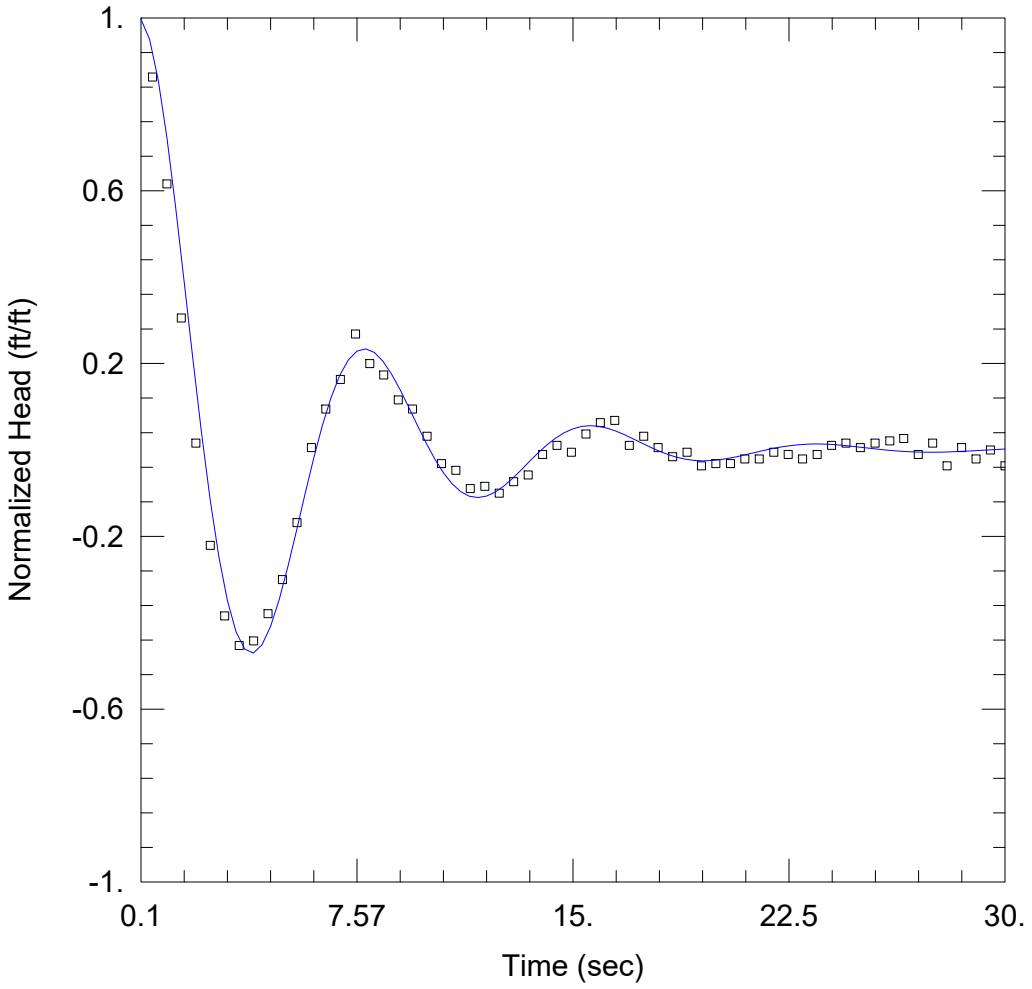
WELL DATA (APW-16)

Initial Displacement: 0.24 ft
Total Well Penetration Depth: 16.3 ft
Casing Radius: 0.086 ft
Static Water Column Height: 64.37 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.124 cm/sec
Kz/Kr = 1.
Ss = 8.12E-7 ft^{-1}
Le = 56.01 ft



APW-16 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-16
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 16.4 ft
Anisotropy Ratio (Kz/Kr): 1.

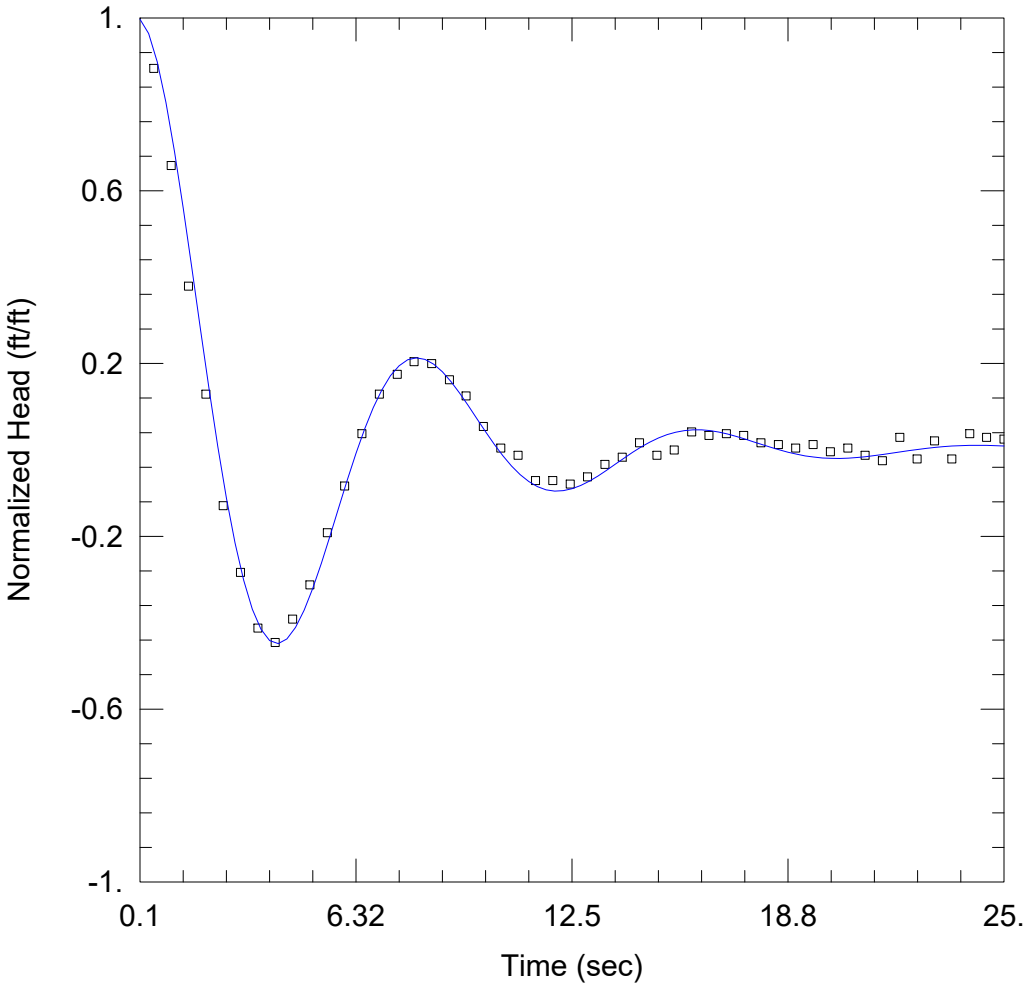
WELL DATA (APW-16)

Initial Displacement: 0.19 ft
Total Well Penetration Depth: 16.3 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 64.22 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.141 cm/sec
Kz/Kr = 1.
Ss = 6.55E-7 ft^{-1}
Le = 48.91 ft



APW-16 FH03

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-16
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 16.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-16)

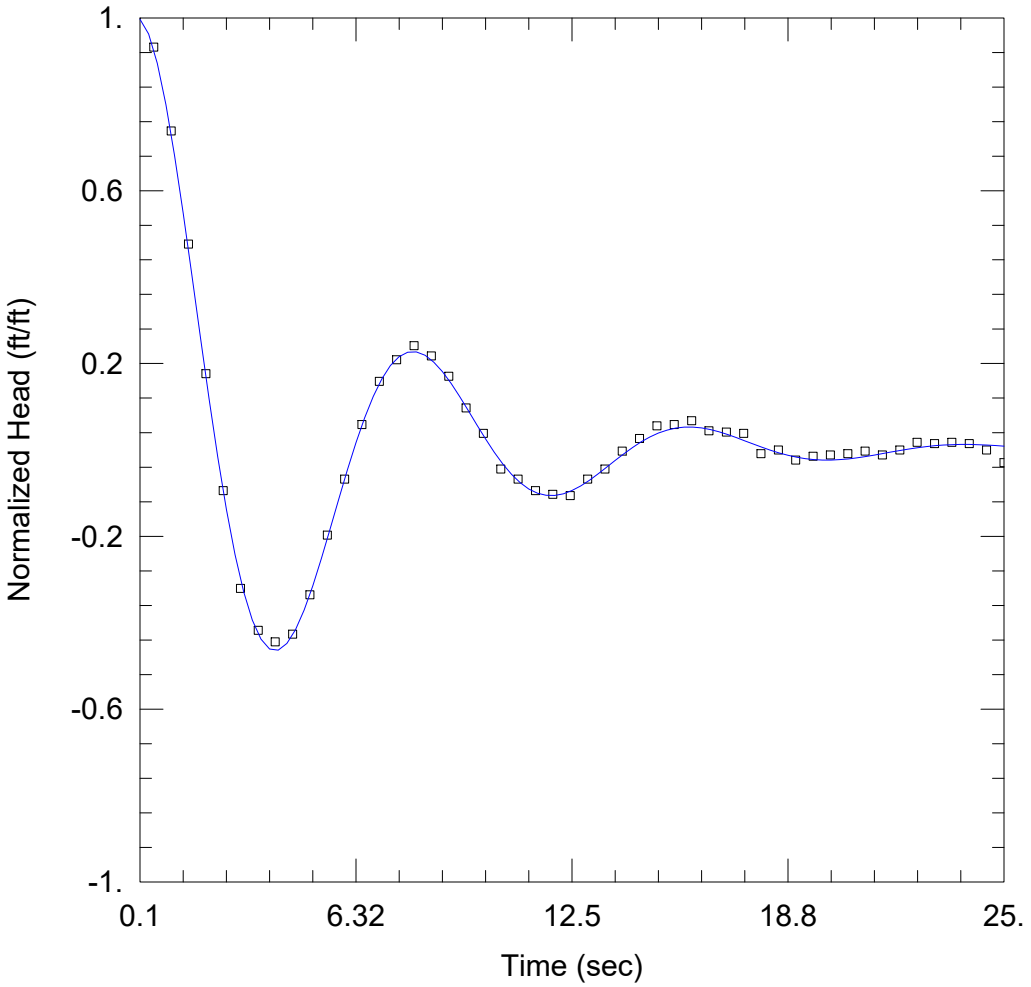
Initial Displacement: 0.24 ft
Total Well Penetration Depth: 16.3 ft
Casing Radius: 0.086 ft
Static Water Column Height: 64.49 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.135 cm/sec
Kz/Kr = 1.
Ss = 1.65E-7 ft^{-1}
Le = 51.68 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-16 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-16
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 16.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-16)

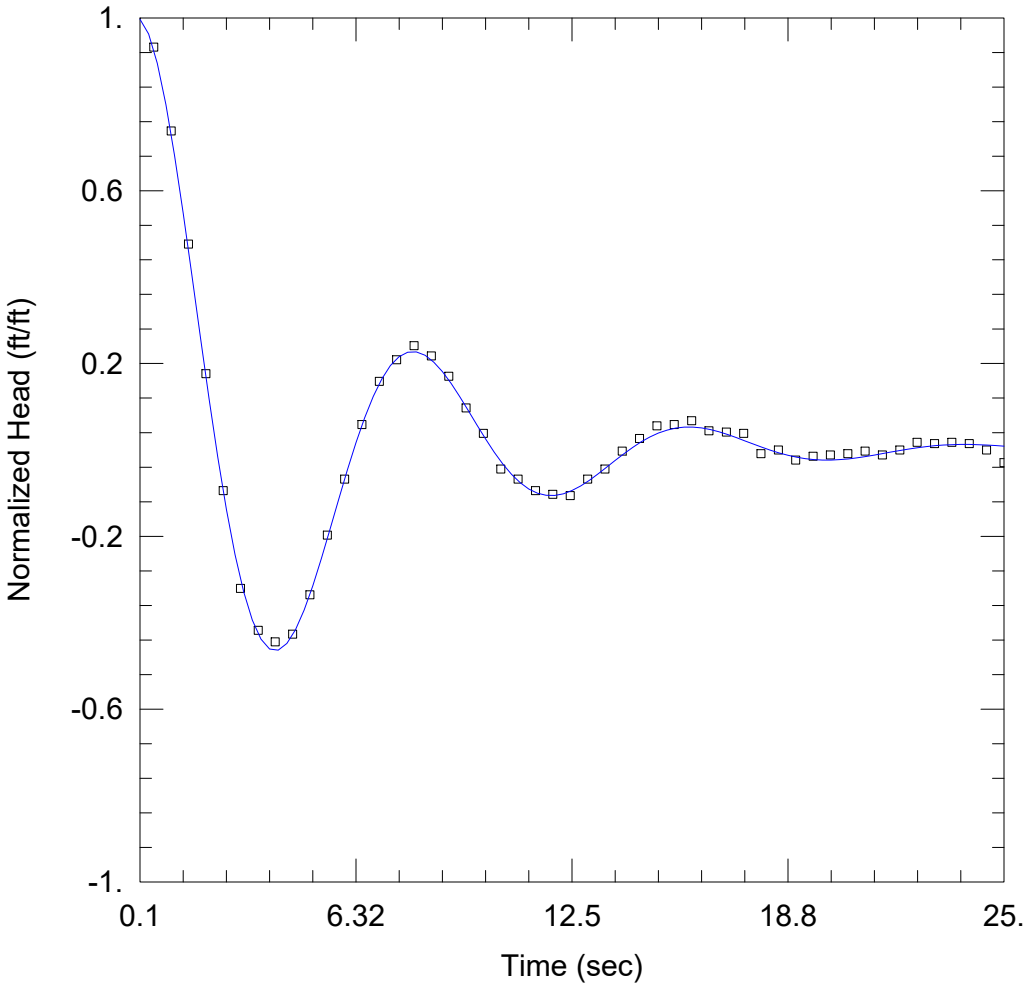
Initial Displacement: 0.34 ft
Total Well Penetration Depth: 16.3 ft
Casing Radius: 0.086 ft
Static Water Column Height: 64.49 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.145 cm/sec
Kz/Kr = 1.
Ss = 1.21E-7 ft^{-1}
Le = 50.37 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-16 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-16
Test Date: 3/11/2021

AQUIFER DATA

Saturated Thickness: 16.4 ft
Anisotropy Ratio (Kz/Kr): 1.

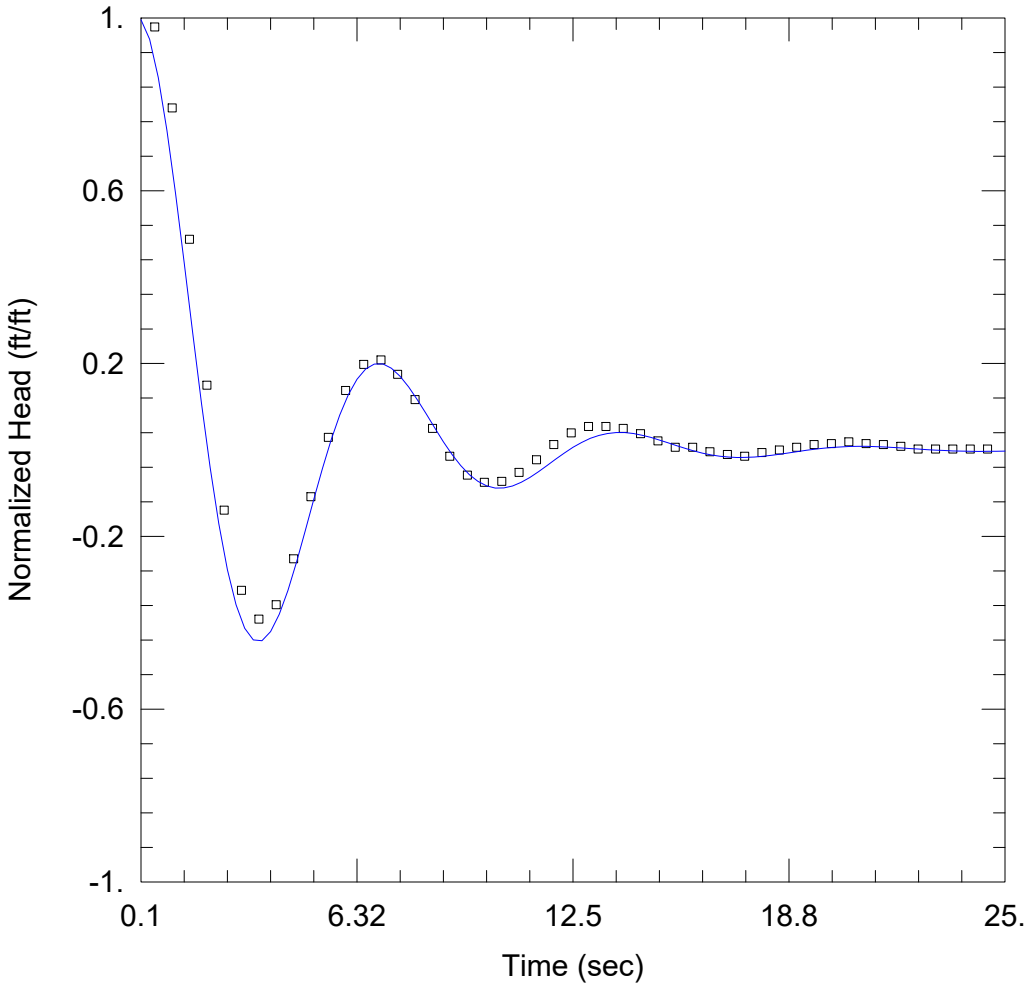
WELL DATA (APW-16)

Initial Displacement: 0.34 ft
Total Well Penetration Depth: 16.3 ft
Casing Radius: 0.086 ft
Static Water Column Height: 64.49 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.145 cm/sec
Kz/Kr = 1.
Ss = 1.21E-7 ft^{-1}
Le = 50.37 ft



APW-17 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-17
Test Date: 02/16/2021

AQUIFER DATA

Saturated Thickness: 84.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-17)

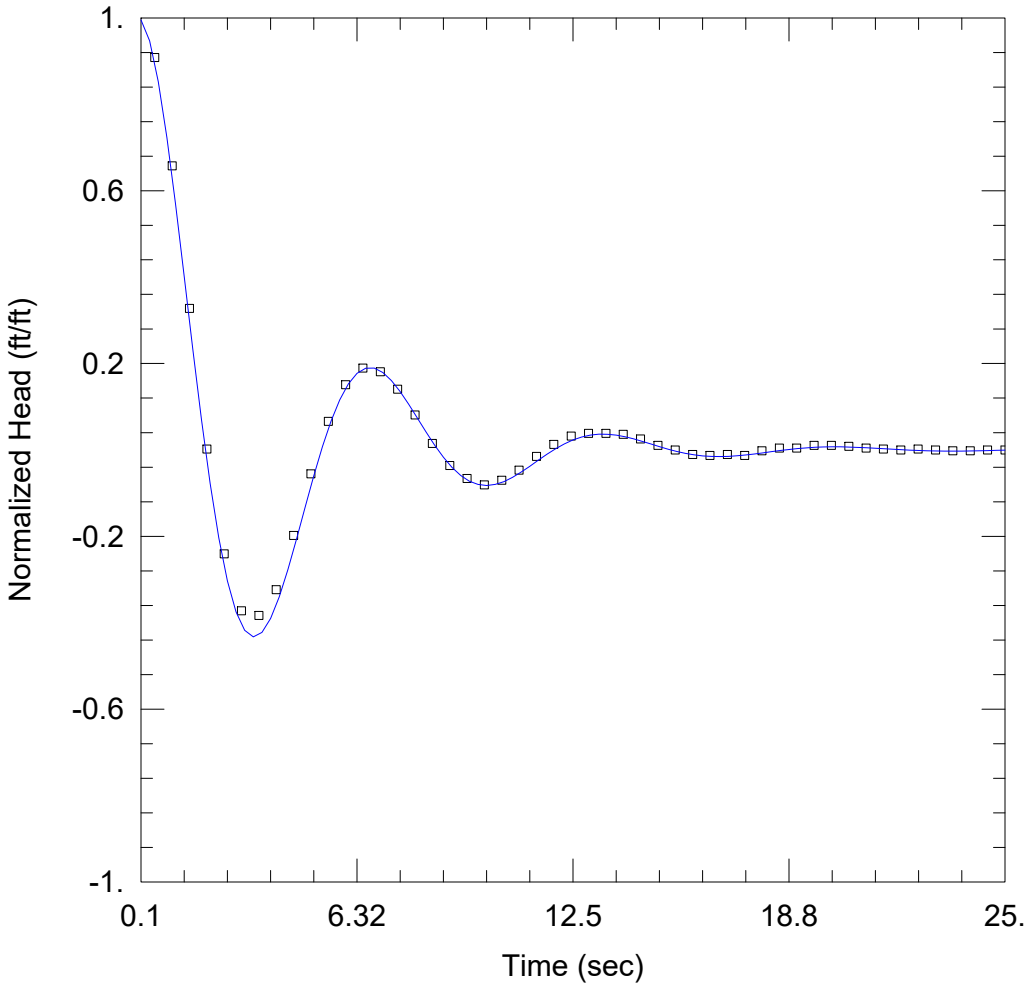
Initial Displacement: 0.48 ft
Total Well Penetration Depth: 79.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 53.93 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.113 cm/sec
Kz/Kr = 1.
Ss = 5.88E-7 ft^{-1}
Le = 37.31 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-17 FH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-17
Test Date: 02/16/2021

AQUIFER DATA

Saturated Thickness: 84.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-17)

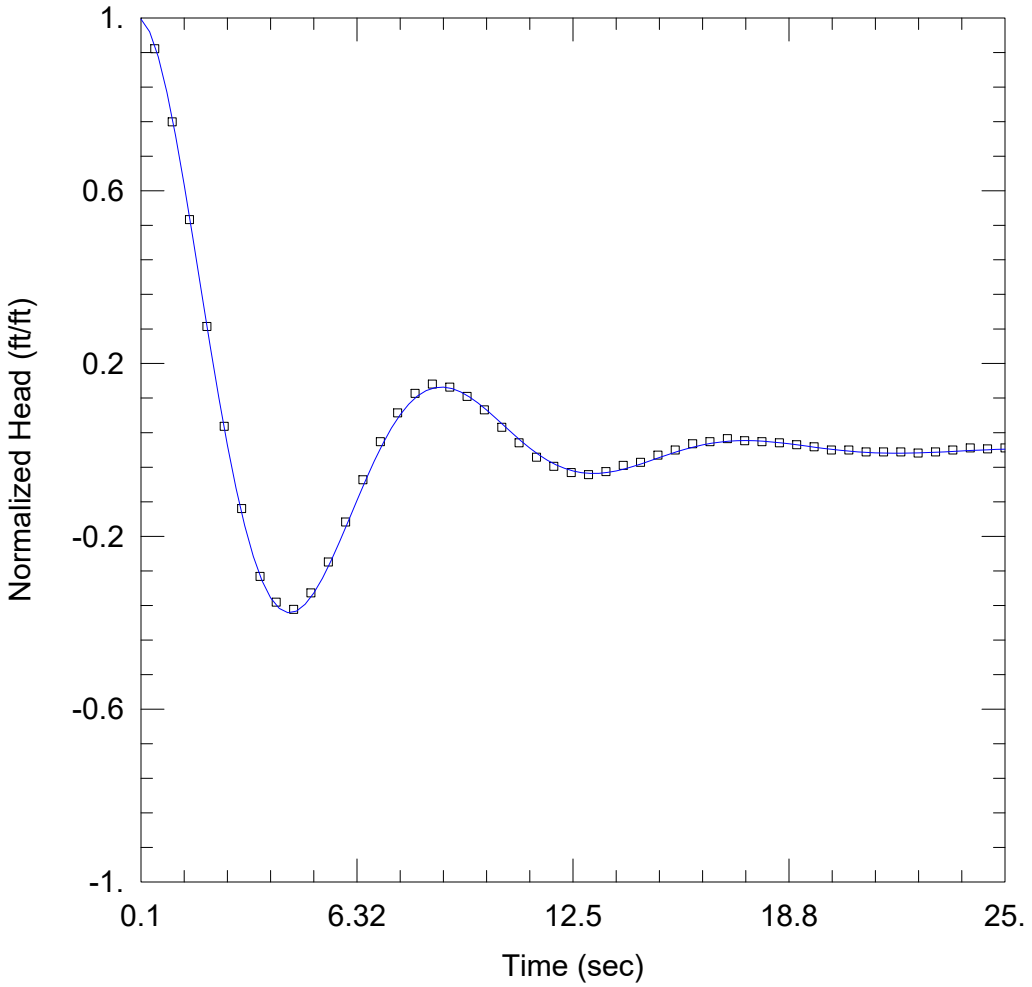
Initial Displacement: 0.47 ft
Total Well Penetration Depth: 79.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 53.93 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.115 cm/sec
Kz/Kr = 1.
Ss = 2.88E-7 ft^{-1}
Le = 34.54 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-17 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-17
Test Date: 02/16/2021

AQUIFER DATA

Saturated Thickness: 84.7 ft
Anisotropy Ratio (Kz/Kr): 1.

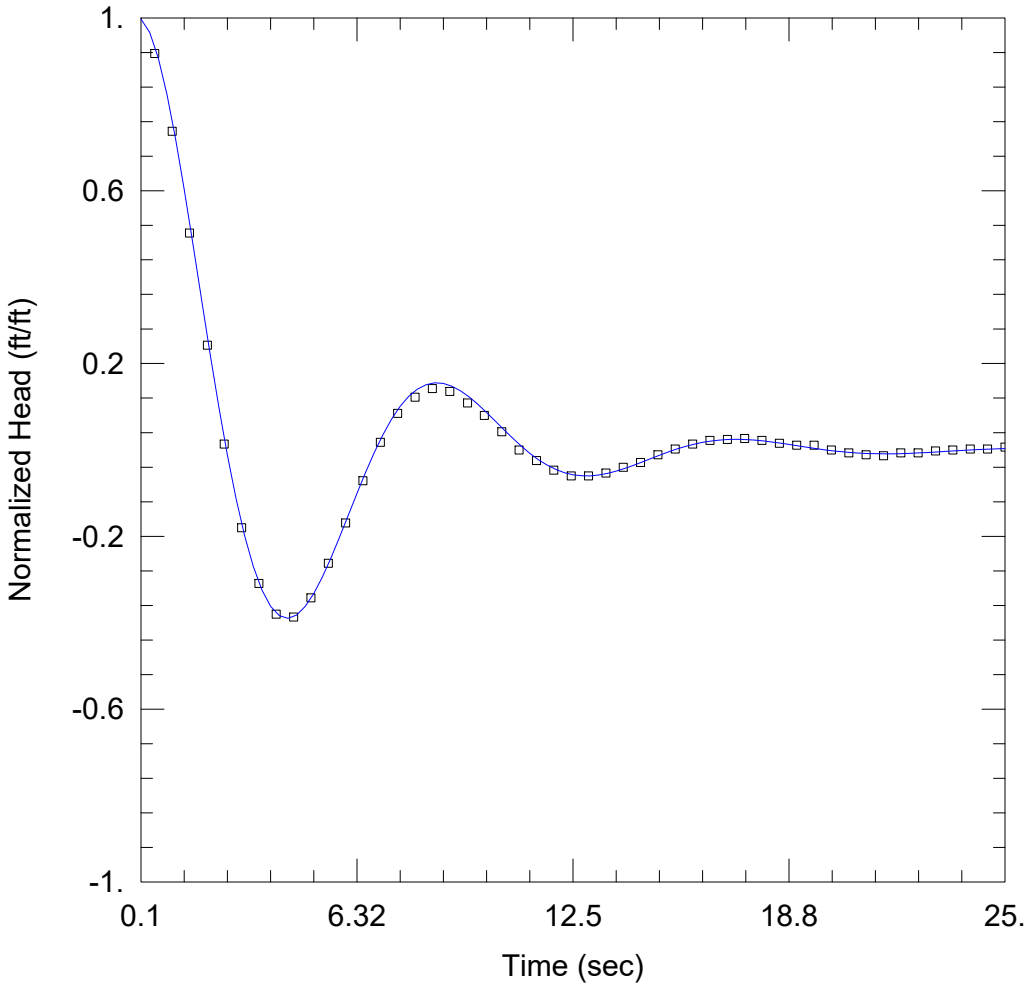
WELL DATA (APW-17)

Initial Displacement: 0.42 ft
Total Well Penetration Depth: 79.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 53.93 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.076 cm/sec
Kz/Kr = 1.
Ss = 2.88E-7 ft^{-1}
Le = 57.77 ft



APW-17 RH02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-17
Test Date: 02/16/2021

AQUIFER DATA

Saturated Thickness: 84.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-17)

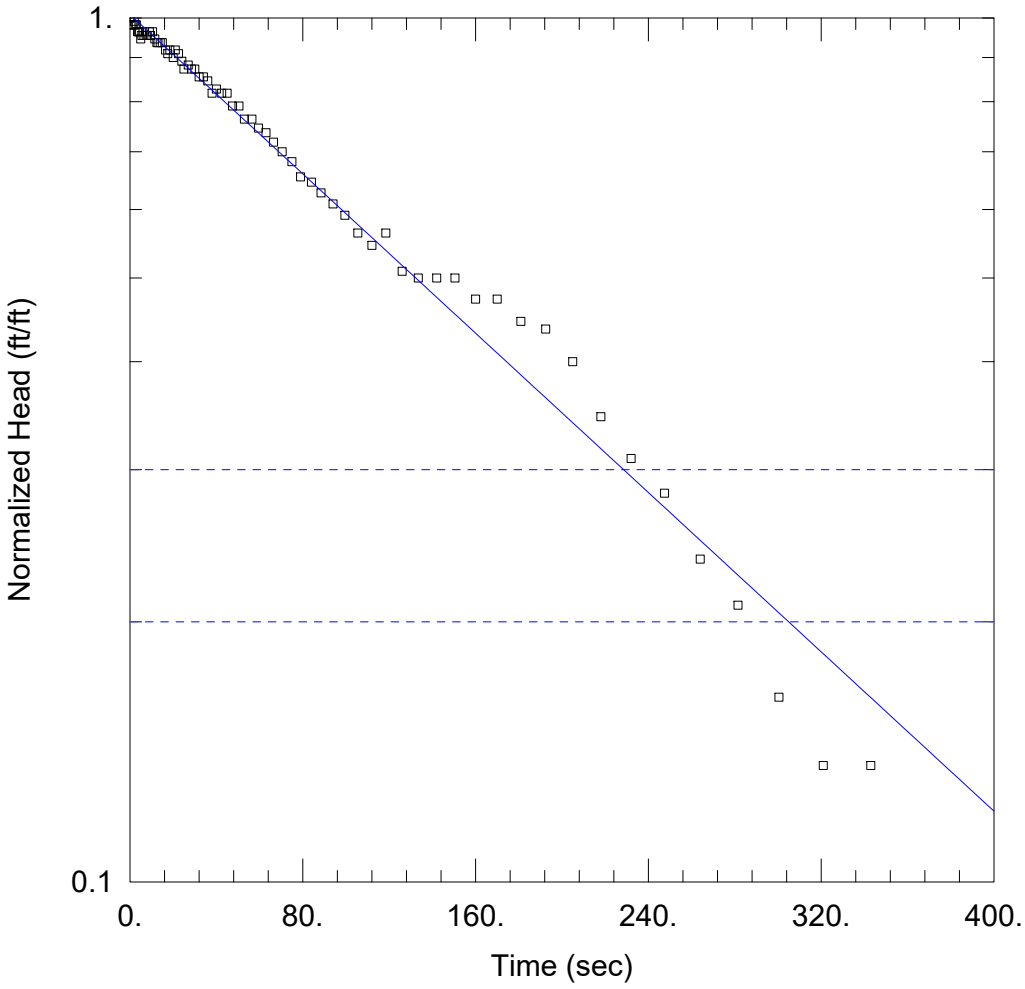
Initial Displacement: 0.45 ft
Total Well Penetration Depth: 79.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 53.93 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Butler-Zhan

Kr = 0.0796 cm/sec
Kz/Kr = 1.
Ss = 2.88E-7 ft^{-1}
Le = 56.31 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



APW-18 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: APW-18
Test Date: 2/16/21

AQUIFER DATA

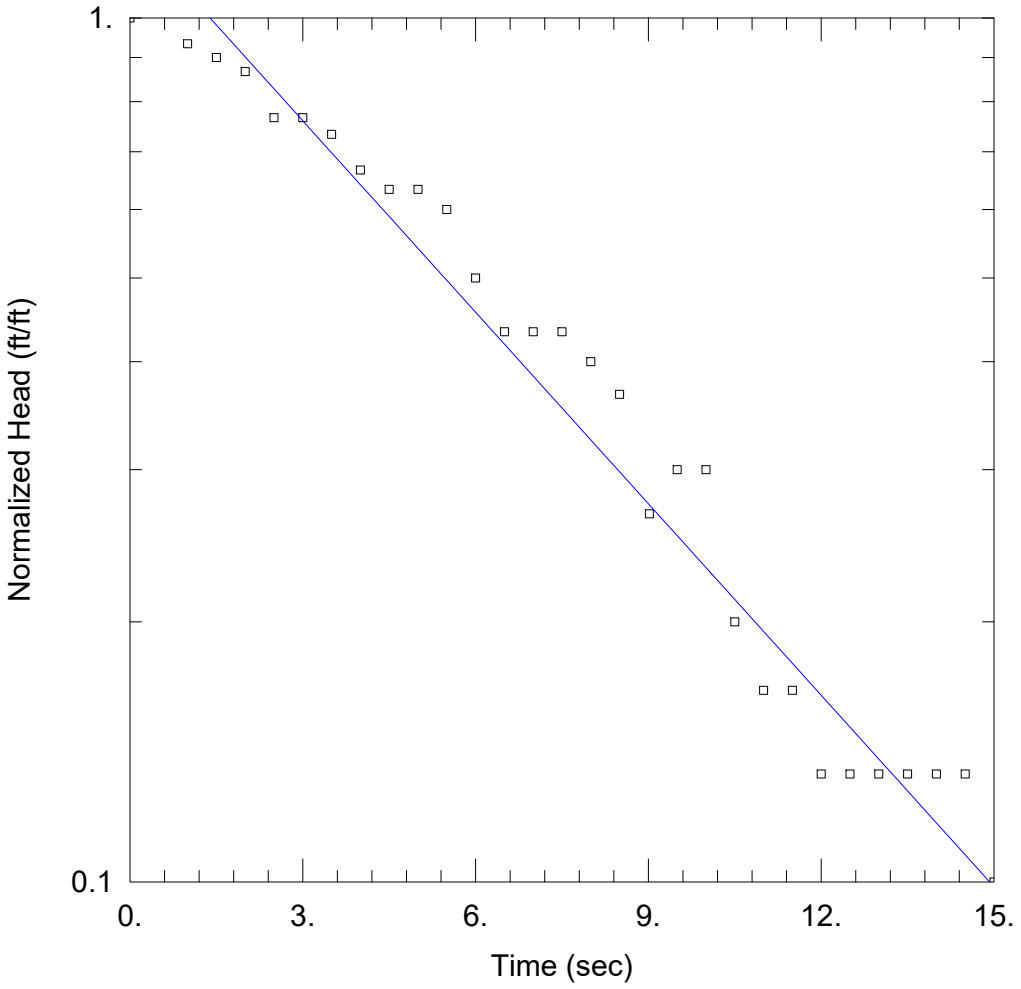
Saturated Thickness: 78.8 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW-18)

Initial Displacement: 0.11 ft
Total Well Penetration Depth: 51.1 ft
Casing Radius: 0.086 ft
Static Water Column Height: 31.38 ft
Screen Length: 5. ft
Well Radius: 0.25 ft

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice
K = 0.000267 cm/sec
y0 = 0.111 ft



XPW-01 FH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW-01
Test Date: 3/11/21

AQUIFER DATA

Saturated Thickness: 8. ft
Anisotropy Ratio (Kz/Kr): 1.

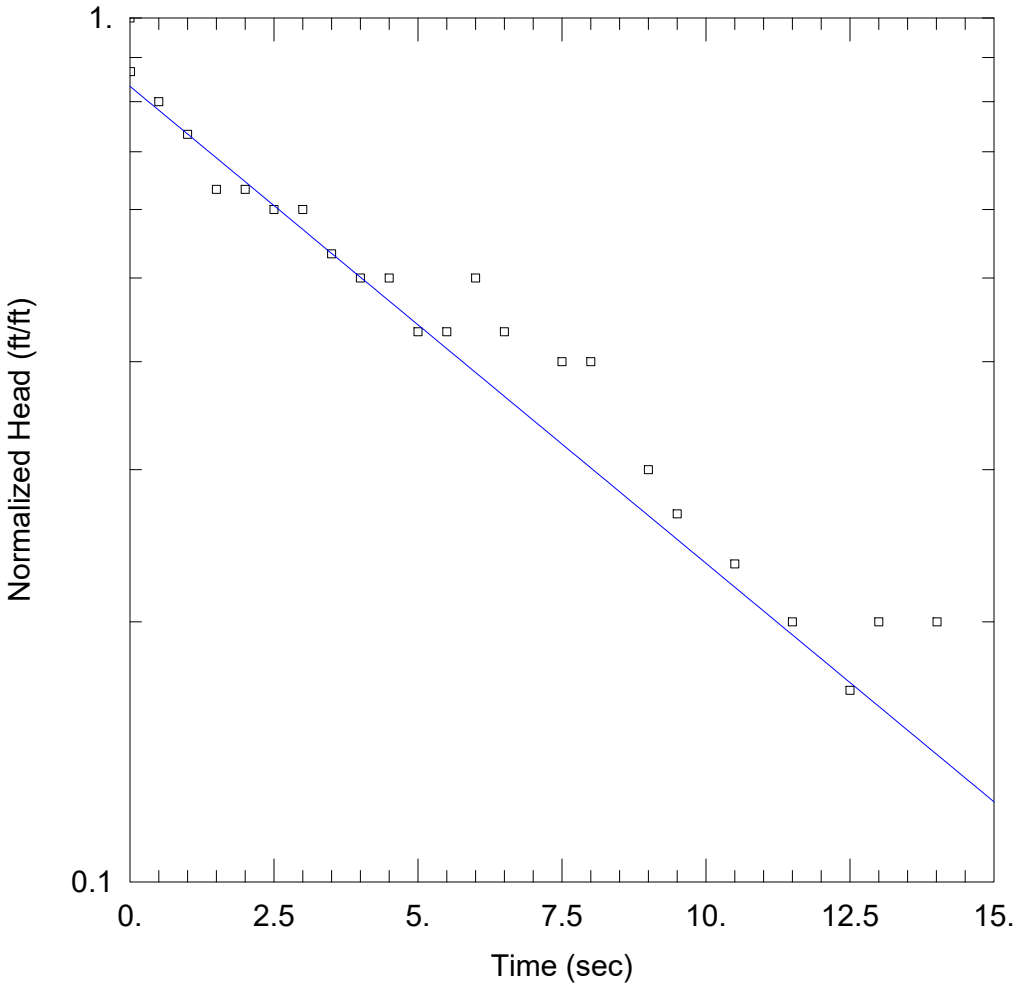
WELL DATA (XPW-01)

Initial Displacement: 0.03 ft
Total Well Penetration Depth: 8.033 ft
Casing Radius: 0.086 ft
Static Water Column Height: 8.033 ft
Screen Length: 8.033 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.25

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.183 cm/sec
y0 = 0.038 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW-01 FH-02

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW-01
Test Date: 3/11/21

AQUIFER DATA

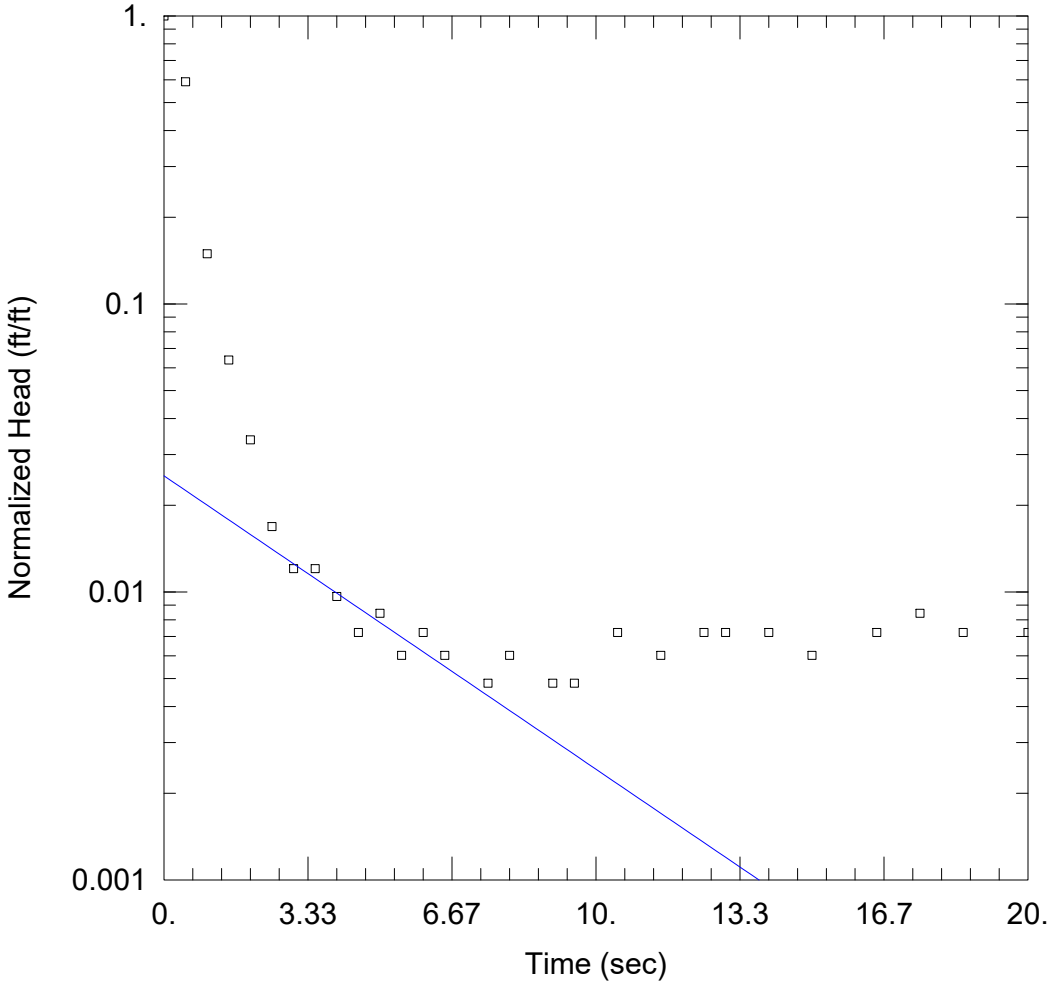
Saturated Thickness: 8. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (XPW-01)

Initial Displacement: 0.03 ft
Total Well Penetration Depth: 8.033 ft
Casing Radius: 0.086 ft
Static Water Column Height: 8.033 ft
Screen Length: 8.033 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.25

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0129 cm/sec
y0 = 0.025 ft



XPW-01 RH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW-01
Test Date: 3/11/21

AQUIFER DATA

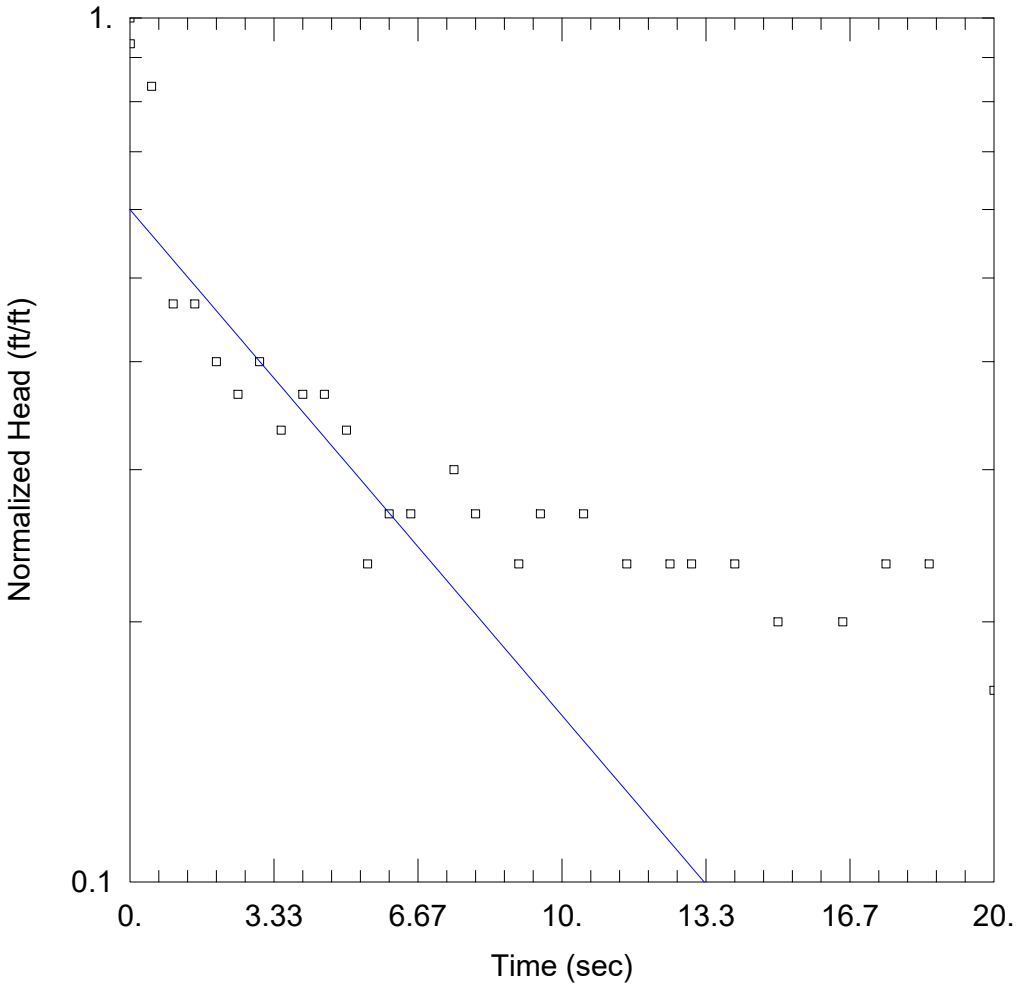
Saturated Thickness: 8. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (XPW-01)

Initial Displacement: 0.83 ft
Total Well Penetration Depth: 8.033 ft
Casing Radius: 0.086 ft
Static Water Column Height: 8.033 ft
Screen Length: 8.033 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.25

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0238 cm/sec
y0 = 0.021 ft



XPW-01 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW-01
Test Date: 3/11/21

AQUIFER DATA

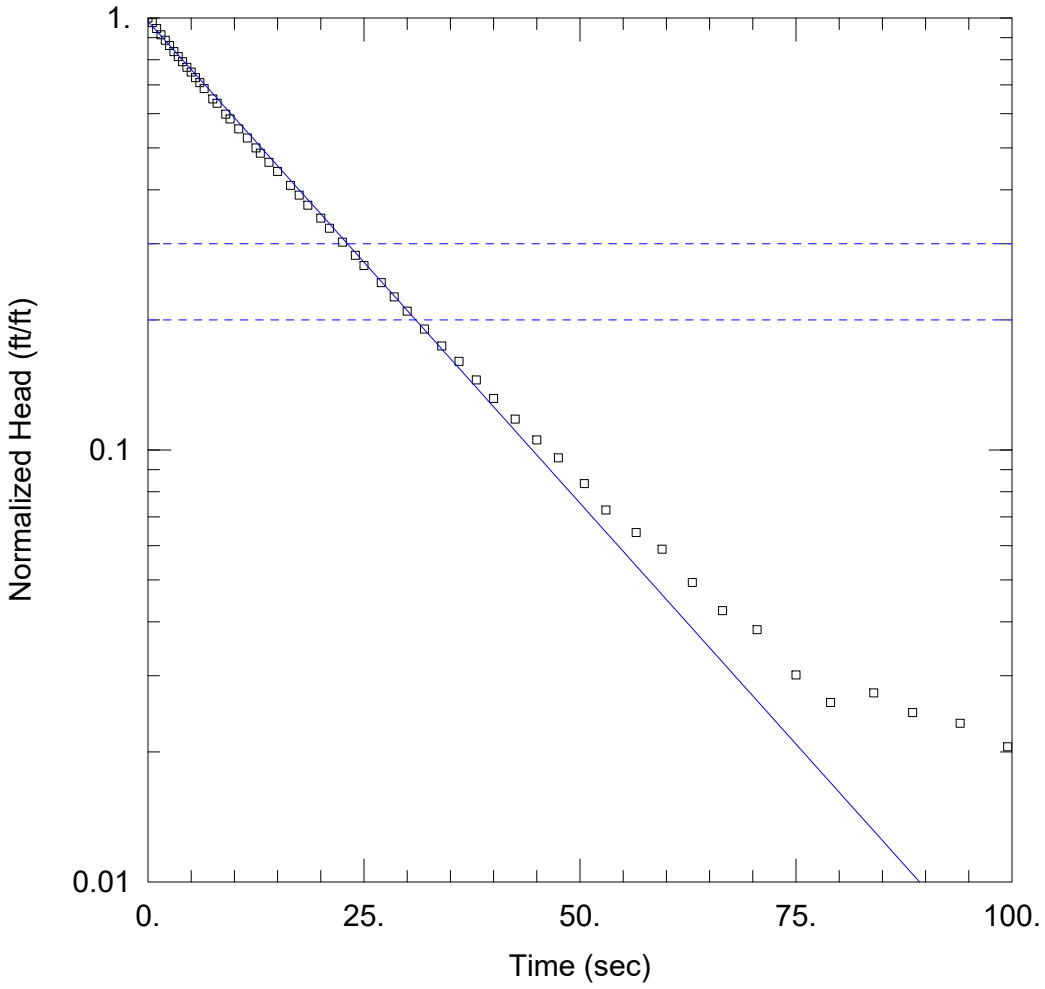
Saturated Thickness: 8. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (XPW-01)

Initial Displacement: 0.03 ft
Total Well Penetration Depth: 8.033 ft
Casing Radius: 0.08625 ft
Static Water Column Height: 8.033 ft
Screen Length: 8.033 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.25

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0137 cm/sec
y0 = 0.018 ft



XPW02 FH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW02
Test Date: 3/11/21

AQUIFER DATA

Saturated Thickness: 7.259 ft
Anisotropy Ratio (Kz/Kr): 1.

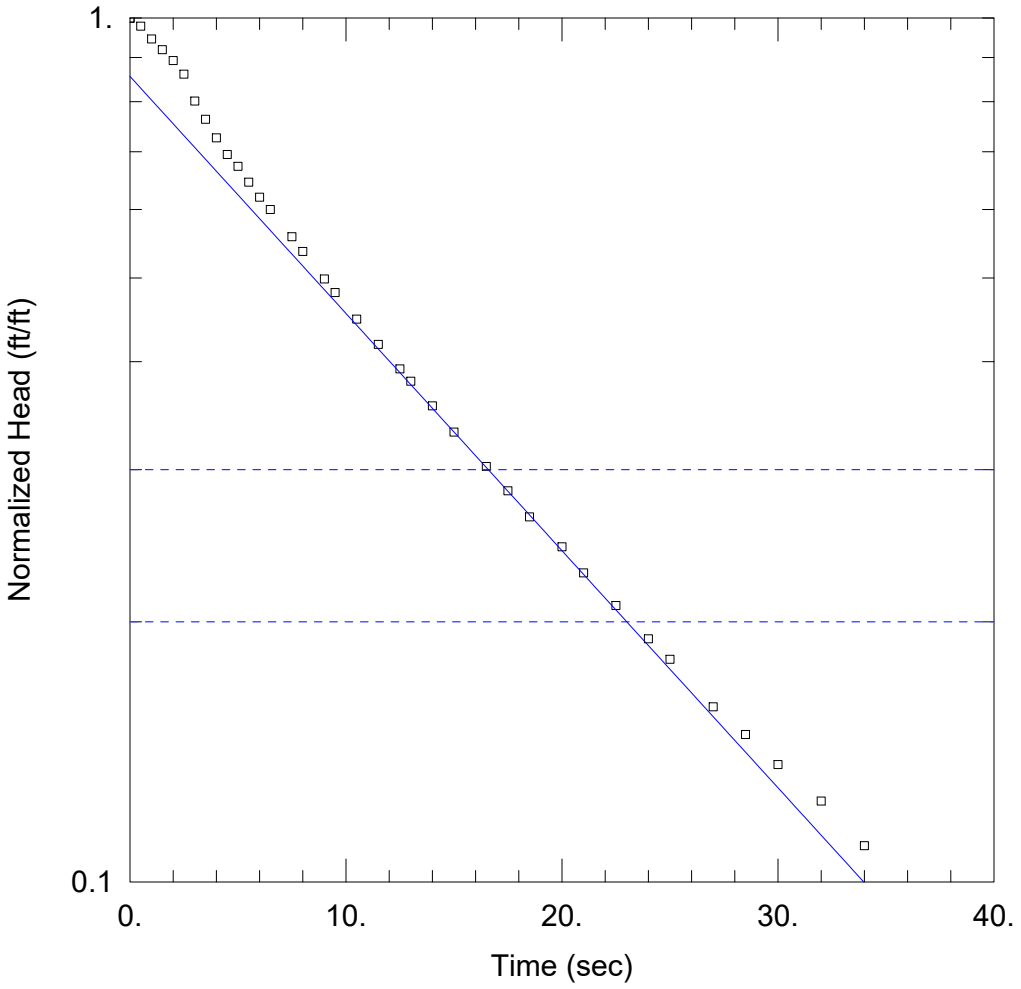
WELL DATA (XPW02)

Initial Displacement: 0.73 ft
Total Well Penetration Depth: 7.259 ft
Casing Radius: 0.086 ft
Static Water Column Height: 9.759 ft
Screen Length: 7.259 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.00197 cm/sec
y0 = 0.717 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW02 FH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW02
Test Date: 3/11/21

AQUIFER DATA

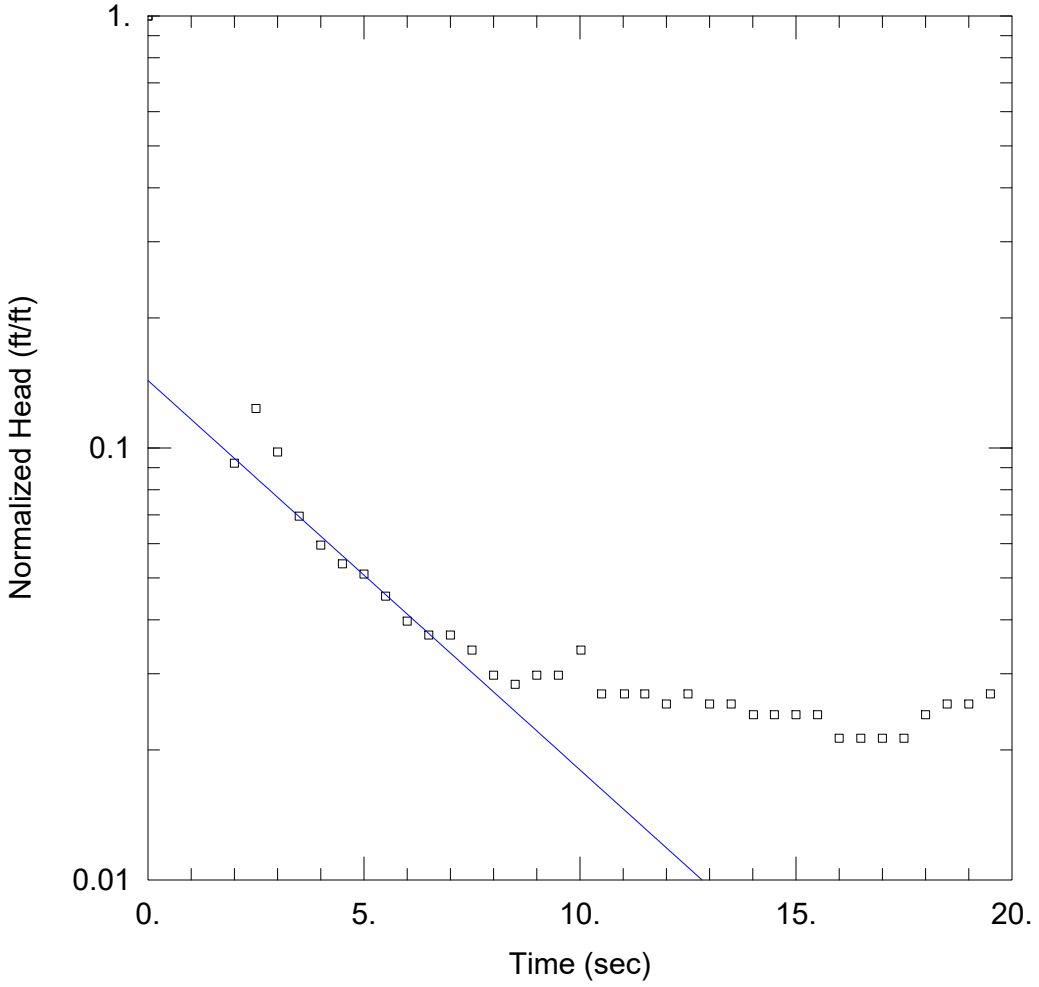
Saturated Thickness: 7.259 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (XPW02)

Initial Displacement: 0.79 ft
Total Well Penetration Depth: 7.259 ft
Casing Radius: 0.086 ft
Static Water Column Height: 9.759 ft
Screen Length: 7.259 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.00257 cm/sec
y0 = 0.676 ft



XPW03 FH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

Saturated Thickness: 7.958 ft
Anisotropy Ratio (Kz/Kr): 1.

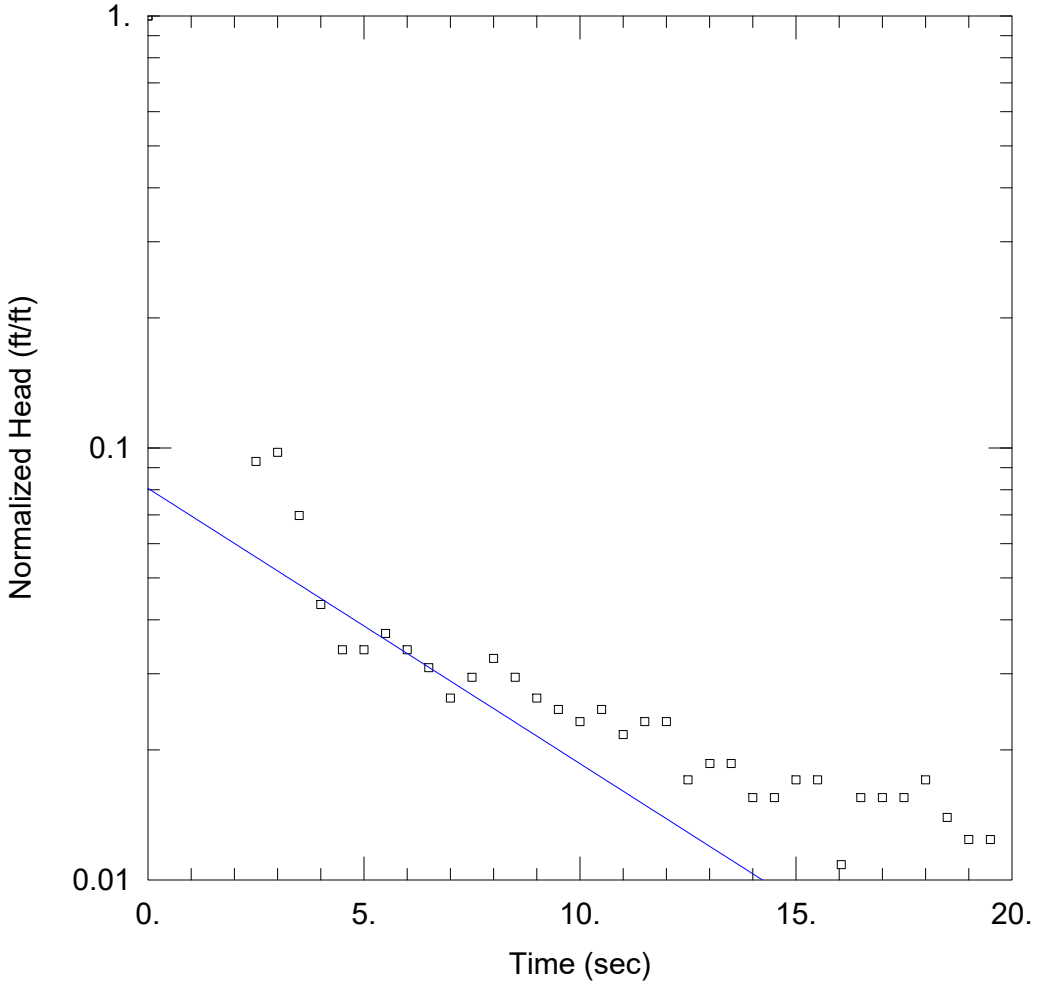
WELL DATA (XPW03)

Initial Displacement: 0.705 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.26 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.0573 cm/sec
y0 = 0.101 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW03 FH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

Saturated Thickness: 7.938 ft
Anisotropy Ratio (Kz/Kr): 1.

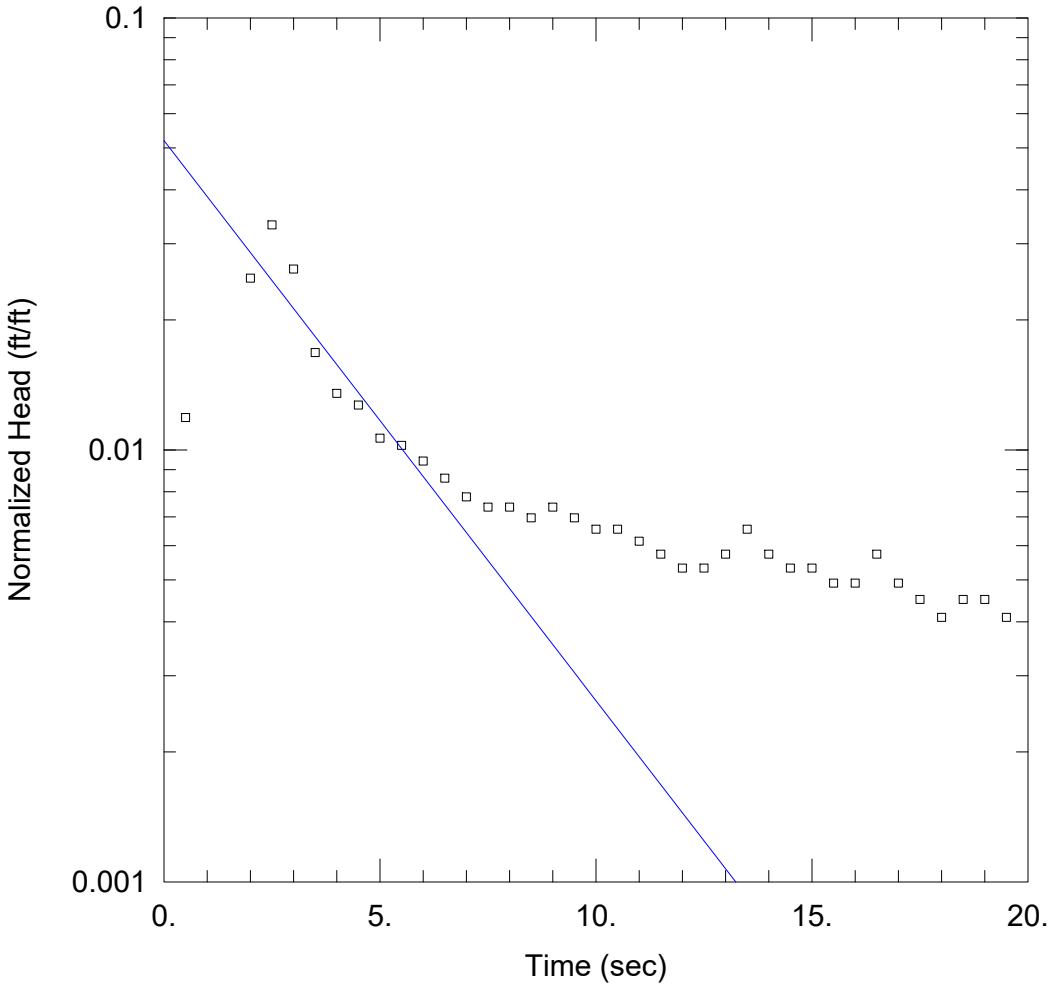
WELL DATA (XPW03)

Initial Displacement: 0.645 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.24 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.072 cm/sec
y0 = 0.052 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW03 FH3

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

Saturated Thickness: 7.948 ft
Anisotropy Ratio (Kz/Kr): 1.

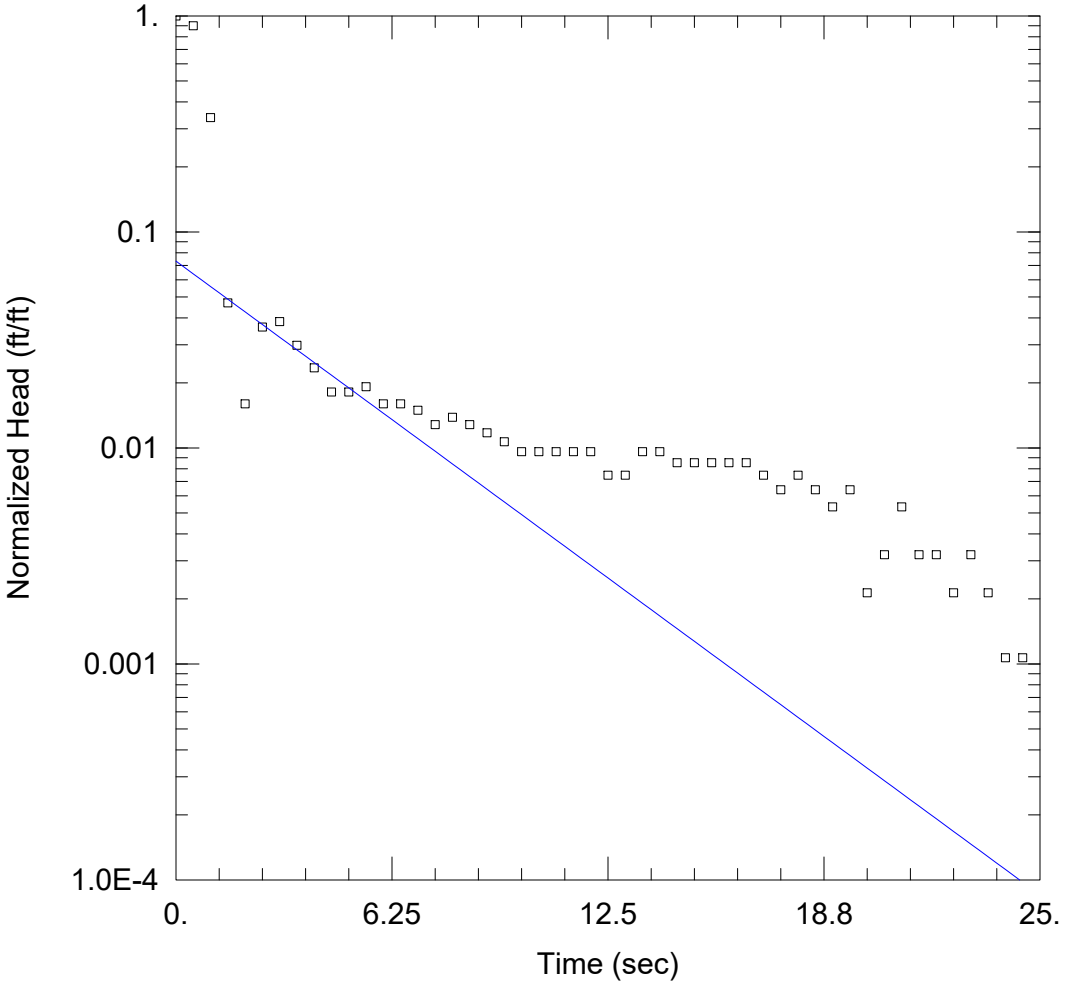
WELL DATA (XPW03)

Initial Displacement: 2.441 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.25 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
K = 0.227 cm/sec
Solution Method: Bouwer-Rice
y0 = 0.127 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW03 RH01

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

Saturated Thickness: 7.948 ft
Anisotropy Ratio (Kz/Kr): 1.

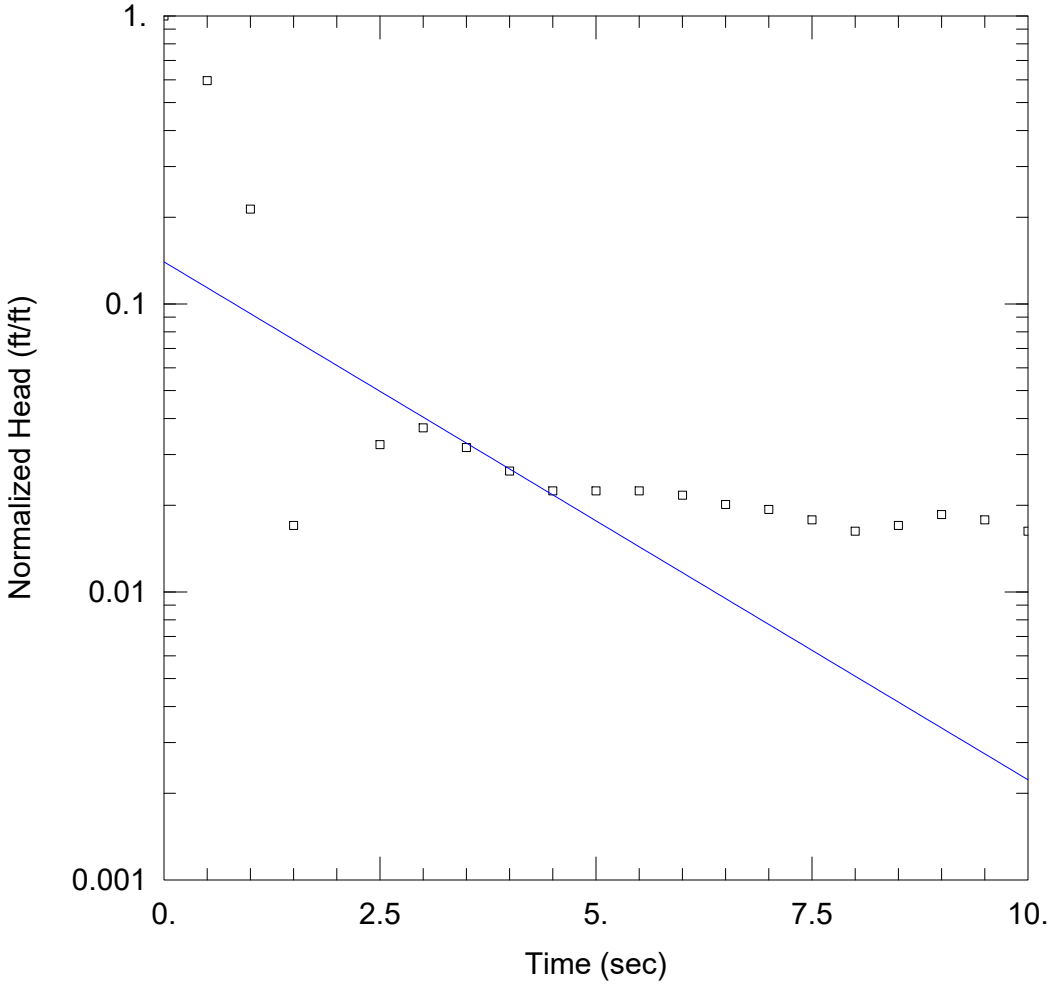
WELL DATA (XPW03)

Initial Displacement: -0.937 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.25 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.146 cm/sec
y0 = -0.0686 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW03 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

Saturated Thickness: 7.948 ft
Anisotropy Ratio (Kz/Kr): 1.

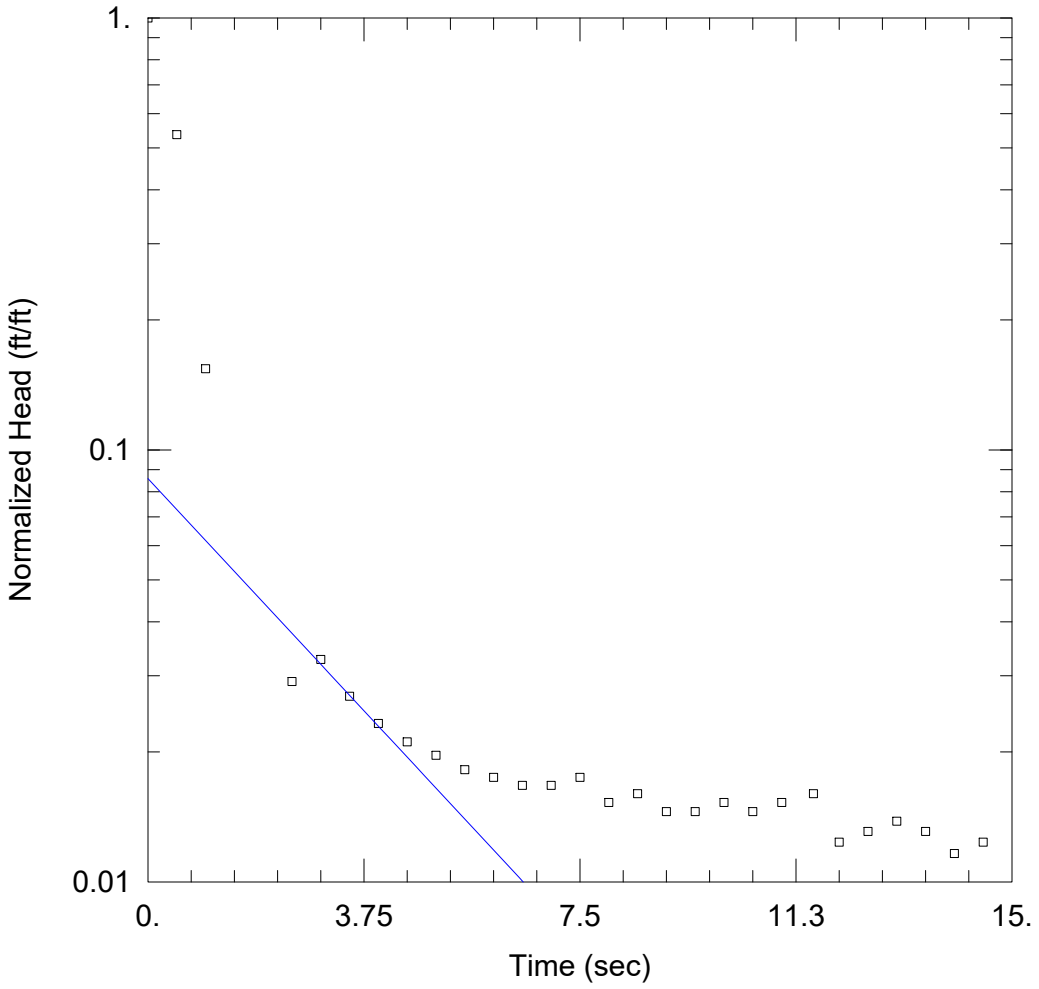
WELL DATA (XPW03)

Initial Displacement: -1.293 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.25 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.117 cm/sec
y0 = -0.181 ft

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW03 RH3

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW03
Test Date: 3/31/21

AQUIFER DATA

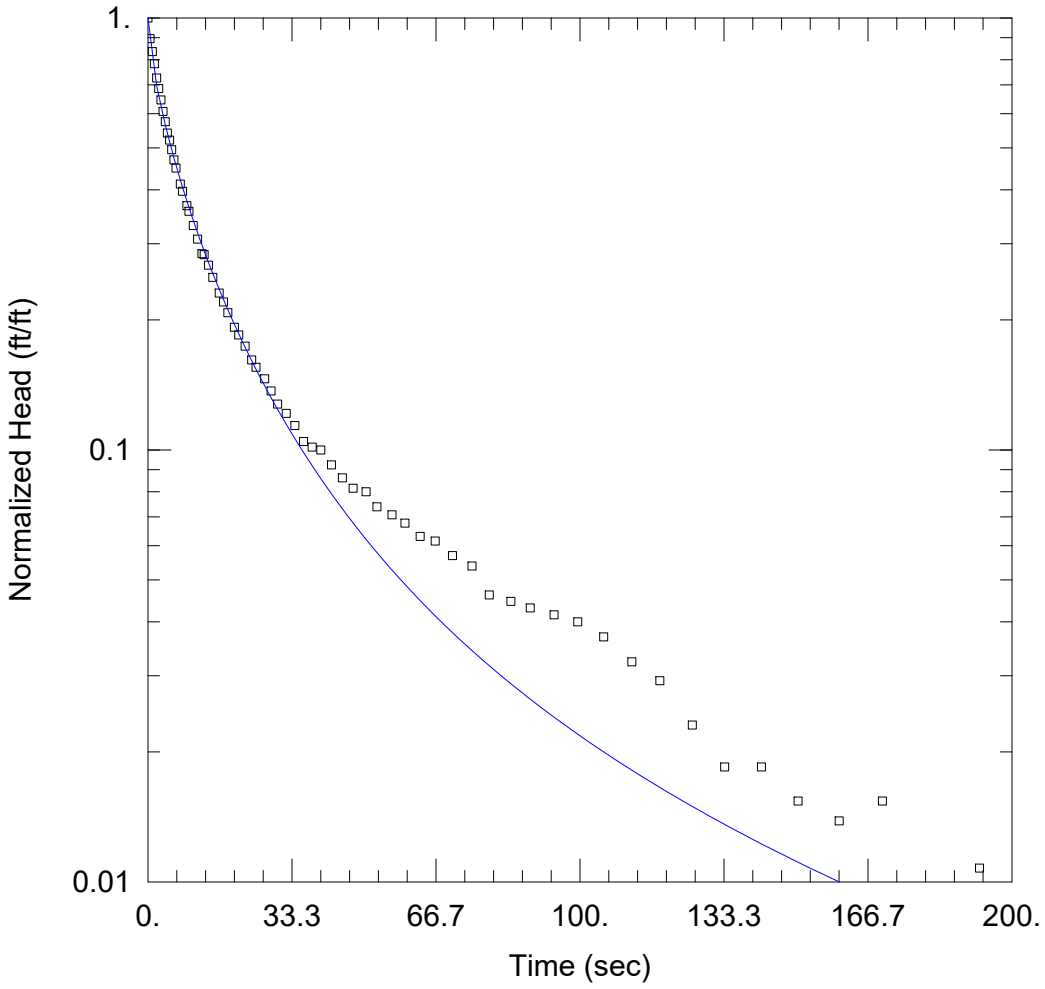
Saturated Thickness: 7.948 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (XPW03)

Initial Displacement: -1.375 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.086 ft
Static Water Column Height: 13.25 ft
Screen Length: 4.7 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice
K = 0.143 cm/sec
y0 = -0.118 ft



XPW04 FH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW04
Test Date: 3/11/21

AQUIFER DATA

Saturated Thickness: 9.9 ft

WELL DATA (XPW04)

Initial Displacement: 0.65 ft
Total Well Penetration Depth: 9.9 ft
Casing Radius: 0.086 ft

Static Water Column Height: 10.4 ft
Screen Length: 9.5 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

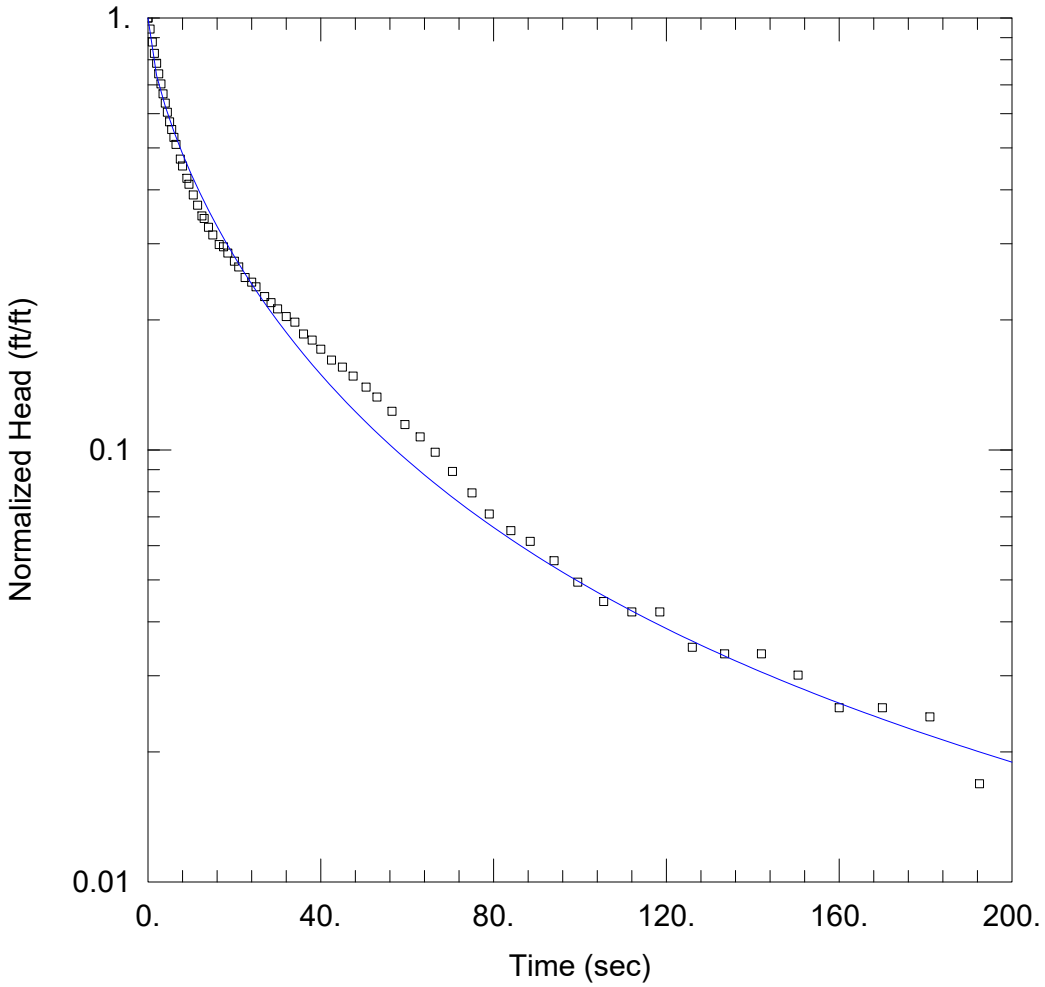
Aquifer Model: Unconfined

Kr = 0.0021 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.00051 ft^{-1}

Electronic Filing: Received, Clerk's Office 07/01/2024



XPW04 RH1

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW04
Test Date: 3/11/21

AQUIFER DATA

Saturated Thickness: 9.9 ft

WELL DATA (XPW04)

Initial Displacement: 0.83 ft
Total Well Penetration Depth: 9.9 ft
Casing Radius: 0.086 ft

Static Water Column Height: 10.4 ft
Screen Length: 9.5 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

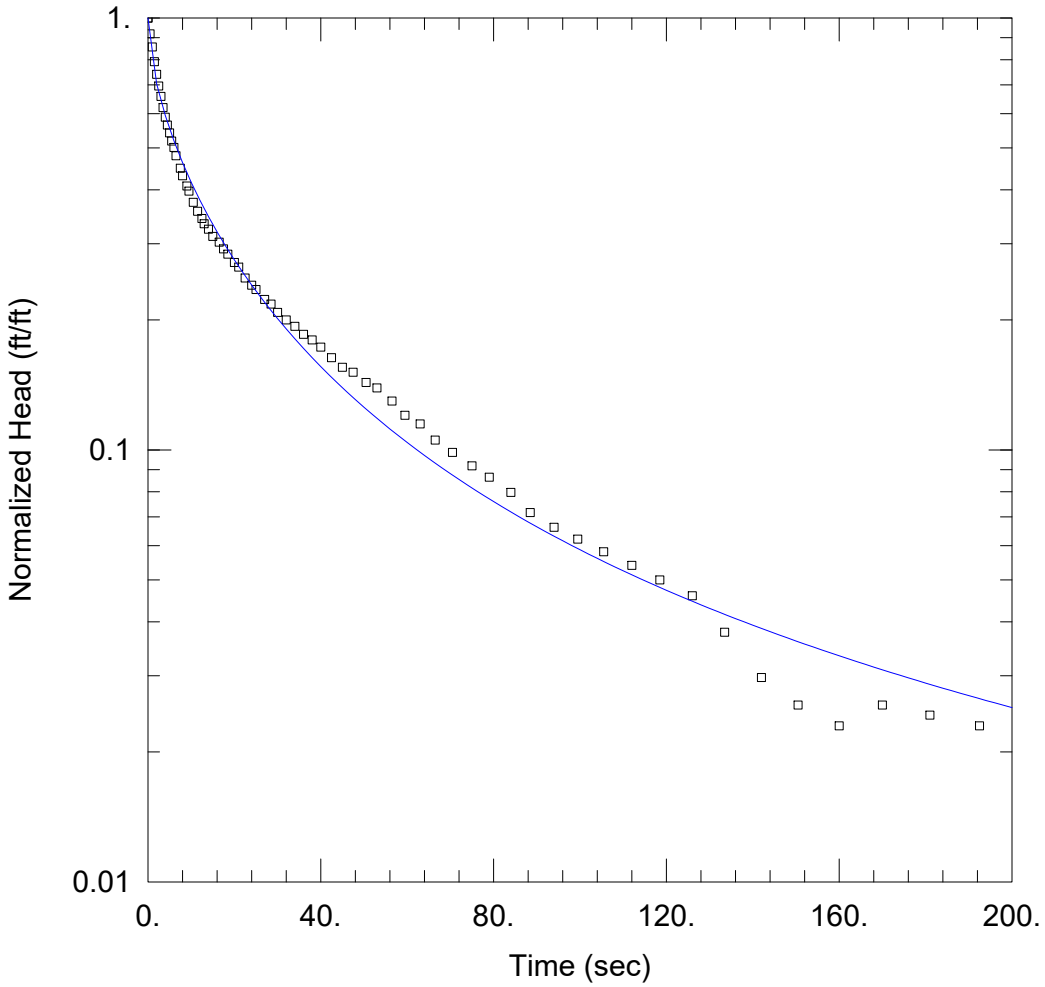
SOLUTION

Aquifer Model: Unconfined

Kr = 0.00122 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.00094 ft^{-1}



XPW04 RH2

PROJECT INFORMATION

Company: Ramboll
Client: IPGC
Project: 1940100499-001
Location: Newton
Test Well: XPW04
Test Date: 3/11/21

AQUIFER DATA

Saturated Thickness: 9.9 ft

WELL DATA (XPW04)

Initial Displacement: 0.74 ft
Total Well Penetration Depth: 9.9 ft
Casing Radius: 0.086 ft

Static Water Column Height: 10.4 ft
Screen Length: 9.5 ft
Well Radius: 0.25 ft
Gravel Pack Porosity: 0.

SOLUTION

Aquifer Model: Unconfined

Kr = 0.00101 cm/sec
Kz/Kr = 1.

Solution Method: KGS Model

Ss = 0.0019 ft^{-1}

2017 HYDRAULIC CONDUCTIVITY TEST DATA

Appendix C - Table 1
Newton Power Station
Slug Test Results - Primary Ash Pond Wells (ID 501)
Hydrogeologic Monitoring Plan

Well ID	Slug In 1	Slug In 2	Slug In 3	Slug Out 1	Slug Out 2	Slug Out 3	Slug Out 4	MIN	MAX	GEOMEAN	Solution
APW2		4.41E-05		4.52E-05		3.45E-05		3.45E-05	4.52E-05	4.1E-05	Bouwer-Rice
APW3	8.44E-06			8.61E-06				8.44E-06	8.61E-06	8.5E-06	Bouwer-Rice
APW4	6.66E-06			5.14E-06				5.14E-06	6.66E-06	5.8E-06	Bouwer-Rice
APW5	5.66E-04	1.42E-03		1.54E-04	2.74E-04	2.56E-04		1.54E-04	1.42E-03	3.9E-04	Bouwer-Rice
APW6	1.64E-03	2.18E-03			2.09E-03	1.98E-03		1.64E-03	2.18E-03	2.0E-03	Bouwer-Rice
APW7	2.25E-03				3.24E-03	2.99E-03	2.75E-03	2.25E-03	3.24E-03	2.8E-03	Bouwer-Rice
APW8	6.60E-04	1.31E-03			1.06E-03	7.89E-04		6.60E-04	1.31E-03	9.2E-04	Bouwer-Rice
APW9	3.21E-03	3.28E-03		3.40E-03	3.00E-03			3.00E-03	3.40E-03	3.2E-03	Bouwer-Rice
APW10	5.27E-04	5.49E-04			5.73E-04	5.60E-04		5.27E-04	5.73E-04	5.5E-04	Bouwer-Rice

All slug test (i.e. hydraulic conductivity) results are in centimeters per second
Not Applicable

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Appendix C - Table 2
Newton Power Station
Slug Test Results - Landfill 2 CCR Wells (ID 502)
Hydrogeologic Monitoring Plan

Well ID	Slug In 1	Slug In 2	Slug In 3	Slug Out 1	Slug Out 2	Slug Out 3	MIN	MAX	GEOMEAN	Solution
G06D				3.92E-08			3.92E-08	3.92E-08	3.9E-08	Bouwer-Rice
G202	1.70E-02	1.43E-02			2.87E-02	2.33E-02	1.43E-02	2.87E-02	2.0E-02	Bouwer-Rice
G203	2.53E-02			2.42E-02	3.47E-02		2.42E-02	3.47E-02	2.8E-02	Bouwer-Rice
G208				1.32E-08			1.32E-08	1.32E-08	1.3E-08	Bouwer-Rice
G217D	2.27E-04	2.92E-04				3.03E-04	2.27E-04	3.03E-04	2.7E-04	Bouwer-Rice
G220				3.51E-07			3.51E-07	3.51E-07	3.5E-07	Bouwer-Rice
G222				1.54E-06			1.54E-06	1.54E-06	1.5E-06	Bouwer-Rice
G223	5.19E-05	2.50E-05		1.37E-05	1.79E-05		1.37E-05	5.19E-05	2.4E-05	Bouwer-Rice
G224	5.15E-02	1.90E-02	4.64E-02	4.31E-02		2.97E-02	1.90E-02	5.15E-02	3.6E-02	Bouwer-Rice

All slug test (i.e. hydraulic conductivity) results are in centimeters per second
Not Applicable

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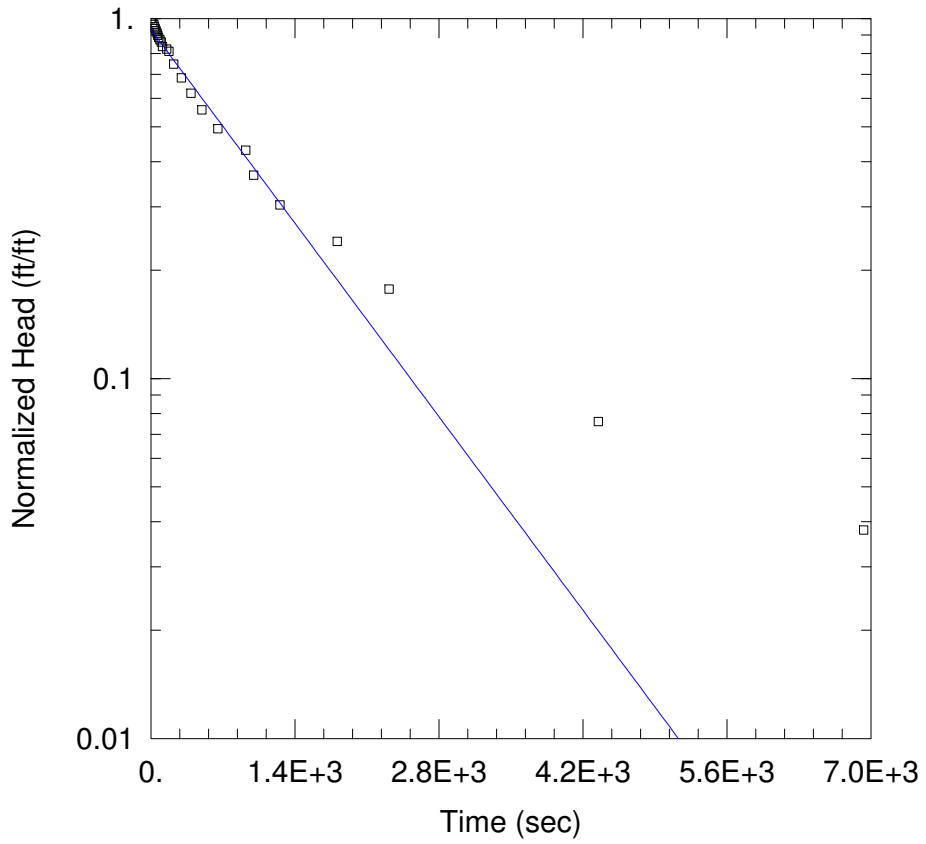


WELL TEST ANALYSIS

Data Set: P:\...\APW2 SI2.aqt
Date: 10/09/17 Time: 15:04:26

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW2
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

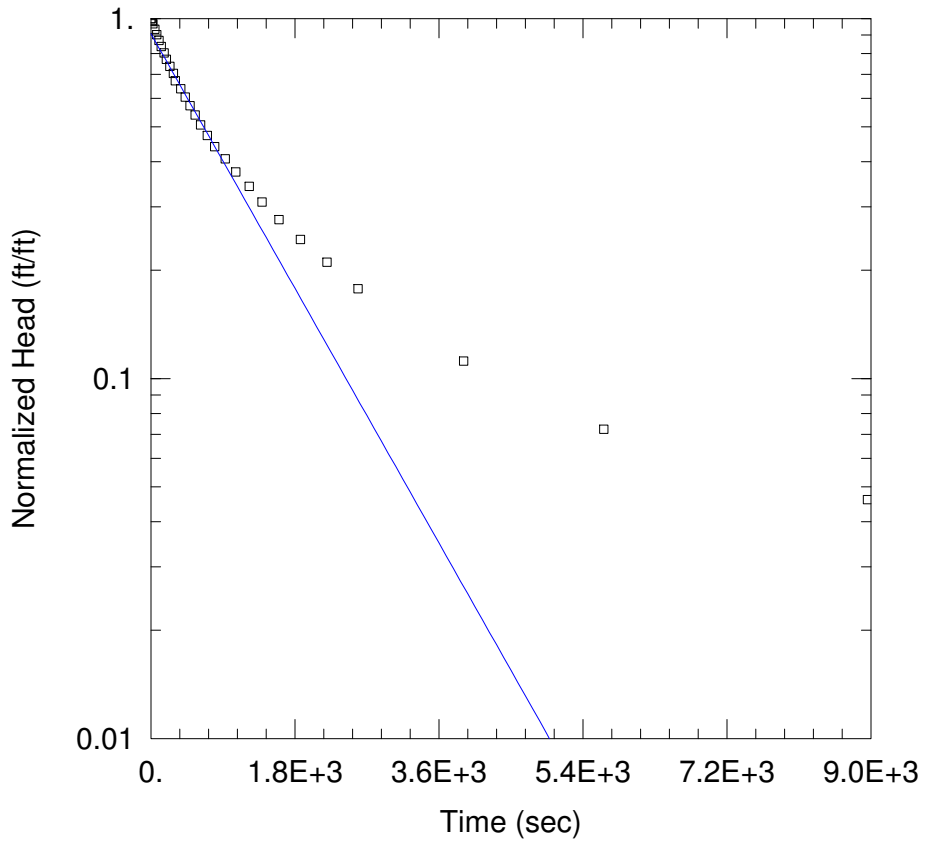
K = 4.414E-5 cm/sec
y0 = 0.7361 ft

AQUIFER DATA

Saturated Thickness: 9. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW2 SI2)

Initial Displacement: 0.79 ft
Total Well Penetration Depth: 6.4 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 9. ft
Screen Length: 3.4 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW2 SO1.aqt
Date: 10/09/17 Time: 15:05:33

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW2
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

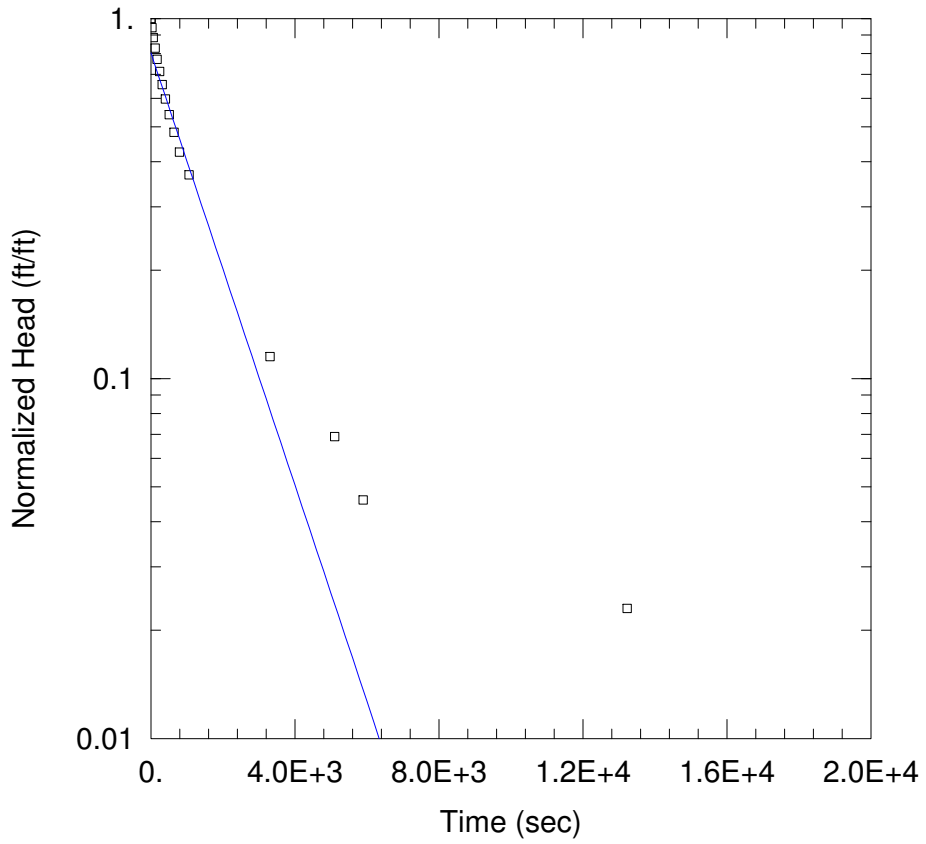
K = 4.517E-5 cm/sec
y0 = 1.38 ft

AQUIFER DATA

Saturated Thickness: 9. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW2 SO1)

Initial Displacement: 1.52 ft
Total Well Penetration Depth: 6.4 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 9. ft
Screen Length: 3.4 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW2 SO3.aqt
Date: 10/09/17 Time: 15:06:23

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW2
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

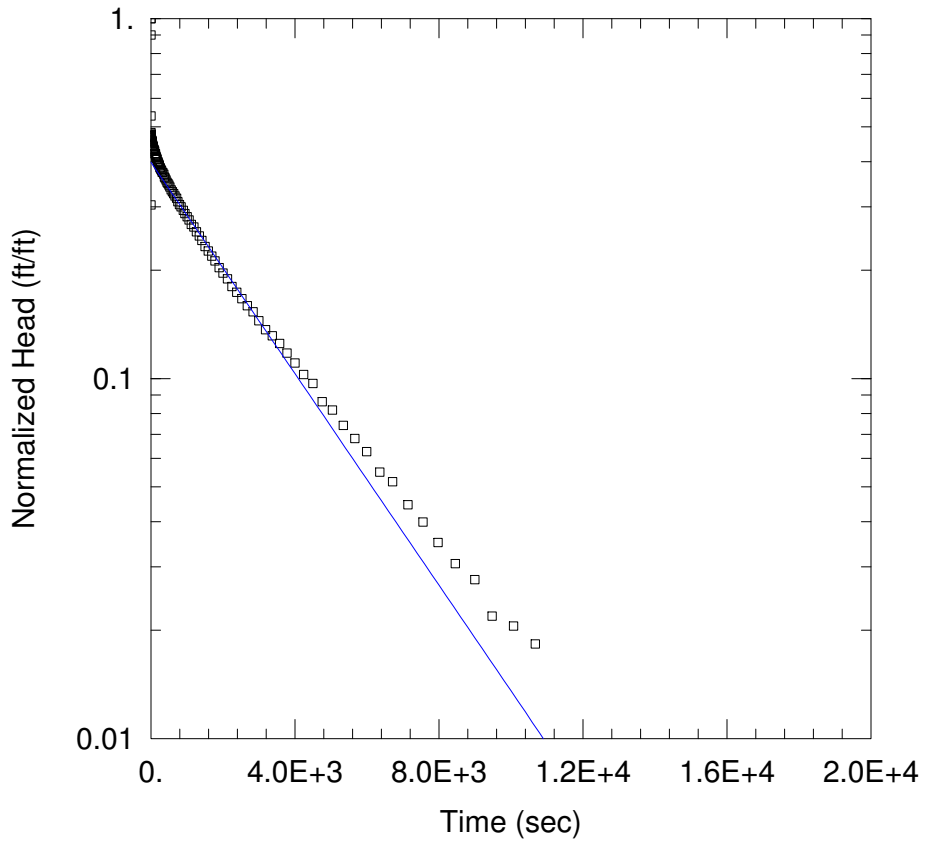
K = 3.449E-5 cm/sec
y0 = 0.698 ft

AQUIFER DATA

Saturated Thickness: 9. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW2 SO3)

Initial Displacement: 0.87 ft
Total Well Penetration Depth: 6.4 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 9. ft
Screen Length: 3.4 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW 3 SI1.aqt
Date: 10/09/17 Time: 15:13:21

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW3
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

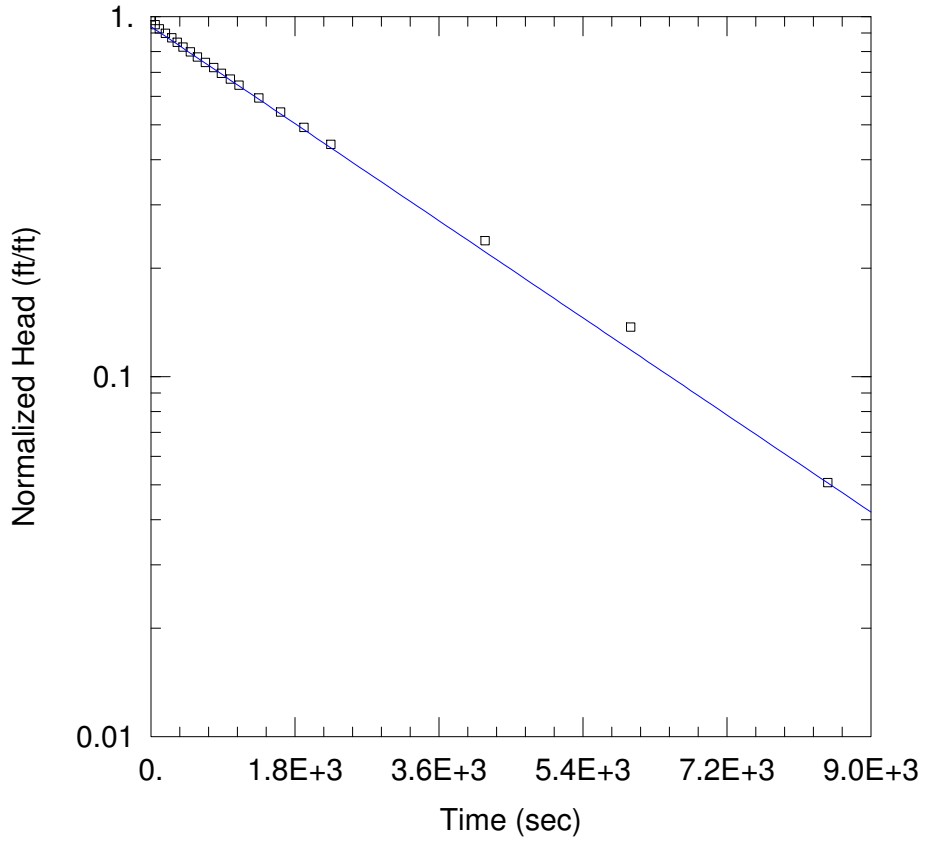
K = 8.437E-6 cm/sec
y0 = 1.458 ft

AQUIFER DATA

Saturated Thickness: 14. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW3 SI1)

Initial Displacement: 3.656 ft
Total Well Penetration Depth: 11.5 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 14. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW 3 SO1.aqt
Date: 10/09/17 Time: 15:08:16

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW3
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

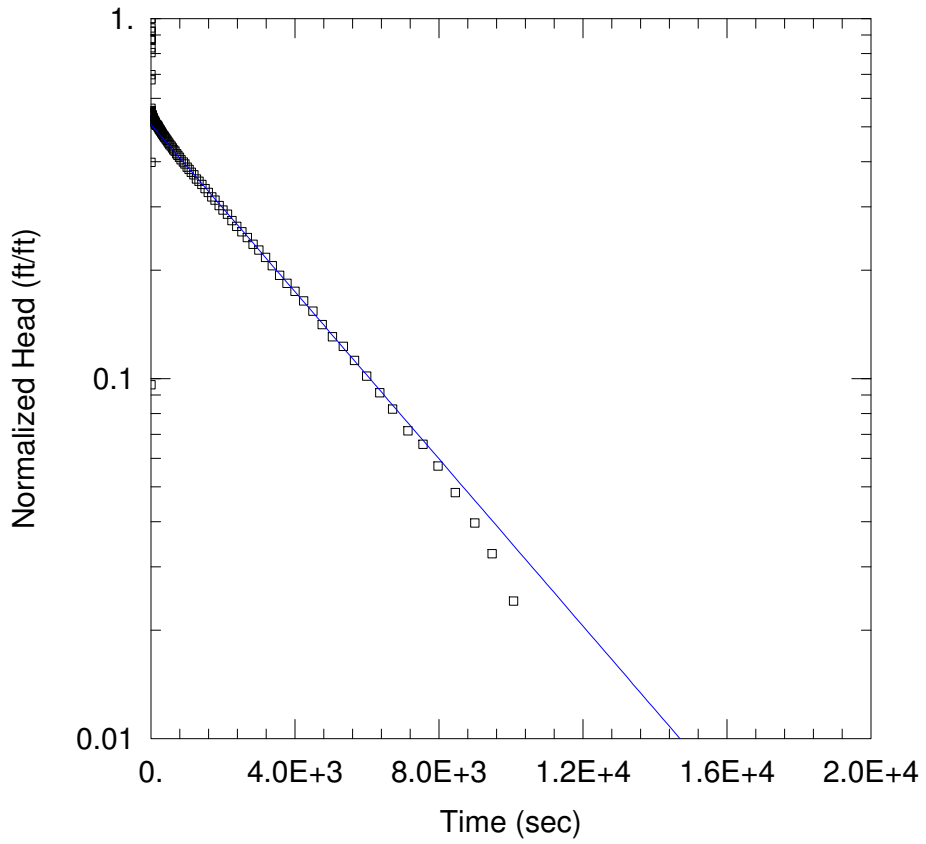
K = 8.611E-6 cm/sec
y0 = 1.848 ft

AQUIFER DATA

Saturated Thickness: 14. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW3 SO1)

Initial Displacement: 1.97 ft
Total Well Penetration Depth: 11.5 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 14. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW 4 SI1.aqt
Date: 10/09/17 Time: 15:15:09

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW4
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

K = 6.66E-6 cm/sec
y0 = 1.37 ft

AQUIFER DATA

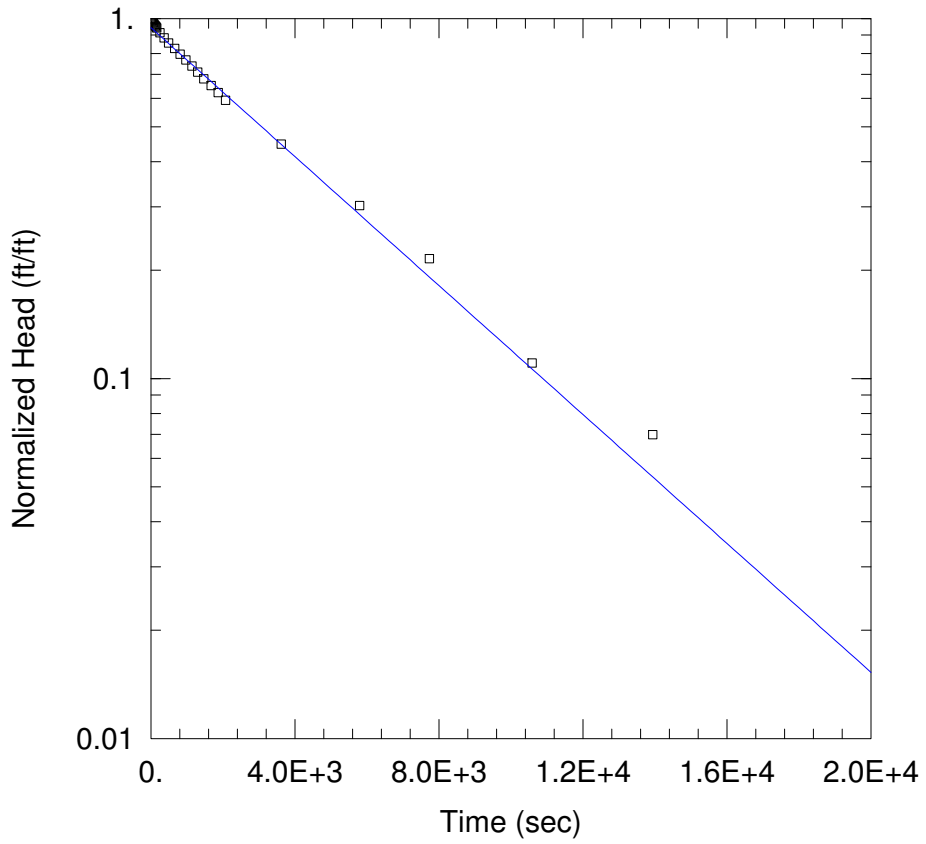
Saturated Thickness: 11. ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW4 S11)

Initial Displacement: 2.697 ft
Total Well Penetration Depth: 10. ft
Casing Radius: 0.08333 ft

Static Water Column Height: 11. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW 4 SO1.aqt
Date: 10/09/17 Time: 15:15:46

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW4
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

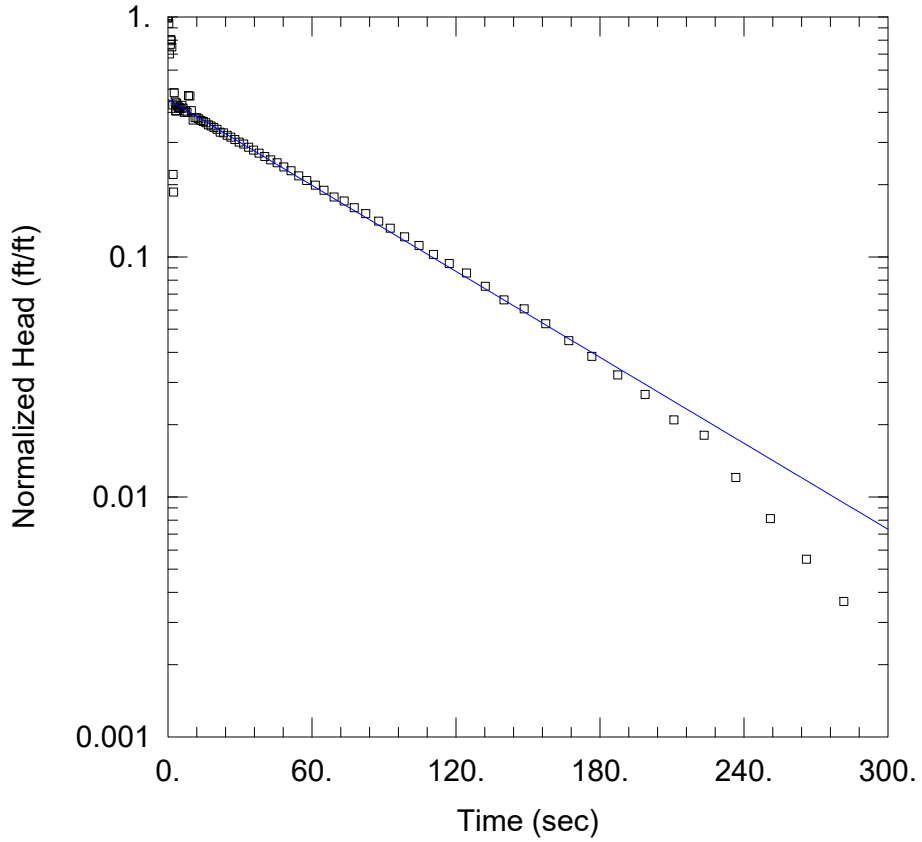
K = 5.137E-6 cm/sec
y0 = 1.622 ft

AQUIFER DATA

Saturated Thickness: 11. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW4 SO1)

Initial Displacement: 1.72 ft
Total Well Penetration Depth: 10. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 11. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW5 SI1.aqt
Date: 06/15/17 Time: 11:53:01

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW5
Test Date: 4/6/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

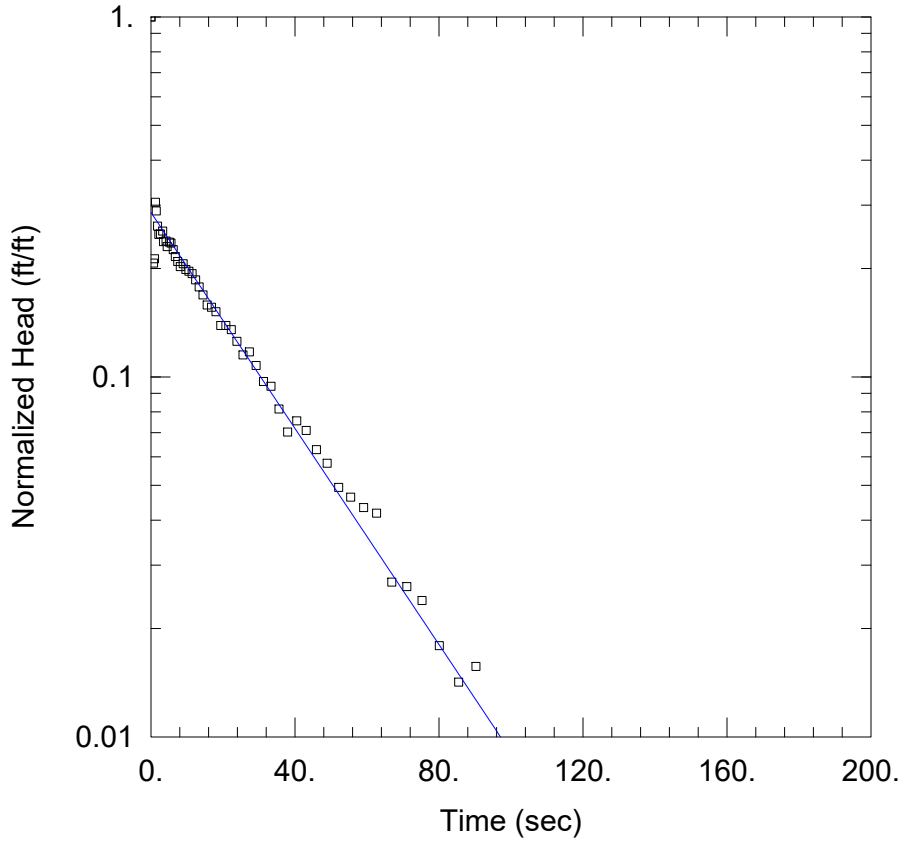
K = 0.0005655 cm/sec
y0 = 1.731 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW5 SI1)

Initial Displacement: 3.818 ft
Total Well Penetration Depth: 6.81 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 4.68 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW5 SI2.aqt
Date: 05/12/17 Time: 17:23:52

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW5
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

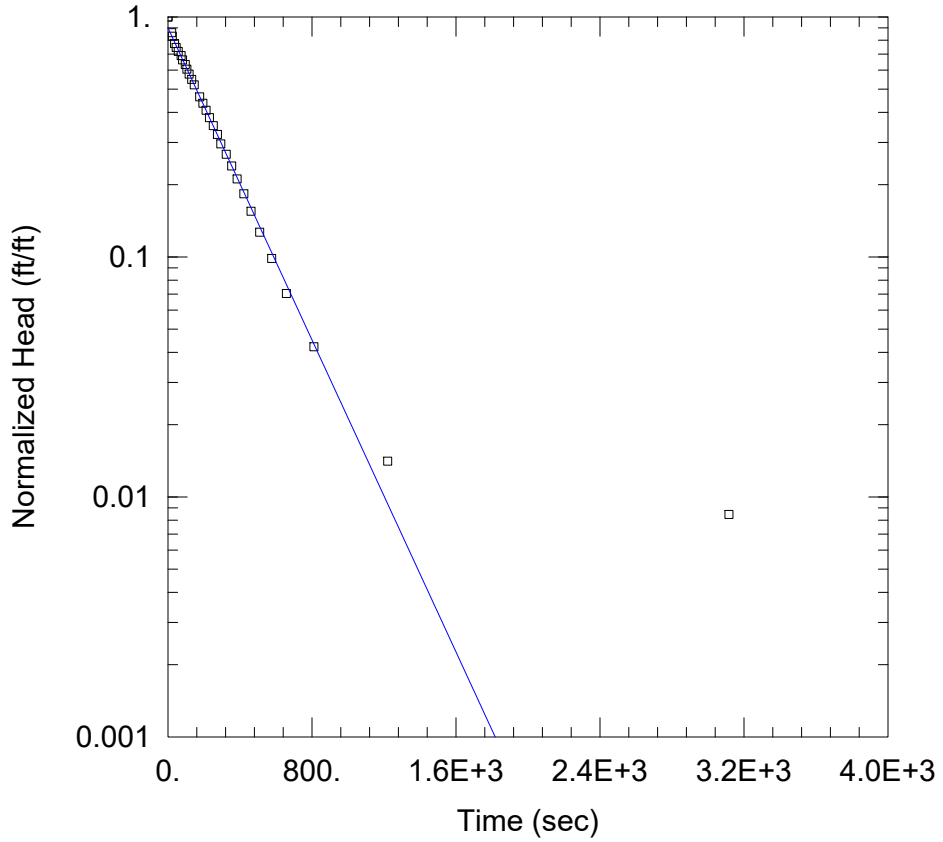
K = 0.001421 cm/sec
y0 = 0.383 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW5 SI2)

Initial Displacement: 1.338 ft
Total Well Penetration Depth: 6.81 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 4.68 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW5 SO1.aqt
Date: 05/12/17 Time: 17:30:12

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW5
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

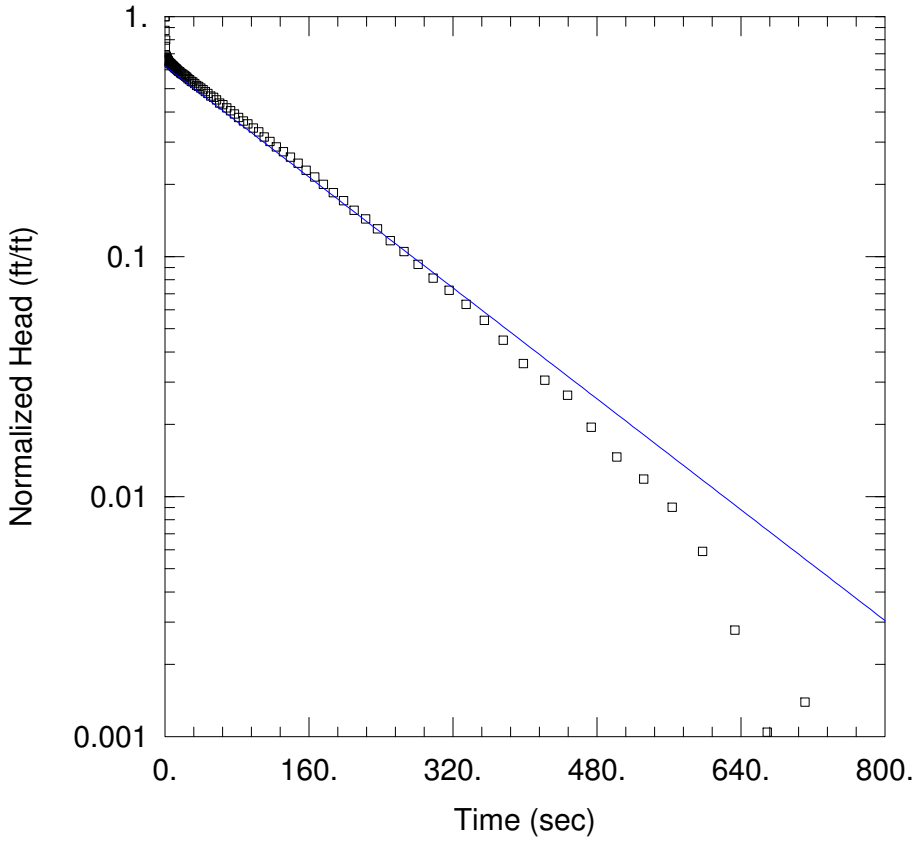
K = 0.0001539 cm/sec
y0 = 3.197 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW5 SO1)

Initial Displacement: 3.55 ft
Total Well Penetration Depth: 6.81 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 4.68 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW5 SO2.aqt
Date: 10/09/17 Time: 14:59:07

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW5
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

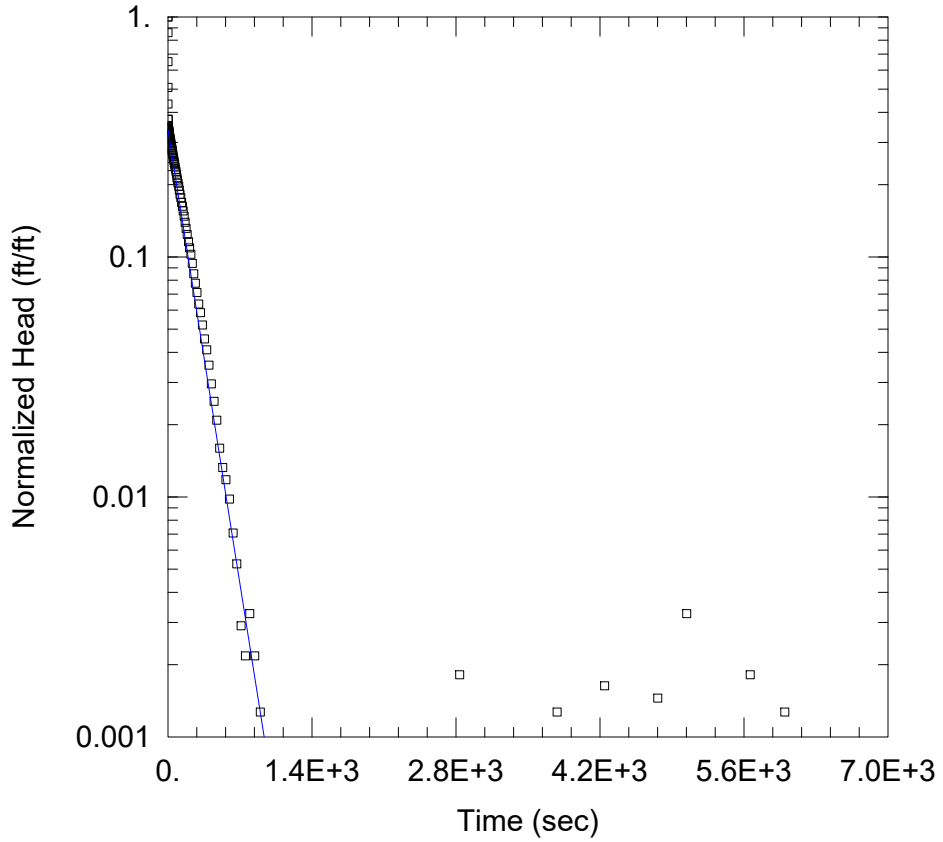
K = 0.0002735 cm/sec
y0 = 1.789 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW5 SO2)

Initial Displacement: 2.879 ft
Total Well Penetration Depth: 6.81 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 4.68 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW5 SO3.aqt
Date: 06/15/17 Time: 11:57:15

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW5
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

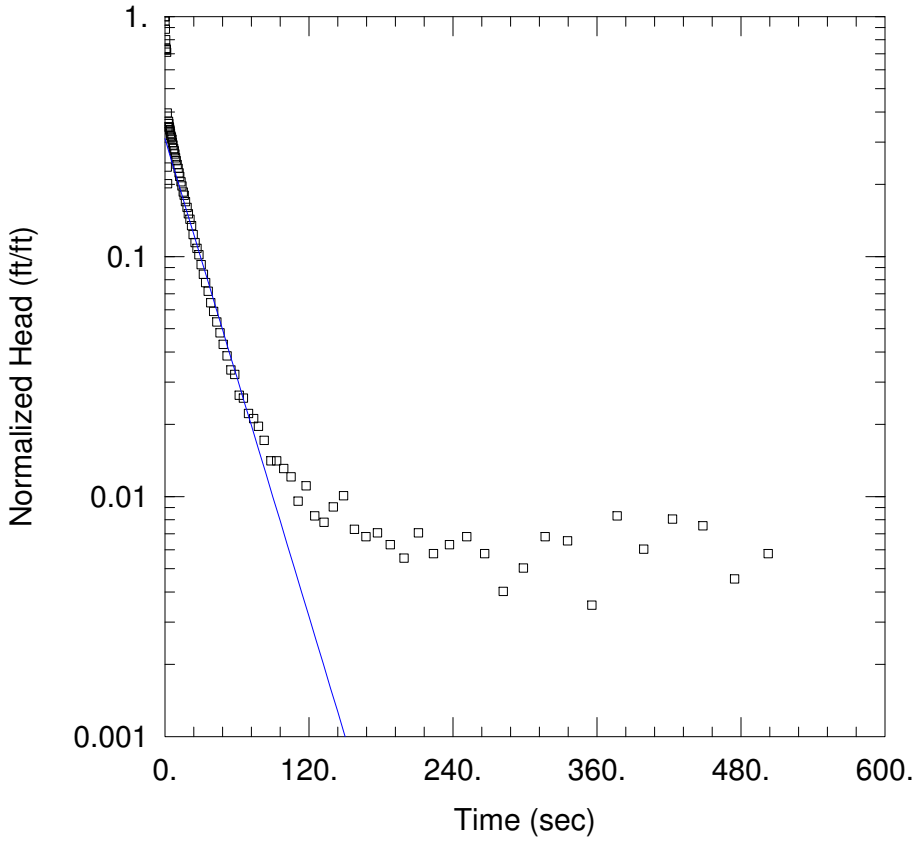
K = 0.0002559 cm/sec
y0 = 1.858 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW5 SO3)

Initial Displacement: 5.512 ft
Total Well Penetration Depth: 6.81 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 4.68 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW6 SI1.aqt
Date: 10/10/17 Time: 08:43:51

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW6
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

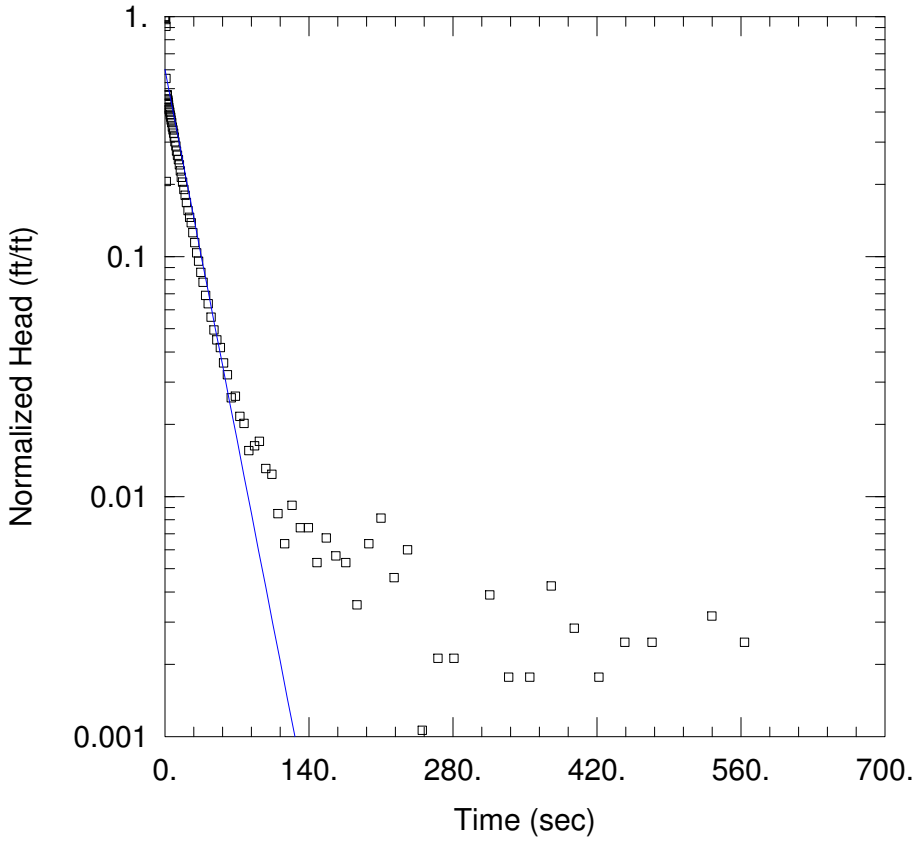
K = 0.001642 cm/sec
y0 = 1.231 ft

AQUIFER DATA

Saturated Thickness: 6.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW6 SI1)

Initial Displacement: 3.973 ft
Total Well Penetration Depth: 3.3 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.5 ft
Screen Length: 3.3 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW6 SI2.aqt
Date: 10/10/17 Time: 08:45:57

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW6
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

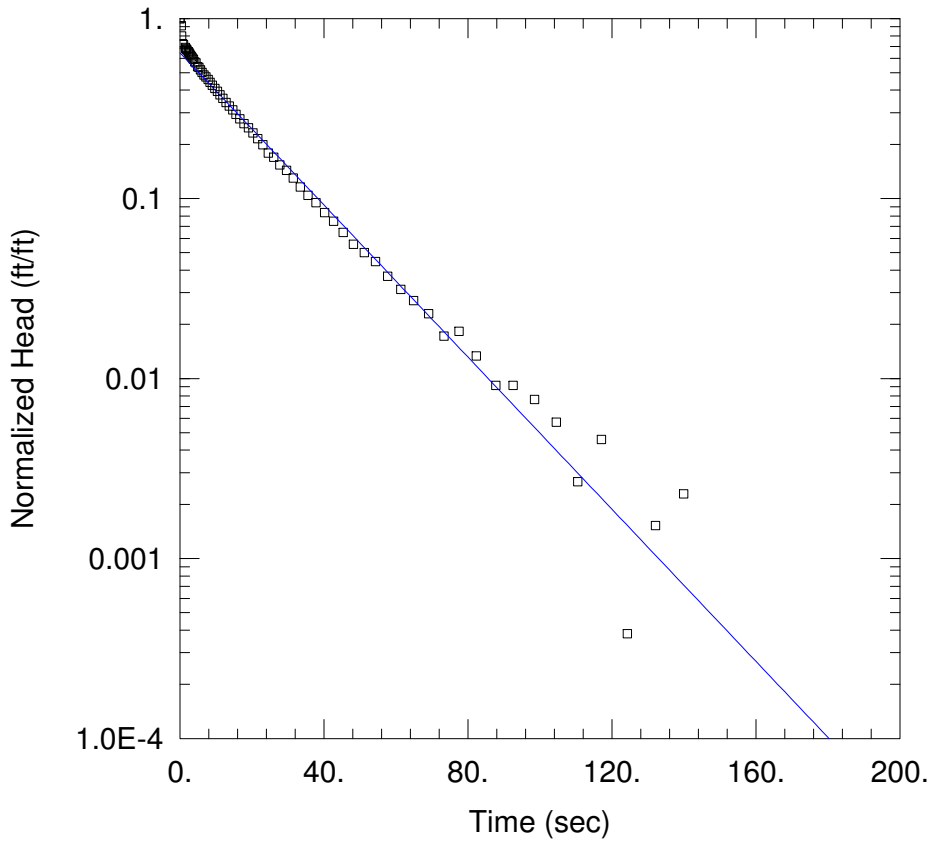
K = 0.002177 cm/sec
y0 = 1.702 ft

AQUIFER DATA

Saturated Thickness: 6.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW6 SI2)

Initial Displacement: 2.83 ft
Total Well Penetration Depth: 3.3 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.5 ft
Screen Length: 3.3 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW6 SO2.aqt
Date: 10/10/17 Time: 08:48:43

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW6
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.002091 cm/sec
y0 = 1.689 ft

AQUIFER DATA

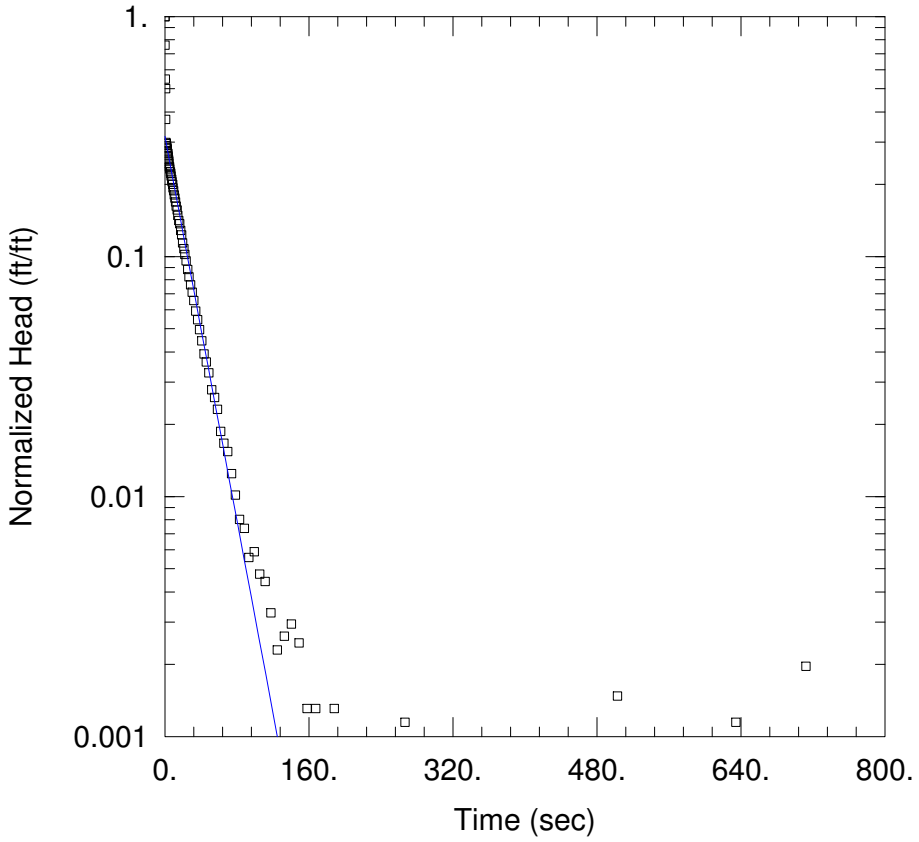
Saturated Thickness: 6.5 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW6 SO2)

Initial Displacement: 2.62 ft
Total Well Penetration Depth: 3.3 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 6.5 ft
Screen Length: 3.3 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW6 SO3.aqt
Date: 10/10/17 Time: 08:51:05

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW6
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

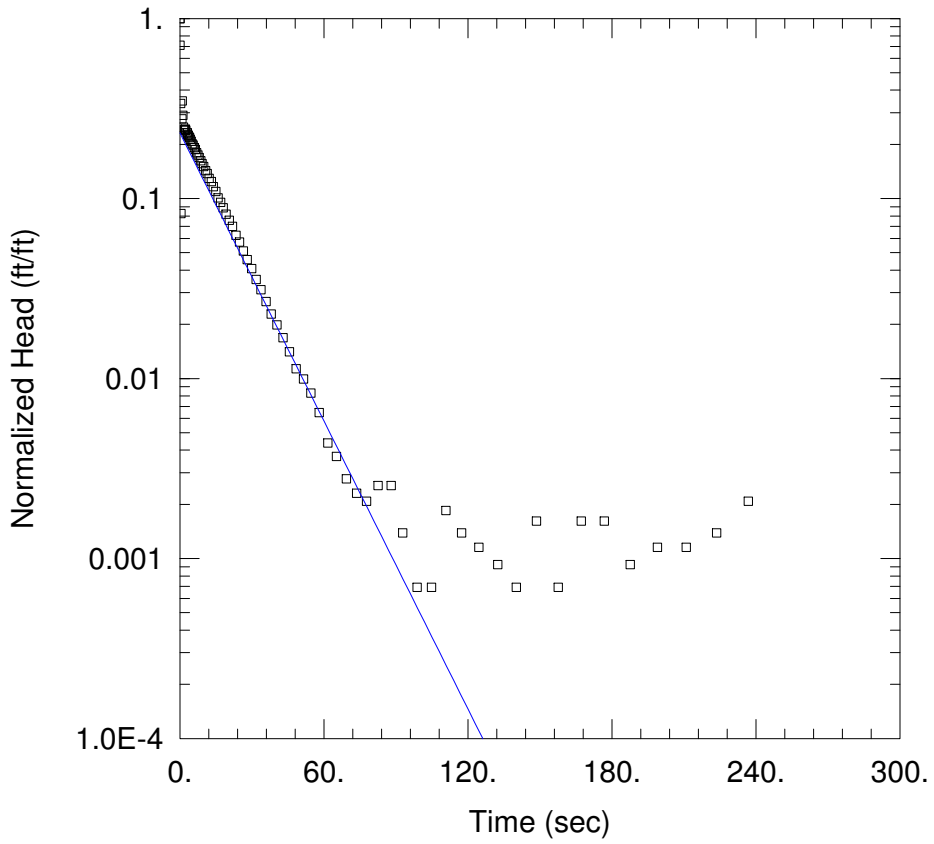
K = 0.001979 cm/sec
y0 = 1.936 ft

AQUIFER DATA

Saturated Thickness: 6.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW6 SO3)

Initial Displacement: 6.109 ft
Total Well Penetration Depth: 3.3 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.5 ft
Screen Length: 3.3 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW7 SI1.aqt
Date: 10/10/17 Time: 09:03:20

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW7
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

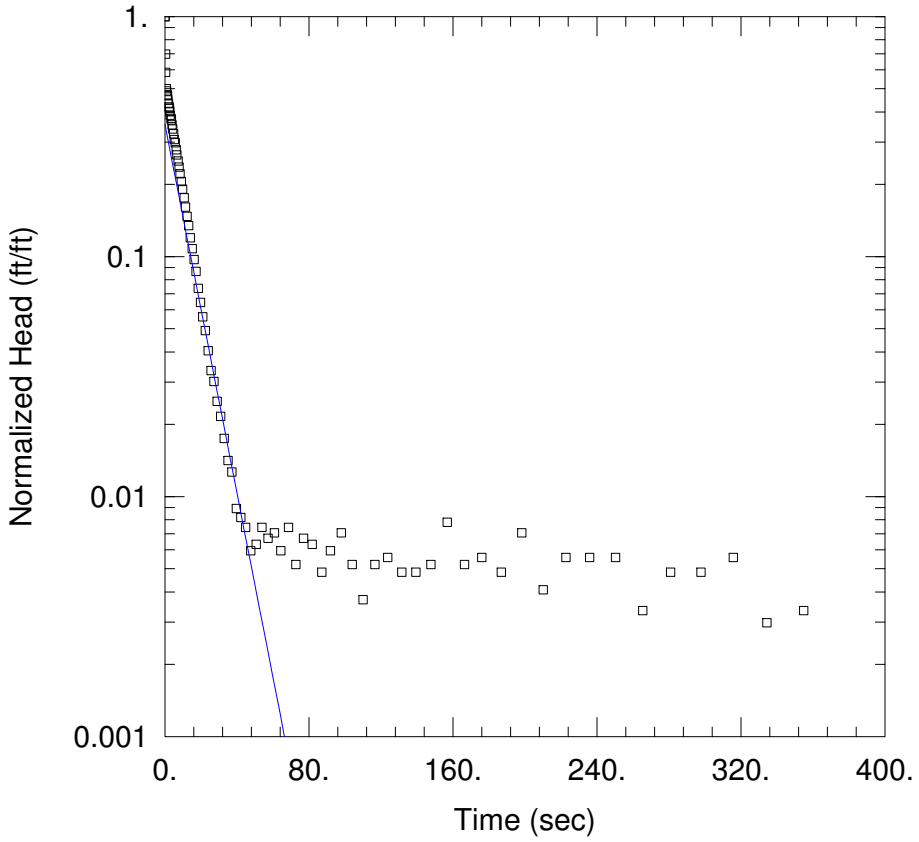
K = 0.00225 cm/sec
y0 = 1.004 ft

AQUIFER DATA

Saturated Thickness: 7.1 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW7 SI1)

Initial Displacement: 4.331 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.1 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW7 SO2.aqt
Date: 10/10/17 Time: 09:05:47

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW7
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

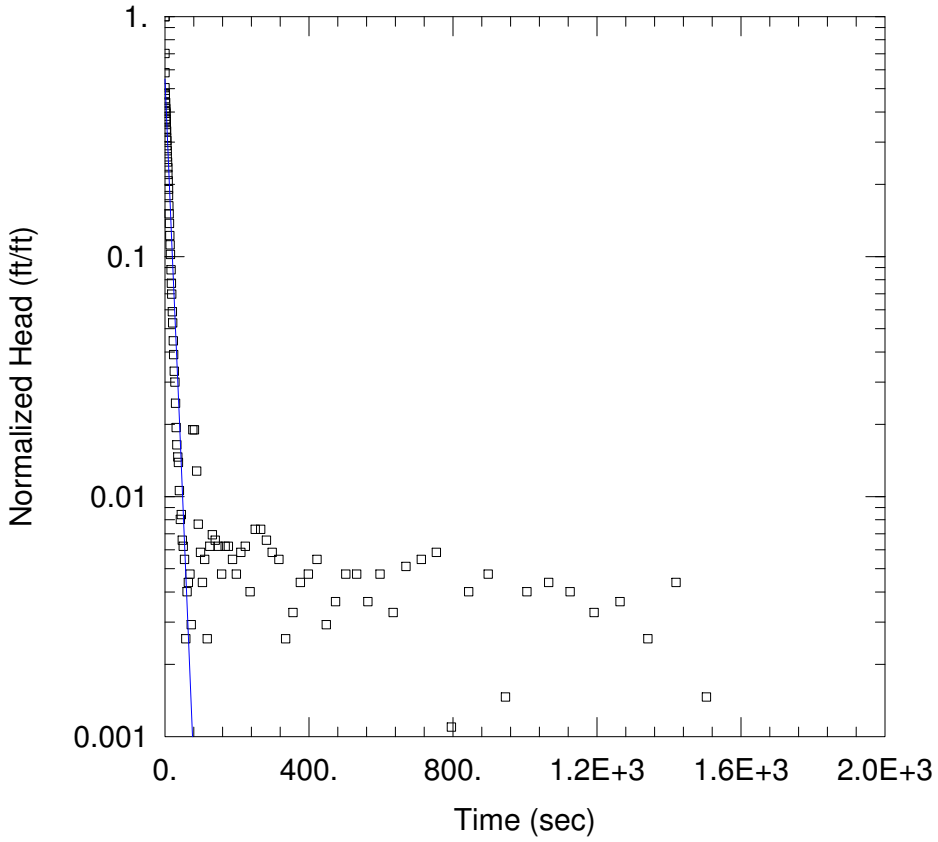
K = 0.003237 cm/sec
y0 = 0.9561 ft

AQUIFER DATA

Saturated Thickness: 7.1 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW7 S02)

Initial Displacement: 2.69 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.1 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW7 SO3.aqt
Date: 10/10/17 Time: 09:07:38

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW7
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

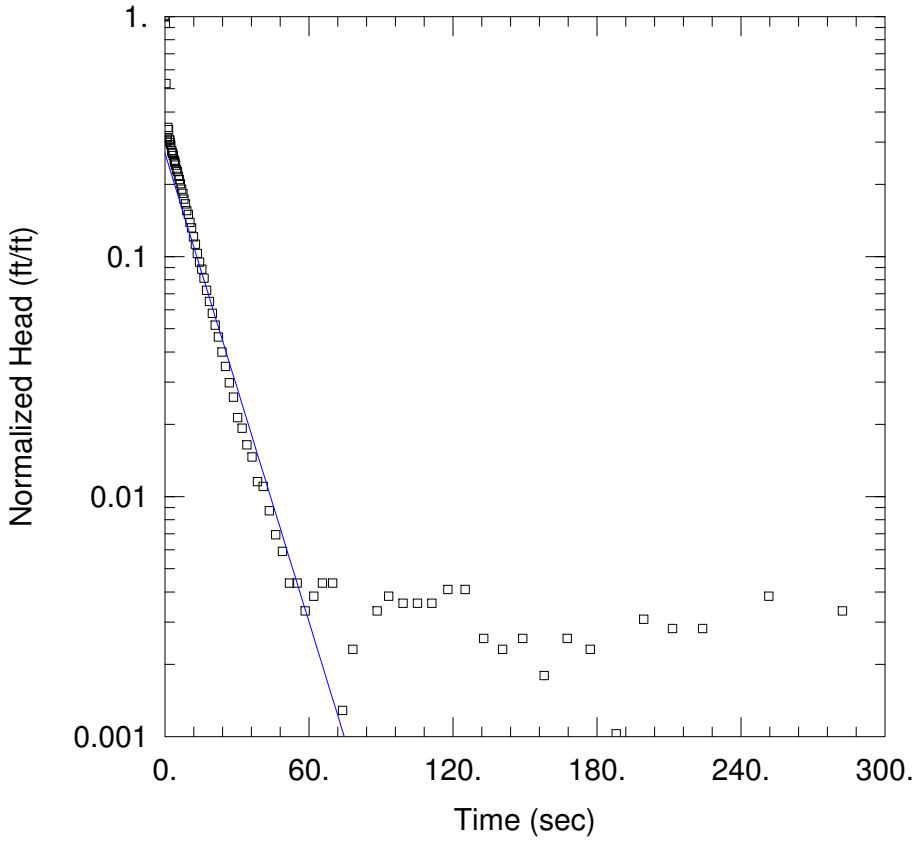
K = 0.002989 cm/sec
y0 = 1.503 ft

AQUIFER DATA

Saturated Thickness: 7.1 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW7 S03)

Initial Displacement: 2.738 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.1 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW7 SO4.aqt
Date: 10/10/17 Time: 09:09:26

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW7
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

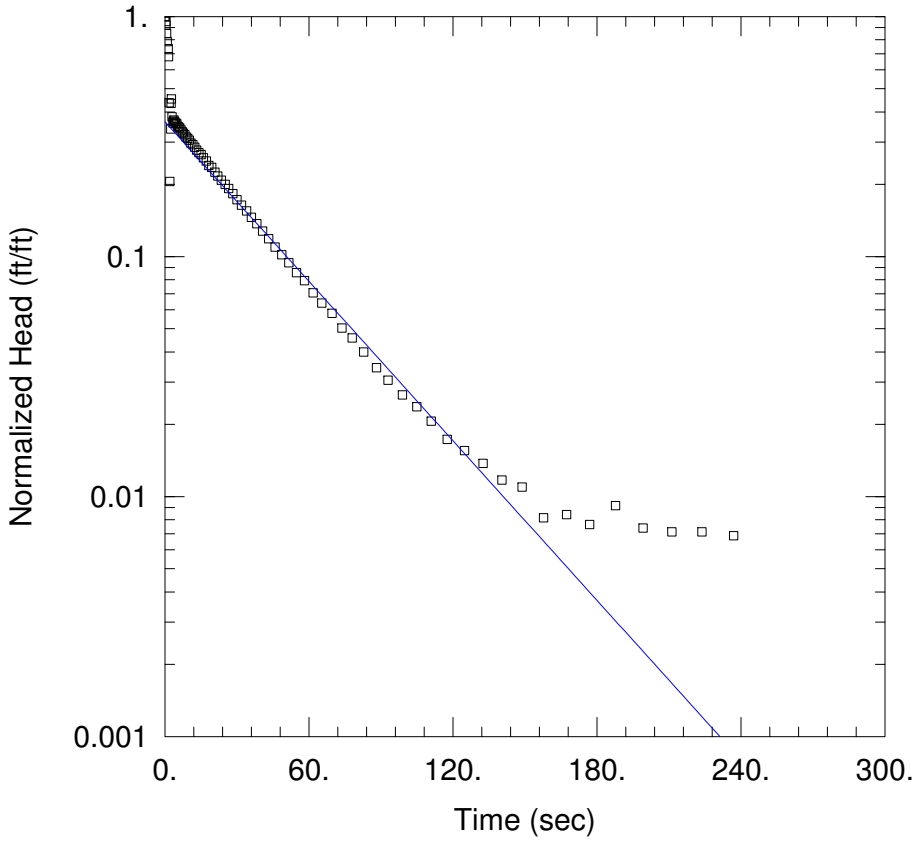
K = 0.002745 cm/sec
y0 = 1.052 ft

AQUIFER DATA

Saturated Thickness: 7.1 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW7 SO4)

Initial Displacement: 3.899 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 7.1 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW8 SI1.aqt
Date: 10/10/17 Time: 09:12:16

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW8
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

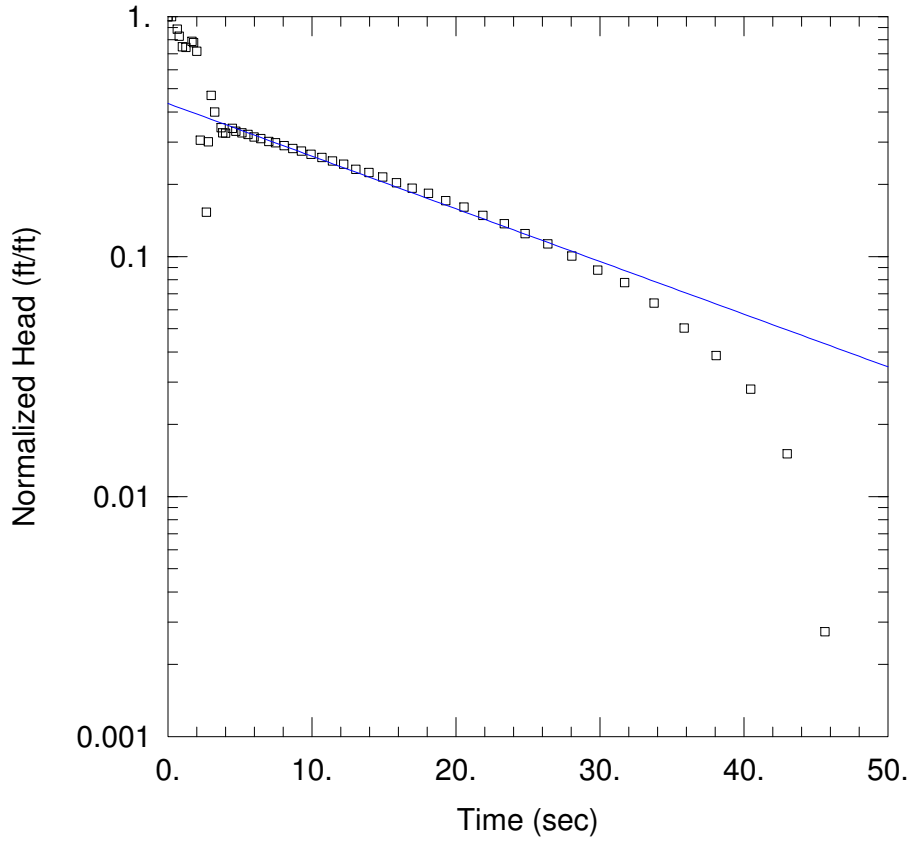
K = 0.0006602 cm/sec
y0 = 1.431 ft

AQUIFER DATA

Saturated Thickness: 16.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW8 SI1)

Initial Displacement: 3.929 ft
Total Well Penetration Depth: 12.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.3 ft
Screen Length: 9.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW8 SI2.aqt
Date: 10/10/17 Time: 09:39:50

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW8
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

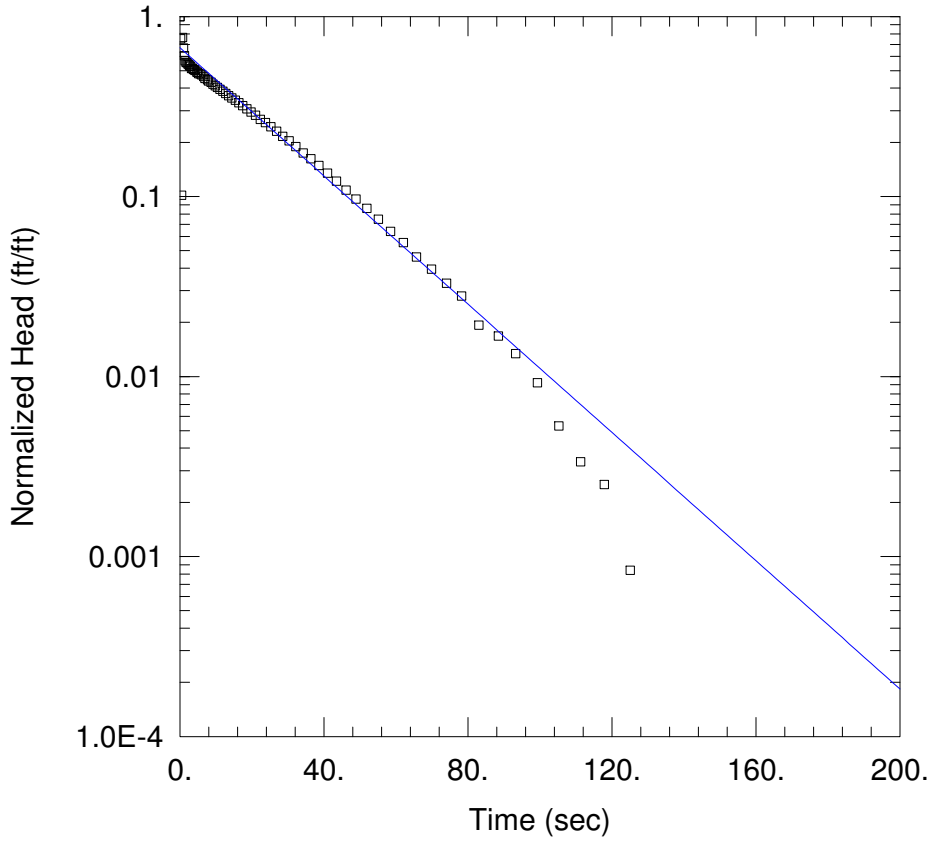
K = 0.001308 cm/sec
y0 = 1.269 ft

AQUIFER DATA

Saturated Thickness: 16.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW8 SI2)

Initial Displacement: 2.924 ft
Total Well Penetration Depth: 12.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.3 ft
Screen Length: 9.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW8 SO2.aqt
Date: 10/10/17 Time: 09:41:42

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW8
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

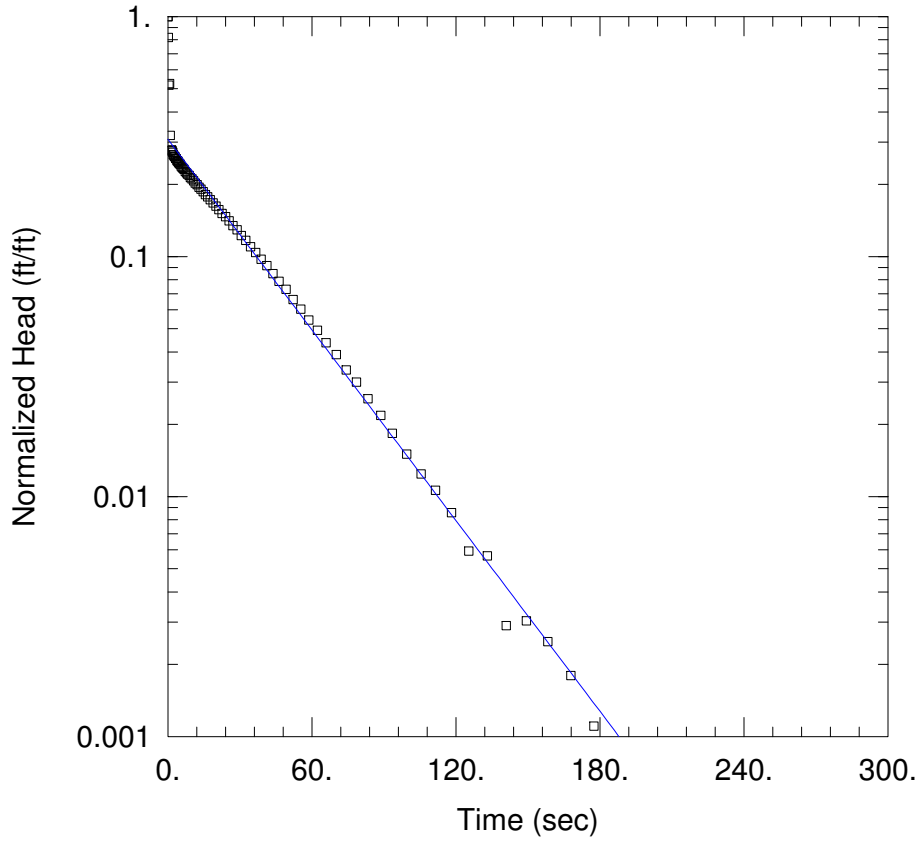
K = 0.001062 cm/sec
y0 = 2.403 ft

AQUIFER DATA

Saturated Thickness: 16.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW8 SO2)

Initial Displacement: 3.577 ft
Total Well Penetration Depth: 12.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.3 ft
Screen Length: 9.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW8 SO3.aqt
Date: 10/10/17 Time: 09:43:26

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW8
Test Date: 4/6/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

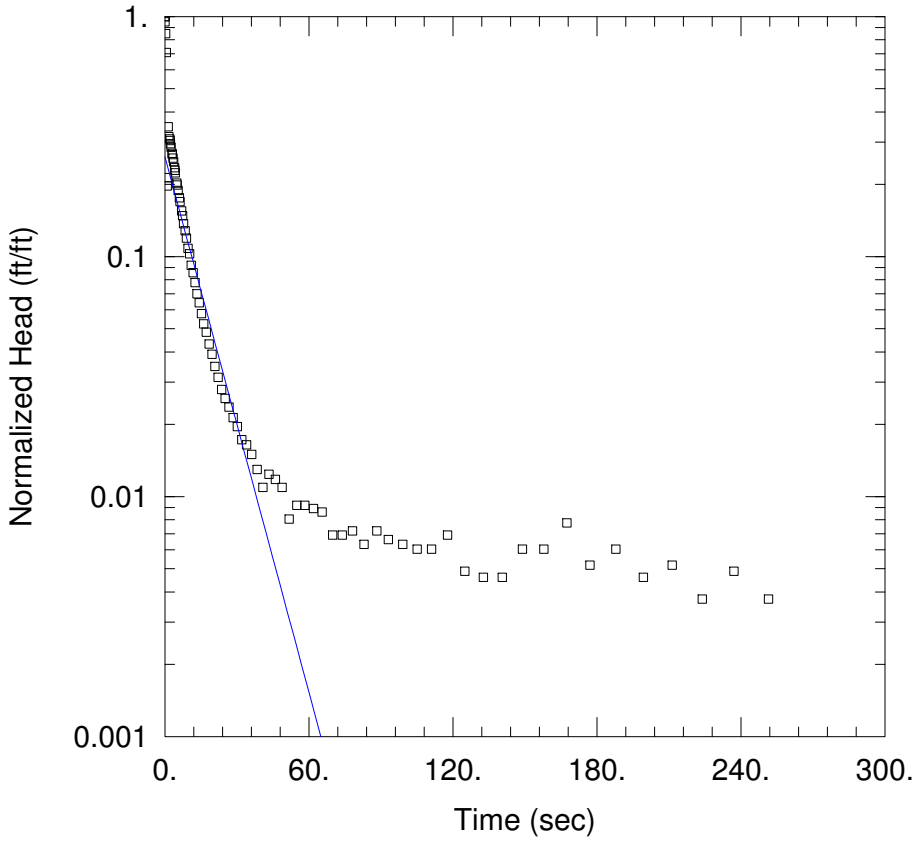
K = 0.0007891 cm/sec
y0 = 2.233 ft

AQUIFER DATA

Saturated Thickness: 16.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW8 SO3)

Initial Displacement: 7.249 ft
Total Well Penetration Depth: 12.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 16.3 ft
Screen Length: 9.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW9 SI1.aqt
Date: 10/10/17 Time: 09:48:54

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW9
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

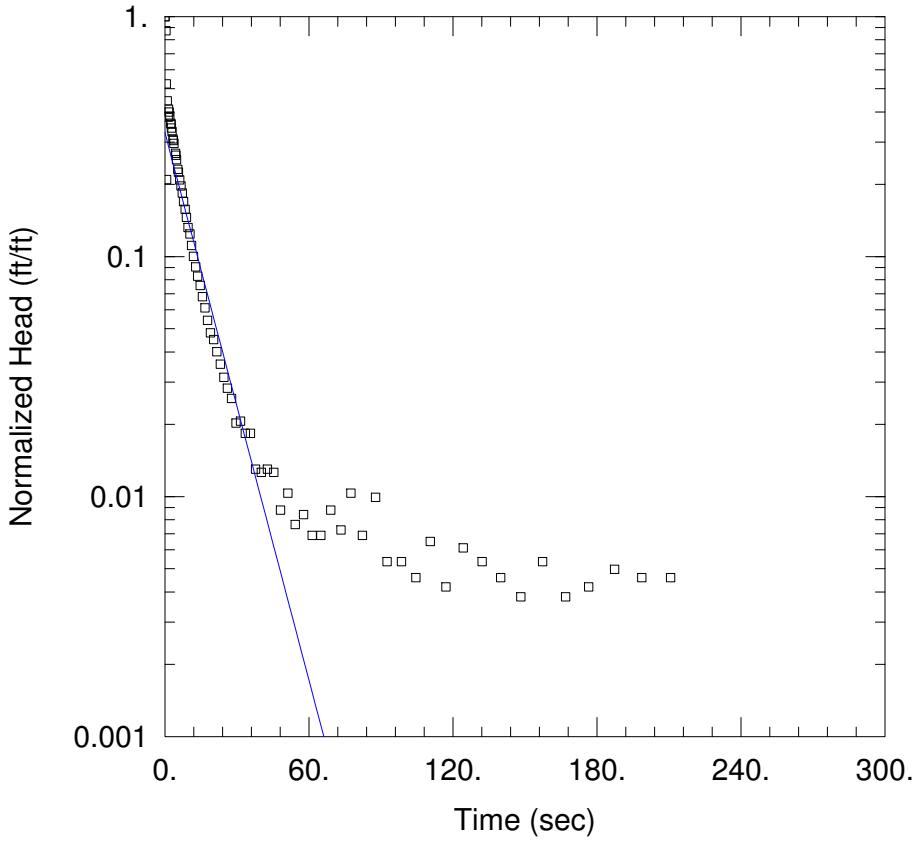
K = 0.00321 cm/sec
y0 = 0.9059 ft

AQUIFER DATA

Saturated Thickness: 6.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW9 SI1)

Initial Displacement: 3.477 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.3 ft
Screen Length: 4.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW9 SI2.aqt
Date: 10/10/17 Time: 09:50:42

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW9
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

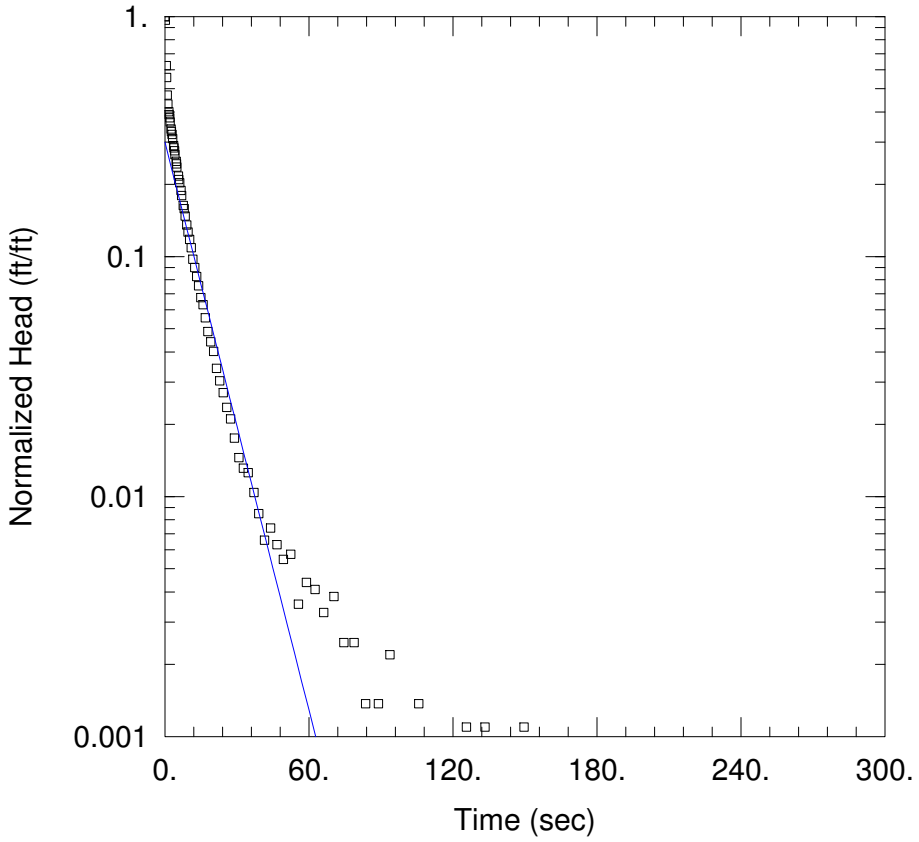
K = 0.003282 cm/sec
y0 = 0.8588 ft

AQUIFER DATA

Saturated Thickness: 6.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW9 SI2)

Initial Displacement: 2.617 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.3 ft
Screen Length: 4.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW9 SO1.aqt
Date: 10/10/17 Time: 09:52:04

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW9
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

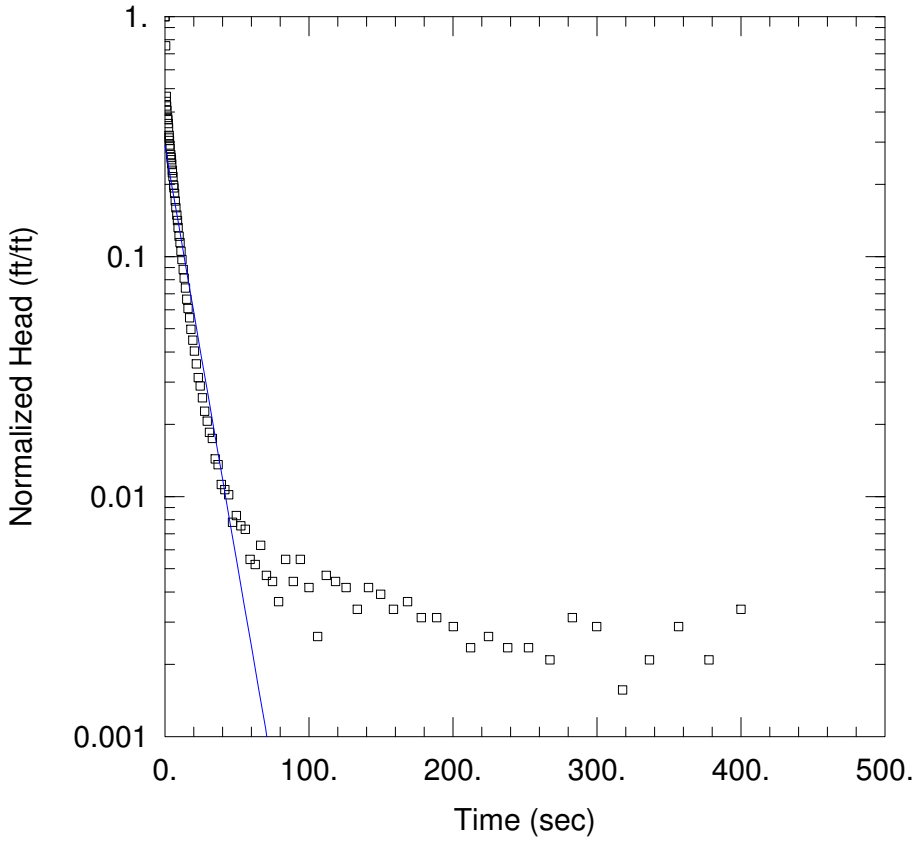
K = 0.003404 cm/sec
y0 = 1.094 ft

AQUIFER DATA

Saturated Thickness: 6.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW9 SO1)

Initial Displacement: 3.654 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.3 ft
Screen Length: 4.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW9 SO2.aqt
Date: 10/10/17 Time: 09:53:49

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW9
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

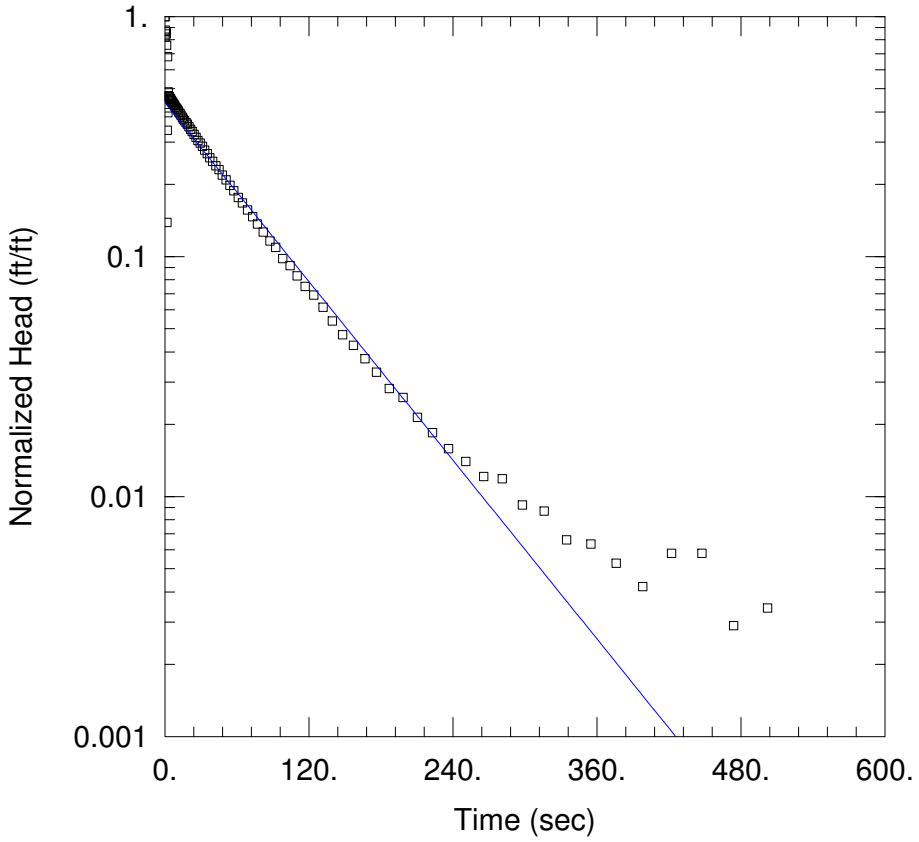
K = 0.003003 cm/sec
y0 = 1.117 ft

AQUIFER DATA

Saturated Thickness: 6.3 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW9 SO2)

Initial Displacement: 3.837 ft
Total Well Penetration Depth: 4.7 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.3 ft
Screen Length: 4.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW10 SI1.aqt
Date: 10/10/17 Time: 09:56:32

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW10
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

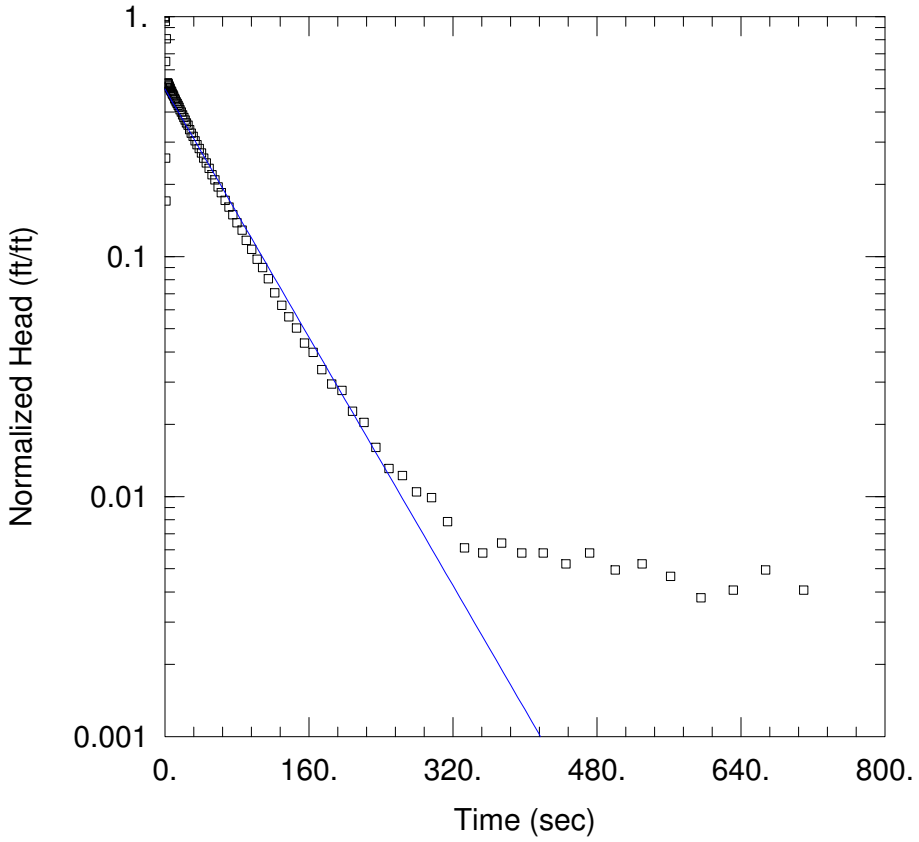
K = 0.0005269 cm/sec
y0 = 1.656 ft

AQUIFER DATA

Saturated Thickness: 6.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW10 SI1)

Initial Displacement: 3.792 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.7 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW10 SI2.aqt
Date: 10/10/17 Time: 09:59:35

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW10
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

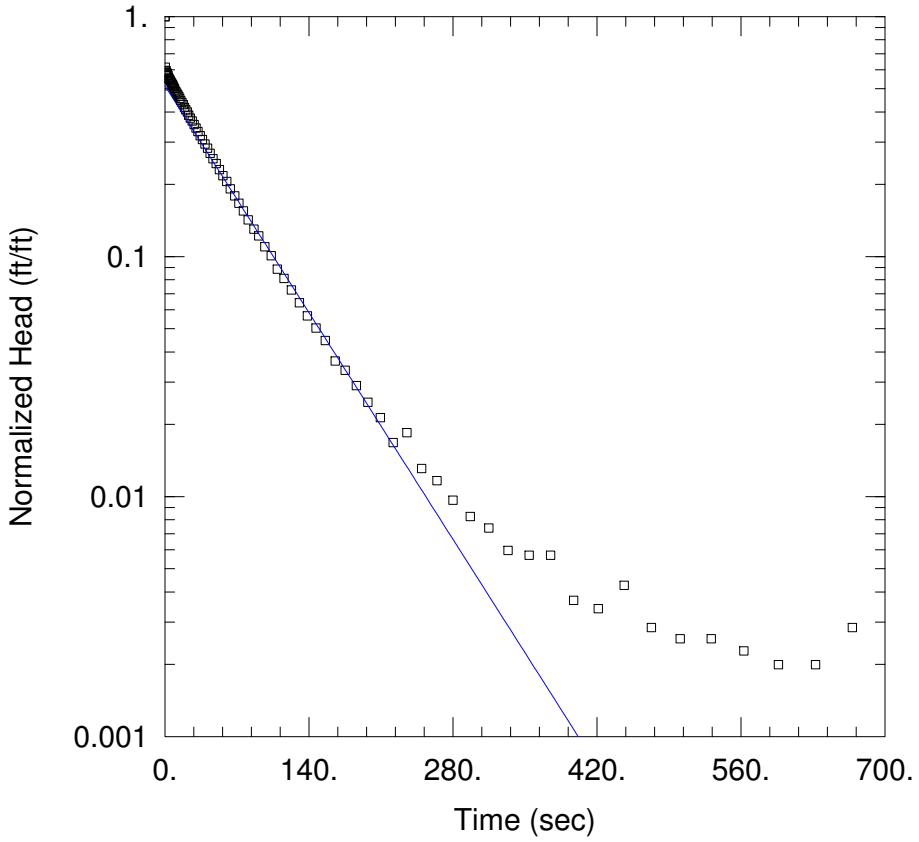
K = 0.0005491 cm/sec
y0 = 1.716 ft

AQUIFER DATA

Saturated Thickness: 6.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW10 SI2)

Initial Displacement: 3.438 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.7 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW10 SO2.aqt
Date: 10/10/17 Time: 10:01:28

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW10
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

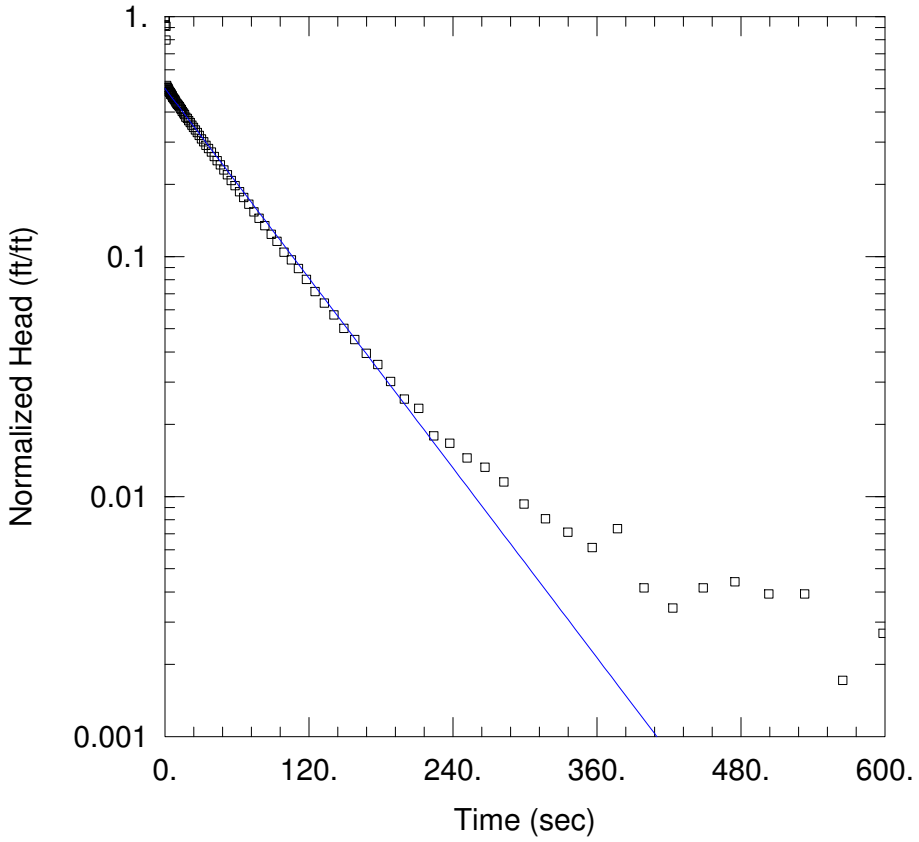
K = 0.0005731 cm/sec
y0 = 1.809 ft

AQUIFER DATA

Saturated Thickness: 6.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW10 SO2)

Initial Displacement: 3.518 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.7 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\APW10 SO3.aqt
Date: 10/10/17 Time: 10:09:04

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Primary Ash Pond
Test Well: APW10
Test Date: 4/7/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

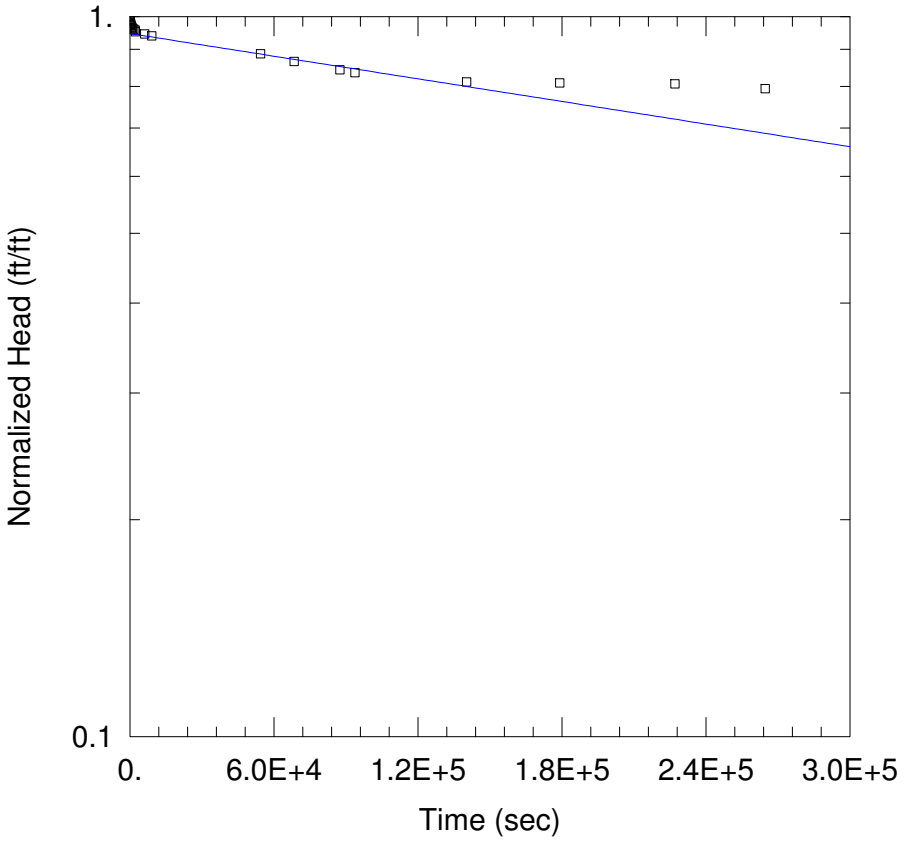
K = 0.0005595 cm/sec
y0 = 2.048 ft

AQUIFER DATA

Saturated Thickness: 6.7 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (APW10 SO2)

Initial Displacement: 4.081 ft
Total Well Penetration Depth: 4.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.7 ft
Screen Length: 4.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G06D SO1.aqt
Date: 10/10/17 Time: 10:15:04

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G06D
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

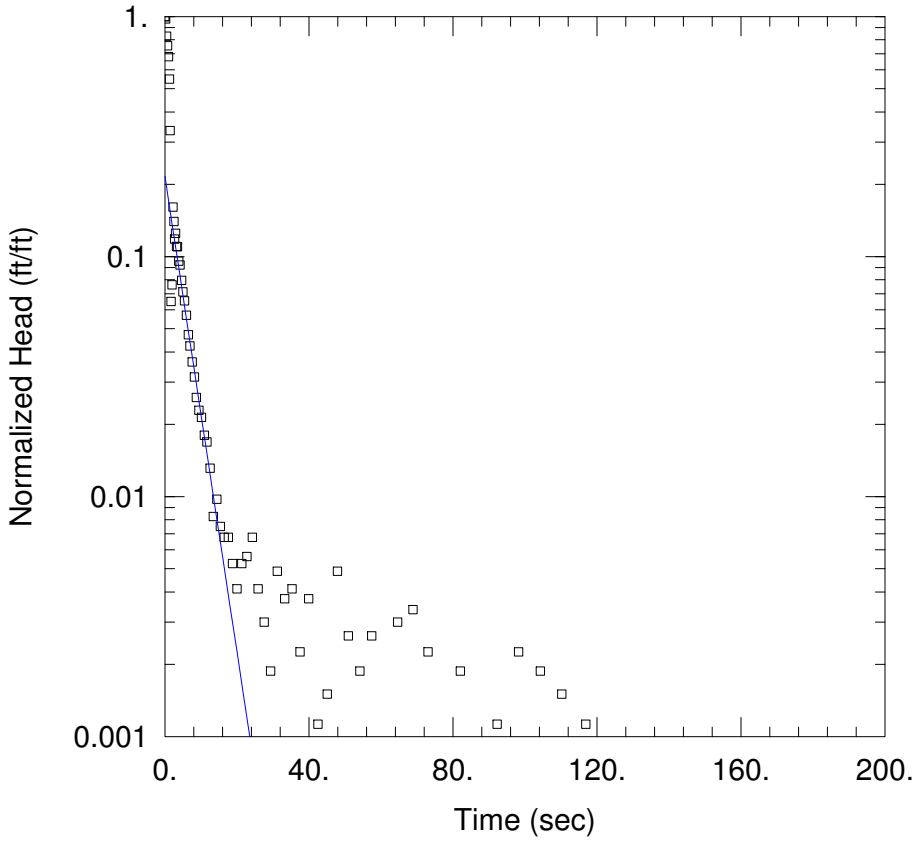
K = 3.917E-8 cm/sec
y0 = 3.807 ft

AQUIFER DATA

Saturated Thickness: 0.4 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G06D)

Initial Displacement: 4.02 ft
Total Well Penetration Depth: 0.4 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 0.4 ft
Screen Length: 0.4 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G202 SI1.aqt
Date: 10/10/17 Time: 10:19:06

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G202
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

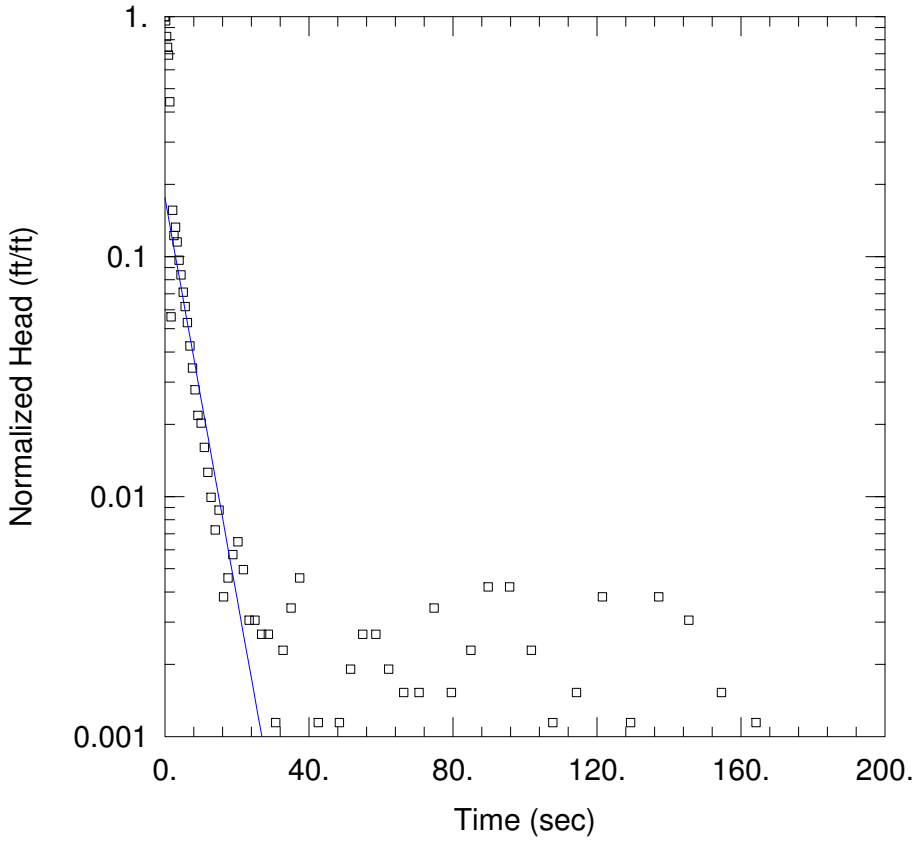
K = 0.01698 cm/sec
y0 = 0.5744 ft

AQUIFER DATA

Saturated Thickness: 0.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G202 SI1)

Initial Displacement: 2.666 ft
Total Well Penetration Depth: 0.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 0.6 ft
Screen Length: 0.6 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G202 SI2.aqt
Date: 10/10/17 Time: 10:20:26

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G202
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

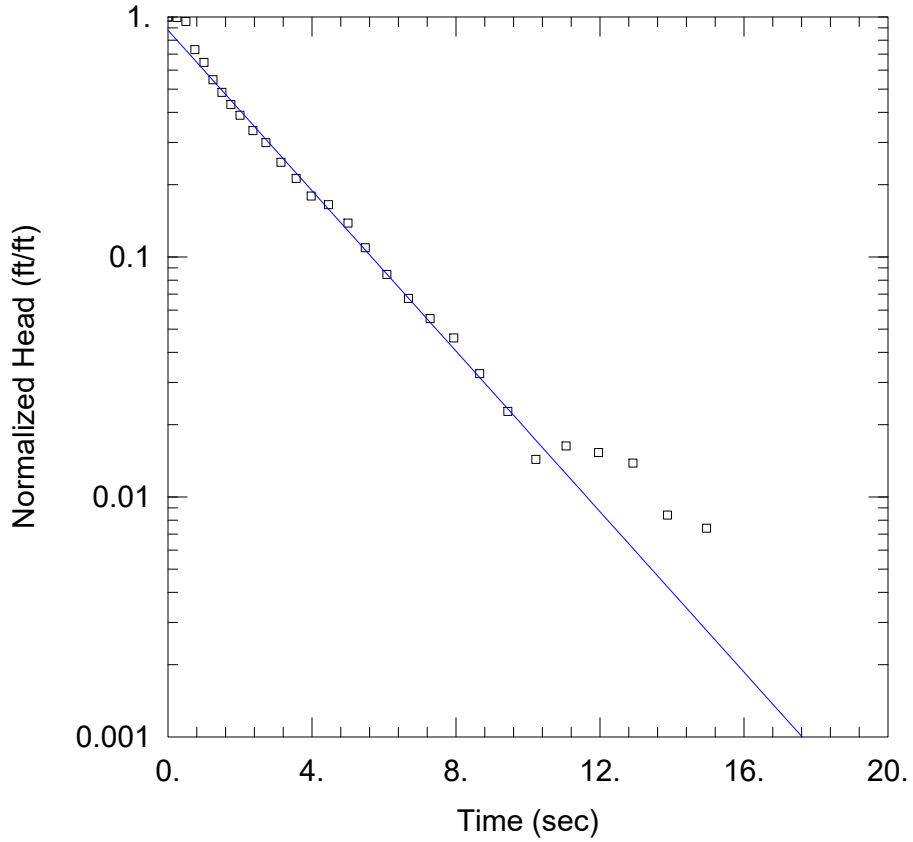
K = 0.0143 cm/sec
y0 = 0.4599 ft

AQUIFER DATA

Saturated Thickness: 0.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G202 SI2)

Initial Displacement: 2.621 ft
Total Well Penetration Depth: 0.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 0.6 ft
Screen Length: 0.6 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G202 SO2.aqt
Date: 06/15/17 Time: 10:21:12

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G202
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

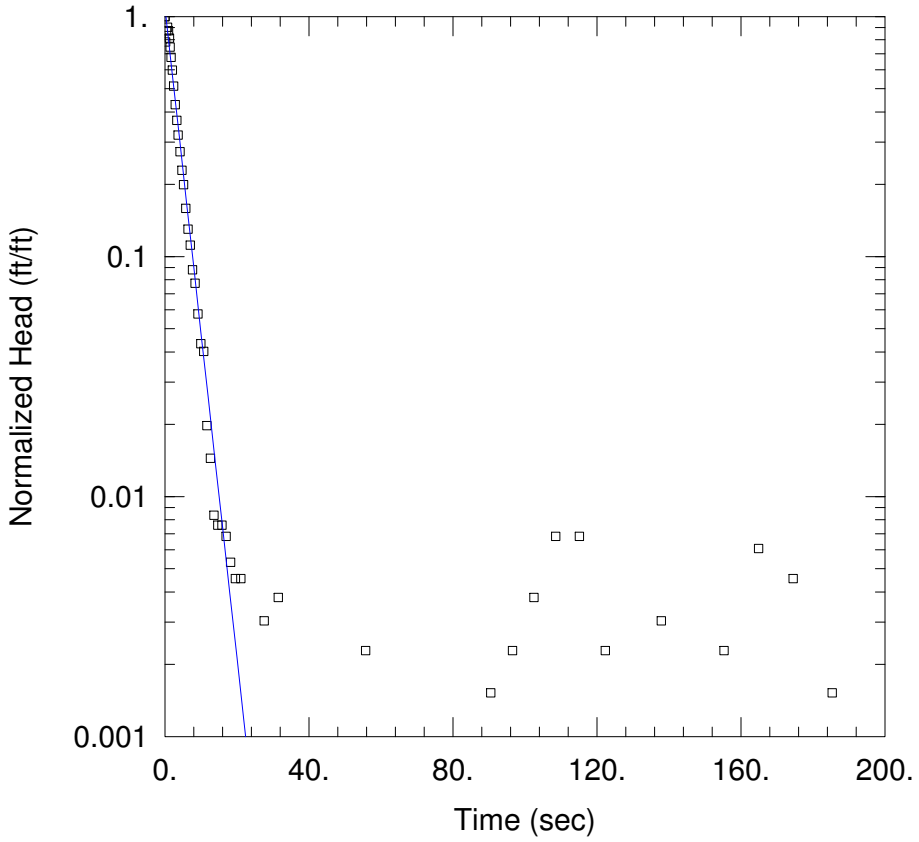
K = 0.02868 cm/sec
y0 = 1.781 ft

AQUIFER DATA

Saturated Thickness: 0.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G202 SO2)

Initial Displacement: 2.024 ft
Total Well Penetration Depth: 0.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 0.6 ft
Screen Length: 0.6 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G202 SO3.aqt
Date: 10/10/17 Time: 10:21:38

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G202
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

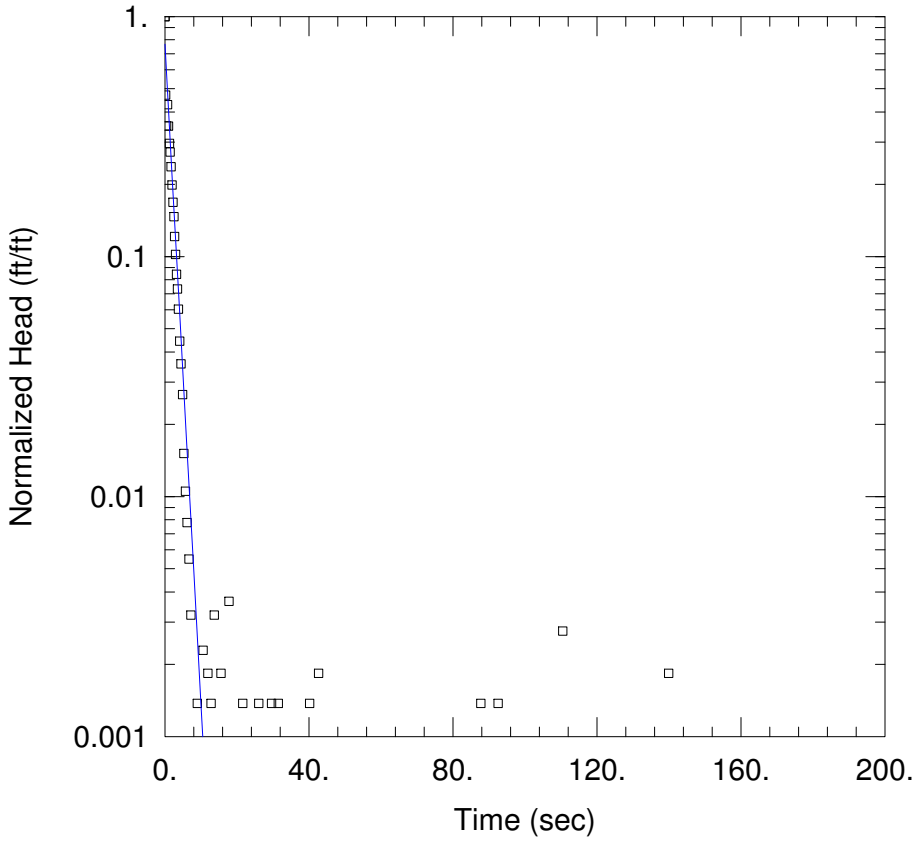
K = 0.02325 cm/sec
y0 = 1.444 ft

AQUIFER DATA

Saturated Thickness: 0.6 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G202 SO3)

Initial Displacement: 1.317 ft
Total Well Penetration Depth: 0.6 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 0.6 ft
Screen Length: 0.6 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G203 SI1.aqt
Date: 10/10/17 Time: 10:24:55

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G203
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

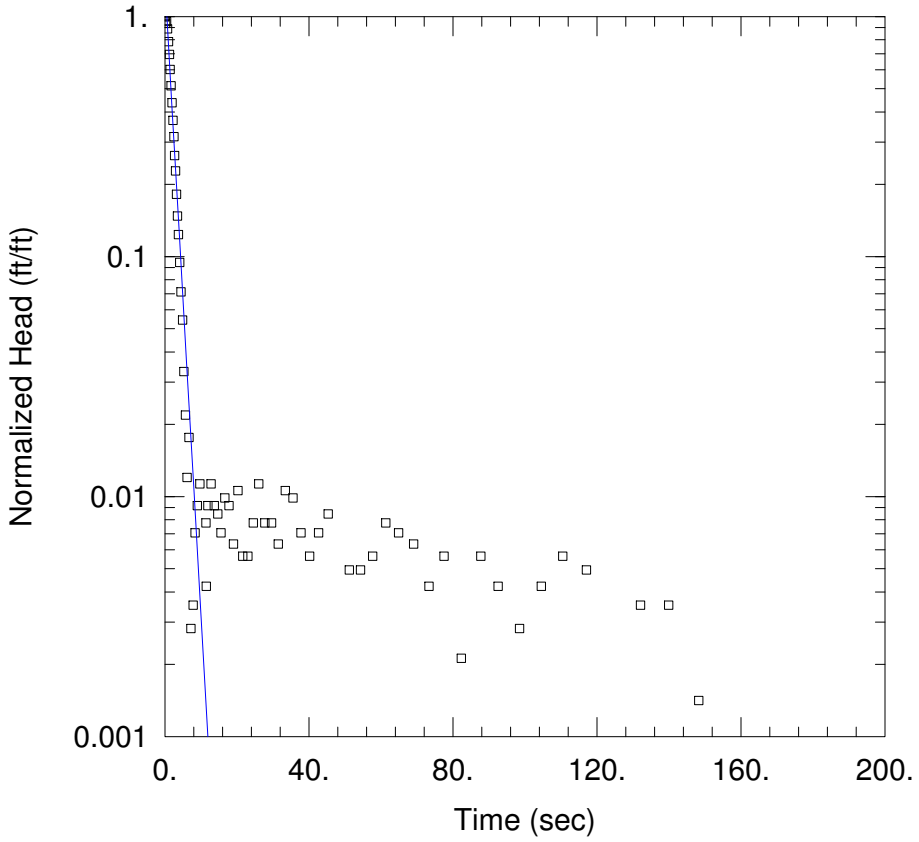
K = 0.02529 cm/sec
y0 = 1.676 ft

AQUIFER DATA

Saturated Thickness: 6.9 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G203 SI1)

Initial Displacement: 2.184 ft
Total Well Penetration Depth: 3.9 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.9 ft
Screen Length: 3.9 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G203 SO1.aqt
Date: 10/10/17 Time: 10:28:31

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G203
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

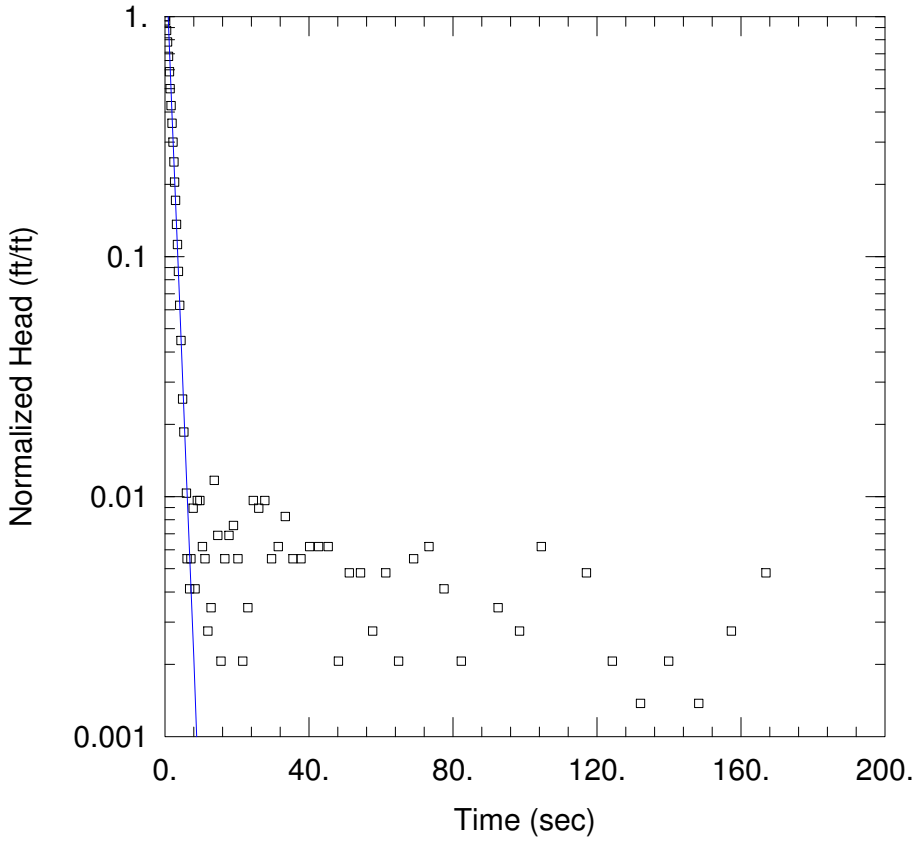
K = 0.02421 cm/sec
y0 = 1.958 ft

AQUIFER DATA

Saturated Thickness: 6.9 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G203 SO1)

Initial Displacement: 1.418 ft
Total Well Penetration Depth: 3.9 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.9 ft
Screen Length: 3.9 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G203 SO2.aqt
Date: 10/10/17 Time: 10:30:34

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G203
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

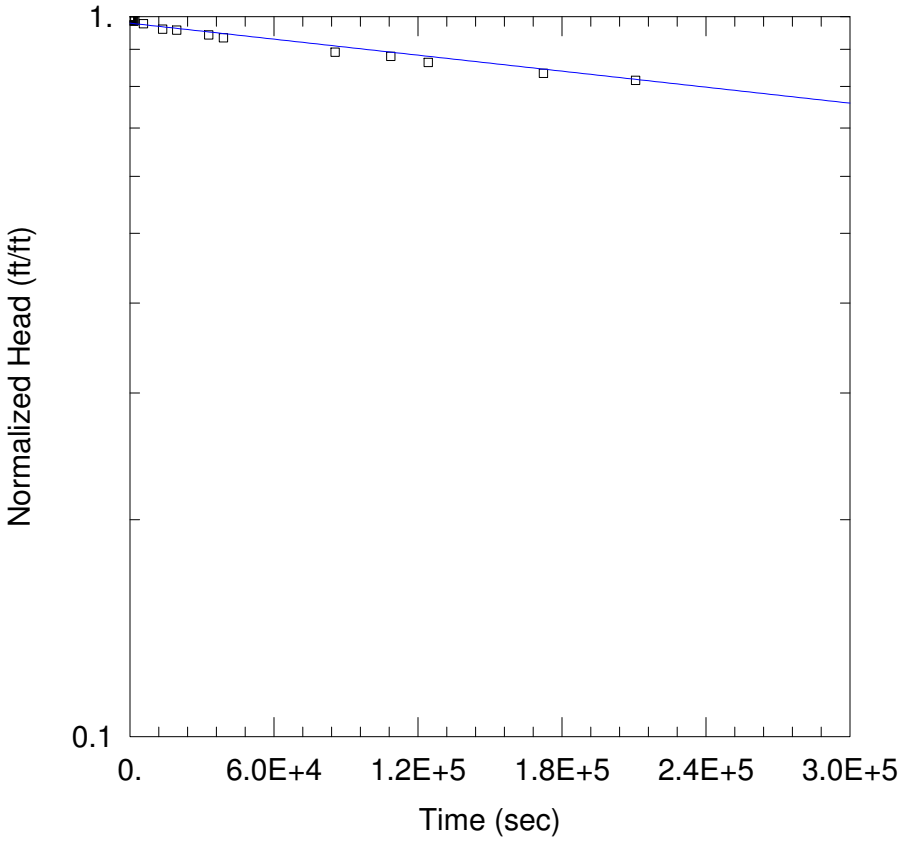
K = 0.03469 cm/sec
y0 = 3.185 ft

AQUIFER DATA

Saturated Thickness: 6.9 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G203 SO2)

Initial Displacement: 1.454 ft
Total Well Penetration Depth: 3.9 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 6.9 ft
Screen Length: 3.9 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G208 SO1.aqt
Date: 10/10/17 Time: 10:33:25

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G208
Test Date: 4/4/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

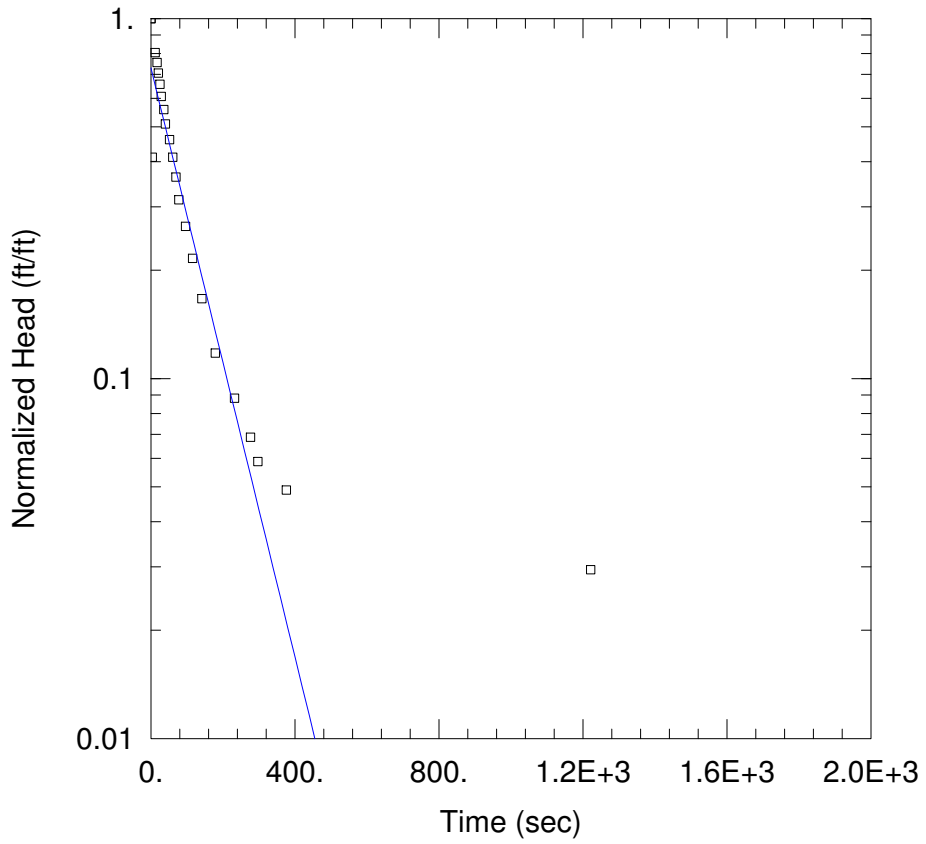
K = 1.315E-8 cm/sec
y0 = 10.16 ft

AQUIFER DATA

Saturated Thickness: 22.1 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G208 SO1)

Initial Displacement: 10.38 ft
Total Well Penetration Depth: 19.8 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 22.1 ft
Screen Length: 19.8 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G217D SI1.aqt
Date: 10/10/17 Time: 10:35:45

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G217D
Test Date: 4/4/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

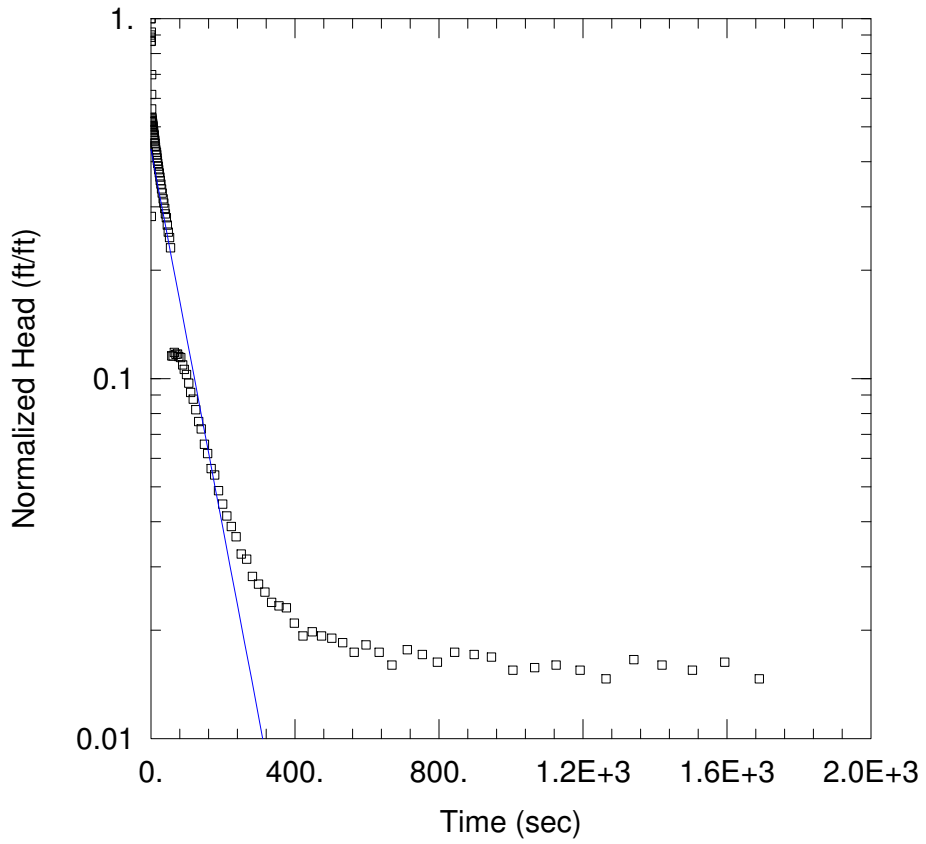
K = 0.0002266 cm/sec
y0 = 0.743 ft

AQUIFER DATA

Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G217D SI1)

Initial Displacement: 1.02 ft
Total Well Penetration Depth: 10. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 13. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G217D SI2.aqt
Date: 10/10/17 Time: 10:38:05

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G217D
Test Date: 4/4/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

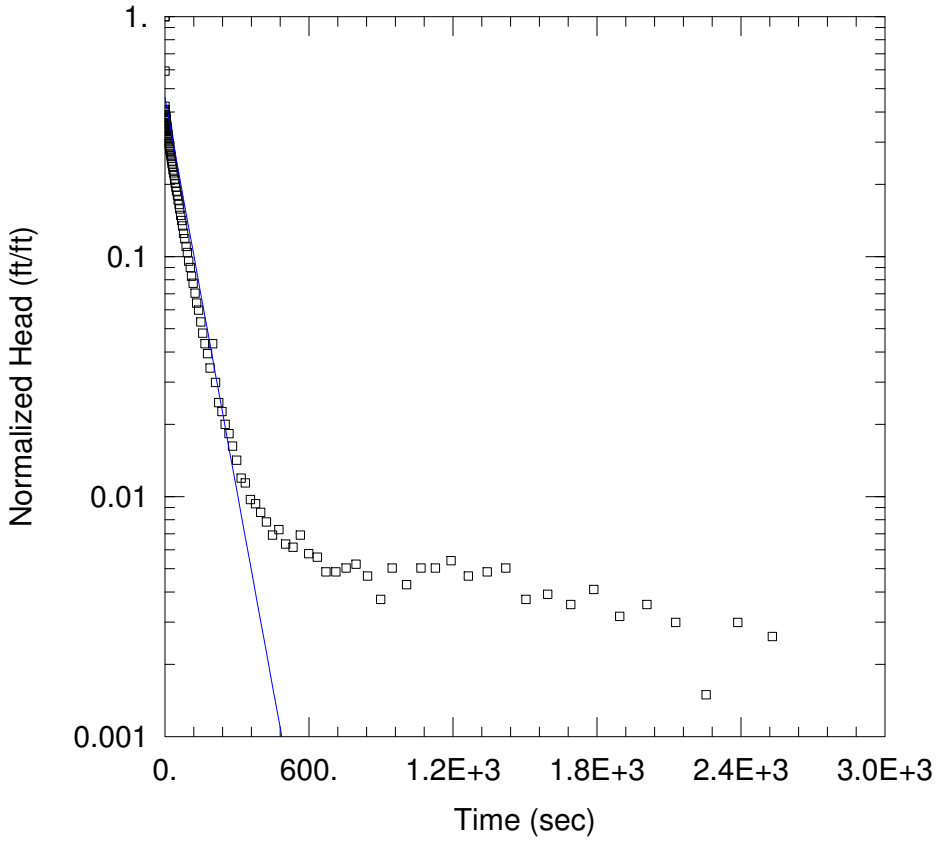
K = 0.0002919 cm/sec
y0 = 1.598 ft

AQUIFER DATA

Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G217D SI2)

Initial Displacement: 3.685 ft
Total Well Penetration Depth: 10. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 13. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G217D SO3.aqt
Date: 10/10/17 Time: 10:40:18

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G217D
Test Date: 4/4/17

SOLUTION

Aquifer Model: Unconfined
Solution Method: Bouwer-Rice

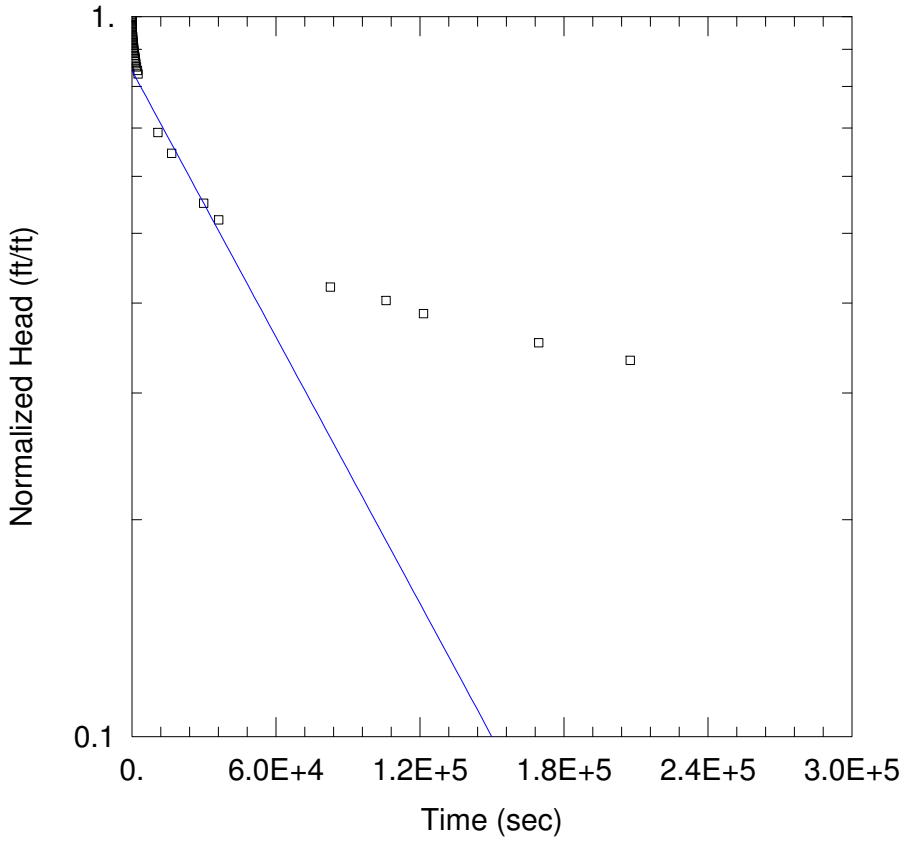
K = 0.0003032 cm/sec
y0 = 2.469 ft

AQUIFER DATA

Saturated Thickness: 13. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G217D SO3)

Initial Displacement: 5.362 ft
Total Well Penetration Depth: 10. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 13. ft
Screen Length: 10. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G220 SO1.aqt
Date: 10/10/17 Time: 10:42:50

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G220
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

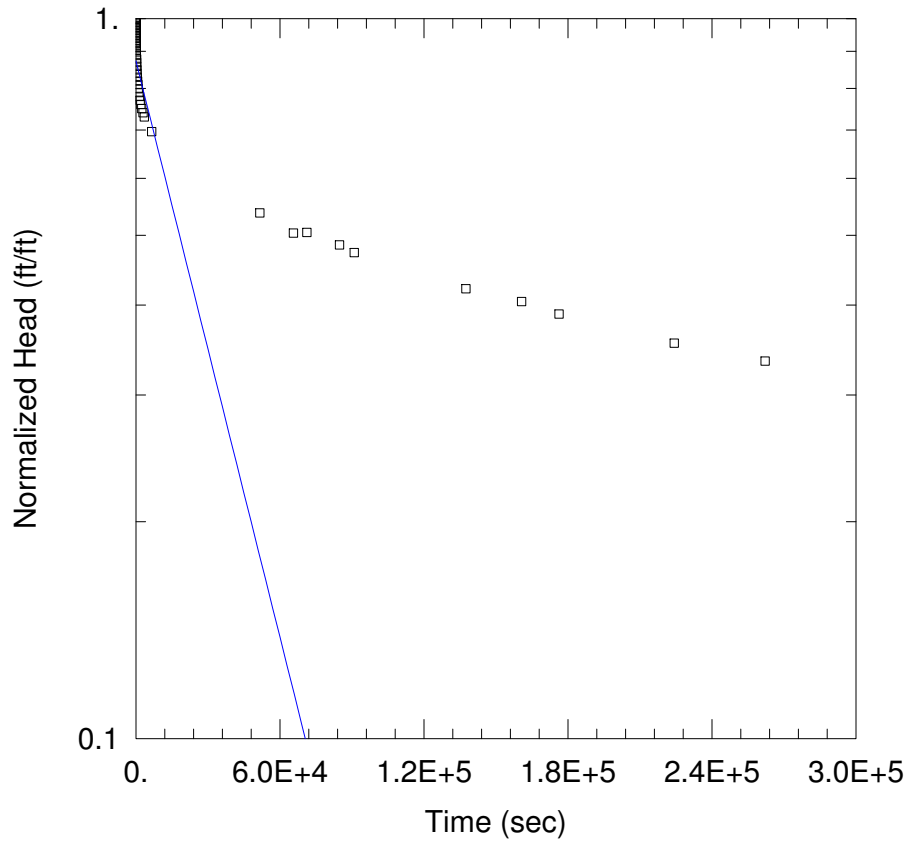
K = 3.513E-7 cm/sec
y0 = 9.098 ft

AQUIFER DATA

Saturated Thickness: 12. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G220 SO1)

Initial Displacement: 10.81 ft
Total Well Penetration Depth: 9.7 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 12. ft
Screen Length: 9.7 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G222 SO1.aqt
Date: 10/10/17 Time: 10:49:55

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G222
Test Date: 4/4/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 1.541E-6 cm/sec
y0 = 8.832 ft

AQUIFER DATA

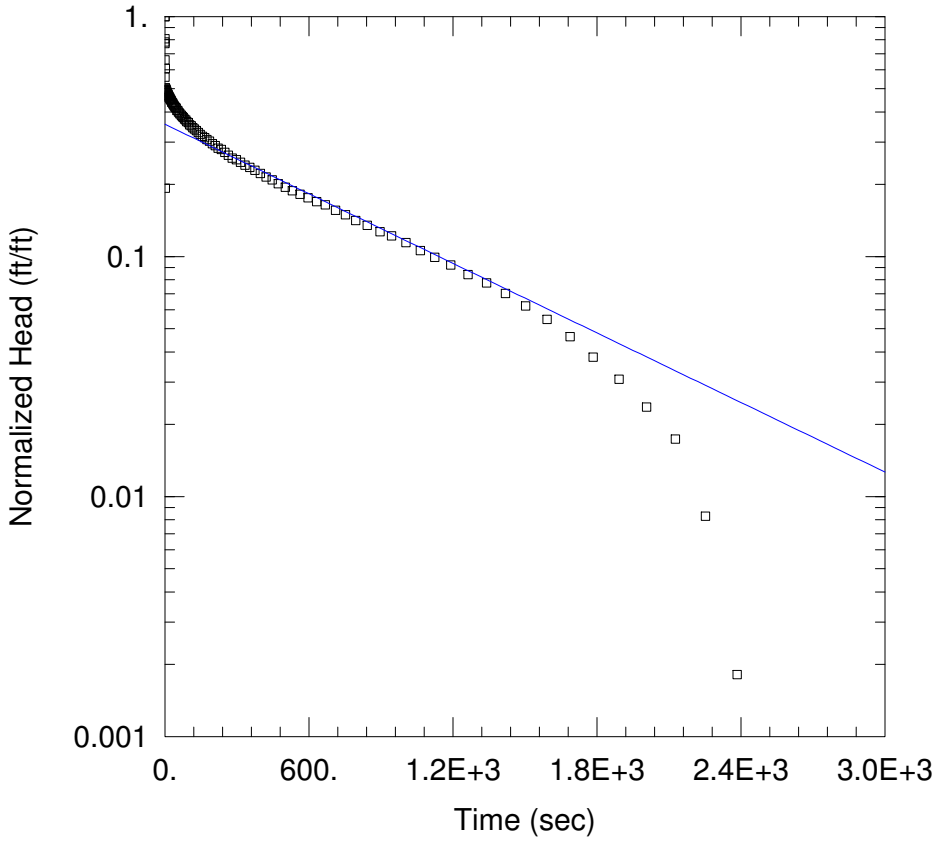
Saturated Thickness: 3.5 ft

Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G222 SO1)

Initial Displacement: 10.11 ft
Total Well Penetration Depth: 3.5 ft
Casing Radius: 0.08333 ft

Static Water Column Height: 3.5 ft
Screen Length: 3.5 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G223 SI1.aqt
Date: 10/10/17 Time: 10:55:09

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G223
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

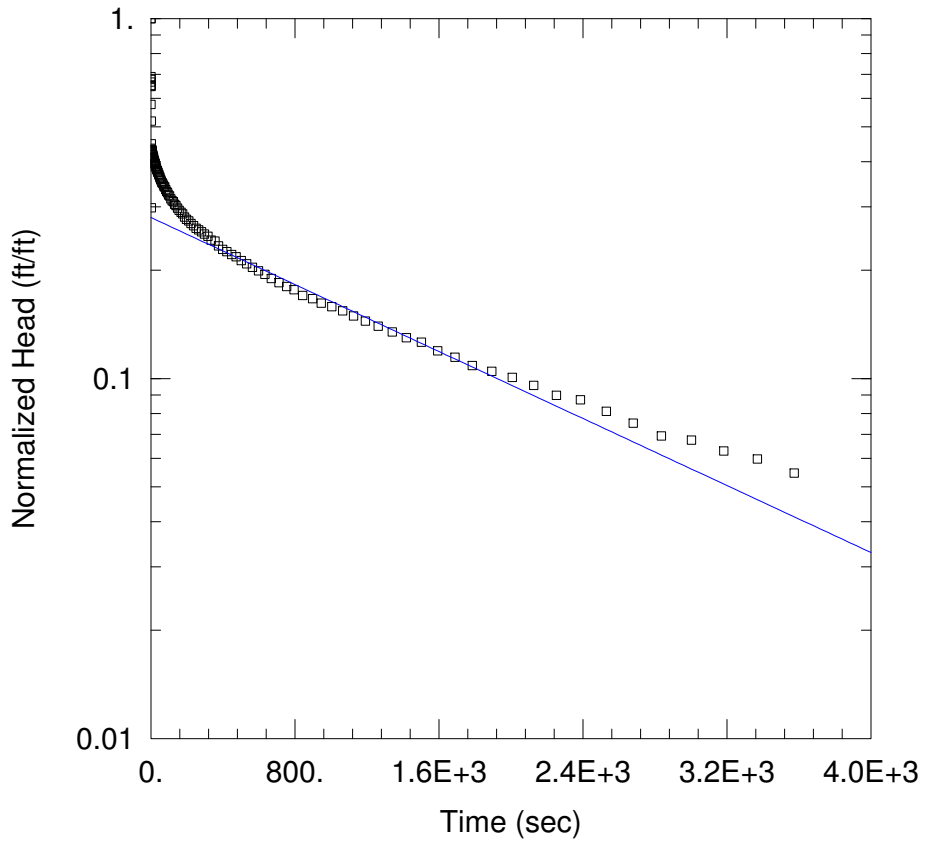
K = 5.19E-5 cm/sec
y0 = 1.374 ft

AQUIFER DATA

Saturated Thickness: 4. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G223 SI1)

Initial Displacement: 3.86 ft
Total Well Penetration Depth: 4. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 4. ft
Screen Length: 4. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G223 SI2.aqt
Date: 10/10/17 Time: 10:57:35

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G223
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

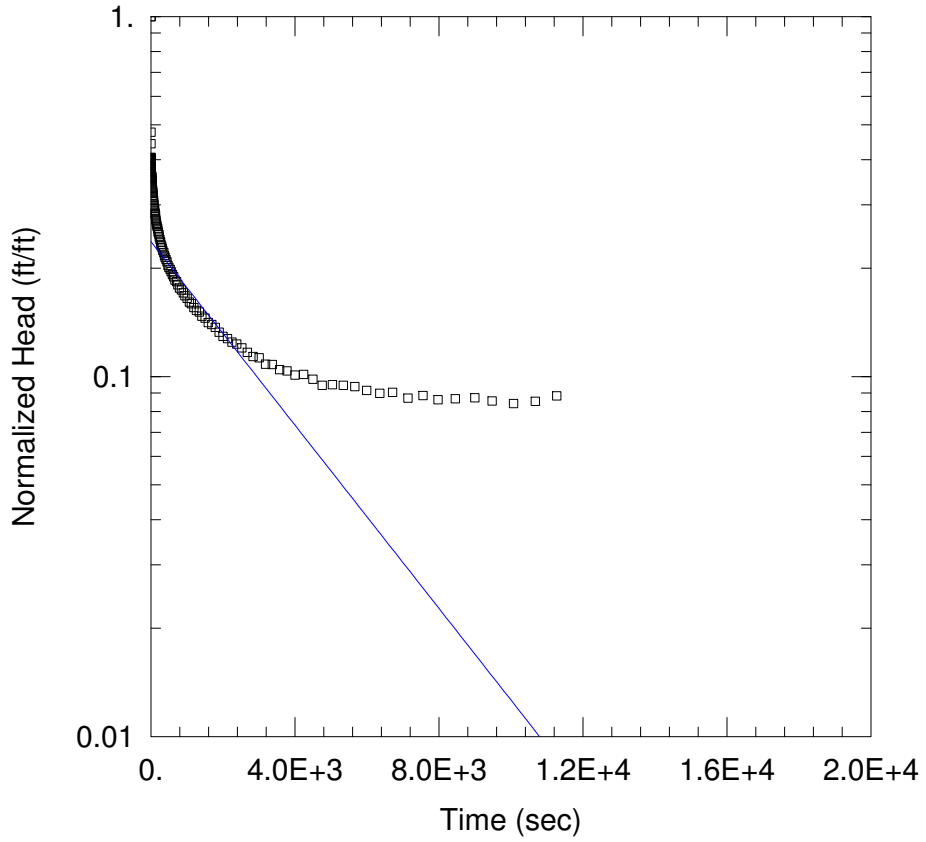
K = 2.5E-5 cm/sec
y0 = 1.251 ft

AQUIFER DATA

Saturated Thickness: 4. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G223 SI2)

Initial Displacement: 4.466 ft
Total Well Penetration Depth: 4. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 4. ft
Screen Length: 4. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G223 SO1.aqt
Date: 10/10/17 Time: 11:00:37

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G223
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

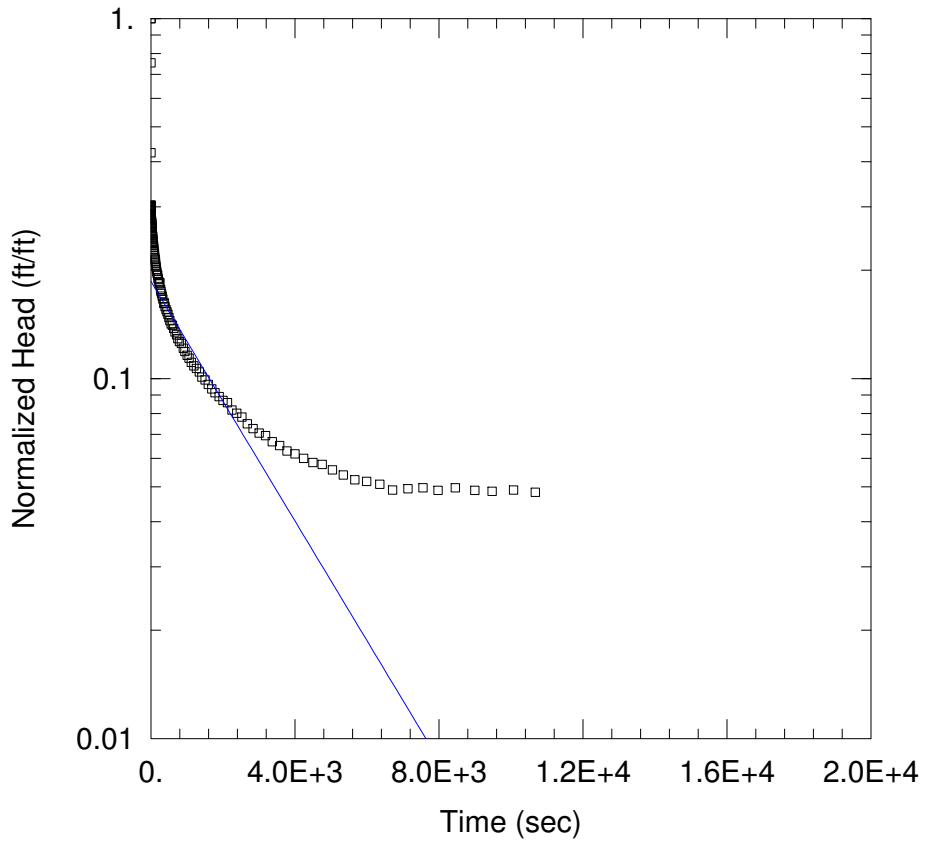
K = 1.368E-5 cm/sec
y0 = 1.281 ft

AQUIFER DATA

Saturated Thickness: 4. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G223 SO1)

Initial Displacement: 5.412 ft
Total Well Penetration Depth: 4. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 4. ft
Screen Length: 4. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G223 SO2.aqt
Date: 10/10/17 Time: 11:01:58

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G223
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

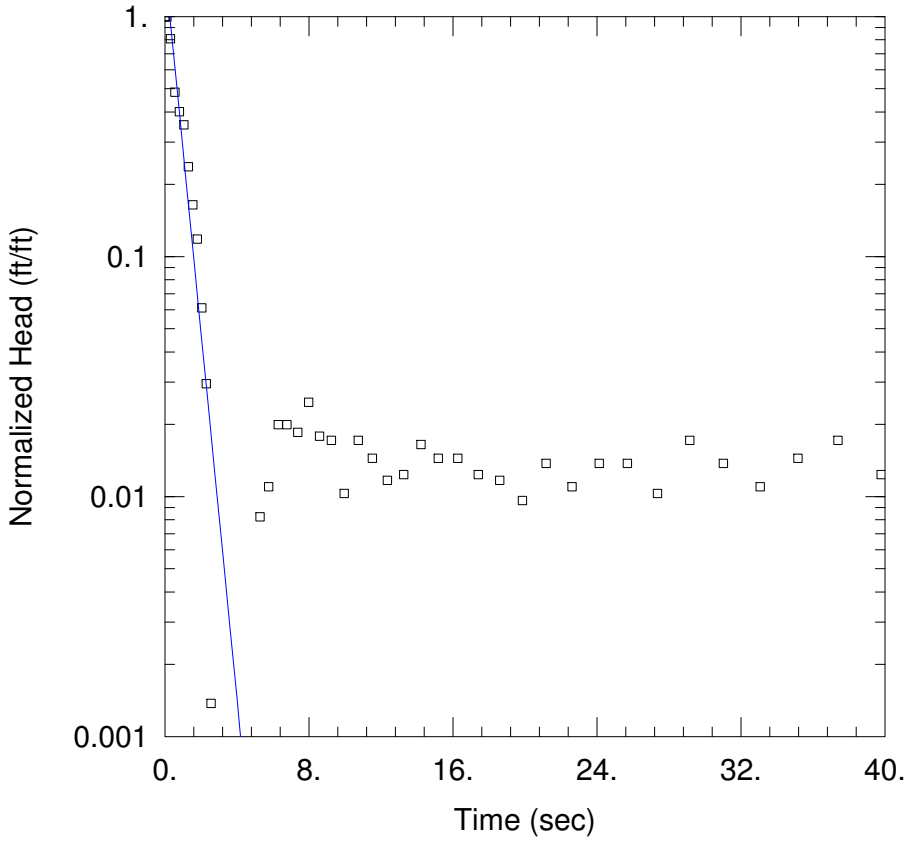
K = 1.786E-5 cm/sec
y0 = 1.359 ft

AQUIFER DATA

Saturated Thickness: 4. ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G223 SO2)

Initial Displacement: 7.304 ft
Total Well Penetration Depth: 4. ft
Casing Radius: 0.08333 ft
Static Water Column Height: 4. ft
Screen Length: 4. ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G224 SI1.aqt
Date: 10/10/17 Time: 11:04:28

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G224
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

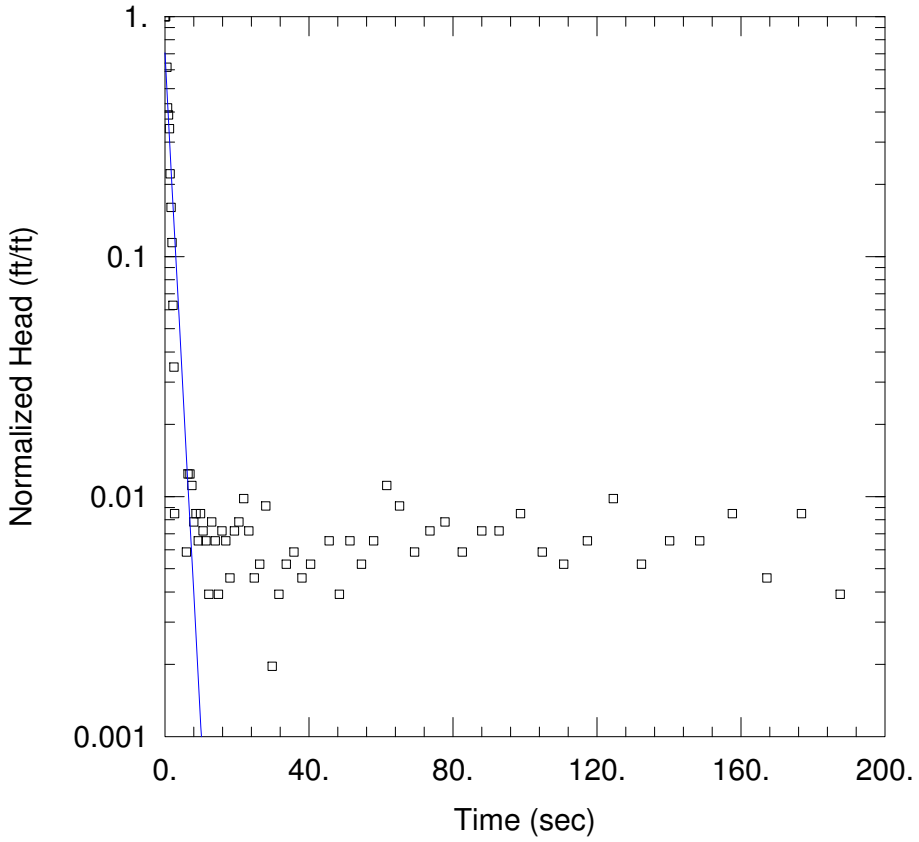
K = 0.05146 cm/sec
y0 = 2.38 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G224 SI1)

Initial Displacement: 1.457 ft
Total Well Penetration Depth: 8.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 8.2 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G224 SI2.aqt
Date: 10/10/17 Time: 11:06:55

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G224
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

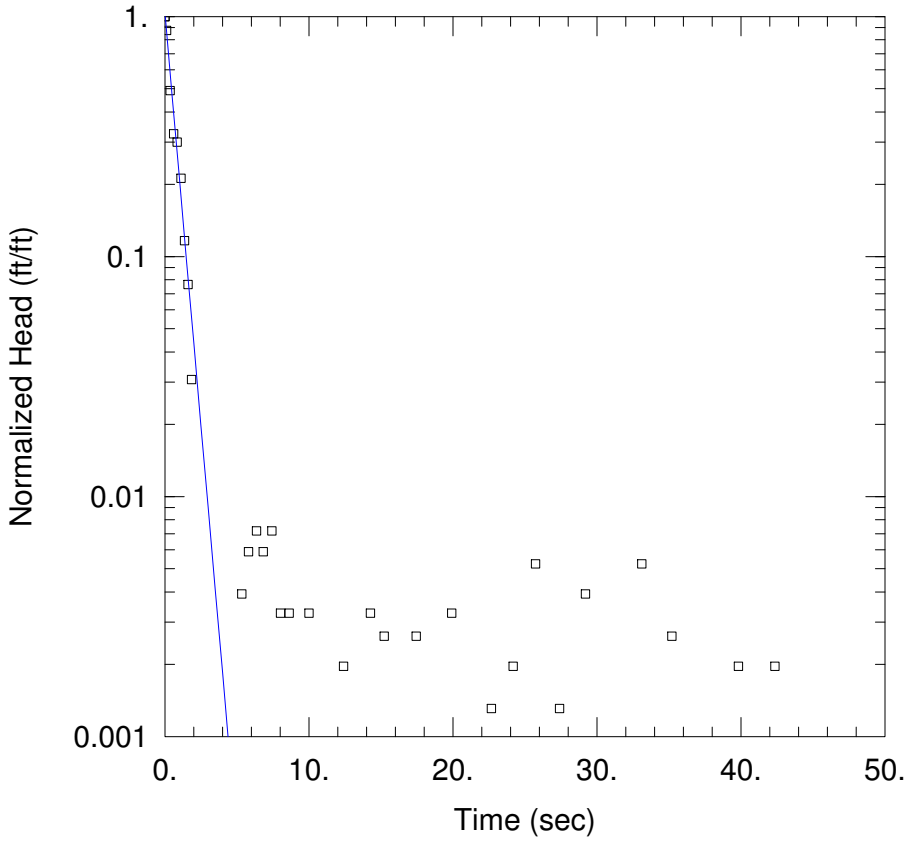
K = 0.01897 cm/sec
y0 = 1.081 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G224 SI2)

Initial Displacement: 1.531 ft
Total Well Penetration Depth: 8.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 8.2 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G224 SI3.aqt
Date: 10/10/17 Time: 11:08:48

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G224
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

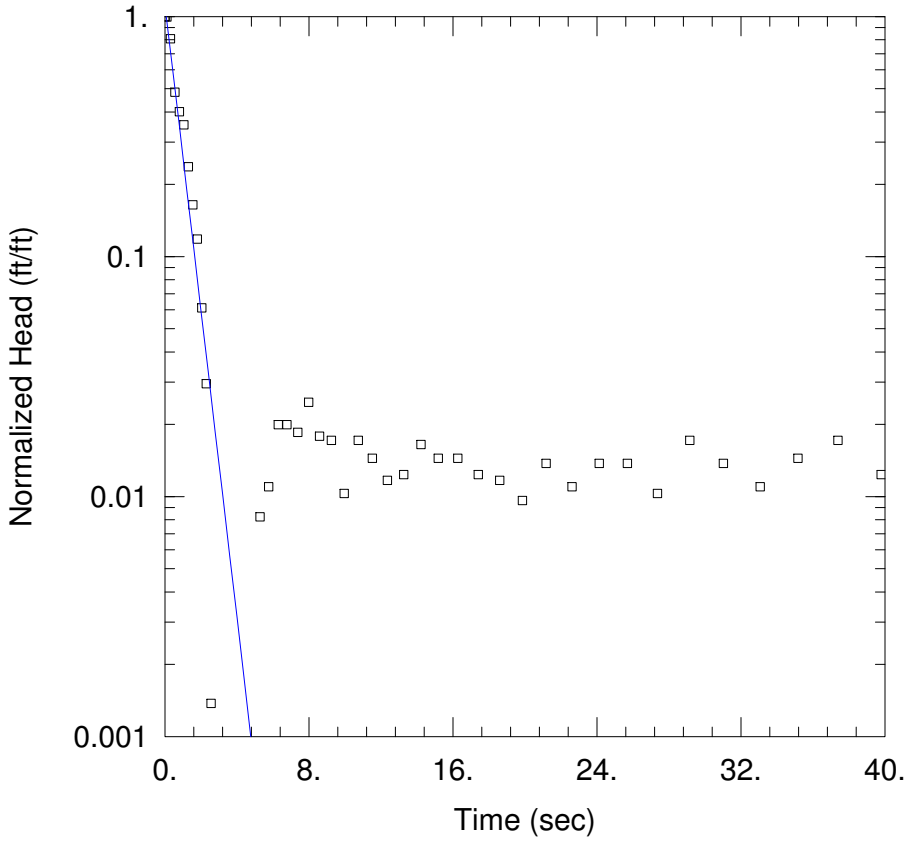
K = 0.04637 cm/sec
y0 = 1.586 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G224 SI3)

Initial Displacement: 1.529 ft
Total Well Penetration Depth: 8.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 8.2 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G224 SO1.aqt
Date: 10/10/17 Time: 11:10:44

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G224
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

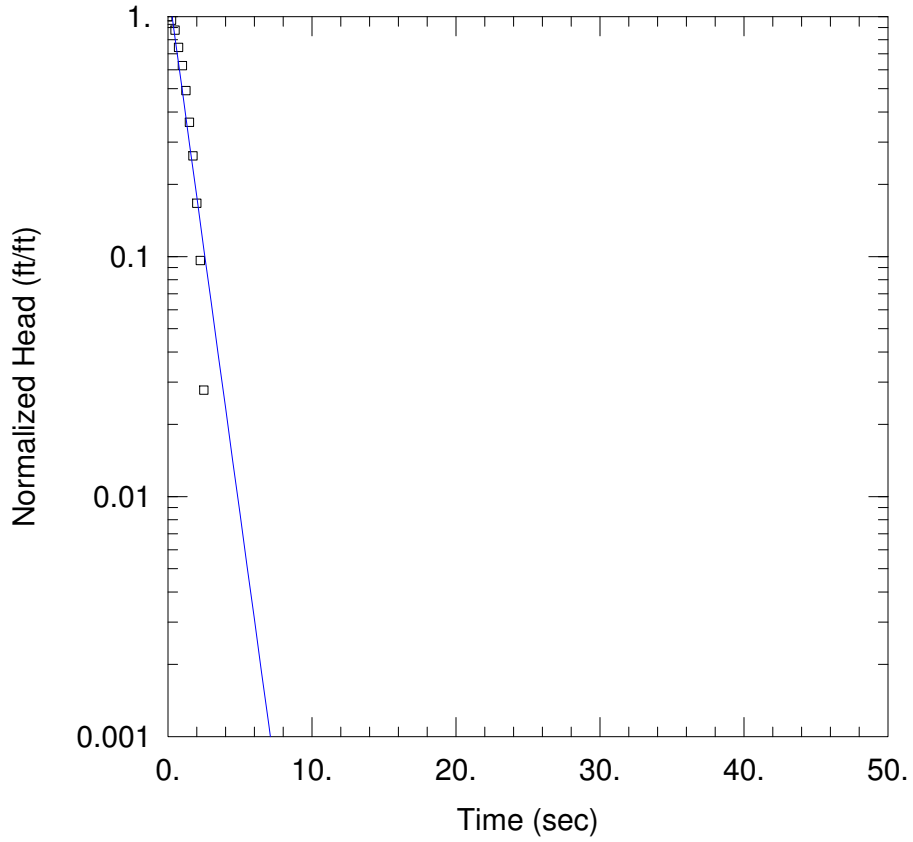
K = 0.04312 cm/sec
y0 = 1.657 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G224 SI1)

Initial Displacement: 1.457 ft
Total Well Penetration Depth: 8.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 8.2 ft
Well Radius: 0.3458 ft



WELL TEST ANALYSIS

Data Set: P:\...\G224 SO3.aqt
Date: 10/10/17 Time: 11:12:56

PROJECT INFORMATION

Company: Natural Resource Technology
Client: Dynegy
Project: 2285
Location: Newton Landfill
Test Well: G224
Test Date: 4/5/17

SOLUTION

Aquifer Model: Confined
Solution Method: Bouwer-Rice

K = 0.0297 cm/sec
y0 = 1.264 ft

AQUIFER DATA

Saturated Thickness: 8.5 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (G224 SO2)

Initial Displacement: 0.936 ft
Total Well Penetration Depth: 8.2 ft
Casing Radius: 0.08333 ft
Static Water Column Height: 8.5 ft
Screen Length: 8.2 ft
Well Radius: 0.3458 ft

APPENDIX G
FEMA FLOOD HAZARD MAP

Electronic Filing: Received, Clerk's Office 07/01/2024



KEY TO MAP

500-Year Flood Boundary
100-Year Flood Boundary
Zone Designations*

100-Year Flood Boundary
500-Year Flood Boundary
Base Flood Elevation Line With Elevation In Feet** — 513
Base Flood Elevation in Feet Where Uniform Within Zone** — (EL 987)
Elevation Reference Mark — RM7×
Zone D Boundary
River Mile — •M1.5

**Referenced to the National Geodetic Vertical Datum of 1929

*EXPLANATION OF ZONE DESIGNATIONS

ZONE	EXPLANATION
A	Areas of 100-year flood; base flood elevations and flood hazard factors not determined.
A0	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; average depths of inundation are shown, but no flood hazard factors are determined.
AH	Areas of 100-year shallow flooding where depths are between one (1) and three (3) feet; base flood elevations are shown, but no flood hazard factors are determined.
A1-A30	Areas of 100-year flood; base flood elevations and flood hazard factors determined.
A99	Areas of 100-year flood to be protected by flood protection system under construction; base flood elevations and flood hazard factors not determined.
B	Areas between limits of the 100-year flood and 500-year flood; or certain areas subject to 100-year flooding with average depths less than one (1) foot or where the contributing drainage area is less than one square mile; or areas protected by levees from the base flood. (Medium shading)
C	Areas of minimal flooding. (No shading)
D	Areas of undetermined, but possible, flood hazards.
V	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors not determined.
V1-V30	Areas of 100-year coastal flood with velocity (wave action); base flood elevations and flood hazard factors determined.

NOTES TO USER

Certain areas not in the special flood hazard areas (zones A and V) may be protected by flood control structures.

This map is for flood insurance purposes only; it does not necessarily show all areas subject to flooding in the community or all planimetric features outside special flood hazard areas.

For adjoining map panels, see separately printed Map Index.

INITIAL IDENTIFICATION:
JULY 27, 1979

FLOOD HAZARD BOUNDARY MAP REVISIONS:

FLOOD INSURANCE RATE MAP EFFECTIVE:
JANUARY 17, 1985

FLOOD INSURANCE RATE MAP REVISIONS:

To determine if flood insurance is available in this community, contact your insurance agent, or call the National Flood Insurance Program, at (800) 638-6620.

APPROXIMATE SCALE
2000 0 2000 FEET

NATIONAL FLOOD INSURANCE PROGRAM

FIRM
FLOOD INSURANCE RATE MAP

JASPER COUNTY, ILLINOIS
(UNINCORPORATED AREAS)

PANEL 125 OF 150
(SEE MAP INDEX FOR PANELS NOT PRINTED)

COMMUNITY-PANEL NUMBER
170990 0125 B

EFFECTIVE DATE:
JANUARY 17, 1985

Federal Emergency Management Agency

Electronic Filing: Received, Clerk's Office 07/01/2024

Intended for
Illinois Power Generating Company

Date
October 25, 2021

Project No.
1940100806-008

GROUNDWATER MONITORING PLAN

PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

Electronic Filing: Received, Clerk's Office 07/01/2024

GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT PRIMARY ASH POND

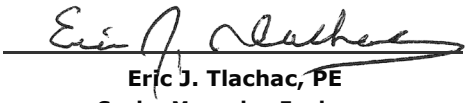
Project Name	**Newton Power Plant Primary Ash Pond**
Project No.	**1940100806-008**
Recipient	**Illinois Power Generating Company**
Document type	**Groundwater Monitoring Plan**
Revision	**FINAL**
Date	**October 25, 2021**

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

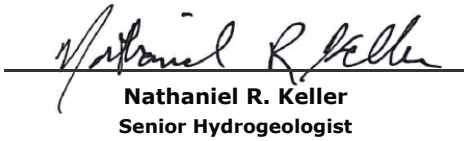
T 414-837-3607
F 414-837-3608
https://ramboll.com



Brian G. Hennings, PG
Senior Managing Hydrogeologist



Eric J. Tlachac, PE
Senior Managing Engineer



Nathaniel R. Keller
Senior Hydrogeologist



Chase J. Christenson, PG
Hydrogeologist

LICENSED PROFESSIONAL CERTIFICATIONS

35 I.A.C. § 845.630 Groundwater Monitoring Systems (PE)

I, Eric J. Tlachac, a qualified professional engineer in good standing in the State of Illinois, certify that the groundwater monitoring system described in this document (Groundwater Monitoring Plan, Newton Power Plant Primary Ash Pond), has been designed and constructed to meet the requirements of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the Hydrogeologic Site Characterization Report (Ramboll 2021; included in the Operating Permit to which this Groundwater Monitoring Plan is attached).



Eric J. Tlachac
Qualified Professional Engineer
062-063091
Illinois
Date: October 25, 2021

35 I.A.C. § 845.630 Groundwater Monitoring Systems (PG)

I, Brian G. Hennings, a qualified professional geologist in good standing in the State of Illinois, certify that the groundwater monitoring system described in this document (Groundwater Monitoring Plan, Newton Power Plant Primary Ash Pond), has been designed and constructed to meet the requirements of 35 I.A.C. § 845.630. The monitoring system was developed based on information included in the Hydrogeologic Site Characterization Report (Ramboll 2021; included in the Operating Permit to which this Groundwater Monitoring Plan is attached).



Brian G. Hennings
Professional Geologist
196.001482
Illinois
Date: October 25, 2021

Electronic Filing: Received, Clerk's Office 07/01/2024

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APPENDICES

Appendix A	Statistical Analysis Plan

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ACRONYMS AND ABBREVIATIONS

35 I.A.C.	Title 35 of the Illinois Administrative Code
40 C.F.R.	Title 40 of the Code of Federal Regulations
ASD	Alternate Source Demonstration
bgs	below ground surface
CCR	coal combustion residuals
cm/s	centimeters per second
GMP	Groundwater Monitoring Plan
GWPS	Groundwater Protection Standard
HCR	Hydrogeologic Site Characterization Report
ID	identification
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
LCU	lower confining unit
LF 1	Phase 1 Landfill
LF 2	Phase 2 Landfill
LVW	low-volume wastewater
NAVD88	North American Vertical Datum of 1988
NID	National Inventory of Dams
No.	Number
NPDES	National Pollutant Discharge Elimination System
NPP	Newton Power Plant
NRT	Natural Resource Technology, Inc.
PAP	Primary Ash Pond
Part 845	Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
PMP	potential migration pathway
QA/QC	quality assurance/quality control
Ramboll	Ramboll Americas Engineering Solutions, Inc.
RL	Reporting Limit
SI	Surface Impoundment
TDS	total dissolved solids
UA	uppermost aquifer
UCU	upper confining unit
UD	upper drift
USEPA	United States Environmental Protection Agency
WLO	water level only

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1. INTRODUCTION

1.1 Overview

In accordance with requirements of the Standards for the Disposal of Coal Combustion Residuals (CCR) in Surface Impoundments (SIs): Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845 (Part 845) (Illinois Environmental Protection Agency [IEPA], April 15, 2021), Ramboll Americas Engineering Solutions, Inc. (Ramboll) has prepared this Groundwater Monitoring Plan (GMP) on behalf of Newton Power Plant (NPP) (**Figure 1-1**), operated by Illinois Power Generating Company (IPGC). This report will apply specifically to the CCR Unit referred to as the Primary Ash Pond (PAP), Vistra identification (ID) number (No.) 501, IEPA ID No. W0798070001-01, and National Inventory of Dams (NID) No. IL50719. This GMP includes Part 845 content requirements specific to 35 I.A.C. § 845.630 (Groundwater Monitoring System), 35 I.A.C. § 845.640 (Groundwater Sampling and Analysis), and 35 I.A.C. § 845.650 (Groundwater Monitoring Program) for the PAP at the NPP.

A checklist which identifies the specific requirements of 35 I.A.C. § 845.630, 35 I.A.C. § 845.640, and 35 I.A.C. § 845.650 is included in **Table 1-1**. The table provides references to sections, tables, and figures included in this document to locate the information that meets specific requirements of 35 I.A.C. § 845.630, 35 I.A.C. § 845.640, and 35 I.A.C. § 845.650.

1.2 Site Location and Background

The NPP is located in Jasper County in the southeastern part of central Illinois, approximately seven miles southwest of the town of Newton (**Figure 1-1**). The NPP operates as a coal-fired power plant with three CCR units present, including the PAP which is the subject of this GMP and two landfills: the Phase 1 Landfill (LF 1) located northwest and west of the PAP, and the Phase 2 Landfill (LF 2) located to the west of the PAP. The PAP is located within Section 26 and the west half of Section 25, Township 6 North, Range 8 East. The PAP is located south of the NPP and surrounded by Newton Lake to the south, east, and west (**Figure 1-2**).

The PAP is an unlined CCR SI used to manage CCR and non-CCR waste streams at the NPP. The PAP was constructed in 1977 and has a design capacity of approximately 9,715 acre-feet. There is also a non-CCR 83.6 acre-feet Secondary Pond located immediately south of the PAP. The PAP has a surface area of 404 acres and the Secondary Pond has an area of 9.3 acres. The PAP currently receives stormwater runoff, bottom ash, fly ash, and low-volume wastewater (LVW) from the plant's two coal-fired boilers. The SI is operated per National Pollutant Discharge Elimination System (NPDES) Permit No. IL0049191, Outfall 001 (located at the Secondary Pond). Areas within the impoundment were excavated during construction for native materials used to build the containment berms.

1.3 Conceptual Model

Significant site investigation has been completed at the NPP to characterize the geology, hydrogeology, and groundwater quality. Based on extensive investigation and monitoring, the PAP has been well characterized and detailed in the Hydrogeologic Site Characterization Report (HCR; included in the Operating Permit to which this Plan is attached). A site conceptual model has been developed and is discussed below.

In addition to the CCR present in the PAP, there are six layers of unlithified material present above the bedrock, which are categorized into the four hydrostratigraphic units below based on stratigraphic relationships and common hydrogeologic characteristics:

- **Upper Drift (UD)/Potential Migration Pathway (PMP):** The UD is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member(*i.e.,* PMP).
  - **Hagarstown Member/PMP:** The Hagarstown Member consists of discontinuous sandier deposits of the UD, where present, and overlies the Vandalia Till.
- **Upper Confining Unit (UCU):** This unit consists of the low permeability clay and silt of the Vandalia Till Member (Vandalia Till).
- **Uppermost Aquifer:** This unit is composed of the Mulberry Grove Formation, which onsite has been classified as poorly graded sand, silty sand, clayey sand, and gravel.
- **Lower Confining Unit (LCU):** This unit is comprised of low permeability silt and clay of the Smithboro Till Member (Smithboro Till) and the Banner Formation.

Groundwater migrates downward through the UD and UCU into the uppermost aquifer. Groundwater in the uppermost aquifer flows from north to south/southwest and converges near a former drainage feature located west of the PAP (**Figure 1-3**). Groundwater elevations vary seasonally, although generally less than one foot per year. The surface water elevation at Newton Lake (at location SG02) measured between February 15 and March 9, 2021 ranged from 504.42 to 504.84 feet North American Vertical Datum of 1988 (NAVD88). Groundwater elevations in the uppermost aquifer at downgradient wells were observed around 491 feet NAVD88 (approximately 15 feet lower than the Lake elevation). The separation between measured groundwater elevations and Lake elevations (and observed downward vertical gradients) indicates groundwater does not flow into Newton Lake from the uppermost aquifer.

Part 845 parameters were monitored in uppermost aquifer and PMP monitoring wells as part of groundwater quality evaluations performed between 2015 and present. These data were supplemented with installation and sampling of additional locations in 2021. The results indicate that the following parameters were detected at concentrations greater than the applicable 35 I.A.C. § 845.600 groundwater protection standards (GWPSs) and are considered potential exceedances:

- Arsenic at six uppermost aquifer wells, including downgradient wells APW08, APW09, APW15, and APW16 and background wells APW05 and APW06.
- Chloride at upgradient UD well APW05S and downgradient uppermost aquifer well APW15.
- Cobalt at PMP well APW12.
- Fluoride at downgradient uppermost aquifer well APW15 and APW18.
- Lead at downgradient uppermost aquifer wells APW08, APW11, and APW18.
- Lithium at three PMP wells APW02, APW04, and APW12; one upgradient UD well APW05S; and two downgradient uppermost aquifer wells APW13 and APW14.
- pH values below the lower range of the GWPS were observed at four PMP wells APW02, APW03, APW04, APW12; one background UA well APW06; and two downgradient uppermost aquifer wells APW11 and APW13.

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- Radium 226 and 228 combined at downgradient uppermost aquifer well APW16.
- Sulfate at three PMP wells APW02, APW04, and APW12; one upgradient UD well APW05S; and one downgradient uppermost aquifer well APW10.
- Thallium at one background well APW06, and two downgradient uppermost aquifer wells APW11 and APW18.
- Total dissolved solids (TDS) at four PMP wells APW02, APW03, APW04, and APW12; and one Upgradient UD well APW05S.

Concentration results for the above parameters were compared directly to 35 I.A.C. § 845.600(a)(1) GWPS, without an evaluation of background concentrations. Evaluation of background groundwater quality has been completed as part of this GMP, and compliance with Part 845 will be determined following the first round of groundwater sampling. The first round of groundwater sampling for compliance will be completed the quarter following issuance of the Operating Permit and in accordance with this GMP.

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2. GROUNDWATER MONITORING SYSTEMS

2.1 Existing Monitoring Well Network and Analysis

This GMP is being provided to propose a groundwater monitoring network and monitoring program specific to the PAP that will comply with Part 845. The remaining discussion in this document will include only these networks and monitoring programs that are applicable and specific to the PAP, specifically the IEPA monitoring program, the Title 40 of the Code of Federal Regulations (40 C.F.R.) § 257 network, and the proposed Part 845 monitoring network.

2.1.1 IEPA Monitoring Program

The current IEPA-required groundwater monitoring program associated with the PAP consists of four groundwater monitoring wells, including two background monitoring wells (G116 and APW02) and two compliance monitoring wells (APW03 and APW04) in accordance with the Special Condition No. 19 of the plant's NPDES Permit IL0049191. Groundwater samples are collected quarterly and analyzed for dissolved manganese, dissolved sulfate, dissolved zinc, TDS, and pH. Upon approval of the Operating Permit application (and by extension the GMP), the NPDES monitoring program Special Condition No. 19 will be discontinued following approval of a future NPDES permit modification submittal. The boring logs, well construction forms, and other related monitoring well forms for the well network are included in Appendix C of the HCR (included in the Operating Permit to which this Plan is attached). The well locations are shown on **Figure 2-1**.

2.1.2 40 C.F.R. § 257 Monitoring Program

The 40 C.F.R. § 257 well network for the PAP consists of six monitoring wells screened in the uppermost aquifer, including two background monitoring wells (APW05 and APW06) and four compliance monitoring wells (APW07, APW08, APW09, and APW10). The boring logs, well construction forms, and other related monitoring well forms are available in the Operating Records as required by 40 C.F.R. § 257.91 for each monitored CCR Unit or CCR Multi-Unit, and are included in Appendix C of the HCR (included in the Operating Permit to which this Plan is attached). The well locations are shown on **Figure 2-1**.

Groundwater is being monitored at the PAP in accordance with the Detection Monitoring Program requirements specified in 40 C.F.R. § 257.94. Details of the procedures and techniques used to fulfill the groundwater sampling and analysis program requirements are found in the Sampling and Analysis Plan for the PAP (Natural Resource Technology, Inc. [NRT], 2017).

Groundwater samples are collected semi-annually and analyzed for the field and laboratory parameters from Appendix III of 40 C.F.R. § 257, summarized in **Table A** below.

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Table A. 40 C.F.R. § 257 Groundwater Monitoring Program Parameters

Field Parameters[1]		
Groundwater Elevation	pH	
Appendix III Parameters (Total, except TDS)		
Boron	Chloride	Sulfate
Calcium	Fluoride	TDS

[1]Dissolved oxygen, temperature, specific conductance, oxidation/reduction potential, and turbidity are recorded during sample collection.

Results and analysis of groundwater sampling are reported annually by January 31 of the following year and made available on the CCR public website as required by 40 C.F.R. § 257.

2.1.3 Part 845 Well Installation and Monitoring

In 2021, nine additional monitoring wells (APW11, APW12, APW13, APW14, APW15, APW16, APW17, APW18, and APW5S) were installed along the perimeter of the PAP to assess the vertical and horizontal lithology, stratigraphy, chemical properties, and physical properties of geologic layers to a minimum of 100 feet below ground surface (bgs) as specified in 35 I.A.C. § 845.620(b). Additionally, four leachate monitoring wells (XPW01, XPW02, XPW03, and XPW04) were installed within the PAP to characterize CCR materials and leachate.

Prospective Part 845 monitoring wells were sampled for eight rounds between February and August 2021 and the results were used for selection of the PAP Part 845 monitoring well network. Groundwater samples were collected and analyzed for 35 I.A.C. § 845.600 parameters as summarized in **Table B** below.

Table B. Part 845 Groundwater Monitoring Program Parameters

Field Parameters[1]			
pH	Turbidity	Groundwater Elevation	
Metals (Total)			
Antimony	Boron	Cobalt	Molybdenum
Arsenic	Cadmium	Lead	Selenium
Barium	Calcium	Lithium	Thallium
Beryllium	Chromium	Mercury	
Inorganics (Total)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1] Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential were recorded during sample collection.

Data and results from the Part 845 background monitoring were included in the water quality discussion included in the HCR (included in the Operating Permit to which this Plan is attached). The data collected from background locations during the Part 845 monitoring were used to evaluate and calculate background concentrations for the PAP. The evaluation and discussion are included in **Section 3.2** of this report.

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Data collected from the 40 C.F.R. § 257 monitoring network from 2015 to 2020, and from the Part 845 background monitoring were used for selection of the Part 845 monitoring well network proposed in **Section 2.2**.

2.2 Proposed Part 845 Monitoring Well Network

The groundwater monitoring network proposed in this plan will include five monitoring wells screened in the UD (APW02[1], APW03[1], APW04[1], APW05S[1], and APW12[1]), 13 monitoring wells screened in the uppermost aquifer (APW05, APW06, APW07, APW08, APW09, APW10, APW11, APW13, APW14, APW15, APW16, APW17, and APW18), and two temporary water level only surface water staff gages (XSG01 and SG02). The proposed network is summarized in **Table C** on the following page and displayed on **Figure 2-1.** Eighteen wells (two background and 16 compliance) will be used to monitor groundwater concentrations within the hydrostratigraphic units.

The groundwater samples collected from the 18 wells will be used to monitor and evaluate groundwater quality and demonstrate compliance with the groundwater quality standards listed in 35 I.A.C. § 845.600(a). The proposed monitoring wells will yield groundwater samples that represent the quality of downgradient groundwater at the CCR boundary (as required in 35 I.A.C. § 845.630(a)(2)). Monitoring well depths and construction details are listed in **Table 2-1** and summarized in **Table C** on the following page.

[1] Monitoring wells APW02, APW03, APW04, APW05S, and APW12 are wells screened in the UD that have been identified to monitor the PMP.

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Table C. Proposed Part 845 Monitoring Well Network

Well ID	Monitored Unit	Well Screen Interval (feet bgs)	Well Type[3]
APW02*	UD	9.7 - 19.7	Compliance
APW03*	UD	9.7 - 19.7	Compliance
APW04*	UD	7.7 - 17.7	Compliance
APW05	UA	62.6 - 67.4	Background
APW05S*	UD	10.0 – 20.0	Compliance
APW06	UA	67.7 - 72.5	Background
APW07	UA	77.9 - 82.7	Compliance
APW08	UA	71.4 - 81.1	Compliance
APW09	UA	56.7 - 61.5	Compliance
APW10	UA	40.7 - 45.5	Compliance
APW11	UA	60.0 - 65.0	Compliance
APW12*	UD	20.0 - 30.0	Compliance
APW13	UA	58.5 - 63.5	Compliance
APW14	UA	50.0 - 55.0	Compliance
APW15	UA	98.0 - 103.0	Compliance
APW16	UA	80.5 - 85.5	Compliance
APW17	UA	87.0 - 92.0	Compliance
APW18	UA	75.0 - 80.0	Compliance
XSG01[1,2]	CCR	NA	WLO
SG02[1,2]	Surface Water	NA	WLO

[1] Surface water level measuring points.
[2] Location is temporary pending implementation of impoundment closure per an approved Construction Permit Application.
[3] Well type refers to the role of the well in the monitoring network.
* Well in the UD that has been identified to monitor the PMP
NA = not applicable
UA = uppermost aquifer
WLO = water level only

2.3 Well Abandonment

No wells are currently proposed for abandonment.

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3. APPLICABLE GROUNDWATER QUALITY STANDARDS

3.1 Groundwater Classification

Per 35 I.A.C. § 620.210, groundwater within the uppermost aquifer at the PAP meets the definition of a Class I - Potable Resource Groundwater based on the following criteria:

- Groundwater is located more than 10 feet bgs and within an unconsolidated silty sand and gravel unit which is five feet or more in thickness.
- Field hydraulic conductivity testing identified a geometric mean horizontal hydraulic conductivity of 6.8 x 10^{-3} centimeters per second (cm/s), which exceeds the 1 x 10^{-4} cm/s criterion.
- Groundwater is not downgradient of or underlying previously mined out areas.

Testing of the unconsolidated materials of the Mulberry Grove member averaged 21 percent fines which is greater than the 12 percent fines criterion; however, this was not deemed prohibitive of the Class I Classification.

3.2 Statistical Evaluation of Background Groundwater Data

A Statistical Analysis Plan (**Appendix A**) has been developed to describe procedures that will be used to establish background conditions and implement compliance monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. The Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in United States Environmental Protection Agency's (USEPA) *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance,* March 2009), and is intended to provide a logical process and framework for conducting the statistical analysis of the data obtained during groundwater monitoring.

In accordance with 35 I.A.C. § 845.640(f)(1), the statistical method chosen for analysis of background groundwater quality was either the tolerance interval or the prediction interval procedure for each constituent listed in 35 I.A.C. § 845.600(a)(1) at this CCR unit per 35 I.A.C. § 845.640(f)(1)(C). A comparison of the statistical background concentrations and groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1) and the resulting GWPSs are summarized in **Table 3-1**.

3.3 Applicable Groundwater Protection Standards

The applicable GWPS will be established in accordance with 35 I.A.C. § 845.600(a)(1) (greater of the background concentration or numerical limit specified in 35 I.A.C. § 845.600(a)(1)). The results of the statistical analysis of background groundwater data (**Table 3-1**) indicate that most background concentrations in the UD and uppermost aquifer are less than the groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1). Therefore, for these parameters the groundwater quality standards listed in 35 I.A.C. § 845.600(a)(1) will be applied to the results from the proposed groundwater monitoring network. The exceptions include arsenic, pH, and radium 226 and 228 combined where the background concentration/measurement is greater (or lower for pH lower limit) than the 35 I.A.C. § 845.600(a)(1) standard. In these instances, the GWPS will be the background concentration/measurement.

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Under most circumstances, the GWPS will be compared to the lower confidence limit for the observed concentrations for each constituent in each compliance well. Exceptions are when there are high percentages (greater than 50 percent) of non-detects in compliance well data, for which a future mean (for 50 to 70 percent non-detects) or median (for 70 percent non-detects) will be compared to the GWPS. Consistent with the *Unified Guidance*, the same general statistical method of confidence interval testing against a fixed GWPS is recommended in compliance and corrective action programs. Confidence intervals provide a flexible and statistically accurate method to test how a parameter estimated from a single sample compares to a fixed numerical limit. Confidence intervals explicitly account for variation and uncertainty in the sample data used to construct them.

Evaluation of the applicable standards will occur in conjunction with the analysis of groundwater quality results. Background calculations and the resulting concentrations may be updated as appropriate, in accordance with the Statistical Analysis Plan included in **Appendix A.**

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4. GROUNDWATER MONITORING PLAN

The groundwater monitoring plan will monitor and evaluate groundwater quality to demonstrate compliance with the groundwater quality standards included in 40 C.F.R. § 257.94(e), 40 C.F.R. § 257.95(h), and 35 I.A.C. § 845.600(a). The groundwater monitoring program will include sampling and analysis procedures that are consistent and that provide an accurate representation of groundwater quality at the background and compliance wells as required by 35 I.A.C. § 845.630. As discussed in **Section 2,** three monitoring programs specific to the PAP exist: the IEPA-required monitoring program, the 40 C.F.R. § 257 monitoring program, and the proposed Part 845 monitoring program. These networks will continue to be monitored until USEPA approves Part 845. It is expected that upon USEPA approval of Part 845, the 40 C.F.R. § 257 monitoring program and reporting will be eliminated, and the proposed Part 845 monitoring and reporting included in this GMP will replace the current IEPA monitoring program. The Part 845 monitoring and reporting will continue until requirements of Part 845 have been achieved.

4.1 Monitoring Networks and Parameters

4.1.1 IEPA Groundwater Monitoring

The existing IEPA-required monitoring program was discussed in detail in **Section 2.1.1**. Four groundwater monitoring wells, including two background monitoring wells (G116 and APW02) and two compliance monitoring wells (APW03 and APW04), are sampled on a quarterly frequency for the parameters listed Special Condition No. 19 of NPDES Permit No. IL0049191.

4.1.2 40 C.F.R. § 257 Groundwater Monitoring

The existing 40 C.F.R. § 257 monitoring program was discussed in detail in Section **2.1.2**. Six wells (two background and four compliance) are sampled for Appendix III parameters on a semi-annual frequency. No changes are proposed to this monitoring network. Well locations and parameters will continue to be monitored and reported as required by 40 C.F.R. § 257 until USEPA approves Part 845.

4.1.3 Part 845 Groundwater Monitoring

The proposed Part 845 Monitoring Network will consist of two background monitoring wells (APW05, and APW06), 16 compliance monitoring wells (APW02, APW03, APW04, APW05S, APW07, APW08, APW09, APW10, APW11, APW12, APW13, APW14, APW15, APW16, APW17, and APW18) and two temporary water level only surface water staff gages (XSG01 and SG02) to monitor potential impacts from the PAP (**Figure 2-1**). These monitoring wells are screened within the UD (APW02[2], APW03[2], APW04[2], APW05S[2], and APW12[2]) and the uppermost aquifer (APW05, APW06, APW07, APW08, APW09, APW10, APW11, APW13, APW14, APW15, APW16, APW17, APW18) along the perimeter of the PAP. Groundwater samples will be collected and analyzed for the laboratory and field parameters in **Table D** below.

[2] Monitoring wells APW02, APW03, APW04, APW05S, and APW12 are wells screened in the UD that have been identified to monitor the PMP.

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Table D. Part 845 Groundwater Monitoring Program Parameters

Field Parameters[1]			
pH	Turbidity	Groundwater Elevation	
Metals (Total)			
Antimony	Boron	Cobalt	Molybdenum
Arsenic	Cadmium	Lead	Selenium
Barium	Calcium	Lithium	Thallium
Beryllium	Chromium	Mercury	
Inorganics (Total)			
Fluoride	Sulfate	Chloride	TDS
Other (Total)			
Radium 226 and 228 combined			

[1] Dissolved oxygen, temperature, specific conductance, and oxidation/reduction potential will be recorded during sample collection.

All parameters listed above were sampled a minimum of eight times by October 18, 2021 to establish background groundwater quality in accordance with 35 I.A.C. § 845.650 (b)(1)(A). Discussion of background groundwater quality is included in **Section 3.2**.

4.2 Sampling Schedule

Groundwater sampling for the Part 845 monitoring well network will initially be performed quarterly according to the following schedule:

Table E. Part 845 Sampling Schedule

Frequency	Duration
Monthly (groundwater elevations only)	Begins: the quarter following approval of this plan and issuance of the Operating Permit.
	Ends: Following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii).
Quarterly (groundwater quality)	Begins: the quarter following approval of this plan and issuance of the Operating Permit.
	Ends: Following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii), or upon IEPA approval of an alternate schedule as allowed by 35 I.A.C. § 845.650(b)(4).
Semi-annual (groundwater quality)	Begins: Following 5 years of quarterly groundwater monitoring and IEPA approval of a demonstration that groundwater concentrations are below standards in 35 I.A.C. § 845.600 and not exhibiting statistically-significant increasing trends, monitoring effectiveness is not compromised by a semi-annual schedule, and sufficient data has been collected to characterize groundwater.
	Ends: Following detection of a statistically-significant increasing trend in groundwater concentrations or an exceedance of the standards in 35 I.A.C. § 845.600 (quarterly monitoring shall be resumed in these circumstances), or following the 30-year post closure care period and following IEPA approval of documentation that groundwater concentrations

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	are below standards in 35 I.A.C. § 845.600 and concentrations exceeding background are not increasing and meet requirements in 35 I.A.C. § 845.780 (c)(2)(B)(i) and (ii).

4.3 Groundwater Sample Collection

Groundwater sampling procedures have been developed and the collection of groundwater samples is being implemented to meet the requirements of 35 I.A.C. § 845.640. In addition to groundwater well samples, quality assurance samples will be collected as described in **Section 4.5** (**Table 4-1**).

4.4 Laboratory Analysis

Laboratory analysis will be performed consistent with the requirements of 35 I.A.C. § 845.640(j) by a state-certified laboratory using methods approved by IEPA and USEPA. Laboratory methods may be modified based on laboratory equipment availability or procedures, but the Reporting Limit (RL) for all parameters analyzed, regardless of method, will be lower than the applicable groundwater quality standard. RLs for the applicable parameters are summarized in **Table 4-2**. Concentrations lower than the RL will be reported as less than the RL.

4.5 Quality Assurance Program

Consistent with the requirements of 35 I.A.C. § 845.640(a)(5), the sampling and analysis program includes procedures and techniques for quality assurance/quality control (QA/QC). Additional quality assurance samples to be collected will include the following:

- Field duplicates will be collected at a frequency of one per group of ten or fewer investigative water samples.
- One equipment blank sample will be collected and analyzed for each day of sampling. If dedicated sampling equipment is used, then equipment blank samples will not be collected.
- The duplicate and equipment blank quality assurance samples will be supplemented by the laboratory QA/QC program, which typically includes:
  - Regular generation of instrument calibration curves to assure instrument reliability
  - Laboratory control samples and/or quality control check standards that have been spiked, and analyses to monitor the performance of the analytical method
  - Matrix spike/matrix spike duplicate analyses to determine percent recoveries and relative percent differences for each of the parameters detected
  - Analysis of replicate samples to check the precision of the instrumentation and/or methodology employed for all analytical methods
  - Analysis of method blanks to assure that the system is free of contamination

Water quality meters used to measure pH and turbidity will be calibrated according to manufacturer’s specifications. At a minimum, it is recommended that calibration of pH occur daily prior to sampling and checked for accuracy at the end of each day. Unusual or suspect pH measurements during sampling events will be flagged, evaluated, and additional calibration may be performed throughout the sampling events. Turbidity meters will be checked daily, prior to and following sampling. Unusual measurements or erratic meter performance will be flagged and evaluated for overall effects on the data prior to reporting.

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4.6 Groundwater Monitoring System Maintenance Plan

Consistent with the requirements of 35 I.A.C. § 845.630(e)(2), maintenance will be performed as needed to assure that the monitoring wells provide representative groundwater samples. Monitoring wells will be inspected during each groundwater sampling event; inspections will consist of the following:

- Visual inspection, clearing of vegetation, replacement of markers, and painting of protective casings as needed to assure that monitoring wells are clearly marked and accessible
- Visual inspection and repair or replacement of well aprons as needed to assure that they are intact, drain water away from the well, and have not heaved
- Visual inspection and repair or replacement of protective casings as needed to assure that they are undamaged, and that locks are present and functional
- Checks to assure that well caps are intact and vented, unless in flood-prone areas in which case caps will not be vented
- Annual measurement of monitoring well depths to determine the degree of siltation within the wells. Wells will be redeveloped as needed to remove siltation from the screened interval if it impedes flow of water into the well
- Checks to assure that wells are clear of internal obstructions, and flow freely

If maintenance of a monitoring well cannot address an identified deficiency, a replacement well will be installed.

4.7 Statistical Analysis

Statistical analysis will be consistent with procedures listed in 35 I.A.C. § 845.640(f). A Statistical Analysis Plan, provided in **Appendix A**, has been developed to summarize the statistical procedures that will be used to evaluate the groundwater results.

4.8 Data Reporting

Data reporting for the 40 C.F.R. § 257 monitoring well network will be consistent with recordkeeping, notification, and internet posting requirements described in 40 C.F.R. § 257.105 through 257.107.

Groundwater monitoring and analysis completed in accordance with the Part 845 monitoring under an approved monitoring program will be reported to IEPA within 60 days after completion of sampling and the data placed in the facility's operating record as required by 35 I.A.C. § 845.610(b)(3)(D). Within 14 days of posting to the operating record, information will be posted to the publicly accessible internet site "Illinois CCR Rule Compliance Data and Information" as required by 35 I.A.C. § 845.810(d). Information will also be submitted to IEPA annually by January 31 as required by 35 I.A.C. § 845.550, for data collected the preceding year. The report will include the status of the groundwater monitoring and any required corrective action plan for the PAP in addition to other requirements detailed in 35 I.A.C. § 845.610(e).

4.9 Compliance with Applicable On-site Groundwater Protection Standards

In accordance with 35 I.A.C. § 845.600(a)(1), the groundwater protection standard at the waste boundary will be the higher of either the 35 I.A.C. § 845.600 standard or the concentration determined by background groundwater monitoring.

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As provided in 35 I.A.C. § 845.780(c)(2), at the end of the 30-year post-closure care period, groundwater monitoring will continue to be conducted in post-closure care until the groundwater results show the concentrations are:

- Below the GWPS in 35 I.A.C. § 845.600(a)(1); and
- Not increasing for those constituents over background, using the statistical procedures and performance standards in 35 I.A.C. § 845.640(f) and (g), provided that:
  - Concentrations have been reduced to the maximum extent feasible; and
  - Concentrations are protective of human health and the environment.

Following detection of an exceedance of the GWPS, an Alternate Source Demonstration (ASD) will be evaluated as described in **Section 4.10**.

4.10 Alternate Source Demonstrations

As allowed in 35 I.A.C. § 845.650(e), following detection of an exceedance of the GWPS, an ASD will be evaluated and, if completed, submitted to IEPA within 60 days. The ASD will provide lines of evidence that a source other than the PAP caused the contamination and the PAP did not contribute to the contamination, or that the exceedance of the GWPS resulted from error in sampling, analysis, statistical evaluation, natural variation in groundwater quality, or a change in the potentiometric surface and groundwater flow direction.

The ASD will include information and analysis that supports the conclusions and a certification of accuracy by a qualified professional engineer. Once the ASD is approved by IEPA, the Part 845 groundwater monitoring will continue as defined in **Section 4.1.3**.

If an ASD is not completed and submitted, or IEPA does not approve the ASD, a notification of the exceedance will be provided to IEPA and placed in the operating record. Additional actions will also be completed as required by 35 I.A.C § 845.650(d)(1) through (3); including, initiation of an assessment of corrective measures under 35 I.A.C § 845.660. As allowed in 35 I.A.C § 845.650(e)(7) a petition for review of IEPA's non-concurrence under 35 I.A.C. § 105 may also be filed.

4.11 Assessment of Corrective Measures and Corrective Action

As described in 35 I.A.C. § 845.660, if the ASD summarized in **Section 4.10** has not been approved by IEPA, an assessment of corrective measures will be initiated within 90 days of the detection of a result exceeding 35 I.A.C. § 845.600 standards (*i.e.,* receipt of laboratory data). The assessment of corrective measures will include at least the following (35 I.A.C. § 845.660 (c)):

- The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;
- The time required to begin and complete the corrective action plan; and
- The institutional requirements, such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the corrective action plan.

Within one year of completing the assessment of corrective measures, a corrective action plan will be developed to identify the selected remedy in accordance with 35 I.A.C. § 845.670. If closure of the CCR Unit is required, a closure alternatives analysis will be completed as specified

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in 35 I.A.C. § 845.710. The analysis and selected alternative will be submitted to IEPA in a Closure Plan as specified by 35 I.A.C. § 845.720. Groundwater monitoring proposed in this Addendum will continue as specified until the post closure care period has expired and IEPA has approved termination of post-closure care.

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5. REFERENCES

Illinois Environmental Protection Agency, 2021. Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845, April 15, 2021.

Natural Resource Technology, Inc. (NRT), 2017. Sampling and Analysis Plan, Newton Primary Ash Pond, Newton Power Station, Newton, Illinois, Project No. 2285, Revision 0, October 17, 2017.

Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. Hydrogeologic Site Characterization Report, Newton Primary Ash Pond, Newton Power Plant, 6725 North 500th St., Newton, Illinois.

United States Environmental Protection Agency (USEPA), March 2009. Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance. Office of Resource Conservation and Recovery, Program Implementation and Information Division, United States Environmental Protection Agency, Washington D.C. EPA/530/R-09/007.

United States Environmental Protection Agency (USEPA), 2015. Title 40 of the Code of Federal Regulations, Part 257.

TABLES

TABLE 1-1. PART 845 REQUIREMENTS CHECKLIST
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in GMP
845.630	**Groundwater Monitoring Systems**	
845.630(a)(2)	Potential contaminant pathways must be monitored.	Sections 2.2 & 4.1.3
845.630(a) 845.630(b) 845.630(c)	At least two upgradient wells and four downgradient wells (min. 1 and 3, but requires additional documentation)	Sections 2.2 & 4.1.3 Table 2-1 Figure 2-1
845.630(a) 845.630(b) 845.630(c)	Downgradient Well Density	Figure 2-1
845.630(a)(2)	Downgradient wells at waste boundary	Figure 2-1
845.640	**Groundwater Sampling and Analysis Requirements**	
845.640(a)	Consistent sampling and analysis procedures	Section 4 Tables 4-1 & 4-2
845.640(b)	Methods are appropriate	Section 4 Tables 4-1 & 4-2
845.640(c)	Groundwater elevations must be measured in each well prior to purging, each time groundwater is sampled.	Section 4.3
845.640 (d)(e)(f)(g)(h)	Establishment of background and application of statistical methods	Sections 3 & 4.7 Appendix A
845.640(i)	Analyze total recoverable metals	Section 4.1.3
845.640(j)	Analyze groundwater samples using a certified laboratory	Section 4.4

TABLE 1-1. PART 845 REQUIREMENTS CHECKLIST

GROUNDWATER MONITORING PLAN

NEWTON POWER PLANT

PRIMARY ASH POND

NEWTON, ILLINOIS

Part 845 Reference	Part 845 Components	Location of Information in GMP
845.650	**Groundwater Monitoring Program**	
845.650(a)	Must include monitoring for all constituents with a groundwater protection standard in Section 845.600(a), calcium, and turbidity	Section 4.1.3
845.650(b)(c)	Groundwater Monitoring Frequency	Sections 4.1.3 & 4.2
845.650(d)(e)	Exceedances of the groundwater protection standard	Sections 4.9, 4.10 & 4.11
845.650(b)(2) 845.650(b)(3)	Staff gauge/ piezometer to monitor head in impoundment	Sections 2.2 & 4.1.3 Figure 2-1 (XSG01)
NA	Staff gauge/ piezometer to monitor head of neighboring surface water body	Sections 2.2 & 4.1.3 Figure 2-1 (SG02)

[O: CJC 08/25/21; C: LDC 09/09/21]

Notes:

GMP = Groundwater Monitoring Plan

NA = Not Applicable

TABLE 2-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	Type	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft BGS)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
APW02	C	UD	06/19/2010	533.61	533.61	Top of Riser	529.90	9.70	19.70	520.20	510.20	20.00	509.90	10	2	38.925918	-88.293907
APW03	C	UD	06/18/2010	532.41	532.41	Top of Riser	528.37	9.70	19.70	518.67	508.67	20.00	508.40	10	2	38.922322	-88.281567
APW04	C	UD	06/19/2010	525.06	525.06	Top of Riser	521.45	7.70	17.70	513.75	503.75	18.00	503.50	10	2	38.927444	-88.273113
APW05	B	UA	10/22/2015	544.07	544.07	Top of Riser	541.08	62.64	67.44	478.44	473.64	67.84	473.10	4.8	2	38.933958	-88.280983
APW05S	C	UD	01/19/2021	543.94	543.94	Top of PVC	541.05	10.00	20.00	531.05	521.05	20.00	518.10	10	2	38.933958	-88.281033
APW06	B	UA	10/21/2015	546.07	546.07	Top of Riser	542.89	67.67	72.48	475.22	470.41	72.88	468.90	4.8	2	38.933746	-88.286276
APW07	C	UA	11/05/2015	538.37	538.37	Top of Riser	535.72	77.89	82.70	457.83	453.02	83.10	452.60	4.8	2	38.928233	-88.292076
APW08	C	UA	10/28/2015	528.97	528.97	Top of Riser	526.26	71.40	81.06	454.86	445.20	81.53	444.30	9.7	2	38.923154	-88.292286
APW09	C	UA	11/03/2015	531.52	531.52	Top of Riser	528.33	56.66	61.46	471.67	466.87	61.85	466.30	4.8	2	38.922319	-88.281585
APW10	C	UA	11/06/2015	524.25	524.25	Top of Riser	521.49	40.74	45.54	480.75	475.95	45.94	475.60	4.8	2	38.927435	-88.273127
APW11	C	UA	01/23/2021	538.63	538.63	Top of PVC	536.05	60.00	65.00	476.05	471.05	65.00	436.10	5	2	38.932811	-88.27545
APW12	C	UD	02/21/2021	546.29	546.29	Top of PVC	543.33	20.00	30.00	523.33	513.33	30.00	456.30	10	2	38.92975	-88.272058
APW13	C	UA	01/22/2021	537.99	537.99	Top of PVC	535.16	58.50	63.50	476.66	471.66	63.50	445.20	5	2	38.92566	-88.274416
APW14	C	UA	01/23/2021	526.29	526.29	Top of PVC	523.85	50.00	55.00	473.85	468.85	55.00	428.90	5	2	38.924057	-88.277994
APW15	C	UA	01/22/2021	524.69	524.69	Top of PVC	522.06	98.00	103.00	424.06	419.06	103.00	412.10	5	2	38.921593	-88.285226
APW16	C	UA	01/20/2021	531.18	531.18	Top of PVC	529.16	80.50	85.50	448.66	443.66	85.50	419.20	5	2	38.920317	-88.291291
APW17	C	UA	01/22/2021	532.52	532.52	Top of PVC	529.84	87.00	92.00	442.84	437.84	92.00	429.80	5	2	38.925916	-88.293928
APW18	C	UA	01/21/2021	543.27	543.27	Top of PVC	540.55	75.00	80.00	465.55	460.55	80.00	433.60	5	2	38.930979	-88.290122
XSG01	WLO	CCR	--	--	536.17	Staff gauge	--	--	--	--	--	--	--	--	--	38.923218	-88.29067
SG02	WLO	SW	--	--	506.89	Staff gauge	--	--	--	--	--	--	--	--	--	38.921234	-88.292057

TABLE 2-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	Type	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft BGS)	Screen Bottom Depth (ft BGS)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft BGS)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)

Notes:
All elevation data are presented relative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
Type refers to the role of the well in the monitoring network: background (B), compliance (C), or water level measurements only (WLO)
WLO wells are temporary pending implementation of impoundment closure per an approved Construction Permit application
-- = data not available
BGS = below ground surface
CCR = Coal Combustion Residual
ft = foot or feet
HSU = Hydrostratigraphic Unit
PVC = polyvinyl chloride
SW = surface water
UA = uppermost aquifer
UD = upper drift

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TABLE 3-1. BACKGROUND GROUNDWATER QUALITY AND STANDARDS
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Parameter	Background Concentration	845 Limit	Groundwater Protection Standard	Unit
Antimony, total	0.003	0.006	0.006	mg/L
Arsenic, total	0.059	0.010	0.059	mg/L
Barium, total	0.3	2.0	2.0	mg/L
Beryllium, total	0.001	0.004	0.004	mg/L
Boron, total	0.26	2	2	mg/L
Cadmium, total	0.001	0.005	0.005	mg/L
Chloride, total	52	200	200	mg/L
Chromium, total	0.011	0.1	0.1	mg/L
Cobalt, total	0.0043	0.006	0.006	mg/L
Fluoride, total	0.633	4.0	4.0	mg/L
Lead, total	0.0074	0.0075	0.0075	mg/L
Lithium, total	0.03	0.04	0.04	mg/L
Mercury, total	0.0002	0.002	0.002	mg/L
Molybdenum, total	0.018	0.1	0.1	mg/L
pH (field)	7.8 / 6.4	9.0 / 6.5	9.0 / 6.4	SU
Radium 226 and 228 combined	6.9	5	6.9	pCi/L
Selenium, total	0.001	0.05	0.05	mg/L
Sulfate, total	36	400	400	mg/L
Thallium, total	0.001	0.002	0.002	mg/L
Total Dissolved Solids	628	1200	1200	mg/L

Notes:
For pH, the values presented are the upper / lower limits
Groundwater protection standards for calcium and turbidity do not apply per 35 I.A.C. § 845.600(b)
mg/L = milligrams per liter
SU = standard units
pCi/L = picocuries per liter

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RAMBOLL

TABLE 4-1. SAMPLING AND ANALYSIS SUMMARY
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Parameter	Analytical Method [1]	Number of Samples	Field Duplicates [2]	Field Blanks [3]	Equipment Blanks [3]	MS/MSD [4]	Total	Container Type	Minimum Volume [5]	Preservation (Cool to 4 °C for all samples)	Sample Hold Time from Collection Date
Metals											
Metals [6]	6020, Li - EPA 200.7	18	2	0	0	1	21	plastic	600 mL	HNO_3 to pH<2	6 months
Mercury	7470A or 6020	18	2	0	0	1	21	plastic	400 mL	HNO_3 to pH<2	28 days
Inorganic Parameters											
Fluoride	9214 or EPA 300	18	2	0	0	1	21	plastic	300 mL	Cool to 4 °C	28 days
Chloride	9251 or EPA 300	18	2	0	0	1	21	plastic	100 mL	Cool to 4 °C	28 days
Sulfate	9036 or EPA 300	18	2	0	0	1	21	plastic	50 mL	Cool to 4 °C	28 days
Total Dissolved Solids	SM 2540 C	18	2	0	0	1	21	plastic	200 mL	Cool to 4 °C	7 days
Radium											
Radium 226	9315 or EPA 903	18	0	0	0	0	18	plastic	1000 mL	HNO_3 to pH<2	6 months
Radium 228	9320 or EPA 904	18	0	0	0	0	18	plastic	1000 mL	HNO_3 to pH<2	6 months
Field Parameters											
pH	SM 4500-H+ B	18	NA	NA	NA	NA	18	flow-through cell	NA	none	immediately
Dissolved Oxygen [8]	SM 4500-O/405.1	18	NA	NA	NA	NA	18	flow-through cell	NA	none	immediately
Temperature [8]	SM 2550	18	NA	NA	NA	NA	18	flow-through cell	NA	none	immediately
Oxidation/Reduction Potential [8]	SM 2580 B	18	NA	NA	NA	NA	18	flow-through cell	NA	none	immediately
Specific Conductance [8]	SM 2510 B	18	NA	NA	NA	NA	18	flow-through cell	NA	none	immediately
Turbidity [7]	SM 2130 B	18	NA	NA	NA	NA	18	flow-through cell or hand-held turbidity meter	NA	none	immediately

[O: CJC 08/25/21; C: LDC 09/09/21]

Notes:
[1] Analytical method numbers are from SW-846 unless otherwise indicated. Analytical methods may be updated with more recent versions as appropriate.
[2] Field duplicates will be collected at a frequency of one per group of 10 or fewer investigative water samples. Field duplicates will not be collected for radium analysis.
[3] Field blanks will be collected at the discretion of the project manager; Equipment blanks will be collected at a rate of 1 per sampling event if non-dedicated equipment is used.
[4] Matrix Spike/Matrix Spike Duplicate (MS/MSD) samples will be collected at a frequency of one per group of 20 or fewer investigative water samples per CCR unit/multi-unit. Additional volume to be determined by laboratory.
[5] Sample volume is estimated and will be determined by the laboratory.
[6] Metals = antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, lead, lithium, molybdenum, selenium, thallium. Metals may be analyzed via ICP/ ICP-MS USEPA methods 6010 or 6020 depending on laboratory instrument availability.
[7] If turbidity exceeds 10 NTUs, a duplicate sample filtered through a .45 micron filter may be collected for metals analysis in addition to the unfiltered sample. Both samples would be submitted for analysis.
[8] Parameter collected for quality assurance and quality control for field sampling purposes only; not required to be collected or reported under Part 845; collection of parameter may be discontinued without notification.
< = less than
°C = degrees Celsius
HNO_3 = nitric acid
mL = milliliter
NA = not applicable
NTU = nephelometric turbidity unit

TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Constituent	CAS	Unit	Analytical Methods [1]	USEPA MCL [2]	35 I.A.C. § 845.600	RL [4, 5]	MDL [5]
Metals							
Antimony	7440-36-0	mg/L	6020	0.006	0.006	0.003	0.00036
Arsenic	7440-38-2	mg/L	6020	0.01	0.01	0.001	0.00013
Barium	7440-39-3	mg/L	6020	2	2	0.001	0.00028
Beryllium	7440-41-7	mg/L	6020	0.004	0.004	0.001	0.000017
Boron	7440-42-8	mg/L	6020	NS	2	0.01	0.0023
Cadmium	7440-43-9	mg/L	6020	0.005	0.005	0.001	0.000042
Calcium	7440-70-2	mg/L	6020	NS	NS	0.15	0.15
Chromium	7440-47-3	mg/L	6020	0.1	0.1	0.004	0.00027
Cobalt	7440-48-4	mg/L	6020	0.006	0.006	0.002	0.000017
Lead	7439-92-1	mg/L	6020	0.015	0.0075	0.001	0.000025
Lithium	7439-93-2	mg/L	6020 or EPA 200.7	0.04	0.04	0.02	0.0001
Mercury	7439-97-6	mg/L	6020 or 7470A	0.002	0.002	0.0002	0.000078
Molybdenum	7439-98-7	mg/L	6020	0.1	0.1	0.001	0.000063
Selenium	7782-49-2	mg/L	6020	0.05	0.05	0.001	0.00032
Thallium	7440-28-0	mg/L	6020	0.002	0.002	0.001	0.000062
Inorganics							
Fluoride	7681	mg/L	9214 or EPA 300	4	4	0.25	0.065
Chloride	16887-00-6	mg/L	9251 or EPA 300	250 [3]	200	1	0.15
Sulfate	18785-72-3	mg/L	9036 or EPA 300	250 [3]	400	1	0.24
Total Dissolved Solids	10052	mg/L	SM 2540C	500 [3]	1200	17	--
Other							
Radium 226 and 228 combined	7440-14-4	pCi/L	9315/9320 or EPA 903/904	5	5	-- [6]	-- [7]
Field							
pH	NA	SU	SM 4500-H+ B	NS	6.5-9.0	NA	NA
Oxidation/Reduction Potential	NA	mV	SM 2580 B	NS	NS	NA	NA
Dissolved Oxygen	NA	mg/L	SM 4500-O/405.1	NS	NS	NA	NA
Temperature	NA	°C	SM 2550	NS	NS	NA	NA
Specific Conductivity	NA	µS/cm	SM 2510 B	NS	NS	NA	NA
Turbidity	NA	NTU	SM 2130 B	NS	NS	NA	NA

[O: CJC 08/25/21; C: LDC 09/09/21]

TABLE 4-2. DETECTION AND REPORTING LIMITS FOR PART 845 PARAMETERS
GROUNDWATER MONITORING PLAN
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Notes:

[1] Analytical method numbers are from SW-846 unless otherwise indicated. Metals will be analyzed via Method 6020 or 6010 depending on laboratory equipment availability. Selected method will ensure reporting limits (RL) are below Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845.600 groundwater protection standards.

[2] USEPA MCL = United States Environmental Protection Agency Maximum Contaminant Level.

[3] USEPA SMCL = United States Environmental Protection Agency Secondary Maximum Contaminant Level.

[4] RLs will be less than the 35 I.A.C. § 845.600 groundwater protection standards.

[5] RLs and method detection limits (MDL) will vary depending on the laboratory performing the work.

[6] All radium results will be reported (values may be positive or negative) and will include uncertainty and the calculated MDC.

[7] Laboratories calculate a minimum detectable concentration (MDC) based on the sample.

°C = degrees Celsius
µS/cm = microSiemens per centimeter
CAS = Chemical Abstract Number
MDL = Method detection limit as established by the laboratory
mg/L = milligrams per liter
mV = millivolts
NS = No standard
NTU = nephelometric turbidity unit
pCi/L = picoCuries per liter
RL = Reporting limit as established by the laboratory
SM = Standard Methods for the Examination of Water and Wastewater
SU = standard units

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FIGURES

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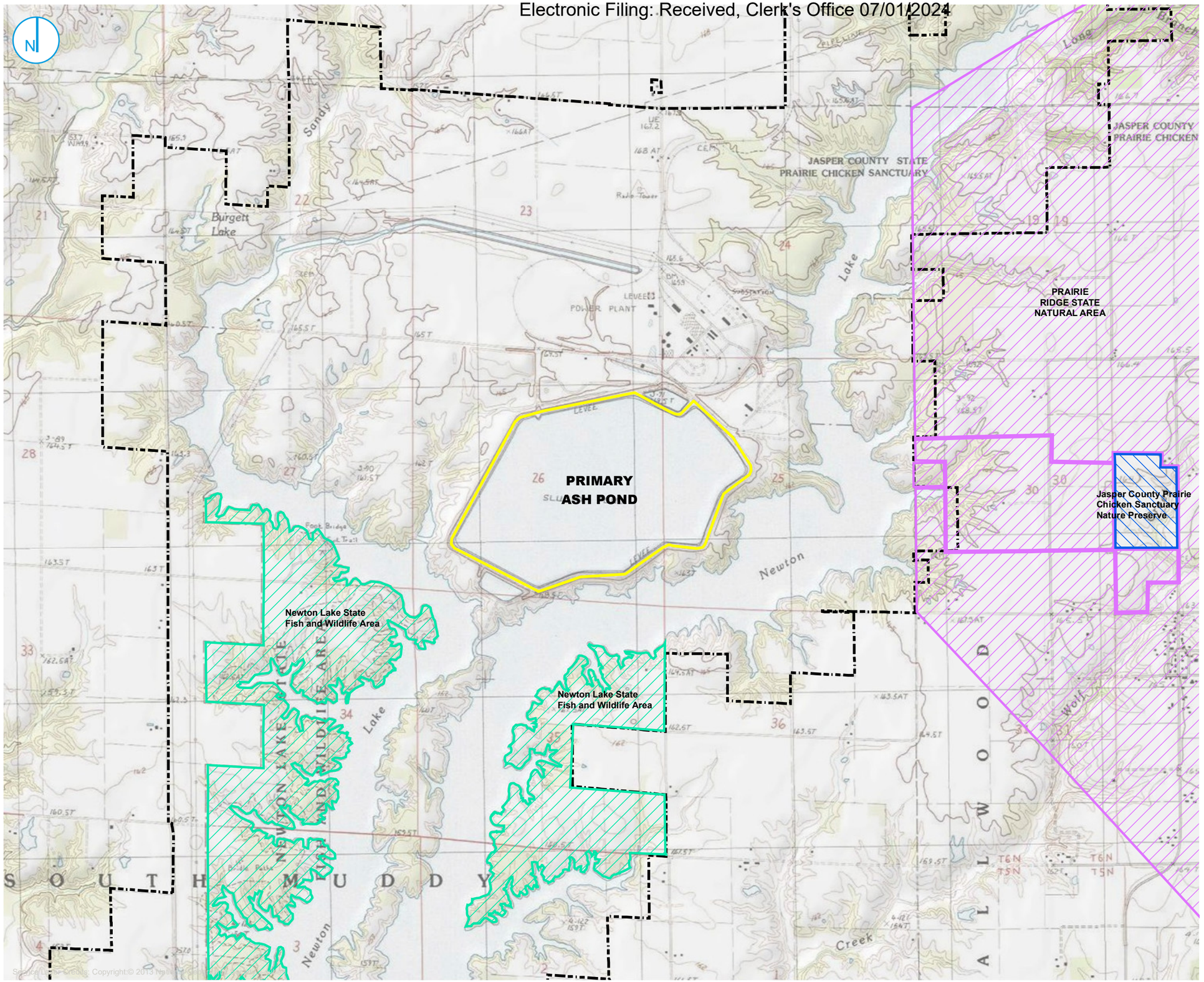

PART 845 REGULATED UNIT FACILITY BOUNDARY

JASPER COUNTY PRAIRIE CHICKEN SANCTUARY NATURE PRESERVE

NEWTON LAKE STATE FISH AND WILDLIFE AREA

PRAIRIE RIDGE STATE NATURAL AREA

PROPERTY BOUNDARY

0 1,000 2,000 Feet

SITE LOCATION MAP

GROUNDWATER MONITORING PLAN
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22851\MXD\845_Operating_Permit\Newton\GMP\Figure 1-1_Site Location Map.mxd

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PART 845 REGULATED UNIT FACILITY BOUNDARY
SITE FEATURE
PROPERTY BOUNDARY

0 500 1,000
Feet

SITE MAP

GROUNDWATER MONITORING PLAN
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2202285\MXD\845_Operating_Permit\Newton\GMP\Figure 1-2_Site Map.mxd

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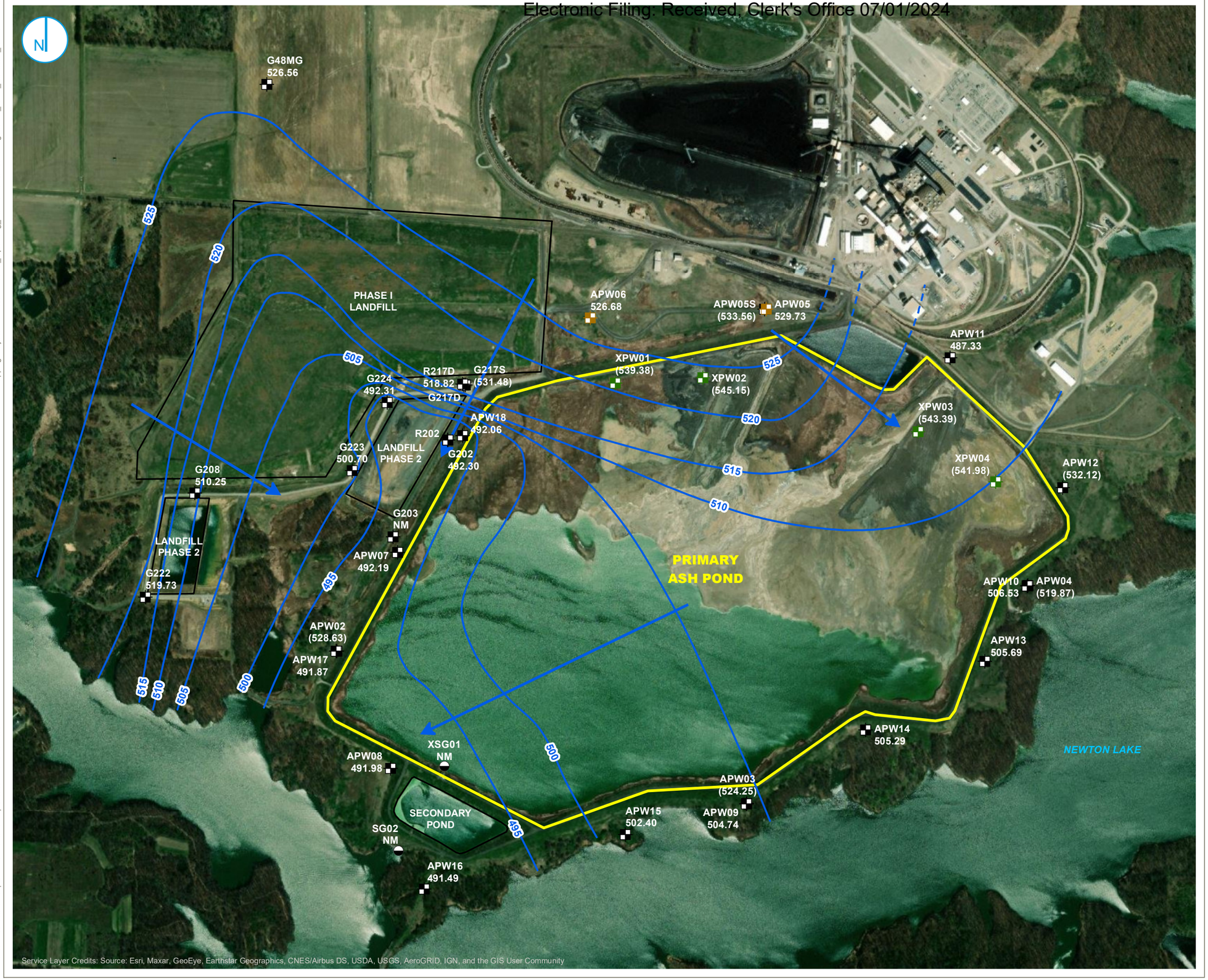

- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

NOTES:

1.ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.

2. NM = NOT MEASURED

3. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

0 400 800 Feet

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS APRIL 27, 2021

GROUNDWATER MONITORING PLAN
PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

FIGURE 1-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2212285\MXD\845_Operating_Permit\Newton\GMP\Figure 1-3_GWE_Contours_20210427.mxd

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COMPLIANCE WELL
BACKGROUND WELL
STAFF GAUGE
PART 845 REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE
PROPERTY BOUNDARY

0 500 1,000
Feet

PROPOSED MONITORING WELL NETWORK

GROUNDWATER MONITORING PLAN
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\GMP\Figure 2-1_Proposed Monitoring Well Network.mxd

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APPENDIX A
STATISTICAL ANALYSIS PLAN

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Prepared for
Illinois Power Generating Company

Date
October 25, 2021

Project No.
1940100806-008

STATISTICAL ANALYSIS PLAN

PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL Bright ideas. Sustainable change.

STATISTICAL ANALYSIS PLAN
NEWTON POWER PLANT PRIMARY ASH POND

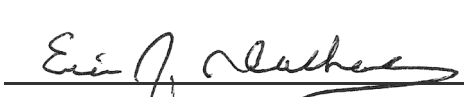
Project Name	**Newton Power Plant Primary Ash Pond**
Project No.	**1940100806-008**
Recipient	**Illinois Power Generating Company**
Document Type	**Statistical Analysis Plan**
Version	**FINAL**
Date	**October 25, 2021**

Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com



Brian G. Hennings, PG
Senior Managing Hydrogeologist



Eric J. Tlachac, PE
Senior Managing Engineer



Rachel A. Banoff, EIT
Project Statistician

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LICENSED PROFESSIONAL CERTIFICATIONS

This certification is based on the description of the statistical methods selected to evaluate groundwater as presented in the following Statistical Analysis Plan; Newton Power Plant Primary Ash Pond. The procedures described in the plan will be used to establish background conditions and implement compliance monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. The Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in the United States Environmental Protection Agency (USEPA)'s *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance,* March 2009), and is intended to provide a logical process and framework for conducting the statistical analysis of the data obtained during groundwater monitoring. In accordance with 35 I.A.C. § 845.640(f)(1), the statistical method chosen for analysis of background groundwater quality will be either the tolerance interval or the prediction interval procedure for each constituent listed in 35 I.A.C. § 845.600(a)(1) at this CCR unit per 35 I.A.C. § 845.640(f)(1)(C). Groundwater Protection Standards (GWPS) will be established in accordance with 35 I.A.C. § 845.600(a) (greater of the background concentration or numerical limit specified in 35 I.A.C. § 845.600(a)(1)). The GWPS will be compared to the lower confidence limit for the observed concentrations for each constituent in each compliance well. Consistent with the *Unified Guidance*, the same general statistical method of confidence interval testing against a fixed GWPS is recommended in compliance and corrective action programs. Confidence intervals provide a flexible and statistically accurate method to test how a parameter estimated from a single sample compares to a fixed numerical limit. Confidence intervals explicitly account for variation and uncertainty in the sample data used to construct them.

Description of the statistical methods chosen for analysis of groundwater monitoring data and application of these methods for determining exceedances of the GWPS identified in 35 I.A.C. § 845.600(a) is provided in this Statistical Analysis Plan.

35 I.A.C. § 845.640 Statistical Analysis (PE)

I, Eric J. Tlachac, a qualified professional engineer in good standing in the State of Illinois, certify that the statistical methods summarized above and described in this document (Statistical Analysis Plan; Newton Power Plant Primary Ash Pond) are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.



Eric J. Tlachac
Qualified Professional Engineer
062-063091
Illinois
Date: October 25, 2021

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35 I.A.C. § 845.640 Statistical Analysis (PG)

I, Brian G. Hennings, a qualified professional geologist in good standing in the State of Illinois, certify that the statistical methods described in this document (Statistical Analysis Plan; Newton Power Plant Primary Ash Pond) are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.





Brian G. Hennings
Professional Geologist
196.001482
Illinois
Date: October 25, 2021

35 I.A.C. § 845.640 Statistical Analysis

I, Rachel A. Banoff, a qualified professional, certify that the statistical methods described in this document (Statistical Analysis Plan; Newton Power Plant Primary Ash Pond), are appropriate for evaluating the groundwater monitoring data collected as described in the attached document and are in substantial compliance with 35 I.A.C. § 845.640.



Rachel A. Banoff, EIT
Project Statistician
Date: October 25, 2021

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ACRONYMS AND ABBREVIATIONS

§	Section
35 I.A.C.	Title 35 of the Illinois Administrative Code
ANOVA	analysis of variance
CCR	coal combustion residuals
COC	constituents of concern
GWPS	groundwater protection standard
IEPA	Illinois Environmental Protection Agency
LCL	lower confidence limit
LTL	lower tolerance limit
MSE	mean squared error
P	probability
Part 845	Residuals in Surface Impoundments: Title 35 of the Illinois Administrative Code § 845
RCRA	Resource Conservation and Recovery Act
RL	reporting limit
ROS	regression on order statistics
SI	surface impoundment
SSI	statistically significant increase
SWFPR	site-wide false positive rate
Unified Guidance	*Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (USEPA, 2009)
UPL	upper prediction limit
USEPA	United States Environmental Protection Agency
UTL	upper tolerance limit

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1. INTRODUCTION

In April 2021, the Illinois Environmental Protection Agency (IEPA) issued a final rule for the regulation and management of Coal Combustion Residuals (CCR) in surface impoundments (SIs) under the Standards for the Disposal of CCR in Surface Impoundments: Title 35 of the Illinois Administrative Code (35 I.A.C.) § 845 (Part 845). Facilities regulated under Part 845 are required to develop and sample a groundwater monitoring well network to evaluate whether impounded CCR materials are impacting downgradient groundwater quality. The groundwater quality evaluation must include selection and certification by a qualified professional engineer of the statistical procedures to be used. The procedures described in the evaluation will be used to establish background conditions and implement compliance and corrective action monitoring as necessary and required by 35 I.A.C. § 845.640 and 35 I.A.C. § 845.650. This Statistical Analysis Plan was prepared in accordance with the requirements of 35 I.A.C. § 845.640(f), with reference to the acceptable statistical procedures provided in United States Environmental Protection Agency's (USEPA's) *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance* (*Unified Guidance*) (March 2009).

This Statistical Analysis Plan does not include procedures for groundwater sample collection and analysis, as these activities are conducted in accordance with the Sampling and Analysis Plan prepared for each CCR unit in accordance with 35 I.A.C. § 845.640. This Statistical Analysis Plan will be used as the primary reference for evaluating groundwater quality during operation and post-closure care.

1.1 Statistical Analysis Objectives

This Statistical Analysis Plan is intended to provide a logical process and framework for conducting the statistical analyses of data obtained during groundwater monitoring conducted in accordance with the Sampling and Analysis Plan for each CCR unit. The Statistical Analysis Plan will enable a qualified professional engineer to certify that the selected statistical methods are appropriate for evaluating the groundwater monitoring data for the applicable CCR unit(s).

1.2 Statistical Analysis Plan Approach

The main sections of this Statistical Analysis Plan should be viewed as a "generic" outline of statistical methods utilized for each CCR unit and constituent required to be monitored. The statistical analysis of the groundwater monitoring data, however, will be conducted on an individual-constituent or well basis, and may involve the use of appropriate statistical procedures depending on multiple factors such as detection frequency and normality distributions.

The CCR Rule outlines two phases of groundwater monitoring:

- Background Monitoring in accordance with 35 I.A.C. § 845.650(b)(1)
- Compliance Monitoring in accordance with 35 I.A.C. § 845.650

Each phase of the groundwater monitoring program requires specific statistical procedures to accomplish the intended purpose. During the background monitoring phase, background groundwater quality will be established utilizing upgradient and background wells and downgradient groundwater quality data will be collected to facilitate statistics in subsequent phases. Compliance Monitoring is then initiated through the evaluation of the downgradient

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groundwater monitoring data for exceedances of the groundwater protection standard (GWPS) established by Part 845 (concentration specified in 35 I.A.C. § 845.600 or an IEPA-approved background concentration). The developed statistical analysis plan will be implemented for each monitoring phase and in accordance with the statistical procedures.

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2. BACKGROUND MONITORING AND DATA PREPARATION

The background and compliance monitoring wells were sampled and analyzed for constituents, as listed in Part 845 (antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chloride, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum, pH, radium 226 and 228 combined, selenium, sulfate, thallium, total dissolved solids, and turbidity), during the baseline phase of the groundwater monitoring program.

The background monitoring well(s) were placed upgradient of the CCR unit, or at an alternative background location, where they are not affected by potential leakage from the CCR unit. Compliance monitoring wells were placed at the waste boundary of the CCR unit, along the same groundwater flow path. As 35 I.A.C. § 845.630(a) specifies, the location of these wells ensures that background accurately represents the quality of unaffected groundwater, while compliance wells accurately represent groundwater quality at the waste boundary and monitor all potential contaminant pathways.

As required by 35 I.A.C. § 845.650(a)(1), eight sampling events were completed within 180 days of April 21, 2021. As outlined, groundwater sampling procedures included sampling of the background and compliance wells using low-flow sampling methods, collection of one field quality control sample per event, and groundwater samples were not field filtered before laboratory analysis of total recoverable metals.

Following completion of the eight sampling events, background groundwater quality was established for Part 845 constituents. Groundwater monitoring will be conducted quarterly for at least the first five years. In accordance with 35 I.A.C. § 845.650(b)(4), after the first five years, a request to reduce the monitoring frequency to semiannual may be submitted to IEPA if all of the following can be demonstrated:

- Groundwater monitoring effectiveness will not be compromised by the reduced frequency
- Sufficient data has been collected to characterize groundwater
- Monitoring to date does not show any statistically significant increasing trends
- The concentrations of monitored constituents at the compliance monitoring wells are below the applicable GWPSs established in 35 I.A.C. § 845.600

The following subsections outline the statistical tests and procedures (methods) that will be utilized to evaluate data collected for each constituent in both background and compliance wells for Background and Compliance Monitoring. When necessary and contingent upon equivalent statistical power, an alternative test not included in this Statistical Analysis Plan may be chosen due to site-specific data requirements.

2.1 Sample Independence

Independence of sample results is a major assumption for most statistical analyses. To ensure physical independence of groundwater sampling results, the minimum time between sampling events must be longer than the time required for groundwater to move through the monitoring well. The sampling schedules for both the baseline and compliance monitoring periods are specified in 35 I.A.C. § 845.650(b) and may conflict with the statistical assumption of independence of sample results.

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2.2 Non-Detect Data Processing

The reporting limit (RL) will be used as the lower level for the reporting of non-detected groundwater quality data. For all summary statistics (box plots, timeseries, etc.), the RL will be substituted for concentrations reported below the RL, including non-detects. With professional judgement, analytical results between the RL and the method detection limit, *i.e.,* estimated values, typically identified with a "J" flag, may be utilized if provided by the laboratory.

For all statistical test procedures:

- If the frequency of non-detect data are less than or equal to 15 percent, half of the RL will be substituted for these data
- If the non-detect frequency is between 15 percent and 50 percent, either the Kaplan-Meier or robust regression on order statistics (ROS) will be used to estimate the mean and standard deviation adjusted for the presence of left-censored values
- If the non-detect frequency is greater than 50 percent, a non-parametric test will be used
- If only one background result is detected that value will be used as the non-parametric upper prediction limit (UPL)

2.3 Testing for Normality

Many statistical analyses assume that sample data are normally distributed (parametric). However, environmental data are frequently not normally distributed (nonparametric). 35 I.A.C. § 845.640(g) requires the knowledge of the background data distribution for comparison to compliance results. The *Unified Guidance* document recommends the Shapiro-Wilk normality test for sample sizes of 50 or less, and the Shapiro-Francia normality test for sample sizes greater than 50.

When possible, transformation of datasets to achieve normal distributions is preferred.

2.4 Testing for Outliers

Part 845 constituents will be screened for the existence of outliers using a method described by the *Unified Guidance*. Outliers are extreme data points that may represent an anomaly or erroneous data point. To test for outliers, one or more of the following outlier tests will be utilized:

- Dixon's test, for well-constituent pairs with less than 25 samples, assumes normally distributed data.
- Rosner's test, for well-constituent pairs with more than 20 samples, assumes normally distributed data.
- Grubb's test for well-constituent pairs with seven or more samples, assumes normally distributed data.
- Time series, box-whisker plots, and probability plots provide visual tools to identify potential outliers, and evaluation of seasonal, spatial, or temporal variability for both normally and non-normally distributed data.

Data quality control, groundwater geochemistry, and sampling procedures will be evaluated as potential sources of error leading to an outlier result. The outlier tests cannot be used alone to determine whether a value is a true outlier that should be excluded from future statistical

analysis. Corroborating evidence needed to exclude values includes a discrete data reporting or analytical error, or potential laboratory bias. Absent corroborating evidence, the flagged values are considered true, but extreme, values in the data set. Professional judgement will be used to exclude extreme outliers from further statistical analyses. Outliers will be retained in the database.

With professional judgement, a confirmatory sample may be collected to allow for the distinction between an outlier and a true representation of groundwater quality at the monitoring point. If re-sampling is conducted, this sample will be collected within 90 days following outlier identification. If the confirmatory sample indicates the original result as an outlier, it will be reported as such.

2.5 Trend Analysis

Statistical analyses supporting the lack of trend are a fundamental step to confirm the assumption that groundwater quality values are stationary or constant over time at a CCR unit. These analyses allow for evaluation of variation in the background and compliance data for each constituent over time. A statistically significant increasing trend in background data could indicate an existing release from the CCR unit or alternate source, requiring further investigation. In addition, statistically significant trending background data can result in increased standard deviation and, therefore, greater prediction or control limits. Consequently, the increased prediction or control limit will have less power or ability to identify a release from the CCR unit.

A linear regression, coupled with a t-test for slope significance at a 95 percent confidence level (0.05 significance level), may be used on datasets for each constituent with few non-detects and a normally distributed variance of the mean to evaluate time trends. The Theil-Sen trend line, coupled with the Mann-Kendall test for slope significance at a 95 percent confidence level (0.05 significance level), will be used for datasets with frequent non-detects or non-normal variance. Similarly, trend analyses could also be used on compliance data to evaluate a possible release from the CCR unit.

2.6 Spatial Variation

Spatial trends and/or variation between background wells could indicate an existing release from a CCR unit. If the spatial variability is not due to an existing release, intrawell comparisons in compliance wells may be used to account for spatial variability and monitor for a future release. However, the CCR unit being monitored was placed into service prior to the start of groundwater monitoring and it is unknown whether a previous release has occurred. Accordingly, intrawell comparisons in compliance wells cannot be used to determine the occurrence of a future release. Interwell comparisons between compliance wells and background wells will be used.

2.7 Temporal Variation

Time series plots can be used to identify temporal dependence. Potentially significant temporal components of variability can be identified by graphing single constituent data from multiple wells together on a time series plot. With temporal dependence, the time series plot as a pattern of parallel traces, in which the individual wells will tend to rise and fall together across the sequence of sampling dates. Time series plots can be helpful by plotting multiple constituents over time for the same well, or averaging values for each constituent across wells on each sampling event and then plotting the averages over time. In either case, the plots can signify whether the general concentration pattern over time is simultaneously observed for different

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constituents. If so, it may indicate that a group of constituents is highly correlated in groundwater or that the same artifacts of sampling and/or lab analysis impacted the results of several monitoring parameters.

Hydrologic factors such as drought, recharge patterns or regular (*e.g.,* seasonal) water table fluctuations may be responsible for the temporal variation. In these cases, it may be useful to test for the presence of a significant temporal effect by first constructing a parallel time series plot and then running a formal one-way analysis of variance (ANOVA) ($\alpha = 0.05$) for temporal effects. A one-way ANOVA for temporal effects considers multiple well data sets for individual sampling events or seasons as the relevant statistical factor. If event-specific analytical differences or seasonality appear to be an important temporal factor, the one-way ANOVA for temporal effects can be used to formally identify seasonality, parallel trends, or changes in lab performance that affect other temporal effects. The one-way ANOVA for temporal effects assumes that the data groups are normally distributed with constant variance. It is also assumed that for each of a series of background wells, measurements are collected at each well on sampling events or dates common to all the wells. Results of the ANOVA can also be used to create temporally stationary residuals, where the temporal effect has been 'subtracted from' the original measurements. These stationary residuals may be used to replace the original data in subsequent statistical testing.

If the data cannot be normalized, a similar test for a temporal or seasonal effect can be performed using the Kruskal-Wallis test ($\alpha = 0.05$). Each sampling event should be treated as a separate 'well,' while each well is treated as a separate 'sampling event.' In this case, no residuals can be computed since the Kruskal-Wallis test employs ranks of the data rather than the measurements themselves.

Where both spatial and temporal variation occur, two-way ANOVA can be considered where both well location and sampling event/season are treated as statistical factors. This procedure is described in Davis (1994).

2.8 Updating Background

Updating the background dataset periodically by adding recent results to an existing background dataset can improve the statistical power and accuracy of the statistical analysis, especially for non-parametric prediction intervals. The *Unified Guidance* recommends updating statistical limits (background) when at least four to eight new measurements (every 1 to 2 years under a quarterly monitoring program), are available for comparison to historical data. Professional judgement will be used to evaluate whether any background data appear to be affected by a release and need to be excluded from a background update. A t-test for equal means (if normal data distribution) or appropriate non-parametric test (if non-normal data distribution) such as a Mann-Whitney (or Wilcoxon) rank-sum or box-whisker plots, will be conducted to evaluate whether the two groups of background sample populations are statistically different prior to updating any background datasets. A 0.05 significance level will be utilized when evaluating the two populations, with the null hypothesis that they are equivalent. In addition, time series graphs or other trend evaluation statistics will be conducted on the new background dataset to verify the absence of a release or changing groundwater quality. If the tests indicate that there are no statistical differences between the two background populations, the new data will be combined with the existing dataset. If the two populations are found to be different, the data will be reviewed to evaluate the cause of the difference. If the differences appear to be caused by a

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release (if the new data are significantly higher, or lower for pH), then the previous background dataset may continue to be used. Furthermore, verified outliers will not be added to an existing background dataset. In accordance with the *Unified Guidance*, continual background updates will not be conducted due to the lack of sufficient samples for a statistical comparison.

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3. COMPLIANCE MONITORING

Compliance monitoring is designed to monitor groundwater for evidence of a release by comparing Part 845 constituents in compliance wells to both background concentrations and the GWPS. Compliance Monitoring will begin the 1st quarter following approval of this Groundwater Monitoring Plan and issuance of the Operating Permit. The selected Compliance Monitoring statistical method used to compare compliance groundwater quality data for each constituent to the GWPS will provide for adequate statistical power, error levels and individual test false positive rates, and be appropriate for the distribution and detection frequency of the background dataset. Statistical power is the ability of a statistical test to detect a true exceedance.

In accordance with 35 I.A.C. § 845.610(b)(3)(D), compliance monitoring statistical analyses will be completed and submitted to IEPA within 60 days after completion of sampling.

3.1 GWPS Establishment and Exceedance Determination

In accordance with 35 I.A.C. § 845.600(a), the GWPS will be the constituent concentrations specified in 35 I.A.C. § 845.600(a)(1) except for when the background concentration is greater, or no concentration is specified (*i.e.,* for calcium and turbidity), in which case the GWPS will be the background concentration. The GWPS based on background concentration will be calculated using a parametric upper tolerance limit (UTL), a parametric UPL for a future mean, or a non-parametric UPL for a future median.

Statistical calculations that will be utilized in Compliance Monitoring procedures are summarized in **Table A** below and listed in **Sections 3.1.1** through **3.1.7**. Depending on the distribution of the data and the percentage of non-detects, it may be more appropriate to use a parametric model over a non-parametric model. As necessary, other techniques as mentioned in the *Unified Guidance* and/or new methods will be implemented.

Table A. Statistical Calculations Used in Compliance Monitoring Procedures

Compliance Monitoring						
Significant Trend?	Background Data			Compliance Data		
	Percent Non-Detects	Distribution	GWPS Determination	Percent Non-Detects	Distribution	Method to Determine Exceedance
No	0 ≤ 50	Normal	35 I.A.C § 845.600(a)(1) constituent concentration or The Upper Tolerance Limit	≤75	Normal	Parametric Lower Confidence Limit around a Normal Mean
				≤75	Log-Normal	Parametric Lower Confidence Limit around a Lognormal Geometric Mean
				NA	Non-Normal	Non-Parametric Lower Confidence Limit around a Median
				>75	Unknown/ Cannot be determined	
	50 ≤ 70	Normal	The Upper Prediction Limit for a Future Mean	NA	NA	Future mean
	>70	Non-Normal	Upper Prediction Limit for a Future Median	NA	NA	Future median
	100	Non-Normal	Double Quantification Rule	NA	NA	Individual Retesting Values
Yes	0 ≤ 50	Normal	UCL of Confidence Band around Linear Regression	≤75	Residuals after subtracting trend are normal, equal variance	Lower Limit from Confidence Band around Linear Regression
	50 ≤ 100	Non-Normal	UCL of Confidence Band around Thiel-Sen trend line	≤75	Residuals not normal	Lower Limit from Confidence Band around Thiel-Sen

3.1.1 The Upper Tolerance Limit

The UTL will be used to calculate the GWPS when pooled background data are normally distributed, with a non-detect frequency of 50 percent or less. When non-detect frequency is 15 percent or less, half the RL will be substituted for non-detects. The *Unified Guidance* recommends 95 percent confidence level and 95 percent coverage (95/95 tolerance interval).

- When non-detect frequency is 15 percent or less, half the RL will be substituted for non-detects (simple substitution), and the normal mean and standard deviation will be calculated.

- The Kaplan-Meier or the ROS method will be used when the detection frequency is between 15 percent and 50 percent. The Kaplan-Meier method assesses the linearity of a censored probability plot to determine whether the background sample can be approximately normalized. If so, then the Kaplan-Meier method will be used to compute estimates of the mean and standard deviation adjusted for the presence of left-censored values. The Kaplan-Meier or ROS estimate of the mean and standard deviation will be substituted for the sample mean and standard deviation.
- If background normality cannot be achieved, non-parametric UTLs will not be calculated until a minimum of 60 background samples have been collected (to achieve 95 percent coverage).

The parametric UTL on a future mean will be calculated from the background dataset as follows:

$$UTL = \overline{x} + \kappa\,(n, \gamma, \alpha - 1) \cdot s$$

$\overline{x}$ = background sample mean

s = background sample standard deviation

$\kappa\,(n, \gamma, \alpha - 1)$ = one-sided normal tolerance factor based on the chosen coverage (γ) and confidence level (α -1) and the size of the background dataset (n). Values are tabulated in Table 17-3 in Appendix D of the *Unified Guidance*. If exact values are not provided, then κ values can be estimated by linear interpolation.

If the UTL is constructed on the logarithms of original observations to achieve normality, where $\overline{y}$ and s_y are the log-mean and log-standard deviation, the limit will be exponentiated for back-transformation to the concentration scale as follows:

$$UTL = \exp\left[\overline{y} + \kappa\,(n, \gamma, \alpha - 1) \cdot s_y\right]$$

$\overline{y}$ = background sample log-mean

s_y = background sample log-standard deviation

When the GWPS is based on the 35 I.A.C. § 845.600(a)(1) constituent concentrations or a UTL derived from the background dataset, an exceedance in compliance wells relative to the GWPS will be evaluated using confidence intervals. A confidence interval defines the upper and lower bound of the true mean of a constituent concentration in groundwater within a specified confidence range.

- Non-detects in compliance data will be handled similarly to upgradient analyses, with half the RL substituted for non-detects when the frequency is 15 percent or less.
- The Kaplan-Meier, or the ROS method, will be used when the detection frequency is between 15 percent and 50 percent to compute estimates of the mean and standard deviation adjusted for the presence of left-censored values. These estimates will then be substituted for the sample mean and standard deviation.

Once the GWPS is established for background data using the UTL, either parametric or non-parametric confidence intervals will be computed for each constituent in compliance wells to identify GWPS exceedances.

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3.1.2 Parametric Confidence Intervals around a Mean

If compliance data are approximately normal, one-sided parametric confidence intervals around a sample mean will be constructed for each constituent and well pair. The lower confidence limit (LCL) will be calculated as:

$$LCL_{1-\alpha} = \overline{x} - t_{1-\alpha,n-1} \cdot \frac{s}{\sqrt{n}}$$

$\overline{x}$ = compliance sample mean

s = compliance sample standard deviation

n = compliance sample size

$t_{1-\alpha,n-1}$ = obtained from a Student's t-table with (n–1) degrees of freedom (Table 16-1 in Appendix D of the *Unified Guidance*)

The chosen t value will aim to achieve both a low false-positive rate, and high statistical power. Minimum α values are tabulated in Table 22-2 of Appendix D of the *Unified Guidance*. The selected minimum α value, from which the t value will be derived, will have at least 80 percent power (1-β = 0.8) when the underlying mean concentration is twice the GWPS.

If compliance data are distributed lognormally, the LCL will be computed around the lognormal geometric mean as:

$$LCL_{1-\alpha} = \exp\left(\overline{y} - t_{1-\alpha,n-1} \cdot \frac{s_y}{\sqrt{n}}\right)$$

$\overline{y}$ = compliance sample log-mean

s_y = compliance sample log-standard deviation

3.1.3 Non-Parametric Confidence Intervals around a Median

Non-parametric confidence intervals around the median will be computed if the compliance data contain greater than 50 percent non-detects or are not normally distributed. The mathematical algorithm used to construct non-parametric confidence intervals is based on the probability (*P*) that any randomly selected measurement in a sample of n concentration measurements will be less than an unknown *P* x 100th percentile of interest (where *P* is between 0 and 1). Then the probability that the measurement will exceed the *P* x 100th percentile is (1–*P*). The number of sample values falling below the *P* x 100th percentile out of a set of n should follow a binomial distribution with parameters n and success probability *P*, where 'success' is defined as the event that a sample measurement is below the *P* x 100th percentile. The probability that the interval formed by a given pair of order statistics will contain the percentile of interest will then be determined by a cumulative binomial distribution *Bin(x;n,p)*, representing the probability of *x* or fewer successes occurring in *n* trials with success probability p. *P* will be set to 0.50 for an interval around the median.

The sample size n will be ordered from least to greatest. Given *P* = 0.50, candidate interval endpoints will be chosen by ordered data values with ranks close to the product of (n+1) x 0.50. If the result of (n+1) x 0.50 is a fraction (for even-numbered sample sizes), the rank values immediately above and below will be selected as possible candidate endpoints. If the result of (n+1) x 0.50 is an integer (for odd-numbered sample sizes), one will be added to and subtracted

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from the result to get the upper and lower candidate endpoints. The ranks of the endpoints will be denoted L* and U*. For a one-sided LCL, the confidence level associated with endpoint L* will be computed as:

$$1 - \alpha = Bin(L^* - 1; n, 0.50) = \sum_{x=L^*}^{n} \binom{n}{x} \left(\frac{1}{2}\right)^n$$

If the candidate endpoint(s) do not achieve the desired confidence level, new candidate endpoints (L*–1) and (U*+1) and achieved confidence levels will be calculated. If one candidate endpoint equals the data minimum or maximum, only the rank of the other endpoint will be changed. Achievable confidence levels are tabulated using these equations in Table 21-11 in Appendix D of the *Unified Guidance*.

Both parametric and non-parametric confidence limits will then be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance monitoring wells. A GWPS exceedance is determined if the LCL exceeds the GWPS.

3.1.4 The Upper Prediction Limit for a Future Mean

The parametric UPL for a future mean will be used to calculate the GWPS if the pooled background data contain 50 to 70 percent non-detects and normality can be achieved. The Kaplan-Meier or ROS methods will be used to estimate the mean and standard deviation. The non-parametric UPL for a future median will be calculated as the GWPS if background samples cannot be normalized or contain greater than 70 percent non-detects. The parametric UPL for a future mean will be calculated from the background dataset at follows:

$$UPL_{1-\alpha} = \overline{x} + \kappa s$$

$\overline{x}$ = background sample mean

s = background standard deviation

κ = multiplier based on the order (p) of the future mean to be predicted, the number of compliance wells to be tested (w), the background sample size (n) the number (c) of constituents of concern (COCs), the "1-of-m" retesting scheme, and the evaluation schedule (annual, semi-annual, quarterly). Values are tabulated in 19-5 to 19-9 in Appendix D of the *Unified Guidance*.

The mean of order p will be computed for each well and compared against the UPL. For any compliance point mean that exceeds the limit, p additional resamples may be collected at that well for a 1-of-2 retesting scheme. Resample means will then be compared to the UPL. A GWPS exceedance has been deemed to occur at a compliance well when the initial mean and all resample means exceed the UPL.

3.1.5 The Non-Parametric Upper Prediction Limit for a Future Median

The non-parametric UPL for a future median will be used to calculate the GWPS if the pooled background data contain greater than 70 percent non-detects and normality cannot be achieved. Non-parametric methods assume that the data does not have an underlying distribution. To calculate the non-parametric UPL on a future value, the target per-constituent false positive rate (α_{const}) will be determined as follows:

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$$\alpha_{const} = 1 - (1 - \alpha)^{1/c}$$

α = the site-wide false positive rate (SWFPR) of 0.10 recommended by the *Unified Guidance*

c = the number of monitoring constituents

The number of yearly statistical evaluation (nE) will be multiplied by the number of compliance wells (w) to determine the look-up table entry, w*. The background sample size (n) and w* will be used to select an achievable per-constituent false positive rate value in Table 19-24 of Appendix D in the *Unified Guidance*. The chosen achievable per-constituent false positive rate value will determine the type of non-parametric prediction limit (maximum or 2nd highest value in background) and a retesting scheme for a future median. The background data will be sorted in ascending order, and the upper prediction limit will be set to the appropriate order statistic previously determined by the achievable per-constituent false positive rate value in Table 19-24. If all constituent measurements in a background sample are non-detect, the Double Quantification rule will be used. The use of the Double Quantification rule in Compliance Monitoring will only be applicable if the RL is above the 35 I.A.C. § 845.600(a)(1) constituent concentration or a constituent concentration is not specified in § 845.600(a)(1). This scenario is highly unlikely. The constituent will also be removed from calculations identifying the target false positive rate.

Two initial measurements per compliance well will be collected. If both do not exceed the upper prediction limit, a third initial measurement will not be collected since the median of order 3 will also not exceed the limit. If both exceed the prediction limit, a third initial measurement will not be collected since the median will also exceed the limit. If one initial measurement is above and one below the limit, a third initial observation may be collected to determine the position of the median relative to the UPL. Up to three resamples will be collected in order to assess the resample median. In all cases, if two or more of the compliance point observations are non-detect, the median will be set equal to the RL. The median value for each compliance well will be compared to the UPL. For the 1-of-2 retesting scheme, if any compliance point median exceeds the limit, up to three additional resamples will may be collected from that well. The resample median will be computed and compared to the UPL. A GWPS exceedance has been deemed to occur at a compliance well when either the initial median, or both the initial median and resample median exceed the UPL.

If the concentrations of detected constituents are below the established GWPS, Compliance Monitoring will continue.

3.1.6 Parametric Linear Regression and Confidence Band

If the t-test detects a significant trend in the parametric linear regression line using either background or compliance data for a particular constituent, confidence bands accounting for trends will be constructed to account for the trend-induced variation. If this is not accounted for, a wider confidence interval will inevitably be calculated for a given confidence level and sample size (n). A wider confidence interval will result in less statistical power, or ability to demonstrate an exceedance or return to compliance. When a linear trend line has been estimated, a series of confidence intervals is estimated at each point along the trend. This creates a simultaneous confidence band that follows the trend line. As the underlying population mean increases or decreases, the confidence band does also to reflect this change at that point in time.

Linear regression will be used when background or compliance data are approximately normally distributed, with a constant sample variance around the mean, and the frequency of non-detects is low. The linear regression of concentration against sampling date (time) will be computed as follows:

$$\hat{b} = \sum_{i=1}^{n} (t_i - \overline{t}) \cdot x_i / (n-1) \cdot s_t^2$$

x_i = i^{th} concentration value and

t_i = i^{th} sampling date

$\overline{t}$ = sampling mean date

s_t^2 = variance of the sampling dates

This estimate leads to the following regression equation:

$$\hat{x} = \overline{x} + \hat{b} \cdot (\mathrm{t} - \overline{t})$$

$\overline{x}$ = mean concentration level

$\hat{x}$ = estimated mean concentration at time t

The regression residuals will also be computed at each sampling event to ensure uniformity and lack of significant skewness. Regression residuals will be computed at each sampling event as follows:

$$r_i = x_i - \hat{x}_i$$

The estimated variance around the regression line, or mean squared error (MSE) will be computed as follows:

$$s_e^2 = \frac{1}{n-2} \sum_{i=1}^{n} r_i^2$$

The confidence intervals around a linear regression trend line given confidence level (1-α) and a point in time (t_0), will be computed as follows:

$$LCL_{1-\alpha} = \hat{x}_0 - \sqrt{2 s_e^2 \cdot F_{1-2\alpha,2,\mathrm{n}-1} \cdot \left[\frac{1}{n} + \frac{(t_0 - \overline{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$$UCL_{1-\alpha} = \hat{x}_0 - \sqrt{2 s_e^2 \cdot F_{1-2\alpha,2,\mathrm{n}-2} \cdot \left[\frac{1}{n} + \frac{(t_0 - \overline{t})^2}{(n-1) \cdot s_t^2}\right]}$$

$\hat{x}_0$ = estimated mean concentration from the regression equation at time t_0

$F_{1-2\alpha,2,\mathrm{n}-2}$ = upper $(1\text{-}2\alpha)^{th}$ percentage point from an F-distribution with 2 and (n-2) degrees of freedom

For background data, the UCL around the linear regression line will be used as the GWPS for the trending constituent. For compliance data, confidence bands around the linear regression line will be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance wells. A GWPS exceedance is determined when the LCL based on the trend line first exceeds the GWPS.

3.1.7 Non-Parametric Thiel-Sen Trend Line and Confidence Band

If the Mann-Kendall test detects a significant trend in the non-parametric Thiel-Sen line using either background or compliance data for a particular constituent, confidence bands accounting for trends will be constructed to account for the trend-induced variation. The Thiel-Sen trend line will be used as a non-parametric alternative to linear regression when trend residuals cannot be normalized or if there are a higher percentage of non-detects in either background or compliance data. The Thiel-Sen trend line estimates the median concentration over time by combining the median pairwise slope with the median concentration value and the median sample date. To compute the Thiel-Sen line, the data will first be ordered by sampling event x1, x2, xn. All possible distinct pairs of measurements (x_i, x_j) for j > i will be considered and the simple pairwise slope estimate will be computed for each pair as follows:

$$m_{ij} = (x_j - x_i)/(j - i)$$

With a sample size of n, there will be a total of N = n(n-1)/2 pairwise estimates (m_{ij}). If a given observation is a non-detect, half the RL will be substituted. The N pairwise slope estimates (m_{ij}) will be ordered from least to greatest (renamed m(1), m(2),..m(N)). The Thiel-Sen estimate of slope (Q) will be calculated as the median value of the list depending on whether N is even or odd as follows:

$$Q = \begin{cases} m_{([N+1]/2)} \; if \; N \; is \; odd \\ (m_{(N/2)} + m_{([N+2]/2)})/2 \; if \; N \; is \; even \end{cases}$$

The sample concentration magnitude will be ordered from least to greatest, x(1), x(2), to x(n) and the median concentration will be calculated as follows:

$$\tilde{x} = \begin{cases} x_{([n+1]/2)} \; if \; n \; is \; odd \\ (x_{(n/2)} + x_{([n+2]/2)})/2 \; if \; n \; is \; even \end{cases}$$

The median sampling date ($\tilde{t}$) with ordered times (t(1), t(2), to t(n)) will also be determined in this way. The Thiel-Sen trend line will then be computed for an estimate at any time (t) of the expected median concentration (x) as follows:

$$x = \tilde{x} + Q \cdot (\mathrm{t} - \tilde{t}) = (\tilde{x} - Q \cdot \tilde{t}) + Q \cdot \mathrm{t}$$

To construct a confidence band around the Thiel-Sen line, sample pairs (ti, xi) will be formed with a sample date (ti) and the concentration measurement from that date (xi). Bootstrap samples (B) will be formed by repeatedly sampling n pairs at random with replacement from the original sample pairs. This will be repeated 500 times. For each bootstrap sample, a Thiel-Sen trend line will be constructed using the equation above. A series of equally spaced time points (tj) will be identified along the range of sampling dates represented in the original sample, j =1 to m. The Thiel-Sen trend line associated with each bootstrap replicate will be used to compute an estimated concentration ($\hat{x}_j^B$). An LCL will be constructed for the lower α^{th} percentile $\hat{x}_j^{[\alpha]}$ from the distribution of estimated concentrations at each time point (tj). For a UCL, compute the upper (1-α)th percentile, $\hat{x}_j^{[1-\alpha]}$ at each time point (tj).

For background data, the UCL around the Thiel-Sen trend line will be used as the GWPS for the trending constituent. For compliance data, confidence bands around the Thiel-Sen trend line will be compared to the GWPS. The CCR unit is considered to be in compliance if the LCL is equal to or lower than the GWPS for all detected constituents at all compliance wells. A GWPS exceedance is confirmed when the LCL based on the trend line first exceeds the GWPS.

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3.2 Determination of Statistically Significant Increases over Background

In accordance with 35 I.A.C. §§ 845.610(b)(3)(B) and 845.640(h), individual monitoring event concentrations for each constituent detected in the compliance monitoring wells during compliance monitoring sampling events will be compared to the background concentration as determined by the methods described above. An exceedance of the background concentration for any constituent measured at any compliance monitoring well, or constituent detection if not detected in the background samples, constitutes a Statistically Significant Increase (SSI). An exception to this method is pH, where two-sided (upper and lower) tolerance limits are established from the distribution of the background groundwater quality data. An exceedance of either the UTL or lower tolerance limit (LTL) would constitute an SSI for pH.

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Intended for
Illinois Power Generating Company

Date
July 28, 2022

Project No.
1940101010-007

GROUNDWATER MODELING REPORT

PRIMARY ASH POND

NEWTON POWER PLANT

NEWTON, ILLINOIS

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GROUNDWATER MODELING REPORT
NEWTON POWER PLANT PRIMARY ASH POND

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Ramboll
234 W. Florida Street
Fifth Floor
Milwaukee, WI 53204
USA

T 414-837-3607
F 414-837-3608
https://ramboll.com



Saskia Noorduijn, PhD
Consultant



Brian G. Hennings, PG
Senior Managing Hydrogeologist

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ACRONYMS AND ABBREVIATIONS

§	Section
±	plus or minus
35 I.A.C.	Title 35 of the Illinois Administrative Code
BCU	bedrock confining unit
bgs	below ground surface
CBR	closure by removal
CBR-Offsite	Closure-by-Removal with Off-Site CCR Disposal
CBR-Onsite	Closure-by-Removal with On-Site CCR Disposal
CCR	coal combustion residuals
CIP	closure in place
cm/s	centimeters per second
CSM	conceptual site model
DEM	Digital Elevation Model
ft/ft	feet per foot
ft^2	square feet
ft/d	feet per day
GHB	general head boundary conditions
GMP	Groundwater Monitoring Plan
GMR	Groundwater Modeling Report
Golder	Golder Associates USA Inc.
GWL	groundwater elevation
GWPS	groundwater protection standard
HCR	Hydrogeologic Site Characterization Report
HDPE	high-density polyethylene
HDR	HDR, Inc.
HELP	Hydrologic Evaluation of Landfill Performance
HUC	Hydrologic Unit Code
ID	identification
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
ISGS	Illinois State Geological Survey
K	hydraulic conductivity
Kd	distribution coefficient
Kh/Kv	anisotropy ratio
LCU	lower confining unit
LF1	Phase 1 Landfill
LF2	Phase 2 Landfill
LVW	low volume wastewater
m	meter
mg/L	milligrams per liter
mL/g	milliliters per gram
NAVD88	North American Vertical Datum of 1988

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NID	National Inventory of Dams
No.	Number
NPDES	National Pollutant Discharge Elimination System
NPP	Newton Power Plant
NRT/OBG	Natural Resource Technology, an OBG Company
Part 845	Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments: 35 I.A.C. § 845
PAP	Primary Ash Pond
PMP	potential migration pathway
Ramboll	Ramboll Americas Engineering Solutions, Inc
Rapps	Rapps Engineering and Applied Science
RMSE	root mean squared error
SI	surface impoundment
std	standard deviation
TDS	total dissolved solids
TVD	total-variation-diminishing
UA	uppermost aquifer
UCU	upper confining unit
UD	upper drift
USEPA	United States Environmental Protection Agency
USDA/NRCS	United States Department of Agriculture/Natural Resources Conservation Service
USGS	United States Geological Survey

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EXECUTIVE SUMMARY

Ramboll Americas Engineering Solutions, Inc. (Ramboll) has prepared this Groundwater Modeling Report (GMR) on behalf of the Newton Power Plant (NPP), operated by Illinois Power Generating Company (IPGC), in accordance with requirements of Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845: Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845) (Illinois Environmental Protection Agency [IEPA], April 15, 2021). This document presents the results of predictive groundwater modeling simulations for proposed closure scenarios for the Primary Ash Pond (PAP), Vistra identification (ID) number (No.) 501, IEPA ID No. W0798070001-01, and National Inventory of Dams (NID) No. IL50719.

The NPP is located in Jasper County in the southeastern part of central Illinois, approximately seven miles southwest of the town of Newton (**Figure 1-1**). The PAP is located south of the NPP and situated in a predominantly agricultural area. The PAP is surrounded by Newton Lake on the west, south, and east. Beyond the lake is additional agricultural land.

A detailed summary of site conditions was provided in the Hydrogeologic Site Characterization Report (HCR; Ramboll, 2021a). This report integrates existing site data and information with the latest hydrogeology and groundwater quality data to generate a conceptual and numerical model of the PAP. The conceptual site model (CSM) includes hydrogeologic and groundwater quality data specific to the PAP, which has been collected between 2015 and 2021. The PAP is a 9,715 acre-feet earthen berm coal combustion residuals (CCR) surface impoundment (SI) located south of the power plant. In addition to the CCR within the PAP, there are six layers of unlithified material present above the Pennsylvanian-Age bedrock. These materials have been categorized into five hydrostratigraphic units presented below in descending order:

- **Upper Drift (UD)/Potential Migration Pathway (PMP):** The UD is composed of the low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.,* PMP).
  - **Hagarstown Member/PMP**: The Hagarstown Member consists of the discontinuous, sandier deposits of the UD where present and overlies the Vandalia Till.
- **Upper Confining Unit (UCU):** The UCU consists of a thick package of low permeability clays and silts of the Vandalia Till. This unit is a laterally continuous layer between the base of the CCR unit and the top of the uppermost aquifer (UA).
- **Uppermost Aquifer (UA)**: The UA is composed of the Mulberry Grove Member, which has been classified as poorly graded sand, silty sand, clayey sand, and gravel.
- **Lower Confining Unit (LCU)**: The LCU is comprised of low permeability silt and clay of the Smithboro Till Member and the Banner Formation.
- **Bedrock Confining Unit (BCU):** The low permeability bedrock underlying the PAP is the Pennsylvanian-Age Mattoon Formation, which consists of a complex sequence of thin limestones, coals, black fissile shales, underclay, thick gray shales, and several well-developed sandstones. The Mattoon Formation has a maximum thickness of more than 600 feet in the central part of the Illinois Basin in Jasper County.

The Cahokia Formation, described in the regional geology of the HCR, occurs in modern river valleys and floodplains. These deposits (which may contain sand, silt, or clay with wood and shell

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fragments) are expected to occur along the southeastern boundary of the PAP associated with the east branch of Newton Lake and may be difficult to distinguish from the deposits of the UD and the top of the UCU given the observed heterogeneity in the Cahokia, UD, and UCU.

Groundwater migrates downward through the UD and UCU into the UA. Groundwater in the UA flows from north to south/southwest and converges near a former drainage feature located west of the PAP. Groundwater elevations vary seasonally, although generally less than one foot per year. The surface water elevation at Newton Lake (at location SG02) measured between February 15 and March 9, 2021 ranged from 504.42 to 504.84 feet North American Vertical Datum of 1988 (NAVD88). Groundwater elevations in the UA at downgradient wells were observed around 491 feet NAVD88 (approximately 15 feet lower than the lake elevation). The separation between measured groundwater elevations and lake elevations (and observed downward vertical gradients in wells) indicates groundwater does not flow into Newton Lake from the UA. As indicated by the observed heads and groundwater flow directions in the UA, surface water from Newton Lake is entering the UA. The UA also approaches the former land surface east of the PAP, now beneath Newton Lake, as illustrated in geologic cross section B'-B" (Figure 2-7 of the HCR). The CSM for modeling the PAP is as follows:

- Most hydrostratigraphic layers are laterally continuous across the area. The flat to gently rolling uplands are dissected by deeply incised streams (into the materials of the UD, UCU, and UA) that are tributaries to river systems in the area. Cahokia formation deposits are also located within the incised streams. Newton Lake was created by damming one of these tributary streams for use by the NPP. Increased water levels within Newton Lake induced flow of surface water into the UA through discrete and limited areas north and east of the PAP, creating the potentiometric surface observed beneath the PAP.
- The UA is separated from the bottom of the PAP by a minimum of 14 feet of low-permeability glacial till that comprises the UCU. This laterally continuous confining unit is a barrier to vertical migration of groundwater from the PAP to the UA. Erosion caused by incised streams and deposition of Cahokia formation deposits has occurred along the southeast corner of the PAP.
- Groundwater in the UA flows from north to south/southwest and converges near a former drainage feature located west of the PAP.
- Surface recharge and groundwater migrate vertically through the low permeability sediments of the UD and Cahokia deposits. Groundwater migrates horizontally through the higher permeability sediments of the PMP and the UA.
- The UA is heterogenous, with materials ranging from clayey sand to coarse gravels. The highly transmissive sands and gravel are prominent in close proximity to the PAP.
- The separation between measured groundwater elevations and lake elevations (and observed downward vertical gradients) indicates groundwater does not flow into Newton Lake from the UA. The connection between the UA and Newton Lake is spatially discrete and limited to areas northeast of the PAP.
- The PAP is constructed such that the earthen berm and base are in contact with the UCU.
- The stage within the PAP is managed with minimal (less than 3 feet) variability throughout the year.

Groundwater quality parameters were monitored in the shallow sands of the PMP and UA monitoring wells at the PAP as part of the groundwater quality investigations performed between

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2015 and 2021. A review and summary of data collected from 2015 through 2021 for parameters with groundwater protection standards (GWPS) listed in 35 I.A.C. § 845.600 is provided in the HCR (Ramboll, 2021a). Groundwater concentrations presented in Table 4-1 of the HCR and summarized in the History of Potential Exceedances (Ramboll, 2021b) are considered potential exceedances because the methodology used to determine them is proposed in the Groundwater Monitoring Plan (GMP) (Ramboll, 2021c) and has not been reviewed or approved by IEPA at the time of this submittal. The following constituents with potential exceedances of the GWPS listed in 35 I.A.C. § 845.600 were identified: lithium, pH, sulfate, and total dissolved solids (TDS) (Ramboll, 2021b).

Multiple lines of evidence that limited potential GWPS exceedances of pH in the PMP are not related to the PAP are provided in the technical memorandum (**Appendix A**), *Evaluation of Potential GWPS Exceedances* (Golder Associates USA Inc. [Golder], 2022a). Statistically significant correlations between sulfate concentrations and concentrations of lithium and TDS indicate sulfate is an acceptable surrogate for lithium and TDS in the groundwater model. Concentrations of these parameters are expected to change along with model predicted sulfate concentrations.

It was assumed that sulfate would not significantly sorb or chemically react with aquifer solids (distribution coefficient [Kd] was set to 0 milliliters per gram [mL/g]), which is a conservative estimate for estimating contaminant transport times in the model. Lithium, sulfate, and TDS transport is likely to be affected by both chemical and physical attenuation mechanisms (i.e., adsorption and/or precipitation reactions as well as dilution and dispersion).

All available hydrological information were used to construct a CSM and numerical model of the PAP. A steady state, 7-layer numerical model was constructed to characterize the long-term groundwater flow conditions at the site. The hydrostratigraphic units included in the model were the UD, PMP, UCU, UA, and LCU. The BCU was not included in the model. Calibration of the model focused on simulating mean groundwater elevations for 30 wells at the site by modifying hydraulic parameters for the different hydrostratigraphic units, alongside river and general head boundary conductance. The calibrated model represents a reasonable match to the observed head and sulfate concentration data.

The calibrated model was used to predict the sulfate concentration for two closure scenarios described in the *Primary Ash Pond Final Closure Plan* (HDR, 2022), including:

- **Scenario 1:** closure in place (CIP) including removal of CCR from the southern portion of the PAP, consolidation into the northern portion of the PAP, and construction of a cover system over the remaining CCR, and;
- **Scenario 2:** closure by removal (CBR) including removal of all CCR and regrading of the removal area.
- Prior to the simulation of these scenarios, a dewatering simulation was included which simulated the removal of free liquids from the PAP prior to the implementation of the two scenarios.

Scenario 1 (CIP) was predicted to reduce total flux in and out of the Fill Unit (CCR) by approximately 94%, when simulated post-construction heads in the groundwater monitoring wells are predicted to stabilize.

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Predictive simulations of pond closure indicate simulated groundwater concentrations in the monitoring wells within the two transport zones, namely the UD/PMP and UA, will achieve the GWPS in 20 years and 16 years for the CIP and CBR closure scenarios, respectively. This indicates that both scenarios are predicted to reach the GWPS for the monitoring wells after approximately 20 years. The model predicted four-year time difference when GWPSs are achieved for CIP (20 years post-closure) and CBR (16 years post-closure) is not significant because the estimated duration of construction activities indicates that CBR will take longer to implement than CIP (3.2-4.3 years for CIP compared to 7.8-9.2 years for Closure-by-Removal with On-Site CCR Disposal [CBR-Onsite] and 22 years for Closure-by-Removal with Off-Site CCR Disposal [CBR-Offsite]; Section 2.1 of the Closure Alternative Analysis [Gradient, 2022]).

The prediction simulations indicate that although the groundwater wells reach the GWPS, sulfate remains within the model beyond 100 years. This is due to the sulfate mass retained within the thick UCU which underlies the PAP. The low vertical hydraulic conductivity of this thick unit leads to low flow rates through the unit which will require time to release the sulfate mass. However, in both the CIP and CBR scenarios, the plume footprint continues to recede with time and remains within the property boundaries, indicating these closure options are equally protective.

Results of groundwater fate and transport modeling conservatively estimate that groundwater concentrations will attain the GWPS for all constituents identified as potential exceedances of the GWPS in the UD/PMP and UA monitoring wells within 20 years of closure implementation for both CIP and CBR. Within the property boundary, residual sulfate will be present within the clay confining unit above the GWPS due to the slow release of sulfate from the UCU.

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1. INTRODUCTION

1.1 Overview

In accordance with the requirements of Part 845 (IEPA, 2021), Ramboll has prepared this GMR on behalf of the NPP, operated by IPGC. This report applies specifically to the CCR unit referred to as the PAP. However, information gathered to evaluate other CCR units in the vicinity regarding geology, hydrogeology, and groundwater quality is included, where appropriate. This GMR presents and evaluates the results of predictive groundwater modeling simulations for two proposed closure scenarios: 1) CIP and 2) CBR.

1.2 Previous Groundwater Reports

Numerous hydrogeologic investigations have been performed at the NPP. The information presented in this GMR includes data collected as part of a 2021 field investigation and previous investigations summarized and presented in the HCR (Ramboll, 2021a) which was provided as an attachment to the initial operating permit application required by 35 I.A.C. § 845.230.

1.3 Site Location and Background

The NPP is located in Jasper County, Illinois approximately 7.5 miles southwest of the town of Newton. The PAP is located in Section 26 and the western half of Section 25, Township 6 North, Range 8 East (**Figure 1-1**). The PAP is located south of the power plant and situated in a predominantly agricultural area. The PAP is surrounded by Newton Lake on the west, south, and east. Beyond the lake is additional agricultural land. The region is characterized by relatively flat to gently rolling topography.

1.4 Site History and CCR Units

Three CCR units are present on the NPP property, including the PAP and two landfills: the Phase 1 Landfill (LF1) is located northwest and west of the PAP, and the Phase 2 Landfill (LF2) is located west of the PAP (**Figure 1-2**). The PAP was constructed in 1977 and has a design capacity of approximately 9,715 acre-feet. There is also a non-CCR 83.6 acre-feet Secondary Pond located immediately south of the PAP. The PAP has a surface area of 404 acres and the Secondary Pond has an area of 9.3 acres. The PAP currently receives stormwater runoff, bottom ash, fly ash, and low-volume wastewater (LVW) from the plant's two coal-fired boilers. The PAP is operated per National Pollutant Discharge Elimination System (NPDES) Permit No. IL0049191, Outfall 001 (located at the Secondary Pond).

Prior to PAP construction, an incised stream gully existed at the site of the PAP. Areas within the impoundment were excavated during construction for native materials used to build the containment berms (AECOM, 2016).

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2. SITE GEOLOGY AND HYDROGEOLOGY

The geology and hydrogeology of the PAP is described in detail in the HCR (Ramboll, 2021a). A short summary is provided below.

2.1 Stratigraphy

The unlithified stratigraphy within and immediately surrounding the PAP consists of the following in descending order: fill material and CCR; silt and clayey silt loess (Peoria Loess); weathered till of the Sangamon Soil; discontinuous gravel and sand (Hagarstown Member), sandy/silty till with discontinuous lenses of sand and gravel (Vandalia Till); sands of the UA (Mulberry Grove Member); and clay till (Smithboro Till and Banner Formation) (Rapps Engineering and Applied Science [Rapps], 1997). The Cahokia Formation, described in the regional geology of the HCR, occurs in modern river valleys and floodplains. These deposits (which may contain sand, silt, or clay with wood and shell fragments) are expected to occur along the southeastern boundary of the PAP associated with the east branch of Newton Lake and may be difficult to distinguish from the deposits of the UD and the top of the UCU given the observed heterogeneity in the Cahokia, UD, and UCU. Unlithified units overlay Pennsylvanian-age shaley bedrock (Mattoon Formation).

CCR is present within most of the PAP at thicknesses between 17 to 19.5 feet thick as observed in porewater wells XPW01 through XPW04. The lowest bottom of ash elevation observed is approximately 486 feet in the center of a former drainage feature oriented north-south through the center of the PAP, whereas ash is potentially highest in elevation at approximately 550 feet along the outer edges of the PAP. The bottom of ash surface appears to mirror the former drainage feature. Comparison of the bottom of ash contours and topographic contours indicate CCR fill may be 40 feet or greater within the former drainage feature.

The Peoria Silt and Sangamon Soils extends from beneath the topsoil to depths ranging from 3 to 46 feet. The Peoria Silt and Sangamon Soils consist predominantly of low permeability lean clay.

The Hagarstown Member of the Pearl Formation underlies the Peoria Silt and Sangamon Soils. This is a discontinuous sandy unit composed of poorly graded sand with silt, with thicknesses up to approximately 7 feet but generally the thickness is less than 2 feet.

The Hagarstown Member is generally underlain by a relatively thick till sequence consisting of the Vandalia Till. The till sequence is encountered at thicknesses up to 59 feet in the area of the PAP, while the average thickness is 26 feet. This thick glacial deposit is laterally continuous beneath the NPP. The Vandalia Till primarily consists of lean clay and silty clay. Alluvial deposits belonging to the Cahokia Formation, which is a Holocene stage deposit in floodplains and channels of modern rivers and streams are expected to occur along the southeastern corner of the PAP. Generally, the Cahokia Formation consists of poorly sorted sand, silt, and clay with wood and shell fragments with local deposits of sandy gravel which is similar in composition to the deposits that comprise the UD and UCU.

The Mulberry Grove Member is a thin to moderately thick (3 to 17 feet) unit composed of silty sand, poorly graded sand with silt and well graded sand with silt. The Mulberry Member generally slopes from approximately 483 feet NAVD88 in the northeast portion of the PAP to 462 feet NAVD88 in the southwest portion of PAP. The maximum observed thickness of this member was 30 feet, while the average thickness is approximately 10 feet.

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Till sequences underlying the Mulberry Grove Member consist of clay and silt of the Smithboro Till Member and Banner Formation. These laterally continuous till units are encountered at thicknesses up to 36 feet, while the average thickness is 32 feet. The till sequences are typically composed of lean clay and silty clay.

The Pennsylvanian Age Mattoon Formation consists of a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well-developed sandstones. The bedrock is dipping to the southwest at the site.

2.2 Hydrogeology

Five distinct hydrostratigraphic units have been identified at the site based on stratigraphic relationships and common hydrogeologic characteristics, which are summarized below:

- **UD/PMP:** this unit includes the lower permeability silts and clays of the Peoria Silt and Sangamon Soil, and the sandier soils of the Hagarstown Member (*i.e.,* PMP). These units are hydraulically connected and underlain by a thick till sequence of Vandalia Till.
- **UCU:** underlying the UD till sequence, the laterally continuous low permeability silts and clays of the Vandalia Till and Cahokia Formation are 26 feet thick on average.
- **UA:** this unit consisting of sands and gravels of the Mulberry Grove Formation is on average 10 feet thick and can be up to 30 feet thick. These sandy deposits are the first laterally continuous sands observed beneath the PAP.
- **LCU:** underlying the UA are the low permeability silts and clays of the Smithboro Till and the Banner Formation. This unit is approximately 5 to 36 feet thick.
- **BCU:** The low permeability bedrock underlying the PAP is the Pennsylvanian Age Mattoon Formation, which consists of a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well-developed sandstones. The Mattoon Formation has a maximum thickness of more than 600 feet in the central part of the Illinois Basin in Jasper County.
- Holocene alluvial deposits of the Cahokia formation are expected to replace UD and UCU deposits along the southeastern boundary of the PAP.

2.2.1 Groundwater Flow

Monitoring well locations are illustrated in **Figure 2-1**. The elevations of water within the PAP (as observed in XPW01 through XPW04 and XSG01) are greater than the surrounding areas (**Figures 2-2** and **2-3**). The phreatic surface within the PAP between February and August 2021 averaged 542 feet NAVD88, ranging from 546.69 feet NAVD88 in XPW02 (located along the northern portion of the PAP) to 535.40 feet NAVD88 in XSG01 (located along the southern portion of the PAP). Groundwater elevations in PMP wells are above those in the UA and range from approximately 518 feet NAVD88 (APW05S) to 535 feet NAVD88 (APW05S).

Groundwater flow in the UA is generally from north to south. However, the UA wells also display flow converging towards a former surface drainage feature located west of the PAP (**Figure 2-2** and **Figure 2-3**) and an area where the UA has the greatest thickness. Groundwater elevations vary seasonally, generally less than one foot per year, while across the PAP they range from approximately 490 to 530 feet NAVD88, although flow directions are generally consistent.

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2.2.2 Hydraulic Properties

Hydraulic field tests were conducted on multiple wells within the CCR, UD, PMP, and UA at NPP and are summarized below:

- Hydraulic properties for the CCR ranged from 1.0×10^{-3} to 2.3×10^{-1} centimeters per second (cm/s) (2.8 to 652 feet per day [ft/d]), with a geometric mean hydraulic conductivity of 2.0×10^{-2} cm/s (56.7 ft/d), based on hydraulic tests on four wells.
- Hydraulic field tests conducted on three wells provided hydraulic properties of the UD unit, which ranged from 5.14×10^{-6} to 4.53×10^{-5} cm/s (0.01 to 128.4 ft/d) with a geometric mean of 1.5×10^{-5} cm/s (0.04 ft/d).
- Hydraulic properties for the PMP ranged from 6.1×10^{-4} to 1.5×10^{-2} cm/s (1.7 to 42.5 ft/d) with a geometric mean hydraulic conductivity of 3.1×10^{-3} cm/s (8.8 ft/d), based on hydraulic tests on two wells.
- Hydraulic properties for the UA ranged from 2.0×10^{-4} to 1.5×10^{-1} cm/s (0.57 to 425.0 ft/d) with a geometric mean of 6.8×10^{-3} cm/s (19.3 ft/d), based on field tests conducted on seven wells.

The absence of wells screened within the UCU, LCU, and BCU at the NPP means that no field based hydraulic data are available for these units.

Additional laboratory analysis of samples from the CCR, UD, PMP, UCU, UA, and LCU provided vertical hydraulic conductivities summarized below:

- Laboratory falling head permeability test results for the six CCR samples indicated a geometric mean vertical hydraulic conductivity of 3.1×10^{-4} cm/s (0.88 ft/d) with a range of 1.6×10^{-5} to 1.3×10^{-3} cm/s (0.05 to 3.7 ft/d).
- Laboratory falling head permeability test results in the UD indicated a geometric mean vertical hydraulic conductivity of 5.9×10^{-8} cm/s (0.0002 ft/d) and ranged from 3.1×10^{-8} to 8.6×10^{-8} cm/s (0.0001 to 0.00024 ft/d). These values are less than previous samples collected in 2017, with a geometric mean hydraulic conductivity of 1.3×10^{-5} cm/s (0.04 ft/d) (Natural Resource Technology, an OBG Company [NRT/OBG], 2017).
- Laboratory falling head permeability test results from three samples collected from the Hagarstown Member (i.e., PMP) within the UD, indicated a geometric mean vertical hydraulic conductivity of 3.5×10^{-5} cm/s (0.1 ft/d) and ranged from 1.1×10^{-7} to 9.6×10^{-5} cm/s (0.0003 to 0.27 ft/d).
- Laboratory falling head permeability test results from four samples collected from the Vandalia Till indicated that the UCU has a geometric mean vertical hydraulic conductivity of 6.7×10^{-8} cm/s (0.0002 ft/d) and ranged from 3.3×10^{-8} to 9.7×10^{-8} cm/s (0.0001 to 0.0003 ft/d).
- Laboratory falling head permeability test results from five samples collected from the Mulberry Grove Formation indicated that the UA has a geometric mean vertical hydraulic conductivity of 3.2×10^{-4} cm/s (0.9 ft/d) and ranged from 3.5×10^{-6} to 7.2×10^{-4} cm/s (0.01 to 2.04 ft/d) (NRT/OBG, 2017).
- Laboratory falling head permeability test results from eight samples collected from the glacial tills of the Smithboro Till indicated a geometric mean vertical hydraulic conductivity of 9.3×10^{-8} cm/s (0.0003 ft/d) and ranged from 2.4×10^{-8} to 2.7×10^{-7} cm/s (0.0001 to 0.0008 ft/d).

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2.2.3 Groundwater Elevation Data

There are 30 wells located around the PAP with most wells located adjacent to the perimeter of the PAP. In most of these wells, water level measurements are available from 2015 to 2021. The well construction details are summarized in **Table 2-1** and groundwater elevation readings are summarized in **Table 2-2**. The observed range in groundwater elevation (GWL) within the PMP wells data set is 17.3 feet and 44.3 feet in the UA wells. For all wells, the mean variation in GWL within each well is 0.8 feet (mean GWL variation), with an observed minimum and maximum variation of 0.2 and 2.5 feet, respectively. The UA approaches the former land surface, now beneath Newton Lake, northeast of the PAP. The UA may intersect the base of Newton Lake allowing groundwater within the UA to mix with surface water from the lake, upgradient of the PAP. Groundwater flow in the UA generally flows southwest across the PAP with potentiometric surface elevations at downgradient wells around 491 feet NAVD88 (approximately 15 feet lower than the Newton Lake elevation). The elevation of water in Newton Lake ranges from 504.42 to 504.84 feet NAVD88. This separation in groundwater and lake elevations (and observed downward vertical gradients) indicates groundwater within the UA does not flow into Newton Lake.

2.2.4 Mining Activity

The areas immediately surrounding the facility have never been mined. Based on the directory of coal mines for Jasper County (Illinois State Geological Survey [ISGS], 2021), the nearest coal mines in the vicinity of the PAP are located approximately 6.7 miles to the northeast.

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3. GROUNDWATER QUALITY

3.1 Groundwater Classification

Per 35 I.A.C. § 620.210, groundwater within the UA at the PAP meets the definition of Class I – Potable Resource Groundwater based on the following criteria:

- Groundwater is located more than 10 feet below ground surface (bgs) and within an unconsolidated silty sand and gravel unit which is five feet or more in thickness.
- Hydraulic conductivity exceeds the 1 x 10^{-4} cm/s criterion.
- Groundwater is not downgradient of or underlying previously mined out areas.

Testing of the unconsolidated materials of the Mulberry Grove Member averaged 21 percent fines, which is greater than the 12 percent fines criterion; however, this was not deemed prohibitive of the Class I Classification (Ramboll, 2021a).

3.2 Potential Groundwater Exceedances

There are potential groundwater exceedances of applicable GWPS attributable to the PAP as described below. Groundwater concentrations from 2015 to 2021 are presented in the HCR Table 4-1 (Ramboll, 2021a), were evaluated and summarized in the History of Potential Exceedance tables (Ramboll, 2021b), and are considered potential exceedances because the methodology used to determine them is proposed in the Statistical Analysis Plan (Appendix A to GMP; Ramboll, 2021c), which has not been reviewed or approved by IEPA at the time of submittal of 35 I.A.C. § 845 operating permit application.

The History of Potential Exceedances attached to the operating permit application summarizes all potential groundwater exceedances following the proposed Statistical Analysis Plan. The following potential exceedances were identified:

- Lithium – UD well APW02;
- pH – UD wells APW04 and APW12;
- Sulfate – UA well APW10 and UD wells APW02 and APW04; and
- TDS – UD wells APW02, APW04, and AP05S

Multiple lines of evidence that limited potential GWPS exceedances of pH are not related to the GMF Pond is provided in the *Evaluation of potential GWPS Exceedances* (**Appendix A**, Golder, 2022a) and summarized below:

- The pH of CCR porewater is significantly higher than the pH in monitoring wells APW04 and APW12.
- The pH ranges recorded in the PMP are likely naturally occurring.

Since potential GWPS exceedances for pH are not related to the Ash Pond, these parameters will not be discussed further in this GMR.

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4. GROUNDWATER MODEL

4.1 Overview

Data collected at the Site from 2004 to the recent 2021 field investigation were used to construct a groundwater model of the PAP. The model was then used to evaluate how the proposed closure options (CIP and CBR) would achieve compliance with the applicable groundwater standards following the closure construction. The modeling results are summarized and evaluated in this GMR. The associated model files are included as **Appendix B**.

4.2 Conceptual Model

The HCR (Ramboll, 2021a) forms the foundation of the PAP hydrogeological setting. The PAP overlies the recharge area for the underlying transmissive geologic media, which are composed of unlithified deposits.

4.2.1 Hydrogeology

As discussed in **Section 2.2**, groundwater flow around the PAP is generally in a southwest direction. The silts of the UD and sands of the PMP are hydraulically connected. The groundwater flow in the silts and clays of the UD and confining units of the UCU, LCU, and BCU are expected to be primarily vertical. The Hagarstown member PMP and sands of the UA are where the majority of the horizontal migration is expected to occur. The geological conceptual model for the site consists of the following layers:

- Silts and Clays (UD) – silt and clayey silt of the Peoria Silt and Sangamon Soil which extends beneath the topsoil.
- Discontinuous sands (PMP) - sandier soils of the Hagarstown Member.
- Vandalia Till (UCU) – a thick layer of low permeability till consisting of the Vandalia Till.
- Sands (UA) – sands and gravels of the Mulberry Grove Formation, laterally continuous sand and gravel deposit identified beneath the site.
- Smithboro Till (LCU) – composed of lean clay Smithboro Till and Banner Formation.
- BCU – lowermost unit identified at the site and underlies all unlithified deposits. This unit, composed of low permeability shale of the Mattoon Formation.
- Alluvial deposits of the Cahokia formation may replace UD and UCU deposits along the southeastern boundary of the PAP.

Surfaces for each of the six major geological units (Silts/Clays, discontinuous sand, Vandalia Till, shallow sand, Smithboro Till and Bedrock) were made by interpolating contacts between the units interpreted from boring logs. Alluvial deposits of the Cahokia formation were represented by zones within the horizontal layers of the major geologic units. Boring log information is centered around the pond and CCR units; the surfaces were extended to the full model domain by extrapolation and verified with off-site well logs, where available.

4.2.2 Extent and Boundaries

The United States Geological Survey (USGS) National Map places the NPP within the upper Illinois-Little Wabash watershed subbasin (Hydrologic Unit Code [HUC] 05120114).

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The PAP CSM extent is bounded by a hydrological catchment (watershed) divide to the east based on watershed data from USGS. Along the north, south, and east the model boundary has been placed along known waterbodies as much as possible. As such, it is assumed groundwater inflow from adjacent watersheds is negligible through both the UA and LCU.

The Newton Lake water levels are managed such that they remain at an elevation between 504.23 and 504.82 feet NAVD88. Newton Lake is the receiving body of water for surface water in the area encompassed by the CSM.

Infiltration of precipitation to the groundwater table is applied as recharge at the site. Groundwater in the UD migrates downward into the discontinuous sands of the Hagarstown Formation. As discussed in **Section 2.2.1**, the Hagarstown Formation is considered a PMP for groundwater adjacent to the PAP. The sands of the UA are separated from the Hagarstown Formation PMP and the base of ash in the PAP by the laterally continuous UCU. The UA receives water from connection with Newton Lake.

4.2.3 Primary Ash Pond

The PAP is constructed with an earthen berm which acts as a low permeability interface between the CCR contained within the PAP and the ambient groundwater system. Findings from the HCR (Ramboll, 2021a) indicate that the PAP does not appear to impact groundwater flow directions in the UA via recharge to groundwater. The PAP does influence the shallower UD/PMP flow system, where there is a component of radial flow from the pond to the thin Hagarstown Formation.

Sulfate was selected for transport modeling. Sulfate is commonly used as an indicator parameter for contaminant transport modeling for CCR because: (i) it is commonly present in coal ash leachate; and (ii) it is mobile and typically not very reactive but conservative (*i.e.*, low rates of sorption or degradation) in groundwater.

4.3 Model Approach

Comparisons of observed lithium and TDS concentrations to sulfate (Figure A and Figure B, respectively, below) indicate statistically significant correlations between these parameters in UD wells where these potential exceedances were observed. Observed concentrations were transformed into Log10 concentrations for evaluation. The correlation coefficient (R2) and p values (indicator of statistical significance) are also provided on Figure A and Figure B. Higher R2 values (i.e., closer to 1) indicate stronger correlation between parameters. A correlation is considered statistically significant when the p value is lower than 0.05. Both correlations have p values less than the target of 0.05, indicating correlations are statistically significant. The correlations are strongest between sulfate and TDS. The statistically significant correlations associated with sulfate concentrations indicate sulfate is an acceptable surrogate for lithium and TDS in the groundwater model, and concentrations of these parameters are expected to change along with model predicted sulfate concentrations.

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Figure A. Sulfate Correlation with Lithium in UD Wells

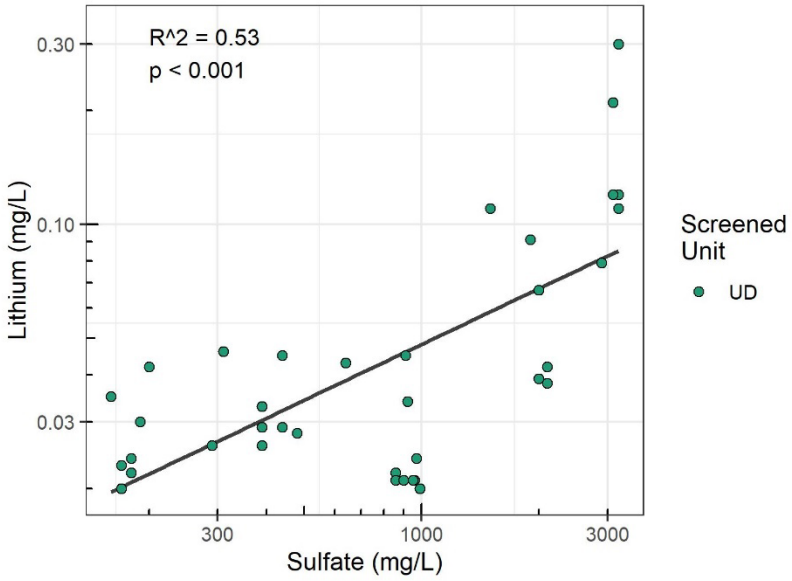
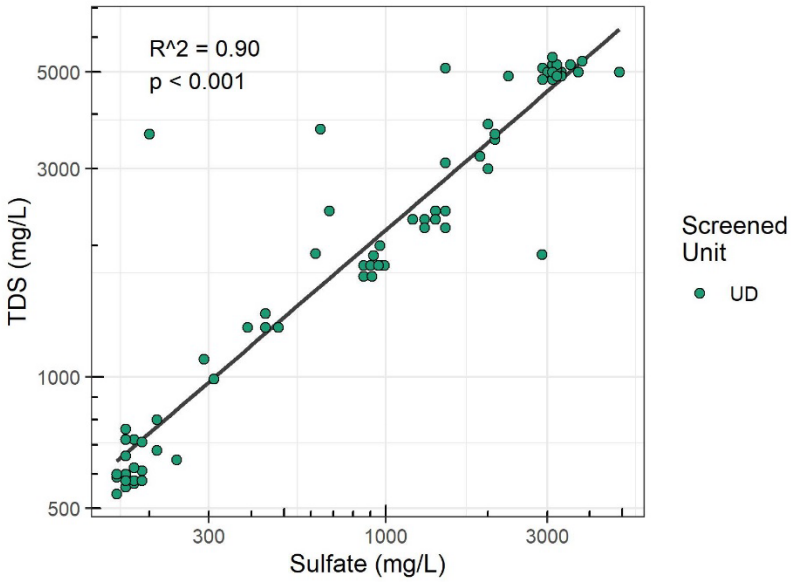


Figure B. Sulfate Correlation with TDS in UD Wells



A three-dimensional groundwater flow model was calibrated to represent the conceptual flow system described above. A steady state model was used to simulate the mean groundwater flow conditions at the site. The model was calibrated to match mean groundwater elevations observed between 2015 to 2021 (**Table 2-2**). Prediction simulations were then performed to evaluate the potential impacts to groundwater from CIP as presented in the *Primary Ash Pond Final Closure Plan* (HDR, 2022) which is an appendix to the Construction Permit Application to which this report is also attached. **Figure 4-1** shows the calibration and predictive modeling timeline.

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Three model codes were used to simulate groundwater flow and contaminant transport:

- Groundwater flow was modeled in three dimensions using MODFLOW 2005.
- Contaminant transport was modeled in three dimensions using MT3DMS.
- Percolation (recharge) was modeled using the results of the Hydrologic Evaluation of Landfill Performance (HELP) model.

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5. MODEL SETUP AND CALIBRATION

5.1 Model Descriptions

For the construction and calibration of the numerical groundwater flow model for the site, Ramboll selected the model code MODFLOW, a publicly-available groundwater flow simulation program developed by the USGS (McDonald and Harbaugh, 1988). MODFLOW is thoroughly documented, widely used by consultants, government agencies and researchers, and is consistently accepted in regulatory and litigation proceedings. MODFLOW uses a finite difference approximation to solve a three-dimensional head distribution in a transient, multi-layer, heterogeneous, anisotropic, variable-gradient, variable-thickness, confined or unconfined flow system—given user-supplied inputs of hydraulic conductivity, aquifer/layer thickness, recharge, wells, and boundary conditions. The program also calculates water balance at wells, rivers, and drains.

MODFLOW was developed by USGS (McDonald and Harbaugh, 1988) and has been updated several times since. Major assumptions of the code are: (i) groundwater flow is governed by Darcy's law; (ii) the formation behaves as a continuous porous medium; (iii) flow is not affected by chemical, temperature, or density gradients; and (iv) hydraulic properties are constant within a grid cell. Other assumptions concerning the finite difference equation can be found in McDonald and Harbaugh (1988). MODFLOW 2005 was used for these simulations with Groundwater Vistas 7 software for model pre- and post- processing tasks (Environmental Simulations, Inc., 2017).

MT3DMS (Zheng and Wang, 1998) is an update of MT3D. It calculates concentration distribution for a single dissolved solute as a function of time and space. Concentration is distributed over a three-dimensional, non-uniform, transient flow field. Solute mass may be input at discrete points (wells, drains, river nodes, constant head cells), or distributed evenly or unevenly over the land surface (recharge).

MT3DMS accounts for advection, dispersion, diffusion, first-order decay, and sorption. Sorption can be calculated using linear, Freundlich, or Langmuir isotherms. First-order decay terms may be differentiated for the adsorbed and dissolved phases.

The program uses the standard finite difference method, the particle-tracking-based Eulerian-Lagrangian methods and the higher-order finite-volume total-variation-diminishing (TVD) method for the solution schemes. The finite difference solution has numerical dispersion for low-dispersivity transport scenarios but conserves good mass balance. The particle-tracking method avoids numerical dispersion but was not accurate in conserving mass. The TVD solution is not subject to significant numerical distribution and adequately conserves mass, but is numerically intensive, particularly for long-term models such as developed for the PAP. The finite difference solution was used for this simulation.

Major assumptions of MT3DMS are: (i) changes in the concentration field do not affect the flow field; (ii) changes in the concentration of one solute do not affect the concentration of another solute; (iii) chemical and hydraulic properties are constant within a grid cell; and (iv) sorption is instantaneous and fully reversible, while decay is not reversible.

The HELP model was developed by the United States Environmental Protection Agency (USEPA). HELP is a one-dimensional hydrologic model of water movement across, into, through and out of a landfill or soil column based on precipitation, evapotranspiration, runoff, and the geometry and

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hydrogeologic properties of a layered soil and waste profile. For this modeling, results of the HELP model, HELP Version 4.0 (Tolaymat and Krause, 2020) completed for the groundwater model were used to estimate the hydraulic flux from beneath the PAP.

5.2 Flow and Transport Model Setup

The modeled area was approximately 7,900 feet by 9,950 feet (382,955,000 square feet [ft^2]) with the PAP located in the southern quadrant (**Figure 5-1**). The model boundaries along the northern, southern and eastern edges of the model were selected to maintain sufficient distance from the PAP to reduce boundary interference with model calculations, while not extending too far past the extent of available calibration data. The east and west edges of the model also approximate topographic highs, surface water divides, watershed boundaries.

The MODFLOW model was calibrated to mean groundwater elevation collected from 2015 to 2021 presented in **Table 2-2**. MT3DMS was run on the calibrated flow model and model-simulated concentrations were calibrated to observed sulfate concentration values at the monitoring wells from March to July 2021 presented in **Table 2-2**. Multiple iterations of MODFLOW and MT3DMS calibration were performed to achieve an acceptable match to observed flow and transport data. For the PAP, the calibrated flow and transport models were used in predictive modeling to evaluate the CIP and CBR closure scenarios. Prior to simulation of CIP and CBR, a dewatering phase, which simulated the removal of free liquid from the CCR material in the PAP was completed. Closure scenarios were simulated by removing saturated ash cells and using HELP modeled recharge values to simulate changes proposed in the closure scenarios.

5.2.1 Grid and Boundary Conditions

A seven-layer, 451 x 508 node grid was established with a variable grid spacing of between 25 and 100 feet (**Figure 5-2 through Figure 5-8**), with a total number of 1,546,703 active cells. The grid is rotated 25 degrees to the east to align the model boundary with the orientation of Newton Lake and Sandy Creek.

The northern boundaries for layers 1, 2, 3, and 4 are general head boundaries placed to simulate flow in the Peoria Silt, Sangamon Soil, and sandier soils of the Hagarstown Member composing the UD, PMP, and UCU. The general head boundaries along the northern and southern model boundaries for layer 6 represents the regional flow conditions within this unit. The eastern and western edges are no flow boundaries in all model layers.

Newton Lake is represented as a constant head boundary based on a reasonably constant surface water elevation measured from February 15 to March 9, 2021 of between 504.42 to 504.84 feet NAVD88. The constant head boundary was simulated with an elevation equal to 504.6 feet. The lake is in hydraulic connection with multiple layers within the model.

The bottom of the model was also a no-flow boundary. The top of the model was a time-dependent specified flux boundary, with specified flux rates equal to the recharge rate. A specified mass flux boundary was used to simulate downward percolation of solute mass from the PAP. This boundary condition assigns a specified concentration to recharge water entering the cells within the PAP, and the resulting concentration in the PAP cells is a function of the relative rate and concentration of recharge water (water percolating from the impoundments) compared to the rate and concentration of other water entering the node.

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Natural (streams) drainage features are present in the modeled area; these are represented as rivers and drains depending on available information in the model.

5.2.2 Flow Model Input Values and Sensitivity

Evaluation of monitoring well data for the PAP has not identified statistically significant seasonal trends in groundwater flow or quality which could affect model applicability for prediction of transport. The MODFLOW model was calibrated to mean groundwater elevations from 2015 to 2021. Multiple iterations of MODFLOW calibration were performed to achieve an acceptable match to observed flow data.

Sensitivity analysis was conducted by changing input values and observing changes in the sum of squared residuals (SSR). Horizontal conductivity, vertical conductivity, and river and general head conductance terms were all varied by one order of magnitude (*i.e.*, between one-tenth and ten times) of the calibrated values. Recharge terms were varied between one-half and two times calibrated values. River stage and drain bottom elevations were obtained from the 10 meter (m) Digital Elevation Model (DEM) from the United States Department of Agriculture/Natural Resources Conservation Service National Geospatial Center of Excellence (USDA/NRCS, 2022). The vertical error of the 10 m DEM is 0.82 m (2.7 feet); therefore, the stream stage and drain bases were varied by adding and subtracting 2.7 feet. General head boundary head terms were varied between 90 and 110 percent of calibrated values. When the calibrated model was tested, the SSR was 794. Sensitivity test results were categorized into negligible, low, moderate, moderately high, and high sensitivity based on the change in the SSR as summarized in the notes in **Table 5-1**.

5.2.2.1 Layer Top/Bottom

A digital elevation model of the area was used to assign the top of layer one. The elevations for the base of each hydrostratigraphic layer were interpolated from boring log data primarily from logs provided in the HCR (Ramboll, 2021a) utilizing Surfer® software for each of the six distinct water-bearing units described in **Section 2** (excluding the BCU). The resulting surfaces were imported into MODFLOW. The silts, clays, and sands of the UD unit (Peoria Silt, Sangamon Soil and Hagarstown Member) were divided into three layers to accommodate the explicit inclusion of the PAP ash deposits and the PMP. The thick UCU comprised of Vandalia Till was divided into two layers for contaminant transport; the Mulberry Grove Formation and Smithboro Till were represented as single layers within the model. **Figures 5-9** to **Figure 5-15** show the seven model layer elevations. The resulting surfaces were imported as layers into the model to represent the distribution and change in thickness of each water-bearing unit across the model domain. Flow model layer descriptions are summarized in **Table A** below.

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Table A. Flow Model Layer Descriptions

Layer	Hydrostratigraphic unit name	Hydrostratigraphic unit used to determine layer thickness	Top Elevation [1]	Bottom Elevation [1]	Thickness (feet)
			Mean (Minimum – Maximum)		
1&2	UD	Silty clay and clay	535.6 (503.71-564.0)	511.1 (472.0-532.5)	24.5 (4.0-76.4)
3	PMP	Sand, silty clay, and clay	511.1 (472.0-532.5)	508.8 (470.0-530.1)	2.3 (2.0-25.56)
4&5	UCU	Silts and lean clays of the Vandalia member	508.8 (470.0-530.1)	472.0 (425.4-486.9)	36.8 (10.7-57.6)
6	UA	Sands and gravels within silty clay	472.0 (425.4-486.9)	465.3 (418.1-483.9)	6.7 (2.0-29.9)
7	LCU	lean clays of the Smithboro Till	465.3 (418.1-483.9)	438.3 (412.2-458.1)	26.9 (5.9-37.8)

Notes:
[1] Elevation is measured in feet, referenced to NAVD88.

5.2.2.2 Hydraulic Conductivity

Hydraulic conductivity values and sensitivity results are summarized in **Table 5-1.** The spatial distribution of the hydraulic conductivities within the UD, UCU, and LCU was considered homogenous. A zone representing the Cahokia deposits was included in UCE layers 4 and 5. The hydraulic properties of this zone is equivalent to those of the rest of the UCU, this zone is discussed further in **Section 5.2.3.5**. In both the PMP and UA layers (model layers 3 and 6, respectively), well log data indicated the presence of silt, sand, and gravel lenses. These were included in the model as zones within these two layers. The spatial extent of these zones was determined using well log data for areas of silt within the PMP, and silt/sand and gravel within the UA. Hydraulic properties within these zones do not vary. **Figures 5-16 through 5-22** show the spatial distribution of the hydrostratigraphic units, PAP and other units on site for each of the seven model layers.

Where available, hydraulic conductivity values were derived from field measured or laboratory tested values reported in the HCR (Ramboll, 2021a) (**Section 2.2.2**). No horizontal anisotropy was assumed. Vertical anisotropy was applied to conductivity zones to simulate preferential flow in the horizontal direction in these materials, and are presented as anisotropy ratio (Kh/Kv) in **Table 5-1**.

The model was highly sensitive to changes in horizontal conductivity in UD (zone 1), UD-PMP sand (zone 5), UA (zone 7), UA-gravel (zone 9), and moderately high sensitivity to the sand deposit in the UA (zone 8). The calibrated model has low to moderate sensitivity to horizontal conductivity in the remaining hydrostratigraphic units. The model was highly sensitive to changes in the vertical conductivity in the UD (zone 1), and the UCU and UCU-Cahokia (zone 6 and 11, respectively). The model had a moderately high sensitivity to changes in vertical conductivity in the UA (zone 7) and the sand deposit in the UA (zone 8), and moderate sensitivity to changes in

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vertical conductivity in UD-PMP sand (zone 5) and UA-gravel (zone 9). The UD fill (zone 2), CCR (zone 3), UD-PMP (zone 4), and LCU (zone 10) exhibited low sensitivity.

5.2.2.3 Recharge

Recharge rates were determined through calibration of the model to observed groundwater elevations. For the calibration model, recharge was applied to the upper most active layer and the rates varied based on different units, namely the PAP, LF1, LF2, Secondary Pond, NPP, and Cooling Pond. Model inputs are summarized in **Table 5-1**. The distribution of recharge is show in **Figure 5-23**.

The calibrated flow model is highly sensitive to recharge to the PAP, moderately sensitive to recharge to the UD, and has negligible sensitivity to all other zones within the model (**Table 5-1**).

5.2.2.4 Storage and Specific Yield

The flow calibration model did not use these terms because it was run at steady state. For the transport model, which was run as a transient simulation, no field data defining these terms were available so published values were used consistent with Fetter (1988). Specific yield was set to equal effective porosity values described in **Section 5.2.3.3**. The spatial distribution of the storage and specific yield zones were consistent with those of the hydraulic conductivity zones. The sensitivity of these parameters was tested by evaluating their effect on the transport model as described in **Section 5.2.3.4**.

5.2.2.5 General Head Boundary Parameters

General head boundary conditions (GHB) were used along the northern boundary of the model for layer 1 through 4 and layer 6. GHB were also used along the southern boundary for layer 6 only (**Figures 5-2** to **5-7**). The GHB at the northern limit of the model in layers 1 through 4 was used to simulate groundwater flow into the model via the UD, PMP, and UCU. The UCU was included in the GHB due to its hydraulic connection to Newton Lake even though it has a low hydraulic conductivity. The groundwater levels used for the northern boundary of the model in layers 1 through 4 were estimated using the Dupuit equation for steady state flow in an unconfined aquifer with recharge.

The DEM of the site provided estimates of the surface water levels for Newton Lake on the east of the model domain (504.6 feet) and the Sandy Creek (525 feet) located 6,500 feet west of Newton Lake. The calibrated ambient recharge to the UD was used in the calculation of the groundwater level distribution at the northern boundary. The hydraulic conductivity value K used in the Dupuit equation was estimated during model calibration.

This GHB was only applied to cells along the northern boundary where the base of the cell was below the calculated groundwater head for a given distance from the constant head boundaries, the head was determined by the Dupuit equation. Cell conductance was then calculated using the calibrated hydraulic conductivity and the cells' saturated thickness and cell width.

The CSM for NPP (layer 6) describes a potential hydraulic connection between the UA and either Big Muddy Creek or Newton Lake dam, both of which are located approximately 14,000 feet southwest of the model domain. The elevation of both Big Muddy Creek and Newton Lake dam at this distance is approximately 460 feet. Therefore, the GHB elevation and distance at the

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southern limits of the model in the UA was set to 460 feet and 14,000 feet. The conductance was determined using the cells calibrated hydraulic conductivity, cell width and thickness (cells were assumed to be fully saturated).

The GHB elevation for northern boundary in the UA was established during calibration (**Table 5-1**). The distance to the GHB head was set to 1, and the GHB conductivity was calculated using the cell width, cell thickness, and calibrated hydraulic conductivity from the model.

The sensitivity to changes in specified head was negligible to moderate for both the northern GHB in layer 1-4, and in the UA (layer 6), and high for the southern GHB in the UA. The flow calibration model had low sensitivity to changes in the conductance for both the northern GHBs (layer 1-4 and layer 6), and high sensitivity in the southern GHB in layer 6 (UA).

5.2.2.6 River Parameters

The Cooling Flume transports water from the Cooling Pond north of the PAP to Newton Lake. The flume consists of three sections, where the surface water elevation is controlled via weirs with decreasing elevation as the flume approaches Newton Lake. The most upstream section is maintained at 530.98 feet, the intermediate section has a surface water elevation of 515.66 feet, and the surface water elevation in the final section is maintained at 499.0 feet. Sandy Creek is the primary natural surface water feature which discharges into Newton Lake west of the PAP.

Both the Cooling Flume and Sandy Creek are included in the model as head dependent flux boundaries that required inputs for elevation of the surface water, bottom of the stream, width, bed thickness, and bed hydraulic conductivity (**Table 5-1**). A total of three river reaches are included in the model; in the absence of river geometry information the DEM was used to estimate stream stage at the upstream and downstream limits of each reach. For Sandy Creek the slope of the river was then linearly interpolated along the reach, providing an estimation of stream stage along the length of each reach for each model grid cell though which the river flows. Bed thickness was set at 1 foot and river width was set at 10 feet.

The width of the Cooling Flume (approximately 32 feet) is larger than the grid cell dimensions (25 feet by 25 feet), therefore the conductance term for the Cooling Flume was based on the area of the cells which coincide with the flume. The DEM provided surface water elevation estimations of the three sections of the Cooling Flume, and the bed thickness was set to 1 foot.

River width, bed thickness, and bed hydraulic conductivity parameters were used to calculate a conductance term for the river cells. This conductance term was determined by adjusting hydraulic conductivity during model calibration.

The river boundaries were placed in layers 1 through 4, corresponding with simulated river elevation and base of the river (**Figure 5-2 through Figure 5-5**).

The calibrated flow model has negligible sensitivity to changes in either river stage or conductance.

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Table B. River and Drain Information

Name	Boundary Type	Length (feet)	Slope (ft/ft)
Cooling Flume	River	7891.0	-
Sandy Creek	River	13082.7	-0.0019
Sandy Creek Tributary 1	Drain	2420.5	-0.0076
Sandy Creek Tributary 2	Drain	6326.4	-0.0038
Sandy Creek Tributary 3A	Drain	4359.1	-0.0015
Sandy Creek Tributary 3B	Drain	4088.8	-0.0058
Landfill Stream	Drain	2706.7	-0.0057
PAP Stream	Drain	5658.5	-0.0038
PAP drain north	Drain	2055.2	-0.0102
Newton Lake Tributary 1	Drain	6854.6	-0.0057
Newton Lake Tributary 2	Drain	3414.8	-0.0083
Newton Lake Tributary 3	Drain	2369.0	-0.0090
Newton Lake Tributary 4	Drain	1603.0	-0.0029
Newton Lake Tributary 5	Drain	2448.4	-0.0078
Newton Lake Tributary 6	Drain	2556.7	-0.0107
Newton Lake Tributary 7	Drain	3002.7	-0.0061
Tributary South 1	Drain	1839.0	-0.0021
Tributary South 2	Drain	4364.0	-0.0041
Tributary South 3	Drain	1200.9	-0.0083
PAP drain north	Drain	2051.2	-0.0137

Notes:
ft/ft = feet per foot

5.2.2.7 Drains

The model contains numerous small tributaries which discharge into both Sandy Creek and Newton Lake. Limited hydrological data are available for these surface water features; therefore, it is uncertain how these interact with the groundwater levels. However, these features are all first-order streams (or headwater streams) and therefore it is highly likely that they are fed by a combination of groundwater discharge and surface runoff (Horton, 1945). Therefore, these streams are included in the model as head dependent flux boundaries (drain) that required inputs for elevation of the bottom on the stream, width, bed thickness, and bed hydraulic conductivity (**Table 5-1**). By using the drain head-dependent flux boundary it is assumed that these streams only act as groundwater discharge features and makes the fewest assumptions regarding stream geometry.

A total of 18 drain reaches are included in the model. In the absence of river geometry information the DEM was used to estimate stream stage at the upstream and downstream limits of each reach. The slope of the river was then linearly interpolated along the reach, which provided an estimate of stream stage along the length of each reach for each model grid cell though which the stream flows.

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The drain boundaries were placed in layers 1 through 4 corresponding with simulated drain depth (**Figure 5-2 through Figure 5-5**).

The calibrated flow model has negligible to low sensitivity to both drain elevation and conductance for most drains. Only the Landfill drain (reach 6) had moderate sensitivity to drain elevation.

5.2.3 Transport Model Input Values and Sensitivity

MT3DMS input values are listed in **Table 5-2** and described below. Sensitivity of the transport model is summarized in **Table 5-3**.

Groundwater transport was calibrated to groundwater sulfate concentration ranges at each well as measured from the monitoring wells between 2015 (where available) and 2021. The transport model calibration targets are summarized in **Table 2-2**.

Sensitivity analysis was conducted by changing input values and observing percent change in sulfate concentration at each well from the calibrated model sulfate concentration. Effective porosity was varied by decreasing and increasing calibrated model values by 0.05. Storage values were multiplied and divided by a factor of 10, and specific yield by a factor of 2. Dispersivity in the Cahokia Alluvium was varied by decreasing and increasing calibrated model dispersivity by 50 percent. The transport model had a negligible sensitivity to changes in storage and specific yield (**Table 5-3**). The transport model ranged from negligible to high sensitivity to effective porosity and negligible to moderately high sensitivity to dispersivity as discussed in **Sections 5.2.3.3** and **5.2.3.5**.

5.2.3.1 Initial Concentrations

No initial concentrations were placed in the steady state flow calibration model. The flow model was run as transient and concentration was added to the model through recharge starting at the same time as flow simulation. Modeling was performed for a sufficient period (45 years) to allow modeled concentrations in the primary transport layer (*i.e.,* UD/PMP and UA) to reach recently observed levels.

5.2.3.2 Source Concentrations

Based on review of CCR placement, initial source concentrations for the pond were set to observed concentrations from porewater samples collected from earlier placement areas (XPW02 and XPW03) with a sulfate concentration of 130 milligrams per liter (mg/L) (**Figure 5-24**). This was applied throughout the pond until 1985, after which discoloration becomes apparent in the CCR deposits and source areas were added using porewater results from XPW01 and XPW04. Three concentration sources in the form of vertical percolation (recharge) through CCR were simulated within the PAP for calibration (**Table 5-2**): (i) percolation through CCR in the northeastern portion of the PAP, (ii) percolation through CCR in the northwestern portion of the PAP, and (iii) percolation through CCR in the remaining area of the PAP (**Figure 5-24**).

Porewater chemistry from within the PAP indicated that the distribution of sulfate concentrations is spatially variable, ranging on average between 19,000 mg/L (XPW01) and 99 mg/L (XPW03). Therefore, zonation of the PAP concentration sources was used to delineate areas with differing sulfate source inputs. The zonation was based on evidence provided by Ramboll (2020) and AECOM's (2016) History of Construction of the PAP. The CCR materials within the PAP shows

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zones of discoloration, suggestive of additional chemical processes occurring within the CCR and/or the presence of deposits other than CCR (Burns & McDonnell Engineering Company, Inc., 2020). Analysis of aerial imagery of the PAP indicates that the zones of discoloration around XWP01 and XPW04 are present from 1998 onwards. The CCR around XWP02 and XWP03 shows no discoloration and are located within the oldest CCR deposits. The sulfate concentration in these wells are similar and possibly more indicative of the sulfate concentrations within the CCR in general. Therefore, the CCR sulfate concentration (excluding the 2 zones) was set to the average concentration from XWP02 and XPW03 (130 mg/L).

All three source areas were simulated by assigning concentration to the recharge input. All source concentrations in the transport model were based on sulfate concentration data collected in 2021. The source concentrations applied to the recharge zones and saturated ash cells immediately below the recharge zones have the same concentration values. Because these are the sources of concentration in the model, the model will be highly sensitive to changes in the input values. For that reason, sensitivity testing was not completed for the source values.

5.2.3.3 Effective Porosity

Effective porosity for each modeled hydrostratigraphic unit were obtained from the HCR (Ramboll, 2021a) and based on the porosity and are presented in **Table 5-2**.

The model had a negligible to high sensitivity to changes in porosity values, not including monitoring locations where the calibration concentration was less than 10.0 mg/L (*i.e.*, AWP05, APW06, APW08, APW11, APW15, and APW16) (**Table 5-3**). For wells with calibration concentrations greater than 10.0 mg/L, the greatest sensitivity for porosity was high for the low porosity sensitivity test at monitoring locations APW07, AWP09, APW17, and APW18.

5.2.3.4 Storage and Specific Yield Sensitivity

Estimates of storage and specific yield for each modeled hydrostratigraphic unit were obtained from the HCR (Ramboll, 2021a) and based on the porosity and are presented in **Table 5-2**.

The model had a negligible sensitivity to changes in storage and specific yield values (**Table 5-3**).

5.2.3.5 Dispersivity

Physical attenuation (dilution and dispersion) of contaminants is simulated in MT3DMS. Dispersion in porous media refers to the spreading of contaminants over a greater region than would be predicted solely from the average groundwater velocity vectors (Anderson, 1979 and 1984). Dispersion is caused by both mechanical dispersion, a result of deviations of actual velocity at a microscale from the average groundwater velocity, and molecular diffusion driven by concentration gradients. Molecular diffusion is generally secondary and negligible compared to the effects of mechanical dispersion and only becomes important when groundwater velocity is very low. The sum of mechanical dispersion and molecular diffusion is termed hydrodynamic dispersion, or simply dispersion (Zheng and Wang, 1998).

Dispersivity values were applied to the entire model domain and determined during calibration. Longitudinal dispersivity was set at 1 foot. The transverse and vertical dispersivity were set at 1/10 and 1/100 of longitudinal dispersivity. The Cahokia Alluvial deposits are represented in layer 4 a distinct zone within the UCU, there is no evidence to indicate that the hydraulic properties of

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this unit differ from those of the UCU; however, there is evidence that there is preferred transport through this unit. Therefore, this unit (**Figure 5-19** and **5-20**) has been included as an area of increased dispersivity. The calibrated longitudinal dispersivity for the Cahokia Alluvium was 20 feet, with the transverse and vertical dispersivity set at 1/10 and 1/100 of longitudinal dispersivity. Changes in hydraulic conductivity within this zone have negative impacts on the flow calibration in the UA. The increased dispersivity allows for migration of mass to wells where elevated sulfate concentrations have been observed and are coincident with the Cahokia deposits illustrated on Figure 2 of the HCR (Ramboll, 2021a) while preserving flow calibration.

The model had a negligible to moderately high sensitivity to changes in the Cahokia Alluvium dispersivity in wells, not including monitoring locations where the calibrated concentration was less than 10 mg/L. For wells with calibration concentrations greater than 10.0 mg/L, the greatest sensitivity for dispersivity was moderately high for the low dispersivity sensitivity test at monitoring locations APW07, APW09, APW17, and APW18.

5.2.3.6 Retardation

It was assumed that sulfate would not significantly sorb or chemically react with aquifer solids (distribution coefficient [Kd] was set to 0 milliliters per gram [mL/g]), which is a conservative estimate for estimating contaminant transport times. Lithium, sulfate, and TDS transport is likely to be affected by both chemical and physical attenuation mechanisms (i.e., adsorption and/or precipitation reactions as well as dilution and dispersion). Batch adsorption testing was conducted to generate site specific partition coefficient results for lithium and sulfate (Golder, 2022b, **Appendix C**) for locations APW-04 and APW-14. Results of the testing are summarized below:

- Lithium: Calculated linear partition coefficient (K_D) values for APW-04 and APW-14 were 4.49 and 5.58 liters per kilogram (L/kg) respectively, Langmuir partition coefficient (K_L) values were 6.2×10^7 and 1.6×10^8 L/kg, respectively, and Freundlich partition coefficients (K_F) values were 135 and 230 L/kg, respectively. In Strenge and Peterson (1989), partition coefficients for lithium range from 0 to 0.8 L/kg, depending on pH conditions and the amount of sorbent present.
- Sulfate: Calculated K_D values for APW-04 and APW-14 were 3.58 and -25.6 L/kg, respectively, K_L values were -626 and -2,200 L/kg, respectively, and K_F values were 4.11 and 2.14×10^{11} L/kg, respectively. In Strenge and Peterson (1989), partition coefficients for sulfate are 0.0 L/kg, regardless of pH conditions and the amount of sorbent present.

The results from site samples have a high degree of variation and little correlation with the literature values provided for comparison. The potential exceedances identified in groundwater (lithium, sulfate and TDS) are affected by natural attenuation processes in multiple ways and to varying degrees. Further assessment of these processes and how they may be applied as a potential groundwater remedy will be completed as part of future remedy selection evaluations as necessary. For the purposes of this modeling report, and as mentioned at the beginning of this section, no retardation was applied to sulfate transport in the model *(i.e.,* Kd was set to 0).

5.3 Flow and Transport Model Assumptions and Limitations

Simplifying assumptions were made while developing this model:

- Natural recharge is constant over the long term.
- Fluctuations in lake stage do not affect groundwater flow and transport over the long term.

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- Hydraulic conductivity is consistent within hydrostratigraphic units and delineated zones.
- The approximate base of ash surface in the PAP was developed with HDR using soil borings and bathymetric survey results.
- Source concentrations are assumed to remain constant over time.
- Sulfate is not adsorbed and does not decay and mixing and dispersion are the only attenuation mechanisms.

The model is limited by the data used for calibration, which adequately define the local groundwater flow system and the source and extent of the plume. Since data used for calibration are near the PAP, model predictions of transport distant spatially and temporally from the calibrated conditions at the CCR units will not be as reliable as predictions closer to the CCR units and concentrations observed in 2021.

5.4 Calibration Flow Model

The groundwater model was manually calibrated to best approximate the mean groundwater elevations in 30 wells at the site. The mean elevations used for calibration and locations of wells within the flow model are summarized in **Table 2-2**. Well locations are shown in **Figure 2-1**. This involved modifying the hydraulic conductivities of the different hydrostratigraphic units, recharge rate, and conductance of the drains, rivers, and general head boundaries within the model to minimize the difference between the mean observed groundwater elevation and simulated groundwater elevation. Where possible, the range of the parameter values used during calibration were based on observed values (*i.e.,* for the range in hydraulic conductivity estimates from the HCR). Where this was not possible, such as for the drain and general head boundary conductance, the range of parameter values were based on other site information or inferred from knowledge from similar sites. Where data were limited, the parameter values were less constrained during calibration (*e.g.,* parameter values had wider ranges). The RMSE was used as a metric to identify the optimal values for the different parameters.

5.5 Calibration Flow Model Results

Results of the MODFLOW modeling are presented below. The model files accompany this report (**Attachment A**). **Table 5-1** shows the calibrated hydraulic conductivity for the different units shown in **Figures 5-16** to **5-22**.

Groundwater model calibration results are presented in **Figure 5-25** and **Figure 5-26**, which shows the observed GWL and simulated groundwater elevations and the observed GWL versus residuals. The near-linear relationship between observed and simulated values presented on **Figure 5-25** indicates that the model adequately represents the calibration dataset. The RMSE of the GWL across all wells was 5.14 feet. The mass balance error for the flow model was 0.00 percent and the ratio of the residual std to the range of heads was 9.2 percent, which is just below the desired target value of 10 percent. Another flow model calibration goal is that residuals are evenly distributed such that there is no bias affecting modeled flow. The observed heads are plotted versus the simulated heads in Figure **5-26** and simulated values are evenly distributed above and below observed values. The residual mean was also near zero with a value of 1.12 feet, indicating a small bias towards overestimating the GWL in the calibrated model; this is also illustrated in the observed versus residuals plot in **Figure 5-26**. The simulated groundwater elevations within the UD/PMP (layer 3) and the UA (layer 6) are shown in **Figure 5-27** and **Figure 5-28**.

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In general, the model is able to simulate the groundwater flow patterns the UA (**Figure 2-2** and **Figure 2-3**) interpreted from the site well data for May and July 2021 respectively. The notable exceptions are 1) those wells located to the north of the PAP, close to the boundary between the UA and UA- sand, and 2) those wells to the east of the PAP close to the boundary between the UA, UA-sand and UA-gravel. The groundwater level is underestimated in both of these areas. The underestimation in groundwater heads suggests that the subsurface heterogeneity (the uppermost aquifer is located in glacial deposits that grade from sand to silt with gravel deposits) is not optimally represented by the zoned layers used in the model. The interpretation of both the UA-sand and UA-gravel areas were based on well log data available near the PAP. These sand and gravel deposits may or may not be present beyond the available well information. Based on the objective of the model to estimate potential impacts from the PAP, and the model's ability to simulate flow within the UA, the zoned representation in hydraulic properties within the UA is suitable.

5.6 Transport Model Results

The range of observed sulfate concentrations for transport calibration locations are summarized in **Table 2-2**. The goals of the transport model calibration were to have predicted concentrations fall within the range of observed concentrations; and, to have predicted concentrations above and below the GWPS for sulfate (400 mg/L) match observed concentrations above or below the standard at each well.

Both these goals were achieved in three of the transport calibration location wells (**Figure 5-29**), and all but two wells achieved the second goal of matching observed concentrations above or below 2 mg/L. Deviations from the observed ranges are discussed below.

- The model over predicts concentration in wells APW02, APW04, and APW12, which are screened in the UD/PMP. The modeled and observed concentration are both above 400 mg/L, so one of the two calibration goals was satisfied.
- The model under predicts concentrations in APW05S, which is screened in the UD/PMP; however, the difference between the lower limit of the range of observed concentrations (200 mg/L) and the predicted concentration of 116.3 mg/L is small. APW05S is located upgradient of the pond and may also be influenced by other factors, notwithstanding the PAP. The modeled and minimum observed concentration are both below 400 mg/L, so one of the two calibration goals was satisfied.
- The model under predicts concentrations in APW03, which is screened in the UD/PMP; however, the difference between the lower limit of the range of observed concentrations (160 mg/L) and the predicted concentration of 128.9.3 mg/L is small. Both the observed and predicted concentrations are below the GWPS, so one of the two calibration goals was satisfied.
- The model slightly under predicts the concentration in APW10, which is screened in the UA. The minimum observed concentration at APW10 is 390 mg/L and simulated sulfate concentration is 340 mg/L. The modeled and minimum observed concentration are both below 400 mg/L, so one of the two calibration goals was satisfied.
- The model under predicts concentrations in APW05, APW06, APW11, APW13, APW14, APW15 and APW17 which are screened in the UA. The range in observed sulfate concentrations in these wells is very small, with an average range of 35 mg/L. The maximum observed

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concentrations in these wells are 15 mg/L, 9.9 mg/L, 300 mg/L, 230 mg/L, 340 mg/L, 1 mg/L and 41 mg/L, respectively. The predicted concentrations are 0.3 mg/L, 0 mg/L, 2.5 mg/L, 85.2 mg/L, 96.8 mg/L, 9 mg/L and 87.6 mg/L for APW05, APW06, APW11, APW13, APW14, APW15 and APW17, respectively. However, observed and predicted concentrations did not exceed the GWPS, satisfying one of the calibration goals.

- The model over predicts the concentration at APW18, which is screened in the UA. The maximum observed sulfate concentration at APW18 is 26 mg/L and the simulated concentration is 87.6 mg/L, which is an overprediction of 61.6 mg/L. However, observed and predicted concentrations did not exceed the GWPS, satisfying one of the calibration goals.

The remaining calibration locations (APW07, APW09, APW16) have predicted concentrations that were within range of the observed sulfate concentration and simulated GWPS exceedances. The UD/PMP well APW02, where the highest concentrations were observed (3,200 mg/L), was also calibrated to the median concentration of the observed values in 2021, indicating the transport calibration model was able to simulate the highest observed concentrations (**Figure 5-29**). The sulfate plume at the end of the transient model simulation of 500 years for the UD/PMP is shown in **Figure 5-30.** There are no simulated exceedances in the UA at the end of the transient model; however, sulfate is approaching the GWPS of 400 mg/L near APW-10 where exceedances of the GWPS have been observed.

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6. SIMULATION OF CLOSURE SCENARIOS

6.1 Overview and Prediction Model Development

Prediction simulations were performed to evaluate the effects of Closure (source control measures) for the PAP on groundwater quality. The prediction simulations evaluated changes in groundwater sulfate concentrations from Scenario 1: CIP (removal of CCR from the southern portion of the PAP and consolidation into the northern portion of the PAP and Scenario 2: CBR (removal of all CCR material from the PAP). As discussed in **Section 5.2.3.5** physical attenuation (dilution and dispersion) of contaminants in groundwater is simulated in MT3DMS, which captures the physical process of natural attenuation as part of corrective actions for both closure scenarios simulated. No retardation was applied to boron transport in the model (i.e., Kd was set to 0) as discussed in **Section 5.2.3.6**.

Closure scenarios were simulated by initially removing free liquid from the CCR material over the course of 1 year by placing constant head cells with an elevation of 520 feet above the base of the CCR material and applying zero recharge to simulate dewatering of the PAP.

HELP-calculated percolation rates, based on removal and final soil backfill grading designs also provided in the *Primary Ash Pond Final Closure Plan* (HDR, 2022), were applied for the different closure scenarios. HELP modeling input and output values are summarized in **Table 6-1** and described in detail below.

The CIP and CBR scenarios were simulated for a 500-year period. The following simplifying assumptions were made during the simulations:

- Removal of free liquids from CCR takes place prior to the CIP and CBR closure scenarios. Constant head cells were placed within the PAP to simulate the target water elevation within the ponds; and recharge was set to zero.
- In the CIP and CBR closure scenarios, HELP-calculated average annual percolation rates were developed from a 30-year HELP model run. This 30-year HELP-calculated percolation rate remained constant over duration of the closure scenario prediction model runs following CCR dewatering period.
- Changes in recharge resulting from removal of free liquids (decrease calibration model recharge rates to zero) and CCR fill removal/ final soil backfill grading (recharge rates are based on HELP-calculated average annual percolation rates) have an instantaneous effect on recharge and percolation through surface materials.
- Sulfate source concentrations were assumed to be negligible (0 mg/L) in CCR removal areas in both the CIP and CBR scenarios. The spatial distribution of CCR concentrations within the consolidation area for the CIP scenario were maintained from the initial transport simulation.
- Cap construction in CIP scenario was assumed to be completed with a cover system consisting of the following (listed from ground surface down): a vegetative cover (6 inches thick), rooting zone (18 inches thick), a 200-mil geocomposite drainage layer and a 40-mil linear low-density polyethylene (LLDPE) geomembrane.
- The start of each closure prediction simulation was initiated at the end of the calibration model period of 45 years plus 1 year to complete removal of free liquid. For example, the

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simulation of Scenario 1: CIP begins at 46 years (45 years for calibration plus 1 year). The prediction modeling timeline for each scenario is illustrated in Figure 4-1.

- CCR removal areas were assumed to be graded following placement of soil backfill based on the design drawings provided in the *Primary Ash Pond Final Closure Plan* (HDR, 2022).
- CCR consolidation/removal areas were assumed to be graded and include proper storm water controls to remove excess water from the surface using the design drawings provided (HDR, 2022).
- The CIP scenario includes the placement of a stormwater drain within the removal area. The outflow elevation of this stormwater pond is 525 feet, which will discharge into Newton Lake adjacent to the PAP. This is represented as a drain in the model whose elevation is equal to the stormwater pond outflow elevation.
- All saturated CCR (constant concentration cells) in the transport calibration model were removed instantaneously in all CCR removal areas for all prediction models.
- Local fill materials applied to the prediction models have similar hydraulic properties as the UD materials used in the transport calibration models. However, the local fill materials were assumed to have reduced vertical anisotropy ratios, approaching isotropic, due to reworking of the material as it is placed as backfill (Kh/Kv decreased from measured values of 100 to 1 for reworked material).

6.2 HELP Model Setup and Results

HELP (Version 4.0; Tolaymat and Krause, 2020) was used to estimate percolation through the PAP in areas of CCR removal with soil backfill, and areas of CCR consolidation with final cover system. HELP input and output files are included electronically and attached to this report.

HELP input data and results are provided in **Table 6-1**. All scenarios were modeled for a period of 30 years. Climatic inputs were synthetically generated using default equations developed for Terra Haute, Indiana (the closest weather station included in the HELP database). Precipitation, temperature, and solar radiation was simulated based on the latitude of the PAP. Thickness of soil backfill and soil runoff input parameters were developed for the ash fill removal scenarios using data provided the *Primary Ash Pond Final Closure Plan* (HDR, 2022).

HELP model results (**Table 6-1**) indicated 4.29 inches of percolation per year for the PAP CCR removal and soil backfill area in the CIP scenario, 0.042 inches of percolation per year through the CCR and final cover system for the CIP scenario, 4.38 inches of percolation per year for the PAP CCR removal and soil backfill area in the CBR scenario. HELP model simulations were also completed to estimate the percolation for the proposed closure of LF2. Model results indicated 0.000003 inches of percolation per year for LF1 and LF2 through the cover system. The differences in HELP model runs for each area included the following parameters: area, soil backfill thickness, slopes, and soil runoff slope length; all other HELP model input parameters were the same for each simulated area. HELP input data and results are provided in **Appendix B.**

Two additional HELP model simulations were completed to support the *Proposed Alternative Final Protective Layer Equivalency Demonstration*, (Geosyntec, 2022) which is an appendix to the Construction Permit Application to which this report is also attached. Results of these two HELP simulations were not incorporated in the MODFLOW simulations for closure. Simulation inputs and output results are presented in **Appendix D**.

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6.3 Simulation of Closure Scenarios

The calibrated model was used to evaluate the effectiveness of the two closure scenarios by adding constant head cells within the PAP, decreasing recharge to simulate removal of free liquid within the ash fill prior to removal, and changing recharge rates to simulate ash fill removal areas at the PAP. Removal of source inputs from the ash removal areas was simulated by reducing the sulfate concentrations associated with recharge in the areas to 0 mg/L. Constant concentration cells that represent areas with potentially saturated CCR were also removed from the ash removal areas.

Each prediction scenario was simulated as a continuation of the PAP dewatering simulation which followed the transient calibrated model. The prediction model input values are summarized in **Table 6-2,** and the modifications to the recharge zones and drain placement for the CIP scenario are illustrated in **Figure 6-1**. **Figure 6-2** illustrates the CCR removal area for the CBR at the PAP. The two closure scenarios are discussed in this report based on predicted changes in sulfate concentrations as described below.

6.3.1 Closure in Place Model Results

In the CIP scenario, the predicted concentrations in the UD/PMP start to decline once the closure actions are implemented within the prediction model. The reduced recharge rate in the northern area of the PAP leads to an increasing number of saturated ash cells (constant concentration cells) becoming inactive. These inactive cells are no longer contributing sulfate source concentration to the model domain. Sulfate concentration continues to be introduced in the CIP consolidation area via recharge, although only at a low rate. In addition, as a result of removal of free liquid and low recharge rate, downward percolation of solute mass from the PAP is reduced.

As previously discussed, the calibrated model over predicts sulfate concentrations in monitoring wells APW02, APW04, and APW12, which are screened in the UD/PMP. The predictive model indicates that these wells will reach the GWPS (400 mg/L) in 15 years, 20 years, and 4 years respectively, after the corrective measures are in place. All UD/PMP groundwater monitoring wells are below the GWPS within 20 years (**Figure 6-3**). The predicted footprint of the sulfate plume within the UD/PMP (Layer 3) shown in **Figure 6-3** is considerably reduced from that at the end of the transient model simulation (**Figure 5-30**).

The predicted concentrations in UA groundwater monitoring wells increase for various periods of time after corrective measures are implemented (**Figure 6-4**). However, only APW10 exceeds the GWPS following closure. The predicted concentration in APW10 rises for approximately 10 years after closure is completed, after which it declines such that the concentrations fall below the GWPS after 20 years.

Most of the UA wells show a delayed response to the implementation of closure, with the concentrations continuing to rise for up to 200 years in the case of APW17 while remaining below the GWPS. This delay can be attributed to the thick layer of UCU materials present between the UA and the CCR. Due to its low vertical hydraulic conductivity (0.0001 ft/d), sulfate will very slowly percolate through the UCU into the UA. The reduced recharge rate in the CIP scenario further reduces the vertical gradient across this unit, thereby slowing the movement of the sulfate within it. This results in the slow rise and fall of sulfate in many of the UA wells.

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The predicted footprint of the sulfate plume within the UA (Layer 6) is shown in **Figure 6-4.** Only a small area to the east of the pond (in close proximity to APW10) shows sulfate concentrations above the GWPS.

Evaluations of post-construction water flux through the consolidated and covered Fill Unit (CCR) were completed using data obtained from the Scenario 1 (CIP) prediction model when simulated post-construction heads in the groundwater monitoring wells are predicted to stabilize (once heads stabilized in the model, the post-construction movement of water in and out of the Fill Unit [CCR] were compared to pre-construction conditions). The pre-construction (calibration model) and post-construction Scenario 1 (CIP) prediction model simulated water flux values are summarized in **Appendix E** and discussed below. Data export files used for flux evaluations are found along with model files in **Appendix B**.

Scenario 1 (CIP) was predicted to reduce total flux in and out of the Fill Unit (CCR) by approximately 94%, when simulated post-construction heads in the groundwater monitoring wells are predicted to stabilize (approximate hydraulic steady state) as illustrated in **Figure 6-5**. **Figure 6-6** is a plot showing the changes in flux reduction (shown as negative percentage) over time starting from implementation of Scenario 1 (CIP) through approximate hydraulic steady state conditions. Both flux in and flux out are reduced greater than 75% after one year of closure. Following implementation of Scenario 1 (CIP), influx into the CCR unit decreases rapidly as illustrated in **Figure 6-6**. Concurrently, outflux from the CCR unit behaves similarly, decreasing rapidly and stabilizing 6 years post-construction, after which a reduction of outflux of at least 94% is maintained as heads approach hydraulic stabilization (**Figure 6-6**).

6.3.2 Closure by Removal Model Results

In the CBR scenario, predicted concentrations in the UD/PMP start to decline once the closure actions are implemented within the prediction model. These declines are due to removal of the CCR and a small reduction in recharge within the PAP. Predicted sulfate concentrations for APW02, APW03, APW04, APW05S, and APW12 are below the GWPS within 14 years (**Figure 6-3**).

As previously discussed, the model over predicts sulfate concentrations in monitoring wells APW02, APW04, and APW12, which are screened in the UD/PMP. The predictive model indicates that these wells will reach the GWPS 14 years, 10 years, and 13 years respectively, after closure.

Similar to the CIP scenario, the predicted footprint of the sulfate plume for the CBR within the UD/PMP (Layer 3) shown in **Figure 6-3** is considerately reduced from that of the transient model simulation (**Figure 5-30**). In comparison to the CIP scenario, the CBR simulation has a smaller plume at both the eastern boundary and western boundary of the PAP.

The simulated sulfate concentrations in the UA wells display a similar lagged response to closure as observed in the CIP scenario. Only APW10 exceeds the GWPS following closure. The predicted concentrations in APW10 continue to rise approximately 9 years after closure is completed, after which it declines such the concentrations fall below the GWPS after 16 years.

Like the CIP scenario, most of the UA wells show a delayed response to the implementation of closure, the concentrations continue to rise for up to 50 years in the case of APW18 while remaining below the GWPS.

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The predicted footprint of the sulfate plume within the UA (Layer 6) is shown in **Figure 6-4**. Only a small area to the east of the pond (in close proximity to APW10) shows sulfate concentrations above the GWPS and is not significantly different from the CIP simulated plume footprint.

6.3.3 Sulfate Composite Plume for CIP and CBR

The maximum footprint of the plume, based on the simulated sulfate concentrations in all model layers 20 years after corrective measures, is shown in **Figure 6-7**. The footprint of the plume includes the sulfate concentrations retained within the UCU and is therefore greater in area than those plumes in either the UD/PMP or UA. As mentioned above, the sulfate within the thick UCU will slowly percolate through the unit, the rate of which is governed by the hydraulic gradient across the unit. **Figure 6-8** shows the maximum plume extent after 100 years for both the CIP and CBR scenarios. The reduced recharge rate in the CIP scenario leads to a slightly larger plume for the CIP scenario than for the CBR scenario.

The maximum plume footprint in both the CIP and CBR scenarios continues to reduce through time and remains within the property boundaries.

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7. CONCLUSIONS

This GMR has been prepared to evaluate how proposed CIP and CBR scenarios will achieve compliance with the applicable groundwater standards at the NPP. Data collected from the recent 2021 field investigations were used to develop a groundwater model to predict the impacts of the closure scenarios on groundwater quality at the NPP. The MODFLOW and MT3DMS models were used to evaluate two scenarios using information provided in the *Primary Ash Pond Final Closure Plan* (HDR, 2022):

- Scenario 1: CIP (consolidation of CCR in the north of the unit with cover system)
- Scenario 2: CBR (CCR is removed)

Scenario 1 (CIP) was predicted to reduce total flux in and out of the Fill Unit (CCR) by approximately 94%, when simulated post-construction heads in the groundwater monitoring wells are predicted to stabilize.

Predictive simulations of pond closure indicate simulated groundwater concentrations in the monitoring well within the two transport zones, namely the UD/PMP and UA, will achieve the GWPS in 20 years and 16 years for the CIP and CBR closure scenarios, respectively. This indicates that both scenarios are predicted to reach the GWPS for the monitoring wells after approximately 20 years. The model predicted four-year time difference when GWPSs are achieved for CIP (20 years post-closure) and CBR (16 years post-closure) is not significant because the estimated duration of construction activities indicates that CBR will take longer to implement than CIP (3.2-4.3 years for CIP compared to 7.8-9.2 years for CBR-Onsite and 22 years for CBR-Offsite; Section 2.1 of the Closure Alternative Analysis [Gradient, 2022]).

The prediction simulations indicate that although the groundwater wells reach the GWPS, sulfate remains within the model beyond 100 years. This is due to the sulfate mass retained within the thick UCU which underlies the PAP. The low vertical hydraulic conductivity of this thick unit leads to low flow rates through the unit which will require time to release the sulfate mass. However, in both the CIP and CBR scenarios, the plume footprint continues to recede with time and remains within the property boundaries indicating these closure options are equally protective.

Results of groundwater fate and transport modeling conservatively estimate that groundwater concentrations will attain the GWPS for all constituents identified as potential exceedances of the GWPS in the UD/PMP and UA monitoring wells within 20 years of closure implementation for both CIP and CBR. Within the property boundary, residual sulfate will be present within the clay confining unit above the GWPS due to the slow release of sulfate from the UCU.

8. REFERENCES

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TABLES

TABLE 2-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft bgs)	Screen Bottom Depth (ft bgs)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft bgs)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
APW02	UD	06/19/2010	533.61	533.61	Top of Riser	529.90	9.70	19.70	520.20	510.20	20.00	509.90	10	2	38.925918	-88.293907
APW03	UD	06/18/2010	532.41	532.41	Top of Riser	528.37	9.70	19.70	518.67	508.67	20.00	508.40	10	2	38.922322	-88.281567
APW04	UD	06/19/2010	525.06	525.06	Top of Riser	521.45	7.70	17.70	513.75	503.75	18.00	503.50	10	2	38.927444	-88.273113
APW05	UA	10/22/2015	544.07	544.07	Top of Riser	541.08	62.64	67.44	478.44	473.64	67.84	473.10	4.8	2	38.933958	-88.280983
APW05S	UD	01/19/2021	543.94	543.94	Top of PVC	541.05	10.00	20.00	531.05	521.05	20.00	518.10	10	2	38.933958	-88.281033
APW06	UA	10/21/2015	546.07	546.07	Top of Riser	542.89	67.67	72.48	475.22	470.41	72.88	468.90	4.8	2	38.933746	-88.286276
APW07	UA	11/05/2015	538.37	538.37	Top of Riser	535.72	77.89	82.70	457.83	453.02	83.10	452.60	4.8	2	38.928233	-88.292076
APW08	UA	10/28/2015	528.97	528.97	Top of Riser	526.26	71.40	81.06	454.86	445.20	81.53	444.30	9.7	2	38.923154	-88.292286
APW09	UA	11/03/2015	531.52	531.52	Top of Riser	528.33	56.66	61.46	471.67	466.87	61.85	466.30	4.8	2	38.922319	-88.281585
APW10	UA	11/06/2015	524.25	524.25	Top of Riser	521.49	40.74	45.54	480.75	475.95	45.94	475.60	4.8	2	38.927435	-88.273127
APW11	UA	01/23/2021	538.63	538.63	Top of PVC	536.05	60.00	65.00	476.05	471.05	65.00	436.10	5	2	38.932811	-88.27545
APW12	UD	02/21/2021	546.29	546.29	Top of PVC	543.33	20.00	30.00	523.33	513.33	30.00	456.30	10	2	38.92975	-88.272058
APW13	UA	01/22/2021	537.99	537.99	Top of PVC	535.16	58.50	63.50	476.66	471.66	63.50	445.20	5	2	38.92566	-88.274416
APW14	UA	01/23/2021	526.29	526.29	Top of PVC	523.85	50.00	55.00	473.85	468.85	55.00	428.90	5	2	38.924057	-88.277994
APW15	UA	01/22/2021	524.69	524.69	Top of PVC	522.06	98.00	103.00	424.06	419.06	103.00	412.10	5	2	38.921593	-88.285226
APW16	UA	01/20/2021	531.18	531.18	Top of PVC	529.16	80.50	85.50	448.66	443.66	85.50	419.20	5	2	38.920317	-88.291291
APW17	UA	01/22/2021	532.52	532.52	Top of PVC	529.84	87.00	92.00	442.84	437.84	92.00	429.80	5	2	38.925916	-88.293928
APW18	UA	01/21/2021	543.27	543.27	Top of PVC	540.55	75.00	80.00	465.55	460.55	80.00	433.60	5	2	38.930979	-88.290122
G48MG	UA	10/20/2015	545.53	545.53	Top of Riser	542.68	71.80	76.65	470.88	466.03	77.06	465.60	4.9	2	38.939248	-88.296012
G202	UA	10/16/1996	539.69	539.69	Top of Riser	536.85	64.00	74.00	472.85	462.85	74.00	462.90	10	2	38.930876	-88.290559
G203	UA	11/15/1996	533.13	533.13	Top of Riser	530.73	62.50	72.50	468.23	458.23	72.50	458.20	10	2	38.928597	-88.292217
G208	UA	10/13/2011	535.03	535.03	Top of Riser	533.19	74.93	94.71	458.26	438.48	94.80	438.20	19.8	2	38.929632	-88.298182
G217S	UD	08/26/1997	537.98	537.98	Top of Riser	535.54	9.00	19.00	526.54	516.54	19.00	510.50	10	2	38.932171	-88.290041

TABLE 2-1. MONITORING WELL LOCATIONS AND CONSTRUCTION DETAILS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Well Number	HSU	Date Constructed	Top of PVC Elevation (ft)	Measuring Point Elevation (ft)	Measuring Point Description	Ground Elevation (ft)	Screen Top Depth (ft bgs)	Screen Bottom Depth (ft bgs)	Screen Top Elevation (ft)	Screen Bottom Elevation (ft)	Well Depth (ft bgs)	Bottom of Boring Elevation (ft)	Screen Length (ft)	Screen Diameter (inches)	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
G217D	UA	12/09/2014	537.92	537.92	Top of Riser	535.51	--	--	--	--	69.30	--	--	--	38.932174	-88.29008
G222	UA	10/25/2011	534.32	534.32	Top of Riser	532.38	64.57	79.24	467.81	453.14	79.30	452.40	14.7	2	38.927194	-88.299669
G223	UA	10/11/2011	533.60	533.60	Top of Riser	531.68	79.09	88.75	452.59	442.93	89.10	442.60	9.7	2	38.93016	-88.293451
G224	UA	10/05/2011	534.31	534.31	Top of Riser	532.31	63.51	73.17	468.80	459.14	73.50	458.30	9.7	2	38.931767	-88.292396
R202	UA	--	--	--	--	--	--	--	--	--	--	--	--	--	38.930879	-88.290581
R217D	UA	09/26/2017	538.18	538.18	Top of Riser	535.60	60.10	65.03	475.50	470.57	65.24	470.40	4.9	2	38.932191	-88.290118
XPW01	CCR	01/20/2021	551.76	551.76	Top of PVC	548.62	7.00	17.00	541.62	531.62	17.00	528.60	10	2	38.932212	-88.285525
XPW02	CCR	01/19/2021	554.43	554.43	Top of PVC	551.97	6.00	16.00	545.97	535.97	16.00	532.00	10	2	38.932343	-88.28289
XPW03	CCR	01/19/2021	553.65	553.65	Top of PVC	550.81	10.00	20.00	540.81	530.81	20.00	530.80	10	2	38.931062	-88.27641
XPW04	CCR	01/19/2021	554.51	554.51	Top of PVC	551.90	10.00	20.00	541.90	531.90	20.00	531.90	10	2	38.929888	-88.274073
XSG01	CCR	--	--	536.17	Staff gauge	--	--	--	--	--	--	--	--	--	38.923218	-88.29067
SG02	SW	--	--	506.89	Staff gauge	--	--	--	--	--	--	--	--	--	38.921234	-88.292057

Notes:
All elevation data are presented relative to the North American Vertical Datum 1988 (NAVD88), GEOID 12A
-- = data not available
bgs = below ground surface
CCR = coal combustion residuals
ft = foot or feet
HSU = Hydrostratigraphic Unit
PVC = polyvinyl chloride
SW = surface water
UA = uppermost aquifer
UD = upper drift

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TABLE 2-2. FLOW AND TRANSPORT MODEL CALIBRATION TARGETS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

				Flow Targets								Transport Targets						
Well Name	Easting	Northing	HSU	Number of Samples	median GWL[1] (ft)	mean GWL[1] (ft)	std GWL[1] (ft)	min GWL[1] (ft)	max GWL[1] (ft)	Earliest Sample Date	Latest Sample Date	Number of Samples	mean Sulfate (mg/L)	std Sulfate (mg/L)	min Sulfate (mg/L)	max Sulfate (mg/L)	Earliest Sample Date	Latest Sample Date
APW02	995466.245	822683.473	UD	34	528.6	528.6	1.0	524.9	530.4	10/07/2015	08/02/2021	8	2913	579	1500	3200	01/13/2015	07/15/2021
APW03	998977.669	821375.539	UD	33	524.4	524.7	1.5	520.8	528.2	10/07/2015	08/02/2021	8	174	9	160	190	01/13/2015	07/15/2021
APW04	1001381.684	823242.504	UD	33	520.1	520.0	0.7	518.2	521.1	10/07/2015	08/02/2021	8	933	43	860	990	01/13/2015	07/15/2021
APW05	999141.384	825613.581	UA	37	529.5	529.5	0.5	528.0	530.8	12/14/2015	08/02/2021	25	3	4	1	15	12/15/2015	07/15/2021
APW05S	999127.161	825613.573	UD	15	533.6	533.1	0.8	531.7	534.4	02/04/2021	07/15/2021	7	1563	794	200	2100	02/17/2021	07/15/2021
APW06	997635.757	825535.544	UA	36	526.5	526.9	1.1	525.4	530.6	12/14/2015	08/02/2021	25	4	3	1	9.9	12/15/2015	07/15/2021
APW07	995986.774	823526.85	UA	29	492.5	492.8	1.4	491.3	497.6	12/14/2015	08/02/2021	17	12	20	1	66	12/15/2015	02/10/2021
APW08	995927.867	821677.002	UA	29	492.2	492.4	0.9	491.3	494.9	12/14/2015	08/02/2021	17	40	5	30	48	12/15/2015	02/10/2021
APW09	998972.548	821374.443	UA	29	505.1	505.7	1.9	503.4	510.9	12/14/2015	08/02/2021	17	19	22	1	62	12/15/2015	02/11/2021
APW10	1001377.703	823239.224	UA	32	506.6	506.8	0.9	505.1	509.4	12/14/2015	08/02/2021	19	422	34	390	540	12/16/2015	07/29/2021
APW11	1000715.588	825196.787	UA	13	514.1	514.2	0.3	513.9	514.7	02/04/2021	07/15/2021	8	266	52	140	300	02/18/2021	07/15/2021
APW12	1001681.255	824082.573	UD	14	532.0	532.0	0.6	531.3	533.1	02/04/2021	07/15/2021	8	391	65	290	480	02/17/2021	07/15/2021
APW13	1001011.414	822592.511	UA	17	505.8	505.8	0.3	505.2	506.5	02/04/2021	07/15/2021	8	216	7	210	230	02/22/2021	07/15/2021
APW14	999993.839	822008.042	UA	16	505.6	505.5	0.3	504.9	506.3	02/04/2021	07/15/2021	8	325	9	310	340	02/22/2021	07/15/2021
APW15	997936.787	821109.457	UA	15	502.4	501.9	0.9	500.5	502.8	02/04/2021	07/14/2021	8	1	0	1	1	02/23/2021	07/14/2021
APW16	996211.429	820643.869	UA	16	491.4	491.4	0.2	491.1	492.1	02/04/2021	07/15/2021	8	1	0	1	1.9	02/23/2021	07/15/2021
APW17	995460.271	822682.742	UA	16	491.7	491.8	0.3	491.4	492.6	02/04/2021	07/15/2021	8	35	6	25	41	02/23/2021	07/15/2021
APW18	996542.186	824527.23	UA	16	491.9	492.0	0.3	491.7	492.7	02/04/2021	07/15/2021	8	7	9	1	26	02/23/2021	07/15/2021
G48MG	994865.387	827538.141	UA	28	526.4	526.6	0.7	525.5	528.5	12/14/2015	08/02/2021	-	-	-	-	-	-	-
G202	996417.888	824489.657	UA	43	492.8	493.1	1.3	491.6	496.7	04/21/2015	07/14/2021	-	-	-	-	-	-	-
G203	995946.602	823659.404	UA	43	492.8	493.2	1.2	491.0	496.4	04/21/2015	08/02/2021	-	-	-	-	-	-	-
G208	994249.502	824035.648	UA	46	509.5	510.1	2.5	504.9	516.0	04/21/2015	08/02/2021	-	-	-	-	-	-	-
G217S	996565.022	824961.379	UD	30	531.5	531.8	1.4	528.6	535.4	04/21/2015	08/02/2021	-	-	-	-	-	-	-
G223	995595.297	824228.508	UA	47	500.4	500.4	1.2	495.6	504.2	04/21/2015	08/02/2021	-	-	-	-	-	-	-
G224	995895.159	824813.927	UA	47	492.7	492.4	1.4	486.5	495.0	04/21/2015	08/02/2021	-	-	-	-	-	-	-
R202	996411.629	824490.747	UA	2	493.1	493.1	0.2	492.9	493.3	05/21/2020	02/08/2021	-	-	-	-	-	-	-
XPW01	997849.684	824976.957	CCR	11	539.6	539.6	0.2	539.3	539.9	02/15/2021	07/14/2021	5	15000	3807.9	11000	19000	02/17/2021	07/14/2021
XPW02	998599.238	825025.074	CCR	12	545.9	545.9	0.6	544.9	546.7	02/04/2021	07/14/2021	5	164	15.2	150	190	02/17/2021	07/14/2021
XPW03	1000442.897	824559.611	CCR	12	544.1	543.9	0.4	543.3	544.4	02/04/2021	07/14/2021	5	99	11.8	92	120	02/17/2021	07/14/2021
XPW04	1001107.994	824132.454	CCR	11	542.2	542.1	0.2	541.8	542.5	02/04/2021	07/14/2021	5	1920	1196.7	600	3800	02/17/2021	07/14/2021

Notes:
[1] Groundwater Elevation (feet)
GWL = groundwater elevation
ft = feet
std = standard deviation from the mean
min = minimum
max = maximum

HSU: Hydrostratigraphic Unit
CCR = coal combustion residual
UD/PMP = upper drift/potential migration pathway
UA = uppermost aquifer

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TABLE 5-1. FLOW MODEL INPUT AND SENSITIVITY ANALYSIS RESULTS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Zone	Hydrostratigraphic Unit	Materials	ft/d	cm/s	Kh/Kv	Value Source	Sensitivity[1]
Horizontal Hydraulic Conductivity			**Calibration Model**				
1	UD	clay and silt	0.41	1.45E-04	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	High
2	UD -Fill (abover riv/drn)	NA	7	2.47E-03	NA	Calibrated - Conductivity Value to Allow Groundwater Flow from UD to Riverand Drain Boundary Conditions	Low
3	CCR	CCR	17.6	6.21E-03	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Moderate
4	UD-PMP	clay and silt	1.5	5.29E-04	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Low
5	UD-PMP Sand	mixed alluvial deposits in the vicinity of the PAP	28	9.88E-03	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	High
6	UCU	lean clay/Cahokia alluvium	0.001	3.53E-07	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Low
7	UA	clay and silt	3	1.06E-03	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	High
8	UA-Sand	sand	3	1.06E-03	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Moderately High
9	UA-Gravel	gravel	50	1.76E-02	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	High
10	LCU	lean clay	0.001	3.53E-07	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Low
11	UCU-cahokia	alluvial deposits	0.001	3.53E-07	NA	Calibrated - Within Range of Field Test Results (Ramboll, 2021a)	Low
Vertical Hydraulic Conductivity			**Calibration Model**				
1	UD	clay and silt	0.0041	1.45E-06	100	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	High
2	UD -Fill (abover riv/drn)	NA	7	2.47E-03	1	Calibrated - Conductivity Value to Allow Groundwater Flow from UD to Riverand Drain Boundary Conditions	Low
3	CCR	CCR	0.2750	9.70E-05	64	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Low
4	UD-PMP	clay and silt	0.0150	5.29E-06	100	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Low
5	UD-PMP Sand	mixed alluvial deposits in the vicinity of the PAP	0.2800	9.88E-05	100	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Moderate
6	UCU	lean clay/Cahokia alluvium	0.0001	3.53E-08	10	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	High
7	UA	clay and silt	0.0010	3.53E-07	10	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Moderately High
8	UA-Sand	sand	0.1000	3.53E-05	21	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Moderately High
9	UA-Gravel	gravel	0.1000	3.53E-05	208	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Moderate
10	LCU	lean clay	0.0001	3.53E-08	10	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	Low
11	UCU-cahokia	alluvial deposits	0.0001	3.53E-08	10	Calibrated - Within Range Laboratory Test Results and near Geomean of Laboratory Test Results (Ramboll, 2021a)	High

TABLE 5-1. FLOW MODEL INPUT AND SENSITIVITY ANALYSIS RESULTS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Zone	Hydrostratigraphic Unit	Materials	ft/d	cm/s	Kh/Kv	Value Source	Sensitivity[1]
Recharge			**Calibration Model**				
1	UD	clay and silt	1.15E-04	0.50	NA	Calibrated	Moderate
2	Fill Unit - PAP	CCR	1.80E-03	7.88	NA	Calibrated	High
3	Fill Unit - Newton Phase II North Landfill	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
4	Fill Unit - Newton Phase II West Landfill	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
5	Fill Unit - Secondary Pond	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
6	Fill Unit - PAP pond north	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
7	Fill Unit - North Pond	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
8	Fill Unit - South Pond	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
9	Fill Unit - Cooling Pond	CCR	8.00E-05	0.35	NA	Calibrated	Negligible
10	NPP	Power Plant footprint	1.00E-05	0.04	NA	Calibrated	Negligible
Storage			**Calibration Model**				
1	UD	clay and silt	*Not used in steady-state calibration model*				
2	UD -Fill (abover riv/drn)	NA					
3	CCR	CCR					
4	UD-PMP	clay and silt					
5	UD-PMP Sand	mixed alluvial deposits in the vicinity of the PAP					
6	UCU	lean clay/Cahokia alluvium					
7	UA	clay and silt					
8	UA-Sand	sand					
9	UA-Gravel	gravel					
10	LCU	lean clay					

River Parameters	Relative Location	River Width (feet)	River depth (feet)	Bed Thickness (feet)	Hydraulic Conductivity (ft/d)	Head (feet)	River Boundary Conductance (ft^2/d)
Reach 0	Cooling Flume-0	varaible	5	1	0.9	535.98	5
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 1	Cooling Flume-1	varaible	5	1	0.9	520.66	5
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 2	Cooling Flume-2	varaible	5	1	0.9	504.60	5
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 3	Sandy Creek	10	6	1	7.5	530.0-504.6	2500
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Value Source	NA	Calibrated	Calibrated	Calibrated	Calibrated	Estimated based on DEM	Calibrated

TABLE 5-1. FLOW MODEL INPUT AND SENSITIVITY ANALYSIS RESULTS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Drain Parameters	Name	Drain Width (feet)	Drain depth (feet)	Bed Thickness (feet)	Hydraulic Conductivity (ft/d)	Stage (feet)	Drain Conductance (ft^2/d)
Reach 1	Sandy Creek Trib 1	5	3	1	7.5	525.6-548.9	36.8-5161
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 2	Sandy Creek Trib 2	5	3	1	7.5	524.2-548	16.6-4541
Sensitivity[1]		- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 3	Sandy Creek Trib 3A	5	3	1	7.5	521-544	129-3988
Sensitivity[1]		- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 4	Sandy Creek Trib 3B	5	3	1	7.5	516-521	2.5-4037.2
Sensitivity[1]		- - -	- - -	- - -	- - -	Low	Negligible
Reach 5	Landfill Stream	5	3	1	7.5	508.6-511	8.7-1153.3
Sensitivity[1]		- - -	- - -	- - -	- - -	Low	Negligible
Reach 6	Landfill Drain	5	3	1	7.5	511-525.9	58.3-769.4
Sensitivity[1]		- - -	- - -	- - -	- - -	Moderate	Low
Reach 7	PAP Stream	5	3	1	7.5	508.6-530	3.3-1325.3
Sensitivity[1]		- - -	- - -	- - -	- - -	Low	Low
Reach 8	Newton Lake Trib 1	5	3	1	7.5	508.6-548	24.7-2282.3
Sensitivity[1]		- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 9	Newton Lake Trib 2	5	3	1	7.5	508.6-537	5.1-1196.7
Sensitivity[1]		- - -	- - -	- - -	---	Negligible	Negligible
Reach 10	Newton Lake Trib 3	5	3	1	7.5	508.6-529.8	54.8-1982.7
Sensitivity[1]		- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 11	Newton Lake Trib 4	5	3	1	7.5	508.6-518	101.98-2895
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 12	Newton Lake Trib 5	5	3	1	7.5	5086.-527.3	20.3-4147.1
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 13	Newton Lake Trib 6	5	3	1	7.5	508.6-535.5	212.5-5306.7
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 14	Newton Lake Trib 7	5	3	1	7.5	508.6-526.9	196.8-3828.5
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Low	Low
Reach 15	Trib South 1	5	3	1	7.5	523-526.9	515.9-4076.7
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 16	Trib South 2	5	3	1	7.5	514-532	5.6-4441.4
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 17	Trib South 3	5	3	1	7.5	519-528.6	607.0-4191.6
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Negligible
Reach 18	PAP North drain	5	3	1	7.5	517-537.6	1.48-1998.7
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Low	Negligible
Value Source	NA	Calibrated	Calibrated	Calibrated	Calibrated	Estimated based on DEM	Calibrated

TABLE 5-1. FLOW MODEL INPUT AND SENSITIVITY ANALYSIS RESULTS
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

General Head Parameters	Relative Location	Width of General Head Boundary Cell (feet)	Distance to General Head Boundary Head (feet)	Saturated Thickness of Cell (feet)	Hydraulic Conductivity (ft/d)	Head (feet)	General Head Boundary Conductance (ft^2/d)
Reach 0	Northern Model Boundary in UD & PMP	*variable*	1	variable	variable	variable	2.5-18325
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Negligible	Low
Reach 1	Northern Model Boundary in UA	variable	1	variable	3	490	229-935
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	Moderate	Low
Reach 2	Southern Model Boundary in UA (silt,sand,gravel)	variable	14000	variable	3,3,50	460	0.033-3.4
Sensitivity[1]	NA	- - -	- - -	- - -	- - -	High	High
Value Source	NA	Calibrated	Calibrated	Calibrated	Calibrated	Estimated based on Groundwater Elevation Targets in UD-PMP and UA around the PAP	Calibrated

Notes:
[1] Sensitivity Explanation:
Negligible - SSR changed by less than 1%
Low - SSR change between 1% and 10%
Moderate - SSR change between 10% and 50%
Moderately High - SSR change between 50% and 100%
High - SSR change greater than 100%
SSR = sum of squared residuals
- - - = not tested
CCR = coal combustion residuals
cm/s = centimeters per second
ft/d = feet per day
ft^2/day = feet squared per day
in/yr = inches per year
Kh/Kv = anisotropy ratio
NA = not applicable
PAP = Primary Ash Pond

Hydrostratigraphic Unit
UD = upper drift
LCU = lower confining unit
UA = uppermost aquifer
UCU = upper confining unit
PMP = potential migration pathway

TABLE 5-2. TRANSPORT MODEL INPUT VALUES (CALIBRATION)
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Zone	Hydrostratigraphic Unit	Materials	Calibration Model			
			Sulfate Concentration (mg/L)		Value Source	Sensitivity
Initial Concentration						
Entire Domain	NA	NA	0		NA	- - -
Source Concentration (recharge)						
			pre-1985	**post 1985**		
1	UD	clay and silt	0	0	NA	- - -
2	Fill Unit - PAP	CCR	130	130	Sulfate concentration data from XWP02 and XWP03	- - -
3	Fill Unit - Newton Phase II North Landfill	CCR	0	0	NA	- - -
4	Fill Unit - Newton Phase II West Landfill	CCR	0	0	NA	- - -
5	Fill Unit - Secondary Pond	CCR	0	0	NA	- - -
6	Fill Unit - PAP pond north	CCR	0	0	NA	- - -
7	Fill Unit - North Pond	CCR	0	0	NA	- - -
8	Fill Unit - South Pond	CCR	0	0	NA	- - -
9	Fill Unit - Cooling Pond	CCR	0		NA	- - -
10	NPP	NPP	0	0	NA	- - -
11	Fill Unit - PAP	CCR	130	11,000	Sulfate concentration data from XWP01	- - -
12	Fill Unit - PAP	CCR	130	3,000	Sulfate concentration data from XWP04 - calibrated	- - -

Storage, Specific Yield and Effective Porosity			**Calibration Model**				
Zone	**Hydrostratigraphic Unit**	**Materials**	**Storage**	**Specific Yield**	**Effective Porosity**	**Value Source**	**Sensitivity**
1	UD	clay and silt	0.003	0.18	0.18	Ramboll (2021a) HCR	see Table 5-3
2	UD -Fill (abover riv/drn)	NA	0.003	0.5	0.5	Ramboll (2021a) HCR	see Table 5-3
3	CCR	CCR	0.003	0.21	0.21	Ramboll (2021a) HCR	see Table 5-3
4	UD-PMP	clay and silt	0.003	0.18	0.18	Ramboll (2021a) HCR	see Table 5-3
5	UD-PMP Sand	mixed alluvial deposits in the vicinity of the PAP	0.003	0.18	0.18	Ramboll (2021a) HCR	see Table 5-3
6	UCU	lean clay/Cahokia alluvium	0.003	0.15	0.15	Ramboll (2021a) HCR	see Table 5-3
7	UA	clay and silt	0.003	0.11	0.11	Ramboll (2021a) HCR	see Table 5-3
8	UA-Sand	sand	0.003	0.11	0.11	Ramboll (2021a) HCR	see Table 5-3
9	UA-Gravel	gravel	0.003	0.11	0.11	Ramboll (2021a) HCR	see Table 5-3
10	LCU	lean clay	0.003	0.155	0.155	Ramboll (2021a) HCR	see Table 5-3

Dispersivity							
Applicable Region	**Hydrostratigraphic Unit**	**Materials**	**Longitudinal (feet)**	**Transverse (feet)**	**Vertical (feet)**	**Value Source**	**Sensitivity**
Cahokia Alluvium	UCU	alluvial deposits	20	2	0.2	calibrated	see Table 5-3
Entire Domain	NA	NA	1	0.1	0.01	calibrated	- - -

Notes:
[1] The concentrations from the end of the calibrated transport model were imported as initial concentrations for the prediction model runs.
- - - = not tested
CCR = coal combustion residuals
mg/L = milligrams per liter
NA = not applicable
PAP = Primary Ash Pond

Hydrostratigraphic Unit
UD = upper drift
LCU = lower confining unit
UA = uppermost aquifer
UCU = upper confining unit
PMP = potential migration pathway

TABLE 5-3. TRANSPORT MODEL INPUT SENSITIVITY (CALIBRATION)
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

		Storage and Specific Yield				Effective Porosity				Dispersivity			
Well ID	**Calibration on Concentration (mg/L)**	**Concentration (mg/L)**	**Sensitivity [1]**	**Concentration (mg/L)**	**Sensitivity [1]**	**Concentration (mg/L)**	**Sensitivity [1]**	**Concentration (mg/L)**	**Sensitivity [1]**	**Concentration (mg/L)**	**Sensitivity [1]**	**Concentration (mg/L)**	**Sensitivity [1]**
APW02	3960.7	3960.5	Negligible	3960.8	Negligible	3982.6	Negligible	3947.1	Negligible	3947.1	Negligible	3960.7	Negligible
APW03	128.9	128.9	Negligible	128.9	Negligible	129.1	Negligible	128.7	Negligible	128.7	Negligible	128.7	Negligible
APW04	1676.9	1676.9	Negligible	1677.0	Negligible	1684.9	Negligible	1664.8	Negligible	1664.8	Negligible	1669.8	Negligible
APW05	0.3	0.3	Negligible	0.3	Negligible	0.8	High	0.2	Moderate	0.2	Moderately High	0.3	Negligible
APW05S	116.3	116.4	Negligible	116.3	Negligible	119.5	Low	113.6	Low	113.6	Low	116.3	Negligible
APW06	0.0	0.0	Negligible	0.0	Negligible	0.0	High	0.0	Moderately High	0.0	Moderately High	0.0	Negligible
APW07	15.7	15.7	Negligible	15.7	Negligible	45.5	High	6.9	Moderately High	6.9	Moderately High	15.7	Negligible
APW08	9.9	9.9	Negligible	9.9	Negligible	38.2	High	3.8	Moderately High	3.8	Moderately High	11.7	Moderate
APW09	16.3	16.3	Negligible	16.3	Negligible	54.8	High	7.0	Moderately High	7.0	Moderately High	22.0	Moderate
APW10	340.4	340.3	Negligible	340.3	Negligible	522.1	Moderately High	226.6	Moderate	226.6	Moderate	467.7	Moderate
APW11	2.5	2.5	Negligible	2.5	Negligible	5.8	High	1.2	Moderately High	1.2	Moderately High	2.5	Negligible
APW12	984.8	984.8	Negligible	984.8	Negligible	1205.2	Moderate	733.7	Moderate	733.7	Moderate	954.4	Low
APW13	85.2	85.2	Negligible	85.1	Negligible	150.5	Moderately High	48.8	Moderate	48.8	Moderate	118.5	Moderate
APW14	96.8	96.8	Negligible	96.7	Negligible	165.0	Moderately High	57.1	Moderate	57.1	Moderate	131.5	Moderate
APW15	9.0	9.0	Negligible	9.0	Negligible	37.9	High	2.0	Moderately High	2.0	Moderately High	11.6	Moderate
APW16	1.8	1.8	Negligible	1.8	Negligible	7.7	High	0.8	Moderately High	0.8	Moderately High	2.8	Moderately High
APW17	15.9	15.9	Negligible	15.9	Negligible	51.7	High	6.2	Moderately High	6.2	Moderately High	15.9	Negligible
APW18	87.6	87.6	Negligible	87.6	Negligible	209.9	High	41.0	Moderately High	41.0	Moderately High	87.7	Negligible
		S*0.1 Sy*0.5[2]		S*10 Sy*2[2]		Porosity-0.05		Porosity+0.05		Disp zone 11*0.5		Disp zone 11*1.5	

Notes:
[1] Sensitivity Explanation:
Negligible = concentration changed by less than 1%
Low = concentration change between 1% and 10%
Moderate = concentration change between 10% and 50%
Moderately High = concentration change between 50% and 100%
High = concentration change greater than 100%
[2] sensitivity test used steady state flow and transient transport
ID = identification
mg/L = milligrams per liter
S = storativity
Sy = specific yield
Disp = dispersivity

TABLE 6-1. HELP MODEL INPUT AND OUTPUT VALUES
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Closure Scenario Number (Drainage Length)	Primary and Secondary AP- CBR	Primary and Secondary AP - CIP Removal Area	Primary Ash Pond - CIP Consolidation and Cover System Area	Landfill Consolidation Area 1 and 2	Notes
Input Parameter					
Climate-General					
City	Newton, IL	Newton, IL	Newton, IL	Newton, IL	Nearby city to the Site within HELP database
Latitude	38.93	38.93	38.93	38.93	Site latitude
Evaporative Zone Depth	18	18	18	18	Estimated based on geographic location (Illinois) and uppermost soil type (Tolaymat, T. and Krause, M 2020)
Maximum Leaf Area Index	4.5	4.5	4.5	4.5	Maximum for geographic location (Illinois) (Tolaymat, T. and Krause, M, 2020)
Growing Season Period, Average Wind Speed, and Quarterly Relative Humidity	Terre Haute, IN	Terre Haute, IN	Terre Haute, IN	Terre Haute, IN	Nearby city to the Newton Ash Pond within HELP database
Number of Years for Synthetic Data Generation	30	30	30	30	
Temperature, Evapotranspiration, and Precipitation	Precipitation, temperature, and solar radiation was simulated based on HELP V4 weather simulation for: Lat/Long: 38.93/-88.28	Precipitation, temperature, and solar radiation was simulated based on HELP V4 weather simulation for: Lat/Long: 38.93/-88.28	Precipitation, temperature, and solar radiation was simulated based on HELP V4 weather simulation for: Lat/Long: 38.93/-88.28	Precipitation, temperature, and solar radiation was simulated based on HELP V4 weather simulation for: Lat/Long: 38.93/-88.29	
Soils-General					
% where runoff possible	100	100	100	100	
Area (acres)	413.3	148.3	265	11.7	CBR - Removal Area based on HCR (Ramboll, 2021); CIP - Consolidation and Cover System Area based on construction drawing for Newton Primary and Secondary Ash Pond; CIP -Removal Area equals the difference; Landfill Consolidation Area based on HDR drawings
Specify Initial Moisture Content	No	No	No	No	
Surface Water/Snow	Model Calculated	Model Calculated	Model Calculated	Model Calculated	
Soils-Layers					
1	Unsaturated UD Material (HELP Final Cover Soil)	Unsaturated UD Material (HELP Final Cover Soil)	Vegetative Soil Layer (HELP Final Cover Soil [topmost layer])	Protective Cover Layer (HELP Final Cover Soil [topmost layer])	Layers details for CBR, CIP, and Landfill areas based on grading plans, construction drawings, and cover system design for Newton Ash Pond and Landfill
2			Protective Soil Layer (HELP Vertical Percolation Layer)	Protective Cover Layer (HELP Vertical Percolation Layer)	
3			Geocomposite Drainage Layer(HELP Geosynthetic Drainage Net)	Geocomposite Drainage Layer(HELP Geosynthetic Drainage Net)	
4			Geomembrane Liner	Geomembrane Liner	
5			Unsaturated CCR Material (HELP Waste)	Unsaturated CCR Material (HELP Waste)	
6				Geocomposite Drainage Layer	
7				Geomembrane Liner	
8				Clay Liner	

TABLE 6-1. HELP MODEL INPUT AND OUTPUT VALUES
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Closure Scenario Number (Drainage Length)	Primary and Secondary AP- CBR	Primary and Secondary AP - CIP Removal Area	Primary Ash Pond - CIP Consolidation and Cover System Area	Landfill Consolidation Area 1 and 2	Notes
Soil Parameters--Layer 1					
Type	1	1	1	1	Vertical Percolation Layer (Cover Soil)
Thickness (in)	60	60	6	4	For CBR and CIP removal areas, layer 1 thickness is the average thickness of unsaturated backfill material placed after removal
Texture	43	43	10	10	Defaults used
Description	Silty Clay	Silty Clay	Sandy Clay Loam	Sandy Clay Loam	
Saturated Hydraulic Conductivity (cm/s)	1.45E-06	1.45E-06	1.20E-04	1.20E-04	Hydraulic conductivity supplied by HDR construction plans
Soil Parameters--Layer 2					
Type	--	--	1	1	Vertical Percolation Layer (PAP) and Cover Soil (Landfill)
Thickness (in)	--	--	18	32	design thickness
Texture	--	--	43	43	Custom for Ash Pond - CIP Consolidation and Cover System Area and default for landfill
Description	--	--	Sandy Silty Clay	Sandy Silty Clay	
Saturated Hydraulic Conductivity (cm/s)	--	--	1.00E-05	1.00E-05	Custom for PAP and default for landfill
Soil Parameters--Layer 3					
Type	--	--	2	2	Lateral Drainage Layer
Thickness (in)	--	--	0.2	0.2	design thickness
Texture	--	--	20	20	Defaults used
Description	--	--	Drainage Net (0.5cm)	Drainage Net (0.5cm)	
Saturated Hydraulic Conductivity (cm/s)	--	--	1.00E+01	1.00E+01	Defaults used
Soil Parameters--Layer 4					
Type	--	--	4	4	Flexible Membrane Liner
Thickness (in)	--	--	0.04	0.04	design thickness
Texture	--	--	36	36	Defaults used
Description	--	--	LDPE Membrane	LDPE Membrane	
Saturated Hydraulic Conductivity (cm/s)		--	4.00E -13	4.00E-13	Defaults used
Soil Parameters--Layer 5					
Type	--	--	1	1	Vertical Percolation Layer (Waste)
Thickness (in)	--	--	156	768	design thickness
Texture	--	--	30	30	Defaults used
Description	--	--	High-Density Electric Plant Coal Fly Ash	High-Density Electric Plant Coal Fly Ash	
Saturated Hydraulic Conductivity (cm/s)		--	5.00E-05	5.00E-05	defaults used

TABLE 6-1. HELP MODEL INPUT AND OUTPUT VALUES
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Closure Scenario Number (Drainage Length)	Primary and Secondary AP- CBR	Primary and Secondary AP - CIP Removal Area	Primary Ash Pond - CIP Consolidation and Cover System Area	Landfill Consolidation Area 1 and 2	Notes
Soil Parameters--Layer 6					
Type	--	--	--	2	Drainage Liner
Thickness (in)	--	--	--	12	design thickness
Texture	--	--	--	44	Defaults used
Description	--	--	--	Drainage Layer	
Saturated Hydraulic Conductivity (cm/s)		--	--	1.00E-01	Defaults used
Soil Parameters--Layer 7					
Type	--	--	--	4	Flexible Membrane Liner
Thickness (in)	--	--	--	0.06	design thickness
Texture	--	--	--	35	Defaults used
Description	--	--	--	HDPE Membrane	
Saturated Hydraulic Conductivity (cm/s)		--	--	2.00E-13	Defaults used
Soil Parameters--Layer 8					
Type	--	--	--	3	Drainage Liner
Thickness (in)	--	--	--	36	design thickness
Texture	--	--	--	16	Defaults used
Description	--	--	--	Liiner Soil (High)	
Saturated Hydraulic Conductivity (cm/s)	--	--	--	1.00E-07	Defaults used
Soils--Runoff					
Runoff Curve Number	88.7	88.9	84.4	89.8	HELP-computed curve number
Slope	1.00%	1.00%	2.00%	2.00%	Estimated from construction design drawings
Length (ft)	3600	2300	1500	600	estimated maximum flow path
Vegetation	fair	fair	fair	fair	fai rindicating fair stand of grass on sruface of soil backfill
Execution Parameters					
Years	30	30	30	30	
Report Daily	No	No	No	No	
Report Monthly	No	No	No	No	
Report Annual	Yes	Yes	Yes	Yes	
Output Parameter					
Unsaturated Percolation Rate (in/yr)	**4.38**	**4.29**	**0.042**	**0.000003**	

Notes:
% = percent
ft = feet
HELP = Hydrologic Evaluation of Landfill Performance
in = inches
in/yr = inches per year
Lat = latitude
Long = longitude
CBR = Closure By Removal
CIP = Closure In Place
HCR = Hydrogeologic Characterization Report

References:
Tolaymat, T. and Krause, M, 2020. Hydrologic Evaluation of Landfill Performance: HELP 4.0 User Manual . United States Environmental Protection Agency, Washington, DC, EPA/600/B 20/219.
Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. Hydrogeologic Site Characterization Report. Newton Primary Ash Pond. Newton Power Plant. Newton, Illinois.

TABLE 6-2. PREDICTION MODEL INPUT VALUES
GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Hydrostratigraphic Unit/Recharge Area	Notes	Recharge Zone	Sulfate Concentration (mg/L)	Recharge (ft/day)	Recharge (in/yr)	Constant Concentration Layer	Constant Concentration (mg/L)
Scenario 1: CIP							
Fill Unit - PAP	CCR	2	130	8.90E-06	0.039	2&3	130.0
Fill Unit - PAP	CCR	11	11,000	8.90E-06	0.039	-	-
Fill Unit - PAP	CCR	12	3,000	8.90E-06	0.039	-	-
Removal Area - PAP	FILL	13	0	9.93E-04	4.35	-	
Scenario 2: CBR							
Removal Area - PAP	FILL	2	0	1.00E-03	4.38	-	-
Removal Area - PAP	FILL	11	0	1.00E-03	4.38	-	-
Removal Area - PAP	FILL	12	0	1.00E-03	4.38	-	-

Notes:
CCR = coal combustion residuals
mg/L = milligrams per liter
ft/day = feet per day
in/yr = inches per year
PAP = Primary Ash Pond

FIGURES

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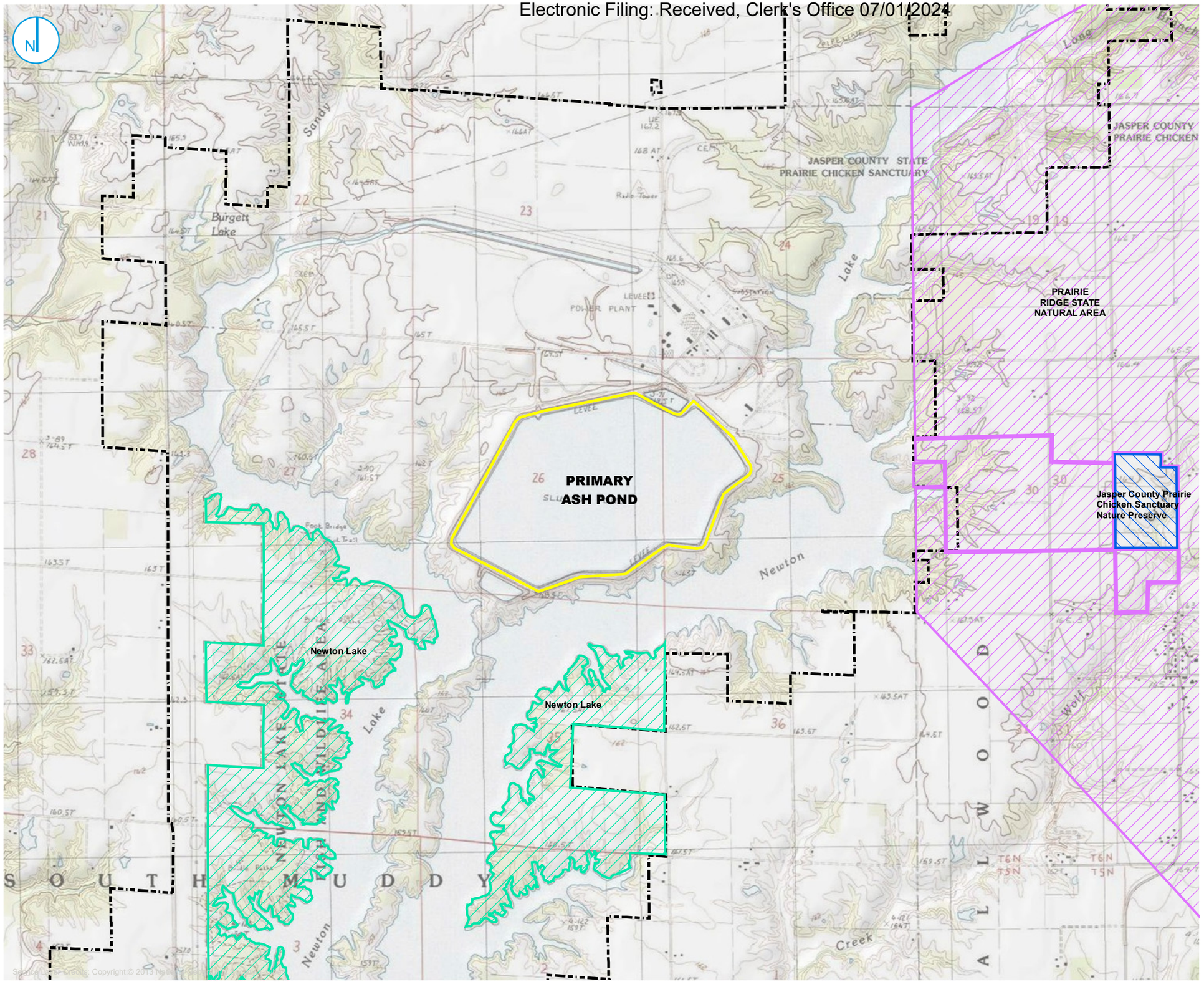

PART 845 REGULATED UNIT FACILITY BOUNDARY
JASPER COUNTY PRAIRIE CHICKEN SANCTUARY NATURE PRESERVE
NEWTON LAKE STATE FISH AND WILDLIFE AREA
PRAIRIE RIDGE STATE NATURAL AREA
PROPERTY BOUNDARY

0 1,000 2,000 Feet

SITE LOCATION MAP

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\2022285\MXD\845_Operating_Permit\Newton\Figure 1-1_Site Location Map.mxd

PROJECT: 1940101010-007 | DATED: 4/11/2022 | DESIGNER: STOLZSD

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PART 845 REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE
PROPERTY BOUNDARY

0 500 1,000
Feet

SITE MAP

GROUNDWATER MODELLING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

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Y:\Mapping\Projects\22\22851\MXD\Model_Figures\Newton\Groundwater_Modelling_Report_2022\Figure 1_Site Map.mxd

PROJECT: 1940101010-007 | DATED: 3/29/2022 | DESIGNER: galarmmc

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- PORE WATER WELL
- MONITORING WELL
- STAFF GAGE, CCR UNIT
- STAFF GAGE, RIVER
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

0 400 800 Feet

MONITORING WELL LOCATION MAP

GROUNDWATER MODELLING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

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PROJECT: 1940101010-007 | DATED: 3/29/2022 | DESIGNER: galarnmc
Y:\Mapping\Projects\22\2285\MXD\Model_Figures\Newton\Groundwater_Modelling_Report_2022\Figure 3_Monitoring Well Location Map.mxd

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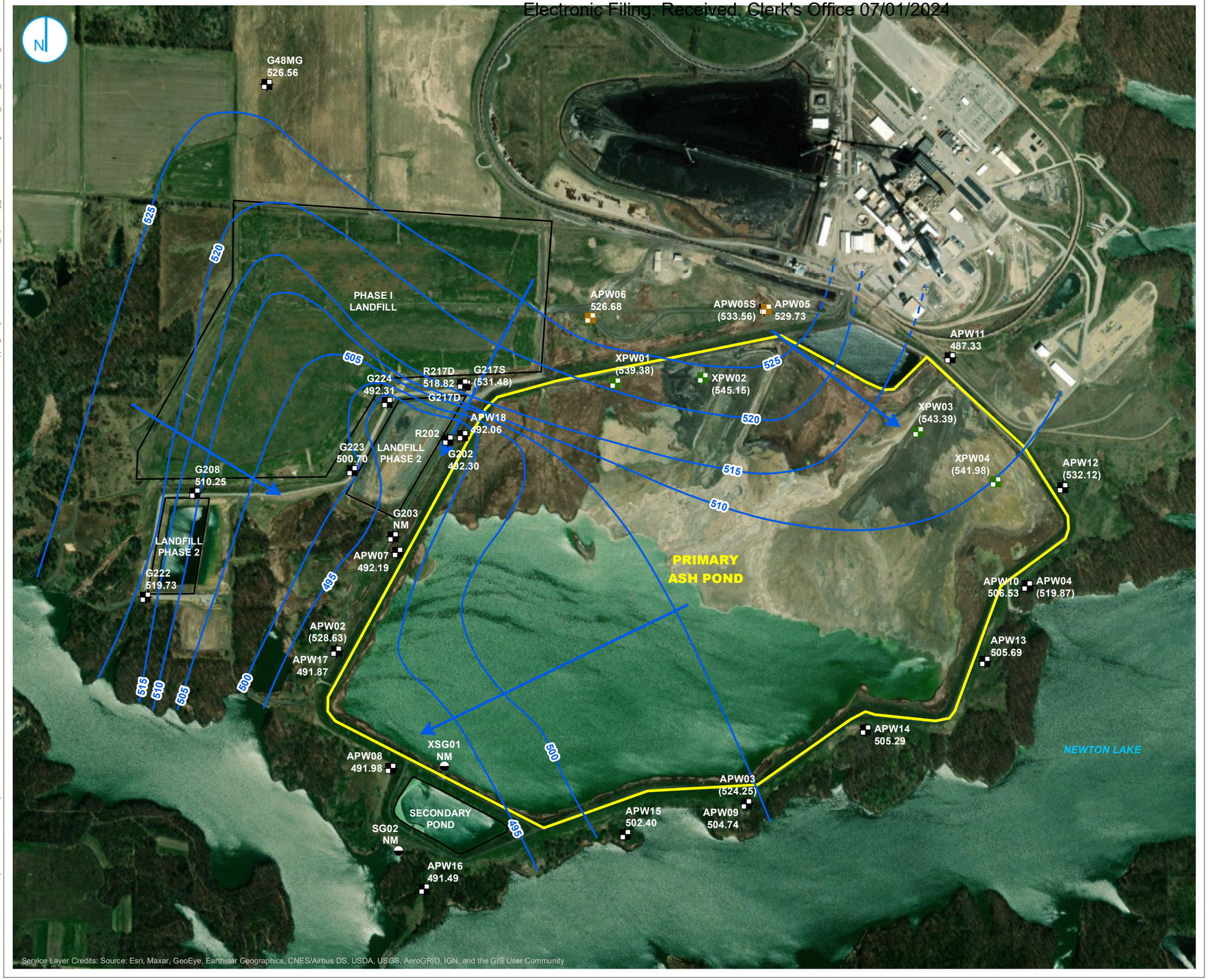

BACKGROUND WELL
MONITORING WELL
SOURCE SAMPLE LOCATION
STAFF GAGE
GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
INFERRED GROUNDWATER ELEVATION CONTOUR
GROUNDWATER FLOW DIRECTION
PART 845 REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE

NOTES:

1.ELEVATIONS IN PARENTHESES WERE NOT USED FOR CONTOURING.
2. NM = NOT MEASURED
3. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

0 400 800
Feet

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS APRIL 27, 2021

GROUNDWATER MODELING REPORT PRIMARY ASH POND

NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-2

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\NewtonFigure 3-3_GWE_Contours_20210427.mxd
PROJECT: 1940101010-007 | DATED: 10/19/2021 | DESIGNER: STOLZSD

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Y:\Mapping\Projects\22\22285\MXD\845_Operating_Permit\NewtonFigure 3-4_GWE_Contours_20210714.mxd



- BACKGROUND WELL
- MONITORING WELL
- SOURCE SAMPLE LOCATION
- STAFF GAGE
- GROUNDWATER ELEVATION CONTOUR (5-FT CONTOUR INTERVAL, NAVD88)
- INFERRED GROUNDWATER ELEVATION CONTOUR
- GROUNDWATER FLOW DIRECTION
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

NOTES:

1.ELEVATIONS IN PARENTHESIS WERE NOT USED FOR CONTOURING.

2. NM = NOT MEASURED

3. ELEVATION CONTOURS SHOWN IN FEET, NORTH AMERICAN VERTICAL DATUM OF 1988

0 400 800
Feet

UPPERMOST AQUIFER GROUNDWATER ELEVATION CONTOURS JULY 14, 2021

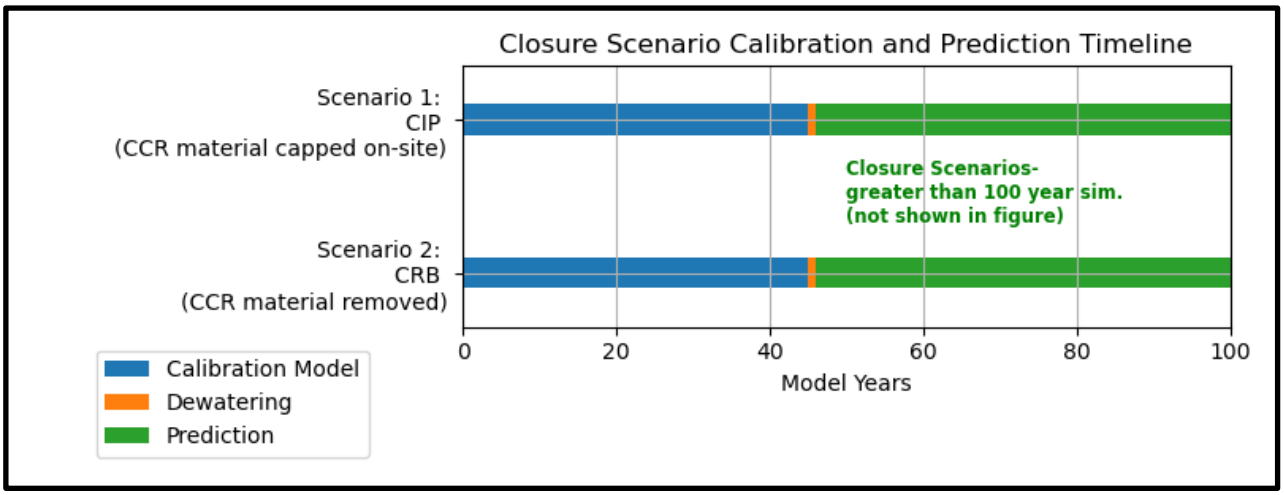
GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 2-3

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

PROJECT: 1940101010-007 | DATED: 10/19/2021 | DESIGNER: STOLZSD



CLOSURE SCENARIO CALIBRATION AND PREDICTION MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTOWN POWER PLANT
NEWTOWN, ILLINOIS

RAMBOLL

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- CCR
- UD
- UA
- RIVER
- LAKE
- COOLING FLUME
- MODEL DOMAIN
- PART 845 REGULATED UNIT (SUBJECT UNIT)
- SITE FEATURE

0 0.25 0.5 Miles

MODEL AREA MAP

GROUNDWATER MODELLING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 5-1

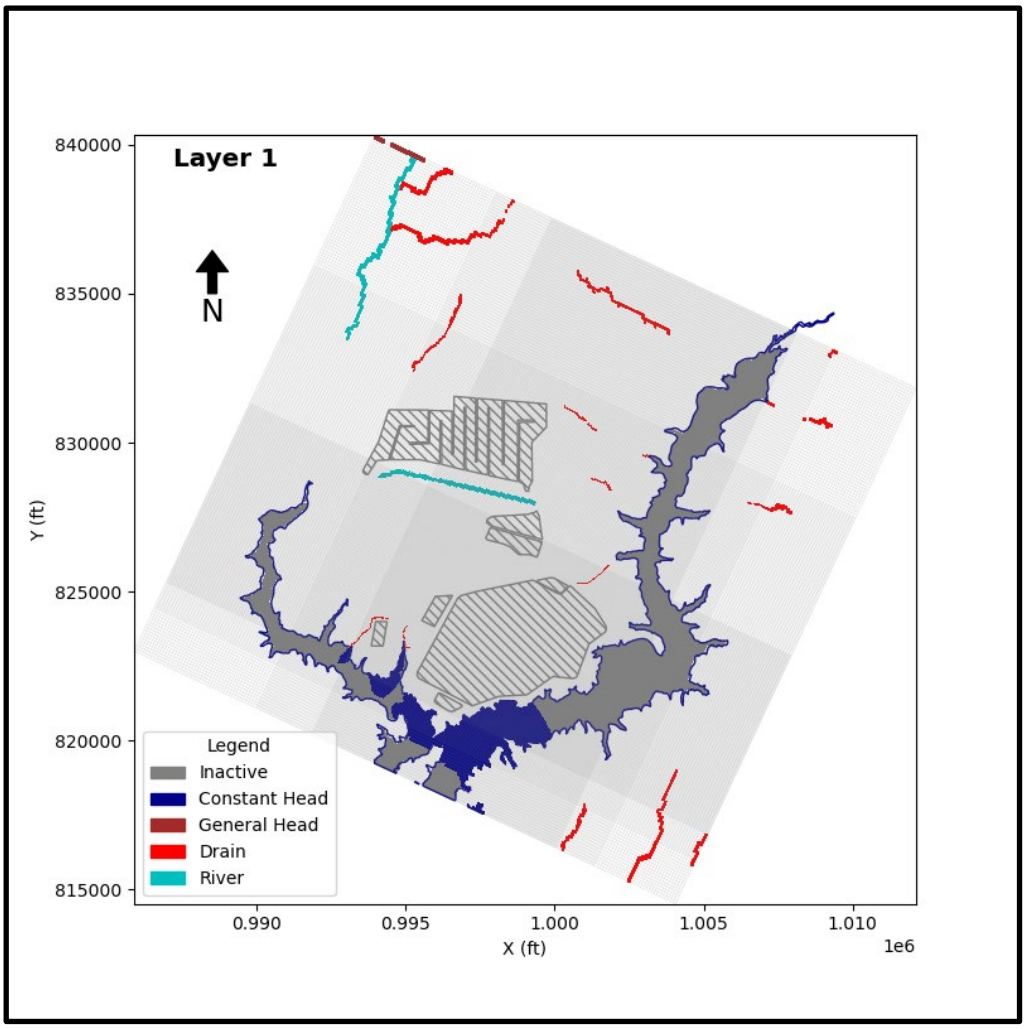
RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\22\22851\MXD\Model_Figures\Newton\Groundwater_Modelling_Report_2022\Figure 4_Model Domain.mxd

PROJECT: 1940101010-007 | DATED: 3/29/2022 | DESIGNER: galammc

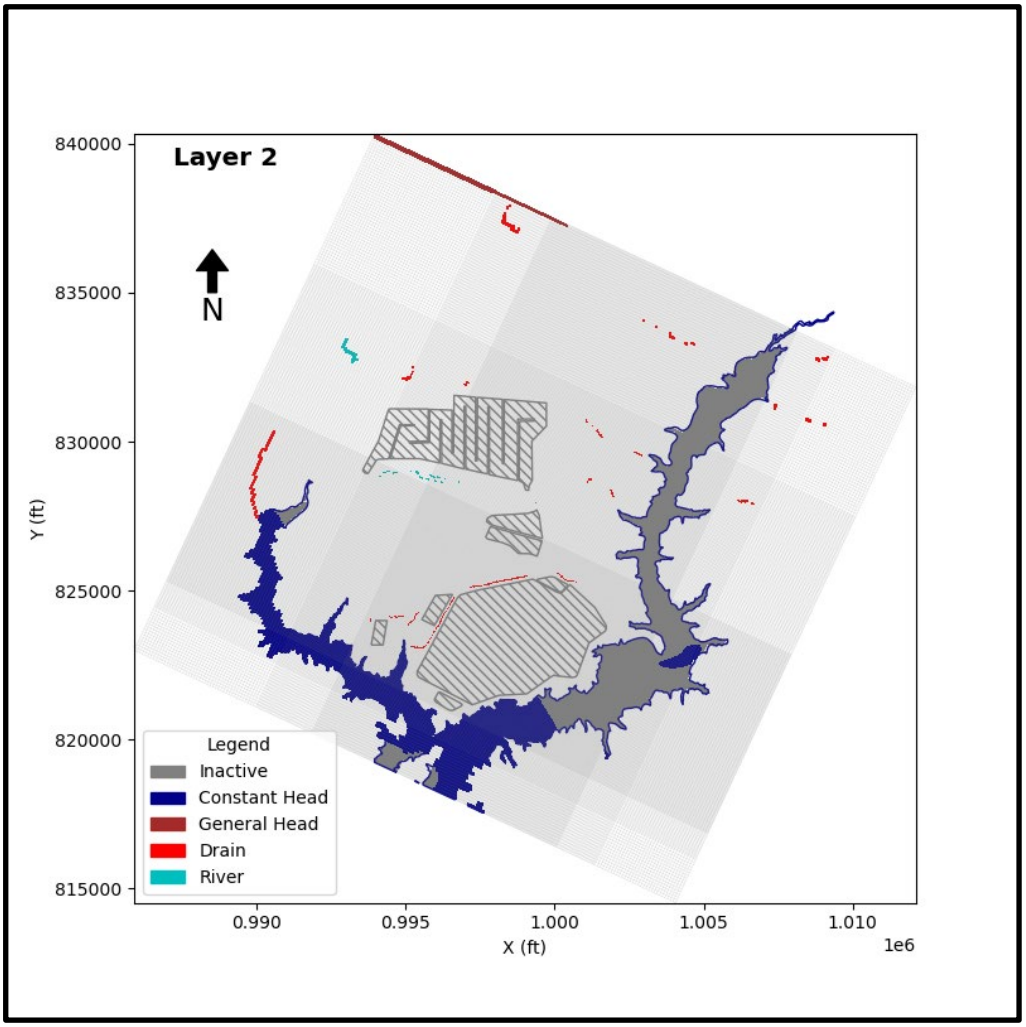
FIGURE 5-2



BOUNDARY CONDITIONS FOR LAYER 1 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

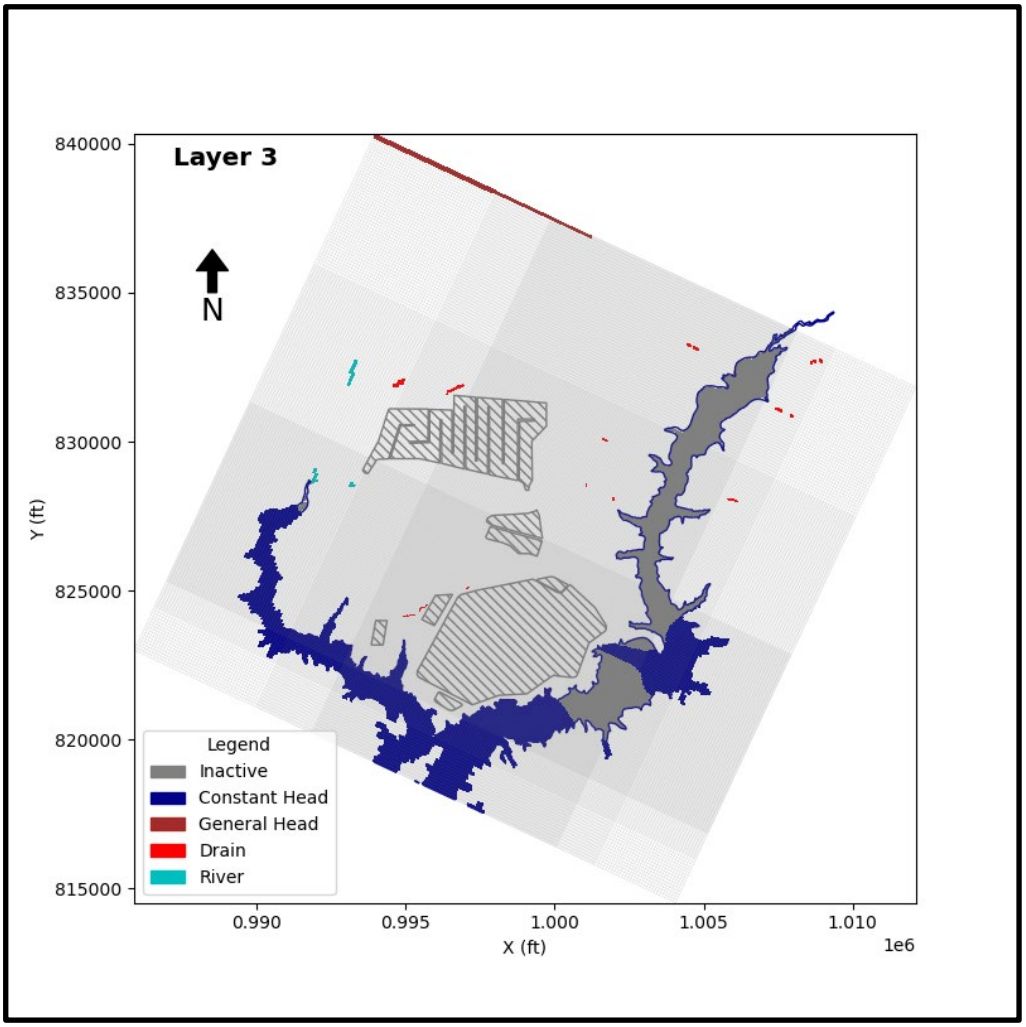


BOUNDARY CONDITIONS FOR LAYER 2 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

FIGURE 5-4

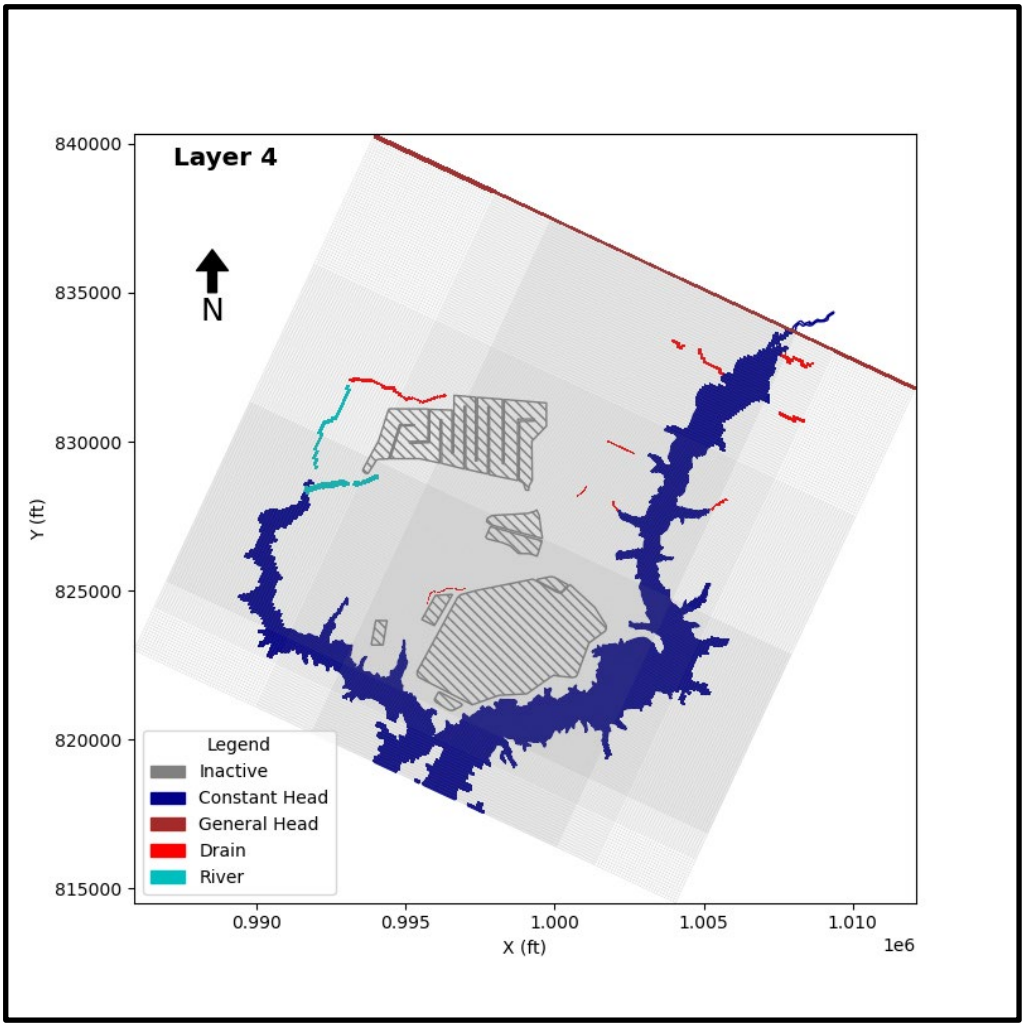


BOUNDARY CONDITIONS FOR LAYER 3 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

FIGURE 5-5

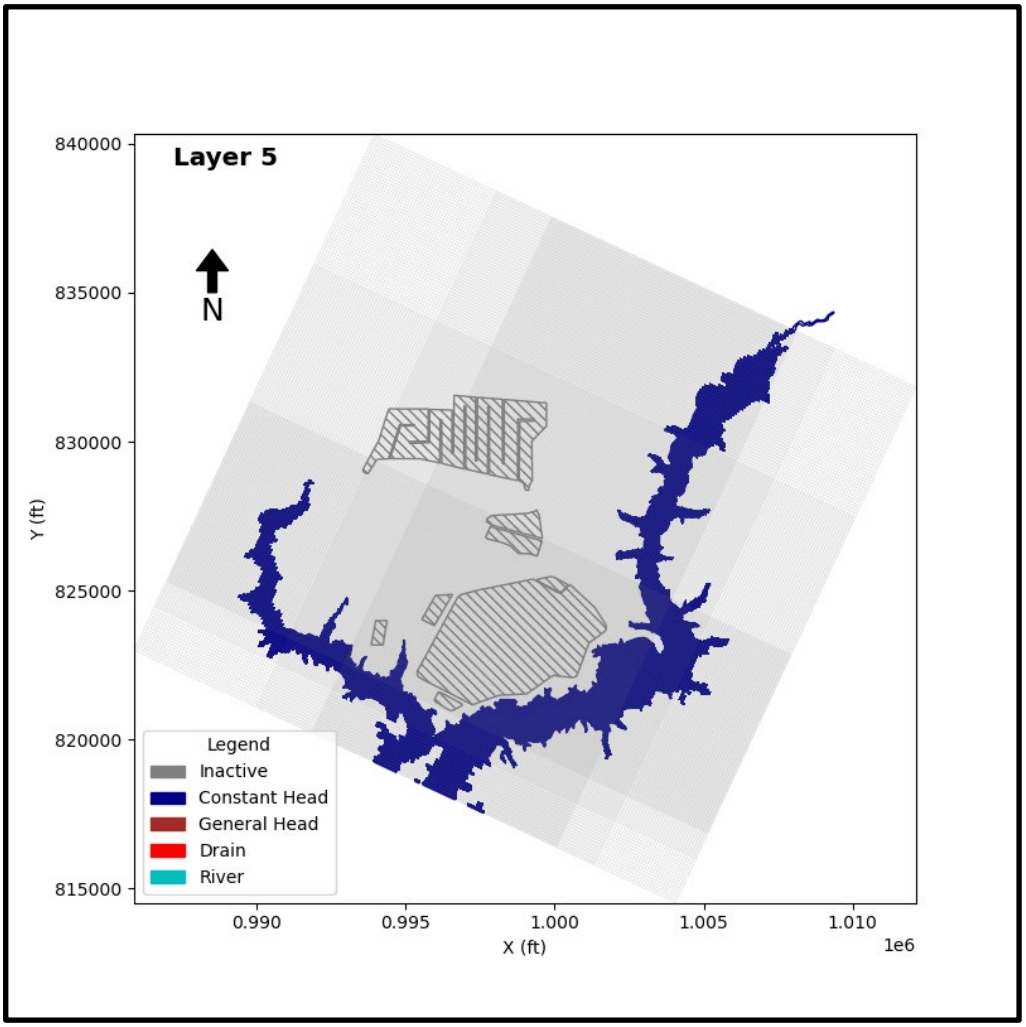


BOUNDARY CONDITIONS FOR LAYER 4 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

FIGURE 5-6

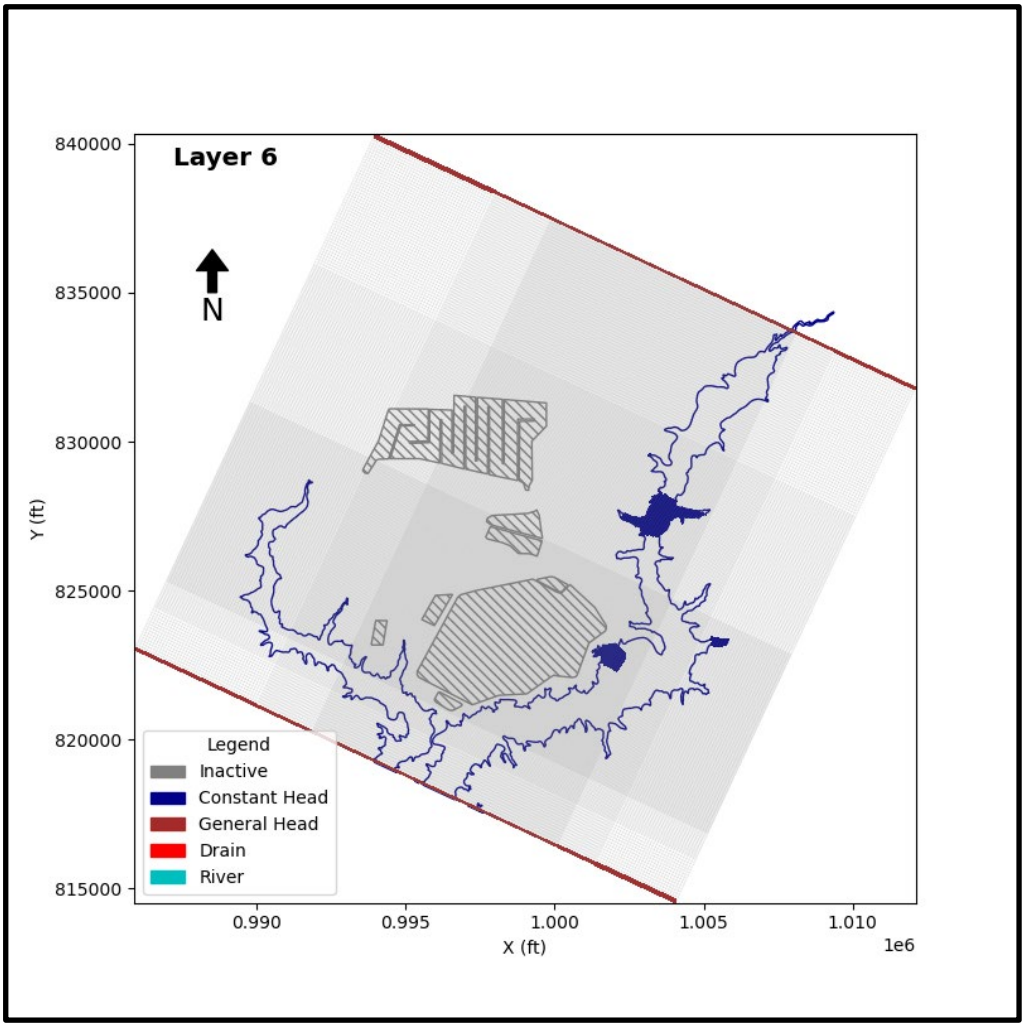


BOUNDARY CONDITIONS FOR LAYER 5 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

FIGURE 5-7

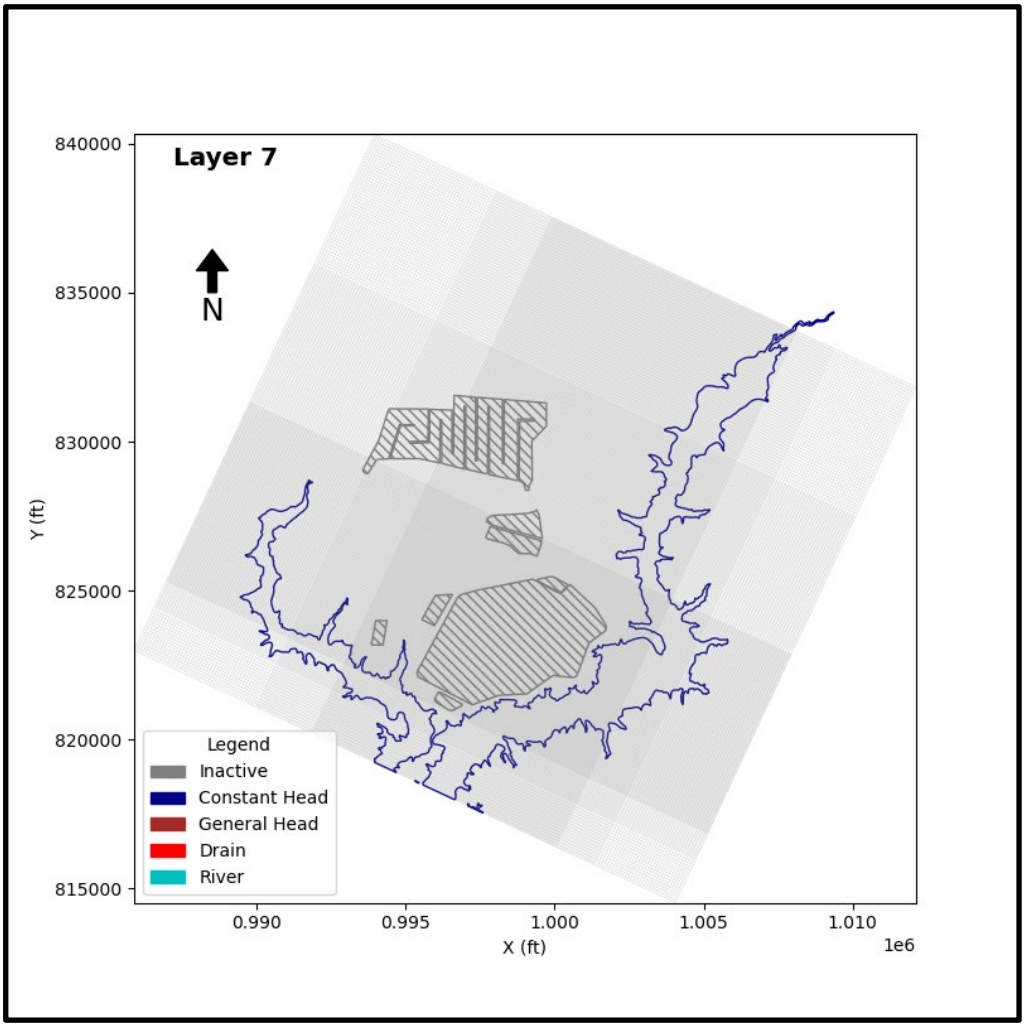


BOUNDARY CONDITIONS FOR LAYER 6 OF THE CALIBRATED NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

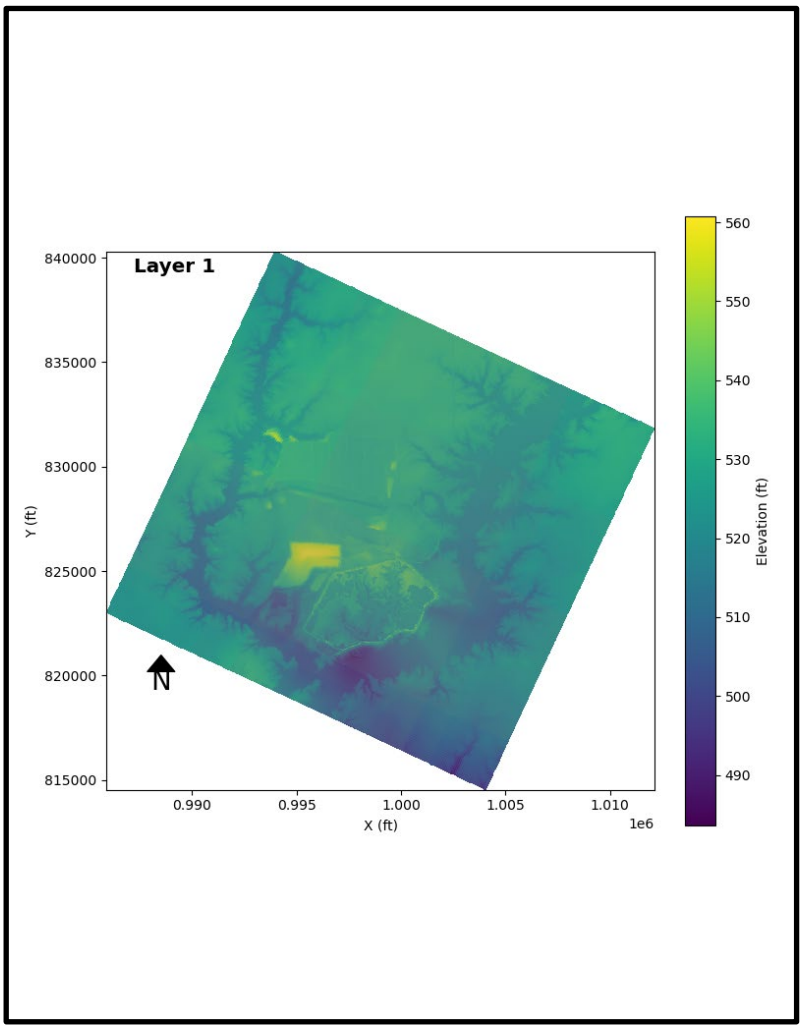
FIGURE 5-8



BOUNDARY CONDITIONS FOR LAYER 7 OF THE CALIBRATED NUMERICAL MODEL

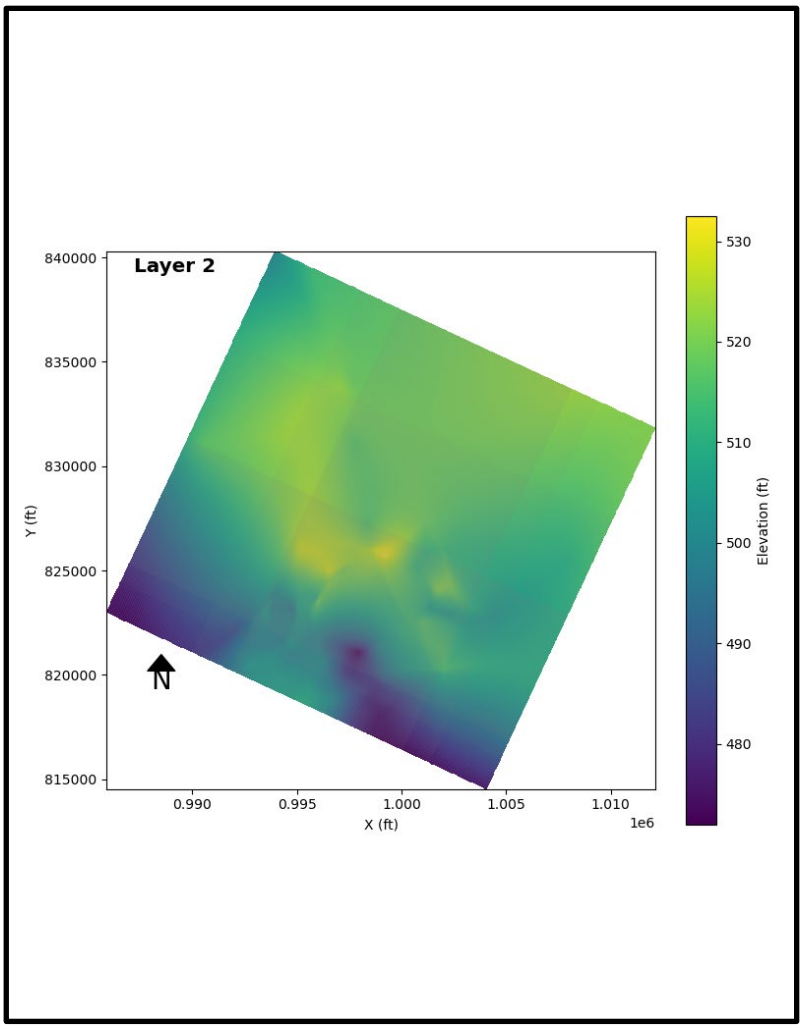
GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



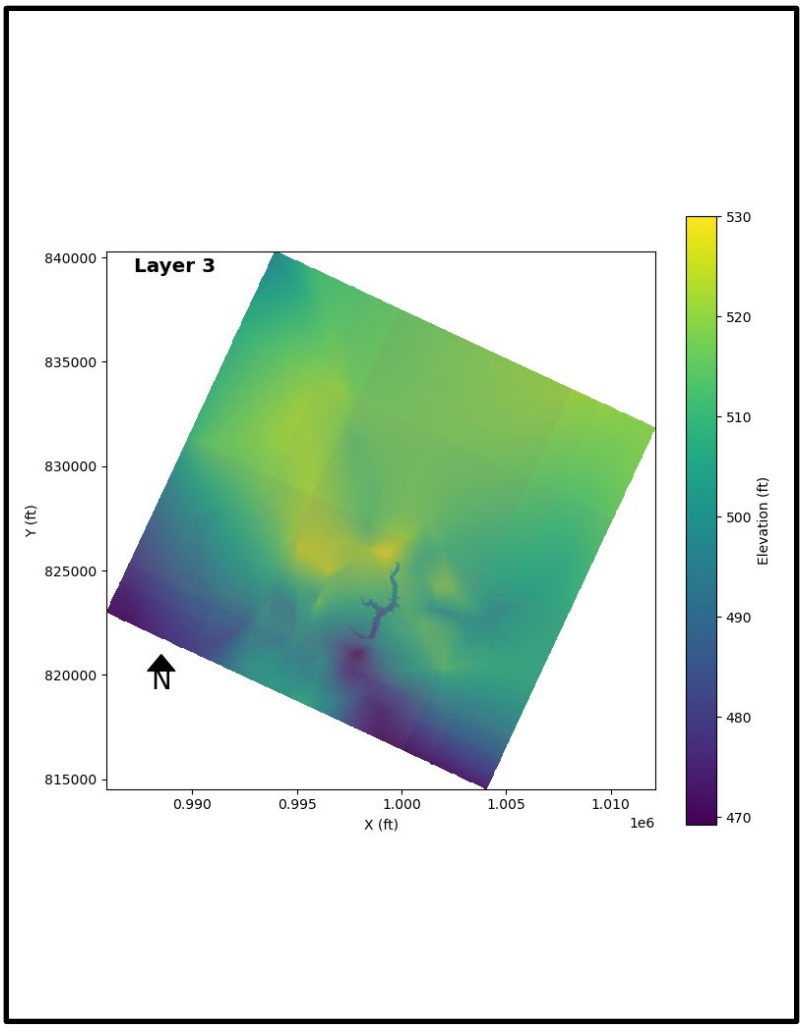
BASE OF MODEL LAYER 1

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



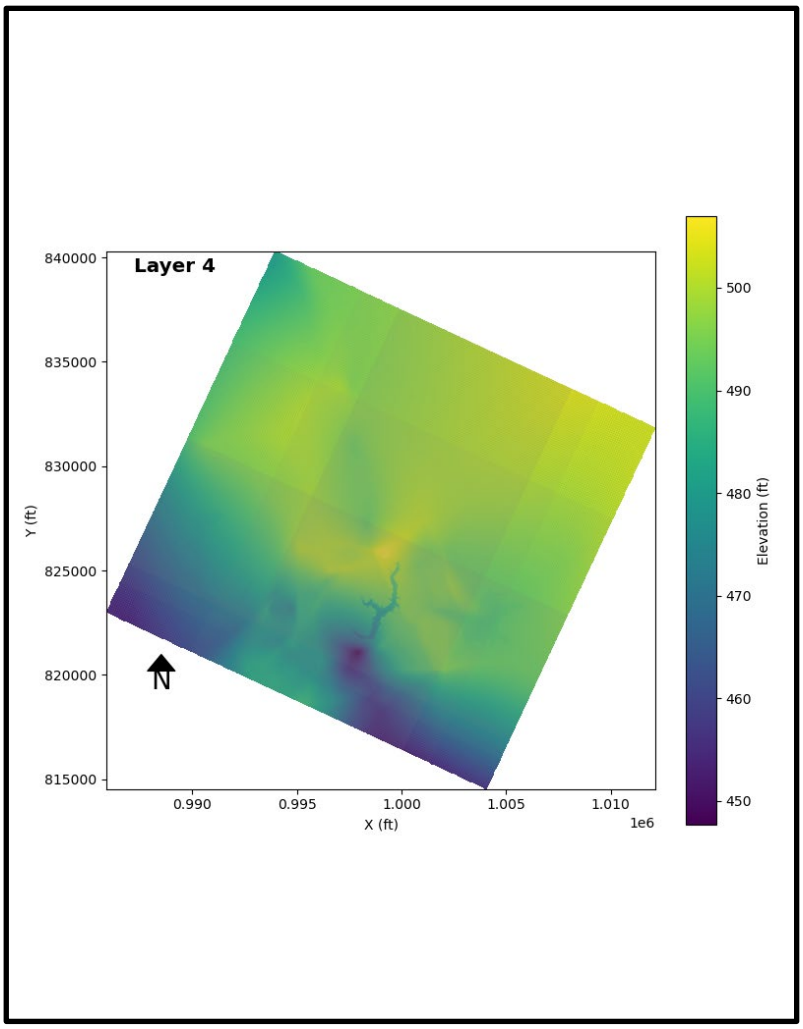
BASE OF MODEL LAYER 2

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



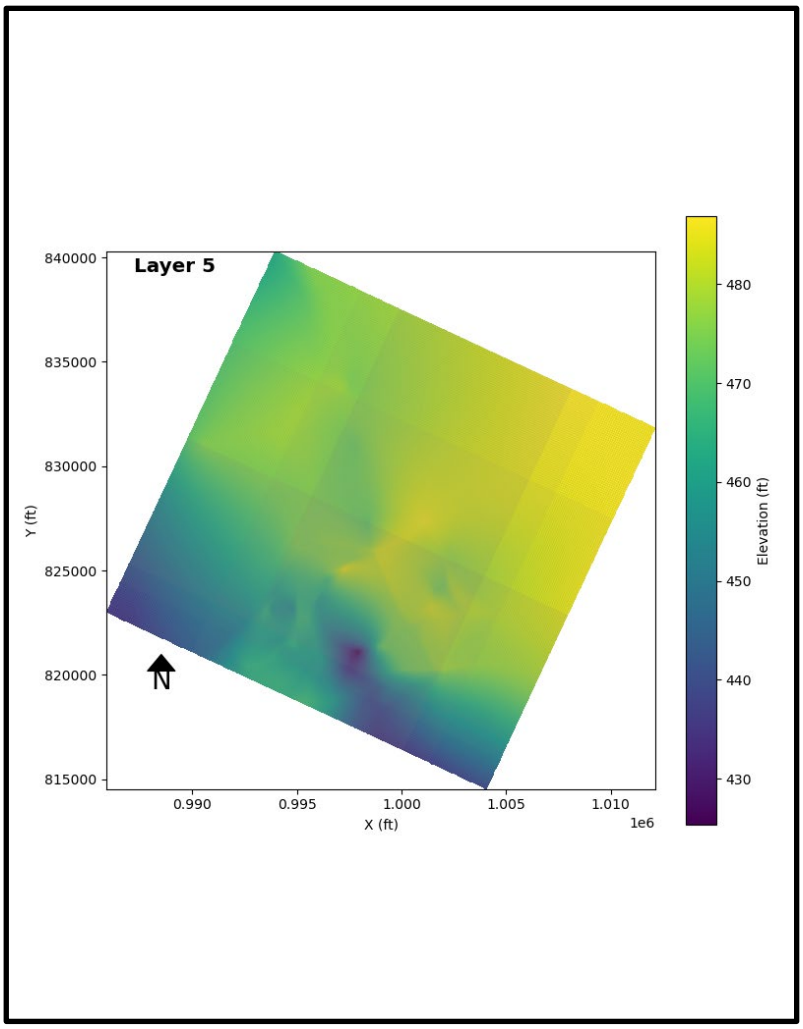
BASE OF MODEL LAYER 3

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



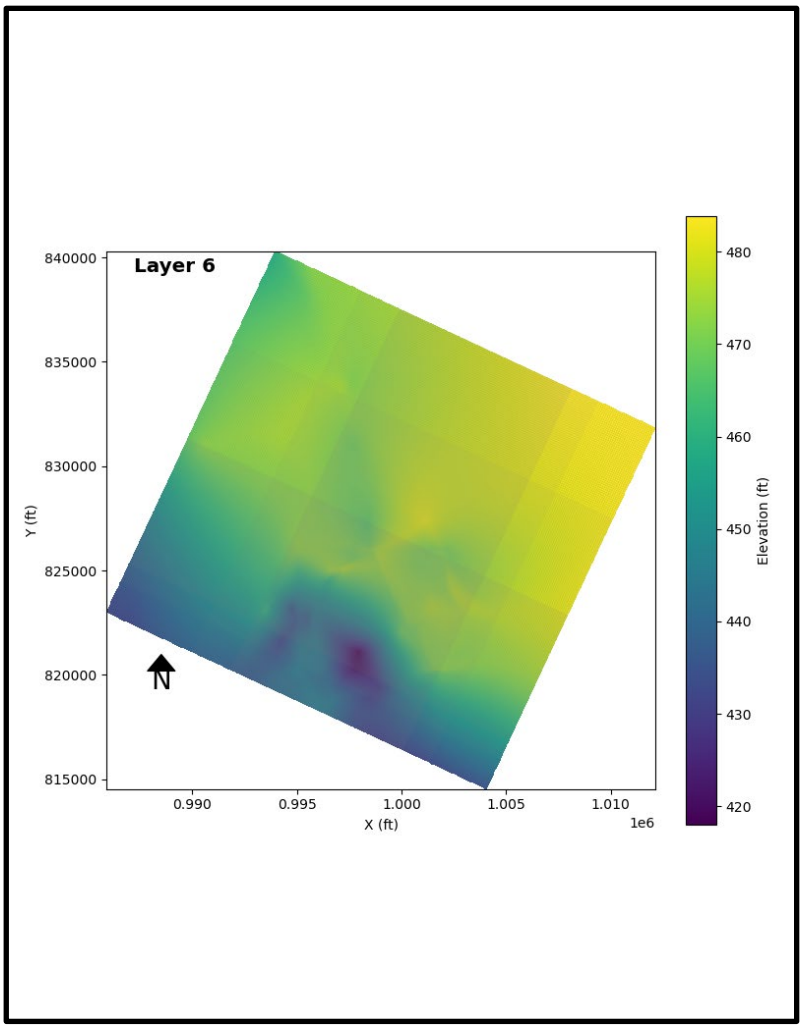
BASE OF MODEL LAYER 4

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



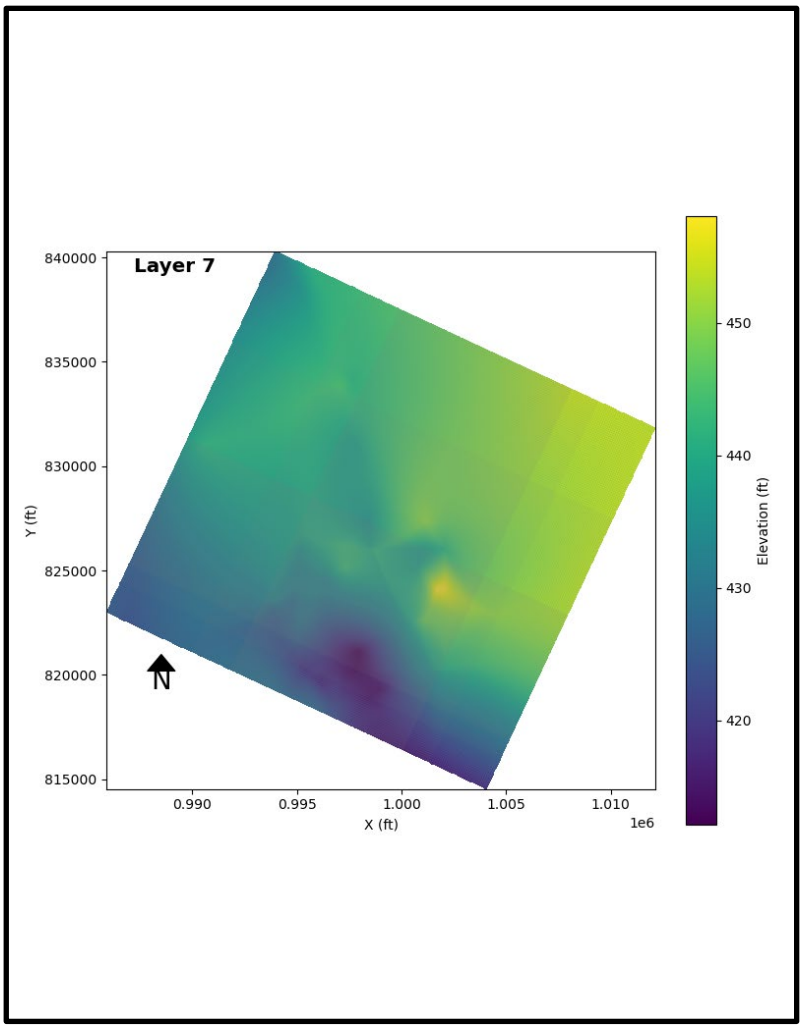
BASE OF MODEL LAYER 5

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



BASE OF MODEL LAYER 6

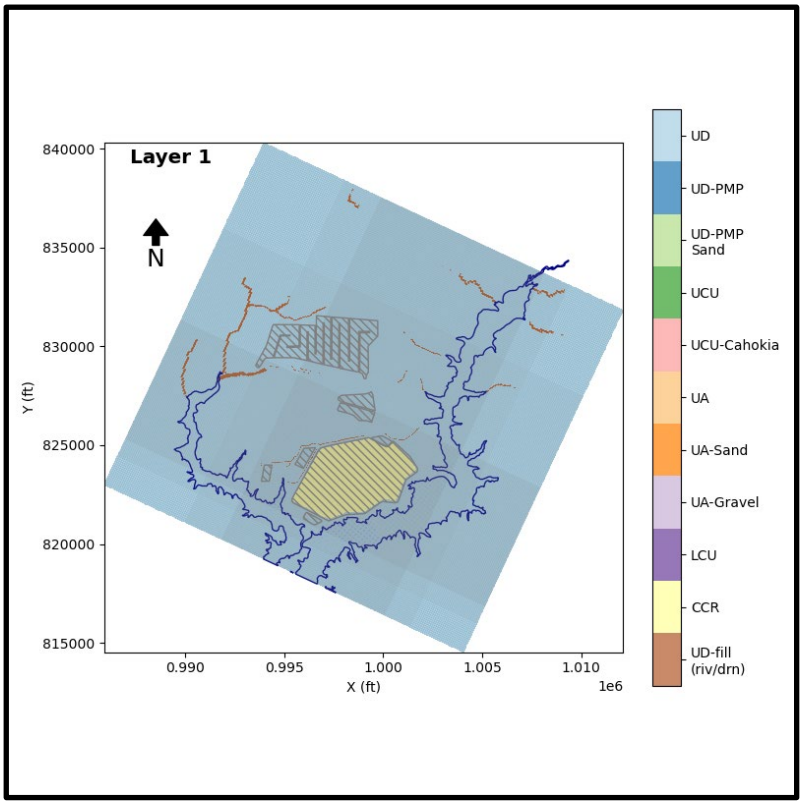
GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



BASE OF MODEL LAYER 7

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

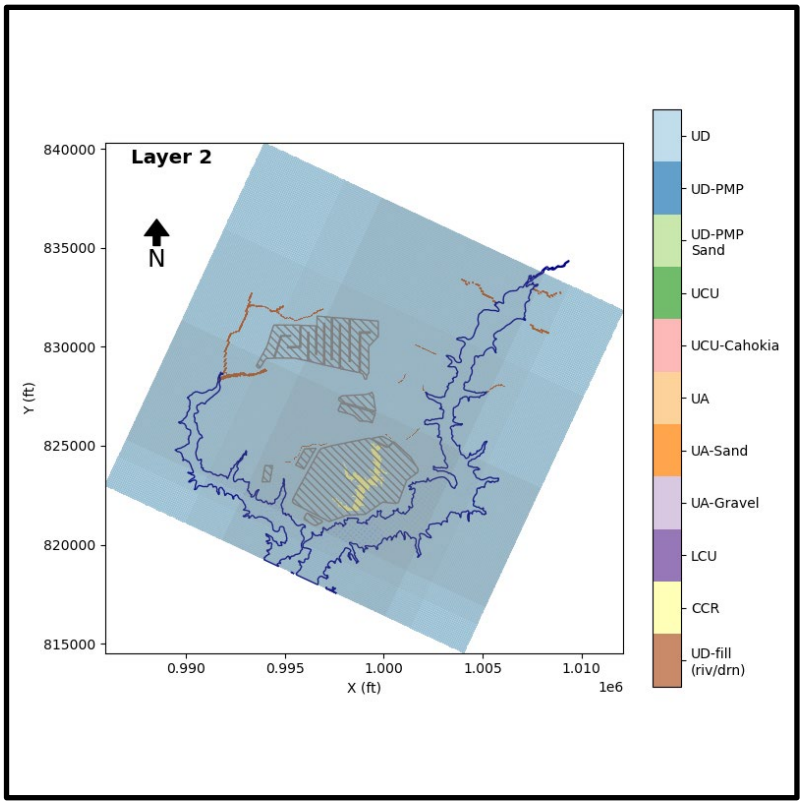
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 1 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

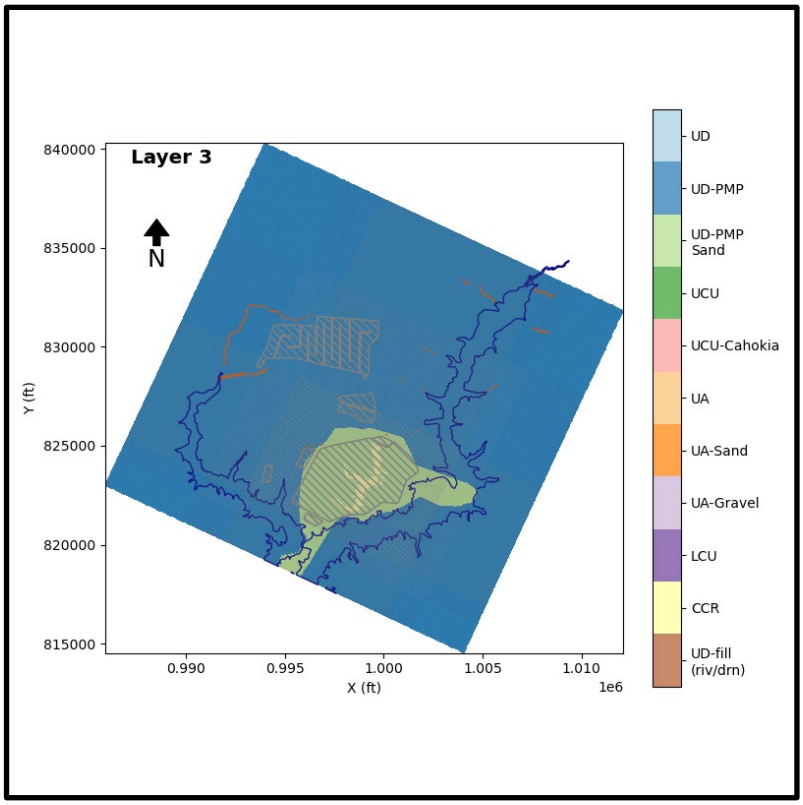
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 2 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

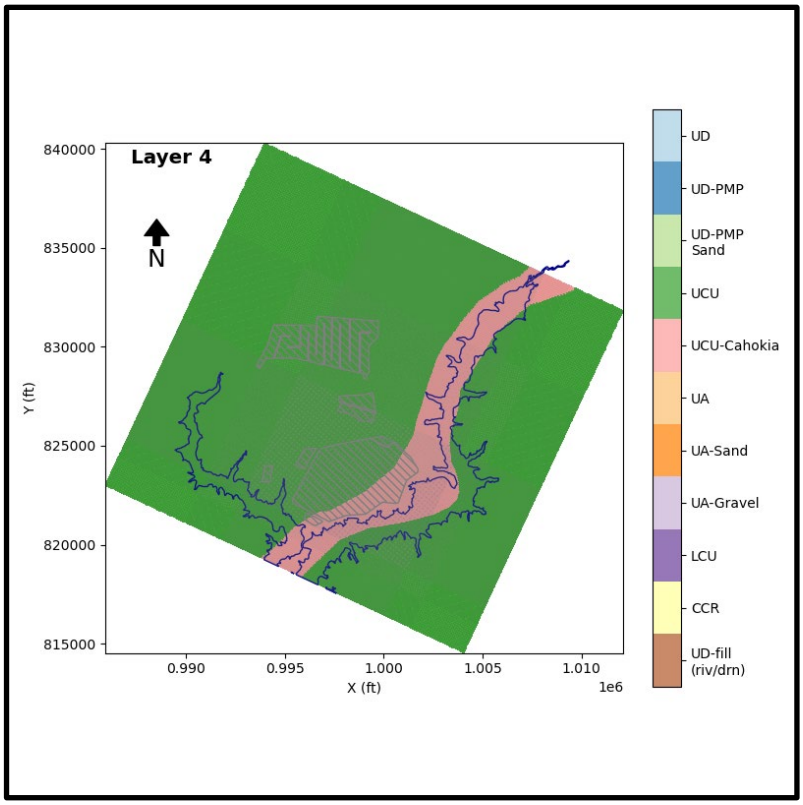
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 3 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

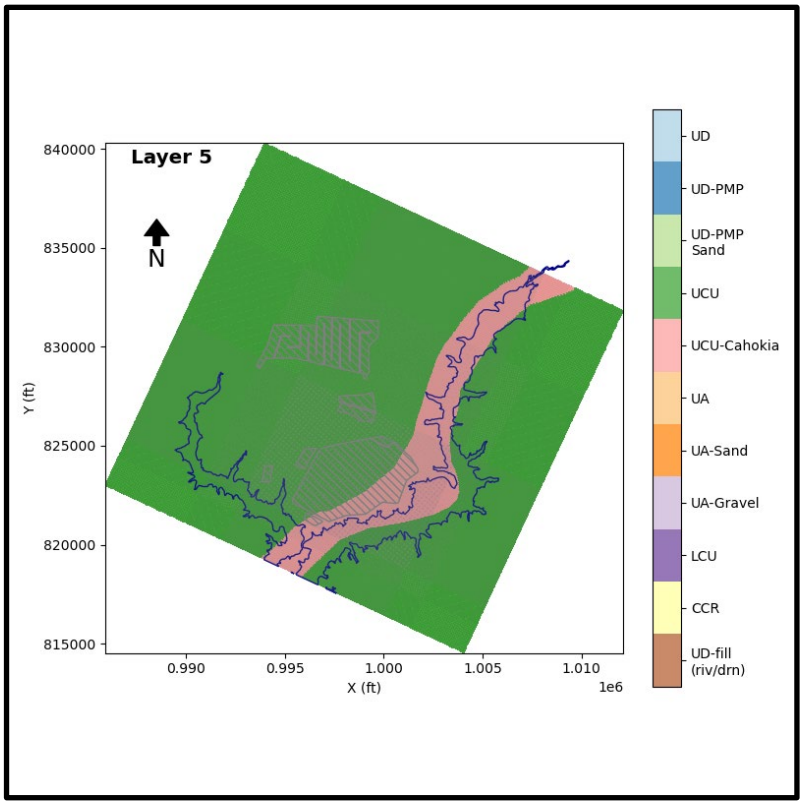
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 4 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

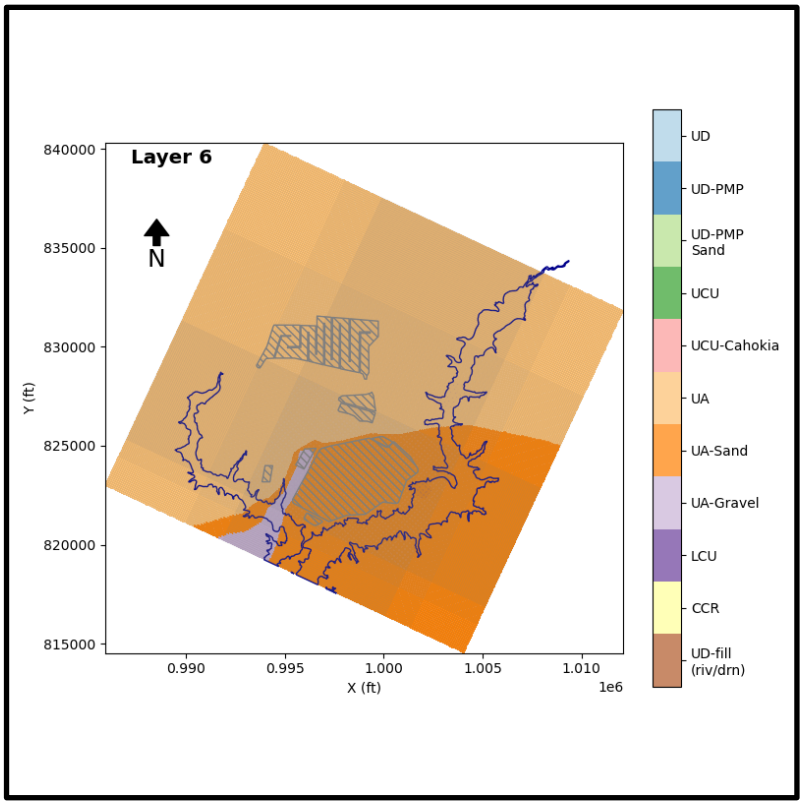
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 5 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

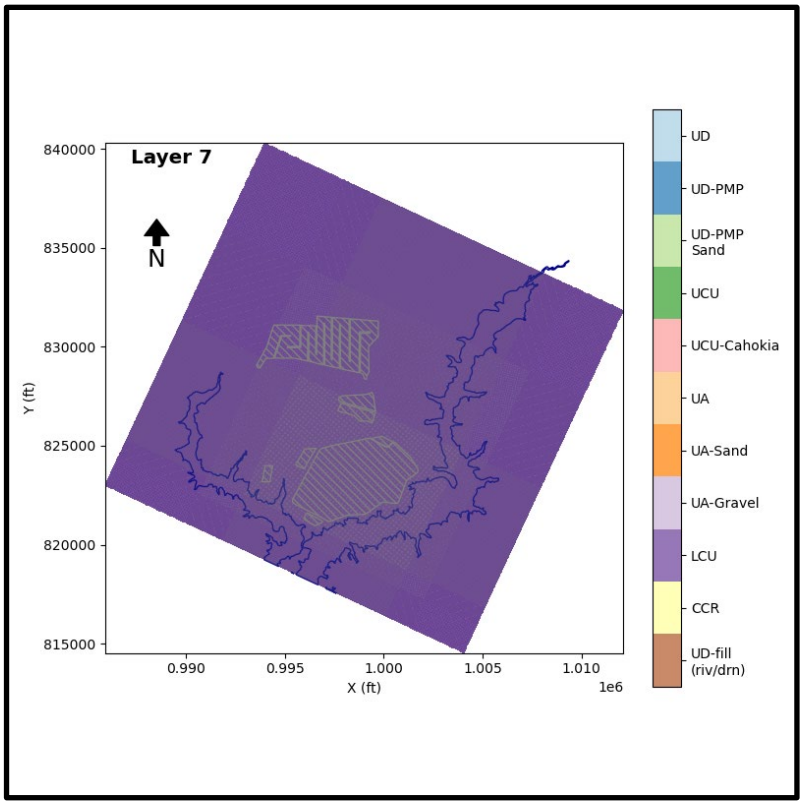
RAMBOLL



SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 6 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

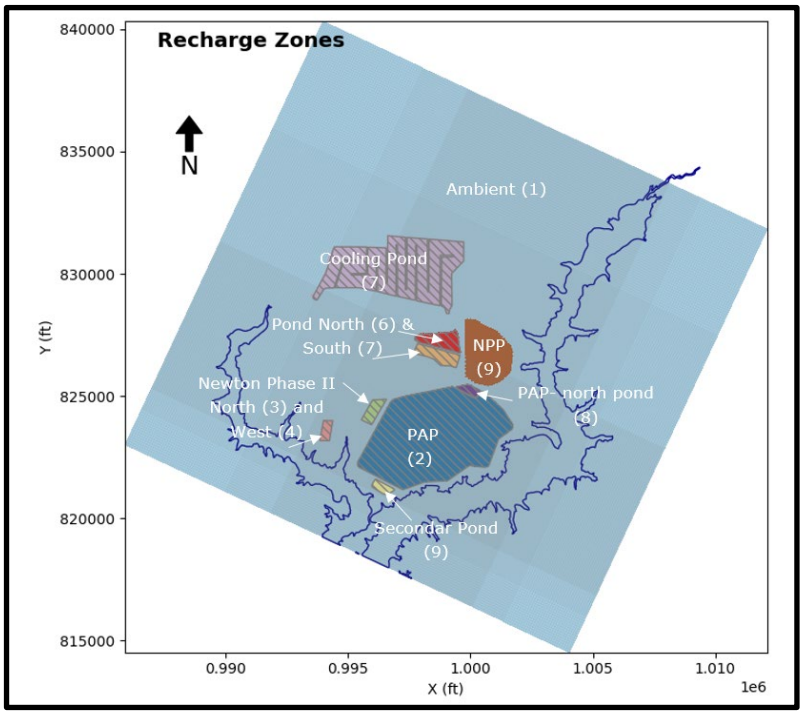


SPATIAL DISTRIBUTION OF HYDROSTRATIGRAPHIC LAYERS FOR LAYER 7 IN THE NUMERICAL MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

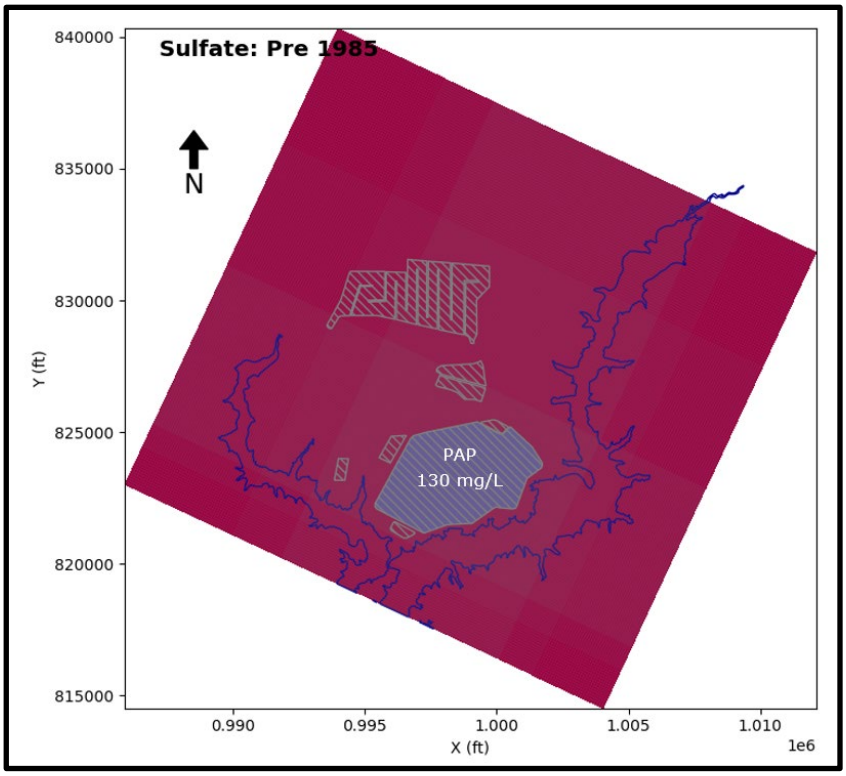
FIGURE 5-23

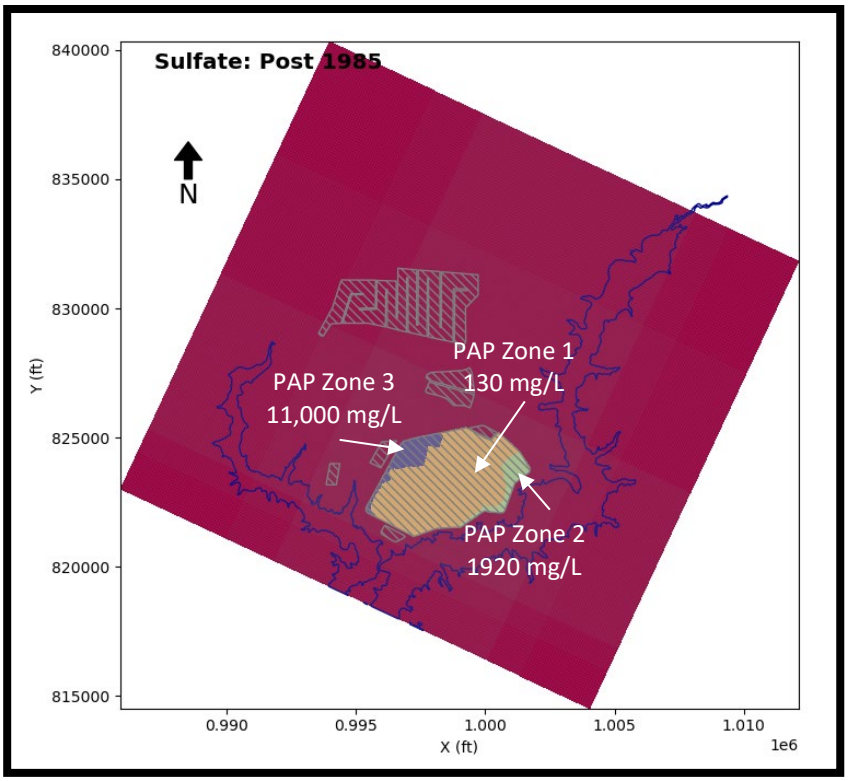


MODEL RECHARGE DISTRIBUTION (STEADY STATE CALIBRATION MODEL)

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



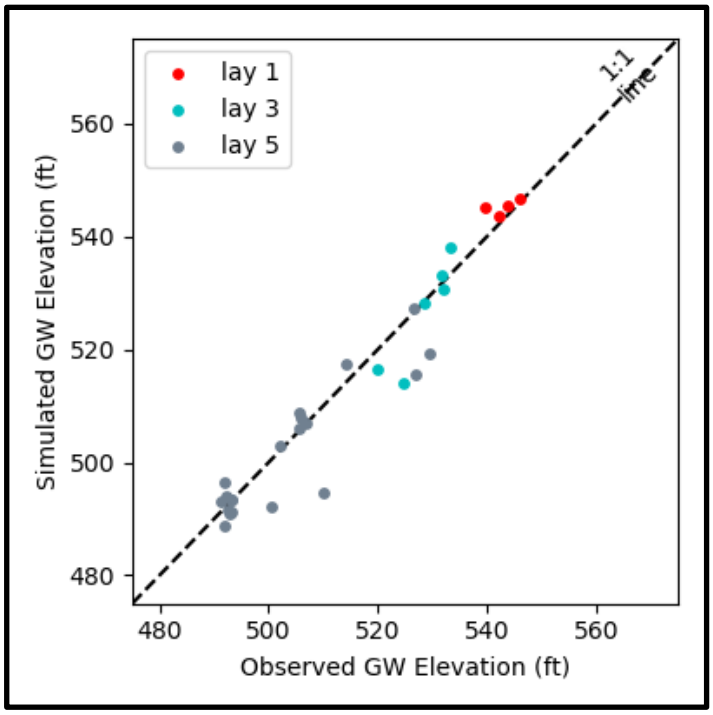


MODEL RECHARGE DISTRIBUTION FOR TRANSPORT MODEL FOR PRE AND POST 1985

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

FIGURE 5-25

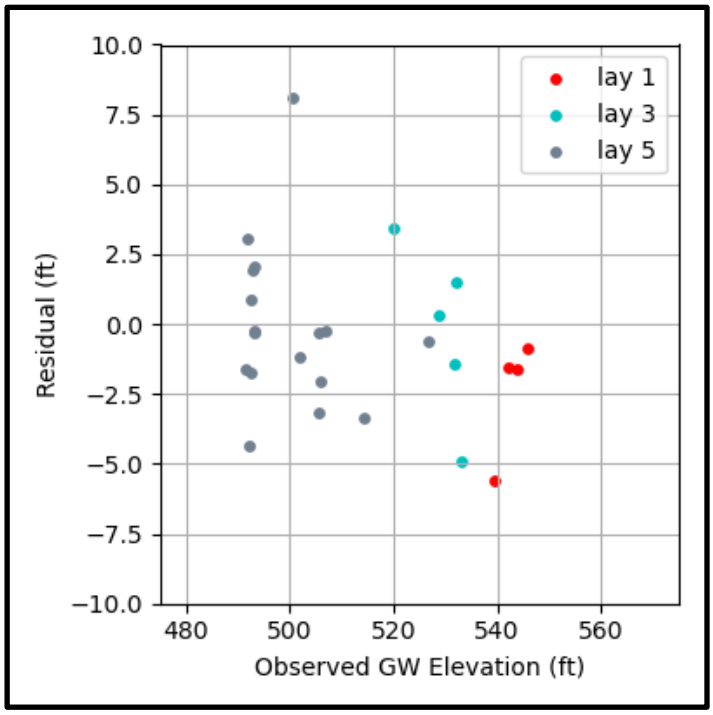


OBSERVED VERSUS SIMULATED STEADY STATE GROUNDWATER LEVELS FROM THE CALIBRATION MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

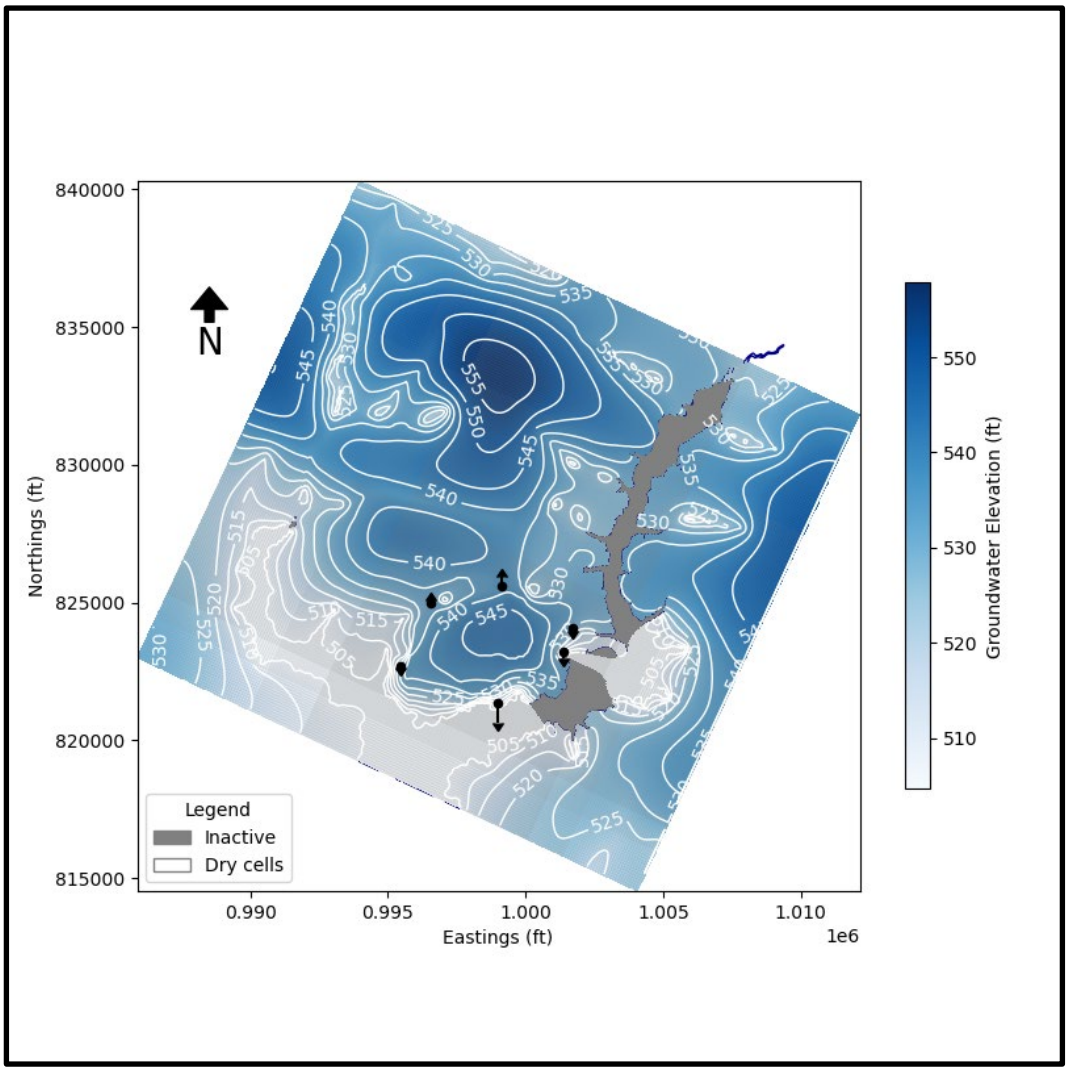
FIGURE 5-26



SIMULATED GROUNDWATER LEVEL RESIDUALS FROM THE CALIBRATED MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

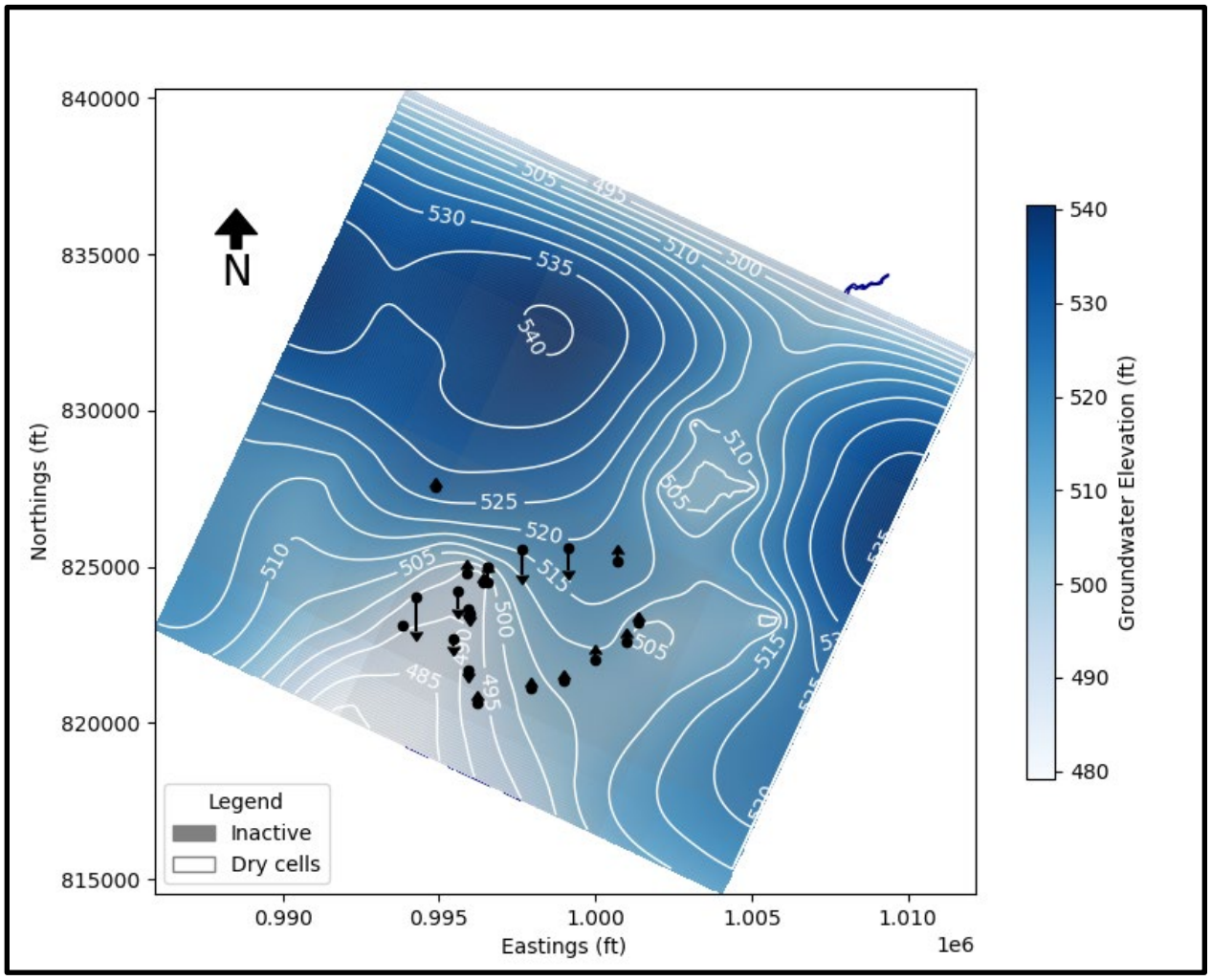


NOTE: BLACK DOTS INDICATE WELLS AND ARROW DIRECTION INDICATES BIAS IN SIMULATED GROUNDWATER LEVEL (NORTH ARROW = OVERESTIMATION, SOUTH ARROW = UNDERESTIMATION)

SIMULATED STEADY STATE GROUNDWATER LEVEL CONTOURS FROM UD/PMP (LAYER 3) FROM THE CALIBRATED MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

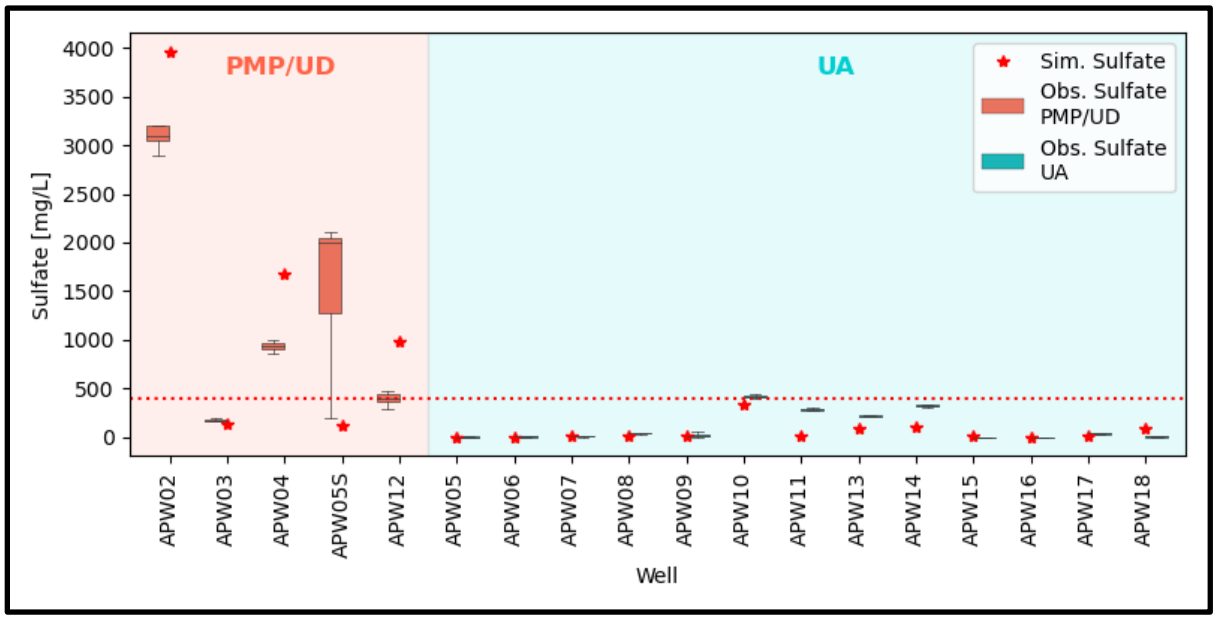


NOTE: BLACK DOTS INDICATE WELLS AND ARROW DIRECTION INDICATES BIAS IN SIMULATED GROUNDWATER LEVEL (NORTH ARROW = OVERESTIMATION, SOUTH ARROW = UNDERESTIMATION)

SIMULATED STEADY STATE GROUNDWATER LEVEL CONTOURS FROM UA (LAYER 6) FROM THE CALIBRATED MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



OBSERVED VERSUS SIMULATED SULFATE CONCENTRATIONS (mg/L)
(Obs. = Observed and Sim. = Simulated)

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

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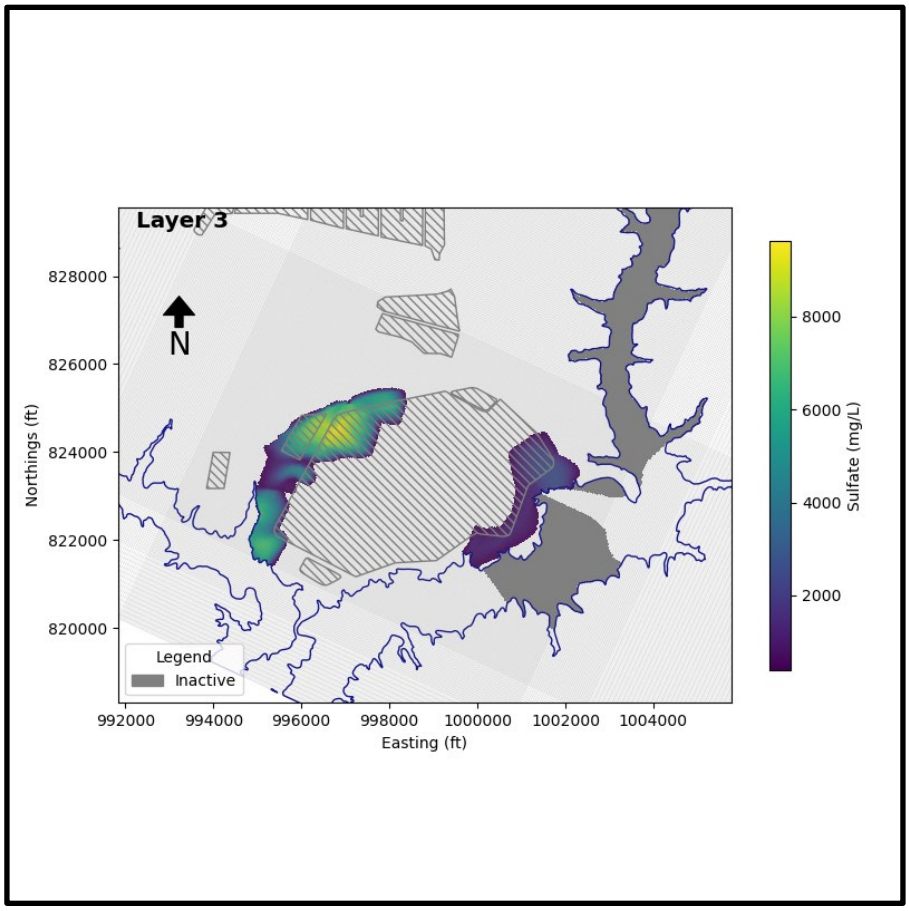
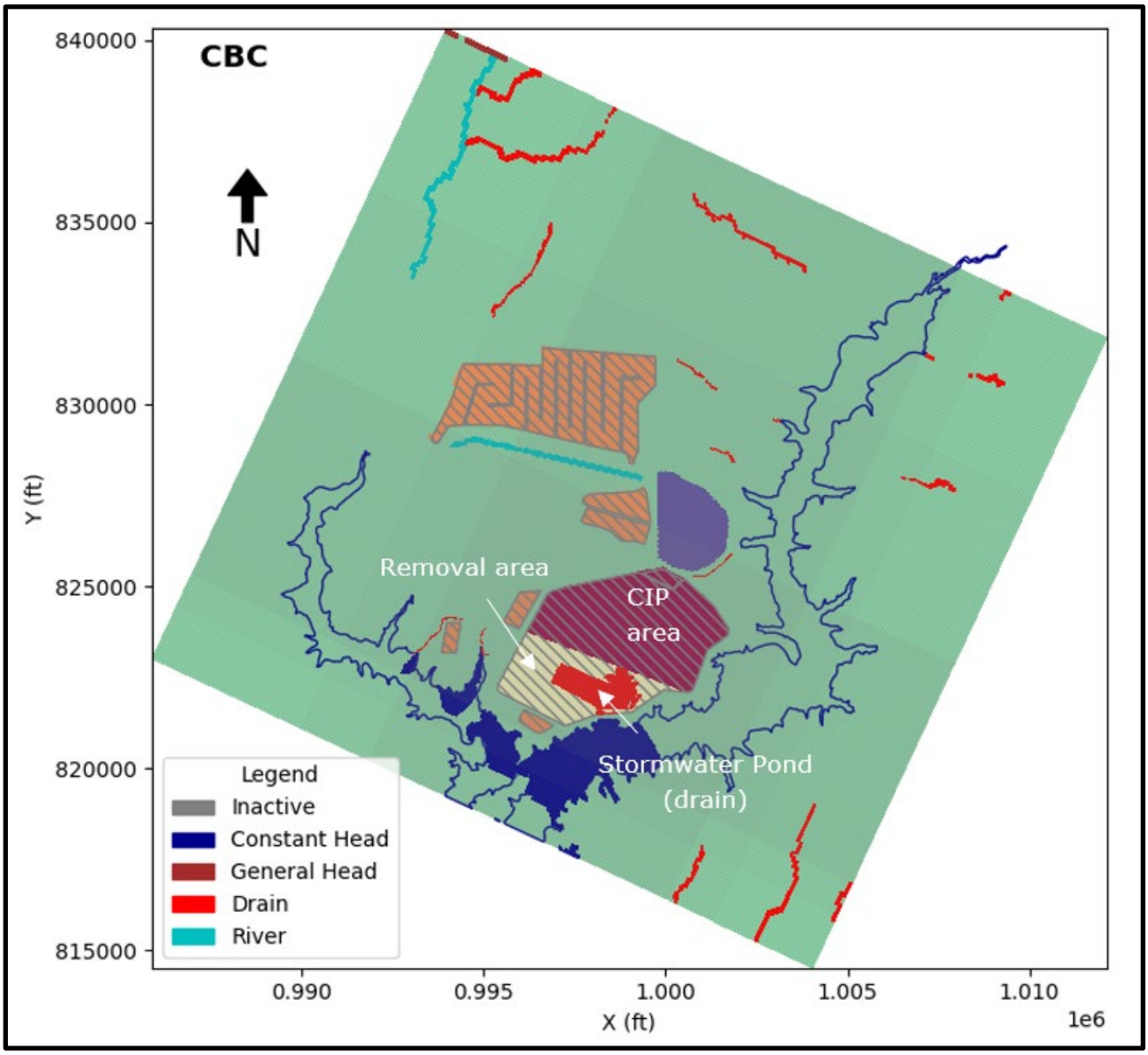


SIMULATED SULFATE PLUME OF THE UD/PMP FROM THE TRANSIENT MODEL

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

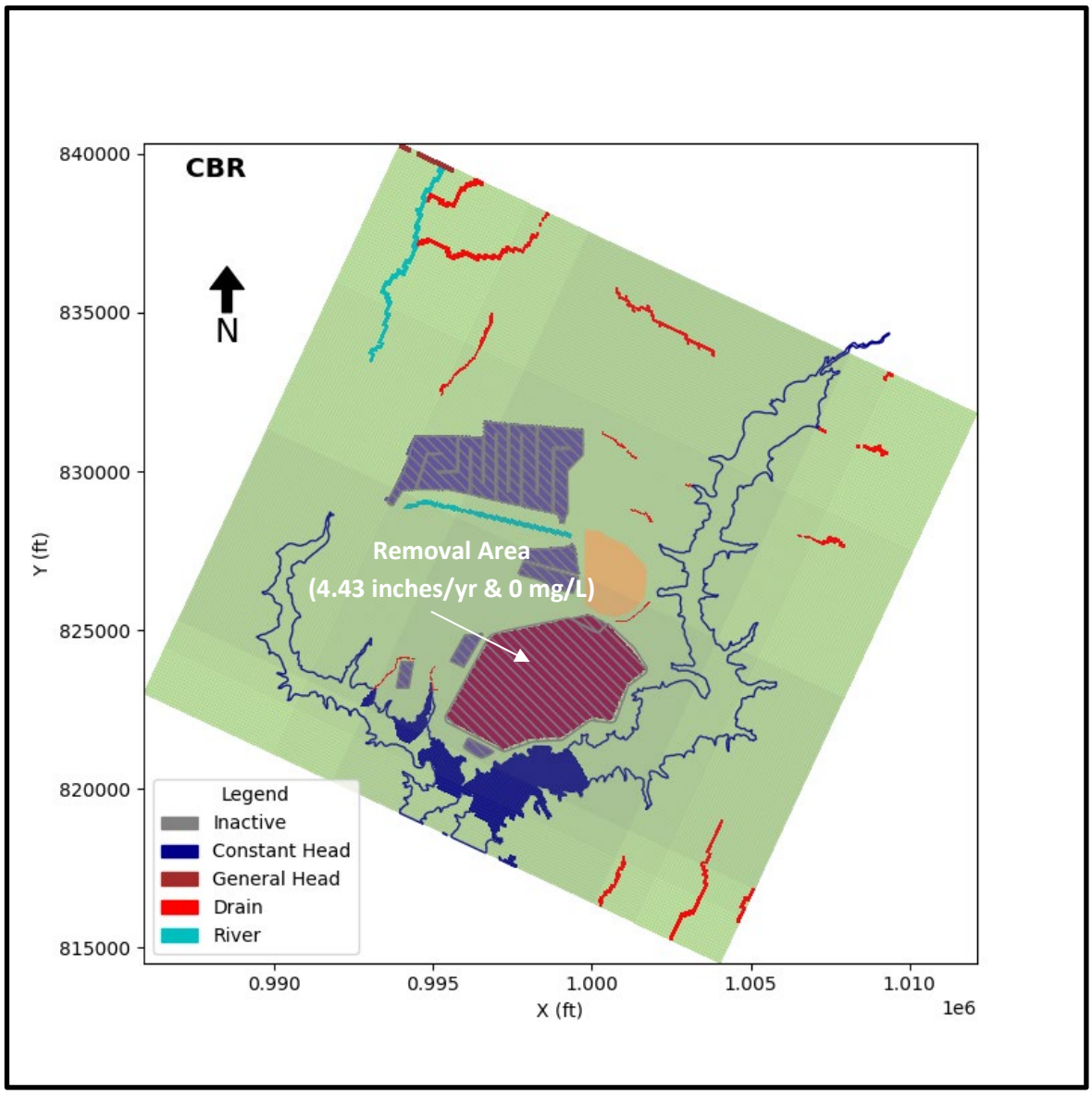
RAMBOLL



CIP RECHARGE AND STORMWATER POND MODIFICATIONS

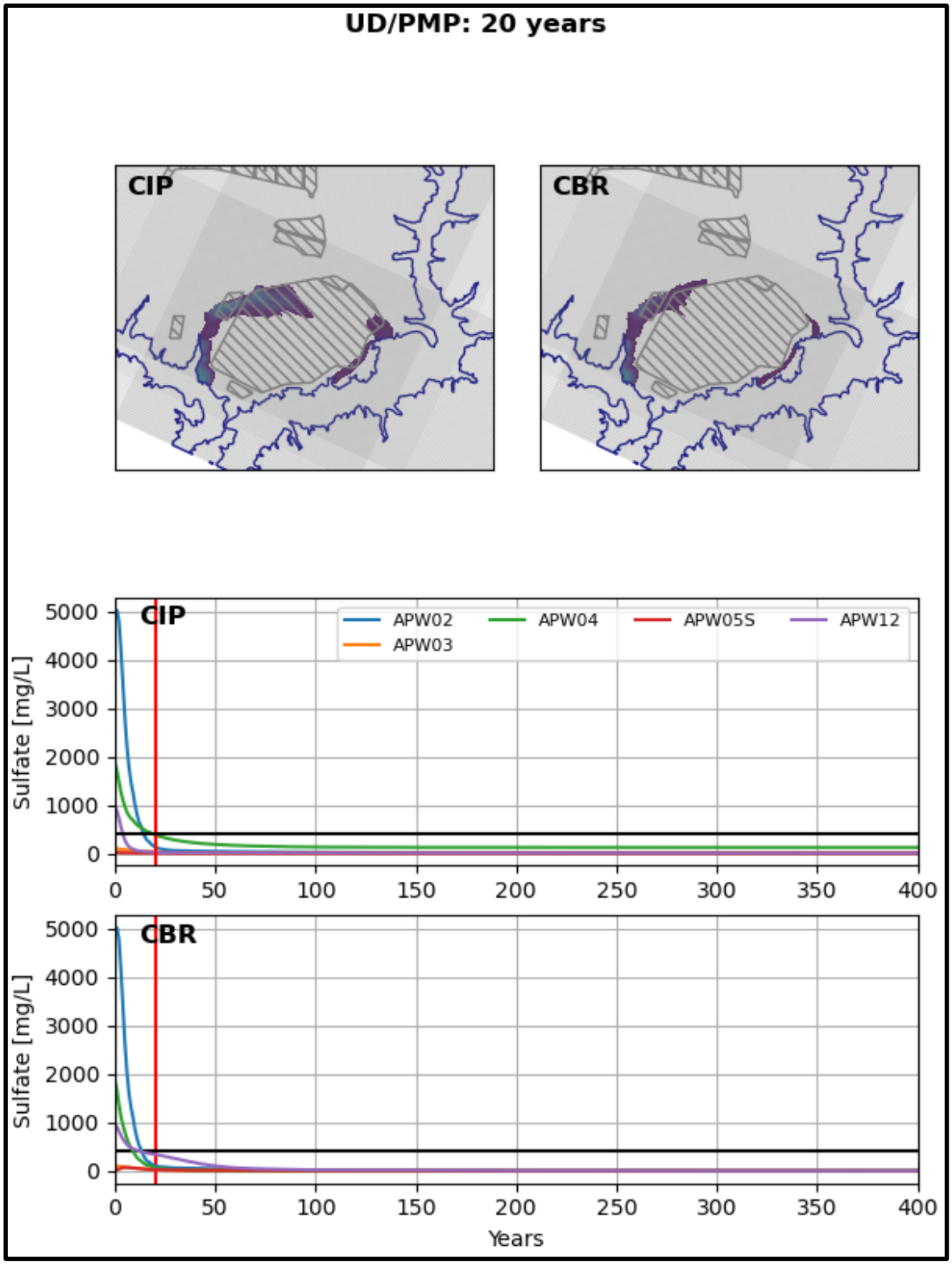
GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



CBR RECHARGE MODIFICATIONS AND REMOVAL AREA

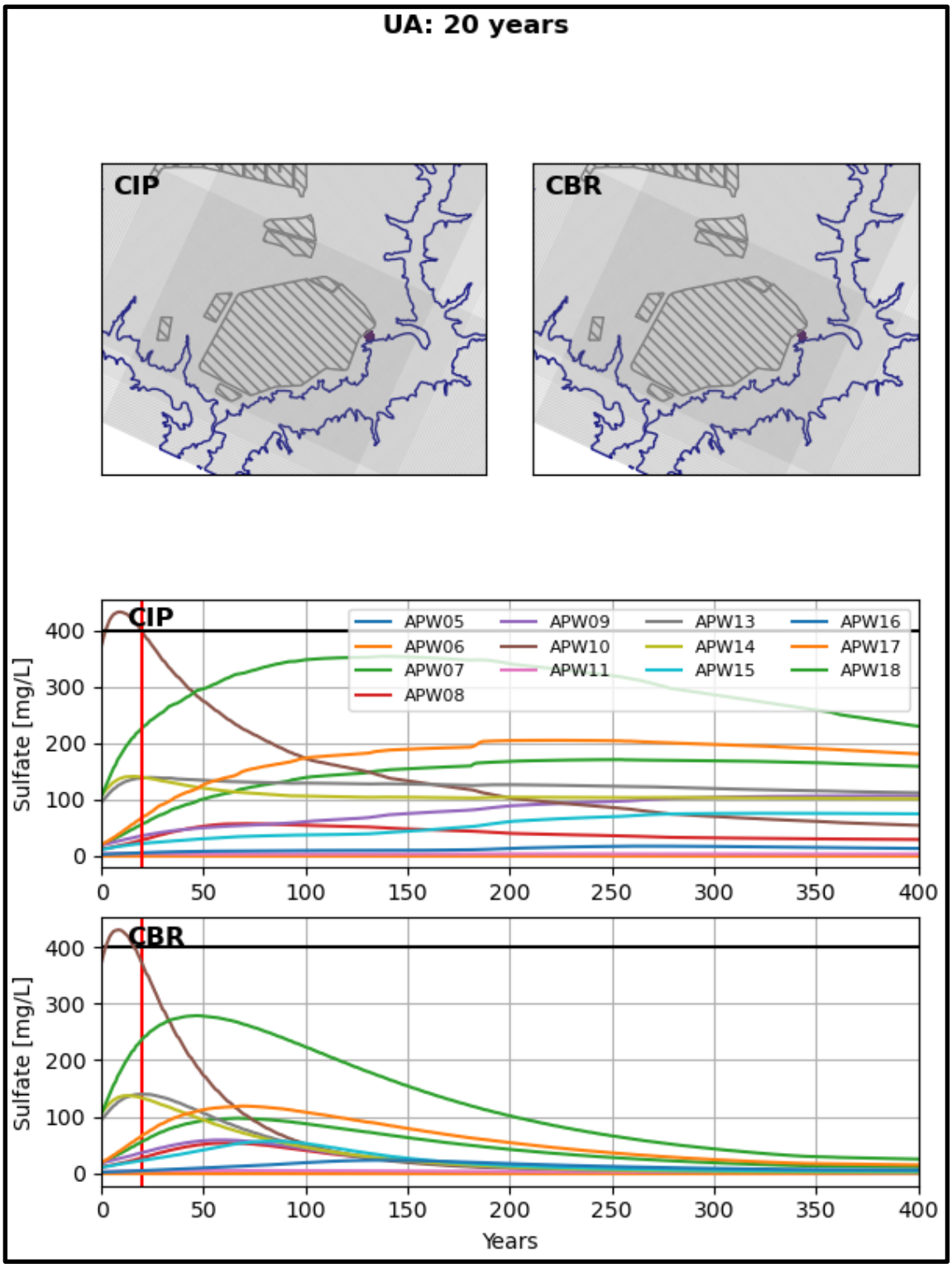
GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS



SIMULATED SULFATE PLUME OF THE UD/PMP FOR THE CIP AND CBR SCENARIOS AFTER 20 YEARS

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

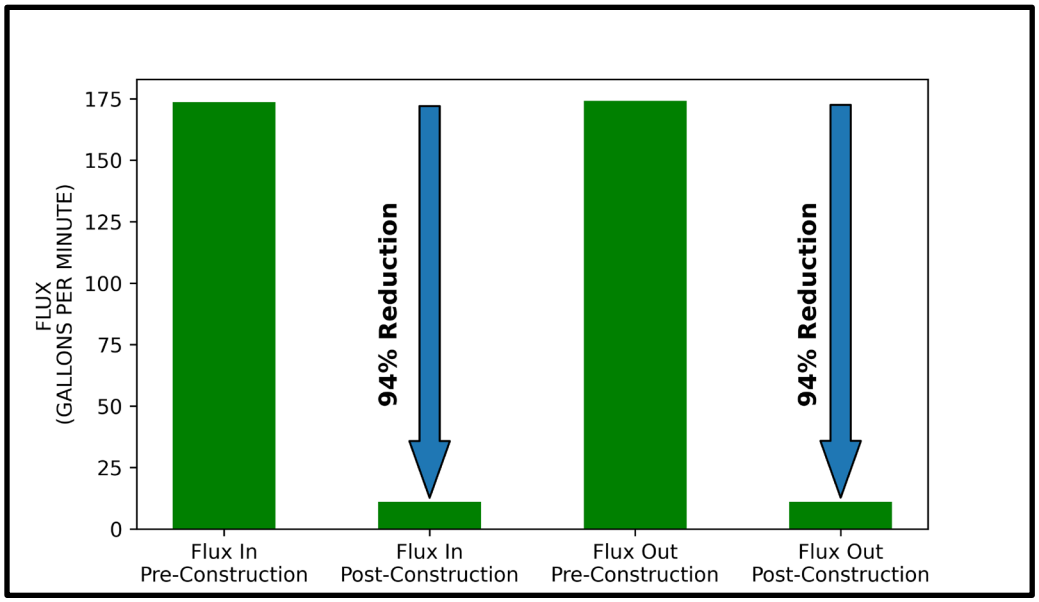
RAMBOLL



SIMULATED SULFATE PLUME OF THE UA FOR THE CIP AND CBR SCENARIOS AFTER 20 YEARS

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

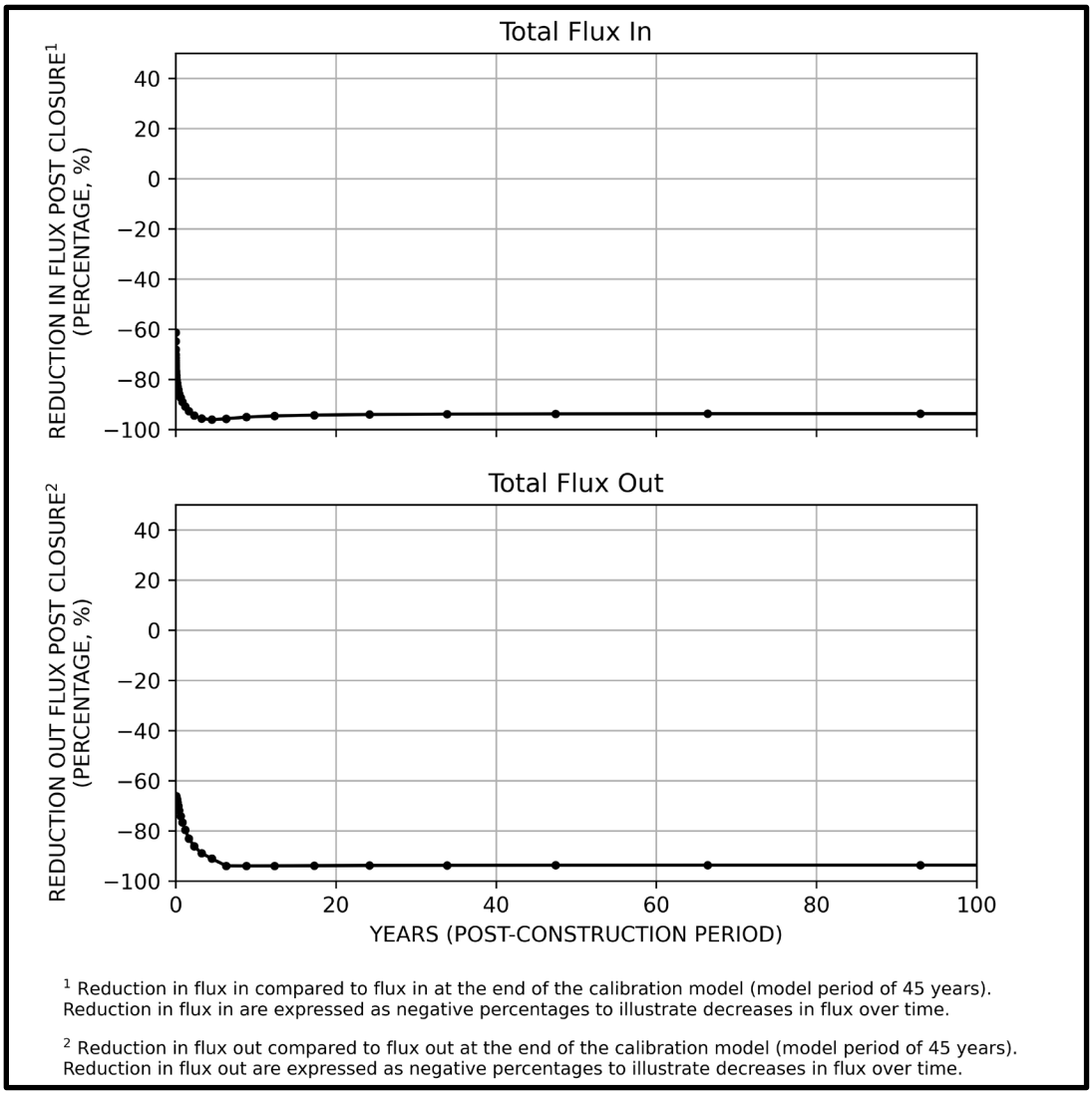
RAMBOLL



SCENARIO 1 (CIP) –
HYDRAULIC STEADY STATE REDUCTIONS IN TOTAL FLUX IN AND OUT OF FILL UNIT (CCR)

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



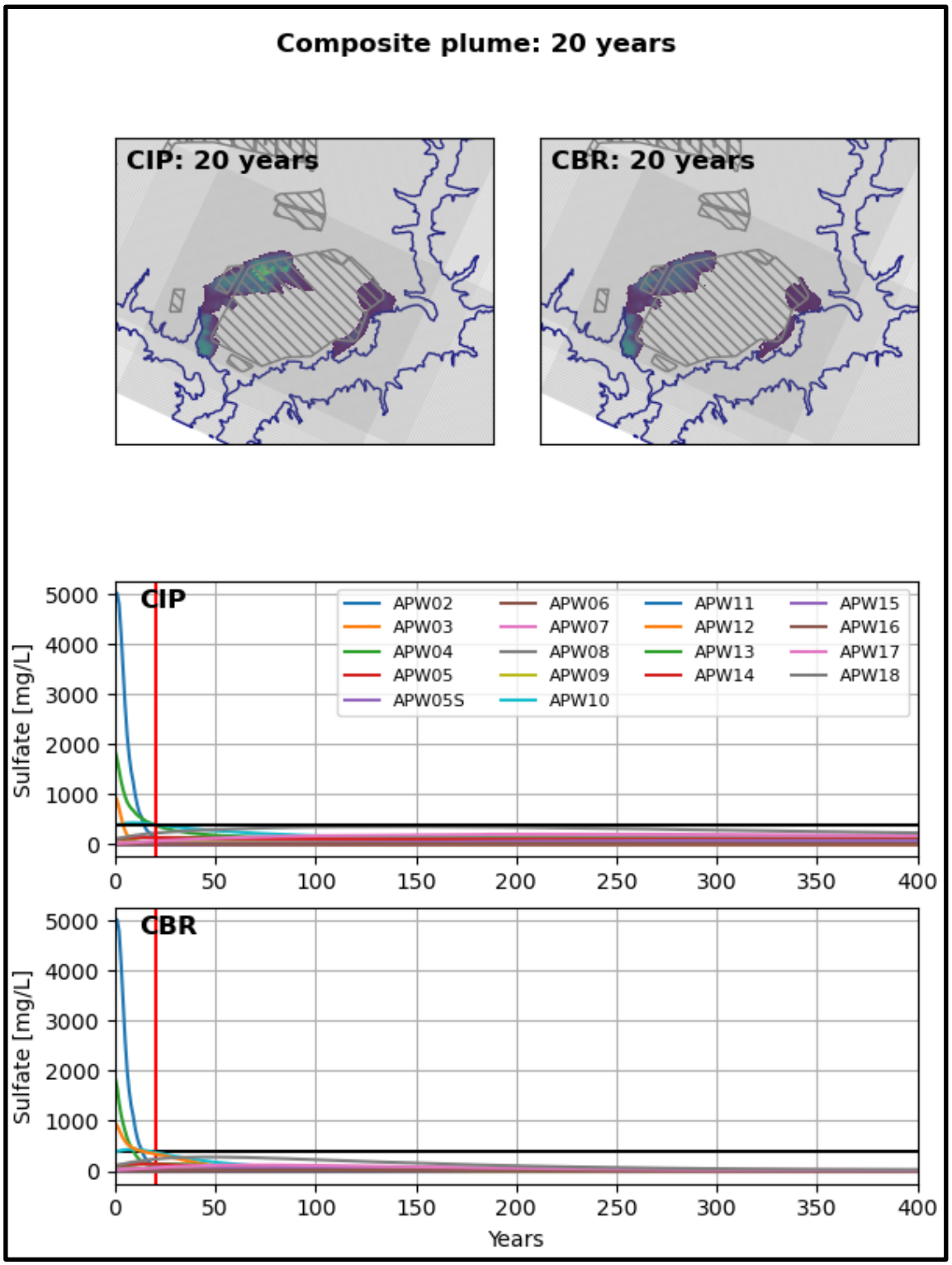
[1] Reduction in flux in compared to flux in at the end of the calibration model (model period of 45 years). Reduction in flux in are expressed as negative percentages to illustrate decreases in flux over time.

[2] Reduction in flux out compared to flux out at the end of the calibration model (model period of 45 years). Reduction in flux out are expressed as negative percentages to illustrate decreases in flux over time.

SCENARIO 1 (CIP) –
REDUCTIONS IN TOTAL FLUX IN AND OUT OF FILL UNIT (CCR)

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

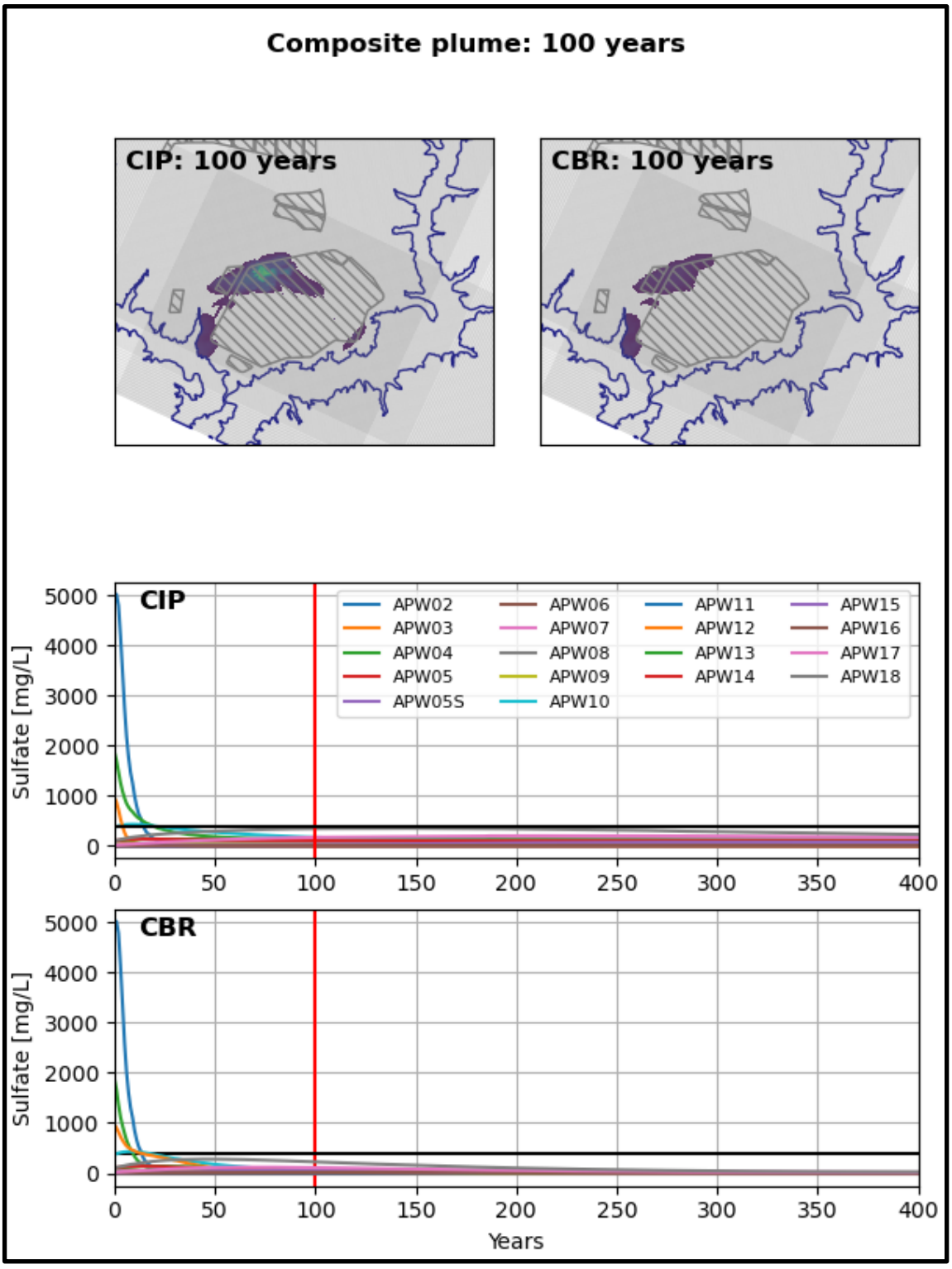
RAMBOLL



MAXIMUM EXTENT OF THE SULFATE PLUME FOR THE CIP AND CBR SCENARIOS AFTER 20 YEARS

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL



MAXIMUM EXTENT OF THE SULFATE PLUME FOR THE CIP AND CBR SCENARIOS AFTER 100 YEARS

GROUNDWATER MODELING REPORT
PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

RAMBOLL

APPENDICES

APPENDIX A
EVALUATION OF POTENTIAL GWPS EXCEEDANCES

Electronic Filing: Received, Clerk's Office 07/01/2024

TECHNICAL MEMORANDUM

DATE	April 15, 2022	21454831
TO	David Mitchell, Stu Cravens, Vic Modeer Illinois Power Generating Company	
CC	Brian Hennings - Ramboll	
FROM	Roberta Russell, Jeffrey Ingram, Pat Behling - Golder	**EMAIL jingram@golder.com**

EVALUATION OF POTENTIAL GWPS EXCEEDANCES, PRIMARY ASH POND, NEWTON POWER PLANT, JASPER COUNTY, ILLINOIS

1.0 INTRODUCTION

Illinois Power Generating Company (IPGC) currently operates the Newton Power Plant (NPP or Site) located in Jasper County, Illinois. The Primary Ash Pond (PAP, Illinois Environmental Protection Agency [IEPA] ID No. W0798070001-01) is a surface impoundment used to manage coal combustion residuals (CCRs) at the NPP. The PAP is regulated under Part 845 *"Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments"* (State CCR Rule or Part 845) which was promulgated by the Illinois Pollution Control Board (IPCB) on April 21, 2021.

IPGC is currently preparing a Construction Permit application for the PAP as required under Section 845.220 which requires groundwater modelling be completed for the known potential exceedances of groundwater protection standards (GWPS) as outlined in the Operating Permit application (Burns and McDonnell 2021). In October 2021, Ramboll Americas Engineering Solutions, Inc. (Ramboll) identified potential GWPS exceedances for pH in certain monitoring wells in the vicinity of the PAP (Ramboll 2021a). This Technical Memorandum was developed to further evaluate these potential GWPS exceedances.

1.1 Site Setting

The NPP is located in Jasper County Illinois, approximately 20 miles southeast of Effingham and 7 miles southwest of Newton, in Section 26 and 25, Township 6 North, Range 8 East. The NPP has one CCR surface impoundment (the PAP) with a surface area of 404 acres and a non-CCR Secondary Pond with a surface area of 9.3 acres. The PAP currently receives bottom ash, fly ash, and low-volume wastewater from the plant's two coal-fired boilers.

The NPP is situated in a predominantly agricultural area with fields located on the north, west and southern boarders of the property. The eastern border of the property is the Prairie Ridge State Natural Area. The PAP is adjacent to Newton Lake on the southern and eastern sides, with the NPP generating station located to the north of the PAP, and the site's Utility Waste Landfills located to the west.

Six hydrogeologic units are present at the NPP. They are described as follows in the Hydrogeologic Site Characterization Report (Ramboll 2021b), in downward order:

Golder Associates USA Inc.
701 Emerson Road, Suite 250, Creve Coeur, Missouri, 63141 T: +1 314 984 8800 F: +1 314 984-8770

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- **CCR:** CCR, consisting mostly of bottom and fly ash. CCR is present from the surface (approximately 545 to 555 feet above mean sea level (ft MSL) down to approximately 475 feet msl at its deepest portions.
- **Upper Drift (UD) / Potential Migration Pathway (PMP):** The UD consists of low-permeability silts and clays of the Peoria Silt and Sangamon Soil units. In some areas, discontinuous lenses of the sandier Hagarstown Member are also present, making up the PMP.
- **Upper Confining Unit (UCU):** the UCU comprises a thick sequence of low-permeability clays and silts of the Vandalia Till Unit. This unit is laterally continuous and is present from the base of the PAP down to the top of the uppermost aquifer.
- **Uppermost Aquifer (UA):** the UA comprises the Mulberry Grove Formation and generally consists of fine to coarse, poorly- to well-graded sands, with occasional clayey sand layers and gravels.
- **Lower Confining Unit (LCU):** This unit consists of the Smithboro Till Member and is generally made up of compact glacial till consisting of low-permeability silty clays and clayey silts with trace sand and gravel.
- **Bedrock Confining Unit (BCU):** Bedrock below the unconsolidated deposits, consisting of shale of the Mattoon Formation.

Groundwater elevations within the PAP are high when compared to the surrounding aquifer, creating a downward gradient between the PAP and the surrounding aquifer. Below the PAP, groundwater migrates downward and laterally through the UD and UCU into the UA. Additionally, as displayed in **Figure 1**, groundwater in the UA flows from the north to the southeast in the eastern portion of the pond and to the south/southwest in the western portion of the pond (Ramboll 2021a).

2.0 POTENTIAL GWPS EXCEEDANCES AND MONITORING WELL DETAILS

As required by Section 845.230 (d)(2)(M), an evaluation of the history of potential GWPS exceedances was completed for the Operating Permit application (Burns and McDonnell 2021; Ramboll 2021b). Data collected since 2015 from the PAP monitoring well network were evaluated using statistical methods described in the Statistical Analysis Plan included in the Operating Permit application (Appendix I, Ramboll 2021c). The following monitoring wells and potential exceedances of the GWPSs are evaluated in this Technical Memorandum:

- **pH at APW04:** For pH, a lower confidence limit (LCL) of 6.1 (in Standard Units; SU) was calculated below the lower GWPS of 6.4. APW04 is located to the east/southeast of the PAP, downgradient of the PAP based on typical flow directions within the UD and UCU. The well is screened in sandy clays of the UD (PMP) from 7.7 to 17.7 FT BGS (513.75 to 503.75 FT MSL).
- **pH at APW12:** For pH, a lower confidence limit (LCL) of 6.2 was calculated below the lower GWPS of 6.4. APW12 is located to the east/northeast of the PAP, typically upgradient of the general groundwater flow direction within the UD and PMP. The well is screened in a mixture of silty clays and sands of the UD (PMP) from 20.0 to 30.0 FT BGS (523.33 to 513.33 FT MSL).

3.0 EVIDENCE THAT POTENTIAL GWPS EXCEEDANCES ARE NOT RELATED TO THE PAP

Groundwater data for monitoring wells that exhibited potential pH GWPS exceedances, background monitoring wells and porewater samples from the PAP were evaluated. The review of these data indicates that the GWPS exceedances are not related to the PAP, as described in the following line of evidence.

- **The pH of CCR porewater is significantly higher than the pH in monitoring wells APW12 and APW04 and the pH ranges recorded in the PMP are likely naturally occurring.**

The pH of porewater within the PAP ranges from approximately 8.6 to 12.2 with an average of 10.7, while pH in all PMP wells (APW02, APW03, APW04, APW5S, APW12) ranges from 6.0 to 7.2, with an average of 6.7 (Table 1). The pH of groundwater in background wells within the UA ranges from 6.4 to 7.8. Due to the high pH values within the PAP, it would be expected that any releases from the PAP would increase the pH in downgradient wells. However, as demonstrated in **Table** 1, downgradient wells within the PMP report pH values significantly lower than in the PAP.

	Background Wells	Upper Drift Wells	PAP Porewater
pH Average	7.5	6.7	10.7
pH Min	6.4	6.0	8.6
pH Max	7.8	7.2	12.4

Table 1. Summary of average, minimum and maximum pH values (in SU) in background wells (APW05, APW06), UD wells (APW02, APW03, APW04, APW05S and APW12) and the PAP.

In addition, pH is consistently slightly lower in all PMP wells compared to background wells (Tables 1 and 2). The average pH values across the PMP wells are similar, i.e. within 0.5 SU of one another. Given the consistency of average pH values across the PMP, it is likely that the slightly lower pH is naturally occurring in the PMP.

Sample Date	APW05	APW06	APW02	APW03	APW04	APW05S	APW12
Well Formation	UA	UA	UD/PMP	UD/PMP	UD/PMP	UD/PMP	UD/PMP
2/17/2021	7.20	6.40	6.60	6.70	6.50	6.60	6.20
3/10/2021	7.70	7.70	7.00	7.20	6.90	7.00	6.50
3/30/2021	7.20	7.10	6.60	6.30	6.10	--	6.00
4/28/2021	7.49	7.69	6.68	7.00	6.86	6.84	6.40
5/25/2021	7.54	7.71	6.67	7.05	6.90	6.86	6.54
6/17/2021	7.73	7.69	6.62	6.98	6.81	6.82	6.45
6/30/2021	7.55	7.61	6.58	7.03	6.80	6.73	6.29
7/15/2021	7.78	7.49	6.55	6.93	6.76	6.77	6.54
Average	**7.52**	**7.42**	**6.66**	**6.90**	**6.70**	**6.80**	**6.37**

Table 2. pH data (in SU) for 2021 sampling events for background wells (APW05, APW06) and PMP wells (APW02, APW03, APW04, APW05S, APW12).

Therefore, the CCR unit is not the cause of the pH values statistically below the lower pH GWPS at APW12 and APW04.

4.0 CLOSING

Golder appreciates the opportunity to serve as your consultant on this project. If you have any questions concerning this Technical Memorandum or need additional information, please contact the undersigned.

Golder Associates USA Inc.





Roberta Russell
Senior Consultant, Geologist

Patrick J. Behling
Principal, Practice Leader

JSI/RR/PJB

5.0 REFERENCES

Burns and McDonnell 2021. Initial Operating Permit, Newton Ash Pond. October 25.

Ramboll 2021a. History of Potential Exceedances, Newton Ash Pond, Newton Power Plant. October 17.

Ramboll 2021b. Hydrogeologic Site Characterization Report, Primary Ash Pond, Newton Power Plant. October 25.

Ramboll 2021c. Statistical Analysis Plan, Primary Ash Pond, Newton Power Plan. October 25.

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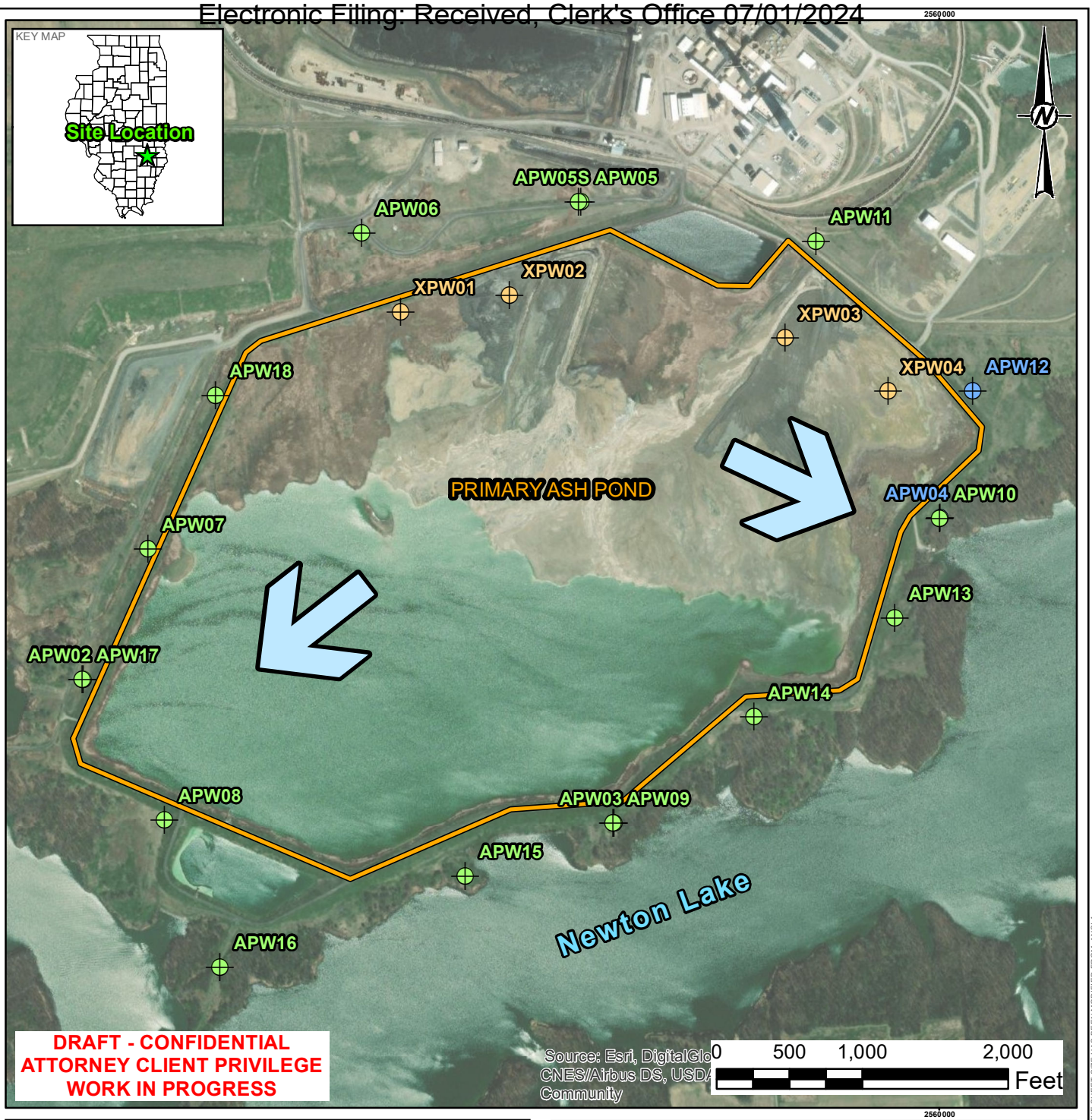

LEGEND

- Primary Ash Pond - CCR Unit ID
- Part 845 Groundwater Sample Location With no Potential pH Exceedance
- CCR Pore Water Sample Location
- Part 845 Groundwater Sample Location With a Potential pH Exceedance
- Typical Groundwater Flow Directions

NOTE(S)
1. ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE.

REFERENCE(S)
1. RAMBOLL 2021, TABLE 2 SUMMARY OF POTENTIAL EXCEEDANCES.
2. RAMBOLL 2021. GROUNDWATER MONITORING PLAN, PRIMARY ASH POND, NEWTON POWER PLANT, NEWTON ILLINOIS.

CLIENT
ILLINOIS POWER GENERATING COMPANY

PROJECT
NEWTON POWER PLANT - EVALUATION OF POTENTIAL GWPS EXCEEDANCES

TITLE
NEWTON MONITORING WELL LOCATIONS AND TYPICAL GROUNDWATER FLOW DIRECTION

CONSULTANT
WSP GOLDER

YYYY-MM-DD	2022-02-01
DESIGNED	BTT
PREPARED	BTT
REVIEWED	JSI
APPROVED	PJB

PROJECT NO.	PHASE	FIGURE
21454831	0004	1

PATH: C:\Users\Vinpam\Golder Associates\21454831 Vistra IL MNA Part 845 Support - Project Files\5 Technical Work\Phase4 - Newton\4.11-Figures\WNA-Figures\Figure 1 - Site Location Map - DRAFT.mxd PRINTED ON: 2022-04-07 AT: 8:20:29 AM

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APPENDIX B
MODFLOW, MT3DMS, HELP MODEL, AND FLUX EVALUATION DATA EXPORT FILES (ELECTRONIC ONLY)

APPENDIX C
EVALUATION OF PARTITION COEFFICIENT RESULTS

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WSP GOLDER

TECHNICAL MEMORANDUM

DATE March 30, 2022 **Project No.** 21454831

TO David Mitchell, Stu Cravens, Vic Modeer
Illinois Power Generating Company

CC Brian Henning - Ramboll

FROM Golder Associates USA Inc. **EMAIL** **Jeffrey_Ingram@golder.com**

EVALUATION OF PARTITION COEFFICIENT RESULTS, PRIMARY ASH POND (CCR UNIT 501), NEWTON POWER PLANT, JASPER COUNTY, ILLINOIS

1.0 INTRODUCTION

Illinois Power Generating Company (IPGC) operates the Newton Power Plant (NPP) located in Jasper County, Illinois. The Primary Ash Pond (PAP or Site), Illinois Environmental Protection Agency [IEPA] ID No. W0798070001-01 is a 404-acre unlined surface impoundment used to manage coal combustion residuals (CCRs) at the NPP. The PAP is regulated under Part 845 *"Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments"* (State CCR Rule or Part 845) which was promulgated by the Illinois Pollution Control Board (IPCB) on April 21, 2021. WSP Golder (Golder) is assisting IPGC with Part 845 compliance at the Site.

IPGC is currently preparing a Construction Permit application for the PAP as required under Section 845.220. As a part of the Construction Permit application, groundwater modeling is being completed for known potential exceedances of groundwater protection standards (GWPS) as outlined in the Operating Permit application for the PAP (Burns and McDonnell 2021). In the Operating Permit (October 2021), Ramboll Americas Engineering Solutions, Inc. (Ramboll) identified potential GWPS exceedances for several compounds potentially associated with the PAP, including lithium and sulfate. Batch adsorption testing was conducted to generate site-specific partition coefficient results for these parameters for use in the groundwater models. Site-specific partition coefficients were also developed for boron for its use in groundwater modeling. This Technical Memorandum summarizes the results of the batch adsorption testing.

2.0 OVERVIEW

In August 2021, Golder conducted a field investigation at the PAP which included the completion of seven (7) soil/rock borings ranging in depth from 15 to 90 feet below ground surface (ft bgs; Golder 2021). As a part of that investigation, soil and groundwater samples were submitted to SiREM laboratories (Guelph, ON) for batch solid/liquid partitioning testing. A summary of the soil samples used for the batch testing is provided in Table 1.

Golder Associates USA Inc
18300 NE Union Hill Road, Suite 200, Redmond, Washington, USA 98052 T: +1 425 883-0777 F: +1 425 882-5498

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Table 1: Batch Attenuation Testing Data Summary

Groundwater Sample ID	Soil Sample ID	Soil: Water Ratio
APW-04	N-SB-05 (60.0-67.1 ft bgs)	2:1
		1:1
		1:5
		1:10
		1:20
APW-14	N-SB-04 (12.0-18.0 ft bgs)	2:1
		1:1
		1:5
		1:10
		1:20

Notes:

1) Ft bgs – Feet below ground surface

Site-specific partitioning coefficients were determined for constituents of interest (COIs) lithium and sulfate, identified based on statistical evaluation of potential groundwater exceedances calculated at the Site (Burns and McDonnell 2021). Site-specific partitioning coefficients were also determined for boron for its potential use in groundwater modeling, despite not being detected at statistically significant levels above the site GWPS. Two groundwater samples (APW-04 and APW-14) and two soil samples (N-SB-05 60.0-67.1 ft bgs and N-SB-04 12.0-18.0 ft bgs) were used for batch attenuation testing at various ratios (Table 1). For each treatment, 0.1 L of groundwater was brought in contact with an amount of soil (0.004 to 0.2 kg, dependent on the ratio) over a seven-day period. Each contact water/soil microcosm was amended (spiked) with meta-arsenite, boric acid, lithium chloride, and sodium sulfate to a target concentration of arsenic, boron, lithium, and sulfate, respectively (Table 2). After the seven-day contact period, COI and boron concentrations were analyzed in the contact water. The control samples (i.e., groundwater samples APW-04 and APW-14) were only analyzed at the initiation of testing. The oxidation/reduction potential (redox) and pH were measured for each batch test at the beginning and end of the contact period and in the control samples. Arsenic is not currently a COI at the Site and, therefore, was not evaluated as part of this report. However, arsenic may be revisited in the future, thus meta-arsenite was included as an amendment (Table 2).

Table 2: Microcosm amendment and target concentration for COIs

COI	Groundwater Sample	Amendment	Target Concentration (mg/L)
Arsenic	APW-04	346.80 µL of a 2 g/L As(III) solution	0.2
	APW-14	344.72 µL of a 2 g/L As(III) solution	
Boron	APW-04	11.40 mL of a 10 g/L H_3BO_3 solution	10

	APW-14	11.32 mL of a 10 g/L H_3BO_3 solution	
Lithium	APW-04	3.40 mL of a 1 g/L LiCl solution	0.3
	APW-14	3.39 mL of a 1 g/L LiCl solution	
Sulfate	APW-04	12.20 mL of a 100 g/L Na_2SO_4 solution	774
	APW-14	24.41 mL of a 100 g/L Na_2SO_4 solution	

Notes:

1) g/L – grams per liter
2) mL – milliliter
3) µg/L – micrograms per liter
4) mg/L – milligrams per liter
5) As(III) – arsenite
6) H_3BO_3 – boric acid
7) LiCl – lithium chloride
8) Na_2SO_4 – sodium sulfate

The results of batch attenuation testing (Tables 3 and 4) were used to calculate the following adsorption isotherms for each COI:

- Linear: $q_e = K_D * C_e$
- Langmuir: $C_e/q_e = 1/(K_L * q_m) + C_e/q_m$
- Freundlich: $\log(q_e) = \log(K_F) + (1/n)\log(C_e)$

Where

K_D, K_L, and K_F = the linear, Langmuir, and Freundlich partition coefficients, respectively (in liters per kilogram; L/kg).

q_e = concentration of the adsorbate in soil

C_e = aqueous concentration of the adsorbate

q_m = 1/slope in the linear expression of the isotherm

n = non-linearity constant

3.0 SUMMARY OF RESULTS

Figures that show the linear, Langmuir, and Freundlich isotherms for each COI are provided in Appendix A. The partition coefficient values for APW-04 and APW-14 are presented in Tables 5 and 6, respectively. The results of the batch adsorption testing can be summarized as follows:

- **Boron**: Calculated K_D values for APW-04 and APW-14 were -1.35 and -0.89 L/kg, respectively, K_L values -6.2E+4 and -1.6E+5 L/kg, respectively, and K_F values 57.4 and 68.7 L/kg, respectively. For comparison, in Strenge and Peterson (1989), partition coefficients for boron range from 0.19 to 1.3 L/kg, depending

on pH conditions and the amount of sorbent (i.e. clay, organic matter, and iron and aluminum oxyhydroxide) present.

- **Lithium:** Calculated K_D values for APW-04 and APW-14 were 4.49 and 5.58 L/kg, respectively, K_L values 6.2E+7 and 1.6E+8 L/kg, respectively, and K_F values 135 and 230 L/kg, respectively. In Strenge and Peterson (1989), partition coefficients for lithium range from 0 to 0.8 L/kg, depending on pH conditions and the amount of sorbent present.
- **Sulfate**: Calculated K_D values for APW-04 and APW-14 were 3.58 and -25.6 L/kg, respectively, K_L values -626 and -2,200 L/kg, respectively, and K_F values 4.11 and 2.14E+11 L/kg, respectively. In Strenge and Peterson (1989), partition coefficients for sulfate are 0.0 L/kg, regardless of pH conditions and the amount of sorbent present.
- **pH and Redox**: Generally, after the seven-day contact time, the pH of each contact water was consistent with the pH of the control samples (7.03 and 7.00 for APW-04 and APW-14, respectively), ranging from 7.02 to 7.06 across the batch tests. The average redox values of the control samples after the seven-day contact time were 40 mV and -26 mV for APW-04 and APW-14, respectively. The redox value of contact water ranged from -111 to +40 mV across treatments.

4.0 REFERENCES

Burns and McDonnell, 2021. Initial Operating Permit Newton Ash Pond.

Golder Associates Inc. 2021. Technical Memorandum: Monitored Natural Attenuation Field Investigation Status Update, Primary Ash Pond (CCR Unit 501) Newton Power Plant, Jasper County, Illinois.

Strenge, D. and Peterson, S. 1989. Chemical Data Bases for the Multimedia Environmental Pollutant Assessment System (MEPAS) (No. PNL-7145). Pacific Northwest Lab., Richland, WA (USA).

5.0 CLOSING

Golder appreciates the opportunity to serve as your consultant on this project. If you have any questions concerning this technical memorandum or need additional information, please contact the undersigned.

Golder Associates USA Inc.





Jeffrey Ingram
Senior Consultant, Geologist

Pat Behling
Practice Leader

CK/JSI/PJB

Attachments Appendix A – Partition Coefficient Graphs

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Table 3: Batch Attenuation Testing Results, APW-04

Geologic Material Sample ID	Treatment	Date	Day	Replicate	Dissolved Boron	Dissolved Lithium	Dissolved Sulfate	pH	ORP
					mg/L	mg/L	mg/L	SU	mV
N-SB-05 (60.0-67.1 ft bgs)	Groundwater Only Control	2/15/2022	0	APW-04-1a	9.2	0.28	1,097	6.92	2
				APW-04-2a	9.5	0.29	1,077	6.92	29
				Average Concentration (mg/L)	9.3	0.28	1,087	6.92	16
		2/22/2022	7	APW-04-1	9.2	0.26	721	7.02	67
				APW-04-2	9.4	0.25	407	7.04	13
				Average Concentration (mg/L)	9.3	0.26	564	7.03	40
	2:1 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-05-(60.0-67.1) :APW-04 2:1-1	5.9	<0.10	440	7.02	-20
				N-SB-05-(60.0-67.1) :APW-04 2:1-2	5.8	<0.10	463	7.02	-43
				Average Concentration (mg/L)	5.9	ND	451	7.02	-32
	1:1 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-05-(60.0-67.1) :APW-04 1:1-1	7.2	0.13	807	7.02	-49
				N-SB-05-(60.0-67.1) :APW-04 1:1-2	7.4	0.14	740	7.02	-48
				Average Concentration (mg/L)	7.3	0.14	773	7.02	-49
	1:5 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-05-(60.0-67.1) :APW-04 1:5-1	8.6	0.17	813	7.04	-40
				N-SB-05-(60.0-67.1) :APW-04 1:5-2	9.6	0.24	788	7.02	-70
				Average Concentration (mg/L)	9.1	0.21	800	7.03	-55
	1:10 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-05-(60.0-67.1) :APW-04 1:10-1	10	0.26	889	7.02	-92
				N-SB-05-(60.0-67.1) :APW-04 1:10-2	9.6	0.25	996	7.02	-52
				Average Concentration (mg/L)	10	0.26	943	7.02	-72
	1:20 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-05-(60.0-67.1) :APW-04 1:20-1	9.2	0.24	776	7.03	-27
				N-SB-05-(60.0-67.1) :APW-04 1:20-2	8.9	0.23	1,212	7.02	-5
				Average Concentration (mg/L)	9.1	0.24	994	7.03	-16

Notes:
1) mg/L- Miligrams per liter
2) SU - Standard Units
3) mV - milivolts
4) ORP - Oxidation Reduction Potential
5) ND - non-detect

Table 4: Batch Attenuation Testing Results, APW-14

Geologic Material Sample ID	Treatment	Date	Day	Replicate	Dissolved Boron	Dissolved Lithium	Dissolved Sulfate	pH	ORP
					mg/L	mg/L	mg/L	SU	mV
N-SB-04 (12.0-18.0 ft bgs)	Groundwater Only Control	2/15/2022	0	APW-14-1a	9.5	0.28	1,010	6.99	17
				APW-14-2a	9.6	0.28	1,004	6.99	4
				Average Concentration (mg/L)	9.5	0.28	1,007	6.99	11
		2/22/2022	7	APW-14-1	9.2	0.25	1,366	7.00	-28
				APW-14-2	10.0	0.25	773	7.00	-24
				Average Concentration (mg/L)	9.6	0.25	1,069	7.00	-26
	2:1 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-04-(12.0-18.0) :APW-14 2:1-1	5.6	<0.10	773	7.02	-72
				N-SB-04-(12.0-18.0) :APW-14 2:1-2	5.6	<0.10	938	7.02	-150
				Average Concentration (mg/L)	5.6	ND	856	7.02	-111
	1:1 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-04-(12.0-18.0) :APW-14 1:1-1	7.2	0.15	853	7.03	-47
				N-SB-04-(12.0-18.0) :APW-14 1:1-2	7.0	0.13	630	7.04	35
				Average Concentration (mg/L)	7.1	0.14	741	7.04	-6
	1:5 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-04-(12.0-18.0) :APW-14 1:5-1	10.2	0.26	716	7.06	53
				N-SB-04-(12.0-18.0) :APW-14 1:5-2	8.9	0.20	1,081	7.05	17
				Average Concentration (mg/L)	9.6	0.23	899	7.06	35
	1:10 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-04-(12.0-18.0) :APW-14 1:10-1	10	0.22	914	7.05	21
				N-SB-04-(12.0-18.0) :APW-14 1:10-2	9.7	0.23	998	7.06	34
				Average Concentration (mg/L)	10	0.23	956	7.06	28
	1:20 Soil:Water Ratio	2/15/2022	0						
		2/22/2022	7	N-SB-04-(12.0-18.0) :APW-14 1:20-1	9.8	0.26	650	7.08	41
				N-SB-04-(12.0-18.0) :APW-14 1:20-2	9.0	0.24	724	7.04	38
				Average Concentration (mg/L)	9.4	0.25	687	7.06	40

Notes:
1) mg/L- Miligrams per liter
2) SU - Standard Units
3) mV - milivolts
4) ORP - Oxidation Reduction Potential
5) ND - non-detect

Table 5: Partition Coefficient Results, APW-04

Analyte	Isotherm	Variable	With Soil Mass
Boron	Raw Data R^2		0.16
	Linear K_D (L/kg)		-1.35
	Langmuir	R^2	0.03
		q_m (mg/g)	-0.003
		K_L (L/kg)	-6.23E+04
	Freundlich	R^2	0.01
		1/n	0.379
		K_F (L/kg)	57.39
Lithium	Raw Data R^2		0.20
	Linear K_D (L/kg)		4.49
	Langmuir	R^2	0.94
		q_m (mg/g)	0.009
		K_L (L/kg)	6.16E+07
	Freundlich	R^2	0.23
		1/n	0.101
		K_F (L/kg)	135.83
Sulfate	Raw Data R^2		0.62
	Linear K_D (L/kg)		3.58
	Langmuir	R^2	0.13
		q_m (mg/g)	-0.999
		K_L (L/kg)	-6.26E+02
	Freundlich	R^2	0.53
		1/n	1.924
		K_F (L/kg)	4.11

Note(s):

K_D: linear partition coefficient

K_L: Langmuir partition coefficient

K_F: Freundlich partition coefficient

q_m: 1/slope in the linear expression of the isotherm

n: non-linearity constant

Table 6: Partition Coefficient Results, APW-14

Analyte	Isotherm	Variable	With Soil Mass
Boron	Raw Data R^2		0.37
	Linear K_D (L/kg)		-0.89
	Langmuir	R^2	0.18
		q_m (mg/g)	0.000
		K_L (L/kg)	-1.56E+05
	Freundlich	R^2	0.99
		1/n	0.280
		K_F (L/kg)	68.65
Lithium	Raw Data R^2		0.57
	Linear K_D (L/kg)		5.58
	Langmuir	R^2	1.00
		q_m (mg/g)	0.034
		K_L (L/kg)	1.55E+08
	Freundlich	R^2	0.54
		1/n	0.031
		K_F (L/kg)	230.83
Sulfate	Raw Data R^2		0.47
	Linear K_D (L/kg)		-25.60
	Langmuir	R^2	0.07
		q_m (mg/g)	0.166
		K_L (L/kg)	-2.20E+03
	Freundlich	R^2	0.33
		1/n	-6.626
		K_F (L/kg)	2.14E+11

Note(s):

K_D: linear partition coefficient

K_L: Langmuir partition coefficient

K_F: Freundlich partition coefficient

q_m: 1/slope in the linear expression of the isotherm

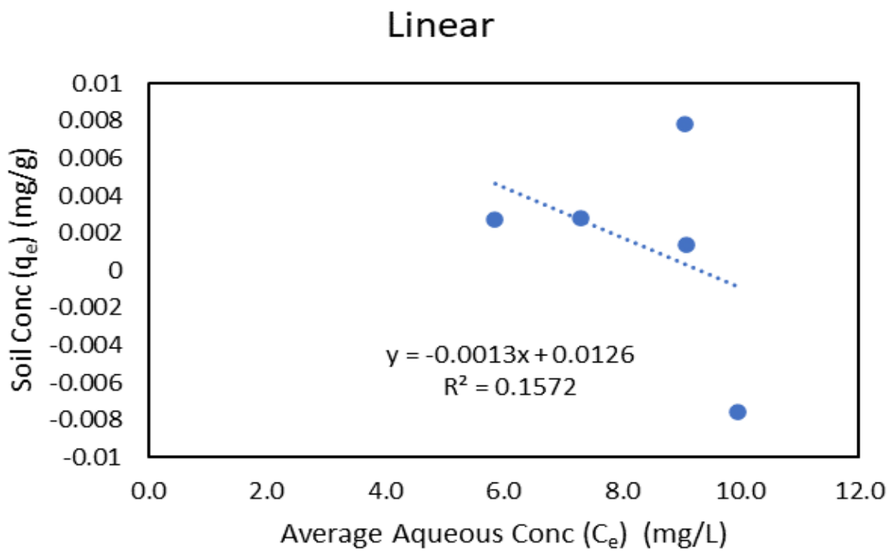
n: non-linearity constant

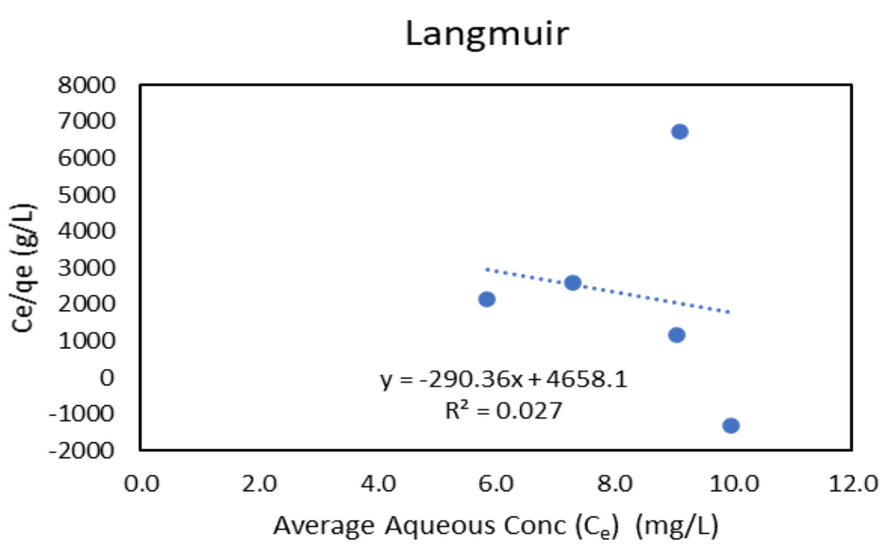
Electronic Filing: Received, Clerk's Office 07/01/2024

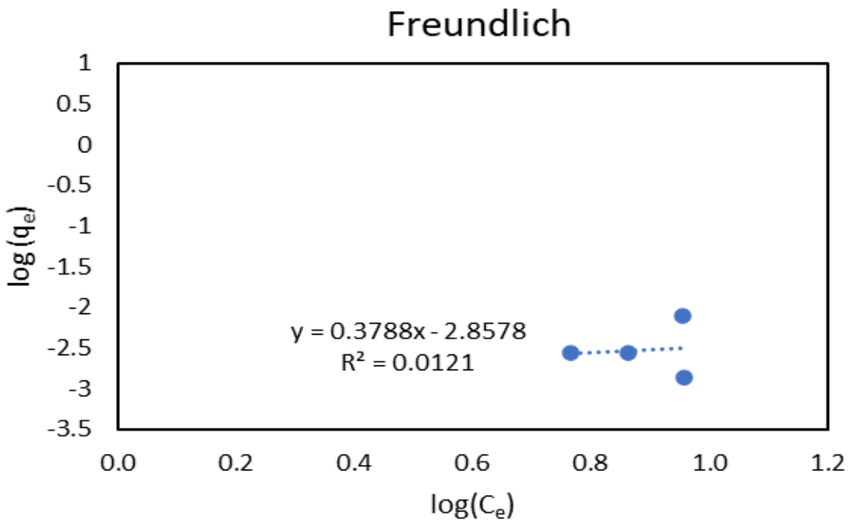
APPENDIX A

Partition Coefficient Graphs

PATH: https://golderassociates.sharepoint.com/sites/141767/Project Files/6 Deliverables/Phase4 - Newton/Kd Tech Memo | FILE NAME: Appendix A.xlsx







Note(s):
mg/L: milligrams per liter
mg/g: milligrams per gram
g/L: grams per liter
Ce: aqueous concentration of the adsorbate
qe: concentration of the adsorbate in soil

CLIENT
ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

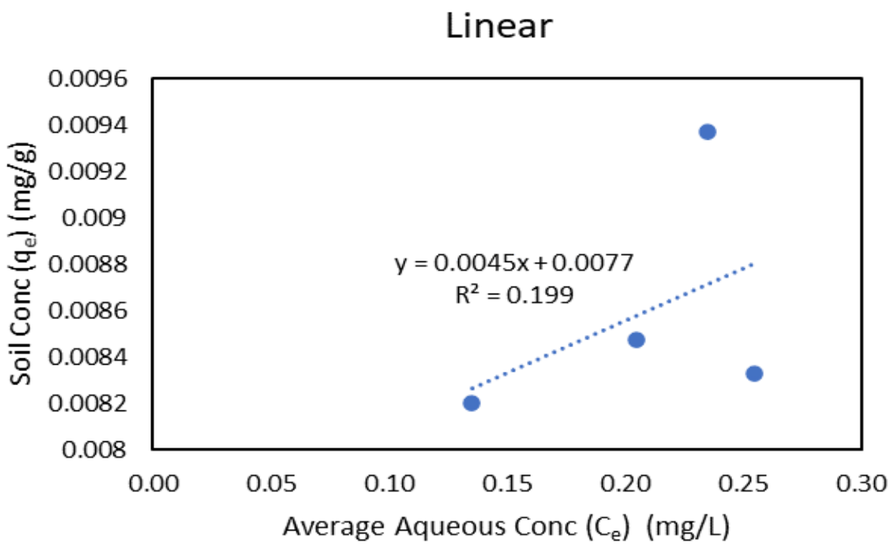
PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

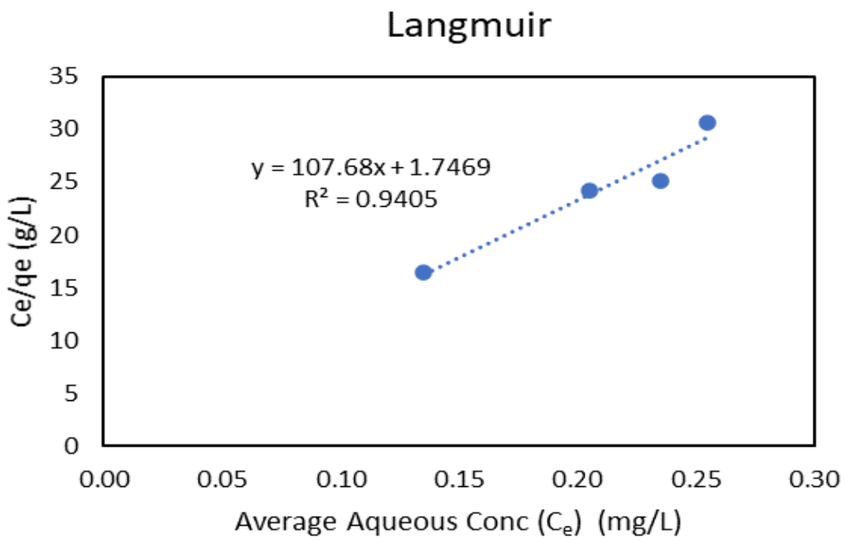
CONSULTANT
wsp GOLDER

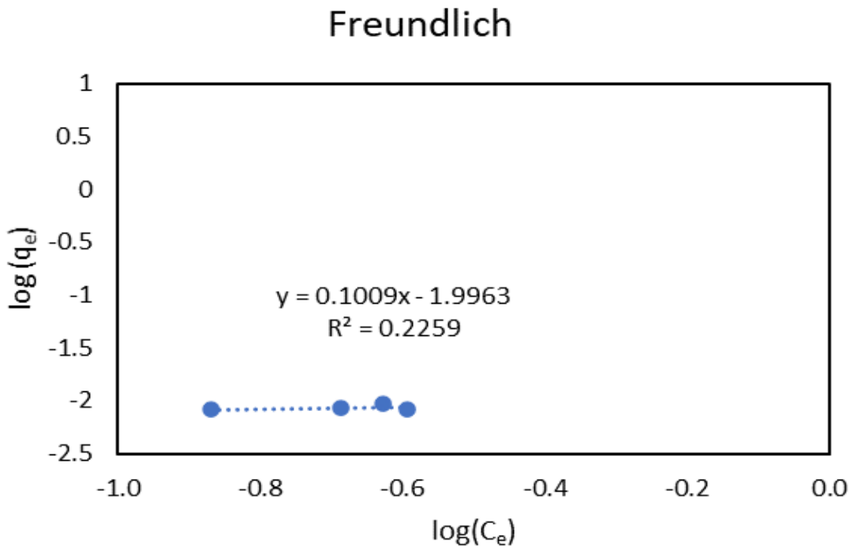
TITLE
APW-04 BORON PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-1

PATH: https://golderassociates.sharepoint.com/sites/141767/Project Files/6 Deliverables/Phase4 - Newton/Kd Tech Memo | FILE NAME: Appendix A.xlsx







Note(s):
mg/L: milligrams per liter
mg/g: milligrams per gram
g/L: grams per liter
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qe: concentration of the adsorbate in soil

CLIENT
ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

CONSULTANT
wsp GOLDER

TITLE
APW-04 LITHIUM PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-2

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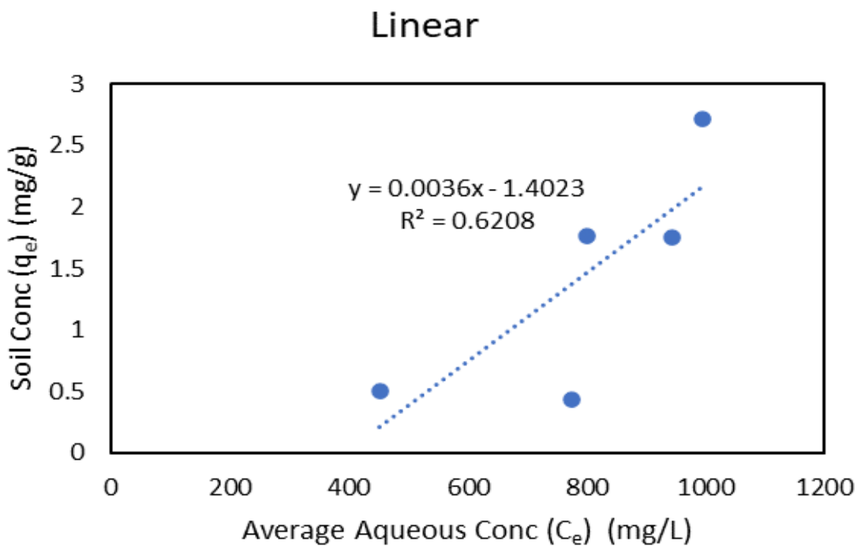

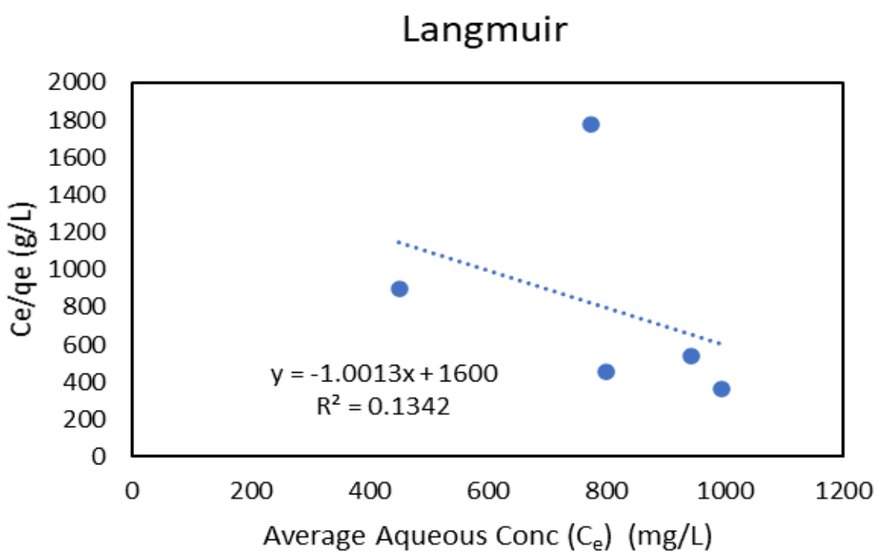

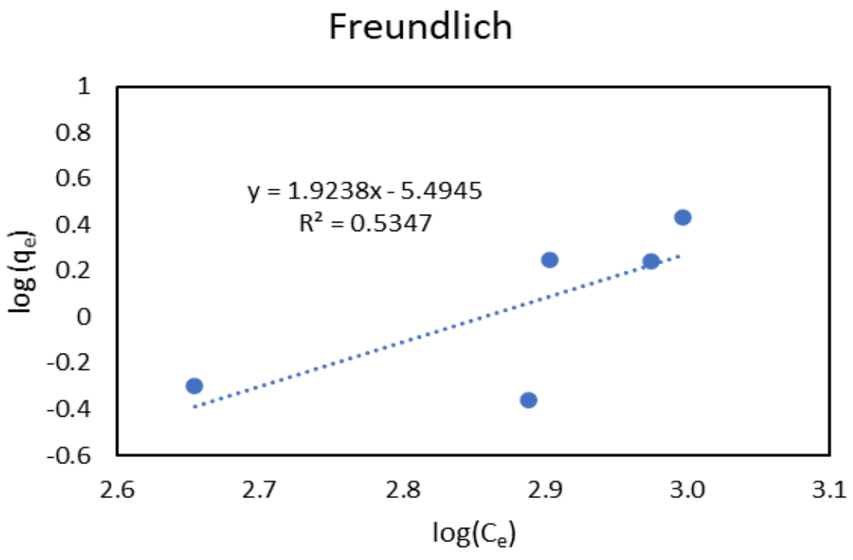

Note(s):
mg/L: milligrams per liter
mg/g: milligrams per gram
g/L: grams per liter
Ce: aqueous concentration of the adsorbate
qe: concentration of the adsorbate in soil

CLIENT
ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

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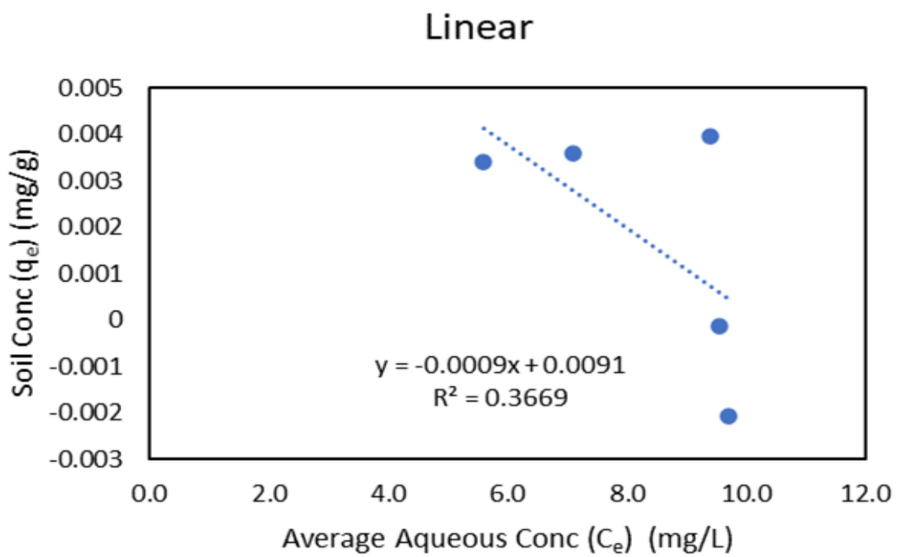
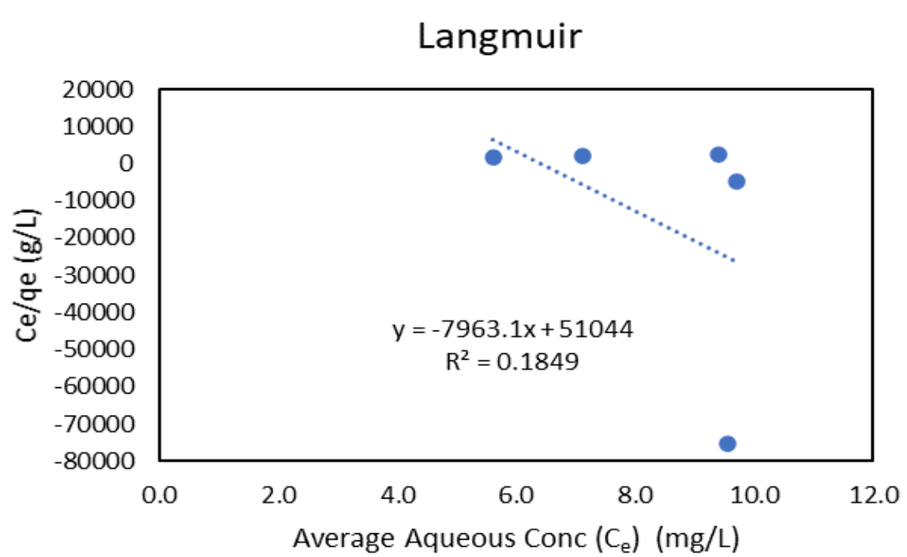
PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

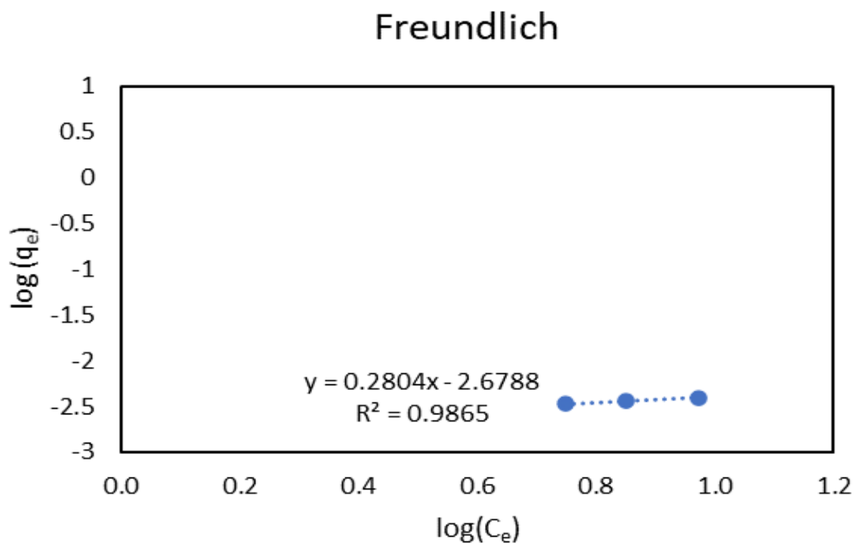
TITLE
APW-04 SULFATE PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-3

PATH: https://golderassociates.sharepoint.com/sites/141767/Project Files/6 Deliverables/Phase4 - Newton/Kd Tech Memo | FILE NAME: Appendix A.xlsx







Note(s):
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mg/g: milligrams per gram
g/L: grams per liter
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CLIENT
ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

CONSULTANT
wsp GOLDER

TITLE
APW-14 BORON PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-4

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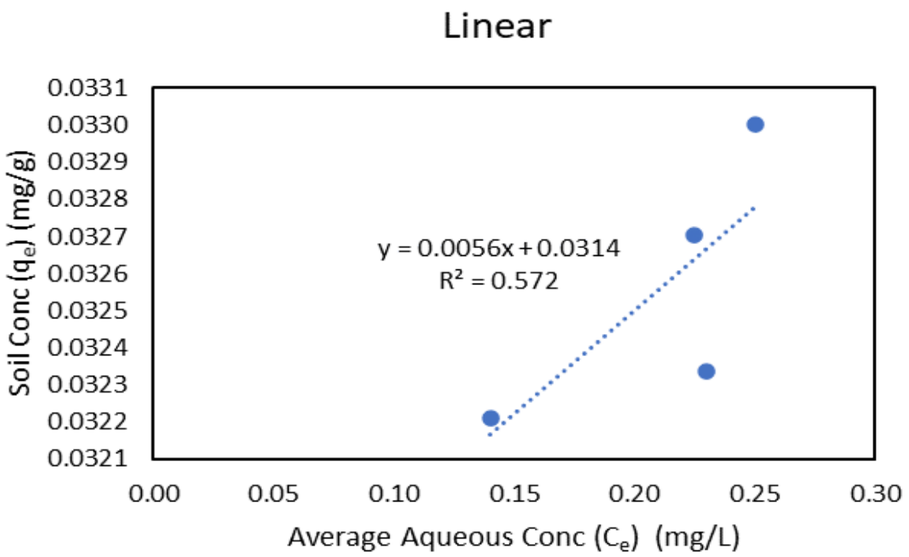

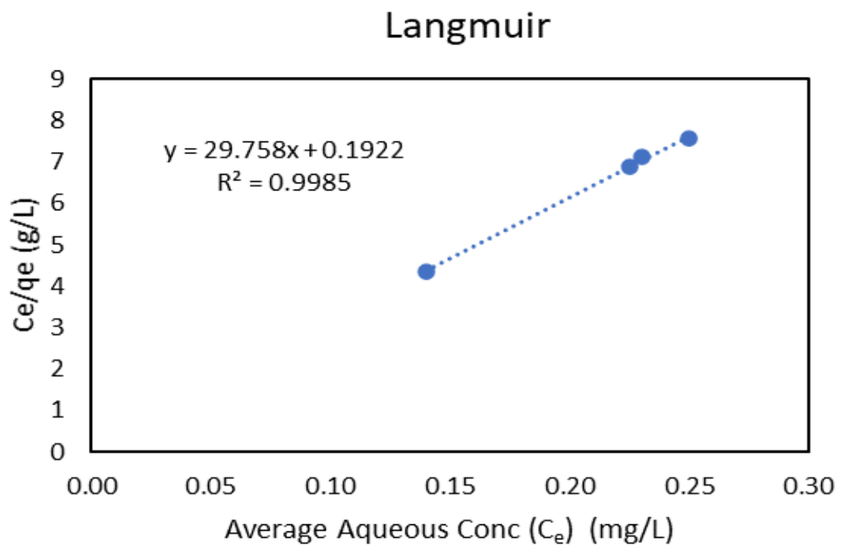

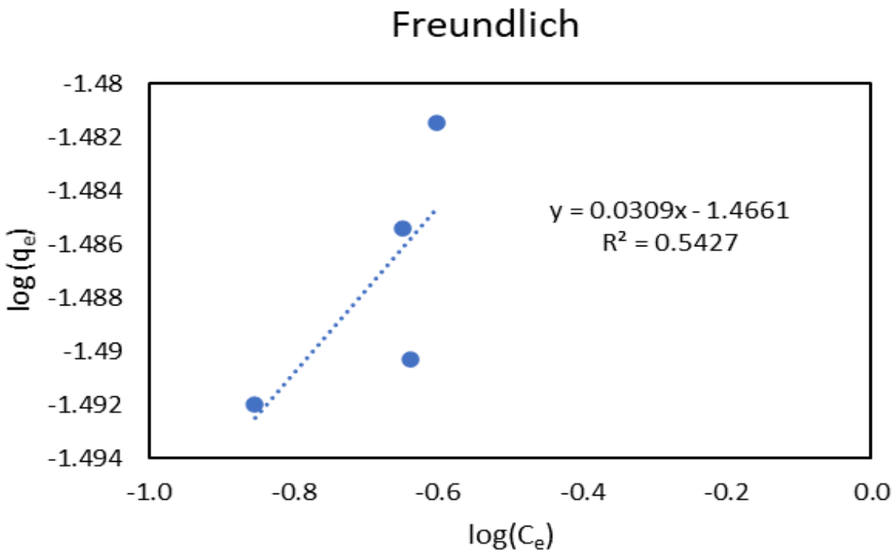

Note(s):
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CLIENT
ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

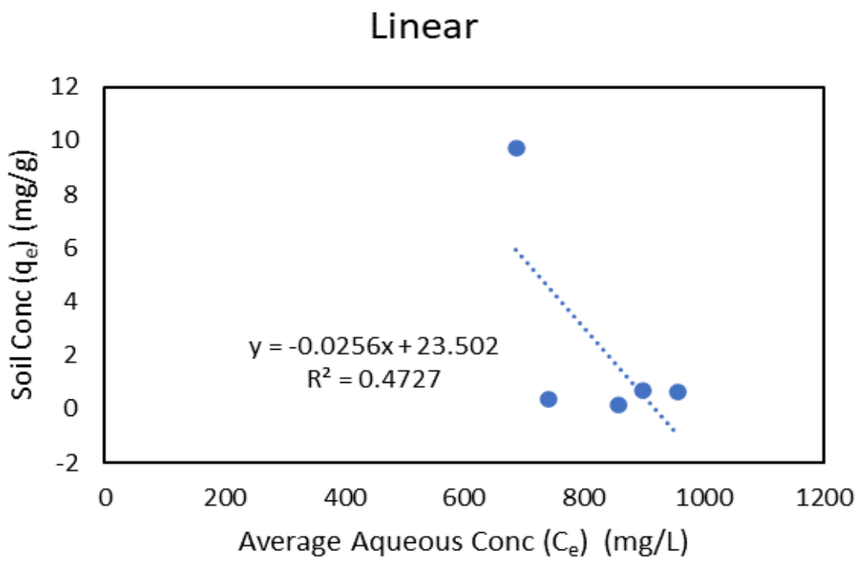
PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

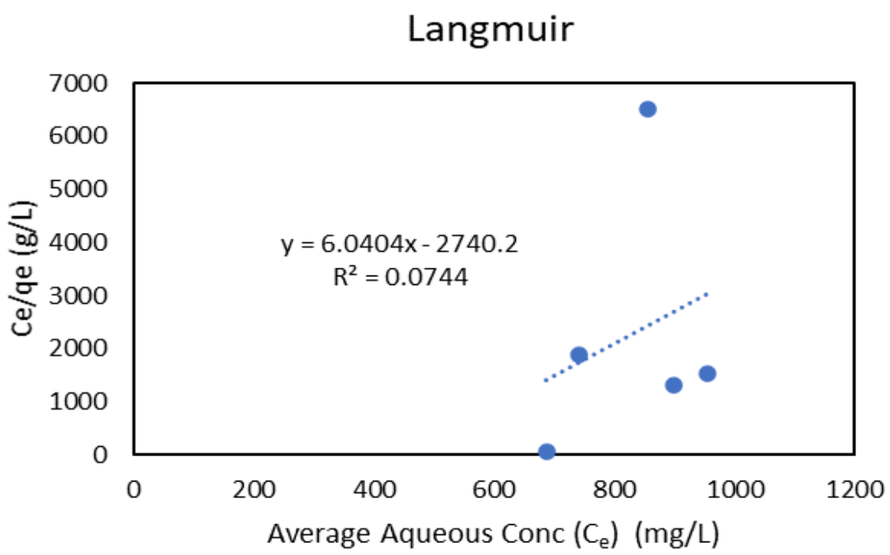
CONSULTANT
wsp GOLDER

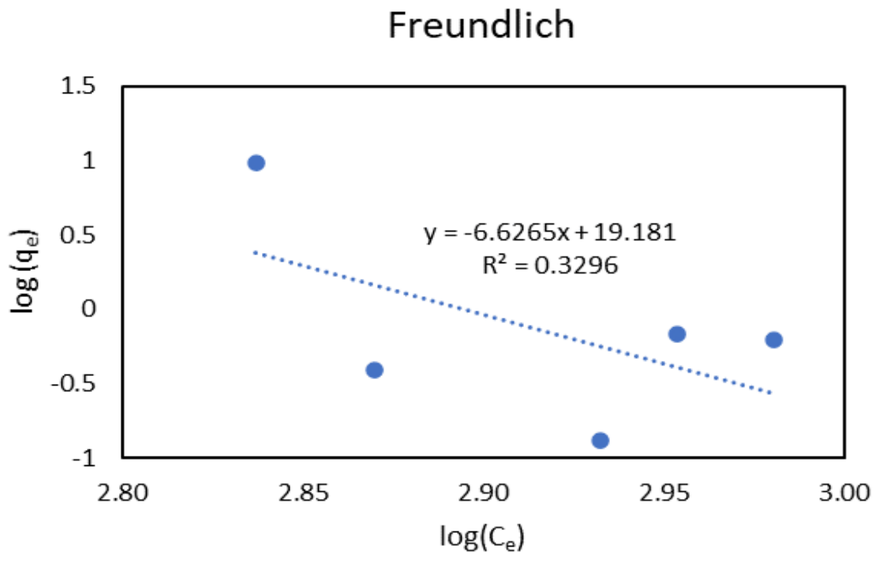
TITLE
APW-14 LITHIUM PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-5

PATH: https://golderassociates.sharepoint.com/sites/141767/Project Files/6 Deliverables/Phase4 - Newton/Kd Tech Memo | FILE NAME: Appendix A.xlsx







Note(s):
mg/L: milligrams per liter
mg/g: milligrams per gram
g/L: grams per liter
Ce: aqueous concentration of the adsorbate
qe: concentration of the adsorbate in soil

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ILLINOIS POWER GENERATING COMPANY
NEWTON PRIMARY ASH POND (CCR UNIT 501)

CONSULTANT
wsp GOLDER

PROJECT
EVALUATION OF PARTITION COEFFICIENT RESULTS PAP

TITLE
APW-14 SULFATE PARTITION COEFFICIENTS

PROJECT NO.	PHASE	REV.	FIGURE
21454831	0004	0	A-6

APPENDIX D
HELP MODEL OUTPUT FILES

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP CBR **Simulated On:** 4/15/2022 8:55

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)

Silty Clay

Material Texture Number 43

Thickness	=	60	inches
Porosity	=	0.452	vol/vol
Field Capacity	=	0.411	vol/vol
Wilting Point	=	0.311	vol/vol
Initial Soil Water Content	=	0.4381	vol/vol
Effective Sat. Hyd. Conductivity	=	1.45E-06	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	88.7	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	413.3	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	7.651	inches
Upper Limit of Evaporative Storage	=	8.136	inches
Lower Limit of Evaporative Storage	=	5.598	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	26.284	inches
Total Initial Water	=	27.854	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days
End of Growing Season (Julian Date)	=	300	days

Average Wind Speed	=	8 mph
Average 1st Quarter Relative Humidity	=	73 %
Average 2nd Quarter Relative Humidity	=	71 %
Average 3rd Quarter Relative Humidity	=	75 %
Average 4th Quarter Relative Humidity	=	75 %

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 4/15/2022 8:57

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	69,740,858.4	100.00
Runoff	12.610	[4.666]	18,918,136.8	27.13
Evapotranspiration	29.590	[2.377]	44,393,677.7	63.66
Subprofile1				
Percolation/leakage through Layer 1	4.380870	[1.077458]	6,572,527.9	9.42
Water storage				
Change in water storage	-0.0956	[1.0769]	-143,483.9	-0.21

* Note: Average inches are converted to volume based on the user-specified area.

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP CIP Rem Simulated On: 15/04/2022 09:58

Layer 1
Type 1 - Vertical Percolation Layer (Cover Soil)
Silty Clay
Material Texture Number 43

Thickness	=	60	inches
Porosity	=	0.452	vol/vol
Field Capacity	=	0.411	vol/vol
Wilting Point	=	0.311	vol/vol
Initial Soil Water Content	=	0.4381	vol/vol
Effective Sat. Hyd. Conductivity	=	1.45E-06	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	88.9	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	148.3	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	7.652	inches
Upper Limit of Evaporative Storage	=	8.136	inches
Lower Limit of Evaporative Storage	=	5.598	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	26.285	inches
Total Initial Water	=	27.855	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days
End of Growing Season (Julian Date)	=	300	days

Average Wind Speed	=	8 mph
Average 1st Quarter Relative Humidity	=	73 %
Average 2nd Quarter Relative Humidity	=	71 %
Average 3rd Quarter Relative Humidity	=	75 %
Average 4th Quarter Relative Humidity	=	75 %

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 15/04/2022 10:00

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	25,024,363.2	100.00
Runoff	12.733	[4.682]	6,854,402.4	27.39
Evapotranspiration	29.555	[2.373]	15,910,257.1	63.58
Subprofile1				
Percolation/leakage through Layer 1	4.293314	[1.064874]	2,311,215.5	9.24
Water storage				
Change in water storage	-0.0957	[1.0763]	-51,511.8	-0.21

* Note: Average inches are converted to volume based on the user-specified area.

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP CIP Cons Simulated On: 15/04/2022 10:12

Layer 1
Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.2475	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2
Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	18	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.3706	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3
Type 2 - Lateral Drainage Layer
Drainage Net (0.5 cm)
Material Texture Number 20

Thickness	=	0.2	inches
Porosity	=	0.85	vol/vol
Field Capacity	=	0.01	vol/vol
Wilting Point	=	0.005	vol/vol
Initial Soil Water Content	=	0.0581	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E+01	cm/sec
Slope	=	2	%
Drainage Length	=	1500	ft

Layer 4

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness	=	0.04	inches
Effective Sat. Hyd. Conductivity	=	4.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 5
Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash
Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1871	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	84.4	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	265	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	5.928	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	37.354	inches
Total Initial Water	=	38.924	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days

End of Growing Season (Julian Date)	=	300 days
Average Wind Speed	=	8 mph
Average 1st Quarter Relative Humidity	=	73 %
Average 2nd Quarter Relative Humidity	=	71 %
Average 3rd Quarter Relative Humidity	=	75 %
Average 4th Quarter Relative Humidity	=	75 %

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 15/04/2022 10:15

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	5.561	[3.492]	5,349,478.7	11.96
Evapotranspiration	30.979	[2.74]	29,800,414.9	66.64
Subprofile1				
Lateral drainage collected from Layer 3	9.9514	[2.1689]	9,572,702.5	21.41
Percolation/leakage through Layer 4	0.041772	[0.018348]	40,183.0	0.09
Average Head on Top of Layer 4	1.4441	[0.6401]	---	---
Subprofile2				
Percolation/leakage through Layer 5	0.042250	[0.019041]	40,642.1	0.09
Water storage				
Change in water storage	-0.0486	[1.0288]	-46,743.0	-0.10

* Note: Average inches are converted to volume based on the user-specified area.

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP LF Cons Simulated On: 15/04/2022 09:22

Layer 1
Type 2 - Lateral Drainage Layer
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	4	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.2658	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec
Slope	=	0	%
Drainage Length	=	0	ft

Layer 2
Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PSL
Material Texture Number 43

Thickness	=	32	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.3679	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3
Type 2 - Lateral Drainage Layer
Drainage Net (0.5 cm)
Material Texture Number 20

Thickness	=	0.2	inches
Porosity	=	0.85	vol/vol
Field Capacity	=	0.01	vol/vol
Wilting Point	=	0.005	vol/vol
Initial Soil Water Content	=	0.0394	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E+01	cm/sec
Slope	=	2	%
Drainage Length	=	600	ft

Layer 4
Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness	=	0.04	inches
Effective Sat. Hyd. Conductivity	=	4.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 5
Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash
Material Texture Number 30

Thickness	=	768	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.187	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Layer 6
Type 2 - Lateral Drainage Layer
Granular Drainage Layer
Material Texture Number 44

Thickness	=	12	inches
Porosity	=	0.417	vol/vol
Field Capacity	=	0.045	vol/vol
Wilting Point	=	0.018	vol/vol
Initial Soil Water Content	=	0.045	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-01	cm/sec
Slope	=	2	%
Drainage Length	=	150	ft

Layer 7
Type 4 - Flexible Membrane Liner
HDPE Membrane
Material Texture Number 35

Thickness	=	0.06	inches
Effective Sat. Hyd. Conductivity	=	2.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 8
Type 3 - Barrier Soil Liner
Liner Soil (High)
Material Texture Number 16

Thickness	=	36	inches
Porosity	=	0.427	vol/vol
Field Capacity	=	0.418	vol/vol
Wilting Point	=	0.367	vol/vol
Initial Soil Water Content	=	0.427	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-07	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	85.2	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	11.7	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	6.13	inches
Upper Limit of Evaporative Storage	=	7.192	inches
Lower Limit of Evaporative Storage	=	4.744	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	172.373	inches
Total Initial Water	=	173.943	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days
End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.29

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.29
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.29

Average Annual Totals Summary

Title: Newton LF Cons
Simulated on: 15/04/2022 09:24

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	1,974,275.4	100.00
Runoff	6.157	[3.7]	261,476.2	13.24
Evapotranspiration	30.509	[2.68]	1,295,750.3	65.63
Subprofile1				
Lateral drainage collected from Layer 3	9.8649	[2.3407]	418,972.5	21.22
Percolation/leakage through Layer 4	0.000668	[0.000143]	28.4	0.00
Average Head on Top of Layer 4	0.0143	[0.0034]	---	---
Subprofile2				
Lateral drainage collected from Layer 6	0.0007	[0.0001]	28.3	0.00
Percolation/leakage through Layer 8	0.000003	[0]	0.1064	0.00
Average Head on Top of Layer 7	0.0000	[0]	---	---
Water storage				
Change in water storage	-0.0460	[1.0053]	-1,952.0	-0.10

* Note: Average inches are converted to volume based on the user-specified area.

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP Default **Simulated On:** 7/12/2022 18:17

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.2475	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2

Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	30	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.3718	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3

Type 2 - Lateral Drainage Layer
Drainage Net (0.5 cm)
Material Texture Number 20

Thickness	=	0.2	inches
Porosity	=	0.85	vol/vol
Field Capacity	=	0.01	vol/vol
Wilting Point	=	0.005	vol/vol
Initial Soil Water Content	=	0.092	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E+01	cm/sec
Slope	=	2	%
Drainage Length	=	1500	ft

Layer 4

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness	=	0.04	inches
Effective Sat. Hyd. Conductivity	=	4.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 5

Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash
Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1872	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	84.4	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	265	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	5.92	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	41.857	inches
Total Initial Water	=	43.427	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days

End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: NEW AP Default
Simulated on: 7/12/2022 18:18

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	5.416	[3.469]	5,210,333.7	11.65
Evapotranspiration	30.948	[2.734]	29,770,001.9	66.57
Subprofile1				
Lateral drainage collected from Layer 3	10.1178	[2.2092]	9,732,826.8	21.77
Percolation/leakage through Layer 4	0.053103	[0.027784]	51,082.0	0.11
Average Head on Top of Layer 4	1.8201	[0.9543]	---	---
Subprofile2				
Percolation/leakage through Layer 5	0.054052	[0.028093]	51,994.9	0.12
Water storage				
Change in water storage	-0.0506	[1.0901]	-48,662.0	-0.11

* Note: Average inches are converted to volume based on the user-specified area.

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP Default Earth Simulated On: 27/06/2022 11:01

Layer 1
Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.3858	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2
Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	30	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.4	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3
Type 3 - Barrier Soil Liner
Liner Soil (High)
Material Texture Number 16

Thickness	=	36	inches
Porosity	=	0.427	vol/vol
Field Capacity	=	0.418	vol/vol
Wilting Point	=	0.367	vol/vol
Initial Soil Water Content	=	0.427	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-07	cm/sec

Layer 4
Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash

Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1996	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	84.4	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	265	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	7.115	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	60.819	inches
Total Initial Water	=	62.389	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days
End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec

3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: NEW AP Default Earth
Simulated on: 27/06/2022 11:02

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	12.238	[4.888]	11,772,719.1	26.33
Evapotranspiration	32.236	[2.871]	31,009,280.2	69.35
Subprofile1				
Percolation/leakage through Layer 3	2.070136	[0.059537]	1,991,367.4	4.45
Average Head on Top of Layer 3	23.9878	[1.7467]	---	---
Subprofile2				
Percolation/leakage through Layer 4	1.821708	[0.604523]	1,752,392.2	3.92
Water storage				
Change in water storage	0.1893	[1.099]	182,103.7	0.41

* Note: Average inches are converted to volume based on the user-specified area.

APPENDIX E
FLUX EVALUATION DATA

Appendix E. Flux Evaluation Data

GROUNDWATER MODELING REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, ILLINOIS

Calibration Model

Model	Model Period (years)	HSU	Total Flux In[1] (ft^3/d)	Total Flux In (gpm)
Calibration Model	45	Fill Unit (CCR)	33427.89	173.65
Model	**Model Period (years)**	**HSU**	**Total Flux Out[1] (ft^3/d)**	**Total Flux Out (gpm)**
Calibration Model	45	Fill Unit (CCR)	-33528.40	-174.17

Scenario 1: CIP (CCR removal from the northwest areas of the Ash Pond, consolidation to the northeast, central and southern areas of the Ash Pond, and construction of a cover system over the remaining CCR)

Prediction Model	Construction Period (years)	HSU	Total Flux In[1] (ft^3/d)	Total Flux In (gpm)	Reduction in Flux In Post Closure[2] (Percentage, %)
CIP	182	Fill Unit (CCR)	2125.05	11.04	94%
Prediction Model	**Construction Period (years)**	**HSU**	**Total Flux Out[1] (ft^3/d)**	**Total Flux Out (gpm)**	**Reduction in Flux Out Post Closure[2] (Percentage, %)**
CIP	182	Fill Unit (CCR)	-2137.29	-11.10	94%

[O: SLN 6/27/22; C: BGH 6/29/22]

Notes:

1. Total flux in and out source data provided in flux calculation data files included in Appendix B.
2. Reduction in flux as compared to flux at the end of calibration model (model period of 45 years).

CCR = coal combustion residuals
CIP = Closure In Place
HSU = Hydrostratigraphic Unit
% = percentage
ft^3/d = cubic feet per day
gpm = gallons per minute

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment C

History of Construction Report

AECOM

October 2016

Illinois Power Generating Company
6725 North 500th Street
Newton, IL 62448

RE: History of Construction
USEPA Final CCR Rule, 40 CFR § 257.73(c)
Newton Power Station
Newton, Illinois

On behalf of Illinois Power Generating Company, AECOM has prepared the following history of construction for the Primary Ash Pond at the Newton Power Station in accordance with 40 CFR § 257.73(c).

BACKGROUND

40 CFR § 257.73(c)(1) requires the owner or operator of an existing coal combustion residual (CCR) surface impoundment that either (1) has a height of five feet or more and a storage volume of 20 acre-feet or more, or (2) has a height of 20 feet or more to compile a history of construction by October 17, 2016 that contains, to the extent feasible, the information specified in 40 CFR § 257.73(c)(1)(i)–(xii).

The history of construction presented herein was compiled based on existing documentation, to the extent that it is reasonably and readily available (see 80 Fed. Reg. 21302, 21380 [April 17, 2015]), and AECOM's site experience. AECOM's document review included record drawings, geotechnical investigations, etc. for the Primary Ash Pond at the Newton Power Station.

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HISTORY OF CONSTRUCTION

§ 257.73(c)(1)(i): The name and address of the person(s) owning or operating the CCR unit; the name associated with the CCR unit; and the identification number of the CCR unit if one has been assigned by the state.

Owner: Illinois Power Generating Company

Address: 1500 Eastport Drive
Collinsville, IL 62234

CCR Unit: Primary Ash Pond

The Primary Ash Pond does not have a state assigned identification number.

§ 257.73(c)(1)(ii): The location of the CCR unit identified on the most recent USGS $7^1/_2$ or 15 minute topographic quadrangle map or a topographic map of equivalent scale if a USGS map is not available.

The location of the Primary Ash Pond has been identified on an USGS 7-1/2 minute topographic quadrangle map in **Appendix A**.

§ 257.73(c)(1)(iii): A statement of the purpose for which the CCR unit is being used.

The Primary Ash Pond is being used to store and dispose of bottom ash and economizer ash and to clarify non-CCR plant process wastewater. A portion of the bottom ash is reclaimed from the Primary Ash Pond for beneficial reuse.

§ 257.73(c)(1)(iv): The name and size in acres of the watershed where the CCR unit is located.

The entire Primary Ash Pond and most of the Newton Power Station are located in the Weather Creek Watershed with a 12-digit Hydrologic Unit Code (HUC) of 051201140504 and a drainage area of 31,573 acres. The other portion of the Newton Power Station is located in the Newton Lake Watershed with a 12-digit Hydrologic Unit Code (HUC) of 051201140503 and a drainage area of 967 acres (USGS, 2016).

§ 257.73(c)(1)(v): A description of the physical and engineering properties of the foundation and abutment materials on which the CCR unit is constructed.

The foundation materials consist of upper clay and lower clay. The physical characteristics properties of the upper clay layer are described as lean clay, fat clay, clayey sand, fat clay with sand, lean clay with sand, silty sand, silty clay, silty clay with sand, sandy lean clay. The upper clay soils exhibit a stiff to hard consistency. The physical characteristics of the lower clay layer are described as glacial till consisting of sandy lean clay, silty sand, clayey silt with sand, silty clay with sand, well graded sand with silt, lean clay, fat clay, clayey sand, silty clay, lean clay with sand, clayey sand with silt, and fat clay with sand. The consistency of the lower clay is very stiff to hard. A summary of the available engineering properties of the

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foundation materials is presented in **Table 1** below. The engineering properties are based on previous geotechnical explorations and laboratory testing.

Table 1. Summary of Foundation Material Engineering Properties

Material	Unit Weight (pcf)	Effective (drained) Shear Strength Parameters		Total (undrained) Shear Strength Parameters	
		Effective Friction Angle ϕ′ (deg)	Effective Cohesion c′ (psf)	S_u/σ'_c	Minimum C_u (psf)
Upper Clay	130	29	0	0.40 ($\sigma'_c \geq$ 2,000 psf) 0.63 ($\sigma'_c <$ 2,000 psf)	-
Lower Clay	130	33	3,700	-	5,000

The Primary Ash Pond is an enclosed impoundment with embankments and does not have abutments.

§ 257.73(c)(1)(vi): A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR unit; the method of site preparation and construction of each zone of the CCR unit; and the approximate dates of construction of each successive stage of construction of the CCR unit.

Physical properties for the embankment are described as lean clay, lean clay with sand, silty clay, silty clay with sand, sandy lean clay, fat clay, fat clay with gravel and sand, fat clay with sand and silt, fat clay with sand, and clayey silt. An available summary of the engineering properties of the Primary Ash Pond embankment is presented in **Table 2** below. The engineering properties are based on previous geotechnical explorations and laboratory testing.

Table 2. Summary of Construction Material Engineering Properties

Material	Unit Weight (pcf)	Drained Strength		Undrained Strength
		Effective Friction Angle ϕ′ (deg)	Effective Cohesion c′ (psf)	S_u/σ'_c
Embankment Fill	130	31	0	0.41 ($\sigma'_c \geq$ 500 psf) 1.39 ($\sigma'_c <$ 500 psf)

The method of site preparation and construction of the Primary Ash Pond is not reasonably and readily available.

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The approximate dates of construction of each successive stage of construction of the Primary Ash Pond are provided in **Table 3** below.

Table 3. Approximate dates of construction of each successive stage of construction.

Date	Event
1977	Construction of Primary Ash Pond
2009	Both Primary Ash Pond discharge pipes were lined with cured-in-place pipe (CIPP)
2014	Three areas along the interior berm were re-graded and covered with rip-rap

§ 257.73(c)(1)(vii): At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit, detailed dimensional drawings of the CCR unit, including a plan view and cross sections of the length and width of the CCR unit, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation.

Drawings that contain items pertaining to the requested information for the Primary Ash Pond are listed in **Table 4** below. Items marked as "Not Available" are items not found during a review of the reasonably and readily available record documentation.

AECOM

Table 4. List of drawings containing items pertaining to the information requested in § 257.73(c)(1)(vii).

	Primary Ash Pond
Dimensional plan view (all zones)	S-69
Dimensional cross sections	S-70
Foundation Improvements	Not Applicable
Drainage Provisions	Not Applicable
Spillways and Outlets	S-50
Diversion Ditches	Not Applicable
Instrument Locations	Plate 2, Fig. No. 2A
Slope Protection	S-70
Normal Operating Pool Elevation	Not Available
Maximum Pool Elevation	Not Available
Approximate Maximum Depth of CCR in 2016	49 feet

All drawings referenced in **Table 4** above can be found in **Appendix B** and **Appendix C**.

Based on the review of the drawings listed above, no natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation were identified.

§ 257.73(c)(1)(viii): A description of the type, purpose, and location of existing instrumentation.

Existing instrumentation at the Primary Ash Pond include vibrating-wire and open-standpipe piezometers. The purpose of the piezometers is to measure the pore water pressures within and around the impoundment. Two (2) open-standpipe piezometers (B-2 and B-3) were installed in 2010 and the locations are presented on Plate 2 in **Appendix C**. Fourteen (14)

vibrating-wire piezometers were installed in 2015 and the locations are presented on Figure 2A in **Appendix C**.

§ 257.73(c)(1)(ix): Area-capacity curves for the CCR unit.

Area-capacity curves for the Primary Ash Pond are not reasonably and readily available.

§ 257.73(c)(1)(x): A description of each spillway and diversion design features and capacities and calculations used in their determination.

The Primary Ash Pond contains two concrete, stop-log weir box structures that discharge to the Secondary Pond. Weir box 1-A is located at the bottom of the embankment and is connected to the lower 30-inch diameter (dia.) cured-in-place pipe (CIPP). Weir Box 1-B is located approximately halfway up the embankment is connected to the upper 30-inch dia. CIPP. Both discharge pipes were originally 30-inch dia. corrugated metal pipe (CMP) and were lined in 2008 (see section § 257.73(c)(1)(xii) below for further information). The lower discharge pipe from weir box 1A passes through the embankment between the Primary Ash Pond and Secondary Pond. The upper discharge pipe from weir box 1B connects to the lower discharge pipe within the embankment. In 2016, the discharge capacity of the Primary Ash Pond was evaluated using HydroCAD 10 software modeling a 1,000-year, 24-hour rainfall event. The results of the HydroCAD 10 analysis are presented below in **Table 5**.

Table 5. Results of HydroCAD 10 analyses

	Primary Ash Pond
Approximate Minimum Berm Elevation[1] (ft)	552.7
Approximate Emergency Spillway Elevation[1] (ft)	Not Applicable
Starting Pool Elevation[1] (ft)	534.0
Peak Elevation[1] (ft)	534.9
Time to Peak (hr)	17.0
Surface Area (ac)	169.0
Storage[2] (ac-ft)	159.4

Note: 1. Elevations are based on NAVD88 datum
2. Storage given is from Starting Pool Elevation to Peak Elevation.

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§ 257.73(c)(1)(xi): The construction specifications and provisions for surveillance, maintenance, and repair of the CCR unit.

The construction specifications for the Primary Ash Pond are not reasonably and readily available.

The provisions for surveillance, maintenance, and repair of the Primary Ash Pond are located in *Operation and Maintenance Manual for Primary and Secondary Ash Ponds* (presented in **Appendix D**).

The operations and maintenance plan for the Primary Ash Pond is currently being revised by Illinois Power Generating Company. This section will be updated when the new operations and maintenance plan is available.

§ 257.73(c)(1)(xii): Any record or knowledge of structural instability of the CCR unit.

In September, 2008, a sinkhole was observed over the Primary Ash Pond discharge pipes. After performing a video inspection, it is believed that an open joint in the primary 30-inch dia. CMP discharge pipe allowed for soil to enter the discharge pipe and cause an internal void in the embankment. The sinkhole was backfilled and compacted with soil and a cured-in-place pipe (CIPP) was installed in both the upper and lower discharge pipes to prevent further internal erosion to the embankment. Following completion of the discharge pipe modification, grout was injected at several locations within the sinkhole to ensure any remaining voids were filled surrounding the discharge pipes. Information about this event can be found in the letter presented in **Appendix E**.

There is no record or knowledge of any other structural instability of the Primary Ash Pond at Newton Power Station.

LIMITATIONS

The signature of AECOM's authorized representative on this document represents that to the best of AECOM's knowledge, information and belief in the exercise of its professional judgment, it is AECOM's professional opinion that the aforementioned information is accurate as of the date of such signature. Any recommendation, opinion or decisions by AECOM are made on the basis of AECOM's experience, qualifications and professional judgment and are not to be construed as warranties or guaranties. In addition, opinions relating to environmental, geologic, and geotechnical conditions or other estimates are based on available data and that actual conditions may vary from those encountered at the times and locations where data are obtained, despite the use of due care.

Sincerely,

Claudia Prado
Project Manager

Victor Modeer, P.E., D.GE
Senior Project Manager

AECOM

REFERENCES

United States Environmental Protection Agency (USEPA). (2015). *Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities; Final Rule.* 40 CFR Parts 257 and 261, 80 Fed. Reg. 21302, 21380 April 17, 2015.

United States Geological Survey (USGS). (2016). The National Map Viewer. http://viewer.nationalmap.gov/viewer/. USGS data first accessed in March of 2016.

APPENDICES

Appendix A: History of Construction Vicinity Map
Appendix B: Newton Power Station Drawings
Appendix C: Newton Primary Ash Pond Boring and Piezometer Locations
Appendix D: Operation and Maintenance Manual for Primary and Secondary Ash Ponds
Appendix E: Newton Power Plant Site Visit Report 9-12-08, Hanson (2008)

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Appendix A: History of Construction Vicinity Map

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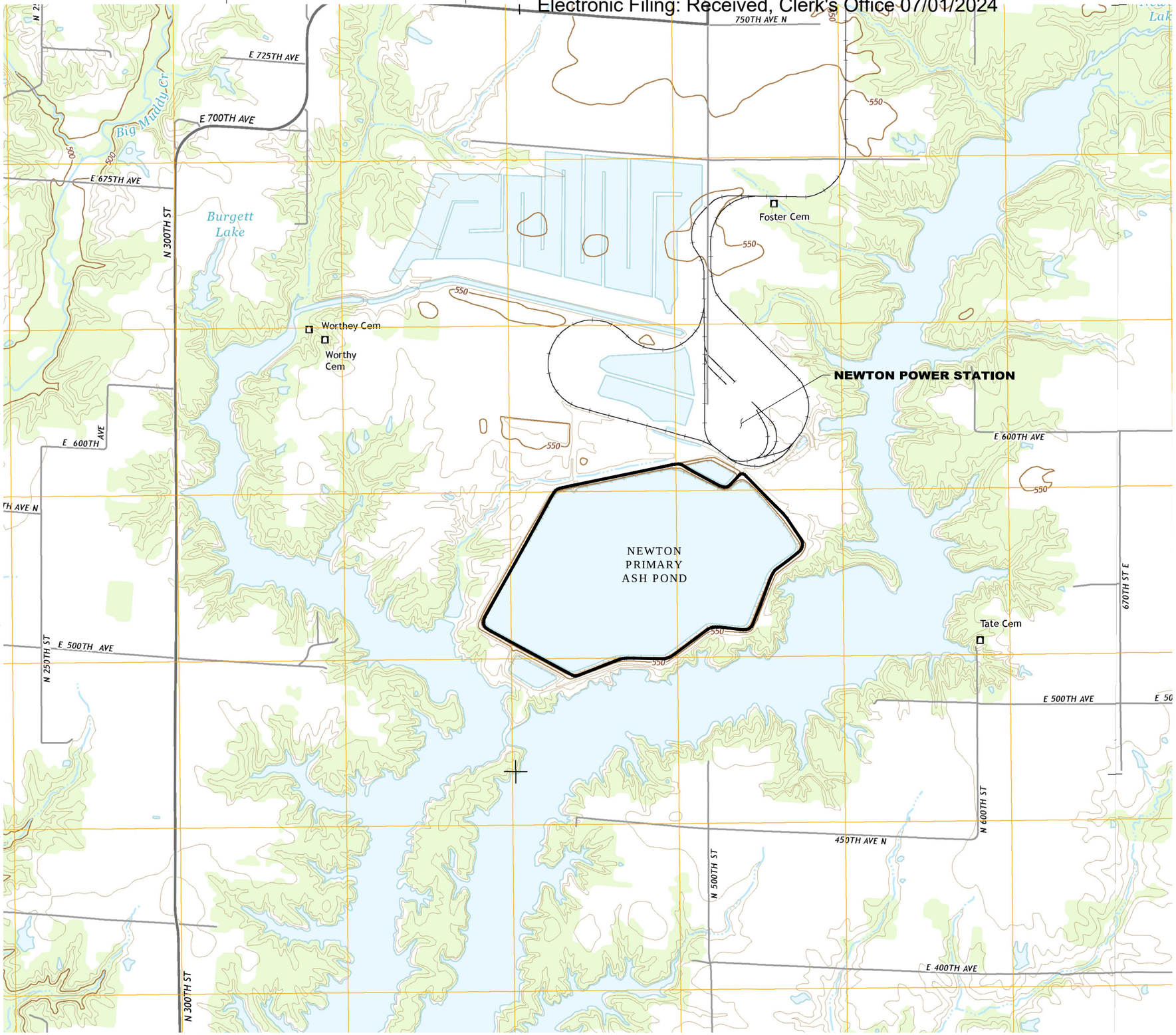


LEGEND

CCR UNITS

SOURCE:
MAP PROVIDED FROM ELECTRONIC USGS DIGITAL RASTER GRAPHIC 7.5 MINUTE TOPOGRAPHIC MAP OF NEWTON, ILLINOIS AND LATONA, ILLINOIS, REVISED 2015.



QUADRANGLE LOCATION

N

0 1000 2000 3000

SCALE IN FEET

AECOM
1001 Highlands Plaza Drive, Suite 300
St. Louis, Mo. 63110
314 429-0100 (phone)
314-429-0462 (fax)

ILLINOIS POWER GENERATING COMPANY
6725 North 500th St.,
Newton, IL 62448

HISTORY OF CONSTRUCTION

NEWTON POWER STATION
NEWTON, ILLINOIS

ISSUED FOR BIDDING	DATE	BY
ISSUED FOR CONSTRUCTION	DATE	BY

REVISIONS

NO.	DESCRIPTION	DATE
△		
△		
△		
△		
△		

AECOM PROJECT NO:	60489731
DRAWN BY:	DJD
DESIGNED BY:	DJD
CHECKED BY:	MN
DATE CREATED:	2016-04-13
PLOT DATE:	
SCALE:	1" = 1000'
ACAD VER:	2014

SHEET TITLE

HISTORY OF CONSTRUCTION VICINITY MAP

01

AECOM DRAWING PATH: P:\Projects\Geotech\60428794_DynegyCCR\13_Construction History\04 Technical Production\9_Newton\References\Vicinity Location Map References\Figures\C-01 History of Construction Vicinity Map (Newton)_2JF.dwg NANAK, MATT, 8/24/2016 5:35 PM

AECOM

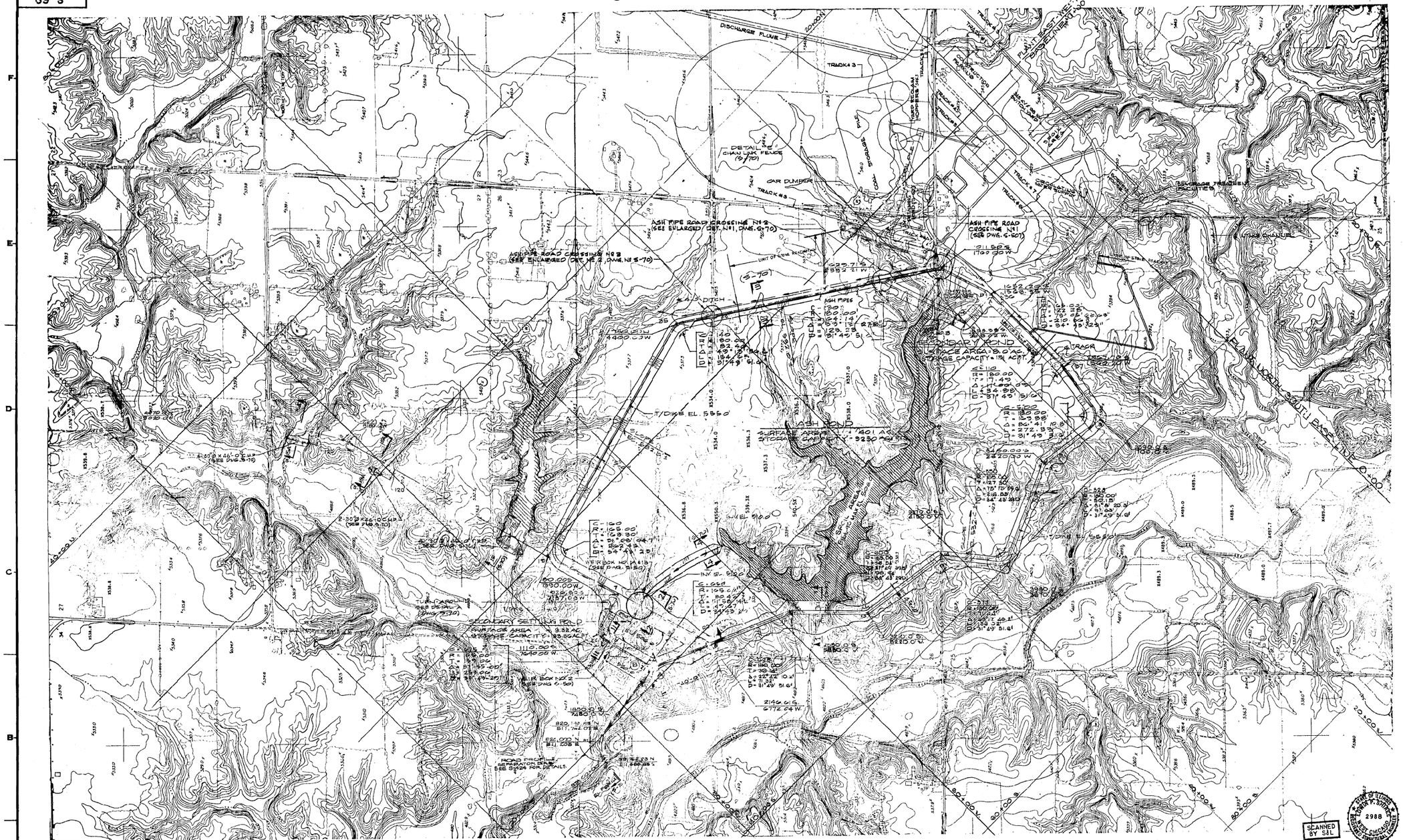
Appendix B: Newton Power Station Drawings

1. "Ash Pond & SO_2 Disposal Pond", Drawing No. S-69, Revision N, 29 July, 1994, Sargent & Lundy Engineers.
2. "Ash Pond Dike, Profile, Details, & Sections", Drawing No. S-70, Revision M, 8 April, 1994, Sargent & Lundy Engineers.
3. "Weir Box Structures at Primary and Secondary Settling Ponds", Drawing No. S-50, Revision K, 25 March, 1994, Sargent & Lundy Engineers.

C:\temp\A53AEC7B-4EA9-416A-AB49-1E8D12116480\ns69.dgn

Electronic Filing: Received, Clerk's Office 07/01/2024

S-69



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Electronic Filing: Received, Clerk's Office 07/01/2024

S-70

ROAD PROFILE (S-69)

(FROM ASH POND DIKE TO SEPARATOR DIKE)
SCALE: 1" = 10'-0" VERT.
1" = 100'-0" HORIZ.

SECTION 15-15 (S-69)

SCALE: 1" = 40'-0"

PLAN - TURN-AROUND

SCALE: 1" = 30'-0"

DETAIL 'B'

SCALE HORIZ.: 1" = 100'
VERT.: 1" = 5'-0"

DETAIL Nº 2 ROAD CROSSING Nº 3 (S-69)

SCALE: 1" = 20'-0"

DETAIL Nº 1 ROAD CROSSING Nº 2 (S-69)

SCALE: 1" = 20'-0"

TYPICAL RIPRAP DETAIL

SECTION A-A

SCALE 1" = 30'-0"

DETAIL A (S-69)

SECTION 20-20 (S-69)

SCALE 1" = 40'-0"

SECTION 1-1 (S-69)

SCALE: 1" = 40'-0"

SECTION 3-3 (S-69)

SCALE: 1" = 40'-0"

SECTION 4-4 (S-69)

SCALE: 1" = 10'-0"

SECTION 15A-15A (S-69)

SCALE: 1" = 20'-0"

SECTION 8-8 (S-69)

SCALE: 1" = 40'-0"

SECTION 2-2 (S-69)

SCALE: 1" = 40'-0"

SECTION 6-6 (S-69)

SCALE: 1" = 40'-0"

SECTION 11-11 (S-69)

SCALE: 1" = 40'-0"

NOTES

1. FOR GENERAL NOTES SEE DWG. S-14.
2. ALL DIKE CONSTRUCTION SHALL CONFORM TO THE REQUIREMENTS AND SHALL BE DONE IN ACCORDANCE WITH JOB SPEC. A-3017.
3. ALL SIDE SLOPES OF DIKES AND DITCHES SHALL BE 3:1 OR LESS STEEP AND SHALL BE PROVIDED WITH 4" TOP SOIL AND SEEDED IN ACCORDANCE WITH JOB SPEC. A-3017 AND A-3022.
4. STONE RIPRAP SHALL BE DONE AS INDICATED ON THIS DRAWING AND SHALL BE IN ACCORDANCE WITH JOB SPEC. A-3017.
5. ALL DIKE FILL SHALL BE IN ACCORDANCE WITH THE REQUIREMENTS FOR COMPACTED FILL TYPE CC-F2.

REFERENCE DRAWINGS

S-69	ASH POND AND SO2 DISPOSAL POND.
S-836	ASH PIPE SUPPORTS - SECTIONS & DETAILS SHT. 2

SCANNED BY S&L

Drawing Release Record			
Rev.	Date	Init	Description
	8-6-74	CEB	ISSUE FOR BID
A	11-25-74	CEB	ADD 2 PIPES
B	2-10-75	CEB	ADD SECTION 15A-15A, REVISE SECTION 15-15
C			REVISE SECTION 15-15
			REVISE SECTION 15-15
			REVISE SECTION 15-15
D	7-15-75	CEB	REVISE SECTION 15-15
E	12-24-75	CEB	ADD SECTION 6-6
F	2-6-76	CEB	REVISE SECTION 15-15
G	7-17-76	CEB	REVISE SECTION 15-15
H	1-24-77	CEB	REVISE SECTION 15-15
J	8-22-77	SAT	ADD DETAIL
K	7-28-80	CEB	REVISE SECTION 15-15
LX	12-29-83	BLL	SENT TO CLIENT
MA	01-08-94		SCANNED BY S&L

ASH POND DIKE
PROFILE, DETAILS & SECTIONS
NEWTON POWER STATION UNIT 1
CENTRAL ILL. PUBLIC SERVICE CO
NEWTON, ILLINOIS

SCALE: AS NOTED
DRAWN: J.M.S.
CHECKED: C.E. Shatburne 8-6-74
ENGINEER: [signature] 8-6-74
APPROVED: [signature] 8-6-74

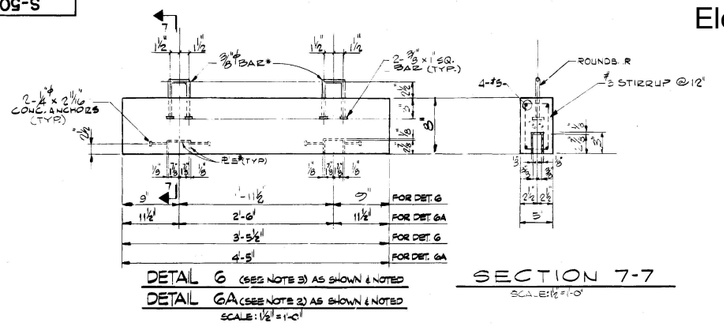
SARGENT & LUNDY ENGINEERS CHICAGO

DRAWING NO. S-70

JOB NO. 4557-20

Electronic Filing: Received, Clerk's Office 07/01/2024

S-50



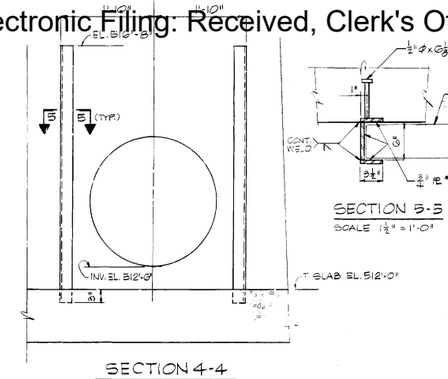
DETAIL G (SEE NOTE 3) AS SHOWN & NOTED

DETAIL GA (SEE NOTE 2) AS SHOWN & NOTED

SCALE: 1½" = 1'-0"

SECTION 7-7

SCALE: 1½" = 1'-0"

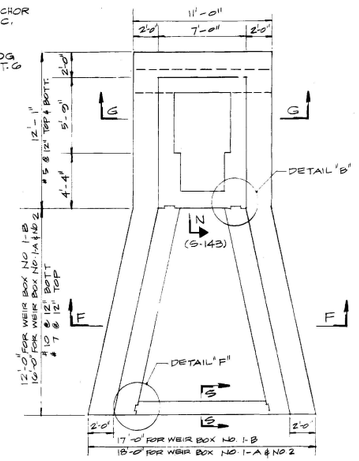


SECTION 4-4

SCALE 1" = 1'-0"

SECTION B-B

SCALE 1½" = 1'-0"



SECTION E-E

WEIR BOX NO 1 & 2

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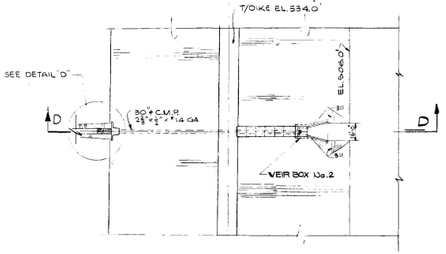
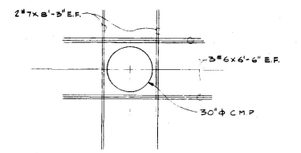


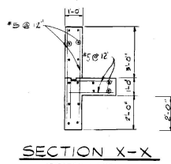
PLAN WEIR BOX NO. 2

SCALE ~ 1"=40'-0"



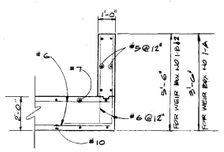
SECTION W-W (TYP OPENING FOR C.M.P.)

SCALE: N.T.S.



SECTION X-X

SCALE: N.T.S.



SECTION S-S

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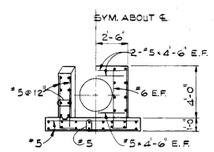

SECTION Z-Z

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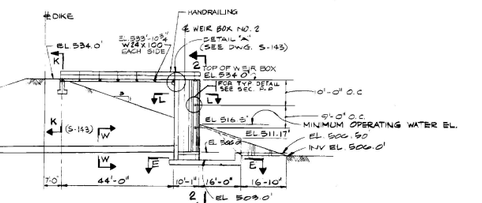


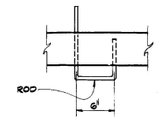
SECTION D-D

SCALE: 1" = 10'-0"



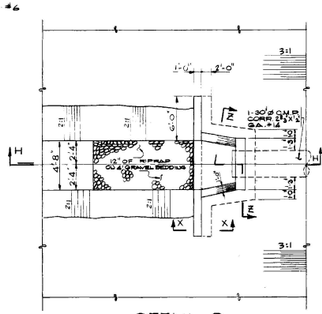
DETAIL F

SCALE: N.T.S.



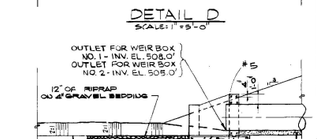
SECTION 10-10

SCALE: 1½"=1'-0"



SECTION G-G

SCALE: 1/4" = 1'-0"



SECTION F-F

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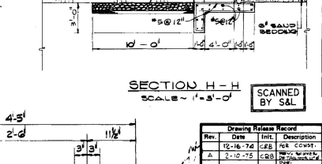
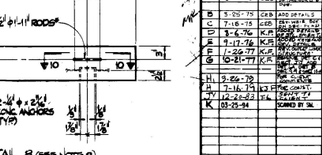


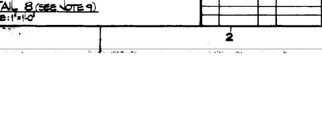
DETAIL B

SCALE: 1"=1'-0"



DETAIL B (SEE NOTE 9)

SCALE: 1"=1'-0"



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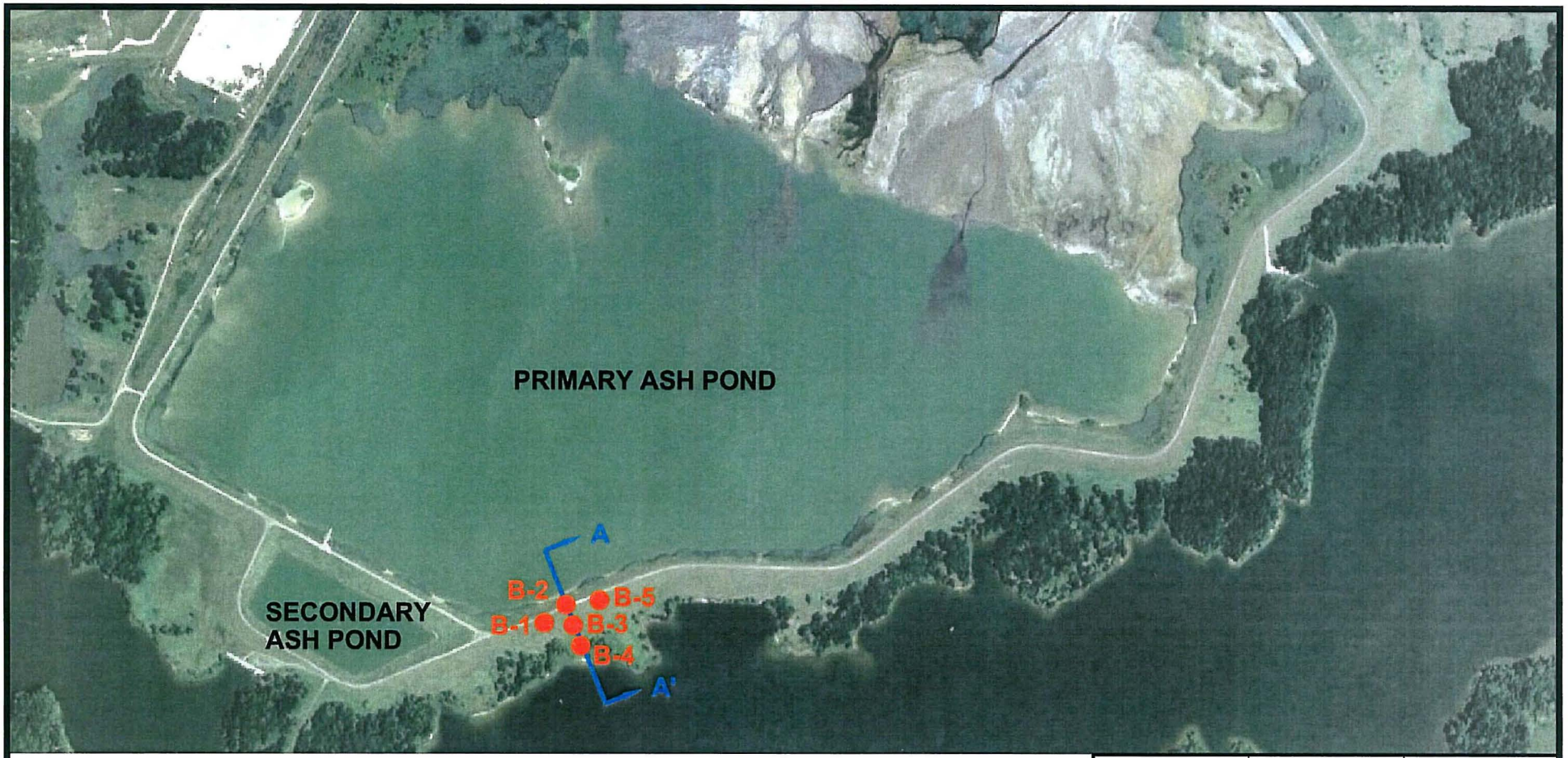
Appendix C: Newton Primary Ash Pond Boring and Piezometer Locations



NOTES

1. Plan adapted from an aerial photograph courtesy of Google Earth.

LEGEND

- Boring Location
- Slope Stability Cross Section

0 400 800 1,600

SCALE IN FEET

N

Drawn By: SLC	Ck'd By: Sca	App'vd By: Sca
Date: 11-10-10	Date: 11/21/10	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

AERIAL PHOTOGRAPH OF SITE AND BORING LOCATIONS

Project Number J017150.01

PLATE 2

Electronic Filing: Received, Clerk's Office 07/01/2024



EXPLORATION METHOD (B=BORING, C=CPT, P=PIEZOMETER)

XXX–X###

ID NUMBER

STATION ABBREVIATION

SOURCE:
MAP PROVIDED BY GOOGLE EARTH PRO 2015

LEGEND

PIEZOMETER LOCATION

CCR UNIT BERM ALIGNMENT

0 600

APPROXIMATE SCALE FEET

N

Illinois Power Generating Company

PROJECT NO. 60440378

AECOM

DRN. BY: djd October 2015
DSGN. BY: eg
CHKD. BY: eg

Newton Primary Ash Pond Piezometer Locations

FIG. NO. 2A

File: P:\PROJECTS\GEOTECH\60428794_DYNEGYCCR\04TASKS\00 PROGRAM TASKS\1.0 TASK 1 INITIAL UNIT ASSESSMENT\CCR FACT SHEETS\SITE MAPS\FIGURE 2A PIEZOMETER LOCATION PLAN (NEWTON PRIMARY ASH POND).DWG Last edited: NOV. 04, 15 @ 1:32 p.m. by: david_dejuire

AECOM

Appendix D: Operation and Maintenance Manual for Primary and Secondary Ash Ponds

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Ameren Energy Generating

Newton Power Station

Operational Procedure

x-xxx-xxxx--xxx

Operation & Maintenance Manual for Primary and Secondary Ash Ponds

Effective Date: xx/xx/xxxx

Reason for Change: New Procedure

Approved By: *x* Date: xx/xx/xxxx

x
Lindel Wenthe

Responsible Department: Newton Power Station, Technical Services Department

- ☐ This entire document shall be in the field during procedure performance.
- ☐ The following portions of this procedure shall be in the field during procedure performance: _____
- ☐ _____ from this procedure shall be in the field during procedure performance.
- ☐ No part of this procedure is required to be in the field during procedure performance.

Table of Contents

Section		Page Number
1.0	Purpose	1
2.0	Scope	1
3.0	Responsibilities	1
4.0	Historical Information	1
5.0	Flow Regulating Structures	2
6.0	Operations Requirements	3
7.0	Maintenance Requirements	3
8.0	Maintenance Logs	4
9.0	Contact Numbers	4
10.0	References	5
11.0	Records	5

1.0 Purpose

1.1 This procedure is intended to ensure the safe and environmentally responsible operation and use of all water impoundment and levee structures at Newton Power Station facility. The primary purpose of Newton's Primary, Secondary Ash Ponds, and SO2 Chemical Pond are for the storage of fly ash and treatment of fly ash sluice water to meet NPDES Permit Conditions. This procedure then assures:

1.1.1 The embankment structures and flow regulating structures are properly operated and maintained.

1.1.2 Inspections of these structures are conducted.

1.1.3 A maintenance program will be performed.

1.1.4 Communication takes place with the Dam Safety Staff regarding the structures' condition and operation.

2.0 Scope

2.1 This procedure applies to all onsite personnel and the Dam Safety Group staff.

3.0 Responsibilities

3.1 On-site Technical Services – Conducts ash pond and levee embankment and structure observations and completes the inspections, reporting any undesirable conditions to the Supervising Engineer, Dam Safety.

3.2 On-site personnel – Operates the facilities as described in this Operational Procedure. Reports any conditions noted during routine activities to the shift supervisor. Coordinates scheduling of maintenance as required to maintain proper operations of the ash pond facility.

3.3 Shift Supervisor (SS) - Calls Technical Service personnel when structure concerns are reported. Make entries into the shift log book indicating the concern and actions taken.

3.4 Supervising Engineer, Dam Safety - Conducts annual detailed dam safety inspections and provides a report with findings and recommendations.

4.0 Historical Information

4.1 Construction began in 1972 and concluded in 1982. Unit 1 was placed in service in 1977; Unit 2 went into commercial operation in 1982.

5.0 Flow Regulating Structures

5.1 Embankments

- Primary Ash Pond (Bottom Ash)
  Top of ash pond berm elevation was designed at Elevation 555.00'. Therefore, normal high pool elevation is 450.00. This allows for 2.9 feet of storage depth over the top of the ash pond outlet structure; or approximately 116 acre-ft storage or 37,850,000 gallons (45% of 89 acres times 2.9' deep).

- Secondary Ash Pond (Bottom Ash)

5.2 Structures

- Primary Ash Pond Outlet Structures - The water level in the pond is regulated by stop logs in the concrete outlet structures on the south side of the Primary Ash pond. Plans showing the outlet structures and walkways are on file. The main pond outlet structure shall be checked regularly (at least weekly or more often if there are excessive rain events) to ensure proper pond discharge. Elevation of the top of the main structure is 537.00'. Elevation of the walkway is 537.00'. Normal depth of flow over the drop structure is 3 to 4 inches during non-rainfall discharge. A 30-inch diameter CMP exits the outlet structure directly to the secondary settling pond.
- Secondary Ash Pond Outlet Structures - The water level in the pond is regulated by the pond outlet structures on the south side of the Secondary Ash pond. Plans showing the outlet structures and walkways are on file. The Secondary Ash Pond outlet structure shall be checked regularly (at least weekly or more often if there are excessive rain events) to ensure proper pond discharge. Elevation of the top of the structure is 534.00'. Elevation of the walkway is 534.00'. Minimum operating water level elevation is 516.50'. Normal depth of flow over the drop structure is 3 to 4 inches during non-rainfall discharge. A 30-inch diameter CMP exits the outlet structure directly to Newton Lake.
- Primary Ash Pond Process Water Discharge Pipe – This culvert regulates the level of water in the Primary Ash Pond. There are two possible inlets in the Primary ash pond outlet structures. Inlet Flowline elevations of the Primary Ash Pond pipe are 512.50' and 536.00'. Both inlets are connected into the same 30" CMP roughly halfway through the embankment. The outlet elevation of these combined pipes is 508.00'. These combined pipes failed once in the past at the point of connection of the top pipe into the main pipe and caused the embankment to erode from the inside and

caused a sinkhole to develop. The solution that was devised to deal with the problem was to line the entire 30" CMP with a cured in place liner. This rehabilitated the corrugated metal pipe and restored the interior integrity of the outlet pipe. The embankment was then filled with clam material and returned to service.

- Secondary Ash Pond Bottom Ash/Process Water Culvert Pipe – This 30" corrugated metal culvert pipe regulates the level of water in the Secondary Ash Pond. This pipe was also lined with a cured in-place liner. Inlet flowline elevation of the Secondary Ash Pond outlet pipe is 506.00'. The outlet elevation of this pipe is 505.00'.

6.0 Operations Requirements

Normal Operation - Plant personnel shall monitor the level of all ash pond basins within the perimeter ash pond berm on a daily basis. If levels within any of the basins exceed the prescribed maximum levels, action shall be taken immediately to remedy the situation.

Normal Operating Levels	
Primary Ash Pond Outlet	508'
Secondary Ash Pond Outlet Structure	505'
Primary Ash Pond Water Level	536'
Secondary Ash Pond Water Level	516.5'

Emergency Conditions – If a condition arises where there is a possibility of an embankment failure, then the following procedures will be followed:

1. Notify the Supervising Engineer Dam Safety immediately.
2. The pond level will be lowered by portable pumps. Monitor the embankment for changed conditions.
3. Initiate Emergency Action Plan

7.0 Maintenance Requirements

7.1 Maintenance Program - The plant's impoundment and flood prevention structures shall be inspected and maintained in a manner to ensure safe and environmentally responsible operations. A regular maintenance program shall be performed and shall consist of the following inspection items:

1. Earth embankments: Walk the crest, side slopes, and downstream toe of the dam concentrating on surface erosion, seepage, cracks, settlement, slumps, slides, and animal burrows. Frequency of inspection: Quarterly.

2. Vegetation: Grass should be a thick vigorous growth to stabilize the earth embankment soils and prevent erosion form occurring. Note the height of the grass; if greater than one foot a mowing of the area should be scheduled before the next inspection. There should be NO trees on the earth embankment and none within a minimum of 20 feet of the embankment toe or other structures. Frequency of inspection: Weekly.
3. Pond Outlet Structure: Check for any debris or other obstructions around the concrete inlet which may block or restrict the flow of water. Check for the development of any rusty areas on the concrete, and seepage, cracking, breaking, or spalling of concrete. Check for settlement or cracking in the walkway structure. Frequency of inspection: Monthly.
4. Outlet Pipe Slide Gate: Check the structure for development of any rusty areas on the concrete, and seepage, cracking, breaking, or spalling of concrete. Check the slide gate stem, grease the stem, and operate the slide gate through its full range of motion to ensure proper operation. Check for buildup of debris in the manhole. Frequency of inspection: Quarterly.
5. Pond/Levee Perimeter: Check the perimeter of the embankment and levee for a distance of at least 100 feet from the toe for signs of seepage or boils. Inspection frequency for levee will be determined by Dam Safety Engineer during flood events. Frequency of ash pond embankment inspection: Quarterly for ash pond embankment.
6. Special Inspections – Special inspections of ash pond berms shall be performed after earthquakes, floods, water level exceedance in the ponds, or heavy rainfall events. Inspection and report shall be equal to an annual inspection level of detail. Water level in the pond should be noted after a heavy rainfall. Dam Safety staff shall accompany plant personnel on special inspections. Frequency: As required.

8.0 Maintenance Logs

8.1 Plant personnel shall maintain an up-to-date log of operations (water levels, gate adjustments, inlet and outlet flows, serpentine channels, etc.), visual observations, unusual occurrences, and maintenance performed. The log book shall be reviewed during the Annual Engineering Inspection. Logs shall be kept for the life of the plant.

9.0 Contact Numbers

Plant Environmental Supervisor: David Heath / 618-783-0311
Plant Shift Supervisors Office: 217-783-0344

Plant Control Room: 217-783-0501 / 217-783-0502
Supervising Engineer Dam Safety: Steve Bluemner / 314-554-6298
Dam Safety Staff Contact: Dan Haarmann / 217-371-4853

10.0 References

10.1 AER - DSP-004, “Dam Safety Program for Non-Illinois Department of Natural Resources (non-IDNR) Regulated Facilities”

10.2 Drawings

Drawing Number	Sheet Name	Date
S-50	Weir Box Structures at Primary and Secondary Settling Ponds	12-16-74
S-69	Ash Pond and SO2 Disposal Pond	8-6-74
S-70	Ash Pond Dike Profile, Details & Sections	8-6-74
S-836	Ash Pipe Supports Sections and Details SHT #2	2-8-80

11.0 Records

	Record Type	Responsible Person	Retention Period	Location
11.1	Copies of weekly inspections	Plant Technical Services	Life of plant	Onsite Environmental Supervisor and Dam Safety Department office
11.2	Copies of Quarterly inspections	Plant Technical Services	Life of plant	Onsite Environmental Supervisor and Dam Safety Department office
11.3	Log Book	Plant Technical Services	Life of plant	Onsite Environmental Supervisor office

AECOM

Appendix E: Newton Power Plant Site Visit Report 9-12-08, Hanson (2008)

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HANSON

MEMORANDUM
(Form QAP 17.2.3, Rev. 2)

TO: Dan Whalen DATE: 9/15/08

FROM: John Jenkins

SUBJECT: Ameren Newton Power Plant
Site Visit Report 9-12-08

On Friday September 12, 2008, I made a site visit to Newton Power Station to observe a sinkhole that has developed on the ash pond dike. I was accompanied by Matt Frerking and Jim Marshall of Ameren.

The sinkhole has developed on the downstream crest of the dike between the primary (upper) and secondary (lower) ash ponds (see attached photos). The sinkhole was first observed the morning of September 12, 2008 after a heavy rain. The sinkhole is circular in shape with a diameter of approximately 12 ft. The depth to the bottom of the sinkhole is estimated to be 10 to 12 ft. The sinkhole has developed directly over the location where two discharge pipes between the primary and secondary ponds are joined (see attached Section C-C). The discharge pipes are 30 in. diameter corrugated metal pipes (CMP) installed in the late 1970's. There was no indication of ground movement in the form of settlement or bulging of the dike embankment outside the area of the sinkhole. The water level in the primary ash pond is approximately El. 536 and the water level in the secondary pond is maintained at minimum El. 516.5. There has been no significant fluctuation of the water levels in either pond for over 6 months. The top of the dike is at El. 555 and the top of the discharge pipe below the sinkhole location is approximately El. 514. Therefore, the depth below the ground surface to the top of the pipe at the sinkhole location is approximately 41 ft.

Based on the location of the sinkhole relative to the discharge pipes and considering the age of the metal pipes, it appears that the most likely cause of the sinkhole is due to loss of soil material through a hole or holes in the discharge pipes. In particular, the connection between the two pipes is suspect. The pipe discharges into the secondary pond below the water level and therefore there is no way to visually observe the discharge for soil deposits. If the cause of the sinkhole is due to loss of material through holes in the pipes, this process could have been occurring over several years. There is the possibility that there is a void or voids that extend from the ground surface to the discharge pipes, and it would be expected that the sinkhole would continue to develop over time. It is possible that additional settlement or sloughing of soil material on the downstream crest of the embankment in the immediate vicinity of the sinkhole will occur in the near future. However, considering the relatively low level of water in the

primary ash pond relative to the top of the dike embankment, the dike should remain stable even if local failures in the upper portion of the dike occur.

It was agreed that the following actions be taken.

- The existing sinkhole should be filled with soil material to prevent further sloughing and expanding of the sides of the sinkhole. The material should be placed with a backhoe and compacted with the backhoe bucket. No mechanical compaction of the soil should be attempted. The top of the filled area should be crowned to prevent ponding in the area of the sinkhole, and the sinkhole area should be monitored daily for additional settlement or movement.
- The primary ash pond level should be lowered in order to allow the pipes to be dewatered and inspected by camera. Jim Marshall estimates that it may take more than a week to draw the water down to the required depth.
- Based on the results of the camera survey, a plan for repair of the discharge pipes will be developed. The repair plan may include slipform lining of the pipes and/or excavation to repair isolated areas.
- Due to the unknown extent of the sinkhole void and to the possibility of additional voids being present along the length of the discharge pipe, Hanson will evaluate alternative methods for investigating the presence of voids below the ground surface, including the use of ground penetrating radar.



View of Sinkhole Looking Northwest Along Dike



View of Sinkhole Looking Southeast Along Dike



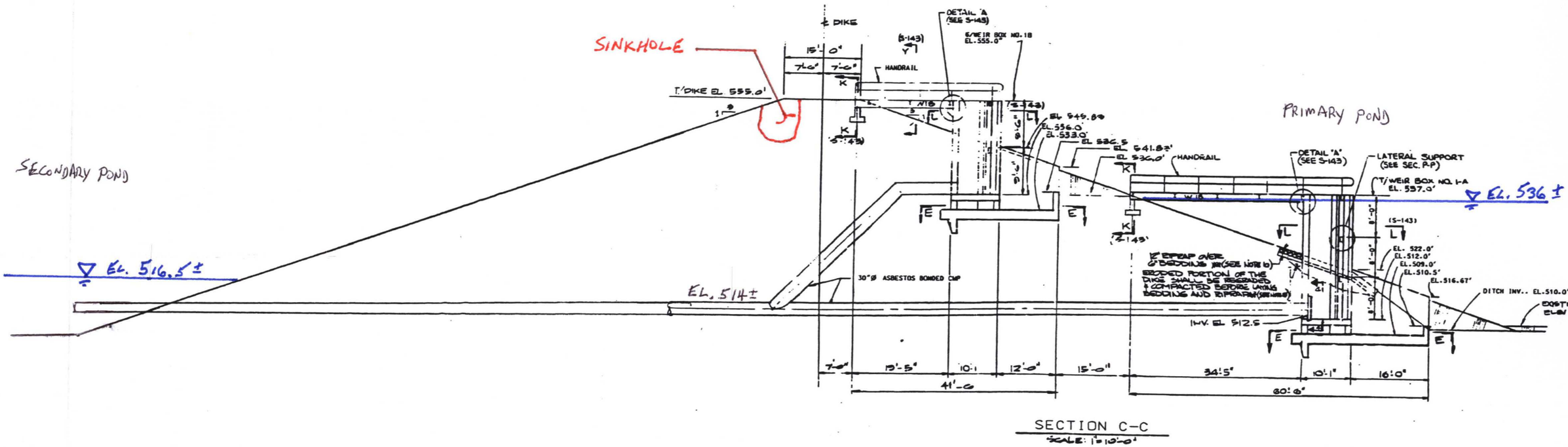
Close-Up of Sinkhole



View of Bottom of Sinkhole



View of Sinkhole Looking Southwest Towards the Secondary Pond and Lake



SECTION C–C
SCALE: 1"=10'-0"

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Geosyntec consultants

1 McBride and Son Center Drive, Suite 202
Chesterfield, MO 63005
PH 636-812-0800
www.geosyntec.com

October 11, 2021

Illinois Power Generating Company
6725 North 500th Street
Newton, Illinois, 62448

Subject: USEPA CCR Rule and IEPA Part 845 Rule Applicability Cross-Reference
2021 USEPA CCR Rule Periodic Certification Report
Primary Ash Pond, Newton Power Plant, Newton, Illinois

At the request of Illinois Power Generating Company (IPGC), Geosyntec Consultants (Geosyntec) has prepared this letter to document how the attached 2021 United States Environmental Protection Agency (USEPA) CCR Rule Periodic Certification Report (Report) was prepared in accordance with both the Federal USEPA CCR Rule[1] and the state-specific Illinois Environmental Protection Agency (IEPA) Part 845 Rule[2]. Specific sections of the report and the applicable sections of the USEPA CCR Rule and Illinois Part 845 Rule are cross-referenced in **Table 1**. A certification from a Qualified Professional Engineer for each of the CCR Rule sections listed in **Table 1** is provided in Section 10 of the attached Report. This certification statement is also applicable to each section of the Part 845 Rule listed in **Table 1.**

Table 1 – USEPA CCR Rule and Illinois Part 845 Rule Cross-Reference

Report Section	USEPA CCR Rule		Illinois Part 845 Rule	
3	§257.73 (a)(2)	Hazard Potential Classification	845.440	Hazard Potential Classification Assessment[3]
4	§257.73 (c)(1)	History of Construction	845.220(a)	Design and Construction Plans (Construction History)
5	§257.73 (d)(1)	Structural Stability Assessment	845.450 (a) and (c)	Structural Stability Assessment
6	§257.73 (e)(1)	Safety Factor Assessment	845.460 (a-b)	Safety Factor Assessment
7	§257.82 (a)(1-3)	Adequacy of Inflow Design Control System Plan	845.510(a), (c)(1), (c)(3)	Hydrologic and Hydraulic Capacity Requirements / Inflow Design Flood Control System Plan
	§257.82 (b)	Discharge from CCR Unit	845.510(b)	Discharge from CCR Surface Impoundment

[1] United Stated Environmental Protection Agency, 2015. *40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule.*
[2] State of Illinois, Joint Committee on Administrative Rule, Administrative Code (2021). *Title 35: Environmental Protection, Subtitle G: Waste Disposal, Chapter I: Pollution Control Board, Subchapter j: Coal Combustion Waste Surface Impoundment, Part 845 Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments.*
[3] "Significant" and "High" hazard, per the CCR Rule[1], are equivalent to Class II and Class I hazard potential, respectively, per Part 845[2].

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CLOSING

This letter has been prepared to demonstrate that the content and Qualified Professional Engineer Certification of the 2021 Periodic USEPA CCR Rule Certification Report fulfills the corresponding requirements of Part 845 of Illinois Administrative Code listed in **Table 1**.

Sincerely,



Panos Andonyadis, P.E.
Senior Engineer



John Seymour, P.E.
Senior Principal

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2021 USEPA CCR RULE PERIODIC CERTIFICATION REPORT §257.73(a)(2), (c), (d[1]), (e) and §257.82 PRIMARY ASH POND

Newton Power Plant

Newton, Illinois

Submitted to

Illinois Power Generating Company

6725 North 500th Street
Newton, Illinois 62448

Submitted by

Geosyntec consultants

engineers | scientists | innovators

1 McBride and Son Center Drive, Suite 202
Chesterfield, Missouri 63005

October 11, 2021

[1] Except for §257.73(d)(1)(vi).

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Attachment C Periodic History of Construction Report Update Letter
Attachment D Periodic Structural Stability and Safety Factor Assessment Analyses
Attachment E Periodic Inflow Design Flood Control System Plan Analyses

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EXECUTIVE SUMMARY

This Periodic United States Environmental Protection Agency (USEPA) Coal Combustion Residuals (CCR) Rule [1] certification report (Periodic Certification Report) for the Primary Ash Pond (PAP) [2] at the Newton Power Plant (NPP), also known as Newton Power Station, has been prepared in accordance with Rule 40, Code of Federal Regulations (CFR) §257, herein referred to as the "CCR Rule" [1]. The CCR Rule requires that initial certifications for existing CCR surface impoundment, completed in 2016 and subsequently posted on Illinois Power Generating Company (IPGC) CCR Website ([2], [3], [4], [5], [6]) be updated on a five-year basis.

The initial certification reports developed in 2016 and 2017 ([2], [3], [4], [5], [6]) were independently reviewed by Geosyntec. Additionally, field observations, interviews with power plant staff, updated engineering analyses, and evaluations were performed to compare conditions in 2021 at the PAP relative to the 2016 and 2017 initial certifications. These tasks identified that updates are not required for the Initial Hazard Potential Classification. However, due to changes at the site and technical review comments, updates were required and were performed for the:

- History of Construction Report,
- Initial Structural Stability Assessment,
- Initial Safety Factor Assessment, and
- Initial Inflow Design Flood Control System Plan.

Geosyntec's evaluations of the initial certification reports and updated analyses identified that the PAP meets all requirements for hazard potential classification, history of construction reporting, structural stability, safety factor assessment, and hydrologic and hydraulic control, with the exception of the structural integrity of hydraulic structures (§257.73(d)(1)(vi)), which was certified by others. **Table 1** provides a summary of the initial 2016 certifications and the updated 2021 periodic certifications.

[2] The PAP is also referred to as ID Number W0798070001-01, Primary Ash Pond by the Illinois Environmental Protection Agency (IEPA); CCR unit ID 401 by EEI; and IL50719 within the National Inventory of Dams (NID) maintained by the Illinois Department of Natural Resources (IDNR). Within this document it is referred to as the PAP.

Table 1 – Periodic Certification Summary

	CCR Rule Reference	Requirement Summary	2016 Initial Certification		2021 Periodic Certification	
			Requirement Met?	Comments	Requirement Met?	Comments
Hazard Potential Classification						
3	§257.73(a)(2)	Document hazard potential classification	Yes	Impoundment was determined to have Significant hazard potential classification [2].	Yes	Updates were not determined to be necessary. Geosyntec recommends retaining the Significant hazard potential classification.
History of Construction						
4	§257.73(c)(1)	Compile a history of construction	Yes	History of Construction report was prepared for the PAP [3].	Yes	A letter listing updates to the History of Construction report is provided in **Attachment C**.
Structural Stability Assessment						
5	§257.73(d)(1)(i)	Stable foundations and abutments	Yes	Foundations were found to be stable. Abutments are not present [7].	Yes	Foundations and abutments were found to be stable after performing updated slope stability analyses.
	§257.73(d)(1)(ii)	Adequate slope protection	Yes	Slope protection is adequate [7].	Yes	No changes were identified that may affect this requirement.
	§257.73(d)(1)(iii)	Sufficiency of embankment compaction	Yes	Embankment compaction is sufficient for expected ranges in loading conditions [7].	Yes	Dike compaction was found to be sufficient after performing updated slope stability analyses.
	§257.73(d)(1)(iv)	Presence and condition of slope vegetation	Yes	Vegetation is present on interior and exterior slopes and is maintained. [7].	Yes	No changes were identified that may affect this requirement.
	§257.73(d)(1)(v)(A) and (B)	Adequacy of spillway design and management	Yes	Spillways are adequately designed and constructed and adequately manage flow during 1,000-year flood [7].	Yes	Spillways were found to be adequately designed and constructed and are expected to adequately manage flow during the 1,000-year flood, after performing updated hydrologic and hydraulic analyses.
	§257.73(d)(1)(vi)	Structural integrity of hydraulic structures	Yes	Hydraulic structures passing through the embankment were inspected and found to maintain structural integrity [7].	Periodic certification of §257.73(d)(1)(vi) was independently completed by Luminant in 2020 [8].	
	§257.73(d)(1)(vii)	Stability of downstream slopes inundated by water body.	Yes	Downstream slopes adjacent to Newton Lake and the Secondary Pond are expected to remain stable during inundation [7].	Yes	Downstream slopes were found to be stable after performing updated sudden drawdown slope stability analyses.
Safety Factor Assessment						
6	§257.73(e)(1)(i)	Maximum storage pool safety factor must be at least 1.50	Yes	Safety factors were calculated to be 1.66 and higher [5].	Yes	Safety factors from updated slope stability analyses were calculated to be 1.66 and higher.
	§257.73(e)(1)(ii)	Maximum surcharge pool safety factor must be at least 1.40	Yes	Safety factors were calculated to be 1.66 and higher [5].	Yes	Safety factors from updated slope stability analyses were calculated to be 1.66 and higher.
	§257.73(e)(1)(iii)	Seismic safety factor must be at least 1.00	Yes	Safety factors were calculated to be 1.07 and higher [5].	Yes	Safety factors from updated slope stability analyses were calculated to be 1.07 and higher.
	§257.73(e)(1)(iv)	For embankment construction of soils that have susceptible to liquefaction, safety factor must be at least 1.20	Not Applicable	Embankment soils were not susceptible to liquefaction [5].	Not Applicable	No changes were identified that may affect this requirement.
Inflow Design Flood Control System Plan						
8	§257.82(a)(1), (2), (3)	Adequacy of inflow design control system plan.	Yes	Flood control system adequately managed inflow and peak discharge during the 1,000-year, 24-hour, Inflow Design Flood [7].	Yes	The flood control system was found to adequately manage inflow and peak discharge during the 1,000-year, 24-hour, Inflow Design Flood, after performing updated hydrologic and hydraulic analyses.
	§257.82(b)	Discharge from CCR Unit	Yes	Discharge from the CCR Unit is routed through a NPDES-permitted outfall during both normal and 1,000-year, 24-hour Inflow Design Flood conditions [6].	Yes	Discharge from the CCR Unit is routed through a NPDES-permitted outfall during both normal and 1,000-year, 24-hour Inflow Design Flood conditions, after performing updated hydrologic and hydraulic analyses.

SECTION 1

INTRODUCTION AND BACKGROUND

This Periodic United States Environmental Protection Agency (USEPA) Coal Combustion Residual (CCR) Rule [1] Certification Report was prepared by Geosyntec Consultants (Geosyntec) for Illinois Power Generating Company (IPGC) to document the periodic certification of the Primary Ash Pond (PAP) at the Newton Power Plant (NPP), also known as the Newton Power Station, located at 6725 N 500th Street, Newton, Illinois, 62448. The location of NPP is provided in **Figure 1**, and a site plan showing the location of the PAP and landfill, among other closed and open CCR units and non-CCR surface impoundments, is provided in **Figure 2**.

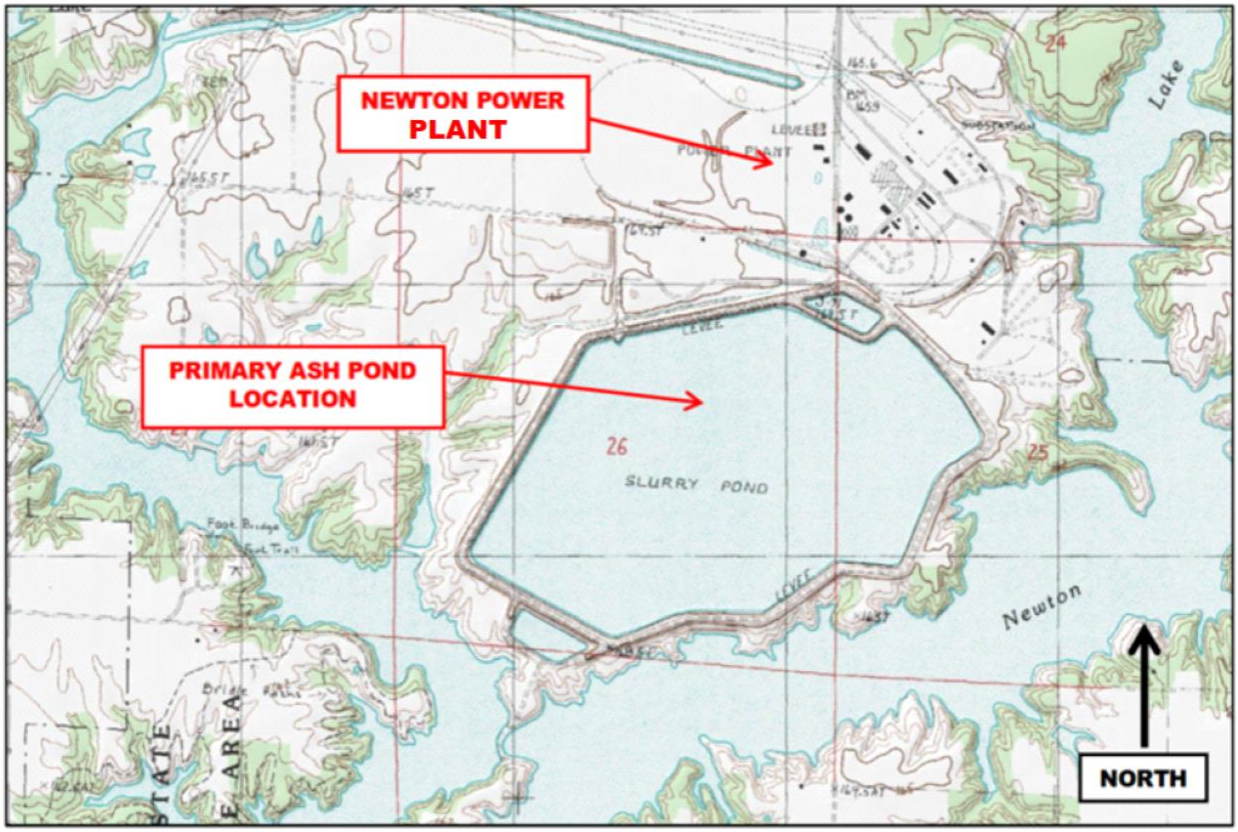

Figure 1 – Site Location Map (from AECOM, 2016)



Figure 2 – Site Plan

1.1 PAP Description

The PAP is utilized for managing CCR materials generated by NPP. The PAP has a Significant hazard potential, based on the initial hazard potential classification assessment performed by Stantec in 2016 in accordance with §257.73(a)(2) [2].

The PAP receives fly ash, bottom ash, and other miscellaneous non-CCR process waters produced by NPP. Bottom ash is sluiced from the north perimeter of the PAP on either side of the Secondary Settlement Pond, which is a non-CCR basin included within the footprint of the Primary Ash Pond. The outfall structure in the PAP discharges through the perimeter embankment into the Secondary Pond, which is a non-CCR basin that ultimately discharges into Newton Lake via a National Pollutant Discharge Elimination System (NPDES)-permitted outfall.

Two adjacent spillway structures are present at the PAP: the principal spillway structure and the secondary spillway structure. Only the principal structure is used to control outflow during both normal operational and flood conditions. The spillway structures are both identical square concrete riser structures, with inflow controlled by a series of stoplogs. Inflow into the structures is transmitted to the Secondary Pond through 30-inch diameter corrugated metal pipes that have been slip lined and now have an inside diameter of 28 inches. The principal spillway structure is located at a lower elevation than the secondary spillway structure, with a top of weir box elevation of 537 feet and a pipe invert elevation of 512.5 feet (presumed to be NGVD29 datum based on the date of the design drawings). The secondary spillway structure is located directly upslope from the primary structure and has a top of weir box elevation of 555 feet, which is the design crest elevation of the earthen embankment, and a pipe invert elevation of 533 feet. The 28-inch diameter slip lined outlet pipes from both structures converge within the earthen embankment into a single 28-inch slip lined outlet pipe that discharges into the Secondary Pond. The purpose of the secondary spillway structure is to be a supplemental spillway for the Primary Ash Pond under conditions where the pool level is significantly increased above the current normal pool to allow for additional storage volume [7].

The surface area of the impoundment is approximately 400 acres, and the embankment is a continuous structure (a ring embankment), which has a total perimeter length of approximately 3.2 miles and a maximum height above the exterior grade of 72 feet where the downstream toe of the embankment is underneath the normal pool level of the downstream Newton Lake. Typical embankment heights range from 14 to 42 feet. The embankment was constructed as a homogenous earthen structure with well-compacted clayey fill. Portions of the south embankment directly adjacent to Newton Lake include crushed stone near the waterline for erosion protection. The upstream and downstream slope orientations are typically 3H:1V (horizontal to vertical) but range from about 2.5H:1V to 3.4H:1V. Embankment crest widths range from approximately 12 to 50 feet, and the crest is covered with a gravel access road [7].

The pool elevation of the pond is controlled by the configuration of the outflow structure and plant process inflows. At the time of the periodic survey, was approximately[3] 535.5 feet. Crest elevations range from approximately 553 to 555 feet, and the minimum crest elevation is 552.7 feet [7].

Initial certifications for the PAP for Hazard Potential Classification (§257.73(a)(2)), History of Construction (§257.73(c)), Structural Stability Assessment (§257.73(d)), Safety Factor Assessment (§257.73(e)(1)), and Inflow Design Flood Control System Plan (§257.82) were completed by Stantec and AECOM in 2016 and 2017 and subsequently posted to IPGC's CCR Website ([2], [3], [4], [5], [6]).

[3] All elevations are in the North American Vertical Datum of 1988 (NAVD88), unless otherwise noted.

1.2 Report Objectives

These following objectives are associated with this report:

- Compare site conditions from 2015/2016 to site conditions in 2020/2021, and evaluate if updates are required to the:
    - §257.73(a)(2) Hazard Potential Classification [2];
    - §257.73(c) History of Construction [3];
    - §257.73(d) Structural Stability Assessment [4];
    - §257.73(e) Safety Factor Assessment [5], and/or
    - §257.82 Inflow Design Flood Control System Plan [6].
- Independently review the Hazard Potential Classification ([2], [9]), Structural Stability Assessment ([4], [7]), Safety Factor Assessment ([5], [7]), and Inflow Design Flood Control System Plan ([6], [7]) reports to determine if updates may be required based on technical considerations.
    - The History of Construction report [3] was not independently reviewed for technical considerations, as this report contained historical information primarily developed prior to promulgation of the CCR Rule [1] for the CCR units at NPP, and did not include calculations or other information used to certify performance and/or integrity of the impoundments under §257.73(a)(2)-(3), §257.73(c)-(e), or §257.82.
- If updates are required, they will be performed and documented within this report.
- Confirm that the PAP meets all of the requirements associated with §257.73(a)(2), (c), (d), (e), and §257.82, or, if the PAP does not meet all requirements, provide recommendations for compliance with these sections of the CCR Rule [1].

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SECTION 2

COMPARISON OF 2015/16 AND 2020/21 SITE CONDITIONS

2.1 Overview

This section describes the comparison of conditions at the PAP between the start of the initial CCR certification program in 2015 and subsequent collection of periodic certification site data in 2020 and 2021.

2.2 Review of Annual Inspection Reports

Annual onsite inspections for the PAP were performed between 2016 and 2020 ([10], [11], [12], [13], [14] and, [15]) and were certified by a licensed professional engineer in accordance with §257.83(b). Each inspection report stated the following information, relative to the previous inspection:

- A statement that no changes in geometry of the impounding structure were observed since the previous inspection.
- Information on maximum recorded instrumentation readings and water levels.
- Approximate volumes of impounded water and CCR at the time of inspection.
- A statement that no appearances of actual or potential structural weakness or other disruptive conditions were observed.
- A statement that no other changes which may have affected the stability or operation of the impounding structure were observed.

In summary, the reports did not indicate any significant changes to the PAP between 2015 and 2020.

2.3 Review of Instrumentation Data

Twelve piezometers are present at the PAP and were monitored monthly between August 5, 2015 and April 29, 2021 [16]. Geosyntec reviewed the piezometer data to evaluate if significant fluctuations, partially increases in phreatic levels, may have occurred between development of the initial structural stability and factor of safety certifications [7], [4], [5]) and April 29, 2021. Available piezometer readings are plotted in **Attachment A**.

In summary, the peak measured groundwater levels for several piezometers were up to 10 ft higher than the phreatic conditions considered during the initial certification. These changes could impact the results of the factor of safety analyses required for the structural stability and factor of safety certifications ([7], [4], [5]). Specifically, up to four cross sections were identified with significant changes in phreatic conditions.

2.4 Comparison of 2015 to 2020 Surveys

Surveys conducted at the site by Weaver Consultants (Weaver) in 2015 [17] and IngenAE, LLC (IngenAE) in 2020 [18] were compared within AutoCAD Civil3D 2021 software. This comparison quantified changes in the volume of CCR placed within the PAP and considered volumetric changes above and below the starting water surface elevation (SWSE) used for the 2016 §257.82 inflow design flood control plan hydraulic analysis [7]. Potential changes to embankment geometry were also evaluated. This comparison is presented in side-by-side views of each survey in **Drawing 1**, and a plan view isopach map denoting changes in ground surface elevation in **Drawing 2**. A summary of the water elevations and changes in CCR volumes is provided in **Table 2**.

Table 2 – 2015 and 2020 Survey Comparison

Initial Surveyed Pool Elevation (ft)	534.0
Periodic Surveyed Pool Elevation (ft)	535.5
Initial §257.82 Starting Water Surface Elevation (SWSE) (ft)	534.0
Total Change in CCR Volume (CY)	98,711 (fill)
Change in CCR Volume Above SWSE (CY)	185,376 (fill)
Change in CCR Volume Below SWSE (CY)	-86,913 (cut)

The comparison indicated that approximately 98,711 CY of CCR was placed in the PAP between the initial and periodic survey, thereby leading to a potential for the peak water surface elevation (PWSE) to increase during the inflow design 1,000-year flood event. Also, the measured water surface elevation for the periodic survey is higher than the water levels estimated for both normal and a 1,000-yr flood events event in the initial certifications (**Section 7**).

No significant changes to embankment geometry appeared to have occurred between the initial and periodic surveys, as shown on the isopach. However, along the northern embankments there appears to be material stockpiled upstream of the embankments which would have increased the loading on the embankments. It is further noted that there are two areas along the southern embankment that appear to be cut and apparently excavated since the initial survey. Such excavation is not known to have occurred and it is likely this apparent cut is a byproduct of survey discrepancy between the initial and periodic bathymetric surveys.

2.5 Comparison of 2015 to 2020 Aerial Photography

Aerial photographs of the PAP collected by Weaver in 2015 [17] and IngenAE in 2020 [18] were compared to visually evaluate if potential site changes (i.e., changes to the embankment, outlet structures, limits of CCR, other appurtenances) may have occurred. A comparison of these aerial photographs is provided in **Drawing 3**, and the following changes were identified:

- A few mounds of new earth built up along the northern embankments; and
- No clear change in the ash delta or shoreline was observed; and
- It appears the water level of the impounded pond may have been higher in 2015.

2.6 Comparison of Initial and Periodic Site Visits

An initial site visit to the PAP was conducted by AECOM in 2015 and documented with a Site Visit Summary and corresponding photographs [19]. A site visit was conducted by Geosyntec on May 21, 2021, with Panos Andonyadis, P.E., conducting the site visit. The site visit was intended to evaluate potential changes at the site since 2015 (i.e., modification to the embankment, outlet structures or other appurtenances, limits of CCR, maintenance programs, repairs), in addition to performing visual observations of the PAP to evaluate if the structural stability requirements (§257.73(d)) were still met. The site visit included walking the perimeter of the PAP, visually observing conditions, recording filed notes, and collecting photographs. The site visit is documented in a photographic log provided in **Attachment B**. A summary of significant findings from the periodic site visit is provided below:

- The perimeter embankments appear to be structurally stable as no signs of structural or foundation instability were observed
- No new development was observed in the vicinity of the PAP, although the observation was limited to the portions of the vicinity visible form the crest of the PAP dike.
- No significant changes were observed since the previous certification.

2.7 Interview with Power Plant Staff

An interview with Ken Schafer of the NPP was conducted by Panos Andonyadis of Geosyntec on May 21, 2021. Mr. Schafer was employed at NPP between 2015 and 2021, The interview included a discussion of potential changes that that may have occurred at the PAP since development of the initial certifications ([2], [3], [4], [5], [6], [7]) in 2015 and 2016. between 2015 and 2020. A summary of the interview is provided below.

- Were any construction projects completed for the PAP between 2015 and 2021, and, if so, are design drawings and/or details available?

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- No repairs were performed since the initial certification.

- Were there any changes to the purpose of the PAP between 2015 and 2021?
    - No, the impoundment continues to receive sluiced ash, sluiced bottom ash, and plant waste water.

- Were there any changes to the to the instrumentation program and/or physical instruments for the PAP between 2015 and 2021?
    - No.

- Are area-capacity curves for the PAP available?
    - No area-capacity curves have been developed.

- Were there any changes to spillways and/or diversion features for the PAP completed between 2015 and 2021?
    - No changes to the spillway were made.

- Were there any changes to construction specifications, surveillance, maintenance, and repair procedures for the PAP between 2015 and 2021?
    - No changes were made.

- Were there any instances of embankment and/or structural instability for the PAP between 2015 and 2021?
    - A repair of a slough was performed on the upstream side of the southernmost embankment. The damage appears to have been caused by wave related erosion and is limited to the area of a previous repair.

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SECTION 3

HAZARD POTENTIAL CLASSIFICATION - §257.73(a)(2)

3.1 Overview of 2016 Initial Hazard Potential Classification

The Initial Hazard Potential Classification (Initial HPC) was prepared by Stantec Consulting Services, Inc. (Stantec) in 2016 ([2], [9]), following the requirements of §257.73(a)(2). The Initial HPC included the following information:

- Performing a visual analysis to evaluate potential hazards associated with a failure of the PAP perimeter embankment, along all sides of the PAP.
- Evaluation of potential breach flow paths were evaluated using elevation data and aerial imagery to evaluate potential impacts to downstream structures, infrastructure, frequently occupied facilities/areas, and waterways [2].
- While a breach map is not included in the Initial HPC, it is included within the §257.73(a)(3) Initial Emergency Action Plan prepared by Stantec [20].

The visual analysis indicated that none of the breach scenarios appeared to impact occupied structures, although a breach of the east embankment could impact an infrequently-used gravel site access road and a breach of the north, northeast or east embankment could impact a nearby railroad. The Initial HPC concluded that none of breach scenarios considered would be likely to result in a probable loss of human life, although the breach could cause CCR to be released into the Newton Lake, thereby causing environmental damage. The Initial HPC therefore recommended a "Significant" hazard potential classification for the PAP [2].

3.2 Review of Initial HPC

Geosyntec performed a review of the Initial HPC ([2], [9]) in terms of technical approach, input parameters, assessment of the results, and applicable requirements of the CCR Rule [1]. No significant technical issues were noted within the technical review, although a detailed review (e.g., check) of the calculations was not performed.

3.3 Summary of Site Changes Affecting the Initial HPC

Geosyntec did not identify any changes at the site that may affect the HPC. No new structures, infrastructure, frequently occupied facilities/areas, or waterways were present in the probable breach area indicated in the Initial EmAP [20], although Geosyntec's evaluation of new structures was limited to visual observations completed from the dike crest during the site visit and a review of available aerial imagery provided by IngenAE in 2020 [18]. Additionally, no significant changes to the topography in the probable breach were identified.

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3.4 Periodic HPC

Geosyntec recommends retaining the "Significant" hazard potential classification for the PAP, per §257.73(A)(2), based on the lack of site changes potentially affecting the Initial HPC occurring since the initial HPC was developed, as described in **Section 3.2**. Updates to the Initial HPC reports ([2], [9]) are not recommended at this time.

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SECTION 4

HISTORY OF CONSTRUCTION REPORT - §257.73(c)

4.1 Overview of Initial HoC

The Initial History of Construction report (Initial HoC) was prepared by AECOM in 2016 [3], following the requirements of §257.73(c), and included information on the PAP. The Initial HoC included the following information for each CCR surface impoundment:

- The name and address of the owner/operator,
- Location maps,
- Statements of purpose,
- The names and size of the surrounding watershed,
- A description of the foundation and abutment materials,
- A description of the embankment materials,
- Approximate dates and stages of construction,
- A list of available design and engineering drawings,
- A summary of instrumentation,
- A statement that area-capacity curves are not available,
- Information on spillway structures,
- A statement that the constructions specifications are not available,
- Inspection and surveillance plans,
- Information on operational and maintenance procedures, and
- A statement of observed historical structural instability that occurred at the PAP.

4.2 Summary of Site Affecting the Initial HoC

Several significant changes were identified at the site that occurred after development of the initial HoC report [3] and are described below:

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- A state identification number (ID) of W0798070001-01 was assigned to the PAP by the Illinois Environmental Protection Agency (IEPA).

- Revised area-capacity curves and spillway design calculations for the PAP were prepared as part of the updated periodic Inflow Design Flood Control System Plan, as described in **Section 7.3**.

A letter documenting changes to the HoC report is provided in **Attachment C**.

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SECTION 5

STRUCTURAL STABILITY ASSESSMENT - §257.73(d)

5.1 Overview of Initial SSA

The Initial Structural Stability Assessment (Initial SSA) was prepared by AECOM in 2016 ([4], [7]) following the requirements of §257.73(d)(1), and included the following evaluations:

- Stability of embankment foundations, embankment abutments, slope protection, embankment compaction, and slope vegetation,
- Spillway stability including capacity, structural stability and integrity;
- Stability and structural integrity of hydraulic structures; and
- Downstream slope stability under sudden drawdown conditions for a downstream water body.

The Initial SSA concluded that the PAP met all structural stability requirements for §257.73(d)(1)(i)-(vii).

A periodic certification of the structural stability and structural integrity of hydraulic outfall structures (§257.73(d)(1)(vi)) was performed by Luminant in 2020 [8]. This certification independently determined that the criteria was met due to the condition of the spillway pipes and the soil types within the embankment. Therefore, the review and certification of §257.73(d)(1)(vi) was not included within the scope of this report.

The Initial SSA referenced the results of the Initial Structural Factor Assessment (Initial SFA) ([5], [7]), to demonstrate stability of the stability of foundations and abutments (§257.73(d)(1)(i)) and sufficiency of dike compaction (§257.73(d)(1)(iii)) portions of the SSA criteria. This included stating that slope stability analyses for slip surfaces passing through the foundation met or exceeded the criteria listed in §257.73(e)(1), for the stability of foundations and abutments. For the sufficiency of dike compaction, this included stating that slope stability analyses for slip surfaces passing through the dike also met or exceeded the §257.73(e)(1) criteria.

Additionally, the Initial SSA included a sudden drawdown slope stability analysis to evaluate the effect of a drawdown event in the adjacent Newton Lake from the 100-year flood pool to an empty-pool condition, as required by §257.73(3)(1)(vii) for CCR units where the downstream slopes are inundated by an adjacent water body. The minimum acceptable factor of safety for this loading condition was assumed to be 1.3 based on US Army Corps of Engineers guidance [21].

5.2 Review of Initial SSA

Geosyntec performed a review of the Initial SSA ([4], [7]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing photographs collected in 2015 and used to demonstrate compliance with §257.73(d)(1)(i)-(vii).

- Reviewing geotechnical calculations used to demonstrate the stability of foundations, per §257.73(d)(1)(i), sufficiency of embankment compaction, per §257.73(d)(1)(iii), and downstream slope inundation/stability, per §257.73(d)(1)(vii), in terms of supporting geotechnical investigation and testing data, input parameters, analysis methodology, selection of critical cross-sections, and loading conditions.

- Reviewing completeness and technical approach of closed-circuit television (CCTV) inspections used to evaluate the stability of hydraulic structures, per §257.73(d)(1)(vi).

No significant technical issues were noted within the technical review, although a detailed review (e.g., check) of the calculations was not performed.

5.3 Summary of Site Changes Affecting the Initial SSA

Several changes at the site that occurred after development of the Initial SSA were identified. These changes required updates to the Initial SSA and are described below:

- The Initial SSA utilized the results of the Initial Inflow Design Flood Control System Plan (IDF) to demonstrate compliance with the adequacy of spillway design and management (§257.73(d)(1)(v)(A)-(B)). The Initial IDF was subsequently updated to develop a Periodic IDF, based on site changes, as discussed in **Section 7**.

- The Initial SSA utilized the slope stability analysis results of the Initial Safety Factor Assessment (SFA) as part of the compliance demonstration for the stability of foundations and abutments (§257.73(d)(1)(i)) and sufficiency of dike compaction (§257.73(d)(1)(iii)) as discussed in **Section 5.1**. The Initial SSA also utilized sudden drawdown slope stability analyses performed using the same cross-sections and input data as the Initial SFA to demonstrate compliance with downstream slope inundation/stability (§257.73(d)(1)(vii). The Initial SFA slope stability analyses, including the sudden drawdown analyses, were subsequently updated to develop a Periodic SFA, based on site changes, as discussed in **Section 6.4**.

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5.4 Periodic SSA

The Periodic SFA (**Section 6.4**) indicates that foundations and abutments are stable and dike compaction is sufficient for expected ranges in loading conditions, as slope stability factors of safety were found to meet or exceed the requirements of §257.73(e)(1), including for static maximums storage pool conditions and post-earthquake (i.e., liquefaction) loading conditions considering seismically-induced strength loss in the foundation soils. Therefore, the requirements of §257.73(d)(1)(i) and §257.73(d)(1)(iii) are met for the Periodic SSA.

The Periodic IDF (**Section 7.4**) indicates that spillways are adequately designed and constructed to adequately manage flow during the PMF flood, as the spillways can adequately manage flow during peak discharge from the PMP storm event without overtopping of the embankments. Therefore, the requirements of §257.73(d)(1)(v)(A)-(B) are met for the Periodic SSA.

Certification of §257.73(d)(1)(vi) was independently performed by Luminant [8] and is not included within the scope of this report.

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SECTION 6

SAFETY FACTOR ASSESSMENT - §257.73(e)(1)

6.1 Overview of Initial SFA

The Initial Safety Factor Assessment (Initial SFA) was prepared by AECOM in 2016 [7], following the requirements of §257.73(e)(1). The Initial SFA included the following information:

- A geotechnical investigation program with in-situ and laboratory testing;
- An assessment of the potential for liquefaction in the embankment and foundation soils;
- The development of ten slope stability cross-sections for limit equilibrium stability analysis utilizing GeoStudio SLOPE/W software; and
- The analysis of all cross-sections for maximum storage pool, maximum surcharge pool, and seismic loading conditions.

The Initial SFA concluded that the PAP met all safety factor requirements, per §257.73(e), as all calculated safety factors were equal to or higher than the minimum required values.

6.2 Review of Initial SFA

Geosyntec performed a review of the Initial SFA ([5], [7]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing geotechnical calculations used to demonstrate the acceptable safety factors, per §257.73(e)(1), in terms of:
    - Completeness and adequacy of supporting geotechnical investigation and testing data;
    - Completeness and approach of liquefaction triggering assessments;
    - Input parameters, analysis methodology, selection of critical cross-sections, and loading conditions utilized for slope stability analyses; and
    - Phreatic conditions based on piezometric data, as discussed in **Section 2.3**.

No significant technical issues were noted within the technical review, although a detailed review (e.g., check) of the calculations was not performed.

6.3 Summary of Site Changes Affecting the Initial SFA

Several changes at the site that occurred after development of the Initial SFA were identified. These changes required updates to the Initial SFA and are described below:

- The groundwater levels measured since 2015 (**Section 2.3**) appear to be up to 10 ft higher than the phreatic surface modeled for the perimeter embankments during the Initial SFA ([5], [7]). Therefore, the phreatic surface needed to be updated to reflect the critical levels observed since 2015.

- The Periodic IDF (**Section 7.4)** found that the normal pool elevation within the PAP increased from 534.0 to 537.0 ft, resulting in 3.0 ft more water loading on the embankment dikes than was considered in the Initial SFA for the maximum storage pool, seismic loading conditions (§257.73(e)(1)(i) and (iii)), and sudden drawdown loading condition (§257.73(d)(1)(ii)). Peak water surface elevations during the IDF also increased from 534.9 to 538.2 ft, resulting in 3.3 ft more water loading on the embankment dikes than was considered in the Initial SFA for the maximum surcharge pool loading conditions (§257.73(e)(1)(i)).

6.4 Periodic SFA

Geosyntec revised existing slope stability analyses associated with the Initial SFA ([5], [7]) for the ten cross- sections of PAP to account for the increase in normal and peak pool loadings, and phreatic level changes as described in **Section 2.3** and **Section 7.4**. This included revising the slope stability analyses evaluating sudden drawdown conditions in the cross-sections adjacent to the downstream water body that were utilized as part of the Initial SSA (**Section 6.2**). The following approach and input data were used to revise the analyses:

- Water levels in the PAP for the maximum storage pool, seismic slope stability analysis, and sudden drawdown loading conditions were increased to El. 537.0 ft, based on the Periodic IDF (**Section 7.4)**.

- Water levels in the PAP for the maximum surcharge pool slope stability analysis loading conditions were increased to El. 538.2 ft, based on the Periodic IDF (**Section 7.4)**.

- According to updated groundwater level monitoring plot (**Section 2.3**), the phreatic level in the location of related piezometers increased for all the loading conditions from El. 534 to El. 538 ft in cross-section “E”, from El. 537 to El. 539 ft in cross-section “F”, from El. 535 to El. 544 ft in cross-section “G”, and from El. 535 to El. 541 ft in cross-section “K”.

- All other analysis input data and settings from the Initial SFA ([5], [7]), were utilized, including, but not limited to, subsurface stratigraphy and soil strengths, phreatic conditions,

ground surface geometry, software package and version, slip surface search routines and methods, and input data for the seismic analyses.

Factors of safety from the Periodic SFA are summarized in **Table 3** and confirm that the PAP meets the requirements of §257.73(e)(1). Slope stability analysis output associated with the Initial SFA is provided in **Attachment D**.

Table 3 – Factors of Safety from Periodic SFA

	Structural Stability Assessment (§257.73(d)) and Safety Factor Assessment (§257.73(e))				Structural Stability Assessment (§257.73(d))
Cross-Section	**Maximum Storage Pool §257.73(e)(1)(i) Minimum Required = 1.50**	**Maximum Surcharge Pool[1] §257.73(e)(1)(ii) Minimum Required = 1.40**	**Seismic §257.73(e)(1)(iii) Minimum Required = 1.00**	**Dike Liquefaction §257.73(e)(1)(iv) Minimum Required = 1.20**	**Sudden Drawdown §257.73(d)(1)(ii) Minimum Required = 1.30**
A	1.82	1.82	1.26	N/A	N/A
B	1.81	1.81	1.07*	N/A	1.59*
C	1.67	1.67	1.11	N/A	1.67
D	1.76	1.76	1.23	N/A	1.76
E	2.18	2.18	1.91	N/A	N/A
F	1.93	1.93	1.45	N/A	N/A
G	1.98	1.98	1.46	N/A	N/A
H	1.81	1.81	1.36	N/A	N/A
I	1.66*	1.66*	1.43	N/A	1.61
K	1.73	1.74	1.17	N/A	1.73

Notes:
*Indicates critical cross-section (i.e., lowest calculated factor of safety out of the ten cross-sections analyzed)
N/A – Loading condition is not applicable.

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SECTION 7

INFLOW DESIGN FLOOD CONTROL SYSTEM PLAN - §257.82

7.1 Overview of 2016 Inflow Design Flood Control System Plan

The Initial Inflow Design Flood Control System Plan (Initial IDF) was prepared by AECOM in 2016 [7], following the requirements of §257.82. The Initial IDF included the following information:

- A hydraulic and hydrologic analysis, performed for the 1,000-year design flood event because of the hazard potential classification of "Significant", which corresponded to 9.01 inches of rainfall over a 24-hour period.
- The Initial IDF utilized a HydroCAD Version 10 model to evaluate spillway flows and pool level increases during the design flood, with a starting water surface elevation of 534.0 ft.

The Initial IDF concluded that the PAP met the requirements of §257.82, as the peak water surface estimated by the HydroCAD model was elevation 534.9 ft, relative to a minimum PAP embankment crest elevation of 552.7 ft. Therefore, overtopping was not expected. The Initial IDF also evaluated the potential for discharge from the CCR unit and determined that discharge from the PAP during normal and inflow design flood conditions was expected to be routed through the existing spillway and NPDES-permitted outfall.

7.2 Review of Initial IDF

Geosyntec performed a review of the Initial IDF ([6], [7]) in terms of technical approach, calculation input parameters and methodology, recommendations, and completeness. The review included the following tasks:

- Reviewing the return interval used vs. the hazard potential classification.
- Reviewing the rainfall depth and distribution for appropriateness.
- Performing a high-level review of the inputs to the hydrological modeling.
- Reviewing the hydrologic model parameters for spillway parameters, starting pool elevation, and storage vs. the reference data.
- Reviewing the overall Initial IDF vs. the applicable requirements of the CCR Rule

Several review comments were identified during review of the Initial IDF. The comments are described below:

- The Initial IDF utilized the National Resource Conservation Service (NRCS) Type II rainfall distribution type [22]. Geosyntec recommend utilizing the Huff 3rd Quartile distribution for areas less than 10 square miles [23] for the reasons listed below.
    - Huff 3rd Quartile distribution was determined to be a more appropriate representation of a 1,000-year, 24-hour storm event per the Illinois State Water Survey (ISWS) Circular 173 [24] which developed standardized rainfall distributions from compiled rainfall data at sites throughout Illinois.
    - Illinois Department of Natural Resources, Office of Water Resources (IDNR-OWR) [25] recommends use of the Huff Quartile distributions in Circular 173 when using frequency events to determine the spillway design flood inflow hydrograph, "*The suggested method to distribute this rainfall is described in the ISWS publication, Circular 173, "Time Distributions of Heavy Rainstorms in Illinois"*.
- The process inflows (ash sluice and wastewater) included within the hydrologic and hydraulic analysis file were daily averages which are less than the maximum pump rate (i.e., worst-case scenario).

7.3 Summary of Site Changes Affecting the Initial IDF

Two changes at the site that occurred after development of the Initial IDF were identified. These changes required updates to the Initial IDF and are described below:

- Approximately 98,700 CY of CRR were placed above the SWSE utilized for the Initial IDF certification, thereby altering the stage-storage curve for the PAP relative to the Initial IDF.
- The operative water level of the impoundment is higher, thereby altering the SWSE for the PAP relative to the Initial IDF.

7.4 Periodic IDF

Geosyntec revised the HydroCAD model associated with the Initial IDF to account for the revised rainfall distribution type, cessation of process flows, and additional CCR placement, as described in **Sections 7.2** and **7.3**. The following approach and input data were used for the revised analyses and are referenced in **Attachment E** as appropriate:

- Stage-storage (i.e., area-capacity) curves for the PAP were updated based on the 2020 site survey [18].

  - A revised stage-volume curves for the PAP and Secondary Pond were prepared based on measuring the storage volume of the ponds at every one-foot increment of depth from an elevation at the bottom of the ponds (495 ft PAP; 505 ft Secondary Pond) to the perimeter dike embankment's approximate minimum crest elevation (552 ft PAP; 532 ft Secondary Pond). This analysis identified an overall increase of 129,070 CY (80 ac-ft) of storage volume at the PAP and an overall decrease of 14,520 CY (9 ac-ft) of storage volume at the Secondary Pond from 2016 to 2021.

- The SWSE within the PAP was updated from 534.0 ft to 537.0 ft as this is the invert of the pond outlet structure. The 2020 site survey showed a water surface elevation (WSE) of 535.5 ft; however, the greater elevation of the outlet invert and the surveyed WSE was used as the SWSE to provide conservatism in the model.

- The SWSE within the Secondary Pond was updated from 520.0 ft to 519.9 ft to reflect the 2020 site survey. The primary outlet invert elevation from the Secondary Pond is 505 ft; however, the greater elevation of the outlet invert and the surveyed WSE was used as the SWSE to provide conservatism in the model.

- Updated the inflows from the Ash Sluice from 3.88 cfs for 14 hours per day to 13.37 cfs for 14 hours per day for the duration of the modeled simulation. This more accurately reflects the full load operation of the pumps described in the Initial Full Certification Report (two pumps at 3,000 gpm each, operating 14 hours/day under full load).

- Wastewater inflows were updated from 11.64 cfs for 24 hours per day to 23.39 cfs for 12 hours per day for the duration of the modeled simulation. This more accurately reflects the full load operation of the pumps described in the Initial Full Certification Report (five pumps at 2,100 gpm each, operating 60 pump hours/day).

- The time of concentration (ToC) was updated for drainage areas to the PAP and Secondary Pond from 16.7 minutes (PAP) and 5 minutes (Secondary Pond) to 6 minutes to reflect direct run-on inflow in accordance with TR-20 [22].

- The primary outlet structure from the PAP was updated to reflect the description in the Initial Full Certification Report with no noted changes to the outlet structures.

  - The outlet invert elevation was updated from 512.0 ft to 512.18 ft to reflect the described invert elevation of 512.5 ft using the NGVD29 datum. This was converted to the NAVD88 datum to be consistent with the vertical datum used for the IDF HydroCAD model.

  - Added a weir box riser structure by routing a 28-inch diameter horizontal orifice to the existing outlet culvert. The invert of the riser was set to 537.0 ft. The dimensions of the riser structure were not available; therefore, the riser structure was sized in the model to be consistent with the downstream culvert; this was assumed to be a conservatively restrictive outlet.

- The routing method for the model was updated to more accurately account for routing between the ponds and Lake Newton. The Reach Routing Method was updated from "Storage Indication+ Translation" to "Dynamic Storage Indication". The Pond Routing Method was updated from "Storage – Indication" to "Dynamic Storage Indication".

- The tailwater conditions of the PAP and Secondary Pond were changed from fixed elevations to "Automated" to more accurately account for routing between the ponds.

- Lake Newton was changed to be represented by a link instead of a pond, which allowed a fixed water surface of 504.33 ft (based on 2020 survey of outlet invert elevation).

- The outlet invert elevation of the culvert outlet from the Secondary Pond was updated to 504.33 ft to reflect the 2020 site survey.

- All other input data and settings from the Initial IDF HydroCAD model were utilized, including, but not limited to software package and version, runoff method, rainfall depth, analysis time span and analysis time step.

The results of the Updated IDF are summarized in **Table 4** and confirm that the PAP meets the requirements of §257.82(a)-(b), as the peak water surface elevation does not exceed the minimum perimeter dike crest elevations. Additionally, all discharge from the PAP is routed through the existing spillway system to the NPDES-permitted outfall, during both normal and IDF conditions. Updated area-capacity curves and HydroCAD model output is provided in **Attachment E**.

Table 4- Water Levels from Periodic IDF

	Primary Ash Pond		
Analysis	**Starting Water Surface Elevation (ft)**	**Peak Water Surface Elevation (ft)**	**Minimum Dike Crest Elevation (ft)**
Initial IDF	534.0	534.9	552.0
Updated Periodic IDF	537.0	538.2	552.0
Initial to Periodic Change[1]	+3.0	+3.3	

Notes:
[1]Postive change indicates increase in the WSE relative to the Initial IDF, negative change indicates decrease in the WSE, relative to the Initial IDF.

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SECTION 8

CONCLUSIONS

The PAP at NPP was evaluated relative to the USEPA CCR Rule periodic assessment requirements for:

- Hazard potential classification (§257.73(a)(2)),
- History of Construction reporting (§257.73(d)),
- Structural stability assessment (§257.73(d)), with the exception of §257.73(d)(1)(vi) that was independently certified by Luminant [8];
- Safety factor assessment (§257.73(e)), and
- Inflow design flood control system planning (§257.82).

Based on the evaluations presented herein, the referenced requirements are satisfied.

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SECTION 9

CERTIFICATION STATEMENT

CCR Unit: Illinois Power Generating Company, Newton Power Plant, Primary Ash Pond

I, Panos Andonyadis, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief that the information contained in this 2021 USEPA CCR Rule Periodic Certification Report, has been prepared in accordance with the accepted practice of engineering. I certify, for the above-referenced CCR Unit, that the periodic assessment of the hazard potential classification, history of construction report, structural stability, safety factors, and inflow design flood control system planning, dated October 2021, were conducted in accordance with the requirements of 40 CFR §257.73(a)(2), (c), (d), (e), and §257.82, with the exception of §257.73(d)(1)(vi)) that was independently certified by others.

Panos Andonyadis

OCTOBER 11, 2021

Date



Electronic Filing: Received, Clerk's Office 07/01/2024

SECTION 10

REFERENCES

[1] United States Environmental Protection Agency, 40 CFR Parts 257 and 261; Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities; Final Rule, 2015.

[2] Stantec Consulting Services Inc., "Initial Hazard Potetnial Classificaiton Assessment, EPA Final CCR Rule, Primary Ash Pond, Newton Power Station, Jasper County, Illinois," Fenton, MO, October 12, 2016.

[3] AECOM, "History of Construction, USEPA Final CCR Rule, Newton Power Station, Newton, Illinois," October 2016.

[4] AECOM, "CCR Rule Report: Initial Structural Stability Assessment For Primary Ash Pond At Newton Power Station," St. Louis, MO, October 2016.

[5] AECOM, "CCR Rule Report: Initial Safety Factor Assessment For Primary Ash Pond At Newton Power Station," St. Louis, MO, October 2016.

[6] AECOM, "CCR Rule Report: Initial Inflow Design Flood Control System Plan For Primary Ash Pond At Newton Power Station," St. Louis, MO, October 2016.

[7] AECOM, "CCR Certification Report: Initial Structural Stability Assessment, Initial Safety Factor Assessment, and Initial Inflow Design Flood Control System Plan for Primary Ash Pond at Newton Power Station," St. Louis, MO, October 2016.

[8] V. Modeer, "Primary Ash Pond Structural Stability Assessment, Illinois Power Resrouces Generationg, LLC, Newton Power Station," Luminant, October 1, 2020.

[9] Stantec Consulting Services, Inc., "Documentation of Initial Hazard Potential Classificaiton Assessment, Primary Ash Pond, Newton Power Station, Jasper County, Illinois," October 12, 2016.

[10] J. Knutelski and J. Campbell, *Annual CCR Surface Impoundment Inspection Report (per 40 CFR 257.83(b)(2)), Newton Power Station, Primary Ash Pond,* January 18, 2016.

[11] J. Knutelski and J. Campbell, *Annual CCR Surface Impoundment Inspection Report (per 40 CFR 257.83(b)(2)), Newton Power Station, Primary Ash Pond,* January 18, 2017.

[12] J. Knutelski and J. Campbell, *Annual CCR Surface Impoundment Inspection Report (per 40 CFR 257.83(b)(2)), Newton Power Station, Primary Ash Pond,* February 7, 2018.

[13] J. Knutelski, *Annual Inspection by a Qualified Professional Engineer, 40 CFR 257.83(b), Newton Power Station, Primary Ash Pond,* January 10, 2019.

[14] Knutelski, James, *Annual Inspection by a Qualified Professional Engineer, 40 CFR §257.83(b), Newton Power Station, Primary Ash Pond,* January 10, 2020.

[15] James Knutelski, *Annual Inspection by a Qualified Professional Engineer, 40 CFR §257.83(b), Newton Power Station, Primary Ash Pond,* January 06, 2021.

[16] Geocyntec Consultants Inc., "Newton Piezo Measurements_20160121," Geocyntec Consultants Inc., Chesterfield, MO, 2021.

[17] Weaver Consultants Group, "Dynegy, Collinsville, IL, 2015 - Newton Topography," Collinsville, IL, December 2015.

[18] IngenAE, "Luminant, Dynegy Midwest Generation, LLC, Newton Power Station, December 2020 Topography," Earth City, Missouri, March 12, 2021.

[19] AECOM, "Draft CCR Unit Initial Site Visit Summary, Dynegy CCR Compliance Program," June 24, 2015.

[20] Stantec Consulting Services Inc, "Illinois Power Generating Company, Newton Power Station, City of Newton, Jasper County, IL, Emergency Action Plan, Primary Ash Pond (NID # IL50719)," Fenton, MO, April 13, 2017.

[21] U.S. Army Corps of Engineers, "Slope Stability, EM 1110-2-1902," October 31, 2003.

[22] Natural Resources Conservation Service, Conservation Engineering Division, "Urban Hydrology for Small Watersheds (TR-55)," United States Department of Agriculture, June 1985.

[23] F. A. Huff and J. R. Angel, "Frequency Distributions and Hydroclimatic Characteristics of Heavy Rainstorms in Illinois," State Water Survey Division, Department of Energy and Natural Resoruces, State of Illinois, Champaign, Illinois, 1989.

[24] F. A. Huff, "Time Distributions of Heavy Rainstorms in Illinois," State Water Survey, Department of Energy and Natural Resoruces, State of Illinois, Champaign, Illinois, 1990.

[25] Office of Natural Resources, "Procedural Guidelines for Preparation of Technical Data to be included in Applications for Permits for Construction and Maintenance of Dams," Department of Natural Resoruces, State of Illinois, Springfield, Illinois, Undated.

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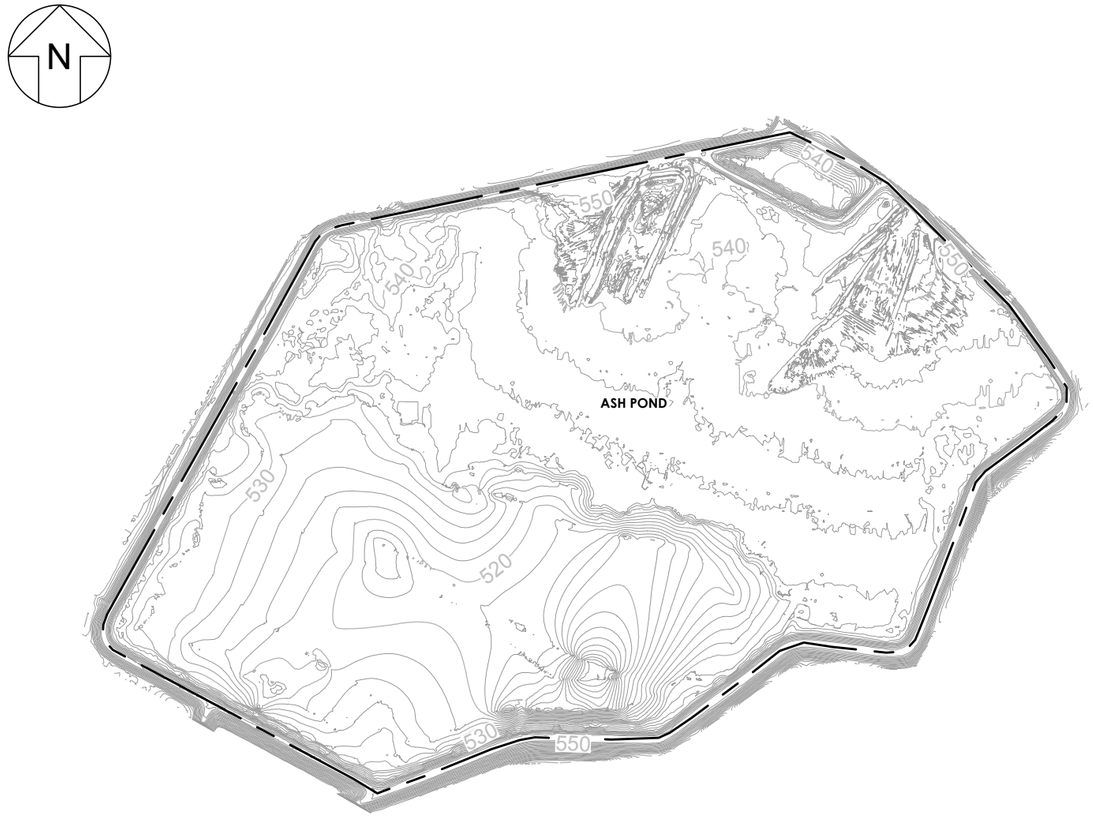
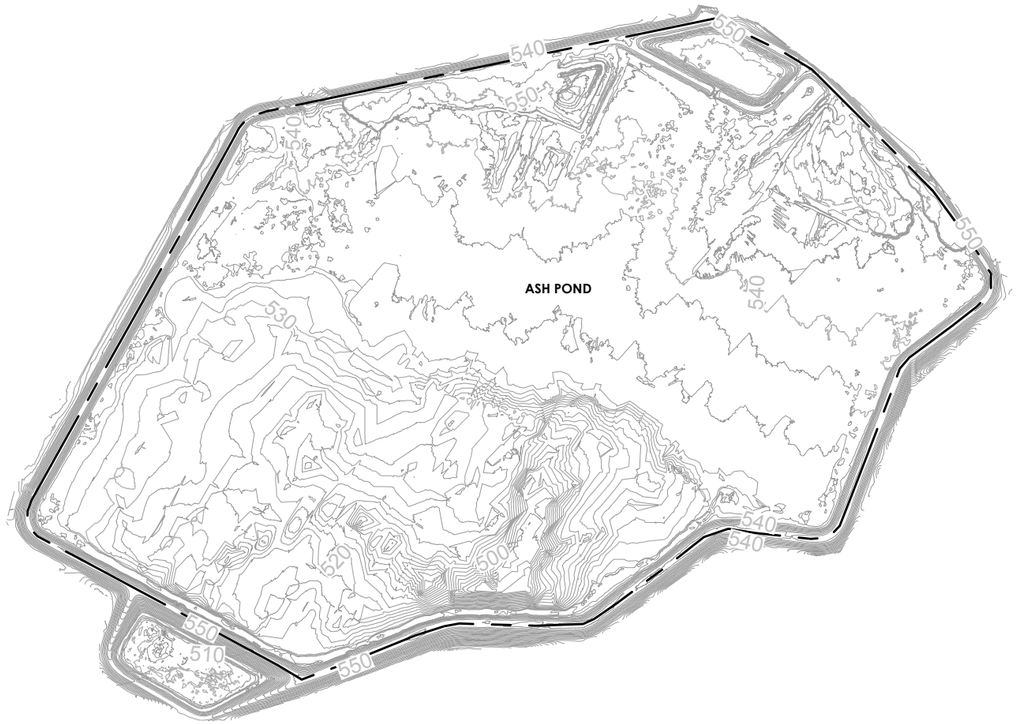
DRAWINGS



INITIAL SURVEY
12-01-2015 TOPOGRAPHY



PERIODIC SURVEY
02-26-2021 TOPOGRAPHY

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SCALE IN FEET

NOTES:

1. THE INITIAL SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - NEWTON TOPOGRAPHY”, PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “LUMINANT, ILLINOIS POWER GENERATING COMPANY, NEWTON POWER STATION, DECEMBER 2020 TOPOGRAPHY”, PREPARED BY INGENAE, DATED FEBRUARY 26, 2021.
3. ALL SURVEY DATA WAS COLLECTED IN THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) AND NORTH AMERICAN DATUM OF 1983 (NAD83) FOR VERTICAL AND HORIZONTAL COORDINATES, RESPECTIVELY.

INITIAL TO PERIODIC SURVEY COMPARISON
ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

Geosyntec consultants

DRAWING 1

GLP8027.08 | MAY 2021

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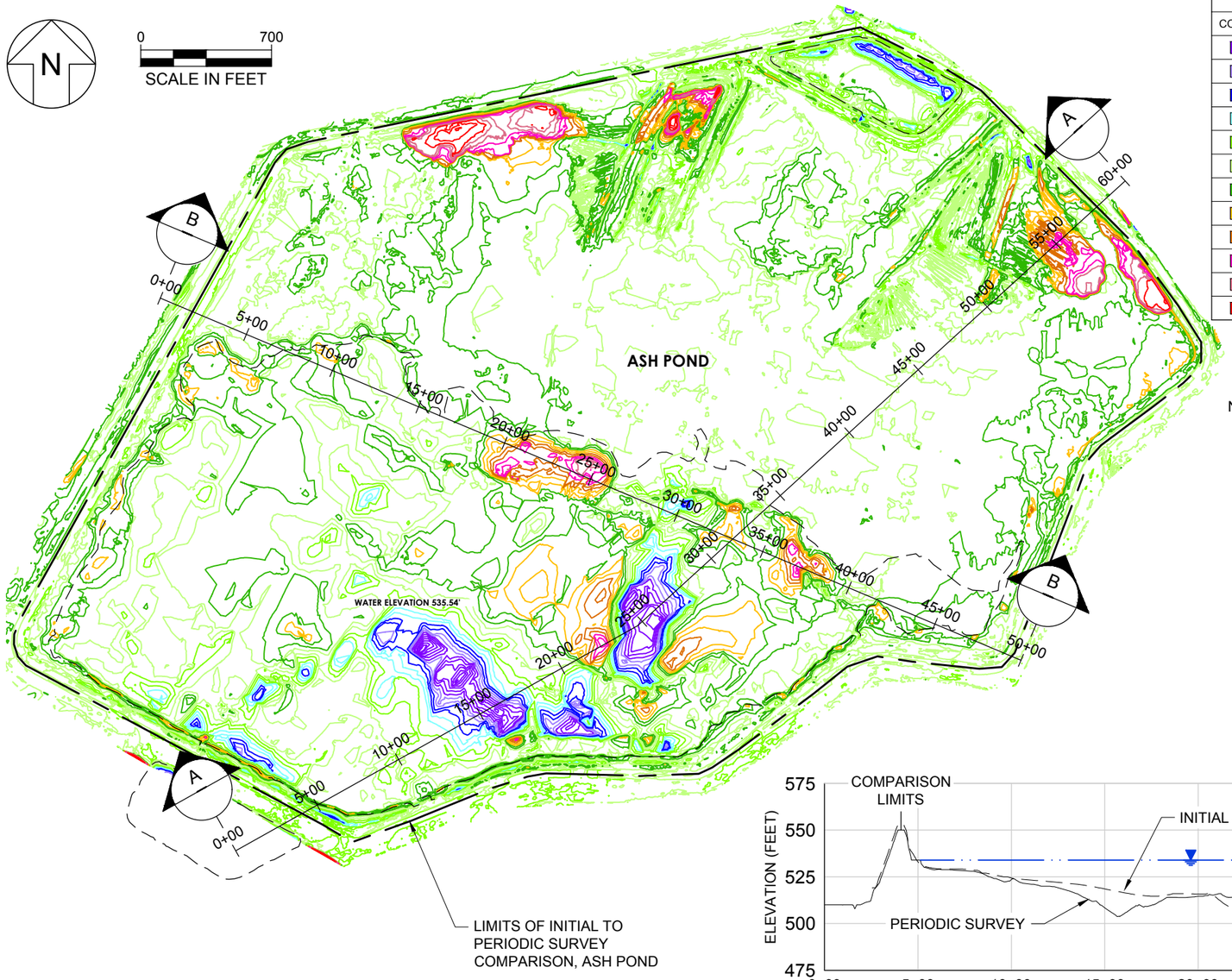
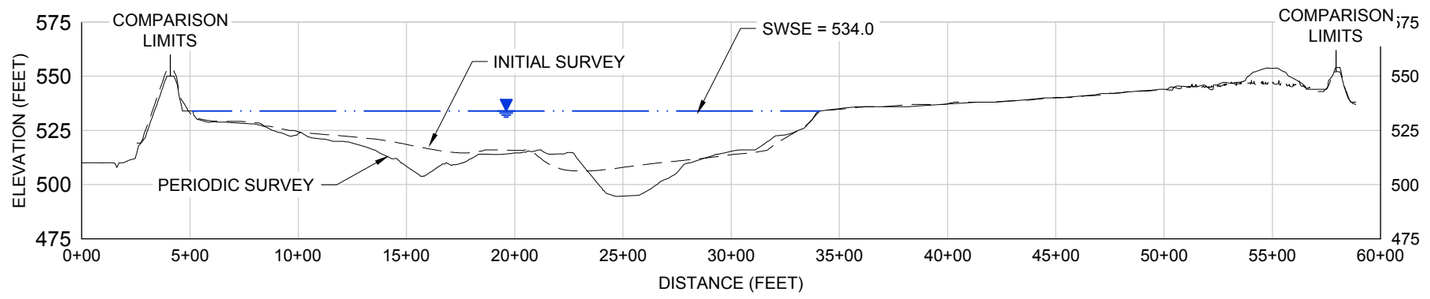


ISOPACH CONTOUR KEY		
COLOR	MIN ELEV	MAX ELEV
	-17	-10
	-10	-8
	-8	-6
	-6	-4
	-4	-2
	-2	0
	0	2
	2	4
	4	6
	6	8
	8	10
	10	26

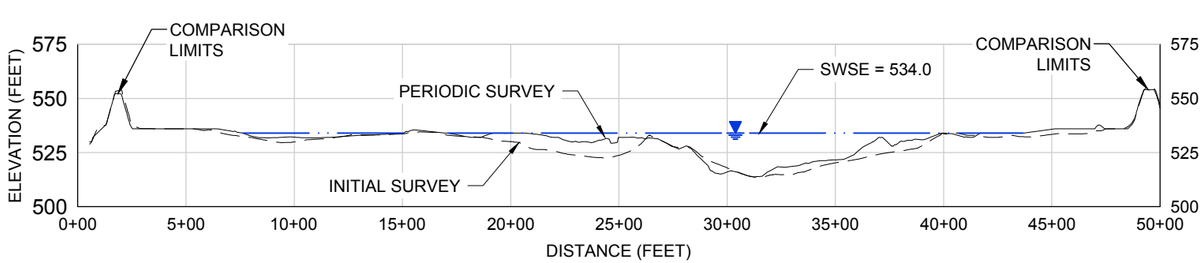
INITIAL TO PERIODIC SURVEY COMPARISON SUMMARY			
SURFACE IMPOUNDMENT	CUT	FILL	NET (CU. YD.)
ASH POND	467,675	566,386	98,711(FILL)
ABOVE SWSE	144,793	330,169	185,376 (FILL)
BELOW SWSE	322,591	235,677	86,913 (CUT)

NOTES:

1. THE INITIAL SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - NEWTON TOPOGRAPHY”, PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC SURVEY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “LUMINANT, ILLINOIS POWER GENERATING COMPANY, NEWTON POWER STATION, DECEMBER 2020 TOPOGRAPHY”, PREPARED BY INGENAE, DATED FEBRUARY 26, 2021.
3. ALL SURVEY DATA WAS COLLECTED IN THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88) AND NORTH AMERICAN DATUM OF 1983 (NAD83) FOR VERTICAL AND HORIZONTAL COORDINATES, RESPECTIVELY.
4. THE STARTING WATER SURFACE ELEVATION (SWSE) OF THE PRIMARY ASH POND IS EL. 534.0 FT, AS NOTED IN THE REPORT TITLED “CCR CERTIFICATION REPORT: INITIAL STRUCTURAL STABILITY ASSESSMENT, INITIAL SAFETY FACTOR ASSESSMENT, AND INITIAL INFLOW DESIGN FLOOD CONTROL SYSTEM PLAN FOR PRIMARY ASH POND AT NEWTON POWER STATION”, PREPARED BY AECOM, DATED OCTOBER, 2016.



SECTION A



SECTION B



SURVEY COMPARISON ISOPACH
NEWTON POWER PLANT
NEWTON, ILLINOIS

Geosyntec consultants

GLP8027.08 | MAY 2021

DRAWING 2

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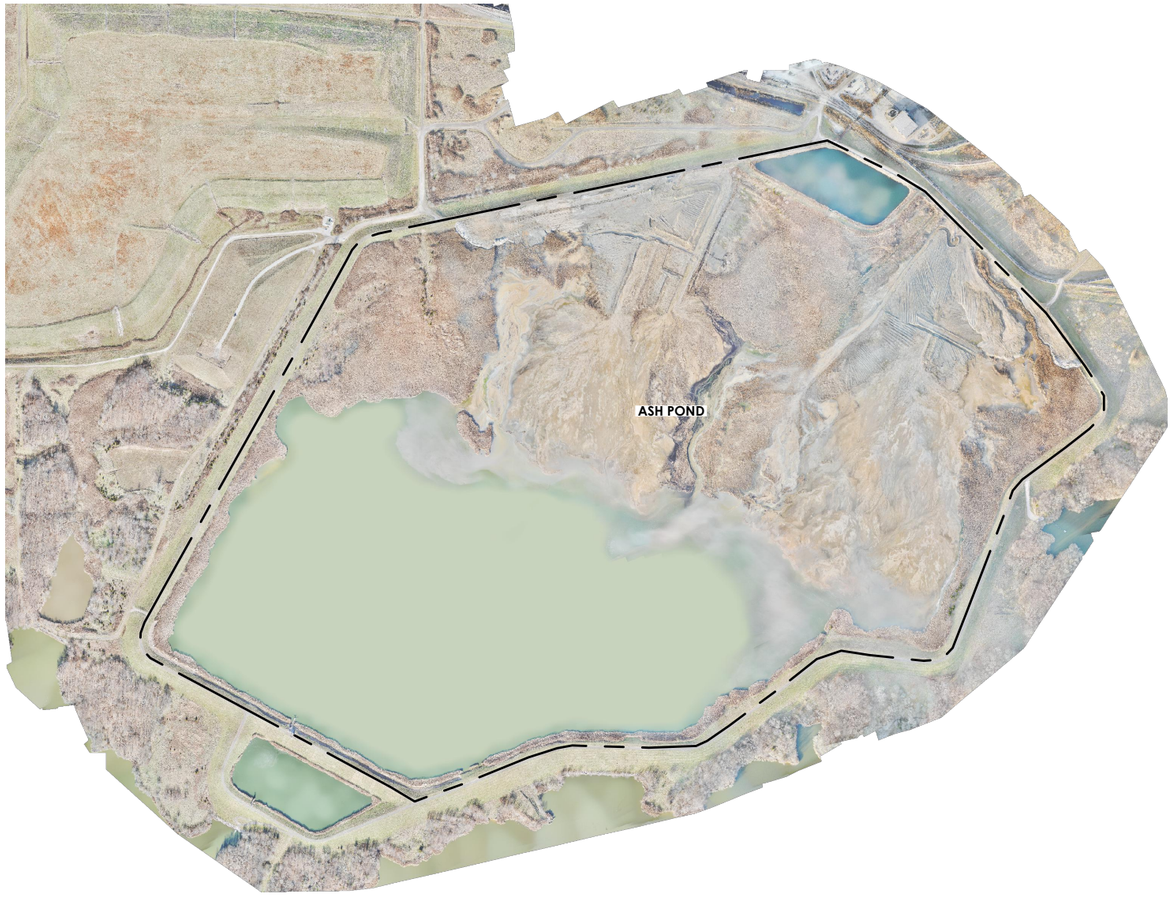
INITIAL AERIAL
12-01-2015 IMAGERY



PERIODIC AERIAL
02-26-2021 IMAGERY

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SCALE IN FEET

NOTES:

1. THE INITIAL IMAGERY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “DYNEGY, COLLINSVILLE, ILLINOIS, 2015 - NEWTON TOPOGRAPHY”, PREPARED BY WEAVER CONSULTANTS GROUP, DATED DECEMBER 1, 2015.
2. THE PERIODIC IMAGERY WAS TAKEN FROM THE DRAWING PACKAGE TITLED “LUMINANT, ILLINOIS POWER GENERATING COMPANY, NEWTON POWER STATION, DECEMBER 2020 TOPOGRAPHY”, PREPARED BY INGENAE, DATED FEBRUARY 26, 2021.

INITIAL TO PERIODIC AERIAL IMAGERY COMPARISON
ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

Geosyntec consultants

DRAWING 3

GLP8027.08 | MAY 2021

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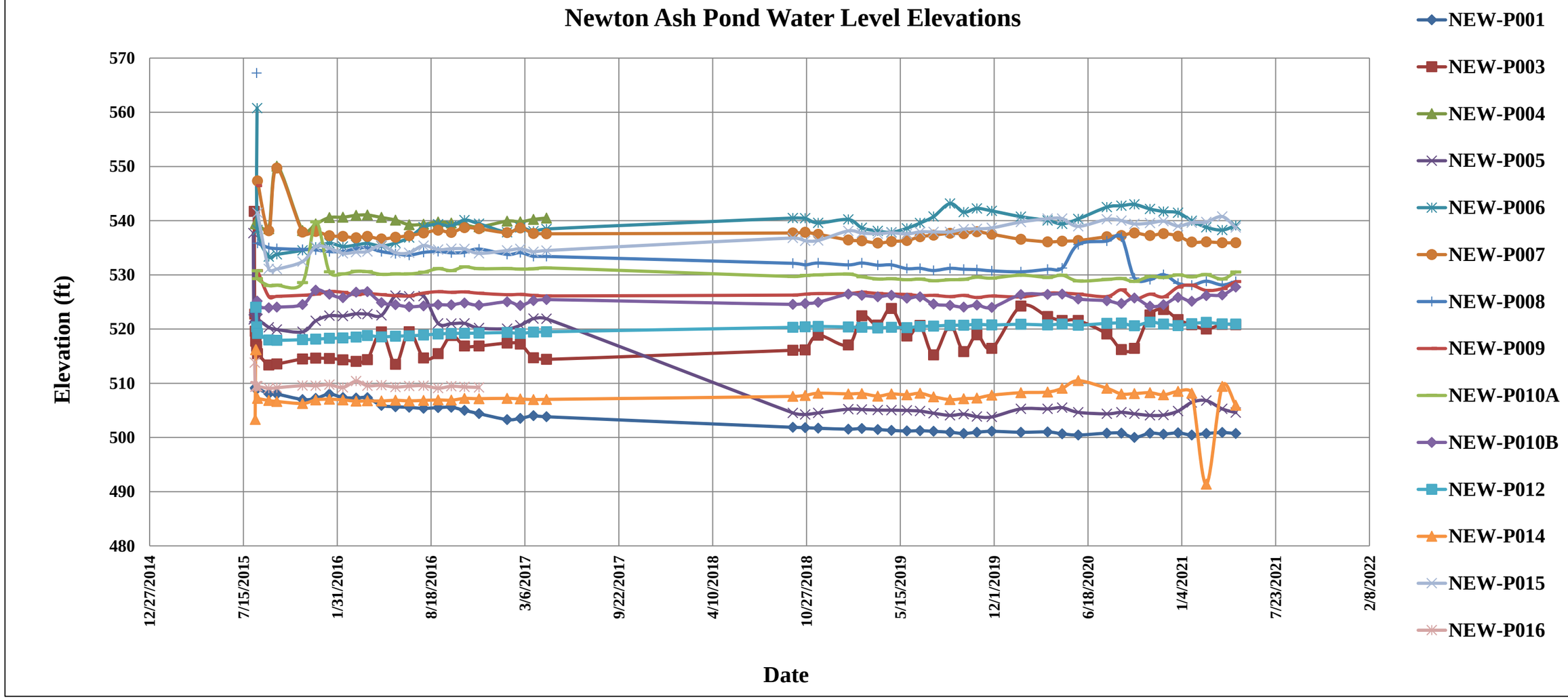
ATTACHMENTS

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment A

PAP Piezometer Data Plots



NOTES:

1. Piezometer data was taken from the spreadsheet titled "Newton Piezo Measurements_20160121", provided by the Newton Power Station.

PIEZOMETER DATA PERIODIC CERTIFICATION NEWTON POWER PLANT NEWTON, ILLINOIS		
Geosyntec consultants		Figure 1
GLP8027	6/2/2021	

\\ELOUISMO01\Data\Company\Projects_post_2014\GLP8027_CCR_RelCert\300_Technical\309_NEW\309d_Periodic_Report\Supporting work\NEW_GWI History Plot_06222021.xlsx]Newton

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment B

PAP Site Visit Photolog

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 01 **Date:** 5/21/2021 **Direction Facing:** NW **Comments:** Photo of the ash pond from the east embankment. Example of vegetative coverage and phragmites within the ash basin.	
Photo: 02 **Date:** 5/21/2021 **Direction Facing:** NE **Comments:** Example of vegetative coverage for the downstream slope along the northeast embankment.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 03 **Date:** 5/21/2021 **Direction Facing:** W **Comments:** Photo taken from the east embankment. Example of vegetative cover along the upstream slope of the embankment.	

Photo: 04 **Date:** 5/21/2021 **Direction Facing:** SW **Comments:** Photo taken from the east embankment. Example of vegetative cover along the downstream slope of the embankment.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 05 **Date:** 5/21/2021 **Direction Facing:** E **Comments:** Example of the vegetative cover of the upstream side of the embankment and within the ash basin. Some tree growth and phragmite growth within the ash basin.	

Photo: 06 **Date:** 5/21/2021 **Direction Facing:** E **Comments:** Tallest downstream slope along the south embankment and Newton Lake. Complete vegetative cover with no signs of instability or evidence of rapid draw down.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 07 **Date:** 5/21/2021 **Direction Facing:** E **Comments:** Upstream side of southern embankment. Example of vegetative cover. No signs of instability and erosion.	

Photo: 08 **Date:** 5/21/2021 **Direction Facing:** W **Comments:** Wave damage erosion observed along the downstream side of the southern embankment. At present this does not appear to be a stability concern for the embankment.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company	**Project Number:** GLP8027
CCR Unit: Primary Ash Pond	**Site:** Newton Power Plant

Photo: 09 **Date:** 5/21/2021 **Direction Facing:** E **Comments:** Downstream side of the southern embankment. Good vegetative cover, no tree growth or signs of erosion or instability.	

Photo: 10 **Date:** 5/21/2021 **Direction Facing:** NW **Comments:** Upstream side of the southwest embankment. Good vegetative cover, no tree growth or signs of erosion or instability.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 11 **Date:** 5/21/2021 **Direction Facing:** N **Comments:** Discharge point for the secondary Pond outlet pipe.	
Photo: 12 **Date:** 5/21/2021 **Direction Facing:** N **Comments:** Secondary pond downstream side embankments. Good vegetative cover, no tree growth or signs of erosion or instability.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 13 **Date:** 5/21/2021 **Direction Facing:** NE **Comments:** Primary ash pond discharge structure. No signs of erosion along the structure and no signs of deterioration or damage of the structure.	

Photo: 14 **Date:** 5/21/2021 **Direction Facing:** N **Comments:** Downstream side of the western embankment. Good vegetative cover, no tree growth or signs of erosion or instability. Some vegetative growth observed on the embankment crest.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company **Project Number:** GLP8027

CCR Unit: Primary Ash Pond **Site:** Newton Power Plant

Photo: 15 **Date:** 5/21/2021 **Direction Facing:** W **Comments:** Some erosion along the access ramp on the western embankment. Geosyntec recommended regrading the ramp as part of regular maintenance.	

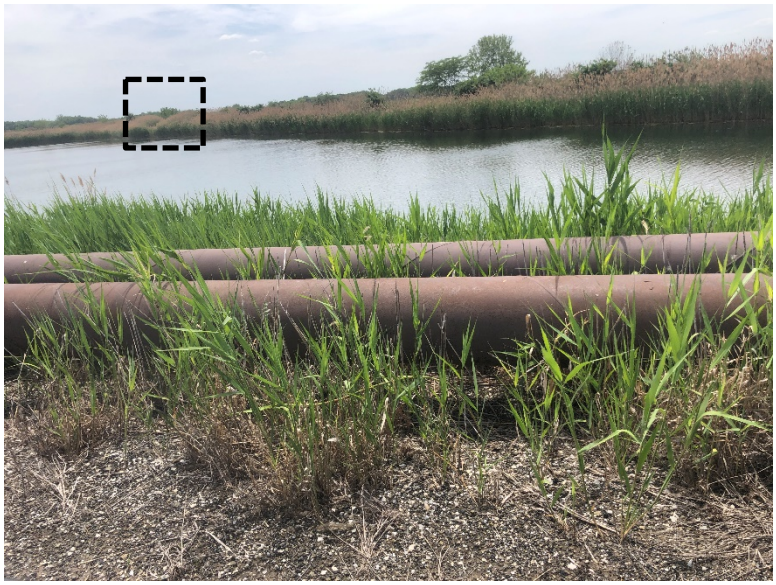
Photo: 16 **Date:** 5/21/2021 **Direction Facing:** N **Comments:** Downstream side of the western embankment. Good vegetative cover, no tree growth or signs of erosion or instability.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company	**Project Number:** GLP8027
CCR Unit: Primary Ash Pond	**Site:** Newton Power Plant

Photo: 17 **Date:** 5/21/2021 **Direction Facing:** S **Comments:** Sluice discharge west of the Secondary Settlement Pond. Discharge channel and sluiced ash flow to the southwest.	

Photo: 18 **Date:** 5/21/2021 **Direction Facing:** S **Comments:** Secondary Settlement Pond. Breach with Primary Ash Pond is visible. Phragmite growth observed along the separation berm between Primary Ash Pond and Secondary Settlement Pond.	

GEOSYNTEC CONSULTANTS
Photographic Record

Geosyntec consultants

Site Owner: Illinois Power Generating Company	**Project Number:** GLP8027
CCR Unit: Primary Ash Pond	**Site:** Newton Power Plant

Photo: 19 **Date:** 5/21/2021 **Direction Facing:** NW **Comments:** Downstream side of the northeastern embankment. Good vegetative cover, no tree growth or signs of erosion or instability.	

Photo: 20 **Date:** 5/21/2021 **Direction Facing:** S **Comments:** Erosion and poor vegetative cover underneath the sluice pipe racks along the northern embankment. Geosyntec recommended reseeding or applying erosion protective features on the side slope as part of regular maintenance.	

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Attachment C

Periodic History of Construction Report Update Letter

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Geosyntec consultants

1 McBride and Son Center Drive, Suite 202
Chesterfield, MO 63005
PH 636-812-0800
www.geosyntec.com

October 2021

Illinois Power Generating Company
6725 North 500th Street
Newton, Illinois 62448

Subject: Periodic History of Construction Report Update Letter
USEPA Final CCR Rule, 40 CFR §257.73(c)
Newton Power Plant
Newton, Illinois

At the request of Illinois Power Generating Company (IPGC), Geosyntec Consultants (Geosyntec) has prepared this Letter to documents updates to the Initial History of Construction (HoC) report for the Newton Power Plant (NPP), also known as the Newton Power Station (NEW). The Initial HoC report was prepared by AECOM in October of 2016 [1] in accordance with 40 Code of Federal Regulations (CFR) §257.73(c) of the United States Environmental Protection Agency (USEPA) Coal Combustion Residuals Rule, known as the CCR Rule [2]. This letter also includes information required by Section 845.220(a)(1)(B) (Design and Construction Plans) of the state-specific Illinois Environmental Protection Agency (IEPA) Part 845 CCR Rule [3] that is not expressly required by §257.73(c).

BACKGROUND

The CCR Rule required that, by October 17, 2016, Initial HoC reports to be compiled for existing CCR surface impoundments with: (1) a height of five feet or more and a storage volume of 20 acre-feet or more, or (2) a height of 20 feet or more. The Initial HoC report was required to contain, to the extent feasible, the information specified in 40 CFR §257.73(c)(1)(i)-(xii). The Initial HoC report for NEW, which included the existing CCR surface impoundment, the Primary Ash Pond (PAP), was prepared and subsequently posted to IPGC's CCR Website prior to October 17, 2016.

The CCR Rule requires that Initial HoC to be updated if there is a significant change to any information complied in the Initial HoC report, as listed below:

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§ 257.73(c)(2): If there is a significant change to any information complied under paragraph (c)(1) of this section, the owner or operator of the CCR unit must update the relevant information and place it in the facility's operating record as required by § 257.105(f)(9).

IPGC retained Geosyntec to review the Initial HoC report, review reasonably and readily available information for the PAP generated since the Initial HoC report was prepared, and perform a site visit to NEW to evaluate if significant changes may have occurred since the Initial HoC report was prepared. This Letter contains the results of Geosyntec's evaluation and documents significant changes that have occurred at the PAP and NPP, as they pertain the requirements of §257.73(c)(1)(i)-(xii)

UPDATES TO HISTORY OF CONSTRUCTION REPORT

Geosyntec's evaluation for the NPP PAP determined that no known significant changes requiring updates to the information in the Initial HoC report pertaining to §257.73(c)(1)(ii)-(vi), (viii), (ix), (xi), and (xii) of the CCR Rule had occurred since the Initial HoC report was developed.

However, Geosyntec's evaluation determined that significant changes at the NEW PAP pertaining to §257.73(c)(1)(i), (vii), and (x) of the CCR Rule had occurred since the Initial HoC report had been developed. Additionally, information how long the CCR surface impoundments have been operating and the types of CCR in the surface impoundments, as required by Section 845.220(a)(1)(B) of the Part 845 Rule were not included in the Initial HoC report, as this information is not required by the CCR Rule. Each change and the subsequent updates to the Initial HoC report is described within this section.

Section 845.220(a)(1)(B): A statement of … how long the CCR surface impoundment has been in operation, and the types of CCR that have been placed in the surface impoundment.

Primary Ash Pond

The PAP was in operation from 1977 until today, for a total of approximately 44 years [1].

CCR placed in the PAP has included bottom ash and economizer ash, in addition to other non-CCR plant process wastewater [1].

engineers | scientists | innovators

§ 257.73(c)(1)(i): The name and address of the person(s) owning or operating the CCR unit; the name associated with the CCR unit; and the identification number of the CCR unit if one has been assigned by the state.

A state identification numbers (IDs) for the PAP was assigned by the Illinois Environmental Protection Agency (IEPA). The ID is listed in **Table 1**.

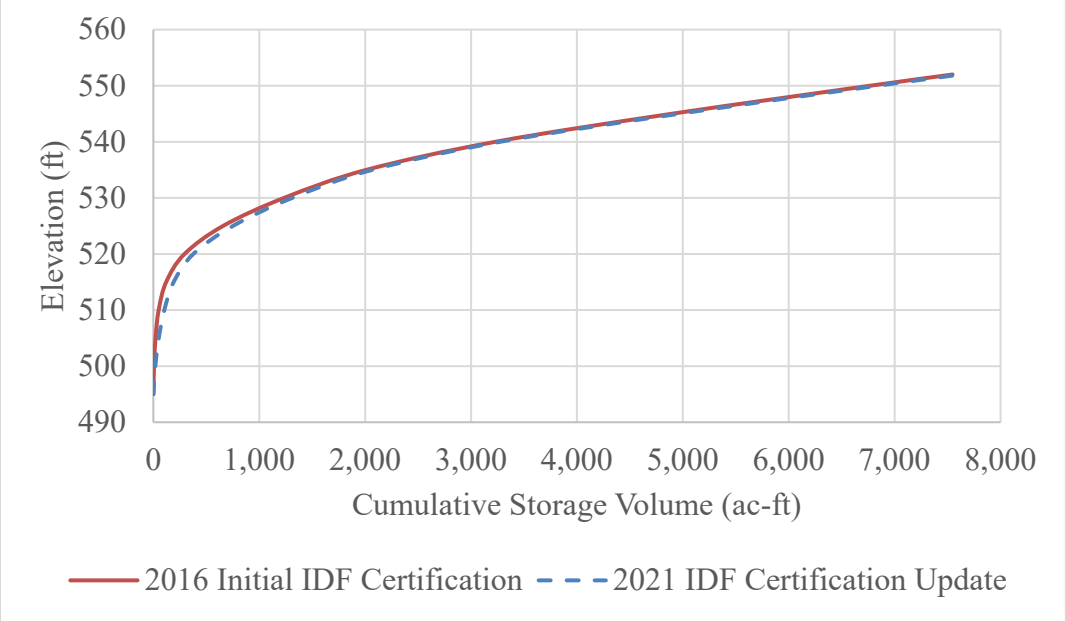
Table 1 – IEPA ID Numbers

CCR Surface Impoundment	State ID
Primary Ash Pond (PAP)	W0798070001-01

§ 257.73(c)(1)(vii): At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit, detailed dimensional drawings of the CCR unit, including a plan view and cross sections of the length and width of the CCR unit, showing all zones, foundation improvements, drainage provisions, spillways diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation.

Updated area-capacity curves were prepared for the PAP in 2021. These curves are provided in **Figures 1**.

Figure 1 – Area-Capacity Curve for Primary Ash Pond



§ 257.73(c)(1)(x): A description of each spillway and diversion design features and capacities and calculations used in their determination.

Updated discharge capacity calculations for the existing spillways were prepared in 2021 using HydroCAD 10 modeling software. The calculations indicate that the PAP has sufficient storage capacity and will not overtop the embankments during the Probable Maximum Precipitation (PMP), 24-hour, storm event. The results of the calculations are provided in **Table 2**.

Table 2 – Results of Updated Discharge Capacity Calculations

	Primary Ash Pond
Approximate Berm Minimum Elevation[1], ft	553.0
Starting Water Surface Elevation[1] (SWSE), ft	537.0
Peak Water Surface Elevation[1] (PWSE), ft	538.2
Time to Peak, hr	24.0
Surface Area[2], ac	272.0
Storage[3], ac-ft	281.1

Notes:
[1]Elevations are based on the NAVD88 datum
[2] Surface Area is defined as the water surface area at the PWSE
[3]Storage is defined as the volume between the SWSE and PWSE

CLOSING

This letter has been prepared to document Geosyntec's evaluation of changes that have occurred at the PAP at the NEW since the Initial HoC was developed, based on reasonably and readily available information provided by IPGC, observed by Geosyntec during the site visit, or generated by Geosyntec as part of subsequent calculations.

Sincerely,

Panos Andonyadis, P.E.
Senior Engineer

John Seymour, P.E.
Senior Principal

REFERENCES

[1] AECOM, "History of Construction, USEPA Final CCR Rule, 40 CFR § 257.73(c), Newton Power Station, Newton, Illinois," October 2016.

[2] United Stated Environmental Protection Agency, "40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule, 2015," 2015.

[3] Illinois Environmental Protection Agency, "35 Ill. Adm. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments," Springfield, IL, 2021.

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment D

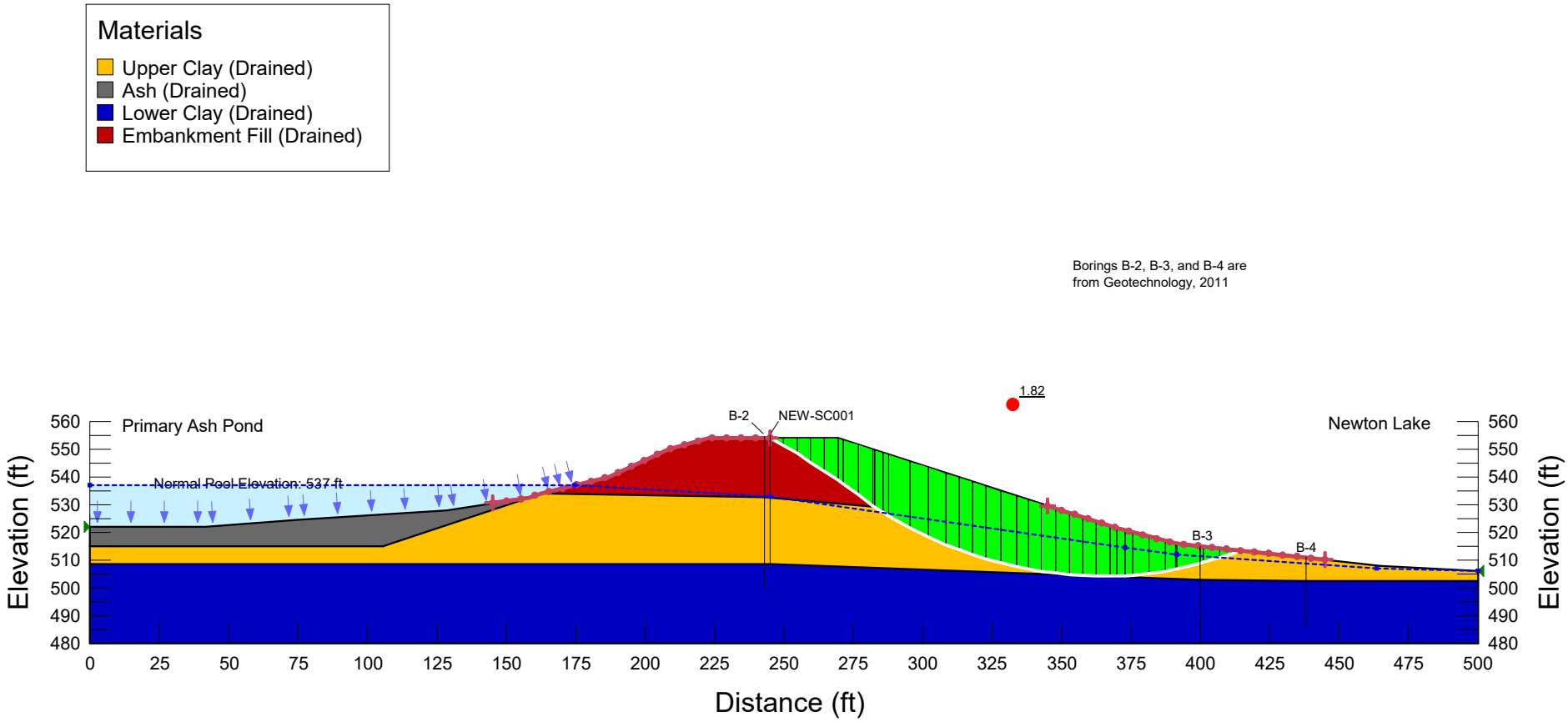
Periodic Structural Stability and Safety Factor Assessment Analyses

Project Name: Newton Primary Ash Pond Stability Analysis-Section A

Analysis: Long Term (Drained)

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section A

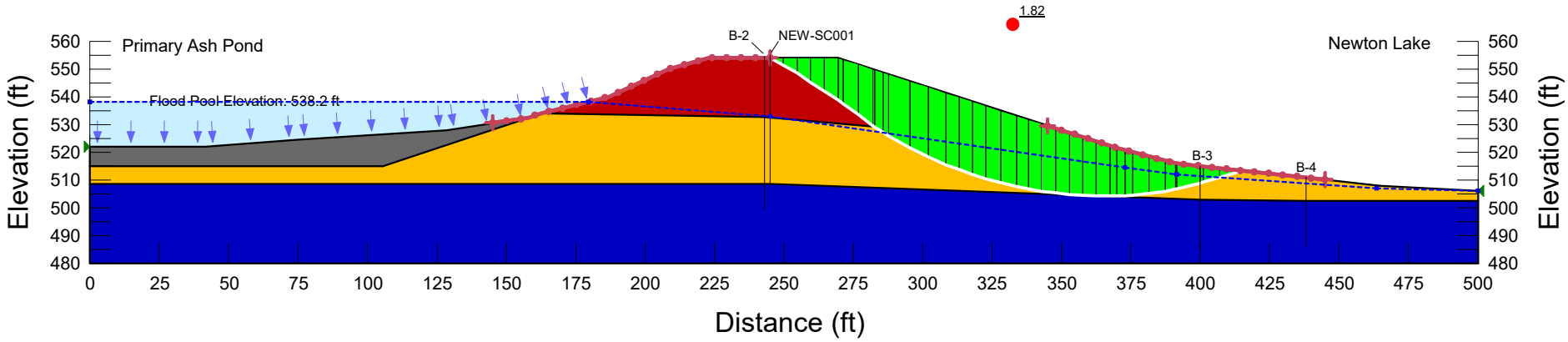
Analysis: Surcharge (Drained)

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °

Materials
- Upper Clay (Drained)
- Ash (Drained)
- Lower Clay (Drained)
- Embankment Fill (Drained)

Borings B-2, B-3, and B-4 are from Geotechnology, 2011



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Electronic Filing: Received, Clerk's Office 07/01/2024

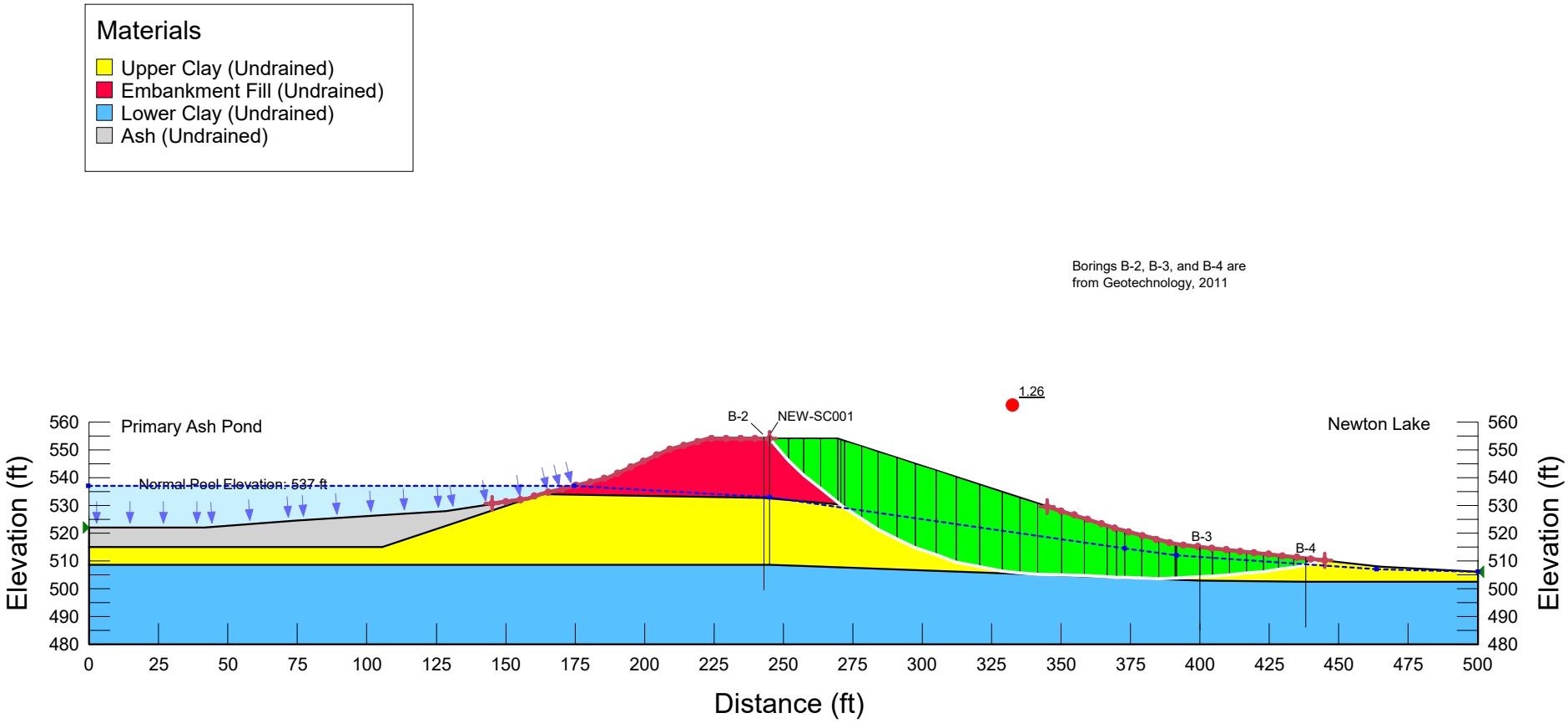
Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Project Name: Newton Primary Ash Pond Stability Analysis-Section A

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °
Name: Ash (Undrained) Model: S=f(overburden) Unit Weight: 90 pcf Tau/Sigma Ratio: 0.05 Minimum Strength: 0 psf



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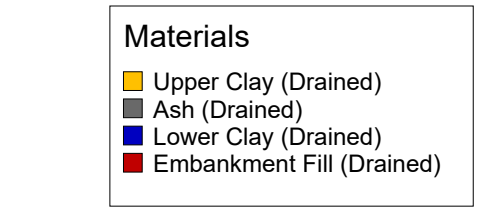
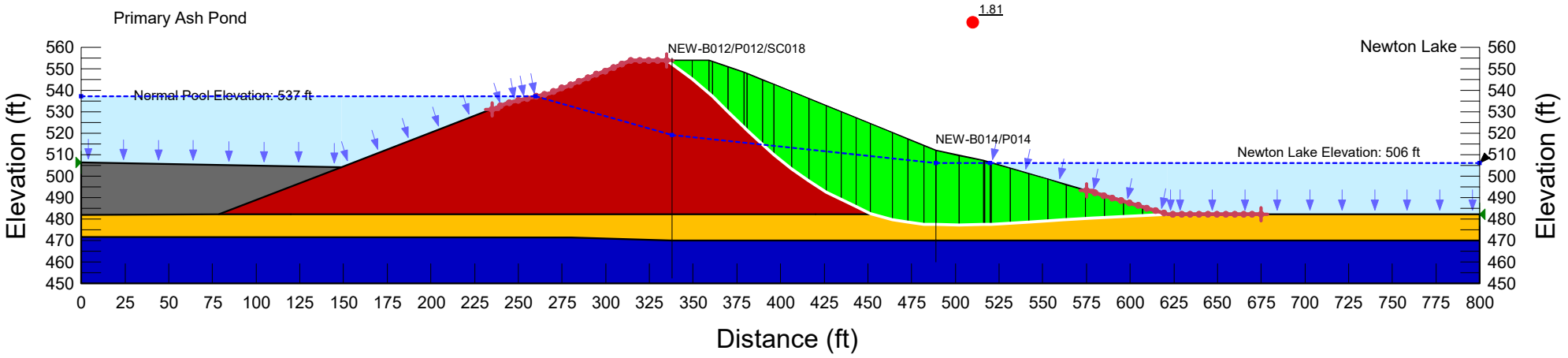
Project Name: Newton Primary Ash Pond Stability Analysis-Section B

Analysis: Long Term (Drained)

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °





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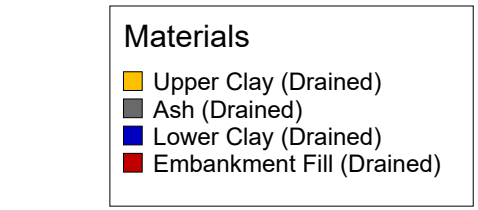
Electronic Filing: Received, Clerk's Office 07/01/2024

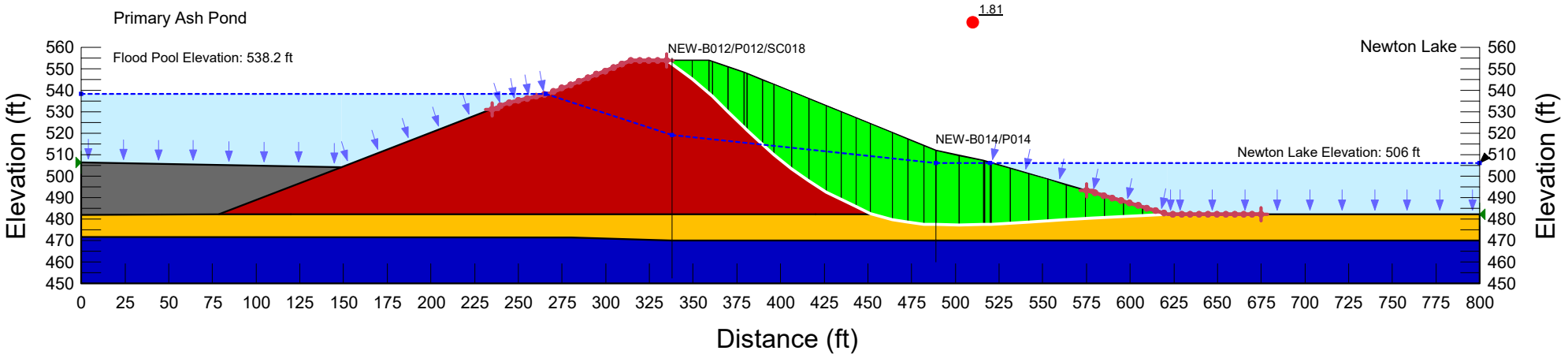
Project Name: Newton Primary Ash Pond Stability Analysis-Section B

Analysis: Surcharge (Drained)

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °





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Electronic Filing: Received, Clerk's Office 07/01/2024

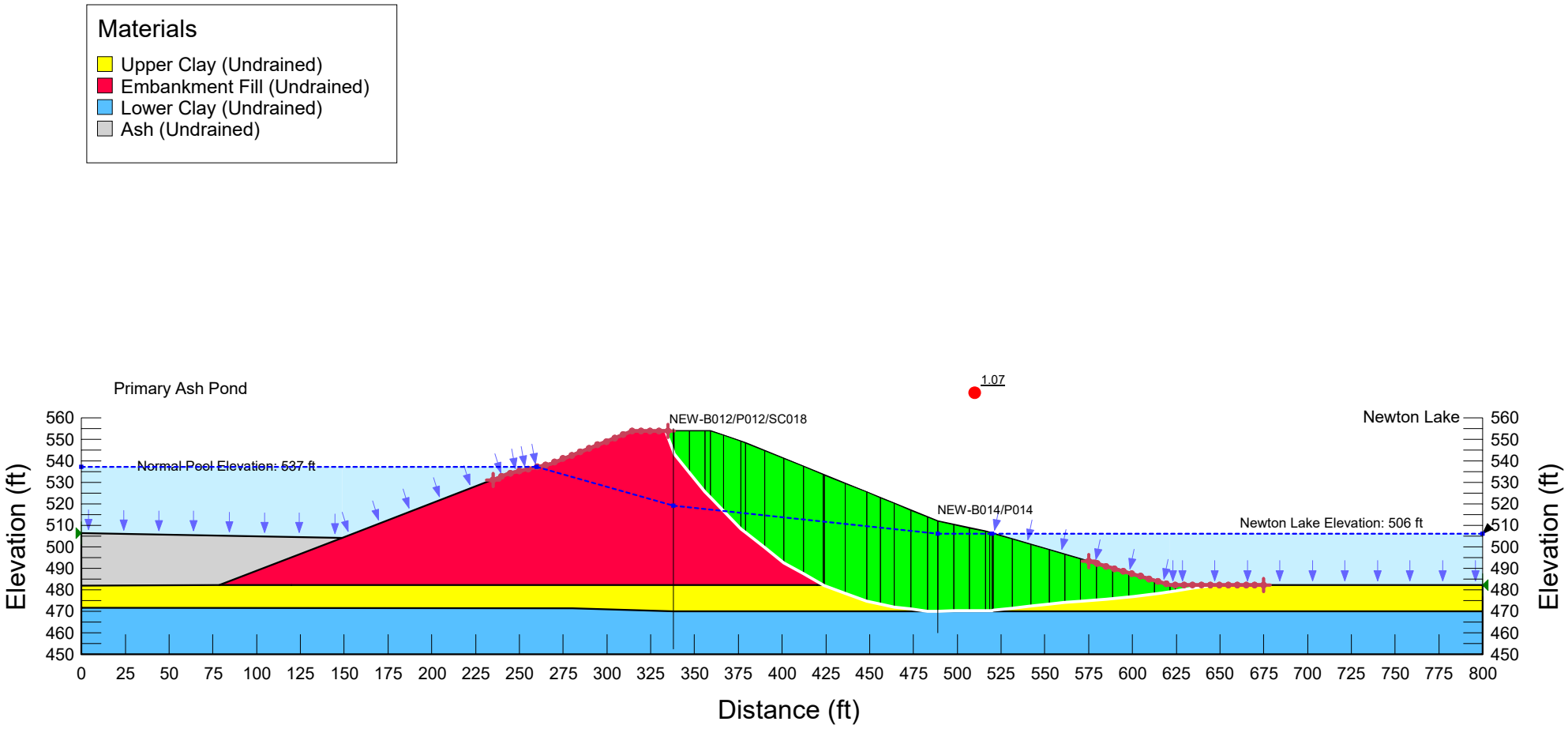
Project Name: Newton Primary Ash Pond Stability Analysis-Section B

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153g

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °
Name: Ash (Undrained) Model: S=f(overburden) Unit Weight: 90 pcf Tau/Sigma Ratio: 0.05 Minimum Strength: 0 psf



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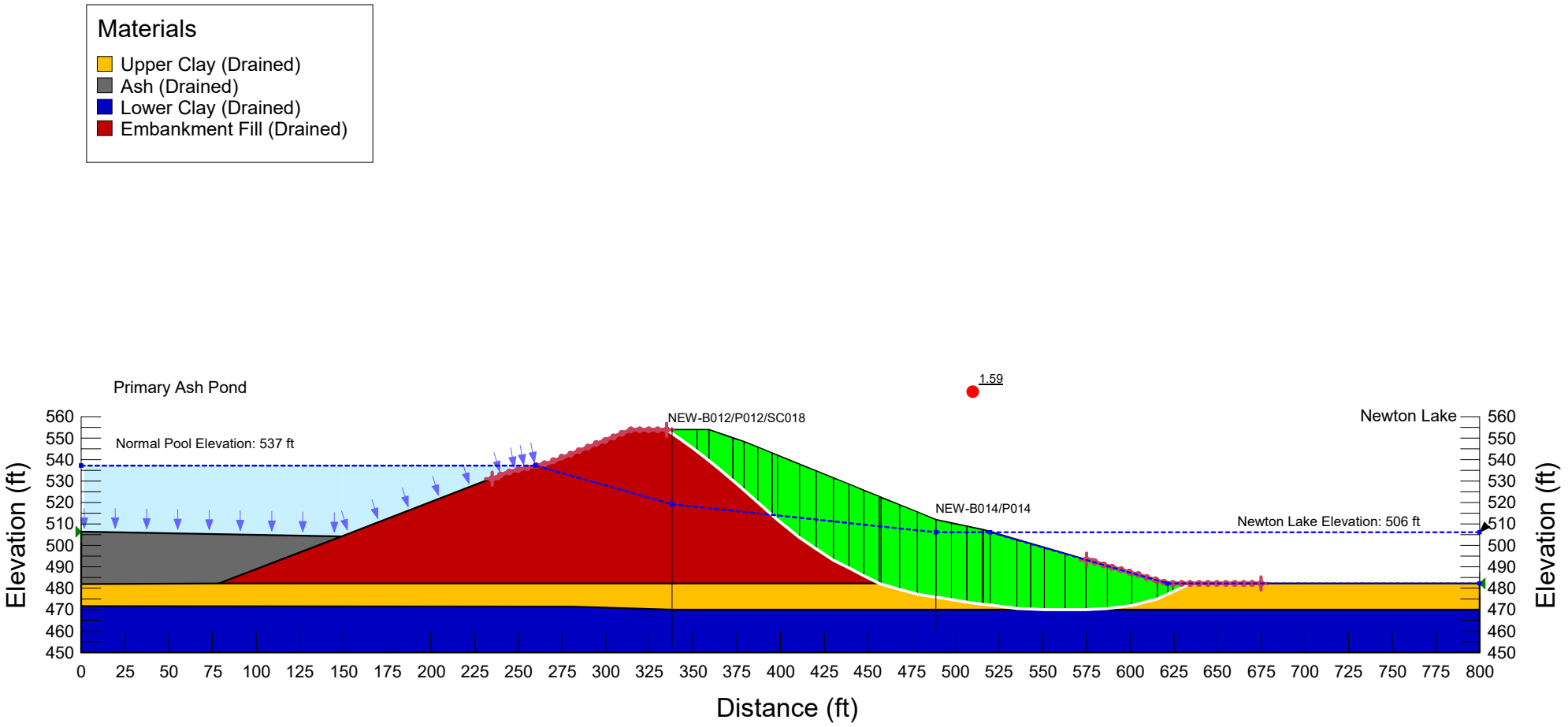
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section B

Analysis: Sudden Drawdown

Calculated By: MJN Date: 6/17/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date: 9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 ° Cohesion R: 470 psf Phi R: 22 ° Piezometric Line After Drawdown: 2
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 ° Cohesion R: 500 psf Phi R: 22 ° Piezometric Line After Drawdown: 2



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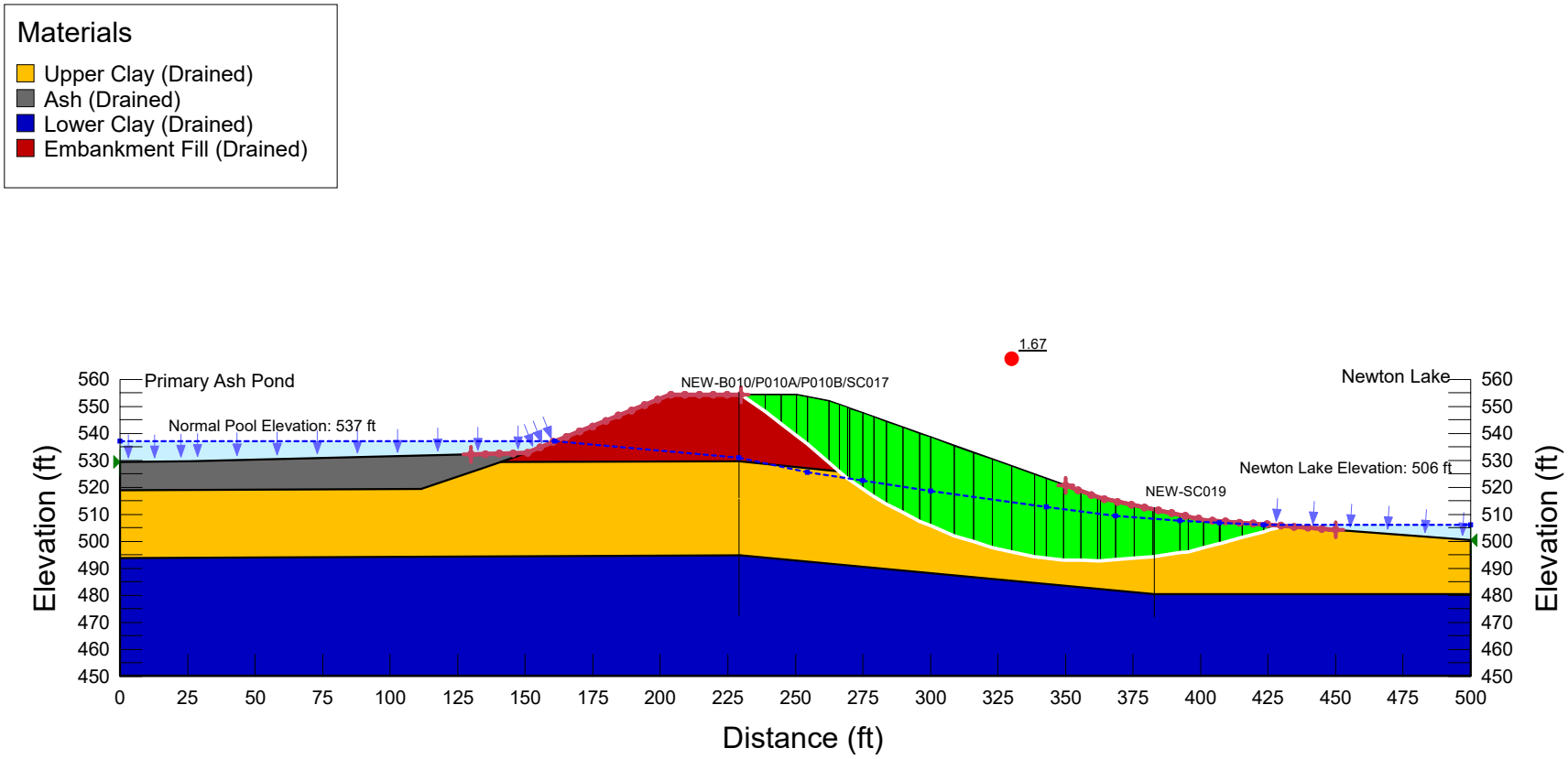
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section C

Analysis: Long Term (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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Electronic Filing: Received, Clerk's Office 07/01/2024

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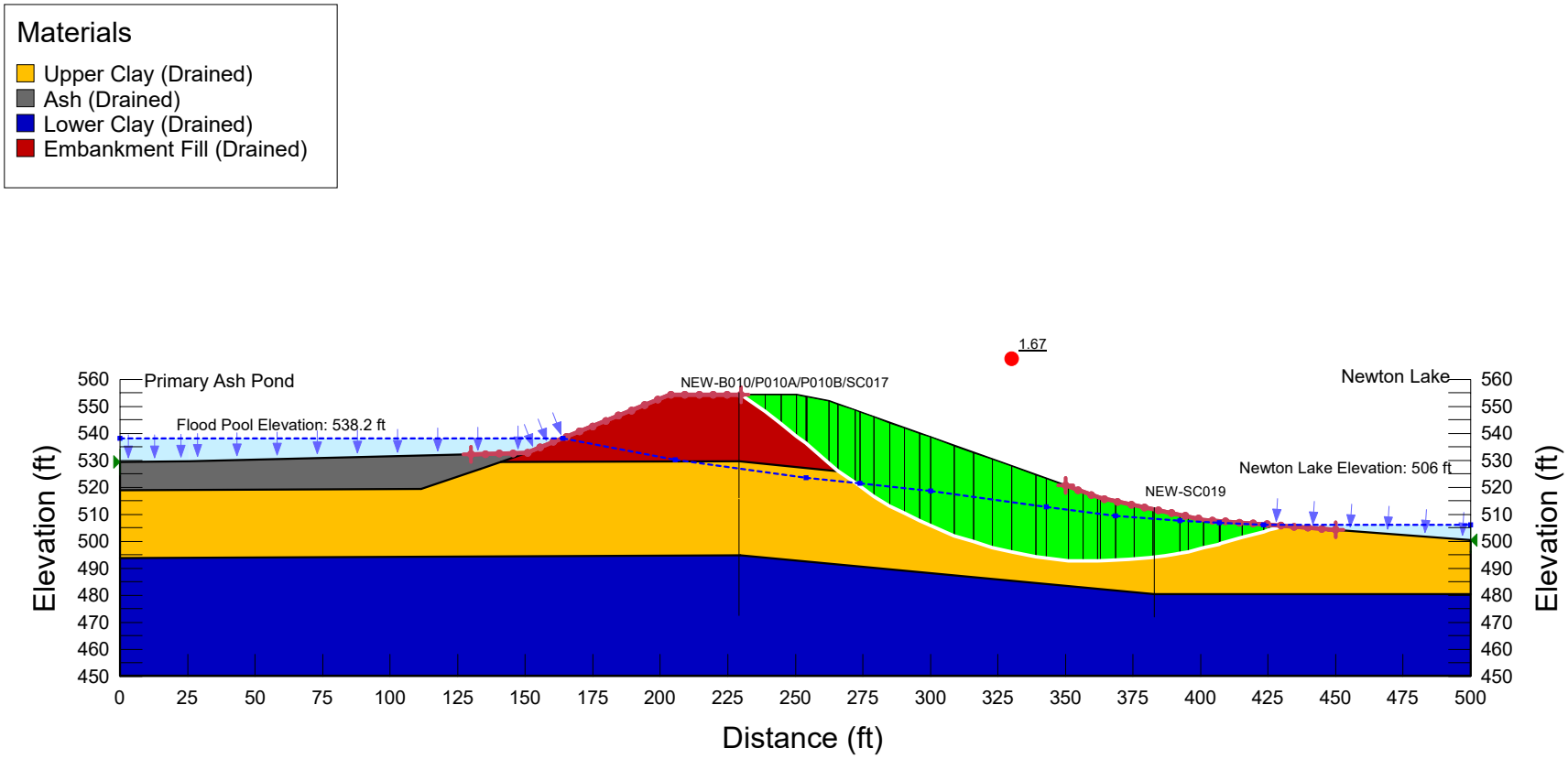
Project Name: Newton Primary Ash Pond Stability Analysis-Section C

Analysis: Surcharge (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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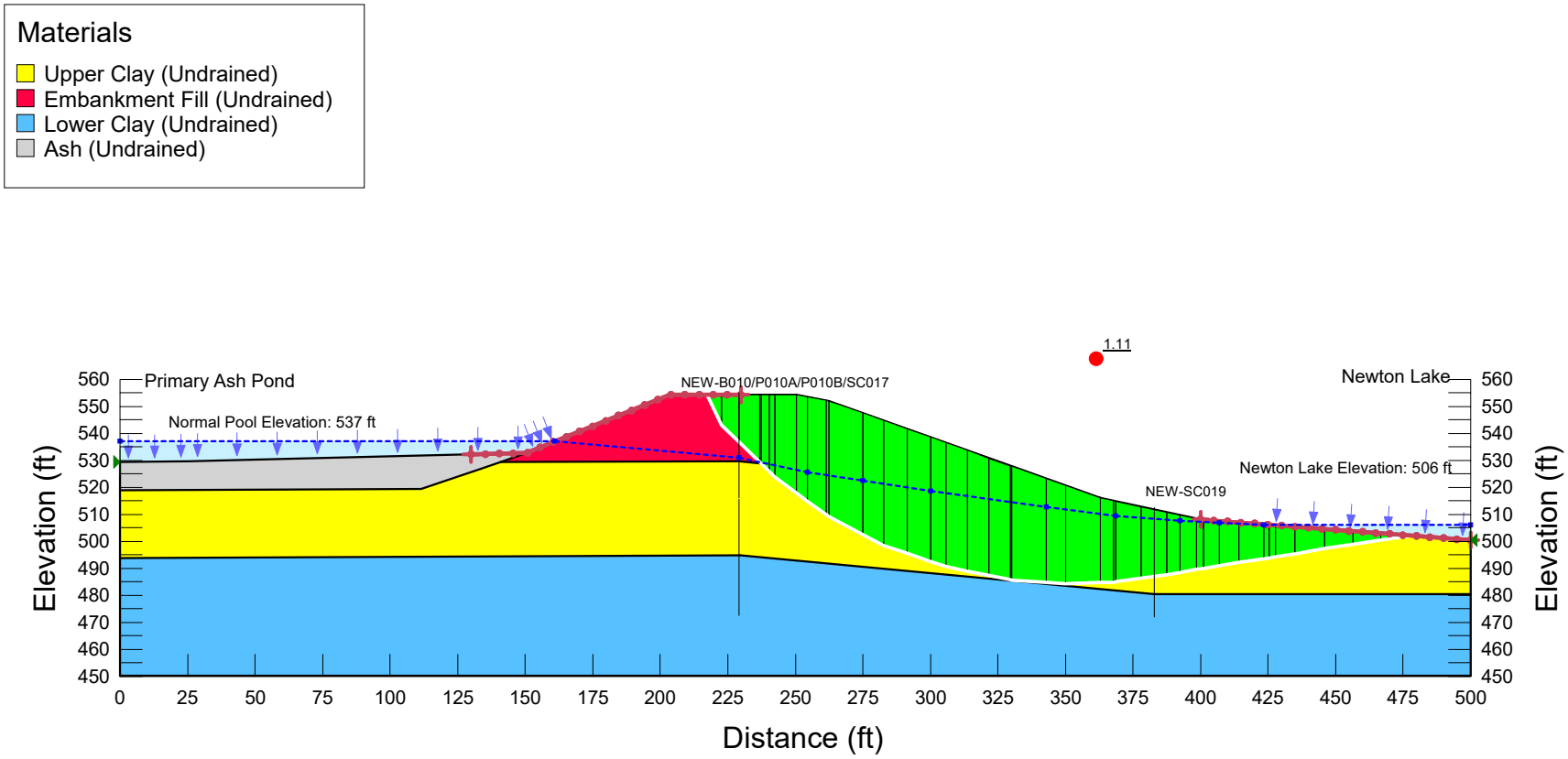
Project Name: Newton Primary Ash Pond Stability Analysis-Section C

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °
Name: Ash (Undrained) Model: S=f(overburden) Unit Weight: 90 pcf Tau/Sigma Ratio: 0.05 Minimum Strength: 0 psf



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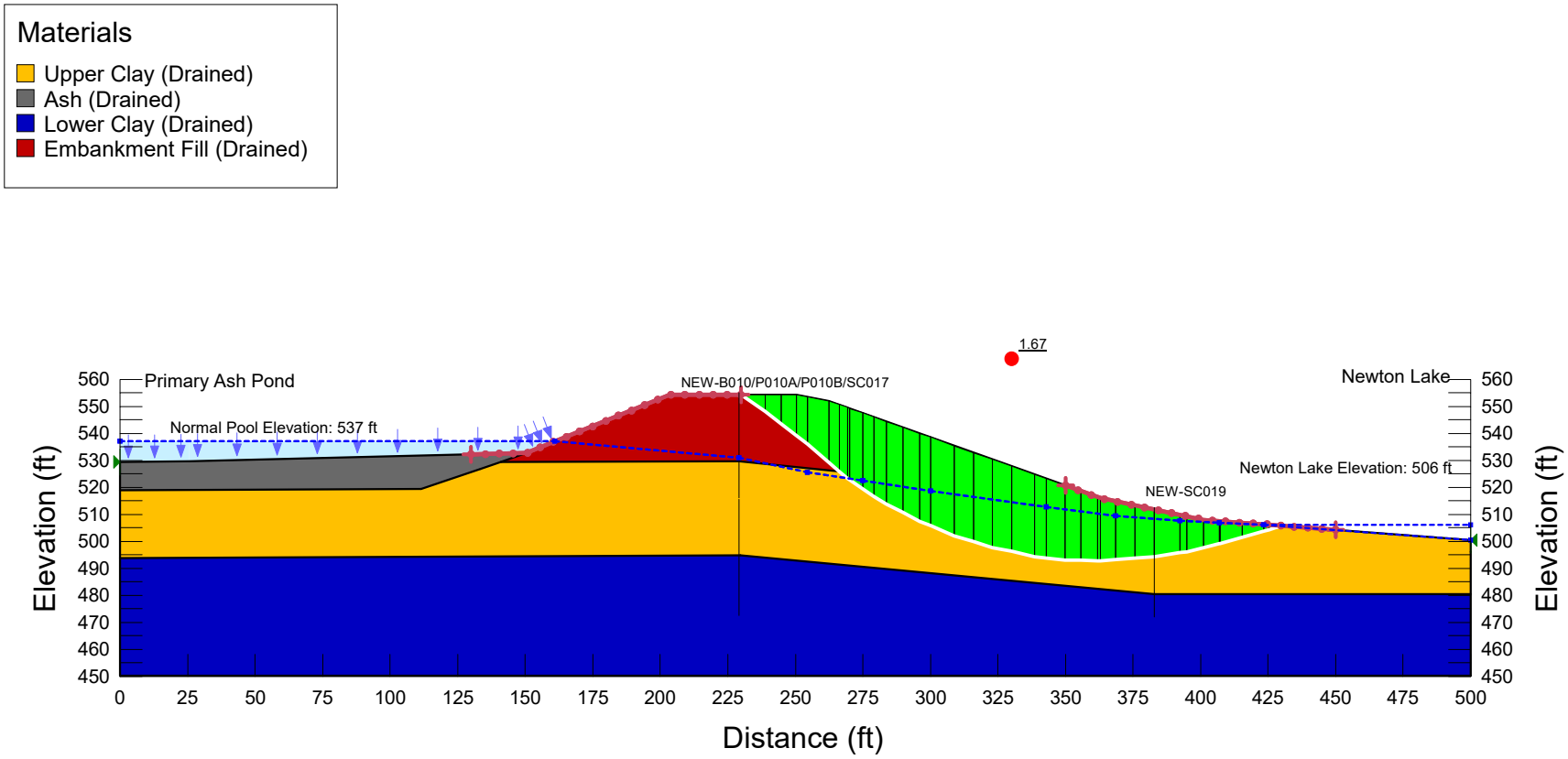
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section C

Analysis: Sudden Drawdown

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 ° Cohesion R: 470 psf Phi R: 22 ° Piezometric Line After Drawdown: 2
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 ° Cohesion R: 500 psf Phi R: 22 ° Piezometric Line After Drawdown: 2



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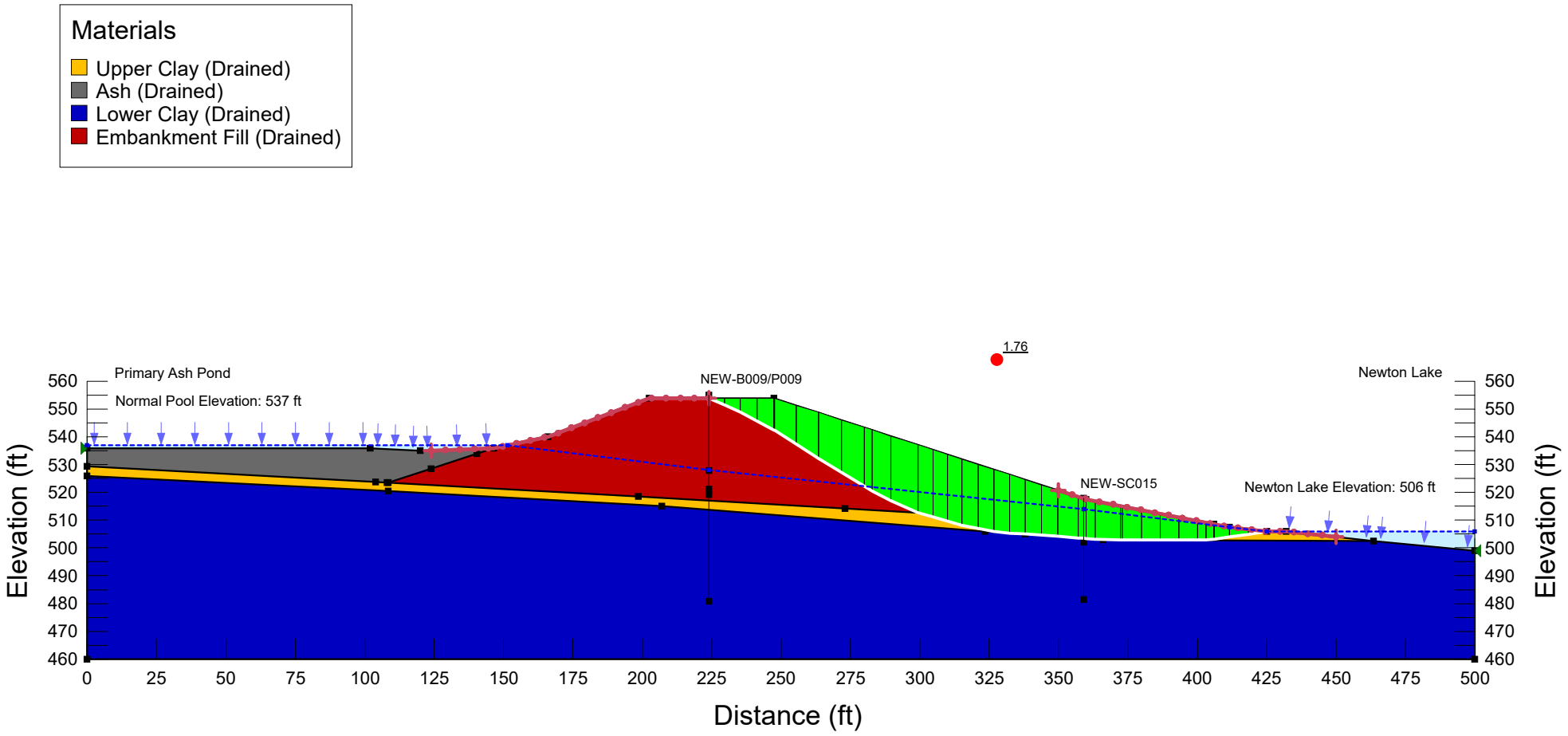
Project Name: Newton Primary Ash Pond Stability Analysis-Section D

Analysis: Long Term (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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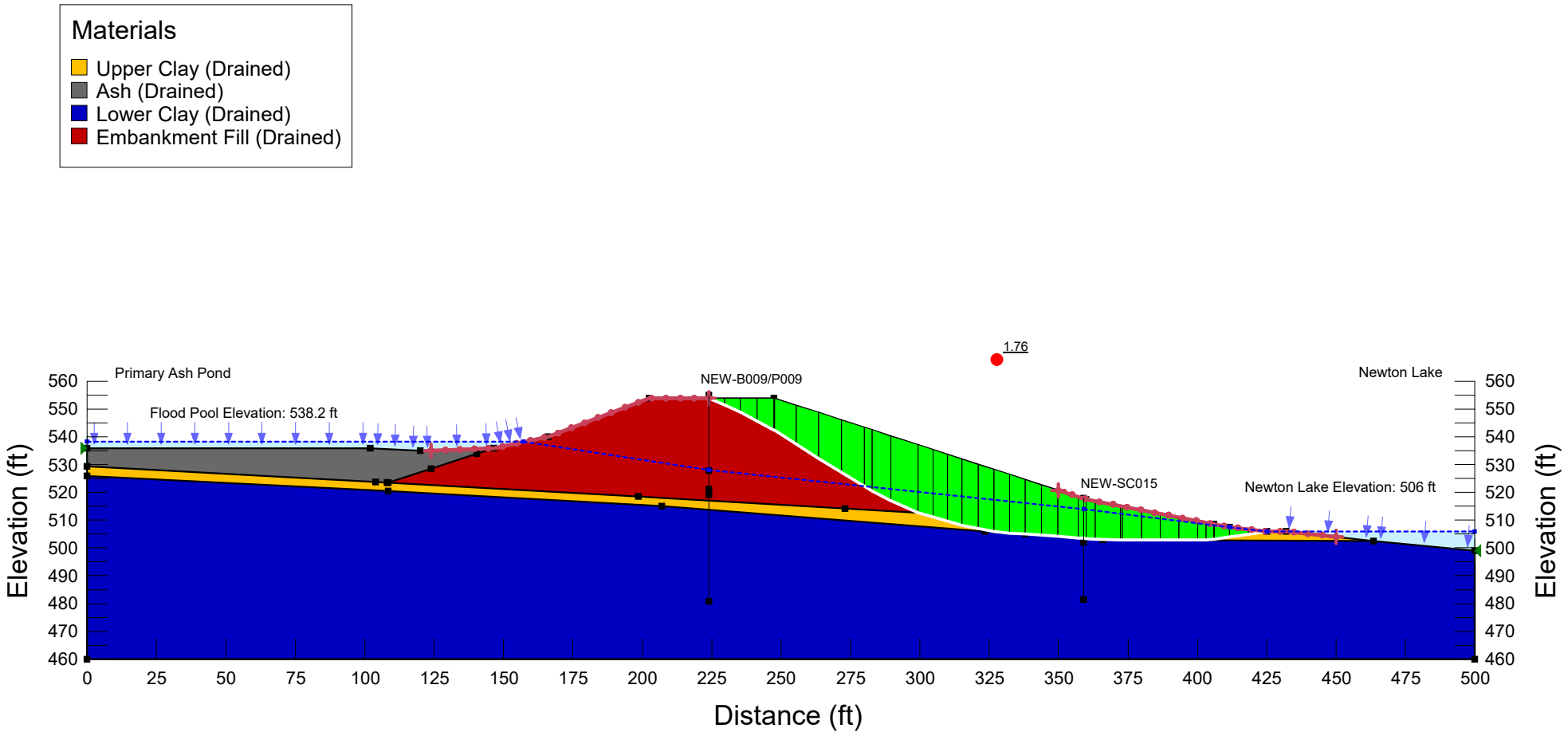
Project Name: Newton Primary Ash Pond Stability Analysis-Section D

Analysis: Surcharge (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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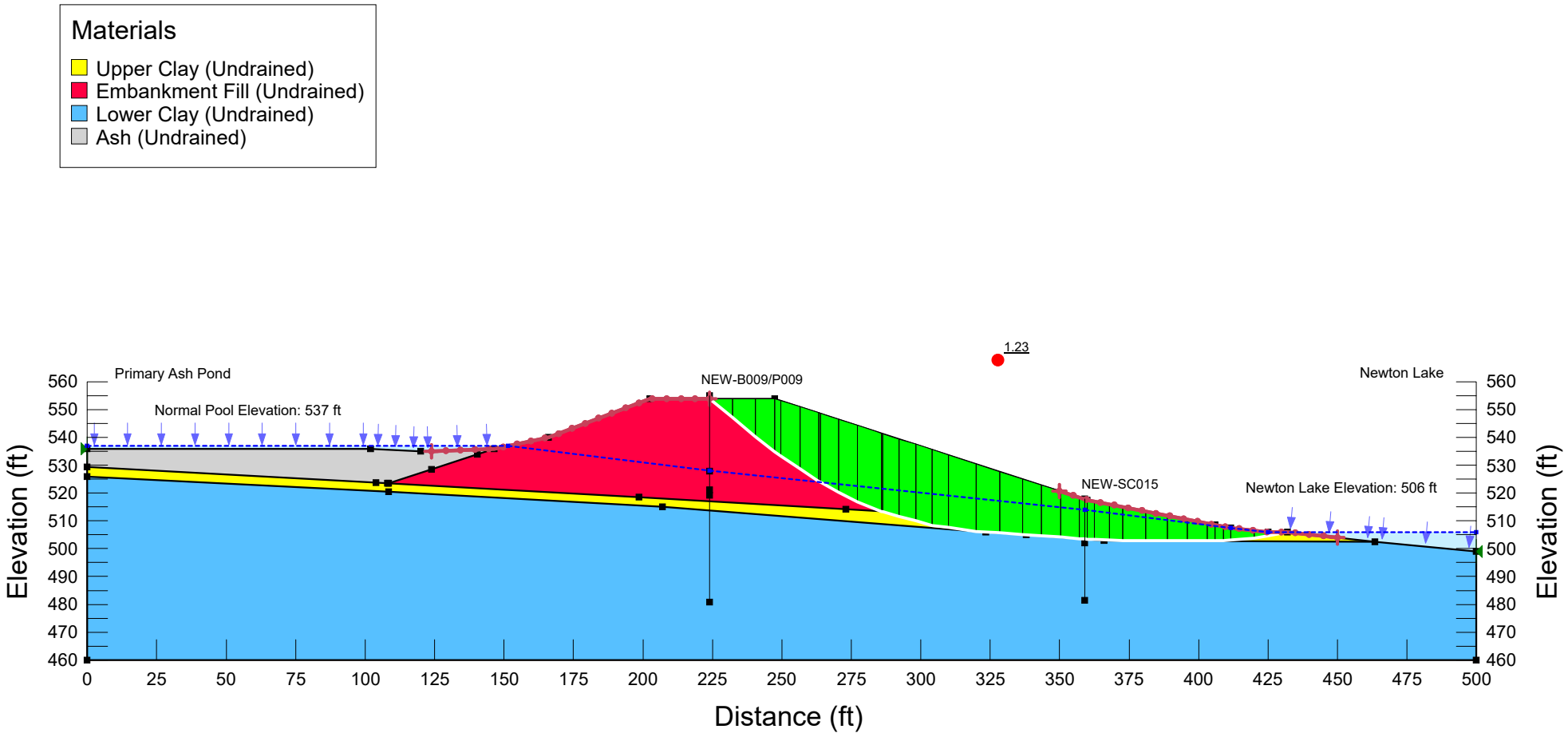
Project Name: Newton Primary Ash Pond Stability Analysis-Section D

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °
Name: Ash (Undrained) Model: S=f(overburden) Unit Weight: 90 pcf Tau/Sigma Ratio: 0.05 Minimum Strength: 0 psf



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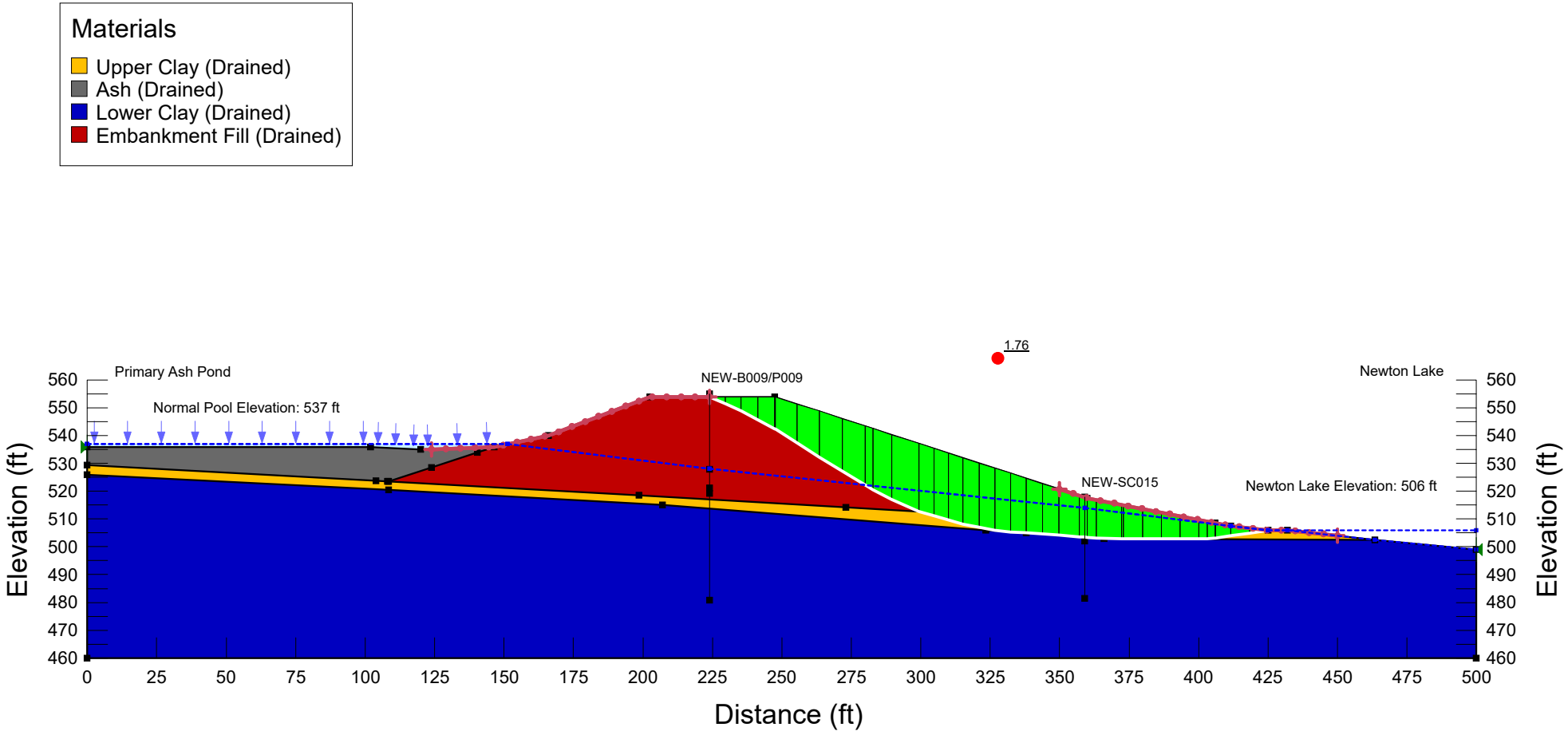
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section D

Analysis: Sudden Drawdown

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 ° Cohesion R: 470 psf Phi R: 22 ° Piezometric Line After Drawdown: 2
Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 ° Cohesion R: 500 psf Phi R: 22 ° Piezometric Line After Drawdown: 2



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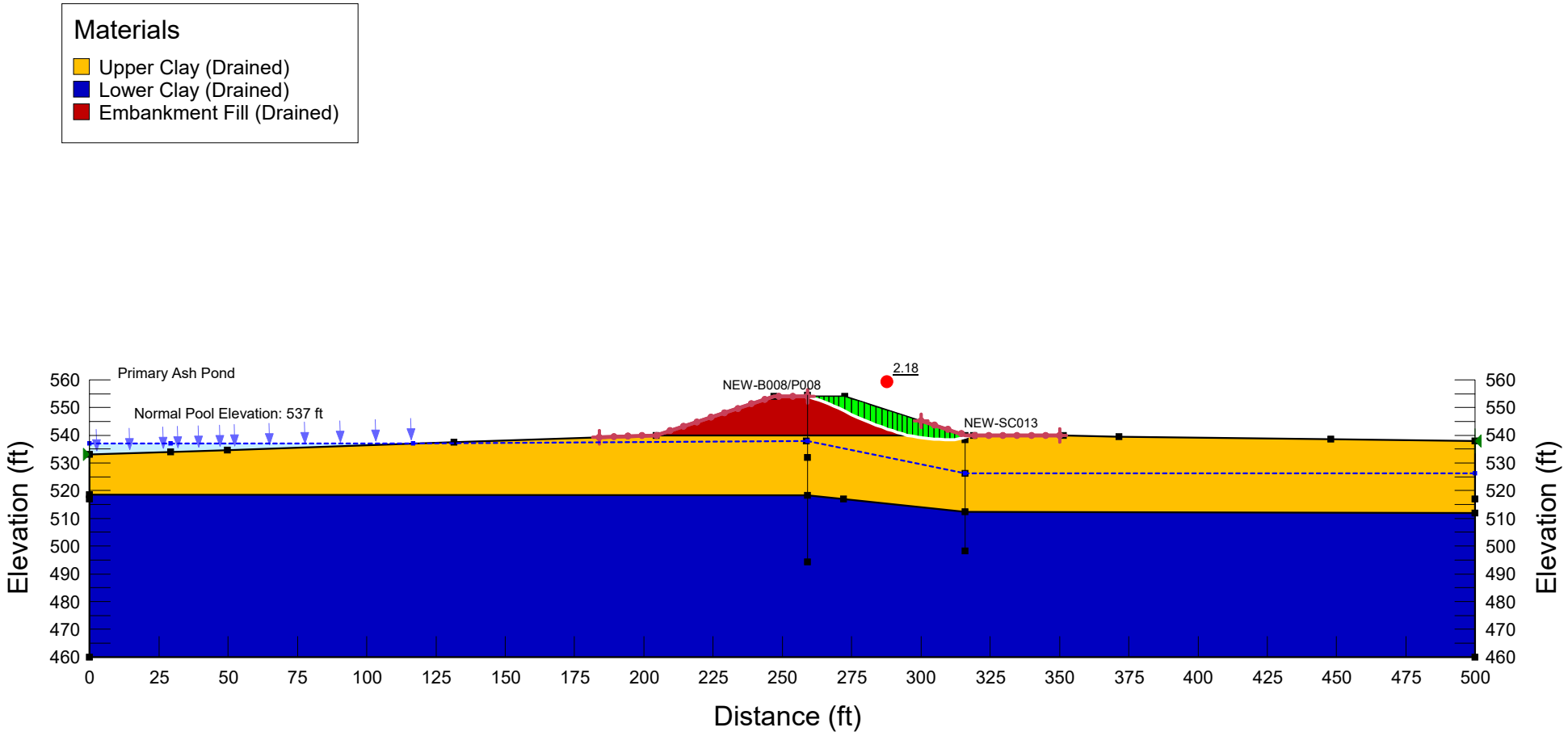
Project Name: Newton Primary Ash Pond Stability Analysis-Section E

Analysis: Long Term (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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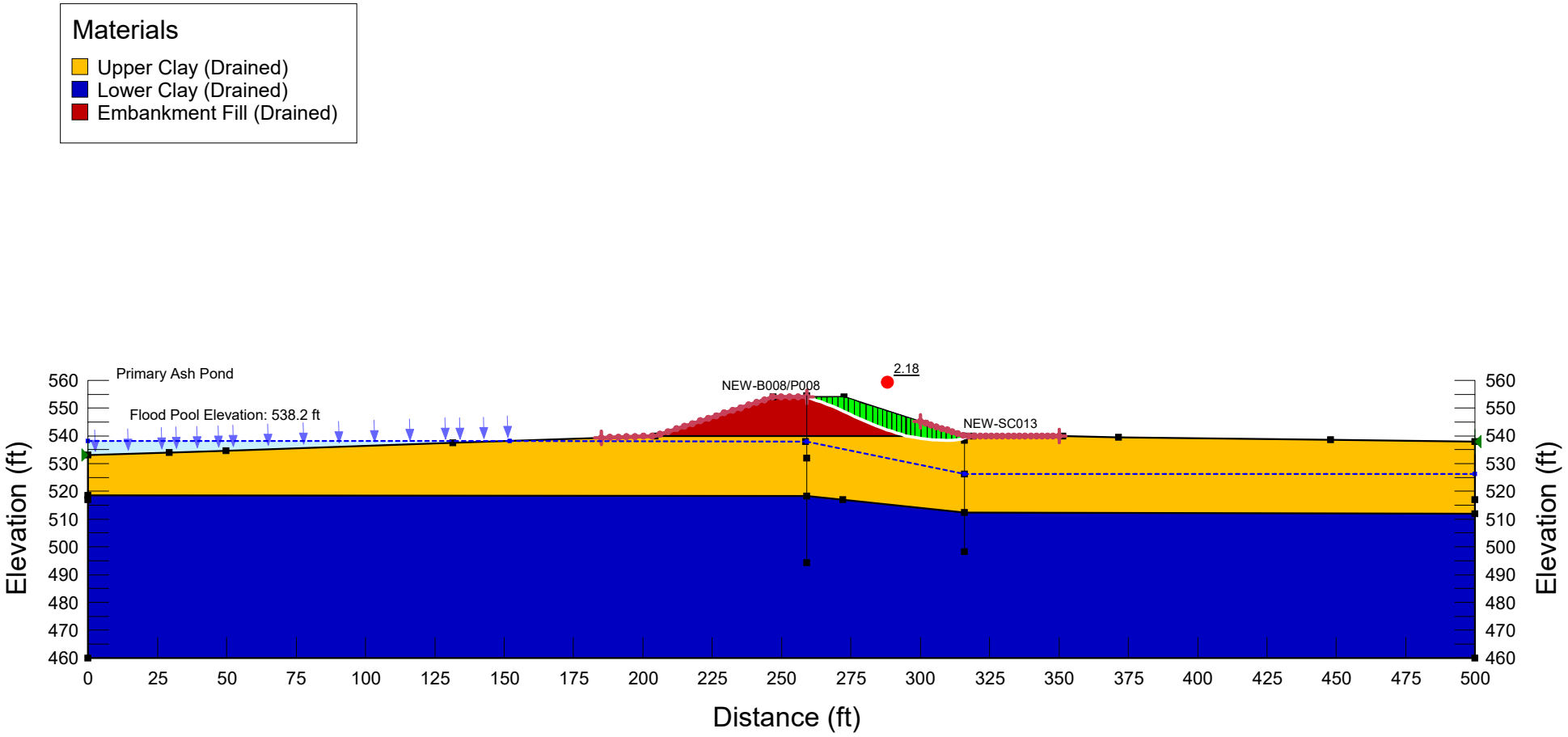
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section E

Analysis: Surcharge (Drained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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Electronic Filing: Received, Clerk's Office 07/01/2024

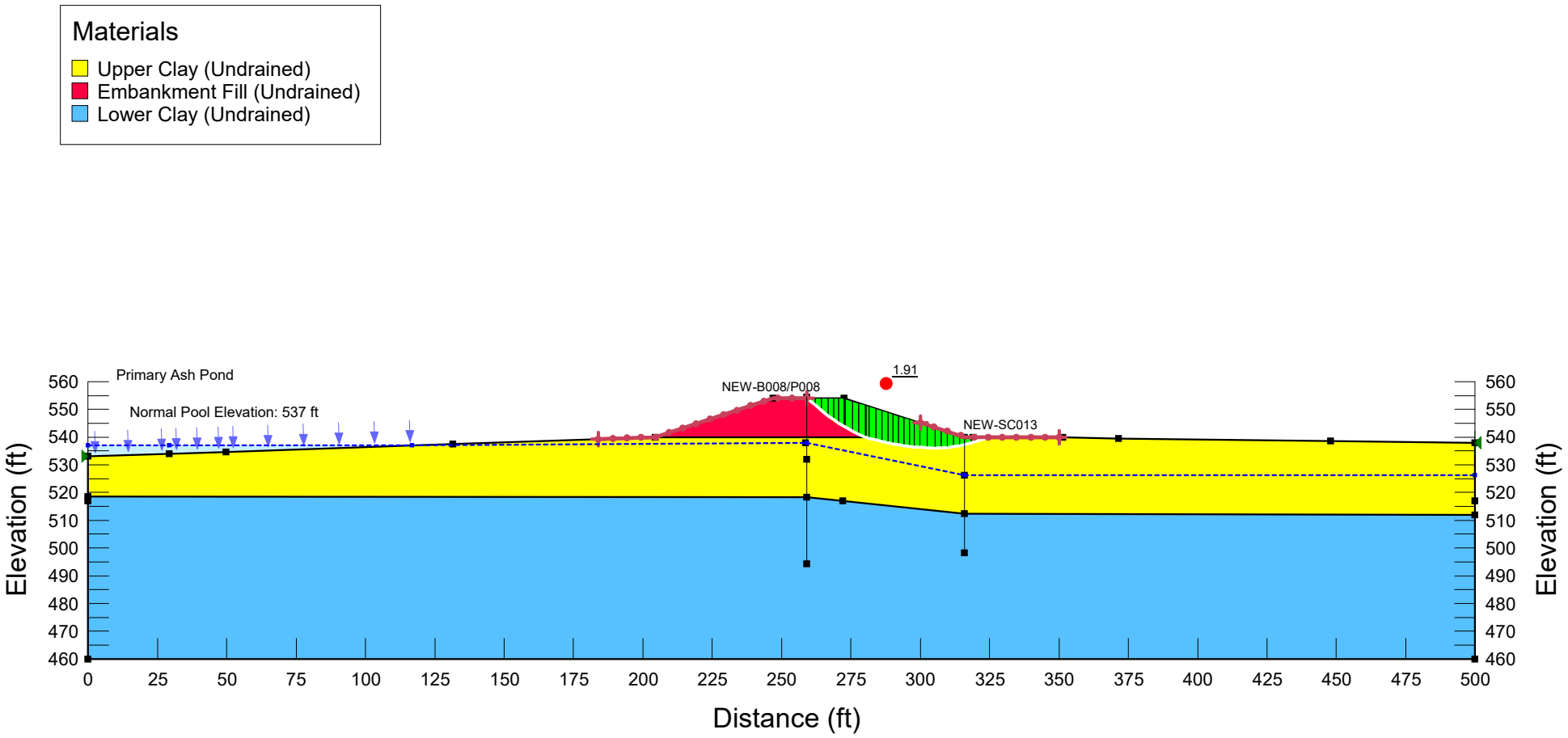
Project Name: Newton Primary Ash Pond Stability Analysis-Section E

Analysis: Pseudostatic (Undrained)

Calculated By: MJN Date: 6/20/2016
Checked By: VMCh Date: 6/20/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Horizontal Seismic Coefficient = 0.153g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °



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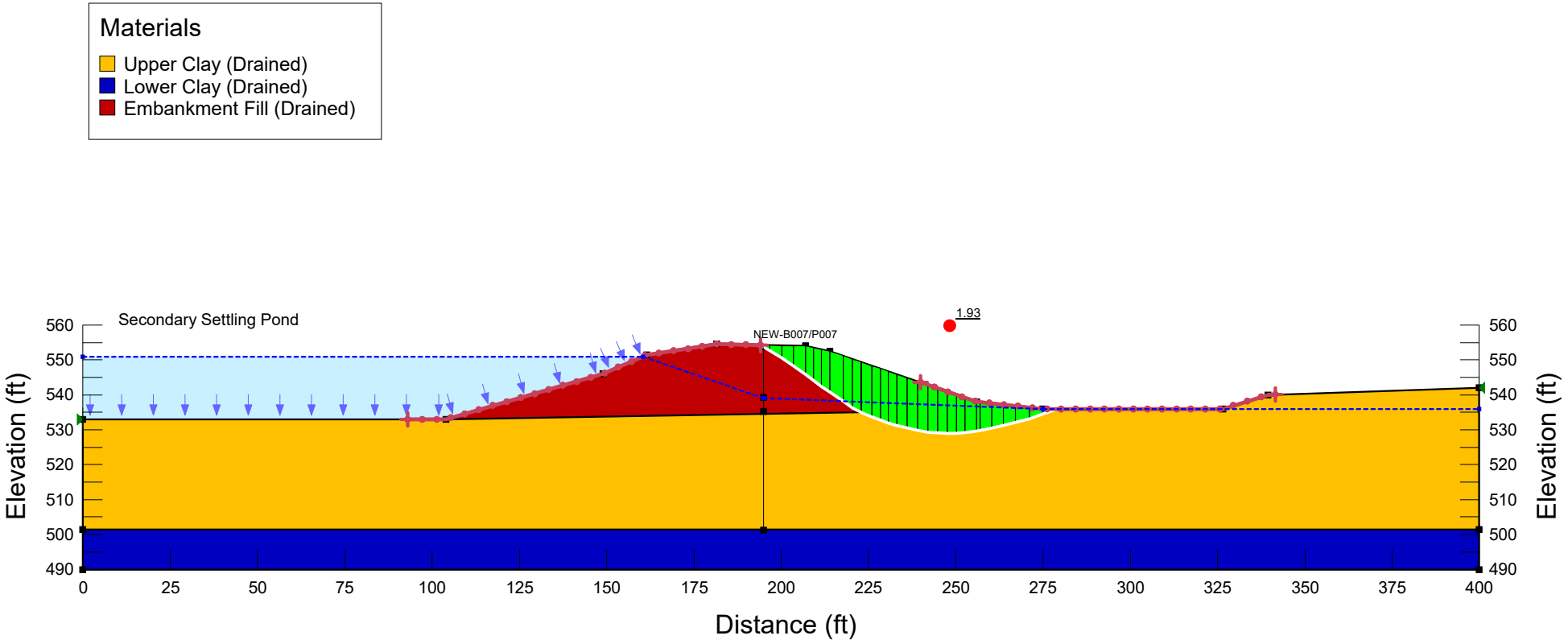
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section F

Analysis: Long Term (Drained)

Calculated By: ZJF Date: 5/23/2016
Checked By: VMCh Date: 6/16/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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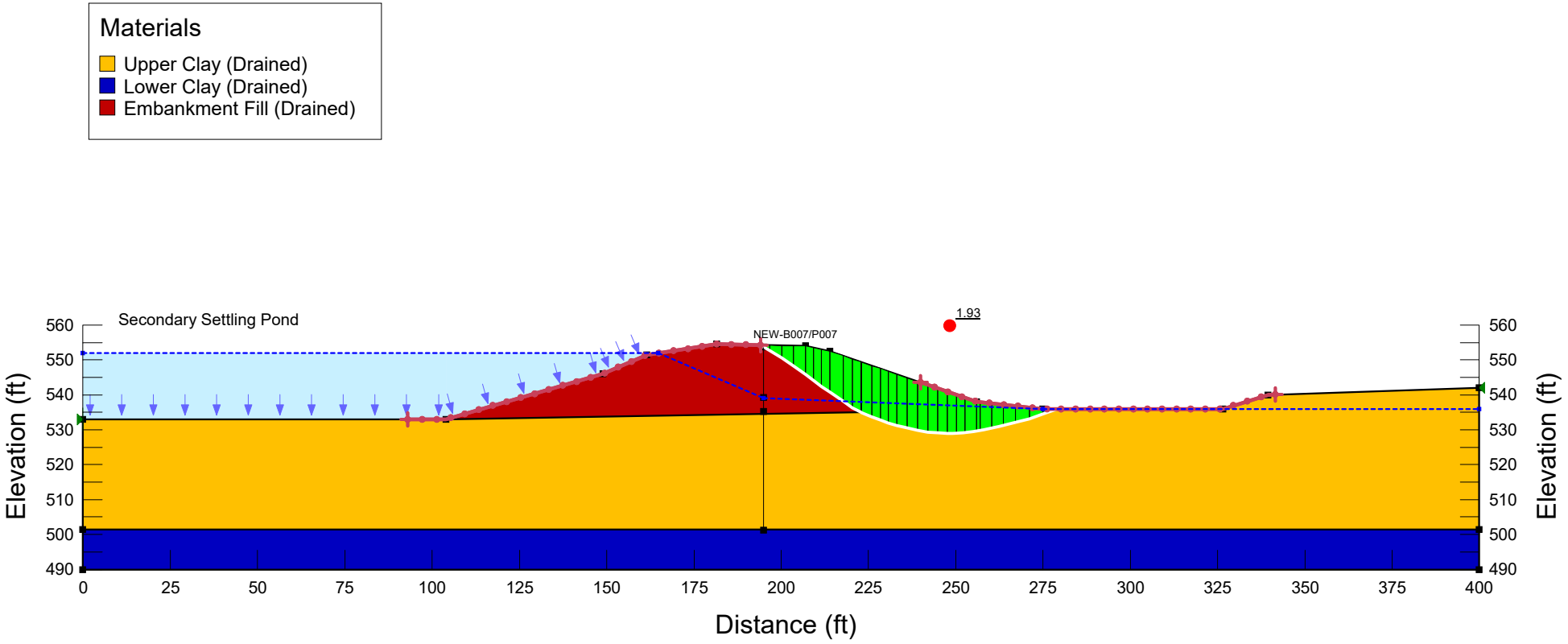
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section F

Analysis: Surcharge (Drained)

Calculated By: ZJF Date: 5/23/2016
Checked By: VMCh Date: 6/16/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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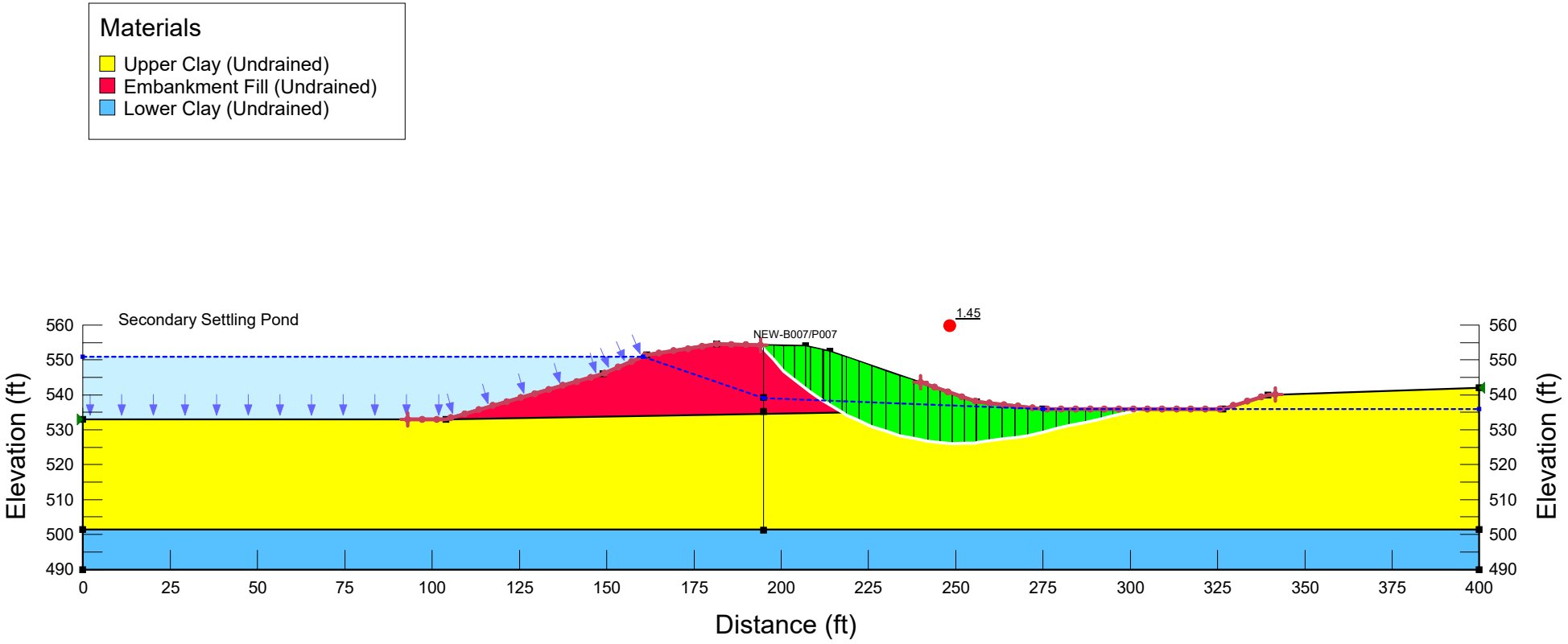
Project Name: Newton Primary Ash Pond Stability Analysis-Section F

Calculated By: ZJF Date: 5/23/2016
Checked By: VMCh Date: 6/16/2016
Modified By: PK Date:9/01/2021
Checked By:ZJF Date: 9/08/2021

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153 g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °



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Electronic Filing: Received, Clerk's Office 07/01/2024

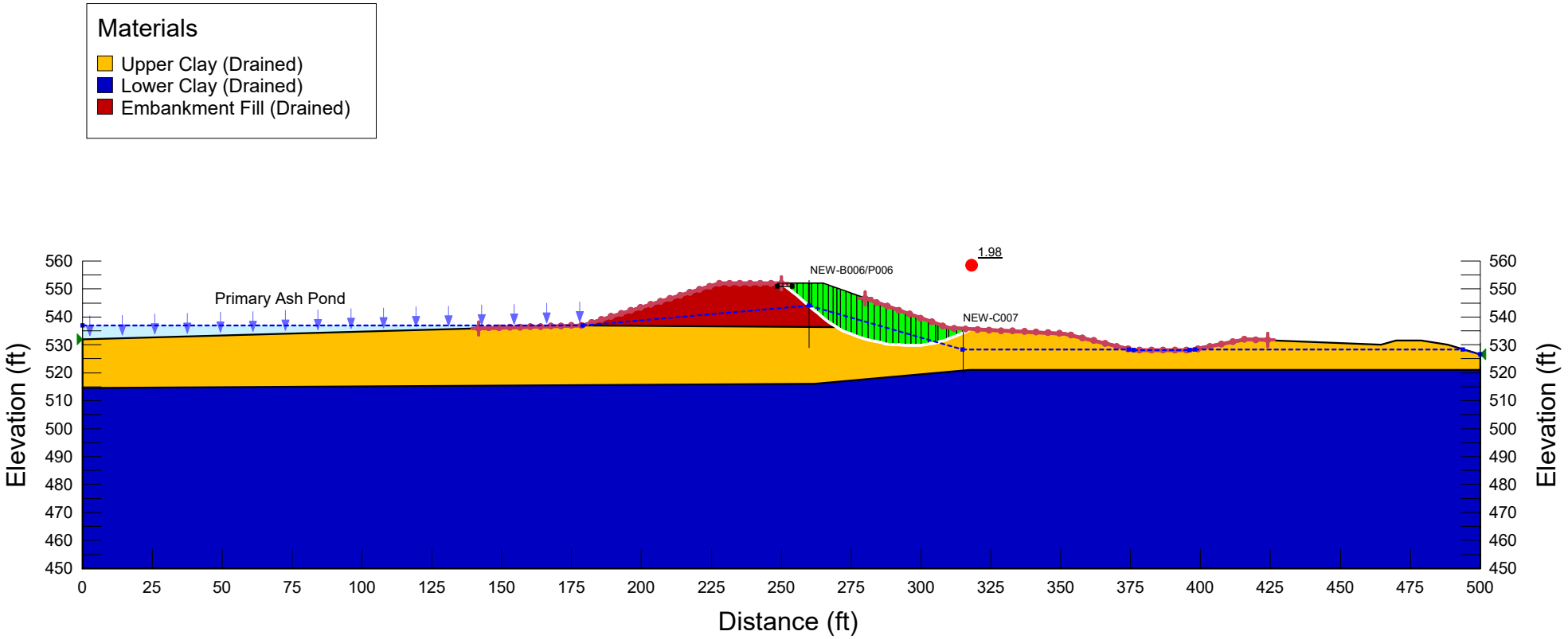
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section G

Analysis: Long Term (Drained)

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 06/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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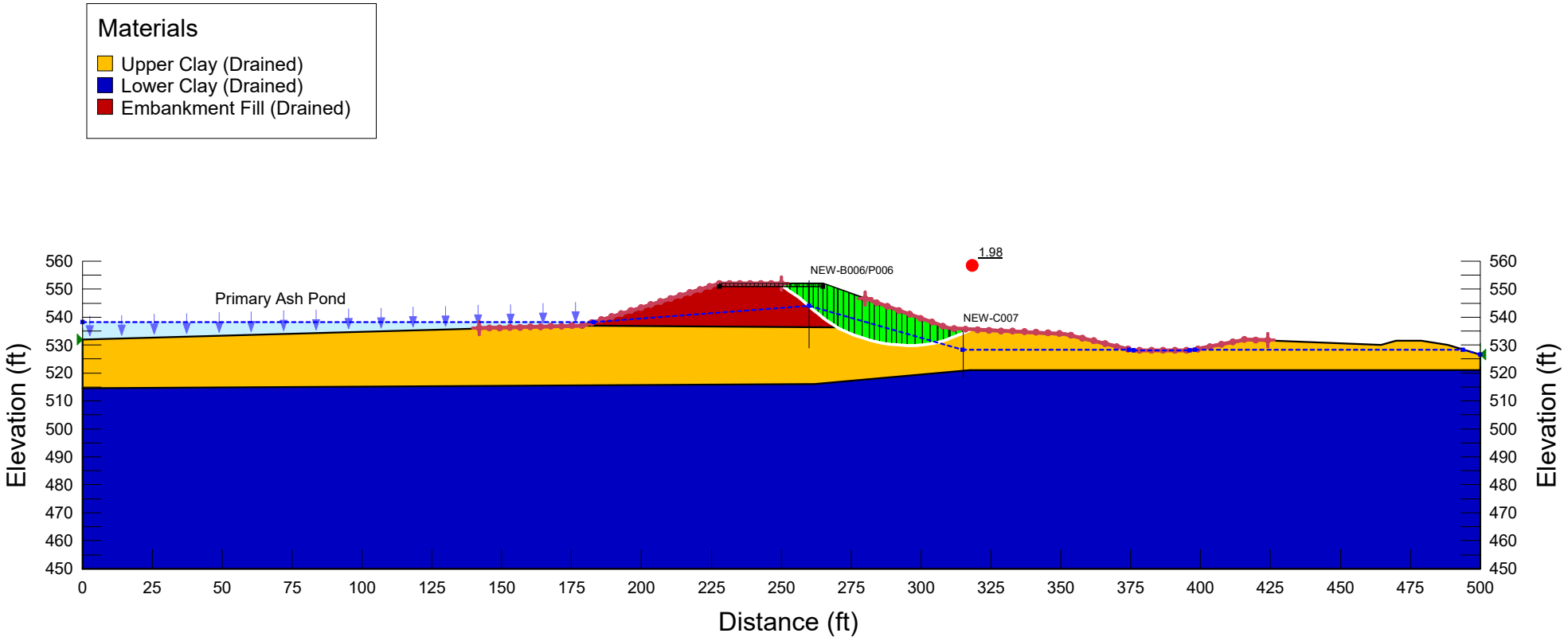
Project Name: Newton Primary Ash Pond Stability Analysis-Section G

Analysis: Surcharge (Drained)

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 06/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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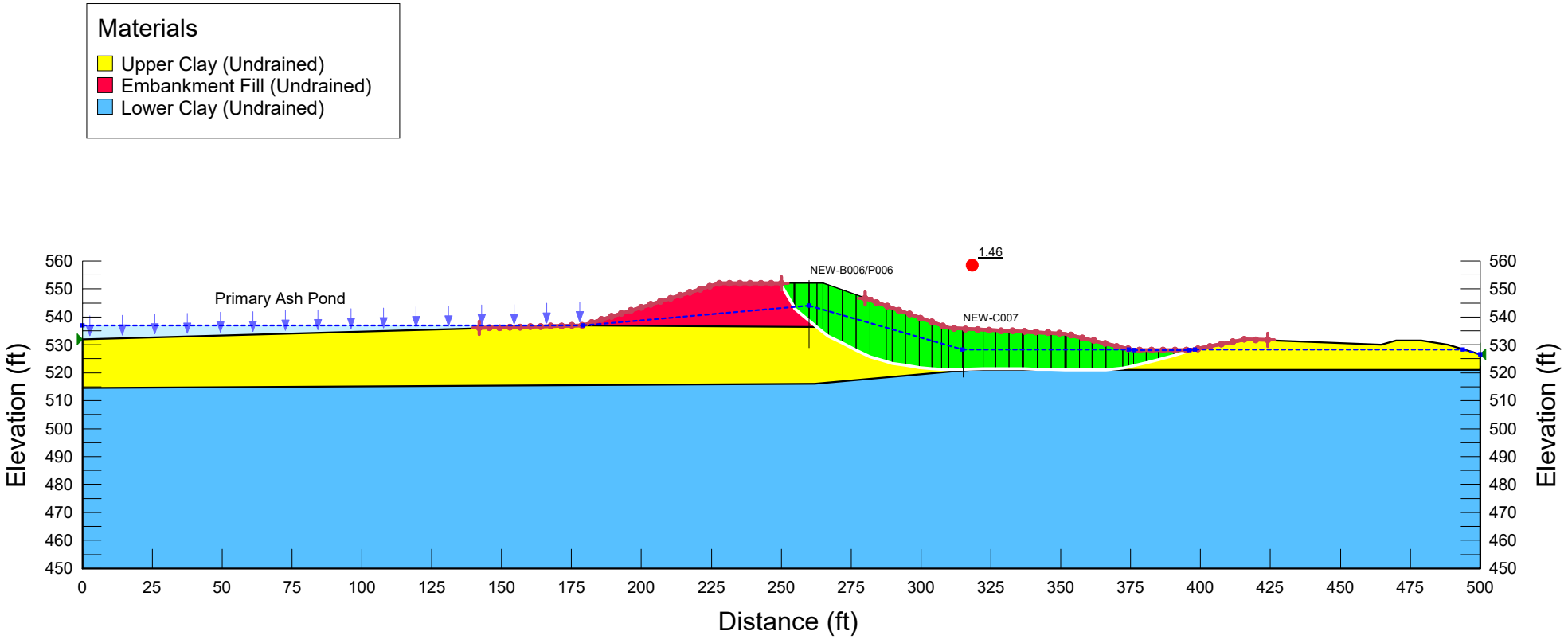
Project Name: Newton Primary Ash Pond Stability Analysis-Section G

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 06/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153 g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °



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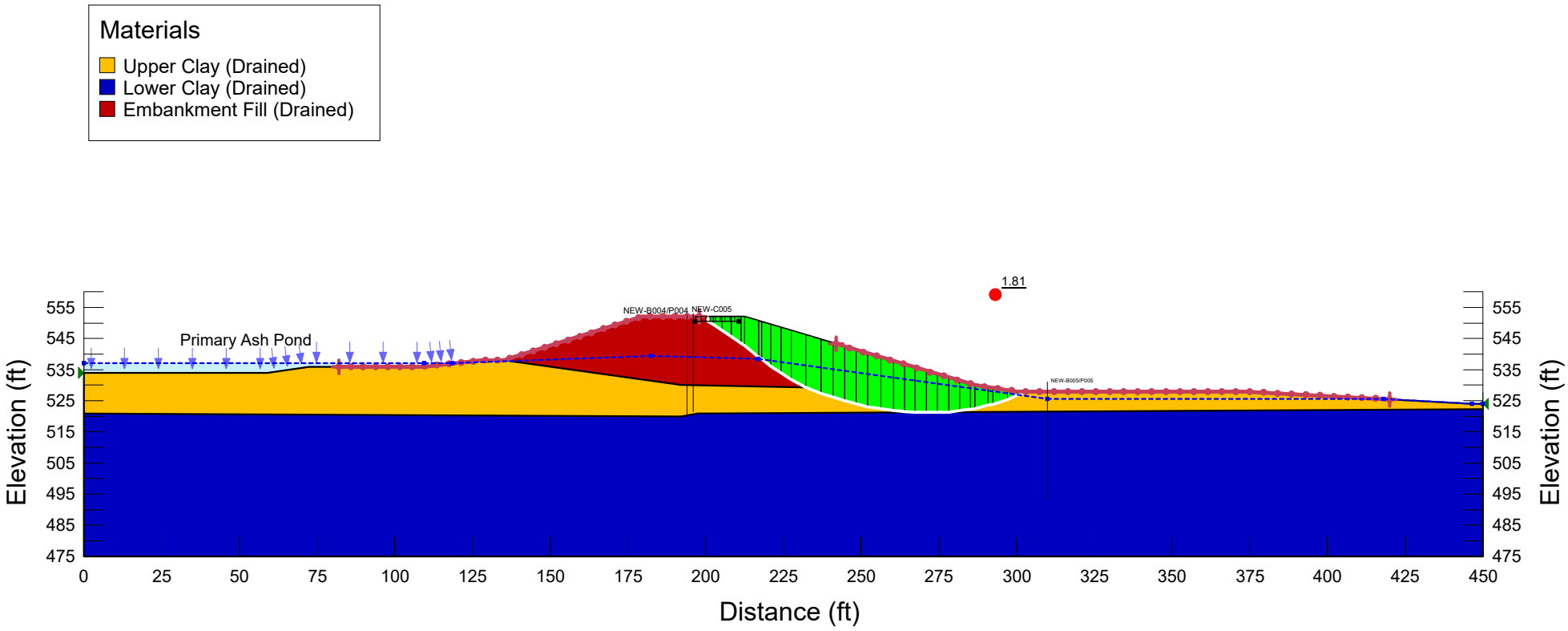
Project Name: Newton Primary Ash Pond Stability Analysis-Section H

Analysis: Long Term (Drained)

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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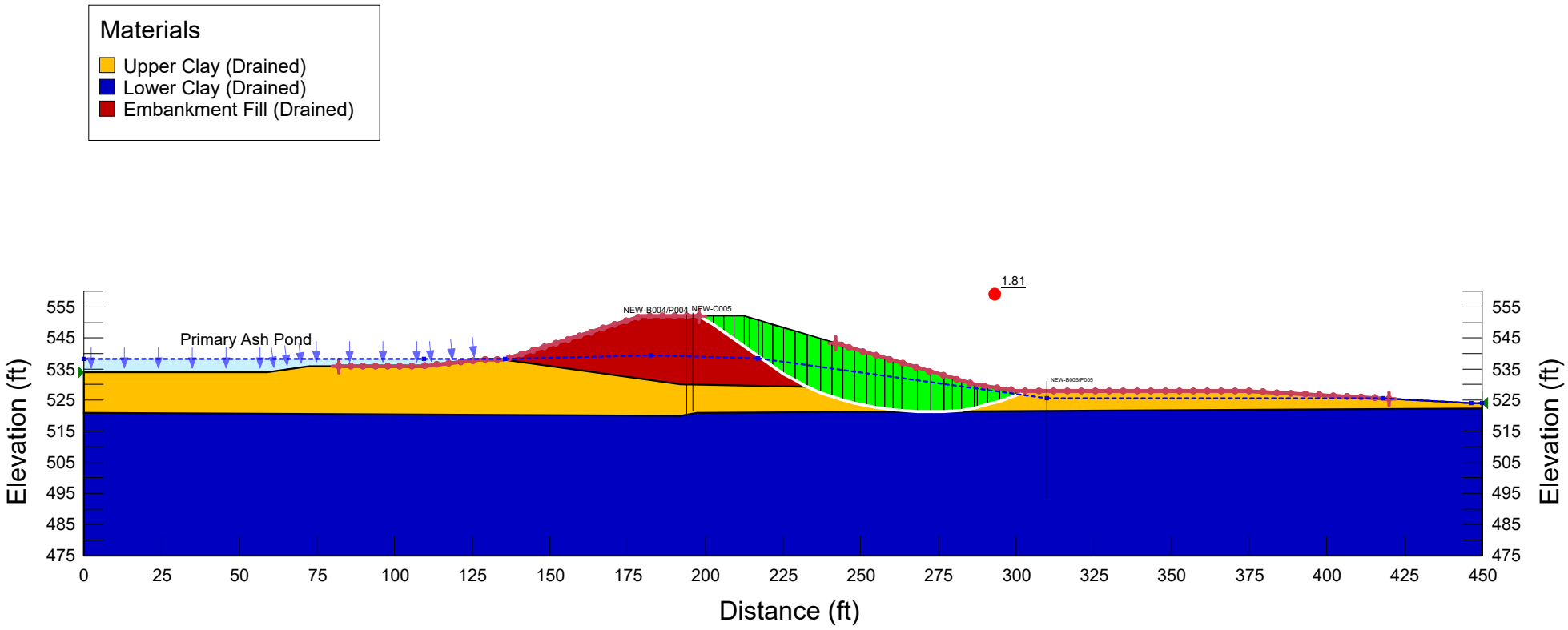
Project Name: Newton Primary Ash Pond Stability Analysis-Section H

Analysis: Surcharge (Drained)

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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Electronic Filing: Received, Clerk's Office 07/01/2024

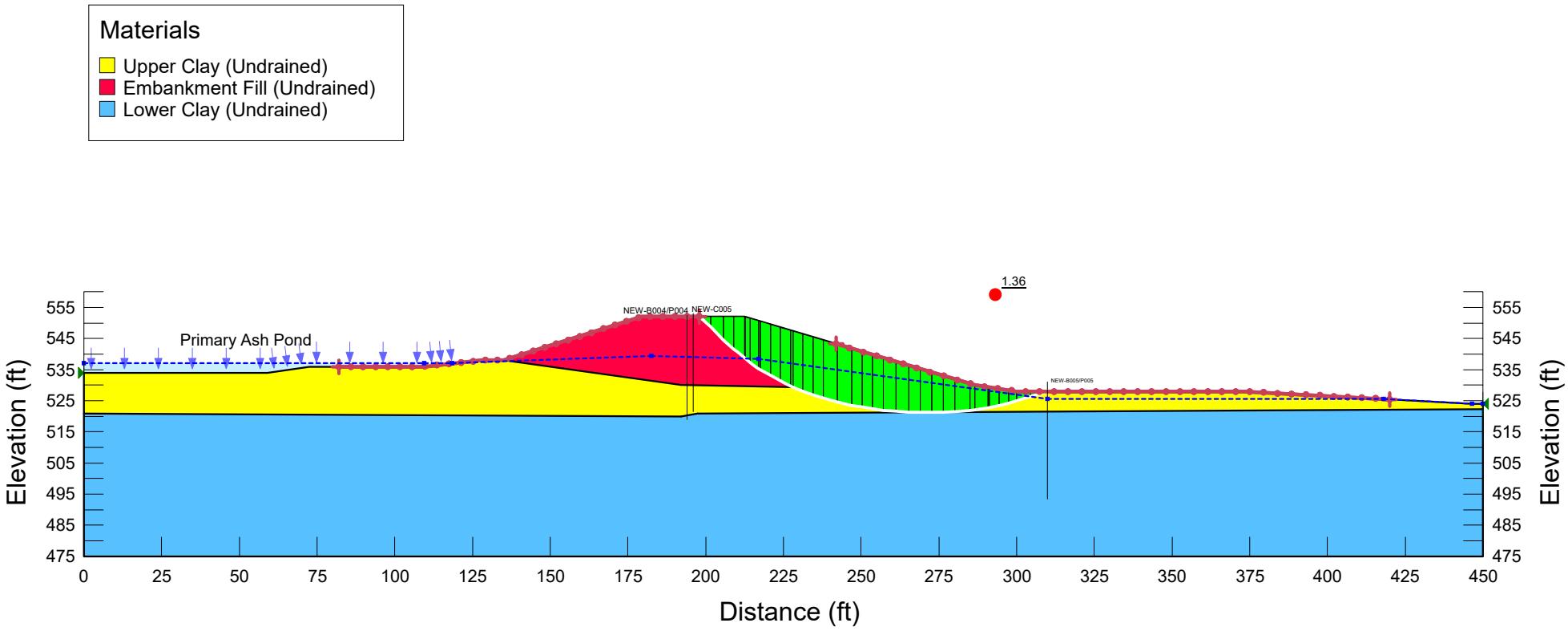
Project Name: Newton Primary Ash Pond Stability Analysis-Section H

Analysis: Pseudostatic (Undrained)

Calculated By: ZJF Date: 5/23/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Horizontal Seismic Coefficient = 0.153 g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °



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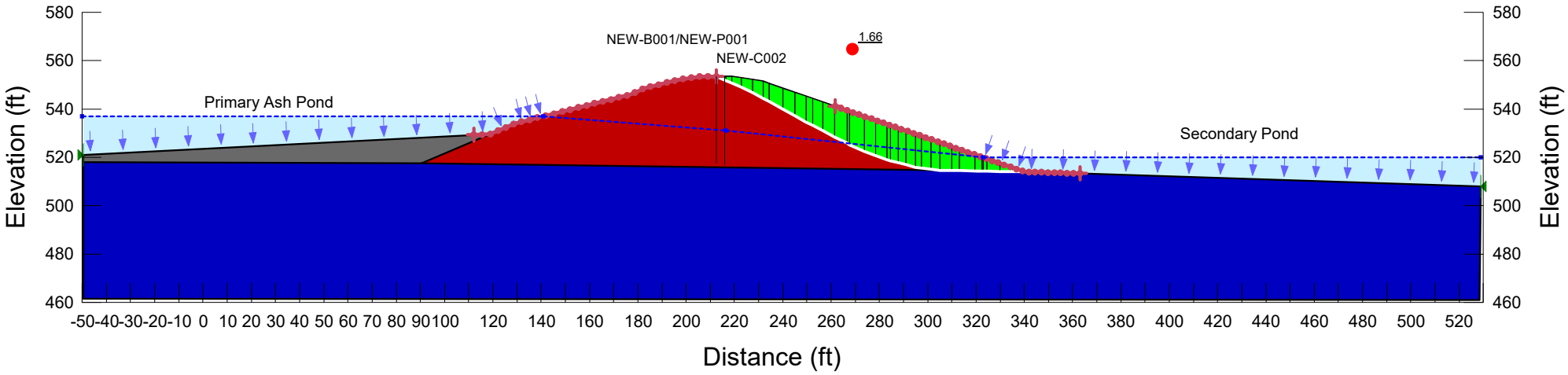
Project Name: Newton Primary Ash Pond Stability Analysis-Section I

Analysis: Long Term (Drained)

Calculated By: NDS Date: 5/25/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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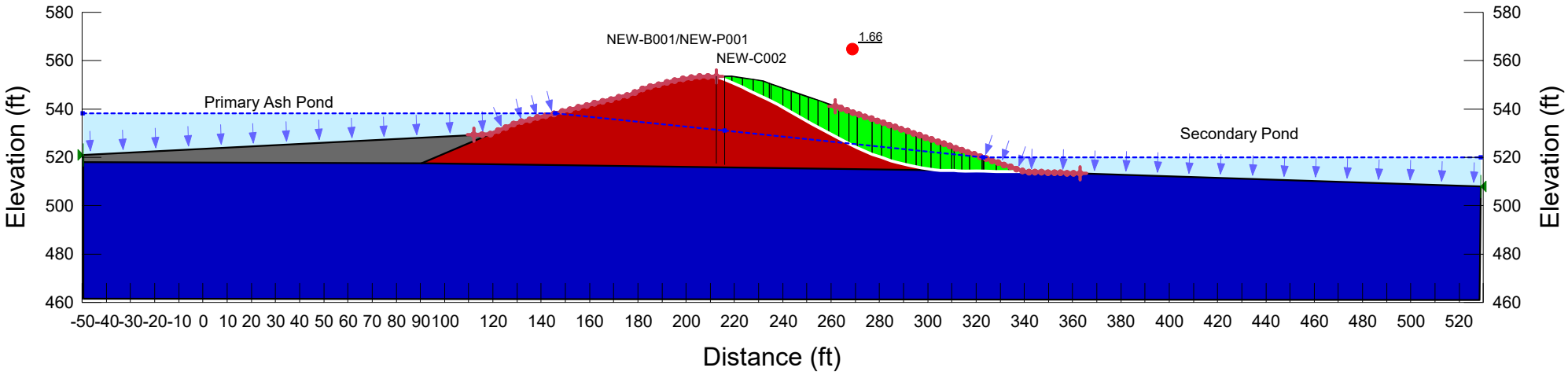
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section I

Analysis: Surcharge (Drained)

Calculated By: NDS Date: 5/25/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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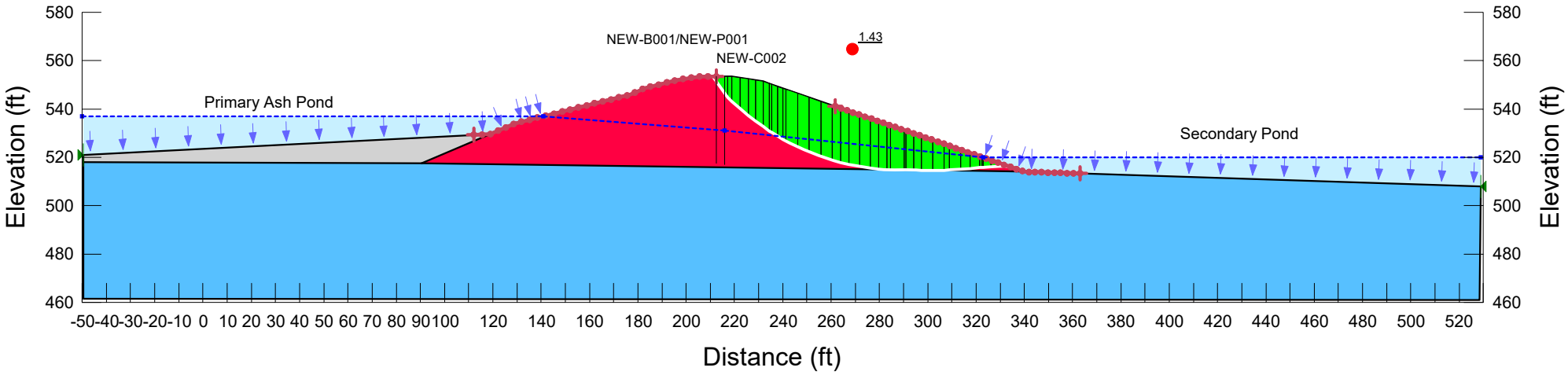
Project Name: Newton Primary Ash Pond Stability Analysis-Section I

Calculated By: NDS Date: 5/25/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Analysis: Pseudostatic (Undrained)

Horizontal Seismic Coefficient = 0.153 g

Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 5,000 psf Phi': 0 °
Name: Ash (Undrained) Model: S=f(overburden) Unit Weight: 90 pcf Tau/Sigma Ratio: 0.05 Minimum Strength: 0 psf



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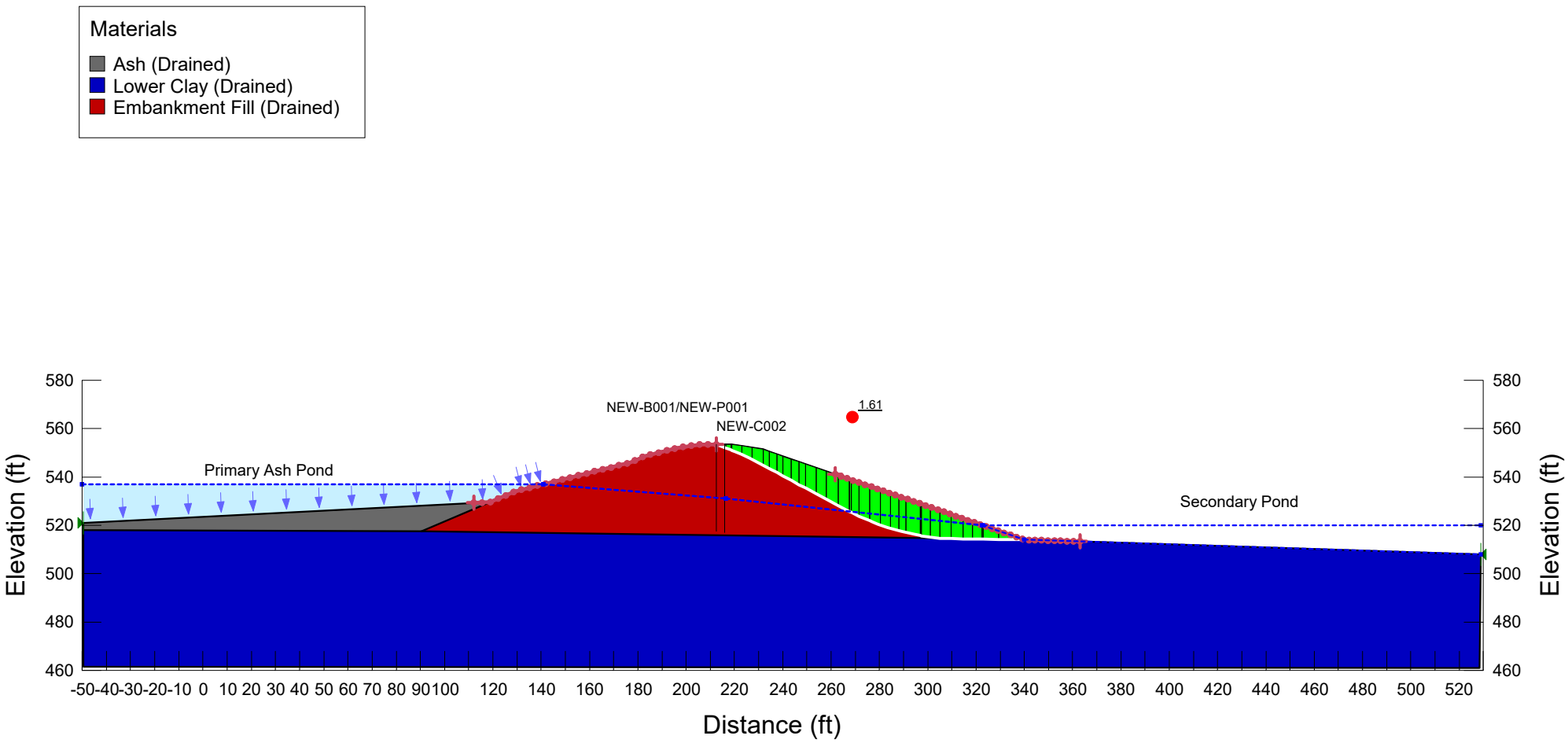
Project Name: Newton Primary Ash Pond Stability Analysis-Section I

Analysis: Sudden Drawdown

Calculated By: NDS Date: 5/25/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Ash (Drained) Model: Mohr-Coulomb Unit Weight: 90 pcf Cohesion': 0 psf Phi': 30 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 ° Cohesion R: 500 psf Phi R: 22 ° Piezometric Line After Drawdown: 2



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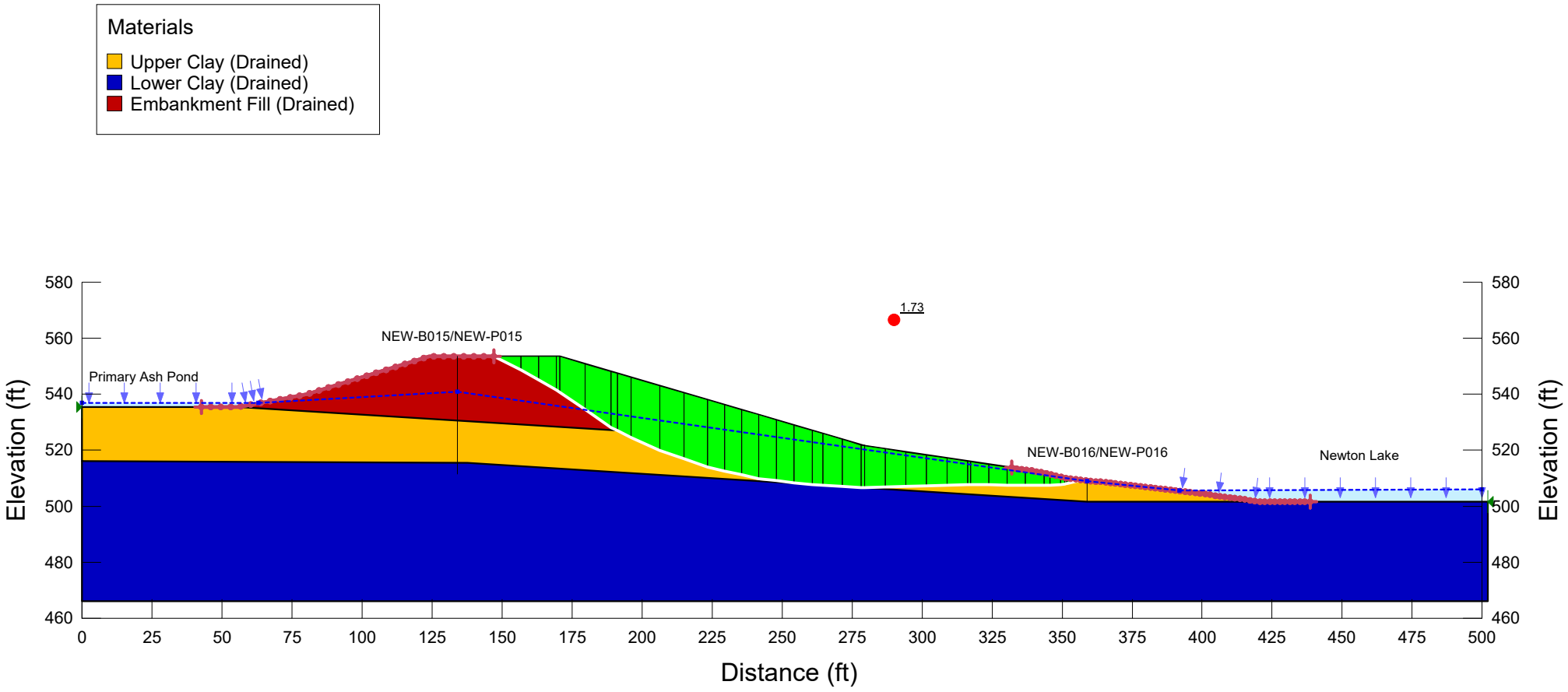
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section K

Analysis: Long Term (Drained)

Calculated By: NDS Date: 5/31/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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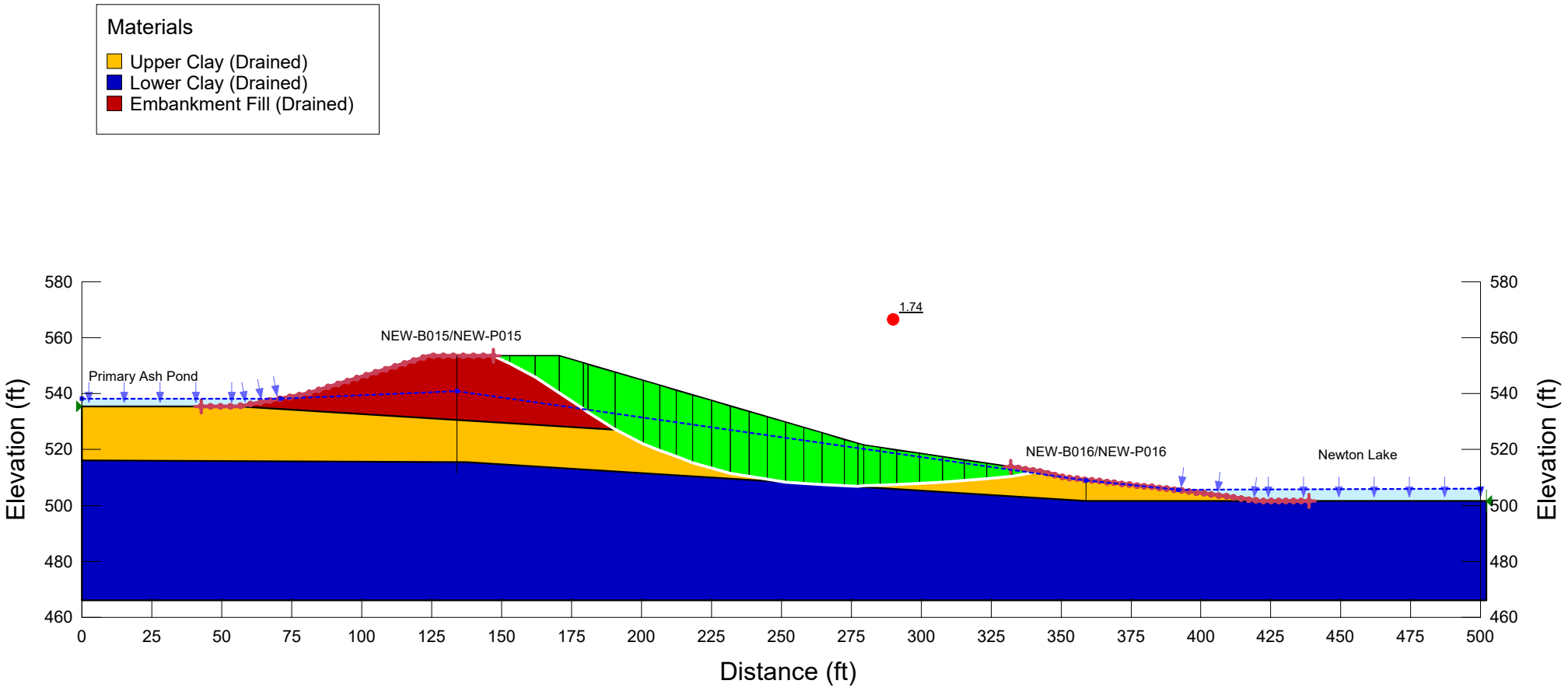
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section K

Analysis: Surcharge (Drained)

Calculated By: NDS Date: 5/31/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 °
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 °
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 °



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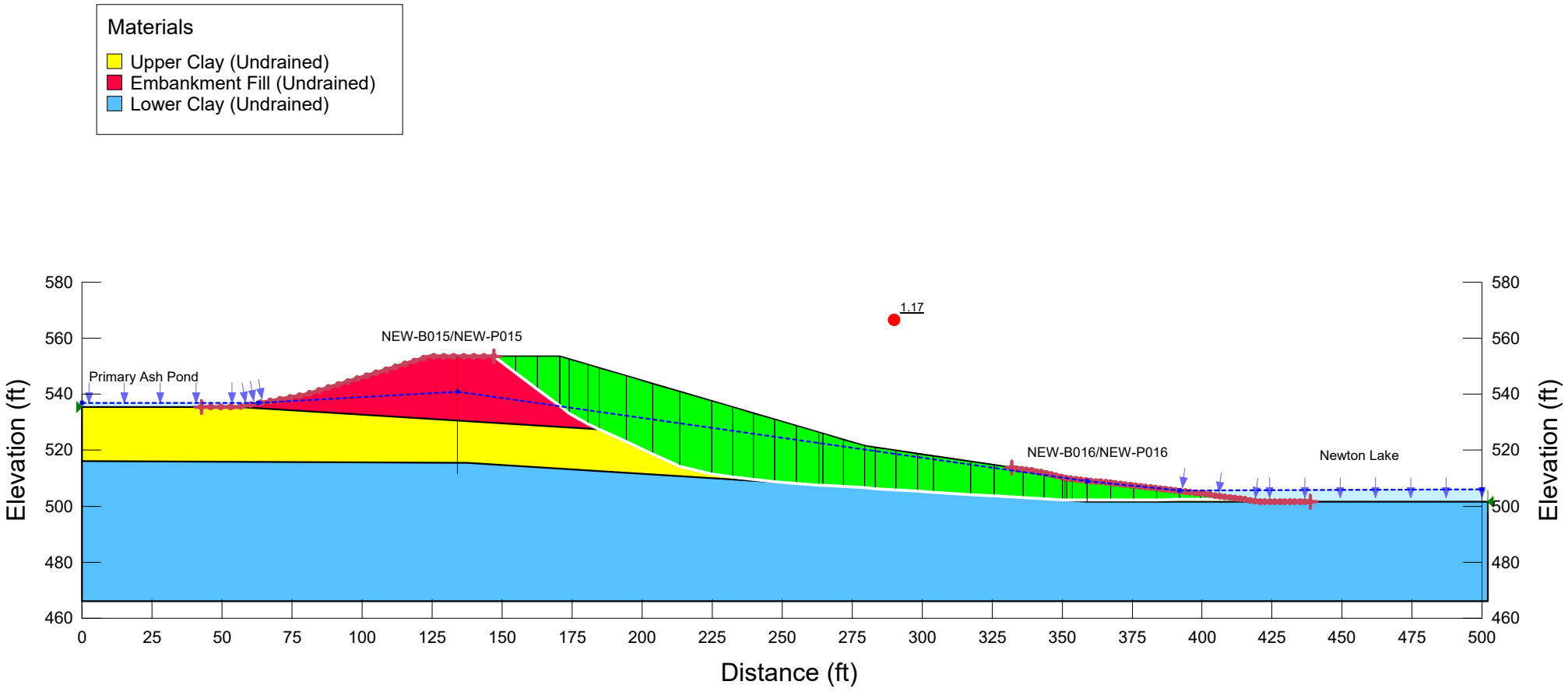
Project Name: Newton Primary Ash Pond Stability Analysis-Section K

Analysis: Pseudostatic (Undrained)

Calculated By: NDS Date: 5/31/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Horizontal Seismic Coefficient = 0.153 g

Name: Upper Clay (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Upper Clay (Undrained)
Name: Embankment Fill (Undrained) Model: Shear/Normal Fn. Unit Weight: 130 pcf Strength Function: Embankment Fill (Undrained)
Name: Lower Clay (Undrained) Model: Undrained (Phi=0) Unit Weight: 130 pcf Cohesion': 5,000 psf



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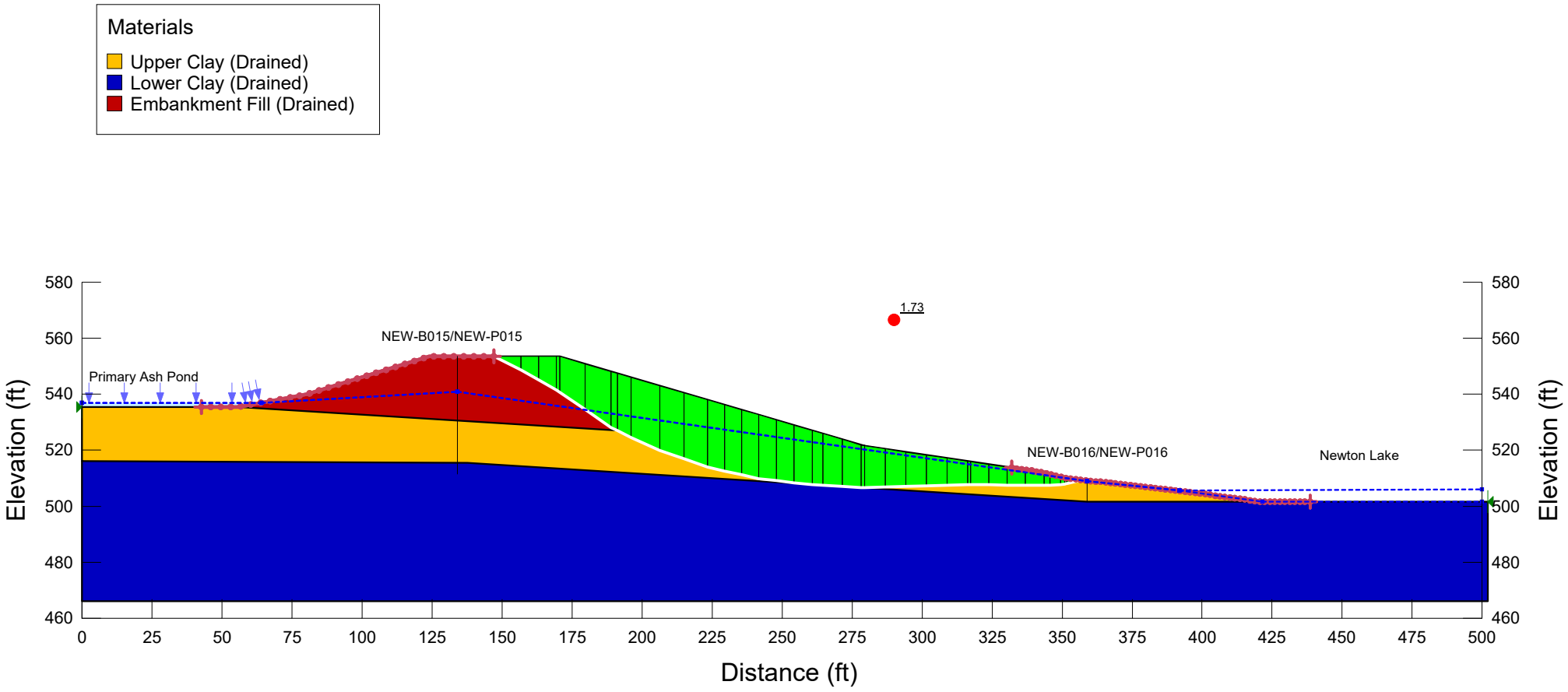
Electronic Filing: Received, Clerk's Office 07/01/2024

Project Name: Newton Primary Ash Pond Stability Analysis-Section K

Analysis: Sudden Drawdown

Calculated By: NDS Date: 5/31/16
Checked By: VMCh Date: 6/20/16
Modified By: PK Date:9/01/21
Checked By:ZJF Date: 9/08/21

Name: Upper Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 29 ° Cohesion R: 470 psf Phi R: 22 ° Piezometric Line After Drawdown: 2
Name: Lower Clay (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 3,700 psf Phi': 33 ° Cohesion R: 0 psf Phi R: 0 ° Piezometric Line After Drawdown: 2
Name: Embankment Fill (Drained) Model: Mohr-Coulomb Unit Weight: 130 pcf Cohesion': 0 psf Phi': 31 ° Cohesion R: 500 psf Phi R: 22 ° Piezometric Line After Drawdown: 2



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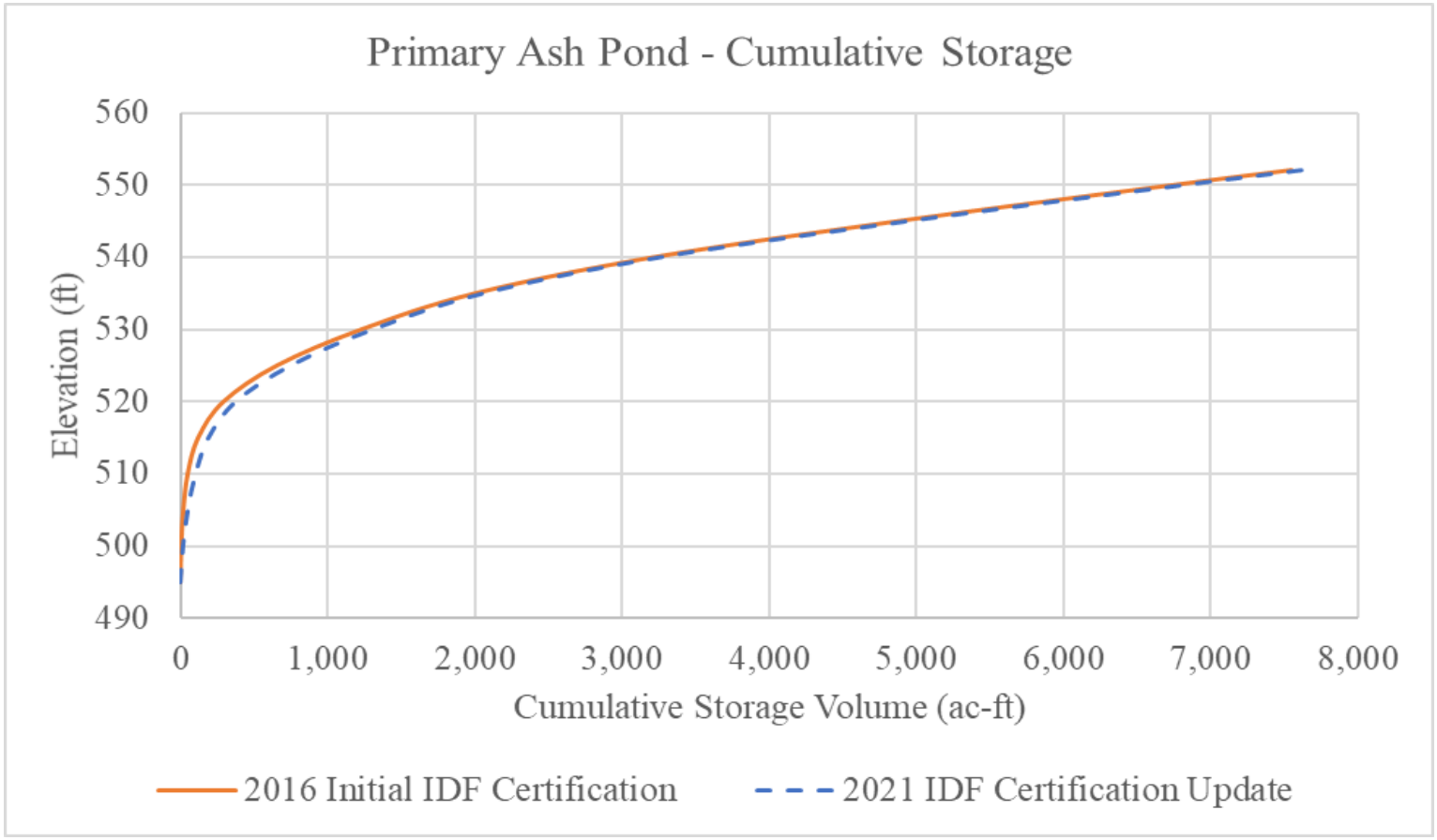
Attachment E

Periodic Inflow Design Flood Control System Plan Analyses

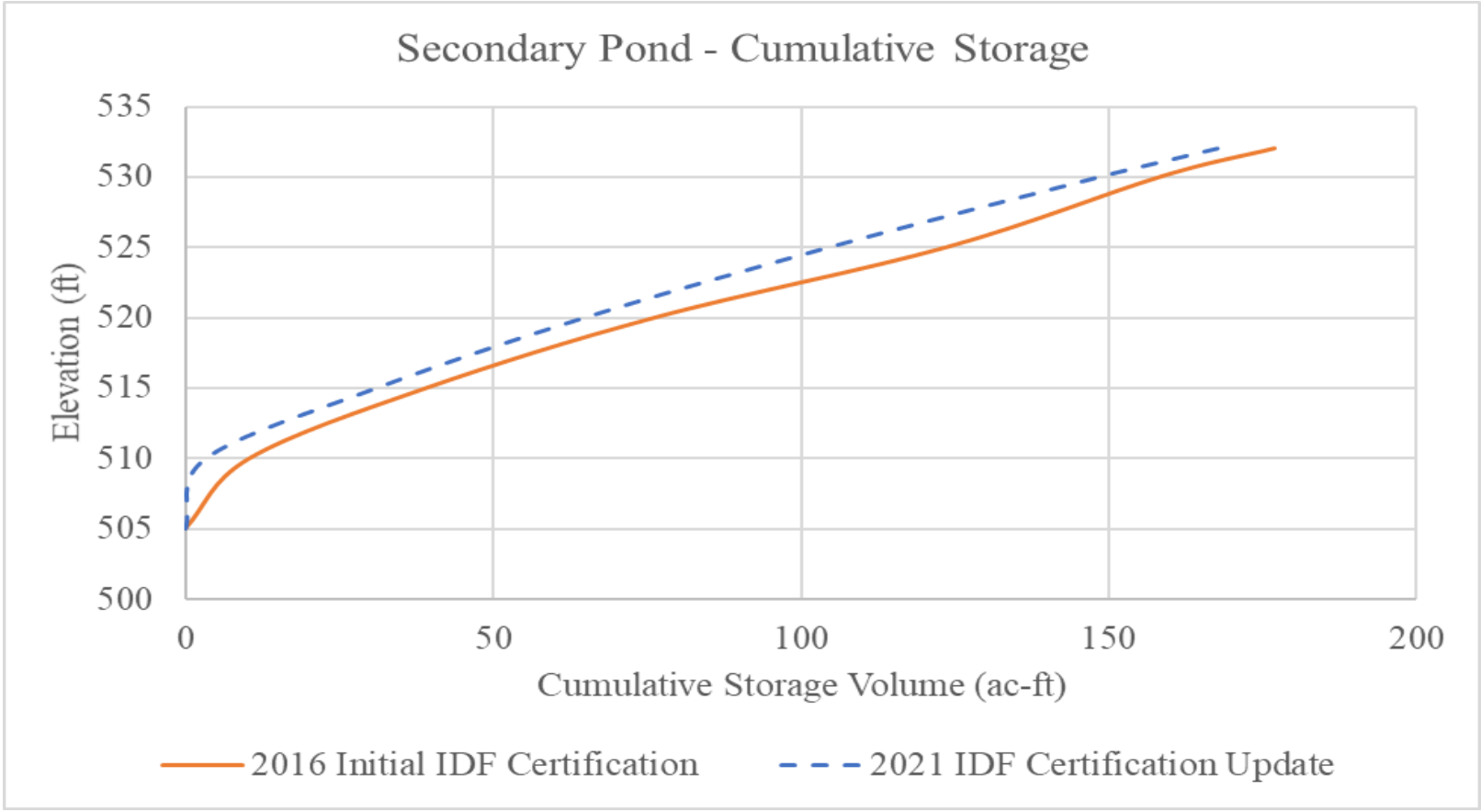


PRIMARY ASH POND CUMULATIVE STORAGE
PERIODIC CERTIFICATION
NEWTON POWER PLANT
NEWTON, ILLINOIS

Geosyntec consultants

Figure E-1

GLP8027 | 9/10/2021

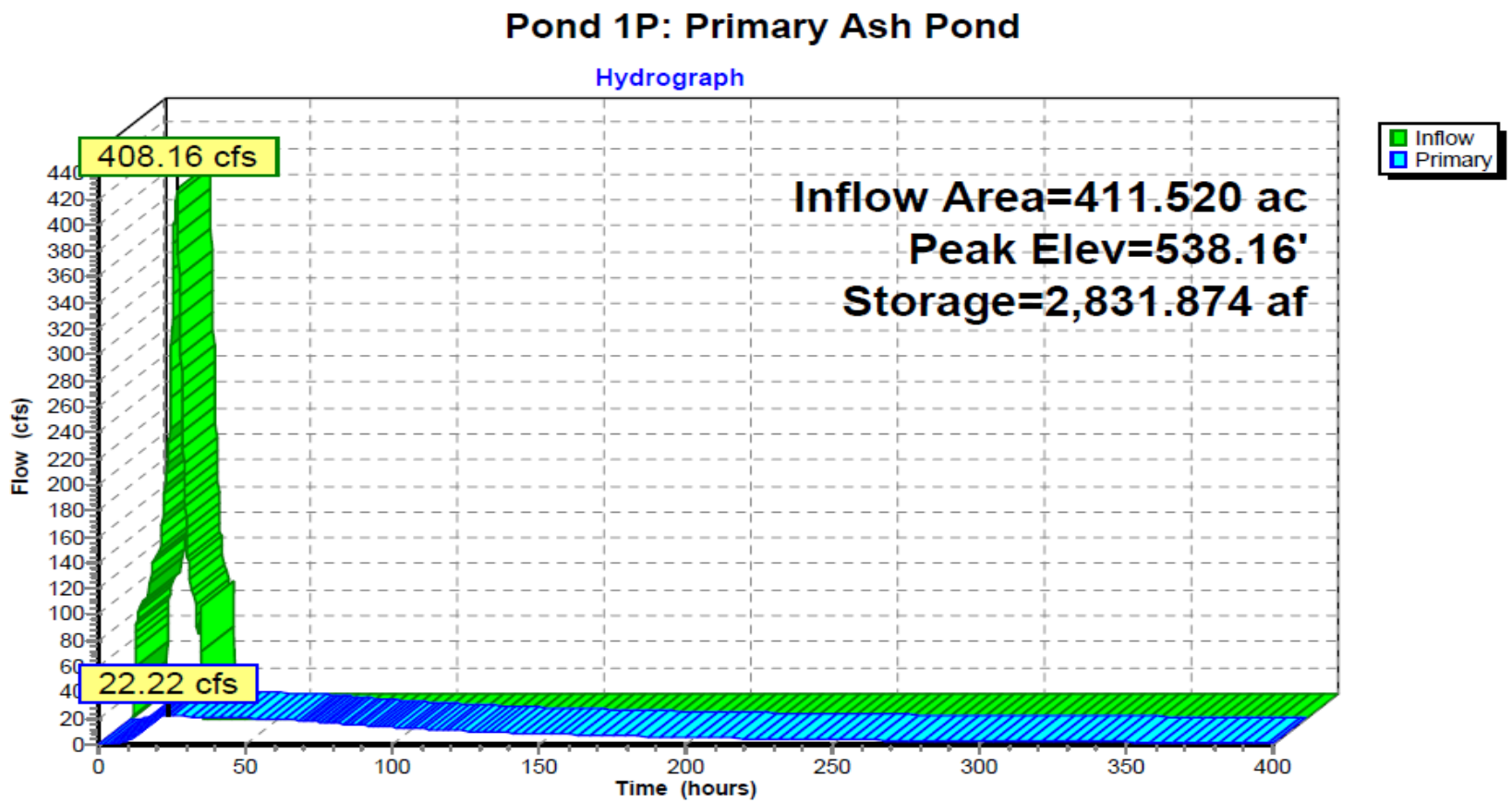


SECONDARY POND CUMULATIVE STORAGE
PERIODIC CERTIFICATION
NEWTON POWER PLANT
NEWTON, ILLINOIS

Geosyntec consultants

Figure E-2

GLP8027 | 9/10/2021



AP1 IDF HYDROGRAPH PERIODIC CERTIFICATION NEWTON POWER PLANT NEWTON, ILLINOIS		
Geosyntec consultants		Figure E-3
GLP8027	9/10/2021	

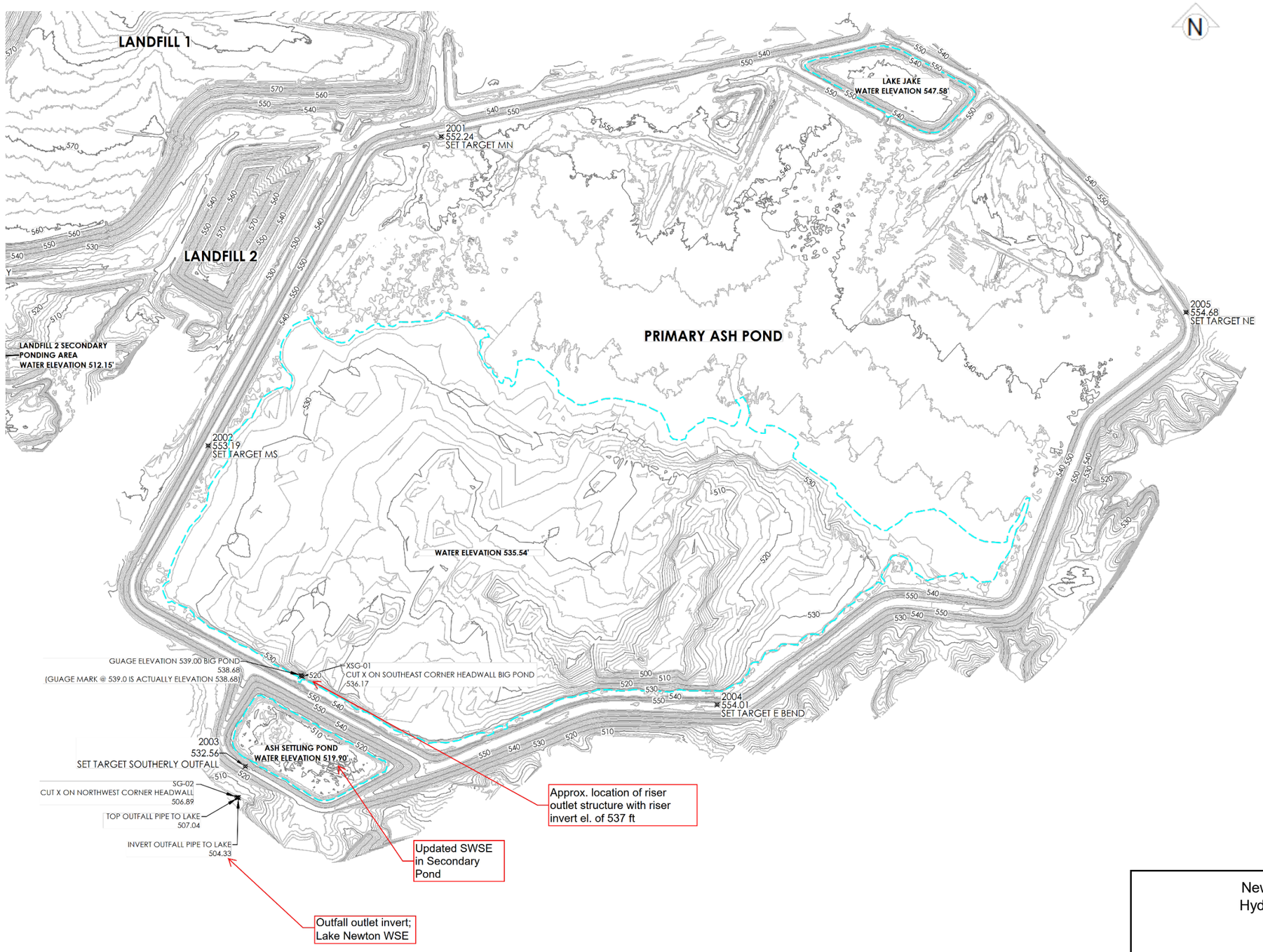


Figure based on IngenAE 2020 Site Topo

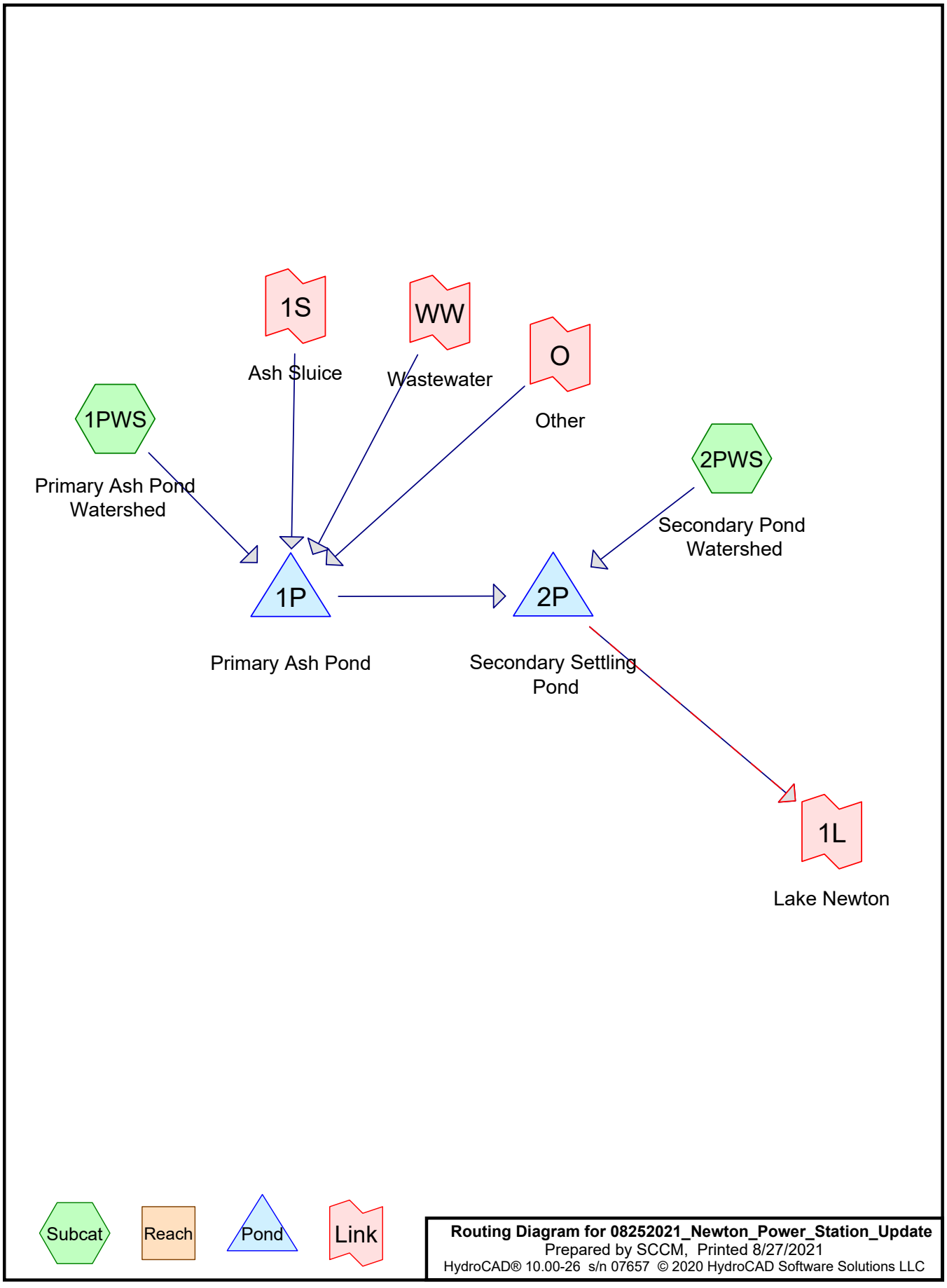
DRAFT - NOT FOR CONSTRUCTION - NOT TO SCALE - ATTORNEY-CLIENT PRIVILEGED & CONFIDENTIAL

Newton Power Plant
Hydrologic Workmap

Geosyntec consultants

GLP8027 | September 2021

Figure E-4


1S
Ash Sluice
WW
Wastewater
O
Other
1PWS
Primary Ash Pond Watershed
2PWS
Secondary Pond Watershed
1P
Primary Ash Pond
2P
Secondary Settling Pond
1L
Lake Newton
Subcat
Reach
Pond
Link
Routing Diagram for 08252021_Newton_Power_Station_Update
Prepared by SCCM, Printed 8/27/2021
HydroCAD® 10.00-26 s/n 07657 © 2020 HydroCAD Software Solutions LLC

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Area Listing (all nodes)

Area (acres)	CN	Description (subcatchment-numbers)
423.520	98	(1PWS, 2PWS)
423.520	**98**	**TOTAL AREA**

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Soil Listing (all nodes)

Area (acres)	Soil Group	Subcatchment Numbers
0.000	HSG A	
0.000	HSG B	
0.000	HSG C	
0.000	HSG D	
423.520	Other	1PWS, 2PWS
423.520		**TOTAL AREA**

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Ground Covers (all nodes)

HSG-A (acres)	HSG-B (acres)	HSG-C (acres)	HSG-D (acres)	Other (acres)	Total (acres)	Ground Cover	Subcatchment Numbers
0.000	0.000	0.000	0.000	423.520	423.520		1PWS, 2PWS
0.000	**0.000**	**0.000**	**0.000**	**423.520**	**423.520**	**TOTAL AREA**	

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Pipe Listing (all nodes)

Line#	Node Number	In-Invert (feet)	Out-Invert (feet)	Length (feet)	Slope (ft/ft)	n	Diam/Width (inches)	Height (inches)	Inside-Fill (inches)
1	1P	512.18	508.00	220.0	0.0190	0.013	28.0	0.0	0.0
2	2P	505.00	504.33	226.0	0.0030	0.013	28.0	0.0	0.0

Time span=0.00-400.00 hrs, dt=0.15 hrs, 2668 points
Runoff by SCS TR-20 method, UH=SCS, Weighted-CN
Reach routing by Dyn-Stor-Ind method - Pond routing by Dyn-Stor-Ind method

Subcatchment 1PWS: Primary Ash Runoff Area=411.520 ac 100.00% Impervious Runoff Depth=8.77"
Tc=6.0 min CN=98 Runoff=408.16 cfs 300.740 af

Subcatchment 2PWS: Secondary Pond Runoff Area=12.000 ac 100.00% Impervious Runoff Depth=8.77"
Tc=6.0 min CN=98 Runoff=11.90 cfs 8.770 af

Pond 1P: Primary Ash Pond Peak Elev=538.16' Storage=2,831.874 af Inflow=408.16 cfs 300.740 af
Outflow=22.22 cfs 260.432 af

Pond 2P: Secondary Settling Pond Peak Elev=519.90' Storage=64.320 af Inflow=28.79 cfs 269.202 af
Primary=61.56 cfs 333.516 af Secondary=0.00 cfs 0.000 af Outflow=61.56 cfs 333.516 af

Link 1L: Lake Newton Inflow=61.56 cfs 333.516 af
Primary=61.56 cfs 333.516 af

Link 1S: Ash Sluice Manual Hydrograph above 13.37 cfs below 13.37 cfs Inflow=13.37 cfs 171.338 af
Primary=0.00 cfs 0.000 af Secondary=13.37 cfs 171.338 af

Link O: Other Manual Hydrograph above 1.54 cfs below 1.54 cfs Inflow=1.54 cfs 50.935 af
Primary=0.00 cfs 0.000 af Secondary=1.54 cfs 50.935 af

Link WW: Wastewater Manual Hydrograph above 23.39 cfs below 23.39 cfs Inflow=23.39 cfs 201.231 af
Primary=0.00 cfs 0.000 af Secondary=23.39 cfs 201.231 af

Total Runoff Area = 423.520 ac Runoff Volume = 309.510 af Average Runoff Depth = 8.77"
0.00% Pervious = 0.000 ac 100.00% Impervious = 423.520 ac

Summary for Subcatchment 1PWS: Primary Ash Pond Watershed

[49] Hint: Tc<2dt may require smaller dt

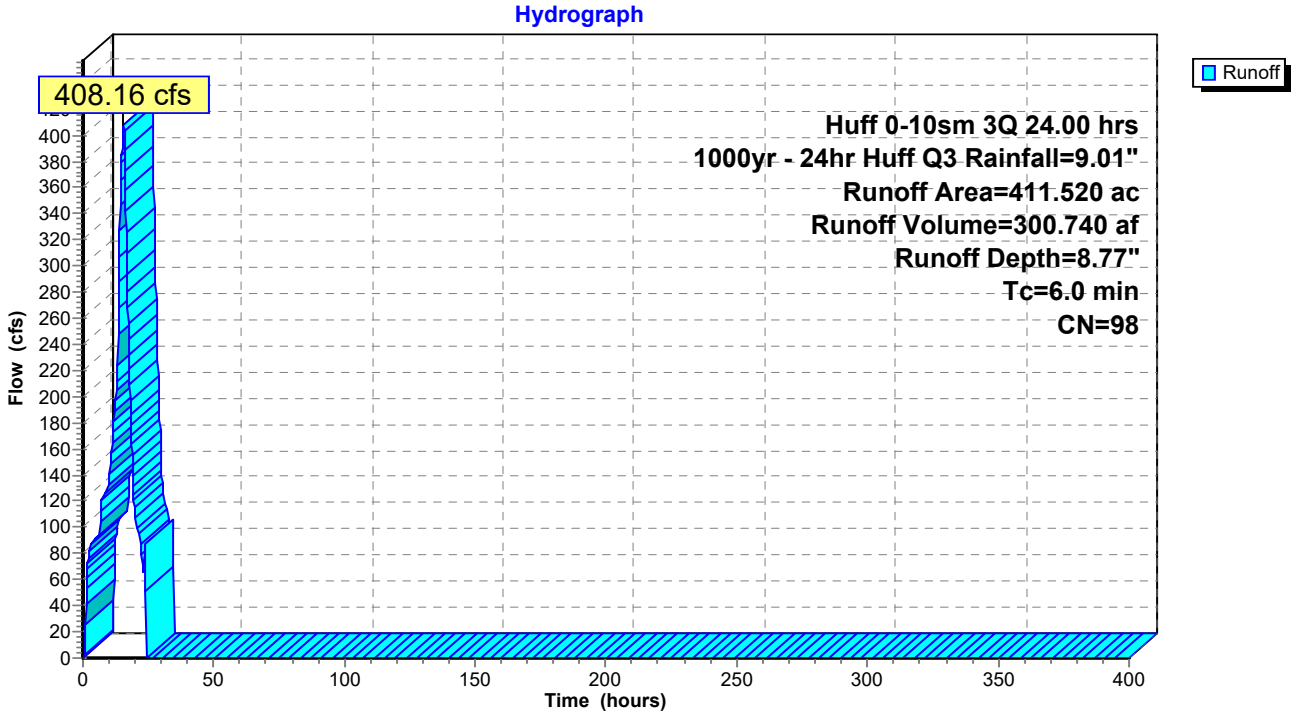
Runoff = 408.16 cfs @ 15.60 hrs, Volume= 300.740 af, Depth= 8.77"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs
Huff 0-10sm 3Q 24.00 hrs 1000yr - 24hr Huff Q3 Rainfall=9.01"

	Area (ac)	CN	Description
*	411.520	98	
	411.520		100.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
6.0					**Direct Entry,**

Subcatchment 1PWS: Primary Ash Pond Watershed



Summary for Subcatchment 2PWS: Secondary Pond Watershed

[49] Hint: Tc<2dt may require smaller dt

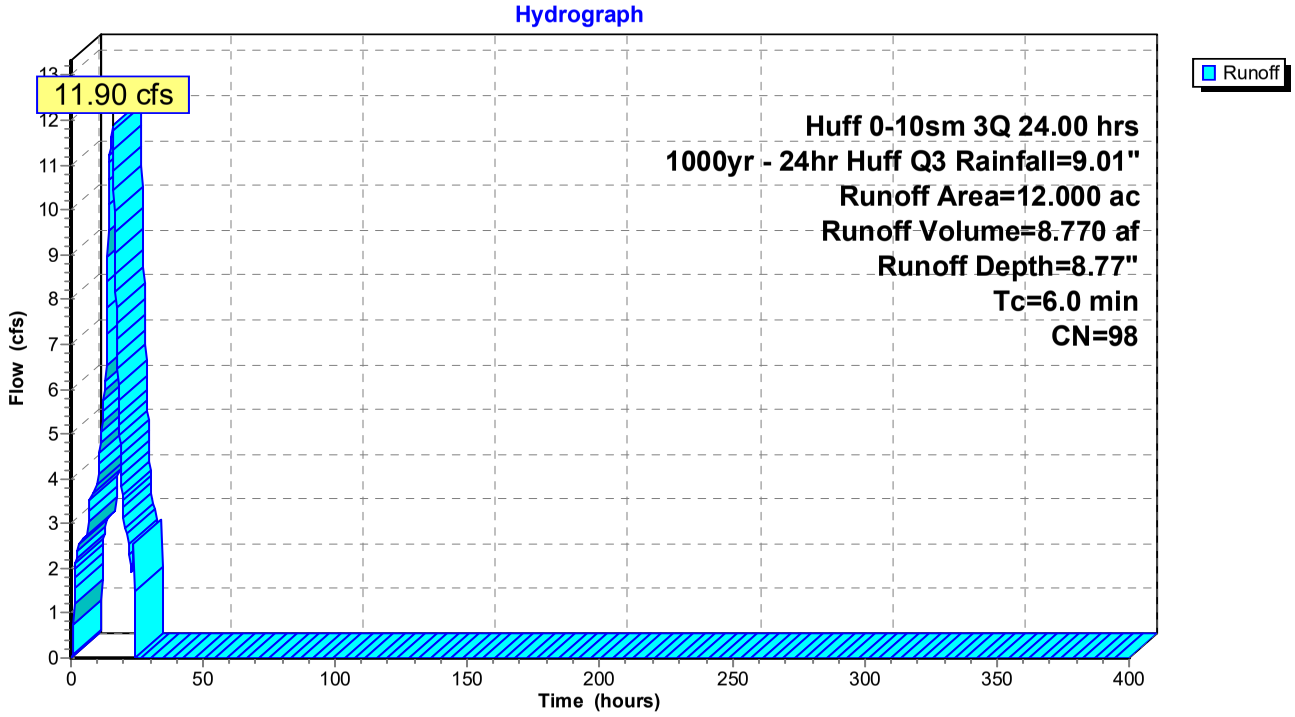
Runoff = 11.90 cfs @ 15.60 hrs, Volume= 8.770 af, Depth= 8.77"

Runoff by SCS TR-20 method, UH=SCS, Weighted-CN, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs
Huff 0-10sm 3Q 24.00 hrs 1000yr - 24hr Huff Q3 Rainfall=9.01"

	Area (ac)	CN	Description
*	12.000	98	
	12.000		100.00% Impervious Area

Tc (min)	Length (feet)	Slope (ft/ft)	Velocity (ft/sec)	Capacity (cfs)	Description
6.0					**Direct Entry,**

Subcatchment 2PWS: Secondary Pond Watershed



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Summary for Pond 1P: Primary Ash Pond

Inflow Area = 411.520 ac,100.00% Impervious, Inflow Depth = 8.77" for 1000yr - 24hr Huff Q3 event
Inflow = 408.16 cfs @ 15.60 hrs, Volume= 300.740 af
Outflow = 22.22 cfs @ 24.18 hrs, Volume= 260.432 af, Atten= 95%, Lag= 514.8 min
Primary = 22.22 cfs @ 24.18 hrs, Volume= 260.432 af

Routing by Dyn-Stor-Ind method, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs
Starting Elev= 537.00' Surf.Area= 0.000 ac Storage= 2,550.800 af
Peak Elev= 538.16' @ 24.18 hrs Surf.Area= 0.000 ac Storage= 2,831.874 af (281.074 af above start)

Plug-Flow detention time= (not calculated: initial storage exceeds outflow)
Center-of-Mass det. time= 6,560.9 min (7,370.8 - 809.8)

Volume	Invert	Avail.Storage	Storage Description
#1	495.00'	7,623.000 af	**Custom Stage Data** Listed below

Elevation (feet)	Cum.Store (acre-feet)
495.00	0.000
500.00	18.000
505.00	51.000
510.00	104.000
515.00	192.000
520.00	377.000
525.00	752.000
530.00	1,312.000
535.00	2,068.000
540.00	3,275.000
545.00	4,965.000
550.00	6,842.000
551.00	7,231.000
552.00	7,623.000

Device	Routing	Invert	Outlet Devices
#1	Primary	512.18'	**28.0" Round Culvert** L= 220.0' Ke= 0.820 Inlet / Outlet Invert= 512.18' / 508.00' S= 0.0190 '/' Cc= 0.900 n= 0.013, Flow Area= 4.28 sf
#2	Device 1	537.00'	**28.0" Horiz. Orifice/Grate** C= 0.600 Limited to weir flow at low heads

Primary OutFlow Max=22.22 cfs @ 24.18 hrs HW=538.16' TW=510.37' (Dynamic Tailwater)
↑**1=Culvert** (Passes 22.22 cfs of 84.54 cfs potential flow)
↑**2=Orifice/Grate** (Orifice Controls 22.22 cfs @ 5.20 fps)

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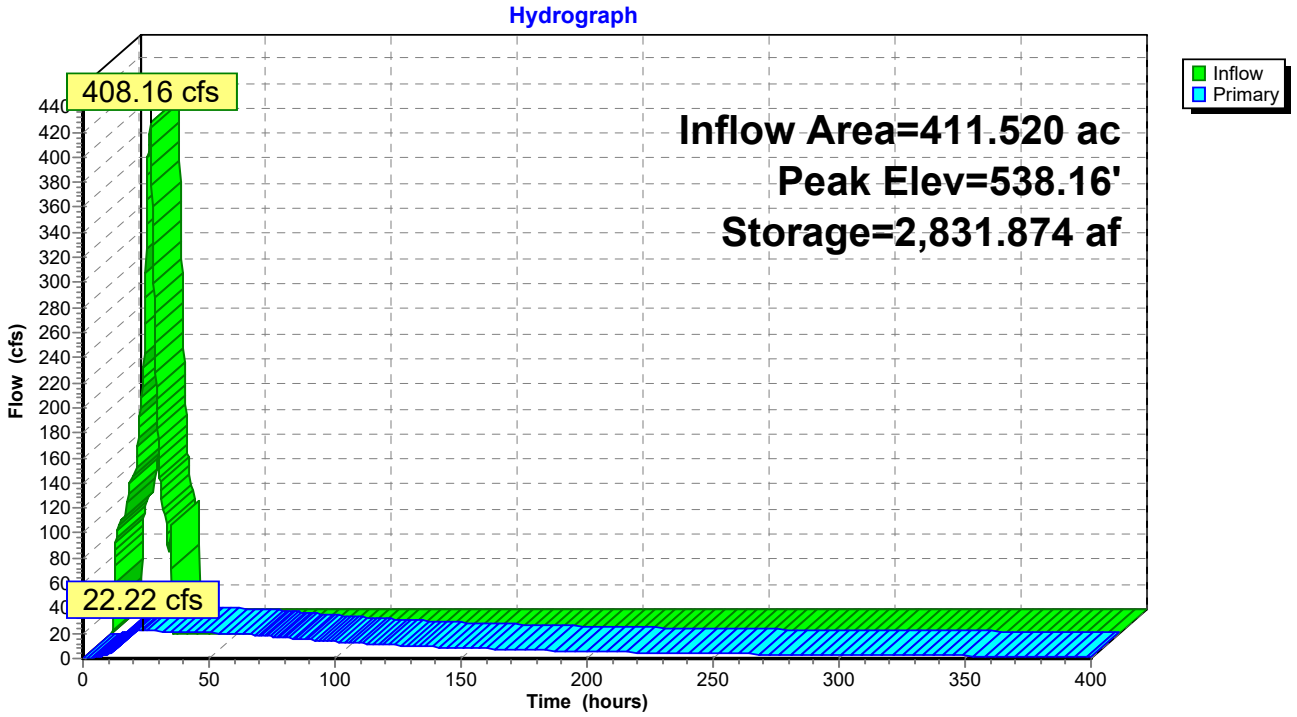
Pond 1P: Primary Ash Pond



Summary for Pond 2P: Secondary Settling Pond

Inflow Area = 423.520 ac,100.00% Impervious, Inflow Depth > 7.63" for 1000yr - 24hr Huff Q3 event
Inflow = 28.79 cfs @ 16.35 hrs, Volume= 269.202 af
Outflow = 61.56 cfs @ 0.00 hrs, Volume= 333.516 af, Atten= 0%, Lag= 0.0 min
Primary = 61.56 cfs @ 0.00 hrs, Volume= 333.516 af
Secondary = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af

Routing by Dyn-Stor-Ind method, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs
Starting Elev= 519.90' Surf.Area= 0.000 ac Storage= 64.320 af
Peak Elev= 519.90' @ 0.00 hrs Surf.Area= 0.000 ac Storage= 64.320 af

Plug-Flow detention time= 67.0 min calculated for 269.095 af (100% of inflow)
Center-of-Mass det. time= (not calculated: outflow precedes inflow)

Volume	Invert	Avail.Storage	Storage Description
#1	505.00'	168.000 af	**Custom Stage Data** Listed below

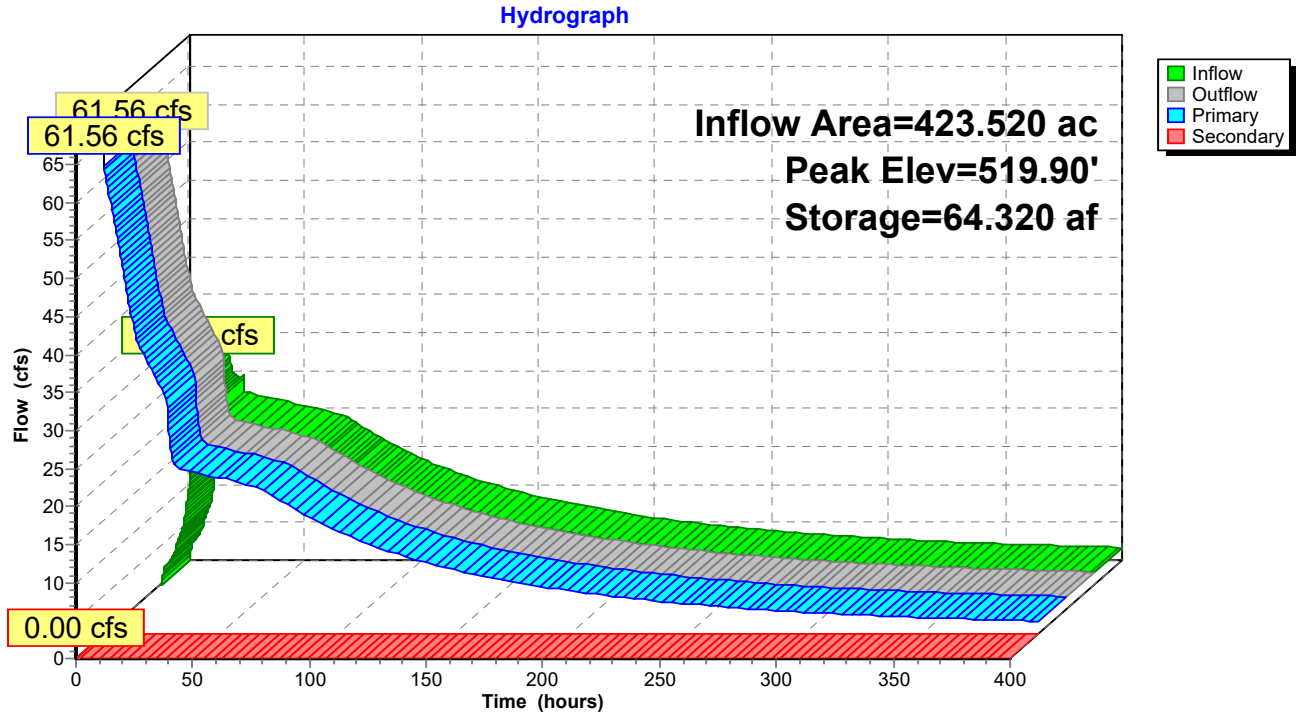
Elevation (feet)	Cum.Store (acre-feet)
505.00	0.000
510.00	3.000
515.00	31.000
520.00	65.000
525.00	105.000
530.00	149.000
531.00	158.000
532.00	168.000

Device	Routing	Invert	Outlet Devices
#1	Primary	505.00'	**28.0" Round Culvert** L= 226.0' Ke= 0.820 Inlet / Outlet Invert= 505.00' / 504.33' S= 0.0030 '/' Cc= 0.900 n= 0.013, Flow Area= 4.28 sf
#2	Secondary	528.50'	**5.0' long Broad-Crested Rectangular Weir** Head (feet) 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 Coef. (English) 2.65 2.65 2.65 2.65 2.65 2.65 2.65 2.65 2.65

Primary OutFlow Max=61.56 cfs @ 0.00 hrs HW=519.90' TW=504.33' (Dynamic Tailwater)
↑—**1=Culvert** (Barrel Controls 61.56 cfs @ 14.40 fps)

Secondary OutFlow Max=0.00 cfs @ 0.00 hrs HW=519.90' TW=504.33' (Dynamic Tailwater)
↑—**2=Broad-Crested Rectangular Weir** (Controls 0.00 cfs)

Pond 2P: Secondary Settling Pond



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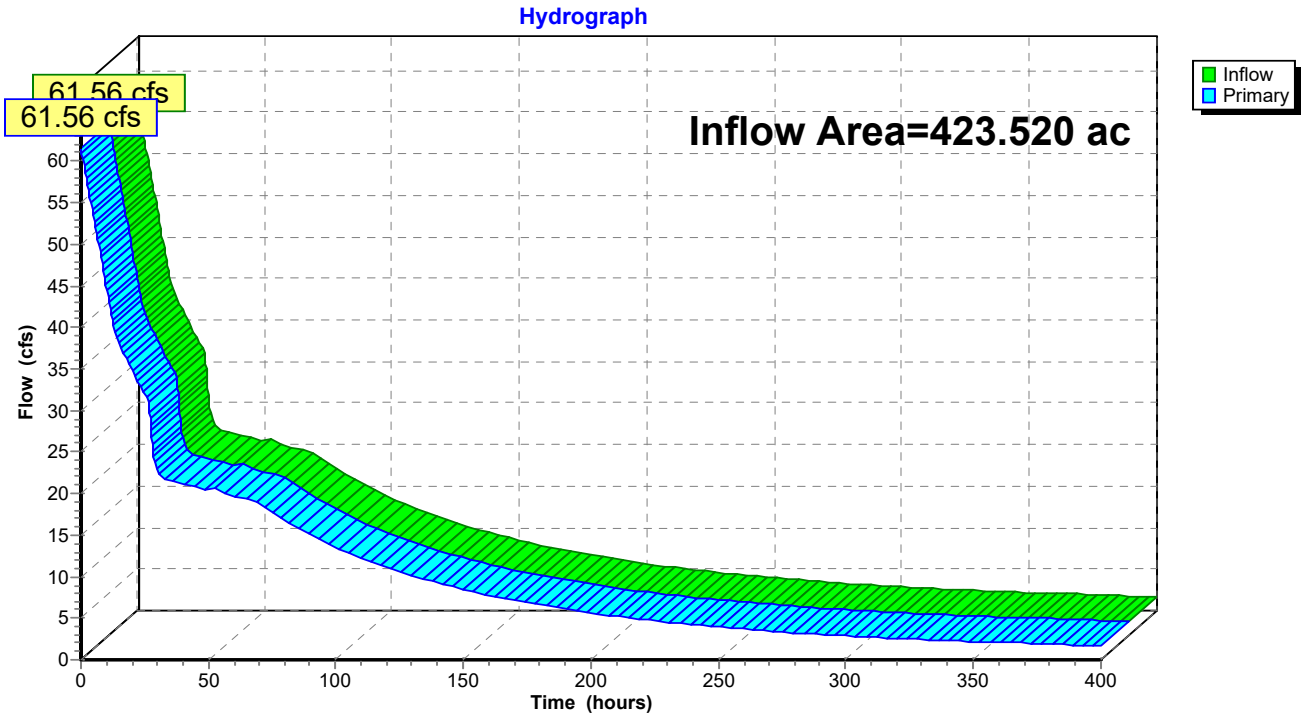
Summary for Link 1L: Lake Newton

Inflow Area = 423.520 ac,100.00% Impervious, Inflow Depth > 9.45" for 1000yr - 24hr Huff Q3 event
Inflow = 61.56 cfs @ 0.00 hrs, Volume= 333.516 af
Primary = 61.56 cfs @ 0.00 hrs, Volume= 333.516 af, Atten= 0%, Lag= 0.0 min

Primary outflow = Inflow, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs

Fixed water surface Elevation= 504.33'

Link 1L: Lake Newton



Summary for Link 1S: Ash Sluice

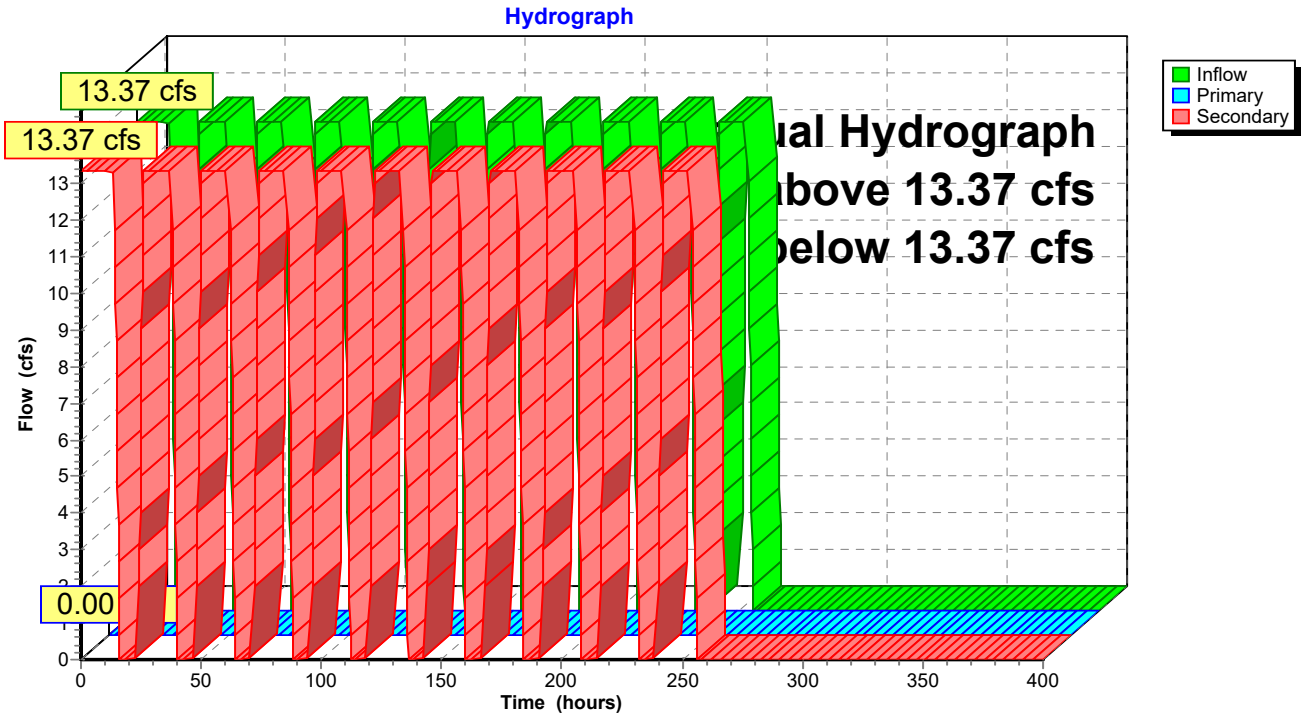
Inflow = 13.37 cfs @ 0.00 hrs, Volume= 171.338 af
Primary = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af, Atten= 100%, Lag= 0.0 min
Secondary = 13.37 cfs @ 0.00 hrs, Volume= 171.338 af

Primary outflow = Inflow above 13.37 cfs below 13.37 cfs, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs

132 Point manual hydrograph, To= 0.00 hrs, dt= 2.00 hrs, cfs =

13.37	13.37	13.37	13.37	13.37	13.37	13.37	13.37	0.00	0.00
0.00	0.00	0.00	13.37	13.37	13.37	13.37	13.37	13.37	13.37
0.00	0.00	0.00	0.00	0.00	13.37	13.37	13.37	13.37	13.37
13.37	13.37	0.00	0.00	0.00	0.00	0.00	13.37	13.37	13.37
13.37	13.37	13.37	13.37	0.00	0.00	0.00	0.00	0.00	13.37
13.37	13.37	13.37	13.37	13.37	13.37	0.00	0.00	0.00	0.00
0.00	13.37	13.37	13.37	13.37	13.37	13.37	13.37	0.00	0.00
0.00	0.00	0.00	13.37	13.37	13.37	13.37	13.37	13.37	13.37
0.00	0.00	0.00	0.00	0.00	13.37	13.37	13.37	13.37	13.37
13.37	13.37	0.00	0.00	0.00	0.00	0.00	13.37	13.37	13.37
13.37	13.37	13.37	13.37	0.00	0.00	0.00	0.00	0.00	13.37
13.37	13.37	13.37	13.37	13.37	13.37	0.00	0.00	0.00	0.00
0.00	13.37	13.37	13.37	13.37	13.37	13.37	13.37	0.00	0.00
0.00	0.00								

Link 1S: Ash Sluice



Summary for Link O: Other

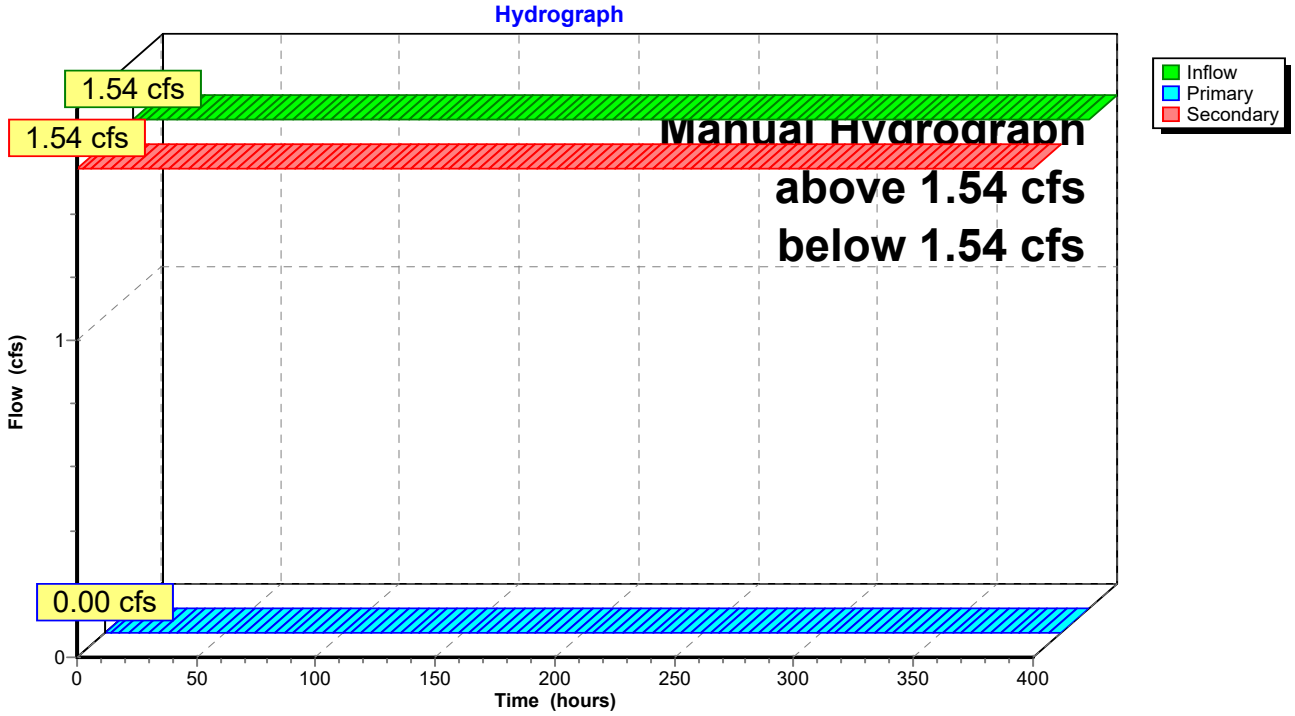
Inflow = 1.54 cfs @ 0.00 hrs, Volume= 50.935 af
Primary = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af, Atten= 100%, Lag= 0.0 min
Secondary = 1.54 cfs @ 0.00 hrs, Volume= 50.935 af

Primary outflow = Inflow above 1.54 cfs below 1.54 cfs, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs

126 Point manual hydrograph, To= 0.00 hrs, dt= 5.00 hrs, cfs =

1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54	1.54
1.54	1.54	1.54	1.54	1.54	1.54				

Link O: Other



Summary for Link WW: Wastewater

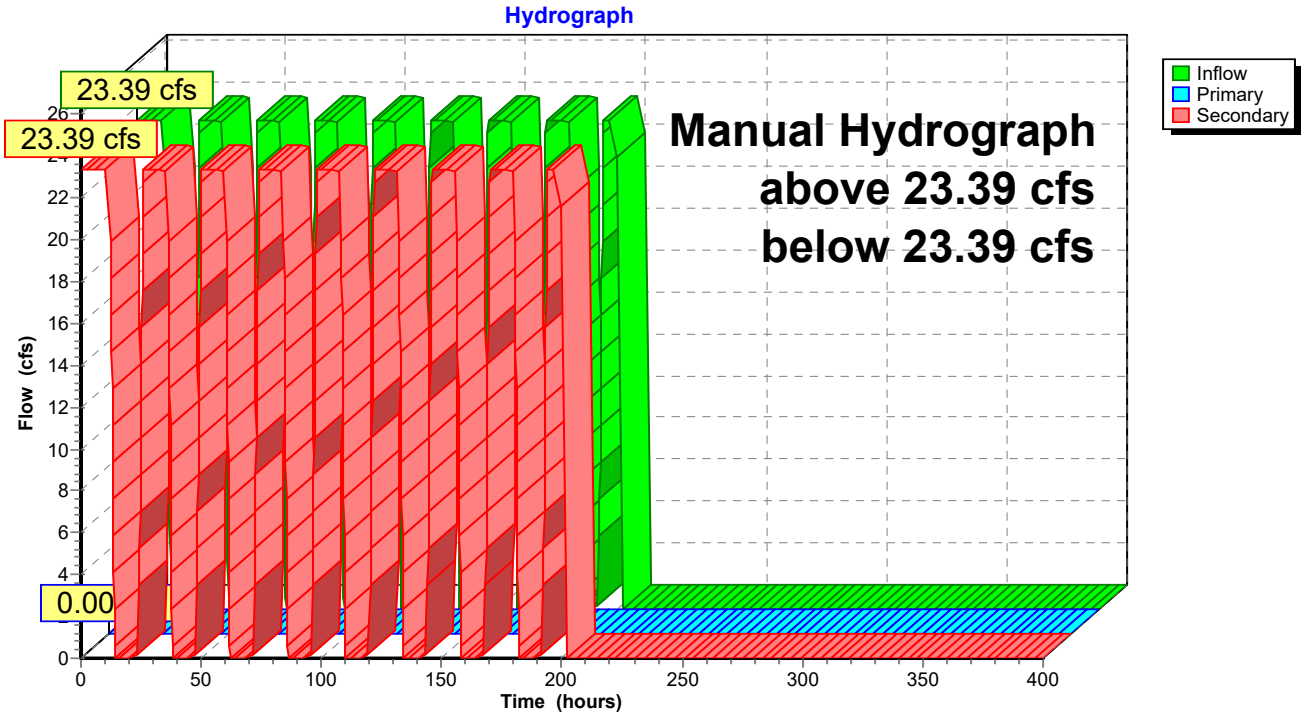
Inflow = 23.39 cfs @ 0.00 hrs, Volume= 201.231 af
Primary = 0.00 cfs @ 0.00 hrs, Volume= 0.000 af, Atten= 100%, Lag= 0.0 min
Secondary = 23.39 cfs @ 0.00 hrs, Volume= 201.231 af

Primary outflow = Inflow above 23.39 cfs below 23.39 cfs, Time Span= 0.00-400.05 hrs, dt= 0.15 hrs

101 Point manual hydrograph, To= 0.00 hrs, dt= 2.00 hrs, cfs =

23.39	23.39	23.39	23.39	23.39	23.39	23.39	0.00	0.00	0.00
0.00	0.00	0.00	23.39	23.39	23.39	23.39	23.39	23.39	0.00
0.00	0.00	0.00	0.00	0.00	23.39	23.39	23.39	23.39	23.39
23.39	0.00	0.00	0.00	0.00	0.00	0.00	23.39	23.39	23.39
23.39	23.39	23.39	0.00	0.00	0.00	0.00	0.00	0.00	23.39
23.39	23.39	23.39	23.39	23.39	0.00	0.00	0.00	0.00	0.00
0.00	23.39	23.39	23.39	23.39	23.39	23.39	0.00	0.00	0.00
0.00	0.00	0.00	23.39	23.39	23.39	23.39	23.39	23.39	0.00
0.00	0.00	0.00	0.00	0.00	23.39	23.39	23.39	23.39	23.39
23.39	0.00	0.00	0.00	0.00	0.00	0.00	23.39	23.39	23.39
23.39									

Link WW: Wastewater



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Attachment D

Types of CCR and Chemical Constituents

Newton Power Plant - Ash Pond's Chemical Constituents

In accordance with 35 I.A.C. 845.230(d)(2)(C), IPGC is submitting available/existing analyses of "the chemical constituents of all waste streams, chemical additives and sorbent materials entering or contained in" the CCR impoundment, Ash Pond.

A list of the chemical constituents' analyses contained in the CCR surface impoundment can be found in Appendix A. As determined through antidegradation studies, this list contains chemical constituents found in the surface free liquid and the subsurface free liquids. IPGC is also including a list of chemical additives, sorbent materials and waste streams that were submitted in the facility's NPDES permit applications to IEPA within the past ten years at a minimum and/or listed in the current NPDES permit (IL0001554) in Appendix B.

Appendix A: Chemical Constituents Contained in the Ash Pond

Pollutant	Units	Surface Free Liquids Average Concentration	Subsurface Free Liquids Average Concentration
Acidity (total)	mg/L	< 20.0	< 20.0
Alkalinity (total)	mg/L	98.3	327
Ammonia Nitrogen	mg/L	< 0.10	3.0
Antimony (dissolved)	mg/L	< 0.00031	0.00105
Antimony (total)	mg/L	< 0.00034	0.0079
Arsenic (dissolved)	mg/L	0.0021	0.0275
Arsenic (total)	mg/L	0.0023	0.0297
Barium (dissolved)	mg/L	0.246	0.191
Barium (total)	mg/L	0.27	0.62
Beryllium (dissolved)	mg/L	< 0.00050	< 0.001
Beryllium (total)	mg/L	< 0.00050	< 0.0011
Boron (dissolved)	mg/L	0.421	4.2
Boron (total)	mg/L	0.416	4.7
Cadmium (dissolved)	mg/L	< 0.00050	0.0007
Cadmium (total)	mg/L	< 0.00050	0.0008
Calcium (total recoverable)	mg/L	19.1	57.9
Chemical Oxygen Demand	mg/L	34.9	46.9
Chloride (total)	mg/L	10.9	19.2
Chromium (dissolved)	mg/L	0.0018	0.00070
Chromium (hexavalent)	mg/L	0.0016	0.0013
Chromium (total)	mg/L	0.002	0.007
Cobalt (dissolved)	mg/L	< 0.00011	0.001
Cobalt (total)	mg/L	< 0.00020	0.016
Copper (dissolved)	mg/L	0.0020	0.001
Copper (total)	mg/L	0.0026	0.0156
Cyanide (dissociable)	mg/L	< 0.010	0.4
Cyanide	mg/L	< 0.010	0.3
Fluoride	mg/L	0.65	0.44
Iron (dissolved)	mg/L	0.055	0.069
Iron (Ferric)	mg/L	0.08	2.89
Iron (Ferrous)	mg/L	< 0.12	< 0.4
Iron (total)	mg/L	0.142	3.1
Kjeldahl Nitrogen (total)	mg/L	1.1	4
Lead (dissolved)	mg/L	< 0.001	0.001
Lead (total)	mg/L	< 0.001	0.005
Lithium (total recoverable)	mg/L	< 0.010	0.028
Magnesium (total recoverable)	mg/L	5.46	2.8
Manganese (dissolved)	mg/L	0.0020	0.003
Manganese (total)	mg/L	0.0083	0.019
Mercury (dissolved)	mg/L	0.000044	0.0023
Mercury (total)	mg/L	0.000095	0.0033

Pollutant	Units	Surface Free Liquids Average Concentration	Subsurface Free Liquids Average Concentration
Molybdenum (dissolved)	mg/L	0.0145	0.267
Molybdenum (total)	mg/L	0.015	0.263
Nickel (dissolved) 200.8 WD	mg/L	< 0.00055	0.007
Nickel (dissolved) 6020 WD	mg/L	< 0.00057	0.007
Nickel (total)	mg/L	< 0.00077	0.0115
Nitrate as N	mg/L	< 0.10	0.09
Nitrite as N	mg/L	< 0.10	0.08
Oil & grease	mg/L	< 5.4	5.1
Oxidation/Reduction Potential	mg/L	-100	-276.7
pH*	SU	9.3	10.0
Phenols	mg/L	< 0.050	0.06
Phosphorus	mg/L	< 0.31	1.8
Potassium (dissolved)	mg/L	7.71	50.9
Potassium (total recoverable)	mg/L	7.7	52.8
Radium - 226	mg/L	0.99	0.63
Radium - 228	mg/L	0.87	1.03
Radium (total)	mg/L	1.87	1.66
Selenium (total)	mg/L	0.0042	0.038
Silica	mg/L	1.75	50.0
Silver (dissolved)	mg/L	< 0.00050	< 0.0009
Silver (total)	mg/L	< 0.00050	0.0009
Sodium (total recoverable)	mg/L	64.6	1365
Specific Conductance	mg/L	430.5	5827
Sulfate	mg/L	117	2554
Sulfide (total)	mg/L	0.051	1.5
Thallium (dissolved)	mg/L	< 0.001	< 0.002
Thallium (total)	mg/L	< 0.001	0.002
Total dissolved solids	mg/L	272	4700
Total Organic Carbon	mg/L	6.5	7.6
Total suspended solids	mg/L	37.9	92.6
Zinc (dissolved)	mg/L	< 0.010	0.013
Zinc (total)	mg/L	< 0.010	0.032

*Used https://calstormcompliance.com/ph-averaging-tool

Appendix B: List of Chemical Additives, Waste Streams and Sorbent Materials

Chemical Additives
Nalco PC-191 or equivalent (Anti-scalant)
Nalco PC-56 or equivalent (Biocide)
Ondeo-Nalco CA-250 or equivalent (Cationic Polymer)
General Chemical Hyper+lon-1090 or equivalent (Aluminum Chlorohydrate)
Aluminum Chlorohydrate
Sodium Hydroxide (50%)
Sulfuric Acid (93%)
GE Betz Spectrus OX1200 or equivalent (Granular Bromine)
Anhydrous Ammonia
Dust suppression agents for coal
Hydrated Lime
Sodium Bicarbonate
Coal Dust Suppression Products*
Calcium Bromide for mercury control*

* Only a very small percentage of these chemicals would enter the ash pond. A high majority of the product would be consumed in the combustion process. Varying products may be used.

Waste Streams and Sorbent Materials*
Bottom & fly ash sluice water
Wastewater sumps
Water treatment filter backwash
Reverse osmosis reject water
Mixed bed waste water
Air heater wash water
Boiler blowdown
Sewage treatment plant #2 discharge
Coal pile runoff
Stormwater runoff
SCR module wastewater
Non-Chemical Metal Cleaning Wastewater

*No sorbent materials

DYNEGY

Safety Data Sheet

Section 1
Identification of the Substance and of the Supplier

1.1 Product Identifier

Product Name/Identification:	ASTM Bottom Ash
Synonyms:	Ash; Ashes; Ash residues; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Coal Fly Ash; Pozzolan; Waste solids.
Formula:	UVCB Substance

1.2 Relevant Identified Uses of the Substance or Mixture and Uses Advices Against

Relevant Identified Uses:	Component of wallboard, concrete, roofing material, bricks, cement kiln feed.
Uses Advised Against:	None known.

1.3 Details of the Supplier of the SDS

Manufacturer/Supplier:	Dynegy, Inc.
Street Address:	601 Travis Street, Suite 1400
City, State and Zip Code:	Houston, TX 77002
Customer Service Telephone:	800-633-4704

Section 2
Hazards Identification

2.1 Classification of the Substance

GHS Classification(s) according to OSHA Hazard Communication Standard (29 CFR 1910.1200):

- Eye Irritant, Category 2A
- STOT-SE, Category 3 (Respiratory Irritation)
- Carcinogen, Category 1A
- STOT-RE, Category 1 (Lungs)
- Toxic to Reproduction, Category 2

2.2 Label Elements

Labelling according to 29 CFR 1910.1200 Appendices A, B and C*	
Hazard Pictogram(s):	
Signal word:	**DANGER**
Hazard Statement(s):	*Causes serious eye irritation.* *May cause respiratory irritation.* *May cause damage to lungs after repeated/prolonged exposure via inhalation.* *May cause cancer of the lung.* *Suspected of damaging fertility or the unborn child.*
Precautionary Statement(s):	*Obtain special instructions before use.* *Do not handle until all safety precautions have been read and understood.* *Avoid breathing dust.* *Wash thoroughly after handling.* *Do not eat drink or smoke when using this product.* *Wear protective gloves/protective clothing/eye protection/face protection.* *Use outdoors or in a well-ventilated area.* *If exposed or concerned: Get medical advice/attention.* *Store in a secure area.* *Dispose of product in accordance with local/national regulations.*

** Fly ash and other coal combustion products (CCPs) are UVCB substances (unknown or variable composition or biological). Various CCPs, noted as ashes/ash residuals; Ashes, residues, bottom; Bottom ash; Bottom ash residues; Waste solids, ashes under TSCA are defined as: "The residuum from the burning of a combination of carbonaceous materials. The following elements may be present as oxides: aluminum, calcium, iron, magnesium, nickel, phosphorus, potassium, silicon, sulfur, titanium, and vanadium." Ashes including fly ash and fluidized bed combustion ash are identified by CAS number 68131-74-8. The exact composition of the ash is dependent on the fuel source and flue additives composed of many constituents. The classification of the final substance is dependent on the presence of specific identified oxides as well as other trace elements.*

2.3 Other Hazards

Listed Carcinogens:

-Respirable Crystalline Silica

IARC: [Yes] **NTP:** [Yes] **OSHA:** [Yes] **Other:** **(ACGIH)** [Yes]

Section 3
Composition/Information on Ingredients

Substance	*CAS No.*	*Percentage (%)*	*GHS Classification*
Crystalline Silica	*14808-60-7*	*20 - 40%*	*Repeat Dose STOT, Category 1* *Carcinogen, Category 1A*
Silica, crystalline respirable (RCS)	*14808-60-7*	*See Footnote 1*	*Repeat Dose STOT, Category 1* *Carcinogen. Category 1A*
Aluminosilicates[2]	*Various, see Footnote 2*	*10 - 60%*	*Single Exposure STOT, Category 3*
Calcium oxide (CaO)	*1305-78-8*	*10 - 30%*	*Skin Irritant, Category 2* *Eye Irritant, Category 1* *Single Exposure STOT, Category 3*
Iron oxide	*1309-37-1*	*1 - 10%*	*Not Classified*
Manganese dioxide (MnO_2)	*1313-13-9*	*<2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Magnesium oxide	*1309-48-4*	*2 - 10%*	*Not Classified*
Phosphorus pentoxide (P_2O_5)	*1314-56-3*	*≤2%*	*Skin Irritant, Category 2* *Eye Irritant, Category 2B*
Sodium oxide	*1313-59-3*	*1 - 10%*	*Not Classified*
Potassium oxide (K_2O)	*12136-45-7*	*≤1%*	*Skin Irritant Category 2* *Eye Irritant Category 2B*
Titanium dioxide (TiO_2)	*13463-67-7*	*<3%*	*Not Classified*

[1]The percentage of respirable crystalline silica has not been determined. Therefore, a GHS classification of Carcinogen 1A has been assigned.

[2]Aluminosilicates (CAS# 1327-36-2) may be in the form of mullite (CAS# 1302-93-8); aluminosilicate glass; pozzolans (CAS# 71243-67-9); or calcium aluminosilicates such as tricalcium aluminate (C3A), or calcium sulfoaluminate (C4A3S). The form is dependent on the source of the coal and or the process used to create the CCP. Pulverized coal combustion would be more likely to create high levels of pozzolans. Aluminosilicates may have inclusions of calcium, titanium, iron, potassium, phosphorus, magnesium and other metal oxides.

Section 4
First Aid Measures

4.1 Description of First Aid Measures

Inhalation:	If product is inhaled and irritation of the nose or coughing occurs, remove person to fresh air. Get medical advice/attention if respiratory symptoms persist.
Skin Contact:	If skin exposure occurs, wash with soap and water.
Eye Contact:	If product gets into the eye, rinse copiously with water for several minutes. Remove contact lenses, if present and easy to do. Seek medical attention/advice if irritation occurs or persists.
Ingestion:	No specific first aid measures are required.

4.2 Most Important Health Effects, Both Acute and Delayed

Acute Effects: Direct exposure may cause respiratory irritation, eye irritation and skin irritation. The product dust can dry and irritate the skin and cause dermatitis and can irritate eyes and skin through mechanical abrasion.

Chronic Effects: Chronic exposure may cause lung damage from repeated exposure. Prolonged inhalation of respirable crystalline silica above certain concentrations may cause lung diseases, including silicosis and lung cancer.

4.3 Indication of Any Immediate Medical Attention and Special Treatment Needed

Seek first aid or call a doctor or Poison Control Center if contact with eyes occurs and irritation remains after rinsing. Get medical advice if inhalation occurs and respiratory symptoms persist.

Section 5
Firefighting Measures

5.1 Extinguishing Media

Suitable Extinguishing Media:	Product is not flammable. Use extinguishing media appropriate for surrounding fire.
Unsuitable Extinguishing Media:	Not applicable, the product is not flammable.

5.2 Special Hazards Arising from the Substance or Mixture

Hazardous Combustion Products:	None known.

5.3 Advice for Firefighters

Special Protective Equipment and Precautions for Firefighters:	As with any fire, wear self-contained breathing apparatus (NIOSH approved or equivalent) and full protective gear.

Section 6
Accidental Release Measures

6.1 Personal Precautions, Protective Equipment and Emergency Procedures

Personal precautions/Protective Equipment:	See Section 8.2.2 Individual Protective Measures. For concentrations exceeding Occupational Exposure Levels (OELs), use a self-contained breathing apparatus (SCBA).
Emergency procedures:	Use scooping, water spraying/flushing/misting or ventilated vacuum cleaning systems to clean up spills. Do not use pressurized air.

6.2 Environmental Precautions

Environmental precautions:	Prevent contamination of drains or waterways and dispose according to local and national regulations.

6.3 Methods and Material for Containment and Cleaning Up

Methods and materials for containment and cleaning up:	Do not use brooms or compressed air to clean surfaces. Use dust collection vacuum and extraction systems. Large spills of dry product should be removed by a vacuum system. Dampened material should be removed by mechanical means and recycled or disposed of according to local and national regulations.

See Sections 8 and 13 for additional information on exposure controls and disposal.

Section 7
Handling and Storage

7.1 Precautions for Safe Handling

Practice good housekeeping. Use adequate exhaust ventilation, dust collection and/or water mist to maintain airborne dust concentrations below permissible exposure limits (note: respirable crystalline silica dust may be in the air without a visible dust cloud).

Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain and test ventilation and dust collection equipment. In cases of insufficient ventilation, wear a NIOSH approved respirator for silica dust when handling or disposing dust from this product. Avoid contact with skin and eyes. Wash or vacuum clothing that has become dusty. Avoid eating, smoking, or drinking while handling the material.

7.2 Conditions for Safe Storage, Including any Incompatibilities

Minimize dust produced during loading and unloading.

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Section 8
Exposure Controls/Personal Protection

8.1 Control Parameters

OCCUPATIONAL EXPOSURE LIMITS					
SUBSTANCE		**OSHA PEL TWA (mg/m^3)**	**NIOSH REL TWA (mg/m^3)**	**ACGIH TLV TWA (mg/m^3)**	**CA - OSHA PEL (mg/m^3)**
Calcium oxide		5	2	2	2
Particulates Not Otherwise Regulated	Total	15	15	10	10
	Respirable	5	5	3	5
Respirable Crystalline Silica	Respirable	0.05	0.05	0.025	0.05
Manganese dioxide (as manganese compounds)	Total	5 (Ceiling)	1 3 (STEL)	0.1	0.2
	Respirable	-	-	0.02	-

8.2 Exposure Controls

8.2.1 Engineering Controls

Provide ventilation to maintain the ambient workplace atmosphere below the occupational exposure limit(s). Use general and local exhaust ventilation and dust collection systems as necessary to minimize exposure.

8.2.2 Personal Protective Equipment (PPE)

Respiratory protection:	Wear a NIOSH approved particulate respirator if exposure to airborne particulates is unavoidable and where occupational exposure limits may be exceeded. If airborne exposures are anticipated to exceed applicable PELs or TLVs, a self-contained breathing apparatus or airline respirator is recommended.
Eye and face protection:	If eye contact is possible, wear protective glasses with side shields. Avoid contact lenses.
Hand and skin protection:	Wear gloves and protective clothing. Wash hands with soap and water after contact with material.

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Section 9
Physical and Chemical Properties

9.1 Information on Basic Physical and Chemical Properties

Property: Value	Property: Value
Appearance (physical state, color, etc.): Fine tan/ gray particulate	**Upper/lower flammability or explosive limits:** Not applicable
Odor: Odorless[1]	**Vapor Pressure (Pa):** Not applicable
Odor threshold: Not applicable	**Vapor Density:** Not applicable
pH (25 °C) (in water): 8 - 11	**Specific gravity or relative density:** 2.2 – 2.9
Melting point/freezing point (°C): Not applicable	**Water Solubility:** Slight
Initial boiling point and boiling range (°C): Not applicable	**Partition coefficient: n-octane/water:** Not determined
Flash point (°C): Not determined	**Auto ignition temperature (°C):** Not applicable
Evaporation rate: Not applicable	**Decomposition temperature (°C):** Not determined
Flammability (solid, gas): Not combustible	**Viscosity:** Not applicable

[1] The use of urea or aqueous ammonia injected into the flue gas to reduce nitrogen oxides (NOx) emissions may result in the presence of ammonium sulfate or ammonium bisulfate in the ash at less than 0.1%. When ash containing these substances becomes wet under high pH (>9), free ammonia gas may be released resulting in objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces.

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Section 10
Stability and Reactivity

10.1 Reactivity:	The material is an inert, inorganic material primarily composed of elemental oxides.
10.2 Chemical stability:	The material is stable under normal use conditions.
10.3 Possibility of hazardous reactions:	The material is a relatively stable, inert material; however, when ash containing ammonia becomes wet under high pH (>9), free ammonia gas may be released resulting in an objectionable/nuisance ammonia odor and potential exposure to ammonia gas especially in confined spaces. Polymerization will not occur.
10.4 Conditions to avoid:	Product can become airborne in moderate winds. Dry material should be stored in silos. Materials stored out of doors should be covered or maintained in a damp condition.
10.5 Incompatible materials:	None known.
10. 6 Hazardous decomposition products:	None known.

Section 11
Toxicological Information

11.1 Information on Toxicological Effects

Endpoint	Data
Acute oral toxicity	LD50 > 2000 mg/kg
Acute dermal toxicity	LD50 > 2000 mg/kg
Acute inhalation toxicity	LD50 > 5.0 mg/L
Skin corrosion/irritation	Does not meet the classification criteria but may cause slight skin irritation. Product dust can dry the skin which can result in irritation.
Eye damage/irritation	Causes serious eye irritation. Positive scores for conjunctiva irritation and chemosis in 2/3 animals based on average of 24, 48 and 72-hour scores with irritation clearing within 21 days; no corneal or iritis effects observed.
Respiratory/skin sensitization	Not a respiratory or dermal sensitizer.
Germ cell mutagenicity	Not mutagenic in in-vitro and in-vivo assays with or without metabolic activation.
Carcinogenicity	Not available. Respirable crystalline silica has been identified as a carcinogen by OSHA, NTP, ACGIH and IARC.
Reproductive toxicity	No developmental toxicity was observed in available animal studies. Reproductive studies on CCPs showed either no reproductive effects, or some effects on male and female reproductive organs and parameters but without a clear dose response.
STOT-SE	CCPs when present as a nuisance dust may result in respiratory irritation.
STOT-RE	In a 180-day inhalation study with fly ash dust, no effects were observed at the highest dose tested. NOEC = 4.2 mg/m^3; it is not possible to assess the level at which toxicologically significant effects may occur. Repeated inhalation exposures to high levels of respirable crystalline silica may result in lung damage (i.e., silicosis).
Aspiration Hazard	Not applicable based product form.

Section 12
Ecological Information

12.1 Toxicity

Fly Ash (CAS# 68131-74-8)	
Toxicity to Fish	LC50 > 100 mg/L
Toxicity to Aquatic Invertebrates	Data indicates that the test substance is not toxic to *Daphnia magna* (EC50 undetermined)
Toxicity to Aquatic Algae and Plants	EC50 = 10 mg/L
Calcium oxide CAS# 1305-78-8	
Toxicity to Fish	LC50 = 50.6 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Invertebrates	EC50 = 49.1 mg/L The findings were closely related to the pH of the test solutions; therefore, pH is considered to be the main reason for the effects.
Toxicity to Aquatic Algae and Plants	NOEC =48 mg/L @ 72 hours based on $Ca(OH)_2$ The initial pH of the test medium was not directly related to the biologically relevant effects. The formation of precipitates is likely the result of the reaction between CO_2 dissolved in the medium.

12.2 Persistence and Degradability

Not relevant for inorganic materials.

12.3 Bioaccumulative Potential

This material does not contain any compounds that would bioaccumulate up the food chain.

12.4 Mobility in Soil

No data available.

12.5 Results of PBT and vPvB Assessment

This material does not contain any compounds classified as “persistent, bioaccumulative or toxic” nor as “very persistent/very bioaccumulative”.

12.6 Other Adverse Effects

None known.

Section 13
Disposal Considerations

See Sections 7 and 8 above for safe handling and use, including appropriate industrial hygiene practices.

Dispose of all waste product and containers in accordance with federal, state and local regulations.

Section 14
Transport Information

Regulatory entity: U.S. DOT	Shipping Name:	Not Regulated
	Hazard Class:	Not Regulated
	ID Number:	Not Regulated
	Packing Group:	Not Regulated

Section 15
Regulatory Information

15.1 Safety, Health and Environmental Regulations/Legislation Specific for the Mixture

- TSCA Inventory Status

  All components are listed on the TSCA Inventory.

- California Proposition 65

  The following substances are known to the State of California to be carcinogens and/or reproductive toxicants:

  - Respirable crystalline silica
  - Titanium dioxide

- State Right-to-Know (RTK)

Component	CAS	MA[1,2]	NJ[3,4]	PA[5]	RI[6]
Ammonium bisulfate	7803-63-6	No	Yes	No	No
Ammonium sulfate	7783-20-2	Yes	No	Yes	No
Calcium oxide	1305-78-8	Yes	Yes	Yes	No
Iron oxide	1309-37-1	Yes	Yes	Yes	No
Magnesium oxide	1309-48-4	No	Yes	No	No
Phosphorus pentoxide (or phosphorus oxide)	1314-56-3	Yes	Yes	Yes	No
Potassium oxide	12136-45-7	No	Yes	No	No
Silica-crystalline (SiO_2), quartz	14808-60-7	Yes	Yes	Yes	No
Sodium oxide	1313-59-3	No	Yes	No	No
Titanium dioxide	13463-67-7	Yes	Yes	Yes	Yes

[1] Massachusetts Department of Public Health, no date
[2] 189th General Court of The Commonwealth of Massachusetts, no date
[3] New Jersey Department of Health and Senior Services, 2010a
[4] New Jersey Department of Health, 2010b
[5] Pennsylvania Code, 1986
[6] Rhode Island Department of Labor and Training, no date

Section 16
Other Information, Including Date of Preparation or Last Revision

16.1 Indication of Changes

Date of preparation or last revision: February 23, 2018

16.2 Abbreviations and Acronyms

- ACGIH: American Conference of Industrial Hygienists
- CA: California
- CAS: Chemical Abstract Services
- CCP: Coal Combustion Product
- CFR: Code of Federal Regulations
- EPA: Environmental Protection Agency
- GHS: Globally Harmonized System of Classification and Labelling
- IARC: International Agency for Research on Cancer
- LC50: Concentration resulting in the mortality of 50 % of an animal population
- LD50: Dose resulting in the mortality of 50 % of an animal population
- MA: Massachusetts
- NA: Not Applicable
- NJ: New Jersey
- NOEC: No observed effect concentration
- NIOSH: National Institute of Occupational Safety and Health
- NOx: Nitrogen oxides
- NTP: US National Toxicology Program
- OEL: Occupational Exposure Limit
- OSHA: Occupational Safety and Health Administration
- PA: Pennsylvania
- PBT: Persistent, Toxic and Bioaccumulative
- PEL: Permissible exposure limit
- PPE: Personal Protective Equipment
- REL: Recommended exposure limit
- RI: Rhode Island
- RCS: Respirable Crystalline Silica
- RTK: Right-to-Know
- SCBA: Self-contained breathing apparatus
- SDS: Safety Data Sheet
- STEL: Short-term exposure limit
- STOT-RE: Specific target organ toxicity-repeated exposure
- STOT-SE: Specific target organ toxicity-single exposure
- TLV: Threshold limit value
- TSCA: Toxic Substances Control Act
- TWA: Time-weighted average
- UEL: Upper explosive limit
- UVCB: Unknown or Variable Composition/Biological
- U.S.: United States
- U.S. DOT: United States of Department of Transportation

16.3 Other Hazards

Hazardous Materials Identification System (HMIS) Degree of hazard (0= low, 4 = extreme)							
Health:	2*	**Flammability:**	0	**Physical Hazards:**	0	**Personal protection:****	

** Chronic Health Effects*
******* *Appropriate personal protection is defined by the activity to be performed.*
See Section 8 for additional information.

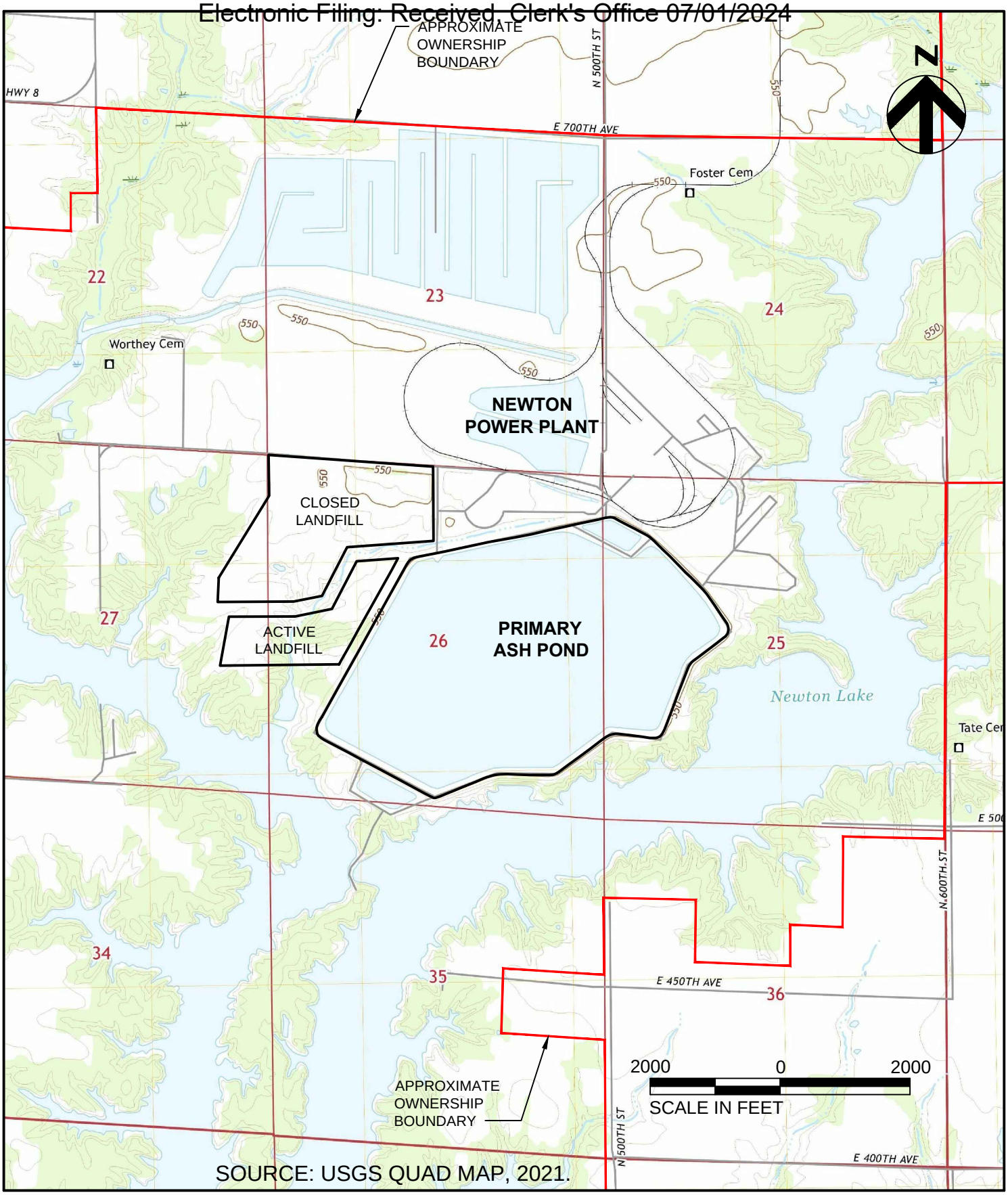
DISCLAIMER:

This SDS has been prepared in accordance with the Hazard Communication Rule 29 CFR 1910.1200. Information herein is based on data considered to be accurate as of date prepared. No warranty or representation, express or implied, is made as to the accuracy or completeness of this data and safety information. No responsibility can be assumed for any damage or injury resulting from abnormal use, failure to adhere to recommended practices, or from any hazards inherent in the nature of the product.

Attachment E

Site Location Maps

Electronic Filing: Received, Clerk's Office 07/01/2024



SOURCE: USGS QUAD MAP, 2021.

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

SITE LOCATION MAP

DATE
JULY 2022

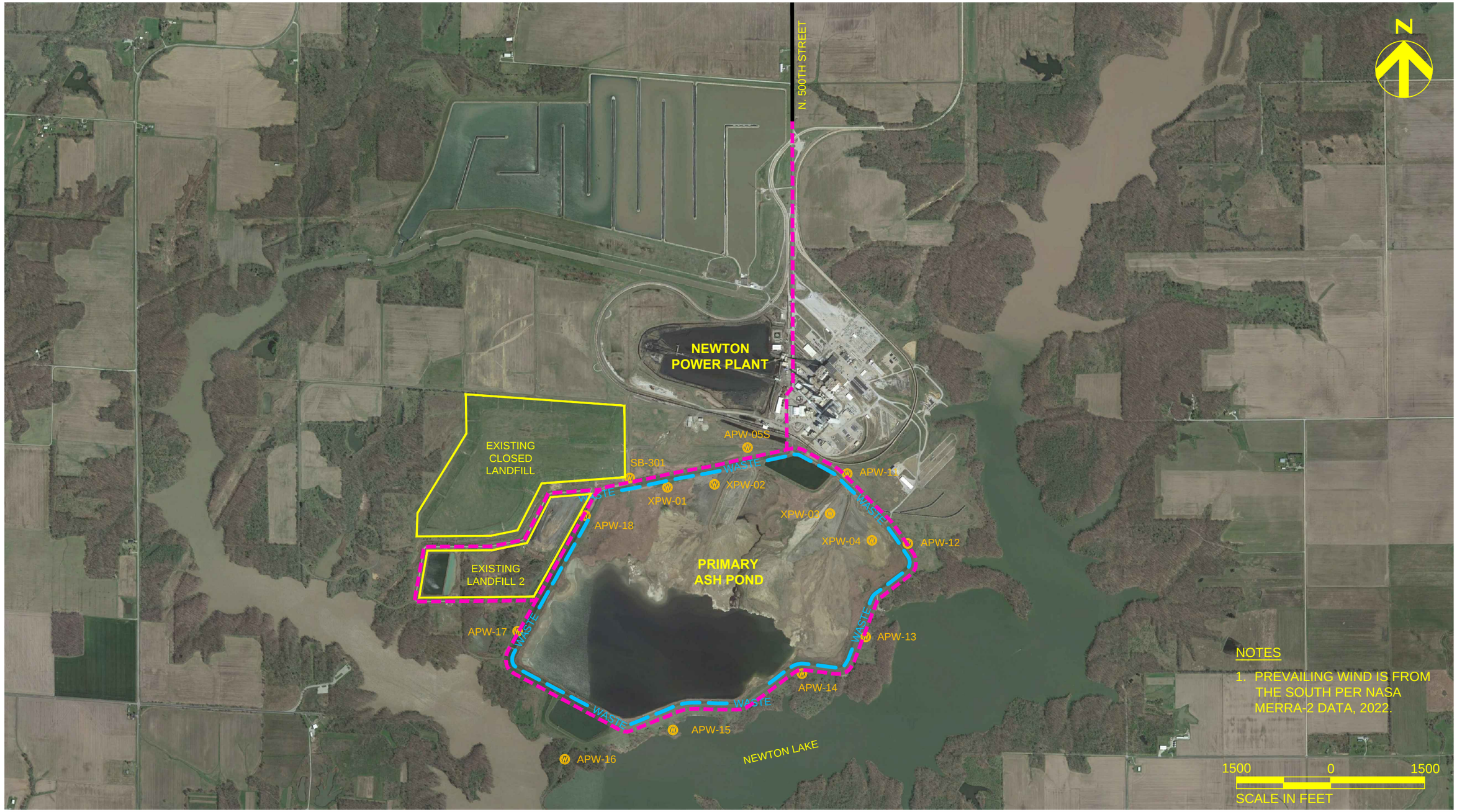
FIGURE
3

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment F

Site Plan Map and On-Site Transportation Plan

Electronic Filing: Received, Clerk's Office 07/01/2024



LEGEND

- WASTE — CCR UNIT LIMITS
- ON-SITE TRAFFIC ROUTES FOR CLOSURE
- PUBLIC ROADWAY TO ACCESS SITE
- EXISTING LANDFILL LIMITS
- EXISTING GROUNDWATER WELL

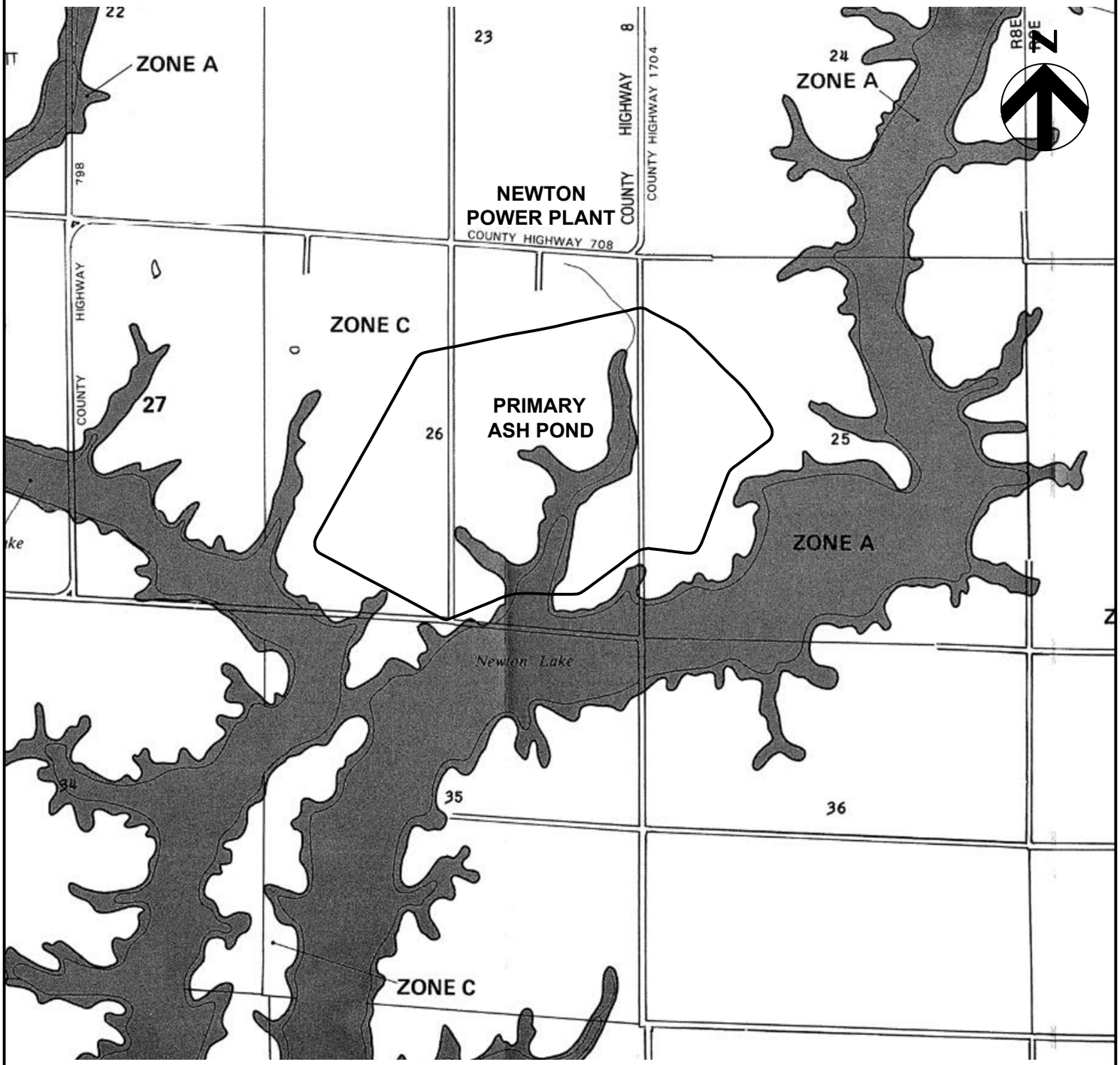
ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

SITE MAP AND TRANSPORTATION PLAN

DATE
JULY 2022

FIGURE
1

Electronic Filing: Received, Clerk's Office 07/01/2024



NOTES

1. SOURCE IMAGERY FROM FIRM PANEL 170990 025 B DATED JANUARY 17, 1985 DOES NOT INCORPORATE POND CONSTRUCTION TOPOGRAPHY FROM 1977.

2000 0 2000

SCALE IN FEET

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

FLOODPLAIN MAP

DATE
JULY 2022

FIGURE
2

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment G

Final Closure Plan and Proposed Closure Schedule

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Power Generating Company

Primary Ash Pond
FINAL CLOSURE PLAN

July 2022

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Attachment E	Alternative Final Protective Layer Equivalency Demonstration

1. INTRODUCTION

Illinois Power Generating Company (IPGC) is the owner of the coal-fired Newton Power Plant (NPP), also referred to as Newton Power Station (NPS), in Jasper County, Illinois.

This facility has a CCR unit called the Primary Ash Pond (PAP). This Closure Plan is for the PAP only. The PAP has an Illinois Environmental Protection Agency (IEPA) identification number of W0798070001-01. As part of the proposed closure, a new photovoltaic (PV) solar power facility will be installed on top of the closed ash pond area with an installed power of approximately 106.4 megawatts DC (MWdc) and a rated power of approximately 81.9 megawatts AC (MWac). Interconnection of the solar facility will occur at the NPP substation.

1.1. Selected Closure Method

Section 845.720(b)(3): The final closure plan must identify the proposed selected closure method and must include the information required in subsection (a)(1) and the closure alternatives analysis specified in Section 845.710.

Based on the Closure Alternatives Analysis, a hybrid closure with a final cover system has been identified as the most appropriate closure method, also known as Closure-in-Place (CIP, per Section 845.740). An alternatives analysis, provided in **Attachment A**, was prepared to evaluate CIP versus Closure by Removal (CBR, per Section 845.750) and a hybrid closure alternative was selected as the most appropriate closure method for the PAP. All CCR in the southern portion of the impoundment will be removed and relocated to the northern portion of the impoundment which will be closed via CIP in accordance with Section 845.750. CCR from approximately 38% of the current footprint of the impoundment will be removed and consolidated to the north.

1.2. Organization of Final Closure Plan

This Final Closure Plan is organized in the following manner:

- **Section 2** includes the Final Closure Plan, as required by Section 875.720(a)(1);
- **Section 3** includes a summary of amendments of the Closure Plan;
- **Section 4** includes a discussion of how the closure using a final cover system will comply with the performance and design requirements of Sections 845.720 and 845.750;
- **Section 5** includes additional information regarding the closure;
- **Section 6** includes a Certification from a Qualified Professional Engineer; and
- **Section 7** includes referenced documents used in the development of this Final Closure Plan.

2. FINAL CLOSURE PLAN

Section 845.720(a)(1): Content of the Preliminary Closure Plan. The owner or operator of a new CCR surface impoundment or an existing CCR surface impoundment not required to close under Section 845.700 must prepare a preliminary written closure plan that describes the steps necessary to close the CCR surface impoundment at any point during the active life of the CCR surface impoundment consistent with recognized and generally accepted engineering practices.

This section includes the final closure plan for the PAP, as required by Section 845.720(a)(1). Specific requirements of the closure plan and the relevant regulatory citations are included in the following sections.

2.1. Narrative Description of Closure

Section 845.720(a)(1)(A): A narrative description of how the CCR surface impoundment will be closed in accordance with this Part.

The PAP will be closed in place and covered with a final cover compliant with 40 C.F.R. § 257.102(d)(3) and Section 845.720(a)(1)(C). The PAP is an unlined CCR surface impoundment. Therefore, closing the PAP with a final cover system will result in a cap with lower permeability than the bottom of the pond.

Closure of the PAP with a final cover system will include the following tasks:

- Preparing the site for closure by establishing perimeter stormwater Best Management Practices (BMPs), as needed, at the construction limits of disturbance.
- Removing free liquids by solidifying waste, as needed, and removing liquid waste by removing liquids and pumping them to the adjacent Settling Pond for ultimate discharge at National Pollutant Discharge Elimination System (NPDES) Outfall 001.
- Removing existing outflow structures and culverts connecting the PAP to the adjacent Settling Pond.
    - Existing piping will be cut and capped below grade and the area backfilled and graded.
    - Aboveground pipes will be removed.
- Abandoning existing geotechnical piezometers that will not be utilized as post-closure instrumentation. Abandonment will be performed in accordance with Illinois monitoring well regulations.
- Establishing a temporary dewatering and water management system within the PAP consisting of ditches and sumps to support passive (i.e., gravity) dewatering of CCR for stabilization and to

collect contact stormwater during closure and maintain the PAP in an unwatered state. Contact stormwater, during construction, will be pumped to the Settling Pond for discharge at NDPES Outfall 001.

- Consolidating the PAP by excavating all CCR from the south and west side of the PAP and using it as fill within the north and east side of the PAP to establish minimum slopes as practical. Based on topography, it is estimated limited waste is located to the south that can be moved to the north side of the site. CCR will be placed in lifts and compacted to provide a subgrade suitable for construction of a final cover system.

- A new soil dike will be constructed along the southern boundary of the CIP portion of the PAP in accordance with Illinois Department of Natural Resources Part 3702 Rules. To alleviate stability concerns for the new dike construction, any saturated soils underlying the proposed location of the new dike will be overexcavated and replaced with compacted, low permeability soils.

- Dewatering will be performed as needed to support construction activity and fill placement, using the water management system. Free liquids will be eliminated by removing liquid wastes.

    - Approximately 1,917,000-cy (2,600,000-tons) of CCR will be consolidated from within the PAP. Material from Area 3 of the Newton Landfill 2, and coal pile material may also be moved from those areas and utilized as subgrade fill in the Ash Pond closure area.
    - Landfill 2 will be closed in place under its existing Permit No. 1997-233-LF.

- Removing the berm between the PAP and adjacent Settling Pond by lowering the grades to be consistent with the closure by removal grades. The Settling Pond will be removed, and the borrow area in the south side of the PAP will be used as a post-closure, non-CCR, stormwater management pond.

- As needed, clean fill material will be placed and graded within the southern portion of the PAP to promote positive stormwater drainage away from the CIP footprint and towards Newton Lake.

- Constructing a final cover system extending over the consolidated footprint of the PAP that contains CCR, and includes, from bottom to top:

    - A 40-mil linear low-density polyethylene (LLDPE) textured geomembrane, placed on a prepared subgrade with rocks no larger than one inch in diameter and other sharp objects removed prior to placement;

    - A geocomposite drainage layer, to convey stormwater that has percolated through the final cover soils to the perimeter stormwater drainage system;

        - Alternatively, the site may use a 50-mil LLDPE geomembrane material called “Microdrain” or “Supergrip” instead of a typical textured 40-mil

LLDPE, that has built in drainage studs on the top side, allowing for use of an 8-oz. geotextile instead of the geocomposite listed above.

- Based on a demonstration to be submitted to IEPA for approval pursuant to Section 845.750(c)(2), the proposed final cover system will be installed including an alternative 1.5 ft thick protective layer (e.g., cover soil) to protect the geomembrane and 0.5 ft of topsoil capable of supporting vegetation, for a total cover soil thickness of 2 ft, equivalent to the minimum regulatory requirement.

- The final cover system grades will be approximately 2% over the majority of the PAP, although 25% (4 horizontal to 1 vertical [4H:1V]) grades will be used in limited areas, where needed to tie the final cover system into existing grades.

- The final cover system will include an anchor trench for the geosynthetic materials along the entire perimeter of the consolidated material to secure the final cover system into existing grades. The anchor trench will be placed beyond the proposed limits of the waste to provide a continuous containment system and encapsulation for the retained CCR.

- Existing groundwater monitoring wells in the closure area will be retained and modified by extending the wells through the final cover system, sealing the penetration with a pipe boot, and constructing a new surface completion on top of the final cover.

- Constructing a post-closure non-contact stormwater management system consisting of:

  - Stormwater channels leading from northeast to southwest to convey stormwater into the new stormwater pond; and

  - Drainage pipes, channels and downchutes where channels flow from the PAP final cover and lead into the stormwater pond, to reduce erosion.

- Establishing vegetation on the final cover system by:

  - Fertilizing the topsoil, as needed to support vegetation, based on agronomical soil tests;

  - Seeding the topsoil with a suitable grass seed for local climatic and soil conditions;

  - Providing temporary BMP measures such as mulch, erosion control blankets, silt fences, and/or straw wattles, as necessary to reduce the potential for soil erosion until vegetation is established; and

  - Restoring the site, after vegetation is established and the site is stabilized, by removing stormwater BMPs and temporary stabilization measures that are no longer needed.

Permit-level engineering drawings and material specifications for the closure are provided in

Attachment B.

2.2. Decontamination of CCR Surface Impoundment

Section 845.720(a)(1)(B): If closure of the CCR surface impoundment will be accomplished through removal of CCR from the CCR surface impoundment, a description of the procedures to remove the CCR and decontaminate the CCR surface impoundment in accordance with Section 845.740.

The PAP will be closed-in-place and will not be closed by removal of CCR. However, the southwest portion of the pond is proposed to be consolidated to the northeast as part of this closure event (i.e. partial closure by removal or 'hybrid' closure). This portion will be completed in accordance with Section 845.740 as applicable to a 'partial CBR'.

In this southern area, all CCR will be removed. The subsoils will be visually observed for signs of CCR. If subsoils with CCR or staining are observed, they will be removed and consolidated to the north. It is anticipated that up to 1-ft of subsoils may be removed beyond pre-pond grades; however, visual inspection will be conducted to confirm all CCR is removed from the southern portion of the PAP.

Section 845.740(b) does not apply to this project, as groundwater monitoring will continue per the groundwater monitoring plan for the site, which is primarily closed in place with a final cover system. Decontamination of areas outside the south consolidation area of the PAP will not be required because there have been no releases of CCR from the PAP and there is no containment system within the PAP.

Section 845.740(c)(1) does not apply to this project, as material is not being transported off site.

Onsite dust controls, a public notice at the property entrance, and temporary control measures to prevent contamination of surface water, groundwater, soil and sediments shall be used throughout construction per Section 845.740. General housekeeping procedures shall be implemented to minimize the amount of time the CCR is exposed to precipitation and wind, and stormwater shall be managed under an NPDES permit and SWPPP.

A modification application to revise the current site NPDES permit will be submitted to include the new flows from unwatering and dewatering. This will be submitted prior to the Closure Construction Permit Application submittal. An NOI will be submitted as needed for coverage under the general NDPES permit for construction activities prior to commencing closure activities.

2.3. Final Cover System

Section 845.720(a)(1)(C): If closure of the CCR surface impoundment will be accomplished by leaving CCR in place, a description of the final cover system, designed in accordance with Section 845.750, and the methods and procedures to be

used to install the final cover. The closure plan must also discuss how the final cover system will achieve the performance standards specified in Section 845.750.

A description of the final cover system design, methods and procedures used for installation, and how the final cover system will achieve the Section 845.750 performance standards is provided in **Section 4** of this Closure Plan.

2.4. Maximum CCR Inventory

Section 845.720(a)(1)(D): An estimate of the maximum inventory of CCR ever on-site over the active life of the CCR surface impoundment.

The maximum inventory of CCR ever on-site within the PAP is approximately 5,000,000 cubic yards. This inventory will increase by approximately 700,000 CY to approximately 5,700,000 CY through the closure process and consolidation of currently in place CCR and soils on the south portion of the pond and utilizing it in the PAP as compacted subgrade fill.

2.5. Largest Surface Area Estimate

Section 845.720(a)(1)(E): An estimate of the largest area of the CCR surface impoundment ever requiring a final cover (see Section 845.750), at any time during the CCR surface impoundment's active life.

The largest surface area of the PAP, in plan view, is approximately 404 acres, as shown in the attached drawings. Final cover will be placed over an area of approximately 260.6 acres to extend completely across the surface area of the consolidated PAP waste and beyond the limits of CCR in plan view.

2.6. Closure Completion Schedule

Section 845.720(a)(1)(F): A schedule for completing all activities necessary to satisfy the closure criteria in this Section, including an estimate of the year in which all closure activities for the CCR surface impoundment will be completed. The schedule should provide sufficient information to describe the sequential steps that will be taken to close the CCR surface impoundment, including identification of major milestones such as coordinating with and obtaining necessary approvals and permits from other agencies, the dewatering and stabilization phases of CCR surface impoundment closure, or installation of the final cover system, and the estimated timeframes to complete each step or phase of CCR surface impoundment closure.

A milestone closure completion schedule has been prepared and is provided in **Table 1**. Key sequential phases and sub-tasks that will be completed as part of the closure will include:

- Agency Coordinating, Approvals, and Permitting
    - Approval of the closure Construction Permit Application by IEPA.

- Obtaining a modification to the existing NPDES permit to allow the disposal of water generated from unwatering and dewatering operations to Newton Lake via the existing NPDES-permitted Outfall 001 for the Site;
- Obtaining a construction permit from the Illinois Department of Natural Resources (IDNR), Office of Water Resources (OWR), Dam Safety Program (DSP) to allow the embankment and spillways of the PAP to be modified as part of closure;
- A coverage under the general NPDES permit for construction activities through IEPA, including construction stormwater controls and other BMPs such as silt fences and other measures; and
- A joint water pollution control construction and operating permit (WPC Permit).

- Final Design and Bidding
  - Completion of final design documents, including drawings and specifications.
  - Bidding and selection of a closure construction contractor.
- Dewater and Stabilize CCR, Install Final Cover System
  - Closure contractor mobilization and material procurement.
  - Installing stormwater BMPs around the construction area, per the Land Disturbance Permit.
  - Unwatering the PAP by pumping impounded water to the Polishing Pond.
  - Abandoning existing outfall structures and culverts.
  - Stabilizing the subgrade through dewatering and the placement of compacted CCR fill.
  - Constructing design final cover subgrades, including stormwater channel subgrades and modifications to the PAP perimeter berm.
  - Installing the final cover system geosynthetics and anchor trench.
  - Placing cover soil and topsoil over the geosynthetics.
- Site Restoration
  - Constructing riprap-lined letdown structures.

- Seeding and stabilizing the surface of the final cover system and other disturbed areas and allowing the vegetation to become established.
- Removing temporary stormwater BMPs and other temporary stabilization measures, after vegetation is established.
- Closure contractor demobilization from the site.

The closure construction project is expected to be completed by October 2028. Full vegetation will be established as soon as practical in the fall of 2028, with reseeding occurring as needed the following spring for establishment of a full stand of grass.

Table 1 – Closure Completion Milestone Schedule

Milestone	Timeframe (Preliminary Estimates)
Final Closure Plan Submittal	July 2022
Agency Coordination, Approvals, and Permitting • Obtain state permits, as needed, for dewatering, water discharge, land disturbance, and dam modifications.	16 to 24 months after Final Closure Plan Approval July 2022 to July 2024
Final Design and Bid Process • Complete final design of the closure and select a construction contractor.	6 to 12 months during Agency Coordination, Approvals, and Permitting July 2023 to July 2024
Dewater and Stabilize CCR, Install Final Cover System • Complete contractor mobilization, installation of stormwater BMPs, and unwatering of the PAP • Abandon outfall structures, stabilize the PAP, and complete grading and consolidation. • Install the final cover system and stormwater downchutes.	36 to 48 months after necessary permits are issued 12 months after final power plant shut down scheduled for September 17, 2027 July 2024 to July 2028
Site Restoration • Seed and stabilize the PAP. • Complete contractor demobilization.	2 to 3 months after the final cover system is complete May 2028 to September 2028
Timeframe to Complete Closure	Prior to October 17, 2028

Section 845.720(a)(1)(F) (Continued): When preparing the preliminary written closure plan, if the owner or operator of a CCR surface impoundment estimates that the time required to complete closure will exceed the timeframes specified in Section 845.760(a), the preliminary written closure plan must include the site-specific information, factors and considerations that would support any time extension sought under Section 845.760(b).

The time required to complete closure construction is not currently expected to exceed the timeframe specified in Section 845.760(a). Therefore, closure extensions for the PAP are not being sought at this time.

3. AMENDMENTS OF FINAL CLOSURE PLAN

Section 845.720(b)(4): If a final written closure plan revision is necessary after closure activities have started for a CCR surface impoundment, the owner or operator must submit a request to modify the construction permit within 60 days following the triggering event.

If revisions are required for this Final Closure Plan, the owner will submit a request to modify the construction permit within 60 days following the triggering event.

Table 2. CCR Final Closure Plan Revisions

Revision Number and Date	Pages or Section	Description of Revision	Professional Engineer Certifying Plan

4. CLOSURE WITH FINAL COVER SYSTEM

This section includes a description of the final closure with a final cover that will be completed for the PAP surface impoundment, including principal design and construction features, material specifications, and a discussion of how each feature is in accordance with the requirements of Section 845.750. Drawings showing each design feature and material specifications are provided in **Attachment B**. The proposed CIP design will control, minimize, or eliminate as much as feasible "post-closure infiltration of liquids" and releases of CCR, leachate, or contaminated runoff as interpreted by Illinois EPA in the Part 845 rulemaking.

4.1. Minimization of Post-Closure Infiltration and Releases

Section 845.750(a)(1): The owner or operator of a CCR surface impoundment must ensure that, at a minimum, the CCR surface impoundment is closed in a manner that will: Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere.

The closure design will result in a reduction of infiltration into the PAP by 94% compared to pre-closure conditions as shown in the Groundwater Modelling Report (Ramboll, 2022). The Groundwater Modelling Report shows that the closure design will result in a reduction of hydraulic flux out of the PAP by 94% compared to pre-closure conditions (Figure 6-5). Due to the reduction in the hydraulic flux out of the PAP, the mass flux out of the PAP will also be controlled or minimized as much as feasible as a result of closure design. This is achieved through the installation of a final cover system with the following design features and specifications:

- An LLDPE geomembrane low-permeability layer will placed on the prepared subgrade to control and minimize vertical infiltration into the surface impoundment. The geomembrane will be constructed on a subgrade that is free of sharp rocks or other debris and will be protected from damage by installing a geocomposite drainage/cushion layer and a total of two feet of cover soil and topsoil over the top of the geomembrane. Alternatively, the geocomposite may be replaced with a geotextile filtration layer if used in conjunction with a microdrain style geomembrane for stormwater infiltration drainage.

- Surface stormwater will be routed from the top of the final cover by the construction of a free-draining post-closure stormwater management system including channels and letdown structures. The stormwater management system and sloped grade of the material will drain by gravity and preclude water impoundment on top of the final cover system, thereby minimizing post-closure infiltration into the CCR.

Releases of CCR leachate and/or contaminated run-off into the groundwater, surface waters, and/or atmosphere will be minimized, to the maximum extent feasible, as:

- The PAP is located on a relatively thick layer of clay estimated to be a low permeability material.
    - The final cover system will tie into the surrounding grades, by constructing a final cover anchor trench at or beyond the horizontal limits of the CCR material.
    - This barrier will result in the CCR being physically isolated from the surrounding environment including stormwater, surface water, and atmosphere and therefore minimizing the releases of CCR, leachate, or contaminated run-off into the ground, surface waters, and atmosphere.
- CCR leachate (e.g., pore water within the CCR) volumes will be minimized via the installation of the final cover system including a low-permeability geomembrane layer. The final cover system will minimize infiltration and therefore the amount of leachate within the CCR.
    - The PAP does not have a base liner or leachate collection system, however, its general location over the site's in-situ clays has shown through its groundwater monitoring system that leachate has not historically been migrating from the site.
    - Efforts for removal of liquid waste to eliminate free liquids during construction are anticipated to remove pore water from within the CCR, followed by capping which will prevent 'recharge' of pore water from stormwater.

4.2. Preclusion of Future Impoundment

Section 845.750(a)(2): Preclude the probability of future impoundment of water, sediment, or slurry.

A final cover system will be installed on top of the PAP. All areas of the final cover system will be sloped to positively drain to the exterior of the PAP and preclude future impoundment of water, sediment, or slurry. This will include installing top deck slopes at approximately 2% grades, sideslopes at up to 25% (e.g., 4 horizontal to 1 vertical [4H:1V]) grades at the tie-in between the final cover system and existing grades, and stormwater channel grades at about 0.5% slopes. Stormwater channels will flow by gravity into the adjacent new stormwater pond via riprap-lined downchutes. Hydrologic and hydraulic calculations used to design the stormwater channels and other control features to preclude impoundment are provided in **Attachment C**.

4.3. Provisions for Preventing Instability, Sloughing and Movement

Section 845.750(a)(3): Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system during the closure and post-closure care period.

The perimeter berms of the PAP are constructed out of compacted fill materials and have been in place for over 40-years. The southwest berm of the PAP will be removed during closure for use as final cover soils and subgrade fill as needed. The northeast berm of the PAP will also be mostly removed, and the final cover system will terminate into the remainder of the berm. The effects of these modifications have been evaluated by performing global slope stability analyses considering post- closure conditions. The resulting factors of safety exceed typical regulatory minimum values for static and seismic loading conditions. Slope stability analyses are provided in **Attachment D**.

Sloughing and movement of the final cover system will be minimized by constructing the final cover system at relatively flat slopes, including 2% over most of the final cover and 25% (4H:1V) at the edges of the final cover, as necessary to tie into existing grades. The potential for sloughing and movement of the final cover system has been evaluated by performing veneer stability analyses for the various interfaces within the final cover system. The resulting factors of safety exceed typical minimum values for static and seismic loading conditions. Veneer stability analyses are provided in **Attachment D**.

4.4. Minimize the Need for Further Maintenance

Section 845.750(a)(4): Minimize the need for further maintenance of the CCR surface impoundment.

Future maintenance needs will be minimized using the following design features:

- The final cover system will be installed at gentle 2% slopes over most of the final closure with 25% slopes in limited areas at the extents of the final cover, as needed to tie into existing grades.
    - These relatively flat slopes will minimize erosion of the final cover soils and thereby minimize maintenance needs by reducing stormwater flow velocities relative to steeper slopes.
    - The relatively flat slopes will also promote routine mowing of vegetation of the final cover system by allowing tractor-based mowing equipment to operate on the slopes with a reduced risk of equipment flip-over.

- The final cover, outside of stormwater channels, will be stabilized by placing topsoil, fertilizing the topsoil, establishing vegetation using suitable grass species.
    - The vegetation will minimize erosion of the final cover system by stabilizing the topsoil.
    - The use of fertilizer and selection of a suitable grass species will minimize maintenance required to repair areas of poor vegetation establishment.
- Stormwater channels will be stabilized with erosion control blankets and straw wattles. Erosion control blankets and riprap will be placed as needed to minimize post-closure erosion and associated maintenance for stormwater channels.
    - Calculations used to design the stormwater channel stabilization and riprap armoring were based on the 100-year, 24-hour, and 25-year, 24-hour storms. These calculations are provided in **Attachment C**.

4.5. Be Completed in Shortest Amount of Time

Section 845.750(a)(5): Be completed in the shortest amount of time consistent with recognized and generally accepted engineering practices.

Closure construction is expected to be completed within an amount of time that is consistent with recognized and generally accepted timeframes required to permit, design, bid, and construct a CCR impoundment final closure system, with a consideration of other permits from multiple agencies that are also required for the project. An estimated closure construction schedule is provided in **Section 2.6**. It should be noted that this schedule may change based on contractor, equipment, and material availability and actual weather conditions at the time at which closure occurs.

4.6. Drainage and Stabilization

Section 845.750(b)(1): Free liquids must be eliminated by removing liquid wastes or solidifying the remaining wastes and waste residues.

Section 845.750(b)(2): Remaining wastes must be stabilized sufficiently to support the final cover system.

Prior to installing the final cover system, free liquids will be eliminated by removing the liquid waste from the PAP. Engineering measures necessary to remove liquid waste that is readily separable under ambient temperature and pressure are being evaluated.

The removal of free liquids will result in the stabilization of the remaining CCR and will therefore allow the final cover to be placed on a stable subgrade.

4.7. Final Cover System

Section 845.750(c): If a CCR surface impoundment is closed by leaving CCR in place, the owner or operator must install a final cover system that is designed to minimize infiltration and erosion, and, at a minimum, meets the requirements of this subsection (c) unless the owner or operator demonstrates that another construction technique or material provides equivalent or superior performance to the requirements of this subsection (c) and is approved by the Agency. The final cover system must consist of a low permeability layer and a final protective layer. The design of the final cover system must be included in the preliminary and final written closure plans required by Section 845.720 and the construction permit application for closure submitted to the Agency.

A final cover system has been designed consistent with the requirements of Section 845.720(c). The final cover will use a geomembrane as a low-permeability layer. The design of the final cover system is discussed within this section.

4.7.1. Low Permeability Layer - Geomembrane

Section 845.750(c)(1)(B): A geomembrane constructed in accordance with the following standards: i) The geosynthetic membrane must have a minimum thickness of 40 mil (0.04 inches) and, in terms of hydraulic flux, must be equivalent or superior to a three-foot layer of soil with a hydraulic conductivity of 1 x 10-7 cm/sec; ii) The geomembrane must have strength to withstand the normal stresses imposed by the waste stabilization process; and (iii) The geomembrane must be placed over a prepared base free from sharp objects and other materials that may cause damage.

The geomembrane will consist of a 40-mil linear low-density polyethylene (LLDPE) layer. HDR completed a Hydrologic Evaluation of Landfill Performance (HELP) [1] model to compare flux through the geosynthetic cover to the regulatory minimum equivalent cover system of a 3-ft layer of soil with hydraulic conductivity of 1 x 10-7 cm/sec in order to demonstrate that the geomembrane cover system is anticipated to be superior to a soil only cover. The HELP modeling estimated a total infiltration of 0.58-inches of waterper year (in/yr) for the geomembrane cover system, compared to 1.35-in/yr for the soil cover. Therefore, the geomembrane final cover system is calculated to be superior to clay in terms of hydraulic flux, as infiltration is reduced by a factor of 2.32.

Alternatively, a 50-mil LLDPE Microdrain geomembrane material may be selected for this project. This material would be expected to meet or exceed the above discussed infiltration reduction factor of 2.32.

The geomembrane will be installed on a prepared subgrade, after the underlying CCR has been stabilized. Therefore, additional normal stresses will not be imparted on the geomembrane due to the waste stabilization process.

The subgrade (e.g., base) for the geomembrane will be visually inspected and sharp objects such as rocks or debris that may damage the geomembrane will be removed, prior to deployment of the geomembrane.

4.7.2. Final Protective Layer

Section 845.750(c)(2): The final protective layer must meet the following requirements

A) Cover the entire low permeability layer;

B) Be at least three feet thick, be sufficient to protect the low permeability layer from freezing, and minimize root penetration of the low permeability layer;

C) Consist of soil material capable of supporting vegetation;

D) Be placed as soon as possible after placement of the low permeability layer; and

E) Be covered with vegetation to minimize wind and water erosion.

A final protective layer will be placed over and extend slightly beyond the entire geomembrane low-permeability layer in plan. Based on the demonstration to be submitted to IEPA for approval pursuant to Section 845.750(c)(2), the protective layer will include, from bottom to top, a nonwoven geotextile or geocomposite based on the geomembrane manufacturer selection, a 1.5-ft thick cover soil layer, and a 0.5-ft thick topsoil layer, for a total thickness of 2 ft.

The nonwoven geotextile (or geocomposite) and 1.5-ft thick cover soil layer will protect the geomembrane from root penetration. Geomembranes are not susceptible to freeze damage. The cushion layer and cover soil will be placed as soon as practical after the geomembrane has been deployed and both quality assurance and quality control testing has been performed on the geomembrane seams.

The 0.5-ft thick topsoil layer will be fertilized, as necessary to support appropriate grass species, to vegetate the final protective layer.

4.8. Certification

Section 845.750(c)(4): The owner or operator of the CCR surface impoundment must obtain and submit with its construction permit application for closure a written certification from a qualified professional engineer that the design of the final cover system meets the requirements of this section.

The undersigned qualified professional engineer registered in Illinois certifies that the design of the final cover system meets the requirements of Section 845.750.

Printed Name: Mark Roberts, P.E.

7/28/2022

Signature *Date*

Registration Number: 062062011
Expiration Date: 11.30.2023

Seal applies to Closure Plan and appendices prepared by HDR. This report relies upon data, analyses, and reports prepared by others.



Affix Seal

4.9. Uses of CCR in Closure

Section 845.750(d): This subsection specifies the allowable uses of CCR in the closure of CCR surface impoundments closing under Section 845.700. Notwithstanding the prohibition on further placement in Section 845.700, CCR may be placed in these surface impoundments, but only for purposes of grading and contouring in the design and construction of the final cover system, if: 1) The CCR placed was generated at the facility and is located at the facility at the time closure was initiated; 2) CCR is placed entirely above the elevation of CCR in the surface impoundment, following dewatering and stabilization (see subsection (b)); 3) The CCR is placed entirely within the perimeter berms of the CCR surface impoundment.

Approximately 700,000 cubic yards of material are located within the pond, in the current landfill open cell, and coal pile that is anticipated to be moved and consolidated to the closure area. This material shall be used to reach slopes needed. Final grades may vary slightly based on field conditions in the pond, however minimum slopes shall be maintained. This waste material was generated onsite.

All CCR will be excavated from the south portion of the PAP and transported to the north portion of the PAP to be beneficially used as compacted subgrade fill below the final cover system. The CCR will be placed on top of the existing subgrade (i.e., existing elevation of CCR in the surface impoundment) after dewatering of the PAP and used as a free-draining subgrade stabilization layer. CCR placement will only occur completely beneath the limits of the PAP final cover system. This is in accordance with the Section 845.750(d) criteria.

4.10. Final Cover System Slopes

Section 845.750(d)(4): The final cover system is constructed with either: A) A slope not steeper than 5% grade after allowance for settlement; or B) At a steeper grade, if the Agency determines that the steeper slope is necessary, based on conditions at the site, to facilitate run-off and minimize erosion, and that side slopes are evaluated for erosion potential based on a stability analysis to evaluate possible erosion potential. The stability analysis, at a minimum, must evaluate the site geology; characterize soil shear strength; construct a slope stability model; establish groundwater and seepage conditions, if any; select loading conditions; locate critical failure surface; and iterate until minimum factor of safety is achieved.

Final cover slopes will typically consist of 2% cross-slopes and 0.5% stormwater flowline slopes within the limits of final cover, which are generally less than 5%.

However, short lengths of 25% final cover slopes will be used in limited areas near the perimeter of the final cover, as needed to tie the final cover into the existing grades, as shown in the drawing package

provided in **Attachment B**. Twenty five percent slopes will be utilized to allow most of the final cover, in area, to ultimately drain towards the southeast, and route stormwater into the new stormwater pond.

The stability of the 25% final cover slopes has been evaluated both for the final cover system itself (e.g., veneer stability) and the global stability of the slope. These calculations included characterizing soil shear strength based on site geology, constructing slope stability models, establishing groundwater seepage conditions, selecting loading conditions, locating the critical failure surface, and iterating until minimum factors of safety were calculated. These calculations are provided in **Attachment D**. Resulting factors of safety exceed typical minimum factors of safety for both global and veneer stability.

4.11. Proposed PV Solar Power Facility

As part of the closure effort, a new photovoltaic (PV) solar power facility will be installed on top of the closed PAP with an installed power of approximately 106.4 megawatts DC (MWdc) and a rated power of approximately 81.9 megawatts AC (MWac). Interconnection of the solar facility will occur at the existing NPP substation.

The solar facility layout is proposed to include a 2V fixed tilt ballasted system using FirstSolar Series 6 CuRe PV modules rated at 480 W and 25 Sungrow 3600 kVA inverters. The layout includes PV modules, inverters and MV transformers, access roads, and entrances. Alternate PV module and inverter models may be installed, as approved by the Engineer, to incorporate the most efficient technology available at the time of installation. The layout includes various access roads to be installed within the site. Transmission line easements intersecting the PAP will be clear of the pond surface and the panels. The facility layout is shown on the Drawings included in Appendix B.

The PV racking system and electrical equipment will be placed on concrete foundations placed directly on the protective soil layer. A thin layer of select aggregate may be placed beneath some of the concrete foundations for leveling purposes. The racks and equipment will be placed to avoid interference with existing monitoring devices or the storm water management system. Final layout of the panel rows and access road may vary with Engineer approval to accommodate stormwater features.

The ballast blocks will be designed to minimize the additional load on the protective soil layer so it will not adversely impact the final cover system. All electric components will be installed above grade or within the protective soil layer; the geomembrane will not be penetrated. If changes are proposed to the closure design, a revised closure plan will be submitted to the Illinois EPA for approval.

5. ADDITIONAL INFORMATION

Both the lateral migration of groundwater and vertical infiltration of liquids, and releases of CCR, leachate, and contaminated run-off into and out of the PAP will be controlled, minimized or eliminated, to the maximum extent feasible, under post-closure conditions.

- The PAP is unlined with underlying soils that are generally clays, as discussed in **Section 2.1**.

- Closure of the PAP will include constructing a final cover system that ties into the perimeter of the waste boundary, as discussed in **Section 4.**

- CCR within the PAP is separated from the uppermost aquifer by an estimated minimum of 14-ft of low permeability glacial tills [Ramboll, 2022].

- Groundwater levels beneath the PAP have been monitored using about 14 piezometers since 2015. During a review of data collected between 2015, and 2021 (a period of over five years), the normal groundwater elevation was typically El. 530 ft or lower, while Lake Newton surface water elevations were approximately El. 504.

- The lowest elevation of CCR within the PAP after closure will be approximately El. 485 ft, as shown in Sheet C-302 in **Attachment B**.

6. CERTIFICATION FROM A QUALIFIED PROFESSIONAL ENGINEER

Section 845.720(b)(S): The owner or operator of the CCR surface impoundment must obtain and submit with its construction permit application for closure a written certification from a qualified professional engineer that the final written closure plan meets the requirements of this Part.

I, Mark Roberts, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief, that the information contained in this construction permit application has been prepared in accordance with the accepted practice of engineering and the requirements of Title 35, Subtitle G, Chapter I, Subchapter j, Section 845.720 of the Illinois Administrative Code.

Printed Name: Mark Roberts, P.E.

7/28/2022

Signature *Date*

Registration Number: 062062011
Expiration Date: 11.30.2023

Seal applies to Closure Plan and appendices prepared by HDR. This report relies upon data, analyses, and reports prepared by others.



Affix Seal

7. REFERENCES

[1] United States Environmental Protection Agency, "Walkthrough to Install and Operate the Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 3.07," 2017.

[2] Ramboll, "Groundwater Modeling Report, Primary Ash Pond, Newton Power Plant, Newton, Illinois," July 2022.

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Attachment A

Closure Alternatives Analysis

Electronic Filing: Received, Clerk's Office 07/01/2024

Closure Alternatives Analysis for the Primary Ash Pond at the Newton Power Plant Newton, Illinois

July 28, 2022

GRADIENT

www.gradientcorp.com
One Beacon Street, 17th Floor
Boston, MA 02108
617-395-5000

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Abbreviations

AACE	Association for the Advancement of Cost Engineering
BMP	Best Management Practice
BCU	Bedrock Confining Unit
CAA	Closure Alternatives Analysis
CBR-Onsite	Closure-by-Removal with On-Site CCR Disposal
CBR-Offsite	Closure-by-Removal with Off-Site CCR Disposal
CCR	Coal Combustion Residual
CIP	Closure-in-Place
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CY	Cubic Yard
EJ	Environmental Justice
GHG	Greenhouse Gas
GWPS	Groundwater Protection Standards
HUC	Hydrologic Unit Code
IAC	Illinois Administrative Code
IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
LCU	Lower Confining Unit
LLDPE	Linear Low-Density Polyethylene
N_2O	Nitrous Oxide
NID	National Inventory of Dams
NO_x	Nitrogen Oxides
NPDES	National Pollutant Discharge Elimination System
PAP	Primary Ash Pond
PM	Particulate Matter
PMP	Potential Migration Pathway
SFWA	State Fish and Wildlife Area
TMDL	Tr3TTotal Maximum Daily Load
TVA	Tennessee Valley Authority
UA	Uppermost Aquifer
UCU	Upper Confining Unit
UD	Upper Drift
US DOT	United States Department of Transportation
VOC	Volatile Organic Compound
WPC Permit	Water Pollution Control Construction and Operating Permit

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Summary of Findings

Title 35, Part 845 of the Illinois Administrative Code (IAC; IEPA, 2021) requires the development of a Closure Alternatives Analysis (CAA) prior to undertaking closure activities at certain surface impoundments containing coal combustion residuals (CCRs) in the State of Illinois. Pursuant to requirements under IAC Section 845.710, this report presents a CAA for the Primary Ash Pond (PAP) located on Illinois Power Generating Company's (IPGC) Newton Power Plant property near the City of Newton, Illinois. The goal of a CAA is to holistically evaluate potential closure scenarios with respect to a wide range of factors, including the efficiency, reliability, and ease of implementation of the closure scenario; its potential positive and negative short- and long-term impacts on human health and the environment; and its ability to address concerns raised by residents (IAC Part 845; IEPA, 2021). Gradient evaluated three specific closure scenarios for the PAP: Closure-in-Place (CIP) with excavation and consolidation, Closure-by-Removal with On-Site CCR Disposal (CBR-Onsite), and Closure-by-Removal with Off-Site CCR Disposal (CBR-Offsite). The CIP scenario would entail excavating CCR from the southern and western portions of the PAP and consolidating it into the northern and eastern portions, followed by capping with a new cover system consisting of a 40-mil linear low-density polyethylene (LLDPE) geomembrane layer, a geocomposite drainage layer, and 24 inches of low-permeability soil with a vegetated surface.[1] The CBR-Onsite scenario would entail excavating the CCR from the PAP and transporting it to an on-Site landfill for disposal. The CBR-Offsite scenario would entail excavating the CCR from the PAP and transporting it to an off-Site landfill for disposal. Even though capping the entire PAP (without any excavation or consolidation) would be an acceptable closure approach based on IAC Section 845.710 (IEPA, 2021a), it was not evaluated in this CAA. IPGC will also continue to evaluate potential opportunities for beneficial re-use of CCR excavated from the PAP as an alternative to disposal.

IAC Section 845.710(c)(2) requires CAAs to "[i]dentify whether the facility has an onsite landfill with remaining capacity that can legally accept CCR, and, if not, whether constructing an onsite landfill is possible" (IEPA, 2021). There is an existing, permitted CCR landfill (Newton CCR Landfill Phase II) located immediately west of the PAP at the Newton Power Plant Site. However, this landfill is not actively being used to store waste and does not have sufficient capacity to contain all of the CCR that would be excavated from the PAP under the CBR-Onsite scenario. Additional landfill capacity would be required for the CBR-Onsite scenario and could be accomplished by reconstructing the current landfill cell, constructing additional sections of the landfill that have already been permitted, and either constructing an additional permitted expansion of the landfill or constructing a separate, additional on-Site landfill (Attachment B). A 25-acre area immediately adjacent to and east of the existing landfill is the most practical location for a potential landfill expansion.

Table S.1 summarizes the expected impacts of the CIP, CBR-Onsite, and CBR-Offsite closure scenarios with regard to each of the factors specified under IAC Section 845.710 (IEPA, 2021). Based on this evaluation and the additional details provided in Section 2 of this report, CIP has been identified as the most appropriate closure scenario for the PAP. Key benefits of the CIP scenario relative to the CBR-Onsite and CBR-Offsite scenarios include the more rapid re-development of the Site for installation of solar panels on the capped impoundment and reduced impacts to workers, community members, and the environment during construction (*e.g.*, fewer construction-related accidents, lower energy demands, less

[1] Alternatively, the final cover system for the PAP may use a 50-mil LLDPE geomembrane material called “Microspike” or “Supergrip," which has built-in drainage studs on the top (HDR, 2022).

air pollution and greenhouse gas [GHG] emissions, reduced duration of traffic-related impacts, and potentially lower impacts to environmental justice [EJ] communities). Moreover, the CIP scenario will meet the requred closure schedule (*i.e.*, closure completed by October 2028) defined in IAC Section 845.700(d)(2)(C)(ii) (IEPA, 2021a), whereas the CBR-Onsite and CBR-Offsite scenarios will be unable to meet this required schedule.

Table S.1 Comparison of Proposed Closure Scenarios

Evaluation Factor (Report Section; IAC Part 845 Section)	Closure Scenario		
	CIP	**CBR-Onsite**	**CBR-Offsite**
Closure Alternative Descriptions (Section 2.1, IAC Section 845.710(c))	The CIP scenario would entail excavation of CCR from the southern and western portions of the PAP and consolidation of it into the northern and eastern portions, followed by capping with a new cover system. During the closure process, we will continue to assess off-Site CCR beneficial use opportunities. Ash consolidation and closure in place in combination with off-Site beneficial use may result in a smaller footprint for purposes of our ultimate cap design along with a reduced construction schedule.	All CCR would be excavated from the PAP and transported *via* truck to the existing on-Site landfill for disposal. The on-Site landfill does not have sufficient capacity at present and would require expansion. This scenario meets the requirements of IAC Section 845.710(c)(2) (IEPA, 2021), which requires an assessment be included in the CAA of whether the Site has an on-Site landfill with available capacity or whether an on-Site landfill can be constructed.	All CCR would be excavated from the PAP and transported *via* truck to an off-Site landfill for disposal. Expansion of the off-Site landfill may be necessary in order to accept all of the CCR from the PAP.
Type and Degree of Long-Term Management, Including Monitoring, Operation, and Maintenance (Section 2.2.3, IAC Section 845.710(b)(1)(C))	Monitoring would be performed for 30 years post-closure or until GWPSs are achieved, whichever is longer. Additionally, the final cover system for the PAP would undergo 30 years of annual inspections, mowing, and maintenance.	Monitoring would be performed for 3 years post-closure or until GWPSs are achieved, whichever is longer.	Monitoring would be performed for 3 years post-closure or until GWPSs are achieved, whichever is longer.
Magnitude of Reduction of Existing Risks (Section 2.2.1, IAC Sections 845.710(b)(1)(A) and 845.710(b)(1)(F))	There are no current unacceptable risks to any human or ecological receptors associated with the PAP. Because there are no current risks, and dissolved constituent concentrations would be expected to decline post-closure, no risks to human or ecological receptors would be expected post-closure.	There are no current unacceptable risks to any human or ecological receptors associated with the PAP. Because there are no current risks, and dissolved constituent concentrations would be expected to decline post-closure, no risks to human or ecological receptors would be expected post-closure.	There are no current unacceptable risks to any human or ecological receptors associated with the PAP. Because there are no current risks, and dissolved constituent concentrations would be expected to decline post-closure, no risks to human or ecological receptors would be expected post-closure.
Likelihood of Future Releases of CCR (Section 2.2.2, IAC Sections 845.710(b)(1)(B) and 845.710(b)(1)(F))	During closure, there would be minimal risk of dike failure occurring at the PAP (*e.g.*, due to flooding or seismic activity) and minimal risk of dike overtopping during flood conditions. Post-closure, the risks of overtopping and dike failure would be even smaller than they are currently, due to the installation of a protective soil cover and new stormwater control structures. Dikes, final cover, and stormwater control features have been designed to withstand earthquakes and storm events.	During closure, there would be minimal risk of dike failure occurring at the PAP (*e.g.*, due to flooding or seismic activity) and minimal risk of dike overtopping during flood conditions. Following excavation, there would be no risk of CCR releases due to dike failure. Changing geochemical conditions during an extended excavation can be a mechanism that results in the mobilization and increased transport of some constituents in groundwater.	During closure, there would be minimal risk of dike failure occurring at the PAP (*e.g.*, due to flooding or seismic activity) and minimal risk of dike overtopping during flood conditions. Following excavation, there would be no risk of CCR releases due to dike failure. Changing geochemical conditions during an extended excavation can be a mechanism that results in the mobilization and increased transport of some constituents in groundwater.
Worker Risks (Section 2.2.4.1, IAC Sections 845.710(b)(1)(D) and 845.710(b)(1)(F))	An estimated 0.018 worker fatalities and 2.8 worker injuries would be expected to occur due to on-Site activities under this closure scenario. An additional 0.019 worker fatalities and 1.4 worker injuries would be expected to occur off-Site due to vehicle accidents during hauling, labor and equipment mobilization and demobilization, and material deliveries. In total, 0.037 worker fatalities and 4.3 worker injuries would be expected under this closure scenario. Overall, risks to workers would likely be highest under the CBR-Offsite scenario and lowest under the CIP scenario.	An estimated 0.032 worker fatalities and 5.0 worker injuries would be expected to occur due to on-Site activities under this closure scenario. An additional 0.032 worker fatalities and 2.5 worker injuries would be expected to occur off-Site due to vehicle accidents during hauling, labor and equipment mobilization and demobilization, and material deliveries. In total, 0.064 worker fatalities and 7.4 worker injuries would be expected under this closure scenario. Overall, risks to workers would likely be highest under the CBR-Offsite scenario and lowest under the CIP scenario.	An estimated 0.0097 worker fatalities and 1.5 worker injuries would be expected to occur due to on-Site activities under this closure scenario. An additional 0.29 worker fatalities and 18 worker injuries would be expected to occur off-Site due to vehicle accidents during hauling, labor and equipment mobilization and demobilization, and material deliveries. In total, 0.30 worker fatalities and 19 worker injuries would be expected under this closure scenario. Overall, risks to workers would likely be highest under the CBR-Offsite scenario and lowest under the CIP scenario.
Community Risks (Section 2.2.4.2, IAC Sections 845.710(b)(1)(D) and 845.710(b)(1)(F))			
▪ *Off-Site Impacts on Nearby Residents and EJ Communities*	Off-Site impacts on nearby residents (including accidents, traffic, noise, and air pollution) would be far less under this closure scenario than under the CBR-Offsite scenario because it does not require off-Site hauling (*i.e.*, off-Site transport of CCR or borrow soil). In total, an estimated 0.012 fatalities and 0.70 injuries would be expected to occur among community members due to off-Site activities under this scenario. No impacts to nearby EJ communities are anticipated under this closure scenario.	Off-Site impacts on nearby residents would be far less under this closure scenario than under the CBR-Offsite scenario because it does not require off-Site hauling (*i.e.*, off-Site transport of CCR or borrow soil). In total, an estimated 0.016 fatalities and 1.1 injuries would be expected to occur among community members due to off-Site activities under this scenario. No impacts to nearby EJ communities are anticipated under this closure scenario.	Off-Site impacts on nearby residents would be far greater under this scenario than under the CIP and CBR-Onsite scenarios, because this scenario requires significantly more off-Site vehicle and equipment travel miles. In total, an estimated 0.76 fatalities and 24 injuries would be expected to occur among community members due to off-Site activities under this scenario. With regard to traffic impacts, a haul truck would be likely to pass a location near the Site every 3.4 minutes on average during working hours for approximately 3,960 working days under this scenario. In addition, the transport of CCR to the off-Site landfill could potentially result in impacts to several EJ communities located along haul routes, including the EJ communities near Lawrenceville, IL, Vincennes, IN, and Terre Haute, IN.

Evaluation Factor (Report Section; IAC Part 845 Section)	Closure Scenario		
	CIP	**CBR-Onsite**	**CBR-Offsite**
▪ *Impacts on Scenic, Historical, and Recreational Value*	Due to (*e.g.*) noise and visual disturbances, construction activities may have short-term negative impacts on the recreational use of Newton Lake and the greater Newton Lake State Fish and Wildlife Area. Because the expected duration of construction activities is shorter under the CIP scenario than under the CBR-Onsite and CBR-Offsite scenarios, short-term impacts on the scenic and recreational value of natural areas near the Site would be less under this closure scenario than under the two CBR scenarios. There are no historical sites in the vicinity of the impoundment or the on-Site landfill. Thus, no impacts on historical sites would be expected under any closure scenario.	Due to (*e.g.*) noise and visual disturbances, construction activities may have short-term negative impacts on the recreational use of Newton Lake and the greater Newton Lake State Fish and Wildlife Area. Because the expected duration of construction activities is longer under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, short-term impacts on the scenic and recreational value of natural areas near the Site would be greater under these two closure scenarios than under the CIP scenario. There are no historical sites in the vicinity of the impoundment or the on-Site landfill. Thus, no impacts on historical sites would be expected under any closure scenario.	Due to (*e.g.*) noise and visual disturbances, construction activities may have short-term negative impacts on the recreational use of Newton Lake and the greater Newton Lake State Fish and Wildlife Area. Because the expected duration of construction activities is longer under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, short-term impacts on the scenic and recreational value of natural areas near the Site would be greater under these two closure scenarios than under the CIP scenario. There are no historical sites in the vicinity of the impoundment or the on-Site landfill. Thus, no impacts on historical sites would be expected under any closure scenario.
Environmental Risks (Section 2.2.4.3, IAC Sections 845.710(b)(1)(D) and 845.710(b)(1)(F))			
▪ *Impacts on Greenhouse Gas Emissions and Energy Consumption*	Total energy demands and GHG emissions would be far smaller under the CIP and CBR-Onsite scenarios than under the CBR-Offsite scenario, because the total on-Site and off-Site vehicle and equipment travel miles required under the CIP scenario (3,550,000 miles) and CBR-Onsite scenario (6,150,000 miles) are far smaller than those required under the CBR-Offsite scenario (75,300,000 miles). The CIP scenario would have an additional, unquantified carbon footprint due to the need to manufacture geomembranes for use in the final cover system. At the grid scale, construction of a solar facility at the Site and installation of solar panels on the capped impoundment would put energy back on the grid and reduce reliance on non-renewable energy sources. Re-development of the capped impoundment for solar facility installation would occur more rapidly under the CIP scenario than under the two CBR scenarios.	Total energy demands and GHG emissions would be far smaller under the CIP and CBR-Onsite scenarios than under the CBR-Offsite scenario, because the total on-Site and off-Site vehicle and equipment travel miles required under the CIP scenario (3,550,000 miles) and CBR-Onsite scenario (6,150,000 miles) are far smaller than those required under the CBR-Offsite scenario (75,300,000 miles). Because expansion of the existing on-Site landfill would be necessary in order to accept all of the CCR from the PAP, the CBR-Onsite scenario would have an additional, unquantified carbon footprint due to the need to manufacture geomembranes for use in the expanded landfill liner. At the grid scale, construction of a solar facility at the Site would put energy back on the grid and reduce reliance on non-renewable energy sources.	Total energy demands and GHG emissions would be far greater under the CBR-Offsite scenario than under the CIP and CBR-Onsite scenarios, because the total on-Site and off-Site vehicle and equipment travel miles required under the CBR-Offsite scenario (75,300,000 miles) are far greater than those required under the CIP scenario (3,550,000 miles) and the CBR-Onsite scenario (6,150,000 miles). If expansion of the off-Site landfill became necessary in order to accept all of the CCR from the PAP, then the CBR-Offsite scenario would have an additional, unquantified carbon footprint due to the need to manufacture geomembranes for use in the expanded landfill liner. At the grid scale, construction of a solar facility at the Site would put energy back on the grid and reduce reliance on non-renewable energy sources.
▪ *Impacts on Natural Resources and Habitat*	Construction activities may have short-term negative impacts on terrestrial and aquatic species located in the vicinity of the PAP, the borrow area, the on-Site landfill, and the off-Site landfill. Short-term impacts on natural resources and habitat would be smaller under the CIP scenario than under the CBR-Onsite and CBR-Offsite scenarios, because the overall duration of construction would be shorter under the CIP scenario than under the two CBR scenarios.	Construction activities may have short-term negative impacts on terrestrial and aquatic species located in the vicinity of the PAP, the borrow area, the on-Site landfill, and the off-Site landfill. Short-term impacts on natural resources and habitat would be greater under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, because the overall duration of construction would be longer under the two CBR scenarios than under the CIP scenario.	Construction activities may have short-term negative impacts on terrestrial and aquatic species located in the vicinity of the PAP, the borrow area, the on-Site landfill, and the off-Site landfill. Short-term impacts on natural resources and habitat would be greater under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, because the overall duration of construction would be longer under the two CBR scenarios than under the CIP scenario.

Evaluation Factor (Report Section; IAC Part 845 Section)	Closure Scenario		
	CIP	**CBR-Onsite**	**CBR-Offsite**
Time Until Groundwater Protection Standards Are Achieved (Section 2.2.5, IAC Sections 845.710(b)(1)(E) and 845.710(d)(2 and 3))	Groundwater modeling was performed to evaluate future groundwater quality in the vicinity of the PAP under each of the proposed closure scenarios (Ramboll, 2022). Model predictions indicate that groundwater concentrations in monitoring wells within the UD/PMP and UA will achieve the GWPS in 20 years under the CIP scenario and 16 years under the CBR closure scenario (Ramboll, 2022). Model predictions also indicate that groundwater concentrations will remain above the GWPSs in the UCU for a period of more than 100 years for both the CIP and CBR scenarios. However, in both the CIP and CBR scenarios, the plume footprint continues to recede over time and remains within the property boundaries, indicating that both closure scenarios perform equivalently with regard to achieving the GWPSs (Ramboll, 2022).	Groundwater modeling was performed to evaluate future groundwater quality in the vicinity of the PAP under each of the proposed closure scenarios (Ramboll, 2022). Model predictions indicate that groundwater concentrations in monitoring wells within the UD/PMP and UA will achieve the GWPS in 20 years under the CIP scenario and 16 years under the CBR closure scenario (Ramboll, 2022). Model predictions also indicate that groundwater concentrations will remain above the GWPSs in the UCU for a period of more than 100 years for both the CIP and CBR scenarios. However, in both the CIP and CBR scenarios, the plume footprint continues to recede over time and remains within the property boundaries, indicating that both closure scenarios perform equivalently with regard to achieving the GWPSs (Ramboll, 2022). Additionally, changing geochemical conditions during an extended excavation can be a mechanism that results in the mobilization and increased transport of some constituents in groundwater. This may result in GWPS exceedance durations in excess of the model predictions.	Groundwater modeling was performed to evaluate future groundwater quality in the vicinity of the PAP under each of the proposed closure scenarios (Ramboll, 2022). Model predictions indicate that groundwater concentrations in monitoring wells within the UD/PMP and UA will achieve the GWPS in 20 years under the CIP scenario and 16 years under the CBR closure scenario (Ramboll, 2022). Model predictions also indicate that groundwater concentrations will remain above the GWPSs in the UCU for a period of more than 100 years for both the CIP and CBR scenarios. However, in both the CIP and CBR scenarios, the plume footprint continues to recede over time and remains within the property boundaries, indicating that both closure scenarios perform equivalently with regard to achieving the GWPSs (Ramboll, 2022). Additionally, changing geochemical conditions during an extended excavation can be a mechanism that results in the mobilization and increased transport of some constituents in groundwater. This may result in GWPS exceedance durations in excess of the model predictions.
Long-Term Reliability of the Engineering and Institutional Controls (Section 2.2.7; IAC Section 845.710(b)(1)(G))	CIP would be expected to be a reliable closure alternative over the long term.	CBR-Onsite would be expected to be a reliable closure alternative over the long term.	CBR-Offsite would be expected to be a reliable closure alternative over the long term.
Potential Need for Future Corrective Action (Section 2.2.8; IAC Section 845.710(b)(1)(H))	Corrective action is expected at the Site. An evaluation of potential corrective measures and corrective actions has not yet been completed, but will be conducted consistent with the requirements in IAC Section 845.660 and IAC Section 845.670.	Corrective action is expected at the Site. An evaluation of potential corrective measures and corrective actions has not yet been completed, but will be conducted consistent with the requirements in IAC Section 845.660 and IAC Section 845.670.	Corrective action is expected at the Site. An evaluation of potential corrective measures and corrective actions has not yet been completed, but will be conducted consistent with the requirements in IAC Section 845.660 and IAC Section 845.670.
Effectiveness of the Alternative in Controlling Future Releases (Section 2.3; IAC Section 845.710(b)(2)(A and B))	There are no current or future risks to any human or ecological receptors associated with the PAP. During closure, there would be minimal risk of dike failure occurring and minimal risk of dike overtopping during flood conditions. Post-closure, the risks of overtopping and dike failure would be even smaller than they are currently, due to the installation of a protective soil cover and new stormwater control structures. Dikes, final cover, and stormwater control features have been designed to withstand earthquakes and storm events.	There are no current or future risks to any human or ecological receptors associated with the PAP. During closure, there would be minimal risk of dike failure occurring and minimal risk of dike overtopping during flood conditions. Following excavation, there would be no risk of CCR releases due to dike failure.	There are no current or future risks to any human or ecological receptors associated with the PAP. During closure, there would be minimal risk of dike failure occurring and minimal risk of dike overtopping during flood conditions. Following excavation, there would be no risk of CCR releases due to dike failure.
Ease or Difficulty of Implementing the Alternative (Section 2.4, IAC Section 845.710(b)(3))			
▪ *Degree of Difficulty Associated with Construction*	CIP is a reliable and standard method for managing and closing waste impoundments. Dewatering saturated CCR to construct a stabilized final cover system subgrade may present challenges during closure; however, these challenges are common to most CCR surface impoundment closures and are commonly addressed *via* surface water management and dewatering techniques.	Relative to CIP, CBR-Onsite and CBR-Offsite pose additional implementation difficulties due to higher earthwork volumes and higher dewatering volumes, and longer construction schedules. The construction schedule for excavation may also be negatively impacted under the CBR-Onsite scenario, because the on-Site landfill would need to be expanded in order to receive all of the materials excavated from the impoundment.	Relative to CIP, CBR-Onsite and CBR-Offsite pose additional implementation difficulties due to higher earthwork volumes and higher dewatering volumes, and longer construction schedules. Hauling would be more difficult to implement under the CBR-Offsite scenario than under the CBR-Onsite scenario, due to the much longer haul distance required (75 miles *versus* 1 mile) and the need to use public roads for hauling. Because the CCR would be hauled on public roads, it would require haul trucks with a smaller capacity (16.5 cubic yards *versus* 34 cubic yards) and would also need to be dewatered to a greater extent than would be necessary under the CBR-Onsite scenario. Off-Site landfilling would additionally require the development of a disposal plan and could raise issues related to the co-disposal of CCR and other non-hazardous wastes. The off-Site landfill may need to be expanded to receive all of the CCR generated during excavation.

Evaluation Factor (Report Section; IAC Part 845 Section)	Closure Scenario		
	CIP	**CBR-Onsite**	**CBR-Offsite**
▪ *Expected Operational Reliability*	Operational reliability would be expected under all closure scenarios.	Operational reliability would be expected under all closure scenarios.	Operational reliability would be expected under all closure scenarios.
▪ *Need for Permits and Approvals*	Permits required under all closure scenarios would include a modification to the existing NPDES permit; a construction permit from the IDNR Dam Safety Program to allow the embankment and spillways of the PAP to be modified as part of closure; a construction stormwater permit through IEPA; and a joint water pollution control construction and operating permit (WPC permit).	Permits required under all closure scenarios would include a modification to the existing NPDES permit; a construction permit from the IDNR Dam Safety Program to allow the embankment and spillways of the PAP to be modified as part of closure; a construction stormwater permit through IEPA; and a joint water pollution control construction and operating permit (WPC permit). On-site landfill expansion would require permitting from IEPA Bureau of Land under Title 35 Sections 811 and 812 as well as local government approval.	Permits required under all closure scenarios would include a modification to the existing NPDES permit; a construction permit from the IDNR Dam Safety Program to allow the embankment and spillways of the PAP to be modified as part of closure; a construction stormwater permit through IEPA; and a WPC permit. Additional permits and approvals may be required under this scenario if the off-Site landfill must be expanded to receive all of the CCR from the PAP.
▪ *Availability of Equipment and Specialists*	CIP and CBR rely on common construction equipment and materials and typically do not require the use of specialists. However, global supply chains have been disrupted due to the COVID-19 pandemic, resulting in shortages in the availability of construction equipment and parts. There may be delays in construction under all scenarios if supply chain resilience does not improve by the time of construction. Due to smaller earthwork volumes and a lesser need for construction equipment under the CIP scenario than under the CBR scenarios, shortages may cause fewer challenges under the CIP scenario than under the CBR scenarios.	CIP and CBR rely on common construction equipment and materials and typically do not require the use of specialists. However, global supply chains have been disrupted due to the COVID-19 pandemic, resulting in shortages in the availability of construction equipment and parts. There may be delays in construction under all scenarios if supply chain resilience does not improve by the time of construction. Due to higher earthwork volumes and a greater need for construction equipment under the CBR scenarios than under the CIP scenario, shortages may cause greater challenges under the CBR scenarios than under the CIP scenario.	CIP and CBR rely on common construction equipment and materials and typically do not require the use of specialists. However, global supply chains have been disrupted due to the COVID-19 pandemic, resulting in shortages in the availability of construction equipment and parts. There may be delays in construction under all scenarios if supply chain resilience does not improve by the time of construction. Due to higher earthwork volumes and a greater need for construction equipment under the CBR scenarios than under the CIP scenario, shortages may cause greater challenges under the CBR scenarios than under the CIP scenario. The current shortage of truck drivers may be particularly impactful under the CBR-Offsite scenario, due to the large volumes of CCR to be hauled from the Site.
▪ *Available Capacity and Location of Treatment, Storage, and Disposal Services*	Under the CIP scenario, all of the CCR currently within the PAP would be stored within the existing footprint of the impoundment. Treatment would consist of unwatering the PAP at the start of construction, performing limited dewatering to stabilize the CCR subgrade, and managing stormwater inflow. Water from unwatering and dewatering of the PAP would be discharged in accordance with the NPDES permit for the facility.	The existing on-Site landfill at the Newton Power Plant Site does not have sufficient capacity to receive all of the CCR that is currently slated for landfilling under the CBR-Onsite scenario. Expansion of the on-Site landfill capacity would thus be necessary. The potential impacts of landfill expansion are included in the analysis as one aspect of the overall closure scenario. Water from unwatering and dewatering of the PAP would be discharged in accordance with the NPDES permit for the facility.	The capacity remaining at the preferred off-Site landfill (the Sycamore Ridge Landfill in Pimento, Indiana) is sufficient to receive all of the CCR in the PAP. However, due to the relatively short period over which CCR would be received at the landfill, vertical and/or lateral expansions may become necessary. Additionally, the landfill operators may need to develop a disposal plan to account for the increased volume of material that would be received and the unique CCR waste characteristics. Water from unwatering and dewatering of the PAP would be discharged in accordance with the NPDES permit for the facility.
Impact of Alternative on Waters of the State (Section 2.5, IAC Section 845.710(d)(4))	No current or future exceedances of any screening benchmarks for surface water would be expected under any closure scenario.	No current or future exceedances of any screening benchmarks for surface water would be expected under any closure scenario.	No current or future exceedances of any screening benchmarks for surface water would be expected under any closure scenario.
Potential Modes of Transportation Associated with CBR (Section 2.1; IAC Section 845.710(c)(1)	This factor is not relevant for CIP.	This factor is not relevant for CBR-Onsite.	IAC Section 845.710(c)(1) requires CBR alternatives to consider multiple methods for transporting CCR off-Site, including rail, barge, and trucks. HDR evaluated the feasibility of transporting CCR to the off-Site landfill *via* rail or barge and found that neither option is viable at this Site. Truck transport has been identified as the preferred option for transport of CCR to the off-Site landfill. The local availability and use of natural gas-powered trucks, or other low-polluting trucks, will be evaluated prior to the start of construction.

Evaluation Factor (Report Section; IAC Part 845 Section)	Closure Scenario		
	CIP	CBR-Onsite	CBR-Offsite
Concerns of Residents Associated with Alternatives (Section 2.6, IAC Section 845.710(b)(4))	Despite the preference for CBR that has been expressed by nonprofits representing community interests near the Site, CIP would effectively address residents' concerns regarding potential impacts to groundwater and surface water quality at the Site. Relative to CBR-Offsite, CIP and CBR-Onsite (which do not require any off-Site hauling) present far fewer risks to nearby residents and potentially EJ communities in the form of off-Site accidents, traffic-related impacts, noise, and air pollution. Moreover, under the CIP scenario, the Site could be more rapidly re-developed for the installation of a solar facility on the capped impoundment. A public meeting was held on May 24, 2022, pursuant to requirements under IAC Section 845.710(e). Questions raised by attendees were addressed at the meeting; subsequently, a written summary of the questions and responses was prepared.	Relative to CBR-Offsite, CIP and CBR-Onsite (which do not require any off-Site hauling) present far fewer risks to nearby residents and potentially EJ communities in the form of off-Site accidents, traffic-related impacts, noise, and air pollution. A public meeting was held on May 24, 2022, pursuant to requirements under IAC Section 845.710(e). Questions raised by attendees were addressed at the meeting; subsequently, a written summary of the questions and responses was prepared.	Relative to CIP and CBR-Onsite, CBR-Offsite (which requires substantial off-Site hauling) presents far greater risks to nearby residents and potentially EJ communities in the form of off-Site accidents, traffic-related impacts, noise, and air pollution. A public meeting was held on May 24, 2022, pursuant to requirements under IAC Section 845.710(e). Questions raised by attendees were addressed at the meeting; subsequently, a written summary of the questions and responses was prepared.

Notes:
AACE = Association for the Advancement of Cost Engineering; CBR = Closure-by-Removal; CBR-Offsite = Closure-by-Removal with Off-Site CCR Disposal; CBR-Onsite = Closure-by-Removal with On-Site CCR Disposal; CCR = Coal Combustion Residual; CIP = Closure-in-Place; EJ = Environmental Justice; GHG = Greenhouse Gas; GWPS = groundwater protection standard; IAC = Illinois Administrative Code; IDNR = Illinois Department of Natural Resources; IEPA = Illinois Environmental Protection Agency; NPDES = National Pollutant Discharge Elimination System; PAP = Primary Ash Pond.

1 Introduction

1.1 Site Description and History

1.1.1 Site Location and History

Illinois Power Generating Company's (IPGC) Newton Power Plant is an electric power generating facility with coal-fired units located approximately seven miles southwest of the City of Newton, Illinois. The facility began operating in approximately 1977 and will be retired by the end of 2027 (Meeker, 2020; Ramboll, 2021).

1.1.2 CCR Impoundment

The Newton Power Plant produces and stores coal combustion residuals (CCRs) as part of its operations. The Primary Ash Pond (PAP; Vistra ID No. CCR Unit 501, Illinois Environmental Protection Agency [IEPA] ID No. W0798070001-01, and National Inventory of Dams [NID] ID No. IL50719), which is the only CCR-containing impoundment at this Site, is the subject of this report.

The PAP (Figure 1.1) is a 404-acre unlined surface impoundment constructed in 1977 for the management of bottom ash, fly ash, and other non-CCR waste generated by the facility (Ramboll, 2021). Decanted water from the PAP discharges into the Secondary Pond, a 9.3-acre non-CCR impoundment located immediately south of the PAP (Ramboll, 2021). The Secondary Pond, which is used to clarify process water, discharges to Newton Lake *via* a National Pollutant Discharge Elimination System (NPDES)-permitted outfall (AECOM, 2016a; Ramboll, 2021). After the Newton Power Plant is retired in 2027, the PAP will no longer receive sluiced ash. Final closure of the PAP is expected to be completed by the end of 2028 (HDR, 2022).



Figure 1.1 Site Location Map. Adapted from Ramboll (2021).

1.1.3 Surface Water Hydrology

The Secondary Pond, which receives decanted water from the PAP, is permitted to discharge to Newton Lake, the approximately 1,650-acre cooling pond for the facility (Figure 1.1, Ramboll, 2021). Newton Lake is a long water body that surrounds the PAP to the east, south, and west. It is located within the Weather Creek and Newton Lake Watersheds (Hydrologic Unit Codes [HUCs] 051201140504 and 051201140503, respectively), which lie within the larger Little Wabash River watershed (HUCs 05120114 and 05120115; Tetra Tech, 2008; US EPA, 2018). The southern boundary of the PAP is approximately 250 to 700 feet (ft) from the northern shore of Newton Lake (Ramboll, 2021).

Newton Lake (Assessment Unit ID IL_RCR) is listed on the 2018 Illinois Section 303(d) List as being impaired for fish consumption due to mercury. In addition, it is listed as being impaired for aesthetic

quality due to Total Suspended Solids (IEPA, 2019a; US EPA, 2018). As of 2008, there is a Total Maximum Daily Load (TMDL) in place to address aesthetic quality impairments in Newton Lake due to an excess of Total Phosphorus (Tetra Tech, 2008).

In addition to Newton Lake, another unnamed 13.7-acre lake is located within 1,000 meters (3,281 feet) of the PAP. There are also several unnamed freshwater ponds located within 1,000 meters of the PAP that range in size from 0.3 acres to 6.2 acres (Figure 1.2; Ramboll, 2021).

Golder collected a total of 28 surface water samples from Newton Lake in the vicinity of the PAP in April and May of 2021 (Golder, 2021). These data are summarized in Gradient's Human Health and Ecological Risk Assessment for the Site, which is provided as Attachment A of this report.

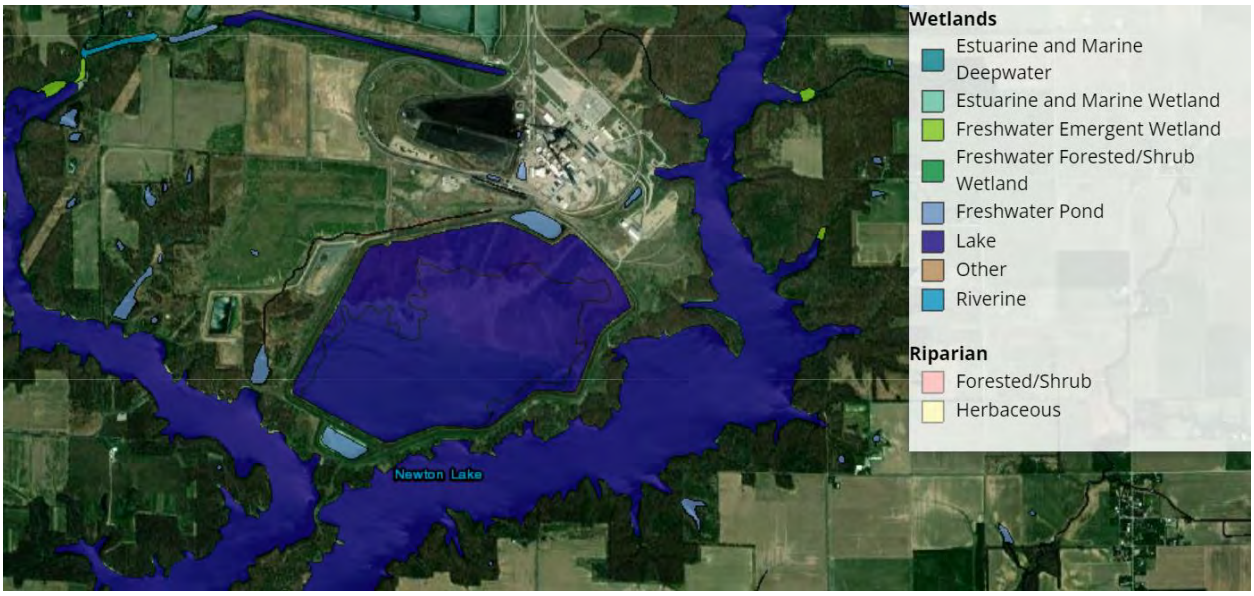

Figure 1.2 Wetlands and Surface Water Bodies in the Vicinity of the Newton Primary Ash Pond. Adapted from US FWS (2021).

1.1.4 Hydrogeology

The geology underlying the Site in the vicinity of the PAP primarily consists of unlithified deposits overlying a shale bedrock unit. The principal types of unlithified materials include the Peoria Silt /Sangman Soil, the Hagarstown Member, the Vandalia Till, the Mulberry Grove Member, and the Smithboro Till/Banner Formation (Ramboll, 2021). These unlithified deposits are underlain by a Pennsylvanian Age shale bedrock of the Mattoon Formation (Ramboll, 2021). Five distinct hydrostratigraphic units in the area are (listed from ground surface down): the Upper Drift (UD)/Potential Migration Pathway (PMP), the Upper Confining Unit (UCU), the Uppermost Aquifer (UA), the Lower Confining Unit (LCU), and the Bedrock Confining Unit (BCU) (Ramboll, 2021).The UD is composed of low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.*, PMP). The Peoria Silt and Sangamon Soil range in thickness from 3 to 46 ft (Ramboll, 2021). The Hagarstown Member is generally 2 feet (ft) thick but is encountered at thicknesses up to about 6.9 ft in the vicinity of the Ash Pond (Ramboll, 2021). The UA is composed of a 3 to 17 ft thick Mulberry Grove Member, which consists of sand, silty- and clayey- sand, and gravel. The UA is sandwiched between two low-permeability confining units: (i) the UCU on top consisting of clay and silt of the Vandalia Till and (ii) the LCU on bottom consisting of silt and clay of the Smithboro Till Member

and the Banner Formation (Ramboll, 2021). No wells are screened within the UCU, the LCU, or the underlying shale BCU.

Groundwater within the UA flows generally from the north towards the south and southwest. In the southern area of the PAP, groundwater flows toward a former drainage feature located west of the PAP (Ramboll, 2021). In the northern area of the PAP, groundwater from the UA may interact with surface water in Newton Lake, as evidenced by relatively higher groundwater head elevations compared to the Newton Lake water level. Groundwater within the UD/PMP may also interact with surface water in Newton Lake (Ramboll, 2021).

The "Hydrogeologic Site Characterization Report" prepared by Ramboll as part of the operating permit for the PAP includes an evaluation of groundwater data collected from PAP monitoring wells between 2015 and 2021 (Ramboll, 2021).

1.1.5 Site Vicinity

The Newton Power Plant Site is located in a predominantly agricultural area. The PAP is located south of the power plant and is bordered by Newton Lake to the west, south, and east (Ramboll, 2021. Scenic and recreational areas within a few miles of the Site include the Newton Lake State Fish and Wildlife Area (SFWA) and the Prairie Ridge State Natural Area / Jasper County Prairie Chicken Sanctuary (Ramboll, 2021. The Newton Lake SFWA, which includes Newton Lake and an additional 5,800 surrounding acres of timber, cropland, and open/non-cultivated land, is preserved by IDNR for fishing, hunting, and wildlife management. Approximately 540 acres of the western shoreline are also used for picnicking, hiking, biking, and horseback riding. The northeastern portion of the Newton Lake SFWA is dedicated to the preservation of the prairie chicken, a state-endangered species (IDNR, 2022). The Prairie Ridge State Natural Area / Jasper County Prairie Chicken Sanctuary, which is located east of Newton Lake, consists of several discontinuous tracts of land that are similarly dedicated to the preservation of the prairie chicken (IDNR, 2022).

Based on a review of the Illinois Department of Natural Resources (IDNR) Historic Preservation Division database and the Illinois State Archaeological Survey database, there are no historic sites located within 1,000 meters of the PAP (Ramboll, 2021).

1.2 IAC Part 845 Regulatory Review and Requirements

Title 35, Part 845 of the Illinois Administrative Code (IAC; IEPA, 2021) requires the development of a Closure Alternatives Analysis (CAA) prior to undertaking closure activities at certain CCR-containing surface impoundments in the State of Illinois. Section 2 of this report presents a CAA for the PAP pursuant to requirements under IAC Section 845.710. The goal of a CAA is to holistically evaluate each potential closure scenario with respect to a wide range of factors, including the efficiency, reliability, and ease of implementation of the closure scenario; its potential positive and negative short- and long-term impacts on human health and the environment; and its ability to address concerns raised by residents (IEPA, 2021). A CAA is a decision-making tool that is designed to aid in the selection of an optimal closure alternative for the impoundments at a site.

2 Closure Alternatives Analysis

2.1 Closure Alternative Descriptions (IAC Section 845.710(c))

This section of the report presents a CAA for the PAP pursuant to requirements under IAC Section 845.710 (IEPA, 2021). The three closure scenarios evaluated in this CAA are Closure-in-Place with consolidation (CIP), Closure-by-Removal with On-Site CCR Disposal (CBR-Onsite), and Closure-by-Removal with Off-Site CCR Disposal (CBR-Offsite). The CIP scenario would entail consolidation of CCR in the northern portion of the PAP, followed by capping with a new cover system. Under the CBR-Onsite scenario, the CCR would be excavated from the impoundment and hauled to an on-Site landfill. Under the CBR-Offsite scenario, the CCR would be excavated from the impoundment and hauled to an off-Site landfill. IPGC will also continue to evaluate potential opportunities for beneficial re-use of CCR excavated from the PAP as an alternative to disposal. In addition to the primary closure activities to be undertaken at the PAP, all three closure scenarios account for the eventual closure of the existing off-Site landfill (which currently contains uncapped waste) *via* capping.

IAC Section 845.710(c)(2) requires CAAs to, "[i]dentify whether the facility has an onsite landfill with remaining capacity that can legally accept CCR, and, if not, whether constructing an onsite landfill is possible" (IEPA, 2021). There is an existing, permitted CCR landfill (Newton CCR Landfill Phase II) located immediately west of the PAP at the Newton Power Plant Site. However, this landfill is not actively being used to store waste and does not have sufficient capacity to contain all of the CCR that would be excavated from the PAP under the CBR-Onsite scenario. Additional landfill capacity would be required for the CBR-Onsite scenario and could be accomplished by reconstructing the current landfill cell, constructing additional sections of the landfill that have already been permitted, and either constructing an additional permitted expansion of the landfill or constructing a separate, additional on-Site landfill (Attachment B). A 25-acre area immediately adjacent to and east of the existing landfill is the most practical location for a potential landfill expansion.

Sections 2.1.1, 2.1.2, and 2.1.3 provide detailed descriptions of the CIP, CBR-Onsite, and CBR-Offsite closure scenarios. These scenarios are based on the Closure Plan for the PAP (HDR, 2022) and additional closure documents and analyses provided to Gradient by HDR, which are attached to this report as Attachment B.

2.1.1 Closure-in-Place

Under the CIP scenario, the CCR in the PAP would be excavated from the southern and western portions of the PAP and consolidated into the northern and eastern portions, then capped in place with a final cover system. This scenario includes the following work elements (HDR, 2022):

- Unwatering and dewatering of the impoundment *via* pumping and the construction of drilled sumps, engineered trenches, and/or horizontal wells. Water from unwatering and dewatering would be pumped to the adjacent Secondary Pond, which discharges to Newton Lake *via* a NPDES-permitted outfall. Dewatering and unwatering would begin as soon as practical with the completion of permitting and continue throughout the construction period.

- Consolidation of the CCR in the PAP by excavating CCR and approximately 1 foot of underlying soils from the southern and western portions of the PAP and using it as fill within the northern and eastern portions of the PAP in order to establish minimum slopes. CCR will be placed in lifts and compacted to provide a subgrade suitable for construction of a final cover system. In addition to CCR, materials within the existing on-Site landfill and/or coal pile may also be relocated and utilized as subgrade fill within the impoundment closure area.
- Removal of existing outflow structures and culverts connecting the PAP to the adjacent Secondary Pond.
- Removal of the berm between the PAP and the Secondary Pond, followed by removal of the Secondary Pond. Post-closure, an area in the southern portion of the PAP will be used as a stormwater management pond.
- Construction of an alternative cover system over the consolidated ash consisting of a 40-mil LLDPE geomembrane layer, a geocomposite drainage layer, and 24 inches of protective soil cover suitable for supporting vegetative growth.[2] An alternative cover performance demonstration has been submitted to IEPA for approval pursuant to Section 845.750(c)(2) (Geosyntec, 2022). A solar facility atop the cover system is currently being designed. Components of the vegetative cover may change as details of the solar facility are finalized. However, any changes to the cover are expected to be protective of human health and the environment and meet the requirements of Section 845.750(c).
- Installation of stormwater control structures, including: (i) stormwater channels designed to convey stormwater into the new stormwater pond post-closure, and (ii) drainage pipes, channels, and downchutes designed to reduce erosion in places where channels flow from the PAP final cover and lead into the stormwater pond.
- Long-term (post-closure) monitoring and maintenance, including at least 30 years of groundwater monitoring at the impoundment, or until such time as groundwater protection standards (GWPSs) are achieved. Additionally, 30 years of post-closure care would be undertaken for the final cover system, including annual cap inspections, mowing, and maintenance.

Under this scenario, the existing on-Site landfill would also be closed *via* capping. The existing on-Site landfill is approximately 12 acres in size.

This CIP plan meets all closure requirements of IAC Part 845.750 (IEPA, 2021). Key closure elements that address the Part 845 closure requirements are summarized below. Further details are provided in the Closure Plan (HDR, 2022).

- An alternative cover system would be installed over the CCR that remains in the PAP. The cover, consisting of an LLDPE geomembrane layer and 24 inches of soil, as described above, would minimize vertical infiltration of precipitation into the basin [Part 845.750(a)(1)] (Geosyntec, 2022). A solar facility atop the cover system is currently being designed. Components of the vegetative cover may change as details of the solar facility are finalized. However, any changes are expected to be protective of human health and the environment and meet the requirements of Section 845.750(c).
- The final cover system would be gently sloped to direct surface water away from the impoundment. Beyond the final cover system, channels would direct surface water away from the PAP to existing site drainages [Part 845.750(a)(2)].

[2] Alternatively, the final cover system for the PAP may use a 50-mil LLDPE geomembrane material called “Microspike” or “Supergrip," which has built-in drainage studs on the top (HDR, 2022).

- Free liquids in the CCR would be eliminated by removing liquid wastes or solidifying the remaining wastes. Engineered trenches would facilitate gravity drainage of liquid wastes in the CCR and direct the liquid wastes to sumps. Other engineering measures, such as drilled sumps and/or horizontal wells, may also be considered to facilitate removal of liquid wastes and stabilization of wastes. Liquid wastes would be managed in accordance with the NPDES permit for the Site [845.750(b)(1) and 845.750(b)(2)].
- The proposed CIP design will control, minimize, or eliminate as much as feasible post-closure infiltration of liquids and releases of CCR, leachate, or contaminated runoff as interpreted by IEPA in the Part 845 rulemaking. Specifically, CIP will result in a reduction of infiltration into the PAP by 94% compared to pre-closure conditions (Ramboll, 2022). Additionally, CIP will result in a reduction of hydraulic flux out of the PAP by 94% compared to pre-closure conditions (Ramboll, 2022). Due to the reduction in the hydraulic flux out of the PAP, the mass flux out of the PAP will also be controlled or minimized as much as feasible as a result of CIP.

As an additional consideration, the PAP is located on a relatively thick layer of low-permeability clay, and the final cover system will tie into the surrounding grades. Post-closure, the CCR remaining in the PAP will therefore be physically isolated from the surrounding environment, including stormwater, surface water, and the atmosphere (HDR, 2022). Moreover, the CCR within the PAP will be located above the uppermost aquifer under normal conditions, and is also expected to be perennially above the uppermost aquifer level during higher-water conditions in Newton Lake. Post-closure, there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations, including the seasonal high-water table (HDR, 2022). Furthermore, during the closure process, we will continue to assess off-Site CCR beneficial use opportunities. Ash consolidation and closure in place, in combination with offsite beneficial use, may result in a smaller footprint for purposes of our ultimate cap design along with a reduced construction schedule.

Under this scenario, approximately 1,920,000 CY of CCR will be relocated to the northern and eastern portions of the PAP (an assumed average travel distance of approximately 1 mile; Attachment B). Construction of the final cover systems for the impoundment and the on-Site landfill would require an additional 976,000 CY of clean soil, which would be sourced from within the footprint of the PAP, existing berms, and if needed, elsewhere on Site (an assumed average travel distance of approximately 1 mile; Attachment B). Borrow soil would be hauled around the Site using haul trucks with an assumed capacity of 34 CY.

Under the CIP scenario, the overall expected duration of construction and earthwork activities (including closure of the impoundment and site restoration) is approximately 38 to 51 months (3.2 to 4.3 years). The total expected number of on-Site working days (excluding, *e.g.*, winter weather delays and weekends) is 720 days (Attachment B). The CIP scenario will meet the requred closure schedule (*i.e.*, closure completed by October 2028) defined in IAC Section 845.700(d)(2)(C)(ii) (IEPA, 2021a). Key parameters for the CIP scenario are shown in Table 2.1.

Table 2.1 Key Parameters for the Closure-in-Place Scenario

Parameter	Value
Surface Area of PAP	404 acres
Surface Area of Final Cover System	268 acres
Surface Area of On-Site Landfill	12 acres
Volume of CCR to be Relocated	1,920,000 CY
Average Travel Distance for Relocation of CCR	1 mile
Required Volume of Borrow Soil	976,000 CY
Average Distance to On-Site Borrow Soil Location	1 mile
Duration of Construction Activities	3.2 to 4.3 years
Labor Hours	
Total On-Site Labor	245,000 hours
Total Off-Site Labor	4,000 hours
30% Contingency	74,600 hours
Total Labor Hours:	323,000 hours
Vehicle and Equipment Travel Miles	
Vehicles On-Site	79,000 miles
Equipment On-Site	720,000 miles
On-Site Haul Trucks (Unloaded + Loaded)	113,000 miles
Labor Mobilization	2,260,000 miles
Equipment Mobilization (Unloaded + Loaded)	66,200 miles
Off-Site Haul Trucks (Unloaded + Loaded)	0 miles
Material Deliveries (Unloaded + Loaded)	308,000 miles
Total On-Site Vehicle and Equipment Travel Miles:	912,000 miles
Total Off-Site Vehicle and Equipment Travel Miles:	2,640,000 miles
Total Vehicle and Equipment Travel Miles:	3,550,000 miles

Notes:
PAP = Primary Ash Pond.
Due to rounding, totals may not match the sum of the values.
Source: Attachment B, HDR (2022).

2.1.2 Closure-by-Removal with On-Site CCR Disposal

Under the CBR-Onsite scenario, all CCR would be excavated from the PAP and transported to an on-Site landfill for disposal. There is an existing, permitted CCR landfill at the Newton Power Plant Site, which is located approximately 1 mile from the PAP along Site roads (Attachment B). However, this landfill does not currently have sufficient capacity to contain all of the CCR that would be excavated from the PAP under the CBR-Onsite scenario (approximately 5,700,000 CY). The existing on-Site landfill would therefore need to be expanded under this scenario.

This scenario includes the following work elements (Attachment B):

- Expansion of the existing on-Site landfill. Landfill expansion would include the reconstruction of the current landfill cell, construction of the remaining permitted capacity for the landfill, and further expansion of the landfill into a 25-acre area located immediately to the east.
    - The landfill expansion area overlaps the footprint of the PAP, requiring phased closure of the PAP. CCR located within the landfill expansion area would be relocated to the existing permitted landfill prior to construction of the expansion.

    - The landfill expansion would also require relocation of an access road, a major drainageway, and possibly a monitoring well.
- Unwatering and dewatering of the impoundment by pumping water to the adjacent Secondary Pond, which discharges to Newton Lake *via* a NPDES-permitted outfall.
- Construction of stormwater control structures, including ditches and sumps, to convey runoff away from the impoundment.
- Excavation of CCR and approximately one foot of underlying soils from the impoundment and transport of these materials to the on-Site landfill.
- Backfilling of the impoundment as needed in order to promote positive drainage and prevent the impoundment of non-contact stormwater within the PAP post-closure.
- Site restoration, including the placement of six inches of topsoil along the side slopes and bottom of the PAP and revegetation with native grasses.
- Monitoring for 3 years post-closure or until such time as GWPSs are achieved, whichever is longer.

Under this scenario, the existing on-Site landfill would be closed *via* capping following the disposal of CCR from the impoundment. After expansion, the existing on-Site landfill would be approximately 66 acres in size.

Soil for expansion of the on-Site landfill, backfilling of the impoundment, site restoration, and on-Site landfill closure would be sourced from within the footprint of the PAP, existing berms, and if needed, elsewhere on Site (an assumed average travel distance of approximately 1 mile; Attachment B). In total, 562,000 CY of clean borrow soil would be required under this scenario. A haul truck capacity of 34 CY is assumed for the on-Site transport of borrow soil and CCR (Attachment B).

The overall expected duration of construction and earthwork activities under this scenario (including closure of the impoundment, backfilling to maintain positive drainage, and site restoration) is approximately 94 to 110 months (7.8 to 9.2 years). The total expected number of on-Site working days (excluding, *e.g.*, winter weather delays and weekends) is 1,440 days (Attachment B). The CBR-Onsite scenario will not meet the required closure schedule (*i.e.*, closure completed by October 2028) defined in IAC Section 845.700(d)(2)(C)(ii) (IEPA, 2021a). Key parameters for the CBR-Onsite scenario are shown in Table 2.2.

Table 2.2 Key Parameters for the Closure-by-Removal with On-Site CCR Disposal Scenario

Parameter	Value
Surface Area of PAP	404 acres
Surface Area of On-Site Landfill (After Expansion)	66 acres
Average Travel Distance to On-Site Landfill	1 mile
Hauled Volume of CCR	5,700,000 CY
Average Distance to On-Site Borrow Soil Location	1 mile
Hauled Volume of Borrow Soil	562,000 CY
Duration of Construction Activities	7.8 to 9.2 years
Labor Hours	
Total On-Site Labor	429,000 hours
Total Off-Site Labor	4,000 hours
30% Contingency	130,000 hours
Total Labor Hours:	563,000 hours
Vehicle and Equipment Travel Miles	
Vehicles On-Site	140,000 miles
Equipment On-Site	1,440,000 miles
On-Site Haul Trucks (Unloaded + Loaded)	335,000 miles
Labor Mobilization	3,940,000 miles
Equipment Mobilization (Unloaded + Loaded)	128,000 miles
Off-Site Haul Trucks (Unloaded + Loaded)	0 miles
Material Deliveries (Unloaded + Loaded)	164,000 miles
Total On-Site Vehicle and Equipment Travel:	1,910,000 miles
Total Off-Site Vehicle and Equipment Travel:	4,230,000 miles
Total Vehicle and Equipment Travel:	6,150,000 miles

Notes:
CCR = Coal Combustion Residual; PAP = Primary Ash Pond.
Due to rounding, totals may not match the sum of the values.
Source: Attachment B.

2.1.3 Closure-by-Removal with Off-Site CCR Disposal

Under the CBR-Offsite scenario, all CCR would be excavated from the PAP and transported to an off-Site landfill for disposal. Evaluation of landfill capacity and permitted use must be taken into consideration for each landfill considered for off-Site disposal. For example, a municipal landfill is often designed and permitted to accept waste from the local community at a specific rate. The landfill owner relies on this information to determine the remaining life of a landfill and determine when it will be necessary to expand or close the landfill. Due to the lengthy permitting and construction process, a landfill would need to continue accepting current waste streams and ash for a significant period of time to be a viable option, assuming the landfill owner and state approve. Furthermore, given the volume of ash that would need to be transported, it is important to evaluate impacts to communities that will be affected by the increase in truck traffic to and from the landfill. The nearest operating landfill to meet these criteria is the Sycamore Ridge Landfill in Pimento, Indiana (5621 East Cottom Drive), which is located approximately 75 miles from the Site (Attachment B). The Sycamore Ridge Landfill is the closest landfill to the Site with sufficient capacity to receive all of the material excavated from the PAP. Nonetheless, as described below in Section 2.4.5, it is possible that the Sycamore Ridge Landfill would have to be expanded during closure in order to accommodate the large amount of CCR to be received at the landfill and the relatively short time frame over which receipt of the CCR would occur.

IAC Section 845.710(c)(1) requires CBR alternatives to consider multiple methods for transporting CCR off-Site, including rail, barges, and trucks. HDR evaluated the feasibility of transporting CCR to the off-Site landfill *via* rail or barges and found that neither option is likely to be viable at this Site (Attachment B). Transporting CCR by rail would require modifications to the existing rail terminal on the Newton Power Plant property and the construction of a new rail terminal near the off-Site landfill. Modification of the existing on-Site rail terminal and construction of a new off-Site rail terminal would require coordination with the railroad and additional design and permitting, which could negatively impact the project schedule. Trucks would still be needed to haul CCR to and from the terminals, and additional CCR exposures could occur during the loading and unloading of CCR into trucks and rail cars. Moreover, because there is no direct rail route from the Site to the off-Site landfill, the transport of CCR to the off-Site landfill would require approximately 75 miles of rail transport (one-way) on tracks owned by 3 separate rail lines.

Barge transport is not a viable option for transporting CCR offsite, because the Newton Power Plant property is not located near a river that can accommodate barge traffic. In fact, the nearest terminal for barge traffic is approximately 125 miles away in St. Louis, Missouri. For these reasons, truck transport has been identified as the preferred option for transport of CCR to the off-Site landfill. Transport *via* truck would not require the construction of additional loading or unloading infrastructure and would not result in project delays due to permitting and coordination with other parties. The existing travel routes from the Site to the off-Site landfill are suitable for CCR transport *via* truck (Attachment B). The local availability and use of natural gas-powered trucks, or other low-polluting trucks, will be evaluated prior to the start of construction.

This scenario includes the following work elements (Attachment B):

- Unwatering and dewatering of the impoundment by pumping water to the adjacent Secondary Pond, which discharges to Newton Lake *via* a NPDES-permitted outfall.
- Construction of stormwater control structures, including ditches and sumps, to convey runoff away from the impoundment.
- Excavation of CCR and approximately one foot of underlying soils from the impoundment and transport of these materials to the off-Site landfill.
- Backfilling of the impoundment as needed in order to promote positive drainage and prevent the impoundment of non-contact stormwater within the PAP post-closure.
- Site restoration, including the placement of six inches of topsoil along the side slopes and bottom of the PAP and revegetation with native grasses.
- Monitoring for 3 years post-closure or until such time as GWPSs are achieved, whichever is longer.

Under this scenario, the existing on-Site landfill would also be closed *via* capping. The existing on-Site landfill is approximately 12 acres in size.

Soil for backfilling of the impoundment, site restoration, and on-Site landfill closure would be sourced from within the footprint of the PAP, existing berms, and if needed, elsewhere on Site (an assumed average travel distance of approximately 1 mile; Attachment B). In total, 68,000 CY of clean borrow soil would be required under this scenario. A haul truck capacity of 34 CY is assumed for the on-Site transport of borrow soil (Attachment B). CCR would be hauled to the off-Site landfill using haul trucks with a capacity of 16.5 CY, a smaller capacity than that of the haul trucks that would haul CCR to the on-

Site landfill under the CBR-Onsite scenario (34 CY) due to restrictions placed on the size of trucks that can be used on public roadways.

The overall expected duration of construction and earthwork activities under this scenario (including closure of the impoundment, backfilling to maintain positive drainage, and site restoration) is approximately 262 to 266 months (22 years). The total expected number of on-Site working days (excluding, *e.g.*, winter weather delays and weekends) is 3,960 days (Attachment B). The CBR-Offsite scenario will not meet the requred closure schedule (*i.e.*, closure completed by October 2028) defined in IAC Section 845.700(d)(2)(C)(ii) (IEPA, 2021a). Key parameters for the CBR-Offsite scenario are shown in Table 2.3.

Table 2.3 Key Parameters for the Closure-by-Removal with Off-Site CCR Disposal Scenario

Parameter	Value
Surface Area of PAP	404 acres
Surface Area of On-Site Landfill	12 acres
Average Travel Distance to Off-Site Landfill	75 miles
Hauled Volume of CCR	5,700,000 CY
Average Distance to On-Site Borrow Soil Location	1 mile
Hauled Volume of Borrow Soil	68,000 CY
Duration of Construction Activities	22 years
Labor Hours	
Total On-Site Labor	129,000 hours
Total Off-Site Labor	1,850,000 hours
30% Contingency	595,000 hours
Total Labor Hours:	2,580,000hours
Vehicle and Equipment Travel Miles	
Vehicles On-Site	611,000miles
Equipment On-Site	3,960,000 miles
On-Site Haul Trucks (Unloaded + Loaded)	0 miles
Labor Mobilization	18,000,000 miles
Equipment Mobilization (Unloaded + Loaded)	738,000 miles
Off-Site Haul Trucks (Unloaded + Loaded)	51,800,000 miles
Material Deliveries (Unloaded + Loaded)	128,000 miles
Total On-Site Vehicle and Equipment Travel:	4,570,000 miles
Total Off-Site Vehicle and Equipment Travel:	70,700,000 miles
Total Vehicle and Equipment Travel:	75,300,000 miles

Notes:
CCR = Coal Combustion Residual; PAP = Primary Ash Pond.
Due to rounding, totals may not match the sum of the values.
Source: Attachment B.

2.2 Long- and Short-Term Effectiveness of the Closure Alternative (IAC Section 845.710(b)(1))

2.2.1 Magnitude of Reduction of Existing Risks (IAC Section 845.710(b)(1)(A))

This section of the report addresses the potential risks to human and ecological receptors due to exposure to CCR-associated constituents in groundwater or surface water. Gradient has performed a Human Health and Ecological Risk Assessment for the Site (Attachment A of this report), which provides a detailed evaluation of the magnitude of existing risks to human and ecological receptors associated with the PAP. This report concluded that there are no current unacceptable risks to any human or ecological receptors associated with the PAP. Because there are no current risks to any human or ecological receptors, and dissolved constituent concentrations would be expected to decline post-closure, no post-closure risks would be expected under any closure scenario. Thus, there would be no current risk or future risk under any closure scenario, and the magnitude of reduction of existing risks would be the same under every closure scenarios.

2.2.2 Likelihood of Future Releases of CCR (IAC Section 845.710(b)(1)(B))

This section of the report quantifies the risk of future releases of CCR that may occur during dike failure and storm-related events.

Storm-Related Releases and Dike Failure During Flood Conditions

Based on the effective Federal Emergency Management Agency (FEMA) Flood Insurance Rate Map for the Site, the PAP is located partially within the 100-year flood zone for Newton Lake (FEMA, 1985; Modeer, 2021). However, as required by IAC Section 845.340(c), "recognized and generally accepted engineering practices have been incorporated into the design of the CCR surface impoundment to ensure that the CCR surface impoundment will not restrict the flow of the base flood, reduce the temporary water storage capacity of a floodplain, or result in washout of CCR." In addition, AECOM and Geosyntec evaluated the risk of flood overtopping occurring at the PAP and found that the impoundment can adequately manage flow during peak discharge from even a 1,000-year storm event, thus preventing overtopping (AECOM, 2016b; Geosyntec, 2021). Engineering analyses similarly show that the PAP dikes are expected to remain stable under static, seismic, and flood conditions (AECOM, 2016c; Geosyntec, 2021). Prior to closure (*i.e.*, under current conditions), the risk of floods or other storm-related events leading to dike failure or overtopping is therefore minimal. Post-closure, the risks of overtopping or dike failure occurring due to floods or other storm-related events would be even smaller than they are currently. Under the CIP scenario, a new cover system would be installed, which would include 24 inches of soil and a geomembrane liner, as well as new stormwater control structures. Relative to current conditions, this cover system would provide increased protection against berm and surface erosion, groundwater infiltration, and other adverse effects that could potentially trigger a dike slope failure event. Under the CBR-Onsite and CBR-Offsite scenarios, all of the CCR in the PAP would be excavated and relocated, eliminating the risk of a CCR release occurring post-closure. In summary, there is minimal current or future risk of sudden CCR releases occurring under any closure scenario either during or following closure.

Dike Failure Due to Seismicity

Sites in Illinois may be subject to seismic risks arising from the Wabash Valley Seismic Zone and the New Madrid Seismic Zone (IEMA, 2020). The Newton Power Plant property lies within approximately 40 miles of the Wabash Valley Fault System, and is therefore located within a seismic impact zone (Ramboll, 2021; Haley & Aldrich, Inc., 2018a). However, all structural components of the PAP have been designed to resist the maximum horizontal acceleration in lithified earth material for the Site. The PAP therefore meets the seismic safety requirements of 40 CFR Section 257.63(a) and IAC Section 845.330(a), and the overall risk of dike failure due to seismicity is expected to be low (Burns & McDonnell, 2021; Haley & Aldrich, Inc., 2018a). Additionally, the PAP does not lie within 200 feet of an active fault or fault damage zone at which displacement has occurred within the current geological epoch (*i.e.*, within the last ~11,650 years; Haley & Aldrich, Inc., 2018b). The nearest known faults are the Albion-Ridgeway and Mt. Carmel-New Harmony faults, which are located about 42 miles southeast of the PAP. These faults do not have known recent activity (Haley & Aldrich, Inc., 2018b). Overall, the risk of dike failure occurring during or following closure activities due to seismic activity is therefore expected to be low.

2.2.3 Type and Degree of Long-Term Management, Including Monitoring, Operation, and Maintenance (IAC Section 845.710(b)(1)(C))

The long-term operation and management plans for the PAP and the on-Site landfill under each closure scenario are described in Section 2.1 (Closure Alternatives Descriptions). In summary, under the CIP scenario, the PAP would undergo monitoring for 30 years post-closure, or until such time as GWPSs are achieved. Under the CBR-Onsite and CBR-Offsite scenarios, the PAP would undergo monitoring for 3 years post-closure, or until such time as GWPSs are achieved. The post-closure care plan for the CIP scenario would additionally include annual inspections, mowing, and maintenance of the final cover system.

2.2.4 Short-Term Risks to the Community or the Environment During Implementation of Closure (IAC Section 845.710(b)(1)(D))

2.2.4.1 Worker Risks

Best practices would be employed during construction in order to ensure worker safety and comply with all relevant regulations, permit requirements, and safety plans. However, it is impossible to completely eliminate the risk of accidents occurring during construction activities, both on- and off-Site. On-Site accidents include injuries and deaths arising from the use of heavy equipment and/or earthmoving operations during construction activities. Off-Site accidents include injuries and deaths due to vehicle accidents during labor and equipment mobilization/demobilization, material deliveries, and CCR hauling.

As shown in Tables 2.1 through 2.3, HDR estimates that the CIP scenario would require 245,000 on-Site labor hours (Attachment B). The CBR-Onsite scenario would require approximately 429,000 on-Site labor hours, and the CBR-Offsite scenario would require approximately 129,000 on-Site labor hours. The US Bureau of Labor Statistics (US DOL, 2020a,b) provides an estimate of the hourly fatality and injury rates for construction workers. Based on the accident rates reported by US Bureau of Labor Statistics and the on-Site labor hours reported in Attachment B, we estimate that approximately 2.8 worker injuries and 0.018 worker fatalities would occur on-Site under the CIP scenario; approximately 5.0 worker injuries and 0.032 worker fatalities would occur on-Site under the CBR-Onsite scenario; and approximately 1.5 worker injuries and 0.0097 worker fatalities would occur on-Site under the CBR-Offsite scenario (Table 2.4).

Table 2.4 Expected Number of On-Site Worker Accidents Under Each Closure Scenario

Closure Scenario	Injuries	Fatalities
CIP	2.8	0.018
CBR-Onsite	5.0	0.032
CBR-Offsite	1.5	0.0097

Notes:
CBR-Offsite = Closure-by-Removal with Off-Site CCR Disposal; CBR-Onsite = Closure-by-Removal with On-Site CCR Disposal; CIP = Closure-in-Place.

Off-Site, a far greater number of total vehicle and equipment travel miles would be required under the CBR-Offsite scenario than would be required under the CIP and CBR-Onsite scenarios (Tables 2.1 through 2.3). Under the CIP scenario, only 2,640,000 total off-Site vehicle and equipment travel miles would be required; under the CBR-Onsite scenario, 4,230,000 total off-Site vehicle and equipment travel miles would be required; and, under the CBR-Offsite scenario, 70,700,000 total off-Site vehicle and equipment travel miles would be required (Attachment B). The United States Department of

Transportation (US DOT, 2020) provides estimates of the expected number of fatalities and injuries "per vehicle mile driven" for drivers and passengers of large trucks and passenger vehicles. Table 2.5 shows the expected number of off-Site accidents under each closure scenario due to all categories of off-Site vehicle usage. For these calculations, it was assumed that labor mobilization/demobilization would rely upon passenger vehicles (cars or light trucks, including pickups, vans, and sport utility vehicles) and that hauling, equipment mobilization/demobilization, and material deliveries would rely upon large trucks. Based on US DOT's accident statistics and the mileage estimates in Attachment B, an estimated 1.4 worker injuries and 0.019 worker fatalities would be expected to occur due to off-Site activities under the CIP scenario; an estimated 2.5 worker injuries and 0.032 worker fatalities would be expected to occur due to off-Site activities under the CBR-Onsite scenario; and an estimated 18 worker injuries and 0.29 worker fatalities would be expected to occur due to off-Site activities under the CBR-Offsite scenario.

Table 2.5 Expected Number of Off-Site Worker Accidents Under Each Closure Scenario

Off-Site Vehicle Use Category	CIP		CBR-Onsite		CBR-Offsite	
	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities
Hauling	0	0	0	0	6.6	0.15
Labor Mobilization/Demobilization	1.4	0.018	2.4	0.031	11	0.14
Equipment Mobilization/Demobilization	0.0085	0.00019	0.016	0.00037	0.094	0.0021
Material Deliveries	0.039	0.00089	0.021	0.00048	0.016	0.00037
Total:	1.4	0.019	2.5	0.032	18	0.29

Notes:
CBR-Offsite = Closure-by-Removal with Off-Site CCR Disposal; CBR-Onsite = Closure-by-Removal with On-Site CCR Disposal; CIP = Closure-in-Place.

Overall, taking into account accidents occurring both on- and off-Site, 4.3 worker injuries and 0.037 worker fatalities would be expected under the CIP scenario; 7.4 worker injuries and 0.064 worker fatalities would be expected under the CBR-Onsite scenario; and 19 worker injuries and 0.030 worker fatalities would be expected under the CBR-Offsite scenario. Thus, overall risks to workers would be highest under the CBR-Offsite scenario and lowest under the CIP scenario. Differences in worker risks between the three scenarios would largely be driven by off-Site activities.

2.2.4.2 Community Risks

Accidents

Vehicle accidents that occur off-Site can result in injuries or fatalities among community members, as well as workers. Based on the accident statistics reported by US DOT (2020) and the off-Site travel mileages reported in Attachment B, off-Site vehicle accidents could result in an estimated 0.70 injuries and 0.012 fatalities among community members (*i.e.*, people involved in haul truck accidents that are neither haul truck drivers nor passengers, including pedestrians, drivers of other vehicles, *etc*.) under the CIP scenario (Table 2.6). Under the CBR-Onsite scenario, off-Site vehicle accidents could result in an estimated 1.1 community injuries and 0.016 community fatalities. Under the CBR-Offsite scenario, off-Site vehicle accidents could result in an estimated 24 community injuries and 0.76 community fatalities. Risks to community members arising from vehicle accidents are therefore much higher under the CBR-Offsite scenario than under the other two scenarios.

Table 2.6 Expected Number of Community Accidents Under Each Closure Scenario

Off-Site Vehicle Use Category	CIP		CBR-Onsite		CBR-Offsite	
	Injuries	Fatalities	Injuries	Fatalities	Injuries	Fatalities
Hauling	0	0	0	0	19	0.69
Labor Mobilization/Demobilization	0.56	0.0071	0.98	0.012	4.5	0.057
Equipment Mobilization/Demobilization	0.024	0.00088	0.047	0.0017	0.27	0.0098
Material Deliveries	0.11	0.0041	0.060	0.0022	0.047	0.0017
Total:	0.70	0.012	1.1	0.016	24	0.76

Notes:
CBR-Offsite = Closure-by-Removal with Off-Site CCR Disposal; CBR-Onsite = Closure-by-Removal with On-Site CCR Disposal; CIP = Closure-in-Place.

Traffic

Haul routes would be expected to use major arterial roads and highways wherever possible, which would reduce the incidence of traffic. However, the heavy use of local roads for construction operations may result in traffic near the Site and the off-Site landfill. Traffic could potentially cause travel delays on local roads and cause damage to local roadways. It could also cause delays in the re-development of the Site for installation of a solar facility on the capped impoundment.

Traffic may increase temporarily around the Site under all closure scenarios due to the daily arrival and departure of the workforce, equipment mobilization/demobilization, and material deliveries. However, these impacts would be expected to largely occur at the beginning or end of each work day (for the arrival/departure of the work force), at the beginning or end of the construction period (for equipment mobilization/demobilization), and at specific times throughout the construction period (for material deliveries). These impacts would therefore likely be less disruptive to community members than the constant and steady movement of haul trucks to and from the Site due to CCR hauling.

Off-Site CCR hauling would only be required under the CBR-Offsite scenario. Under this scenario, hauling-related construction activities would be expected to span approximately 3,960 working days and require approximately 345,000 truckloads (Attachment B). Assuming 10-hour working days, a haul truck would need to pass a given location near the Site once every 3.4 minutes on average for the duration of hauling-related activities under this closure scenario.

Noise

Construction generates a great deal of noise, both in the vicinity of the Site and along haul routes. In a closure impact analysis performed by the Tennessee Valley Authority (TVA, 2015), the authors found that "[T]ypical noise levels from construction equipment used for closure are expected to be 85 dBA or less when measured at 50 ft. These types of noise levels would diminish with distance…at a rate of approximately 6 dBA per each doubling of distance and therefore would be expected to attenuate to the recommended EPA noise guideline of 55 dBA at 1,500 ft." Because there are no residences or businesses within 1,500 feet of any of the construction areas on the Site (the impoundment, the on-Site borrow soil location, and the on-Site landfill), we do not anticipate that any residences or businesses would be adversely impacted by noise pollution at the Site under any closure scenario. However, recreators and wildlife on Newton Lake or within the greater Newton Lake SFWA, which lie within 1,500 feet of the PAP, could be temporarily impacted by construction noise under all scenarios. Noise impacts in the vicinity of the Site would likely be smaller under the CIP scenario than under the CBR-Onsite and CBR-Offsite scenarios, because the overall duration of construction would be shorter under the CIP scenario than under the two CBR scenarios (3.2 to 4.3 years for CIP *vs*. 7.8 to 9.2 years for CBR-Onsite *vs*. 22 years for CBR-Offsite).

In addition to impacts in the immediate vicinity of planned construction areas at the Site, local roads near the Site and the off-Site landfill may also experience noise pollution under the CBR-Offsite scenario due to high volumes of haul truck traffic. As described above (Traffic), the construction schedule for the CBR-Offsite scenario requires haul trucks to pass by a given location every 3.4 minutes on average for 10 hours each day over the course of approximately 3,960 working days. Dump trucks generate significant noise pollution, with noise levels of approximately 88 decibels or higher expected within a 50-foot radius of the truck (Exponent, 2018). This noise level is similar to the noise level of a gas-powered lawnmower or leaf blower (CDC, 2019). Decibel levels above 80 can damage hearing after 2 hours of exposure (CDC, 2019).

In addition to haul truck impacts, noise pollution may also arise under all closure scenarios due to the daily arrival and departure of the workforce, equipment mobilization/demobilization, and material deliveries. These impacts would be expected to largely occur at the beginning or end of each work day (for the arrival/departure of the work force), at the beginning or end of the construction period (for equipment mobilization/demobilization), and at specific times throughout the construction period (for material deliveries). These impacts would therefore likely be less disruptive to community members than the constant and steady movement of haul trucks to and from the Site. As such, off-Site noise impacts are likely to be greatest under the CBR-Offsite scenario (for which substantial off-Site hauling is required) and least under the CIP and CBR-Onsite scenarios (for which no off-Site hauling is required).

Air Quality

Construction can adversely impact air quality. Air pollution can occur both on-Site and off-Site (*e.g.*, along haul routes), potentially impacting workers as well as community members. With regard to construction activities, two categories of air pollution are of particular concern: equipment emissions and fugitive dust. The equipment emissions of greatest concern are those found in diesel exhaust. Most construction equipment is diesel-powered, including the dump trucks that would be used to haul material to and from the Site. Diesel exhaust contains numerous air pollutants, including nitrogen oxides (NO_x), particulate matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs; Hesterberg *et al*., 2009; Mauderly and Garshick, 2009). Fugitive dust, another major air pollutant at construction sites, is generated by earthmoving operations and other soil- and CCR-handling activities. Along haul routes, an additional source of fugitive dust is road dust along unpaved dirt roads. Careful planning and the use of Best Management Practices (BMPs) such as wet suppression are used to minimize and control fugitive dust during construction activities; however, it is not possible to prevent dust generation entirely.

On-Site, emissions would be higher under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, due to the greater amount of on-Site vehicle and equipment travel miles required under these scenarios (912,000 total on-Site travel miles under the CIP scenario *versus* 1,910,000 total on-Site travel miles under the CBR-Onsite scenario *versus* 4,570,000 total on-Site travel miles under the CBR-Offsite scenario; Tables 2.1 through 2.3). Off-Site, emissions would be substantially higher under the CBR-Offsite scenario than under the CIP and CBR-Onsite scenarios, due to the demands of off-Site hauling (2,640,000 total off-Site travel miles under the CIP scenario *versus* 4,230,000 total off-Site travel miles under the CBR-Onsite scenario *versus* 70,700,000 total off-Site travel miles under the CBR-Offsite scenario).

Environmental Justice

The State of Illinois defines EJ communities to be those communities with a minority population above twice the state average and/or a total population below twice the state poverty rate (IEPA, 2019b).

IEPA's EJ Start mapper (IEPA, 2019b) uses income and demographics data collected by the U.S. Census Bureau to map all of the EJ communities throughout the state. In order to extend the boundaries of the EJ Start mapper into the neighboring state of Indiana (the location of the preferred off-Site landfill), Gradient used U.S. Census Bureau data reported in the national-level EJScreen tool (US EPA, 2020) to create a new EJ community mapping tool that was identical to EJ Start for communities in Illinois but also included EJ communities located in Indiana.

Gradient's analysis demonstrated that the outer perimeters of the 1-mile buffer zones for the two EJ communities located closest to the Site (the EJ community near Effingham, IL and the EJ community near Olney, IL) are both located approximately 15.5 miles from the Site (Figure 2.1). As described above (Noise), significant noise impacts due to construction are expected to be limited to potential receptors located within 1,500 ft (0.28 miles) of the Site. Similarly, the air quality impacts of construction are expected to be limited to potential receptors located within 1,000 ft (0.19 miles) of the Site (CARB, 2005; BAAQMD, 2017). Along heavily trafficked roadways, air quality impacts are expected to be limited to potential receptors located within 600 feet of the roadway (0.11 miles; US EPA, 2014). Thus, the EJ communities near Effingham and Olney are unlikely to be directly impacted by on-Site air emissions, noise pollution, or other negative impacts arising at the Site. However, they may be impacted by off-Site impacts, including CCR hauling (CBR-Offsite scenario only), labor and equipment mobilization/demobilization, and material deliveries. Off-Site impacts due to labor and equipment mobilization/demobilization and material deliveries would be expected to be diffuse (*i.e.,* to span a wide range of transport routes originating over a wide area). Additionally, these impacts would be expected to largely occur at the beginning or end of each work day (for the arrival/departure of the work force), at the beginning or end of the construction period (for equipment mobilization/demobilization), and at specific times throughout the construction period (for material deliveries). Hauling, in contrast, would rely on a single transport route that would be in continuous use throughout the entire excavation period. Off-Site hauling is therefore more likely to have a significant impact on EJ communities than other types of off-Site vehicle use.

Under the CBR-Offsite scenario, EJ communities located along the haul route to the off-Site landfill or near the off-Site landfill itself could potentially be negatively impacted throughout the excavation period by the air pollution, noise, traffic, and accidents generated by CCR-hauling activities. Figure 2.1 demonstrates that the off-Site landfill is not located within one mile of any EJ communities. However, based on the three major haul routes suggested by Google Maps (Google, 2022), transport of CCR to the off-Site landfill could potentially entail hauling CCR through the EJ communities near Lawrenceville, IL, Vincennes, IN, or Terre Haute, IN (Figure 2.1; IEPA, 2019b; US EPA, 2020).

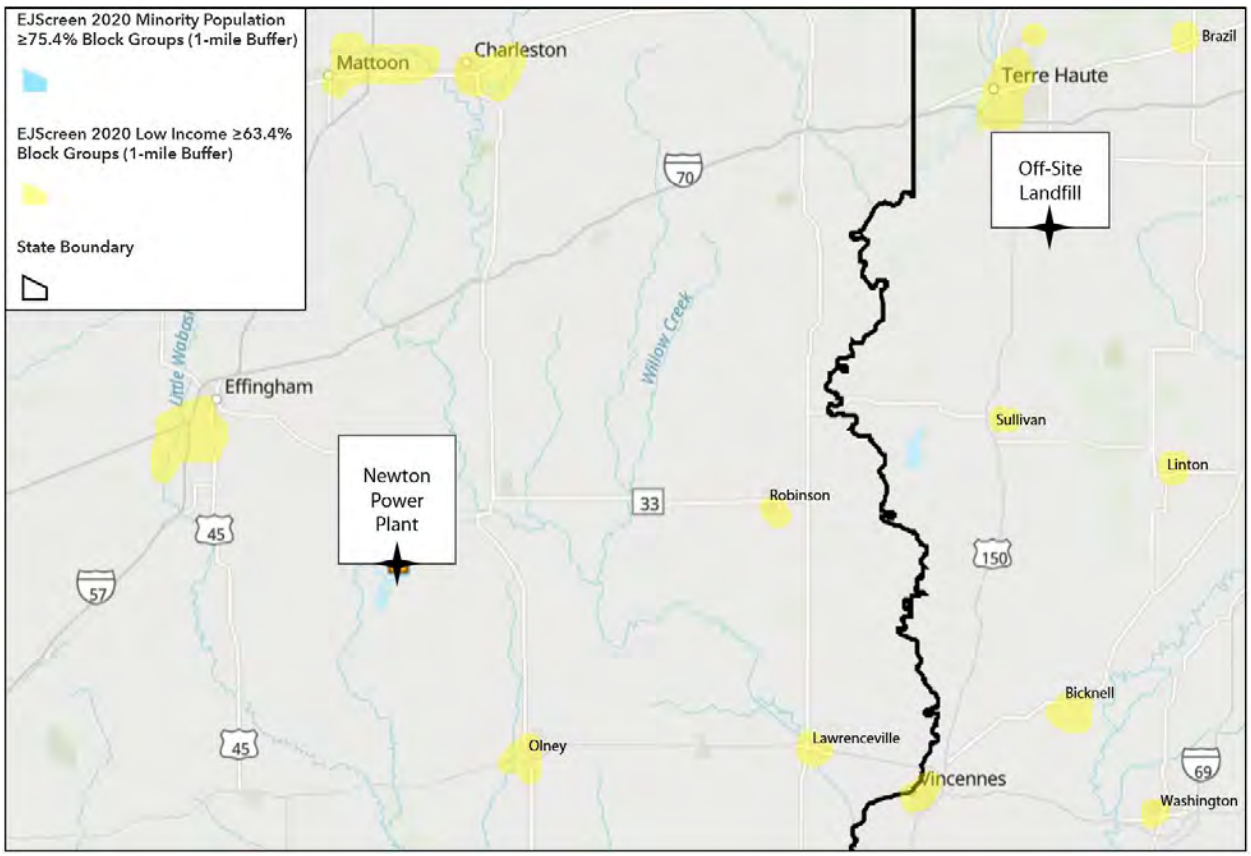

Figure 2.1 Environmental Justice Communities in the Vicinity of the Site and the Off-Site Landfill. Sources: IEPA (2019b) and US EPA (2020).

Scenic, Historical, and Recreational Value

During construction activities, negative impacts on scenic and recreational value may occur on Newton Lake and within the greater Newton Lake SFWA. Noise impacts were described above. In addition, construction activities at the PAP may be visible to recreators using Newton Lake and the Newton Lake SFWA, potentially interfering with enjoyment of the view. Negative impacts would not be expected to occur within any scenic, recreational, or conservation areas located further away from the Site, including the Prairie Ridge State Natural Area and Jasper County Prairie Chicken Sanctuary. Because the expected duration of construction activities is longer under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario (3.2 to 4.3 years for CIP *vs*. 7.8 to 9.2 years for CBR-Onsite *vs*. 22 years for CBR-Offsite), short-term impacts on the scenic and recreational value of natural areas near the Site would be greater under these two closure scenarios than under the CIP scenario.

Based on a review of the IDNR Historic Preservation Division database and the Illinois State Archaeological Survey database, there are no historic sites located within 1,000 meters of the PAP or the on-Site landfill (Ramboll, 2021).

2.2.4.3 Environmental Risks

Greenhouse Gas Emissions

In addition to the air pollutants listed above in Section 2.2.4.2, construction equipment emits greenhouse gases (GHGs), including carbon dioxide (CO_2) and possibly nitrous oxide (N_2O). The potential impact of each closure scenario on GHG emissions is proportional to the potential impact of each closure scenario on other emissions from construction vehicles and equipment, as described above in Section 2.2.4.2. In summary, GHG emissions from construction equipment and vehicles would be far greater under the CBR-Offsite scenario than under the CIP and CBR-Onsite scenarios, because the total on-Site and off-Site vehicle and equipment travel miles required under the CBR-Offsite scenario (75,300,000 miles) is greater than those required under the CIP scenario (3,550,000 miles) and the CBR-Onsite scenario (6,150,000 miles; Tables 2.1 through 2.3).

We did not quantify the carbon footprint of the approximately 268 acres of geomembrane liner material required for the final PAP cover system under the CIP scenario. The carbon footprint of this geomembrane (*i.e.*, the fossil fuel emissions required to manufacture it) is an additional source of GHG emissions at the Site under the CIP scenario. Expansion of the on-Site landfill under the CBR-Onsite scenario and the potential expansion of the off-Site landfill under the CBR-Offsite scenario would have an additional, unquantified carbon footprint due to the manufacture of geomembranes used in the expanded landfill liners.

Energy Consumption

Energy consumption at a construction site is synonymous with fossil fuel consumption, because the energy to power construction vehicles and equipment comes from the burning of fossil fuels. Fossil fuel demands considered in this analysis include the burning of diesel fuel during construction activities and the carbon footprint of manufacturing geomembrane textiles. Because GHG emission impacts and energy consumption impacts both arise from the same sources at construction sites, the trends discussed above with respect to GHG emissions also apply to the evaluation of energy demands. Specifically, the energy demands of construction equipment and vehicles would be far greater under the CBR-Offsite scenario than under the CIP or CBR-Onsite scenarios. We did not quantify the energy demands of the geomembranes required for the construction of the final cover system under the CIP scenario, the geomembranes required for the expansion of the on-Site landfill under the CBR-Onsite scenario, or, potentially, the geomembranes required for expansion of the off-Site landfill under the CBR-Offsite scenario.

The Newton Power Plant Site is slated for re-development as a utility-scale solar power generating facility and a battery energy storage facility. The installation of the utility-scale solar power generating facility and a battery energy storage facility will provide additional tax revenue to the local community, create jobs, benefit the reliability of the electrical grid, and support Illinois' path toward 100 percent clean energy by 2050. The CIP scenario would result in more rapid re-development of a solar facility on the capped impoundment– and, hence, the more rapid realization of grid-scale solar energy benefits – than the two CBR scenarios.

Natural Resources and Habitat

During closure, major construction activities such as the excavation of the impoundment, the excavation of the borrow area, the expansion of the on-Site landfill, and, potentially, the expansion of the off-Site landfill may require the destruction of some existing habitat atop portions of these construction areas,

resulting in negative impacts to natural resources and habitat within the footprint of these areas. Construction may also have indirect negative impacts on the natural resources and habitat in the immediate vicinity of these locations by causing alarm and escape behavior in nearby wildlife (*e.g.*, due to noise disturbances). Finally, although erosion prevention and sediment control measures will be undertaken under all closure scenarios, it is possible that limited negative short-term impacts could occur to sensitive aquatic species in Newton Lake and the other minor surface water bodies located near the PAP (see Section 1.1.3) due to sediment runoff during construction. Short-term impacts on natural resources and habitat would be greater under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, because the overall duration of construction would be longer under the two CBR scenarios than under the CIP scenario (3.2 to 4.3 years for CIP *vs*. 7.8 to 9.2 years for CBR-Onsite *vs*. 22 years for CBR-Offsite).

In addition to the short-term negative habitat impacts caused by construction activities, closure may also result in long-term shifts in the habitat types overlying the major construction locations associated with closure. This assessment does not make any value judgments regarding the relative value of the habitat types currently overlying these locations and the habitat types that could potentially overlie these locations post-closure under the various closure scenarios.

According to the IDNR Natural Heritage Database, there are 18 endangered species and 7 threatened species within Jasper County (Ramboll, 2021). To our knowledge, however, no threatened or endangered species have been identified at the Site. Based on the information that is currently available, we do not expect construction activities to have negative impacts on any threatened or endangered species.

2.2.5 Time Until Groundwater Protection Standards Are Achieved (IAC Sections 845.710(b)(1)(E) and 845.710(d)(2 and 3))

The time horizon over which GWPSs would be exceeded at the Site is immaterial from a risk perspective, because there is no unacceptable risk associated with exceedances of a GWPS at the Site (see Section 2.2.1). Nonetheless, pursuant to requirements under IAC Section 845.710, this section of the text describes the time required to achieve GWPSs at the Site.

As described above in Section 1.1.4 (Hydrogeology), water and CCR-associated constituents from the PAP may migrate vertically downward until they reach the UD/PMP and the UA. Beneath the PAP, groundwater within the UA generally flows from the north towards the south/southwest, converging near a former drainage feature located along the western edge of the PAP (Ramboll, 2021). In the northern area of the PAP, groundwater from the UA may interact with surface water in Newton Lake, as evidenced by groundwater head elevations in this area that are higher than the surface water level in Newton Lake. Groundwater within the UD/PMP may also interact with surface water in Newton Lake.

At the Newton Site, seasonal variation in groundwater levels generally results in groundwater elevation fluctuations of less than one foot. Surface water elevations in Newton Lake similarly do not fluctuate significantly over time, since the lake elevation is controlled by a dam. As a result, groundwater flow directions at the Site are not generally affected by seasonal variabilities (Ramboll, 2021).

Groundwater modeling was performed to evaluate future groundwater quality in the vicinity of the PAP under each of the proposed closure alternatives (Ramboll, 2022). Model predictions indicate that groundwater concentrations in monitoring wells within the UD/PMP and UA will achieve the GWPS within 20 years after closure under the CIP scenario and within 16 years after closure under both CBR closure scenarios (Ramboll, 2022). The model predicted a four-year time difference when GWPSs are

achieved for CIP (20 years post-closure) and CBR (16 years post-closure) is not significant. Furthermore, because the estimated duration of construction activities for CBR is at least about four years longer than the duration of construction activities for CIP (3.2-4.3 years for CIP compared to 7.8-9.2 years for CBR-Onsite and 22 years for CBR-Offsite; Section 2.1), CIP may actually achieve the GWPSs faster than either the CBR-Onsite or CBR-Offsite scenarios.

Model predictions also indicate that groundwater concentrations will remain above the GWPSs in the UCU for a period of more than 100 years for both the CIP and CBR scenarios. This is due to the retention of constituent mass within the thick, low conductivity layer which underlies the PAP. However, in both the CIP and CBR scenarios, the plume footprint continues to recede over time and remains within the property boundaries, indicating that both closure scenarios perform equivalently with regard to achieving the GWPSs (Ramboll, 2022).

Additionally, changing geochemical conditions during the extended excavation associated with the CBR-Offsite and CBR-Onsite scenarios can be a mechanism that results in the mobilization and increased transport of some constituents in groundwater. This may result in GWPS exceedance durations in excess of the model predictions for the CBR-Offsite and CBR-Onsite scenarios.

2.2.6 Potential for Exposure of Humans and Environmental Receptors to Remaining Wastes, Considering the Potential Threat to Human Health and the Environment Associated with Excavation, Transportation, Re-disposal, Containment, or Changes in Groundwater Flow (IAC Section 845.710(b)(1)(F))

Section 2.2.1 evaluates potential risks to human and ecological receptors arising from the leaching of CCR-associated constituents into groundwater during closure activities and following closure of the PAP. Section 2.2.2 evaluates the potential for CCR releases to occur due to dike failure or overtopping during floods or other storm-related events. In summary, there is no current or future risk to any human or ecological receptors associated with the PAP. Additionally, there is minimal current or future risk of overtopping occurring at the embankments due to flood conditions at the Site. Dike failure due to, *e.g.*, seismic activity and storm-related events is also exceedingly unlikely.

Section 2.2.4 evaluates several potential risks to human health and the environment during closure activities, including risks of accidents occurring among workers; risks to nearby residents and EJ communities related to accidents, traffic-related impacts, noise, and air pollution; and risks to natural resources and wildlife. The findings from this section of the text are summarized in Table S.1 (Summary of Findings).

2.2.7 Long-Term Reliability of the Engineering and Institutional Controls (IAC Section 845.710(b)(1)(G))

Post-closure, there is minimal risk of engineering or institutional failures leading to sudden releases of CCR from the impoundment under the CIP scenario. There is no post-closure risk of engineering or institutional failures under the two CBR scenarios (see Section 2.2.2 above). Additionally, there are no current or future unacceptable risks to any human or ecological receptors under any closure scenario (see Section 2.2.1 above). Moreover, reliable engineering and institutional controls (*e.g.*, a bottom liner, a leachate management system, and groundwater monitoring) would be implemented at the on-Site and off-Site landfills under the CBR-Onsite and CBR-Offsite scenarios. All of the evaluated closure scenarios are therefore reliable with respect to long-term engineering and institutional controls.

2.2.8 Potential Need for Future Corrective Action Associated with the Closure (IAC Section 845.710(b)(1)(H))

Corrective action is expected at the Site. An evaluation of potential corrective measures and corrective actions has not yet been completed, but will be conducted consistent with the requirements in IAC Section 845.660 and IAC Section 845.670.

2.3 Effectiveness of the Closure Alternative in Controlling Future Releases (IAC Section 845.710(b)(2))

2.3.1 Extent to Which Containment Practices Will Reduce Further Releases (IAC Section 845.710(b)(2)(A))

The CCR in the PAP currently poses no unacceptable risks to human health or the environment (Section 2.2.1). Because current conditions do not present a risk to human health or the environment, and dissolved constituent concentrations would be expected to decline post-closure, there would also be no unacceptable risks to human health or the environment following closure, regardless of the closure scenario.

Section 2.2.2 discussed the potential for dike failure or overtopping to occur during or following closure activities, resulting in a sudden release of CCR. That analysis showed that there is minimal risk of sudden CCR releases occurring during or following closure under any closure scenario.

2.3.2 Extent to Which Treatment Technologies May Be Used (IAC Section 845.710(b)(2)(B))

Under all three closure scenarios, water generated during the dewatering and unwatering of the impoundment would be treated, if necessary, prior to disposal. Following treatment, water from unwatering and dewatering would be discharged to Newton Lake in accordance with the NPDES permit for the facility.

2.4 Ease or Difficulty of Implementing Closure Alternative (IAC Section 845.710(b)(3))

2.4.1 Degree of Difficulty Associated with Constructing the Closure Alternative

CIP using a final cover system is a reliable and standard method for managing and closing impoundments that relies on common construction activities. Dewatering saturated CCR to construct a stabilized final cover system subgrade can present challenges during closure; however, these challenges are common to most CCR surface impoundment closures and are commonly addressed *via* surface water management and dewatering techniques.

Excavation and landfilling of CCR is also a reliable and standard method for closing impoundments. However, relative to CIP, CBR-Onsite and CBR-Offsite pose additional implementation difficulties due to higher earthwork volumes and higher dewatering volumes, and longer construction schedules. Relative to the CBR-Onsite scenario, hauling would be far more difficult to implement under the CBR-Offsite scenario due to the longer haul distance required for off-Site disposal than for on-Site disposal

(approximately 75 miles *versus* 1 mile) and the need to haul the CCR over public roads. Hauling over public roads rather than private roads would require the use of lower-volume haul trucks (16.5 CY *versus* 34 CY), which would increase the number of trucks and trips required for CCR excavation and transport. Additionally, because the CBR-Offsite scenario would involve hauling CCR off-Site (*i.e.*, intrastate travel), a higher level of dewatering would be required under this scenario compared to the CBR-Onsite scenario. As described in Section 2.2.4.2 ("Community Risks"), off-Site hauling may also have detrimental community impacts due to vehicle accidents, traffic-related impacts, noise, and air pollution.

In addition to off-Site hauling, off-Site landfilling under the CBR-Offsite scenario may pose particular challenges. A disposal plan would need to be developed between IPGC and the owner/operator of the third-party landfill in order to outline acceptable waste conditions upon delivery, daily waste production rates, and the expected duration of the project. Off-Site landfilling may additionally raise issues related to the co-disposal of CCR and other non-hazardous wastes and may require additional permitting. Finally, the construction schedule for excavation may be negatively impacted if, during the course of closure, it is determined that the off-Site landfill must be expanded in order to receive all of the materials excavated from the PAP.

2.4.2 Expected Operational Reliability of the Closure Alternative

There is no post-closure risk of operational failures leading to sudden releases of CCR from the impoundment under the two CBR scenarios. There is minimal post-closure risk of sudden CCR releases occurring under the CIP scenario, because: (i) the final cover system will be constructed and maintained in accordance with all relevant state and federal safety regulations, and (ii) the dikes, final cover, and stormwater control features have all been designed to withstand earthquakes and storm events (see Section 2.2.2 above). Moreover, appropriate operational controls are expected to be implemented at the on-Site and off-Site landfills under the CBR-Onsite and CBR-Offsite scenarios. As such, operational reliability would be expected under all closure scenarios.

2.4.3 Need to Coordinate with and Obtain Necessary Approvals and Permits from Other Agencies

Permits and approvals would be needed under all closure scenarios. Components of the three closure scenarios that would be expected to require a permit include:

- A modification to the existing NPDES permit through IEPA to allow the disposal of water generated from unwatering and dewatering operations to Newton Lake *via* the existing NPDES-permitted outfall for the Site;
- A construction permit from the Illinois Department of Natural Resources, Office of Water Resources, Dam Safety Program to allow the embankment and spillways of the PAP to be modified as part of closure;
- A construction stormwater permit through IEPA, including construction stormwater controls and other BMPs such as silt fences and other measures; and
- A joint water pollution control construction and operating permit (WPC permit).

As discussed below in Section 2.4.5, the existing on-Site landfill would require expansion under the CBR-Onsite scenario in order to accommodate all of the material excavated from the PAP. Expansion of the onsite landfill would require permitting from the IEPA Bureau of Land, under Title 35 Section 811 and 812, and approval from local government. Under the CBR-Offsite scenario, it may similarly be

necessary to expand the off-Site landfill. Additional permitting may be required under this scenario for transport of the CCR and to expand the off-Site landfill. It may also be necessary to modify the operating plan for the off-Site landfill in order to accommodate the increased rate of filling of the landfill and the likely need for additional equipment and personnel to manage the receipt and disposal of the CCR.

2.4.4 Availability of Necessary Equipment and Specialists

CIP, CBR-Onsite, and CBR-Offsite are reliable and standard methods for managing waste that rely on common construction equipment and materials and typically do not require the use of specialists, outside of typical construction labor and equipment operators. However, global supply chains have been disrupted due to the COVID-19 pandemic, resulting in shortages in the availability of construction equipment and parts. There may be some shortages in construction equipment under all scenarios, if supply chain resilience does not improve by the time of construction. Alternatively, extended downtime may be required for equipment repairs and maintenance. A national shortage of truck drivers has also developed during the COVID-19 pandemic. Due to higher earthwork volumes and a longer construction schedule under the CBR-Onsite and CBR-Offsite scenarios than under the CIP scenario, shortages in construction equipment may cause greater challenges under these scenarios than under the CIP scenario. The current shortage of truck drivers may be particularly impactful under the CBR-Offsite scenario, due to the large volume of CCR to be hauled from the Site. If sufficient trucks and truck drivers are not available, the construction schedule at the impoundment may lengthen based on hauling-related delays.

The availability of critical materials such as metal, wood, and electronic chips has also been impacted by the COVID-19 pandemic. However, soil materials and geomembrane liner materials have generally been available during 2021 and early 2022 for landfill development and closure projects.

2.4.5 Available Capacity and Location of Needed Treatment, Storage, and Disposal Services

Under the CIP scenario, all of the CCR currently within the PAP would be stored within the existing footprint of the PAP. Treatment would consist of unwatering the PAP at the start of construction, performing limited dewatering to stabilize the CCR subgrade, and managing stormwater inflow. Water from unwatering and dewatering of the PAP would be discharged in accordance with the NPDES permit for the facility. Under the two CBR scenarios, water treatment would similarly consist of unwatering and dewatering the PAP at the start of construction and discharging water from unwatering/dewatering in accordance with the NPDES permit for the facility. Due to the need for dewatering prior to CCR hauling, a higher volume of water would be expected to be generated during dewatering under the two CBR scenarios than under the CIP scenario.

Under the CBR-Onsite and CBR-Offsite scenarios, 5.7 million CY of CCR would be excavated from the PAP and require disposal. The existing landfill on the Newton Power Plant property does not have sufficient capacity to receive all of the CCR that is currently slated for landfilling under the CBR-Onsite scenario. Expansion of the on-Site landfill would thus be necessary. The steps required for on-Site landfill expansion were described above in Section 2.1.2. Under the CBR-Offsite scenario, CCR would be sent to the Sycamore Ridge Landfill in Pimento, Indiana, which is located approximately 75 miles from the Site (Attachment B). The Sycamore Ridge Landfill has approximately 10 million CY of remaining capacity, and should therefore be able to accept all of the material excavated from the PAP without expansion (Attachment B). However, closure of the PAP would increase the annual waste receipt rate at the off-Site landfill. Due to the short time frame over which CCR would be received at the landfill, vertical and/or lateral expansions may become necessary. Additionally, the landfill operators may need to develop a disposal plan to account for the increased volume of material that would be received and the unique CCR waste characteristics. Elements of this disposal plan might include increasing daily

operational capacity and procedures, expediting planned airspace construction, and potentially expediting landfill expansion.

2.5 Impact of Closure Alternative on Waters of the State (IAC Section 845.710(d)(4))

As demonstrated in Gradient's Human Health and Ecological Risk Assessment (Attachment A), both modeled and measured surface water concentrations in Newton Lake are below relevant human health and ecological screening benchmarks. Surface water concentrations of CCR-associated constituents would be expected to decline over time under all closure scenarios. Thus, no current or future exceedances of any human health or ecological screening benchmarks would be anticipated under any closure scenario.

The lined landfills that would receive the CCR excavated from the impoundment under the CBR-Onsite and CBR-Offsite scenarios would be managed to ensure that no surface water impacts would occur in the vicinity of the landfill. In summary, no impacts on any waters of the state would be expected under any closure scenario.

2.6 Concerns of Residents Associated with Closure Alternatives (IAC Section 845.710(b)(4))

Several nonprofits representing community interests near the Site have raised concerns regarding the potential impacts of the PAP on groundwater and surface water quality, including Earthjustice, the Prairie Rivers Network, and the Sierra Club (Earthjustice *et al*., 2018; Sierra Club and CIHCA, 2014). These parties generally prefer CBR to CIP, citing fears that allowing CCR to remain in place "allows the widespread groundwater contamination to continue indefinitely" (Earthjustice *et al*., 2018). However, it is not the case that closing the PAP *via* CIP rather than CBR would result in undue risks to groundwater and surface water post-closure. As described in Sections 2.2.1 and 2.2.2, no current or future unacceptable risks to human or ecological receptors are associated with the PAP under any scenario. There is also minimal risk of future CCR releases occurring under any scenario. Furthermore, groundwater modeling conducted at the Site demonstrated that both closure scenarios perform equivalently with regard to achieving the GWPSs (Ramboll, 2022). All three closure scenarios are therefore responsive to residents' concerns regarding impacts to groundwater and surface water quality. Additionally, the CIP and CBR-Onsite scenarios have several advantages over the CBR-Offsite scenario with regard to likely community concerns. Specifically, because the CIP and CBR-Onsite scenarios do not require any off-Site hauling, they present fewer risks to workers, nearby residents, and potentially EJ communities than the CBR-Offsite scenario during construction in the form of off-Site accidents, traffic-related impacts, noise, and air pollution (Section 2.2.4 above). Closure would also be achieved more rapidly under the CIP scenario than under the CBR-Onsite and CBR-Offsite scenarios, due to the shorter duration of construction activities. Finally, the Site can be more rapidly re-developed for installation of solar panels on the capped impoundment under the CIP scenario than under the CBR-Onsite and CBR-Offsite scenarios. Re-development of the Site for use in solar generation and battery energy storage would bring new jobs to the community and contribute positively to Illinois's growing renewable energy portfolio.

A public meeting was held on May 24, 2022, pursuant to requirements under IAC Section 845.710(e). Questions raised by attendees were addressed at the meeting; subsequently, a written summary of the questions and responses was prepared.

2.7 Class 4 Estimate (IAC Section 845.710(d)(1))

Analyses in the Final Closure Plan were prepared consistent with Class 4 estimates based on the Association for the Advancement of Cost Engineering (AACE) Classification Standard (or a comparable classification practice as provided in the AACE Classification Standard), as required by IAC Section 845.710 (IEPA, 2021a).

2.8 Summary

Table S.1 (Summary of Findings) summarizes the expected impacts of the CIP, CBR-Onsite, and CBR-Offsite closure scenarios with regard to each of the factors specified under IAC Section 845.710 (IEPA, 2021). Based on this evaluation and the details provided in Section 2 above, CIP has been identified as the most appropriate closure scenario for the PAP. Key benefits of the CIP scenario relative to the CBR-Onsite and CBR-Offsite scenarios include more rapid re-development of the Site for installation of solar panels on the capped impoundment and reduced impacts to workers, community members, and the environment during construction (*e.g.*, fewer constructed-related accidents, lower energy demands, less air pollution and GHG emissions, reduced duration of traffic-related impacts, and potentially lower impacts to EJ communities). Moreover, the CIP scenario will meet the requred closure schedule (*i.e.*, closure completed by October 2028) defined in IAC Section 845.700(d)(2)(C)(ii) (IEPA, 2021a), whereas the CBR-Onsite and CBR-Offsite scenarios will be unable to meet this required schedule.

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Attachment A

Human Health and Ecological Risk Assessment

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Human Health and Ecological Risk Assessment
Primary Ash Pond
Newton Power Plant
Newton, Illinois

July 28, 2022

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Abbreviations

ADI	Acceptable Daily Intake
BCF	Bioconcentration Factor
BCG	Biota Concentration Guide
BCU	Bedrock Confining Unit
CAA	Closure Alternatives Assessment
CCR	Coal Combustion Residual
CEM	Conceptual Exposure Model
COI	Constituent of Interest
COPC	Constituent of Potential Concern
CSF	Cancer Slope Factor
CSM	Conceptual Site Model
ESV	Ecological Screening Value
GWPS	Groundwater Protection Standard
GWQS	Groundwater Quality Standards
HTC	Human Threshold Criteria
IAC	Illinois Administrative Code
IDNR	Illinois Department of Natural Resources
IEPA	Illinois Environmental Protection Agency
ILWATER	Illinois Water and Related Wells
IPGC	Illinois Power Generating Company
ISGS	Illinois State Geological Survey
LCU	Lower Confining Unit
LF 1	Phase 1 Landfill
LF 2	Phase 2 Landfill
MCL	Maximum Contaminant Level
NPDES	National Pollutant Discharge Elimination System
NPP	Newton Power Plant
NRWQC	National Recommended Water Quality Criteria
ORNL RAIS	Oak Ridge National Laboratory's Risk Assessment Information System
PAP	Primary Ash Pond
PMP	Potential Migration Pathway
PRG	Preliminary Remediation Goal
RfD	Reference Dose
RME	Reasonable Maximum Exposure
RSL	Regional Screening Level
SWQS	Surface Water Quality Standards
TEC	Threshold Effect Concentration
TSS	Total Suspended Solids
UA	Uppermost Aquifer
UCU	Upper Confining Unit
UD	Upper Drift
US DOE	United States Department of Energy
US EPA	United States Environmental Protection Agency

1 Introduction

Illinois Power Generating Company's (IPGC) Newton Power Plant (NPP, or "the Site") is an electric power generating facility with coal-fired units located approximately seven miles southwest of the city of Newton, Illinois. The facility began operating in approximately 1977 and will be retired by the end of 2027 (Meeker, 2020; Ramboll, 2021). The NPP has one surface impoundment for storage of coal combustion residuals (CCR), known as the Primary Ash Pond (PAP), that was constructed in 1977 and covers approximately 404 acres (Ramboll, 2021). Closure of the PAP (Illinois Environmental Protection Agency [IEPA] ID No. W0798070001-01), which is the subject of this report, is planned to commence by the end of 2022.

This report presents the results of an evaluation that characterizes potential risk to human and ecological receptors that may be exposed to CCR constituents in environmental media originating from the PAP. This risk evaluation was performed to support the Closure Alternatives Assessment (CAA) for the PAP in accordance with requirements in Title 35 Part 845 of the Illinois Administrative Code (IAC) (IEPA, 2021). Human and ecological risks were evaluated for Site-specific constituents of interest (COIs). The conceptual site model (CSM) assumed that Site-related COIs in groundwater may migrate to the adjacent Newton Lake and affect surface water and sediment in the vicinity of the Site.

Consistent with United States Environmental Protection Agency (US EPA) guidance (US EPA, 1989), this report used a tiered approach to evaluate potential risks, which included the following steps:

1. Identify complete exposure pathways and develop a conceptual exposure model (CEM).
2. Identify Site-related COIs: Constituents detected in groundwater were considered COIs if their maximum detected concentration over the period from 2015 to 2021 exceeded a groundwater protection standard (GWPS) identified in Part 845.600 (IEPA, 2021), or a relevant surface water quality standard (IEPA, 2019; US EPA Region IV, 2018).
3. Perform screening-level risk analysis: Compare maximum measured or modeled COI concentrations in surface water and sediment to conservative, health-protective benchmarks in order to determine constituents of potential concern (COPCs).
4. Perform refined risk analysis: If COPCs are identified, perform a refined analysis to evaluate potential risks associated with the COPCs.
5. Formulate risk conclusions and discuss any associated uncertainties.

This assessment relies on a conservative (*i.e.*, health-protective) approach and is consistent with the risk approaches outlined in US EPA guidance. Specifically, we considered evaluation criteria detailed in IEPA guidance documents (*e.g.*, IEPA, 2013, 2019), incorporating principles and assumptions consistent with the Federal CCR Rule (US EPA, 2015a) and US EPA's "Human and Ecological Risk Assessment of Coal Combustion Residuals" (US EPA, 2014).

US EPA has established acceptable risk metrics. Risks above these US EPA-defined metrics are termed potentially "unacceptable risks". Based on the evaluation presented in this report, no unacceptable risks to human or ecological receptors resulting from CCR exposures associated with the PAP were identified. This means that the risks from the Site are likely indistinguishable from normal background risks. Specific risk assessment results include the following:

- No unacceptable risks were identified for recreators boating in Newton Lake adjacent to the Site.
- No unacceptable risks were identified for recreators exposed to sediment in Newton Lake adjacent to the Site.
- No unacceptable risks were identified for anglers consuming locally caught fish.
- No unacceptable risks were identified for ecological receptors exposed to surface water or sediment.
- No bioaccumulative ecological risks were identified.

It should be noted that this evaluation incorporates a number of conservative assumptions that tend to overestimate exposure and risk. Moreover, it should be noted that because current conditions do not present a risk to human health or the environment, there will also be no unacceptable risk to human health or the environment for future conditions when the PAP is closed. For all future closure scenarios, potential releases of CCR-related constituents will decline over time and consequently potential exposures to CCR-related constituents in the environment will also decline.

2 Site Overview

2.1 Site Description

The NPP is located in Jasper County Illinois, approximately seven miles southwest of the city of Newton. The PAP is located south of the power plant in a predominantly agricultural area. The PAP is surrounded by Newton Lake on the west, south, and east (Figure 2.1) (Ramboll, 2021). Three CCR units are present on the NPP property, including the PAP and two landfills; the Phase 1 Landfill (LF 1) is located northwest and west of the PAP, and the Phase 2 Landfill (LF 2) is located west of the PAP. The PAP is the subject of this report (Ramboll, 2021). The PAP discharges into a secondary pond located immediately south of the PAP, which then discharges to Newton Lake under a National Pollutant Discharge Elimination System (NPDES) permit (No. IL0049191) (Ramboll, 2021).

Newton Lake was formed by the construction of a dam in 1975 (US National Dams, 2022), and is used as a cooling water supply for the NPP (IDNR, 2019). Water is drawn from the eastern arm near the power plant and thermal effluent is released at two locations in the western arm via NPDES permitted outfalls (IEPA, 2016).



Figure 2.1 Site Location Map. Source: Ramboll, 2021.

2.2 Geology/Hydrogeology

The geology underlying the Site in the vicinity of the PAP primarily consists of unlithified deposits overlying a shale bedrock unit. The principal types of unlithified materials include the Peoria Silt /Sangman Soil, the Hagarstown Member, the Vandalia Till, the Mulberry Grove Member, and the Smithboro Till/Banner Formation (Ramboll, 2021). These unlithified deposits are underlain by a Pennsylvanian Age shale bedrock of the Mattoon Formation (Ramboll, 2021). Five distinct hydrostratigraphic units in the area are (listed from ground surface down): the Upper Drift (UD)/Potential Migration Pathway (PMP), the Upper Confining Unit (UCU), the Uppermost Aquifer (UA), the Lower Confining Unit (LCU), and the Bedrock Confining Unit (BCU) (Ramboll, 2021).

The UD is composed of low permeability silts and clays of the Peoria Silt and Sangamon Soil and the sandier soils of the Hagarstown Member (*i.e.*, PMP). The Hagarstown Member is generally 2 feet (ft) thick but is encountered at thicknesses up to about 6.9 ft in the vicinity of the Ash Pond (Ramboll, 2021). The UD/PMP has a geometric mean horizontal hydraulic conductivity of 3.1 x 10^{-3} cm/s (Ramboll, 2021). The UA is composed of a 3 to 17 ft thick Mulberry Grove Member, which consists of sand, silty- and clayey-sand, and gravel. The UA has a geometric mean horizontal hydraulic conductivity of 6.8 x 10^{-3} cm/s (Ramboll, 2021). The UA is sandwiched between two low-permeability confining units: (i) the UCU on

top consisting of clay and silt of the Vandalia Till and (ii) the LCU on bottom consisting of silt and clay of the Smithboro Till Member and the Banner Formation (Ramboll, 2021). No wells are screened within the UCU, the LCU, or the underlying shale BCU. Field hydraulic conductivity tests were not performed in any of these confining units (Ramboll, 2021).

Groundwater within the UA flows generally from the north towards the south and southwest. In the southern area of the PAP, groundwater flows toward a former drainage feature located west of the PAP (Ramboll, 2021). In the northern area of the PAP, groundwater from the UA may interact with surface water in Newton Lake, as evidenced by relatively higher groundwater head elevations compared to the Newton Lake water level. Groundwater velocities in the UA range from 0.04 to 1.9 ft/day. Horizontal hydraulic gradients calculated for the UA range from 0.0025 to 0.0071 ft/ft (Ramboll, 2021). Groundwater within the UD/PMP may also flow into Newton Lake; however, flow velocity or hydraulic gradient have not been calculated or measured within the PMP (Ramboll, 2021).

2.3 Conceptual Site Model

A CSM describes sources of contamination, the hydrogeological units, and the physical processes that control the transport of water and solutes. In this case, the CSM describes how groundwater underlying the PAP migrates and interacts with surface water and sediment in the adjacent Newton Lake. The CSM was developed using available hydrogeologic data specific to the PAP (Ramboll, 2021), including information on groundwater flow and surface water characteristics.

CCR-related constituents may migrate vertically downward beneath the PAP and into groundwater; these constituents may subsequently migrate with groundwater in the UA and the PMP and flow into the eastern arm of Newton Lake. CCR-related constituents from the PAP may migrate vertically downward through the UD/PMP and the UCU into the UA (Ramboll, 2021). The north to south groundwater flow within the UA is mostly in the horizontal direction because the UA is underlain by two low-permeability confining units (*i.e.*, LCU and BCU) that inhibit vertical flow (Ramboll, 2021). A component of the CCR-related constituents from the PMP may also flow into Newton Lake, particularly on the eastern portion of the PAP where groundwater and surface water interact. After groundwater flows into the lake, dissolved constituents in groundwater may partition between sediments and surface water.

2.4 Groundwater Monitoring

A total of 29 wells have been used to monitor the groundwater quality near and downgradient of the PAP. Of these, 23 wells are screened in the UA, and 6 wells are screened in the UD (Table 2.1). The analyses presented in this report relied on all available data from the 29 wells collected between 2015 and 2021, which is the period subsequent to the promulgation of the Federal CCR Rule. Groundwater samples were analyzed for a suite of total metals, specified in Illinois CCR Rule Part 845.600 (IEPA, 2021).[1] A summary of the groundwater data used in this risk evaluation is presented in Table 2.2. The PAP well locations are shown in Figure 2.2. Note that there are additional wells in the vicinity of the PAP (shown in Figure 2.1) that were not used in this risk analysis, because they were screened in the CCR and are not reflective of groundwater conditions. The use of groundwater data in this risk evaluation does not imply that detected constituents are associated with the PAP or that they have been identified as potential groundwater exceedances.

[1] Samples were analyzed for a longer list of inorganic constituents and general water quality parameters (chloride, fluoride, sulfate, and total dissolved solids), but these constituents were not evaluated in the risk evaluation.



Figure 2.2 Monitoring Well Locations. Source: Ramboll, 2021, Figure 3-1.

Table 2.1 Groundwater Monitoring Wells Related to Newton Primary Ash Pond

Well	Hydrogeologic Unit	Date Constructed	Screen Top Depth (ft bgs)	Screen Bottom Depth (ft bgs)	Well Depth (ft bgs)
APW02	UD	06/19/2010	9.70	19.70	20.00
APW03	UD	06/18/2010	9.70	19.70	20.00
APW04	UD	06/19/2010	7.70	17.70	18.00
APW05	UA	10/22/2015	62.64	67.44	67.84
APW05S	UD	01/19/2021	10.00	20.00	20.00
APW06	UA	10/21/2015	67.67	72.48	72.88
APW07	UA	11/05/2015	77.89	82.70	83.10
APW08	UA	10/28/2015	71.40	81.06	81.53
APW09	UA	11/03/2015	56.66	61.46	61.85
APW10	UA	11/06/2015	40.74	45.54	45.94
APW11	UA	01/23/2021	60.00	65.00	65.00
APW12	UD	02/21/2021	20.00	30.00	30.00
APW13	UA	01/22/2021	58.50	63.50	63.50
APW14	UA	01/23/2021	50.00	55.00	55.00
APW15	UA	01/22/2021	98.00	103.00	103.00
APW16	UA	01/20/2021	80.50	85.50	85.50
APW17	UA	01/22/2021	87.00	92.00	92.00
APW18	UA	01/21/2021	75.00	80.00	80.00
G48MG	UA	10/20/2015	71.80	76.65	77.06
G202	UA	10/16/1996	64.00	74.00	74.00
G203	UA	11/15/1996	62.50	72.50	72.50
G208	UA	10/13/2011	74.93	94.71	94.80
G217S	UD	08/26/1997	9.00	19.00	19.00
G217D	UA	12/09/2014	--	--	69.30
G222	UA	10/25/2011	64.57	79.24	79.30
G223	UA	10/11/2011	79.09	88.75	89.10
G224	UA	10/05/2011	63.51	73.17	73.50
R202	UA	--	--	--	--
R217D	UA	09/26/2017	60.10	65.03	65.24

Notes:
-- = Data Unavailable.
bgs = Below Ground Surface; ft = Feet; UA = Uppermost Aquifer; UD = Upper Drift.
Source: Ramboll, 2021.

Table 2.2 Groundwater Data Summary

Constituent	Samples with Constituent Detected	Samples Analyzed	Minimum Detected Value	Maximum Detected Value	Maximum Laboratory Detection Limit
Total Metals (mg/L)					
Antimony	2	225	0.0035	0.0036	0.003
Arsenic	204	225	0.001	0.13	0.001
Barium	225	225	0.0075	1.5	0.001
Beryllium	3	225	0.0025	0.0033	0.001
Boron	358	358	0.023	0.66	0.02
Cadmium	4	225	0.0012	0.0034	0.001
Chromium	39	225	0.004	0.09	0.004
Cobalt	37	225	0.002	0.036	0.002
Lead	59	225	0.001	0.065	0.001
Lithium	106	225	0.01	0.3	0.02
Mercury	14	225	0.0002	0.002	0.0002
Molybdenum	195	225	0.0011	0.045	0.001
Selenium	9	225	0.001	0.006	0.001
Thallium	5	225	0.0011	0.0036	0.001
Radionuclides (pCi/L)					
Radium-226+228	225	225	0.0127	15.2	1.85
Other (mg/L, unless otherwise noted)					
Chloride	372	372	8	550	500
Fluoride	316	360	0.258	8.16	6.25
Sulfate	331	370	1	3200	500
Total Dissolved Solids	482	482	300	5500	34

Notes:
pCi/L = PicoCuries Per Liter.

2.5 Surface Water Monitoring

Golder collected a total of 28 surface water samples from Newton Lake in the vicinity of the PAP in April and May, 2021 (Golder Associates Inc., 2021). The sample locations are shown in Figure 2.3, and the sampling results are summarized in Table 2.3.

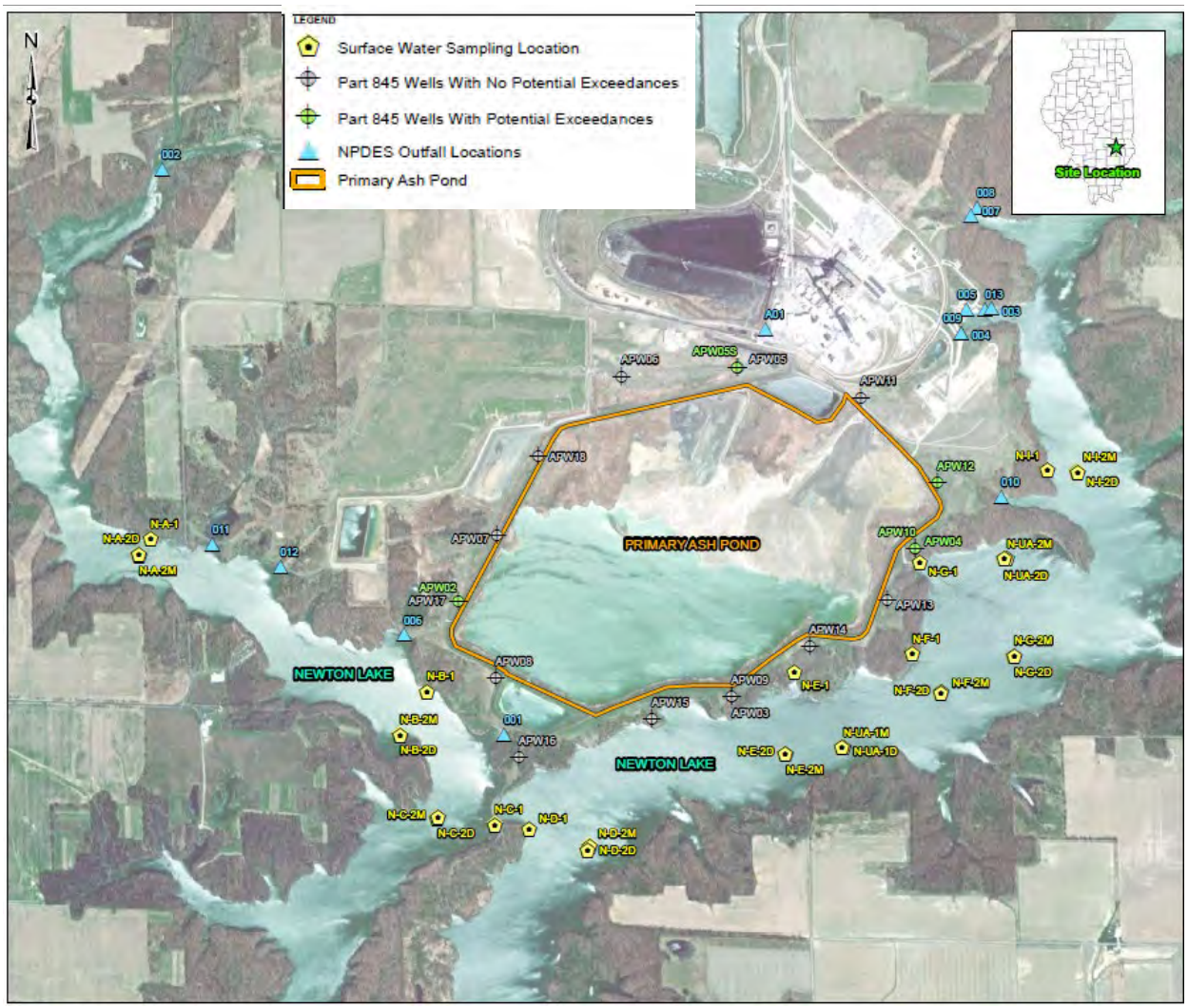

Figure 2.3 Surface Water Sampling Locations. Source: Golder Associates Inc., 2021.

Table 2.3 Surface Water Data Summary

Constituent	Samples with Constituent Detected	Samples Analyzed	Minimum Detected Value	Maximum Detected Value	Maximum Laboratory Detection Limit
Total Metals (mg/L)					
Antimony	0	28			0.003
Arsenic	28	28	0.0018	0.0042	0.001
Barium	28	28	0.052	0.64	0.001
Beryllium	0	28			0.001
Boron	28	28	0.11	0.14	0.01
Cadmium	0	28			0.001
Calcium	28	28	19	22	0.2
Chromium	1	28	0.0067	0.0067	0.004
Cobalt	0	28			0.002
Iron	28	28	0.027	1.2	0.01
Lead	0	28			0.001
Lithium	0	28			0.02
Magnesium	28	28	5.0	5.8	0.1
Manganese	28	28	0.044	0.69	0.001
Mercury	0	28			0.0002
Molybdenum	28	28	0.0046	0.0062	0.001
Potassium	28	28	5.6	10	0.1
Selenium	0	28			0.001
Sodium	28	28	19	22	0.1
Thallium	0	28			0.001
Radionuclides (pCi/L)					
Radium-226+228	28	28	0.012	2.1	1.09
Other (mg/L)					
Chloride	28	28	8.5	9.6	1
Fluoride	28	28	0.35	0.51	0.25
Sulfate	28	28	35	95	25
Total Dissolved Solids	28	28	170	240	34

Notes:

COI = Constituent of Interest; pCi/L = PicoCuries Per Liter.

Surface water was analyzed for both total and dissolved metals; only total metals are reported here because they generally have higher concentrations than dissolved metals. However, the maximum dissolved concentrations for boron, manganese, and molybdenum are slightly higher (up to a factor of two) than the maximum total concentrations, but boron, manganese, and molybdenum have not been identified as COIs.

3 Risk Evaluation

3.1 Risk Evaluation Process

A risk evaluation was conducted to determine whether constituents present in groundwater underlying and downgradient of the PAP have the potential to pose adverse health effects to human and ecological receptors. The risk evaluation is consistent with the principles of risk assessment established by US EPA and has considered evaluation criteria detailed in Illinois guidance documents (*e.g.*, IEPA, 2013, 2019).

The general risk evaluation approach is summarized in Figure 3.1 and discussed below.

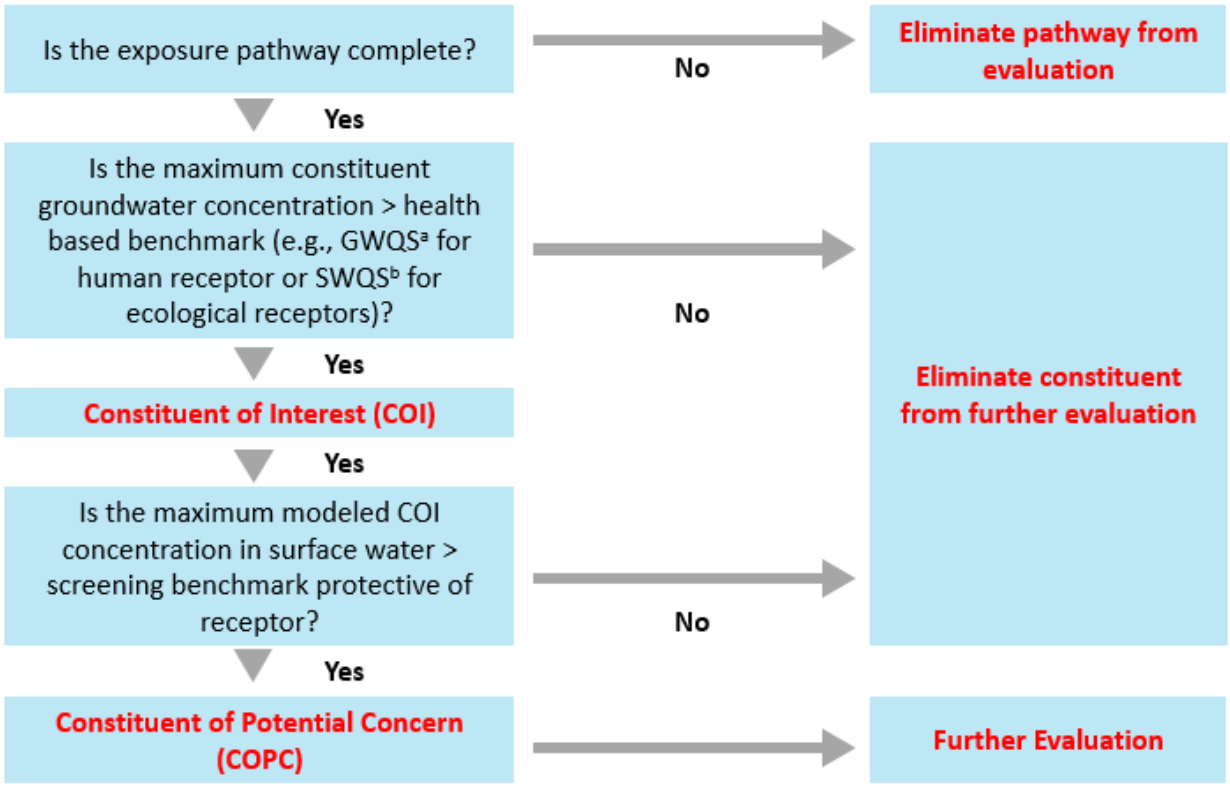

Figure 3.1 Overview of Risk Evaluation Methodology. IEPA = Illinois Environmental Protection Agency; GWQS = IEPA Groundwater Quality Standards; SWQS = IEPA Surface Water Quality Standards. (a) The IEPA Part 845 Groundwater Protection Standards (GWPS) were used to identify COIs. (b) IEPA SWQS protective of chronic exposures to aquatic organisms were used to identify ecological COIs. In the absence of an SWQS, US EPA Region IV Ecological Screening Values (ESVs) were used.

The first step in the risk evaluation was to develop the CEMs and identify complete exposure pathways. All potential receptors and exposure pathways based on groundwater use and surface water use in the vicinity of the Site were considered. Exposure pathways that are incomplete were excluded from the evaluation.

Groundwater data were used to identify COIs. COIs were identified as constituents with maximum concentrations in groundwater in excess of groundwater quality standards (GWQS)[2] for human receptors and surface water quality standards (SWQS) for ecological receptors. Based on the CSM (Section 2.2), some groundwater underlying the PAP has the potential to interact with surface water in Newton Lake. Therefore, potential PAP-related constituents in groundwater may potentially flow toward and into surface water in Newton Lake.

Surface water samples have been collected from Newton Lake adjacent to the Site; however, sediment samples have not been collected from the lake. Gradient modeled the potential migration of COIs from groundwater to surface water and sediment to evaluate potential risks to receptors (see Section 3.3.3).

Gradient modeled the COI concentrations in surface water and sediment based on the groundwater data from the PAP-related wells. The measured and modeled COI concentrations in surface water and sediment were compared to conservative, generic risk-based screening benchmarks for human health and ecological receptors. These generic screening benchmarks rely on default assumptions with limited consideration of site-specific characteristics. Human health benchmarks are receptor-specific values calculated for each pathway and environmental medium that are designed to be protective of human health. Ecological benchmarks are medium-specific values designed to be protective of all potential ecological receptors exposed to surface water. Ecological and human health screening benchmarks are inherently conservative because they are intended to screen out chemicals that are of no concern with a high level of confidence. Therefore, a measured or modeled COI concentration exceeding a screening benchmark does not indicate an unacceptable risk, but only that further risk evaluation is warranted. COIs with maximum concentrations exceeding a conservative screening benchmark are identified as COPCs requiring further evaluation.

As described in more detail below, this evaluation relied on the screening assessment to demonstrate that constituents present in groundwater underlying the PAP do not pose an unacceptable human health or ecological risk. That is, after the screening step, no COPCs were identified and further assessment was not warranted.

3.2 Human and Ecological Conceptual Exposure Models

A CEM provides an overview of the receptors and exposure pathways requiring risk evaluation. The CEM describes the source of the contamination, the mechanism that may lead to a release of contamination, the environmental media to which a receptor may be exposed, the route of exposure (exposure pathway), and the types of receptors that may be exposed to these environmental media.

3.2.1 Human Conceptual Exposure Model

The human CEM for the Site depicts the relationships between the off-Site environmental media potentially impacted by constituents in groundwater and human receptors that could be exposed to these media. Figure 3.2 presents a human CEM for the Site. It considers a human receptor who could be exposed to COIs hypothetically released from the PAP into groundwater, surface water, sediment, and fish. The following human receptors and exposure pathways were evaluated for inclusion in the Site-specific CEM.

[2] As discussed further in Section 3.3.2, GWQS are protective of human health and not necessarily of ecological receptors. While ecological receptors are not exposed to groundwater, groundwater can potentially enter into the adjacent surface water and impact ecological receptors. Therefore, two sets of COIs were identified: one for humans and another for ecological receptors.

- Residents – exposure to groundwater/surface water as drinking water;
- Residents – exposure to groundwater/surface water used for irrigation;
- Recreators in the lake adjacent to the Site:
  - Boaters – exposure to surface water and sediment while boating;
  - Swimmers – exposure to surface water and sediment while swimming;
  - Anglers – exposure to surface water and sediment and consumption of locally caught fish.

All of these exposure pathways were considered to be complete, except for residential exposure to groundwater or surface water used for drinking water or irrigation, and swimming. Section 3.2.1.1 explains why the residential drinking water and irrigation pathways are incomplete, and Section 3.2.1.2 provides additional description of the recreational exposures. While a recreator's potential exposure to surface water in Newton Lake was evaluated, swimming does not occur in Newton Lake, because it is owned by IPGC and used as a cooling reservoir (IDNR, 2022).

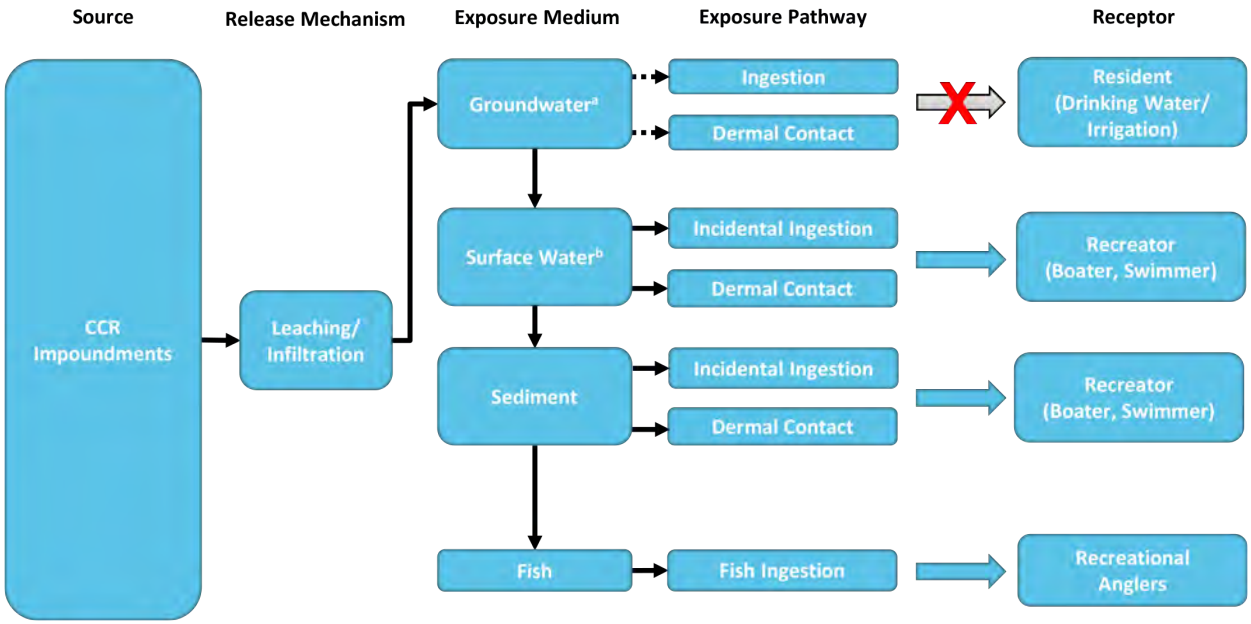

Figure 3.2 Human Conceptual Exposure Model. CCR = Coal Combustion Residual. Dashed line/Red X = Incomplete or insignificant exposure pathway. (a) Groundwater in the vicinity of the Site is not used as a drinking water or irrigation source. (b) Surface water is not used as a drinking water source.

3.2.1.1 Groundwater or Surface Water as a Drinking Water/Irrigation Source

Groundwater as a source of drinking water and/or irrigation water is not a complete exposure pathway for CCR-related constituents originating from the PAP. Specifically, shallow groundwater from the UA and the PMP in the vicinity of the PAP is not used as a source of drinking water, and no potable wells were identified downgradient of the PAP. A summary of the evidence supporting the conclusion that there are no residential uses of the shallow groundwater and Newton Lake surface water as a source of drinking water is presented below:

- **No potential groundwater receptors are in the vicinity of the PAP**. Relying on state databases, Ramboll completed a potable water well survey in 2021 (Ramboll, 2021). Two wells[3] were identified within a 1,000-meter radius of the PAP boundary during a comprehensive search of the Illinois State Geological Survey's (ISGS) Illinois Water and Related Wells (ILWATER) Map (ISGS, 2020) (Figure 3.3). Both wells are listed as dry/abandoned and are not currently in use as a source of drinking water (Ramboll, 2021).
- **There is no off-Site migration of CCR-related constituents in groundwater**. Newton Lake is intersected by both the UA and the PMP; thus, groundwater from the UA and the PMP may interact with surface water in the lake in some areas. The two water wells that are identified within a 1,000 m radius of the PAP are located on the southeast side of Newton Lake, *i.e.*, the opposite side of the lake from the PAP. Thus, Newton Lake separates the wells from the PAP (Figure 3.3). CCR-constituents in groundwater within the UA and the PMP are not expected to flow underneath or bypass Newton Lake.
- **Newton Lake adjacent to the PAP is not used as a public water supply.** Newton Lake is a cooling water pond owned and maintained by IPGC. IPGC restricts the use of the pond as a source of drinking water. Therefore, the human exposure pathway of surface water ingestion (as potable water) adjacent to the PAP was not evaluated further.
- **The PAP has a limited hydraulic connection to underlying groundwater**. The LCU and the shale BCU underlying the shallow aquifers (*i.e.*, the UA and the PMP) form a hydraulic barrier between the PAP and deeper groundwater resources. Due to the very low hydraulic conductivity of these confining units, downward migration of shallow groundwater is expected to be limited. Therefore, the likelihood of PAP-related impacts to deep groundwater is minimal.

[3] These are well numbers 120790038600 and 120790043600 (Ramboll, 2021).

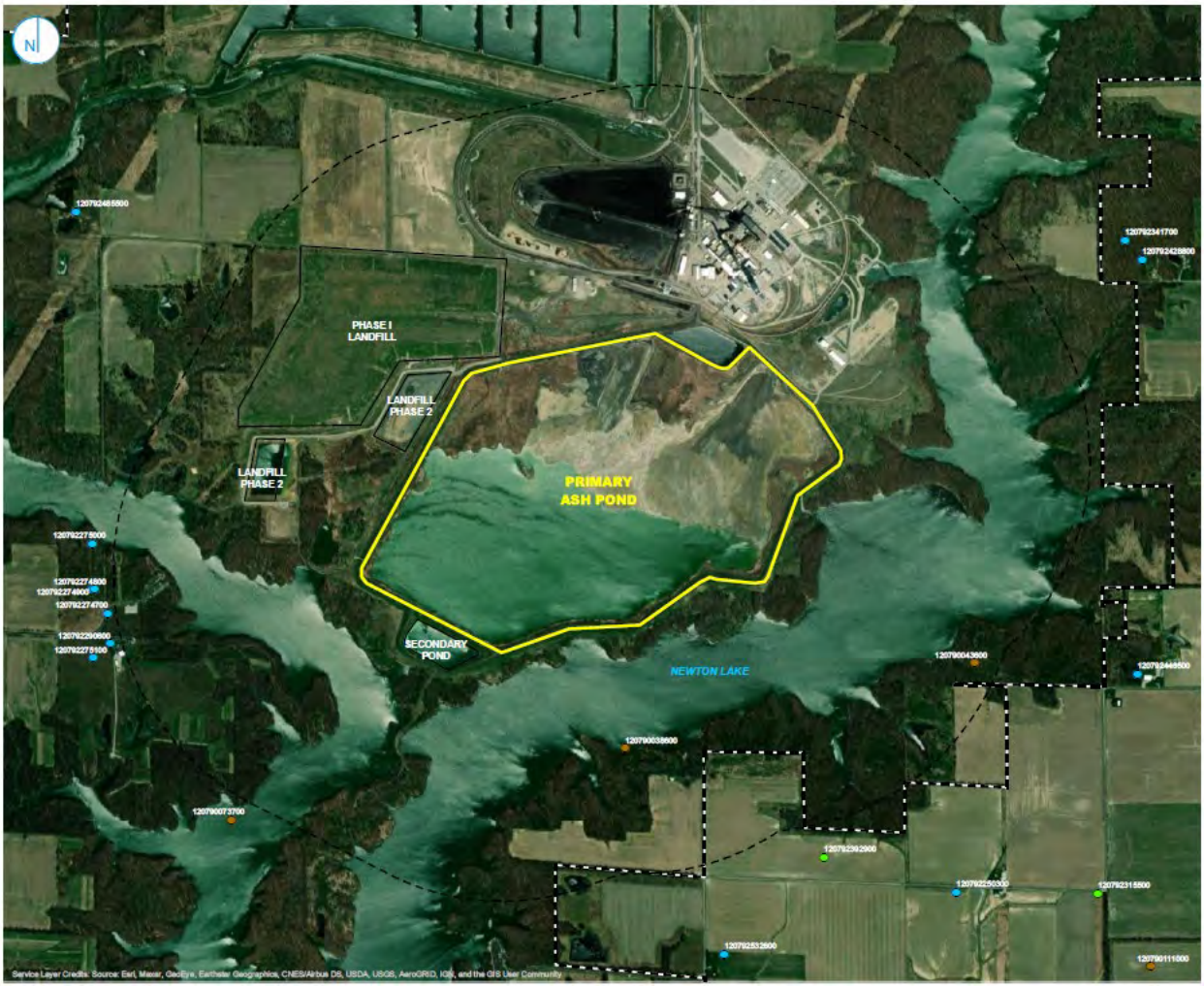

Figure 3.3 Water Wells Within 1,000 meters of the Primary Ash Pond. Source: Ramboll, 2021, Figure B-1.

3.2.1.2 Recreational Exposures

Newton Lake is located adjacent to the Site and is owned by IPGC. A portion of the NPP property along the lake has been leased to the Illinois Department of Natural Resources (IDNR) for use as a State Fish and Wildlife Area; thus, the lake is used for recreational fishing (IDNR, 2019). Recreational exposure to surface water and sediment may occur during activities such as boating or fishing in the lake. Recreational anglers may also consume locally caught fish from Newton Lake. Swimming does not occur in Newton Lake because it is owned by IPGC and used as a cooling reservoir (IDNR, 2022).

3.2.2 Ecological Conceptual Exposure Model

The ecological CEM for the Site depicts the relationships between off-Site environmental media (surface water and sediment) potentially impacted by COIs in groundwater and ecological receptors that may be exposed to these media. The ecological risk evaluation considered both direct toxicity as well as secondary toxicity *via* bioaccumulation. Figure 3.4 presents the ecological CEM for the Site. The following ecological receptor groups and exposure pathways were considered:

- **Ecological Receptors Exposed to Surface Water:**
  - Aquatic plants, amphibians, reptiles, and fish.
- **Ecological Receptors Exposed to Sediment:**
  - Benthic invertebrates (*e.g.*, insects, crayfish, mussels).
- **Ecological Receptors Exposed to Bioaccumulative COIs:**
  - Higher trophic-level wildlife (avian and mammalian) *via* direct exposures (surface water and sediment exposure) and secondary exposures through the consumption of prey (*e.g.*, plants, invertebrates, small mammals, fish).

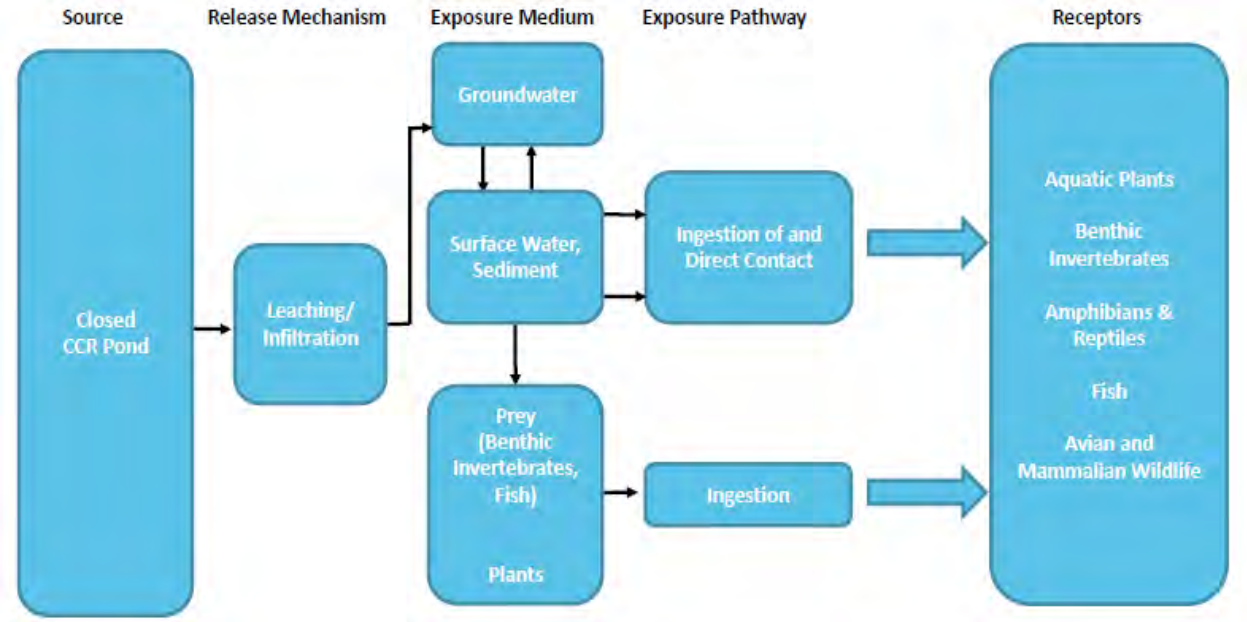

Figure 3.4 Ecological Conceptual Exposure Model. CCR = Coal Combustion Residual.

3.3 Identification of Constituents of Interest

Risks were evaluated for COIs. A constituent was considered a COI if the maximum detected constituent concentration in groundwater exceeded a health-based benchmark. According to US EPA risk assessment guidance (US EPA, 1989), this screening step is designed to reduce the number of constituents carried through the risk evaluation that are anticipated to have a minimal contribution to the overall risk. Identified COIs are the constituents that are most likely to pose a risk concern in the surface water adjacent to the Site.

3.3.1 Human Health Constituents of Interest

For the human health risk evaluation, COIs were conservatively identified as constituents with maximum concentrations in groundwater above the GWPS listed in the Illinois CCR Rule Part 845.600 (IEPA, 2021). Gradient used the maximum detected concentrations from groundwater samples collected from all of the PAP-associated wells, regardless of hydrostratigraphic unit. The use of groundwater data in this risk evaluation does not imply that detected constituents are associated with the PAP or that they have been identified as potential groundwater exceedances. Using this approach, 7 COIs (arsenic, cobalt, lead,

lithium, thallium, radium-226+228, and fluoride) were identified for the human health risk evaluation *via* the surface water pathway (Table 3.1).

The water quality parameters that exceeded the GWPS included chloride, sulfate, and total dissolved solids; however, these constituents were not included in the risk evaluation because the GWPS is based on aesthetic quality and there is an absence of studies regarding toxicity to human health. The US EPA secondary maximum contaminant levels (MCLs) for chloride, sulfate, and total dissolved solids are based on aesthetic quality. The secondary MCLs for chloride and sulfate (250 mg/L) are based on salty taste (US EPA, 2021a). The secondary MCL for total dissolved solids (500 mg/L) is based on hardness, deposits, colored water, staining, and salty taste (US EPA, 2021a). Given that these parameters are not likely to pose a human health risk concern in the event of exposure, they were not considered to be human health COIs.

Table 3.1 Human Health Constituents of Interest

Constituents[a]	Maximum Concentration	GWPS[b]	Human Health COI[c]
Total Metals (mg/L)			
Antimony	0.0036	0.0060	No
Arsenic	0.13	0.010	Yes
Barium	1.5	2.0	No
Beryllium	0.0033	0.0040	No
Boron	0.66	2.0	No
Cadmium	0.0034	0.0050	No
Chromium	0.090	0.10	No
Cobalt	0.036	0.0060	Yes
Lead	0.065	0.0075	Yes
Lithium	0.30	0.040	Yes
Mercury	0.0020	0.0020	No
Molybdenum	0.045	0.10	No
Selenium	0.0060	0.050	No
Thallium	0.0036	0.0020	Yes
Radionuclides (pCi/L)			
Radium-226+228	15	5.0	Yes
Other (mg/L)			
Chloride	550	200	No[d]
Fluoride	8.2	4.0	Yes
Sulfate	3,200	400	No[d]
Total Dissolved Solids	5,500	1,200	No[e]

Notes:
COI = Constituent of Interest; GWPS = Groundwater Protection Standard; MCL = Maximum Contaminant Level; pCi/L = PicoCuries Per Liter.
Shaded = Compound identified as a COI.
(a) The constituents are those listed in the IL Part 845.600 GWPS (IEPA, 2021).
(b) The IL Part 845.600 GWPS (IEPA, 2021) were used to identify COIs.
(c) COIs are constituents for which the maximum concentration exceeds the groundwater standard.
(d) This constituent is not likely to pose a human health risk concern due to the absence of studies regarding toxicity to human health. Therefore, this constituent is not considered a COI.
(e) Total dissolved solids are not considered a COI because the MCL is based on aesthetic quality.

3.3.2 Ecological Constituents of Interest

The Illinois GWPS, as defined in IEPA's guidance, were developed to protect human health but not necessarily ecological receptors. While ecological receptors are not exposed to groundwater, groundwater can potentially migrate into the adjacent surface water and impact ecological receptors. Therefore, to identify ecological COIs, the maximum concentrations of constituents detected in groundwater were compared to ecological surface water benchmarks protective of aquatic life.

The surface water screening benchmarks for freshwater organisms were obtained from the following hierarchy of sources:

- IEPA (2019) SWQS. IEPA SWQS are health-protective benchmarks for aquatic life exposed to surface water on a long-term basis (*i.e.*, chronic exposure). The SWQS for several metals are hardness dependent (cadmium, chromium, copper, lead, manganese, nickel, and zinc). Screening benchmarks for these constituents were calculated assuming US EPA's default hardness of 100 mg/L (US EPA, 2022).[4]
- US EPA Region IV (2018) surface water Ecological Screening Values (ESVs) for hazardous waste sites.

Benchmarks from the United States Department of Energy's (US DOE) guidance document ("A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota") were used for radium (US DOE, 2019). US DOE presents benchmarks for radium-226 and radium-228 (4 and 3 picoCuries per liter [pCi/L], respectively). Given that radium concentrations are expressed as total radium (radium-226+228, *i.e.*, the sum of radium-226 and radium-228), Gradient used the lower of the two benchmarks (3 pCi/L for radium-228) to evaluate total radium concentrations.

Consistent with the human health risk evaluation, Gradient used the maximum detected concentrations from groundwater samples collected from all of the PAP-associated wells, (regardless of hydrostratigraphic unit) without considering spatial or temporal representativeness for ecological receptor exposures. The use of the maximum constituent concentrations in this evaluation is designed to conservatively identify COIs that warrant further investigation. Cadmium, cobalt, lead, mercury, radium-226+228, chloride, and fluoride were identified as COIs for ecological receptors (Table 3.2).

[4] Hardness data are not available for Newton Lake adjacent to the Site, therefore, the US EPA (2022) default hardness of 100 mg/L was used. Use of a higher hardness value would result in less stringent screening values, thus, use of the US EPA default hardness is conservative.

Table 3.2 Ecological Constituents of Interest

Constituents[a]	Maximum Groundwater Concentration	Ecological Benchmark[b]	Basis	Ecological COI[c]
Total Metals (mg/L)				
Antimony	0.0036	0.19	US EPA R4 ESV	No
Arsenic	0.13	0.19	IEPA SWQC	No
Barium	1.5	5.0	IEPA SWQC	No
Beryllium	0.0033	0.064	US EPA R4 ESV	No
Boron	0.66	7.6	IEPA SWQC	No
Cadmium	0.0034	0.0011	IEPA SWQC	Yes
Chromium	0.09	0.21	IEPA SWQC	No
Cobalt	0.036	0.019	US EPA R4 ESV	Yes
Lead	0.065	0.020	IEPA SWQC	Yes
Lithium	0.3	0.44	US EPA R4 ESV	No
Mercury	0.002	0.0011	IEPA SWQC	Yes
Molybdenum	0.045	7.2	US EPA R4 ESV	No
Selenium	0.006	1.0	IEPA SWQC	No
Thallium	0.0036	0.0060	US EPA R4 ESV	No
Radionuclides (pCi/L)				
Radium-226+228	15.2	3.0	US DOE	Yes
Other (mg/L, unless otherwise noted)				
Chloride	550	500	IEPA SWQC	Yes
Fluoride	8.16	4.0	IEPA SWQC	Yes
Sulfate	3200	NA	NA	No
Total Dissolved Solids	5500	NA	NA	No

Notes:
COI = Constituent of Interest; DOE = Department of Energy; GWPS = Groundwater Protection Standard; IEPA SWQS = Illinois Environmental Protection Agency Surface Water Quality Standards; NA = Not Available; PAP = Primary Ash Pond; pCi/L = PicoCuries Per Liter; US EPA R4 ESV = US Environmental Protection Agency Region IV Ecological Screening Value.
Shaded = Compound identified as a COI.
(a) The constituents are those listed in the IL Part 845.600 GWPS (IEPA, 2021) that were detected in at least one groundwater sample from the wells related to the Newton PAP.
(b) Ecological benchmarks are from the hierarchy of sources discussed in Section 3.3.2: IEPA SWQS (IEPA, 2019); US EPA R4 "Ecological Risk Assessment Supplemental Guidance" (US EPA Region IV, 2018); and US DOE's guidance document "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (US DOE, 2019).
(c) Constituents with maximum detected concentrations exceeding a benchmark protective of surface water exposure are considered ecological COIs.

3.3.3 Surface Water and Sediment Modeling

Surface water sampling has been conducted in Newton Lake adjacent to the Site. To estimate the potential contribution to surface water (and sediment) from groundwater specifically associated with the PAP, Gradient modeled concentrations in Newton Lake surface water and sediment from groundwater flowing into the lake for the detected human and ecological COIs. This is because the constituents detected in groundwater above an ecological or health-based benchmark are most likely to pose a risk concern in the adjacent surface water. Gradient modeled human health and ecological COI concentrations in the surface water and sediment using a mass balance calculation based on the surface water and groundwater mixing. The model assumes a well-mixed groundwater-surface water location. The maximum detected

concentrations in groundwater (regardless of well location) from 2015 to 2021 were conservatively used to model COI concentrations in surface water and sediment. The groundwater data were measured as total metals. Use of the total metal concentration for these COIs may overestimate surface water concentrations because dissolved concentrations, which are lower than total concentrations, represent the mobile fractions of constituents that could likely flow into and mix with surface water.

The modeling approach does not account for geochemical transformations that may occur during groundwater mixing with surface water. Gradient assumed that predicted surface water concentrations were influenced only by the physical mixing of groundwater as it enters the surface water and were not further influenced by the geochemical reactions in the water and sediment, such as precipitation. In addition, the model only predicts surface water and sediment concentrations as a result of the potential migration of COI concentrations in PAP-related groundwater and does not account for background concentrations in surface water or sediment.

For this evaluation, Gradient adapted a simplified and conservative form of US EPA's indirect exposure assessment methodology (US EPA, 1998) that was used in US EPA's coal combustion waste risk assessment (US EPA, 2014). The model is a mass balance calculation based on surface water and groundwater mixing and the concept that the dissolved and sorbed concentrations can be related through an equilibrium partitioning coefficient (K_d). The model assumes a well-mixed groundwater-surface water location, with partitioning among total suspended solids, dissolved water column, sediment pore water, and solid sediments.

Sorption to soil and sediment is highly dependent on the surrounding geochemical conditions. To be conservative, we ignored the natural attenuation capacity of soil and sediment and estimated the surface water concentration based only on the physical mixing of groundwater and surface water (*i.e.*, dilution) at the point where groundwater flows into surface water.

The aquifer and surface water properties used to estimate the volume of groundwater flowing into Newton Lake and surface water concentrations are presented in Table 3.3. The COI concentrations in sediment were modeled using the COI-specific sediment-to-water partitioning coefficients and the sediment properties presented in Table 3.4. In the absence of Site-specific information for Newton Lake, Gradient used default assumptions (*e.g.*, depth of the upper benthic layer and bed sediment porosity) to model sediment concentrations. The modeled surface water and sediment concentrations are presented in Table 3.5. These modeled concentrations reflect conservative contributions from groundwater. A description of the modeling and the detailed results are presented in Appendix A.

Table 3.3 Groundwater and Surface Water Properties Used in Modeling

Parameter	Unit	Values	Notes/Source
Groundwater			
COI Concentration	mg/L	Constituent specific	Maximum detected concentration in groundwater.
Cross Section Area for the Uppermost Aquifer[a]	m^2	18,330	The sum of the maximum thicknesses of the PMP and the UA (*i.e.*, approximately 7.3 m) multiplied by the length of the ash pond intersecting Newton Lake (*i.e.*, about 2,500 m) (Ramboll, 2021).
Hydraulic Gradient	m/m	0.0048	The average hydraulic gradient determined for the UA was used (Ramboll, 2021).
Hydraulic Conductivity of the Uppermost Aquifer	cm/s	0.00495	Average of the geometric mean horizontal hydraulic conductivities measured for the PMP (3×10^{-3} cm/s) and the UA (6.8×10^{-3} cm/s).
Surface Water			
Surface Water Flow Rate	L/yr	3.37×10^{13}	An overflow dam located in the south portion of the lake (between the two lake arms) regulates water discharge out of the lake. The total discharge rate through the dam is 59,450 cubic feet per second [cfs] (US National Dams, 2022). This flow is assumed to be representative of the sum of discharges from the eastern and western arms of the Lake. A flow rate of 37,701 cfs was determined for the eastern arm adjacent to the PAP based on watershed ratio analysis (Archfield & Vogel, 2010; Gianfagna *et al*., 2015) using the USGS StreamStats application (USGS, 2022).
Total Suspended Solids	mg/L	9.2	Average of TSS concentrations measured at four monitoring locations in Newton Lake (USGS *et al*., 2022).
Depth of the Water Column	m	5.08	Depth of Newton Lake near the power plant (Ramboll, 2021).
Suspended Sediment to Water Partition Coefficient	mg/L	Constituent specific	Values based on US EPA (2014).

Notes:
cfs = Cubic Feet per Second; COI = Constituent of Interest; L/yr = Liter Per Year; m^2 = Square Meter; PAP = Primary Ash Pond; PMP = Primary Migration Pathway; TSS = Total Suspended Solids; UA = Uppermost Aquifer; US EPA = United States Environmental Protection Agency.
(a) Cross-sectional area represents the area through which groundwater flows from the UA into Newton Lake (*i.e.*, the area where groundwater intersects Newton Lake).

Table 3.4 Sediment Properties Used in Modeling

Parameter	Unit	Value	Notes/Source
Sediment			
Depth of Upper Benthic Layer	m	0.03	Default (US EPA, 2014)
Depth of Water Body	m	5.11	Depth of water column (5.08 m, depth of Newton Lake near the power plant (Ramboll, 2021) plus depth of upper benthic layer (0.03 m) (US EPA, 2014)
Bed Sediment Particle Concentration	g/cm^3	1	Default (US EPA, 2014)
Bed Sediment Porosity	-	0.6	Default (US EPA, 2014)
TSS Mass per Unit Area	kg/m^2	0.047	Depth of water column × TSS × conversion factors (10^{-6} kg/mg and 1,000 L/m^3)
Sediment Mass per Unit Area	kg/m^2	30	Depth of upper benthic layer × bed sediment particulate concentration × conversion factors (0.001 kg/g, 10^6 cm^3/m^3)
Sediment to Water Partition Coefficients	mg/L	Constituent specific	Values based on US EPA (2014)

Notes:
TSS = Total Suspended Solids; US EPA = United States Environmental Protection Agency.

Table 3.5 Surface Water and Sediment Modeling Results

COI	Groundwater Concentration (mg/L or pCi/L)	Mass Discharge Rate (mg/year or pCi/year)	Total Water Column Concentration (mg/L or pCi/L)	Concentration Sorbed to Bottom Sediments (mg/kg or pCi/kg)
Total Metals				
Arsenic	0.13	1.8E+07	5.3E-07	1.2E-04
Cadmium	0.0034	4.7E+05	1.4E-08	1.6E-05
Cobalt	0.036	4.9E+06	1.5E-07	1.2E-04
Lead	0.065	8.9E+06	2.7E-07	1.9E-03
Lithium	0.30	4.1E+07	1.2E-06	(a)
Mercury	0.0020	2.7E+05	8.2E-09	2.3E-04
Thallium	0.0036	4.9E+05	1.5E-08	2.6E-07
Radionuclides				
Radium-226+228	15	2.1E+09	6.2E-05	4.3E-01
Other				
Chloride	550	7.6E+10	2.3E-03	(a)
Fluoride	8.2	1.1E+09	3.4E-05	5.3E-03
Sulfate	3,200	4.4E+11	1.3E-02	(a)

Notes:
COI = Constituent of Concern; K_d = Equilibrium Partition Coefficient; pCi/L = PicoCuries Per Liter; pCi/kg = PicoCuries Per Kilogram.
(a) Lithium, chloride, and sulfate do not readily sorb to soil or sediment particles; a K_d value of 0 was used for the modeling.

3.4 Human Health Risk Evaluation

The section below presents the results of the human health risk evaluation for recreators (boaters and anglers) in Newton Lake adjacent to the Site. Risks were assessed using the maximum measured or modeled COIs in surface water.

3.4.1 Recreators Exposed to Surface Water

Screening Exposures: Recreators could be exposed to surface water *via* incidental ingestion and dermal contact while boating. In addition, anglers could consume fish caught in Newton Lake. The maximum measured or modeled COI concentrations in surface water were used as conservative upper-end estimates of the COI concentrations to which a recreator might be exposed directly (incidental ingestion of COIs in surface water while boating) and indirectly (consumption of locally caught fish exposed to COIs in surface water).

Screening Benchmarks: Illinois surface water criteria (IEPA, 2019), known as human threshold criteria (HTC), are based on incidental exposure through contact or ingestion of small volumes of water while swimming or during other recreational activities, as well as the consumption of fish. The HTC values were calculated from the following equation (IEPA, 2019):

$$\mathrm{HTC} = \frac{\mathrm{ADI}}{\mathrm{W} + (\mathrm{F} \times \mathrm{BCF})}$$

where:

HTC = Human health protection criterion in milligrams per liter (mg/L)
ADI = Acceptable daily intake (mg/day)
W = Water consumption rate (L/day)
F = Fish consumption rate (kg/day)
BCF = Bioconcentration factor (L/kg-tissue)

Illinois defines the acceptable daily intake (ADI) as the "maximum amount of a substance which, if ingested daily for a lifetime, results in no adverse effects to humans" (IEPA, 2019). US EPA defines its chronic reference dose (RfD) as an "estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral exposure for a chronic duration (up to a lifetime) to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime" (US EPA, 2011a). Illinois lists methods to derive an ADI from the primary literature (IEPA, 2019). In accordance with Illinois guidance, Gradient derived an ADI by multiplying the MCL by the default water ingestion rate of 2 L/day (IEPA, 2019). In the absence of an MCL, Gradient applied the RfD used by US EPA to derive its Regional Screening Levels (RSLs) (US EPA, 2021b) as a conservative estimate of the ADI. The RfDs are given in mg/kg-day, while the ADIs are given in mg/day; thus, Gradient multiplied the RfD by a standard body weight of 70 kg to obtain the ADI in mg/day. The calculation of the HTC values is shown in Appendix B, Table B.1.

Gradient used bioconcentration factors (BCFs) from a hierarchy of sources. The primary BCFs were those that US EPA used to calculate the National Recommended Water Quality Criteria (NRWQC) for human health (US EPA, 2002). Other sources included BCFs used in the US EPA coal combustion ash risk assessment (US EPA, 2014) and BCFs reported by Oak Ridge National Laboratory's Risk Assessment

Information System (ORNL RAIS) (ORNL, 2020).[5] Lithium did not have a BCF value available from any authoritative source; therefore, the water quality criterion for lithium was calculated assuming a BCF of 1. This is a conservative assumption, as lithium does not readily bioaccumulate in the aquatic environment (ECHA, 2020a,b; ATSDR, 2010).

Illinois recommends a fish consumption rate of 0.020 kg/day (20 g/day) for an adult weighing 70 kg (IEPA, 2019). Illinois recommends a water consumption rate of 0.01 L/day for "incidental exposure through contact or ingestion of small volumes of water while swimming or during other recreational activities" (IEPA, 2019). Appendix B, Table B.1 presents the calculated HTC for fish and water and for fish consumption only.

The HTC for fish consumption for radium-226+228 was calculated as follows:

$$\mathrm{HTC} = \frac{\mathrm{TCR}}{(\mathrm{SF} \times \mathrm{BAF} \times \mathrm{F})}$$

where:

HTC = Human health protection criterion in picoCuries per liter (pCi/L)
TCR = Target cancer risk ($1x10^{-5}$)
SF = Food ingestion slope factor (risk/pCi)
BAF = Bioaccumulation factor (L/kg-tissue)
F = Fish consumption rate (kg/day)

The food ingestion slope factor (lifetime excess total cancer risk per unit exposure, in risk/pCi) used to calculate the HTC was the highest value of those for radium-226 (Ra-226), radium-228 (Ra-228), and "Ra-228+D" (US EPA, 2001). According to US EPA (2001), "+D" indicates that "the risks from associated short-lived radioactive decay products (*i.e.,* those decay products with radioactive half-lives less than or equal to 6 months) are also included."

Screening Risk Evaluation: The maximum modeled and measured COI concentrations in surface water were compared to the calculated Illinois HTC values (Table 3.6). All surface water concentrations were below their respective benchmarks. The HTC values are protective of recreational exposure *via* water and/or fish ingestion and do not account for dermal exposures to COIs in surface water while boating. However, given that the measured and modeled COI surface water concentrations are orders of magnitude below HTC protective of water and/or fish ingestion, dermal exposures to COIs are not expected to be a risk concern. Moreover, the dermal uptake of metals is considered to be minimal and only a small proportion of ingestion exposures. Thus, none of the COIs evaluated would be expected to pose an unacceptable risk to recreators exposed to surface water while boating and anglers consuming fish caught in Newton Lake.

[5] Although recommended by US EPA (2015b), US EPA EpiSuite 4.1 (US EPA, 2019) was not used as a source of BCFs because inorganic compounds are outside the estimation domain of the program.

Table 3.6 Risk Evaluation for Recreators (Boaters and Anglers)

COI	Maximum SW Concentration		HTC for Water and Fish	HTC for Water Only	HTC for Fish Only	COPC	
	Modeled	Measured[a]				Based on Modeled Concentrations	Based on Measured Concentrations
Total Metals (mg/L)							
Arsenic	5.3E-07	4.2E-03	0.022	2.0	0.023	No	No
Cobalt	1.5E-07	ND	0.0035	2.1	0.0035	No	NA
Lead	2.7E-07	ND	0.015	0.015	0.015	No	NA
Lithium	1.2E-06	ND	4.7	14	7.0	No	NA
Thallium	1.5E-08	ND	0.0017	0.40	0.0017	No	NA
Radionuclides (pCi/L)							
Radium-226+228	6.2E-05	2.1E+00	1,000	1,000	87,413	No	No
Other (mg/L)							
Fluoride	3.4E-05	5.1E-01	143	800	174	No	No

Notes:
COI = Constituent of Interest; COPC = Constituent of Potential Concern; HTC = Human Threshold Criteria; NA = Not Applicable; ND = Not Determined; pCi/L = PicoCuries Per Liter; SW = Surface Water.
(a) Measured concentrations are listed only for the constituents identified as COIs. Measured surface water concentrations may be different from modeled concentrations because measured data include the effects of background and other industrial sources. Modeled concentrations only represent the potential effect on surface water quality resulting from the measured groundwater concentrations.

3.4.2 Recreators Exposed to Sediment

Recreational exposure to sediment may occur during boating activity in Newton Lake; exposure to sediment may occur through incidental ingestion and dermal contact.

Screening Exposures: COIs in impacted groundwater flowing into the river can sorb to sediments. In the absence of sediment data, sediment concentrations were modeled using maximum detected groundwater concentrations.

Screening Benchmarks: There are no established recreator RSLs that are protective of recreational exposures to sediment (US EPA, 2021c). Therefore, benchmarks that are protective of recreational exposures to sediment *via* incidental ingestion and dermal contact were calculated using US EPA's RSL guidance (US EPA, 2021c). These benchmarks were calculated using the recommended assumptions (*i.e.*, oral bioavailability, body weights, averaging time) and toxicity reference values (*i.e.*, RfD and cancer slope factor [CSF]). Recreators were assumed to be exposed to sediment while recreating 60 days a year (or two weekend days per week for 30 weeks a year, from April to October). The exposure duration was assumed for a child 6 years of age and an adult 20 years of age, per US EPA guidance (Stalcup, 2014). The daily recommended residential soil ingestion rates of 200 mg/day for a child and 100 mg/day for an adult are based on an all-day exposure to residential soils (Stalcup, 2014; US EPA, 2011b). Since recreational exposures to sediment are assumed to occur for less than four hours per day, one-third of the daily residential soil ingestion (67 mg/day for a child and 33 mg/day for an adult) was used as a conservative assumption. For dermal exposures, recreators were assumed to be exposed to sediment on their lower legs and feet (1,026 cm^2 for the child and 3,026 cm^2 for the adult, based on the age-weighted surface areas reported in US EPA, 2011b). While other body parts may be exposed to sediment, the contact time will likely be very short, as the sediment would wash off in the surface water. Gradient used US EPA's recommended adherence factor of 0.2 mg/cm^2 based on child exposure to wet soil (US EPA, 2004; Stalcup, 2014), which was used in the US EPA RSL User's Guide for a child recreator exposed to soil or sediment

(US EPA, 2021c). The sediment screening benchmarks were calculated based on a target hazard quotient of 1, or a target cancer risk of $1x10^{-5}$. Appendix B, Table B.2 presents the calculation of screening benchmarks protective of recreational exposures to sediment. A recreator sediment screening benchmark for radium-226+228 was based on soil Preliminary Remediation Goals (PRGs) calculated for radium-226 and radium-228 using US EPA's PRG calculator (US EPA, 2020). The lower of the two values was used as the recreator sediment screening benchmark for radium-226+228 (Appendix B, Table B.3).

Screening Risk Evaluation: The modeled sediment concentrations were well below the recreational sediment screening benchmarks (Table 3.7). Therefore, exposure to sediment is not expected to pose an unacceptable risk to recreators while boating.

Table 3.7 Risk Evaluation for Recreators Exposed to Sediment

COI	Modeled Sediment Concentration (mg/kg)	Recreator Sediment Screening Benchmark (mg/kg)	COPC
Total Metals (mg/kg)			
Arsenic	1.2E-04	6.8E+01	No
Cobalt	1.2E-04	4.1E+02	No
Lead	1.9E-03	4.0E+02	No
Lithium	(a)	2.7E+03	NA
Thallium	2.6E-07	1.4E+01	No
Radionuclides (pCi/kg)			
Radium-226+228	4.3E-01	7.9E+03	No
Other (mg/kg)			
Fluoride	5.3E-03	5.5E+04	No

Notes:
COI = Constituent of Interest; COPC = Constituent of Potential Concern; K_d = Equilibrium Partition Coefficient; NA = Not Applicable; pCi/kg = PicoCuries Per Kilogram.
(a) Lithium does not readily sorb to soil or sediment particles; a K_d value of 0 was used for the modeling.

3.5 Ecological Risk Evaluation

Based on the ecological CEM (Figure 3.4), ecological receptors could be exposed to surface water and dietary items (*i.e.*, prey and plants) potentially impacted by identified COIs (cadmium, cobalt, lead, mercury, radium-226+228, chloride, and fluoride).

3.5.1 Ecological Receptors Exposed to Surface Water

Screening Exposures: The ecological evaluation considered aquatic communities in Newton Lake potentially impacted by identified ecological COIs. Measured and modeled surface water concentrations were compared to risk-based ecological screening benchmarks.

Screening Benchmarks: Surface water screening benchmarks protective of aquatic life were obtained from the following hierarchy of sources:

- IEPA SWQS (IEPA, 2019), regulatory standards that are intended to protect aquatic life exposed to surface water on a long-term basis (*i.e.*, chronic exposure). For cadmium, the surface water

benchmark is hardness dependent and calculated using a default hardness of 100 mg/L (US EPA, 2022)[6];

- US EPA Region IV (2018) surface water ESVs for hazardous waste sites; and
- US DOE benchmarks from the guidance document, "A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota" (US DOE, 2019).

Risk Evaluation: The maximum measured and modeled COI concentrations in surface water were compared to the benchmarks protective of aquatic life (Table 3.8). The measured and modeled surface water concentrations for the COIs were below their respective benchmarks. Thus, none of the COIs evaluated are expected to pose an unacceptable risk to aquatic life in Newton Lake.

Table 3.8 Risk Evaluation of Ecological Receptors Exposed to Surface Water

COI	Maximum Surface Water Concentration		Ecological Freshwater Benchmark	Basis	COPC	
	Modeled	Measured			Based on Modeled Concentrations	Based on Measured Concentrations
Total Metals (mg/L)						
Cadmium	1.4E-08	ND	0.0011	IEPA SWQC	No	NA
Cobalt	1.5E-07	ND	0.019	US EPA R4 ESV	No	NA
Lead	2.7E-07	ND	0.020	IEPA SWQC	No	NA
Mercury	8.2E-09	ND	0.0011	IEPA SWQC	No	NA
Radionuclides (pCi/L)						
Radium-226+228	6.2E-05	2.1	3.0	US DOE	No	No
Other (mg/L)						
Chloride	2.3E-03	9.6	500	IEPA SWQC	No	No
Fluoride	3.4E-05	0.51	4.0	IEPA SWQC	No	No

Notes:
COI = Constituent of Interest; COPC = Constituent of Potential Concern; IEPA SWQC = Illinois Environmental Protection Agency Surface Water Quality Standard; NA = Not Applicable; ND = Not Detected; pCi/L = PicoCuries Per Liter; US DOE = United States Department of Energy; US EPA R4 ESV = United States Environmental Protection Agency Region IV Ecological Screening Value.

3.5.2 Ecological Receptors Exposed to Sediment

Screening Exposures: COIs in impacted groundwater discharging into Newton Lake can sorb to sediments *via* chemical partitioning. In the absence of sediment data, sediment concentrations were modeled using maximum detected groundwater concentrations. Therefore, the modeled COI sediment concentrations reflect the potential maximum Site-related sediment concentration originating from groundwater.

Screening Benchmarks: Sediment screening benchmarks were obtained from US EPA Region IV (2018). The majority of the sediment ESVs are based on threshold effect concentrations (TECs) from MacDonald *et al.* (2000), which provide consensus values that identify concentrations below which harmful effects on sediment-dwelling organisms are unlikely to be observed. In the absence of an ESV for radium-226+228, a sediment screening value of 90,000 pCi/kg was used, based on the biota concentration guide (BCG) for radium-228 (US DOE, 2019).[7] Chloride and fluoride are not expected to sorb to sediment; therefore, risk

[6] Conservatisms associated with using a default hardness value are discussed in Section 3.6.
[7] The biota concentration guide (BCG) for sediment is 90 pCi/g for Ra-228 and 100 pCi/g for Ra-226; the lower of the two values was used for Ra-226+228, and converted to pCi/kg (US DOE, 2019).

to ecological receptors exposed to sediment was not evaluated for these constituents. The benchmarks used in this evaluation are listed in Table 3.9.

Screening Risk Results: The maximum modeled COI sediment concentrations were below their respective sediment screening benchmarks (Table 3.9). The modeled sediment concentrations attributed to potential contributions from Site groundwater for all COIs were less than 1% of the sediment screening benchmark. Therefore, the modeled sediment concentrations attributed to potential contributions from Site groundwater are not expected to significantly contribute to ecological exposures in Newton Lake adjacent to the Site.

Table 3.9 Risk Evaluation of Ecological Receptors Exposed to Sediment

COI	Modeled Sediment Concentration	ESV[a]	COPC	% of Benchmark
Total Metals (mg/kg)				
Cadmium	1.6E-05	0.99	No	0.0016%
Cobalt	1.2E-04	50	No	0.00024%
Lead	1.9E-03	35.8	No	0.0053%
Mercury	2.3E-04	0.18	No	0.13%
Radionuclides (pCi/kg)				
Radium-226+228	4.3E-01	90,000[b]	No	0.00048%
Other (mg/kg)				
Chloride	-	-	-	-
Fluoride	5.3E-03	NA	-	-

Notes:
COI = Constituent of Interest; COPC = Constituent of Potential Concern; ESV = Ecological Screening Value; NA = Not available; pCi/kg = PicoCuries Per Kilogram; US DOE = United States Department of Energy; US EPA = United States Environmental Protection Agency.
(a) ESV from US EPA Region IV (2018).
(b) ESV from US DOE (2019); value converted from 90 pCi/g to 90,000 pCi/kg.

3.5.3 Ecological Receptors Exposed to Bioaccumulative Constituents of Interest

Screening Exposures: COIs with bioaccumulative properties can impact higher-trophic-level wildlife exposed to these COIs *via* direct exposures (surface water and sediment exposure) and secondary exposures through the consumption of dietary items (*e.g.*, plants, invertebrates, small mammals, and fish).

Screening Benchmark: US EPA Region IV (2018) guidance and IEPA SWQS (IEPA, 2019) guidance were used to identify constituents with potential bioaccumulative effects.

Risk Evaluation: With the exception of mercury, the ecological COIs (cadmium, cobalt, lead, radium-226+228, chloride, and fluoride) were not identified as having potential bioaccumulative effects. Therefore, these COIs are not considered to pose an ecological risk *via* bioaccumulation. IEPA (2019) identifies mercury as the only metal with bioaccumulative properties. US EPA Region IV (2018) also identifies mercury (including methyl mercury) as having potential bioaccumulative effects.[8]

The modeled mercury concentration in surface water (8.2×10^{-9} mg/L) was below the mercury surface water ESV for wildlife (1.3×10^{-6} mg/L), and the modeled mercury concentration in sediment (2.3×10^{-4} mg/kg) was below the sediment ESV for wildlife (0.18 mg/kg) (US EPA Region IV, 2018). Both the

[8] US EPA Region IV (2018) identifies selenium as having potential bioaccumulative effects. Although selenium was detected in groundwater, it was not considered an ecological COI.

modeled surface water and sediment concentrations were below benchmarks protective of receptors accounting for bioacccumulative properties. Therefore, in addition to not posing an ecological risk from direct toxicity, mercury does not pose a risk from bioaccumulation exposures.

3.6 Uncertainties and Conservatisms

A number of uncertainties and their potential impact on the risk evaluation are discussed below. Wherever possible, conservative assumptions were used in an effort to minimize uncertainties and overestimate rather than underestimate risks.

Exposure Estimates:

- The risk evaluation included the IL Part 845.600 constituents detected in groundwater samples (above GWPS) collected from wells associated with the PAP. However, it is possible that not all of the detected constituents are related specifically to the PAP.
- The human health and ecological risk characterizations were based on the maximum measured or modeled COI concentrations, rather than on averages. Thus, the variability in exposure concentrations was not considered. Assuming continuous exposure to the maximum concentration overestimates human and ecological exposures, given that receptors are mobile and concentrations change over time. For example, US EPA guidance states that risks should be estimated using average exposure concentrations as represented by the 95% upper confidence limit on the mean (US EPA, 1992). Given that exposure estimates based on the maximum concentrations did not exceed risk benchmarks, Gradient has greater confidence that there is no risk concern.
- Only constituents detected in groundwater were used to identify COIs and model COI concentrations in surface water and sediment. For the constituents that were not detected in PAP groundwater, the detection limits were below the IL Part 845.600 GWPS and thus do not require further evaluation.
- COI concentrations in surface water were modeled using the maximum detected total COI concentrations in groundwater. Modeling surface water concentrations using total metal concentrations may overestimate surface water concentrations because dissolved concentrations, which are lower than total concentrations, represent the mobile fractions of constituents that could likely flow into and mix with surface water.
- The COIs identified in this evaluation also occur naturally in the environment. Contributions to exposure from natural or other non-AP-related sources were not considered in the evaluation of modeled concentrations; only exposure contributions potentially attributable to Site groundwater mixing with surface water were evaluated. While not quantified, exposures from potential PAP-related groundwater contributions are likely to represent only a small fraction of the overall human and ecological exposure to COIs that also have natural or non-AP-related sources.
- Screening benchmarks for human health were developed using exposure inputs based on US EPA's recommended values for reasonable maximum exposure (RME) assessments (Stalcup, 2014). RME is defined as "the highest exposure that is reasonably expected to occur at a site but that is still within the range of possible exposures" (US EPA, 2004). US EPA states the "intent of the RME is to estimate a conservative exposure case (*i.e.*, well above the average case) that is still within the range of possible exposures" (US EPA, 1989). US EPA also notes that this high-end exposure "is the highest dose estimated to be experienced by some individuals, commonly stated as approximately equal to the 90th percentile exposure category for individuals" (US EPA, 2015c). Thus, most individuals will have lower exposures than those presented in this risk assessment.

Toxicity Benchmarks:

- Screening-level ecological benchmarks were compiled from IEPA and US EPA guidance and designed to be protective of the majority of Site conditions, leaving the option for Site-specific refinement. In some cases, these benchmarks may not be representative of the Site-specific conditions or receptors found at the Site, or may not accurately reflect concentration-response relationships encountered at the Site. For example, the ecological benchmark for cadmium is hardness dependent. However, hardness data are not available for Newton Lake; therefore, Gradient relied on US EPA's default hardness of 100 mg/L. Use of a higher hardness value would increase the cadmium SWQS because benchmarks become less stringent with higher levels of hardness. Regardless of the hardness, the maximum modeled cadmium concentration is orders of magnitude below the SWQS.
- In addition, for the ecological evaluation, Gradient conservatively assumed all constituents to be 100% bioavailable. Modeled COI concentrations in surface water are considered total COI concentrations. In addition, the measured surface water data used in this report represent total concentrations. US EPA recommends using dissolved metals as a measure of exposure to ecological receptors because it represents the bioavailable fraction of metal in water (US EPA, 1993). Therefore, the modeled surface water COI concentrations may be an overestimation of exposure concentrations to ecological receptors.
- In general, it is important to appreciate that the human health toxicity factors used in this risk evaluation are developed to account for uncertainties, such that safe exposure levels used as benchmarks are often many times lower (even orders of magnitude lower) than the levels that cause effects that have been observed in human or animal studies. For example, toxicity factors incorporate a 10-fold safety factor to protect sensitive subpopulations. This means that a risk exceedance does not necessarily equate to actual harm.

4 Summary and Conclusions

A screening-level risk evaluation was performed for Site-related constituents in groundwater at the NPP in Newton, Illinois. The CSM developed for the Site indicates that groundwater beneath the PAP flows into Newton Lake adjacent to the Site and may potentially impact surface water and sediment.

CEMs were developed for human and ecological receptors. The complete exposure pathways for humans include recreators (boaters) in Newton Lake who are exposed to surface water and sediment, and anglers who consume locally caught fish. Based on the local hydrogeology, residential exposure to groundwater used for drinking water or irrigation is not a complete pathway and was not evaluated. The complete exposure pathways for ecological receptors include aquatic life (including aquatic and marsh plants, amphibians, reptiles, and fish) exposed to surface water; benthic invertebrates exposed to sediment; and avian and mammalian wildlife exposed to bioaccumulative COIs in surface water, sediment, and dietary items.

Groundwater data collected from 2015 to 2021 were used to estimate exposures. Surface water data collected from Newton Lake were also evaluated. For groundwater constituents retained as COIs, surface water and sediment concentrations were modeled using the maximum detected groundwater concentration. Surface water and sediment exposure estimates were screened against benchmarks protective of human health and ecological receptors for this risk evaluation.

US EPA has established acceptable risk metrics. Risks above these US EPA-defined metrics are termed potentially "unacceptable risks". Based on the evaluation presented in this report, no unacceptable risks to human or ecological receptors resulting from CCR exposures associated with the PAP were identified. This means that the risks from the Site are likely indistinguishable from normal background risks. Specific risk assessment results include the following:

- For recreators exposed to surface water, all COIs were below the conservative risk-based screening benchmarks. Therefore, none of the COIs evaluated in surface water are expected to pose an unacceptable risk to recreators in Newton Lake adjacent to the Site.
- For recreators exposed to sediment *via* incidental ingestion and dermal contact, the modeled sediment concentrations were below health-protective sediment benchmarks. Therefore, the modeled sediment concentrations are not expected to pose an unacceptable risk to recreators exposed to sediment in Newton Lake adjacent to the Site.
- For anglers consuming locally caught fish, the modeled concentrations of all COIs in surface water (as well as the measured data) were below conservative benchmarks protective of fish consumption. Therefore, none of the COIs evaluated are expected to pose an unacceptable risk to recreators consuming fish caught in Newton Lake.
- Ecological receptors exposed to surface water include aquatic and marsh plants, amphibians, reptiles, and fish. The risk evaluation showed that none of the modeled or measured COIs in surface water exceeded protective screening benchmarks. Ecological receptors exposed to sediment include benthic invertebrates. The modeled sediment COIs did not exceed the conservative screening benchmarks; therefore, none of the COIs evaluated in sediment are expected to pose an unacceptable risk to ecological receptors.

- Ecological receptors were also evaluated for exposure to bioaccumulative COIs. This evaluation considered higher-trophic-level wildlife with direct exposure to surface water and sediment and secondary exposure through the consumption of dietary items (*e.g.*, plants, invertebrates, small mammals, fish). Mercury was the only ecological COI identified as having potential bioaccumulative effects. However, the modeled concentrations did not exceed benchmarks protective of bioaccumulative effects. Therefore, mercury is not considered to pose an ecological risk *via* bioaccumulation. Overall, this evaluation demonstrated that none of the COIs evaluated are expected to pose an unacceptable risk to ecological receptors.

It should be noted that this evaluation incorporates a number of conservative assumptions that tend to overestimate exposure and risk. The risk evaluation was based on the maximum detected COI concentration; however, US EPA guidance states that risks should be based on a representative average concentration such as the 95% upper confidence limit on the mean; thus, using the maximum concentration tends to overestimate exposure. Although the COIs identified in this evaluation also occur naturally in the environment, the contributions to exposure from natural background sources and nearby industry were not considered; thus, CCR-related exposures were likely overestimated. Exposure estimates assumed 100% metal bioavailability, which likely results in overestimates of exposure and risks. Exposure estimates were based on inputs to evaluate the "reasonable maximum exposure"; thus, most individuals will have lower exposures than those estimated in this risk assessment.

Finally, it should be noted that because current conditions do not present a risk to human health or the environment, there will also be no unacceptable risk to human health or the environment for future conditions when the PAP is closed. For all future closure scenarios, potential releases of CCR-related constituents will decline over time and, consequently, potential exposures to CCR-related constituents in the environment will also decline.

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Appendix A

Surface Water and Sediment Modeling

Gradient modeled concentrations in river surface water and sediment based on available groundwater data. First, Gradient estimated the flow rate of constituents of interest (COIs) that may flow into Newton Lake *via* groundwater. Then, Gradient adapted United States Environmental Protection Agency's (US EPA's) indirect exposure assessment methodology (US EPA, 1998) in order to model surface water and sediment water concentrations in Newton Lake.

Model Overview

Groundwater flow into Newton Lake is represented by a one-dimensional steady-state model. In this model, the groundwater plume migrates horizontally in the Uppermost Aquifer (UA) and the potential migration pathway (PMP) prior to discharging into Newton Lake. The groundwater flow entering the lake is the flow going through a cross-sectional area with a length equal to the length of the lake adjacent to the Primary Ash Pond (PAP) with potential CCR-related impacts and a height equal to the maximum saturated thicknesses of the UA and the PMP. This is a conservative assumption because groundwater elevation data indicate that only groundwater on the eastern side of the PAP has potential to interact with surface water in the lake. It was assumed that groundwater flowing through the shallow water bearing zones (*i.e.*, the UA and the PMP) may flow into Newton Lake. The length of the groundwater discharge zone was estimated using Google Earth Pro (Google LLC, 2022).

Groundwater flow into Newton Lake mixes with the surface water in the lake. The COIs entering the lake *via* groundwater can dissolve into the water column, sorb to suspended sediments, or sorb to benthic sediments. Using US EPA's indirect exposure assessment methodology (US EPA, 1998), the model evaluates the surface water and sediment concentrations at a location downstream of the groundwater discharge, assuming a well-mixed water column.

Groundwater Discharge Rate

The groundwater discharge rate was evaluated using conservative assumptions. Gradient conservatively assumed that the groundwater concentrations were uniformly equal to the maximum detected concentration for each individual COI. Gradient ignored adsorption by subsurface soil and assumed that groundwater flowing through the shallow aquifers was discharged into the lake.

For each groundwater unit, the groundwater flow rate into the river was derived using Darcy's Law:

$$Q = KiA$$

where:

Q = Groundwater flow rate (m^3/s)
K = Hydraulic conductivity (m/s)
i = Hydraulic gradient (m/m)
A = Cross-sectional area (m^2)

For each COI, the mass discharge rate into the lake was then calculated by:

$$m_c = C_c \times Q \times CF$$

where:

m_c = Mass discharge rate of the COI (mg/year)
C_c = Maximum groundwater concentration of the COI (mg/L)
Q = Groundwater flow rate (m^3/s)

CF = Conversion factors: 1,000 L/m^3; 31,557,600 s/year

The values of the aquifer parameters used for these calculations are provided in Table A.1. The calculated mass discharge rates were then used as inputs for the surface water and sediment partitioning model.

The cross-sectional area for the shallow aquifers was 18,330 m^2. The length of the discharge zone was estimated to be approximately 2,500 m. The height of the discharge zone was assumed to be the sum of the maximum thicknesses of the PMP and the UA (*i.e.*, approximately 7.3 m) (Ramboll, 2021).

The hydraulic gradient was 0.0048 m/m, based on the average horizontal hydraulic gradient determined for the UA (Ramboll, 2021). Hydraulic gradient was not measured in the PMP.

The hydraulic conductivity was 0.00495 cm/s, based on the average of the geometric mean horizontal hydraulic conductivities measured for the PMP (3 x 10^{-3} cm/s) and the UA (6.8 x 10^{-3} cm/s) (Ramboll, 2021).

Surface Water and Sediment Concentration

Groundwater that flows into the lake will be diluted in the surface water flow. Constituents transported by groundwater into the surface water migrate into the water column and the bed sediments. The surface water model Gradient used to estimate the surface water and sediment concentrations is a steady-state model described in US EPA's indirect exposure assessment methodology (US EPA, 1998), and also used in US EPA's "Human and Ecological Risk Assessment of Coal Combustion Residuals" (US EPA, 2014). This model describes the partitioning of constituents between surface water, suspended sediments, and benthic sediments based on equilibrium partition coefficients. It estimates the concentrations of constituents in surface water, suspended sediments, and benthic sediments at steady-state equilibrium at a theoretical location downstream of the discharge point after complete mixing of the water column. In the analysis, Gradient used the partitioning coefficients given in Table J-1 of the US EPA CCR Risk Assessment for all COIs (US EPA, 2014). These coefficients are presented in Table A.2.

To be conservative, Gradient assumed that the constituents were not affected by dissipation or degradation once they entered the water body. The total water body concentration of the COI was calculated as (US EPA, 1998):

$$C_{wtot} = \frac{m_c}{V_f \times f_{water}}$$

where:

C_{wtot} = Total water body concentration of the constituent (mg/L)
m_c = Mass discharge rate of the COI (mg/year)
V_f = Water body annual flow (L/year)
f_{water} = Fraction of COI in the water column (unitless)

Newton Lake was formed by damming and is used as a cooling water supply for Newton Power Plant (NPP) (US National Dams, 2022). Water is drawn from the eastern arm near the power plant and thermal effluent is released at two locations in the western arm *via* NPDES permitted outfalls (IEPA, 2016). A small overflow dam located in the south portion of the lake (between the two lake arms) regulates water discharge out of the lake. The total discharge rate of 59,450 cubic feet per second (cfs) through the overflow dam (US National Dams. 2022) is assumed to be representative of the sum of discharges from the eastern and western arms of the Newton Lake. A flow rate of 37,701 cfs was determined for the eastern arm based on watershed ratio analysis (Archfield & Vogel, 2010; Gianfagna *et al.*, 2015) using the USGS StreamStats application (USGS, 2022). The surface water parameters are presented in Table A.3.

The fraction of COIs in the water column was calculated for each COI using the sediment/water and suspended solids/water partition coefficients (US EPA, 2014, Table J-1). The fraction of COIs in the water column is defined as (US EPA, 2014):

$$f_{water} = \frac{(1 + [K_{dsw} \times TSS \times 0.000001]) \times \frac{d_w}{d_z}}{\left([1 + (K_{dsw} \times TSS \times 0.000001)] \times \frac{d_w}{d_z}\right) + ([bsp + K_{dbs} \times bsc] \times \frac{d_b}{d_z})}$$

where:

K_{dsw}	=	Suspended sediment-water partition coefficient (mL/g)
K_{dbs}	=	Sediment-water partition coefficient (mL/g)
TSS	=	Total suspended solids in the surface water body (mg/L), set equal to 9.2 mg/L, which is the average of TSS concentrations measured at four monitoring locations at Newton Lake (*i.e.*, IL_EPA_WQX-RCR-1, IL_EPA_WQX-RCR-2, IL_EPA_WQX-RCR-3, and IL_EPA_WQX-RCR-4) (USGS *et al*., 2022)
0.000001	=	Units conversion factor
d_w	=	Depth of the water column (m). The depth of the water column was estimated as 5.08 m, based on the geologic cross-section in Ramboll (2021 Figure 2-7). .
d_b	=	Depth of the upper benthic layer (m), set equal to 0.03 m (US EPA, 2014)
$d_z = d_w + d_b$	=	Depth of the water body (m) = 5.11 m
bsp	=	Bed sediment porosity (unitless), set equal to 0.6 (US EPA, 2014)
bsc	=	Bed sediment particle concentration (g/cm^3), set equal to 1.0 g/cm^3 (US EPA, 2014)

The fraction of COIs dissolved in the water column (f_d) is calculated as (US EPA 2014):

$$f_d = \frac{1}{1 + K_{dsw} \times TSS \times 0.000001}$$

The values of the fraction of COIs in the water column and other calculated parameters are presented in Table A.4.

The total water column concentration (C_{wcTot}) of the COIs, comprising both the dissolved and suspended sediment phases, is then calculated as (US EPA, 2014):

$$C_{wcTot} = C_{wtot} \times f_{water} \times \frac{d_z}{d_w}$$

Finally, the dissolved water column concentration (C_{dw}) for the COIs is calculated as (US EPA, 2014):

$$C_{dw} = f_d \times C_{wcTot}$$

The dissolved water column concentration was then used to calculate the concentration of COIs sorbed to suspended solids in the water column (US EPA, 1998):

$$C_{sw} = C_{dw} \times K_{dsw}$$

where:

C_{sw} = Concentration sorbed to suspended solids (mg/kg)
C_{dw} = Concentration dissolved in the water column (mg/L)
K_{dsw} = Suspended solids/water partition coefficient (mL/g)

In the same way, using the total water body concentration and the fraction of COIs in the benthic sediments, the model derives the total concentration in benthic sediments (US EPA, 2014, Table J-1-12):

$$C_{bstot} = f_{benth} \times C_{wtot} \times \frac{d_z}{d_b}$$

where:

C_{bstot} = Total concentration in bed sediment (mg/L or g/m^3)
C_{wtot} = Total water body concentration of the constituent (mg/L)
f_{benth} = Fraction of contaminant in benthic sediments (unitless)
d_b = Depth of the upper benthic layer (m)
$d_z = d_w + d_b$ = Depth of the water body (m)

This value can be used to calculate dry weight sediment concentration as follows:

$$C_{sed-dw} = \frac{C_{bstot}}{bsc}$$

where:

C_{sed-dw} = Dry weight sediment concentration (mg/kg)
C_{bstot} = Total sediment concentration (mg/L)
bsc = Bed sediment bulk density (default value of 1 g/cm^3 from US EPA, 2014)

The total sediment concentration is composed of the concentration dissolved in the bed sediment pore water (equal to the concentration dissolved in the water column) and the concentration sorbed to benthic sediments (US EPA, 1998).

The concentration sorbed to benthic sediments was calculated from (US EPA, 1998):

$$C_{sb} = C_{dbs} \times K_{dbs}$$

where:

C_{sb} = Concentration sorbed to bottom sediments (mg/kg)
C_{dbs} = Concentration dissolved in the sediment pore water (mg/L)
K_{dbs} = Sediments/water partition coefficient (mL/kg)

For each COI, the modeled total water column concentration, the modeled dry weight sediment concentration, and the modeled concentration sorbed to sediment are presented in Table A.5.

Table A.1 Parameters Used to Estimate Groundwater Discharge to Surface Water

Groundwater Unit	Parameter	Name	Value	Unit
Uppermost Aquifer and Potential Migration Pathway	A	Cross-Sectional Area[a]	18,330	m^2
Uppermost Aquifer and Potential Migration Pathway	i	Hydraulic Gradient[b]	0.0048	m/m
Uppermost Aquifer and Potential Migration Pathway	K	Hydraulic Conductivity[c]	0.00495	cm/s

Notes:
Source: Hydraulic gradient and hydraulic conductivity values from Ramboll (2021).
Cross-sectional area was estimated from Ramboll (2021).
(a) The sum of the maximum thicknesses of the PMP and the UA (i.e., approximately 7.3 m) multiplied by the length of the ash pond intersecting Newton lake (*i.e.*, about 2,500 m).
(b) Hydraulic gradient measurements are not available for the PMP. The average hydraulic gradient determined for the UA was used.
(c) Average of the geometric mean horizontal hydraulic conductivities measured for the PMP (3×10^{-3} cm/s) and the UA (6.8×10^{-3} cm/s).

Table A.2 Partition Coefficients

Constituent	Sediment-Water, Mean, K_{dbs}		Suspended Sediment-Water, Mean, K_{dsw}	
	Value (log_{10}) (mL/g)	Value (mL/g)	Value (log_{10}) (mL/g)	Value (mL/g)
Metals				
Arsenic	2.4	2.51E+02	3.9	7.94E+03
Cadmium	3.3	2.00E+03	4.9	7.94E+04
Cobalt	3.1	1.26E+03	4.8	6.31E+04
Lead	4.6	3.98E+04	5.7	5.01E+05
Lithium	-	-	-	-
Mercury	4.9	7.94E+04	5.3	2.00E+05
Thallium	1.3	2.00E+01	4.1	1.26E+04
Radionuclides				
Radium-226+228	-	7.40E+03	-	7.40E+03
Other				
Chloride	-	-	-	-
Fluoride	2.2	1.58E+02	2.2	1.58E+02
Sulfate	-	-	-	-

Notes:
Source: US EPA (2014).
Lithium, chloride, and sulfate do not readily sorb to soils and sediments. Consequently, sediment concentrations were not modeled for these constituents (K_d was assumed to be 0).

Table A.3 Surface Water Parameters

Parameter	Name	Value	Unit
TSS	Total Suspended Solids	9.2	mg/L
V_{fx}	Surface Water Flow Rate	3.37×10^{13}	L/yr
d_b	Depth of Upper Benthic Layer (default)	0.03	m
d_w	Depth of Water Column	5.08	m
d_z	Depth of Water Body	5.11	m
bsc	Bed Sediment Bulk Density (default)	1	g/cm^3
bsp	Bed Sediment Porosity (default)	0.6	-
M_{TSS}	TSS Mass per Unit Area[a]	0.047	kg/m^2
M_S	Sediment Mass per Unit Area[b]	30	kg/m^2

Notes:
Source of default values: US EPA (2014).
Source of TSS data: USGS *et al*., 2022.
(a) Determined by multiplying total suspended solids, TSS by the depth of water column, d_w.
(b) Determined by multiplying depth of upper benthic layer, d_b, with sediment bed particle concentration of 1 g/cc.

Table A.4 Calculated Parameters

COI	Fraction of Constituent in the Water Column f_{water}	Fraction of Constituent in the Benthic Sediments $f_{benthic}$	Fraction of Constituent Dissolved in the Water Column $f_{dissolved}$
Arsenic	0.419	0.581	0.932
Cadmium	0.1280	0.8720	0.5778
Cobalt	0.175	0.825	0.633
Lead	0.023	0.977	0.178
Lithium	0.996	0.004	
Mercury	0.006	0.994	0.353
Thallium	0.902	0.098	0.896
Radionuclides			
Radium-226+228	0.024	0.976	0.936
Other			
Fluoride	0.516	0.484	0.999

Note:
COI = Constituent of Interest.

Table A.5 Surface Water and Sediment Modeling Results

COI	Groundwater Concentration (mg/L or pCi/L)	Mass Discharge Rate (mg/year or pCi/year)	Total Water Column Concentration (mg/L or pCi/L)	Concentration Sorbed to Bottom Sediments (mg/kg or pCi/kg)
Total Metals				
Arsenic	0.13	1.8E+07	5.3E-07	1.2E-04
Cadmium	0.0034	4.7E+05	1.4E-08	1.6E-05
Cobalt	0.036	4.9E+06	1.5E-07	1.2E-04
Lead	0.065	8.9E+06	2.7E-07	1.9E-03
Lithium	0.30	4.1E+07	1.2E-06	(a)
Mercury	0.0020	2.7E+05	8.2E-09	2.3E-04
Thallium	0.0036	4.9E+05	1.5E-08	2.6E-07
Radionuclides				
Radium-226+228	15	2.1E+09	6.2E-05	4.3E-01
Other				
Chloride	550	7.6E+10	2.3E-03	(a)
Fluoride	8.2	1.1E+09	3.4E-05	5.3E-03
Sulfate	3,200	4.4E+11	1.3E-02	(a)

Notes:

COI = Constituent of Interest; pCi/kg = PicoCuries Per Kilogram; pCi/L = PicoCuries Per Liter.

(a) Lithium, chloride, and sulfate do not readily sorb to soil or sediment particles; a K_d value of 0 was used for the modeling.

Appendix B

Screening Benchmarks

Table B.1 Calculated Water Quality Standards Protective of Incidental Ingestion and Fish Consumption

Human Health COI	BCF[a] (L/kg-tissue)	Basis	MCL (mg/L)	RfD (mg/kg-day)	ADI[b] (mg/day)	Human Threshold Criteria		
						Water & Fish (mg/L)	Water Only (mg/L)	Fish Only (mg/L)
Arsenic	44	NRWQC (2002)	0.010	0.00030	0.020	0.022	2.0	0.023
Cobalt	300	ORNL (2020)	NC	0.00030	0.021	0.0035	2.1	0.0035
Fluoride	2.3	US EPA (2014)	4.0	0.040	8.0	143	800	174
Lead	46	US EPA (2014)	0.015	NC	0.030	0.015	0.015	0.015
Lithium	1	(c)	NC	0.002	0.14	4.7	14	7.0
Thallium	116	NRWQC (2002)	0.0020	0.000010	0.0040	0.0017	0.40	0.0017

Human Health COI	BAF (L/kg-tissue)		MCL (pCi/L)	ADI (pCi/day)	Food Ingestion Slope Factor[d] (risk/pCi)	Human Threshold Criteria		
	SW-Fish	Basis				Water & Fish (pCi/L)	Water Only (pCi/L)	Fish Only (pCi/L)
Radium-226 + 228	4.0	ORNL (2020)	5	10	1.43E-09	1,000	1,000	87,413

Notes:

ADI = Acceptable Daily Intake; BAF = Bioaccumulation Factor; BCF = Bioconcentration Factor; MCL = Maximum Contaminant Level; NC = No Criterion Available; NRWQC = National Recommended Water Quality Criteria; ORNL = Oak Ridge National Laboratory; pCi = picocurie; Ra = Radium; RAIS = Risk Assessment Information System; RfD = Reference Dose; US EPA = United States Environmental Protection Agency.

(a) BCFs from the following hierarchy of sources:

NRWQC (US EPA, 2002). National Recommended Water Quality Criteria: 2002. Human Health Criteria Calculation Matrix.

US EPA (2014). Human and Ecological Risk Assessment of Coal Combustion Residuals.

ORNL RAIS (ORNL, 2020). Risk Assessment Information System (RAIS) Toxicity Values and Chemical Parameters.

(b) ADI based on the MCL is calculated as the MCL (mg/L) multiplied by a water ingestion rate of 2 L/day. In the absence of an MCL, the ADI was calculated as the RfD (mg/kg-day) multiplied by the body weight (70 kg).

(c) BCF of 1 was used as a conservative assumption, due to lack of published BCF.

(d) Food ingestion slope factors for Ra-226+D and Ra-228+D were compared and the higher factor (Ra-228+D) was selected. The "+D" indicates that the risks from "associated short-lived radioactive decay products are also included" (US EPA, 2001).

Equations from IEPA (2019):

Consumption of Water and Fish

$$HTC = \frac{ADI}{W + (F \times BCF)}$$

Incidental Consumption of Water Only

$$HTC = \frac{ADI}{W}$$

Consumption of Fish Only

$$HTC = \frac{ADI}{F \times BCF}$$

Where:

Human Threshold Criteria (HTC)	Chemical-specific	mg/L
Acceptable Daily Intake (ADI)	Chemical-specific	mg/day
Fish Consumption Rate (F)	0.02	kg/day
Bioconcentration Factor (BCF)/ Bioaccumulation Factor (BAF)	Chemical-specific	L/kg-tissue
Water Consumption Rate (W)	0.01	L/day
Body Weight	70	kg
Target Cancer Risk (TCR)	1.0E-05	

Radium-226+228

$$HTC = \frac{TCR}{(SF \times BAF \times F)}$$

Table B.2 Recreator Exposure to Sediment

COI	Relative Bioavailability (unitless)	Dermal Absorption Fraction (unitless)	Cancer				Cancer SL (mg/kg)	Non-Cancer								Recreator RSL Sediment (mg/kg)	Basis[a]
			TRV		Child + Adult			TRV		Child		Adult		Child	Adult		
			CSF (mg/kg-day)$^{-1}$	Dermal CSF (mg/kg-day)$^{-1}$	Incidental Ingestion SL (mg/kg)	Dermal Contact SL (mg/kg)		RfD (mg/kg-day)	Dermal RfD (mg/kg-day)	Incidental Ingestion SL (mg/kg)	Dermal Contact SL (mg/kg)	Incidental Ingestion SL (mg/kg)	Dermal Contact SL (mg/kg)	Non-Cancer SL (mg/kg)			
Total Metals																	
Arsenic	1	3.0E-02	1.5E+00	1.5E+00	8.1E+01	4.1E+02	6.8E+01	3.0E-04	3.0E-04	4.1E+02	4.4E+03	4.4E+03	8.0E+03	3.8E+02	2.8E+03	6.8E+01	c
Cobalt	1	NA	NC	NC	NC	NC	NC	3.0E-04	3.0E-04	4.1E+02	NA	4.4E+03	NA	4.1E+02	4.4E+03	4.1E+02	nc
Lead	1	NA	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	4.0E+02	L
Lithium	1	NA	NC	NC	NC	NC	NC	2.0E-03	2.0E-03	2.7E+03	NA	2.9E+04	NA	2.7E+03	2.9E+04	2.7E+03	nc
Thallium	1	NA	NC	NC	NC	NC	NC	1.0E-05	1.0E-05	1.4E+01	NA	1.5E+02	NA	1.4E+01	1.5E+02	1.4E+01	nc
Other																	
Fluoride	1	NA	NC	NC	NC	NC	NC	4.0E-02	4.0E-02	5.5E+04	NA	5.8E+05	NA	5.5E+04	5.8E+05	5.48E+04	nc
Radionuclides																**Total Soil PRG (pCi/kg)**	
Radium-226 + 228																7.9E+03	

Notes:

ABS = Dermal Absorption Fraction; COI = Constituent of Interest; CSF = Cancer Slope Factor; NC = No Criterion Available; pCi = PicoCurie; PRG = Preliminary Remediation Goal; RfD = Reference Dose; RSL = Regional Screening Level; SL = Screening Level; TRV = Toxicity Reference Value; US EPA = United States Environmental Protection Agency.

(a) Screening benchmark defined as the lower of the Screening Levels for cancer and non-cancer. The basis of the benchmark presented as c = based on cancer endpoint, nc = based on non-cancer endpoint, or L = based on blood lead levels.

Equations for Screening Benchmark and Screening Levels:

$$\text{Screening Benchmark} = \frac{1}{\frac{1}{SL_{ing}} + \frac{1}{SL_{derm}}}$$

$$\text{Non-cancer } SL_{ing} = \frac{THQ * RfD}{Intake} \qquad \text{Cancer } SL_{ing} = \frac{TR}{Intake * CSF}$$

$$\text{Non-cancer } SL_{derm} = \frac{THQ * RfD}{Intake * ABS} \qquad \text{Cancer } SL_{derm} = \frac{TR}{Intake * ABS * CSF}$$

Where:

Target Risk (TR)	1E-05	
Target Hazard Quotient (THQ)	1	
Reference Dose (RfD)	Chemical-specific	mg/kg-day
Dermal Absorption Fraction (ABS)	Chemical-specific	
Cancer Slope Factor (CSF)	Chemical-specific	mg/kg
Incidental Ingestions Screening Level (SL_{ing})	Chemical-specific	mg/kg
Dermal Contact Screening Level (SL_{derm})	Chemical-specific	mg/kg

Sediment – Ingestion (Chemical)

Intake Factor (IF) = $\frac{IR \times EF \times ED \times CF}{BW \times AT}$ =

			Non-Cancer		Cancer		Basis
			7.3E-07 Child	6.8E-08 Adult	6.3E-08 Child	2.0E-08 Adult	
	IR	Ingestion Rate (mg/day)	67	33	67	33	One-third of US EPA residential soil ingestion rate (Professional Judgment)
	EF	Sediment Exposure Frequency (days/year)	60	60	60	60	2 days/week between April and October when air temperature > 70°F (Professional Judgment)
	ED	Exposure Duration (years)	6	20	6	20	Default value for Resident (US EPA, 2021b)
	CF	Conversion Factor (kg/mg)	0.000001	0.000001	0.000001	0.000001	
	BW	Body Weight (kg)	15	80	15	80	Default value for Resident (US EPA, 2021b)
	AT	Averaging Time (days)	2,190	7,300	25,550	25,550	Default value for Resident (US EPA, 2021b)

Sediment – Dermal Contact (Chemical)

Intake Factor (IF) = $\frac{SA \times AF \times EF \times ED \times CF}{BW \times AT}$ =

			Non-Cancer		Cancer		Basis
			2.2E-06 Child	1.2E-06 Adult	1.9E-07 Child	3.6E-07 Adult	
	SA	Surface Area Exposed to Sediment (cm^2/day)	1,026	3,026	1,026	3,026	Age weighted SA for lower legs and feet (US EPA, 2011b)
	AF	Sediment Skin Adherence Factor (mg/cm^2)	0.2	0.2	0.2	0.2	Age weighted AF for children exposed to sediment (US EPA, 2011b)
	EF	Sediment Exposure Frequency (days/year)	60	60	60	60	2 days/week between April and October when air temperature > 70°F (Professional Judgment)
	ED	Exposure Duration (years)	6	20	6	20	Default value for Resident (US EPA, 2021b)
	CF	Conversion Factor (kg/mg)	0.000001	0.000001	0.000001	0.000001	
	BW	Body Weight (kg)	15	80	15	80	Default value for Resident (US EPA, 2021b)
	AT	Averaging Time (days)	2,190	7,300	25,550	25,550	Default value for Resident (US EPA, 2021b)

Table B.3.1 Recreator PRGs for Soil, input values

Variable	Recreator Soil Default Value	Form-input Value
A (PEF Dispersion Constant)	16.2302	16.8653
B (PEF Dispersion Constant)	18.7762	18.7848
City (Climate Zone)	Default	Chicago, IL (7)
C (PEF Dispersion Constant)	216.108	215.0624
Cover layer thickness for GSF (gamma shielding factor) cm	0 cm	0 cm
$CF_{rec\text{-}fowl}$ (fowl contaminated fraction) unitless	1	1
$CF_{rec\text{-}game}$ (game contaminated fraction) unitless	1	1
ED_{rec} (exposure duration - recreator) yr		26
EF_{rec} (exposure frequency - recreator) day/yr		60
$f_{p\text{-}fowl}$ (fowl on-site fraction) unitless	1	1
$f_{p\text{-}game}$ (land game on-site fraction) unitless	1	1
$f_{s\text{-}fowl}$ (fraction of year fowl is on site) unitless	1	1
$f_{s\text{-}game}$ (fraction of year land game is on site) unitless	1	1
$MLF_{pasture}$ (pasture plant mass loading factor) unitless	0.25	0.25
t_{rec} (time - recreator) yr		26
TR (target risk) unitless	0.000001	0.000001
F(x) (function dependent on U_m/U_t) unitless	0.194	0.182
PEF (particulate emission factor) m^3/kg	1,359,344,438	1,560,521,177
Q/C_{wind} (g/m^2-s per kg/m^3)	93.77	98.431
A_s (acres)	0.5	0.5
Site area for ACF (area correction factor) m^2	1,000,000 m^2	1,000 m^2
ED_{rec} (exposure duration - recreator) yr		26
$ED_{rec\text{-}a}$ (exposure duration - recreator adult) yr		20
$ED_{resc\text{-}c}$ (exposure duration - recreator child) yr		6
EF_{rec} (exposure frequency - recreator) day/yr		60
$EF_{rec\text{-}a}$ (exposure frequency - recreator adult) day/yr		60
$EF_{rec\text{-}c}$ (exposure frequency - recreator child) day/yr		60
ET_{rec} (exposure time - recreator) hr/day		8
$ET_{rec\text{-}a}$ (exposure time - recreator) hr/day		8
$ET_{rec\text{-}c}$ (exposure time - recreator) hr/day		8
$IFA_{rec\text{-}adj}$ (age-adjusted inhalation rate - recreator) m^3		9,200
$IFS_{rec\text{-}adj}$ (age-adjusted soil intake rate - recreator) mg		63,720
$IRA_{rec\text{-}a}$ (inhalation rate - recreator adult) m^3/day	20	20
$IRA_{rec\text{-}c}$ (inhalation rate - recreator child) m^3/day	10	10
$IRS_{rec\text{-}a}$ (soil intake rate - recreator adult) mg/day	100	33
$IRS_{rec\text{-}c}$ (soil intake rate - recreator child) mg/day	200	67
t_{rec} (time - recreator) yr		26
TR (target risk) unitless	0.000001	0.000001
U_m (mean annual wind speed) m/s	4.69	4.65
U_t (equivalent threshold value)	11.32	11.32
V (fraction of vegetative cover) unitless	0.5	0.5

Notes:

IL = Illinois; PRG = Preliminary Remediation Goal; yr = year.

Table B.3.2 Recreator PRGs for Soil, Ra-226

Isotope	ICRP Lung Absorption Type	Soil Ingestion Slope Factor (risk/pCi)	Inhalation Slope Factor (risk/pCi)	External Exposure Slope Factor (risk/yr per pCi/g)	Food Ingestion Slope Factor (risk/pCi)	Lambda (1/yr)	Half-life (yr)	1,000 m^2 Soil Volume Area Correction Factor	0 cm Soil Volume Gamma Shielding Factor	Particulate Emission Factor (m^3/kg)	Dry Soil-to-plant transfer factor (pCi/g-fresh plant per pCi/g-dry soil)	Beef Transfer Factor (pCi/kg per pCi/d)	Poultry Transfer Factor (pCi/kg per pCi/d)	Ingestion PRG TR=1.0E-06 (pCi/g)	Inhalation PRG TR=1.0E-06 (pCi/g)	External Exposure PRG TR=1.0E-06 (pCi/g)	Total PRG TR=1.0E-06 (pCi/g)	Total PRG TR=1.0E-06 (mg/kg)	Total PRG TR=1.0E-06 (pCi/kg)
Ra-226	S	6.77E-10	2.82E-08	2.50E-08	5.14E-10	4.33E-04	1.60E+03	6.85E-01	1.00E+00	1.56E+09	1.95E-02	1.70E-03	-	2.32E+01	6.02E+03	4.10E+01	1.48E+01	1.50E-05	1.48E+04

Notes:

d = Day; ICRP = International Commission on Radiological Protection; Ra = Radium; S = Slow; pCi = Picocurie; PRG = Preliminary Remediation Goal; TR = Target Risk; yr = Year.

Table B.3.3 Recreator PRGs for Soil, Ra-228

Isotope	ICRP Lung Absorption Type	Soil Ingestion Slope Factor (risk/pCi)	Inhalation Slope Factor (risk/pCi)	External Exposure Slope Factor (risk/yr per pCi/g)	Food Ingestion Slope Factor (risk/pCi)	Lambda (1/yr)	Half-life (yr)	1,000 m^2 Soil Volume Area Correction Factor	0 cm Soil Volume Gamma Shielding Factor	Particulate Emission Factor (m^3/kg)	Dry Soil-to-plant transfer factor (pCi/g-fresh plant per pCi/g-dry soil)	Beef Transfer Factor (pCi/kg per pCi/d)	Poultry Transfer Factor (pCi/kg per pCi/d)	Ingestion PRG TR=1.0E-06 (pCi/g)	Inhalation PRG TR=1.0E-06 (pCi/g)	External Exposure PRG TR=1.0E-06 (pCi/g)	Total PRG TR=1.0E-06 (pCi/g)	Total PRG TR=1.0E-06 (mg/kg)	Total PRG TR=1.0E-06 (pCi/kg)
Ra-228	S	1.98E-09	4.37E-08	3.43E-11	1.42E-09	1.21E-01	5.75E+00	1.00E+00	1.00E+00	1.56E+09	1.95E-02	1.70E-03	-	7.93E+00	3.89E+03	2.04E+04	7.91E+00	2.90E-08	7.91E+03

Notes:

d = Day; ICRP = International Commission on Radiological Protection; Ra= Radium; S = Slow; pCi = Picocurie; PRG = Preliminary Remediation Goal; TR = Target Risk; yr = Year.

Attachment B

Supporting Information for the Closure Alternatives Analysis – Primary Ash Pond at the Newton Power Plant

Electronic Filing: Received, Clerk's Office 07/01/2024



Illinois Power Generating Company
CLOSURE ALTERNATIVES ANALYSIS SUPPORTING INFORMATION REPORT

Newton Power Plant
Primary Ash Pond

July 2022

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1. INTRODUCTION AND BACKGROUND

Illinois Power Generating Company (IPGC) is the owner of the coal-fired Newton Power Plant (NPP), located in Jasper County, Illinois. Newton is an active power plant and will remain active until 2027, at which time electricity production will cease and it will become inactive. This power plant has a surface impoundment called the Primary Ash Pond. Closure of the Primary Ash Pond (PAP) will take place in phases and upon shut down of the power plant in 2027, with final closure complete in fall of 2028.

This supplemental information was developed for the closure alternatives analysis as required in accordance with 35 Illinois Administrative Code (IAC) 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845). Closure of the PAP will be performed under the relevant Illinois Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments (Part 845) [1] and the United States Environmental Protection Agency (USEPA) CCR Rule [2].

Part 845 requires a Closure Alternatives Analysis (CAA) to be completed, pursuant to the requirements of Section 845.710, to support the Closure Plan prepared pursuant to Section 845.720. The CAA for the Newton PAP will be performed by Gradient Corporation (Gradient). HDR has prepared this Closure Alternatives Analysis Supporting Information Report (Report) to provide information requested by Gradient to support their preparation of the CAA.

1.1. Report Contents

The following information is contained within this report:

- **Section 1** includes the Introduction and Background;
- **Section 2** includes information related to closure-by-removal (CBR) including:
    - A feasibility evaluation of CBR using an onsite landfill (CBR-Onsite);
    - An evaluation of potential offsite landfills to receive the CCR for CBR-Offsite; and
    - A feasibility evaluation of CCR transportation for CBR-Offsite using over-the-road trucks, rail, and barging.
- **Section 3** includes an overview of the planned construction for closure-in-place (CIP), CBR-Onsite, and CBR-Offsite;
- **Section 4** includes a project schedule for CIP, CBR-Onsite and CBR-Offsite; and
- **Section 5** includes estimates for construction material quantities, cost, labor, vehicle miles, and equipment miles, for CIP, CBR-Onsite, and CBR-Offsite.
- **Section 6** includes references for information used in this report.

2. CLOSURE-BY-REMOVAL INFORMATION

Section 845.710(c)(1) of the IAC requires the evaluation of complete removal of CCR (e.g., CBR), and Section 845.710(c)(2) requires the CAA to identify if the Power Plant has an existing onsite landfill that can accept the CCR, or if constructing a new onsite landfill is feasible. Additionally, Section 845.710(c)(1) requires the evaluation of multiple modes of transportation of CCR, including rail, barge, and truck. This section includes evaluation of onsite landfill options, potential offsite landfills, and potential methods for transporting CCR to offsite landfills.

2.1. Potential CBR - Onsite Landfill Options

2.1.1. Existing Newton CCR Landfill

An existing CCR landfill, the Newton CCR Landfill Phase II, is currently open at the site, but is not actively used to store CCR. The current landfill cell (Area 3) is approximately 7.2-acres in size, however, this cell would require reconstruction prior to use.

Cell Area 1 is 7.2-acres
+ Cell Area 2 is 4.5-acres
+ Cell Area 3 is 7.2-acres (unused, assumed rebuild required)
18.9-acres constructed in total

There are about 34 permitted landfill acres remaining to construct (including a rebuild of Area 3), resulting in about 3.2-million cubic yards of permitted capacity remaining. The current landfill is adjacent to a historic closed landfill to the north that does not have additional permitted capacity.

The PAP contains approximately 5.7-million cubic yards of CCR. Therefore, disposal of the CCR in an onsite landfill would require a permitted landfill expansion or permitted new landfill on-site.

2.1.2. Feasibility of New Onsite Landfill Construction

The NPP site boundary was evaluated for suitable areas for the construction of an onsite landfill. Three primary options were identified, as shown in **Figure 1**. The feasibility of constructing a new landfill or landfill expansion in each area is described below:

- The Option 1 area is approximately 28-acres in size and is located immediately north of the existing landfill. This expansion would require removal of a portion of the final cover system on the historic landfill to the north, and installation of an overliner system over the historic landfill.
    - The leachate drainage system of the current landfill would require re-evaluation and reconstruction to facilitate an expansion to the north. Existing site infrastructure would require re-routing.

- The national wetlands inventory mapper indicates possible presence of wetlands in the area and to the south. This represents a potential impact to a protected area.
- This area is not in the 100-year floodplain, per the Jasper County FIRM, panel number 170990-0125-B.
- Therefore, constructing a landfill within the Option 1 area is considered less preferred, due to impacts to the existing site infrastructure and potential impacts to adjacent protected areas.

- The Option 2 area is approximately 25-acres in size and is located east of the existing landfill.
  - Option 2 overlaps with the existing PAP. This area would require phased closure of the pond where waste was first moved from the pond and into the existing permitted landfill, and then the landfill would be expanded into the clean closed footprint to hold the remaining waste.
  - This area would require relocation of the site access road and possible relocation of a monitoring well.
  - This area is not in the 100-year floodplain, per the Jasper County FIRM, panel number 170990-0125-B. However, it would require rerouting a major site drainageway.
  - Based on a review of the national wetlands inventory mapper and current site conditions, this area is not anticipated to impact potential wetlands.
  - Therefore, with phasing considerations taken into account, the Option 2 Area represents potentially the most practical option for onsite landfilling, because it expands an existing landfill, thus requiring less acreage for volume required, and is not anticipated to be in a protected area or buffer zone.

- The Option 3 area is approximately 33-acres in size and is located to the north of the existing closed landfill.
  - Option 3 represents the option of a new onsite landfill, rather than expanding the existing landfill. With this option, a greater area is needed and requires use of an area currently used for farming. An estimated 33-acres, with 4:1 sideslopes and 50-ft in height would be required.
  - This area represents an increased haul distance from the current PAP, adding time to the total project.
  - This area is not in the 100-year floodplain, per the Jasper County FIRM, panel number 170990-0125-B.
  - Based on a review of the national wetlands inventory mapper and current site conditions,

this area is not anticipated to impact potential wetlands.

- Therefore, constructing a landfill in the Option 3 area is not preferred, due to use of land that has agricultural value, increased haul distance, and increased landfill footprint.

In summary, the areas available for potentially constructing a landfill within the site boundary each have challenges and potential limitations. The option considered potentially feasible above is the Option 2 Area – which is evaluated further on the attached tables.

2.2. Potential CBR-Offsite Receiving Landfills

Potential offsite landfills suitable for disposing of the approximately 5.7-million cubic yards of CCR within the PAP were evaluated using IEPA's online Illinois Disposal Capacity Report [3], and Indiana's Solid Waste Reporting website [4]. The closest landfills to the site, by road miles, were determined to be:

- Sanitation Service's Landfill 33, Ltd., located in Effingham, IL, (21-miles);
- Republic Services Sumner Landfill, located in Sumner, IL, (46-miles);
- Republic Services Sycamore Ridge Landfill, located in Pimento, Indiana, (75-miles).

Sycamore Ridge Landfill is the landfill evaluated in the supporting information tables due to its estimated potential to have sufficient capacity for the volume of CCR to be removed. This landfill is the furthest distance of the identified sites at about 75-miles. No landfills have not yet been contacted, as of the date of this report, to confirm that they would be willing and able to accept the CCR. Information on the landfills is provided in **Table 1** and the location of each landfill relative to the site is provided in **Figure 2**.

2.3. Potential CBR-Offsite Transportation Methods

Section 845.710(c)(1) requires CBR to consider multiple methods for transporting removed CCR, including using rail, barge, and trucks. An evaluation of each method is included within this section.

2.3.1. Transportation by Rail

The power plant does currently have an established rail terminal, although modifications would be required in order for it to be used to load and transport CCR material. Modifications would increase the project schedule due to the need to coordinate with the railroad, complete design and permitting, and construct the loading area. CCR would still need to be hauled by truck to the loading area and loaded into rail cars, resulting in additional CCR handling and potential exposure to the surrounding environment.

A direct rail route to Sumner Landfill does not exist. A direct route to Landfill 33 does exist, however, an existing terminal suitable for unloading CCR is not present at the landfill. The amount of permitted airspace remaining at both of the Illinois landfills is not sufficient for the total volume of waste from the PAP, and therefore not practical for development of rail lines or terminals.

Sycamore Ridge Landfill is located adjacent to an existing rail line, however, an existing terminal suitable for unloading CCR is not present at the landfill. A rail unloading terminal would need to be constructed which would increase the project schedule due to the need to coordinate with the railroad, complete design and permitting, and construct the terminal. CCR would still need to be hauled from the rail terminal to the active area of the landfill, resulting in additional CCR handling and potential exposure to the surrounding environment.

Hauling CCR to Sycamore Ridge Landfill in Indiana would require approximately 75-miles (one-way) of hauling by rail on tracks owned by three separate rail lines (CSX, Indiana Rail Road Company, and PVTX), as shown on **Figure 2**. The ability of CCR to be hauled over multiple lines and transferred from line to line is currently unknown.

Therefore, transporting CCR by rail is unlikely to be a viable option for PAP CBR, due to the need to design, permit, and construct additional loading and unloading infrastructure, resulting in corresponding project schedule delays, and the distance and number of rail lines over which the CCR would need to be transported.

2.3.2. Transportation by Barge

The Newton Power Plant is not near rivers that accommodate barge traffic. It is estimated the nearest terminal for barge traffic is in St. Louis, approximately 125-miles away. This requires more trucking than the option to haul directly to a landfill, as well as installation of unloading infrastructure and additional hauling after the barge. Therefore, this option is not considered feasible.

2.3.3. Transportation by Truck

The PAP is located approximately eight miles from IL-33, which is suitable for receiving on-road truck hauling traffic. North 500th Street routinely receives truck traffic associated with the power plant. Potential travel routes between the PAP and landfills are shown on **Figure 2**, although actual travel routes may vary.

Transporting CCR by truck will not require the construction of additional loading or unloading infrastructure at either the receiving landfills or PAP. CCR would be loaded into trucks using heavy equipment at the PAP. CCR will then be unloaded at the receiving landfill by the truck directly. Since no construction is required, project delays related to coordination with other entities, design, and permitting are unlikely to occur. Therefore, transporting CCR by truck is a viable option for the PAP.

3. CLOSURE DESCRIPTION NARRATIVES

Section 845.720(a)(1)(A) requires a narrative description of CCR impoundment closures to be prepared. Narrative descriptions have been prepared for CIP, CBR-Onsite, and CBR-Offsite and are included within this section.

3.1. Closure in Place

A narrative description of how the PAP will be closed in place is provided in Section 2.1 of the PAP Closure Plan.

3.2. CBR-Onsite

A narrative description of CBR-Onsite of the PAP is as follows:

- The PAP will be unwatered by pumping free surface water to the adjacent Settling Pond for ultimate discharge at NPDES Outfall 001.
- A temporary water management system will be constructed within the PAP, including ditches and sumps. The system will maintain the PAP in an unwatered state by collecting contact stormwater during closure construction. Unwatering flows will be pumped to the Settling Pond for ultimate discharge at NDPES Outfall 001.
- CCR will be removed from the PAP using mass mechanical excavation techniques. Much of the CCR will be saturated or nearly saturated, so mass excavation will include the use of dewatering seepage trenches or other forms of passive dewatering (i.e., rim ditching or windrowing) to moisture-condition the CCR prior to handling. Dewatering flows will be pumped to the Settling Pond for ultimate discharge at NPDES Outfall 001.
- CCR will be loaded into dump trucks and hauled to the existing landfill, which will be expanded as the project progresses.
- The PAP outlet structure will be removed and disposed of at the offsite receiving landfill. Soil backfill will be placed at the previous outlet structure location.
- The PAP bottom and side- slopes will be decontaminated by removing approximately one foot of soil beneath the side-slope and bottom grades. The soils will be disposed of in the offsite receiving landfill.
- Once CBR is complete, the former PAP will be backfilled as needed to drain towards the south, in order to allow stormwater to gravity flow and preclude the impoundment of water. Backfill materials would include clean soil material excavated from the soil perimeter berm.
- The PAP will be restored by placing six inches of topsoil on the bottom and side slopes of the PAP and establishing vegetation. Stormwater best management practices (BMPs) such as erosion

control blankets and straw wattles will be used, as needed to reduce erosion during vegetation establishment.

- After vegetation is established, BMPs will be removed, and closure construction will be considered completed.

3.3. CBR-Offsite

A narrative description of CBR-Offsite of the PAP is as follows:

- The PAP will be unwatered by pumping free surface water to the adjacent Settling Pond for ultimate discharge at NPDES Outfall 001.
- A temporary water management system will be constructed within the PAP, including ditches and sumps. The system will maintain the PAP in an unwatered state by collecting contact stormwater during closure construction. Unwatering flows will be pumped to the Settling Pond for ultimate discharge at NDPES Outfall 001.
- CCR will be removed from the PAP using mass mechanical excavation techniques. Much of the CCR will be saturated or nearly saturated, so mass excavation will include the use of dewatering seepage trenches or other forms of passive dewatering (i.e., rim ditching or windrowing) to moisture-condition the CCR prior to handling. Dewatering flows will be pumped to the Settling Pond for ultimate discharge at NPDES Outfall 001.
- CCR will be loaded into on-road dump trucks and hauled to the offsite receiving landfill.
- The PAP outlet structure will be removed and disposed of at the offsite receiving landfill. Soil backfill will be placed at the previous outlet structure location.
- The PAP bottom and side- slopes will be decontaminated by removing approximately one foot of soil beneath the side-slope and bottom grades. The soils will be disposed of in the offsite receiving landfill.
- Once CBR is complete, the former PAP will be backfilled as needed to drain towards the south, in order to allow stormwater to gravity flow and preclude the impoundment of water. Backfill materials would include clean soil material excavated from the soil perimeter berm.
- The PAP will be restored by placing six inches of topsoil on the bottom and side slopes of the PAP and establishing vegetation. Stormwater best management practices (BMPs) such as erosion control blankets and straw wattles will be used, as needed to reduce erosion during vegetation establishment.
- After vegetation is established, BMPs will be removed, and closure construction will be considered completed.

4. CONSTRUCTION SCHEDULES

Section 845.720(a)(1)(F) requires a schedule including all activities necessary to complete closure to be prepared. Schedules have been prepared for CIP, CBR-Onsite, and CBR-Offsite and are included within this section. Schedules were prepared using estimates of task durations based on HDR's experience, typical weather conditions at the site, and expected construction rates relative to estimated construction quantities.

4.1. CIP

The proposed closure completion schedule for CIP is provided in Section 2.6 of the PAP Closure Plan.

4.2. CBR-Onsite

The proposed closure construction schedule for CBR-Onsite is provided in **Table 2**.

4.3. CBR-Offsite

The proposed closure construction schedule for CBR-Offsite is provided in **Table 2**.

5. MATERIAL, QUANTITY, LABOR, AND MILEAGE ESTIMATES

5.1. Quantity and Cost Estimates

Section 845.710(d)(1) requires a cost estimate to be prepared in accordance with the Class 4 standards of the Association for the Advancement of Cost Engineering (AACE) [5]. Cost estimates for CIP, CBR-Onsite, and CBR-Offsite were prepared in accordance with the AACE Class 4 standards, utilizing the following approach:

- Major construction components and line-items were identified, in accordance with the narrative closure description (**Section 3**).
- Construction quantities were estimated based on volume estimates, area estimates, and proposed construction schedules (**Section 4**).
- Unit costs were estimated for each construction line-item utilizing RSMeans Heavy Construction Cost Data [6] (RS Means). For line-items where RSMeans data was not available, unit costs were estimated based on recent industry pricing observed by HDR on projects of similar size, scope, and complexity.
    - RSMeans unit costs were developed assuming Union labor for Effingham, Illinois (located approximately 23 miles from the PAP), for 2022.
- Soil fill was assumed to come from onsite borrow sources located within 4,000-ft of the construction on average. Soil borrow is currently planned to be obtained from within the pond area, existing berms, and if needed, elsewhere on site.
- A contingency of 30% was applied for the construction cost estimate total, based on the level of design and quantity estimate prepared as part of this Report.

5.2. Labor and Mileage Estimates

In addition to construction cost and quantity estimates, Gradient also utilized HDR's estimates of construction labor hours, equipment usage, haul truck mileage, daily labor mobilization vehicle mileage, material delivery mileage, and onsite vehicle mobilization mileage. These estimates were prepared using the following approach:

- For line items where RSMeans [6] was utilized to develop the costs, the corresponding RSMeans crew size, equipment description, and daily output were utilized to estimate the total number of man-hours and equipment hours.
- For line items where RSMeans data was unavailable, the crew size, equipment description, and daily output were estimated based on recent industry pricing observed by HDR on projects of similar size, scope, and complexity.

- Daily labor mobilization miles were estimated assuming an average one-way commute of 35 miles for each individual working onsite. The number of working days were estimated from the construction schedules (**Section 4**).

- Estimates of haul truck mileage were based on the assumed round-trip haul distance and dump truck size. All dump trucks were assumed to be filled to capacity.

- Estimates of material delivery miles were prepared based on HDR's experience.

5.3. Results

The detailed labor and mileage estimates are provided in **Tables 3a** and **3b**, respectively for CIP.

The detailed labor and mileage estimates are provided in **Tables 4a** and **4b**, respectively for CBR-onsite.

The detailed labor and mileage estimates are provided in **Tables 5a** and **5b**, respectively for CBR-offsite.

6. REFERENCES

[1] Illinois Environmental Protection Agency, "35 Ill. Adm. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments," Springfield, IL, 2021.

[2] United Stated Environmental Protection Agency, "40 CFR Parts 257 and 261, Hazardous and Solid Waste Management System, Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule, 2015," 2015.

[3] Illinois Environmental Protection Agency, "Illinois Landfill Disposal Capacity Report," August 2021.

[4] Indiana Department of Environmental Management, “Solid Waste Reporting - 2020,” accessed March 10, 2022.

[5] AACE International, "Recommended Practice 18R-97: Cost Estimate Classification System - As Applied in Engineering, Procurement, and Construction for the Process Industries," 2020.

[6] RSMeans, "Heavy Construction Costs with RSMeans Data," Gordian, 2022.

Figures



Source: Google Earth Imagery, 2022.
Note: Areas and boundaries are approximate/conceptual, for estimating purposes only.

IPGC NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE
NEWTON, ILLINOIS

ONSITE LANDFILL -POTENTIAL AREA OPTIONS

DATE
7.28.2022

FIGURE
1

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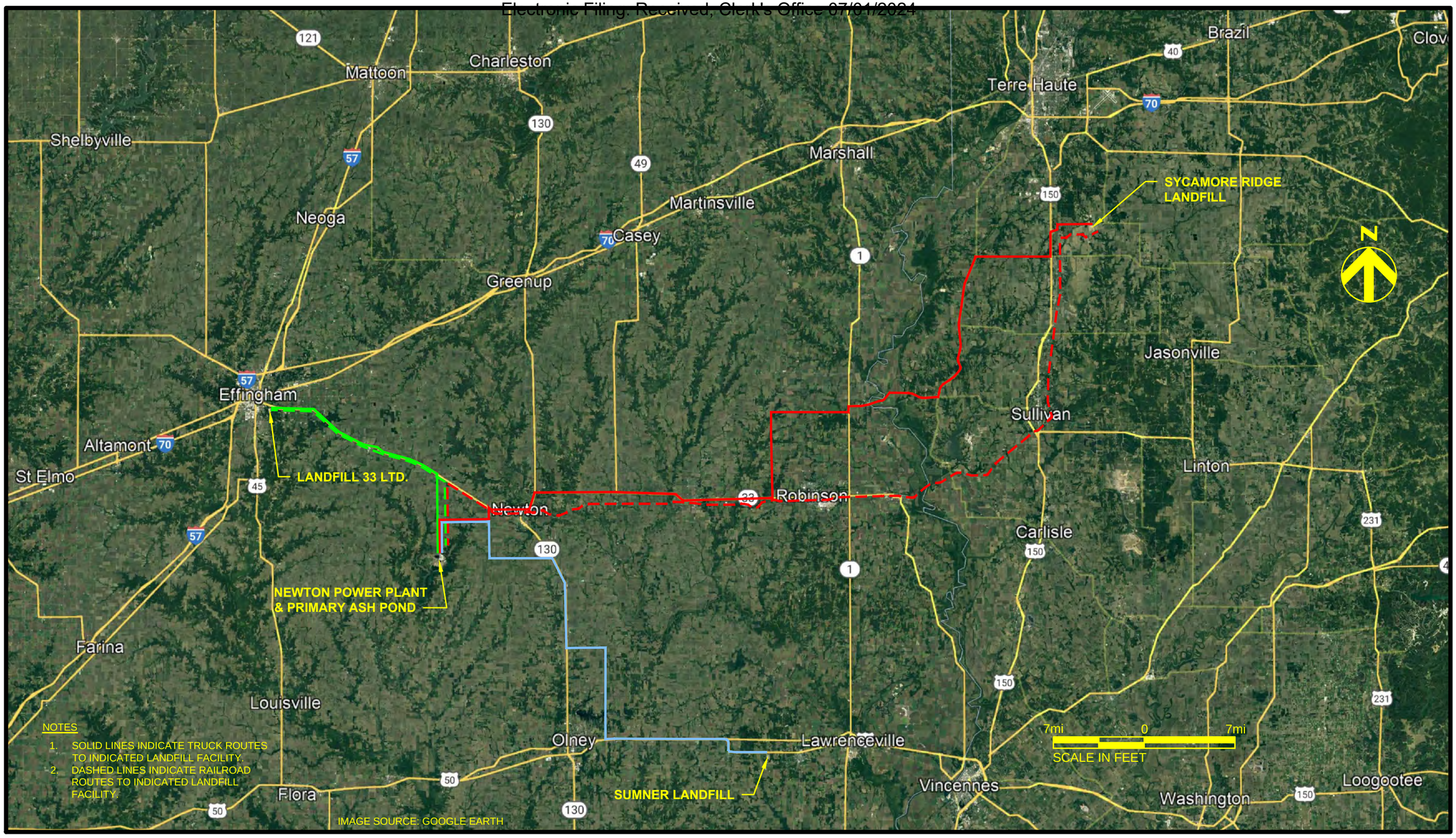

NOTES

1. SOLID LINES INDICATE TRUCK ROUTES TO INDICATED LANDFILL FACILITY.
2. DASHED LINES INDICATE RAILROAD ROUTES TO INDICATED LANDFILL FACILITY.

IPGC NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE
NEWTON, ILLINOIS

ALTERNATIVE LANDFILL PROXIMITY MAP

DATE 7.28.2022

FIGURE 1

C:\pwworking\central01\d2372207_Fig 1 - Alternate Landfill Map.dwg, Layout1, 3/14/2022 4:10:04 PM, MBICKFORD

Tables

Table 1: Offsite Landfill Information

Landfill Name:	Owner:	Location:	One-way Distance From Site:	5-yr Average Disposal Volume (CY):	Remaining Site Capacity (CY)
Sycamore Ridge Landfill	Republic Services, Inc.	Pimento, IN	75 miles	524,173 (tons)(2)	10,000,000 (1)
Landfill 33 Ltd. (3)	Sanitation Service, Inc.	Effingham, IL	21 miles	111,290	527,135
Sumner Landfill, Inc. (3)	Republic Services, Inc.	Sumner, IL	46 miles	93,890	2,807,604

1 Estimated - remaining permitted footprint
2 IDEM: Managing Waste: Solid Waste Reporting
3 Landfill Capacity Report - Landfill Capacity (illinois.gov)

Table 2: Closure Schedule

Milestone	Timeframe		
	Closure in Place	**Closure by Removal - On-site**	**Closure by Removal Off-Site**
Agency Coordination, Approvals, Permitting Obtain state permits, as needed, for dewatering/unwatering, water discharge, land disturbance, and outlet modifications	16 to 24 months after final Closure Plan Approval	16 to 24 months after final Closure Plan Approval	12 to 18 months after final Closure Plan Approval
Final Design and Bid Process* Complete final design of the closure and select a construction contractor	6 to 12 months during Agency Coordination, Approvals, and Permitting	6 to 12 months during Agency Coordination, Approvals, and Permitting	6 to 12 months during Agency Coordination, Approvals, and Permitting
Close CCR Unit Complete Contractor mobilization, installation of stormwater control measures for construction Complete dewatering and unwatering Complete Mass Excavation of CCR and decontamination of Ash Pond Install final cover system (closure in place only) Winter weather delays are assumed between November and March of each construction year	36 to 48 months after necessary permits are issued	12 months for grading and ash removal for lined landfill 24 months for construction of lined area after necessary permits are issued 48 to 60 months for ash removal and closure	252 months after necessary permits are issued
Slope to drain -backfill soil to maintain positive drainage	Concurrent with above item	6 to 8 months after final plant shutdown	6 to 8 months after final plant shutdown
Site Restoration Seed and stabilize the Ash Pond Complete Contractor demobilization	2-3 months after grading is complete	4 to 6 months after grading is complete	4 to 6 months after grading is complete
Timeframe to Complete Closure	**54 to 75 months**	**110 to 134 months**	**274 to 284 months**

*Assume final design and bidding is concurrent with final approvals and permitting

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Table 3a: Quantity Estimate - Closure in Place

Item No.	Item	Crew	Worker Type	Workers (#)	Equipment Type	Equipment (#)	Daily Output	Labor Hours	Equipment Hours	Units	Quantity	Notes
1	**Pre-Construction**											
	Mobilization and Demobilization									LS	1	5% of project, based on experience, project size.
2	**Site Preparation**											
	Site Preparation: Clearing and Grubbing	B7	Operator x 1 Laborer x 5	6	Brush Chipper x 1 Crawler Loader x 1 Chainsaws x 2	4	1	3,000	2,000	AC	50	311110100020, Clearing and grubbing, cut and chip light trees
	Construction Soil Erosion and Sediment Controls	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	650	2,308	769	LF	50,000	312514161000, Silt fence, install and remove
	Construction Facilities - Office Trailer	-	-	-	-	-	-	-	-	LS	1	015213200400, Office Trailer, buy, 50'x10'
	Construction Facilities - Storage Trailers (2)	-	-	-	-	-	-	-	-	LS	2	015213200200, Office trailer, buy, 20'x8'
	Construction Facilities - Portable Toilets (4)	-	-	-	-	-	-	-	-	MO	36	015433406410, Rent toilet portable chemical
	Dust Control	B59	Truck Driver x 1	1	Water Truck x 1	1	1	4,800	4,800	DAY	480	312323202510, Hauling, heavy, dust control
	Haul Road Maintenance	B86A	Operator x 1	1	Grader x 1	1	1	1,440	1,440	DAY	144	312323202600, Hauling, haul road maintenance
3	**Dewatering, Unwatering, and Stormwater Management**											
	Unwatering, Dewatering, and Stormwater Management for the Primary Ash Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	21,900	14,600	DAY	1460	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Water Management (additives, sampling)	-	-	-	-	-	-	-	-	DAY	1460	Based on experience, project size.
	Unwatering, Dewatering, and Stormwater Management for Lake Jake and Settling Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	2,700	1,800	DAY	180	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Outlet structure modification and temporary drainage features	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.05	300	200	LS	1	Based on experience, modification of existing infrastructure to re-route. Additional cost for piping
	Dewatering Sumps Installation	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	1	6,000	4,000	EA	400	Based on experience, project size.
4	**Closure**											
	Excavation of Ash Material											
	Excavation of ash material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	7,570	5,047	CY	1,917,700	312316432500, Excavating, large volume projects, restricted loading - doubled based on project experience
	Hauling material to northern portion of site	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	36,320	36,320	CY	1,917,700	Based on experience, project size.
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	28,766	19,177	CY	1,917,700	312323170020, spread dumped material, by dozer
	Compaction of Material	B10Y	Operator x 1 Laborer x 0.5	1.5	Vibratory Roller x 1	1	2,300.00	12,507	8,338	CY	1,917,700	312323235020, compaction, riding, vibrating roller, 3 passes, 6" lifts
	Fine grading of ash surface OR clean closed area	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	4,394	2,197	AC	404	312216103300, fine grading, slopes, gentle, finish grading
	Piezometer and Monitoring Well Extensions	C18	Laborer x 1.125	1.125	Concrete Cart x 1	1	1.00	45	40	EA	4	Based on experience.
	Material Conditioning (drying, stabilizing)	-	-	-	-	-	-	-	-	CY	958,850	Based on experience. Approx. half of consolidated material.
	Offsite Disposal Fee	-	-	-	-	-	-	-	-	CY	0	Based on experience.
5	**Onsite Landfill and Pond Capping**											
	Clay layer, 1.5-ft (onsite landfill closure)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800	186	124	CY	47,110	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528	892	892	CY	47,110	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000	707	471	CY	47,110	312323170020, spread dumped material, by dozer
	Compacting Material	B10D	Operator x 1 Laborer x 0.5	1.5	Dozer x 1 Compactor x 1	1	2,000	353	236	CY	47,110	312323235620, Compaction, 3 passes, 6" lifts, sheepsfoot
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	3,040	1,520	AC	280	312216103300, fine grading, slopes, gentle, finish grading
	Geomembrane, 40-mil LLDPE	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	16,770	6,988	AC	280	Based on experience.
	Geotextile, 8-oz.	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	16,770	6,988	AC	280	Based on experience, est. $0.50/SF
	Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	810	540	LF	13,500	
	Temporary Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	379	253	LF	6,320	
	Drainage Pipes on Geomembrane	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	7,500	590	246	LF	36,893	Based on experience.
	Placement of Protective Cover Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	2,750	1,833	CY	696,682	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	13,195	13,195	CY	696,682	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	10,450	6,967	CY	696,682	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	3,040	1,520	AC	280	312216103300, fine grading, slopes, gentle, finish grading
	Placement of Vegetative Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	917	611	CY	232,227	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	4,398	4,398	CY	232,227	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	3,483	2,322	CY	232,227	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	3,040	1,520	AC	280	312216103300, fine grading, slopes, gentle, finish grading
	Installation of drainage channels									*LF*	*15,884*	
	Erosion Control Blanket	2 Clab	Laborer x 2	2	-	0	1000	1,765	0	SY	88,244	312514160120, synthetic erosion control, revegetation mat, webbed
	Installation of drainage letdowns									*LF*	*5,028*	
	Riprap	B30	Operator x 1 Truck Driver x 2	3	Excavator x 1 Dump Trucks x 2	3	100	2,682	2,682	SY	8,939	313713100200, Riprap and rock lining, not grouted, crew and output adjusted for site.
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	107	36	SY	8,939	Based on experience, est. $0.60/SF
6	**Stormwater and Perimeter**											
	Removal of Outlet Structure	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience.
	Removal of Outlet Pipe	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.20	75	50	LS	1	Based on experience.
	Installation of permanent stormwater culverts, riprap aprons, a	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience, includes final pond outlet.
	Establish Access Roads									*LF*	*13,500*	
	Gravel	B32	Operator x 3 Laborer x 1	4	Grader x 1 Roller x 1 Dozer x 1	3	5,000	360	270	SY	45,000	321123230370, base course, aggregate base course, 6"
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	540	180	SY	45,000	Based on experience, est. $0.60/SF
	Seed, fertilize, and maintain vegetated surfaces											
	Seeding	B66	Operator x 1	1	Loader-Backhoe x 1	1	1.5	**3,000**	3,000	AC	450	329219130020, mechanical seeding, 215 lb/ac
	Fertilizing	B66	Operator x 1	1	Loader-Backhoe x 1	1	3	1,500	1,500	AC	450	320190130110, fertilizing, dry granular, 4 lb/MSF, crew per project experience.
	Mulch (select areas/steep slopes)	B66	Operator x 1	1	Loader-Backhoe x 1	1	140,000	124	124	SF	1,742,400	329113160760, soil preparation, mulching
	Repair initial erosion	B66	Operator x 1	1	Loader-Backhoe x 1	1	1	400	400	AC	40	Based on experience, reseed 10% to establish vegetation
7	**Engineering and Construction Support**											
	Final Closure Design, Local Permitting Support, and Bid Support	HDR2	Engineering Staff x 4	4	-	0	0.01	4,000	0	LS	1	1% of total project, based on project scale.
	Engineering Support and CQA during Construction	HDR3	CQA Staff x 1 Engineering Staff x 1	2	Truck x 1	1	0.001	20,000	10,000	LS	1	5% of total project, based on duration of construction.
								Labor Hours:	**Equipment Hours:**			
								248,673	**169,793**			
							Contingency (30%)	**323,275**	**220,730**			

Notes:

1. RS Means used as reference - adjusted based on project size, location, type.
2. Grey crews were established based on HDR relevant project experience.

Table 3b: Labor, Equipment, and Mileage Estimate - Closure in Place - Totals

Item	Quantity	Assumptions
Labor Total Hours	323,275	10-hr days
Duration of Onsite Construction in Days	720	Working days, 9 months per year for 4 yrs, 20-working days per month average
Average Daily Crew Size	45	Crew Members
Daily Labor Mobilization Miles	2,262,925	Average of 70 miles round trip per day
Vehicles Miles Onsite	79,040	2 mile round trip from gate to parking 5 miles per day for CQA tech and Construction Supervisor 10% Contingency for site visitors (client and engineering support)
Equipment Mobilization Miles - Unloaded	33,110	Average of 300 miles one way for equipment hauling Average 1 load of equipment 2,000 Equipment working hours
Equipment Mobilization Miles - Loaded	33,110	Average of 300 miles one way for equipment hauling Average 1 load of equipment per working week
Daily Equipment Miles Onsite	720,000	Average of ~20 crew members running equipment Assume 50 miles per piece of equipment (average 5 mph, 10-hrs per day)
Onsite Haul Truck Miles - Unloaded	56,403	34 CY Haul Truck 1-mile route out
Onsite Haul Truck Miles - Loaded	56,403	34 CY Haul Truck 1-mile route back
Offsite Haul Truck Miles - Unloaded	0	16.5 CY Dump Truck 75 mile trip
Offsite Haul Truck Miles - Loaded	0	16.5 CY Dump Truck 75 mile trip
Material Delivery Miles - Unloaded	154,080	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Material Delivery Miles - Loaded	154,080	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Estimated Total	**3,549,150**	**miles**

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Table 4a: Quantity Estimate - Onsite Landfill

Item No.	Item	Crew	Worker Type	Workers (#)	Equipment Type	Equipment (#)	Daily Output	Labor Hours	Equipment Hours	Units	Quantity	Notes
1	**Pre-Construction**											
	Mobilization and Demobilization									LS	1	5% of project, based on experience, project size.
2	**Site Preparation**											
	Site Preparation: Clearing and Grubbing	B7	Operator x 1 Laborer x 5	6	Brush Chipper x 1 Crawler Loader x 1 Chainsaws x 2	4	1	3,000	2,000	AC	50	311110100020, Clearing and grubbing, cut and chip light trees
	Construction Soil Erosion and Sediment Controls	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	650	2,308	769	LF	50,000	312514161000, Silt fence, install and remove
	Construction Facilities - Office Trailer	-	-	-	-	-	-	-	-	LS	1	015213200400, Office Trailer, buy, 50'x10'
	Construction Facilities - Storage Trailers (2)	-	-	-	-	-	-	-	-	LS	2	015213200200, Office trailer, buy, 20'x8'
	Construction Facilities - Portable Toilets (4)	-	-	-	-	-	-	-	-	MO	36	015433406410, Rent toilet portable chemical
	Dust Control	B59	Truck Driver x 1	1	Water Truck x 1	1	1	4,800	4,800	DAY	480	312323202510, Hauling, heavy, dust control
	Haul Road Maintenance	B86A	Operator x 1	1	Grader x 1	1	1	1,440	1,440	DAY	144	312323202600, Hauling, haul road maintenance
3	**Dewatering, Unwatering, and Stormwater Management**											
	Unwatering, Dewatering, and Stormwater Management for the Primary Ash Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	43,800	29,200	DAY	2920	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Water Management (additives, sampling)	-	-	-	-	-	-	-	-	DAY	2920	Based on experience, project size.
	Unwatering, Dewatering, and Stormwater Management for Lake Jake and Settling Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	2,700	1,800	DAY	180	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Outlet structure modification and temporary drainage features	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.05	300	200	LS	1	Based on experience, modification of existing infrastructure to re-route. Additional cost for piping
	Dewatering Sumps Installation	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	1	6,000	4,000	EA	400	Based on experience, project size.
4	**Closure**											
	Excavation of Ash Material											
	Excavation of ash material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	22,500	15,000	CY	5,700,000	312316432500, Excavating, large volume projects, restricted loading - doubled based on project experience
	Hauling material to onsite landfill area	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	107,955	107,955	CY	5,700,000	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	85,500	57,000	CY	5,700,000	312323170020, spread dumped material, by dozer
	Compaction of Material	B10Y	Operator x 1 Laborer x 0.5	1.5	Vibratory Roller x 1	1	2,300.00	37,174	24,783	CY	5,700,000	312323235020, compaction, riding, vibrating roller, 3 passes, 6" lifts
	Fine grading of ash surface OR clean closed area	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	4,394	2,197	AC	404	312216103300, fine grading, slopes, gentle, finish grading
	Piezometer and Monitoring Well Extensions	C18	Laborer x 1.125	1.125	Concrete Cart x 1	1	1.00	45	40	EA	4	Based on experience.
	Material Conditioning (drying, stabilizing)	-	-	-	-	-	-	-	-	CY	5,700,000	Based on experience.
	Offsite Disposal Fee	-	-	-	-	-	-	-	-	CY	0	Based on experience.
5	**Onsite Landfill Closure**											
	Landfill Bottom liner system (clay, 60-mil HDPE, drainage layer)											
	Mass Excavation	B14J	Operator x 1	1.5	Front End Loader x 1	1	3,800	3,947	2,632	CY	1,000,000	312316432500, Excavating, large volume projects, restricted loading
	Mas Excavation - Hauling	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528	18,939	18,939	CY	1,000,000	Based on experience, project size.
	Clay layer, 2-ft (bottom liner - onsite landfill)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800	708	472	CY	179,467	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528	3,399	3,399	CY	179,467	Based on experience, project size.
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000	2,692	1,795	CY	179,467	312323170020, spread dumped material, by dozer
	Compacting Material	B10D	Operator x 1 Laborer x 0.5	1.5	Dozer x 1 Compactor x 1	1	2,000	1,346	897	CY	179,467	312323235620, Compaction, 3 passes, 6" lifts, sheepsfoot
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	587	294	AC	54	312216103300, fine grading, slopes, gentle, finish grading
	Geomembrane, 60-mil HDPE	HDR2	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	3,240	1,350	AC	54	Based on experience.
	Geotextile, 8-oz.	HDR2	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	3,240	1,350	AC	54	Based on experience, est. $0.50/SF
	Anchor Trench (bottom liner)	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	180	120	LF	3,000	Based on experience.
	Drainage Layer (bottom liner)											
	Purchase Material	-	-	-	-	-	-	-	-	CY	89,734	Based on experience.
	Hauling Material	B34C	Truck Driver x 1	1	16.5-CY Truck x 1	1	99	9,064	9,064	CY	89,734	312323203314, 16.5-cy truck, 50 mph, 50-mile cycle
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000	1,346	897	CY	89,734	312323170020, spread dumped material, by dozer
	Capping											
	Clay layer, 1.5-ft (onsite landfill closure)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800	646	431	CY	163,764	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528	3,102	3,102	CY	163,764	Based on experience, project size.
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000	2,456	1,638	CY	163,764	312323170020, spread dumped material, by dozer
	Compacting Material	B10D	Operator x 1 Laborer x 0.5	1.5	Dozer x 1 Compactor x 1	1	2,000	1,228	819	CY	163,764	312323235620, Compaction, 3 passes, 6" lifts, sheepsfoot
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	715	357	AC	66	312216103300, fine grading, slopes, gentle, finish grading
	Geomembrane, 40-mil LLDPE	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	3,942	1,643	AC	66	Based on experience.
	Geotextile, 8-oz.	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	3,942	1,643	AC	66	Based on experience, est. $0.50/SF
	Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	-	-	LF	-	
	Temporary Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	-	-	LF	-	
	Drainage Pipes on Geomembrane	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	7,500	315	131	LF	19,710	Based on experience.
	Placement of Protective Cover Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	646	431	CY	163,764	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	3,102	3,102	CY	163,764	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	2,456	1,638	CY	163,764	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	715	357	AC	66	312216103300, fine grading, slopes, gentle, finish grading
	Placement of Vegetative Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	215	144	CY	54,588	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	1,034	1,034	CY	54,588	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	819	546	CY	54,588	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	715	357	AC	66	312216103300, fine grading, slopes, gentle, finish grading
	Installation of drainage channels									*LF*	*19,710*	
	Erosion Control Blanket	2 Clab	Laborer x 2	2	-	0	1000	2,190	0	SY	109,500	312514160120, synthetic erosion control, revegetation mat, webbed
	Installation of drainage letdowns									*LF*	*6,570*	
	Riprap	B30	Operator x 1 Truck Driver x 2	3	Excavator x 1 Dump Trucks x 2	3	100	3,504	3,504	SY	11,680	313713100200, Riprap and rock lining, not grouted, crew and output adjusted for site.
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	140	47	SY	11,680	Based on experience, est. $0.60/SF
6	**Stormwater and Perimeter**											
	Removal of Outlet Structure	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience.
	Removal of Outlet Pipe	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.20	75	50	LS	1	Based on experience.
	Installation of permanent stormwater culverts, riprap aprons, a	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience, includes final pond outlet.
	Establish Access Roads									*LF*	*13,500*	
	Gravel	B32	Operator x 3 Laborer x 1	4	Grader x 1 Roller x 1 Dozer x 1	3	5,000	360	270	SY	45,000	321123230370, base course, aggregate base course, 6"
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	540	180	SY	45,000	Based on experience, est. $0.60/SF
	Seed, fertilize, and maintain vegetated surfaces											
	Seeding	B66	Operator x 1	1	Loader-Backhoe x 1	1	1.5	3,000	3,000	AC	450	329219130020, mechanical seeding, 215 lb/ac
	Fertilizing	B66	Operator x 1	1	Loader-Backhoe x 1	1	3	1,500	1,500	AC	450	320190130110, fertilizing, dry granular, 4 lb/MSF, crew per project experience.
	Mulch (select areas/steep slopes)	B66	Operator x 1	1	Loader-Backhoe x 1	1	140,000	124	124	SF	1,742,400	329113160760, soil preparation, mulching
	Repair initial erosion	B66	Operator x 1	1	Loader-Backhoe x 1	1	1	410	410	AC	41	Based on experience, reseed 10% to establish vegetation
7	**Engineering and Construction Support**											
	Final Closure Design, Local Permitting Support, and Bid Support	HDR2	Engineering Staff x 4	4	-	0	0.01	4,000	0	LS	1	1% of total project, based on project scale.
	Engineering Support and CQA during Construction	HDR3	CQA Staff x 1 Engineering Staff x 1	2	Truck x 1	1	0.001	20,000	10,000	LS	1	2% of total project, based on duration of construction.

	Labor Hours:	Equipment Hours:
	432,797	**329,049**
Contingency (30%)	**562,636**	**427,763**

Notes:

1. RS Means used as reference - adjusted based on project size, location, type.
2. Grey crews were established based on HDR relevant project experience.

Table 4b: Labor, Equipment, and Mileage Estimate - Closure by Removal -Onsite Landfill- Totals

Item	Quantity	Assumptions
Labor Total Hours	562,636	10-hr days
Duration of Onsite Construction in Days	1,440	Working days, 9 months per year for 8 yrs, 20-working days per month average
Average Daily Crew Size	39	Crew Members
Daily Labor Mobilization Miles	3,938,451	Average of 70 miles round trip per day
Vehicles Miles Onsite	139,620	2 mile round trip from gate to parking 5 miles per day for CQA tech and Construction Supervisor 10% Contingency for site visitors (client and engineering support)
Equipment Mobilization Miles - Unloaded	64,164	Average of 300 miles one way for equipment hauling Average 1 load of equipment 2,000 Equipment working hours
Equipment Mobilization Miles - Loaded	64,164	Average of 300 miles one way for equipment hauling Average 1 load of equipment per working week
Daily Equipment Miles Onsite	1,440,000	Average of ~20 crew members running equipment Assume 50 miles per piece of equipment (average 5 mph, 10-hrs per day)
Onsite Haul Truck Miles - Unloaded	167,647	34 CY Haul Truck 4000 ft cycle
Onsite Haul Truck Miles - Loaded	167,647	34 CY Haul Truck 4000 ft cycle
Offsite Haul Truck Miles - Unloaded	0	16.5 CY Dump Truck 75 mile trip
Offsite Haul Truck Miles - Loaded	0	16.5 CY Dump Truck 75 mile trip
Material Delivery Miles - Unloaded	82,115	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Material Delivery Miles - Loaded	82,115	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Estimated Total	**6,145,923**	**miles**

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Table 5a: Quantity Estimate - Offsite Landfill

Item No.	Item	Crew	Worker Type	Workers (#)	Equipment Type	Equipment (#)	Daily Output	Labor Hours	Equipment Hours	Units	Quantity	Notes
1	**Pre-Construction**											
	Mobilization and Demobilization									LS	1	5% of project, based on experience, project size.
2	**Site Preparation**											
	Site Preparation: Clearing and Grubbing	B7	Operator x 1 Laborer x 5	6	Brush Chipper x 1 Crawler Loader x 1 Chainsaws x 2	4	1	3,000	2,000	AC	50	311110100020, Clearing and grubbing, cut and chip light trees
	Construction Soil Erosion and Sediment Controls	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	650	2,308	769	LF	50,000	312514161000, Silt fence, install and remove
	Construction Facilities - Office Trailer	-	-	-	-	-	-	-	-	LS	1	015213200400, Office Trailer, buy, 50'x10'
	Construction Facilities - Storage Trailers (2)	-	-	-	-	-	-	-	-	LS	2	015213200200, Office trailer, buy, 20'x8'
	Construction Facilities - Portable Toilets (4)	-	-	-	-	-	-	-	-	MO	36	015433406410, Rent toilet portable chemical
	Dust Control	B59	Truck Driver x 1	1	Water Truck x 1	1	1	4,800	4,800	DAY	480	312323202510, Hauling, heavy, dust control
	Haul Road Maintenance	B86A	Operator x 1	1	Grader x 1	1	1	1,440	1,440	DAY	144	312323202600, Hauling, haul road maintenance
3	**Dewatering, Unwatering, and Stormwater Management**											
	Unwatering, Dewatering, and Stormwater Management for the Primary Ash Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	49,275	32,850	DAY	3285	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Water Management (additives, sampling)	-	-	-	-	-	-	-	-	DAY	3285	Based on experience, project size.
	Unwatering, Dewatering, and Stormwater Management for Lake Jake and Settling Pond	B10K	Operator x 1 Laborer x 0.5	1.5	Pump x 1	1	1	2,700	1,800	DAY	180	312309201100, Dewatering, pumping 8 hrs, times 3 for continuous
	Outlet structure modification and temporary drainage features	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.05	300	200	LS	1	Based on experience, modification of existing infrastructure to re-route. Additional cost for piping
	Dewatering Sumps Installation	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	1	6,000	4,000	EA	400	Based on experience, project size.
4	**Closure**											
	Excavation of Ash Material											
	Excavation of ash material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	22,500	15,000	CY	5,700,000	312316432500, Excavating, large volume projects, restricted loading - doubled based on project experience
	Hauling material offsite	B34C	Truck Driver x 1	1	Haul Truck x 1	1	33	1,727,273	1,727,273	CY	5,700,000	312323203304, cycle hauling, adjusted for 150-mile cycle, Crew B34C -assume 2 cycles per day
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	85,500	57,000	CY	5,700,000	312323170020, spread dumped material, by dozer
	Compaction of Material	B10Y	Operator x 1 Laborer x 0.5	1.5	Vibratory Roller x 1	1	2,300.00	37,174	24,783	CY	5,700,000	312323235020, compaction, riding, vibrating roller, 3 passes, 6" lifts
	Fine grading of ash surface OR clean closed area	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	4,394	2,197	AC	404	312216103300, fine grading, slopes, gentle, finish grading
	Piezometer and Monitoring Well Extensions	C18	Laborer x 1.125	1.125	Concrete Cart x 1	1	1.00	0	0	EA	0	Based on experience.
	Material Conditioning (drying, stabilizing)	-	-	-	-	-	-	-	-	CY	5,700,000	Based on experience.
	Offsite Disposal Fee	-	-	-	-	-	-	-	-	CY	5,700,000	Based on experience.
5	**Onsite Landfill Closure**											
	Clay layer, 1.5-ft (onsite landfill closure)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800	115	77	CY	29,163	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528	552	552	CY	29,163	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000	437	292	CY	29,163	312323170020, spread dumped material, by dozer
	Compacting Material	B10D	Operator x 1 Laborer x 0.5	1.5	Dozer x 1 Compactor x 1	1	2,000	219	146	CY	29,163	312323235620, Compaction, 3 passes, 6" lifts, sheepsfoot
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	127	64	AC	12	312216103300, fine grading, slopes, gentle, finish grading
	Geomembrane, 40-mil LLDPE	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	702	293	AC	12	Based on experience.
	Geotextile, 8-oz.	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	2	702	293	AC	12	Based on experience, est. $0.50/SF
	Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	0	0	LF		
	Temporary Anchor Trench	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	250	0	0	LF		
	Drainage Pipes on Geomembrane	HDR1	Operator x 2 Laborer x 10	12	Skid Steer x 1 Forklift x 1	5	7,500	56	23	LF	3,510	Based on experience.
	Placement of Protective Cover Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	115	77	CY	29,163	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	552	552	CY	29,163	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	437	292	CY	29,163	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	127	64	AC	12	312216103300, fine grading, slopes, gentle, finish grading
	Placement of Vegetative Soil (onsite source)											
	Excavation and Loading of Material	B14J	Operator x 1 Laborer x 0.5	1.5	Front End Loader x 1	1	3,800.00	38	26	CY	9,721	312316432500, Excavating, large volume projects, restricted loading
	Hauling Material	B34F	Truck Driver x 1	1	Dump Truck x 1	1	528.00	184	184	CY	9,721	312323206470, Cycle hauling, 34-cy, 1-mile
	Spreading of Material	B10B	Operator x 1 Laborer x 0.5	1.5	Dozer x 1	1	1,000.00	146	97	CY	9,721	312323170020, spread dumped material, by dozer
	Finish grading material	B11L	Operator x 1 Laborer x 1	2	Grader x 1	1	1.84	127	64	AC	12	312216103300, fine grading, slopes, gentle, finish grading
	Installation of drainage channels									*LF*	*3,510*	
	Erosion Control Blanket	2 Clab	Laborer x 2	2	-	0	1000	390	0	SY	19,500	312514160120, synthetic erosion control, revegetation mat, webbed
	Installation of drainage letdowns									*LF*	*1,170*	
	Riprap	B30	Operator x 1 Truck Driver x 2	3	Excavator x 1 Dump Trucks x 2	3	100	624	624	SY	2,080	313713100200, Riprap and rock lining, not grouted, crew and output adjusted for site.
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	25	8	SY	2,080	Based on experience, est. $0.60/SF
6	**Stormwater and Perimeter**											
	Removal of Outlet Structure	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience.
	Removal of Outlet Pipe	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.20	75	50	LS	1	Based on experience.
	Installation of permanent stormwater culverts, riprap aprons, a	B14A	Operator x 1 Laborer x 0.5	1.5	Excavator x 1	1	0.10	150	100	LS	1	Based on experience, includes final pond outlet.
	Establish Access Roads									*LF*	*13,500*	
	Gravel	B32	Operator x 3 Laborer x 1	4	Grader x 1 Roller x 1 Dozer x 1	3	5,000	360	270	SY	45,000	321123230370, base course, aggregate base course, 6"
	Geotextile, 10 oz.	B62	Operator x 1 Laborer x 2	3	Skid Steer x 1	1	2,500	540	180	SY	45,000	Based on experience, est. $0.60/SF
	Seed, fertilize, and maintain vegetated surfaces											
	Seeding	B66	Operator x 1	1	Loader-Backhoe x 1	1	1.5	3,000	3,000	AC	450	329219130020, mechanical seeding, 215 lb/ac
	Fertilizing	B66	Operator x 1	1	Loader-Backhoe x 1	1	3	1,500	1,500	AC	450	320190130110, fertilizing, dry granular, 4 lb/MSF, crew per project experience.
	Mulch (select areas/steep slopes)	B66	Operator x 1	1	Loader-Backhoe x 1	1	140,000	124	124	SF	1,742,400	329113160760, soil preparation, mulching
	Repair initial erosion	B66	Operator x 1	1	Loader-Backhoe x 1	1	1	410	410	AC	41	Based on experience, reseed 10% to establish vegetation
7	**Engineering and Construction Support**											
	Final Closure Design, Local Permitting Support, and Bid Support	HDR2	Engineering Staff x 4	4	-	0	0.01	4,000	0	LS	1	1% of total project, based on project scale.
	Engineering Support and CQA during Construction	HDR3	CQA Staff x 1 Engineering Staff x 1	2	Truck x 1	1	0.001	20,000	10,000	LS	1	1% of total project, reduced with closure by removal scenario.
								Labor Hours:	**Equipment Hours:**			
								1,982,651	**1,893,572**			
						Contingency (30%)		**2,577,446**	**2,461,643**			

Notes:

1. RS Means used as reference - adjusted based on project size, location, type.
2. Grey crews were established based on HDR relevant project experience.

Table 5b: Labor, Equipment, and Mileage Estimate - Closure by Removal -Offsite Landfill- Totals

Item	Quantity	Assumptions
Labor Total Hours	2,577,446	10-hr days
Duration of Onsite Construction in Days	3,960	Working days, 9 months per year for 22 yrs, 20-working days per month average
Average Daily Crew Size	65	Crew Members
Daily Labor Mobilization Miles	18,042,120	Average of 70 miles round trip per day
Vehicles Miles Onsite	610,598	2 mile round trip from gate to parking 5 miles per day for CQA tech and Construction Supervisor 10% Contingency for site visitors (client and engineering support)
Equipment Mobilization Miles - Unloaded	369,247	Average of 300 miles one way for equipment hauling Average 1 load of equipment 2,000 Equipment working hours
Equipment Mobilization Miles - Loaded	369,247	Average of 300 miles one way for equipment hauling Average 1 load of equipment per working week
Daily Equipment Miles Onsite	3,960,000	Average of ~20 crew members running equipment Assume 50 miles per piece of equipment (average 5 mph, 10-hrs per day)
Onsite Haul Truck Miles - Unloaded	0	34 CY Haul Truck 4000 ft cycle
Onsite Haul Truck Miles - Loaded	0	34 CY Haul Truck 4000 ft cycle
Offsite Haul Truck Miles - Unloaded	25,909,091	16.5 CY Dump Truck 75 mile trip
Offsite Haul Truck Miles - Loaded	25,909,091	16.5 CY Dump Truck 75 mile trip
Material Delivery Miles - Unloaded	63,938	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Material Delivery Miles - Loaded	63,938	Assume geosynthetic source ~850-miles from site (possibly South Carolina) 60 extra trips for piping, seed, fertilizer, mulch, straw wattles, and concrete - source 1000 miles away average
Estimated Total	**75,297,270**	**miles**

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment B

Final Closure Plans and Material Specifications

Electronic Filing: Received, Clerk's Office 07/01/2024

Closure Drawings For

IPGC Newton Power Station

Primary Ash Pond Closure

Construction Permit Application

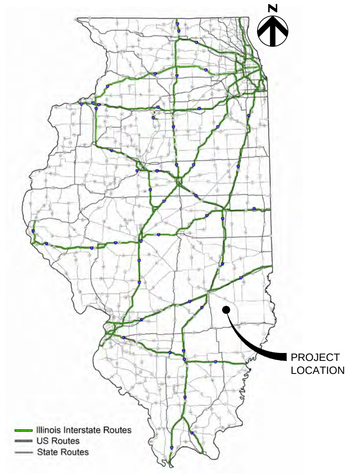
Project No.
10296144

Jasper County, IL
July 2022

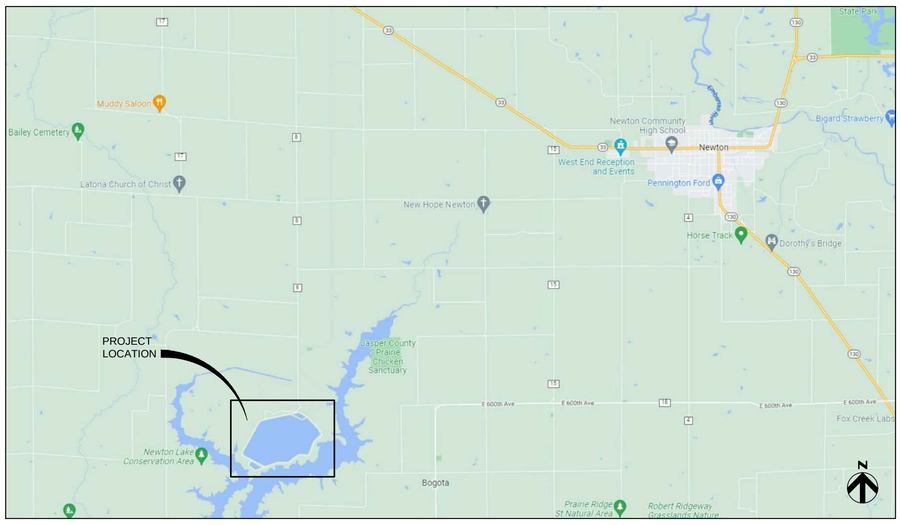
INDEX OF DRAWINGS

GENERAL
00G000 COVER SHEET

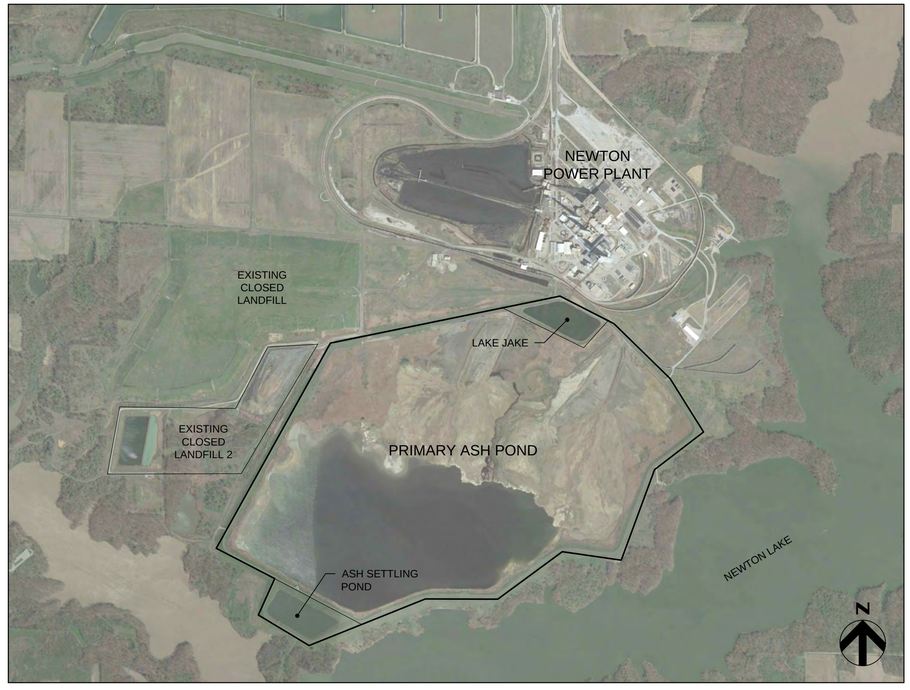
CIVIL
00C101 PHASE 1 - DEWATERING | EXISTING CONDITIONS PLAN
00C102 PHASE 2 - CLOSURE | WEST ASH POND CLOSURE GRADING
00C103 PHASE 3 - CLOSURE | EAST ASH POND CLOSURE GRADING
00C104 PHASE 4 - CLOSURE | REMAINING ASH POND CLOSURE GRADING
00C105 PHASE 5 - CLOSURE | REMAINING ASH POND CLOSURE CAPPING
00C106 FINAL CLOSURE CONDITIONS
00C107 SOLAR LAYOUT PLAN
00C301 CROSS SECTIONS
00C302 CROSS SECTIONS
00C501 DETAILS
00C502 DETAILS
00C503 DETAILS



STATE MAP
NOT TO SCALE



PROJECT LOCATION MAP
SCALE: 1" = 6000'



PROJECT SITE MAP
SCALE: 1" = 1000'

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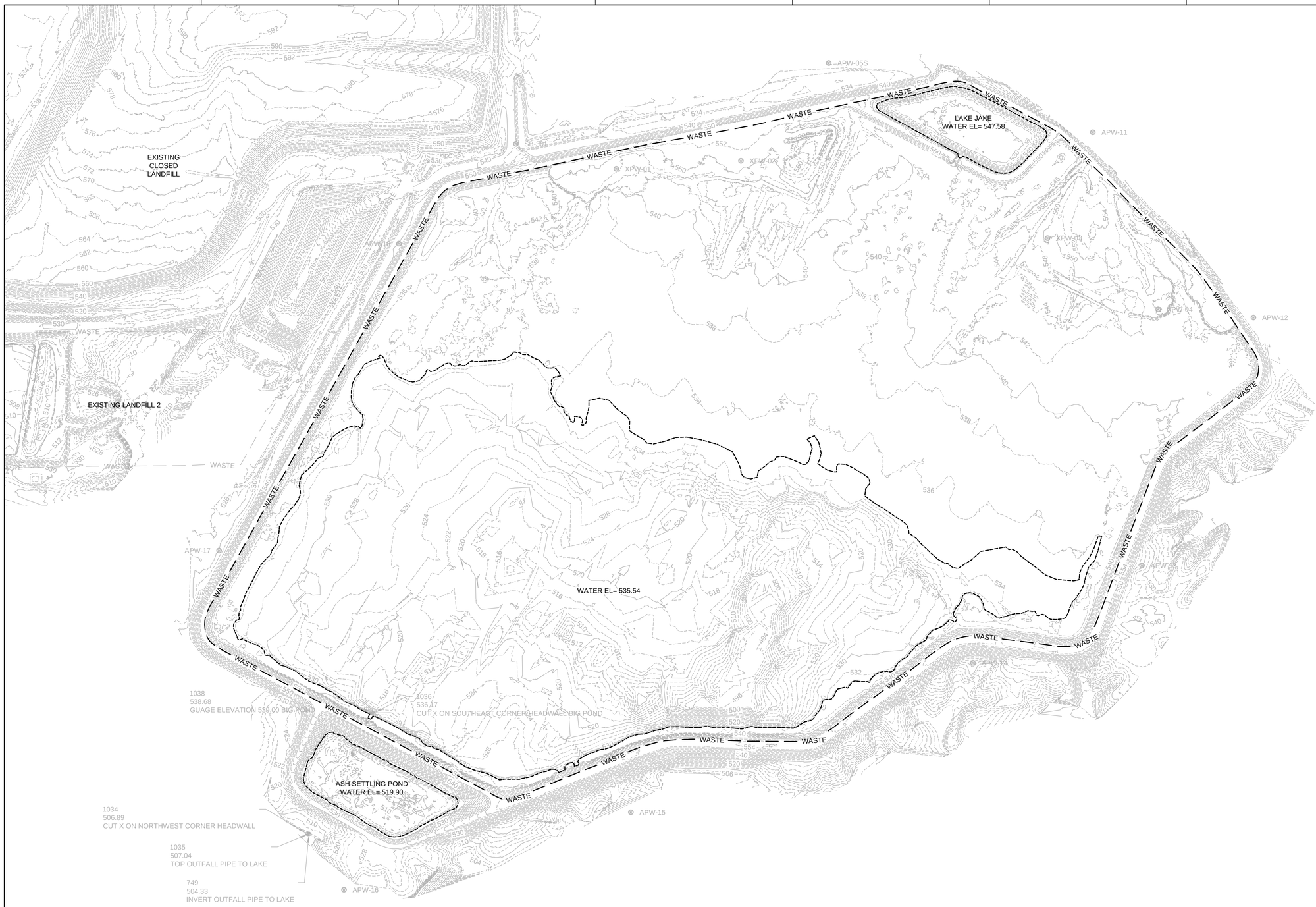

N

LEGEND

- WASTE — ESTIMATED ASH POND BOUNDARY
- WASTE — EXISTING LANDFILL BOUNDARY
- LIMITS OF BATHYMETRIC SURVEY
- 550 — EXISTING MAJOR CONTOUR
- EXISTING MINOR CONTOUR
- EXISTING GROUNDWATER WELL

NOTES

1. EXISTING GRADES REPRESENT EXISTING TOPOGRAPHIC AND BATHYMETRIC SURVEY PROVIDED BY INGENAE DATE DECEMBER 2, 2020 AND DECEMBER 14, 2020 RESPECTIVELY.
2. SOLID WASTE BOUNDARY ESTIMATED FROM INTERIOR EDGE OF CONTAINMENT BERM.

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

PHASE 1 - DEWATERING EXISTING CONDITIONS PLAN

0 1" 2"

FILENAME 00C101.DWG
SCALE 1" = 300'

SHEET **00C101**

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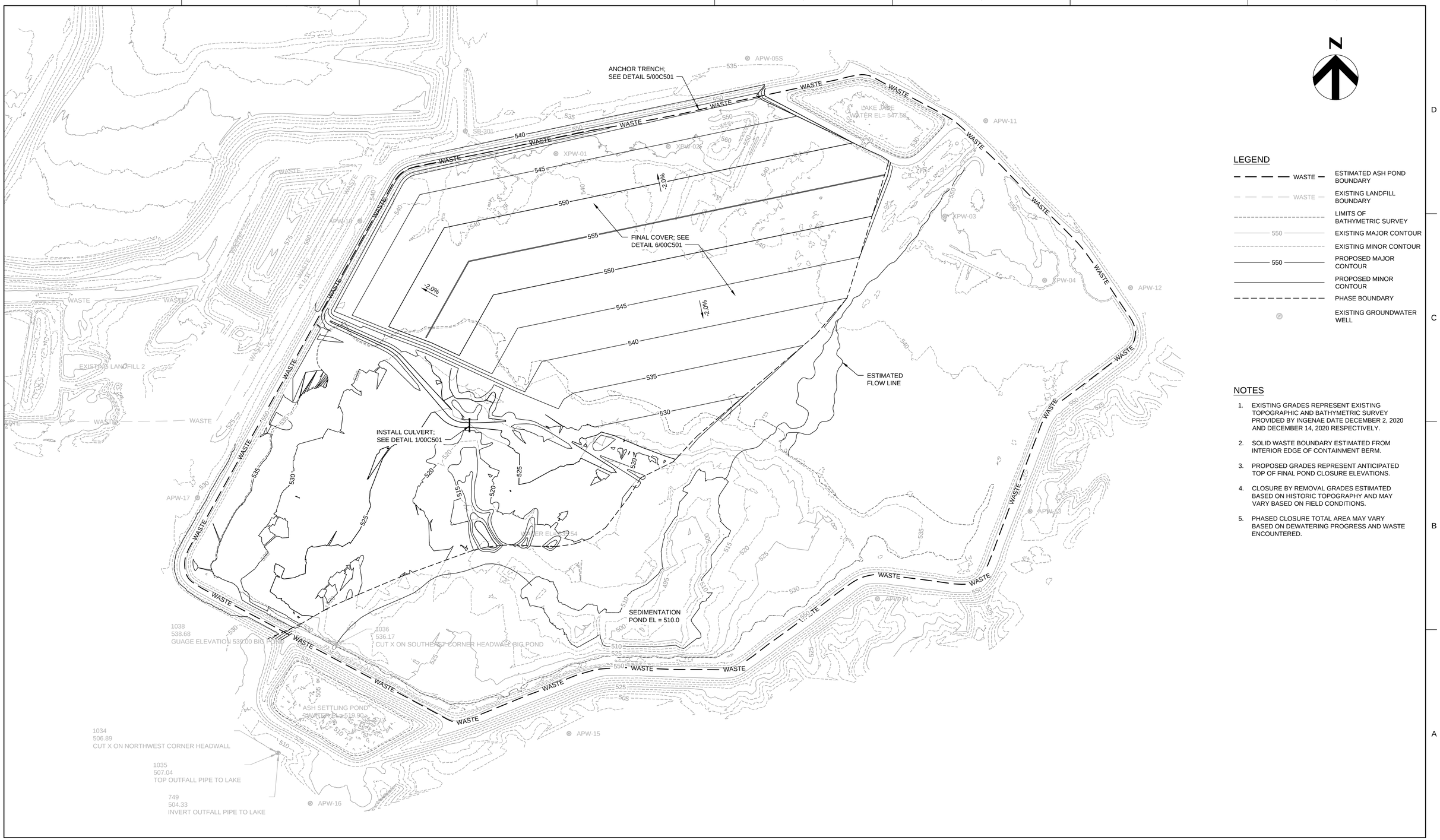

LEGEND

- WASTE — ESTIMATED ASH POND BOUNDARY
- WASTE — EXISTING LANDFILL BOUNDARY
- LIMITS OF BATHYMETRIC SURVEY
- 550 — EXISTING MAJOR CONTOUR
- EXISTING MINOR CONTOUR
- 550 — PROPOSED MAJOR CONTOUR
- PROPOSED MINOR CONTOUR
- PHASE BOUNDARY
- EXISTING GROUNDWATER WELL

NOTES

1. EXISTING GRADES REPRESENT EXISTING TOPOGRAPHIC AND BATHYMETRIC SURVEY PROVIDED BY INGENAE DATE DECEMBER 2, 2020 AND DECEMBER 14, 2020 RESPECTIVELY.
2. SOLID WASTE BOUNDARY ESTIMATED FROM INTERIOR EDGE OF CONTAINMENT BERM.
3. PROPOSED GRADES REPRESENT ANTICIPATED TOP OF FINAL POND CLOSURE ELEVATIONS.
4. CLOSURE BY REMOVAL GRADES ESTIMATED BASED ON HISTORIC TOPOGRAPHY AND MAY VARY BASED ON FIELD CONDITIONS.
5. PHASED CLOSURE TOTAL AREA MAY VARY BASED ON DEWATERING PROGRESS AND WASTE ENCOUNTERED.

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

PHASE 2 - CLOSURE
WEST ASH POND CLOSURE GRADING

0 1" 2"

FILENAME 00C102.DWG
SCALE 1" = 300'

SHEET **00C102**

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N

LEGEND

- WASTE — ESTIMATED ASH POND BOUNDARY
- WASTE — EXISTING LANDFILL BOUNDARY
- LIMITS OF BATHYMETRIC SURVEY
- 550 — EXISTING MAJOR CONTOUR
- EXISTING MINOR CONTOUR
- 550 — PROPOSED MAJOR CONTOUR
- PROPOSED MINOR CONTOUR
- PHASE BOUNDARY
- EXISTING GROUNDWATER WELL
- FINAL COVER DRAIN PIPE
- DRAINAGE CHANNEL WITH DRAIN PIPE; SEE DETAIL 3/00C501
- LETDOWN STRUCTURE WITH DRAIN PIPE; SEE DETAIL 2/00C501
- ESTIMATED PHASE 3 CLOSURE-IN-PLACE (CIP); SEE DETAIL 6/00C501
- ESTIMATED PHASE 3 CLOSURE-BY-REMOVAL (CBR)

NOTES

1. EXISTING GRADES REPRESENT EXISTING TOPOGRAPHIC AND BATHYMETRIC SURVEY PROVIDED BY INGENAE DATE DECEMBER 2, 2020 AND DECEMBER 14, 2020 RESPECTIVELY.
2. SOLID WASTE BOUNDARY ESTIMATED FROM INTERIOR EDGE OF CONTAINMENT BERM.
3. PROPOSED GRADES REPRESENT ANTICIPATED TOP OF FINAL POND CLOSURE ELEVATIONS.
4. CLOSURE BY REMOVAL GRADES ESTIMATED BASED ON HISTORIC TOPOGRAPHY AND MAY VARY BASED ON FIELD CONDITIONS.
5. PHASED CLOSURE TOTAL AREA MAY VARY BASED ON DEWATERING PROGRESS AND WASTE ENCOUNTERED.
6. POND GRADES MAY VARY IN ORDER TO FIND SUITABLE SOILS.

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

PHASE 3 - CLOSURE
EAST ASH POND CLOSURE GRADING

0 1" 2"

FILENAME 00C103.DWG
SCALE 1" = 300'

SHEET **00C103**

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NOTES

1. EXISTING GRADES REPRESENT EXISTING TOPOGRAPHIC AND BATHYMETRIC SURVEY PROVIDED BY INGENAE DATE DECEMBER 2, 2020 AND DECEMBER 14, 2020 RESPECTIVELY.
2. SOLID WASTE BOUNDARY ESTIMATED FROM INTERIOR EDGE OF CONTAINMENT BERM.
3. PROPOSED GRADES REPRESENT ANTICIPATED TOP OF FINAL POND CLOSURE ELEVATIONS.
4. CLOSURE BY REMOVAL GRADES ESTIMATED BASED ON HISTORIC TOPOGRAPHY AND MAY VARY BASED ON FIELD CONDITIONS.
5. PHASED CLOSURE TOTAL AREA MAY VARY BASED ON DEWATERING PROGRESS AND WASTE ENCOUNTERED.
6. POND GRADES MAY VARY IN ORDER TO FIND SUITABLE SOILS.

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

PHASE 4 - CLOSURE
REMAINING ASH POND CLOSURE GRADING

0 1" 2"

FILENAME 00C104.DWG
SCALE 1" = 300'

SHEET **00C104**

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N

LEGEND

- WASTE — ESTIMATED ASH POND BOUNDARY
- WASTE — EXISTING LANDFILL BOUNDARY
- 550 — EXISTING MAJOR CONTOUR
- EXISTING MINOR CONTOUR
- 550 — PROPOSED MAJOR CONTOUR
- PROPOSED MINOR CONTOUR
- PHASE BOUNDARY
- EXISTING GROUNDWATER WELL
- FINAL COVER DRAIN PIPE
- DRAINAGE CHANNEL WITH DRAIN PIPE; SEE DETAIL 3/00C501
- LETDOWN STRUCTURE WITH DRAIN PIPE; SEE DETAIL 2/00C501
- ESTIMATED PHASE 5 CLOSURE-IN-PLACE (CIP); SEE DETAIL 6/00C501
- ESTIMATED PHASE 5 CLOSURE-BY-REMOVAL (CBR)
- PREVIOUS CLOSURE AREA

NOTES

1. EXISTING GRADES REPRESENT EXISTING TOPOGRAPHIC AND BATHYMETRIC SURVEY PROVIDED BY INGENAE DATE DECEMBER 2, 2020 AND DECEMBER 14, 2020 RESPECTIVELY.
2. SOLID WASTE BOUNDARY ESTIMATED FROM INTERIOR EDGE OF CONTAINMENT BERM.
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4. CLOSURE BY REMOVAL GRADES ESTIMATED BASED ON HISTORIC TOPOGRAPHY AND MAY VARY BASED ON FIELD CONDITIONS.
5. PHASED CLOSURE TOTAL AREA MAY VARY BASED ON DEWATERING PROGRESS AND WASTE ENCOUNTERED.
6. POND GRADES MAY VARY IN ORDER TO FIND SUITABLE SOILS.

ISSUE	DATE	DESCRIPTION
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CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

PHASE 5 - CLOSURE
REMAINING ASH POND CLOSURE CAPPING

0 1" 2"

FILENAME 00C105.DWG
SCALE 1" = 300'

SHEET **00C105**

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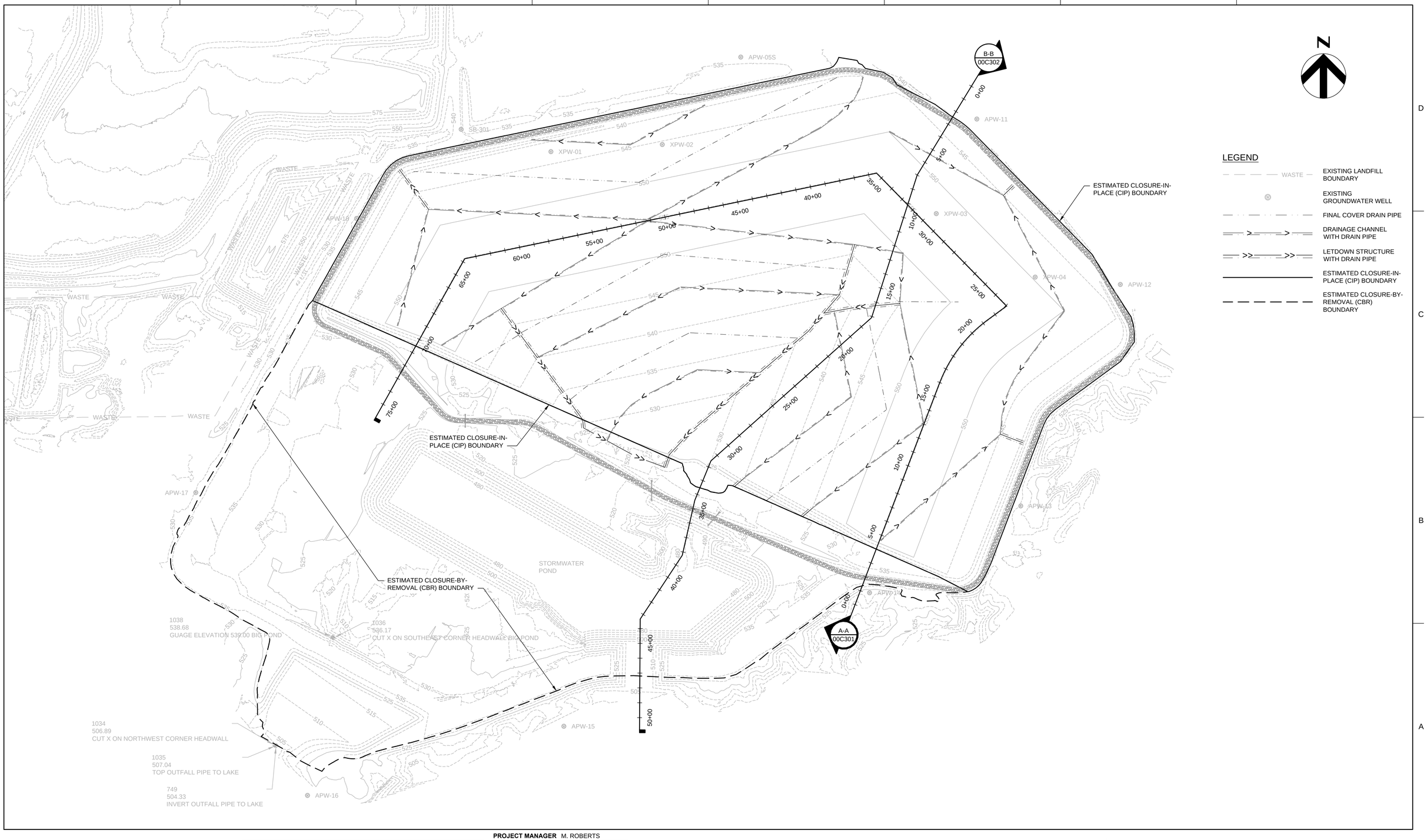

ISSUE	DATE	DESCRIPTION
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PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

FINAL CLOSURE CONDITIONS

0 1" 2"

FILENAME 00C106.DWG
SCALE 1" = 300'

SHEET **00C106**

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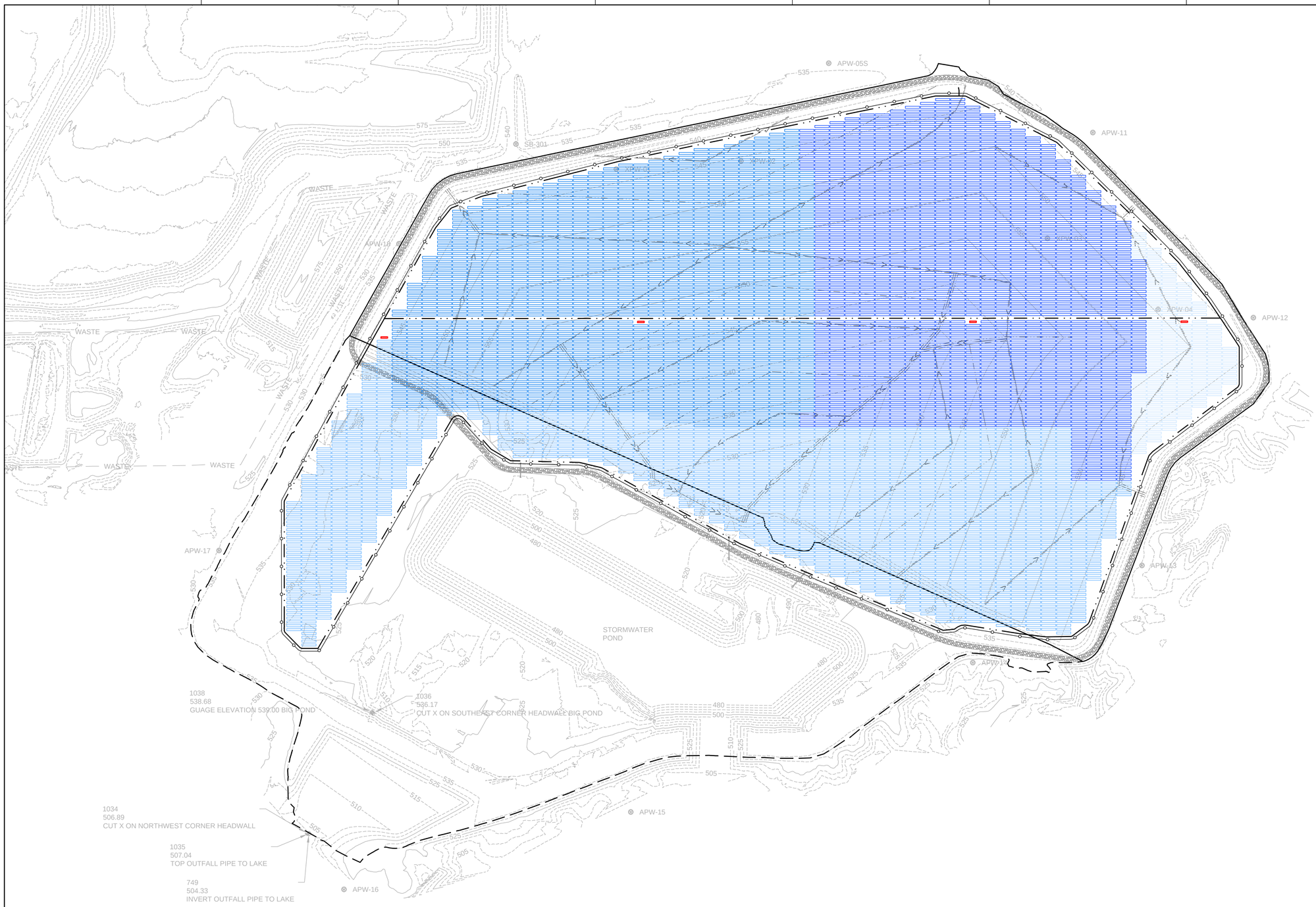

LEGEND

- WASTE — EXISTING LANDFILL BOUNDARY
- EXISTING GROUNDWATER WELL
- ESTIMATED CLOSURE-IN-PLACE (CIP) BOUNDARY
- ESTIMATED CLOSURE-BY-REMOVAL (CBR) BOUNDARY
- CLOSED POND PERIMETER ROAD
- SOLAR FIELD SECURITY FENCE
- SOLAR FIELD ACCESS ROAD
- COLLECTION POWER STATION
- SOLAR ARRAY PHASE 1
- SOLAR ARRAY PHASE 2
- SOLAR ARRAY PHASE 3
- SOLAR ARRAY PHASE 4

NOTES

1. LAYOUT REPRESENTS INITIAL DESIGN CONCEPT. FINAL LAYOUT MAY VARY TO ACCOMMODATE STORMWATER FEATURES, ROADS, AND CONSTRUCTION TIMING.

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

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CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

SOLAR LAYOUT PLAN

0 1" 2"

FILENAME 00C107.DWG
SCALE 1" = 300'

SHEET **00C107**

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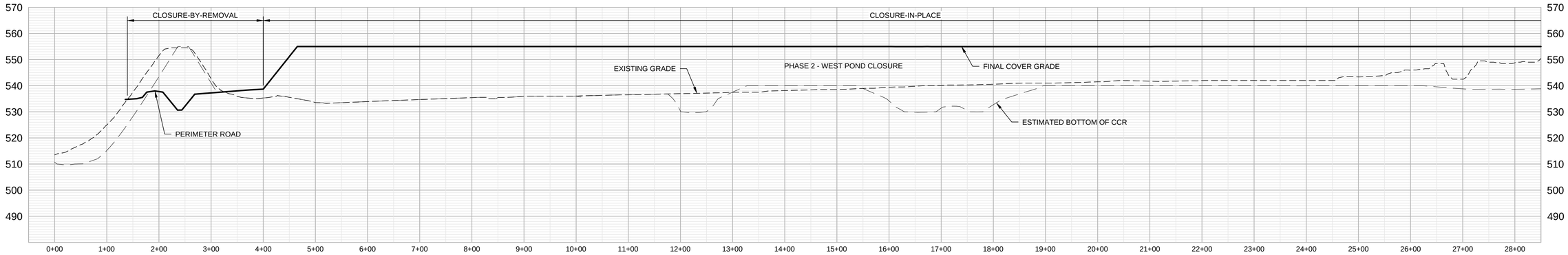
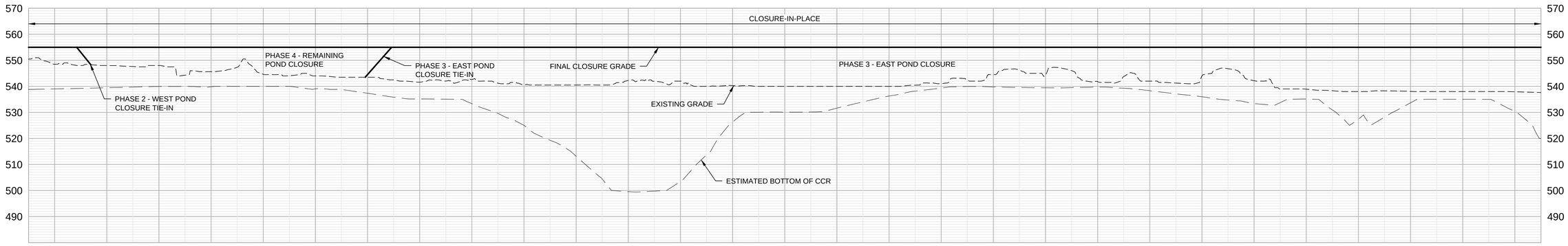


A-A 00C106 SECTION A-A
HORIZ: 1" = 100' | VERT: 1" = 20'



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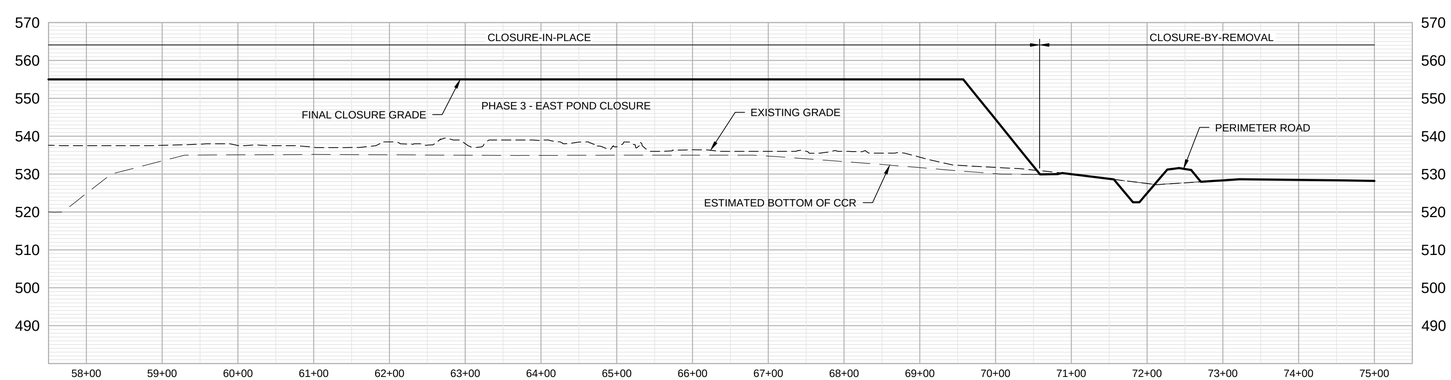

A-A 00C106 SECTION A-A (cont.)
HORIZ: 1" = 100' | VERT: 1" = 20'

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

CROSS SECTIONS

0 1" 2"

FILENAME 00C301.DWG
SCALE AS NOTED

SHEET **00C301**

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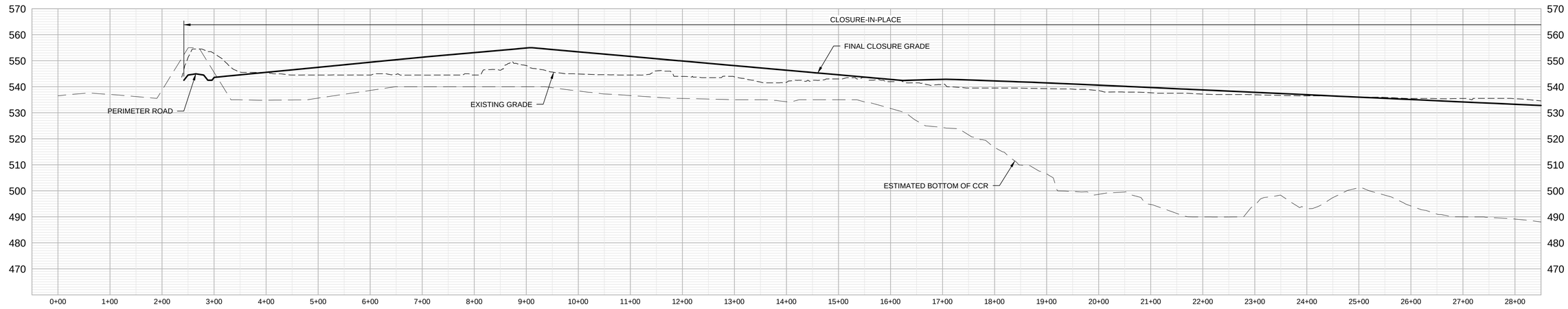

B-B 00C106 SECTION B-B
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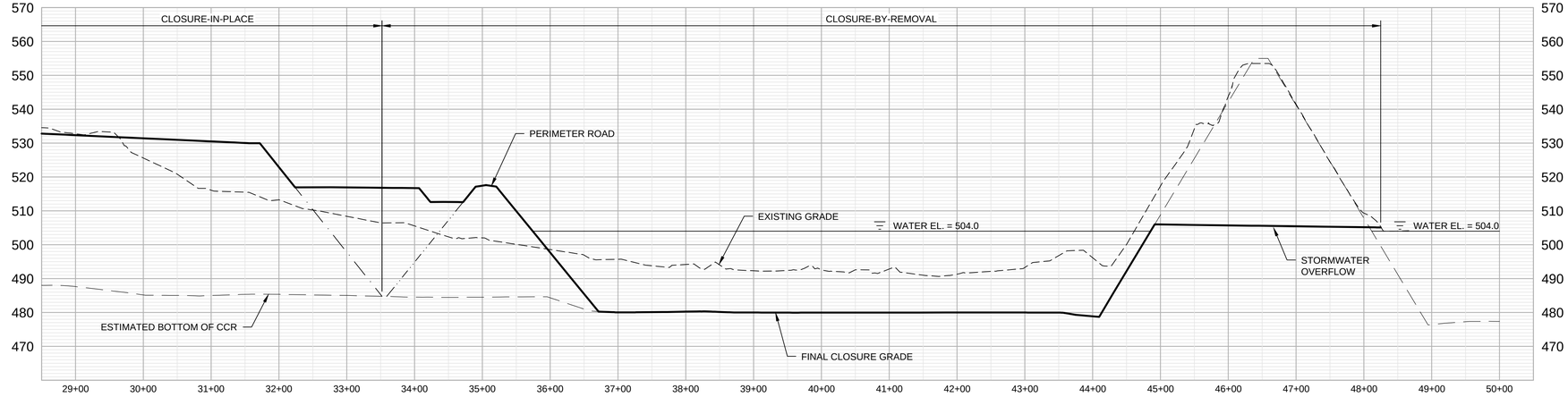

B-B 00C106 SECTION B-B (cont.)
HORIZ: 1" = 100' | VERT: 1" = 20'

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

CROSS SECTIONS

0 1" 2"

FILENAME 00C302.DWG
SCALE AS NOTED

SHEET **00C302**

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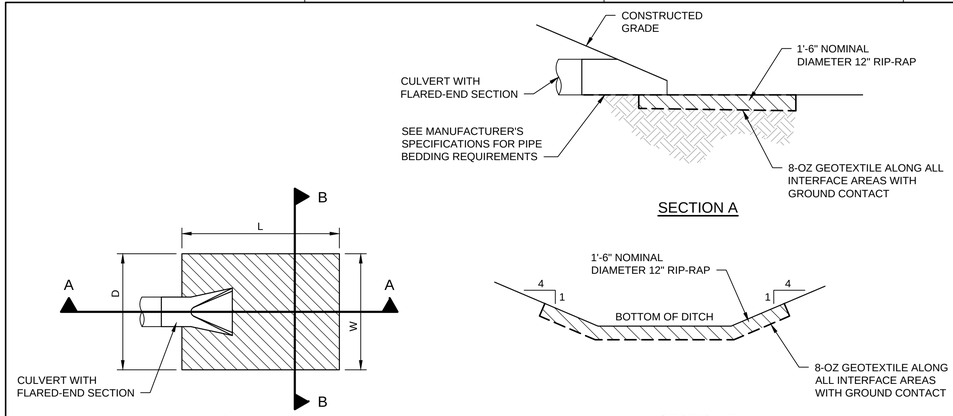
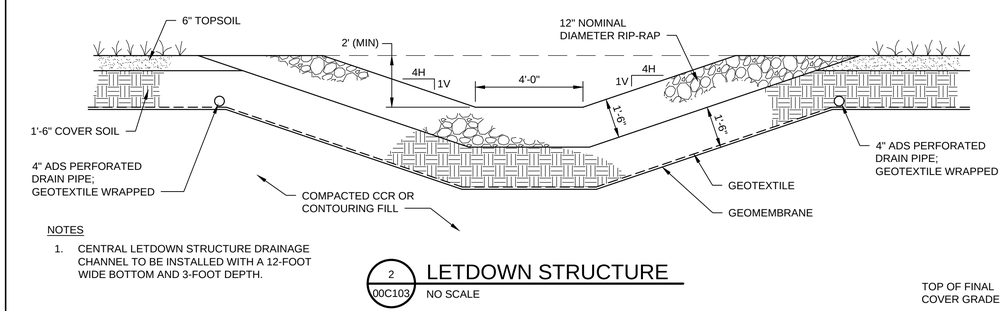


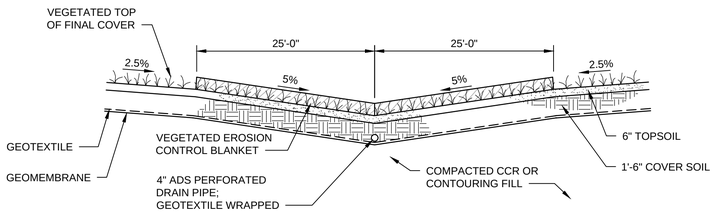
1 00C102 **FLARED-END SECTION AND REVETMENT STONE APRON**
NO SCALE



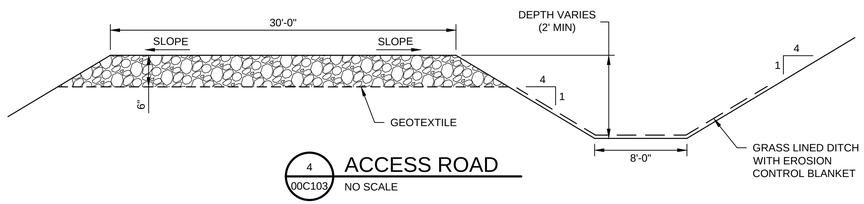
NOTES

1. CENTRAL LETDOWN STRUCTURE DRAINAGE CHANNEL TO BE INSTALLED WITH A 12-FOOT WIDE BOTTOM AND 3-FOOT DEPTH.

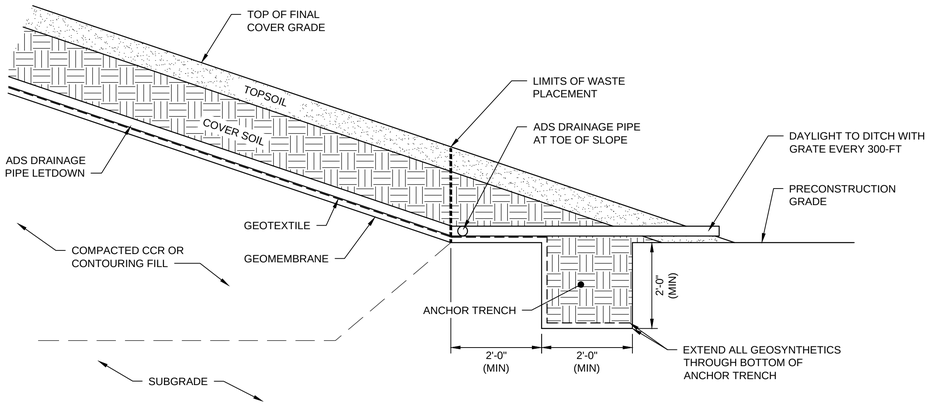
2 00C103 **LETDOWN STRUCTURE**
NO SCALE



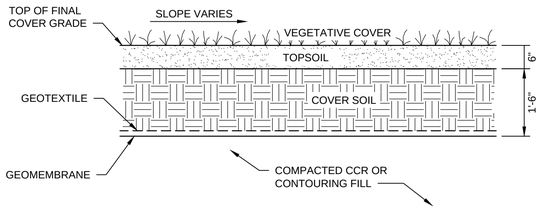
3 00C103 **DRAINAGE CHANNEL**
NO SCALE



4 00C103 **ACCESS ROAD**
NO SCALE



5 00C103 **ANCHOR TRENCH**
NO SCALE

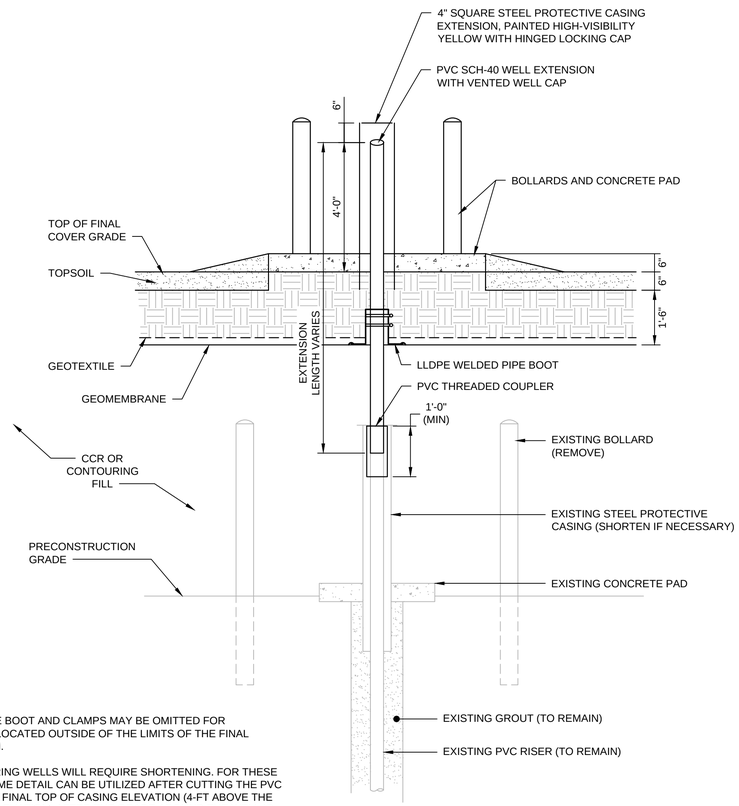


6 00C103 **FINAL COVER**
NO SCALE

NOTES

1. THE FINAL COVER IS DESIGNED WITH A 50-MIL LLDPE MICRODRAIN GEOMEMBRANE MATERIAL WITH DRAINAGE STUDS INSTALLED UPWARDS ND TEXTURED SIDE INSTALLED DOWNWARDS OVERLAIN WITH 8-OZ. GEOTEXTILE.

2. OPTIONALLY, THE MICRODRAIN GEOMEMBRANE AND GEOTEXTILE MAY BE REPLACED WITH A TEXTURED 40-MIL LLDPE GEOMEMBRANE OVERLAIN WITH A GEOCOMPOSITE DRAINAGE LAYER. ENGINEER TO VERIFY GEOCOMPOSITE MATERIAL MEETS DESIGN REQUIREMENTS FOR DRAINAGE.



NOTES

1. THE LLDPE PIPE BOOT AND CLAMPS MAY BE OMITTED FOR PIEZOMETERS LOCATED OUTSIDE OF THE LIMITS OF THE FINAL COVER SYSTEM.

2. SOME MONITORING WELLS WILL REQUIRE SHORTENING. FOR THESE WELLS, THE SAME DETAIL CAN BE UTILIZED AFTER CUTTING THE PVC CASING TO THE FINAL TOP OF CASING ELEVATION (4-FT ABOVE THE FINAL COVER ELEVATION) AFTER THE GRADE AROUND THE WELL IS LOWERED.

3. FOR MONITORING WELLS LOCATED IN AN ACTIVE SITE ROADWAY, THE ABOVE-GRADE PROTECTIVE CASING, BOLLARDS, AND CONCRETE PAD MAY BE SUBSTITUTED WITH A FLUSH MOUNT CASING AND A CONCRETE PAD AT LEAST 3-FT IN DIAMETER AND 4-INCHES IN THICKNESS. ALL OTHER DETAILS ARE TO REMAIN THE SAME.

7 00C103 **MONITORING WELL EXTENSION**
NO SCALE

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PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

DETAILS

0 1" 2"

FILENAME 00C501.DWG
SCALE AS NOTED

SHEET
00C501

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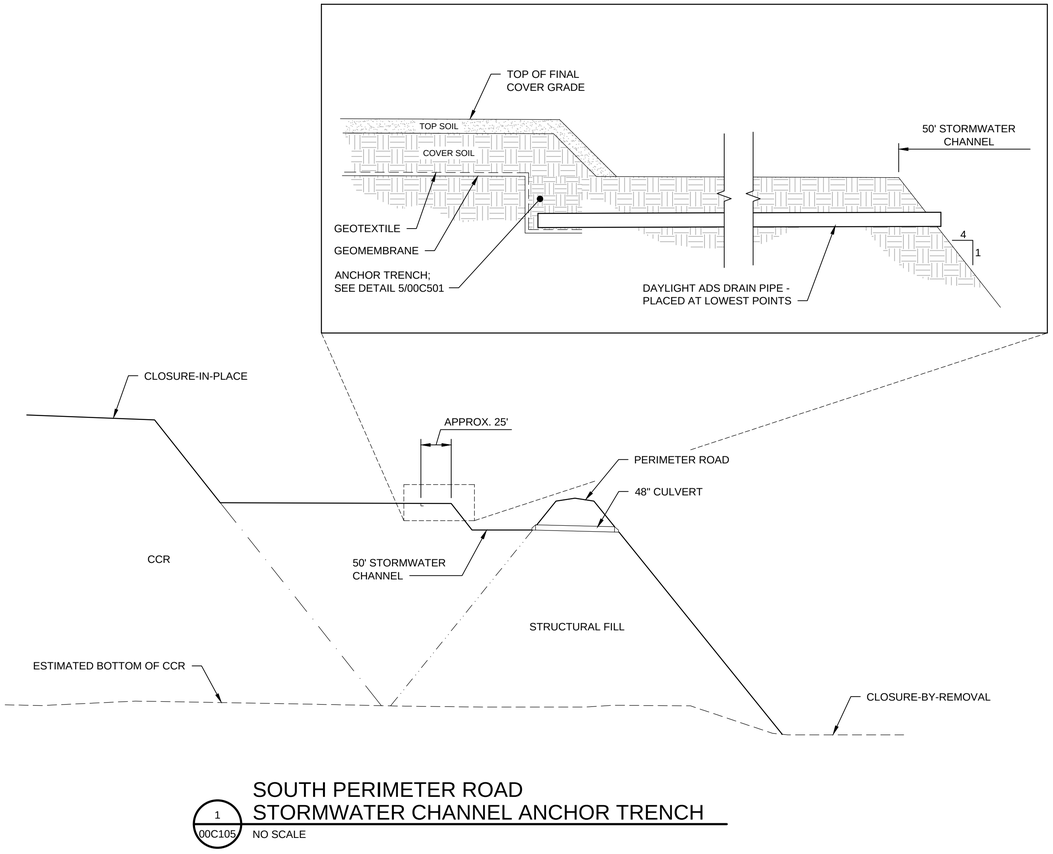

1
00C105

SOUTH PERIMETER ROAD
STORMWATER CHANNEL ANCHOR TRENCH
NO SCALE

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

DETAILS

0 1" 2"

FILENAME 00C502.DWG
SCALE AS NOTED

SHEET
00C502

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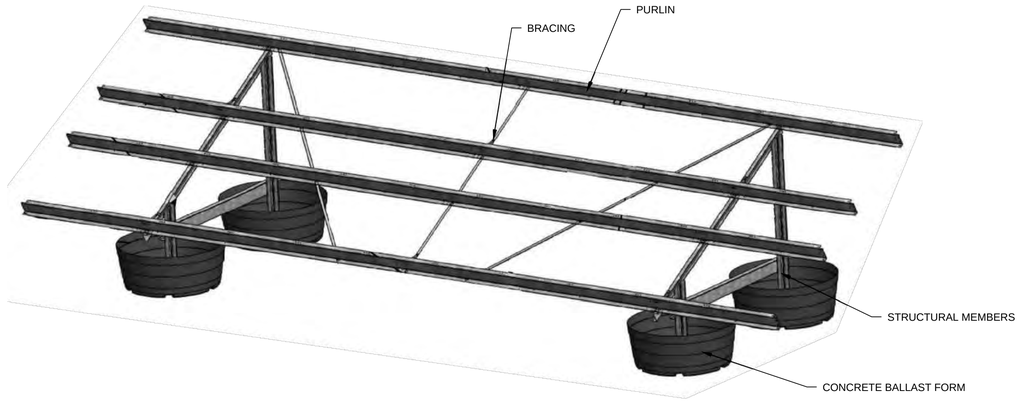
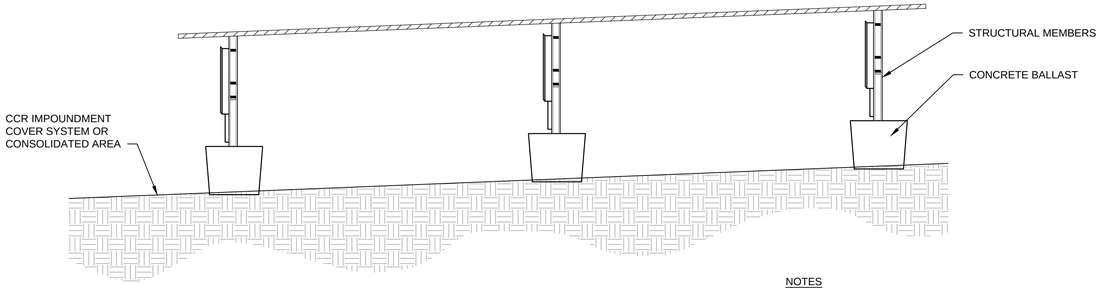


1 00C107 TYP. FIXED TILT BALLAST RACKING
NO SCALE



2 00C107 TYP. SOLAR MODULE
NO SCALE



NOTES

1. SOLAR ARRAY AND BALLAST SYSTEM SIT ON TOP OF FINAL COVER SYSTEM WITHOUT PENETRATING THE FINAL COVER. IN SOME LOCATIONS, ELECTRICAL LINES MAY BE BURIED IN THE TOP 24-INCHES OF THE CAP WITHOUT DISTURBING GEOSYNTHETICS IN ORDER TO MAINTAIN ACCESS ROUTES.

3 00C107 PROFILE VIEW OF BALLAST ON CLOSED AREA
NO SCALE

ISSUE	DATE	DESCRIPTION
0	07/28/2022	ISSUED TO IEPA

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

DETAILS

0 1" 2"

FILENAME 00C503.DWG
SCALE AS NOTED

SHEET **00C503**

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Attachment C

Hydrologic and Hydraulic Design of Stormwater Management System

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Illinois Power Generating Company
HYDROLOGIC AND HYDRAULIC DESIGN OF STORMWATER MANAGEMENT SYSTEM

Newton Power Plant
Primary Ash Pond

April 2022

Table of Contents

1. PURPOSE 1

2. ASSUMPTIONS AND DATA INPUT 1
   2.1 Hydrology Inputs 1
   2.2 Hydraulic Inputs and Results 2

3. CALCULATION OUTPUTS 3

FIGURES

Figure 1 Drainage Map with Subcatchments

APPENDICES

Appendix A: NOAA Precipitation Frequency Estimate & WebSoil Survey Output
Appendix B: Hydroflow Hydrographs Output
Appendix C: Hydroflow Express Output

1. PURPOSE

This calculation package provides documentation of the hydrologic and hydraulic calculations of the cover design for final closure of the approximately 400-acre Illinois Power Generating Company (IPGC) Newton Power Station Primary Ash Pond closure area. The analysis evaluates whether the proposed drainage features are adequate to manage 25-year and 100-year, 24-hour storm events. This analysis was completed to satisfy Illinois Administrative Code Part 845.510 and in support of the Closure Plan requirements detailed in IAC Section 845.750(a) to design a final cover with stormwater features promoting drainage away from the closure area and minimizing the need for future maintenance of the CCR surface impoundment.

2. ASSUMPTIONS AND DATA INPUT

The proposed drainage features were designed to convey both 25-year and 100-year, 24-hour storm events. AutoCAD Civil 3D Hydroflow Hydrographs Extension was used for the hydrologic analysis. The model estimated peak runoff rate for each subcatchment based on precipitation volumes derived from NOAA Atlas 14 data. AutoCAD Civil 3D Hydroflow Express Extension was used to confirm that proposed culverts would be sufficient to handle peak flows from 25-year and 100-year, 24-hour storm event. The following presents a summary of the assumptions and inputs used in the stormwater model.

2.1 Hydrology Inputs

Summary of Site Data

The existing surface grades for the Newton Ash Landfill are based on a topographic and bathymetric survey provided by IngenAE, LLC, dated December 2, 2020, and December 14, 2020. The proposed grades used for the hydrologic and hydraulic evaluation represent anticipated conditions and may be further modified during the design process, or due to field conditions at the time of construction.

Rainfall Depth and Distribution

Rainfall depths are based on the National Oceanic and Atmospheric Administration's (NOAA) Precipitation Frequency Data Server (PFDS). Precipitation estimates for the site location were input into the Hydrographs model for the 25-, and 100-year, 24-hour storm events. The NOAA PFDS outputs for the site location are included in **Appendix A**.

The Type II SCS storm distribution was used to evaluate the high rainfall intensity portion of the storm as a critical flood risk analysis. The SCS is considered a conservative model and is therefore considered adequate for design purposes. The following storm events were used to size the proposed stormwater features:

- Type II SCS 25-year, 24-hour event is 5.26 inches (Design)
- Type II SCS 100-year, 24-hour event is 6.58 inches (Convey Safely)

Curve Number (CN)

Curve numbers (CN) were estimated using Table 2-2 in the TR-55 manual embedded in the Hydrographs model. The curve numbers assumed soil conditions in the immediate vicinity of the landfill were generally type C, based on a review of the United States Department of Agriculture's (USDA) Web Soil Survey as

shown on the map print out in **Appendix A**. The final cover will include, from bottom to top, a geomembrane, geotextile, 1.5-ft of cover soil, 0.5-feet of topsoil, and established vegetation. The selected SCS curve number for the site was based on the following parameters:

- Open spaces, lawns, and parks
- Condition – Good
- Hydrologic Soil Group – C
- CN = 74

Subcatchments

The Newton basin design is comprised of seven (7) areas which stormwater drainage was analyzed. These approximate areas are indicated on Figure 1 and comprised as follows:

- Western Channel Area – 69-acres
- Eastern Channel Area – 61-acres
- Central Channel Area – 73-acres
- West Central Channel Area – 39-acres
- East Central Area – 14 Acres
- Inside Perimeter Road Area – 29-acres
- Storage and Outlet Area 144-acres of which 35-acresis wetted pond

The total approximate 400-acres is comprised of approximately 255-acres of cover, 144-acres of closure by removal, and 30-acres of ancillary areas. The areas were subdivided based on the grading plan and proposed drainage features, including drainage channels and letdowns to the perimeter ditch. Dividing the area into multiple subcatchments allows for a refined model that provides detailed information on stormwater flow over the site. The drainage map and associated subcatchment parameters are shown in **Figure 1**.

2.2 Hydraulic Inputs and Results

The following section summarizes the design assumptions and hydraulic parameters used to perform the hydraulic analysis.

Perimeter Ditches

The location and slope of the perimeter ditches were based on the permit application grading plans, approximated as 30% design. Perimeter drainage ditches were calculated as west and east channels and represent the interior ditch of the perimeter roadway. These perimeter drainage ditches originate at the north end of the construction and route stormwater toward the south. Initially the ditches are two (2) feet deep but increase depth as the flow continues south. Both ditches are minimally, 8-ft wide, 2-ft deep with 4:1 sideslopes. Channels were modeled at a minimum section of 2 ft of depth and a nominal 4-ft of depth and found to be sufficient to convey the 100-year, 24-hour storm event in both cases.

Drainage Channels

Areas of final cover have a 2% slope. The drainage terraces are designed as V-ditches with sideslopes of 5%, a longitudinal slope of about 0.5%, and a maximum flow depth of 1.25-ft. According to Manning's n for channels, a roughness coefficient of 0.022 was used for a clean, straight channel without rifts or deep pools.

Letdowns

The letdown structures were designed as trapezoidal structures with 1.5-feet of 12-inch diameter riprap. The riprap overlays a geomembrane, geotextile, and 1.5-feet of cover soil. The base of each letdown is 4-feet wide with 3:1 side slopes. The Manning's n used for the letdown structures was 0.026. The longitudinal slope of the letdowns varied based on location.

Central Drainageway

Much like the letdowns described above, the central drainage way consists of a trapezoidal channel with 1.5 feet of 12-inch diameter riprap. The central drainageway flows at 1% slopes, is 3 feet deep and 12 feet wide. This profile is similar to the letdowns across the side but increased in size to accommodate the larger drainage area and flow.

Culverts

Culverts for the work will be installed to route stormwater under the perimeter roadway and into the borrow area pond. The culverts will be category 2 or 3 reinforced concrete pipes with appropriate bedding, and inlet and outlet protections. It may be advantageous to install headwalls to manage the pipe inlets and outlets. Pipes will be 48" and laid at 2 percent slope.

Outlet Weir

The overall drainage path for the project culminates at an area of ponded water and outlet weir. The weir is designed to be 150 feet wide, with 4:1 sideslopes and approximately a 0.2% slope. The outlet weir is intended to convey stormwater originating from the development area out to the neighboring Lake Newton. The elevation of the outfall is such that no back flow from the Lake is expected into the project area.

3. CALCULATION OUTPUTS

This calculation package is intended to compute and model various stormwater features of the site as described in the previous section. This section indicates the anticipated flow and performance of the individual drainage features.

Perimeter Ditches

The West Drainage Channel consists of 68.65-acres where a calculated flow of 199.78-cfs is expected from the 100-year, 24-hour storm event. This results in approximately 2.6-feet of flow depth, at a velocity slightly above 4 feet per second. During establishment of vegetation, it would be advantageous to utilize an erosion control matting.

The East Drainage Channel consists of 61.34-acres where a calculated flow of 178.51-cfs is expected from the 100-year, 24-hour storm event. This results in approximately 2.64-feet of flow depth, at a velocity of 3.65 feet per second. During establishment of vegetation, it would be advantageous to utilize an erosion control matting.

Drainage Channels

The design drainage terrace was indicated by the largest drainage area flowing to a terrace. This area was measured at about 12-acres, resulting in approximately 35 cubic feet per second for a 100-year, 24-hour storm event. The drainage terrace can successfully manage this flow with over 5 inches of freeboard remaining at a velocity of 2.60 feet per second.

Letdowns

The letdown structures carry various flows around the project site with minimal flows being appropriately managed through short, robust riprap letdowns.

Central Drainageway

The central drainageway consists of 72.85-acres where a calculated flow of 211-cfs is expected from the 100-year, 24-hour storm event. This results in approximately 2.14 feet of flow depth, at a velocity of 4.8 feet per second.

Culverts

The culverts will convey approximately 285-acres of runoff resulting in 827-cfs from a 100-year, 24-hour storm event. Multiple culverts are to be installed to lessen the size of necessary culvert but also to provide redundancy to the system. The 48-inch RCP culvert flowing approximately full results is 217.5-cfs at the design slope and length. Installing four total pipes, two at each location as shown on the plans, will provide a free flow scenario to limit potential of holding water within the consolidation area. Flow out of each pipe will result in the potential for highly erosive velocities. Protections of the inlet and outlet areas should be further designed prior to construction.

Outlet Weir

The outlet weir provides conveyance for the entire project area. The weir will discharge all 428.5-acres of runoff. The runoff is calculated to be 1194-cfs from the 100-year, 24-hour storm event. The weir is 150-feet wide with a 0.2 percent slope. This equates to a flow depth of 1.78 feet at a velocity of 4.27 feet per second. The tailwater condition should be even or approximately even. Final design should confirm this condition.

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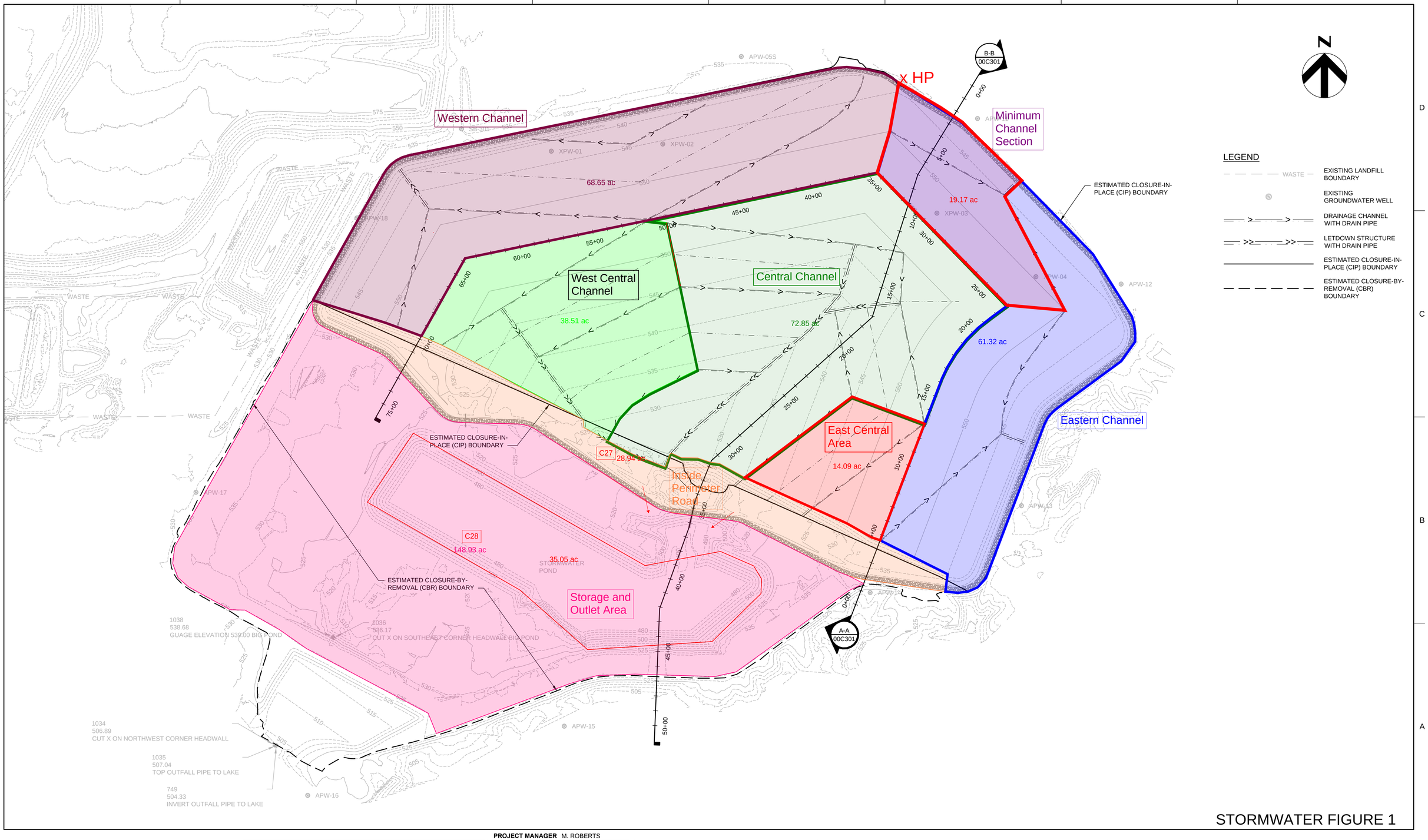
Figures

Drainage Mapping



STORMWATER FIGURE 1

		PROJECT MANAGER	M. ROBERTS
		CIVIL	G. WILLIAMS
		CIVIL	K. KINLEY
		DRAWN BY	M. BICKFORD
ISSUE	DATE	DESCRIPTION	PROJECT NUMBER 10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

FINAL CLOSURE CONDITIONS

FILENAME 00C106.DWG
SCALE 1" = 300'

SHEET **00C106**

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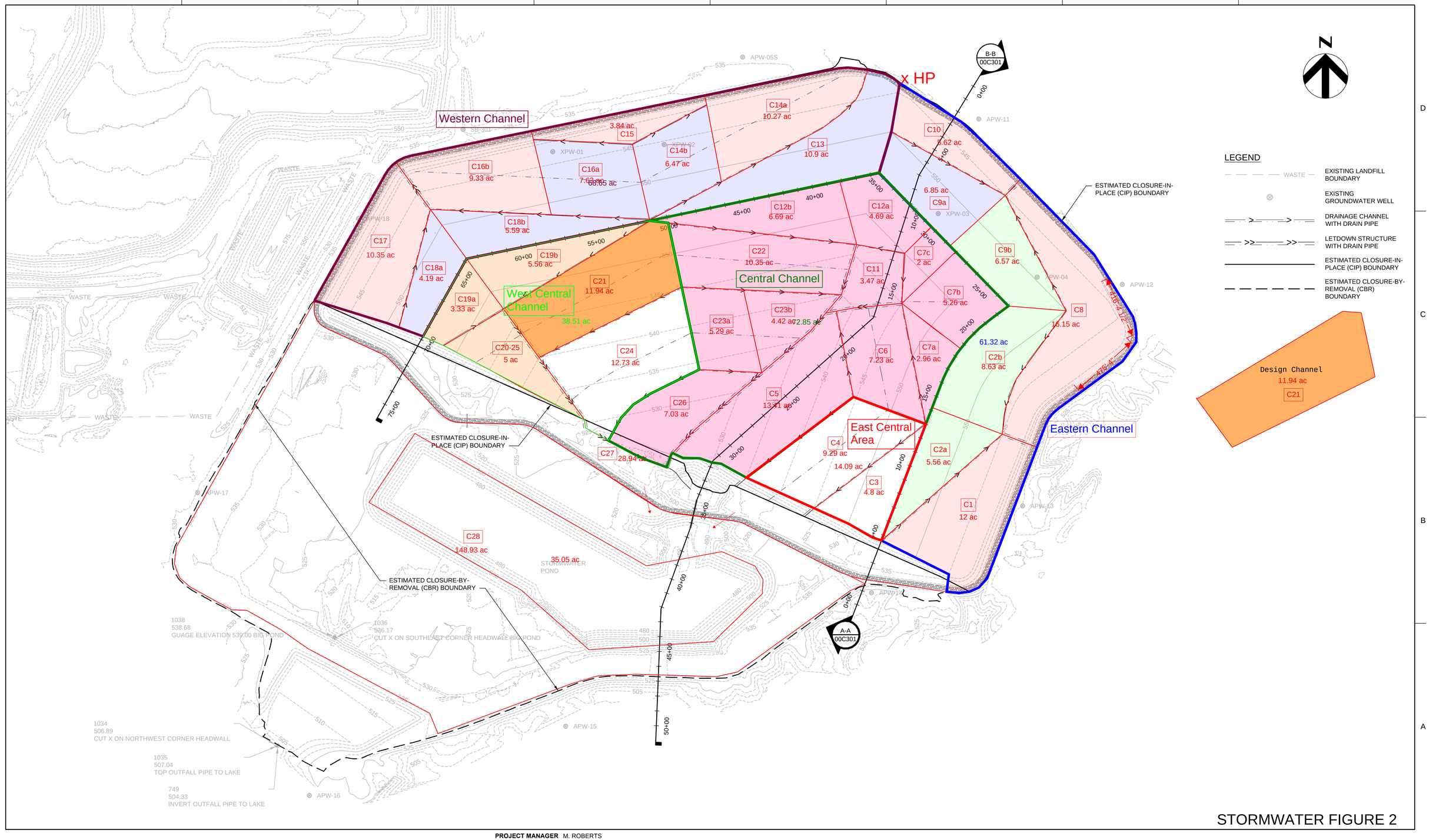

STORMWATER FIGURE 2

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ISSUE	DATE	DESCRIPTION

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

FINAL CLOSURE CONDITIONS

0 1" 2"

FILENAME 00C106.DWG
SCALE 1" = 300'

SHEET **00C106**

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Appendix A

NOAA Rainfall and WebSoil Survey Reports

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NOAA Atlas 14, Volume 2, Version 3
Location name: Newton, Illinois, USA*
Latitude: 38.9287°, Longitude: -88.2879°
Elevation: 533.87 ft**
* source: ESRI Maps
** source: USGS

POINT PRECIPITATION FREQUENCY ESTIMATES

G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley

NOAA, National Weather Service, Silver Spring, Maryland

PF_tabular | PF_graphical | Maps_&_aerials

PF tabular

PDS-based point precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.402 (0.364-0.445)	0.477 (0.433-0.528)	0.563 (0.510-0.623)	0.632 (0.571-0.699)	0.719 (0.646-0.793)	0.787 (0.705-0.868)	0.853 (0.761-0.939)	0.920 (0.818-1.01)	1.01 (0.891-1.11)	1.08 (0.944-1.18)
10-min	0.625 (0.565-0.691)	0.745 (0.676-0.825)	0.875 (0.792-0.968)	0.976 (0.882-1.08)	1.10 (0.989-1.21)	1.19 (1.07-1.32)	1.28 (1.15-1.41)	1.37 (1.22-1.51)	1.49 (1.31-1.63)	1.57 (1.38-1.72)
15-min	0.766 (0.693-0.847)	0.910 (0.826-1.01)	1.07 (0.973-1.19)	1.20 (1.09-1.33)	1.36 (1.22-1.50)	1.48 (1.32-1.63)	1.59 (1.42-1.76)	1.71 (1.52-1.88)	1.85 (1.64-2.04)	1.96 (1.72-2.15)
30-min	1.01 (0.916-1.12)	1.22 (1.11-1.35)	1.47 (1.33-1.63)	1.67 (1.51-1.84)	1.92 (1.73-2.12)	2.11 (1.89-2.33)	2.30 (2.05-2.54)	2.49 (2.22-2.74)	2.75 (2.42-3.02)	2.94 (2.58-3.22)
60-min	1.24 (1.12-1.37)	1.50 (1.36-1.66)	1.85 (1.67-2.04)	2.12 (1.92-2.34)	2.49 (2.24-2.74)	2.78 (2.49-3.07)	3.08 (2.75-3.39)	3.38 (3.01-3.72)	3.80 (3.35-4.17)	4.12 (3.62-4.53)
2-hr	1.49 (1.35-1.66)	1.80 (1.63-2.00)	2.24 (2.02-2.48)	2.57 (2.32-2.85)	3.04 (2.73-3.35)	3.41 (3.05-3.76)	3.79 (3.38-4.17)	4.18 (3.72-4.60)	4.72 (4.16-5.18)	5.14 (4.52-5.65)
3-hr	1.58 (1.43-1.77)	1.91 (1.73-2.13)	2.37 (2.14-2.64)	2.74 (2.47-3.05)	3.25 (2.91-3.60)	3.66 (3.27-4.05)	4.09 (3.64-4.53)	4.55 (4.03-5.03)	5.18 (4.55-5.71)	5.68 (4.95-6.26)
6-hr	1.89 (1.70-2.11)	2.27 (2.05-2.54)	2.80 (2.53-3.13)	3.24 (2.91-3.61)	3.84 (3.43-4.27)	4.33 (3.86-4.81)	4.84 (4.29-5.37)	5.38 (4.74-5.96)	6.12 (5.36-6.78)	6.72 (5.83-7.45)
12-hr	2.22 (2.02-2.44)	2.67 (2.43-2.94)	3.28 (2.98-3.60)	3.77 (3.42-4.14)	4.44 (4.01-4.87)	4.98 (4.49-5.46)	5.55 (4.97-6.07)	6.14 (5.48-6.71)	6.95 (6.15-7.59)	7.59 (6.67-8.29)
24-hr	2.64 (2.47-2.84)	3.17 (2.96-3.41)	3.89 (3.63-4.18)	4.47 (4.16-4.80)	5.26 (4.88-5.65)	5.91 (5.45-6.34)	6.58 (6.04-7.06)	7.28 (6.63-7.81)	8.24 (7.44-8.88)	9.01 (8.06-9.72)
2-day	3.09 (2.89-3.33)	3.70 (3.46-3.99)	4.52 (4.22-4.87)	5.17 (4.81-5.57)	6.05 (5.61-6.51)	6.75 (6.23-7.26)	7.46 (6.85-8.04)	8.19 (7.48-8.84)	9.18 (8.32-9.94)	9.96 (8.96-10.8)
3-day	3.30 (3.10-3.53)	3.95 (3.71-4.22)	4.81 (4.52-5.15)	5.50 (5.15-5.87)	6.42 (5.99-6.86)	7.15 (6.65-7.65)	7.90 (7.30-8.46)	8.66 (7.96-9.30)	9.69 (8.83-10.4)	10.5 (9.49-11.4)
4-day	3.51 (3.31-3.73)	4.20 (3.96-4.46)	5.11 (4.82-5.42)	5.82 (5.48-6.18)	6.79 (6.37-7.21)	7.56 (7.06-8.04)	8.34 (7.75-8.88)	9.13 (8.43-9.75)	10.2 (9.34-11.0)	11.0 (10.0-11.9)
7-day	4.09 (3.87-4.34)	4.90 (4.63-5.20)	5.93 (5.60-6.29)	6.72 (6.33-7.12)	7.74 (7.28-8.21)	8.53 (8.00-9.06)	9.32 (8.70-9.91)	10.1 (9.38-10.8)	11.1 (10.3-11.9)	11.9 (10.9-12.8)
10-day	4.65 (4.39-4.94)	5.55 (5.25-5.89)	6.68 (6.30-7.09)	7.52 (7.09-7.99)	8.63 (8.11-9.15)	9.47 (8.87-10.1)	10.3 (9.61-10.9)	11.1 (10.3-11.8)	12.2 (11.2-13.0)	13.0 (11.9-13.9)
20-day	6.42 (6.08-6.78)	7.62 (7.22-8.06)	9.05 (8.57-9.58)	10.1 (9.57-10.7)	11.5 (10.9-12.2)	12.6 (11.8-13.3)	13.6 (12.7-14.4)	14.6 (13.6-15.5)	15.8 (14.7-16.9)	16.8 (15.5-17.9)
30-day	7.87 (7.49-8.28)	9.29 (8.85-9.78)	10.9 (10.3-11.4)	12.0 (11.4-12.7)	13.5 (12.8-14.2)	14.6 (13.9-15.4)	15.7 (14.8-16.6)	16.7 (15.7-17.7)	18.0 (16.8-19.1)	19.0 (17.6-20.2)
45-day	9.81 (9.35-10.3)	11.6 (11.0-12.1)	13.4 (12.8-14.1)	14.7 (14.0-15.5)	16.5 (15.6-17.3)	17.7 (16.8-18.6)	18.9 (17.9-19.9)	20.1 (18.9-21.2)	21.5 (20.2-22.7)	22.5 (21.0-23.9)
60-day	11.6 (11.1-12.2)	13.7 (13.0-14.3)	15.7 (15.0-16.5)	17.3 (16.4-18.0)	19.1 (18.2-20.0)	20.5 (19.5-21.5)	21.8 (20.7-22.9)	23.1 (21.8-24.2)	24.6 (23.1-25.9)	25.6 (24.0-27.1)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

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PF graphical

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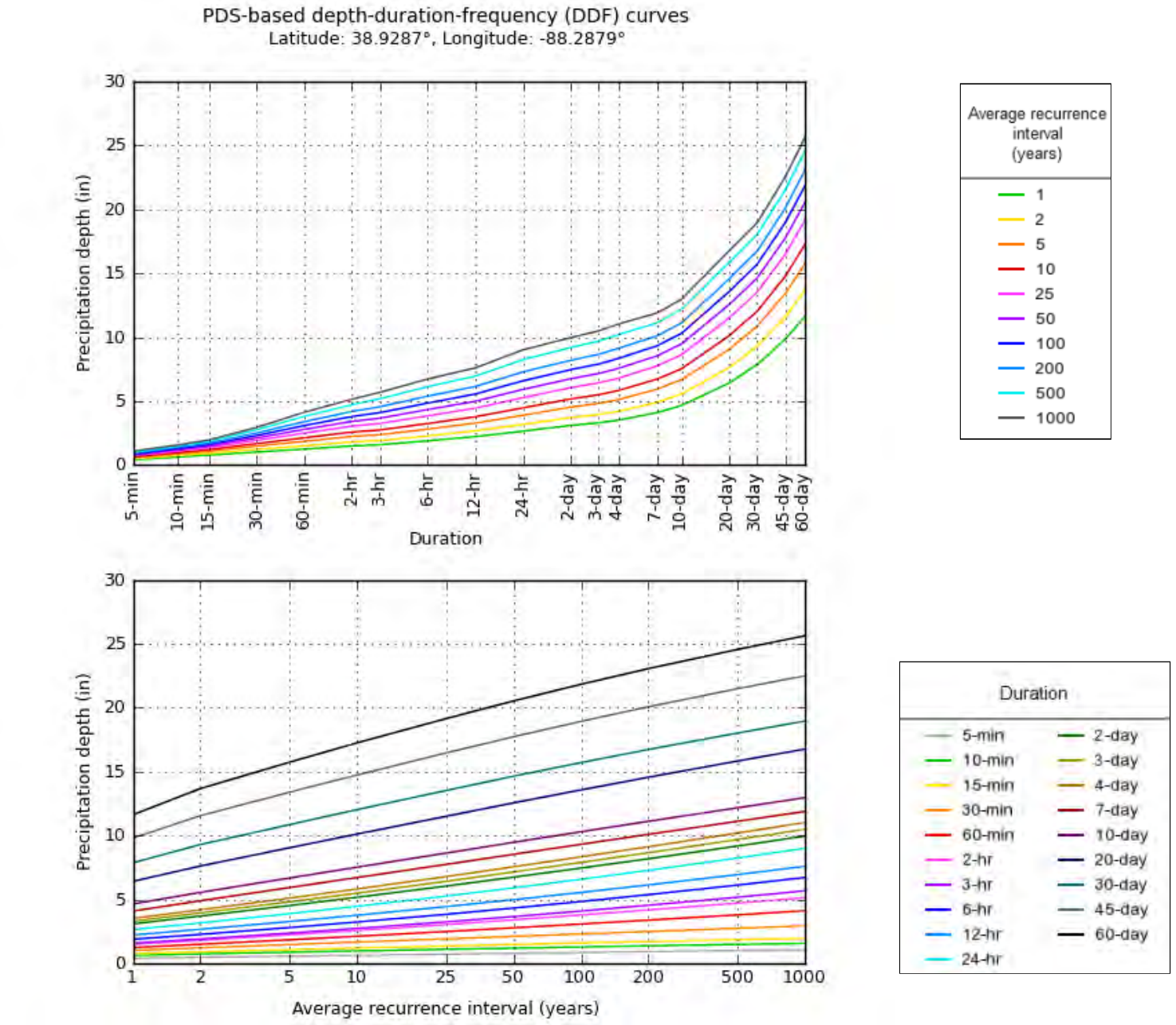

NOAA Atlas 14, Volume 2, Version 3

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Maps & aerials

Small scale terrain

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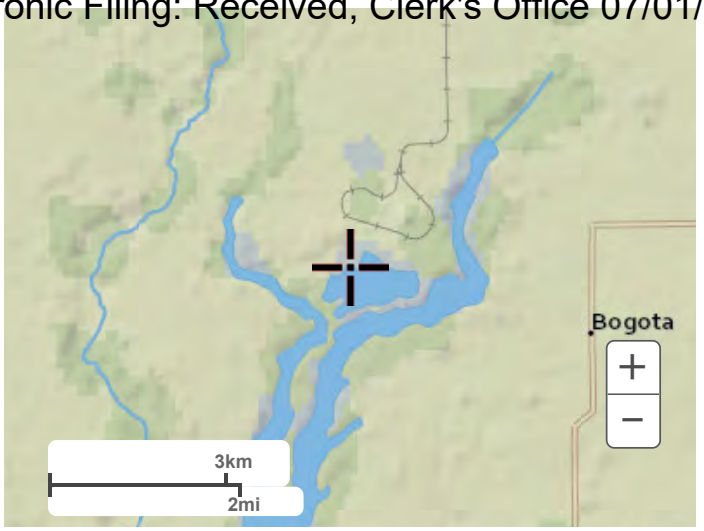
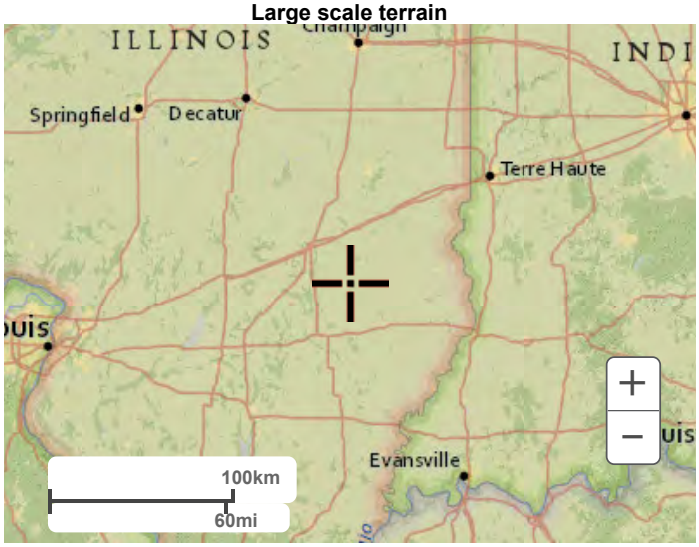
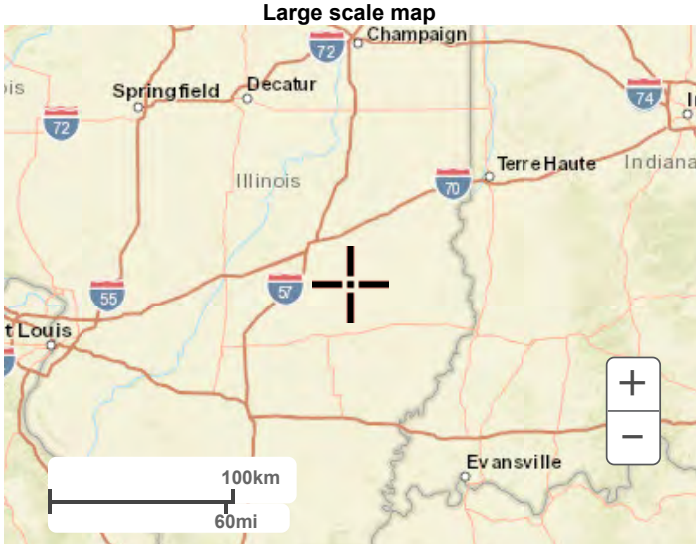


Large scale terrain



Large scale map



Large scale aerial

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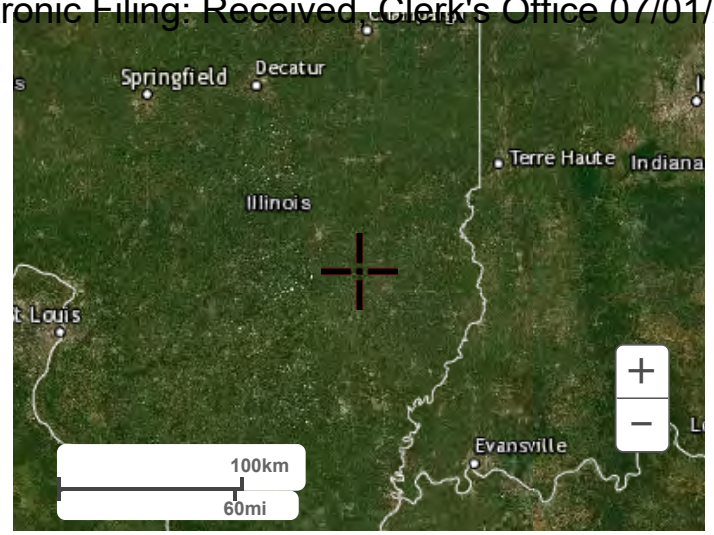

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US Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
National Water Center
1325 East West Highway
Silver Spring, MD 20910
Questions?: HDSC.Questions@noaa.gov

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United States Department of Agriculture

Natural Resources Conservation Service

A product of the National Cooperative Soil Survey, a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local participants

Custom Soil Resource Report for Jasper County, Illinois



April 19, 2022

Preface

Soil surveys contain information that affects land use planning in survey areas. They highlight soil limitations that affect various land uses and provide information about the properties of the soils in the survey areas. Soil surveys are designed for many different users, including farmers, ranchers, foresters, agronomists, urban planners, community officials, engineers, developers, builders, and home buyers. Also, conservationists, teachers, students, and specialists in recreation, waste disposal, and pollution control can use the surveys to help them understand, protect, or enhance the environment.

Various land use regulations of Federal, State, and local governments may impose special restrictions on land use or land treatment. Soil surveys identify soil properties that are used in making various land use or land treatment decisions. The information is intended to help the land users identify and reduce the effects of soil limitations on various land uses. The landowner or user is responsible for identifying and complying with existing laws and regulations.

Although soil survey information can be used for general farm, local, and wider area planning, onsite investigation is needed to supplement this information in some cases. Examples include soil quality assessments (http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/health/) and certain conservation and engineering applications. For more detailed information, contact your local USDA Service Center (https://offices.sc.egov.usda.gov/locator/app?agency=nrcs) or your NRCS State Soil Scientist (http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/contactus/?cid=nrcs142p2_053951).

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

The National Cooperative Soil Survey is a joint effort of the United States Department of Agriculture and other Federal agencies, State agencies including the Agricultural Experiment Stations, and local agencies. The Natural Resources Conservation Service (NRCS) has leadership for the Federal part of the National Cooperative Soil Survey.

Information about soils is updated periodically. Updated information is available through the NRCS Web Soil Survey, the site for official soil survey information.

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How Soil Surveys Are Made

Soil surveys are made to provide information about the soils and miscellaneous areas in a specific area. They include a description of the soils and miscellaneous areas and their location on the landscape and tables that show soil properties and limitations affecting various uses. Soil scientists observed the steepness, length, and shape of the slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They observed and described many soil profiles. A soil profile is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed or from the surface down to bedrock. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

Currently, soils are mapped according to the boundaries of major land resource areas (MLRAs). MLRAs are geographically associated land resource units that share common characteristics related to physiography, geology, climate, water resources, soils, biological resources, and land uses (USDA, 2006). Soil survey areas typically consist of parts of one or more MLRA.

The soils and miscellaneous areas in a survey area occur in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how they were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted soil color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil

scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

The objective of soil mapping is not to delineate pure map unit components; the objective is to separate the landscape into landforms or landform segments that have similar use and management requirements. Each map unit is defined by a unique combination of soil components and/or miscellaneous areas in predictable proportions. Some components may be highly contrasting to the other components of the map unit. The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The delineation of such landforms and landform segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, onsite investigation is needed to define and locate the soils and miscellaneous areas.

Soil scientists make many field observations in the process of producing a soil map. The frequency of observation is dependent upon several factors, including scale of mapping, intensity of mapping, design of map units, complexity of the landscape, and experience of the soil scientist. Observations are made to test and refine the soil-landscape model and predictions and to verify the classification of the soils at specific locations. Once the soil-landscape model is refined, a significantly smaller number of measurements of individual soil properties are made and recorded. These measurements may include field measurements, such as those for color, depth to bedrock, and texture, and laboratory measurements, such as those for content of sand, silt, clay, salt, and other components. Properties of each soil typically vary from one point to another across the landscape.

Observations for map unit components are aggregated to develop ranges of characteristics for the components. The aggregated values are presented. Direct measurements do not exist for every property presented for every map unit component. Values for some properties are estimated from combinations of other properties.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and

identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

Soil Map

The soil map section includes the soil map for the defined area of interest, a list of soil map units on the map and extent of each map unit, and cartographic symbols displayed on the map. Also presented are various metadata about data used to produce the map, and a description of each soil map unit.

Custom Soil Resource Report

Soil Map



MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Unit Polygons
- Soil Map Unit Lines
- Soil Map Unit Points

Special Point Features
- Blowout
- Borrow Pit
- Clay Spot
- Closed Depression
- Gravel Pit
- Gravelly Spot
- Landfill
- Lava Flow
- Marsh or swamp
- Mine or Quarry
- Miscellaneous Water
- Perennial Water
- Rock Outcrop
- Saline Spot
- Sandy Spot
- Severely Eroded Spot
- Sinkhole
- Slide or Slip
- Sodic Spot
- Spoil Area
- Stony Spot
- Very Stony Spot
- Wet Spot
- Other
- Special Line Features

Water Features
- Streams and Canals

Transportation
- Rails
- Interstate Highways
- US Routes
- Major Roads
- Local Roads

Background
- Aerial Photography

MAP INFORMATION

The soil surveys that comprise your AOI were mapped at 1:12,000.

Please rely on the bar scale on each map sheet for map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL:
Coordinate System: Web Mercator (EPSG:3857)

Maps from the Web Soil Survey are based on the Web Mercator projection, which preserves direction and shape but distorts distance and area. A projection that preserves area, such as the Albers equal-area conic projection, should be used if more accurate calculations of distance or area are required.

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Jasper County, Illinois
Survey Area Data: Version 18, Aug 31, 2021

Soil map units are labeled (as space allows) for map scales 1:50,000 or larger.

Date(s) aerial images were photographed: Jun 16, 2011—Oct 15, 2011

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Map Unit Legend

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
2A	Cisne silt loam, 0 to 2 percent slopes	0.0	0.0%
7C2	Atlas silt loam, 5 to 10 percent slopes, eroded	17.6	1.6%
8F	Hickory silt loam, 18 to 35 percent slopes	76.7	6.9%
12A	Wynoose silt loam, 0 to 2 percent slopes	11.5	1.0%
13A	Bluford silt loam, 0 to 2 percent slopes	29.4	2.7%
14B	Ava silt loam, 2 to 5 percent slopes	31.9	2.9%
14C2	Ava silt loam, 5 to 10 percent slopes, eroded	1.3	0.1%
533	Urban land	178.2	16.1%
805C	Orthents, clayey, sloping	186.5	16.9%
866	Dumps, slurry	375.5	33.9%
M-W	Miscellaneous water	11.5	1.0%
W	Water	186.5	16.9%
Totals for Area of Interest		**1,106.7**	**100.0%**

Map Unit Descriptions

The map units delineated on the detailed soil maps in a soil survey represent the soils or miscellaneous areas in the survey area. The map unit descriptions, along with the maps, can be used to determine the composition and properties of a unit.

A map unit delineation on a soil map represents an area dominated by one or more major kinds of soil or miscellaneous areas. A map unit is identified and named according to the taxonomic classification of the dominant soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural phenomena, and they have the characteristic variability of all natural phenomena. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of other taxonomic classes. Consequently, every map unit is made up of the soils or miscellaneous areas for which it is named and some minor components that belong to taxonomic classes other than those of the major soils.

Most minor soils have properties similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting, or similar, components. They may or may not be mentioned in a particular map unit description. Other minor components, however, have properties

and behavioral characteristics divergent enough to affect use or to require different management. These are called contrasting, or dissimilar, components. They generally are in small areas and could not be mapped separately because of the scale used. Some small areas of strongly contrasting soils or miscellaneous areas are identified by a special symbol on the maps. If included in the database for a given area, the contrasting minor components are identified in the map unit descriptions along with some characteristics of each. A few areas of minor components may not have been observed, and consequently they are not mentioned in the descriptions, especially where the pattern was so complex that it was impractical to make enough observations to identify all the soils and miscellaneous areas on the landscape.

The presence of minor components in a map unit in no way diminishes the usefulness or accuracy of the data. The objective of mapping is not to delineate pure taxonomic classes but rather to separate the landscape into landforms or landform segments that have similar use and management requirements. The delineation of such segments on the map provides sufficient information for the development of resource plans. If intensive use of small areas is planned, however, onsite investigation is needed to define and locate the soils and miscellaneous areas.

An identifying symbol precedes the map unit name in the map unit descriptions. Each description includes general facts about the unit and gives important soil properties and qualities.

Soils that have profiles that are almost alike make up a *soil series*. Except for differences in texture of the surface layer, all the soils of a series have major horizons that are similar in composition, thickness, and arrangement.

Soils of one series can differ in texture of the surface layer, slope, stoniness, salinity, degree of erosion, and other characteristics that affect their use. On the basis of such differences, a soil series is divided into *soil phases*. Most of the areas shown on the detailed soil maps are phases of soil series. The name of a soil phase commonly indicates a feature that affects use or management. For example, Alpha silt loam, 0 to 2 percent slopes, is a phase of the Alpha series.

Some map units are made up of two or more major soils or miscellaneous areas. These map units are complexes, associations, or undifferentiated groups.

A *complex* consists of two or more soils or miscellaneous areas in such an intricate pattern or in such small areas that they cannot be shown separately on the maps. The pattern and proportion of the soils or miscellaneous areas are somewhat similar in all areas. Alpha-Beta complex, 0 to 6 percent slopes, is an example.

An *association* is made up of two or more geographically associated soils or miscellaneous areas that are shown as one unit on the maps. Because of present or anticipated uses of the map units in the survey area, it was not considered practical or necessary to map the soils or miscellaneous areas separately. The pattern and relative proportion of the soils or miscellaneous areas are somewhat similar. Alpha-Beta association, 0 to 2 percent slopes, is an example.

An *undifferentiated group* is made up of two or more soils or miscellaneous areas that could be mapped individually but are mapped as one unit because similar interpretations can be made for use and management. The pattern and proportion of the soils or miscellaneous areas in a mapped area are not uniform. An area can be made up of only one of the major soils or miscellaneous areas, or it can be made up of all of them. Alpha and Beta soils, 0 to 2 percent slopes, is an example.

Some surveys include *miscellaneous areas*. Such areas have little or no soil material and support little or no vegetation. Rock outcrop is an example.

Jasper County, Illinois

2A—Cisne silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 2rkjg
Elevation: 360 to 840 feet
Mean annual precipitation: 35 to 42 inches
Mean annual air temperature: 53 to 57 degrees F
Frost-free period: 175 to 195 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Cisne and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Cisne

Setting

Landform: Ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Silty loess over silty drift

Typical profile

Ap - 0 to 8 inches: silt loam
E - 8 to 17 inches: silt loam
Bt1 - 17 to 37 inches: silty clay loam
2Bt2 - 37 to 60 inches: silty clay loam
2C - 60 to 77 inches: silt loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 12 to 19 inches to abrupt textural change
Drainage class: Poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.02 to 0.20 in/hr)
Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: None
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 13.0
Available water supply, 0 to 60 inches: Low (about 3.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D
Ecological site: R113XY903IL - Wet Upland Prairie (silky dogwood/big bluestem - switchgrass) (Cornus obliqua/Andropogon gerardii - Panicum virgatum)
Hydric soil rating: Yes

Minor Components

Huey

Percent of map unit: 10 percent
Landform: Depressions
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Talf
Down-slope shape: Concave
Across-slope shape: Concave
Ecological site: F114BY502IN - Wet Till Upland Forest
Hydric soil rating: Yes

7C2—Atlas silt loam, 5 to 10 percent slopes, eroded

Map Unit Setting

National map unit symbol: 2tp1z
Elevation: 330 to 840 feet
Mean annual precipitation: 38 to 46 inches
Mean annual air temperature: 54 to 58 degrees F
Frost-free period: 180 to 195 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Atlas, eroded, and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Atlas, Eroded

Setting

Landform: Till plains
Landform position (two-dimensional): Shoulder, backslope
Landform position (three-dimensional): Head slope, side slope
Down-slope shape: Concave
Across-slope shape: Concave
Parent material: Loess over paleosol formed in till

Typical profile

Ap - 0 to 7 inches: silt loam
2Btg1 - 7 to 29 inches: silty clay loam
2Btg2 - 29 to 79 inches: silty clay loam

Properties and qualities

Slope: 5 to 10 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Low to moderately low (0.01 to 0.06 in/hr)
Depth to water table: About 6 to 18 inches

Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 5 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 2.0
Available water supply, 0 to 60 inches: Moderate (about 8.5 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3e
Hydrologic Soil Group: D
Ecological site: F114BY502IN - Wet Till Upland Forest
Hydric soil rating: No

Minor Components

Ava, eroded

Percent of map unit: 10 percent
Landform: Hillslopes, ridges
Landform position (two-dimensional): Backslope, summit, shoulder
Landform position (three-dimensional): Side slope, interfluve
Down-slope shape: Convex
Across-slope shape: Linear, convex
Ecological site: F113XY910IL - Fragic Backslope Woodland (post oak - black oak/ aromatic sumac/little bluestem - tick trefoil) (Quercus stellata - Quercus velutina/Rhus aromatica/Schizachyrium scoparium - Desmodium spp.)
Hydric soil rating: No

8F—Hickory silt loam, 18 to 35 percent slopes

Map Unit Setting

National map unit symbol: 2yb19
Elevation: 370 to 680 feet
Mean annual precipitation: 39 to 46 inches
Mean annual air temperature: 54 to 57 degrees F
Frost-free period: 185 to 195 days
Farmland classification: Not prime farmland

Map Unit Composition

Hickory and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Hickory

Setting

Landform: Ground moraines
Landform position (two-dimensional): Shoulder, backslope
Landform position (three-dimensional): Side slope
Down-slope shape: Linear

Across-slope shape: Linear
Parent material: Loamy till

Typical profile

A - 0 to 4 inches: silt loam
E - 4 to 12 inches: loam
Bt1 - 12 to 26 inches: clay loam
Bt2 - 26 to 46 inches: clay loam
Bt3 - 46 to 60 inches: clay loam

Properties and qualities

Slope: 18 to 35 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Well drained
Runoff class: High
Capacity of the most limiting layer to transmit water (Ksat): Moderately high to high (0.60 to 2.00 in/hr)
Depth to water table: More than 80 inches
Frequency of flooding: None
Frequency of ponding: None
Calcium carbonate, maximum content: 15 percent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Available water supply, 0 to 60 inches: High (about 10.6 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 6e
Hydrologic Soil Group: B
Ecological site: F113XY911IL - Loamy Till Backslope Forest (white oak - hickory/ flowering dogwood/common blue wood aster) (Quercus alba - Carya spp./ Cornus florida/Symphyotrichum cordifolium)
Hydric soil rating: No

Minor Components

Ava

Percent of map unit: 5 percent
Landform: Ridges
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Interfluve
Down-slope shape: Convex
Across-slope shape: Convex
Ecological site: F113XY910IL - Fragic Backslope Woodland (post oak - black oak/ aromatic sumac/little bluestem - tick trefoil) (Quercus stellata - Quercus velutina/Rhus aromatica/Schizachyrium scoparium - Desmodium spp.)
Hydric soil rating: No

Atlas, eroded

Percent of map unit: 3 percent
Landform: Ground moraines
Landform position (two-dimensional): Shoulder, backslope
Landform position (three-dimensional): Head slope, side slope
Down-slope shape: Concave
Across-slope shape: Concave
Ecological site: F114BY502IN - Wet Till Upland Forest
Hydric soil rating: No

Belknap, frequently flooded

Percent of map unit: 2 percent
Landform: Flood plains
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: F113XY919IL - Wet Silty Floodplain Forest (common hackberry - green ash/roughleaf dogwood/Canadian woodnettle) (Celtis occidentalis - Fraxinus pennsylvanica /Cornus drummondii /Laportea canadensis)
Hydric soil rating: No

12A—Wynoose silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 2t959
Elevation: 360 to 840 feet
Mean annual precipitation: 35 to 46 inches
Mean annual air temperature: 53 to 58 degrees F
Frost-free period: 175 to 195 days
Farmland classification: Farmland of statewide importance

Map Unit Composition

Wynoose and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Wynoose

Setting

Landform: Ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loess over mixed loess and drift over sangamon age paleosol till

Typical profile

Ap - 0 to 7 inches: silt loam
Eg - 7 to 19 inches: silt loam
Btg - 19 to 36 inches: silty clay
2Btg - 36 to 66 inches: silty clay loam
3Btgb - 66 to 79 inches: silty clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 13 to 24 inches to abrupt textural change
Drainage class: Poorly drained
Runoff class: Negligible
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.02 to 0.20 in/hr)

Depth to water table: About 0 to 12 inches
Frequency of flooding: None
Frequency of ponding: Frequent
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 12.0
Available water supply, 0 to 60 inches: Low (about 4.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3w
Hydrologic Soil Group: C/D
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: Yes

Minor Components

Bluford

Percent of map unit: 10 percent
Landform: Ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Rise
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/ green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: No

13A—Bluford silt loam, 0 to 2 percent slopes

Map Unit Setting

National map unit symbol: 2t95c
Elevation: 360 to 840 feet
Mean annual precipitation: 35 to 46 inches
Mean annual air temperature: 53 to 58 degrees F
Frost-free period: 175 to 195 days
Farmland classification: Prime farmland if drained

Map Unit Composition

Bluford and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Bluford

Setting

Landform: Ground moraines
Landform position (two-dimensional): Summit

Landform position (three-dimensional): Rise
Down-slope shape: Linear
Across-slope shape: Linear
Parent material: Loess over mixed loess and drift

Typical profile

Ap - 0 to 7 inches: silt loam
E - 7 to 19 inches: silt loam
Btg - 19 to 35 inches: silty clay
2Btgx - 35 to 42 inches: silty clay loam
2Btg - 42 to 60 inches: silty clay loam

Properties and qualities

Slope: 0 to 2 percent
Depth to restrictive feature: 10 to 24 inches to abrupt textural change; 24 to 48 inches to fragipan
Drainage class: Somewhat poorly drained
Runoff class: Low
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.06 to 0.20 in/hr)
Depth to water table: About 6 to 24 inches
Frequency of flooding: None
Frequency of ponding: None
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 13.0
Available water supply, 0 to 60 inches: Low (about 4.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2w
Hydrologic Soil Group: C/D
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: No

Minor Components

Wynoose

Percent of map unit: 10 percent
Landform: Ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Talf
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/ green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: Yes

14B—Ava silt loam, 2 to 5 percent slopes

Map Unit Setting

National map unit symbol: 2t95h
Elevation: 360 to 840 feet
Mean annual precipitation: 38 to 46 inches
Mean annual air temperature: 54 to 58 degrees F
Frost-free period: 180 to 195 days
Farmland classification: All areas are prime farmland

Map Unit Composition

Ava and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Ava

Setting

Landform: Ridges
Landform position (two-dimensional): Summit, shoulder
Landform position (three-dimensional): Interfluve
Down-slope shape: Convex
Across-slope shape: Convex
Parent material: Loess over mixed loess and drift over till

Typical profile

Ap - 0 to 6 inches: silt loam
E - 6 to 14 inches: silt loam
Bt - 14 to 34 inches: silty clay loam
2Btx - 34 to 50 inches: silty clay loam
3Btb - 50 to 79 inches: loam

Properties and qualities

Slope: 2 to 5 percent
Depth to restrictive feature: 25 to 40 inches to fragipan
Drainage class: Moderately well drained
Runoff class: Medium
Capacity of the most limiting layer to transmit water (Ksat): Moderately low (0.02 to 0.06 in/hr)
Depth to water table: About 18 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: Moderate (about 6.3 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 2e
Hydrologic Soil Group: C

Ecological site: F113XY910IL - Fragic Backslope Woodland (post oak - black oak/ aromatic sumac/little bluestem - tick trefoil) (Quercus stellata - Quercus velutina/Rhus aromatica/Schizachyrium scoparium - Desmodium spp.)
Hydric soil rating: No

Minor Components

Bluford
Percent of map unit: 10 percent
Landform: Ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Rise
Down-slope shape: Linear
Across-slope shape: Linear
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/ green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: No

14C2—Ava silt loam, 5 to 10 percent slopes, eroded

Map Unit Setting
National map unit symbol: 2t95l
Elevation: 360 to 840 feet
Mean annual precipitation: 38 to 46 inches
Mean annual air temperature: 54 to 58 degrees F
Frost-free period: 180 to 195 days
Farmland classification: Farmland of statewide importance

Map Unit Composition
Ava, eroded, and similar soils: 90 percent
Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Ava, Eroded

Setting
Landform: Hillslopes, ridges
Landform position (two-dimensional): Backslope, summit, shoulder
Landform position (three-dimensional): Side slope, interfluve
Down-slope shape: Convex
Across-slope shape: Linear, convex
Parent material: Loess over mixed loess and drift over till

Typical profile
Ap - 0 to 9 inches: silt loam
Bt and E - 9 to 28 inches: silty clay loam
Btx - 28 to 36 inches: silty clay loam
2Btx - 36 to 64 inches: silt loam
3Btb - 64 to 78 inches: silt loam

Properties and qualities

Slope: 5 to 10 percent
Depth to restrictive feature: 25 to 40 inches to fragipan
Drainage class: Moderately well drained
Runoff class: High
Capacity of the most limiting layer to transmit water (Ksat): Low to moderately low (0.01 to 0.06 in/hr)
Depth to water table: About 18 to 36 inches
Frequency of flooding: None
Frequency of ponding: None
Maximum salinity: Nonsaline to very slightly saline (0.0 to 2.0 mmhos/cm)
Sodium adsorption ratio, maximum: 5.0
Available water supply, 0 to 60 inches: Low (about 5.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3e
Hydrologic Soil Group: C
Ecological site: F113XY910IL - Fragic Backslope Woodland (post oak - black oak/ aromatic sumac/little bluestem - tick trefoil) (Quercus stellata - Quercus velutina/Rhus aromatica/Schizachyrium scoparium - Desmodium spp.)
Hydric soil rating: No

Minor Components

Bluford, eroded

Percent of map unit: 10 percent
Landform: Ground moraines
Landform position (two-dimensional): Shoulder, backslope
Landform position (three-dimensional): Rise
Down-slope shape: Convex
Across-slope shape: Convex
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/ green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: No

533—Urban land

Map Unit Setting

National map unit symbol: 1q78h
Elevation: 510 to 980 feet
Mean annual precipitation: 28 to 40 inches
Mean annual air temperature: 45 to 54 degrees F
Frost-free period: 140 to 180 days
Farmland classification: Not prime farmland

Map Unit Composition

Urban land: 90 percent

Minor components: 10 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Urban Land

Setting
Down-slope shape: Linear
Across-slope shape: Linear

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8
Hydric soil rating: No

Minor Components

Orthents, loamy, nearly level
Percent of map unit: 4 percent
Landform: Lake plains, ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Hydric soil rating: No

Orthents, clayey, nearly level
Percent of map unit: 4 percent
Landform: Ground moraines, lake plains
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Hydric soil rating: No

Orthents, loamy-skeletal, nearly level
Percent of map unit: 2 percent
Landform: Lake plains, ground moraines
Landform position (two-dimensional): Summit
Landform position (three-dimensional): Interfluve
Down-slope shape: Linear
Across-slope shape: Linear
Hydric soil rating: No

805C—Orthents, clayey, sloping

Map Unit Setting
National map unit symbol: y5ns
Elevation: 360 to 840 feet
Mean annual precipitation: 35 to 42 inches
Mean annual air temperature: 53 to 57 degrees F
Frost-free period: 175 to 195 days

Farmland classification: Not prime farmland

Map Unit Composition

Orthents, clayey, and similar soils: 90 percent
Minor components: 3 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Orthents, Clayey

Setting

Parent material: Earthy cut and fill

Typical profile

H1 - 0 to 4 inches: silty clay loam
H2 - 4 to 60 inches: silty clay loam

Properties and qualities

Slope: 1 to 16 percent
Depth to restrictive feature: More than 80 inches
Drainage class: Somewhat poorly drained
Runoff class: Very high
Capacity of the most limiting layer to transmit water (Ksat): Moderately low to moderately high (0.02 to 0.20 in/hr)
Depth to water table: About 12 to 24 inches
Frequency of flooding: None
Frequency of ponding: None
Available water supply, 0 to 60 inches: Moderate (about 7.2 inches)

Interpretive groups

Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 3e
Hydrologic Soil Group: C/D
Hydric soil rating: Unranked

Minor Components

Wynoose

Percent of map unit: 3 percent
Landform: Till plains
Ecological site: F113XY905IL - Wet Upland Woodland (pin oak - swamp white oak/ green hawthorn /sweet woodreed) (Quercus palustris - Quercus bicolor/ Crataegus viridis /Cinna arundinacea)
Hydric soil rating: Yes

866—Dumps, slurry

Map Unit Setting

National map unit symbol: y5nt
Mean annual precipitation: 35 to 46 inches
Mean annual air temperature: 54 to 57 degrees F
Frost-free period: 175 to 195 days

Farmland classification: Not prime farmland

Map Unit Composition
Dumps, slurry: 90 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Dumps, Slurry

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8
Hydric soil rating: No

M-W—Miscellaneous water

Map Unit Setting
National map unit symbol: 1qg37
Frost-free period: 175 to 195 days
Farmland classification: Not prime farmland

Map Unit Composition
Miscellaneous water: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Miscellaneous Water

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8w
Hydric soil rating: Unranked

W—Water

Map Unit Composition
Water: 100 percent
Estimates are based on observations, descriptions, and transects of the mapunit.

Description of Water

Setting
Landform: Channels, perenial streams, drainageways, lakes, oxbows, rivers

Interpretive groups
Land capability classification (irrigated): None specified
Land capability classification (nonirrigated): 8w

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Appendix B

Hydroflow Hydrograph Output

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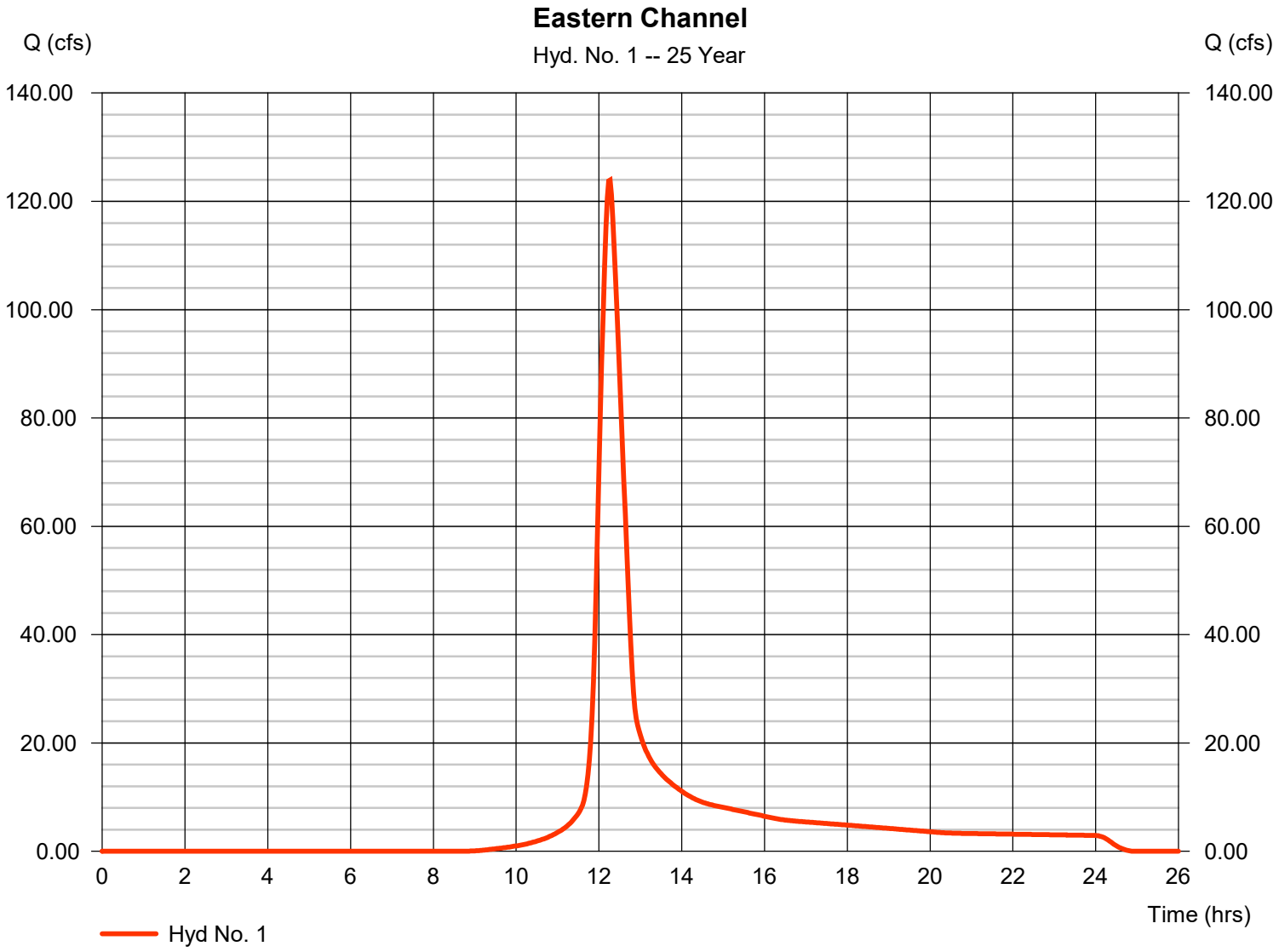
Hydrograph Report

Hyd. No. 1

Eastern Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	123.93 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	566,480 cuft
Drainage area	=	61.340 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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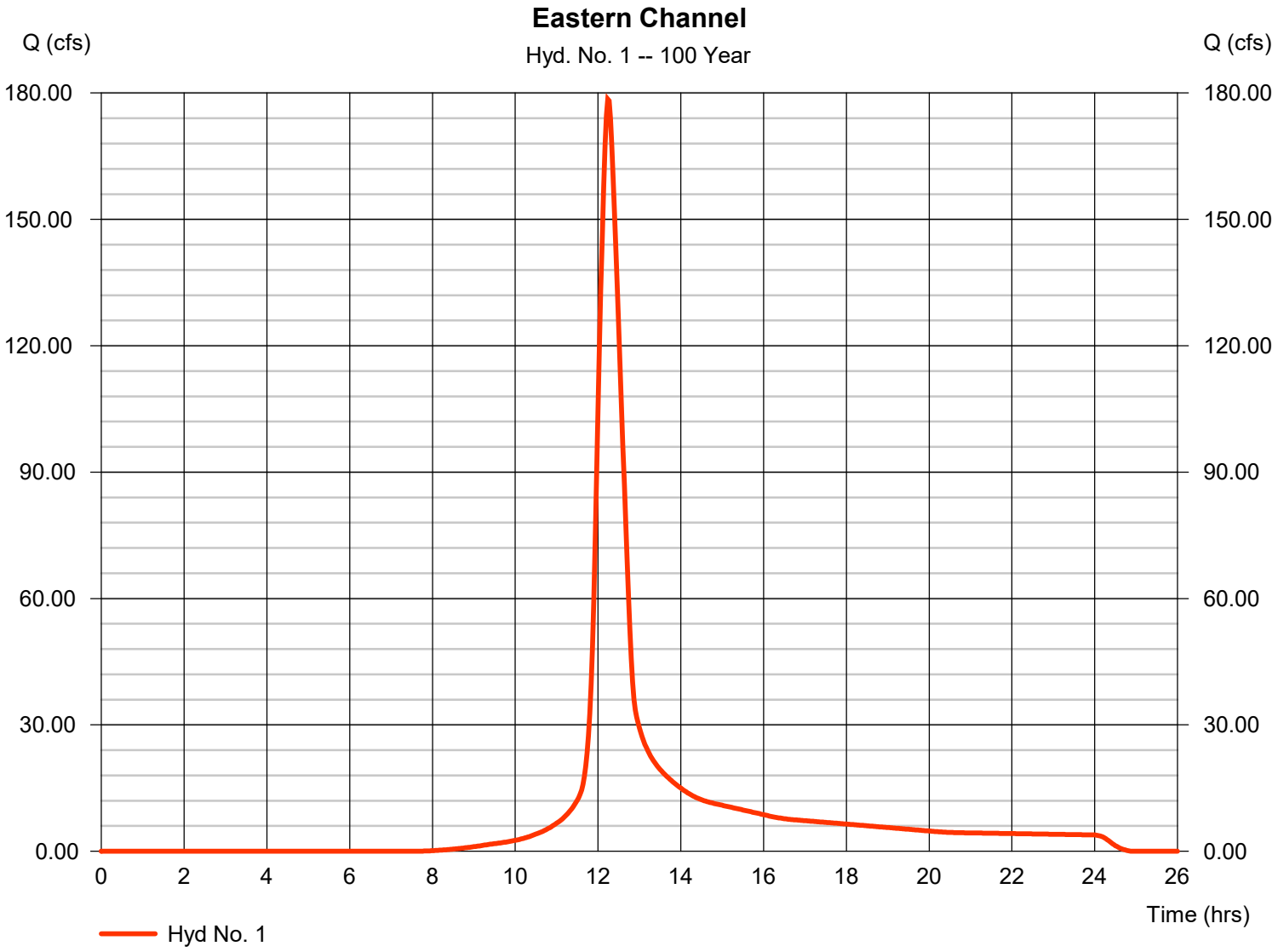
Hydrograph Report

Hyd. No. 1

Eastern Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	178.51 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	809,728 cuft
Drainage area	=	61.340 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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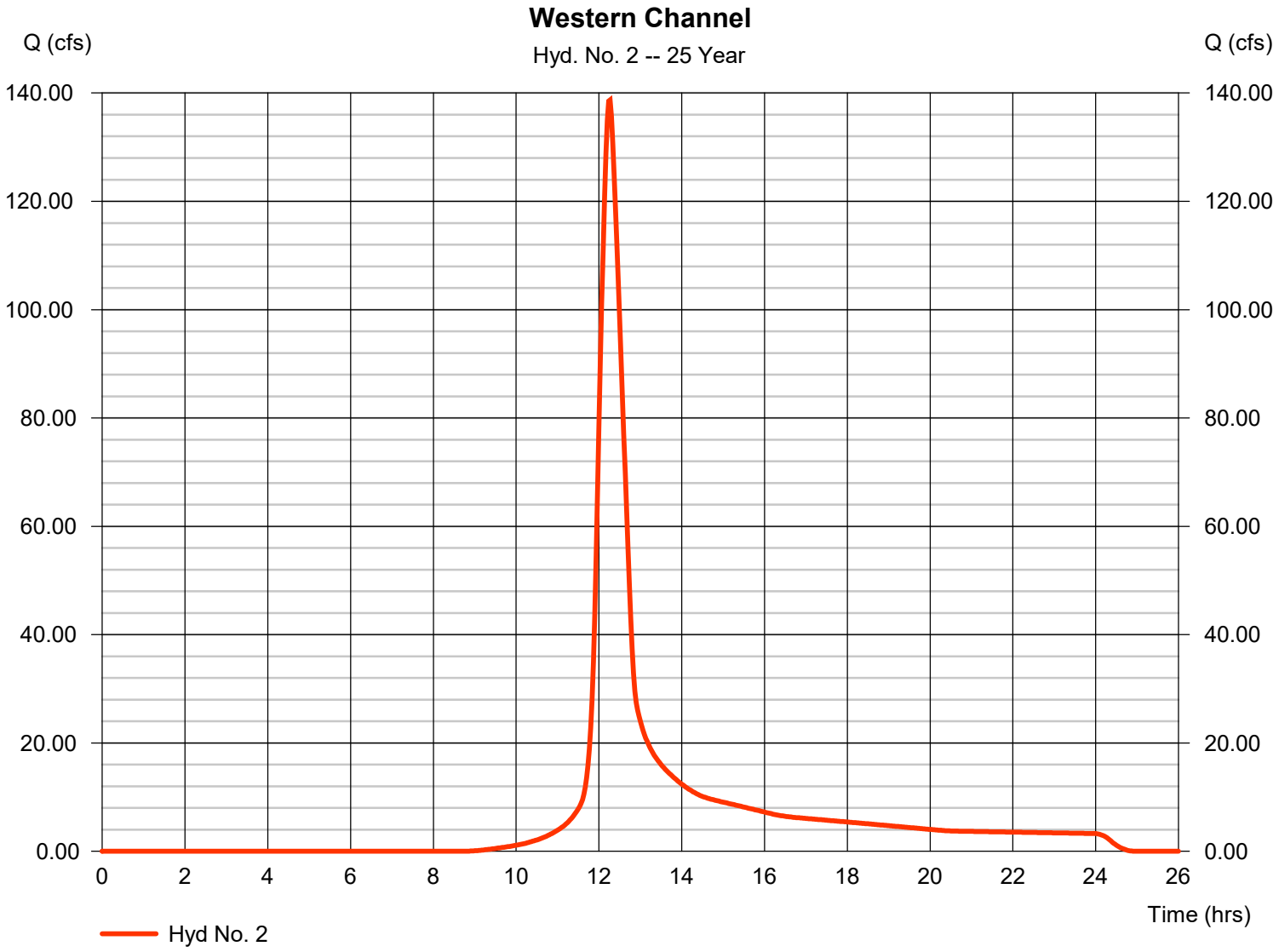
Hydrograph Report

Hyd. No. 2

Western Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	138.69 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	633,988 cuft
Drainage area	=	68.650 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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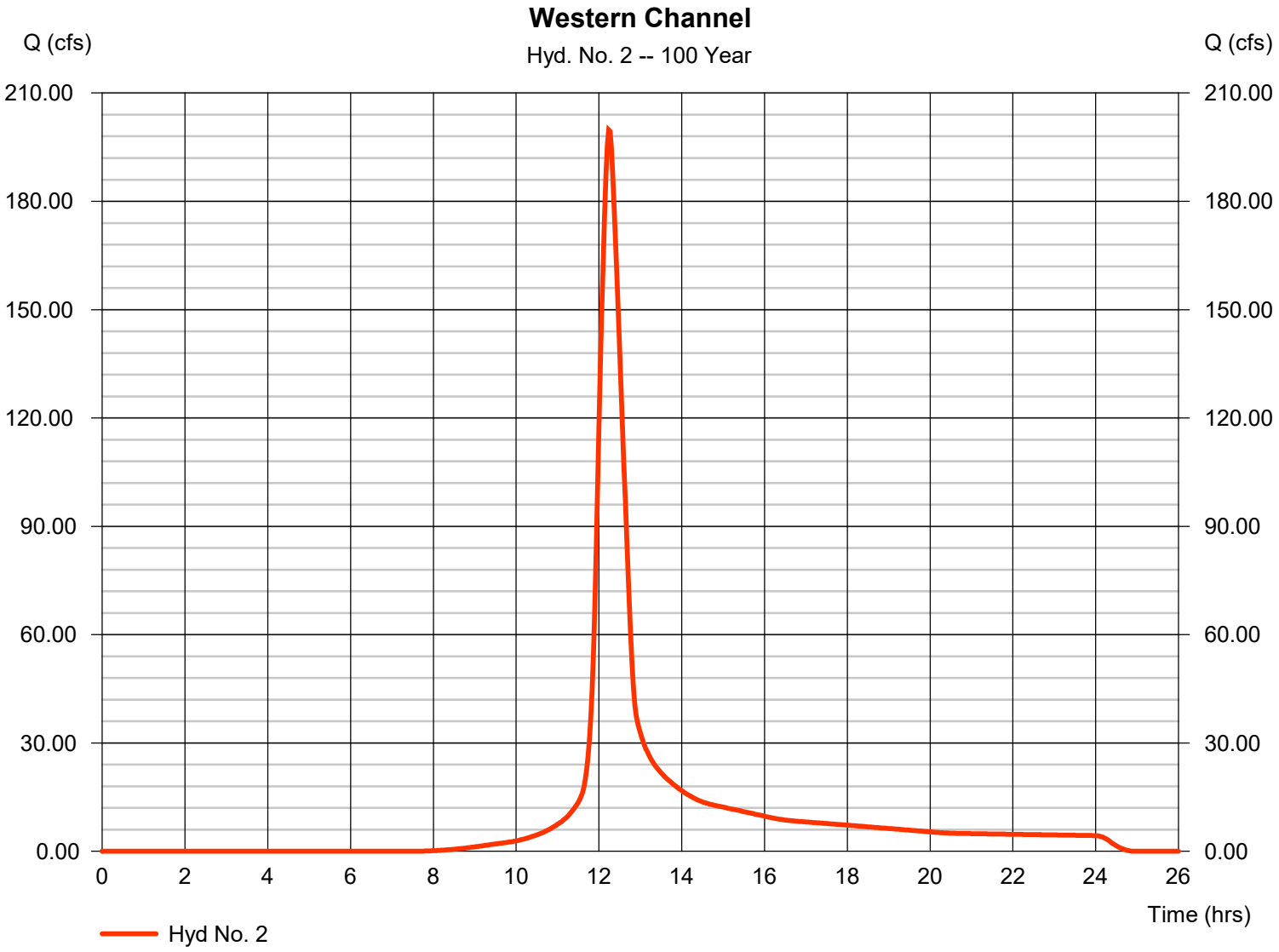
Hydrograph Report

Hyd. No. 2

Western Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	199.78 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	906,225 cuft
Drainage area	=	68.650 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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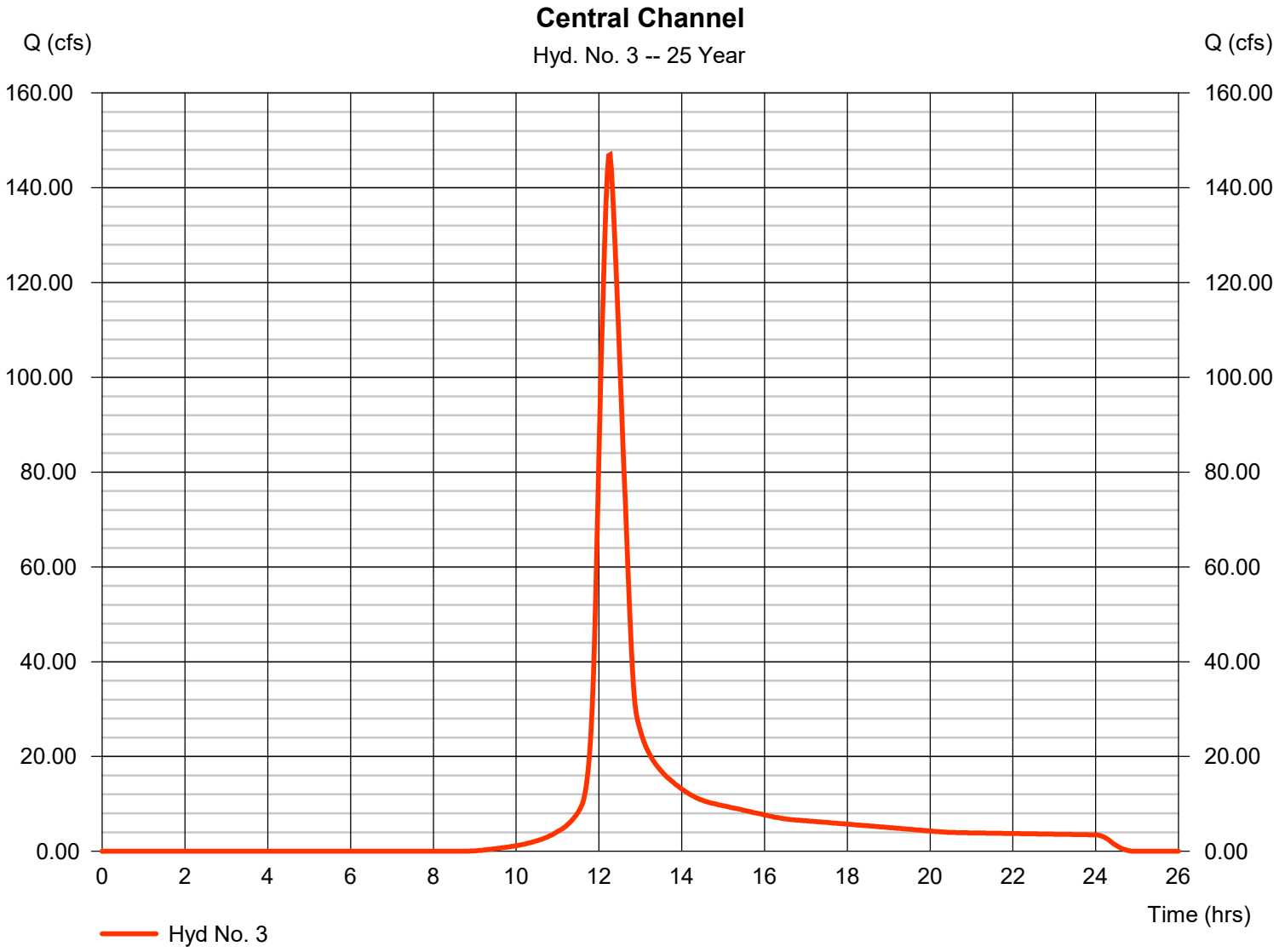
Hydrograph Report

Hyd. No. 3

Central Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	146.98 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	671,851 cuft
Drainage area	=	72.750 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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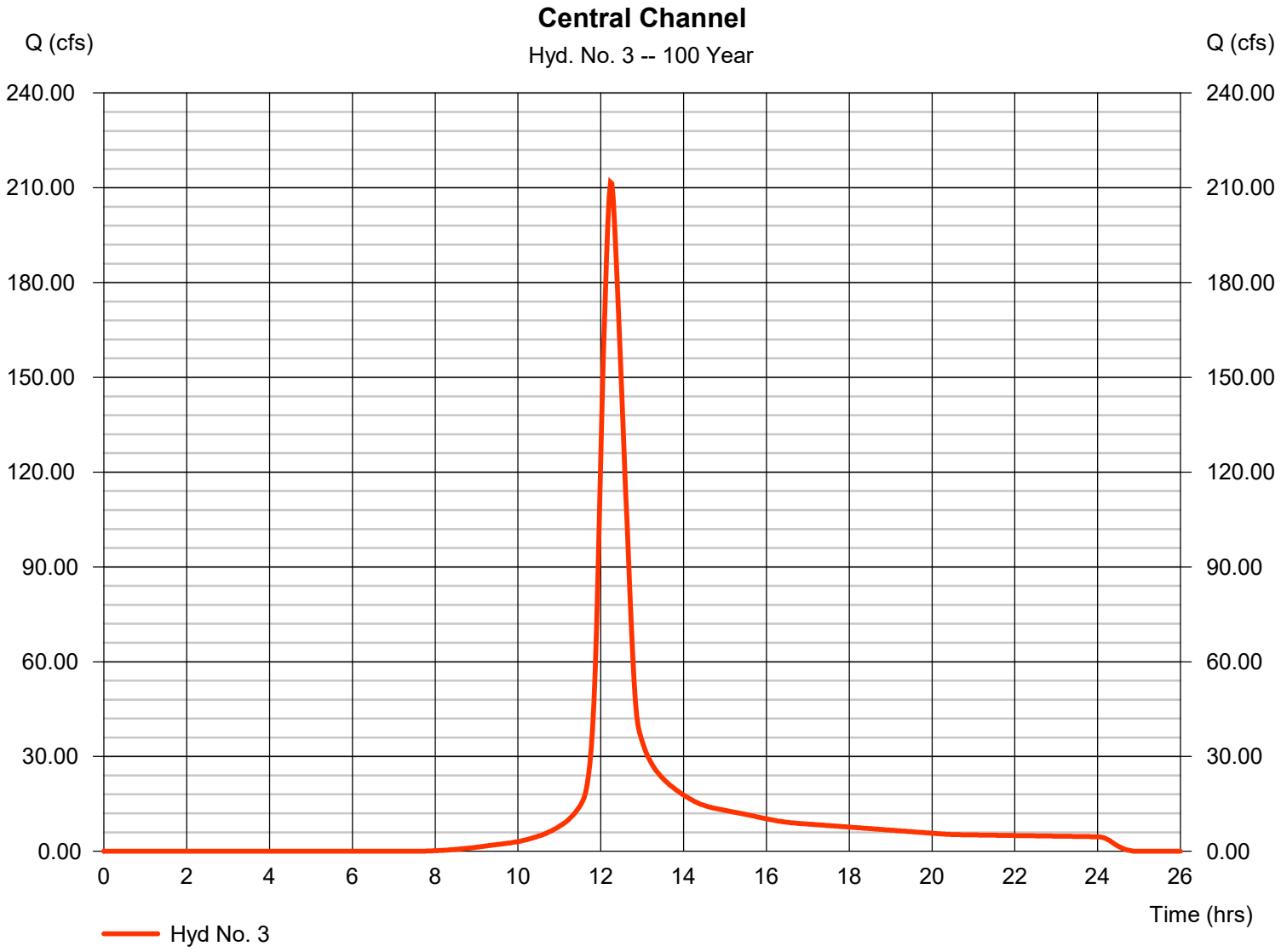
Hydrograph Report

Hyd. No. 3

Central Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	211.72 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	960,347 cuft
Drainage area	=	72.750 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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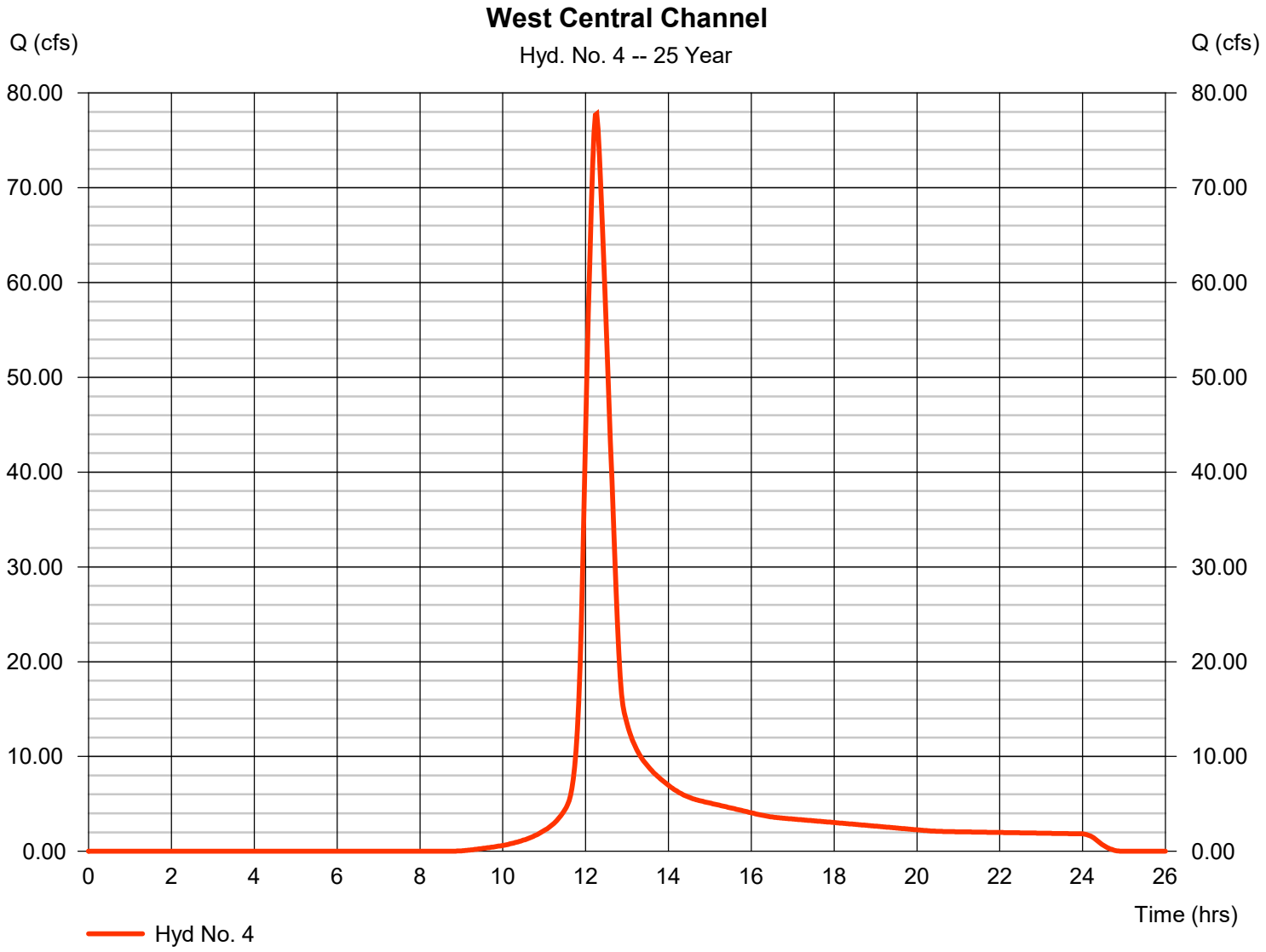
Hydrograph Report

Hyd. No. 4

West Central Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	77.80 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	355,643 cuft
Drainage area	=	38.510 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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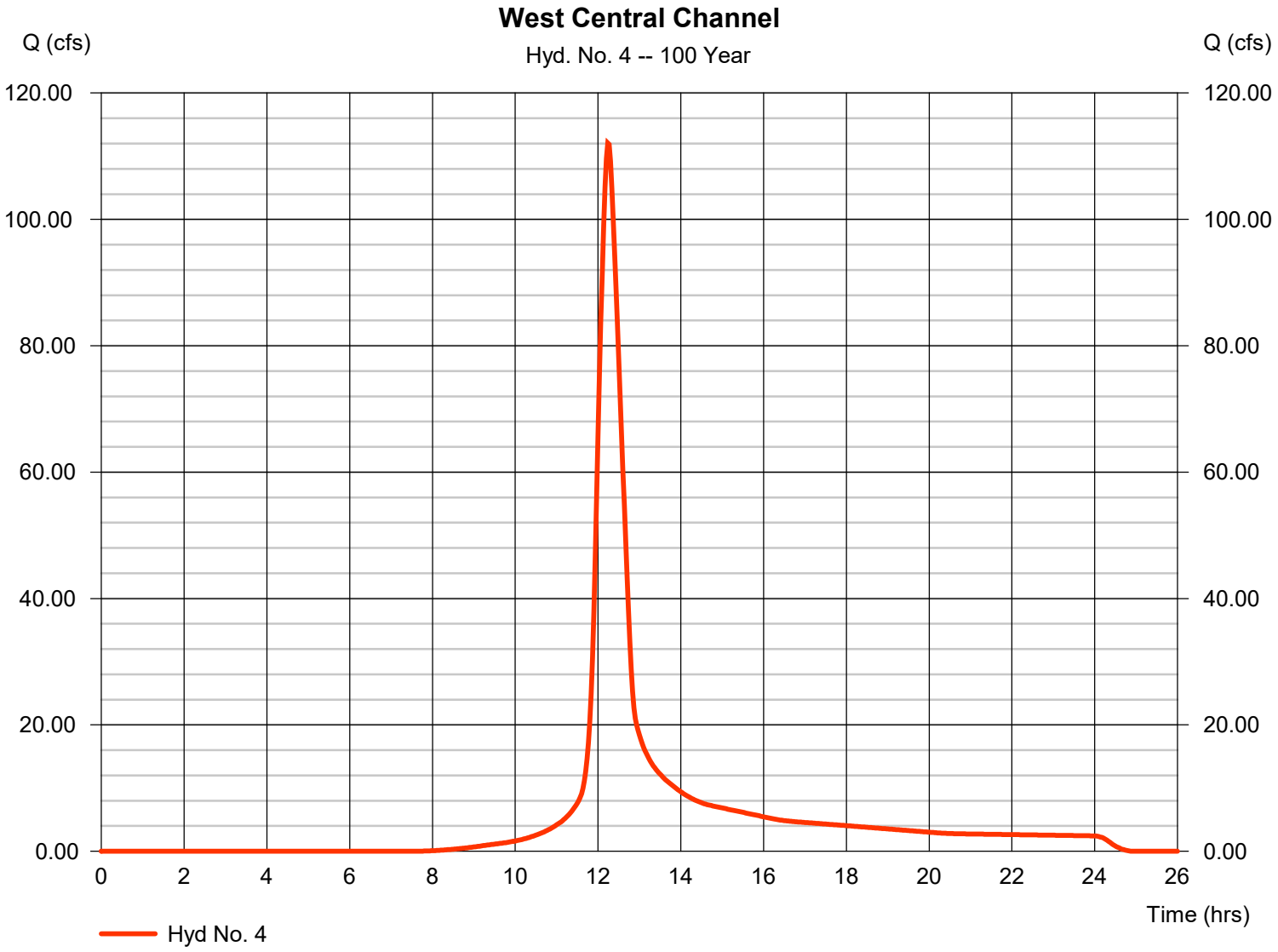
Hydrograph Report

Hyd. No. 4

West Central Channel

Hydrograph type	=	SCS Runoff	Peak discharge	=	112.07 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	508,357 cuft
Drainage area	=	38.510 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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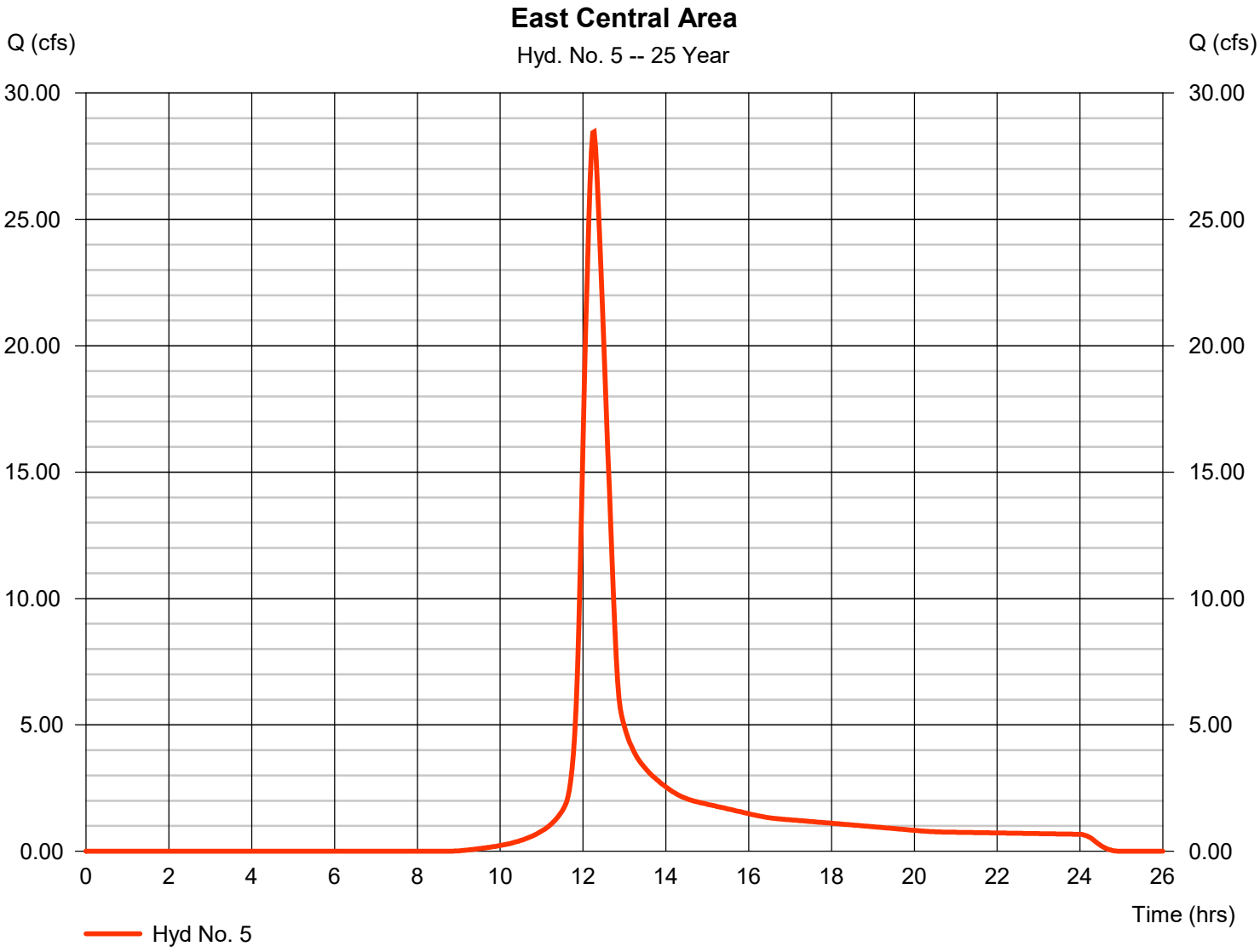
Hydrograph Report

Hyd. No. 5

East Central Area

Hydrograph type	=	SCS Runoff	Peak discharge	=	28.47 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	130,122 cuft
Drainage area	=	14.090 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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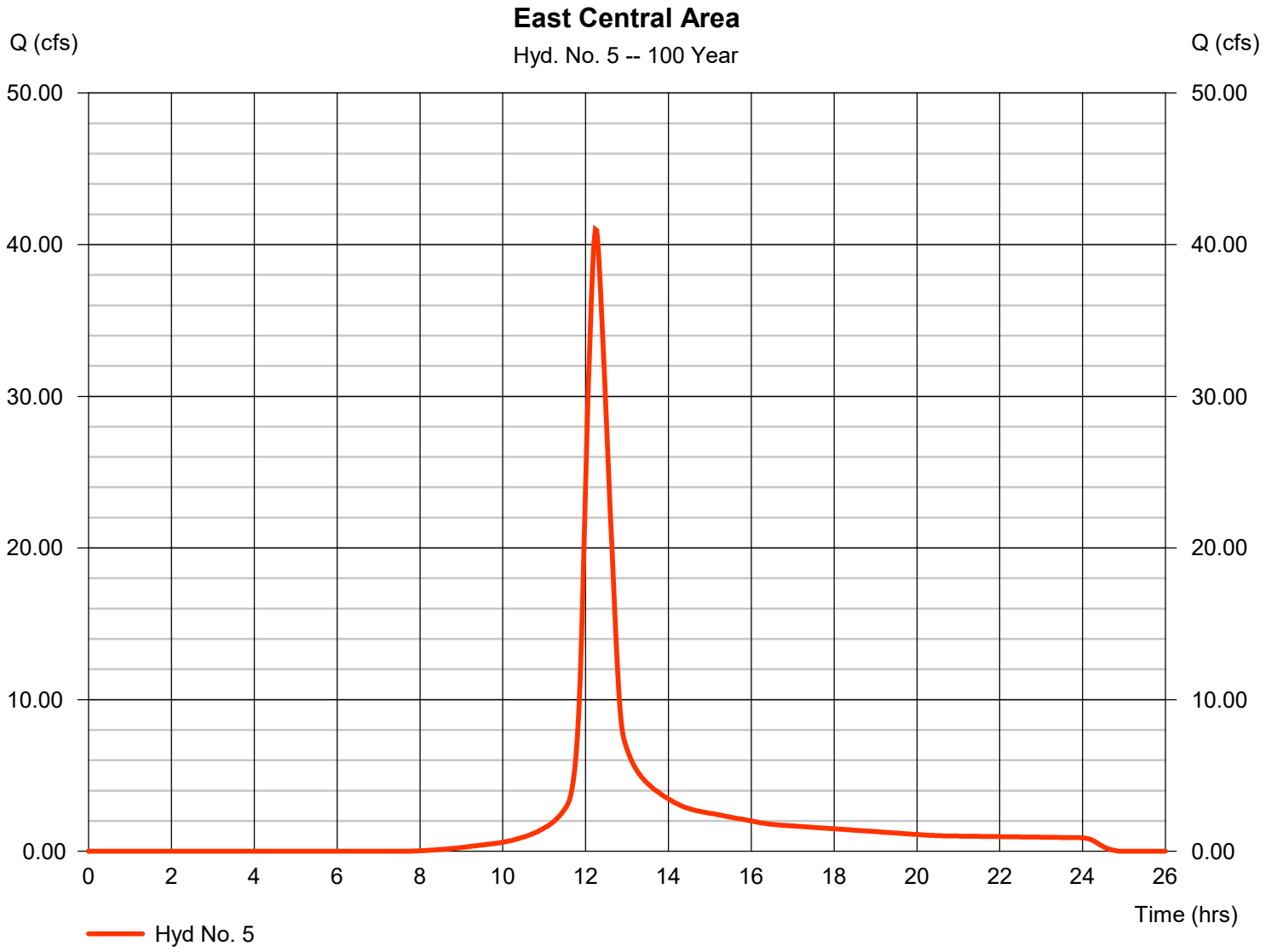
Hydrograph Report

Hyd. No. 5

East Central Area

Hydrograph type	=	SCS Runoff	Peak discharge	=	41.00 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	185,997 cuft
Drainage area	=	14.090 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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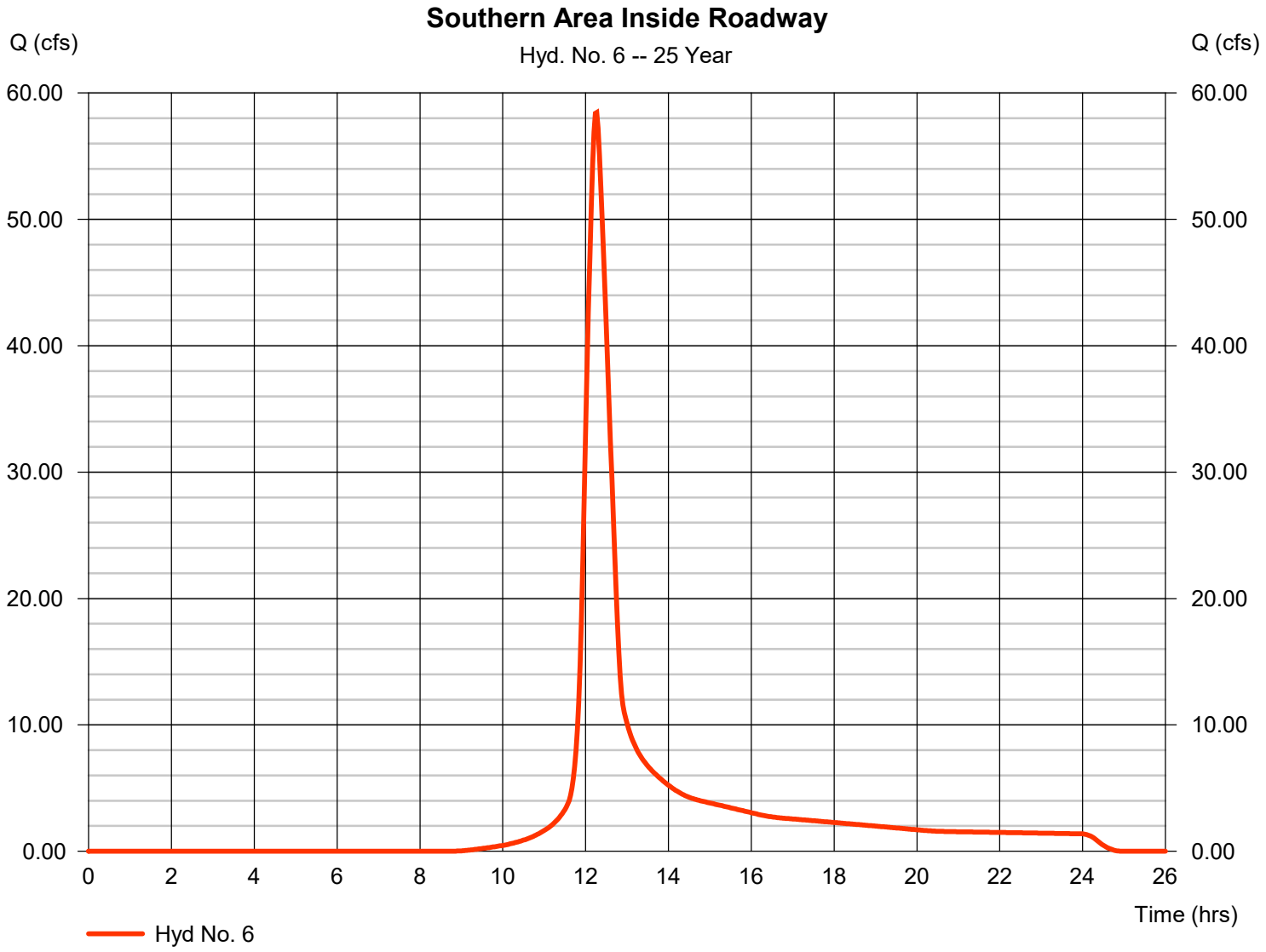
Hydrograph Report

Hyd. No. 6

Southern Area Inside Roadway

Hydrograph type	=	SCS Runoff	Peak discharge	=	58.47 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	267,263 cuft
Drainage area	=	28.940 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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Hydrograph Report

Hyd. No. 6

Southern Area Inside Roadway

Hydrograph type	=	SCS Runoff	Peak discharge	=	84.22 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	382,027 cuft
Drainage area	=	28.940 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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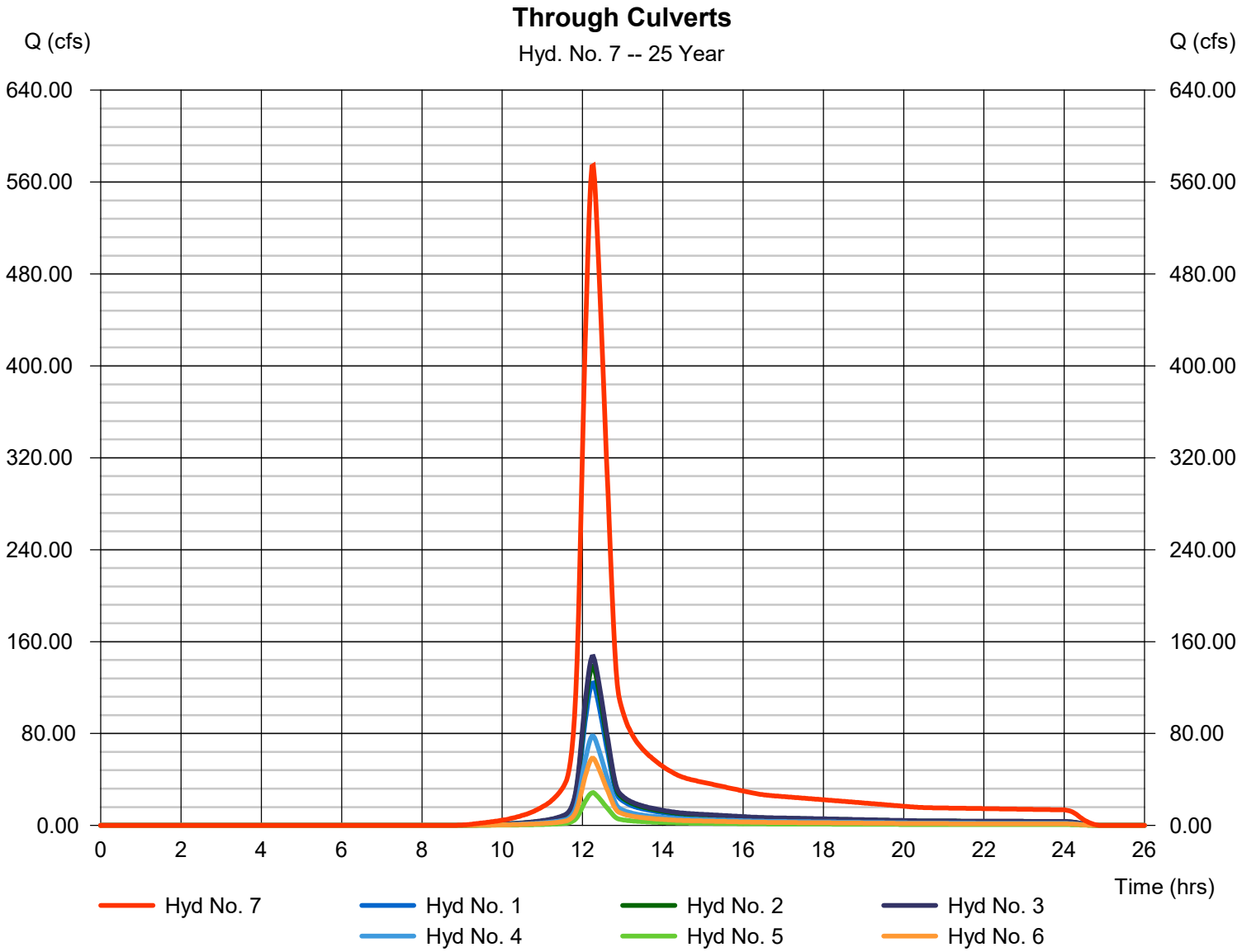
Hydrograph Report

Hyd. No. 7

Through Culverts

Hydrograph type	= Combine	Peak discharge	= 574.33 cfs
Storm frequency	= 25 yrs	Time to peak	= 12.27 hrs
Time interval	= 2 min	Hyd. volume	= 2,625,349 cuft
Inflow hyds.	= 1, 2, 3, 4, 5, 6	Contrib. drain. area	= 284.280 ac



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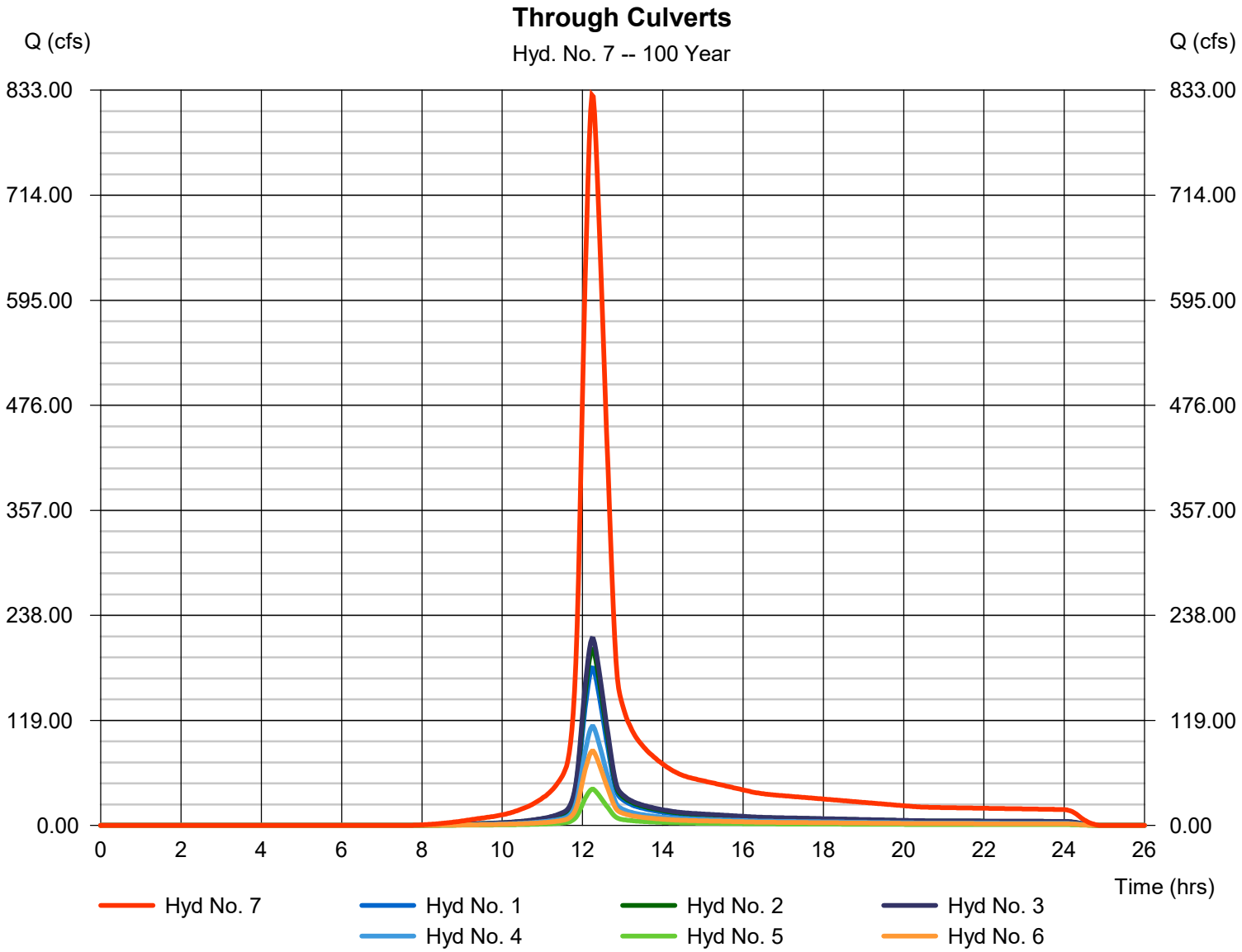
Hydrograph Report

Hyd. No. 7

Through Culverts

Hydrograph type	= Combine	Peak discharge	= 827.31 cfs
Storm frequency	= 100 yrs	Time to peak	= 12.23 hrs
Time interval	= 2 min	Hyd. volume	= 3,752,680 cuft
Inflow hyds.	= 1, 2, 3, 4, 5, 6	Contrib. drain. area	= 284.280 ac



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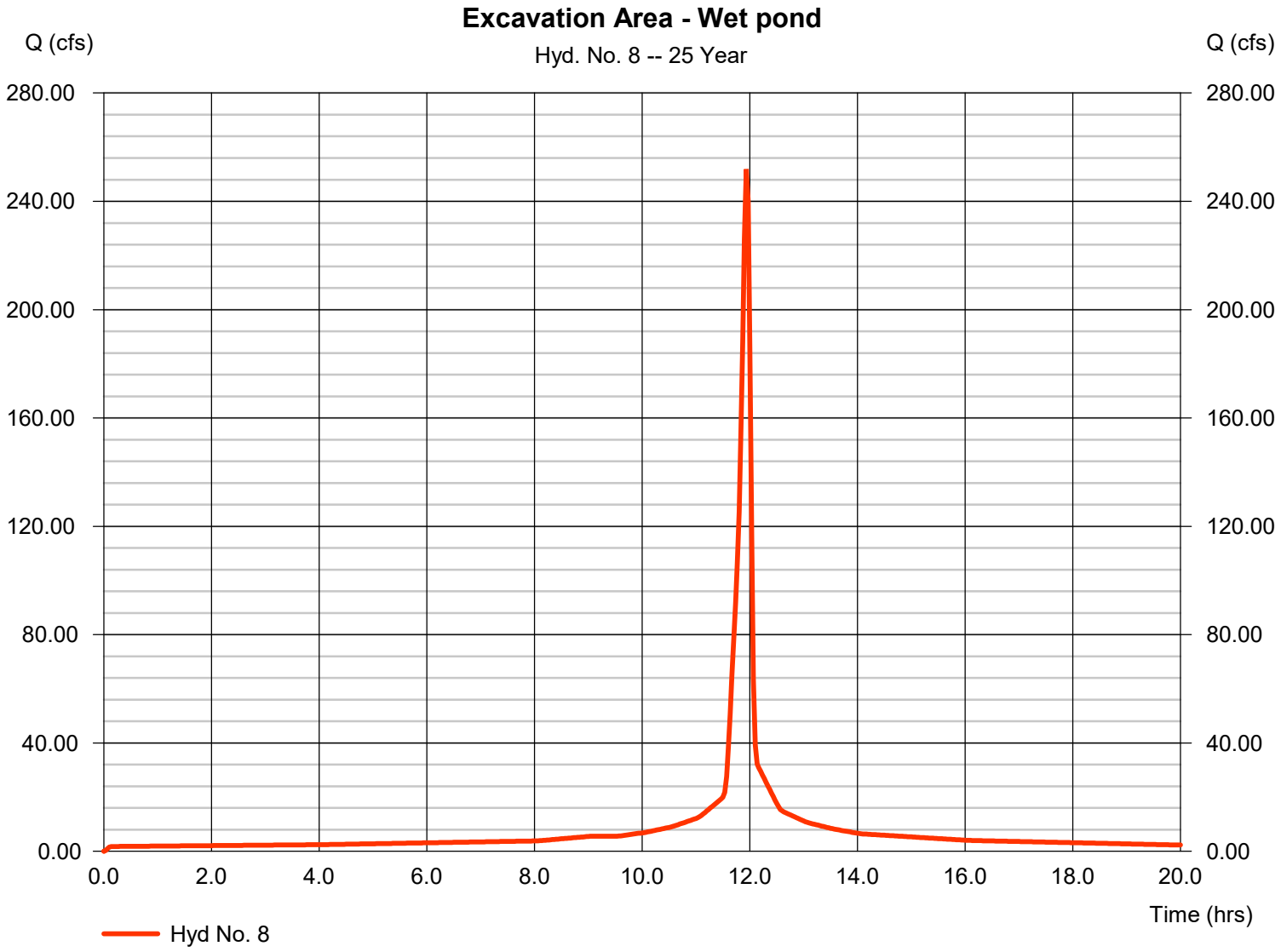
Hydrograph Report

Hyd. No. 8

Excavation Area - Wet pond

Hydrograph type	=	SCS Runoff	Peak discharge	=	251.91 cfs
Storm frequency	=	25 yrs	Time to peak	=	11.93 hrs
Time interval	=	2 min	Hyd. volume	=	627,410 cuft
Drainage area	=	35.050 ac	Curve number	=	100
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	User	Time of conc. (Tc)	=	5.00 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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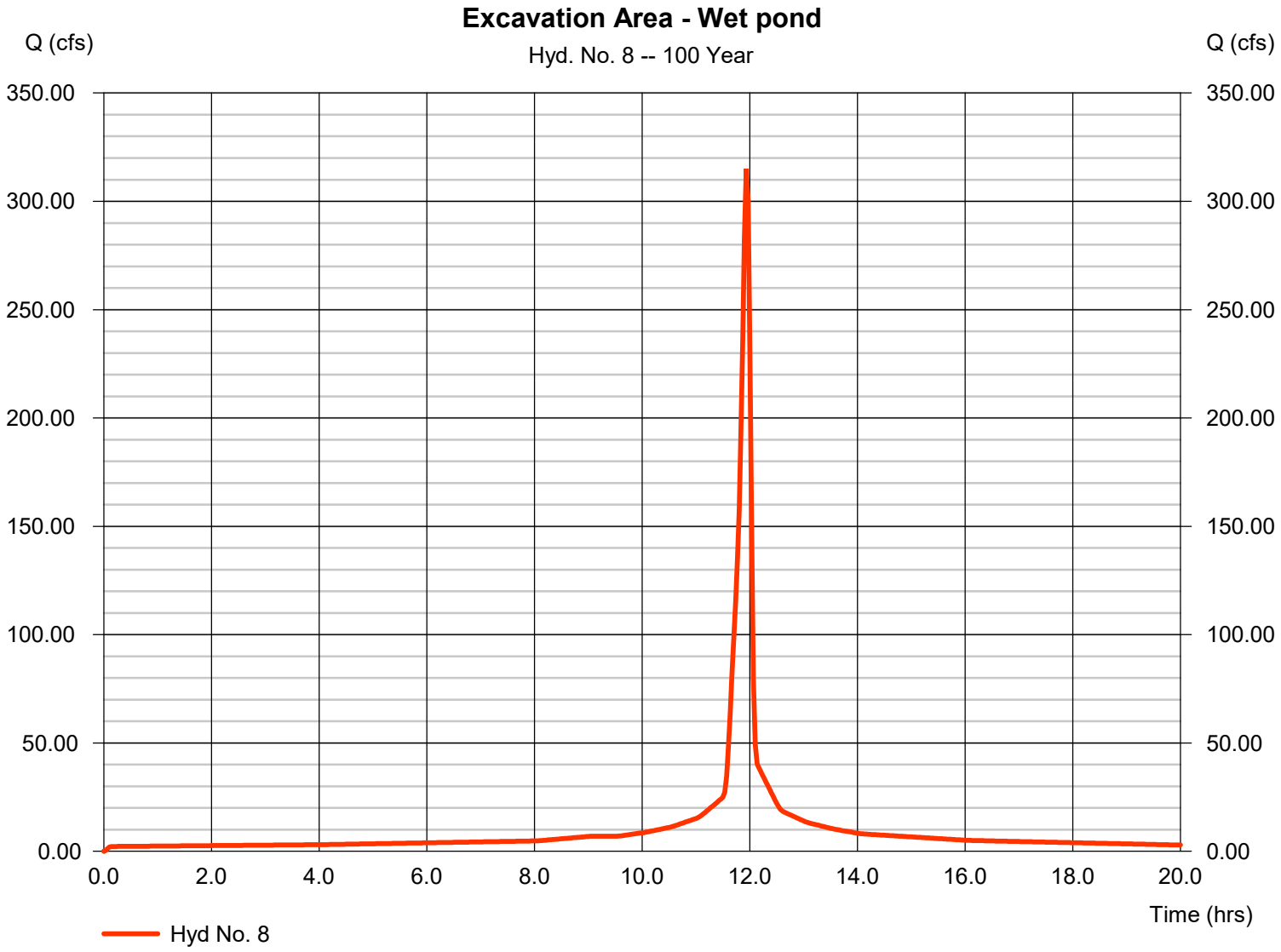
Hydrograph Report

Hyd. No. 8

Excavation Area - Wet pond

Hydrograph type	= SCS Runoff	Peak discharge	= 315.13 cfs
Storm frequency	= 100 yrs	Time to peak	= 11.93 hrs
Time interval	= 2 min	Hyd. volume	= 784,859 cuft
Drainage area	= 35.050 ac	Curve number	= 100
Basin Slope	= 0.0 %	Hydraulic length	= 0 ft
Tc method	= User	Time of conc. (Tc)	= 5.00 min
Total precip.	= 6.58 in	Distribution	= Type II
Storm duration	= 24 hrs	Shape factor	= 484



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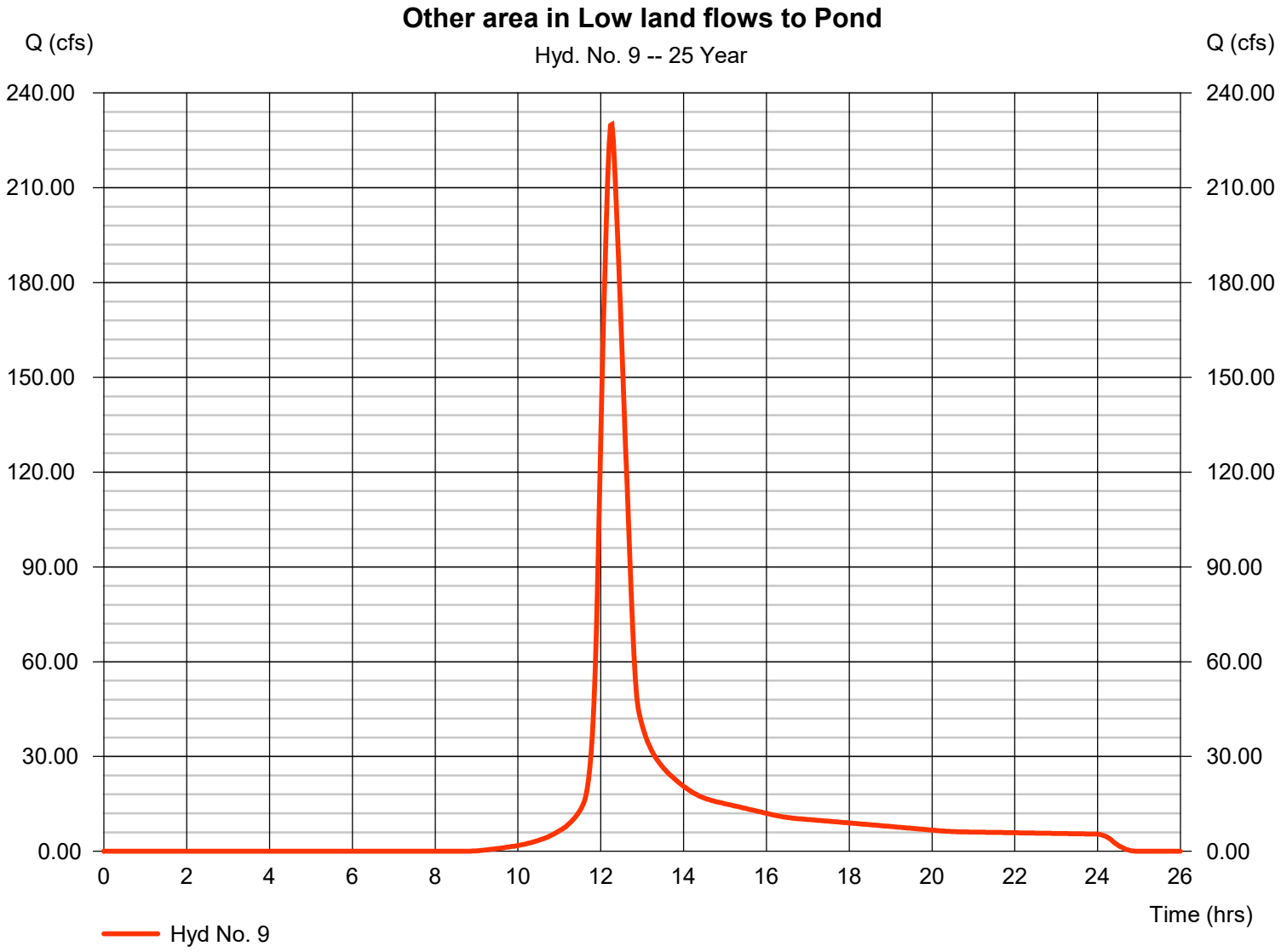
Hydrograph Report

Hyd. No. 9

Other area in Low land flows to Pond

Hydrograph type	=	SCS Runoff	Peak discharge	=	230.07 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	1,051,690 cuft
Drainage area	=	113.880 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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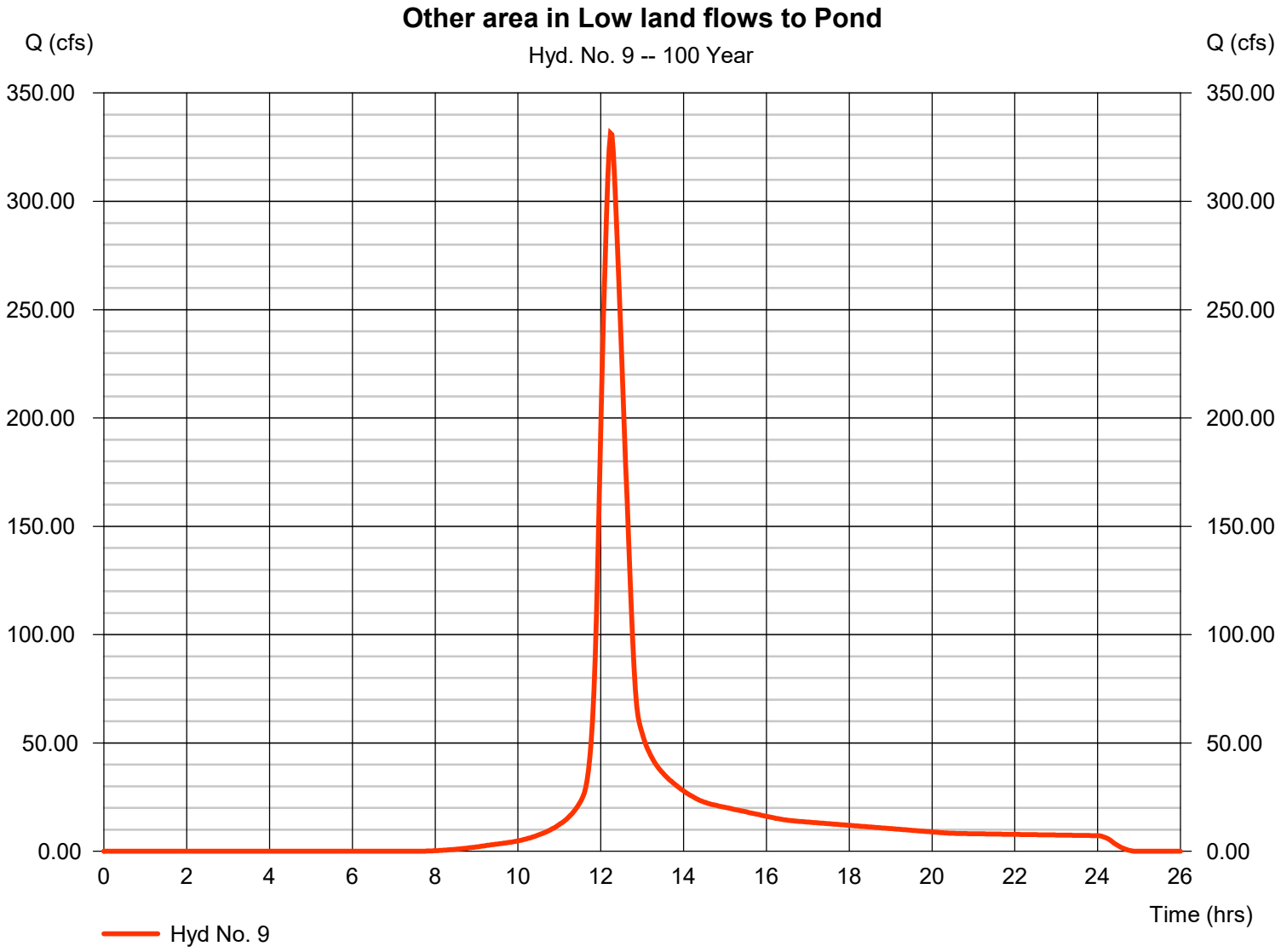
Hydrograph Report

Hyd. No. 9

Other area in Low land flows to Pond

Hydrograph type	=	SCS Runoff	Peak discharge	=	331.41 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	1,503,291 cuft
Drainage area	=	113.880 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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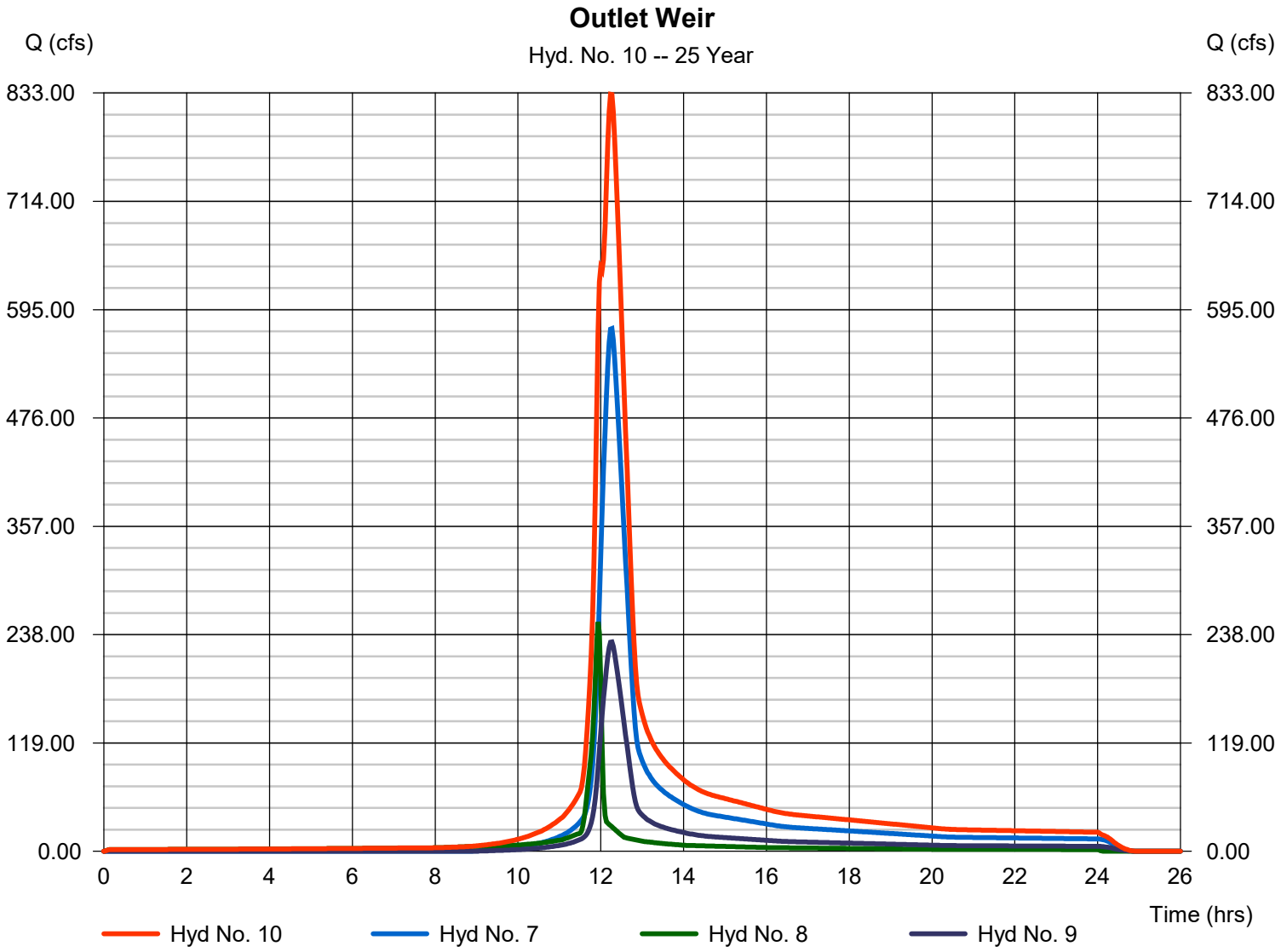
Hydrograph Report

Hyd. No. 10

Outlet Weir

Hydrograph type	= Combine	Peak discharge	= 831.51 cfs
Storm frequency	= 25 yrs	Time to peak	= 12.23 hrs
Time interval	= 2 min	Hyd. volume	= 4,304,447 cuft
Inflow hyds.	= 7, 8, 9	Contrib. drain. area	= 148.930 ac



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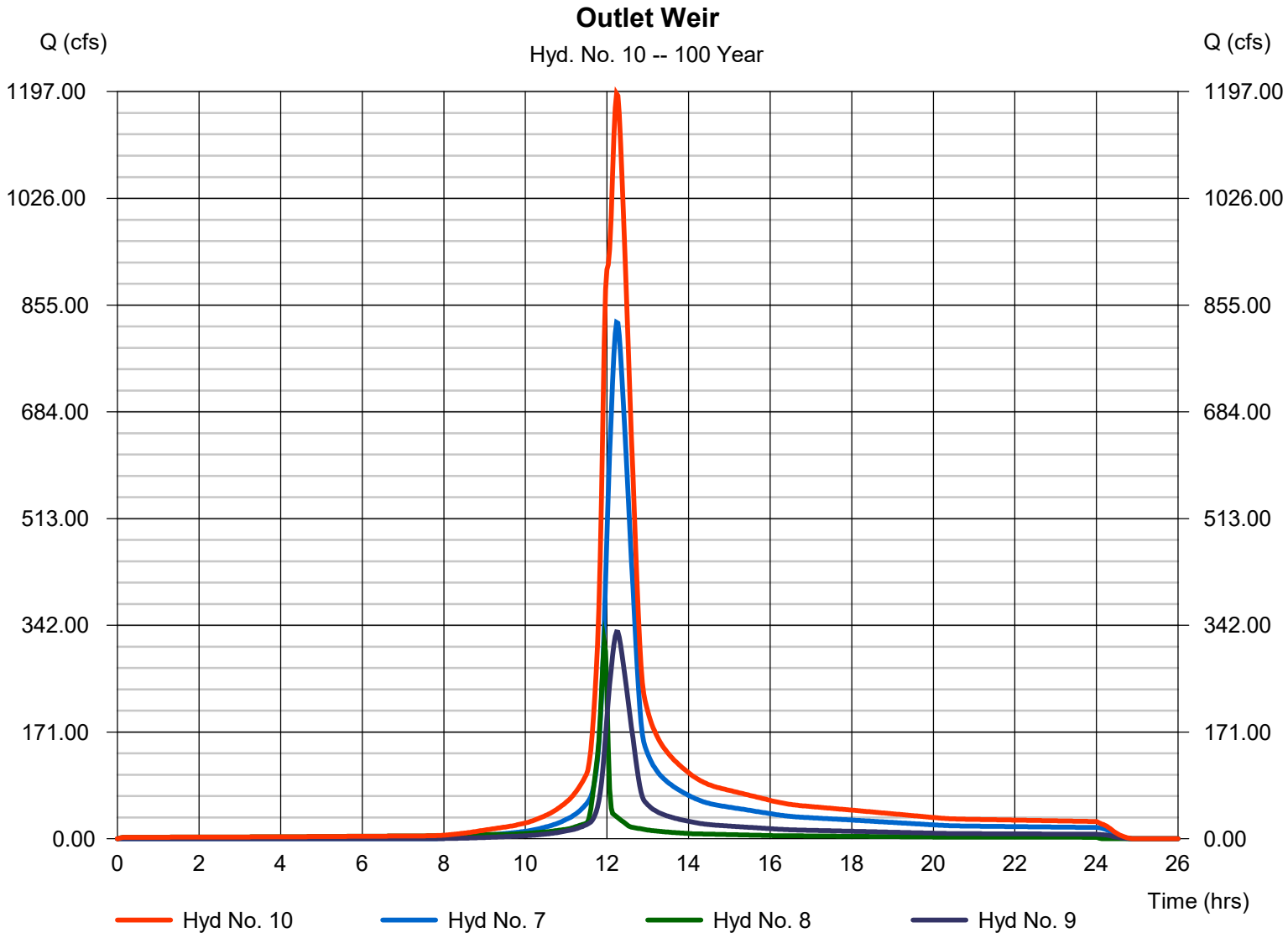
Hydrograph Report

Hyd. No. 10

Outlet Weir

Hydrograph type	= Combine	Peak discharge	= 1193.98 cfs
Storm frequency	= 100 yrs	Time to peak	= 12.23 hrs
Time interval	= 2 min	Hyd. volume	= 6,040,827 cuft
Inflow hyds.	= 7, 8, 9	Contrib. drain. area	= 148.930 ac



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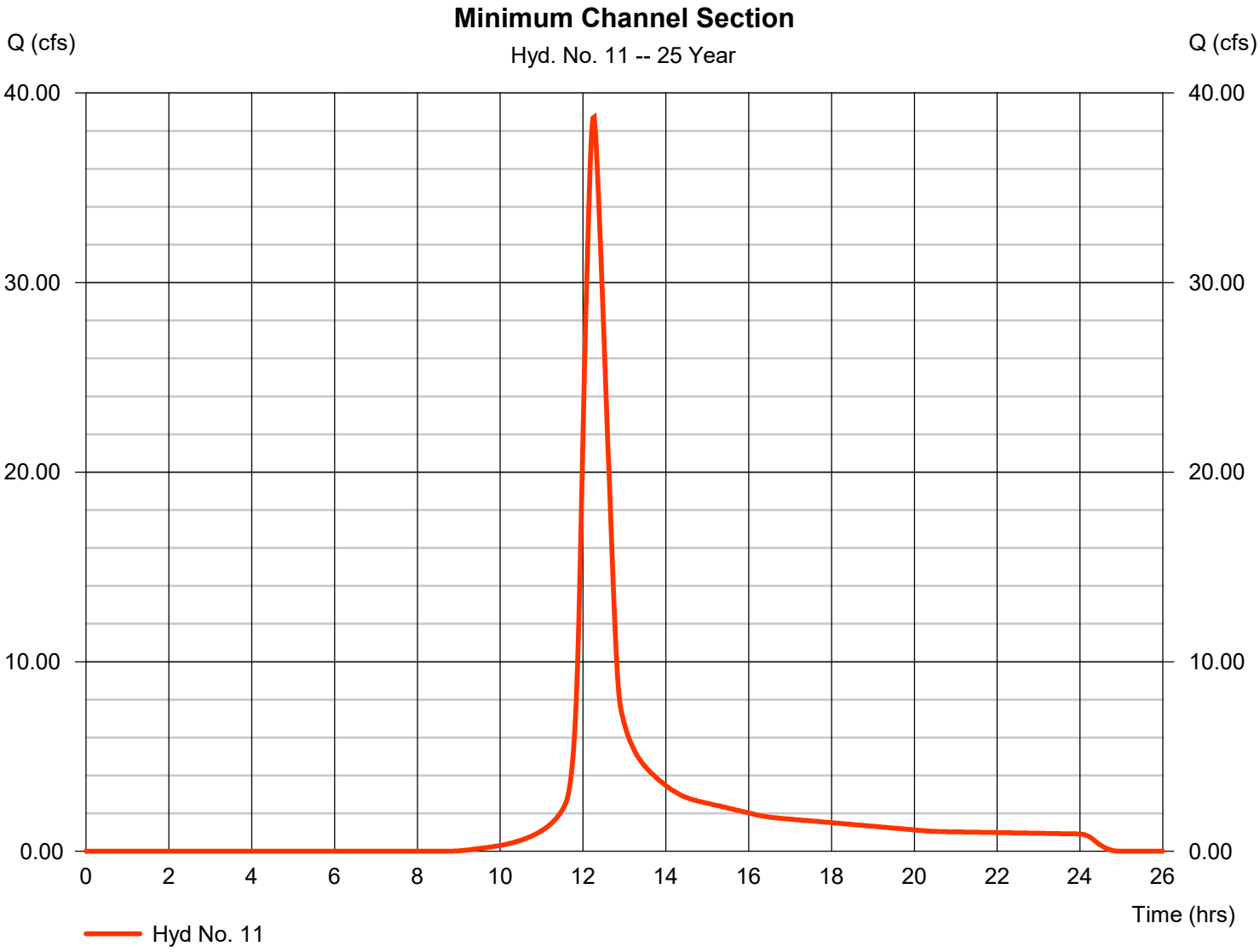
Hydrograph Report

Hyd. No. 11

Minimum Channel Section

Hydrograph type	=	SCS Runoff	Peak discharge	=	38.73 cfs
Storm frequency	=	25 yrs	Time to peak	=	12.27 hrs
Time interval	=	2 min	Hyd. volume	=	177,036 cuft
Drainage area	=	19.170 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	5.26 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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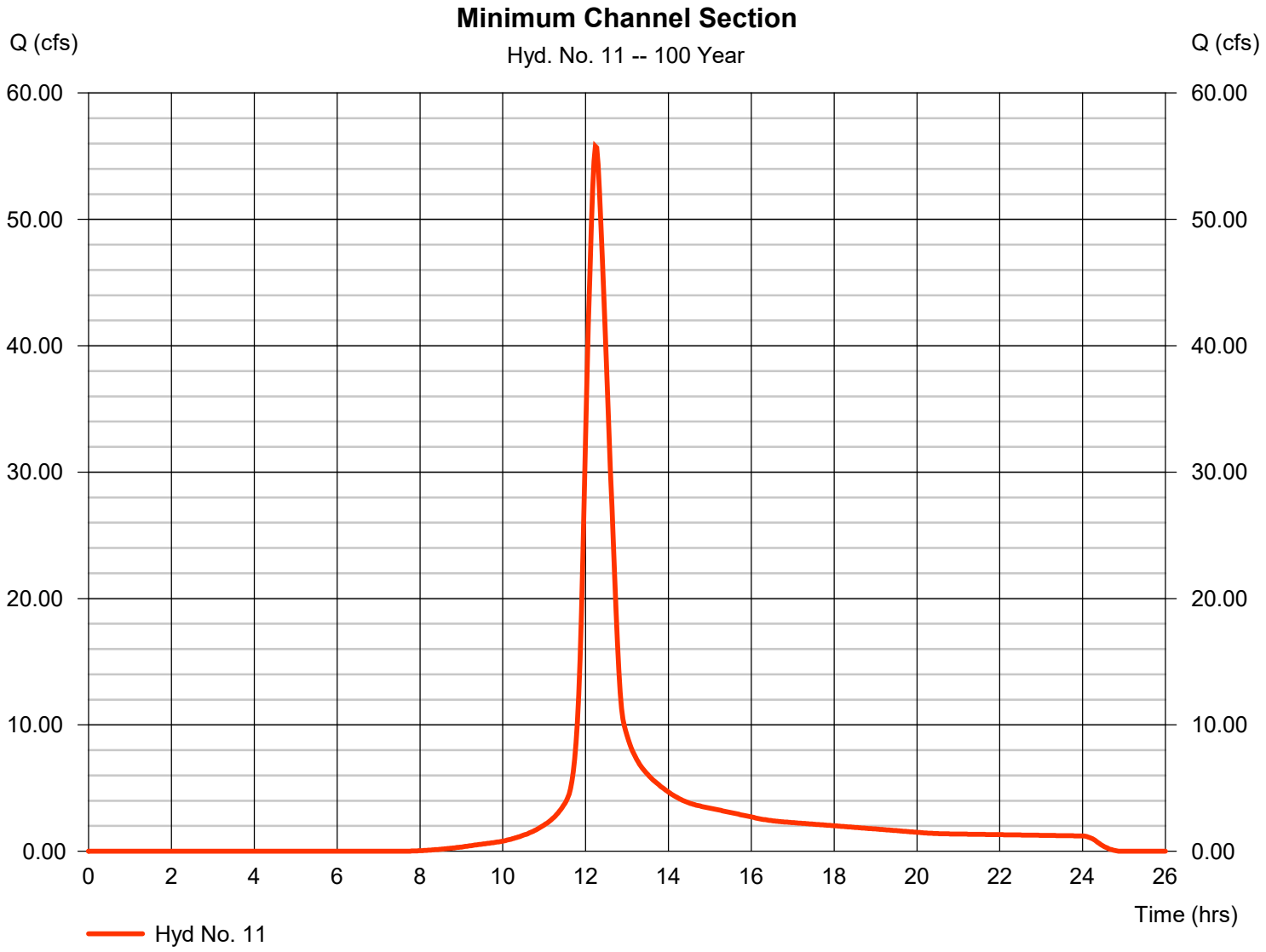
Hydrograph Report

Hyd. No. 11

Minimum Channel Section

Hydrograph type	=	SCS Runoff	Peak discharge	=	55.79 cfs
Storm frequency	=	100 yrs	Time to peak	=	12.23 hrs
Time interval	=	2 min	Hyd. volume	=	253,056 cuft
Drainage area	=	19.170 ac	Curve number	=	74
Basin Slope	=	0.0 %	Hydraulic length	=	0 ft
Tc method	=	TR55	Time of conc. (Tc)	=	34.50 min
Total precip.	=	6.58 in	Distribution	=	Type II
Storm duration	=	24 hrs	Shape factor	=	484



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Appendix C

Hydroflow Express Output

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Channel Report

East Channel Lower Reach

Trapezoidal

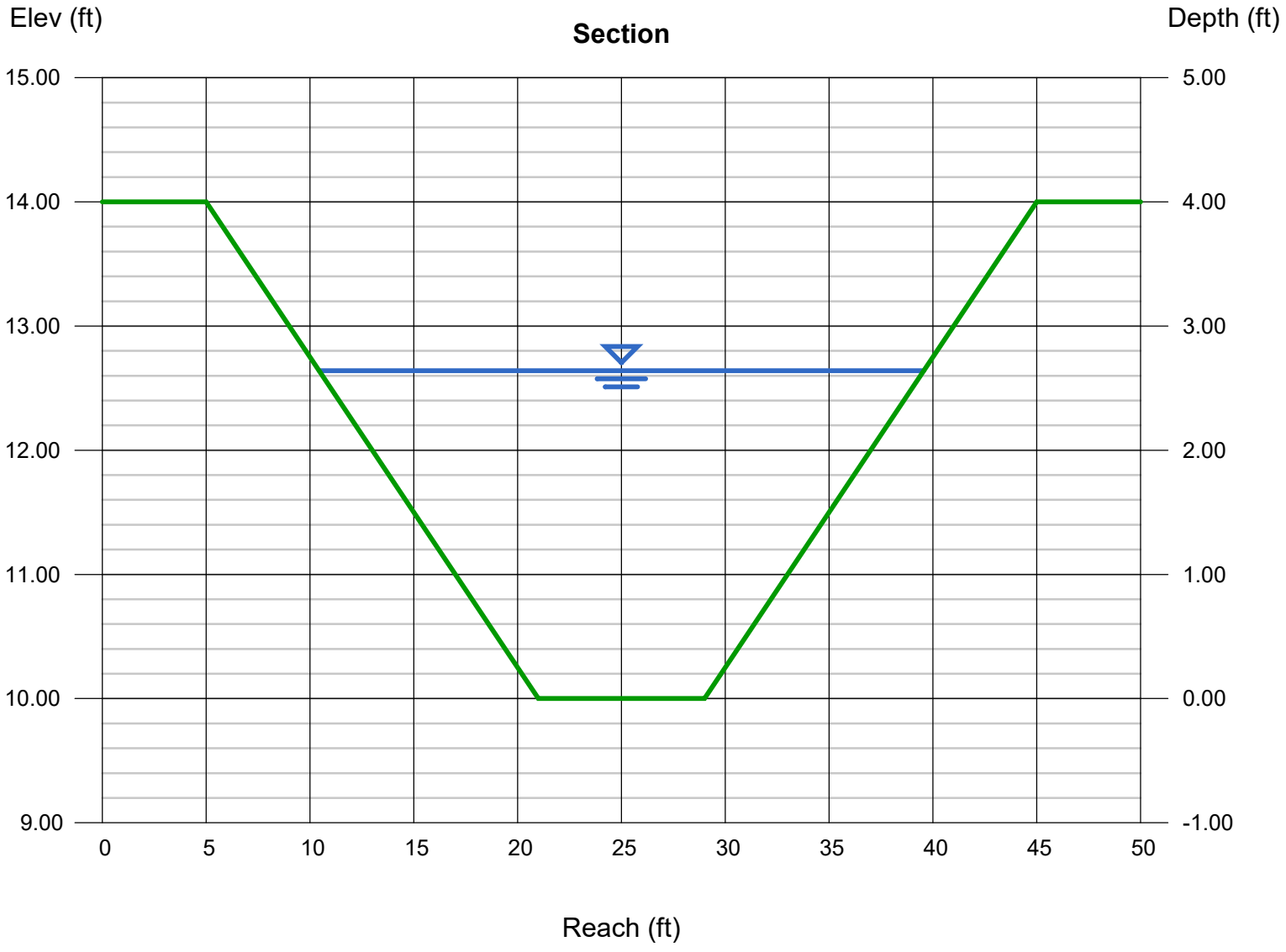
Bottom Width (ft)	= 8.00
Side Slopes (z:1)	= 4.00, 4.00
Total Depth (ft)	= 4.00
Invert Elev (ft)	= 10.00
Slope (%)	= 0.15
N-Value	= 0.022

Calculations

Compute by:	Known Q
Known Q (cfs)	= 178.63

Highlighted

Depth (ft)	= 2.64
Q (cfs)	= 178.63
Area (sqft)	= 49.00
Velocity (ft/s)	= 3.65
Wetted Perim (ft)	= 29.77
Crit Depth, Yc (ft)	= 1.84
Top Width (ft)	= 29.12
EGL (ft)	= 2.85



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Channel Report

West Channel

Trapezoidal

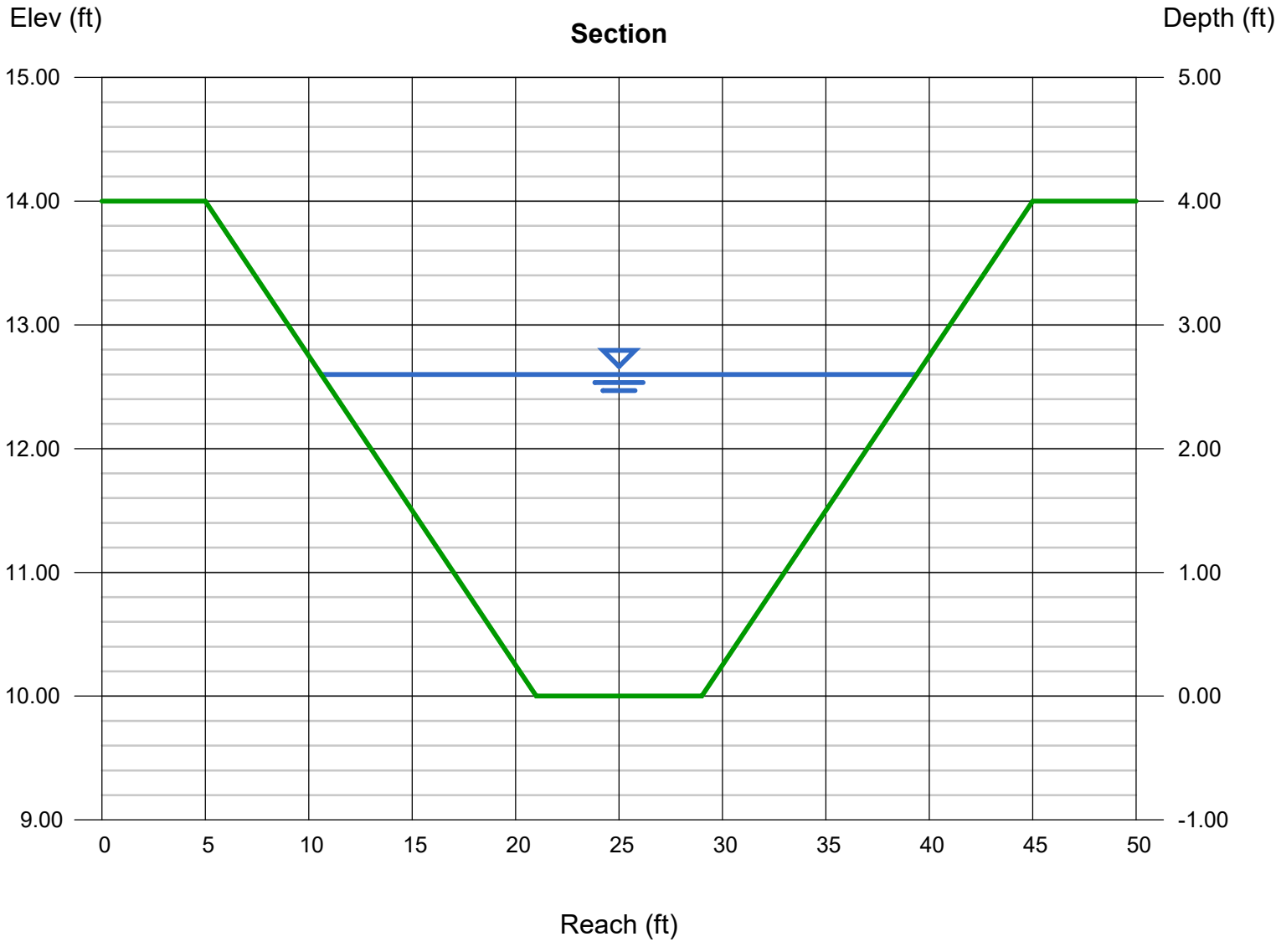
Bottom Width (ft)	= 8.00
Side Slopes (z:1)	= 4.00, 4.00
Total Depth (ft)	= 4.00
Invert Elev (ft)	= 10.00
Slope (%)	= 0.20
N-Value	= 0.022

Calculations

Compute by:	Known Q
Known Q (cfs)	= 199.60

Highlighted

Depth (ft)	= 2.60
Q (cfs)	= 199.60
Area (sqft)	= 47.84
Velocity (ft/s)	= 4.17
Wetted Perim (ft)	= 29.44
Crit Depth, Yc (ft)	= 1.95
Top Width (ft)	= 28.80
EGL (ft)	= 2.87



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Channel Report

Central Drainageway

Trapezoidal

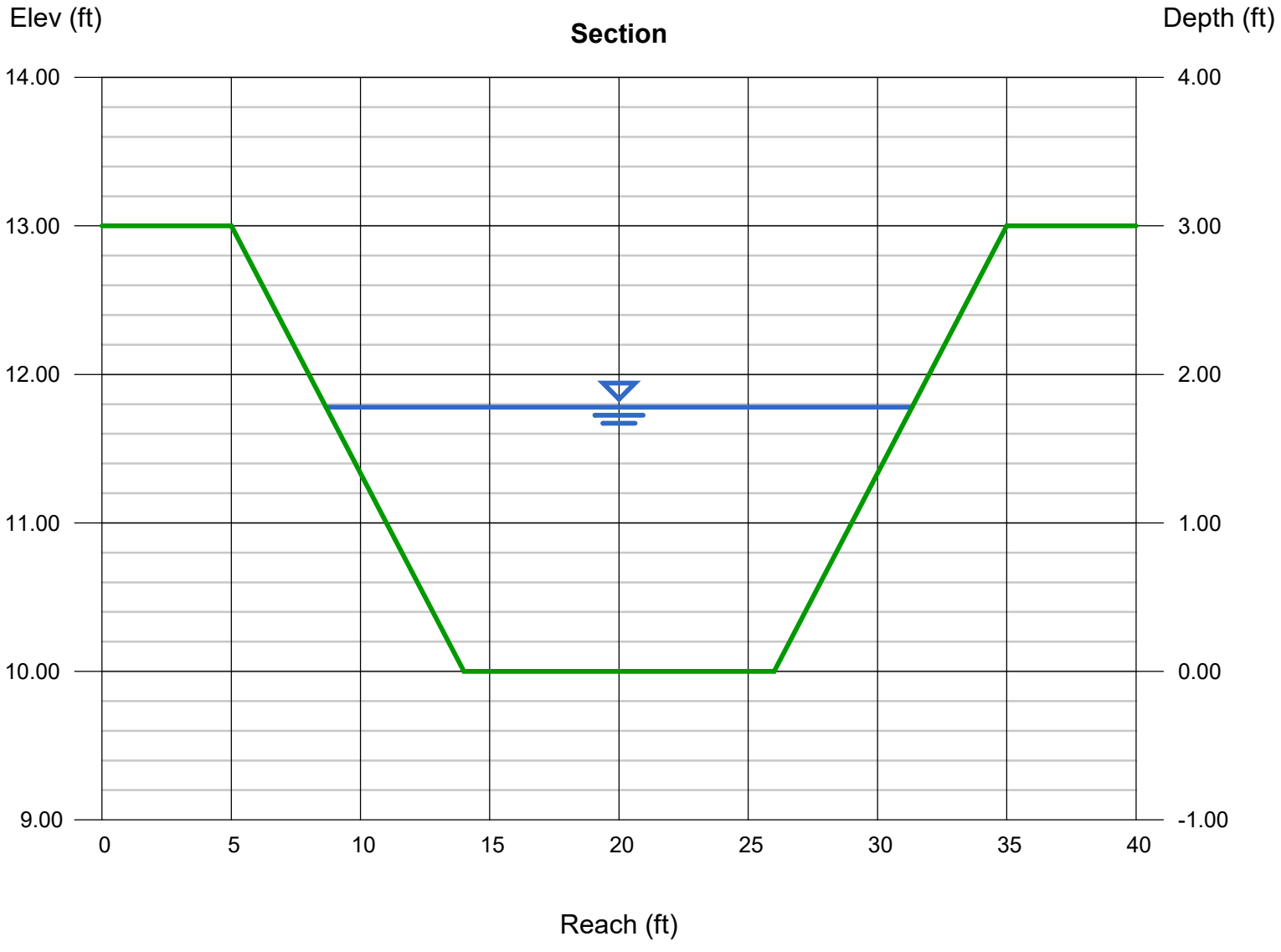
Bottom Width (ft)	= 12.00
Side Slopes (z:1)	= 3.00, 3.00
Total Depth (ft)	= 3.00
Invert Elev (ft)	= 10.00
Slope (%)	= 1.00
N-Value	= 0.026

Calculations

Compute by:	Known Q
Known Q (cfs)	= 212.00

Highlighted

Depth (ft)	= 1.78
Q (cfs)	= 212.00
Area (sqft)	= 30.87
Velocity (ft/s)	= 6.87
Wetted Perim (ft)	= 23.26
Crit Depth, Yc (ft)	= 1.82
Top Width (ft)	= 22.68
EGL (ft)	= 2.51



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Channel Report

Culvert Under Perimeter Road x4

Circular

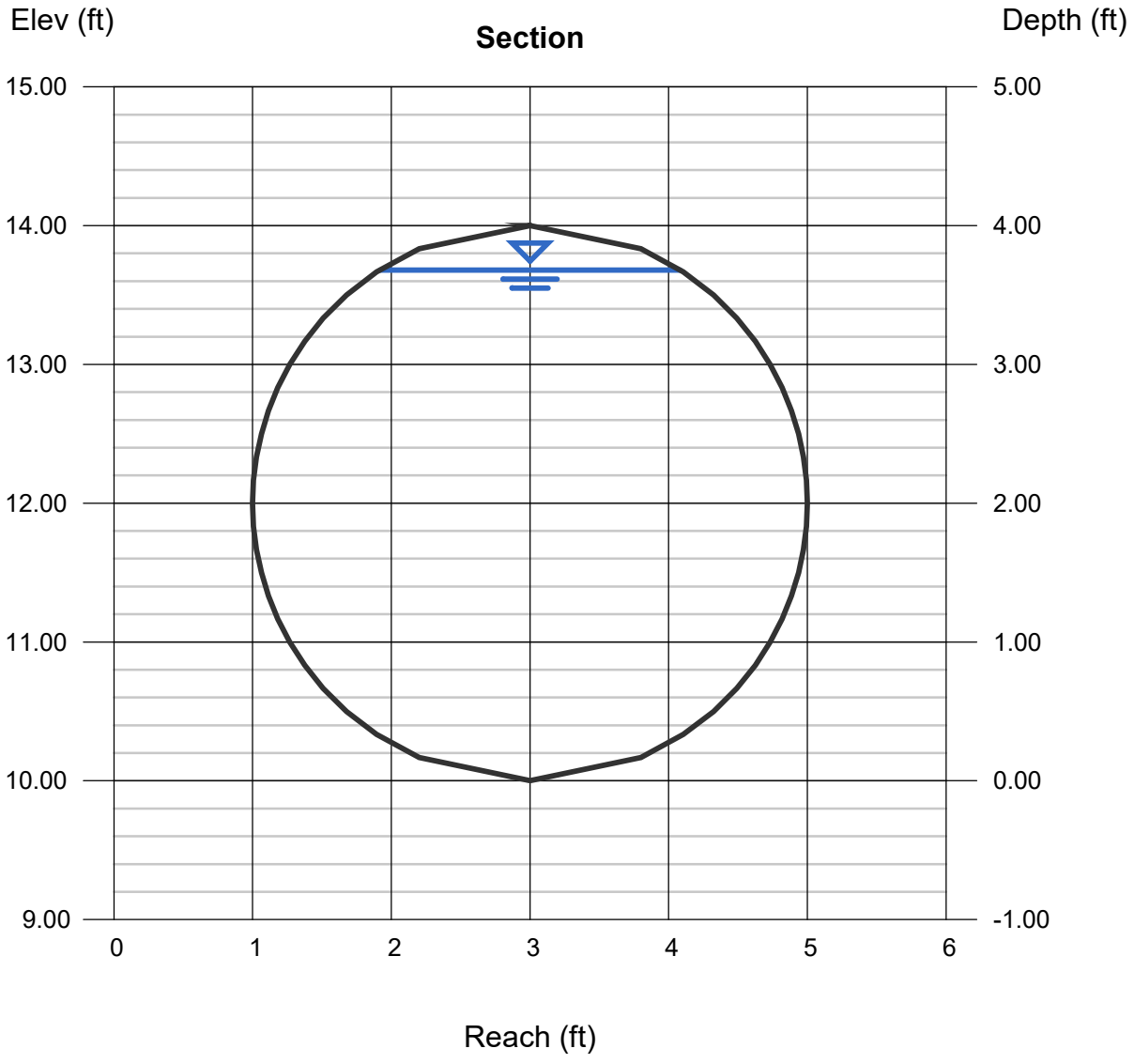
Diameter (ft)	= 4.00
Invert Elev (ft)	= 10.00
Slope (%)	= 2.00
N-Value	= 0.013

Calculations

Compute by:	Q vs Depth
No. Increments	= 25

Highlighted

Depth (ft)	= 3.68
Q (cfs)	= 218.07
Area (sqft)	= 12.10
Velocity (ft/s)	= 18.02
Wetted Perim (ft)	= 10.28
Crit Depth, Yc (ft)	= 3.89
Top Width (ft)	= 2.16
EGL (ft)	= 8.73



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Channel Report

Outlet Weir

Trapezoidal

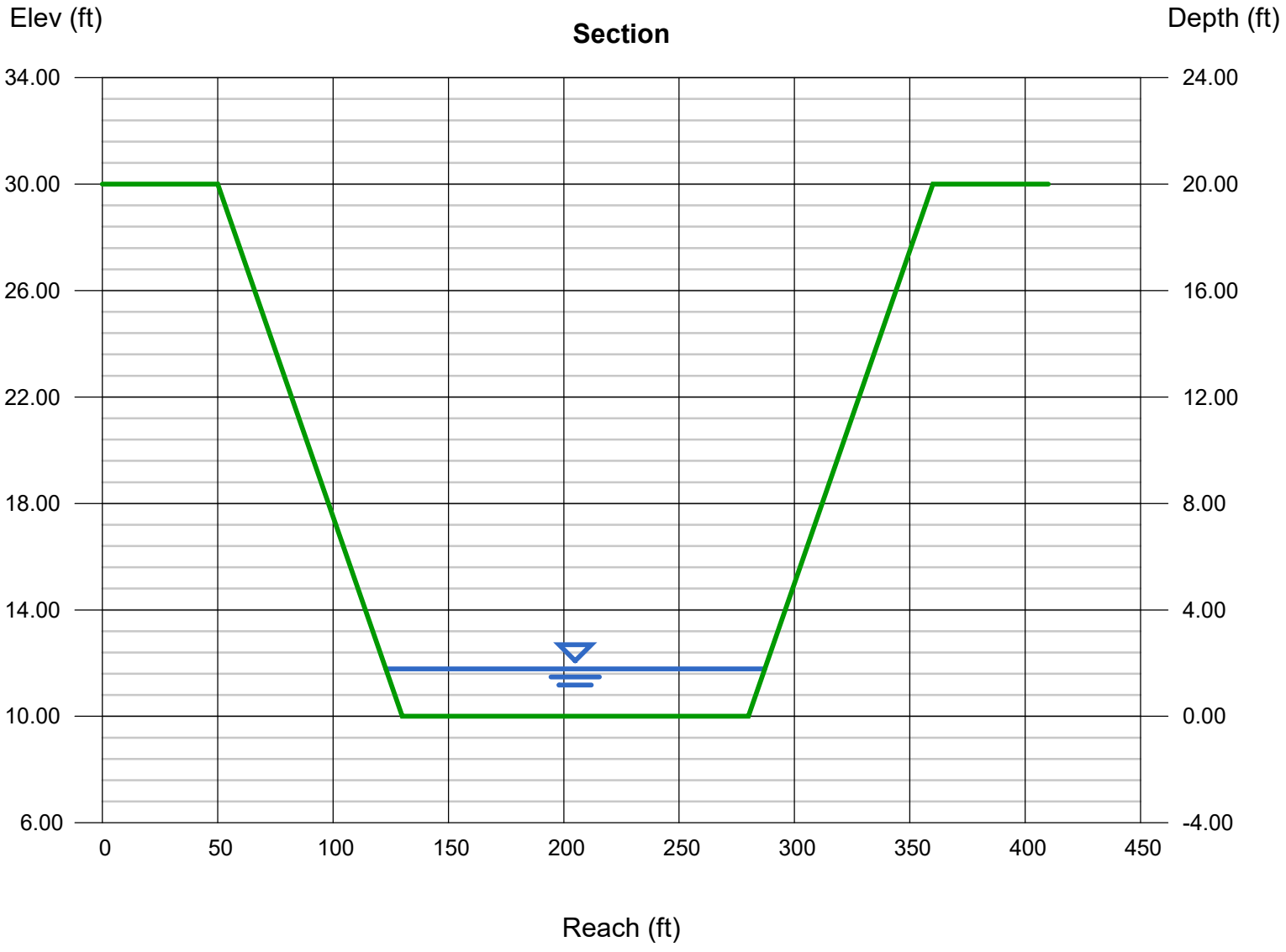
Bottom Width (ft)	= 150.00
Side Slopes (z:1)	= 4.00, 4.00
Total Depth (ft)	= 20.00
Invert Elev (ft)	= 10.00
Slope (%)	= 0.20
N-Value	= 0.022

Calculations

Compute by:	Known Q
Known Q (cfs)	= 1194.00

Highlighted

Depth (ft)	= 1.78
Q (cfs)	= 1,194
Area (sqft)	= 279.67
Velocity (ft/s)	= 4.27
Wetted Perim (ft)	= 164.68
Crit Depth, Yc (ft)	= 1.24
Top Width (ft)	= 164.24
EGL (ft)	= 2.06



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Channel Report

East Channel Minimum Section

Trapezoidal

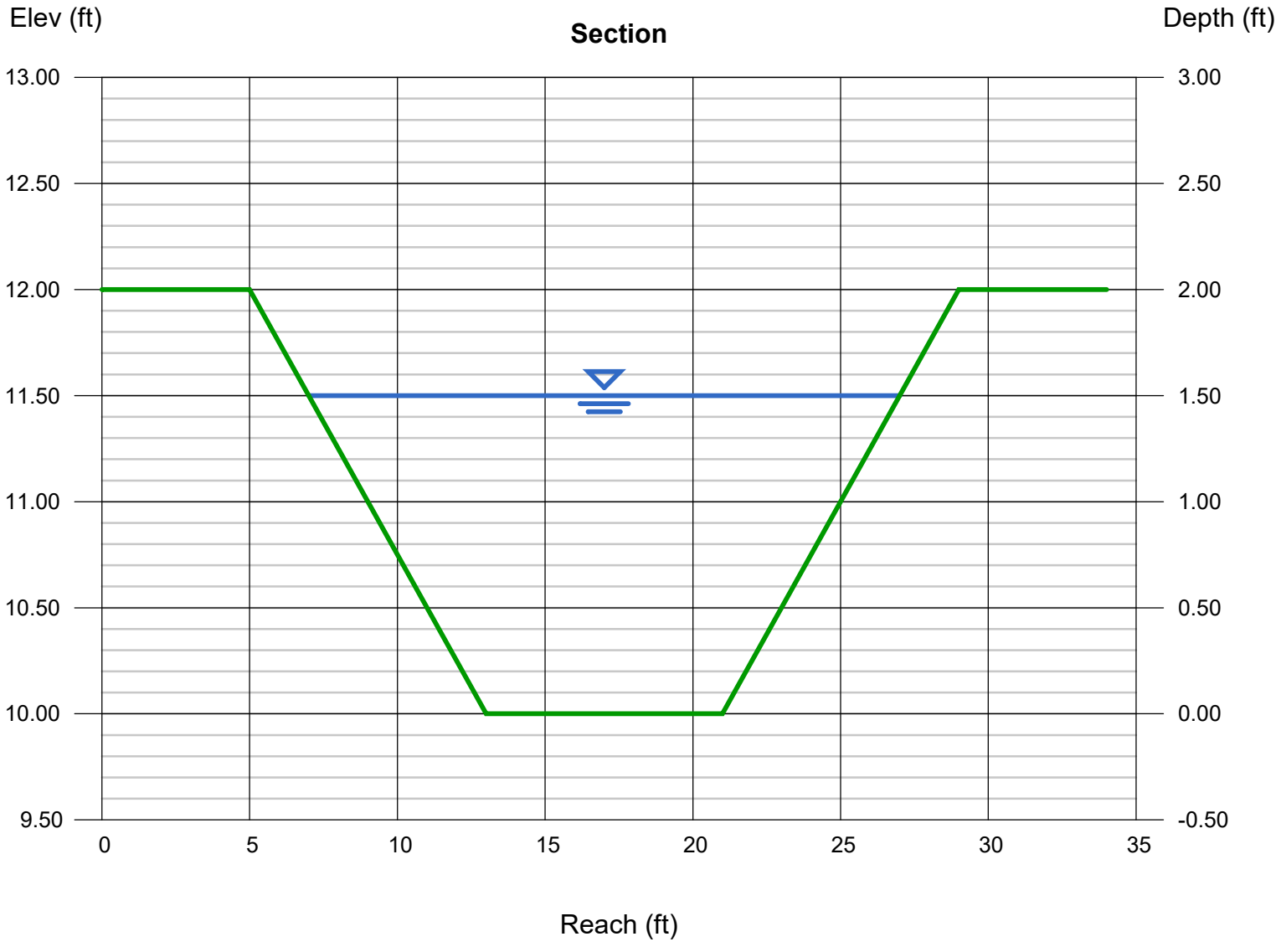
Bottom Width (ft)	= 8.00
Side Slopes (z:1)	= 4.00, 4.00
Total Depth (ft)	= 2.00
Invert Elev (ft)	= 10.00
Slope (%)	= 0.15
N-Value	= 0.022

Calculations

Compute by:	Known Q
Known Q (cfs)	= 56.00

Highlighted

Depth (ft)	= 1.50
Q (cfs)	= 56.00
Area (sqft)	= 21.00
Velocity (ft/s)	= 2.67
Wetted Perim (ft)	= 20.37
Crit Depth, Yc (ft)	= 0.98
Top Width (ft)	= 20.00
EGL (ft)	= 1.61



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Attachment D

Geotechnical Design of Slopes and Final Cover System

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Slope Stability Report for IPGC Newton Primary Ash Pond Closure

Newton, Illinois

July 2022

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Certification



I hereby certify that these engineering documents were prepared by me or under my direct personal supervision and that I am a duly licensed Professional Engineer under the laws of the State of Illinois.

7/28/2022

Mark Roberts, P.E. Date
Illinois License No. 062062011
My license renewal date is November 30, 2023.

Pages or sheets covered by this seal:

All pages.

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1 Purpose....1
2 Approach....2
3 Material Properties and Sections....2
3.1 Slope Stability....2
4 Stability Analysis Results and Conclusions....3
4.1 Ash Fill Scenarios....3
4.2 Conclusions....3

Figures

Sheet 00C106 – Final Closure Conditions
Figure 1 – Closure Cross Sections
Figure 2 – Final Closure Slope – Cross Section AA – Circular
Figure 3 – Final Closure Slope – Cross Section AA – Circular – Seismic Impact
Figure 4 – Final Closure Slope – Cross Section AA – Sliding Block
Figure 5 – Final Closure Slope – Cross Section AA – Sliding Block – Seismic Impact
Figure 6 – Final Closure Slope – Cross Section BB – Circular
Figure 7 – Final Closure Slope – Cross Section BB – Circular – Seismic Impact
Figure 8 – Final Closure Slope – Cross Section BB – Sliding Block
Figure 9 – Final Closure Slope – Cross Section BB – Sliding Block – Seismic Impact

Attachments

Attachment A – Final Cover Veneer Stability
Attachment B – Reference Information

References

1. Slope/W Version v11.14.1.3, build 212549 x64_n6; GeoStudio 2019, Geo-Slope International, Ltd.
2. Global Stability Evaluation for Newton Power Station, Primary Ash Pond, Newton, Illinois, January 4, 2011.
3. Slope Stability Calculations, AECOM, 2016.
4. Geotechnical Engineering Properties of Fly Ash and Bottom Ash.
5. U.S. Geological Survey – Earthquake Hazards Program

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1 Purpose

The purpose of this report is to evaluate the global slope stability for the IPGC Newton Power Station Primary Ash Pond Closure slopes. These calculations focus on the stability of the existing base grades, placed ash, and final cover system, assuming typical material properties based on static and seismic conditions.

The global slope stability through the ash fill final closure slope for the following scenarios were evaluated:

- Run A – A northeast-southwest section through the south side slope in order to evaluate the slope stability of the ash fill on a 4H:1V slope. **Figure 2, Section A-A**.
- Run B – A northeast-southwest section through the south side slope in order to evaluate the slope stability of the ash fill on a 4H:1V slope and seismic impact. **Figure 3, Section A-A**.
- Run C – A northeast-southwest section through the south side slope in order to evaluate the sliding block slope stability of the ash fill on a 4H:1V slope. **Figure 4, Section A-A**.
- Run D – A northeast-southwest section through the south side slope in order to evaluate the sliding block slope stability of the ash fill on a 4H:1V slope and seismic impact. **Figure 5, Section A-A**.
- Run E – A northeast-southwest section through the south side slope in order to evaluate the slope stability of the ash fill on a 4H:1V slope. **Figure 6, Section B-B**.
- Run F – A northeast-southwest section through the south side slope in order to evaluate the slope stability of the ash fill on a 4H:1V slope and seismic impact. **Figure 7, Section B-B**.
- Run G – A northeast-southwest section through the south side slope in order to evaluate the sliding block slope stability of the ash fill on a 4H:1V slope. **Figure 8, Section B-B**.
- Run H – A northeast-southwest section through the south side slope in order to evaluate the sliding block slope stability of the ash fill on a 4H:1V slope and seismic impact. **Figure 9, Section B-B**.

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2 Approach

Two-dimensional limit equilibrium methods were used to evaluate slope stability for the static condition. Per the historical permit documentation, the site was determined to be in a seismic impact zone.

Per the Illinois Department of Natural Resources, the seismic hazard analysis should use bedrock peak ground accelerations with a 2% probability of exceedance (PE) in 50 years (mean return time of 2,500 years). The National Seismic Hazards Mapping Project (NSHMP) interactive deaggregations model (2014 edition) was used to obtain the probabilistic bedrock accelerations at the site. The NSHMP model considers ground motion from many sources surrounding the site location with the assumption that the site condition is rock with an average shear wave velocity of 2,500 ft/s. Bedrock spectral response acceleration 0.2286 g were obtained from the NSHMP model (**Attachment B**). The seismic coefficient for the seismic slope stability runs was determined via the United States Army Corps of Engineers 'Rationalizing the Seismic Coefficient Method Report', published in July 1984, which states: "carry out a conventional pseudostatic stability analysis using a seismic coefficient equal to one-half the predicted peak bedrock acceleration". This method yields a seismic coefficient of 0.115 g based on a peak bedrock acceleration of 0.2286 g.

The base computer program Slope/W was used to run Morgenstern-Price analysis type circular arc surfaces and sliding block surfaces. Search techniques within Slope/W were used to find the critical slip surface producing the minimum factor of safety for each analysis. The location of the critical slip surface is a function of the site geometry (slope angle and height), material stratigraphy, physical properties of the soil and fly ash, external loads; weight of soil and/or waste above the slip surface and groundwater conditions.

3 Material Properties and Sections

3.1 Slope Stability

The materials were grouped into four (4) basic types similar to previous analyses (see references 2 and 3). Material properties were determined by review of site specific information and experience with similar materials. See Table 1 below. For this analysis, an internal angle of friction of 25-degrees for the fly ash was used based on typical results for dry fly ash. Each scenario is based on long-term properties, to be conservative.

In addition, final cover veneer slope stability analysis was conducted to evaluate the stability of the final cover soil over the final cover membrane system. Final cover veneer results are provided in **Attachment A.**

Table 1: Material Characteristics

Material/Description	Moist Unit Weight (PCF)	Cohesion (PSF)	Friction Angle (DEG)
Embankment Fill	125	50	25
Existing Silty-Clay/Clay	120	50	30
Fly Ash	112	0	25
Final Cover System	125	50	25

Notes (Basis):

1. Embankment Fill and Existing Silty-Clay/Clay characteristics are based on the Global Stability Evaluation Report.
2. Fly ash characteristics are based on industry standard values for dry fly ash.
3. Final cover system is based on average values.

4 Stability Analysis Results and Conclusions

4.1 Ash Fill Scenarios

The table below summarizes results from the stability analyses for the slopes:

Run	Case	Slope	Condition	Slip Surface	Factor of Safety
Final Cover Ash Fill Slope – Cross Section A-A					
A	Ash Fill Slope – Final Cover **(Figure 2)**	4H:1V	Long Term	Circular	1.971
B	Ash Fill Slope – Final Cover **(Figure 3)**	4H:1V	Long Term	Circular - Seismic	1.318
C	Ash Fill Slope – Final Cover **(Figure 4)**	4H:1V	Long Term	Sliding Block	1.893
D	Ash Fill Slope – Final Cover **(Figure 5)**	4H:1V	Long Term	Sliding Block - Seismic	1.272
Final Cover Ash Fill Slope – Cross Section B-B					
E	Ash Fill Slope – Final Cover **(Figure 6)**	4H:1V	Long Term	Circular	1.683
F	Ash Fill Slope – Final Cover **(Figure 7)**	4H:1V	Long Term	Circular - Seismic	1.596
G	Ash Fill Slope – Final Cover **(Figure 8)**	4H:1V	Long Term	Sliding Block	1.744
H	Ash Fill Slope – Final Cover **(Figure 9)**	4H:1V	Long Term	Sliding Block - Seismic	1.046
Final Cover Veneer Stability					
-	Final Cover Veneer – Static	4H:1V	Long Term	Veneer	2.11
-	Final Cover Veneer – Seismic	4H:1V	Long Term	Veneer	1.12

4.2 Conclusions

Illinois Department of Natural Resources recommends a minimum factor of safety of 1.5 for long-term stability. During an extreme event, such as an earthquake, a factor of safety of 1.0 or more is recommended. Based on the results of our analyses, the embankment slopes have satisfactory factors of safety for global stability and veneer stability.

This model was generated using typical material properties. Results are based on design assumptions as stated and HDR is not responsible for deviations from the operational/design assumptions.

The outputs from the computer results of stability analyses are attached to this report with the **Figures** section.

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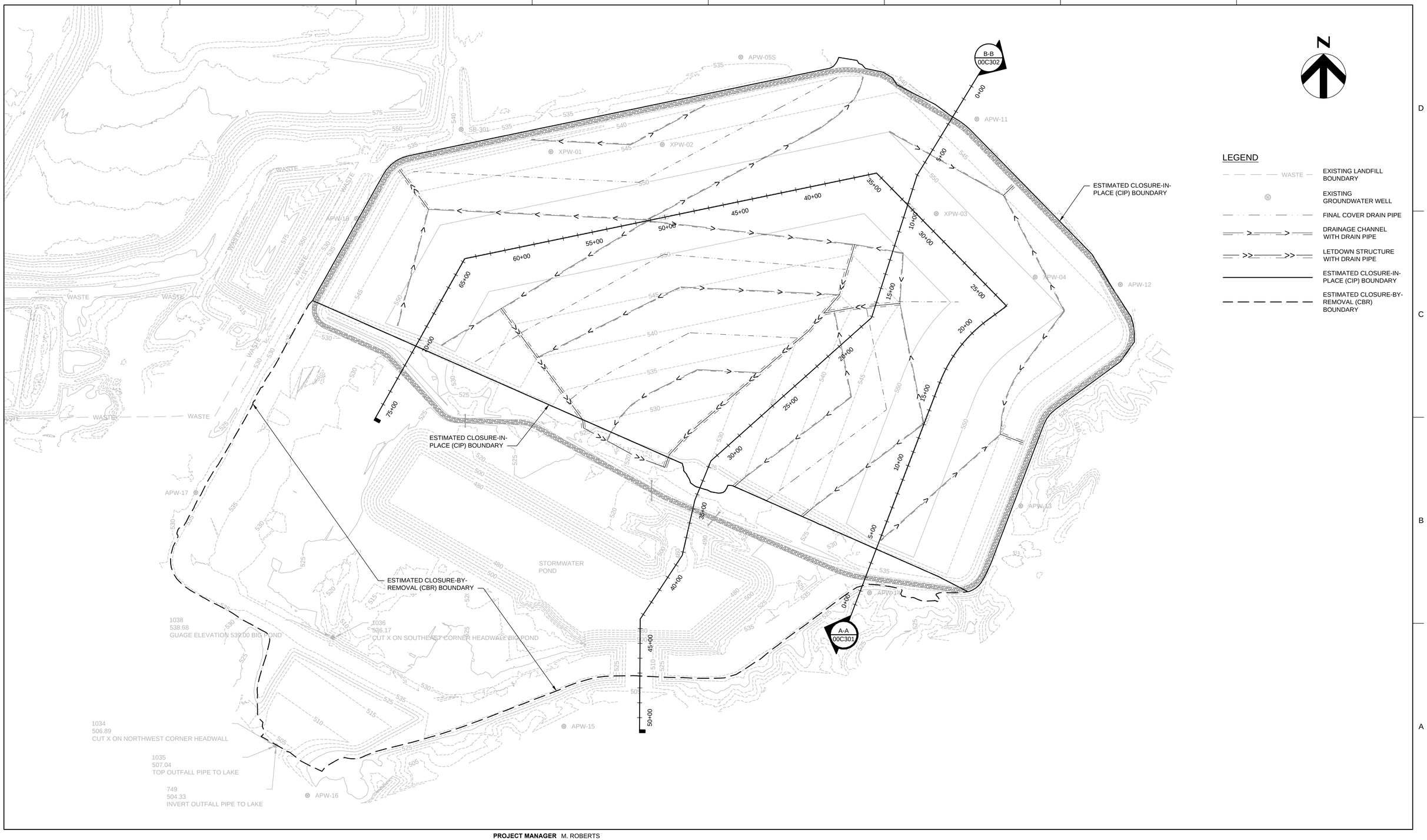
Figures

Plans, Cross Sections, and Slope Stability Output



ISSUE	DATE	DESCRIPTION

PROJECT MANAGER	M. ROBERTS
CIVIL	G. WILLIAMS
CIVIL	K. KINLEY
DRAWN BY	M. BICKFORD
PROJECT NUMBER	10296144

ILLINOIS POWER GENERATING COMPANY
NEWTON POWER PLANT
PRIMARY ASH POND CLOSURE

FINAL CLOSURE CONDITIONS

0 1" 2"

FILENAME	00C106.DWG
SCALE	1" = 300'

SHEET **00C106**

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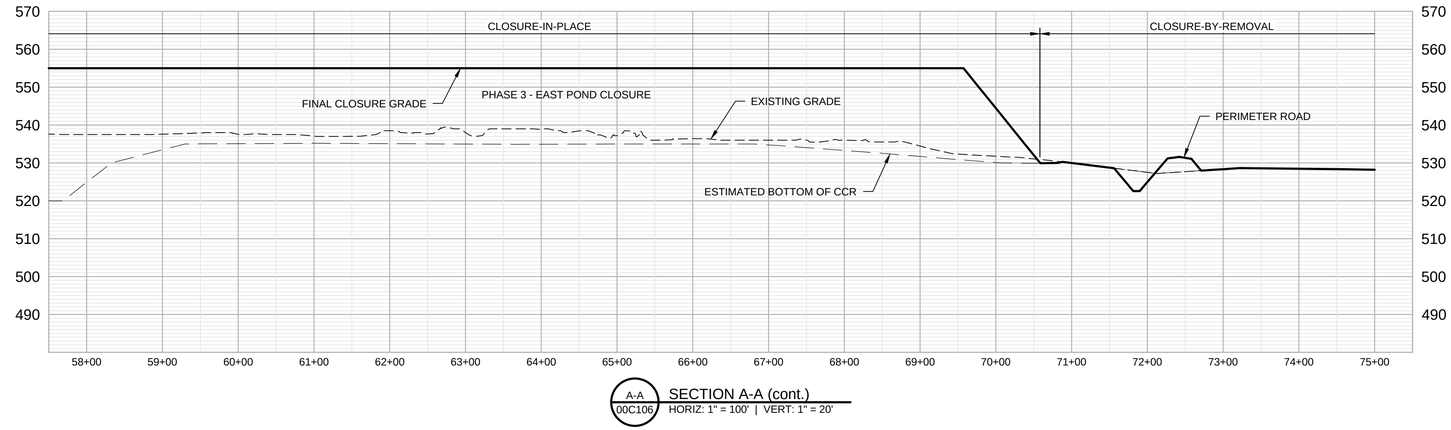
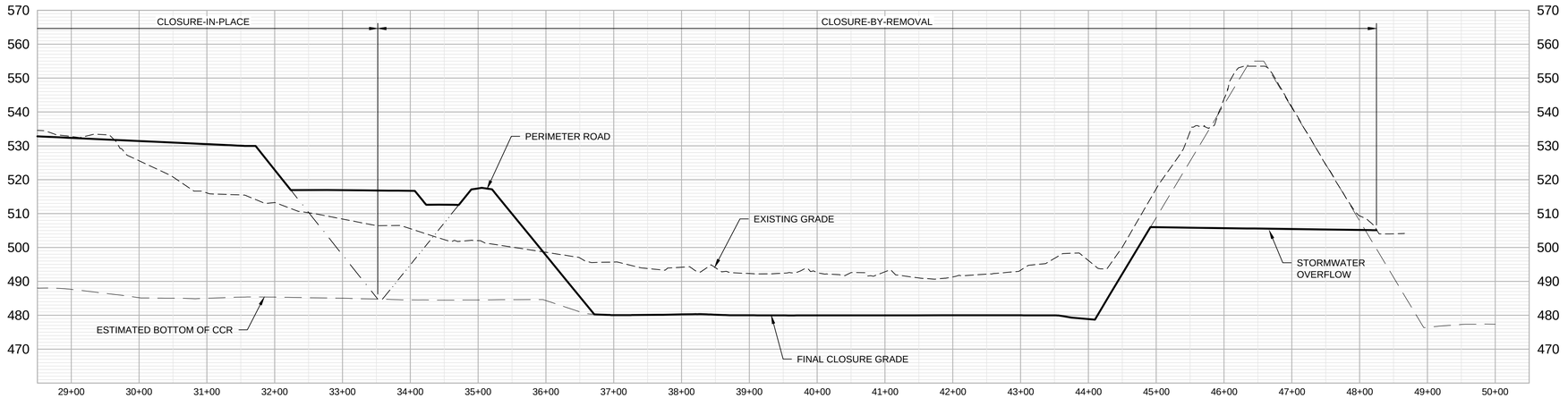


A-A
00C106
SECTION A-A (cont.)
HORIZ: 1" = 100' | VERT: 1" = 20'



B-B
00C106
SECTION B-B (cont.)
HORIZ: 1" = 100' | VERT: 1" = 20'

Figure 1
Closure Cross Sections

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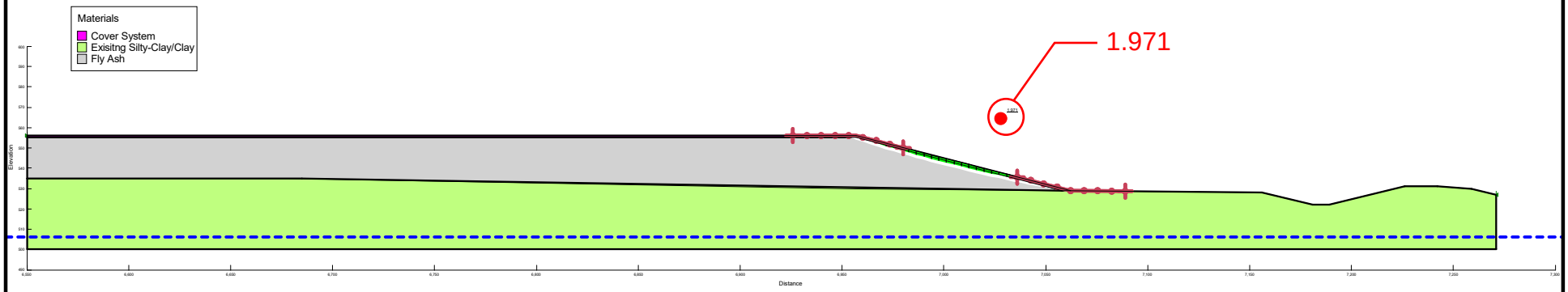

FIGURE 2

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis	
AA Slope Circular.gsz	
07/20/2022	1:917

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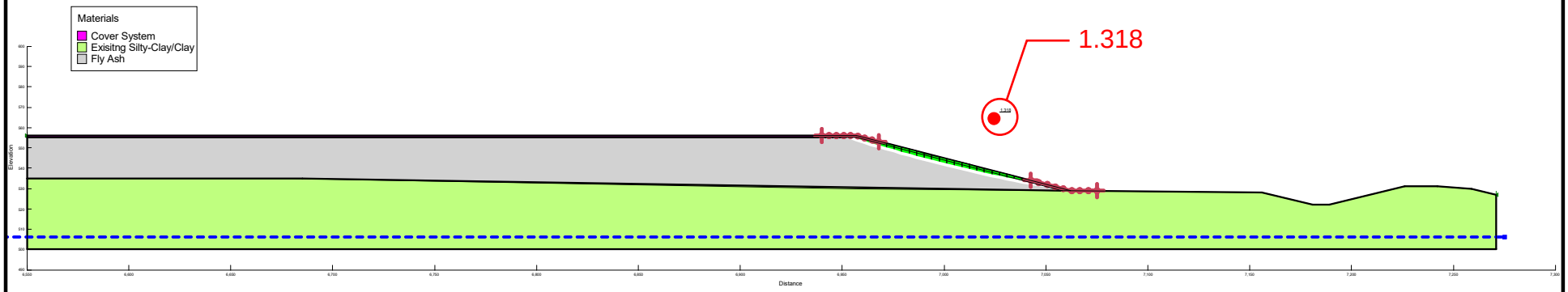

FIGURE 3

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis	
AA Slope Circular - Seismic.gsz	
07/20/2022	1:917

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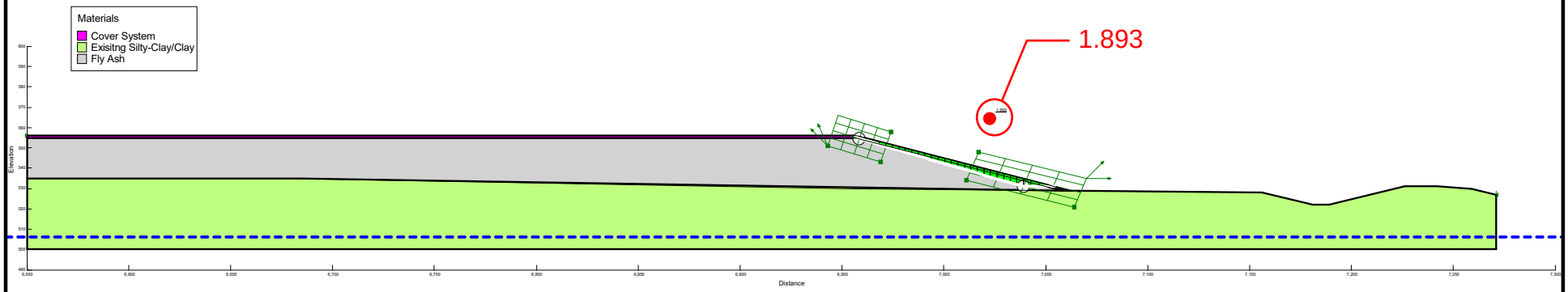

FIGURE 4

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis
AA Slope - Sliding Block.gsz
07/20/2022 1:917

Electronic Filing: Received, Clerk's Office 07/01/2024

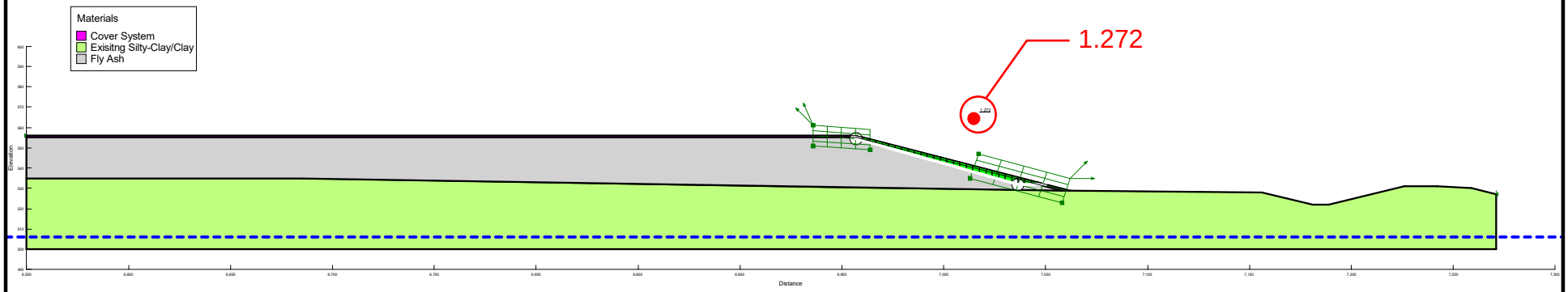

FIGURE 5

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis
AA Slope - Sliding Block - Seismic.gsz
07/19/2022 1:917

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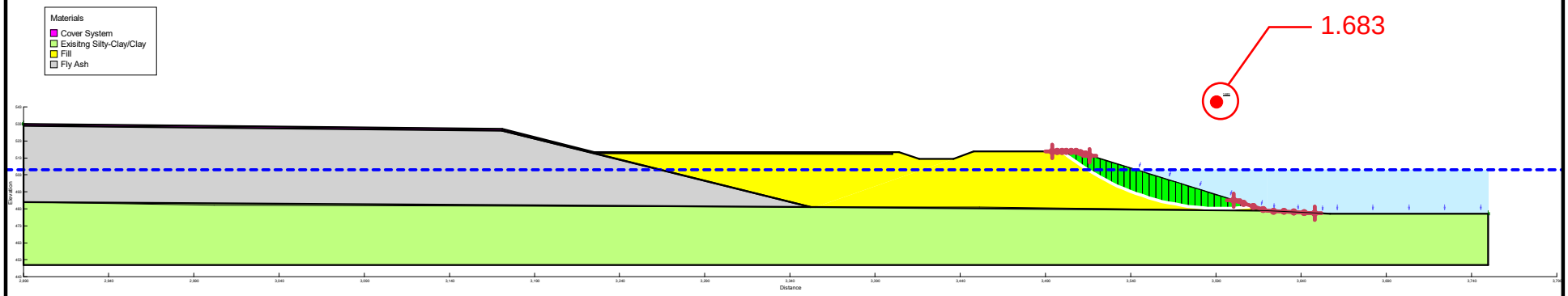

FIGURE 6

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

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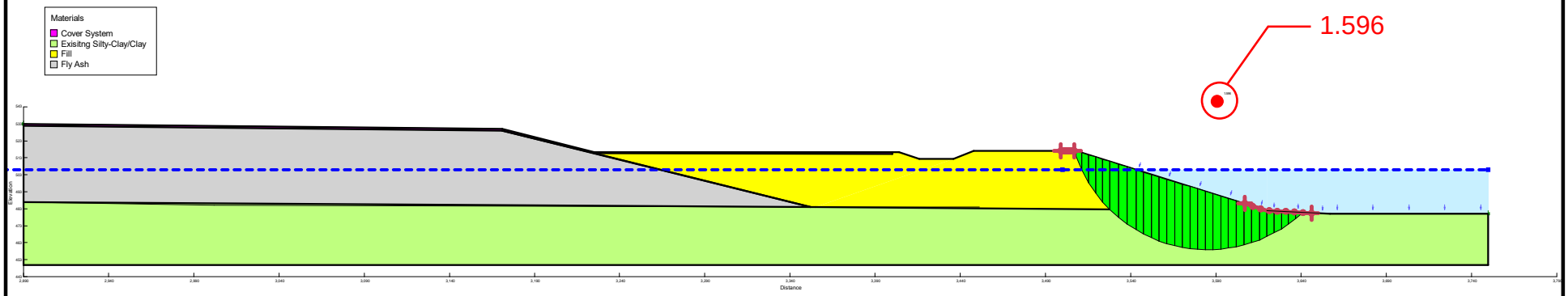

FIGURE 7

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis
BB Slope Circular - Seismic.gsz
07/20/2022 1:1,097

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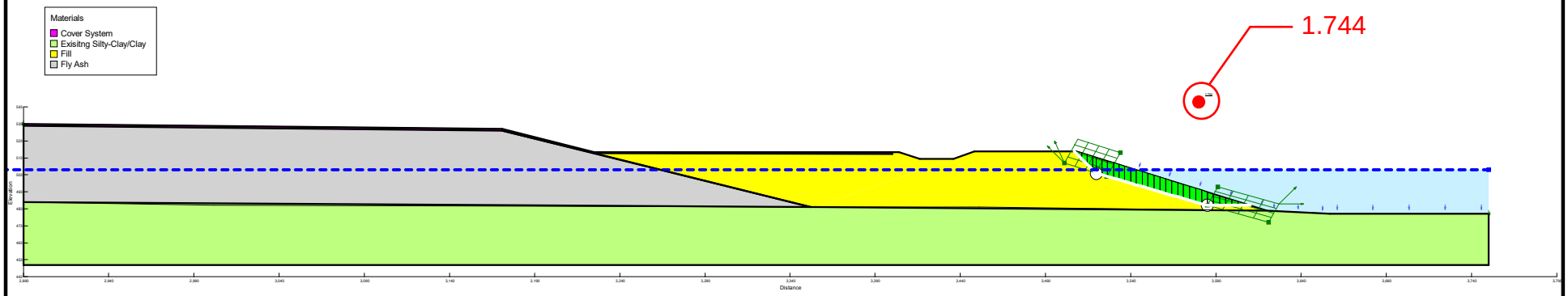

FIGURE 8

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis	
BB Slope-Sliding Block.gsz	
07/20/2022	1:1,097

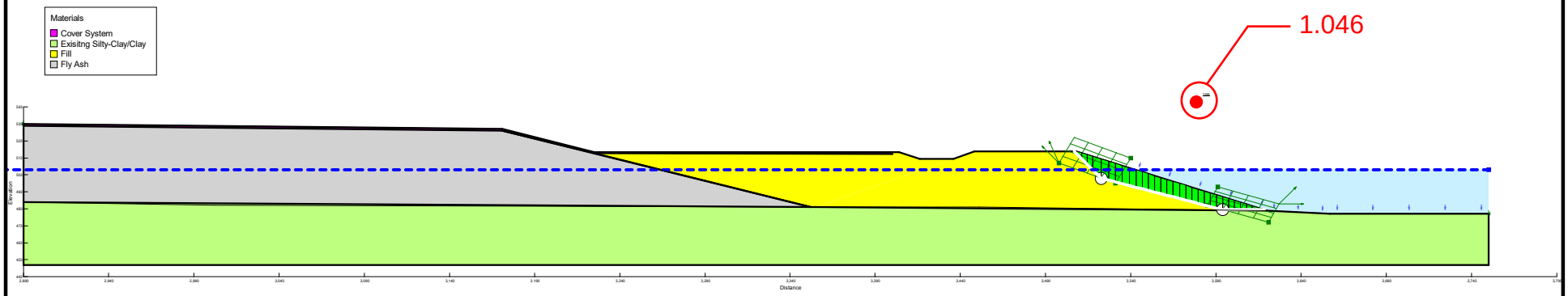

FIGURE 9

Note:
1. Water elevation estimated from Groundwater Modeling Report, Figure 2-2 Uppermost Aquifer Groundwater Elevation Contours, prepared by Ramboll, dated July 2022.

SLOPE/W Analysis	
BB Slope-Sliding Block - Seismic.gsz	
07/20/2022	1:1,097

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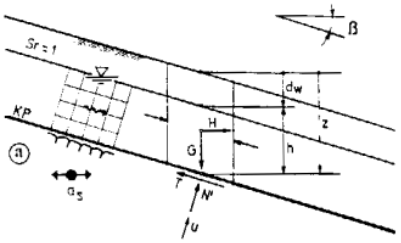
Attachment A

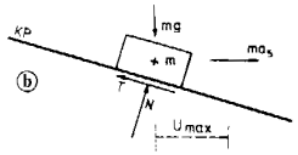
Final Cover Veneer Stability

Project: IPGC Newton Power Station – Primary Ash Pond Closure
Project Number: 10296144
Date: April-22
Calculation: G. Shafer

Objective: Evaluate the stability of the cover veneer against sliding
Reference: Matasovic, N. (1991), "Selection of Method for Seismic Slope Stability Analysis", Proc. 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamaics, St. Louis, Vol. 2, pp 1057-1062
Requirements: FSmin (Static) = 1.5; Fsmin (Dynamic) = 1.0 (If Applicable)
Analysis: Infinite Slope (Matasovic, 1991); See eqjua

0.115	**Ks**	Seismic coefficient - See next page 0.5*max horizontal accel
125	**gc**	Unit wight of protective cover materials (pcf)
62.4	**gw**	Unit weight of water (pcf)
	c	Cohesion/adhesion along assumed failure surface (psf)
	F	Interface friction angle along assumed failure surface (degrees)
2	**Zc**	Depth of protective cover (depth to failure surface) (ft)
1.95	**dw**	Depth to seepage surface (assumed parallel to slope (ft)
14	**b**	Slope angle of protective cover (degrees); 4H:1V





- Ground Water Level
- Seismic Exitation
- Steady Seepage
U_{max} - Permanent Displacement of sliding mass
KP - Sliding Surface

Fig. 2 Model of an infinite slope

Calculate Static FS Against Sliding

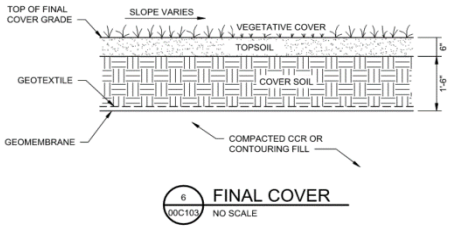
Soil Conditions at Interface	Interface Friction Angle (F)*	Cohesion/Adhesion (psf)	Resisting Force	Driving Force	F.S.	Normal Load	Interface Shear Strength
	28.0	0.0	0.408	0.364	1.12	125	66
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
			0.000	0.364	0.00	125	0
Iteration							
	26.0	0.0	0.37	0.36	1.03	125	61
	27.0	0.0	0.39	0.36	1.07	125	64
	28.0	0.0	0.41	0.36	1.12	125	66
	29.0	0.0	0.43	0.36	1.17	125	69
	30.0	0.0	0.44	0.36	1.22	125	72

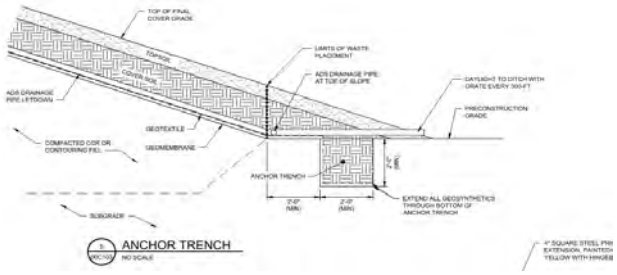
Based on the above assumptions, the principles of limit equilibrium and the notation introduced in Figure 2, the following expression for the factor of safety, F_s, has been derived (Matasovic, 1989):

$$F_s = \frac{c/(\gamma z \cos^2 ß) + \tan \Phi[1 - \gamma_w(z-d_w)/(\gamma z)] - k_s \tan ß \tan \Phi}{k_s + \tan ß} \quad (1)$$

where γ, γ_w, c and Φ are the unit weight of slope material, the unit weight of water, cohesion and the angle of internal friction respectively.

Sketches:
*Note: the geomembrane includes a microspike which acts as a drainage composite with the addition of the geotextile shown below.





***Conclusion:**
The proposed configuration is stable using 28 degrees as an assumed value for interface friction. Prior to construction, the interface friction value should be confirmed with on-site site specific and geosynthetics.

Link: Unified Hazard Tool (usgs.gov)
Result: 0.2274 Use half for coefficient in analysis.

Ref: Rationalizing the Seismic Coefficient Method, Hynes-Griffin, Franklin USACE
Link: MP GL-84-13, Rationalizing the Seismic Coefficient Method (dren.mil)



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Project: IPGC Newton Power Station – Primary Ash Pond Closure
Project Number: 10296144
Date: April-22
Calculation: G. Shafer

Objective: Evaluate the stability of the cover veneer against sliding

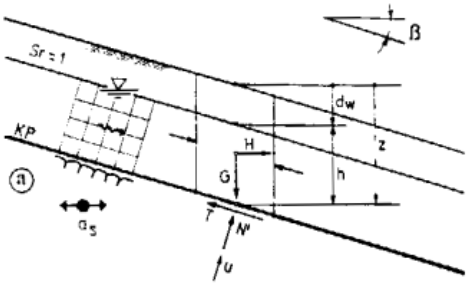
Reference: Matasovic, N. (1991), "Selection of Method for Seismic Slope Stability Analysis", Proc. 2nd International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamaics, St. Louis, Vol. 2, pp 1057-1062

Requirements: FSmin (Static) = 1.5; Fsmin (Dynamic) = 1.0 (If Applicable)

Analysis: Infinite Slope (Matasovic, 1991); See eqjua

Seismic coefficient (= peak horizontal acceleration) (= 0 for static stability)

0	**Ks**	Static
125	**gc**	Unit wight of protective cover materials (pcf)
62.4	**gw**	Unit weight of water (pcf)
	c	Cohesion/adhesion along assumed failure surface (psf)
	F	Interface friction angle along assumed failure surface (degrees)
2	**Zc**	Depth of protective cover (depth to failure surface) (ft)
1.95	**dw**	Depth to seepage surface (assumed parallel to slope (ft)
14	**b**	Slope angle of protective cover (degrees); 4H:1V



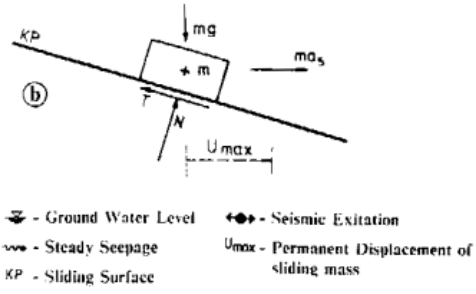


Fig. 2 Model of an infinite slope

Based on the above assumptions, the principles of limit equilibrium and the notation introduced in Figure 2, the following expression for the factor of safety, F_s, has been derived (Matasovic, 1989):

$$F_s = \frac{c/(\gamma z \cos^2 ß) + \tan \Phi [1 - \gamma_w (z - d_w)/(\gamma z)] - k_s \tan ß \tan \Phi}{k_s + \tan ß} \quad (1)$$

where γ, γ_w, c and Φ are the unit weight of slope material, the unit weight of water, cohesion and the angle of internal friction respectively.

Calculate Static FS Against Sliding

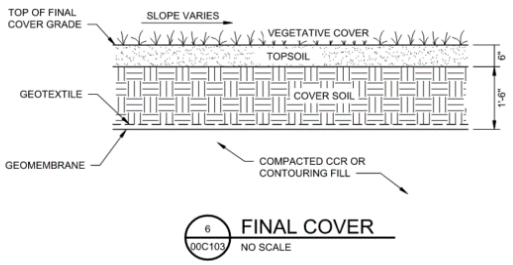
Soil Conditions at Interface	Interface Friction Angle (F)*	Cohesion/Adhesion (psf)	Resisting Force	Driving Force	F.S.	Normal Load	Interface Shear Strength
	28.0	0.0	0.525	0.249	2.11	125	66
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0
			0.000	0.249	0.00	125	0

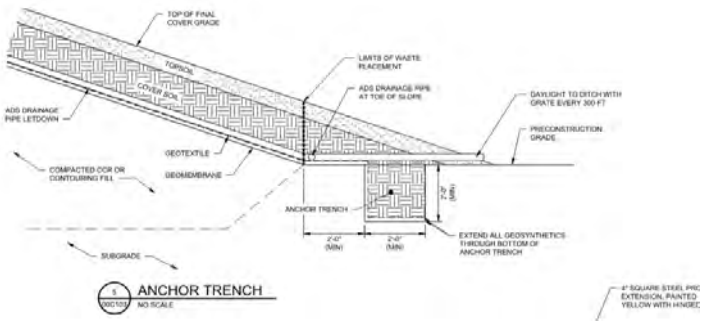
Iteration

26.0	0.0	0.48	0.25	1.93	125	61
27.0	0.0	0.50	0.25	2.02	125	64
28.0	0.0	0.53	0.25	2.11	125	66
29.0	0.0	0.55	0.25	2.20	125	69
30.0	0.0	0.57	0.25	2.29	125	72
31.0	0.0	0.59	0.25	2.38	125	75

Sketches:

*Note: the geomembrane includes a microspike which acts as a drainage composite with the addition of the geotextile shown below.





***Conclusion:**

The proposed configuration is stable using 28 degrees as an assumed value for interface friction. Prior to construction, the interface friction value should be confirmed with on-site site specific and geosynthetics.

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Attachment B

Reference Information

-Soil Characteristics Data

-Seismic Support Data

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U.S. Geological Survey - Earthquake Hazards Program

Unified Hazard Tool

Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the U.S. Seismic Design Maps web tools (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

Input

Edition
Conterminous U.S. 2014 (v4.0.x)

Spectral Period
Peak Ground Acceleration

Latitude
Decimal degrees
38.933

Time Horizon
Return period in years
2475

Longitude
Decimal degrees, negative values for western longitudes
-88.279

Site Class
760 m/s (B/C boundary)

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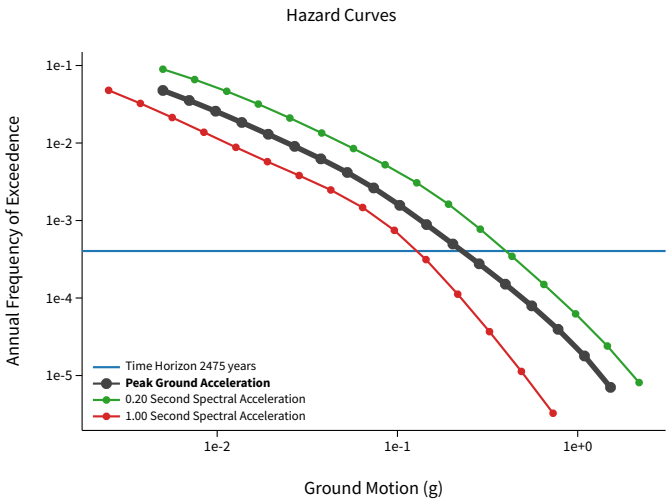
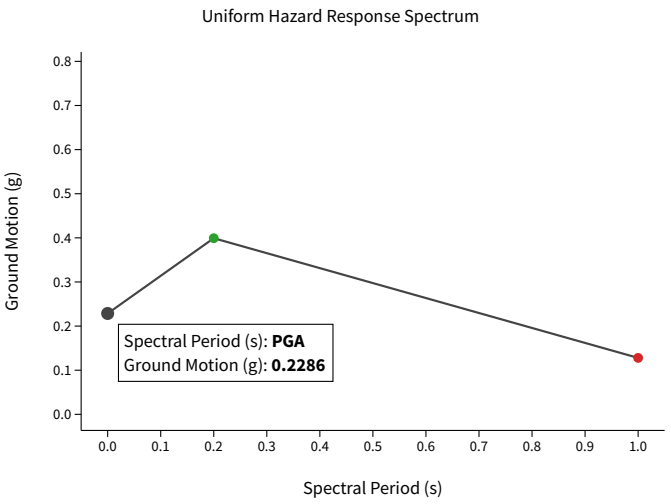
Hazard Curve





View Raw Data

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GLOBAL STABILITY EVALUATION
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, ILLINOIS

Prepared for:

AMEREN ENERGY RESOURCES
St. Louis, Missouri

Prepared by:

GEOTECHNOLOGY, INC.
St. Louis, Missouri

Geotechnology Project No. J017150.01

January 4, 2011

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GEOTECHNOLOGY INC
FROM THE GROUND UP

January 4, 2011 J017150.01

Mr. Gerald R. Ryckman, C.P.M.
Ameren Energy Resources
One Ameren Plaza
1901 Chouteau Avenue
St. Louis, Missouri 63166-6146

GLOBAL STABILITY EVALUATION
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, ILLINOIS

Dear Mr. Ryckman:

Presented in this report are the results of an embankment stability evaluation conducted for the referenced project. This exploration was conducted in general accordance with our May 21, 2010 revised proposal. This report includes our project understanding, observed site conditions, conclusions and/or recommendations, and support data as given in the Table of Contents.

It has been our pleasure to provide these services to you, and we would welcome the opportunity to provide other services during the course of the project. Please contact us if you need further information or clarification about this document.

Very truly yours,

GEOTECHNOLOGY, INC.

STATE OF ILLINOIS
SENTHIL B. KUMAR
062-054233
REGISTERED PROFESSIONAL ENGINEER

Senthil Kumar, P.E.
Senior Engineer
Geotechnical Group

Dale M. Smith, P.E.
Collinsville Branch Manager

SK/DMS/JAB:sk/jsj

Copies submitted: (3) hard copies
(1) pdf format on CD

Dale M. Smith
Exp. 11/30/11

J017150.01

GLOBAL STABILITY EVALUATION
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, ILLINOIS

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J017150.01

GLOBAL STABILITY EVALUATION
NEWTON POWER STATION
PRIMARY ASH POND
NEWTON, ILLINOIS

SECTION I - PROJECT DATA

AUTHORIZATION

The services documented in this report were provided in accordance with the terms, conditions and scope of services described in Geotechnology's May 21, 2010 revised proposal numbered P017237.01A. The project was authorized by issuance of Ameren Purchase Order No. 496284, dated June 14, 2010.

PURPOSE AND SCOPE OF SERVICES

The purpose of our services was to perform a stability analysis of the ash pond embankment. Briefly, services consisted of site reconnaissance, drilling five borings, installing two piezometers, laboratory testing, engineering analyses and preparation of this report. Important information prepared by The Association of Engineering Firms Practicing in the Geosciences (ASFE) for studies of the type is included in Appendix A for your review.

PROJECT AND SITE DESCRIPTION

We understand that the coal-ash waste materials from the power generating process at the Ameren Newton Power Plant are stored in the primary ash pond located south of the plant. The site location and general topography of the area as per U.S.G.S. map of the vicinity are shown on Plate 1. We understand that the ash pond was constructed circa 1974. Based on data provided by Ameren, the ash pond is contained by an approximately 17,000-foot long embankment. The ash pond is bordered to the south by Newton Lake. We understand that the normal pool level of Newton Lake is El 505[1]. At the time of our investigation, water was ponding along the inbound slope of the embankment at El 534. The slope of the embankment in the vicinity of our exploration was approximately 1V:3H (Vertical:Horizontal) and 40 feet wide at the top, which was at approximately El 555. The slope is generally covered with grass and weeds. An approximately 20-foot wide gravel access road is present on top of the embankment.

[1] All elevations herein refer to the mean sea level (msl) datum in feet.

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SECTION II - FIELD EXPLORATION AND LABORATORY TESTING

FIELD EXPLORATION

The field exploration consisted of drilling five borings, designated as Borings B-1 through -5, at approximately the locations shown on Plate 2. The borings were located in the field by Geotechnology by measuring distances from existing site features at a representative section for height and steepness. Subsequently, the boring locations and the selected section of the embankment were surveyed by Milano & Grunloh Engineers LLC, and the location coordinates and elevations were provided to Geotechnology. Also, the surveyors obtained spot elevations along the crest of the embankment. These section details and spot elevations are included in Appendix E.

The borings were drilled to auger refusal or predetermined depths of 25 to 55 feet using a CME 750 rotary drill rig equipped with hollow stem augers. Standard Penetration Tests (SPT's) were performed using an automatic hammer. Split-spoon samples and relatively undisturbed Shelby tube samples were obtained at the depths indicated on the boring logs presented in Appendix B. An explanation of the terms and symbols used on the borings is provided in Appendix B.

At the completion of drilling, all borings except the borings where piezometers were installed were backfilled with a cement-bentonite grout or bentonite chips. Grout was pumped through a grout pipe inserted to the bottom of the boring, with grout backfilling bore holes from the bottom up. Grout was pumped until visible at the surface prior to withdrawing the grout pipe. A continuous positive head of grout was maintained during removal of the grout pipe.

A staff scientist from Geotechnology provided technical direction during field exploration, observed drilling and sampling, assisted in obtaining samples and prepared descriptive logs of the material encountered. The boring logs represent conditions observed at the time of exploration, and have been edited to incorporate results of the laboratory tests as appropriate.

Unless noted on the logs, the lines designating the changes between various strata represent approximate boundaries. The transition between materials may be gradual or may occur between recovered samples. The stratification given on the logs, or described herein, is for use by Geotechnology in its analyses and should not be used as the basis of design or construction cost estimates without realizing that there can be variation from that shown or described.

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The logs and related information depict subsurface conditions only at the specific locations and times where sampling was conducted. The passage of time may result in changes in conditions, interpreted to exist, at or between the locations where sampling was conducted.

LABORATORY TESTING

Laboratory testing was performed to estimate pertinent engineering and index properties of the soil. Moisture contents were determined for cohesive soil samples, and Atterberg limits tests were accomplished on selected samples. Consolidated-undrained triaxial, unconfined compression and percent passing #200 sieve tests were performed on representative samples. Laboratory test results are presented in Appendices B and C.

SECTION III - SUBSURFACE CONDITIONS

STRATIGRAPHY

Fill is present in all borings drilled along the embankment (Borings B-1, -2 and -5). Fill consists of silty clay and clay with a trace of sand and gravel and extends to depths of 22 to 37 feet. Representative samples of the fill had unit dry densities in the range of 104 to 121 pounds per cubic foot (pcf). Moisture content percentages ranged from the mid teens to the lower twenties. SPT N-values in the embankment fill varied from 8 to 16 blows per foot (bpf).

Below the fill, and at the surface in Borings B- 3 and -4, an alluvial deposit of interbedded soft to very stiff, silty clay and clay is present. The thickness of the cohesive stratum varies between 8 and 25 feet. A representative sample had a unit dry density of 105 pcf. Moisture contents ranged from the upper single digits to upper teens. Below the silty clay/clay stratum hard, sandy clay, clay or silty clay is present. This stratum extends to the depths of exploration or auger refusal.

Auger refusal was encountered in Borings B-1 and -5 at depths of 57.5 and 47.5 feet, respectively. Auger refusal may represent either a hard soil layer or bedrock. Since rock coring was not performed, the character of these materials could not be determined.

GROUNDWATER

Groundwater was observed in the crest and toe borings while drilling at depths of 33 to 34, and 2 to 5 feet, respectively. Groundwater levels shown on the boring logs may not have stabilized before backfilling, which is typical in less permeable cohesive soil. Consequently, the indicated groundwater levels may not represent present or future levels.

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Open-standpipe piezometers were installed in Borings B-2 and -3 to permit subsequent measurement of the groundwater levels. The piezometers consist of 2-inch diameter PVC pipe, with a 10-foot length of screen placed within the boring. The annular space within the screened interval was backfilled with sand, sealed above the screen with bentonite pellets, and the remainder backfilled with cement-bentonite grout or bentonite pellets. A protective steel well casing was placed over the riser pipe. Details of the piezometer installation at each of the borings are presented on the Piezometer construction diagrams in Appendix D. Groundwater was observed in Piezometers B-2 and -3 at depths of 26 feet and 1 foot, approximately 90 days after completion of drilling. Groundwater levels may vary significantly over time due to the effects of seasonal variation in precipitation, recharge, the level of Newton Lake or other factors not evident at the time of exploration.

SECTION IV –GLOBAL STABILITY EVALUATION

As part of the embankment evaluation, slope stability analyses were performed. A current topographic plan of the site was not available. However, the project surveyor provided the latitude, longitude and the surface elevation of the boring locations and points along the representative section. This information was used to develop the slope profile for the analyses. Results of the analyses are discussed in subsequent sections.

SLOPE STABILITY ANALYSIS

Slope stability analysis consists of comparing the driving forces within a cross-section of slope to the resisting forces and determining the factor of safety. Gravity forces tend to move the slope downwards (driving force), while resisting forces derived from the soil shear strength tend to keep the slope in place. When the driving force acting on the slope is greater than the resisting force, sliding can occur. The factor of safety of the slope is the ratio of the restraining force divided by the driving force. Generally, when the factor of safety is 1 or less, the slope is considered to be unstable. The accepted standard in local practice and consistent with Illinois Department of Natural Resources (IDNR) dam safety requirement is to have a factor of safety of 1.5 for long term static stability of a slope, and 1.0 for pseudo-static conditions (seismic loading).

Slope stability analyses were performed for a representative section of the embankment along the south perimeter of the primary ash pond. The location of the cross-section of the embankment analyzed is represented by Section A-A, and is shown on Plate 2. Soil properties used in the stability analysis were selected based on laboratory test results and Geotechnology's experience with similar materials. In our analyses the pond was assumed to be filled with fly ash. The soil properties used in the models are summarized in the following table:

SOIL PROPERTIES			
Soil Type	**Density (pcf)**	**Cohesion (psf)**	**Friction Angle (°)**
Embankment Fill	125	50	25
Silty Clay/Clay	120	50	30
Hard, Silty/Sandy Clay	120	50	30
Fly Ash	112	0	0

Geotechnology performed stability analysis for deep seated, global failure of the embankment. The cross-section of the embankment analyzed is shown on the attached Plate 3. Since the embankment has been in place for more than 35 years, long-term stability of the embankment was analyzed (i.e. effective stress conditions). Based on the piezometer data and the level of ponding groundwater to the north, a groundwater table for the analysis of the ash pond embankment was established as shown on Plate 3. A pseudo-static seismic analysis was performed on the selected embankment section using a horizontal acceleration of 0.18g, which corresponds to a seismic event with a mean return time of 2,500 years (Plate 4). Details of the methodology used in determining the horizontal acceleration is given in a subsequent section. The Morgenstern-Price procedure was used to compute factors of safety. The computer program SLOPE/W was used to perform the computations. The calculated factors of safety are given in the following table.

SLOPE STABILITY ANALYSIS RESULTS			
Analysis Condition	**Calculated Factor of Safety**	**Target Factor of Safety[a]**	**Reference Plate No.**
Existing Conditions, Steady State Seepage	1.8	1.5	3
Partially Saturated Slope, Steady State Seepage	1.5	1.5	4
Slope with Seismic Forces Mean Return Time 2,500 Years	1.1	1.0	5
Partially Saturated Slope Slope with Seismic Forces Mean Return Time 2,500 Years	0.9	1.0	6

[a] **"Procedural Guidelines for Preparation of Technical Data to be included in Application for Permits for Construction and Maintenance of Dams" issued by Illinois Department of Natural Resources.**

IDNR recommends a minimum factor of safety of 1.5 for long-term stability. During an extreme event, such as an earthquake, a factor of safety of 1.0 or more is recommended. Based on the results of our analyses, the embankment slopes have satisfactory factors of safety for global stability. Exception is the seismic event occurring when the slope is partially saturated (Plate 6).

SEISMICITY

The site is located in a region of the country that has a significant seismic risk due to the presence of the New Madrid Seismic Zone (NMSZ) in southeastern Missouri and the Wabash Valley Seismic Zone (WVSZ) in southeastern Illinois and southwestern Indiana. The NMSZ is the site of three of the largest magnitude earthquake events (estimated surface-wave magnitudes greater than or equal to 8.0) to strike North America in recorded history (December 1811 through February 1812). Researchers predict that the WVSZ is capable of producing large earthquakes similar in magnitude to the 1811-1812 NMSZ earthquakes.

Per the previously referenced Illinois Department of Natural Resources procedural guidelines for application of dam construction permit, the seismic hazard analysis should use bedrock peak ground accelerations with a 2% probability of exceedence (PE) in 50 years (mean return time of 2,500 years). The National Seismic Hazards Mapping Project (NSHMP) interactive deaggregations models (2002 edition) were used to obtain the probabilistic bedrock accelerations at the site. The NSHMP models consider ground motion from many sources surrounding the site location with the assumption that the site condition is rock with an average shear wave velocity of 2,500 ft/s. Bedrock spectral response acceleration at short periods (S_s), and at 1-second periods (S_1) of 0.58 g and 0.17 g, respectively, were obtained from the NSHMP models.

A detailed site-specific seismic hazard analysis was beyond our scope of services. The guidelines established by the International Building Code, 2006 edition (IBC 2006) were used to propagate the bedrock acceleration to the ground surface. Based on the boring data and Section 1613.5.6 of the IBC 2006, we calculated that the underlying soil profile within the upper 100 feet could be defined as Site Class C (Very Dense Soil and Soft Rock). Using Site Class C and guidelines in Section 1802 of IBC 2006, we were able to calculate an approximate surficial horizontal peak ground acceleration of 0.18g, which was used in the pseudo-static slope stability analysis.

SECTION V - LIMITATIONS OF REPORT

This report has been prepared on behalf of and for the exclusive use of the client for specific application to the named project as described herein. If this report is provided to prospective contractors, the client should make it clear that the information is provided for factual data only and not as a warranty of subsurface conditions included in this report. Unanticipated soil or rock conditions may require the expenditure of additional funds to attain a properly constructed project. Therefore, some contingency fund is recommended to accommodate such potential extra costs.

Geotechnology has attempted to conduct the services reported herein in a manner consistent with that level of care and skill ordinarily exercised by members of the profession currently practicing in the same locality and under similar conditions. The recommendations and conclusions contained in this report are professional opinions. No other representation, expressed or implied, is included or intended.

Unless specifically stated in our proposal or this report, the scope of our services for this phase of the project did not include any environmental assessment or investigation for the presence or absence of wetlands or hazardous or toxic material in the soil, surface water, groundwater or air, on or below or around this site. Any statements in this report or on the boring logs regarding odors noted or unusual or suspicious items or conditions observed are strictly for the information of our client.

The analyses, conclusions, and recommendations contained in this report are based on the data obtained from the subsurface exploration. The field exploration methods used indicate subsurface conditions only at the specific locations where samples were obtained, only at the time they were obtained, and only to the depths penetrated. Discrete sampling cannot be relied on to accurately reflect natural variations in stratigraphy that may exist between sample locations and/or intervals. Unless specifically noted, the scope of our services did not include an assessment of the effects of flooding and natural erosion of adjacent creeks or rivers on the project site.

The conclusions or recommendations presented in this report should not be used if the nature, design, or location of the facilities is changed or if there is a substantial lapse in time between the submittal of this report and the start of work at the site. If changes are contemplated, Geotechnology must review them to assess their impact on findings, conclusions, and/or design recommendations given in this report. Geotechnology will not be responsible for any claims, damages, or liability associated with any other party's interpretations of the subsurface data or reuse of the subsurface data or engineering analyses in this report without our express written authorization.

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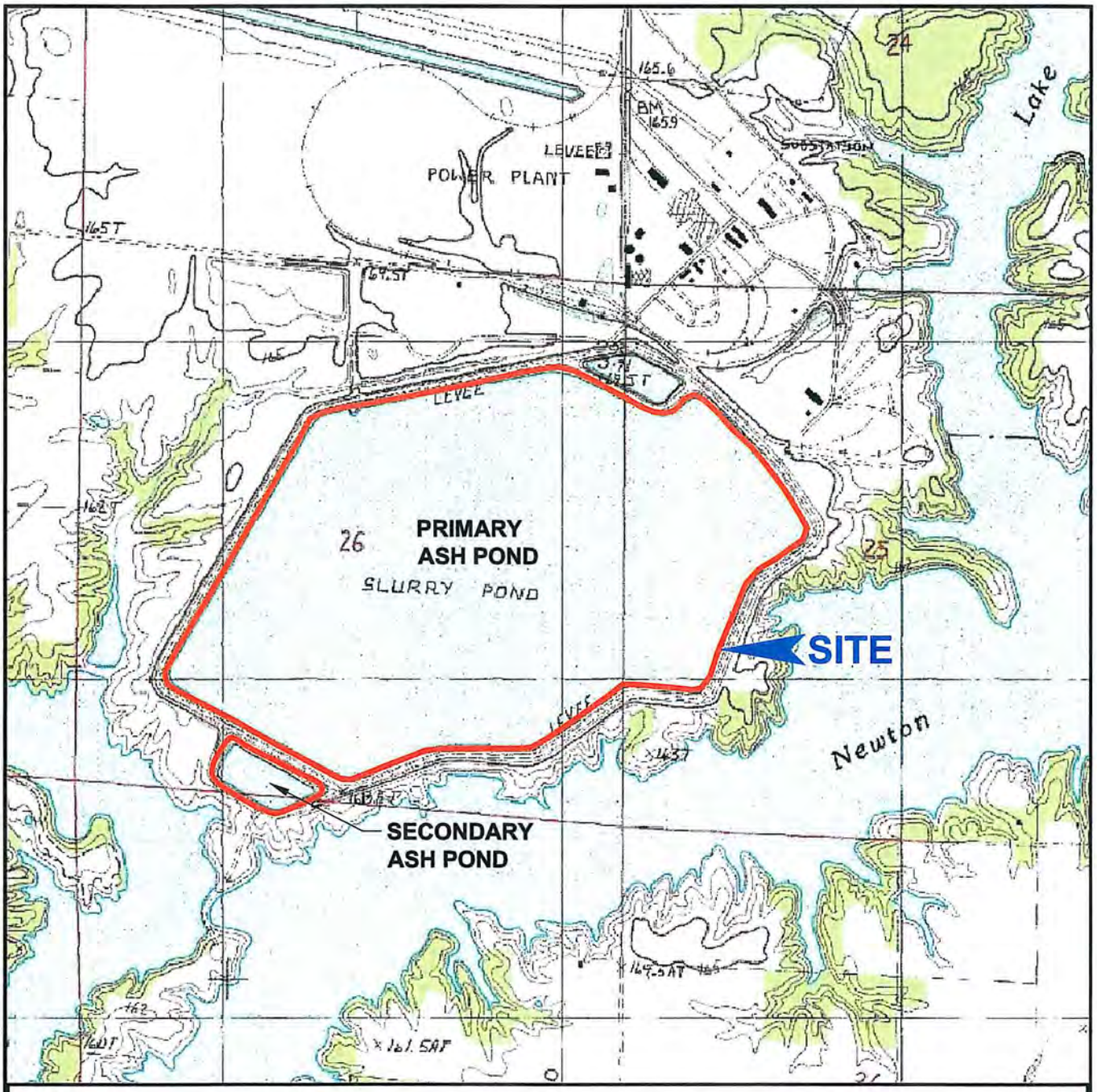


NOTES

Plan adapted from a 7.5 minute U.S.G.S. map for Jasper County, Illinois Quadrangle, last revised in 1985.

0 2,000 4,000

SCALE IN FEET

LEGEND

Approximate Location of Ash Pond

N

Drawn By: SLC	Ck'd By: SLC	App'vd By: SLC
Date: 11-10-10	Date: 12/21/10	Date: 1/4/11

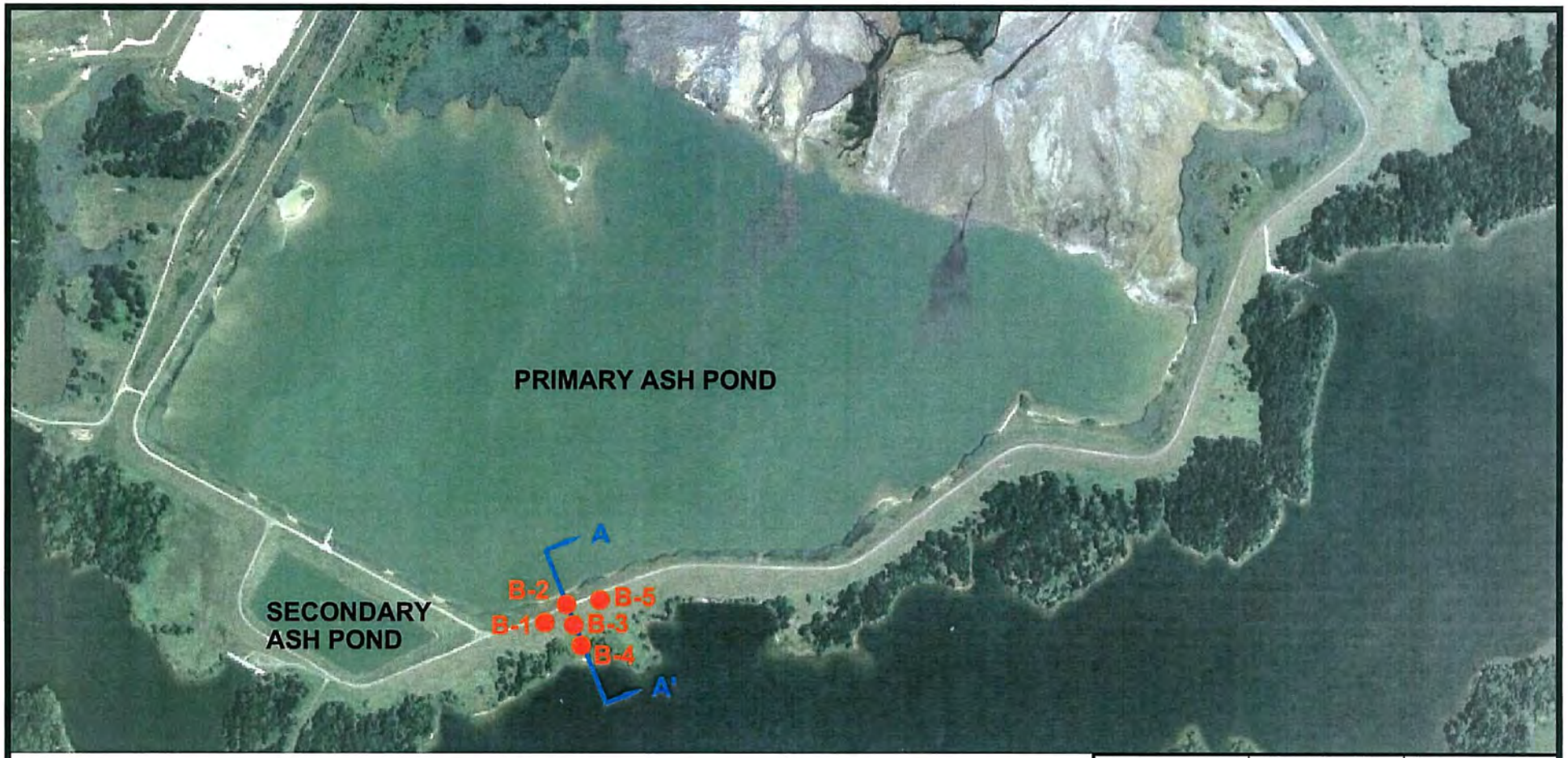
GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

SITE LOCATION AND TOPOGRAPHY

Project Number J017150.01

PLATE 1



NOTES

1. Plan adapted from an aerial photograph courtesy of Google Earth.

LEGEND

- Boring Location
- Slope Stability Cross Section

0 400 800 1,600

SCALE IN FEET

N

Drawn By: SLC	Ck'd By: Sic	App'vd By: Sic
Date: 11-10-10	Date: 11/21/10	Date: 1/4/11

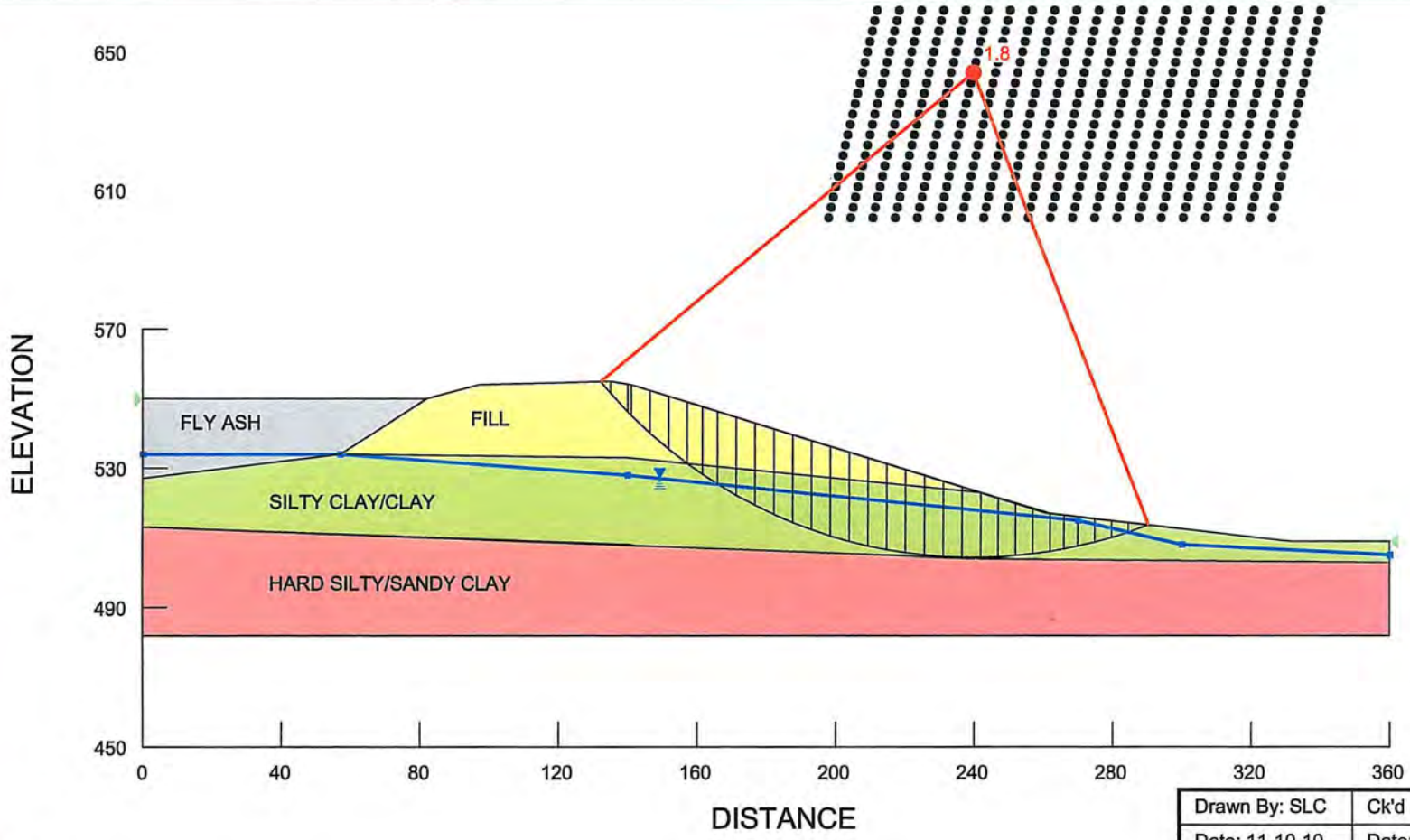
GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

AERIAL PHOTOGRAPH OF SITE AND BORING LOCATIONS

Project Number J017150.01

PLATE 2



NOTE

See plate 2 for location of cross section.

Material	Density (pcf)	Cohesion (psf)	Friction Angle (deg)
Fill	125	50	25
Silty Clay/Clay	120	50	30
Hard, Silty/Sandy Clay	120	50	30
Fly Ash	112	0	0

Drawn By: SLC	Ck'd By: SLC	App'vd By: DNV
Date: 11-10-10	Date: 12/21/10	Date: 1/4/11

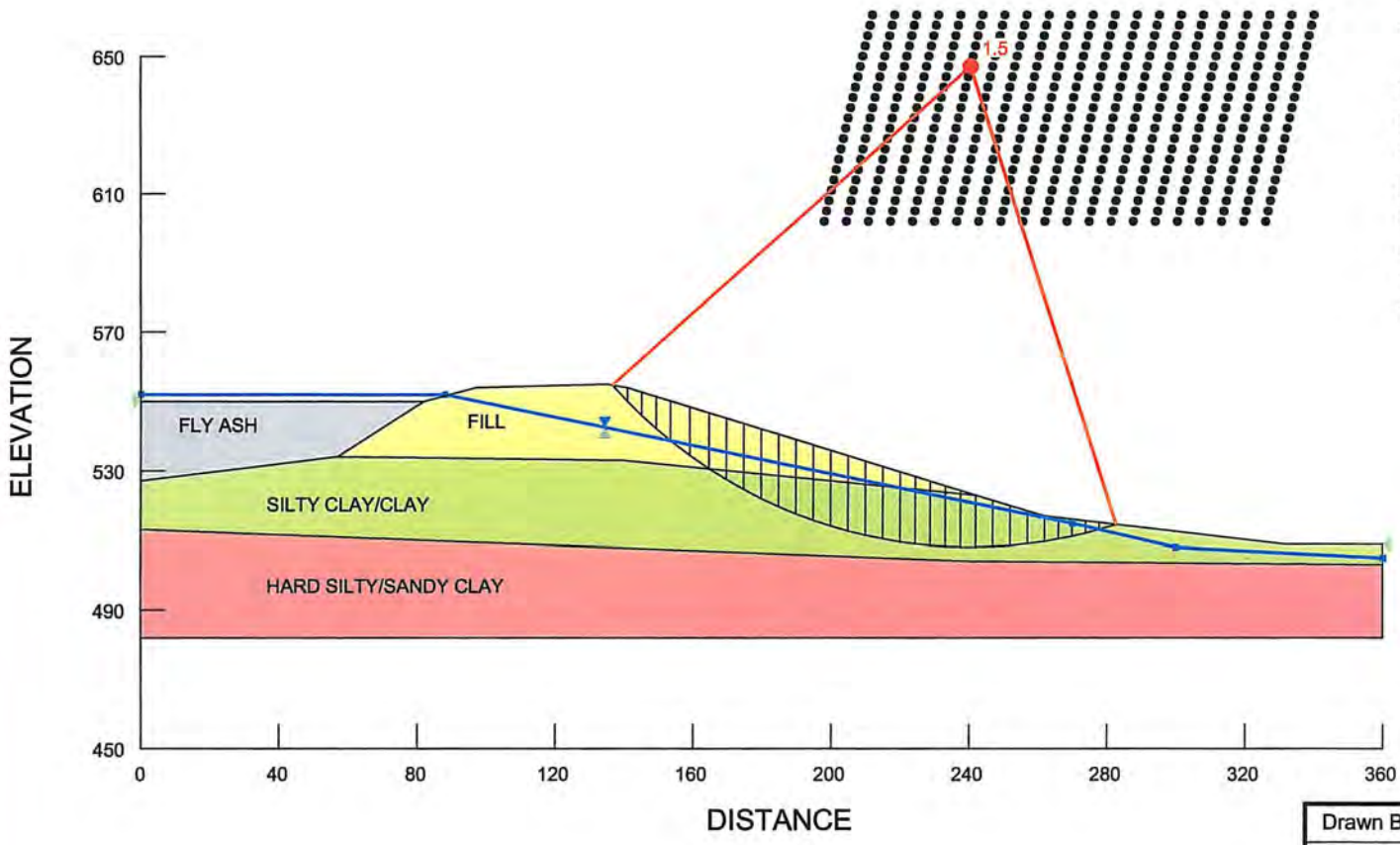
GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

SLOPE STABILITY CROSS SECTION A-A'
STEADY STATE SEEPAGE

Project Number
J017150.01

PLATE 3



NOTES

1. See plate 2 for location of cross section.

2. Analysis is a parametric study of piezometric surface for a corresponding FOS=1.5. The piezometric surface shown does not represent observed conditions but represents an upper limit below which the FOS is equal to or greater than the target FOS 1.5.

Material	Density (pcf)	Cohesion (psf)	Friction Angle (deg)
Fill	125	50	25
Silty Clay/Clay	120	50	30
Hard, Silty/Sandy Clay	120	50	30
Fly Ash	112	0	0

Drawn By: SLC	Ck'd By: [illegible]	App'vd By: [illegible]
Date: 11-10-10	Date: 12/21/10	Date: 1/4/11

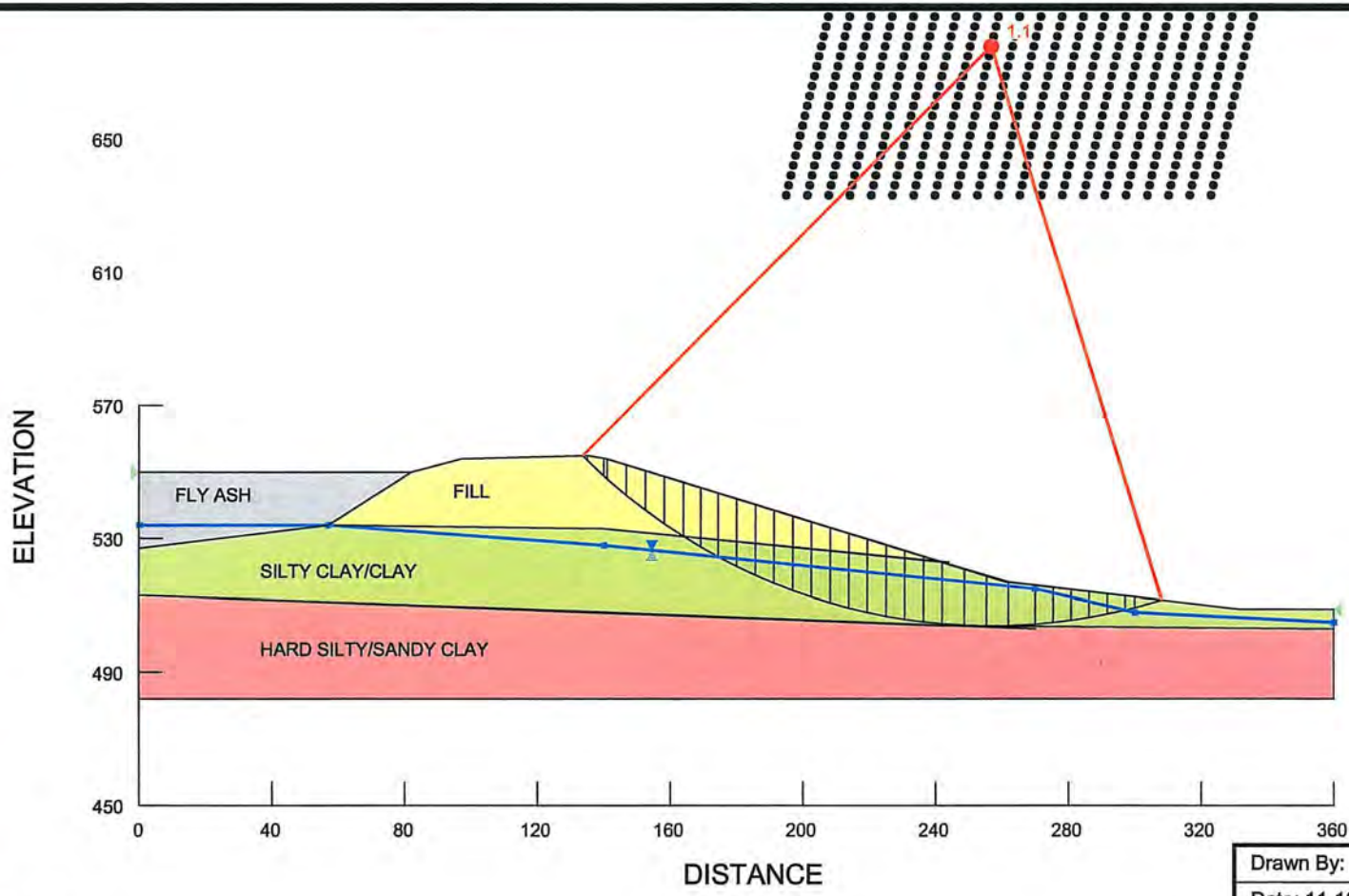
GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

SLOPE STABILITY CROSS SECTION A-A'
STEADY STATE SEEPAGE
SATURATED SLOPE

Project Number
J017150.01

PLATE 4



NOTE

See plate 2 for location of cross section.

Material	Density (pcf)	Cohesion (psf)	Friction Angle (deg)
Fill	125	50	25
Silty Clay/Clay	120	50	30
Hard, Silty/Sandy Clay	120	50	30
Fly Ash	112	0	0

Drawn By: SLC	Ck'd By: SLC	App'vd By: JAM
Date: 11-10-10	Date: 12/21/10	Date: 1/6/11

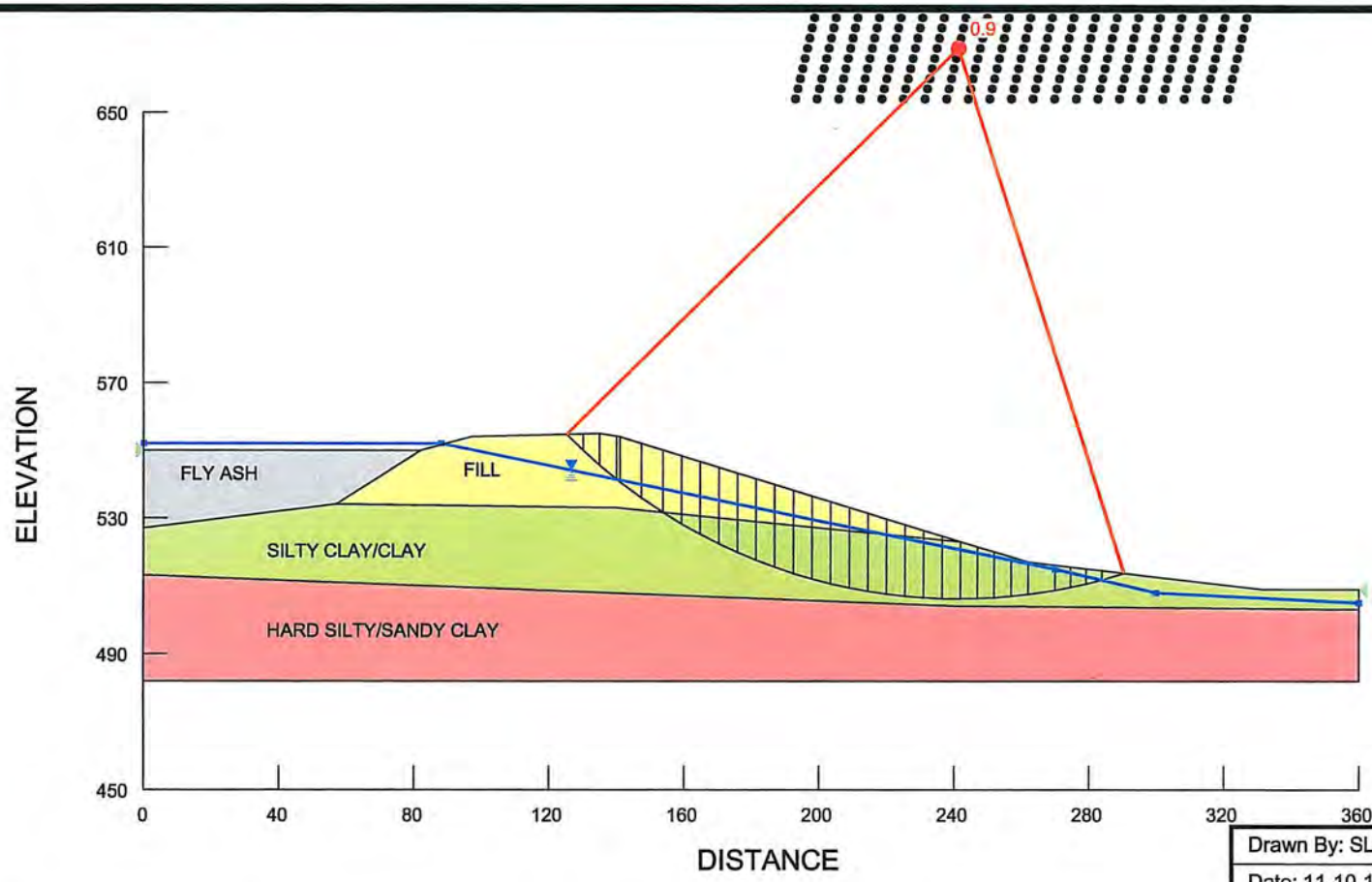
GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

SLOPE STABILITY CROSS SECTION A-A'
SEISMIC ANALYSIS
(MEAN RETURN TIME 2,500 YEARS)

Project Number
J017150.01

PLATE 5



NOTE

See plate 2 for location of cross section.

Material	Density (pcf)	Cohesion (psf)	Friction Angle (deg)
Fill	125	50	25
Silty Clay/Clay	120	50	30
Hard, Silty/Sandy Clay	120	50	30
Fly Ash	112	0	0

Drawn By: SLC	Ck'd By: Sec	App'vd By: DMV
Date: 11-10-10	Date: 12/21/10	Date: 1/14/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

SLOPE STABILITY CROSS SECTION A-A'
SEISMIC ANALYSIS
PARTIALLY SATURATED SLOPE
(MEAN RETURN TIME 2,500 YEARS)

Project Number
J017150.01

PLATE 6

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX A

IMPORTANT INFORMATION ABOUT YOUR GEOTECHNICAL ENGINEERING REPORT

Electronic Filing: Received, Clerk's Office 07/01/2024

Important Information about Your Geotechnical Engineering Report

Subsurface problems are a principal cause of construction delays, cost overruns, claims, and disputes.

While you cannot eliminate all such risks, you can manage them. The following information is provided to help.

Geotechnical Services Are Performed for Specific Purposes, Persons, and Projects

Geotechnical engineers structure their services to meet the specific needs of their clients. A geotechnical engineering study conducted for a civil engineer may not fulfill the needs of a construction contractor or even another civil engineer. Because each geotechnical engineering study is unique, each geotechnical engineering report is unique, prepared *solely* for the client. No one except you should rely on your geotechnical engineering report without first conferring with the geotechnical engineer who prepared it. *And no one — not even you* — should apply the report for any purpose or project except the one originally contemplated.

Read the Full Report

Serious problems have occurred because those relying on a geotechnical engineering report did not read it all. Do not rely on an executive summary. Do not read selected elements only.

A Geotechnical Engineering Report Is Based on A Unique Set of Project-Specific Factors

Geotechnical engineers consider a number of unique, project-specific factors when establishing the scope of a study. Typical factors include: the client's goals, objectives, and risk management preferences; the general nature of the structure involved, its size, and configuration; the location of the structure on the site; and other planned or existing site improvements, such as access roads, parking lots, and underground utilities. Unless the geotechnical engineer who conducted the study specifically indicates otherwise, do not rely on a geotechnical engineering report that was:

- not prepared for you,
- not prepared for your project,
- not prepared for the specific site explored, or
- completed before important project changes were made.

Typical changes that can erode the reliability of an existing geotechnical engineering report include those that affect:

- the function of the proposed structure, as when it's changed from a parking garage to an office building, or from a light industrial plant to a refrigerated warehouse,
- elevation, configuration, location, orientation, or weight of the proposed structure,
- composition of the design team, or
- project ownership.

As a general rule, *always* inform your geotechnical engineer of project changes—even minor ones—and request an assessment of their impact. *Geotechnical engineers cannot accept responsibility or liability for problems that occur because their reports do not consider developments of which they were not informed.*

Subsurface Conditions Can Change

A geotechnical engineering report is based on conditions that existed at the time the study was performed. *Do not rely on a geotechnical engineering report* whose adequacy may have been affected by: the passage of time; by man-made events, such as construction on or adjacent to the site; or by natural events, such as floods, earthquakes, or groundwater fluctuations. *Always* contact the geotechnical engineer before applying the report to determine if it is still reliable. A minor amount of additional testing or analysis could prevent major problems.

Most Geotechnical Findings Are Professional Opinions

Site exploration identifies subsurface conditions only at those points where subsurface tests are conducted or samples are taken. Geotechnical engineers review field and laboratory data and then apply their professional judgment to render an opinion about subsurface conditions throughout the site. Actual subsurface conditions may differ—sometimes significantly—from those indicated in your report. Retaining the geotechnical engineer who developed your report to provide construction observation is the most effective method of managing the risks associated with unanticipated conditions.

A Report's Recommendations Are *Not* Final

Do not overrely on the construction recommendations included in your report. *Those recommendations are not final,* because geotechnical engineers develop them principally from judgment and opinion. Geotechnical engineers can finalize their recommendations only by observing actual

subsurface conditions revealed during construction. *The geotechnical engineer who developed your report cannot assume responsibility or liability for the report's recommendations if that engineer does not perform construction observation.*

A Geotechnical Engineering Report Is Subject to Misinterpretation

Other design team members' misinterpretation of geotechnical engineering reports has resulted in costly problems. Lower that risk by having your geotechnical engineer confer with appropriate members of the design team after submitting the report. Also retain your geotechnical engineer to review pertinent elements of the design team's plans and specifications. Contractors can also misinterpret a geotechnical engineering report. Reduce that risk by having your geotechnical engineer participate in prebid and preconstruction conferences, and by providing construction observation.

Do Not Redraw the Engineer's Logs

Geotechnical engineers prepare final boring and testing logs based upon their interpretation of field logs and laboratory data. To prevent errors or omissions, the logs included in a geotechnical engineering report should *never* be redrawn for inclusion in architectural or other design drawings. Only photographic or electronic reproduction is acceptable, *but recognize that separating logs from the report can elevate risk.*

Give Contractors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can make contractors liable for unanticipated subsurface conditions by limiting what they provide for bid preparation. To help prevent costly problems, give contractors the complete geotechnical engineering report, *but* preface it with a clearly written letter of transmittal. In that letter, advise contractors that the report was not prepared for purposes of bid development and that the report's accuracy is limited; encourage them to confer with the geotechnical engineer who prepared the report (a modest fee may be required) and/or to conduct additional study to obtain the specific types of information they need or prefer. A prebid conference can also be valuable. *Be sure contractors have sufficient time* to perform additional study. Only then might you be in a position to give contractors the best information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions.

Read Responsibility Provisions Closely

Some clients, design professionals, and contractors do not recognize that geotechnical engineering is far less exact than other engineering disciplines. This lack of understanding has created unrealistic expectations that have led to disappointments, claims, and disputes. To help reduce the risk of such outcomes, geotechnical engineers commonly include a variety of explanatory provisions in their reports. Sometimes labeled "limitations" many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. *Read these provisions closely.* Ask questions. Your geotechnical engineer should respond fully and frankly.

Geoenvironmental Concerns Are Not Covered

The equipment, techniques, and personnel used to perform a *geoenvironmental* study differ significantly from those used to perform a *geotechnical* study. For that reason, a geotechnical engineering report does not usually relate any geoenvironmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. *Unanticipated environmental problems have led to numerous project failures.* If you have not yet obtained your own geoenvironmental information, ask your geotechnical consultant for risk management guidance. *Do not rely on an environmental report prepared for someone else.*

Obtain Professional Assistance To Deal with Mold

Diverse strategies can be applied during building design, construction, operation, and maintenance to prevent significant amounts of mold from growing on indoor surfaces. To be effective, all such strategies should be devised for the *express purpose* of mold prevention, integrated into a comprehensive plan, and executed with diligent oversight by a professional mold prevention consultant. Because just a small amount of water or moisture can lead to the development of severe mold infestations, a number of mold prevention strategies focus on keeping building surfaces dry. While groundwater, water infiltration, and similar issues may have been addressed as part of the geotechnical engineering study whose findings are conveyed in this report, the geotechnical engineer in charge of this project is not a mold prevention consultant; ***none of the services performed in connection with the geotechnical engineer's study were designed or conducted for the purpose of mold prevention. Proper implementation of the recommendations conveyed in this report will not of itself be sufficient to prevent mold from growing in or on the structure involved.***

Rely on Your ASFE-Member Geotechnical Engineer for Additional Assistance

Membership in ASFE/The Best People on Earth exposes geotechnical engineers to a wide array of risk management techniques that can be of genuine benefit for everyone involved with a construction project. Confer with you ASFE-member geotechnical engineer for more information.

ASFE
THE BEST PEOPLE ON EARTH
8811 Colesville Road/Suite G106, Silver Spring, MD 20910
Telephone: 301/565-2733 Facsimile: 301/589-2017
e-mail: info@asfe.org www.asfe.org

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IIGER030815.0MRP

Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX B

DETAILED LOGS OF BORINGS
BORING LOG: TERMS AND SYMBOLS

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.1 | Completion Date: 6/15/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	FILL: brown, silty clay, trace sand and gravel		3-4-5	SS1
	FILL: brown clay		2-3-6	SS2
5	FILL: brown and gray, silty clay		107	ST3
			2-3-6	SS4
10				
	FILL: brown clay		2-4-7	SS5
15				
	FILL: brown, silty clay, trace sand		2-8-8	SS6
20				
	FILL: brown clay		2-4-6	SS7
25				
	Stiff, brown and gray CLAY - (CH)		2-4-6	SS8
30		▽		
			2-4-6	SS9
35				
	trace gravel		4-4-6	SS10

SHEAR STRENGTH, tsf
Δ - UU/2 ○ - QU/2 □ - SV
0.5 1.0 1.5 2.0 2.5

STANDARD PENETRATION RESISTANCE
(ASTM D 1586)
▲ N-VALUE (BLOWS PER FOOT)

WATER CONTENT, %
PL 10 20 30 40 50 LL

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AT THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/4/13

GROUNDWATER DATA

ENCOUNTERED AT 33 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821256.011' E: 997512.963'

Drawn by: KA	Checked by: SR	App'vd. by: DW
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

LOG OF BORING: B-1

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.1 Completion Date: 6/15/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES	SHEAR STRENGTH, tsf (Δ - UU/2, ○ - QU/2, □ - SV; 0.5 1.0 1.5 2.0 2.5) STANDARD PENETRATION RESISTANCE (ASTM D 1586) ▲ N-VALUE (BLOWS PER FOOT) WATER CONTENT, % PL LL (10 20 30 40 50)
	Stiff, brown and gray CLAY - (CH) *(continued)*				
	Very stiff, brown, silty CLAY, trace gravel - CL				
45			4-7-15	SS11	
	Hard, brown, sandy CLAY - CL				
	43.2 percent passing the No. 200 sieve.		26-48 -50/3"	SS12	98 9"
50					
			27-45 -50/5"	SS13	95 11"
55					
			13-24-37	SS14	61
	Auger refusal at 57.5 feet.				
60					
65					
70					
75					

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC.0638301.GPJ 12/8/10

GROUNDWATER DATA

ENCOUNTERED AT 33 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821256.011' E: 997512.963'

Drawn by: KA	Checked by: SJC	App'vd. by: DJV
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

CONTINUATION OF
LOG OF BORING: B-1

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.6 | Completion Date: 6/16/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES	SHEAR STRENGTH, tsf (Δ - UU/2, ○ - QU/2, □ - SV; 0.5 1.0 1.5 2.0 2.5) / STANDARD PENETRATION RESISTANCE (ASTM D 1586) ▲ N-VALUE (BLOWS PER FOOT) / WATER CONTENT, % (PL — LL; 10 20 30 40 50)
	FILL: brown, silty clay, interbedded with occasional clay				
			2-4-4	SS1	
			2-4-4	SS2	
5					
			117	ST3	
			117	ST4	
10					
			2-4-5	SS5	
15					
			107	ST6	
			104	ST7	
20					
	Stiff, brown, silty CLAY - CL				
			2-5-5	SS8	
25					
	Stiff, brown CLAY, trace gravel - CH				
			2-5-6	SS9	
30					
	Medium stiff to hard, brown, silty CLAY, trace sand - CL ▽				
	68.8 percent passing the No. 200 sieve.		1-3-4	SS10	
35					
			9-14-19	SS11	

GROUNDWATER DATA

ENCOUNTERED AT 33 FEET ▽

DRILLING DATA

__ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM __ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821332.544' E: 997697.278'

Drawn by: KA	Checked by: SJE	App'vd. by: DAV
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

LOG OF BORING: B-2

Project No. J017150.01

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/3/10

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.6 Completion Date: 6/16/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES	SHEAR STRENGTH, tsf Δ - UU/2 ○ - QU/2 □ - SV (0.5 1.0 1.5 2.0 2.5) STANDARD PENETRATION RESISTANCE (ASTM D 1586) ▲ N-VALUE (BLOWS PER FOOT) WATER CONTENT, % PL LL (10 20 30 40 50)
45	Medium stiff to hard, brown, silty CLAY, trace sand - CL *(continued)*		10-17-29	SS12	
50	Hard to very stiff, brown CLAY with sand and gravel - CH		11-16-22	SS13	
55			8-13-16	SS14	
	Boring terminated at 55 feet.				
60					
65					
70					
75					

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/3/10

GROUNDWATER DATA

ENCOUNTERED AT 33 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821332.544' E: 997697.278'

Drawn by: KA	Checked by: SA	App'vd. by: DM
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

CONTINUATION OF
LOG OF BORING: B-2

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 515.0 Completion Date: 6/17/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	Medium stiff to soft, brown, silty CLAY - CL			
			3-3-4	SS1
			1-1-2	SS2
5				
			105	ST3
				ST4
10				
	Hard, brown to gray silty CLAY - CL			
			7-16-21	SS5
15				
			9-16-23	SS6
20				
			12-15-23	SS7
25				
			8-14-22	SS9
30	Boring terminated at 30 feet.			
35				

SHEAR STRENGTH, tsf

Δ - UU/2 ○ - QU/2 □ - SV

0.5 1.0 1.5 2.0 2.5

STANDARD PENETRATION RESISTANCE

(ASTM D 1586)

▲ N-VALUE (BLOWS PER FOOT)

WATER CONTENT, %

PL 10 20 30 40 50 LL

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002.WL J017150.01 - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/13/11

GROUNDWATER DATA

ENCOUNTERED AT 5 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM

WASHBORING FROM ___ FEET

MVU DRILLER KCR LOGGER

CME 750X DRILL RIG

HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821206.705' E: 997735.386'

Drawn by: KA	Checked by: SA	App'vd. by: DW
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

LOG OF BORING: B-3

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 510.9 | Completion Date: 6/18/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES	SHEAR STRENGTH, tsf (Δ - UU/2, O - QU/2, □ - SV; 0.5, 1.0, 1.5, 2.0, 2.5) / STANDARD PENETRATION RESISTANCE (ASTM D 1586) ▲ N-VALUE (BLOWS PER FOOT) / WATER CONTENT, % (PL, LL; 10, 20, 30, 40, 50)
	Soft, brown, silty CLAY - (CL)				
			2-1-1	SS1	
			1-1-1	SS2	
5	Stiff, brown and gray CLAY - CH				
			1-3-8	SS3	
	Hard, brown and gray, silty CLAY - CL				
			25-24-53	SS4	77
10					
			11-24-20	SS5	
15					
			8-14-20	SS6	
20					
			12-17-27	SS7	
25	Boring terminated at 25 feet.				
30					
35					

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC.0638301.GPJ 12/4/10

GROUNDWATER DATA

ENCOUNTERED AT 2 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821177.029' E: 997745.742'

Drawn by: KA	Checked by: Sa	App'vd. by: DW
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

LOG OF BORING: B-4

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.0 | Completion Date: 6/17/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES
	FILL: brown, silty clay			
			4-6-4	SS1
			121	ST2
5				
	trace sand		3-5-7	SS3
	FILL: brown and gray, clay			
	trace gravel		3-5-6	SS4
10				
			2-4-6	SS5
15				
			2-4-7	SS6
20				
			2-4-6	SS7
25				
	trace sand and gravel		4-7-7	SS8
30				
	FILL: brown, silty clay			
	▽		3-3-5	SS9
35				
	Stiff to hard, brown, silty CLAY - CL			
			2-5-6	SS10

SHEAR STRENGTH, tsf

Δ - UU/2 ○ - QU/2 □ - SV

0.5 1.0 1.5 2.0 2.5

STANDARD PENETRATION RESISTANCE

(ASTM D 1586)

▲ N-VALUE (BLOWS PER FOOT)

WATER CONTENT, %

PL 10 20 30 40 50 LL

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150.01 - AMEREN-NEWTON.GPJ GTINC 0638301.GPJ 12/4/11

GROUNDWATER DATA

ENCOUNTERED AT 34 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM

WASHBORING FROM ___ FEET

MVU DRILLER KCR LOGGER

CME 750X DRILL RIG

HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821405.69' E: 997881.328'

Drawn by: KA	Checked by: SK	App'vd. by: DMS
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

LOG OF BORING: B-5

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

Surface Elevation: 554.0 Completion Date: 6/17/10

Datum msl

DEPTH IN FEET	DESCRIPTION OF MATERIAL	GRAPHIC LOG	DRY UNIT WEIGHT (pcf) SPT BLOW COUNTS CORE RECOVERY/RQD	SAMPLES	SHEAR STRENGTH, tsf (Δ - UU/2, ○ - QU/2, □ - SV; 0.5, 1.0, 1.5, 2.0, 2.5) STANDARD PENETRATION RESISTANCE (ASTM D 1586) ▲ N-VALUE (BLOWS PER FOOT) WATER CONTENT, % (PL, LL; 10, 20, 30, 40, 50)
	Stiff to hard, brown, silty CLAY - CL *(continued)*				
			7-14-24	SS11	
45	Hard, brown, sandy CLAY - CL				
			44-50/2"	SS12	2"
	Sampler and auger refusal at 47.5 feet.				
50					
55					
60					
65					
70					
75					

NOTE: STRATIFICATION LINES REPRESENT THE APPROXIMATE BOUNDARIES BETWEEN SOIL TYPES AND/OR THE TRANSITION MAY BE GRADUAL. GRAPHIC LOG FOR ILLUSTRATION PURPOSES ONLY.

LOG OF BORING 2002 WL J017150 01 AMEREN NEWTON GPJ GTINC 0638301 GPJ 12/9/10

GROUNDWATER DATA

ENCOUNTERED AT 34 FEET ▽

DRILLING DATA

___ AUGER 3 3/4" HOLLOW STEM
WASHBORING FROM ___ FEET
MVU DRILLER KCR LOGGER
CME 750X DRILL RIG
HAMMER TYPE Auto

REMARKS: Datum: IL State Plane Coordinates, East Zone. N: 821405.69' E: 997881.328'

Drawn by: KA	Checked by: JA	App'vd. by: DM
Date: 6/23/10	Date: 1/3/11	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

CONTINUATION OF
LOG OF BORING: B-5

Project No. J017150.01

Electronic Filing: Received, Clerk's Office 07/01/2024

BORING LOG: TERMS AND SYMBOLS

GENERAL NOTES

1. *Information on each boring log is a compilation of subsurface conditions based on soil or rock classifications obtained from the field as well as from laboratory testing of samples. The strata lines on the logs may be approximate or the transition between the strata may be gradual rather than distinct. Water level measurements refer only to those ob - served at the times and places indicated, and may vary with time, geologic condition or construction activity.*
2. *Relative composition and Unified Soil Classification designations are based on visual estimates and are approximate only. If laboratory tests were performed to classify the soil, the unified designation is show in parenthesis.*
3. *Value given in Unit Dry Weight/SPT Column is either a unit dry weight in pounds per cubic foot, if adjacent to a ST sample designation, or blows per 6-inch increment if adjacent to a SS sample designation.*

ABBREVIATIONS

UU/2	*Shear Strength from Unconsolidated – Undrained Triaxial Test (ASTM D2850)*
QU/2	*Shear Strength from Unconfined Compression Test (ASTM D2166)*
SV	*Shear Strength from Field Vane (ASTM D2573)*
PL	*Plastic Limit (ASTM D4318)*
LL	*Liquid Limit (ASTM D4318)*

LEGEND

CS	Continuous Sampler
GB	Grab Sample Taken From Auger Cuttings Or Wash Water Return
NX 100/42	NX Rock Core with Percent Recovery/R.Q.D. Given In Adjacent Column
PST	Three Inch Diameter Piston Tube Sample
SS	Split Spoon Sample (Standard Penetration Test)
ST	Three Inch Diameter Shelby Tube Sample
*	Sample Not Recovered
SV	Field Vane Test

SPLIT – BARREL SAMPLER DRIVING RECORD

Blow Per Foot (N-Value)	*Description*
25	*25 blows drove sampler 12 inches after initial 6 inches of seating.*
75/10”	*75 blows drove sampler 10 inches after initial 6 inches of seating.*
50/S3”	*50 blows drove sampler 3 inches during initial 6 inch seating interval.*

NOTES: 1. To avoid damage to sampling tools, driving is limited to 50 blows during any six inch interval.
2. N-Value (Blow Count) is the standard penetration resistance based on the total number of blows, using a 140-lb hammer with 30-inch free fall, required to drive a split spoon the last two of three, 6-inch drive increments. (Example: 4/7/9, N = 7 + 9 = 16). Values are shown as a summation on grid plot and may be shown as 4/7/9 in Unit Dry Weight – SPT column.

RELATIVE COMPOSITION

Trace……..0-10 %
With/Some……..11-35 %
Soil modifier such……. > 35 %
As silty, clayey, sandy, etc.

DENSITY OF GRANULAR SOILS

Descriptive Term:	***N—Value***
Very Loose	*0 - 4*
Loose	*5 - 10*
Medium Dense	*11 - 30*
Dense	*31 - 50*
Very Dense	*> 50*

STRENGTH OF COHESIVE SOILS

Consistency	**Undrained Shear Strength Tons Per Sq. Ft.**	**Field Test**	**Approximate N-Value Range**
Very Soft	*less than 0.12*	*Thumb will penetrate soil more than 1”*	*0 - 1*
Soft	*13 to 0.25*	*Thumb will penetrate soil about 1”*	*2 - 4*
Medium Stiff	*0.26 to 0.50*	*Thumb will penetrate soil about ¼”*	*5 – 8*
Stiff	*0.51 to 1.00*	*Thumb hardly indents soil*	*9 – 15*
Very Stiff	*1.01 to 2.00*	*Thumb will not indent soil, but readily indented with thumbnail*	*16 – 30*
Hard	*greater than 2.00*	*Thumbnail will not indent soil*	*> 30*

SOIL GRAIN SIZE

U.S. STANDARD SIEVE

12”	3”	¾“	4	10	40	200		
BOULDERS	COBBLES	GRAVEL		SAND			SILT	CLAY
		COARSE	FINE	COARSE	MEDIUM	FINE		
300	76.2	19.1	4.76	2.00	0.42	0.074	0.002	

SOIL GRAIN SIZE IN MILLIMETERS

SOIL STRUCTURE

Calcareous *– Having appreciable quantities of carbonate.*
Fissured *– Containing shrinkage or relief cracks, often filled with sand or silt; usually more or less vertical.*
Slickensided *– Having planes of weakness that appear slick and glossy. The degree of slickensidedness depends upon the spacing of slickensides and the ease of breaking along those planes.*
Layer *-- Inclusion greater than 3 inches thick.*
Seam *– Inclusion 1/8 inch to 3 inches thick extending through the sample*
Parting *– Inclusion less than 1/8 inch thick.*
Pocket *– Inclusion of material of different texture that is smaller than the diameter of the sample.*
Interlayered *– Soil samples composed of alternating layers of different soil types.*
Intermixed *– Soil samples composed of pockets of different soil types and a layered or laminated structure is not evident.*
Laminated *– Soil sample composed of alternating partings or seams of different soil type.*

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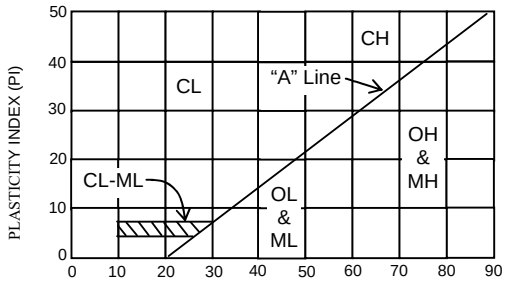
UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			SYMBOL	DESCRIPTION
Coarse-Grained Soils (More than 50% Larger than No 200 Sieve Size)	Gravel and Gravelly Soils	Clean Gravels Little or no Fines	GW	Well-Graded Gravel, Gravel-Sand Mixture
			GP	Poorly –Graded Gravel, Gravel-Sand Mixture
		Gravels with Appreciable Fines	GM	Silty Gravel, Gravel-Sand-Silt Mixture
			GC	Clayey-Gravel, Gravel-Sand-Clay Mixture
	Sand and Sandy Soils	Clean Sands Little or no Fines	SW	Well-Graded Sand, Gravelly Sand
			SP	Poorly Graded Sand, Gravelly Sand
		Sands with Appreciable Fines	SM	Silty Sand, Sand-Silt Mixture
			SC	Clayey Sand, Sand-Clay Mixture
Fine-Grained Soils (More than 50% Smaller than No 200 Sieve Size)	Silts and Clays	Liquid Limit Less Than 50	ML	Silt, Clayey Silt, Silty or Clayey Very Fine Sand, Slight Plasticity
			CL	Clay, Sandy Clay, Silty Clay, Low to Medium Plasticity
			OL	Organic Silts, or Silty Clays of Low Plasticity
	Silts and Clays	Liquid Limit More Than 50	MH	Silt, Fine Sandy or Silt Soil with High Plasticity
			CH	Clay, High Plasticity
			OH	Organic Clay of Medium to High Plasticity
	Highly Organic Soils		PT	Peat, Humus, Swamp Soil

PLASTICITY CHART



RELATIVE PLASTICITY

Nonplastic	Cannot Roll Into Ball
Trace Plasticity	Barely Roll Into Ball
Medium Plastic	Can be Rolled Into Ball
Highly Plastic	No Rupture by Kneading

VISUAL DESCRIPTION CRITERIA*

TABLE 1: CRITERIA FOR DESCRIBING ANGULARITY OF COARSE-GRAINED PARTICLES

Description	Criteria
Angular	Particles have sharp edges and relatively plane sides with unpolished surfaces
Subangular	Particles are similar to angular description but have rounded edges
Subrounded	Particles have nearly plane sides but have well-rounded corners and edges
Rounded	Particles have smoothly curved sides and no edges

TABLE 2: CRITERIA FOR DESCRIBING PARTICLE SHAPE

Description	Criteria
Flat	Particles with width/thickness X3
Elongated	Particles with length/width X3
Flat and Elongated	Particles meet criteria for both flat and elongated

TABLE 3: CRITERIA FOR DESCRIBING MOISTURE CONDITION

Description	Criteria
Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp, but no visible water
Wet	Visible free water, usually soil is below the water table

TABLE 4: CRITERIA FOR DESCRIBING REACTION WITH HCL

Description	Criteria
None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming rapidly

TABLE 6: CRITERIA FOR DESCRIBING CEMENTATION

Description	Criteria
Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

*NOTES: 1. Tables adapted from ASTM D2488 "Description and identification of Soils" (Visual-Manual Procedure)
2. Tables 5, 7 and 11 incorporated into other information on this plate.

TABLE 8: CRITERIA FOR DESCRIBING DRY STRENGTH

Description	Criteria
None	The dry specimen crumbles into powder with mere pressure of handling
Low	The dry specimen crumbles into powder with some finger pressure
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between the thumb and a hard surface

TABLE 9: CRITERIA FOR DESCRIBING DILATANCY

Description	Criteria
None	No visible change in the specimen
Slow	Water appears slowly on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
Rapid	Water appears quickly on the surface of the specimen during shaking and disappears quickly upon squeezing.

TABLE 10: CRITERIA FOR DESCRIBING TOUGHNESS

Description	Criteria
Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness

TABLE 12: IDENTIFICATION OF INORGANIC FINE-GRAINED SOILS FROM MANUAL TESTS

Soil Symbol	Dry Strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	none	High

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APPENDIX C

LABORATORY TEST DATA

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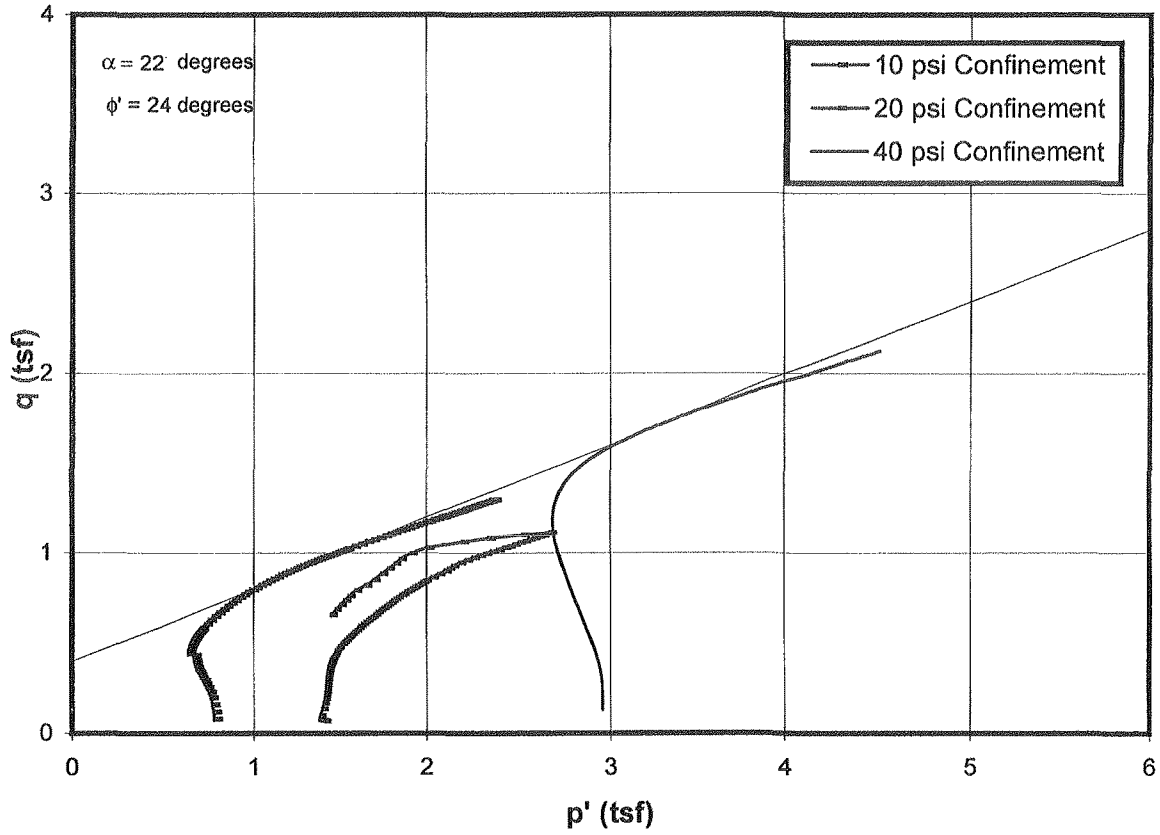
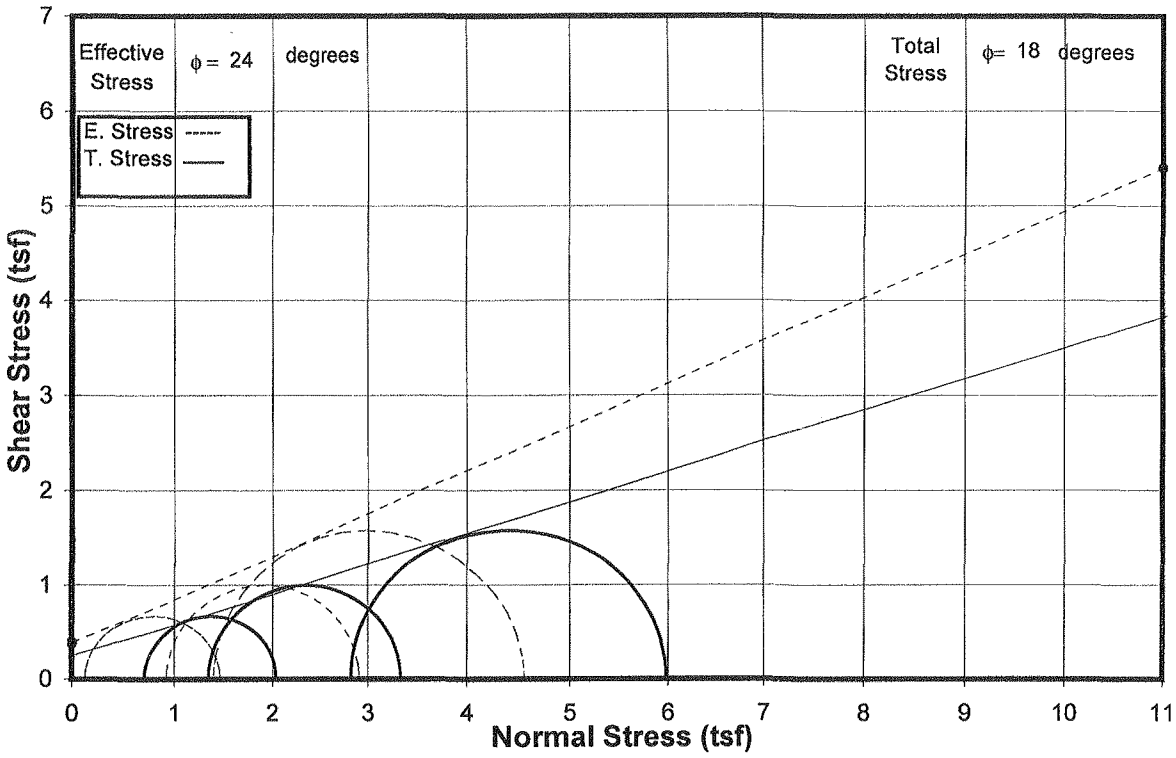
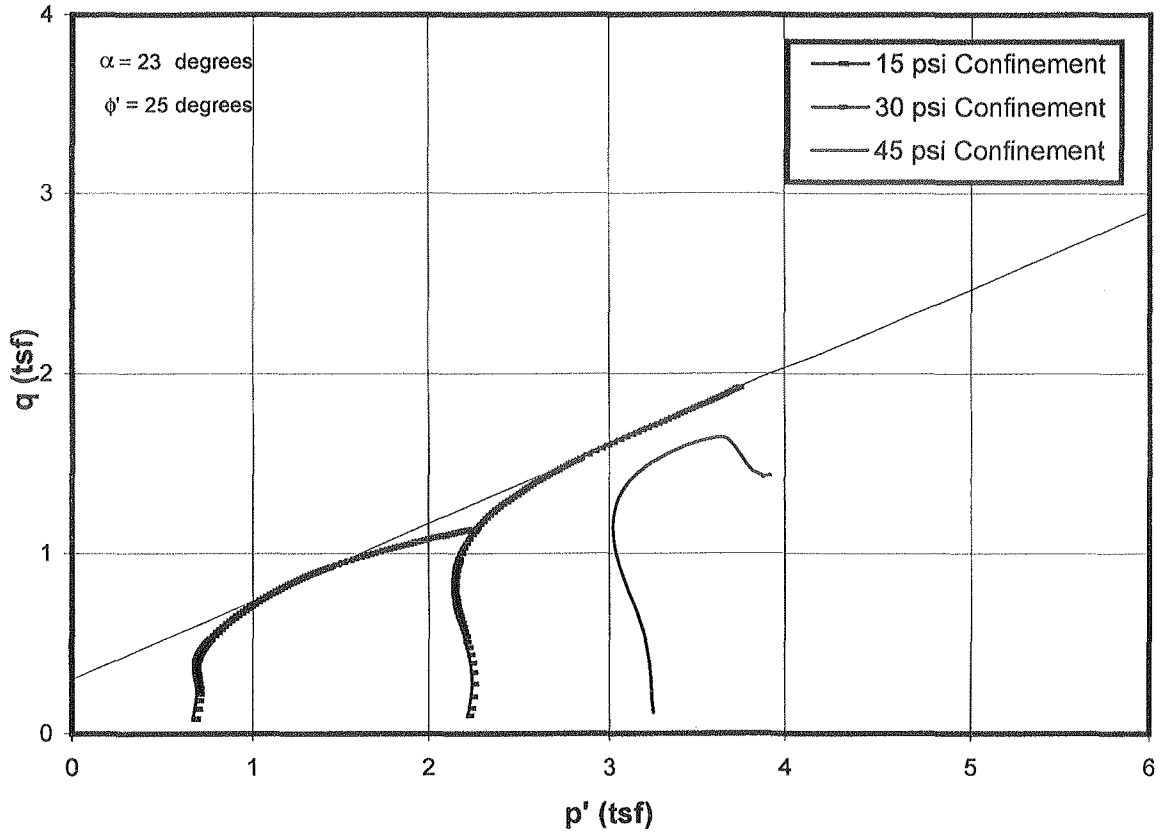
FROM THE GROUND UP

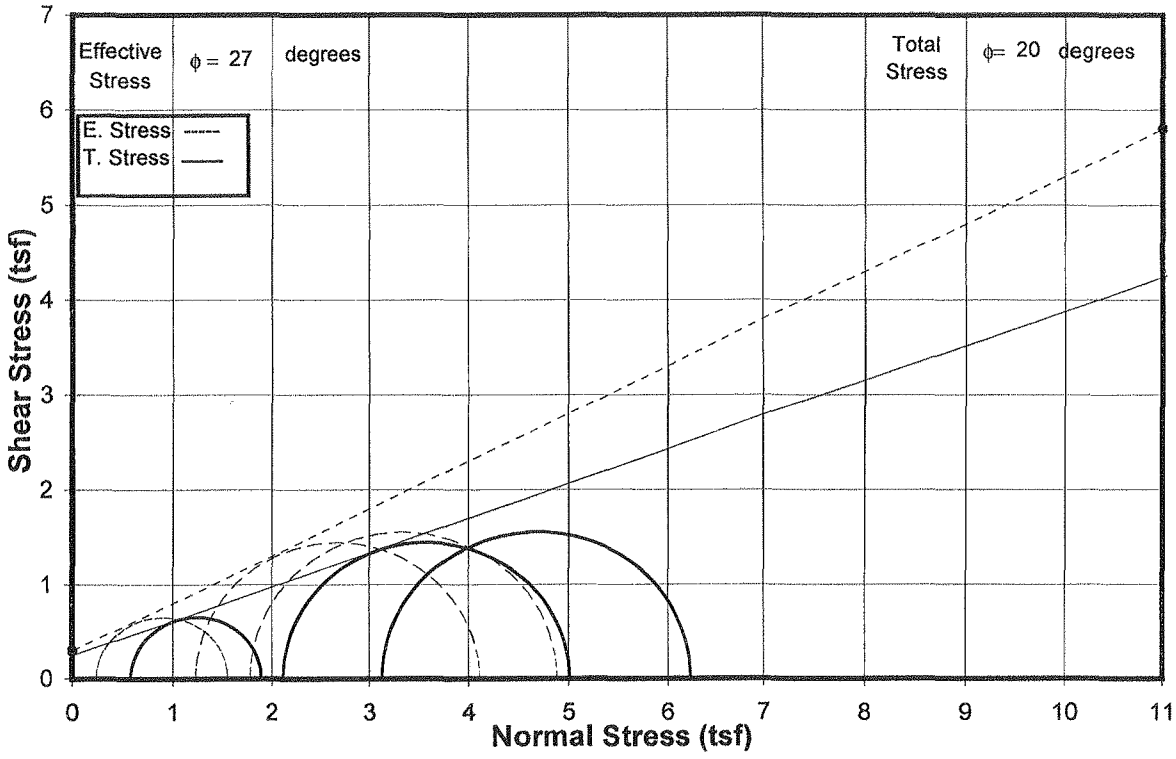




CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
ASTM D 4767
Project No.: J017150.01
Boring: B-2
Sample: ST-3, ST-4, ST-4 - Depth: 6, 8, 8

GEOTECHNOLOGY, INC.
FROM THE GROUND UP





CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION TEST
ASTM D 4767
Project No.: J017150.01
Boring: B-2
Sample: ST-6, ST-7, ST-7 - Depth: 16, 18, 18

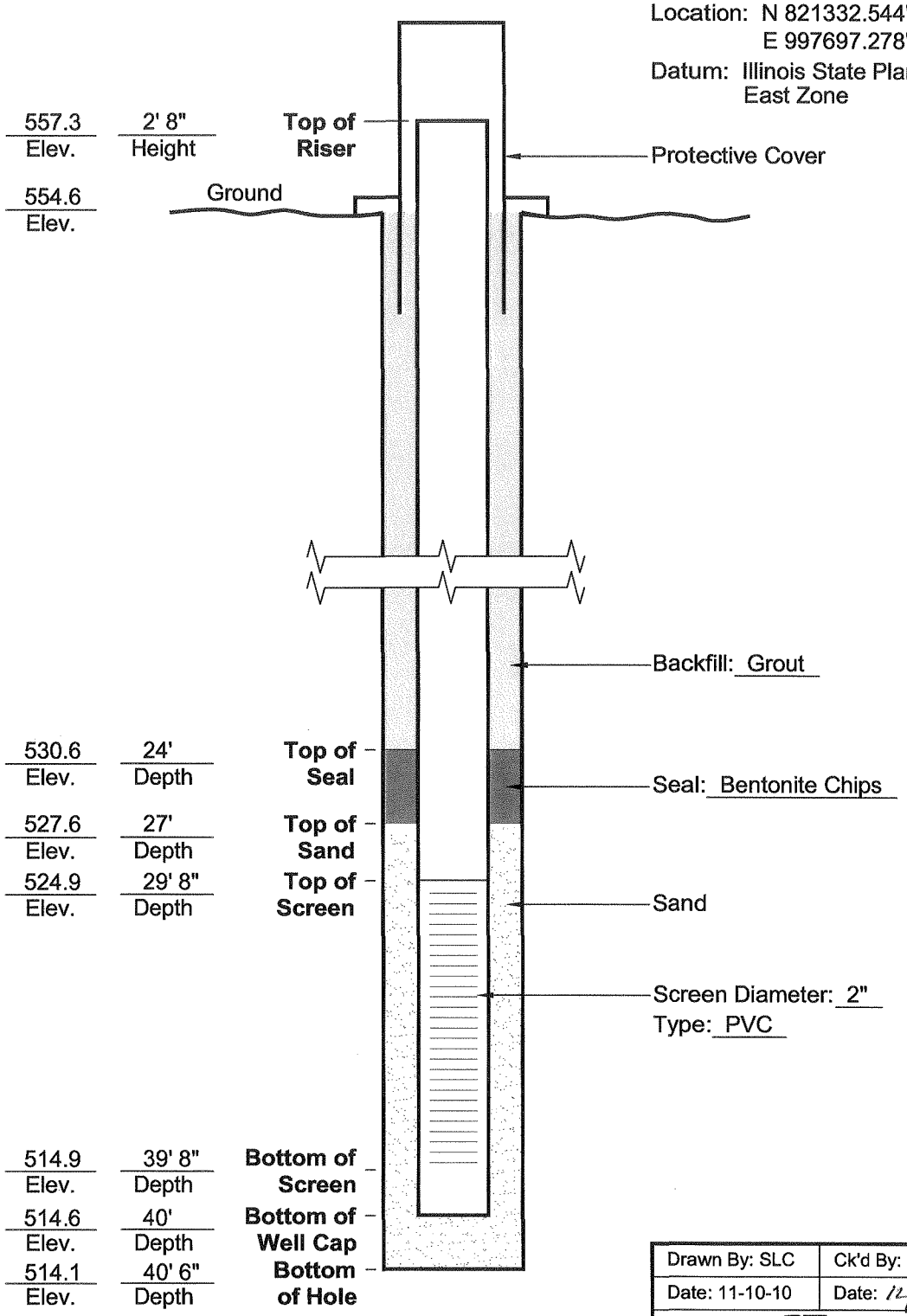
Electronic Filing: Received, Clerk's Office 07/01/2024

APPENDIX D

PIEZOMETER INSTALLATION DETAILS

Electronic Filing: Received, Clerk's Office 07/01/2024

Date Installed: 06-16-10
Location: N 821332.544'
E 997697.278'
Datum: Illinois State Plane Coordinates, East Zone



Drawn By: SLC	Ck'd By: Sm	App'vd By: DM
Date: 11-10-10	Date: 12/21/10	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

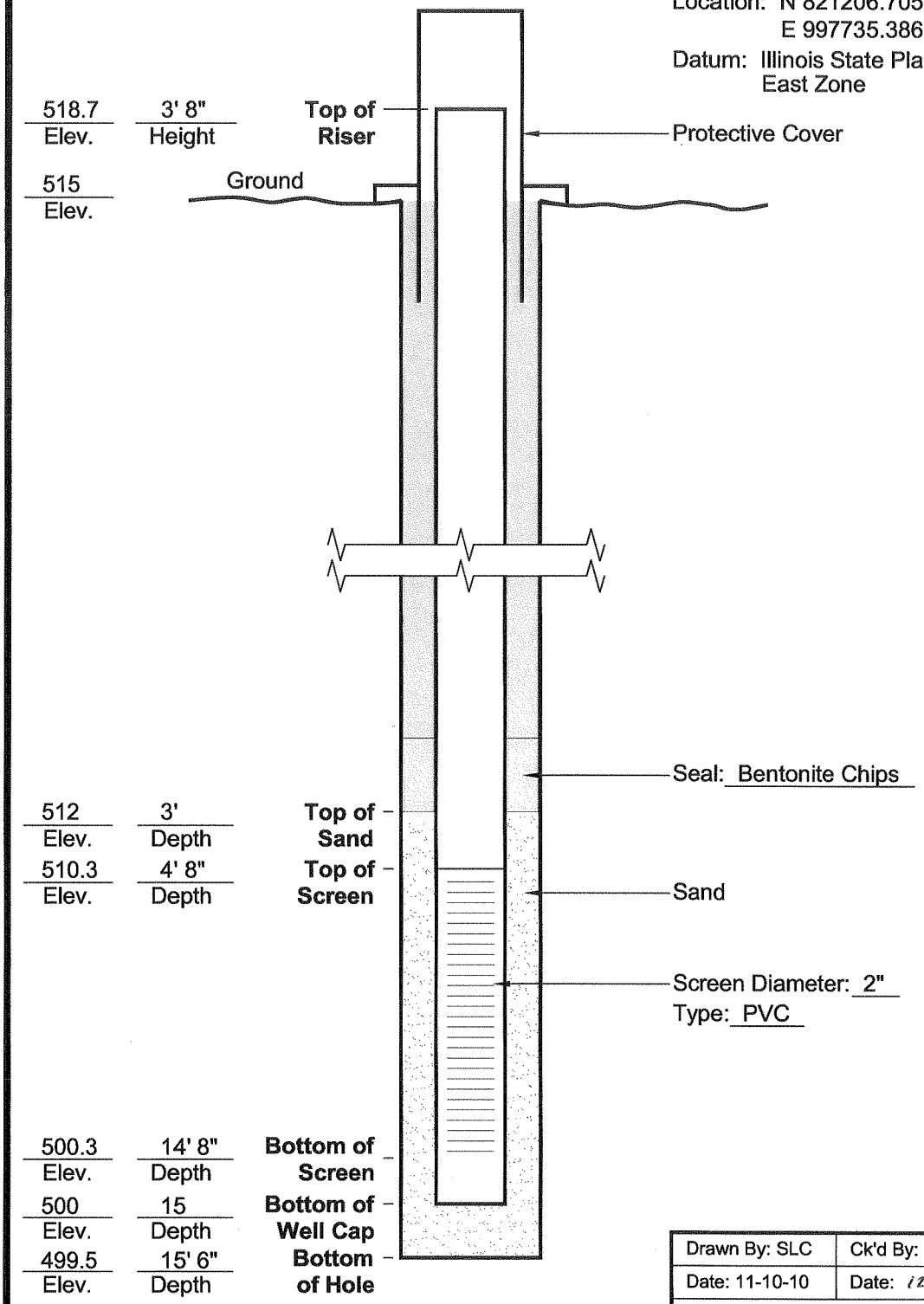
Newton Power Station
Newton, Illinois

PIEZOMETER CONSTRUCTION DIAGRAM

Project Number	
J017150.01	B-2

Electronic Filing: Received, Clerk's Office 07/01/2024

Date Installed: 06-17-10
Location: N 821206.705'
E 997735.386'
Datum: Illinois State Plane Coordinates, East Zone



Drawn By: SLC	Ck'd By:	App'vd By: DW
Date: 11-10-10	Date: 12/15/10	Date: 1/4/11

GEOTECHNOLOGY INC
FROM THE GROUND UP

Newton Power Station
Newton, Illinois

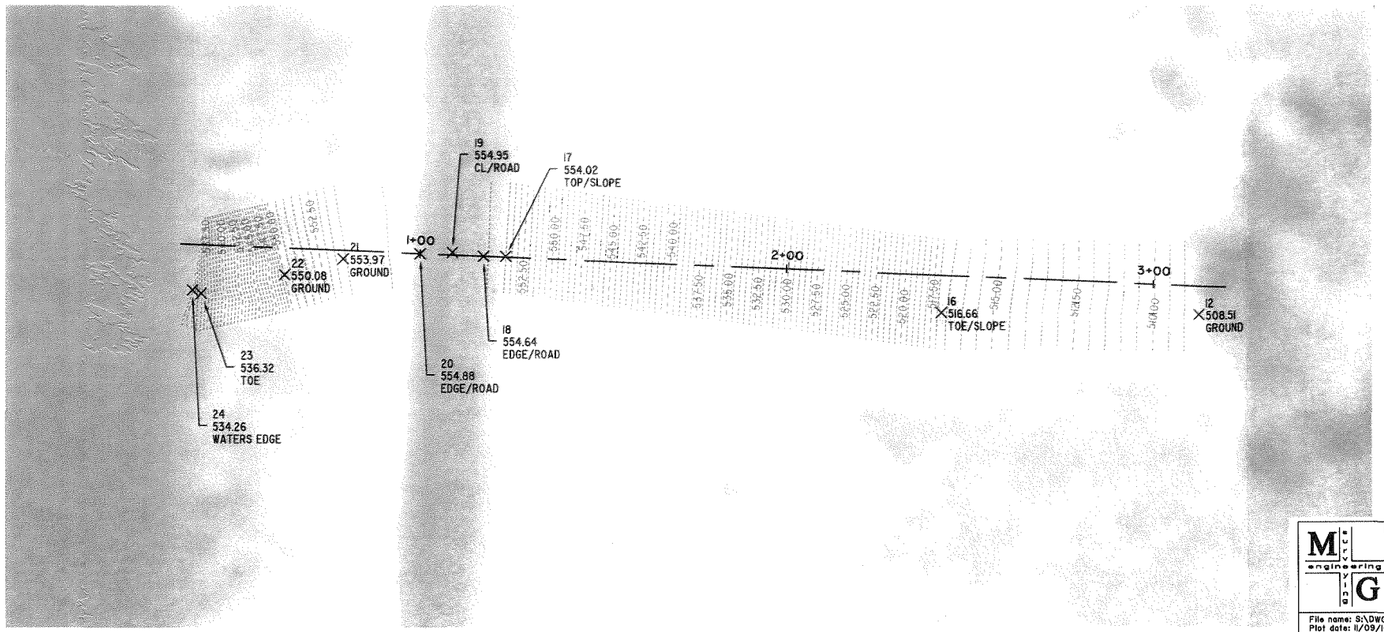
PEIZOMETER CONSTRUCTION DIAGRAM

Project Number	
J017150.01	B-3

APPENDIX E

SURVEY DATA

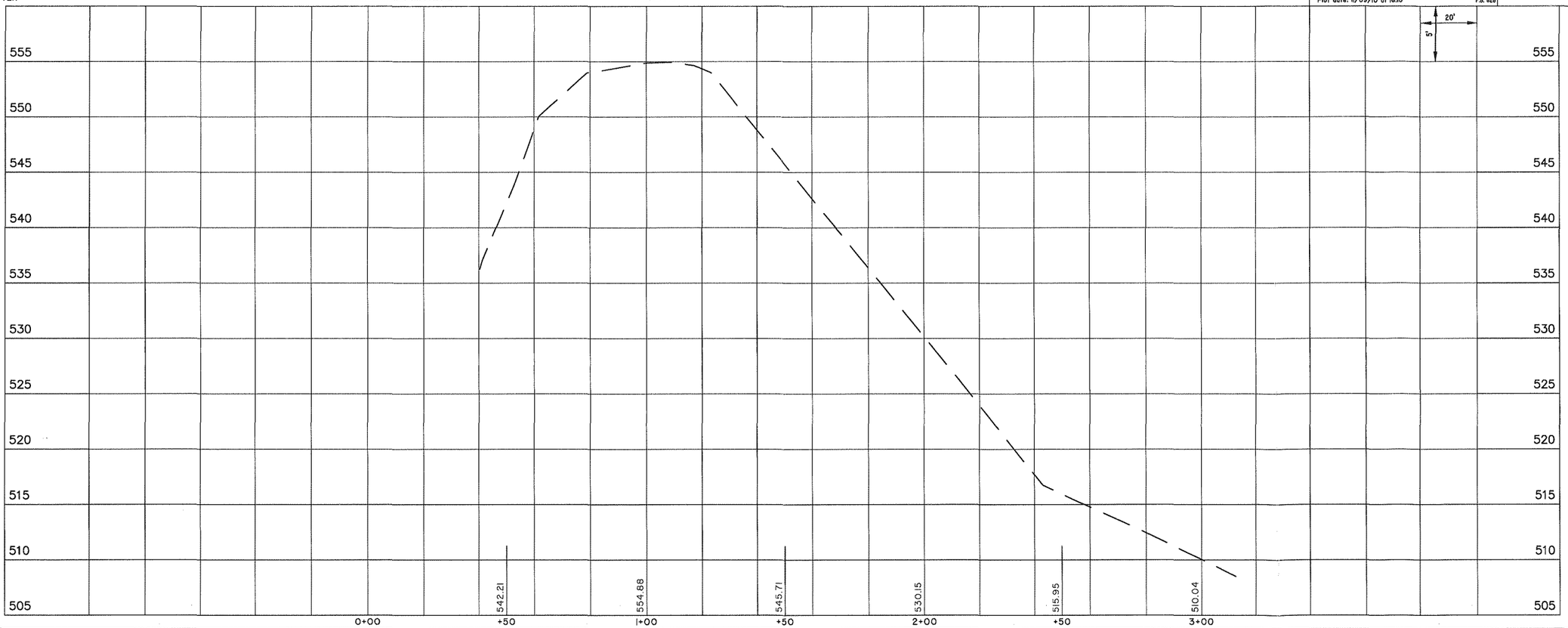
Point	Station	Offset	Elevation	Description
12	3+12.97	7.724'	508.511'	GROUND
16	2+42.81	10.140'	516.664'	TOE/SLOPE
17	1+23.30	−0.246'	554.015'	TOP/SLOPE
18	1+17.28	0.000'	554.641'	EDGE/ROAD
19	1+08.75	−0.738'	554.950'	CL/ROAD
20	1+00.00	0.000'	554.879'	EDGE/ROAD
21	0+79.42	2.185'	553.969'	GROUND
22	0+63.83	7.278'	550.079'	GROUND
23	0+41.20	13.241'	536.323'	TOE
24	0+38.67	12.423'	534.256'	WATERS EDGE

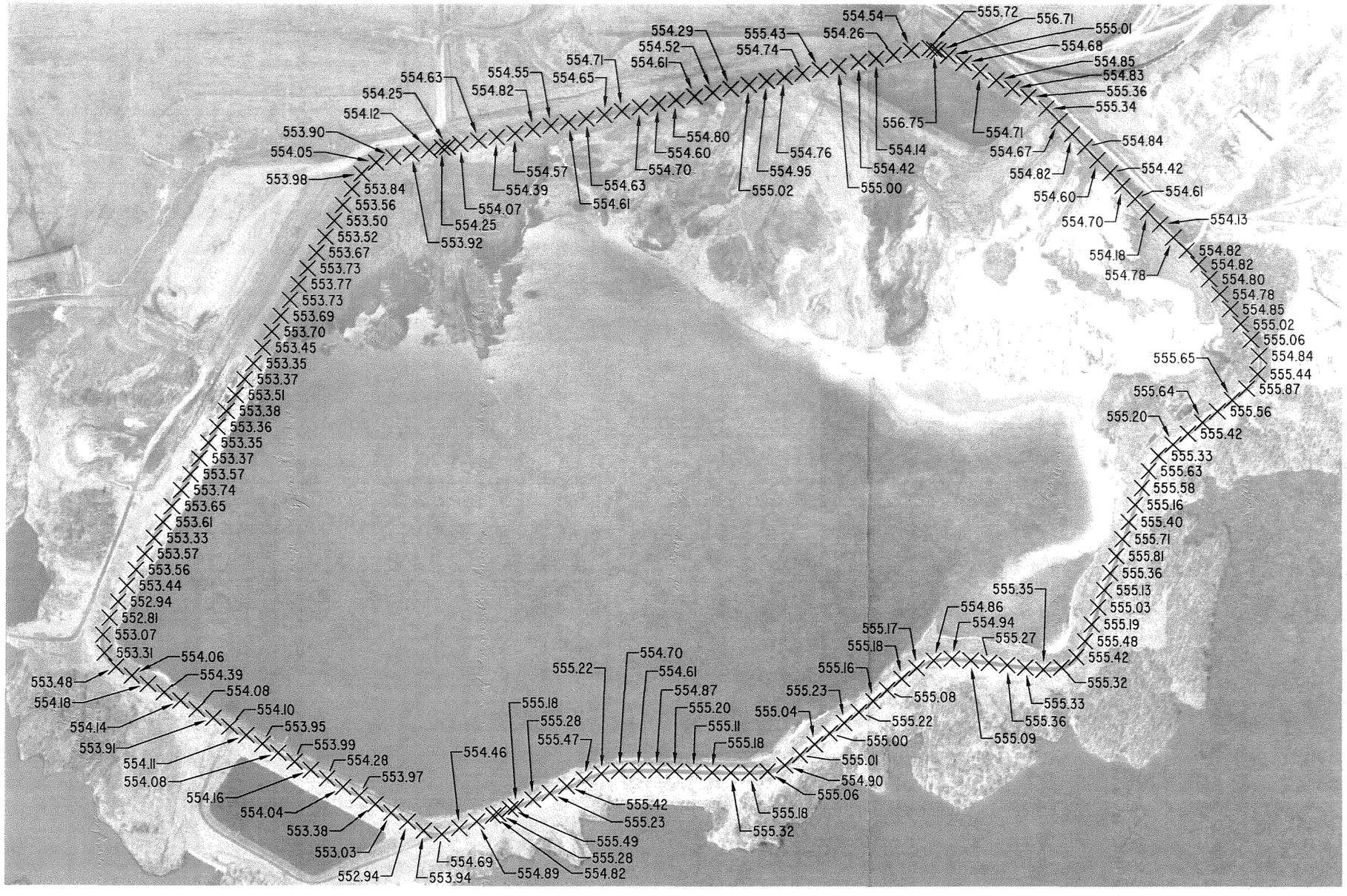


SCALES:
1" =20' HOR
1" =5' VER

MILANO & GRUNLOH ENGINEERS, LLC
114 WEST WASHINGTON
P.O. BOX 897
EFFINGHAM, ILLINOIS 62401
Phone: (217) 347-7262
(800) 677-2714
Fax #: (217) 342-3433
Web Address: www.mgengineers.com
Design File #: 184-003018
File name: S:\DWG\10\0165bg5\dwg\Section.dwg
Plot date: 11/09/10 at 16:10
F.B. 628

AMEREN-CIPS
NEWTON FACILITY
CROSS SECTION





MILANO & GRUNLOH ENGINEERS, LLC
114 WEST WASHINGTON
P.O. BOX 897
EFFINGHAM, ILLINOIS 62401
Phone: (217) 347-7262
(800) 677-2714
Fax #: (217) 342-3433
Web Address: www.mgengineers.com
Design Firm #: 184-003108

File name: S:\DWG\10\10165bg5\dwg\Elevations.dwg
Plot date: 10/29/10 at 15:25 F.B. 628

AMEREN-CIPS
NEWTON FACILITY

S:\dwg\10\10165bg5\dwg\Elevations.dwg, 11x17, 10/29/2010 3:40:32 PM

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Attachment E

Alternative Final Protective Layer Equivalency Demonstration

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Geosyntec consultants

134 N. La Salle Street, Suite 300
Chicago, Illinois 60602
PH 312.658.0500
FAX 312.658.0576
www.geosyntec.com

Technical Memorandum

Date:	July 25, 2022
To:	Victor Modeer, P.E., DGE, Vistra on behalf of Illinois Power Generating Company
Copies to:	Phil Morris, Rhys Fuller, Vistra on behalf of Illinois Power Generating Company
From:	John Seymour, P.E., Geosyntec Consultants (Geosyntec) Lucas Carr, P.E., Geosyntec
Subject:	Proposed Alternative Final Protective Layer Equivalency Demonstration Primary Ash Pond, Newton Power Plant Jasper County, Illinois Geosyntec Project: GLP8025

PROPOSAL

An alternative final protective layer is proposed by Illinois Power Generating Company (IPGC) for the Primary Ash Pond (PAP) surface impoundment that will be closed-in-place at the Newton Power Plant (NPP). The closure will be in accordance with Illinois Administrative Code (IAC) Part 845 Rule [1] (Part 845). Overall, the proposal will meet the requirements of Section 845.750 c) 2).

This Technical Memorandum presents a demonstration that a 2-foot-thick alternative final protective layer consisting of an 18-inch-thick soil layer and a 6-inch layer of topsoil provide equivalent or superior performance to the default protective layer set forth in Section 845.750 c) 2). The alternative final protective layer works in combination with an underlying low permeability (geomembrane) layer in place of the default three-foot thick, low permeability compacted earth layer required by Section 845.750 c) 1) A). In addition, a geocomposite drainage layer consisting of geogrid web with geotextiles molded on top and bottom of the geogrid ("drainage layer") will be placed on top of the geomembrane prior to installation of the final protective layer. The combination of the above materials comprises the final "alternative final cover system".

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A discussion of how the closure, including the proposed alternative final cover system discussed herein, meets the performance standards is contained in the Closure Plan [2], which includes the Closure Alternatives Assessment required by Section 845.710.

REQUIREMENTS OF SECTION 845

Section 845.750 provides requirements for both the final protective layer and underlying low permeability layer. They work in tandem to provide protection of groundwater and surface exposure conditions. A principal intention of the low permeability layer is to reduce the infiltration of liquid through the final cover system and into the CCR waste mass during post-closure conditions, in accordance with Section 845.720 (a), which states in part:

> *The owner or operator of a CCR surface impoundment must ensure that, at a minimum, the CCR surface impoundment is closed in a manner that will*:
>
> *1) Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate or contaminated run-off to the ground or surface waters or to the atmosphere;*

Specific default requirements for the final cover system are included in Section 845.750(c), which requires the final cover system to have either: 1) a three-foot thick soil low permeability compacted earth layer overlain by a three-foot-thick final protective layer (final protective layer), or 2) a geomembrane low permeability layer with a three-foot-thick final protective layer.

The specific Section 845.750 (c) (2) design requirements for the final protective layer are as follows (emphasis added):

> *Standards for the Final Protective Layer: The final protective layer must meet the following requirements,* ***unless the owner or operator demonstrates that another final protective layer construction technique or material provides equivalent or superior performance to the requirements of this subsection (c)(2****) and is approved by the Agency.*

Therefore, Section 845.750 (c) (2) specifically allows the use of an alternate final protective layer as long as it provides an equivalent or superior performance to the default standards set forth in Section 845.750(c)(2), which are as follows:

A) Cover the entire low permeability layer;

B) Be at least three feet thick, be sufficient to protect the low permeability layer from freezing, and minimize root penetration of the low permeability layer;

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C) Consist of soil material capable of supporting vegetation;

D) Be placed as soon as possible after placement of the low permeability layer; and

E) Be covered with vegetation to minimize wind and water erosion.

The alternate design is only requesting an alternate to Section 845.740(c)(2)(B) related to the thickness of the of the final protective layer.

PROPOSED FINAL COVER SYSTEM SUMMARY

The proposed final cover systems will include:

- A low permeability layer consisting of a linear low-density polyethylene (LLDPE) geomembrane that is at least 40-mil in thickness, placed on a smooth CCR subgrade;
- A drainage layer[1]; and
- A final protective layer consisting of 18 inches of protective cover soil with a 6-inch layer of topsoil capable of supporting vegetation.

The final protective layer will meet all Section 845.750(c)(2) criteria, will not need any supplemental engineering measures, and will be designed by a qualified professional engineer licensed in Illinois.

The concepts of the alternative cover system are illustrated on **Figure 1**.

[1] The drainage layer is not required by Section 845 but has been included to provide for additional reduction of water available for infiltration and for protection for the geomembrane.

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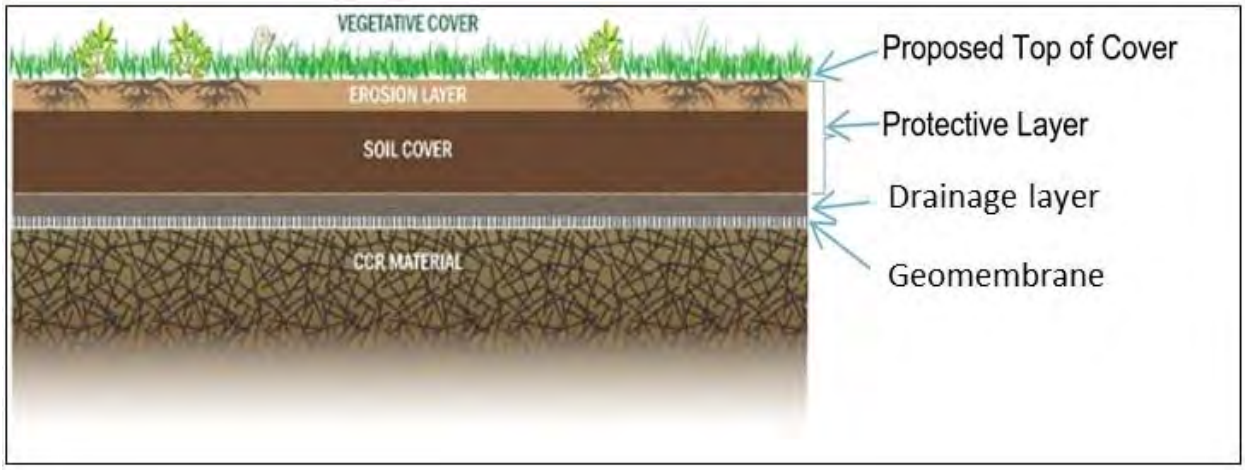

Figure 1: Proposed Alternative Final Cover System

The NPP Site is slated for re-development as a utility-scale solar facility if closure-in-place (CIP) is approved. A solar facility atop the cover system is currently being designed. Components of the vegetative cover may change as details of the solar facility are finalized. This will be discussed further under "Additional Considerations."

DEMONSTRATION

The proposed alternate final protective layer will address the five requirements of Section 845.750 (c)(2)(A) to (E), as described in this section.

Section 845.750(c)(2)(A) Cover the entire low permeability layer

The final protective layer will horizontally cover the entire low-permeability layer, as indicated in the drawings in Appendix B of the Closure Plan [2].

Therefore, the use of the two-foot-thick final protective layer will meet the minimum requirements of Section 845 750(c)(2)(A) because it will completely cover the low-permeability layer.

Section 845.750(c)(2)(B) Be sufficient to protect the low permeability layer from freezing, and minimize root penetration of the low permeability layer

The existing Part 845, which has the same requirements as Part 814 (closure rule for landfills), requires a three-foot-thick final protective layer to protect the underlying low permeability layer from freeze-thaw effects and root penetration. However, when a geomembrane is used as the low permeability layer it does not need these protections since it is not subject to the same impacts (i.e.,

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causing an increase in hydraulic conductivity) as a compacted earth layer as discussed in more detail below.

A geomembrane low permeability layer will be used for the NPP PAP. Geomembranes have the following characteristics:

- Geomembranes do not have pores that can contain water and are therefore not susceptible to freeze-thaw damage that may reduce their performance as a low permeability layer and/or lead to degradation of the geomembrane.
    - In fact, geomembrane panel strength and stiffness both increase with decreasing temperatures ([3], [4]). In 1996, the United States Bureau of Reclamation [5] (USBR) performed testing of both geomembrane panels and seams subjected to up to 500 freeze-thaw cycles, in both constrained and unconstrained conditions, with temperature cycles as severe as +30º C to -20º C.
    - The testing showed no changes in the strength of the geomembrane panels or seams. The USBR concluded that *"...there is simply "no change" in tensile behavior of geomembrane sheets or their seams after freeze-thaw cycling"*.
    - In 2013, the Geosynthetic Institute, upon reviewing the results of the USBR and other studies, concluded that *"the essential question often raised in this regard, i.e., "will freeze-thaw conditions affect geomembrane sheets or their seam behavior," is answered with a resounding "NO""* [6].
- Geomembranes are not susceptible to grass plant root penetration because the geomembranes do not provide organic nutrients to plant roots and do not have pores or other areas where roots can enter the geomembrane.
    - Consequently, geomembranes are not a hospitable material that would either encourage root penetration or allow root penetration. Additionally, the geomembrane will be covered with a or geocomposite drainage layer with a geotextile filter on top, which will provide an additional barrier to root penetration.

U.S. EPA research [7] states that *"...a typical minimum thickness of the cover soil is 0.45 to 0.6 m..." (18 to 24 inches) thick "... for cover systems with hydraulic barriers"* (low permeability layer). This is particularly appropriate when using a geomembrane low permeability which is not susceptible to any impact from freezing. U.S. EPA research also states that cover thickness design for root penetration into the low permeability layer is only a concern for compacted clay layers or geosynthetic clay barriers. This is when using an appropriate design of cover vegetation.

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Therefore, the use of the two-foot-thick final protective layer will provide equivalent or superior performance to the requirements of Section 845.750 (c) (2) (B) when coupled with a geocomposite drainage layer covered by a geotextile filter, and a geomembrane low permeability layer, as geomembranes are not susceptible to freeze-thaw damage or root penetration as compared to a low permeability compacted earth layer.

Section 845.750(c)(2)(C) Consist of soil material capable of supporting vegetation.

The uppermost six inches of the final protective layer will consist of topsoil that is capable of supporting vegetation, which is the same requirement as the default (three-foot thick) final protective layer. This is also consistent with the Federal CCR Rule, which requires a six-inch-thick "erosion" (topsoil) layer. Research [7] and Geosyntec's experience indicate topsoil layers are designed to have shallow-rooted grasses and most shallow-rooted grasses do not typically penetrate more than six inches into the subsurface. Shallow-rooted grasses will be specified based on recommendations from specialists at nurseries in the location of NPP and Illinois Department of Transportation guidelines. The topsoil layer will be fertilized and/or amended, as necessary, on a site-specific basis based on agronomical soil testing, to provide a growing medium for the vegetation that provides the required levels of nutrients and water storage during drought conditions.

Grass species will also be selected on a site-specific basis to minimize long-term vegetation maintenance, based on the climatic conditions at each site and the soil types. Vegetation will be established by applying seed and mulch and watering to establish the vegetation. Temporary erosion control measures will also be used during vegetation establishment to protect the topsoil layer from erosion. These measures may include erosion control blankets (ECBs), silt fences, hydroseeding, and/or other methods. The Post-Closure Care Plan includes the commitment to maintain the vegetation of the surface for the closed NPP PAP within the Construction Permit Application [8].

The 18-inches of the protective layer below the topsoil will consist of a soil type suitable for retaining moisture to provide additional support for vegetation during times of drought, and to support any grass species with roots that exceed six inches. Such soil types may include sandy clay loam, silty loam, silts, silty clays, lean clays, sandy clays, and/or sandy silts.

Therefore, the use of the two-foot-thick protective layer will meet the requirements of Section 845.750(c)(2)(C), as the final protective layer will utilize soil capable of supporting vegetation.

Section 845.750(c)(2)(D) Be placed as soon as possible after placement of the low permeability layer

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The NPP PAP Closure Plan (Section 4.7.2 [2]) states that the geotextile and cover soil "…will be placed as soon as practical after the geomembrane has been deployed and both quality assurance and quality control testing has been performed on the geomembrane seams."

The use of a two-foot-thick protective layer will allow the final protective layer to be placed on top of the low permeability layer and vegetation to be established on top of the final protective layer sooner than if a three-foot thick final protective layer is used. This is due to the 33% reduction in earthwork volumes associated with the thinner 2-ft-thick final protective layer.

Therefore, the use of the two-foot-thick final protective layer will exceed the minimum requirements of Section 845.750(c)(2)(D), by allowing the protective layer to be installed sooner than when using a three-foot-thick protective layer.

Section 845.750(c)(2)(E) Be covered with vegetation to minimize wind and water erosion.

The topsoil layer placed as part of the final protective layer will be fertilized and vegetated, as noted in the discussion regarding Section 4.7.2 of the Closure Plan [2]. Additionally, the following design and engineering features, construction techniques, and maintenance procedures will be used to reduce the potential for wind and water erosion under both long-term conditions and during vegetation establishment.

- Design and Engineering Features
    - Final cover system slopes will be installed at relatively gentle grades (e.g., typically 2%). The use of gentle grades will reduce water runoff velocities and therefore reduce the potential for water erosion of the final cover soils.
    - The geocomposite drainage layer helps to facilitate lateral drainage of infiltration off the geomembrane, thereby reducing the amount of water available for infiltration through the geomembrane and provides cushioning over the geomembrane. This layer is not required by Section 845.750, but it enhances the final cover system performance.
    - A stormwater management system consisting of channels, pipes, and letdown structures is included in the drawings within the Closure Plan [2] and will be designed to collect stormwater in a controlled manner and route it off the final cover system which will minimize infiltration into the CCR waste mass. The stormwater management system will minimize the overland flow distance between stormwater channels. Channels will be lined with an appropriate material, based on estimated stormwater velocities, to limit water erosion.

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- Construction Techniques
    - The final protective layer is typically the most susceptible to wind and water erosion in the period between the placement of the protective layer and the establishment of vegetation. To reduce the potential for both wind and water erosion during this time, the following approaches will be utilized:
        - Temporary erosion and sediment controls (ESCs) will be installed to reduce the potential for erosion, such as erosion control blankets (ECBs), silt socks (e.g., straw wattles), silt fences, and other methods. These ESCs will be regularly inspected and maintained until vegetation is established.
        - The entire surface of the final protective layer will be stabilized during seeding and until vegetation is established. Coverings may consist of straw mulch, hydroseeding binder, ECBs, or engineering growing media.
        - The final protective layer will be regularly inspected and maintained during vegetation establishment. Any areas that become eroded by wind and water will be repaired until vegetation is established to a suitable level over the surface of the final cover.
- Maintenance Procedures
    - During the post-closure care period, vegetation established on the final protective cover layer will be regularly maintained using a written and IEPA-approved maintenance program. The program will consist of regular mowing and inspections. Any bare areas or areas of erosion will be repaired by seeding and stabilizing the area, and observing the area until vegetation becomes re-established.
    - The final cover slopes will be relatively gentle at 2%; these slopes experience less erosion in general, especially less than typical landfill covers sloped at predominately 25 to 33%. Typically, after three to five years, it is Geosyntec's experience that the cover vegetation becomes fully stabilized and experiences less erosion.

In conclusion, the use of the two-foot-thick final protective layer will exceed the minimum requirements of Section 845 750 c) 2) E), using a robust program to support the establishment of protective vegetation, prevent and address any erosion that may occur during vegetation establishment, and monitor and maintain the vegetation during post-closure conditions.

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ADDITIONAL CONSIDERATIONS

Infiltration Analysis

The use of the proposed two-foot-thick final protective layer, when coupled with a geomembrane low permeability layer, will also meet the criteria contained within Section 845.750 (a) (1). Section 845.750 (a) (1) provides the following requirement:

> *Section 845.750(a)(1) Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;*

Section 845.750(a)(1) is an important overall measure of the effectiveness of the final cover system because it requires control of post-closure infiltration of liquids through the final cover and into the waste and releases of CCR.

An infiltration analysis was performed to by Ramboll, within the NPP PAP Construction Permit Application [8], to estimate post-closure liquid infiltration rates through both the default and the proposed alternate final cover systems at the NPP PAP. The infiltration analysis used the Hydrologic Evaluation of Landfill Performance (HELP) software promulgated by the USEPA [9]. The HELP model estimates the infiltration rates from the top of the cover, through the final protective layer and through the low permeability layer (either a geomembrane or the three-foot thick compacted earth layer). The results are included in **Appendix A**. The resulting estimated infiltration rates are provided in **Table 1**.

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Table 1 – NPP PAP Final Cover Systems for Infiltration Analysis

Description	Low Permeability Layer[2]	Final Protective Layer	Infiltration Rate[3]
Proposed Alternative Final Cover System	40-mil Linear Low-Density Polyethylene (LLDPE) Geomembrane	2 ft of cover material, including, from bottom to top, a 200-mil geosynthetic drainage net layer, 1.5 ft of sandy silty clay and 0.5 ft of sandy clay loam	0.042 in/yr
Default Cover with Geomembrane Barrier	40-mil LLDPE Geomembrane	3 ft of cover material, including, from bottom to top, a 200-mil geosynthetic drainage net layer, 2.5 ft of sandy silty clay and 0.5 ft of sandy clay loam	0.053 in/yr
Default Cover with Compacted Earth Layer	3-ft thick compacted earth layer (1×10-7 cm/sec)	3 ft of cover material, including, from bottom to top, 2.5 ft of sandy silty clay and 0.5 ft of sandy clay loam	2.07 in/yr

The NPP PAP analysis indicated that the performance of the proposed alternative final cover system with a geomembrane and a two-foot-thick final protective cover exceeds the performance offered by the default final cover system utilizing a geomembrane with the default three-foot-thick protective layer and cushion layer, with the infiltration rate reduced by a factor of 1.3.

Furthermore, the proposed alternate final cover system performance excess the performance of a final cover system using a three-foot-thick compacted earthen low permeability layer and a three-foot-thick final protective layer (a total cover thickness of six feet) by reducing infiltration by a factor of 49.

Post-Closure Construction of Solar Panel Electrical Generating System

The NPP Site is slated for re-development as a utility-scale solar facility if closure-in-place (CIP) is approved. A solar facility atop the cover system is currently being designed. Components of the vegetative cover may change as details of the solar facility are finalized. The system will be designed, installed, and operated such that the closure performance standards will be maintained at an equivalent level as proposed in the NPP PAP Closure Plan [2].

For example, the panels are expected to be supported by concrete slab ballast foundations that will replace portions of the erosion (topsoil) layer and not cause excessive settlement of the cover and

[2] All HELP run versions used a pinhole density of 1 hole per acre, installation defects of 1 hole/acre, and construction quality as "good".
[3] Infiltration is out the bottom of the low permeability layer.

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will reduce the amount of infiltration. The ballast foundations will not penetrate the geomembrane low-permeability layer to reduce the potential for defects that could otherwise increase infiltration. The space around the panel foundations will be replaced with an alternative to shallow rooted vegetation and will include stormwater runoff and erosion materials that will meet the erosion control standards of Section 845.750 and may also include forbs (herbaceous flowering plants).

Environmental and Societal Benefits

The use of the proposed two-foot-thick final protective layer will provide the following additional environmental and societal benefits, relative to the default three-foot-thick final protective layer:

- The final cover system earthwork quantities will be reduced by 33%. This will result in a corresponding 33% reduction in the amount of onsite soil fill that needs to be excavated, hauled to the construction location, and placed. This provides multiple benefits, such as:
    - Reduced disruption to onsite areas caused by the excavation of fill materials and corresponding disturbance to the natural environment.
    - Reduced haul truck traffic on site access roadways, thereby reducing air pollution and carbon emissions.
    - Reduced earthwork effort during installation of the final cover system, thereby reducing air pollution and carbon emissions.
- Construction of the alternate final cover system can be completed faster than the default final cover, providing multiple benefits, such as:
    - Initiation of the reduction of infiltration at a sooner date than with the default final cover system.
    - Ceasing construction-related impacts to offsite residents (e.g., air pollution, carbon emissions) at a sooner date than otherwise possible.
- The installation of a solar panel electrical generating system will provide green energy to the community and reduce the maintenance associated with the shallow rooted vegetation.

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SUMMARY

The proposed alternate final protective layer will:

- Provide equivalent or superior performance to the requirements of Section 845.750 (c)(2).
- Have a drainage layer, which is not required by Section 845.750, over the geomembrane that adds both lateral drainage layer to reduce the amount of water available for infiltration through the geomembrane and physical protection for the geomembrane.
- Have a lower infiltration rate than the infiltration through the default soil final cover system.
- Meet or exceed the same criteria for long term performance and all other requirements of Section 845.750(c)(2).
- Provide other benefits by reducing the amount of final cover earthwork by 33% for the NPP PAP.
- A solar panel electrical generating system will provide green energy to the community and reduce the maintenance of the cover.

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REFERENCES

[1] Illinois Environmental Protection Agency, "35 Ill. Adm. Code Part 845, Standards for the Disposal of Coal Combustion Residuals in Surface Impoundments," Springfield, IL, 2021.

[2] HDR, "Primary Ash Pond Final Closure Plan," 2022.

[3] A. L. Rollin, J. Lafleur, M. Marcotte, O. Dascal and Z. Akber, "Selection Criteria for the Use of Geomembranes in Dams and Dykes in Northern Climate," in *Proceedings of the International Conference on Geomembranes*, Denver, Colorado, 1945.

[4] D. E. Thorton and P. Blackall, "Report EPA-3-76-13: Field Evaluation of Plastic Film Liners for Petroleum Storage Areas in the Mackenzie Delta," Canadian Environmental Protection Service, 1976.

[5] A. I. Comer and Y. G. Hsuan, "Report R-96-03: Freeze-Thaw Cycling and Cold Temperature Effects on Geomembrane Sheets and Seams," U.S. Bureau of Reclamation, 1996.

[6] Y. G. Hsuan, R. M. Koerner and A. I. Comer, "GSI White Paper #28: Cold Temperature and Freeze-Thaw Cycling Behavior of Geomembranes and their Seams," Geosynthetic Institute, Folsom, Pennsylvania, 2013.

[7] United States Environmental Protection Agency, "(Draft) Technical Guidance For RCRA/CERCLA Final Covers," Office of Solid Waste and Emergency Response, Washington D.C., 2004.

[8] HDR, "Illinois Power Generating Company, Primary Ash Pond, Construction Permit Application," 2022.

[9] T. Tolaymat and M. Krause, "Hydrologic Evaluation of Landfill Performance: HELP 4.0 User Manual," United States Environmental Protection Agency, Washington, DC, 2020.

APPENDIX A: HELP MODEL OUTPUT

A-1: NPP PAP- 2-FT FINAL PROTECTIVE COVER SOIL

A-2: NPP PAP-3-FT FINAL PROTECTIVE COVER SOIL

A-3: NPP PAP-3-FT COMPACTED EARTH LAYER, 3-FT FINAL PROTECTIVE COVER SOIL

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APPENDIX A-1

NPP PAP- 2-FT FINAL PROTECTIVE COVER SOIL

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP CIP Cons **Simulated On:** 6/21/2022 10:43

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.2475	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2

Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	18	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.3706	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3

Type 2 - Lateral Drainage Layer
Drainage Net (0.5 cm)
Material Texture Number 20

Thickness	=	0.2	inches
Porosity	=	0.85	vol/vol
Field Capacity	=	0.01	vol/vol
Wilting Point	=	0.005	vol/vol
Initial Soil Water Content	=	0.0581	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E+01	cm/sec
Slope	=	2	%
Drainage Length	=	1500	ft

Layer 4

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness	=	0.04	inches
Effective Sat. Hyd. Conductivity	=	4.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 5

Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash
Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1871	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	84.4	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	265	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	5.928	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	37.354	inches
Total Initial Water	=	38.924	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days

End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:44

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	5.561	[3.492]	5,349,478.7	11.96
Evapotranspiration	30.979	[2.74]	29,800,414.9	66.64
Subprofile1				
Lateral drainage collected from Layer 3	9.9514	[2.1689]	9,572,702.5	21.41
Percolation/leakage through Layer 4	0.041772	[0.018348]	40,183.0	0.09
Average Head on Top of Layer 4	1.4441	[0.6401]	---	---
Subprofile2				
Percolation/leakage through Layer 5	0.042250	[0.019041]	40,642.1	0.09
Water storage				
Change in water storage	-0.0486	[1.0288]	-46,743.0	-0.10

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:44

	Peak Values for Years 1 - 30*		
	(inches)		(cubic feet)
Precipitation	3.43		3,301,549.4
Runoff	3.048		2,931,612.5
Subprofile1			
Drainage collected from Layer 3	0.1514		145,634.4
Percolation/leakage through Layer 4	0.001891		1,818.8
Average head on Layer 4	24.0066		---
Maximum head on Layer 4	38.7320		---
Location of maximum head in Layer 3	289.48	(feet from drain)	
Subprofile2			
Percolation/leakage through Layer 5	0.001526		1,467.8
Other Parameters			
Snow water	3.0807		2,963,435.7
Maximum vegetation soil water	0.3993	(vol/vol)	
Minimum vegetation soil water	0.2453	(vol/vol)	

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:44
Simulation period: 30 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	1.6232	0.2705
2	6.6658	0.3703
3	0.0052	0.0262
4	0.0000	0.0000
5	29.1717	0.1870
Snow water	0.0000	---

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APPENDIX A-2

NPP PAP- 3-FT FINAL PROTECTIVE COVER SOIL

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP Default **Simulated On:** 6/21/2022 10:56

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.2475	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2

Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	30	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.3718	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3

Type 2 - Lateral Drainage Layer
Drainage Net (0.5 cm)
Material Texture Number 20

Thickness	=	0.2	inches
Porosity	=	0.85	vol/vol
Field Capacity	=	0.01	vol/vol
Wilting Point	=	0.005	vol/vol
Initial Soil Water Content	=	0.092	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E+01	cm/sec
Slope	=	2	%
Drainage Length	=	1500	ft

Layer 4

Type 4 - Flexible Membrane Liner
LDPE Membrane
Material Texture Number 36

Thickness	=	0.04	inches
Effective Sat. Hyd. Conductivity	=	4.00E-13	cm/sec
FML Pinhole Density	=	1	Holes/Acre
FML Installation Defects	=	1	Holes/Acre
FML Placement Quality	=	3	Good

Layer 5

Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash
Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1872	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

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Initial Water in Evaporative Zone	=	5.92	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	41.857	inches
Total Initial Water	=	43.427	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days

End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
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3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
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84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:57

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	5.416	[3.469]	5,210,333.7	11.65
Evapotranspiration	30.948	[2.734]	29,770,001.9	66.57
Subprofile1				
Lateral drainage collected from Layer 3	10.1178	[2.2092]	9,732,826.8	21.77
Percolation/leakage through Layer 4	0.053103	[0.027784]	51,082.0	0.11
Average Head on Top of Layer 4	1.8201	[0.9543]	---	---
Subprofile2				
Percolation/leakage through Layer 5	0.054052	[0.028093]	51,994.9	0.12
Water storage				
Change in water storage	-0.0506	[1.0901]	-48,662.0	-0.11

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:57

	Peak Values for Years 1 - 30*		
	(inches)		(cubic feet)
Precipitation	3.43		3,301,549.4
Runoff	3.048		2,931,607.7
Subprofile1			
Drainage collected from Layer 3	0.1514		145,640.0
Percolation/leakage through Layer 4	0.002901		2,790.3
Average head on Layer 4	35.9348		---
Maximum head on Layer 4	54.8096		---
Location of maximum head in Layer 3	355.60	(feet from drain)	
Subprofile2			
Percolation/leakage through Layer 5	0.001630		1,567.7
Other Parameters			
Snow water	3.0807		2,963,435.7
Maximum vegetation soil water	0.3993	(vol/vol)	
Minimum vegetation soil water	0.2453	(vol/vol)	

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Newton Ash Pond
Simulated on: 6/21/2022 10:57
Simulation period: 30 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	1.6232	0.2705
2	11.1032	0.3701
3	0.0112	0.0560
4	0.0000	0.0000
5	29.1720	0.1870
Snow water	0.0000	---

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APPENDIX A-3

NPP PAP-3-FT COMPACTED EARTH LAYER, 3-FT FINAL PROTECTIVE COVER SOIL

HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE
HELP MODEL VERSION 4.0 BETA (2018)
DEVELOPED BY USEPA NATIONAL RISK MANAGEMENT RESEARCH LABORATORY

Title: NEW AP Default Earth **Simulated On:** 6/21/2022 11:11

Layer 1

Type 1 - Vertical Percolation Layer (Cover Soil)
SCL - Sandy Clay Loam
Material Texture Number 10

Thickness	=	6	inches
Porosity	=	0.398	vol/vol
Field Capacity	=	0.244	vol/vol
Wilting Point	=	0.136	vol/vol
Initial Soil Water Content	=	0.3858	vol/vol
Effective Sat. Hyd. Conductivity	=	1.20E-04	cm/sec

Layer 2

Type 1 - Vertical Percolation Layer
Sandy Silty Clay - PAP
Material Texture Number 43

Thickness	=	30	inches
Porosity	=	0.4	vol/vol
Field Capacity	=	0.35	vol/vol
Wilting Point	=	0.3	vol/vol
Initial Soil Water Content	=	0.4	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-05	cm/sec

Layer 3

Type 3 - Barrier Soil Liner
Liner Soil (High)
Material Texture Number 16

Thickness	=	36	inches
Porosity	=	0.427	vol/vol
Field Capacity	=	0.418	vol/vol
Wilting Point	=	0.367	vol/vol
Initial Soil Water Content	=	0.427	vol/vol
Effective Sat. Hyd. Conductivity	=	1.00E-07	cm/sec

Layer 4

Type 1 - Vertical Percolation Layer (Waste)
High-Density Electric Plant Coal Fly Ash

Material Texture Number 30

Thickness	=	156	inches
Porosity	=	0.541	vol/vol
Field Capacity	=	0.187	vol/vol
Wilting Point	=	0.047	vol/vol
Initial Soil Water Content	=	0.1996	vol/vol
Effective Sat. Hyd. Conductivity	=	5.00E-05	cm/sec

Note: Initial moisture content of the layers and snow water were computed as nearly steady-state values by HELP.

General Design and Evaporative Zone Data

SCS Runoff Curve Number	=	84.4	
Fraction of Area Allowing Runoff	=	100	%
Area projected on a horizontal plane	=	265	acres
Evaporative Zone Depth	=	18	inches
Initial Water in Evaporative Zone	=	7.115	inches
Upper Limit of Evaporative Storage	=	7.188	inches
Lower Limit of Evaporative Storage	=	4.416	inches
Initial Snow Water	=	1.570044	inches
Initial Water in Layer Materials	=	60.819	inches
Total Initial Water	=	62.389	inches
Total Subsurface Inflow	=	0	inches/year

Note: SCS Runoff Curve Number was calculated by HELP.

Evapotranspiration and Weather Data

Station Latitude	=	38.93	Degrees
Maximum Leaf Area Index	=	4.5	
Start of Growing Season (Julian Date)	=	120	days
End of Growing Season (Julian Date)	=	300	days
Average Wind Speed	=	8	mph
Average 1st Quarter Relative Humidity	=	73	%
Average 2nd Quarter Relative Humidity	=	71	%
Average 3rd Quarter Relative Humidity	=	75	%
Average 4th Quarter Relative Humidity	=	75	%

Note: Evapotranspiration data was obtained for Newton, Illinois

Normal Mean Monthly Precipitation (inches)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec

3.464157	2.363177	4.307613	4.875747	5.596821	4.968593
3.874885	3.10377	3.080127	3.602883	4.376843	2.870644

Note: Precipitation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Normal Mean Monthly Temperature (Degrees Fahrenheit)

Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
39	38.7	47.8	61.1	70.7	80.8
84.9	82.3	72.7	58.1	47.1	38.2

Note: Temperature was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28
Solar radiation was simulated based on HELP V4 weather simulation for:
Lat/Long: 38.93/-88.28

Average Annual Totals Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 11:12

	Average Annual Totals for Years 1 - 30*			
	(inches)	[std dev]	(cubic feet)	(percent)
Precipitation	46.49	[5.78]	44,716,495.2	100.00
Runoff	12.238	[4.888]	11,772,719.1	26.33
Evapotranspiration	32.236	[2.871]	31,009,280.2	69.35
Subprofile1				
Percolation/leakage through Layer 3	2.070136	[0.059537]	1,991,367.4	4.45
Average Head on Top of Layer 3	23.9878	[1.7467]	---	---
Subprofile2				
Percolation/leakage through Layer 4	1.821708	[0.604523]	1,752,392.2	3.92
Water storage				
Change in water storage	0.1893	[1.099]	182,103.7	0.41

* Note: Average inches are converted to volume based on the user-specified area.

Peak Values Summary

Title: Newton Ash Pond
Simulated on: 6/21/2022 11:12

	Peak Values for Years 1 - 30*		
	(inches)		(cubic feet)
Precipitation	3.43		3,301,549.4
Runoff	3.183		3,062,071.3
Subprofile1			
Percolation/leakage through Layer 3	0.006803		6,544.2
Average head on Layer 3	35.9998		
Subprofile2			
Percolation/leakage through Layer 4	0.009219		8,868.7
Other Parameters			
Snow water	3.0807		2,963,435.7
Maximum vegetation soil water	0.3993	(vol/vol)	
Minimum vegetation soil water	0.2453	(vol/vol)	

Final Water Storage in Landfill Profile at End of Simulation Period

Title: Newton Ash Pond
Simulated on: 6/21/2022 11:12
Simulation period: 30 years

	Final Water Storage	
Layer	(inches)	(vol/vol)
1	2.1868	0.3645
2	11.9241	0.3975
3	15.3720	0.4270
4	38.5853	0.2473
Snow water	0.0000	---

Attachment H

Public Notification and Public Meeting Certification

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Luminant

James Marshall
Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234

July 28, 2022

Illinois Environmental Protection Agency
DWPC – Permits MC # 15
ATTN: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, IL 62794-9276

Re: 35 IAC 845.220(a)(9) Certification Statement
Newton Power Plant Primary Ash Pond (IEPA ID # W0798070001-01)

Dear Mr. Darin LeCrone:

For the above-refenced CCR surface impoundment and in accordance with 35 IAC 845.220(a)(9), Illinois Power Generating Company certifies that the public notification and public meetings required under 35 IAC 845.240 were completed. Please find enclosed both the public meeting summary and listserv.

Sincerely,
Illinois Power Generating Company

James R Marshall

James Marshall
Plant Manager

Newton Public Meeting Summary, May 24, 2022

On April 24, 2022, Illinois Power Generating Company (IPGC) made available to the public its plans to close the Primary Ash Pond (PAP) located at the Newton Power Plant. On Tuesday, May 24, 2022, Illinois Power Generating Company held in-person public meetings at West End Reception and Events, in Newton, Illinois at 3:00 pm and 5:30 pm to present its decision-making process. A comparison of projected groundwater impacts for the alternatives presented, and an objective comparison of the pros and cons of each alternative were presented at these meetings. During the question-and-answer portion of the meeting, the public asked questions relating to the proposed closure and the company provided answers. As required by Section 845.240(g), this document provides a general summary of the issues or comments raised by the public relating to the closure, and a summary of the company's responses to those issues or comments. All questions asked during the meeting were addressed.

Issue / Topic		Summary of Response Provided at Meeting	Additional Written Response
1.	On-Site Landfill	There is an existing landfill located on the Newton Power Plant Property. The landfill is located west of the PAP. The use of this existing landfill for disposal of ash in the PAP was evaluated in the Closure Alternatives Analysis (CAA); the evaluation concluded that the landfill would need to be reconstructed and expanded prior to receiving ash from the PAP. The use of the on-site landfill for disposal of ash in the PAP was not the selected closure alternative in the CAA.	The existing composite lined landfill onsite has approximately 11.7-acres constructed and been closed/capped. There is an area of about 7.2-acres that was constructed and not used. This area would require re-construction prior to use. There are about 33.96-acres remaining to construct in the permitted landfill footprint (including the area requiring reconstruction). Even with the remaining area to construct, the permitted landfill area is not adequate to hold the volume of waste that is held in the PAP. Expansion of the onsite landfill would require additional infrastructure to be installed, time for permitting efforts, and the closure itself would take significantly longer to complete. Additionally, landfill height would have to be increased and potentially more visible to surrounding areas.
2.	Ash Pond Closure	Closure of an ash pond means that that ash within the pond is either capped in place or excavated and disposed in an alternative landfill. In Part 845, IEPA allows different closure approaches to be evaluated and sets criteria that must be evaluated for each	The Closure Alternatives Analysis (CAA) provides a detailed evaluation of the different factors that were evaluated for the closure alternatives that were considered for the PAP at the Newton Power Plant as required by Part 845. These factors include, but are not limited to, reduction of risks,

Issue / Topic		Summary of Response Provided at Meeting	Additional Written Response
		potential closure approach. The IEPA will review the site's closure and post closure plans prior to approval of a closure approach and may re-evaluate groundwater corrective action during post-closure based on closure conditions or monitoring results. The post closure care period is a minimum of 30 years.	likelihood of future releases, impacts to workers and the community, impacts to scenic, historic, and recreational areas, time until the GWPSs are achieved, and reliability and implementability of the closure approach.
3.	Groundwater/ Groundwater Protection Standards (GWPS)s	Under the Illinois Part 845 regulations, the groundwater monitoring has demonstrated that there currently are "potential" exceedances of the GWPSs. These exceedances are still considered "potential" because IEPA has not yet approved the statistical approach used to evaluate the groundwater data. If these "potential" GWPS exceedances are confirmed, corrective measures will be evaluated as required by Part 845. Groundwater monitoring is on-going at the site. While there are some monitoring wells that have existed at the property for many years, additional monitoring wells were installed as a result of the Federal CCR rule in 2015. Moreover, monitoring wells were also installed more recently as a result of the Illinois Part 845 regulations. Groundwater at these monitoring wells is sampled and analyzed routinely to comply with both the Federal and State requirements.	

Issue / Topic		Summary of Response Provided at Meeting	Additional Written Response
4.	Closure-in Place/Ash Consolidation	Closure in place includes consolidating to the north, and placement of a geomembrane liner over the consolidated ash.	The composite cap components used for final cover include an LLDPE geomembrane liner, cover soil, vegetation, and stormwater control features. Consolidation to the north allows for a smaller closure footprint than the current PAP area and ash will remain above the upper most aquifer. Also, it provides for the establishment of slopes that direct stormwater away from the composite cap to the stormwater management system south of the closure area.
5.	Groundwater Monitoring	For the closure-in-place alternative, groundwater monitoring will continue on the property for at least 30 years. However, if GWPSs have not been achieved in that timeframe, groundwater monitoring will continue as required.	
6.	Post-Closure Conditions	The selected closure approach involves removing liquid waste from the ash, consolidating the ash within a smaller portion of the ash pond located above the uppermost aquifer, and covering the consolidated ash with a geomembrane. By removing liquid waste, consolidating the ash, and installing a geomembrane over the ash, infiltration into the ash and releases to groundwater will be minimized. Modeling has demonstrated that this closure process will result in groundwater concentrations achieving the groundwater protection standards at the same or similar rate as closure by removal. After closure is completed, slopes will be maintained, and the southern berm will be	

Issue / Topic		Summary of Response Provided at Meeting	Additional Written Response
		removed to ensure that water is not impounded on top of the consolidated and capped ash.	
7.	Public Meeting Announcements and Advertising	The advertising and announcements for this public meeting were conducted consistent with IEPA and Part 845 requirements. Specifically, 30 days prior to the meeting, notices were mailed to all residents that live within 1 mile of the Newton Power Plant. Moreover, notices were posted in public areas including local libraries and post offices within 10 miles of the Newton Power Plant. With the ongoing application process, the IEPA will circulate a public notice of its tentative decision following submittal of the application in August. This will be followed by a 45-day public comment period. If the IEPA determines there is significant public interest, a public hearing will be held.	

In accordance with 845.240(f)(4), a list of people who requested to be added to the IEPA Listserv for Newton is as follows:

Newton construction permit public meetings	
People requesting to be added to IEPA Listserv	
Name	Email address
Phil Rauch	philiprauch63@icloud.com
Paula Frohning	dprnf67@gmail.com
Rick Cochran	rpcochran73@gmail.com
Debby & Greg Fehn	debbyjfeh@yahoo.com

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Attachment I

Closure Prioritization Category Letter

Electronic Filing: Received, Clerk's Office 07/01/2024

Phil Morris
Illinois Power Generating Company
Luminant
1500 Eastport Plaza Drive
Collinsville, IL 62234

May 19, 2021

Mr. Darin LeCrone, P.E.
Manager, Industrial Unit
Bureau of Water, Division of Water Pollution Control, Permits Section
Illinois Environmental Protection Agency
1021 North Grand Avenue, East
Springfield, IL 62794-9276

Re: CCR Surface Impoundment Category Designation and Justification for Illinois Power Generating Company

Dear Mr. LeCrone:

Pursuant to 35 I.A.C. 845.700(c), Illinois Power Generating Company submits the information necessary to categorize the CCR surface impoundments located at the Newton Power Plant and the now retired Coffeen Power Plant. The following parameters were used in assessing and justifying each assigned category.

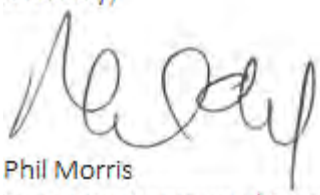
- Category 1 – *Impacts to existing potable water supply well or impacts to groundwater quality within the setback of an existing potable water supply well.*
  - This review includes an assessment of potable water wells within 2,500 feet of CCR surface impoundments to determine whether any potential impacts are occurring within the setback zone of any community water supply well established under the Illinois Groundwater Protection Act.
  - This information was developed during the Part 845 rulemaking and is summarized in Attachment 1, Table 2: Impacts to Potable Water Supply.
- Category 2 – *Imminent threat to human health or the environment or have been designated by IEPA under (g)(5)*
  - The surface impoundments at Newton and Coffeen Power Plants do not pose an imminent threat to human health or the environment. There are no known conditions at or around the facility where someone or something may be exposed to contaminant concentrations reasonably expected to cause harm
- Category 3 – *Located in areas of environmental justice ("EJ") concern*
  - EJ areas were evaluated using the EJ mapping link from IEPA's webpage located at https://www2.illinois.gov/epa/topics/environmental-justice. Per the IEPA mapping tool, the EJ Status thresholds were determined as twice the state averages for Minority and Low Income consistent with 35 IAC 845.700(g)(6).
  - An EJ map denoting the facilities with impoundments is located in Attachment 2.

- Category 4-7
    - Category 4 - Inactive CCR surface impoundments that have an exceedance of the groundwater protection standards in Section 845.600
    - Category 5 - Existing CCR surface impoundments that have exceedances of the groundwater protection standards in Section 845.600
    - Category 6 - Inactive CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600.
    - Category 7 – Existing CCR surface impoundments that are in compliance with the groundwater protection standards in Section 845.600

Based on the information above, category designations have been assigned. The category designations for each CCR impoundment are shown in Attachment 1, Table 1: Category Designations.

If you have any questions regarding this submittal, please contact Phil Morris at 618-343-7794 or phil.morris@vistracorp.com.

Sincerely,



Phil Morris
Senior Environmental Director

Attachments

Attachment 1

Table 1: Category Designation

Facility	Pond Description	Classifications	Potable Water Supply Impacts (Category 1)	Human Health or Environment Threat (Category 2)	Located within Environmental Justice Areas[1] (Category 3)	Standards Exceedances[2] (Categories 4,5,6,7)	Impoundment Category 845.700(g)
Coffeen	Ash Pond 1	Inactive	No	No	No	Yes	5
	GMF Pond	Inactive	No	No	No	Yes	5
	GMF Recycle Pond	Inactive	No	No	No	Yes	5
Newton	Primary Ash Pond	Existing	No	No	No	Yes	5

[1] See Attachment 2 Environmental Justice Area Map

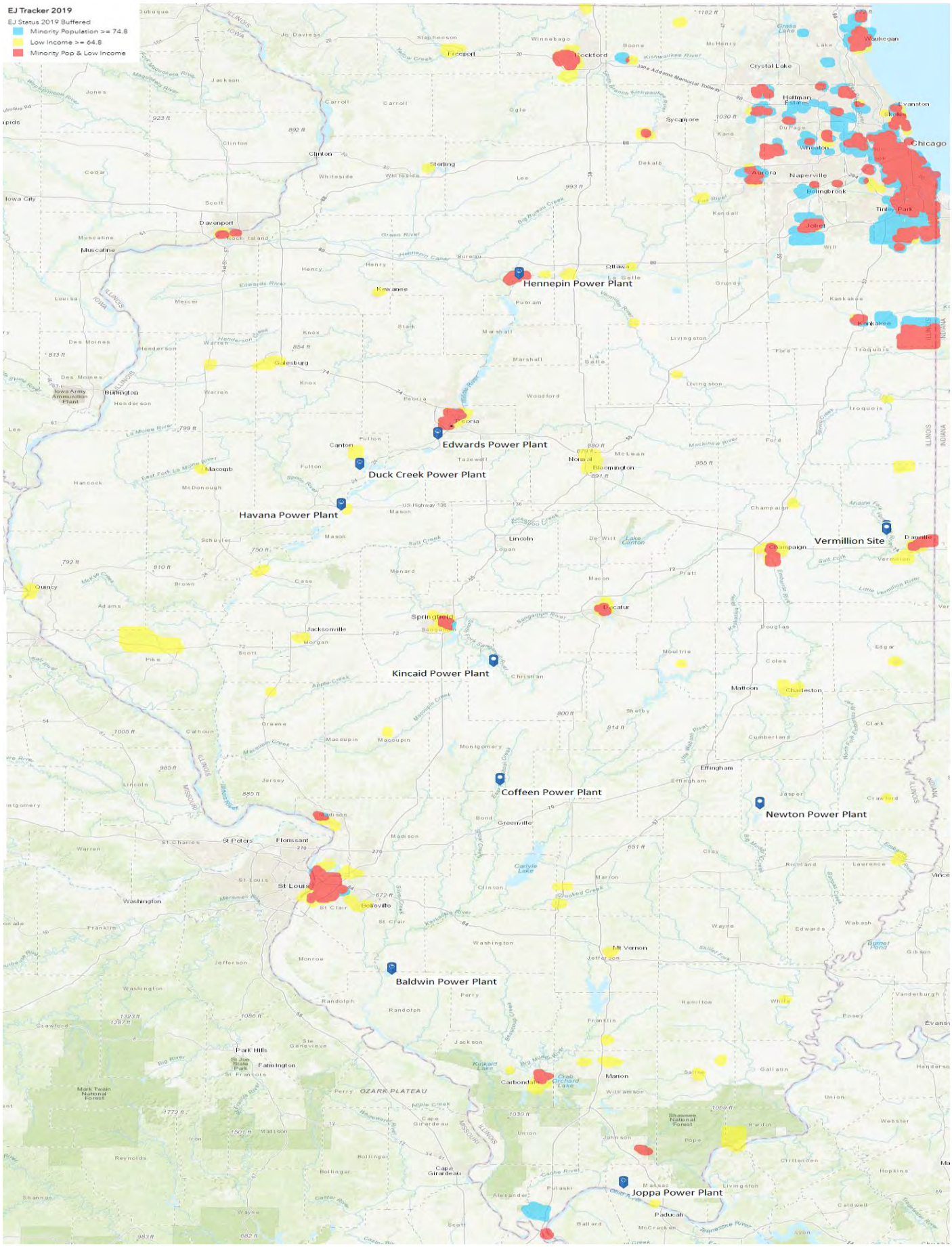
[2] Ground water analyses for purposes of categories 4-7, assumptions have been made based on current groundwater data. However, since sampling and analysis is ongoing and subject to IEPA review and approval, IPGC reserves the right to update its category designations for Categories 4-7.

Table 2: Impacts to Potable Water Supply[1]

Site Name	Private and Semi-Private Wells	Non-Community Water Supply (CWS) Wells	Non-CWS Surface Water Intakes	Community Water Supply Wells	CWS Surface Water Intakes
Coffeen	**Present, but not at risk** Thirty-four (34) water wells were identified; however, they are unlikely to be at risk because of their hydrogeologic location relative to the power plant, they are abandoned, or they do not appear to be used for potable purposes. None of the off-site wells are located in a downgradient direction.	**Present, but not at risk** Three (3) non-CWS wells were identified; however, they are unlikely to be at risk because of their hydrogeologic location relative to the power plant and/or their inactive status.	Absent	Absent	Absent
Newton	**Present, but not at risk** Twenty-four (24) water wells were identified; however, they are unlikely to be at risk because of their hydrogeologic location relative to the power plant, they are abandoned, and/or they are unlikely to be present based on the mapped location. None of the offsite wells are located in a downgradient direction.	Absent	Absent	Absent	Absent

[1] Ramboll, WELL/WATER SUPPLY SURVEY AND EVALUATION COAL-FIRED POWER PLANTS IN ILLINOIS (September 24, 2020), filed with the Illinois Pollution Control Board in R2020-019.

Attachment 2: EJ Mapping Denoting Facilities with Impoundments



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Attachment J

Post-Closure Care Plan

POST-CLOSURE PLAN FOR EXISTING CCR SURFACE IMPOUNDMENT
40 C.F.R. § 257.104 rule and 35 I.A.C. 845.780
REV 0 – 10/30/2021

SITE INFORMATION			
Site Name / Address	Newton Power Plant / 6725 North 500th Street, Newton, IL 62448		
Owner Name / Address	Illinois Power Generating Company / 6555 Sierra Drive Irving, Texas 75039		
CCR Unit	Primary Ash Pond	Closure Method and Final Cover Type	Close In-Place Clayey Soil Cover with Vegetation

POST-CLOSURE PLAN DESCRIPTION	
40 C.F.R. § 257.104(c)(1) and 35 I.A.C. 845.780(c)(1) – Length of post-closure care period.	Post-closure care will be conducted for a period of 30 years as required by 40 C.F.R. § 257.104(c)(1) and 35 I.A.C. 845.780(c)(1), except as provided by 40 C.F.R. § 257.104(c)(2) and 35 I.A.C. 845.780(c)(2).
40 C.F.R. § 257.104(c)(2) and 35 I.A.C. 845.780(c)(2) – Circumstances extending the post closure care period.	If at the end of the post-closure care period the CCR unit is operating under assessment monitoring in accordance with §257.95, the post-closure care as described in this plan will continue until returning to detection monitoring in accordance with §257.95. Under 35 I.A.C. 845.780(c)(2), the post-closure care period will be extended until groundwater monitoring data demonstrate that concentrations are below the groundwater protection standards in Section 845.600 and are not increasing for those constituents over background, using the statistical procedures and performance standards in Section 845.640(f) and (g), provided that concentrations have been reduced to the maximum extent feasible and concentrations are protective of human health and the environment.
40 C.F.R. § 257.104(d)(1)(i) and 35 I.A.C. 845.780(d)(1)(A) – A description of the monitoring and maintenance activities required in 40 C.F.R. § 257.104(b) and 35 I.A.C. 845.780(b), and the frequency at which these activities will be performed, to maintain the integrity and effectiveness of the final cover system, maintain the groundwater monitoring system and monitor the groundwater.	Pursuant to § 257.104(b)(1) and 35 I.A.C. 845.780(b)(1), throughout the post-closure care period, periodic visual observations of the final cover system and stormwater management system will be performed at least annually for evidence of settlement, subsidence, erosion, or other damage that may adversely affect the integrity and effectiveness of the final cover system. When practical, visual observations of the final cover will be made concurrent with groundwater monitoring activities. Noted evidence of damage, such as rills, surface cracks and settlement, will be repaired to maintain the integrity and effectiveness of the final cover system. Vegetation will be established and maintained on the final cover system, including storm drainage areas, where appropriate, to provide long-term erosion control. Established vegetation and the slope design of the final cover system will prevent potential erosion and damage that may be caused by run-on and run-off.

	Repair activities may include, but are not limited to, replacing and compacting soil cover, repairing drainage channels that have been eroded, filling in depressions with soil, regrading, and reseeding areas of failed vegetation, as necessary. Pursuant to § 257.104(b)(3) and 35 I.A.C. 845.780(b)(3), the groundwater monitoring system will be maintained, and groundwater will be monitored as required by 40 C.F.R. § 257.90 through 40 C.F.R. § 257.98 and 35 I.A.C. 845.600 through 35 I.A.C. 845.680. Monitoring wells will be inspected during each groundwater sampling event. Monitoring wells and associated instrumentation will be maintained so that they perform to the design specifications throughout the life of the monitoring program. Groundwater monitoring frequency will be at least quarterly, except as provided in 40 C.F.R. § 257.94(d) and 35 I.A.C. 845.650(b)(4).
40 C.F.R. § 257.104(d)(1)(ii) and 35 I.A.C. 845.780(d)(1)(B) – The name, address, telephone number and email address of the person or office to contact about the facility during the post-closure care period.	Illinois Power Generating Company 6555 Sierra Drive Irving, Texas 75039 800.633.4704 ccr@dynegy.com
40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780(d)(1)(C) – A description of the planned uses of the property during the post-closure period.	The CCR unit is located at an operating electric generation facility. Planned uses of the property during the post-closure period are currentlyunknown, except for post-closure care of the CCR unit. Post-closure use of the property will not disturb the integrity of the final cover system or other components of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements of 40 C.F.R. Part § 257, Subpart D and 35 I.A.C. Part 845. Any other disturbance will be conducted following a demonstration that it will not increase the potential threat to human health or the environment as required by 40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780 (d)(1)(C). The demonstration will be certified by a qualified professional engineer and submitted to the Illinois Environmental Protection Agency (IEPA). Per 40 C.F.R. § 257.104(d)(1)(iii) notification shall be provided to the State Director that the demonstration has been placed in the operating record and on the owners or operator's publicly accessible internet site. Following closure of the CCR unit, a notation on the deed to the property, or some other instrument that is normally examined during title search, will be recorded in accordance with 40 C.F.R. § 257.102(i) and 35 I.A.C. 845.760(h). The notation will notify potential purchasers of the property that the land has been used as a CCR unit and its use is restricted under the post- closure care requirements in 40 C.F.R. § 257.104(d)(1)(iii) and 35 I.A.C. 845.780(d)(1)(C) or groundwater monitoring requirements per 35 I.A.C. 845.740(b). Within 30 days of recording the deed notation, a notification stating that the notation has been recorded will be submitted to the IEPA and placed in the facility's operating record per 35 I.A.C. 845.760(h)(3). The notification will be placed on the owner or operator's publicly accessible CCR Web site in accordance with 40 C.F.R. § 257.107(i)(9) and 35 I.A.C. 845.810(e) and placed in the facility's operating record as required by 35 I.A.C. 845.800(d)(26) and §257.105(i)(9).

40 C.F.R. § 257.104(d)(3)and 35 I.A.C. 845.780(d)(3) – Amendments to the initial or subsequent written post-closure plan.	Pursuant to 40 C.F.R. § 257.104(d), the initial post closure care plan for the Newton Primary Ash Pond was prepared on October 17, 2016. That plan is being amended pursuant to 40 C.F.R. § 257.104(d)(3)(i). This plan also serves as the initial post-closure care plan, prepared in accordance with 35 I.A.C. 845.780(d). Pursuant to § 257.104(d)(3) and 35 I.A.C. 845.780(d)(3), an operating permit modification application to amend the initial or any subsequent written post-closure care plan developed under 35 I.A.C. 845.780 (d)(1) and § 257.104(d)(1) will be submitted to IEPA. The written post-closure care plan will be amended whenever there is a change in the operation of the CCR surface impoundment that would substantially affect the written post-closure care plan in effect; or unanticipated events necessitate a revision of the written post-closure care plan, after post-closure activities have started. The written post-closure care plan will be amended at least 60 days before a planned change in the operation of the facility or CCR surface impoundment, or within 60 days after an unanticipated event requires the need to revise the existing plan. If the plan is revised after post-closure activities have started, a request to modify the operating permit, including an amended written post-closure care plan, will be submitted to the IEPA within 30 days following the triggering event.
40 C.F.R. § 257.104(d)(4) and 35 I.A.C. 845.780(d)(4) – Qualified professional engineering certification.	Certification by a qualified professional engineer will be appended to this plan and any amendment of this plan.
35 I.A.C. 845.780(e) – Termination of post-closure care	Upon completion of the post-closure period, a request to terminate post-closure care will be submitted to the IEPA. The request will include a certification by a qualified professional engineer verifying that post-closure care has been completed in accordance with the post-closure care plan specified in 35 I.A.C.845.780(d) and the requirements of 35 I.A.C. 845.780.
40 C.F.R. § 257.104(e) and 35 I.A.C. 845.780(f) – Notification of completion of the post-closure care period.	A notification of completion of post-closure care will be prepared and placed in the facility's operating record within 30 days after IEPA approval of the request to terminate post-closure care. The notification will be placed in the facility's operating record in accordance with 35 I.A.C. 845.800(d)(31) and § 257.105(i)(13). The notification will be placed on the owner or operator's publicly accessible CCR Internet site in accordance with the requirements of § 257.107(i)(13) and 35 I.A.C. 845.810(e). The IEPA will be notified when the notification has been placed in the operating record and on the owner or operator's publicly accessible Internet site in accordance with the requirements of § 257.106(i)(13).

Certification Statement 40 C.F.R. § 257.104 (d)(4) and 35 I.A.C. 845.780(d)(4) – Amended/Initial Written Post Closure Plan for a CCR Surface Impoundment

CCR Unit: Dynegy Midwest Generation, LLC; Newton Power Plant; Primary Ash Pond

I, John R. Hesemann, being a Registered Professional Engineer in good standing in the State of Illinois, do hereby certify, to the best of my knowledge, information, and belief, that the information contained in this certification has been prepared in accordance with the accepted practice of engineering. I certify, for the above referenced CCR Unit, that the information contained in the amended/initial written post closure plan, dated October 30, 2021, meets the requirements of 40 C.F.R. § 257.104 and 35 I.A.C.845.780.

John R. Hesemann

Printed Name

10/18/2021

Date



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Attachment K

Contractor Training Certification

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Phil Morris
Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234

July 28, 2022

Illinois Environmental Protection Agency
DWPC – Permits MC # 15
ATTN: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
P.O. Box 19276
Springfield, Illinois 62794-9276

Re: 415 ILCS 5/22.59(b)(4) Certification Statement
Newton Power Plant Primary Ash Pond (IEPA ID# W0798070001-01)

Dear Mr. Darin LeCrone:

For the above-referenced CCR surface impoundment and in accordance with 415 ILCS 5/22.59(b)(4), Illinois Power Generating Company certify that all contractors, subcontractors, and installers utilized to construct, install, modify, or close a CCR surface impoundment will be participants in a training program that is approved by and registered with the US Department of Labor's Employment and Training Administration and that includes instruction in the following: erosion control, environmental remediation, operation of heavy equipment and excavation.

Sincerely,
Illinois Power Generating Company

Phil Morris, P.E.
Senior Director, Environmental

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Appendix 2

Natural Resource Technology, an OBG Company (NRT/ OBG), 2017. Hydrogeologic Monitoring Plan, Newton Primary Ash Pond – CCR Unit ID 501, Newton Landfill 2 – CCR Unit ID 502, Newton Power Station, Canton, Illinois, Illinois Power Generating Company. October 17, 2017.

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OBG

Hydrogeologic Monitoring Plan

Newton Primary Ash Pond – CCR Unit ID 501
Newton Landfill 2 – CCR Unit ID 502

Newton Power Station
Canton, Illinois

Illinois Power Generating Company

October 17, 2017

Natural Resource Technology
AN OBG COMPANY

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OCTOBER 17, 2017 | PROJECT #2285

Hydrogeologic Monitoring Plan

Newton Primary Ash Pond – CCR Unit ID 501
Newton Landfill 2 – CCR Unit ID 502

Newton Power Station
Canton, Illinois

Prepared for:
Illinois Power Generating Company

STUART J. CRAVENS, PG
Principal Hydrogeologist

ROBERT J KARNAUSKAS, PG, PH
Principal Hydrogeologist

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ACRONYMS AND ABBREVIATIONS

bgs	below ground surface
CCR	coal combustion residual
CFR	Code of Federal Regulations
cm/s	centimeters per second
CPT	Cone Penetrometer Test
ft	feet
ft/ft	feet per feet
ft MSL	feet above Mean Sea Level
HMP	Hydrogeologic Monitoring Plan
ID	Identification number
IEPA	Illinois Environmental Protection Agency
IPGC	Illinois Power Generating Company
ISGS	Illinois State Geological Survey
NPS	Newton Power Station
NRT	Natural Resource Technology, an OBG Company
PWS	Public Water Supply
RCRA	Resource Conservation and Recovery Act
SAP	Sampling and Analysis Plan
USEPA	United States Environmental Protection Agency

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1 INTRODUCTION

1.1 OVERVIEW

This Hydrogeologic Monitoring Plan (HMP) has been prepared by Natural Resource Technology, an OBG Company (NRT) to provide background information necessary to support the monitoring well network established for development of the Sampling and Analysis Plan (SAP) requirements of the United States Environmental Protection Agency (USEPA) Final Rule to regulate the disposal of Coal Combustion Residual (CCR) as solid waste under Subtitle D of the Resource Conservation and Recovery Act (RCRA) [40 CFR 257 Subpart D; published in 80 FR 21302-21501, April 17, 2015] for the Newton Power Station, Jasper County, Illinois. The Newton Power Station is owned by Illinois Power Generating Company (IPGC). This HMP will apply specifically to the following CCR Units: Newton Primary Ash Pond (CCR Unit ID 501) and Newton Landfill 2 (CCR Unit ID 502), as defined further below.

1.2 PREVIOUS INVESTIGATIONS AND REPORTS

Numerous hydrogeologic investigations have been performed concerning the CCR Units located at the Newton Power Station. The information presented in this HMP includes data collected in support of the monitoring well network established for development of the Sampling and Analysis Plan (SAP) and supplements comprehensive data collection and evaluations from prior hydrogeologic investigation reports (most recent to oldest), including, but not limited to, the following:

- ***Rapps Engineering and Applied Science, April 10 2013, Phase I Hydrogeological Assessment Report, Coal Combustion Product Impoundment, Ameren Energy Generating Company, Newton Energy Center, Jasper County, Illinois.*** A hydrogeologic study to assess the potential for constituent migration from this impoundment. Report includes: water well survey, development of a groundwater monitoring plan, and an initial groundwater quality assessment. This report summarizes hydrogeologic information pertinent to the site, evaluates groundwater quality data to determine if operation of the impoundment has adversely affected groundwater, and makes recommendations for future actions related to groundwater quality management.
- ***Geotechnology, Inc., February 8, 2011, Initiation of Monitoring Report, Ameren, Newton Power Station, Newton, Illinois.*** This report documents the results of the monitoring well installation and groundwater monitoring activities performed at the site. Three wells were installed, developed and sampled.
- ***Rapps Engineering and Applied Science, November 2009, Site Characterization and Groundwater Monitoring Plan for CCP Impoundment, Ameren Energy Generating Company, Newton Power Station, Jasper County, Illinois.*** Hydrogeologic study and groundwater monitoring plan to assess the potential for constituent migration from this impoundment. Includes an assessment of subsurface hydrogeologic conditions at the site, identification of private, potable water wells and oil and gas wells within 2,500 feet of the facility, public water supply (PWS) wells within 10 miles of the facility, and plans for a groundwater monitoring well network designed to characterize and monitor groundwater quality.
- ***Rapps Engineering and Applied Science, 1997, Hydrogeologic Investigation and Groundwater Monitoring Program, Newton Power Station, Jasper County, Illinois.*** Investigation presents site-specific data obtained through the completion of approximately 40 borings, 20 monitoring wells, and review of regional information and an evaluation of subsurface data from nearby residential wells. Part of Application for Landfill Permit – Rapps 1997.

The HMP supports the monitoring well network established for development of the SAP and provides the following background information:

- Site Geology and Hydrogeology
- Aquifer Properties
- Monitoring Network Placement and Rationale

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1.3 SITE LOCATION AND DESCRIPTION

The Newton Power Station (NPS) is located in Jasper County in the southeastern part of central Illinois, approximately 7 miles southwest of the town of Newton (Figure 1). The plant is located on the north side of Newton Lake and has one active CCR impoundment (Newton Primary Ash Pond) located in Section 26 and the western half of Section 25, Township 6 North, Range 8 East. The site also contains the Newton Landfill 2, located in the western half of Section 26 and eastern half of Section 27, Township 6 North, Range 8 East. The area is also bounded by agricultural land and Newton Lake to the west, south, and east. Beyond the lake is additional agricultural land.

1.4 DESCRIPTION OF CCR MANAGEMENT UNITS

The CCR Units at the Newton Power Station, including the Newton Primary Ash Pond (CCR Unit ID 501) and the Newton Landfill 2 (CCR Unit ID 502), will hereafter be referred to as the 'Site'.

1.4.1 Newton Primary Ash Pond (CCR Unit ID 501)

The NPS's sole CCR impoundment, consisting of a Primary Ash Pond, was constructed in 1977 and has a design capacity of approximately 9,715 acre-feet for the primary pond. There is also a non-CCR 83.6 acre-feet Secondary Pond. The Primary Ash Pond has a surface area of 400 acres and a height of approximately 71 feet above grade. The Secondary Pond has an area of 9.3 acres and a height of approximately 29 feet above grade. The Primary Ash Pond currently receives bottom ash, fly ash, and low-volume wastewater (LVW) from the plant's two coal-fired boilers. The CCR impoundment is operated per NPDES Permit IL0049191, Outfall 001. The impoundment was not excavated during construction except for native materials used to build the containment berms.

1.4.2 Newton Landfill 2 (CCR Unit ID 502)

Newton Landfill 2 includes two cells, Phase I (west) cell and Phase II (east) cell. The Phase I cell, built around 1977, was unlined, and accepted sodium-based flue gas desulfurization (FGD) wastes. Phase I was closed in 1999 with a 40-millimeter thick geomembrane cap and currently has a Groundwater Management Zone (GMZ) established. Following a switch by the NPS to western coal in 1997, the Phase II cell began receiving coal ash that same year; a portion of the Phase II cell is still operational. The Phase II cell has a geomembrane liner with a leachate collection system.

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2 GEOLOGY AND HYDROGEOLOGY

The results of the site characterization activities performed at the Site are discussed below.

2.1 GEOLOGY

Geologic units present at the Site include fill, ash generated at the site, unlithified alluvial sediments, unlithified glacial deposits, and Pennsylvanian-age bedrock.

2.1.1 Regional Setting

Illinois is situated in the south-central part of the great Central Lowland Province near the confluence of two major lines of drainage, the Mississippi and Ohio Rivers (Leighton et al., 1948). The NPS lies at the southeastern portion of the Springfield Plain of the Till Plains section, the largest physiographic division in Illinois, covering approximately four-fifths of the state. It is characterized by its flatness and shallowly entrenched drainage. Drainage systems are well developed, and the district is in a late youthful stage of dissection.

The unlithified geologic deposits in the region range from 100 to 120 feet (ft) thick and are derived from recent river deposition (alluvium), glacial outwash, and glacial till deposits. The unlithified deposits directly overly Pennsylvanian Mattoon Formation bedrock. The Mattoon Formation is the youngest formation in the Pennsylvanian System in Illinois. It is underlain by the Bond Formation, while the top is mostly an erosional surface overlain by Pleistocene glacial deposits. The Mattoon Formation has a maximum thickness of more than 600 feet in the central part of the Illinois Basin in Jasper County. It is characterized by a complex sequence of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well developed sandstones. The lateral extent of many of the named units has not been determined due to widely scattered outcrops and scarce subsurface data. However, coals and limestone units are considered to be as persistent as those in the underlying Bond Formation.

Borings advanced at the NPS as part of a hydrogeologic site investigation for a CCP landfill indicate that the elevation of the top of the bedrock surface at the site is approximately 400 to 450 ft MSL. The depth to bedrock varies widely in the area owing to the undulatory nature of the eroded upper bedrock surface and ranges from approximately 90 to 120 ft. Logs indicate that the lithology of the uppermost bedrock is mostly shale.

2.1.2 Site Geology

The geology has been evaluated during previous hydrogeologic investigations and groundwater quality assessments since the first borings and monitoring wells were installed. Quaternary deposits in the Newton area consist mainly of diamictons and outwash deposits that were deposited during Illinoian and Pre-Illinoian glaciations. The unconsolidated deposits which occur at Newton Power Station include the following units (beginning at the ground surface):

- Ash/Fill Units – CCR and fill within the various CCR Units
- Upper Confining Unit – Low permeability clays and silts, including the Peoria Silt (Loess Unit) in upland areas and the Cahokia Formation in the flood plain and channel areas to the south and east, underlain by the Sangamon Soil, and the predominantly clay diamictons of the Hagarstown (Till) Member of the Pearl Formation and the Vandalia (Till) Member of the Glasford Formation
- Uppermost Aquifer (Groundwater Monitoring Zone) – Thin to moderately thick (3 to 17 ft), moderate to high permeability sand, silty sand, and sandy silt/clay units of the Mulberry Grove Member of the Glasford Formation
- Lower Confining Unit – Thick, very low permeability silty clay diamicton of the Smithboro (Till) Member of the Glasford Formation and the silty clay diamictons of the Banner Formation
- Bedrock – Pennsylvanian-age Mattoon Formation that is mostly shale near the bedrock surface, but is characterized at depth by a complex sequence of shales, thin limestones, coals, underclays, and several

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sandstones. The erosional surface of the Pennsylvanian-age Mattoon Formation bedrock ranges widely in depth in the vicinity of the site, but is typically encountered at 90 to 120 ft below ground surface (bgs).

The major unconsolidated materials present at the site are discussed in greater detail below:

2.1.2.1 Ash/Fill Units

Ash is present within the Newton Primary Ash Pond as well as the Newton Landfill 2. The majority of ash fill at the Newton Primary Ash Pond lies on top of the loess and clay.

2.1.2.2 Cahokia Formation

The Cahokia Formation of the Holocene Stage consists of deposits in floodplains and channels of modern rivers and streams and consists of mostly poorly sorted sand, silt, and clay with wood and shell fragments and local deposits of sandy gravel. The Cahokia is likely present in the Big Muddy Creek valley west of the site and along the bottom of Newton Lake to the east, which used to be the bottomland for Law Creek (Lineback, 1979; Berg and Kempton, 1987).

2.1.2.3 Peoria Silt (Loess Unit)

The Peoria Silt is a Loess Unit which extends from beneath the topsoil, derived from the loess, to the top of the Hagarstown Member. The loess, ranging in thickness from 3 to 9 ft where present, has been described as silt, clayey silt, and silty clay. The Loess Unit is generally considered unsaturated.

2.1.2.4 Sangamon Soil

The Sangamon Soil formed between the interglacial period between the Illinoian and Wisconsinan stages of glaciation as a result of weathering of the upper portion of the Illinoian drift. This layer occurs throughout the site and consists of approximately 2 to 6 ft of light brown to light gray silty clay

2.1.2.5 Hagarstown (Till) Member

The Hagarstown Member (also referred to as Hagarstown Beds) of the Pearl Formation, consists of clay till with varying amounts of sand and gravel. Where present at the site, the clay till ranges in thickness from 3 to over 24 ft. Where present, the sandy portion of the Hagarstown is generally less than 5 ft thick. The composition of the sandy portion of the Hagarstown unit varies across the site and was classified as gravelly till, poorly sorted gravel, well sorted gravel, sand and silty sand.

2.1.2.6 Vandalia (Till) Member

The Vandalia Member is a sandy/silty till with thin, discontinuous lenses of silt, sand, and gravel. The Vandalia Till was encountered in all borings advanced at the site. The Vandalia Till typically ranges in thickness from 20 to 60 ft. Results from laboratory tests completed for vertical hydraulic conductivity indicate the Vandalia unit has a very low vertical hydraulic conductivity.

2.1.2.7 Mulberry Grove Member

As described by Willman et al. (1975), the Mulberry Grove Member of the Glasford Formation typically consists of a thin, lenticular unit of gray sandy silt (Willman et al., 1975). It represents the interval between the retreat of the glacier that deposited the Smithboro Member and the advance of the glacier that deposited the Vandalia Member. At the site, the Mulberry Grove Member consists of fine to coarse sand with varying amounts of silt and small to large gravel. The portion of the Mulberry Grove Member at the site that is defined as a sand layer ranges in thickness from 3 to 17 ft with an average thickness of 8 ft. This unit generally occurs across the site at depths between 55 and 88 ft bgs.

2.1.2.8 Smithboro (Till) Member

The Smithboro Member is described as a gray, compact, silty-clay diamicton. The Smithboro Member typically ranges in thickness from 10 to 20 ft.

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2.1.2.9 Banner Formation

The Banner Formation consists of pre-Illinoian undifferentiated diamictons and intercalated sand and gravel outwash that generally rest directly on bedrock. The Banner Formation is approximately 20 to 30 ft thick at the site and consist of greenish-gray silty clay with traces of sand.

Name	Age	Description
Cahokia	Holocene	poorly sorted sand, silt, and clay (alluvial)
Peoria Silt	Wisconsinan	sandy silt along bluffs to clayey silt away from bluffs; local lenses of fine to med grained sand; 3-9 ft thick
Sangamon Soil	Sangamonian	light brown to light gray silty clay; weathered upper portion of Illinoisan drift; 2.5-5.5 ft thick
Hagarstown Member	Illinoisan	gravel, sand, and gravelly diamicton; 3-24' thick where present; reddish-brown silty clay with some sand and gravel; surface at 510 to 532 ft; can also be gravelly till with poorly sorted gravel, well sorted gravel, and sand
Vandalia Member	Illinoisan	gray silty to sandy clay diamicton with traces sand and gravel; thin lenses of silt, sand, and gravel; 20-60 ft thick
Mulberry Grove	Illinoisan	fine to coarse sand with varying amounts of silt and fine to coarse gravel; 3 - 17 ft thick; may contain lenses of silt, sand and gravel
Smithboro Member	Illinoisan	gray, silty clay diamicton w/ traces sand and gravel; 10-20 ft thick
Banner Formation	pre-Illinoisan	undifferentiated diamictons; greenish-gray moist silty clay with traces of sand; 20-30 ft thick

2.2 HYDROGEOLOGY

The information used to describe the hydrogeology is based on the local geology obtained from published sources, hydrogeologic investigation data, and boring data collected during monitoring well installation.

2.2.1 Uppermost Aquifer

The uppermost aquifer is the Mulberry Grove Member, typically consisting of fine to coarse sand with varying amounts of clay, silt and fine to coarse gravel. The portion of the Mulberry Grove Member at the site that is defined as a sand layer ranges in thickness from 3 to 17 ft. with an average thickness of 8 ft and with only a few exceptions occurs between depths of 55 to 88 ft bgs.

2.2.2 Lower Limit of Aquifer

The lower hydrostratigaphic units consist of the Smithboro Member and the Banner Formation, both of which are predominantly low permeability clay diamictons with varying amounts of silt, sand and gravel. The lower unlithified confining unit is 30 to more than 50 ft thick above the underlying bedrock.

2.2.3 Hydraulic Conductivity

Hydraulic conductivity/slug tests were completed in wells screened in the unlithified material during prior site investigations and by NRT in April 2017. The hydraulic conductivity values determined from 15 individual monitoring wells (Appendix C) within the uppermost aquifer (Mulberry Grove Member) ranged from 3.9×10^{-8} to 3.6×10^{-2} centimeters per second (cm/s). The geometric mean of the hydraulic conductivity for NRT tested monitoring wells in the Uppermost Aquifer, excluding one outlier, is 2.5×10^{-4} cm/s. Monitoring wells around the Primary Ash Pond had a geometric mean hydraulic conductivity of 1.2×10^{-3} cm/s and those around Landfill 2, excluding one outlier, had a geometric mean hydraulic conductivity of 7.4×10^{-5} cm/s. Field hydraulic conductivity test results reported by Rapps (1997) for six locations near Landfill 1 ranged from 2.5×10^{-6} to 6.0×10^{-3} cm/s with a geometric mean of 9.8×10^{-4} cm/s.

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The uppermost unit intercepted in the area of the Primary Ash Pond and Landfill 2 is the silty to sandy clay of the "Upper Drift", or aquitard, as identified in the Rapp's 1997 landfill investigation and consists of Peoria Silt, Sangamon Soil, and/or Hagarstown Member. The hydraulic conductivity of this unit, as tested at monitoring wells near the landfill with screen depths between 8 and 36 ft bgs (Rapps, 1997), ranged from 2.4 x 10^{-6} to 6.1 x 10^{-5} cm/s with a geometric mean of 1.7 x 10^{-5} cm/s. Three in-situ tests conducted by NRT of the uppermost materials near the Primary Ash Pond, on wells screened between 7 and 20 ft bgs, had a geometric mean hydraulic conductivity of 1.3 x 10^{-5} cm/s. Laboratory testing results for five soil samples collected from depths of 20 to 32 ft bgs in the underlying Vandalia Member (Rapps, 1997) ranged from 6.3 x 10^{-9} to 2.1 x 10^{-8} cm/s with a geometric mean hydraulic conductivity of 1.1 x 10^{-8} cm/s.

The hydraulic conductivity value determined from one field (i.e. in-situ) test of the upper part of the Lower Confining Unit by Rapps (1997), at a depth of 79 to 87 ft bgs, was 1.4 x 10^{-7} cm/s.

2.2.4 Groundwater Elevations, Flow Direction and Velocity

Seasonal variation of groundwater levels and flow direction at the Landfill is indicated in the series of 2015-2017 groundwater elevation contour maps (Appendix D). Groundwater elevations across Landfill 2 ranged from approximately 441 to 520 ft MSL (NAVD88) from 2015 to 2017. Overall groundwater flow beneath the two phases of Landfill 2 within the uppermost aquifer is southward toward Newton Lake, but with predominantly eastward flow under Phase I (west phase of Landfill 2) and an east and south component of flow under Phase II (east phase of Landfill 2). Horizontal hydraulic gradients (Table 1) were moderate at 0.016 ft/ft. Calculated groundwater flow velocity based on the January and June 2017 groundwater contour maps was 1.42 ft per day (ft/day).

Seasonal variation of groundwater levels and flow direction at the Primary Ash Pond is indicated in the series of 2015-2017 groundwater elevation contour maps (Appendix D). Groundwater elevations across the GMF Pond ranged from approximately 492 to 508 ft MSL. Groundwater flow across Primary Ash Pond within the uppermost aquifer is consistently in a south to southwest direction toward Newton Lake. Horizontal hydraulic gradients (Table 1) were low at 0.007 ft/ft. Calculated groundwater flow velocity based on the January and June 2017 groundwater contour maps was 0.12 ft/day.

Vertical hydraulic gradients as measured between shallow water table wells and uppermost aquifer monitoring wells was consistently downward at both the Landfill 2 and the Primary Ash Pond (Table 1).

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3 GROUNDWATER MONITORING

In August 2015, NRT began an assessment of the existing monitoring well network(s) at the Newton Power Station with respect to the existing CCR units. Included in the assessment was a review of the current placement and number of monitoring wells with respect to individual and contiguous CCR units as well as potential locations for new monitoring wells, as appropriate. The discussion below summarizes the results of this assessment and the supplemental well installations.

3.1 CCR Monitoring Well Network

The 40 CFR Part 257 well network consists of seventeen monitoring wells installed in the uppermost aquifer and adjacent to the Newton Landfill 2 (G06D, G48MG, G201, G202, G203, G208, G217D, G220, G222, G223, G224) and the Newton Primary Ash Pond (APW5, APW6, APW7, APW8, APW9, APW10). The Site utilizes four upgradient (or background) monitoring wells (APW5, APW6, G201, and G48MG) as part of their CCR monitoring well network. The boring logs, well construction forms and other related monitoring well forms are available in the Operating Records as required by Title 40 CFR Part 257 Section 257.91 for each monitored CCR Unit. Sampling of these wells commenced December 2015. The 40 CFR Part 257 groundwater monitoring network well locations are shown on Figure 1. Details on the procedures and techniques used to fulfill the groundwater sampling and analysis program requirements are found in the SAPs for Newton Power Station. The well depths, well screen intervals, depth to groundwater and monitored units at the 40 CFR Part 257 monitoring well network locations are summarized below:

Table 3: CCR Groundwater Monitoring Well Information

Primary Ash Pond Monitoring Well Information (Unit ID: 501)					
Well Number	Well Depth (ft bgs)	Well Screen Interval (ft bgs)	Depth to Water (ft bgs)	Unit Monitored	Screened Interval Lithology
APW5	68	63-68	13.89	Upgradient Shallow Unlithified	Sand
APW6	74	68-73	19.21	Upgradient Shallow Unlithified	Sand
APW7	83	78-83	45.05	Downgradient Shallow Unlithified	Sand
APW8	82	71-81	35.29	Downgradient Shallow Unlithified	Sand
APW9	62	56-61	26.00	Downgradient Shallow Unlithified	Sand
APW10	46	41-46	16.98	Downgradient Shallow Unlithified	Sand

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Landfill 2 Monitoring Well Information (Unit ID: 502)					
Well Number	Well Depth (ft bgs)	Well Screen Interval (ft bgs)	Depth to Water (ft bgs)	Unit Monitored	Screened Interval Lithology
G06D	96	74-94	30.12	Downgradient Shallow Unlithified	Clay
G48MG	77	71.5-76.5	18.59	Upgradient Shallow Unlithified	Sand
G201	69	59-69	18.54	Upgradient Shallow Unlithified	Sand
G202	74	64-74	43.21	Downgradient Shallow Unlithified	Clay/Gravel
G203	73	63-73	37.60	Downgradient Shallow Unlithified	Sand/Silt
G208	95	74-94	19.13	Downgradient Shallow Unlithified	Silty Clay
G217D	69.3	* - 69.3	16.14	Downgradient Shallow Unlithified	N/A*
G220	87	76-86	16.59	Downgradient Shallow Unlithified	Silt/Sand
G222	80	64-79	14.09	Downgradient Shallow Unlithified	Silty Clay/Sand
G223	89	79-89	33.64	Downgradient Shallow Unlithified	Silty/ Clay/Silty Sand
G224	74	63-73	41.73	Downgradient Shallow Unlithified	Silty Sand/Sand

Notes:
Groundwater depth measurements were collected June 12, 2017.
NM indicates groundwater depth was not measured.
*boring log not available for review

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Tables

Table 1. Vertical Gradients
Newton Power Station
January 2017 and June 2017
Hydrogeologic Monitoring Plan

Date	06/12/2017					
	Groundwater Elevation	Reference Elevation	Head Change (dH)	Dist. Change (dL)	Vertical Hydraulic Gradient (dH/dL)*	
APW-7	493.32	455.92	2.10	7.55	0.278	down
G203	495.42	463.47				
APW-9	505.52	469.76	18.85	44.04	0.428	down
APW-3	524.37	513.80				
APW-10	507.27	478.84	2.54	30.06	0.084	down
APW-4	509.81	508.90				
Date	01/16/2017					
	Groundwater Elevation	Reference Elevation	Head Change (dH)	Dist. Change (dL)	Vertical Hydraulic Gradient (dH/dL)*	
APW-7	492.98	455.92	0.04	7.55	0.005	down
G203	493.02	463.47				
APW-9	505.67	469.76	20.93	44.04	0.475	down
APW-3	526.60	513.80				
APW-10	506.96	478.84	14.05	30.06	0.467	down
APW-4	521.01	508.90				

Notes:
1. The reference point is equal to the water elevation when the water table intersects the screen, or the screen midpoint if the screen is submerged.
*: Vertical gradients less than ±0.0015 are considered flat, and they typically have less than 0.02 foot difference between wells

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Table 2. Groundwater Flow Velocities
Newton Power Station
January 2017 and June 2017
Hydrogeologic Monitoring Plan

6/12/2017 (Round 8)				
	Average Hydraulic Conductivity (cm/s)	**Horizontal Hydraulic Gradient***	**Effective Porosity**	**Velocity (ft/day)**
Newton Primary Ash Pond	1.2E-03	0.007	0.2	0.12
Newton Landfill 2	7.4E-05	0.016	0.2	1.42
1/16/2017 (Round 6)				
	Average Hydraulic Conductivity (cm/s)	**Horizontal Hydraulic Gradient***	**Effective Porosity**	**Velocity (ft/day)**
Newton Primary Ash Pond	1.2E-03	0.007	0.2	0.12
Newton Landfill 2	7.4E-05	0.016	0.2	1.42

Note:

1) cm/sec x 2,835 = feet/day

2) Source of hydraulic conductivity values is the geometric mean value for the aquifer unit.

3) The effective porosity of the clayey sand/silty sand aquifer (20%) was estimated from literature values (Sanders, 1998)

* Horizontal hydraulic gradient calculated from water levels in CCR wells near the primary ash pond and landfill 2

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Figures

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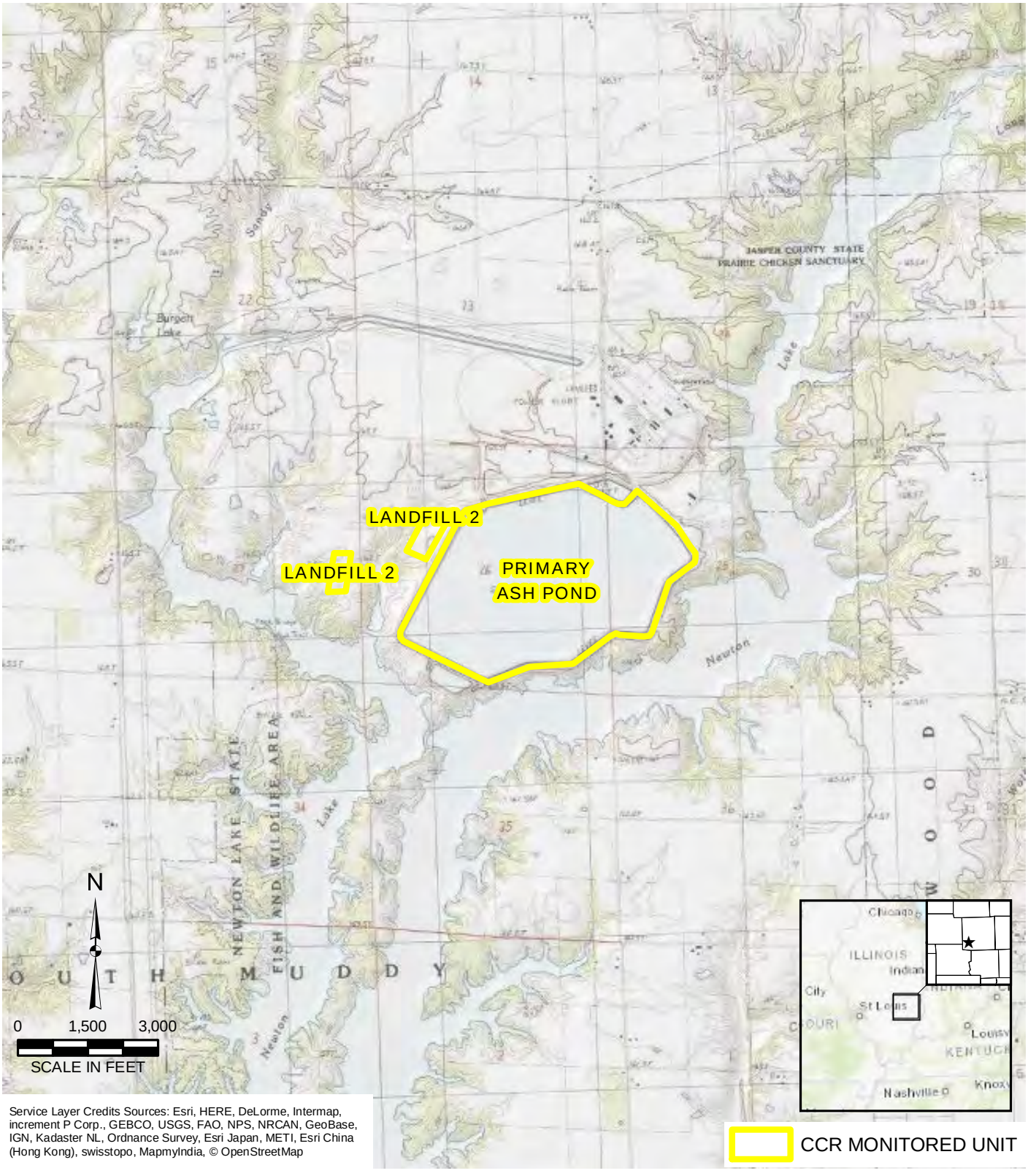

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Y:\Mapping\Projects\2212285MXD\Newton_HGMP\Figure 1_Topo Vicinity Map.mxd Author: stolzsd; Date/Time: 10/3/2017, 2:30:47 PM

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SDS 7/27/17
REVIEWED BY/DATE:
TBN 10/2/17
APPROVED BY/DATE:
SJC 10/3/17

SITE LOCATION MAP

HYDROGEOLOGIC MONITORING PLAN
NEWTON POWER PLANT
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

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CCR RULE MONITORING WELL LOCATION

CCR MONITORED UNIT

DRAWN BY/DATE:
SDS 7/27/17
REVIEWED BY/DATE:
TBN 10/2/17
APPROVED BY/DATE:
SJC 10/3/17

GROUNDWATER SAMPLING WELL LOCATION MAP

HYDROGEOLOGIC MONITORING PLAN
NEWTON POWER PLANT
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 2

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Y:\Mapping\Projects\2212285\MXD\Newton_HGMP\Figure 2_Well Location Map - Newton.mxd Author: stolzsd Date/Time: 10/4/2017, 5:03:47 PM

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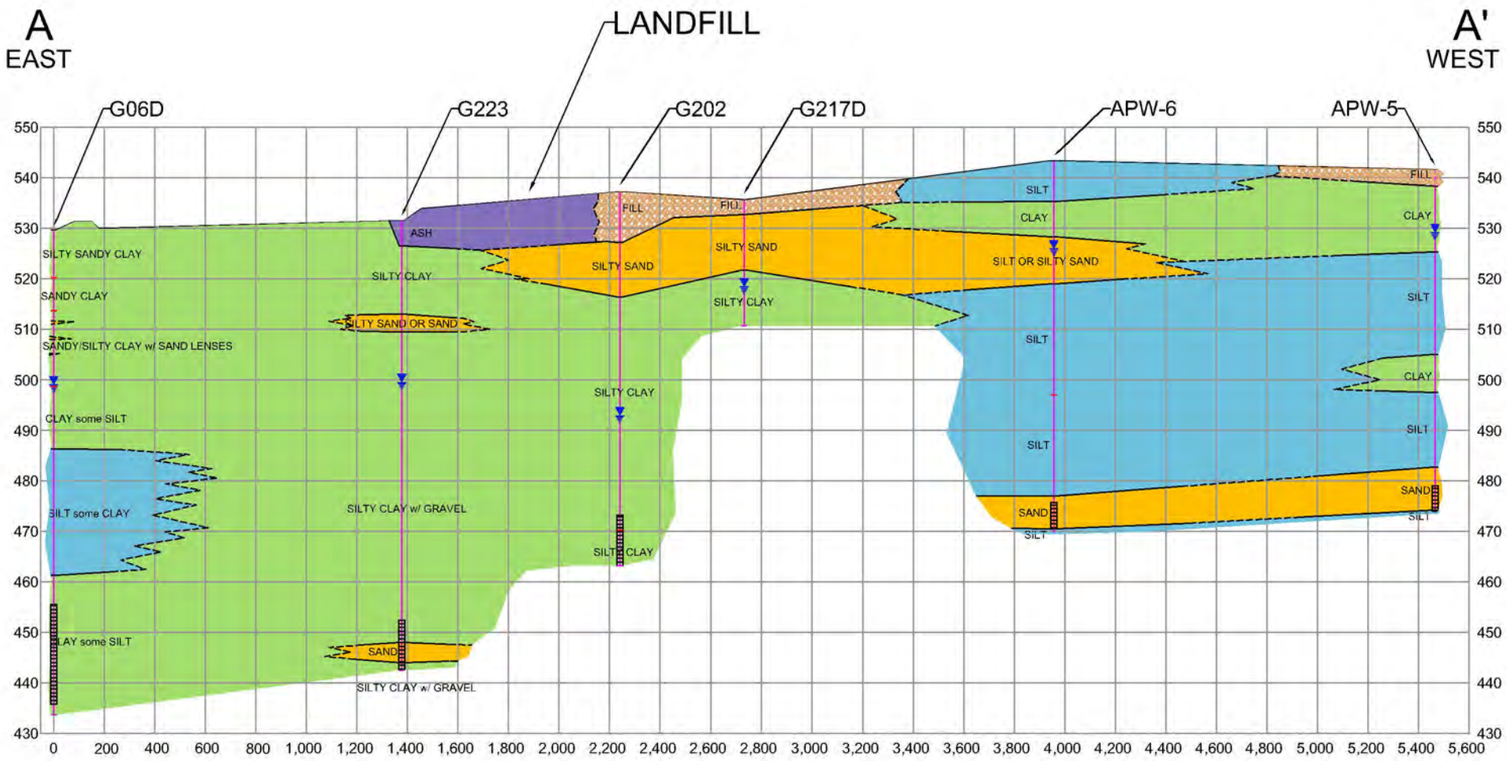
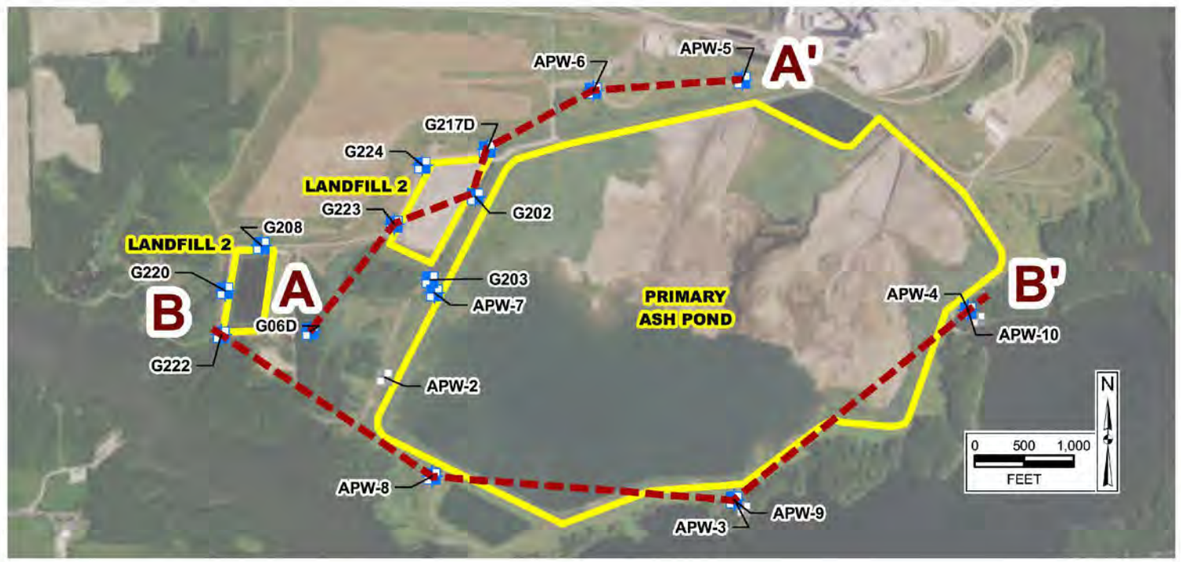
Appendix A

Geologic Cross Sections



FILL
ASH
CLAY
SILT
SAND
WELL SCREEN
GROUNDWATER ELEVATION

VERTICAL SCALE IN FEET: 30
HORIZONTAL SCALE IN FEET: 600
VERTICAL EXAGGERATION =20



DRAWN BY: JMO DATE: 08/29/2017
CHECKED BY: TBN DATE: 10/2/2017
APPROVED BY: SJC DATE: 10/2/2017
DRAWING NO: Fig A - Geologic Cross-Section A-A'
REFERENCE: .

GEOLOGIC CROSS-SECTION A-A'

HYDROGEOLOGIC MONITORING PLAN

NEWTON POWER STATION
NEWTON, ILLINOIS

Natural Resource Technology
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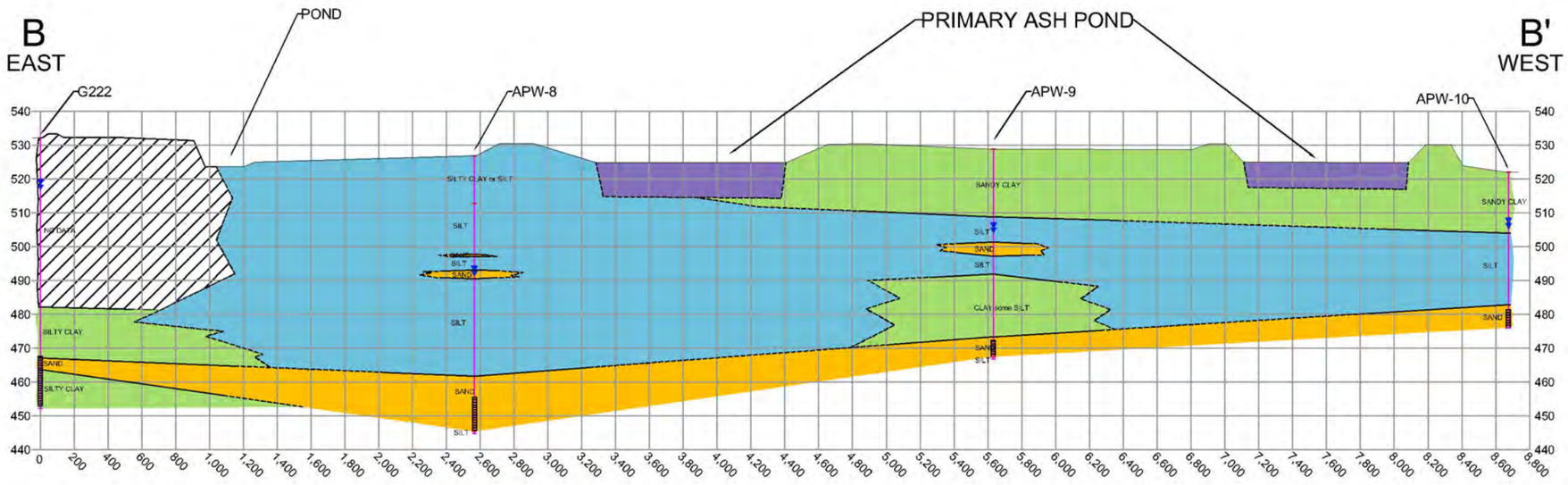
PROJECT NO.
2285

FIGURE NO.
APPENDIX A-1

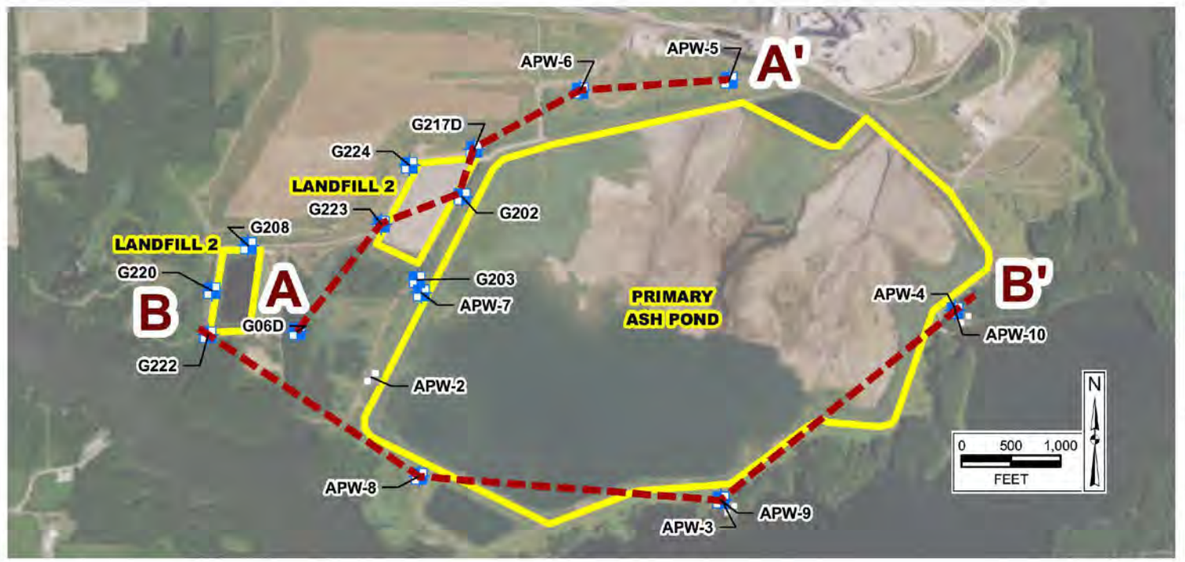


NO DATA
ASH
CLAY
SILT
SAND
WELL SCREEN
GROUNDWATER ELEVATION

NOTE THAT THE DEPTH OF THE ASH IN THE ASH POND IS APPROXIMATE.

VERTICAL SCALE IN FEET: 40
HORIZONTAL SCALE IN FEET: 800

VERTICAL EXAGGERATION =20



GEOLOGIC CROSS-SECTION B-B'

HYDROGEOLOGIC MONITORING PLAN

NEWTON POWER STATION
NEWTON, ILLINOIS

DRAWN BY:	JMO	DATE: 08/29/2017
CHECKED BY:	TBN	DATE: 10/2/2017
APPROVED BY:	SJC	DATE: 10/2/2017
DRAWING NO:	Fig X_Geologic Cross-Section A-A'	
REFERENCE:	.	

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2285

FIGURE NO.
APPENDIX A-2

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Appendix B

Geotechnical Exploration Locations and Laboratory Test Results

Appendix B From:
AECOM, 2015, Dynegy CCR-Newton Investigation

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Legend

- AECOM Boring Location
- AECOM CPT Location

N
W E
S

0.1 0 0.1 0.2 Miles

DYNEGY

Figure D-01
Exploration Locations
Newton Power Station
Jasper County, Illinois

AECOM

AECOM #60428794-108
Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B001	ST-5	10-12								125.4								
NEW-B001	ST-5	10.55	19.3															
NEW-B001	ST-5B	10.75	18.1	50	14	36	CH	79.1		132.6	112.3		CIU@1.5	2.3	21.3			T3937
NEW-B001	ST-7	20-22								130.1								
NEW-B001	ST-7	20.3	22.8															
NEW-B001	ST-7	20.85	18.4															
NEW-B001	ST-7B	21.1	16.2	49	13	36	CL	59.9		134.5	115.7		CIU@3.0	2.6	20.6			T3939
NEW-B001	S-8	25-27	17.1				CL	65.3										
NEW-B001	S-10	35-37	15.8	25	14	11	CL	55.6	17									
NEW-B001	S-11	40-41	14.6	22	13	9	CL	57.0	11									
NEW-B001	S-13	45-47	11.8															
NEW-B001	S-15	50-52	12.3	27	18	9	CL											
NEW-B001	S-16	55-57	11.5	30	13	17	CL	63.3	16									
NEW-B001	S-18	65-67	12.8	33	14	19	CL	64.6	18									
NEW-B001	S-19	70-70.92	12.4	24	15	9	CL											
NEW-B001	S-20	75-77	13.0															
NEW-B001	S-23	90-92	12.8	28	14	14	CL											
NEW-B001	S-24	95-97	11.0				SM	13.4	2									
NEW-B003	S-3	9-11	16.1															
NEW-B003	ST-1	14-15.9								129.5								
NEW-B003	ST-1	14.55	16.3															
NEW-B003	ST-1	15.1	23.7															
NEW-B003	ST-1C	15.35	20.9	59	15	44	CH	77.3		129.5	107.1		CIU@2.5	1.7	15.7			T3940
NEW-B003	S-4	20-22	17.7															
NEW-B003	ST-2	23-24.6								130.6								
NEW-B003	ST-2	23.35	16.6															
NEW-B003	ST-2	23.9	19.5															
NEW-B003	ST-2B	24.15	19.4	43	17	26	CL	82.7		130.9	109.7		UU@4	2.5	15.0			UU296a
NEW-B003	S-5	25-27	19.2															
NEW-B003	ST-3	27.5-29.5								128.1								
NEW-B003	ST-3	28.05	19.7															
NEW-B003	ST-3B	28.3	21.2				CH			126.4	104.3	9.6E-8						P10611
NEW-B003	ST-3	28.6	22.8															
NEW-B003	ST-3C	28.8	21.1	55	16	39	CH			129.2	106.7		UU@3	3.0	15.0			UU296b

AECOM #60428794-108
Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER	LIQUID	PLASTIC	PLAS.	USCS	SIEVE	HYDRO.	TOTAL	DRY		TEST	PEAK	STRAIN	INITIAL CONDITIONS		
NO.	NO.		CONTENT	LIMIT	LIMIT	INDEX	SYMB. (1)	MINUS NO. 200	% MINUS 2 μm	UNIT WEIGHT	UNIT WEIGHT		TYPE @STRESS	SHEAR STRESS	@ PEAK STRESS	VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B003	S-6	30-32	19.6	42	14	28	CL	69.8	23									
NEW-B003	S-7	35-37	17.0	41	15	26	CL											
NEW-B003	S-8	40-42	22.9	50	18	32	CH	88.2	25									
NEW-B003	S-9B	46-47	11.7															
NEW-B003	S-12	60-62	13.3	32	35	17	CL											
NEW-B003	S-13	65-67	12.7				CL	67.6	19									
NEW-B004	S-3	5-7	13.9				CL	64.2										
NEW-B004	ST-4	8-10								132.3								
NEW-B004	ST-4	8.15	16.1															
NEW-B004	ST-4	8.7	18.5															
NEW-B004	ST-4	9.25	17.9															
NEW-B004	ST-4C	9.5	18.5	50	13	37	CH	83.9	28	131.3	110.9		CIU@0.5	1.4	17.9			T3936
NEW-B004	S-5	10-12	20.0															
NEW-B004	S-6	15-17	20.3				CL	79.3										
NEW-B004	ST-7	18-20								126.9								
NEW-B004	ST-7	18.55	18.1															
NEW-B004	ST-7	19.1	16.7															
NEW-B004	ST-7C	19.35	18.3	52	15	37	CH			128.5	108.7		CIU@3.0	2.4	20.5			T3941
NEW-B004	S-8	20-22	20.3															
NEW-B004	S-9	25-27	20.7															
NEW-B004	S-10	27.5-29.5	17.7	37	14	23	CL	61.7	25									
NEW-B004	ST-12	33-33.5								106.5								
NEW-B004	ST-12A	33.2	9.7	24	13	11	CL			136.2	124.2	6.4E-6						P10610
NEW-B004	ST-12	33.5	10.2															
NEW-B004	S-13	33.5-35.5	9.0				CL	52.8	16									
NEW-B004	S-14	36-37.92	8.9	26	13	13	CL											
NEW-B004A	S-1	45-46	10.4				CL	63.2	13									
NEW-B004A	S-2	50-52	11.3	29	15	14	CL											
NEW-B004A	S-3	55-57	10.0															
NEW-B004A	S-4	60-62	11.4				CL	68.1										
NEW-B004A	S-6	70-72	16.8	32	14	18	CL											
NEW-B004A	S-8	80-82	12.5	31	14	17	CL											
NEW-B004A	S-10	90-92	10.9															
NEW-B004A	S-11	95-97	11.1				SW-SM	11.2	3									

AECOM #60428794-108
Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B005	S-3	5-7	17.9	47	15	32	CL											
NEW-B005	S-5	10-12	9.8	24	13	11	CL											
NEW-B005	S-6	15-16.5	9.4	27	12	15	CL	54.6	16									
NEW-B005	S-7	20-20.92	10.8	26	13	13	CL											
NEW-B005	S-8	25-26	11.6				CL	54.6	18									
NEW-B005	S-10	35-37	11.3				ML	66.4										
NEW-B005	S-11	40-42	14.0															
NEW-B005	S-12	45-47	13.1	33	15	18	CL	70.2	19									
NEW-B006	S-3	10-12	21.2	66	14	52	CH	88.2	36									
NEW-B006	ST-1	20-22								128.0								
NEW-B006	ST-1	20.4	21.6															
NEW-B006	ST-1	20.95	16.4															
NEW-B006	ST-1B	21.2	18.2	40	17	23	CL	78.4	22	130.8	110.6		UU@3.5	2.3	8.7			UU301f
NEW-B006	ST-2	25-27								140.1								
NEW-B006	ST-2	25.4	17.9															
NEW-B006	ST-2	25.95	18.2															
NEW-B006	ST-2	26.5	18.6															
NEW-B006	ST-2C	26.75	19.7	44	12	32	CL	65.6	28	128.8	107.6		CIU@7.5	3.0	12.8			T3945
NEW-B006	S-6	27-29	19.4	54	13	41	CH											
NEW-B006	ST-3	30-32								133.0								
NEW-B006	ST-3	30.45	29.1															
NEW-B006	ST-3	31.0	20.4															
NEW-B006	ST-3B	31.25	20.7				CL			130.6	108.1	1.6E-7						P10597
NEW-B006	ST-3	31.55	18.5															
NEW-B006	ST-3C	31.8	18.3	37	15	22	CL	52.1	21	133.3	112.8		CIU@7.2	4.0	14.8			T3915
NEW-B006	S-7	32-34	17.5															
NEW-B006	ST-4	35-35.8		30	13	17	CL	58.3	20	148.8								
NEW-B006	ST-4	35.4	11.1				CL			140.2	126.2		DS@9	6.6				DS1619
NEW-B006	ST-4	35.6	15.8				CL			147.4	127.2		DS@18	11.5				DS1617
NEW-B006	ST-4	35.7	11.2															
NEW-B006	S-9	40-42	13.0															
NEW-C006	ST-1	10-12								115.2								
NEW-C006	ST-1	10.5	26.7															
NEW-C006	ST-1	11.05	27.1															

AECOM #60428794-108
Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-C006	ST-1B	11.3	25.2	54	16	38	CH			124.1	99.2		CIU@1.5	1.2	13.7			T3916
NEW-C006	ST-2	12-14								121.4								
NEW-C006	ST-2	12.75	19.3															
NEW-C006	ST-2B	13.0	18.9	53	14	39	CH			131.5	110.6		CIU@2.0	2.4	16.7			T3917
NEW-B007	S-4	7.5-9.5	13.2															
NEW-B007	ST-1	10-12								131.6								
NEW-B007	ST-1	10.75	16.5															
NEW-B007	ST-1	11.3	17.3															
NEW-B007	ST-1C	11.55	15.4	38	14	24	CL			135.1	117.1		CIU@1.0	2.3	21.5			T3933
NEW-B007	ST-2	20-22								143.6								
NEW-B007	ST-2	20.25	10.1															
NEW-B007	ST-2	20.8	12.7															
NEW-B007	ST-2B	21.0	12.1	30	13	17	CL	52.3		140.5	125.4		CIU@2.5	3.7	21.1			T3934
NEW-B007	S-6	25-27	16.3															
NEW-B007	ST-3	30-32								131.1								
NEW-B007	ST-3	30.35	17.8															
NEW-B007	ST-3	30.9	20.1															
NEW-B007	ST-3	31.45	19.2															
NEW-B007	ST-3C	31.7	21.5	52	12	40	CH	71.5	29	132.0	108.6		UU@6.0	2.6	11.7			UU288d
NEW-B007	S-7	35-37	14.8															
NEW-B007	ST-4	40-42																
NEW-B007	ST-4	40.85	25.1															
NEW-B007	ST-4B	41.0	17.5	57	13	44	CH			129.9	110.5		DS@5	2.7				DS1620
NEW-B007	ST-4C	41.3	14.7				CH			128.7	112.2		DS@10	5.4				DS1621
NEW-B007	ST-4B	41.5	16.1				CH			132.6	114.2		DS@15	7.6				DS1622
NEW-B007	ST-5	50-51.5								131.5								
NEW-B007	ST-5A	50.3	16.3				CH			137.1	117.9	5.1E-9						P10598
NEW-B007	ST-5	50.8	14.0															
NEW-B007	ST-5B	51.05	13.9	32	16	16	CL			136.1	119.5		DSS@7.6	3.5	5.6			DSS855
NEW-B008	ST-1	15-17								132.9								
NEW-B008	ST-1	15.85	11.1															
NEW-B008	ST-1	16.4	16.9															
NEW-B008	ST-1C	16.65	16.7	50	13	37	CH	74.4		136.3	116.8		UU@2.5	3.1	15.0			UU288e
NEW-B008	S-4	20-22	20.1															

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Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B008	S-5	22.5-24.5	22.6															
NEW-B008	S-6	25-27	23.2															
NEW-B008	ST-2	27.5-28.75								130.3								
NEW-B008	ST-2A	27.7	20.3				CL			122.5	101.8		DS@2	1.2				DS1624
NEW-B008	ST-2B	28	14.4	49	14	35	CL			133.8	117.0		DS@4	2.9				DS1626
NEW-B008	ST-2C	28.4	16.4				CL			133.2	114.5		DS@8	4.4				DS1628
NEW-B008	S-7	35-37	13.8															
NEW-B008	S-8	40-42	14.6				SC	46.9	9									
NEW-B008	S-10	50-51.5	15.4	32	16	16	CL	65.4	20									
NEW-B009	ST-1	9-11								131.1								
NEW-B009	ST-1	9.5	20.0															
NEW-B009	ST-1B	9.75	19.0	47	15	32	CL			132.3	111.2		UU@2.0	2.5	15.0			UU288f
NEW-B009	S-3	14-16	15.3															
NEW-B009	S-4	19-21	18.3															
NEW-B009	ST-2	29-31.3								128.8								
NEW-B009	ST-2B	30.0	16.7	31	14	17	CL			132.6	113.6		CIU@4.0	2.9	10.5			T3942
NEW-B009	ST-2	30.35	19.5															
NEW-B009	S-6	34-35.5	8.6	24	12	12	CL	51.6										
NEW-B009	S-7	37.5-38	16.9		19	NP	ML											
NEW-B009	S-9	42.5-44.5	15.0															
NEW-B009	S-10	50-52	13.7				CL	74.0	21									
NEW-B009	S-11	55-57	14.6															
NEW-B009	S-12	60-62	13.5	24	16	8	CL	66.4	18									
NEW-B009	S-14	70-71.42	12.2				CL	51.5	12									
NEW-B010	ST-1	5-7								137.3								
NEW-B010	ST-1	5.55	10.9															
NEW-B010	ST-1	6.1	15.8															
NEW-B010	ST-1C	6.3	10.2	24	13	11	CL			140.5	127.5		CIU@1.0	4.4	21.3			T3943
NEW-B010	S-4	10-12	13.7															
NEW-B010	ST-2	15-17								137.9								
NEW-B010	ST-2	15.7	13.9															
NEW-B010	ST-2	16.25	12.7															
NEW-B010	ST-2C	16.5	13.8	33	13	20	CL			137.3	120.6		CIU@2	3.5	20.9			T3944
NEW-B010	S-5	20-22	16.1															

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Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B010	S-6	25-27	19.1															
NEW-B010	S-7	30-32	21.0	49	16	33	CL	62.3	24									
NEW-B010	S-8	35-37	8.5	23	12	11	CL											
NEW-B010	S-12	47.5-48.2	13.5															
NEW-B010	S-13	50-50.8	10.1				SC	22.3	6									
NEW-B010	S-16	65-67	15.0				CL	70.6										
NEW-B010	S-18	75-77	14.5	28	15	13	CL											
NEW-B010	S-19	80-82	14.7	25	15	10	CL											
NEW-B012	ST-4	8-10								134.0								
NEW-B012	ST-4	8.65	15.5															
NEW-B012	ST-4	9.2	14.9															
NEW-B012	ST-4C	9.45	12.6	34	13	21	CL			139.6	123.9		UU@1.5	4.1	15.0			UU296d
NEW-B012	ST-7	20-21.7								135.0								
NEW-B012	ST-7	20.35	14.8															
NEW-B012	ST-7A	20.6	13.3				CL			137.1	121.0	7.8E-9						P10609
NEW-B012	ST-7	20.9	16.7															
NEW-B012	ST-7B	21.15	13.3	35	13	22	CL	52.1		138.4	122.1		CIU@2.5	3.2	21.8			T3938
NEW-B012	S-8	25-27	15.2	36	13	23	CL											
NEW-B012	S-9	30-32	12.9															
NEW-B012	S-10	35-37	16.8	40	15	25	CL											
NEW-B012	S-11	40-42	9.9				CL	55.9	17									
NEW-B012	ST-12	45-47								131.7								
NEW-B012	ST-12	45.55	19.8															
NEW-B012	ST-12	46.15	14.3															
NEW-B012	ST-12C	46.4	17.5	43	14	29	CL	62.1	30	133.6	113.8		CIU@6	3.4	23.3			T3883
NEW-B012	S-13	50-52	20.0															
NEW-B012	S-14	55-57	15.8	41	13	28	CL											
NEW-B012	ST-15	60-62								136.2								
NEW-B012	ST-15	60.65	18.7															
NEW-B012	ST-15	61.2	14.1															
NEW-B012	ST-15C	61.45	12.8	42	14	28	CL			132.5	117.6		DSS@7.2	2.8	7.1			DSS849
NEW-B012	S-17	70-72	10.9															
NEW-B012	S-18	75-77	11.8	29	13	16	CL	53.3	17									
NEW-B012	ST-19	80-82								139.7								

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Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B012	ST-19	80.85	12.2															
NEW-B012	ST-19	80.95	11.7															
NEW-B012	ST-19	81.1	11.2	25	14	11	SC			136.8	122.9		DS@6	4.2				DS1611
NEW-B012	ST-19	81.5	10.5				SC			139.2	126.0		DS@24	15.1				DS1612
NEW-B012	ST-19	81.8	16.9				SC			130.5	111.7		DS@12	7.2				DS1613
NEW-B012	S-20	85-87	16.2	34	14	20	CL											
NEW-B012	S-22	95-97	15.7															
NEW-B014	ST-1	2.5-4.1								140.5								
NEW-B014	ST-1A	2.95																
NEW-B014	ST-1	3.25	13.5															
NEW-B014	ST-1B	3.5	9.5	28	13	15	SC	46.2	16	142.7	130.3		UU@0.5	5.8	8.4			UU260f
NEW-B014	S-3	7.5-9.5	13.7	41	14	27	CL											
NEW-B014	S-4	10-12	18.7	42	15	27	CL											
NEW-B014	ST-2	15-16.9								133.8								
NEW-B014	ST-2	15.6	11.6															
NEW-B014	ST-2B	15.85	12.2	31	14	17	CL			139.2	124.1		EXT CIU	-1.6	-8.4			TE15001
NEW-B014	ST-2	16.15	10.2															
NEW-B014	S-5	20-22	9.6				SC	49.8										
NEW-B014	S-6	25-27	16.1	40	15	25	CL	59.0										
NEW-B014	S-7	30-31.33	16.7															
NEW-B014	S-7A	31.33-32	17.5				CL	60.4										
NEW-B014	ST-3	35-37								135.0								
NEW-B014	ST-3	35.3	19.7															
NEW-B014	ST-3	35.85	15.9															
NEW-B014	ST-3	36.4	12.6															
NEW-B014	ST-3C	36.65	16.3	38	13	25	SC	13.5	4	132.6	114.0		CIU@3	4.2	12.9			T3884
NEW-B014	S-8	40-42	16.2	39	14	25	CL											
NEW-B014	S-10	48-50	17.5															
NEW-B015	ST-1	10-12								130.3								
NEW-B015	ST-1A	10.4																
NEW-B015	ST-1	10.7	20.7															
NEW-B015	ST-1B	10.95	23.0	59	15	44	CH			126.0	102.5		CIU@1.5	1.3	18.0			T3885
NEW-B015	S-5	15-17	18.4															
NEW-B015	S-6	20-22	18.2															

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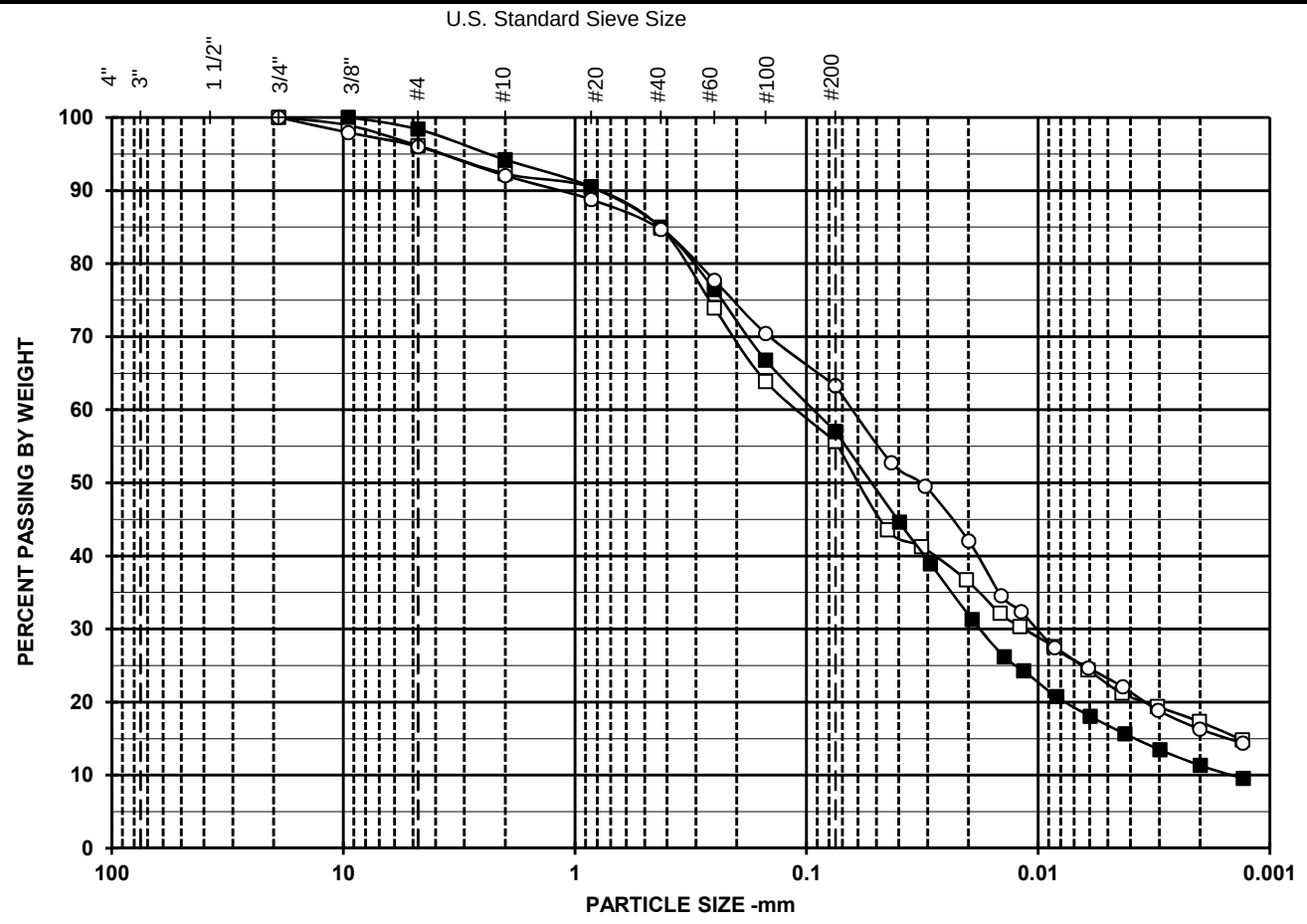
Dynegy CCR - Newton
LABORATORY TESTING DATA SUMMARY

BORING	SAMPLE	DEPTH	IDENTIFICATION TESTS									PERMEABILITY	STRENGTH			CONSOLIDATION		REMARKS
			WATER CONTENT	LIQUID LIMIT	PLASTIC LIMIT	PLAS. INDEX	USCS SYMB. (1)	SIEVE MINUS NO. 200	HYDRO. % MINUS 2 μm	TOTAL UNIT WEIGHT	DRY UNIT WEIGHT		TEST TYPE @STRESS	PEAK SHEAR STRESS	STRAIN @ PEAK STRESS	INITIAL CONDITIONS		
NO.	NO.															VOID RATIO	SATUR-ATION	
		(ft)	(%)	(-)	(-)	(-)		(%)	(%)	(pcf)	(pcf)	(cm/sec)	(ksf)	(ksf)	(%)	(-)	(%)	
NEW-B015	ST-2	25-27								130.2								
NEW-B015	ST-2	25.2	15.6															
NEW-B015	ST-2A	25.45	24.0				CH			126.1	101.7	1.8E-9						P10608
NEW-B015	ST-2	25.75	24.7															
NEW-B015	ST-2B	26.0	19.5	52	15	37	CH			131.4	110.0		CIU@5	3.1	13.2			T3935
NEW-B015	S-7	30-32	16.3	37	13	24	CL											
NEW-B015	S-8	35-37	21.5	46	14	32	CL	84.5	36									
NEW-B015	S-9	40-42	8.1															
NEW-B015	S-11	50-52	14.1															
NEW-B015	ST-3	60-61.3								137.7								
NEW-B015	ST-3	60.15	11.7															
NEW-B015	ST-3	60.35	11.2				CL			139.6	125.5		DS@3.75	3.2				DS1623
NEW-B015	ST-3	60.75	11.9	30	15	15	CL			140.2	125.3		DS@7.5	5.4				DS1625
NEW-B015	ST-3	61.05	12.7				CL			139.8	124.1		DS@15	9.1				DS1627
NEW-B015	ST-4	70-70.3																no tests
NEW-B016	S-3A	5-6	16.4	35	13	22	CL											
NEW-B016	S-3B	6.5-7					SM	13.2	7									
NEW-B016	S-4B	8-9	11.3															
NEW-B016	S-5	10-12	12.1				ML	62.6										
NEW-B016	S-6	15-17	11.1	52	14	38	CH	73.0	20									
NEW-B016	S-7	20-22	14.5															
NEW-B016	S-9	30-32	11.6	29	15	14	CL											
NEW-B016	S-10	35-37	13.2															

Note: (1) USCS symbol based on visual observation and Sieve and Atterberg limits reported.

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	15.8	25	14	11	CL	Brown, Sandy lean clay	9/2/2015
■	14.6	22	13	9	CL	Brown, Sandy lean clay	9/2/2015
○	11.5	30	13	17	CL	Dark brown, Sandy lean clay	9/2/2015

Symbol	□	■	○
Boring	NEW-B001	NEW-B001	NEW-B001
Sample	S-10	S-11	S-16
Depth	35-37	40-41	55-57
% +3"	0.0	0.0	0.0
% Gravel	3.9	1.6	4.0
% SAND	40.5	41.4	32.7
%C SAND	3.9	4.2	4.0
%M SAND	7.5	9.2	7.4
%F SAND	29.2	28.0	21.4
% FINES	55.6	57.0	63.3
% -2μ	17	11	16
D_{100} (mm)	19.00	9.50	19.00
D_{60} (mm)	0.11	0.10	0.07
D_{30} (mm)	0.01	0.02	0.01
D_{10} (mm)			
Cc			
Cu			

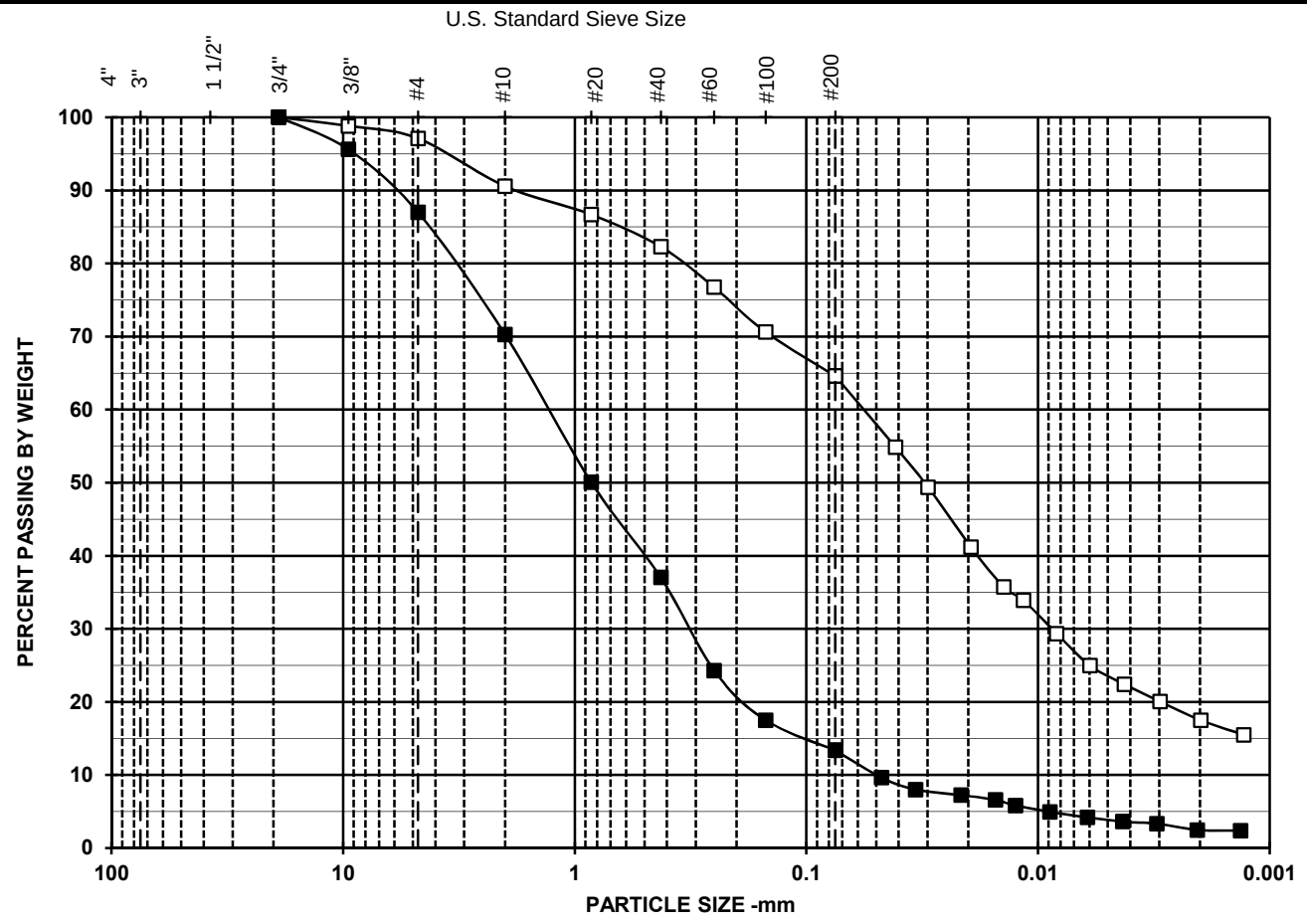
Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"	100.0		100.0
3/8"	98.9	100.0	97.9
4	96.1	98.4	96.0
10	92.3	94.2	92.0
20	90.4	90.5	88.8
40	84.8	85.0	84.7
60	73.9	76.4	77.7
100	63.9	66.8	70.4
200	55.6	57.0	63.3

TerraSense, LLC	AECOM
T60428794	60428794-108

PARTICLE SIZE DISTRIBUTION

Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B001	NEW-B001	
Sample	S-18	S-24	
Depth	65-67	95-97	
% +3"	0.0	0.0	
% Gravel	2.9	13.0	
% SAND	32.5	73.6	
%C SAND	6.6	16.7	
%M SAND	8.3	33.3	
%F SAND	17.7	23.6	
% FINES	64.6	13.4	
% -2μ	18	2	
D_{100} (mm)	19.00	19.00	
D_{60} (mm)	0.06	1.41	
D_{30} (mm)	0.01	0.33	
D_{10} (mm)			
Cc			
Cu			

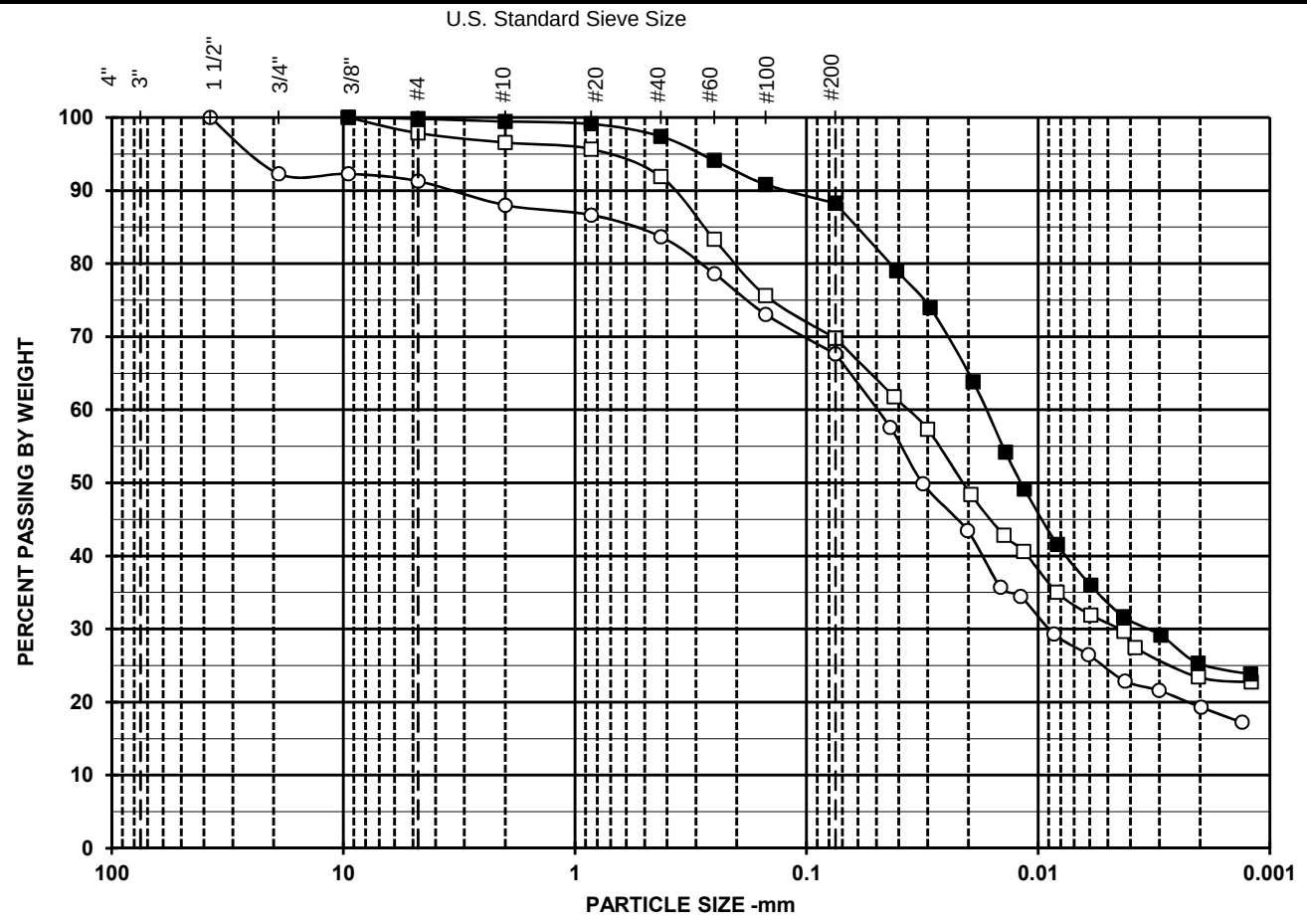
Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"	100.0	100.0	
3/8"	98.8	95.6	
4	97.1	87.0	
10	90.6	70.3	
20	86.7	50.1	
40	82.3	37.0	
60	76.7	24.3	
100	70.6	17.5	
200	64.6	13.4	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	12.8	33	14	19	CL	Dark brown, Sandy lean clay	9/2/2015
■	11.0				SM	Brown, Silty sand	9/2/2015
○							

TerraSense, LLC	AECOM
T60428794	60428794-108

PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	19.6	42	14	28	CL	Brown , Sandy lean clay	9/3/2015
■	22.9	50	18	32	CH	Brown, Fat clay	9/3/2015
○	12.7				CL	Brown, Sandy lean clay	8/31/2015

Symbol	□	■	○
Boring	NEW-B003	NEW-B003	NEW-B003
Sample	S-6	S-8	S-13
Depth	30-32	40-42	65-67
% +3"	0.0	0.0	0.0
% Gravel	2.1	0.2	8.7
% SAND	28.1	11.6	23.7
%C SAND	1.3	0.4	3.3
%M SAND	4.7	2.0	4.3
%F SAND	22.1	9.2	16.0
% FINES	69.8	88.2	67.6
% -2μ	23	25	19
D_{100} (mm)	9.50	9.50	37.50
D_{60} (mm)	0.04	0.02	0.05
D_{30} (mm)	0.00	0.00	0.01
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			100.0
3/4"			92.3
3/8"	100.0	100.0	92.3
4	97.9	99.8	91.3
10	96.6	99.4	88.0
20	95.7	99.1	86.6
40	91.9	97.4	83.7
60	83.3	94.1	78.6
100	75.6	90.8	73.0
200	69.8	88.2	67.6

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PARTICLE SIZE DISTRIBUTION

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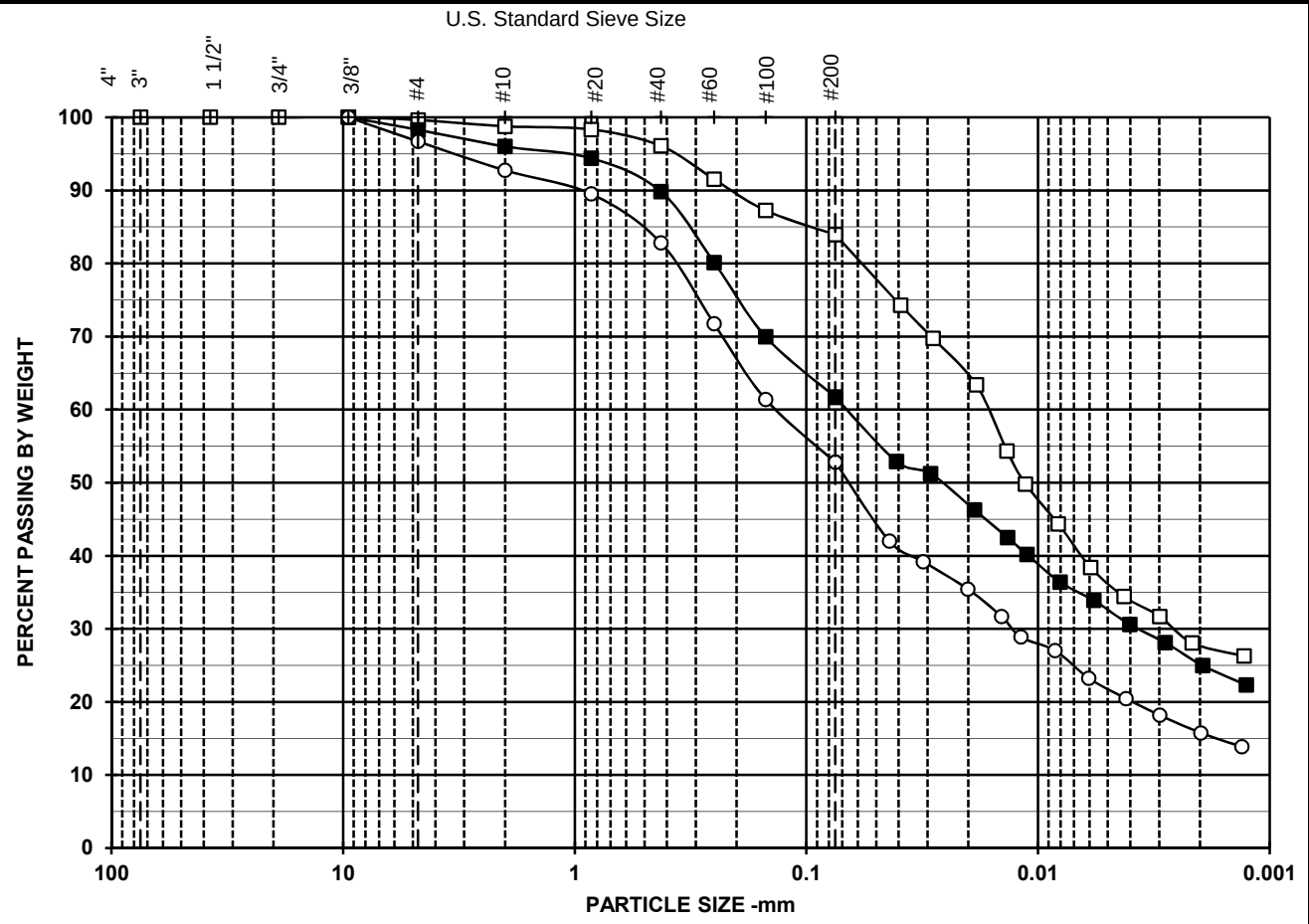
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□		50	13	37	CH	Gray brown , Fat clay with sand	10/27/2015
■	17.7	37	14	23	CL	Brown, Sandy lean clay	9/2/2015
○	9.0				CL	Light brown, Sandy lean clay	8/31/2015

Symbol	□	■	○
Boring	NEW-B004	NEW-B004	NEW-B004
Sample	ST-4C	S-10	S-13
Depth	9.5	27.5-29.5	33.5-35.5
% +3"	0.0	0.0	0.0
% Gravel	0.4	1.7	3.3
% SAND	15.7	36.6	43.9
%C SAND	0.9	2.3	4.0
%M SAND	2.7	6.2	9.9
%F SAND	12.1	28.1	30.0
% FINES	83.9	61.7	52.8
% -2μ	28	25	16
D_{100} (mm)	9.50	9.50	9.50
D_{60} (mm)	0.02	0.07	0.14
D_{30} (mm)	0.00	0.00	0.01
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"	100.0		
3"	100.0		
1 1/2"	100.0		
3/4"	100.0		
3/8"	100.0	100.0	100.0
4	99.6	98.3	96.7
10	98.8	96.0	92.7
20	98.3	94.4	89.5
40	96.1	89.8	82.8
60	91.5	80.1	71.7
100	87.2	70.0	61.4
200	83.9	61.7	52.8

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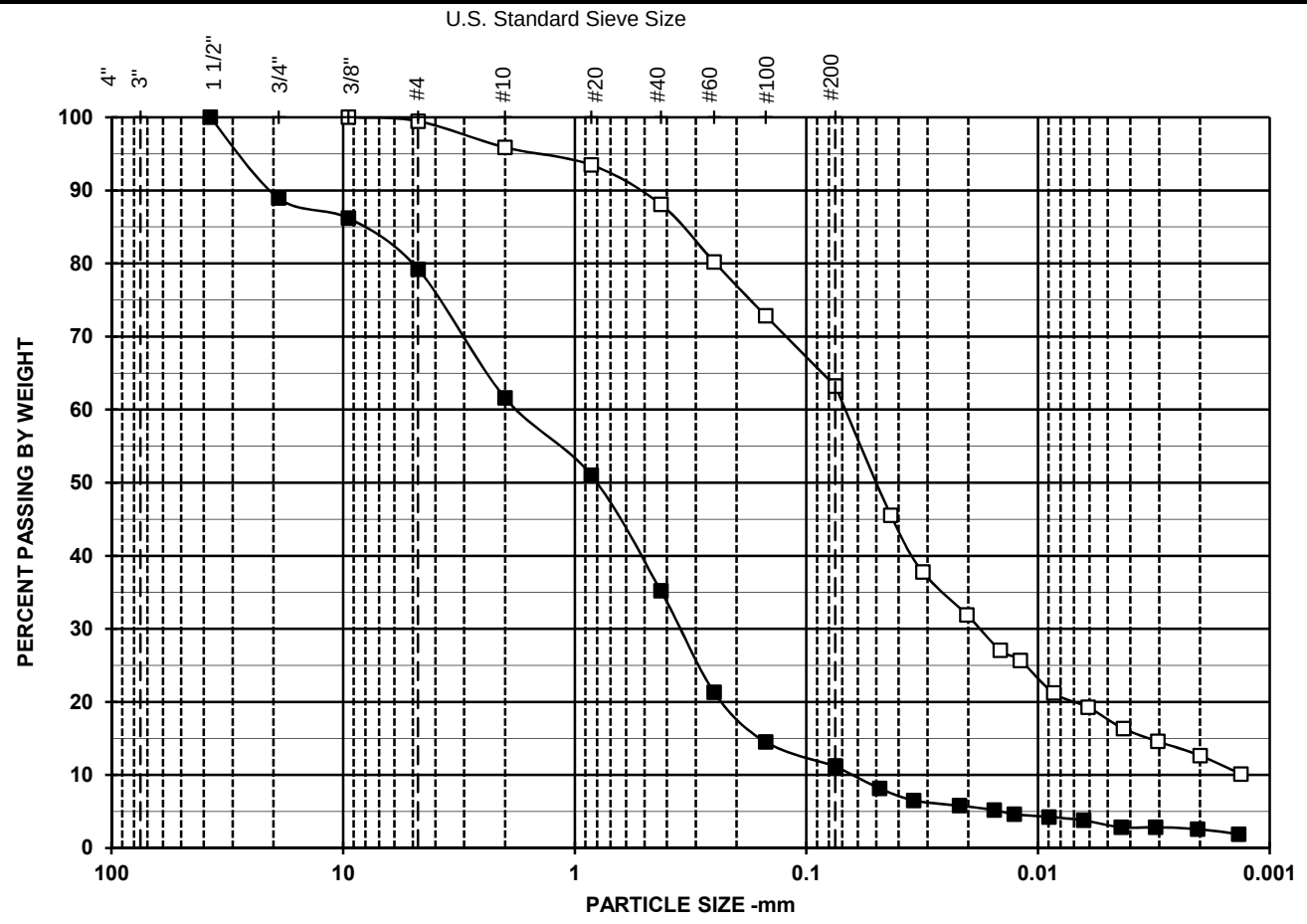
PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B004A	NEW-B004A	
Sample	S-1	S-11	
Depth	45-46	95-96.5	
% +3"	0.0	0.0	
% Gravel	0.5	20.8	
% SAND	36.3	68.0	
%C SAND	3.6	17.6	
%M SAND	7.8	26.4	
%F SAND	24.9	24.0	
% FINES	63.2	11.2	
% -2μ	13	3	
D_{100} (mm)	9.50	37.50	
D_{60} (mm)	0.07	1.82	
D_{30} (mm)	0.02	0.36	
D_{10} (mm)		0.06	
Cc		1.1	
Cu		28.4	

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"		100.0	
3/4"		88.9	
3/8"	100.0	86.2	
4	99.5	79.2	
10	95.9	61.6	
20	93.5	51.0	
40	88.1	35.2	
60	80.2	21.3	
100	72.8	14.5	
200	63.2	11.2	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	10.4				CL	Brown, Sandy lean clay	8/31/2015
■	11.1				SW-SM	Brown, Well-graded sand with silt and gravel	8/31/2015
○							

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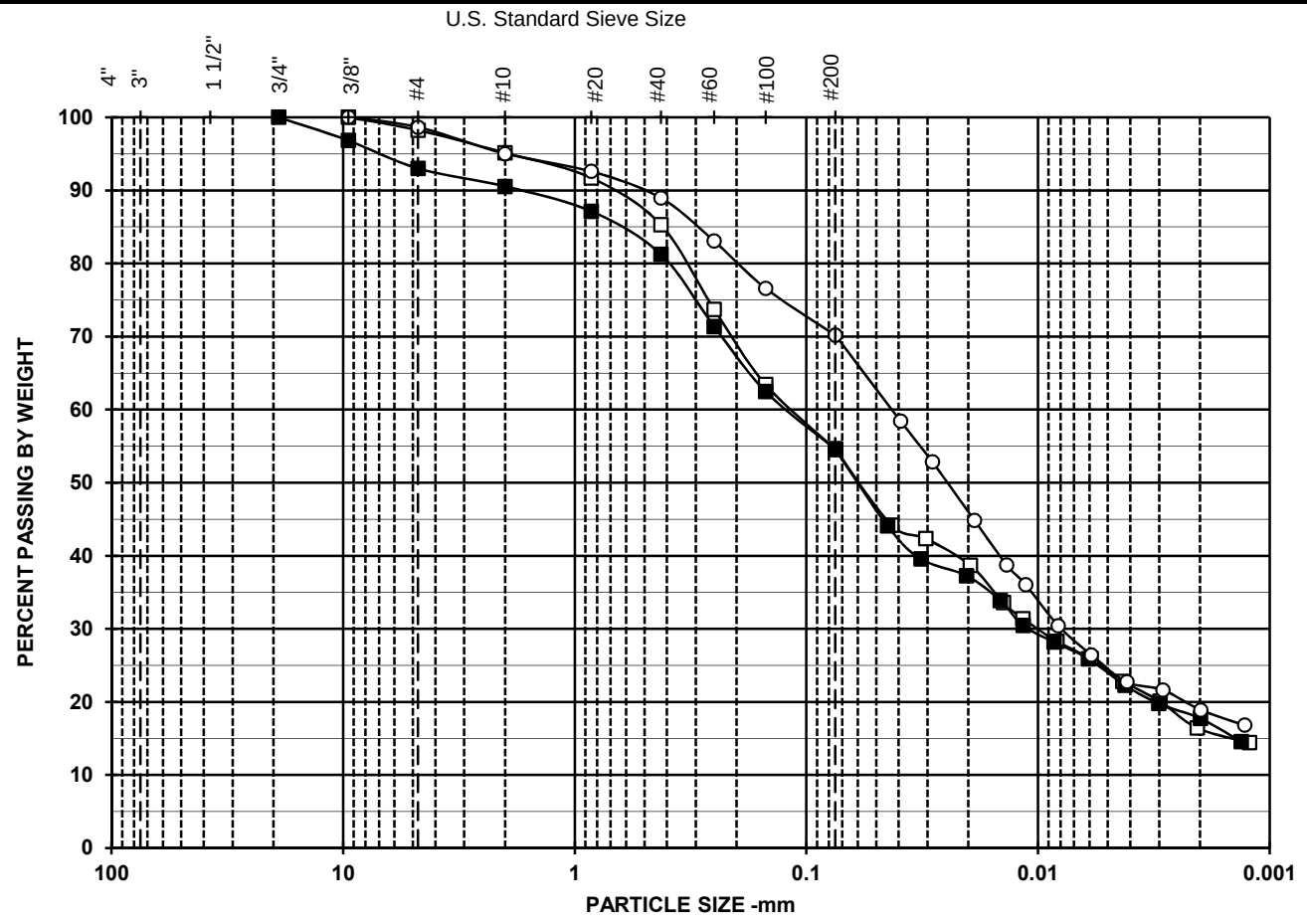
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B005	NEW-B005	NEW-B005
Sample	S-6	S-8	S-12
Depth	15-16.5	25-26	45-47
% +3"	0.0	0.0	0.0
% Gravel	1.8	7.0	1.4
% SAND	43.6	38.4	28.4
%C SAND	3.1	2.5	3.6
%M SAND	9.8	9.3	6.1
%F SAND	30.7	26.7	18.8
% FINES	54.6	54.6	70.2
% -2μ	16	18	19
D_{100} (mm)	9.50	19.00	9.50
D_{60} (mm)	0.12	0.13	0.04
D_{30} (mm)	0.01	0.01	0.01
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"		100.0	
3/8"	100.0	96.8	100.0
4	98.2	93.0	98.6
10	95.1	90.5	95.0
20	91.7	87.1	92.6
40	85.3	81.2	89.0
60	73.7	71.4	83.1
100	63.4	62.5	76.6
200	54.6	54.6	70.2

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	9.4	27	12	15	CL	Brown, Sandy lean clay	9/3/2015
■	11.6				CL	Brown, Sandy lean clay	8/31/2015
○	13.1	33	15	18	CL	Dark brown, Lean clay with sand	9/2/2015

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PARTICLE SIZE DISTRIBUTION

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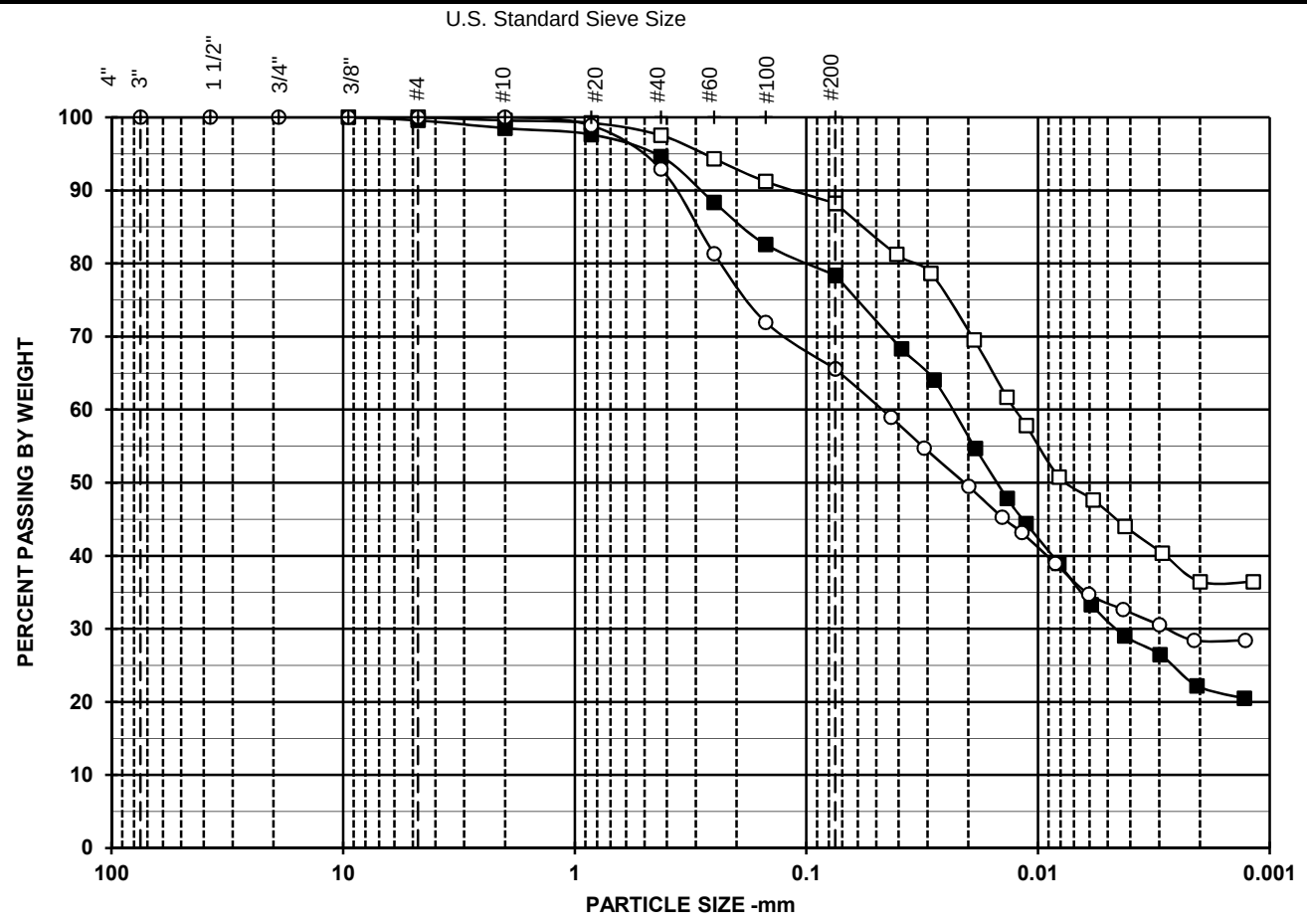
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	21.2	66	14	52	CH	Brown, Fat clay	9/3/2015
■	18.2	40	17	23	CL	Brown, Lean clay with sand	10/29/2015
○		44	12	32	CL	Brown, Sandy lean clay	11/5/2015

Symbol	□	■	○
Boring	NEW-B006	NEW-B006	NEW-B006
Sample	S-3	ST-1B	ST-2
Depth	10-12	21.20	26.75
% +3"	0.0	0.0	0.0
% Gravel	0.0	0.4	0.0
% SAND	11.8	21.2	34.4
%C SAND	0.4	1.1	0.0
%M SAND	2.0	3.9	7.1
%F SAND	9.3	16.3	27.4
% FINES	88.2	78.4	65.6
% -2μ	36	22	28
D_{100} (mm)	4.75	9.50	2.00
D_{60} (mm)	0.01	0.02	0.05
D_{30} (mm)	0.00	0.00	0.00
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			100.0
3"			100.0
1 1/2"			100.0
3/4"			100.0
3/8"		100.0	100.0
4	100.0	99.6	100.0
10	99.6	98.5	100.0
20	99.2	97.6	98.9
40	97.5	94.6	92.9
60	94.3	88.3	81.3
100	91.2	82.6	71.9
200	88.2	78.4	65.6

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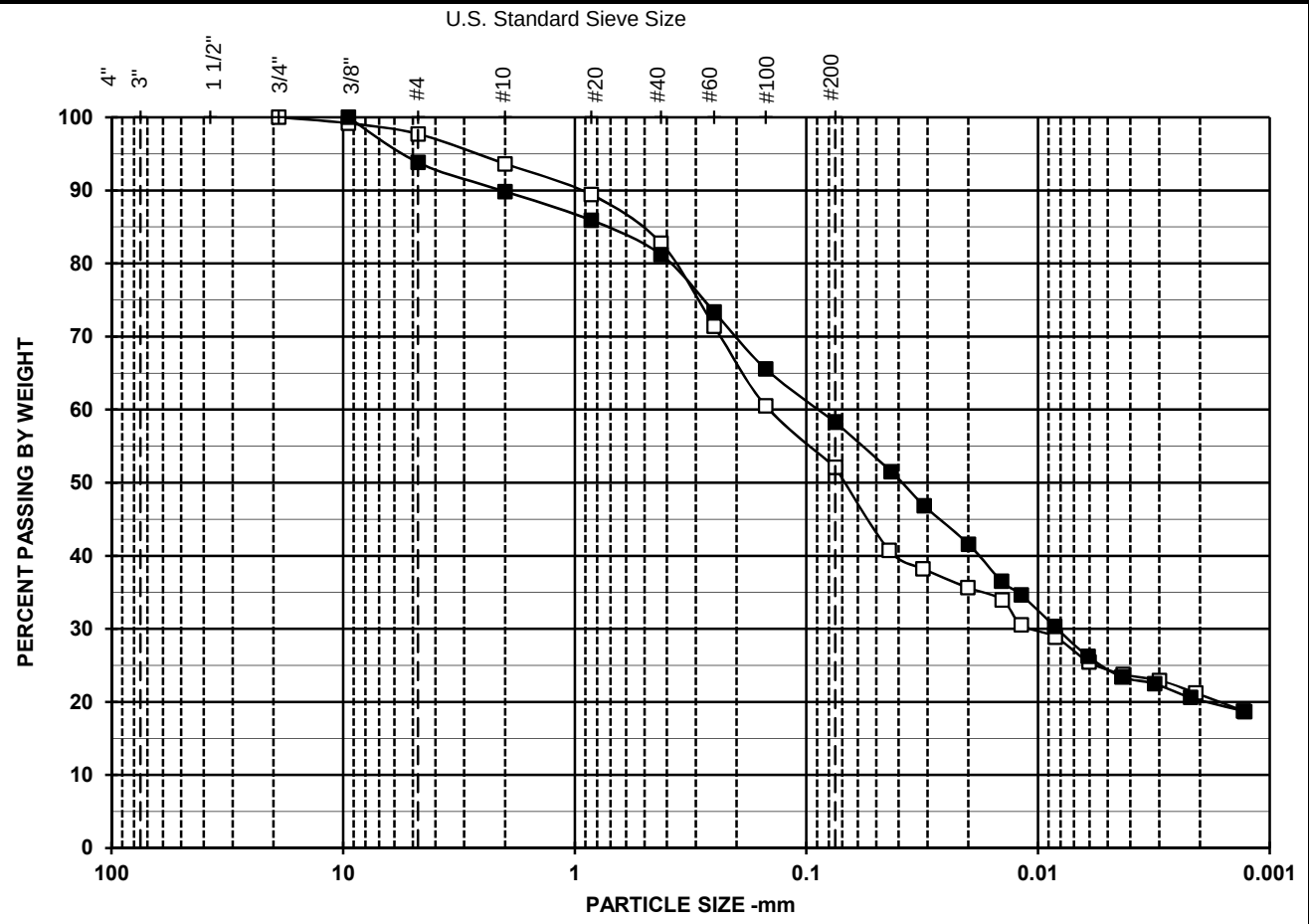
PARTICLE SIZE DISTRIBUTION

Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B006	NEW-B006	
Sample	ST-3C	ST-4	
Depth	31.8	35-35.8	
% +3"	0.0	0.0	
% Gravel	2.3	6.2	
% SAND	45.6	35.5	
%C SAND	4.1	4.0	
%M SAND	10.8	8.6	
%F SAND	30.7	22.9	
% FINES	52.1	58.3	
% -2μ	21	20	
D_{100} (mm)	19.00	9.50	
D_{60} (mm)	0.15	0.09	
D_{30} (mm)	0.01	0.01	
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"	100.0		
3/8"	99.2	100.0	
4	97.7	93.8	
10	93.6	89.8	
20	89.4	85.9	
40	82.8	81.2	
60	71.4	73.4	
100	60.5	65.6	
200	52.1	58.3	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□		37	15	22	CL	Dark brown, Sandy lean clay	10/13/2015
■		30	13	17	CL	Light brown, Sandy lean clay	9/28/2015
○							

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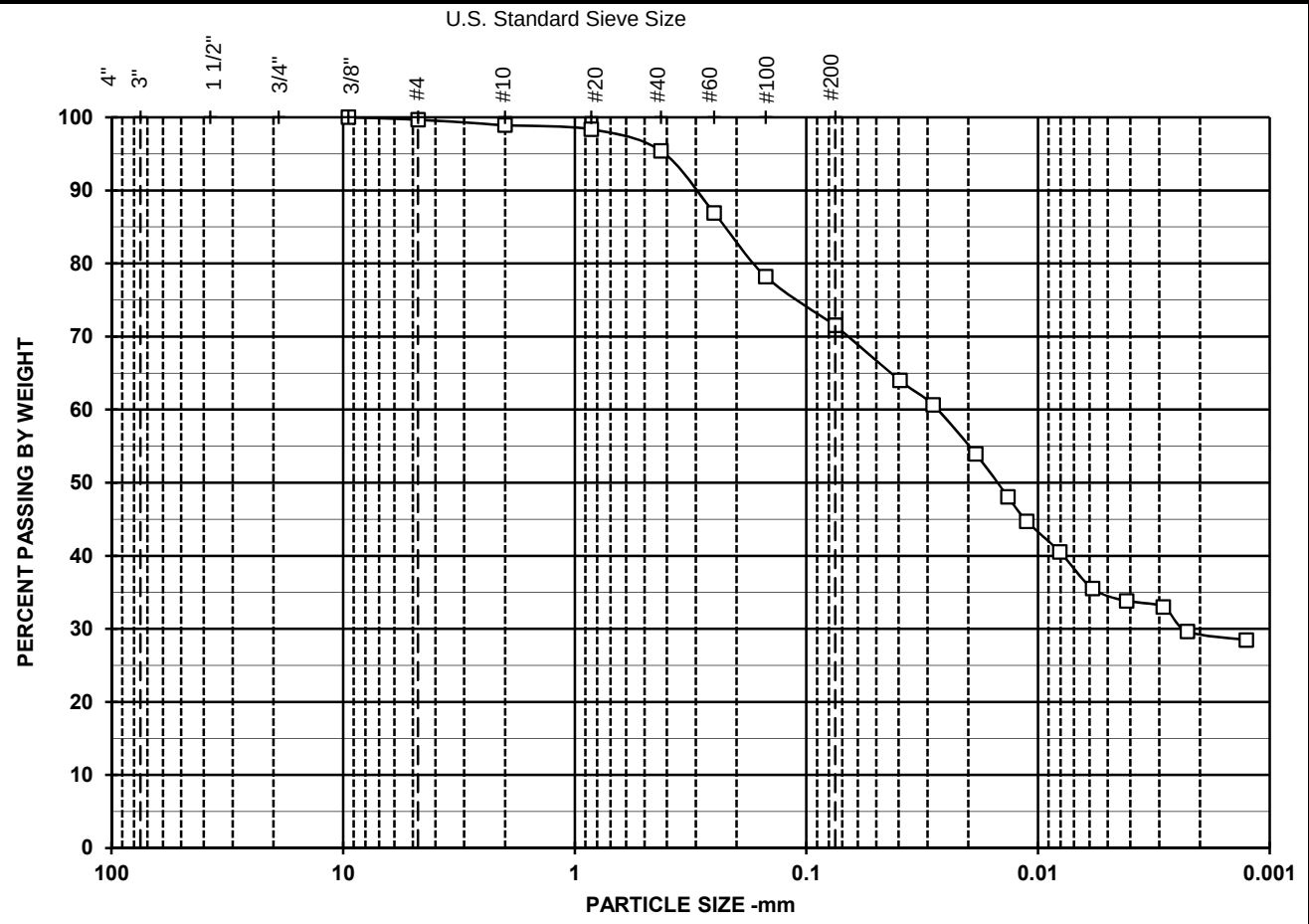
PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B007		
Sample	ST-3C		
Depth	31.7		
% +3"	0.0		
% Gravel	0.3		
% SAND	28.2		
%C SAND	0.7		
%M SAND	3.5		
%F SAND	23.9		
% FINES	71.5		
% -2μ	29		
D_{100} (mm)	9.50		
D_{60} (mm)	0.03		
D_{30} (mm)	0.00		
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"			
3/8"	100.0		
4	99.7		
10	98.9		
20	98.4		
40	95.4		
60	86.9		
100	78.2		
200	71.5		

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	21.5	52	12	40	CH	Brown , Fat clay with sand	10/19/2015
■							
○							

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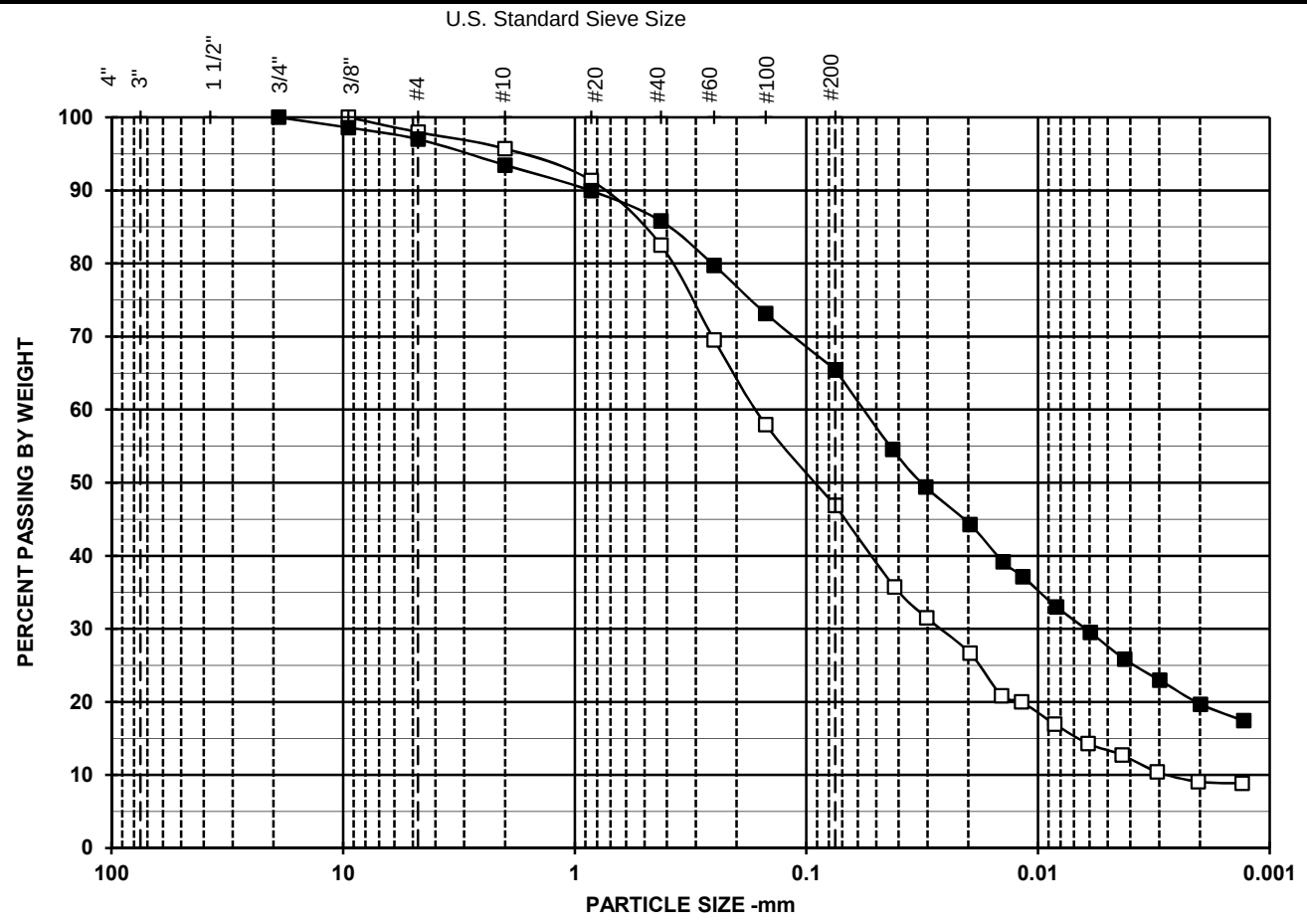
PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B008	NEW-B008	
Sample	S-8	S-10	
Depth	40-42	50-51.5	
% +3"	0.0	0.0	
% Gravel	2.0	3.0	
% SAND	51.1	31.6	
%C SAND	2.3	3.5	
%M SAND	13.2	7.7	
%F SAND	35.7	20.4	
% FINES	46.9	65.4	
% -2μ	9	20	
D_{100} (mm)	9.50	19.00	
D_{60} (mm)	0.17	0.06	
D_{30} (mm)	0.03	0.01	
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"		100.0	
3/8"	100.0	98.6	
4	98.0	97.0	
10	95.7	93.5	
20	91.4	89.9	
40	82.5	85.8	
60	69.5	79.7	
100	58.0	73.1	
200	46.9	65.4	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	14.6				SC	Brown , Clayey sand	9/2/2015
■	15.4	32	16	16	CL	Brown, Sandy lean clay	9/2/2015
○							

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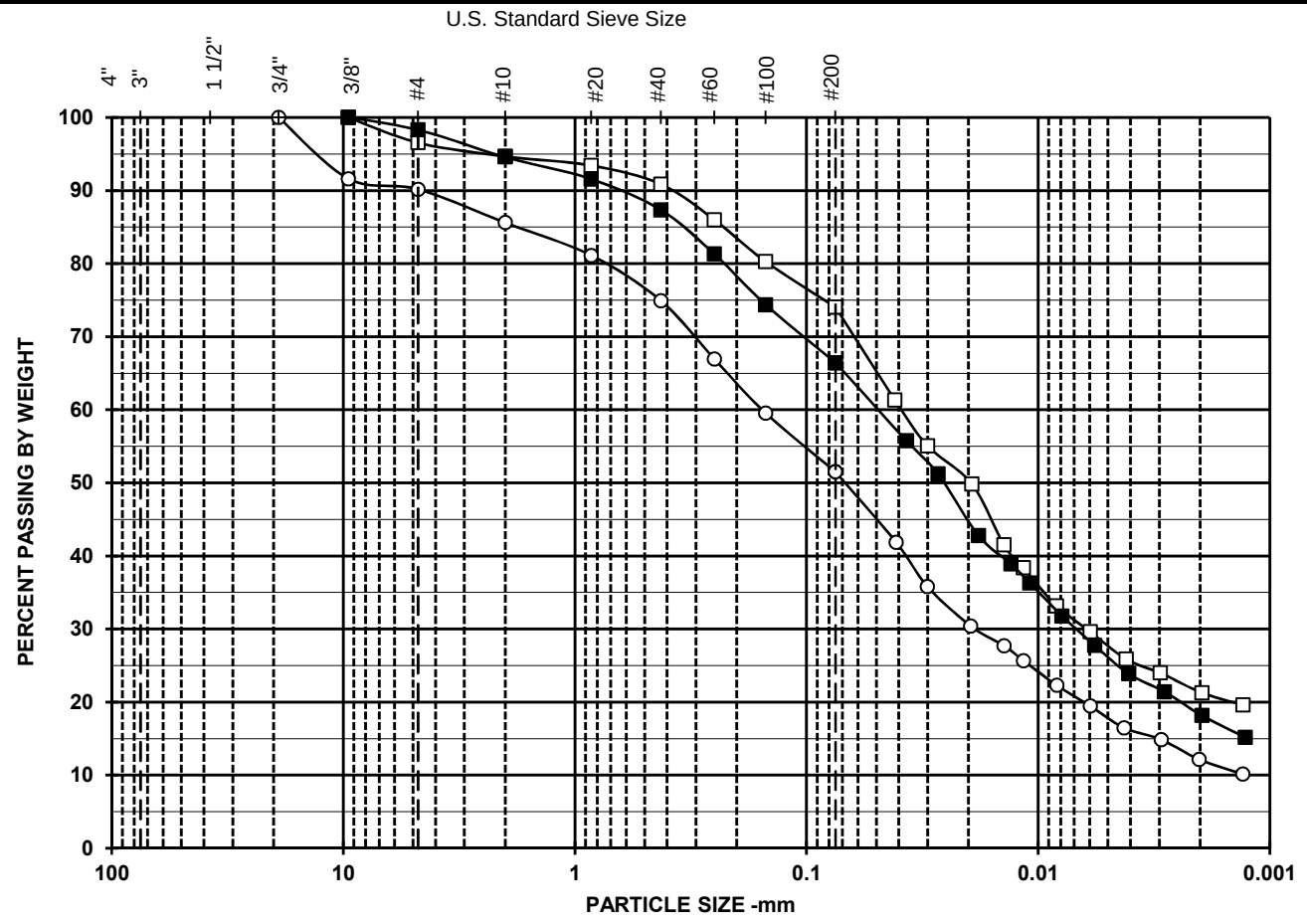
PARTICLE SIZE DISTRIBUTION

Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	13.7				CL	Brown, Lean clay with sand	8/31/2015
■	13.5	24	16	8	CL	Brown, Sandy lean clay	9/2/2015
○	12.2				CL	Brown, Sandy lean clay	9/2/2015

Symbol	□	■	○
Boring	NEW-B009	NEW-B009	NEW-B009
Sample	S-10	S-12	S-14
Depth	50-52	60-62	70-71.4
% +3"	0.0	0.0	0.0
% Gravel	3.5	1.7	9.8
% SAND	22.5	31.9	38.7
%C SAND	1.9	3.7	4.6
%M SAND	3.8	7.3	10.7
%F SAND	16.8	20.9	23.4
% FINES	74.0	66.4	51.5
% -2μ	21	18	12
D_{100} (mm)	9.50	9.50	19.00
D_{60} (mm)	0.04	0.05	0.16
D_{30} (mm)	0.01	0.01	0.02
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"			100.0
3/8"	100.0	100.0	91.6
4	96.5	98.3	90.2
10	94.7	94.6	85.6
20	93.4	91.6	81.1
40	90.9	87.3	74.9
60	86.0	81.3	67.0
100	80.3	74.4	59.5
200	74.0	66.4	51.5

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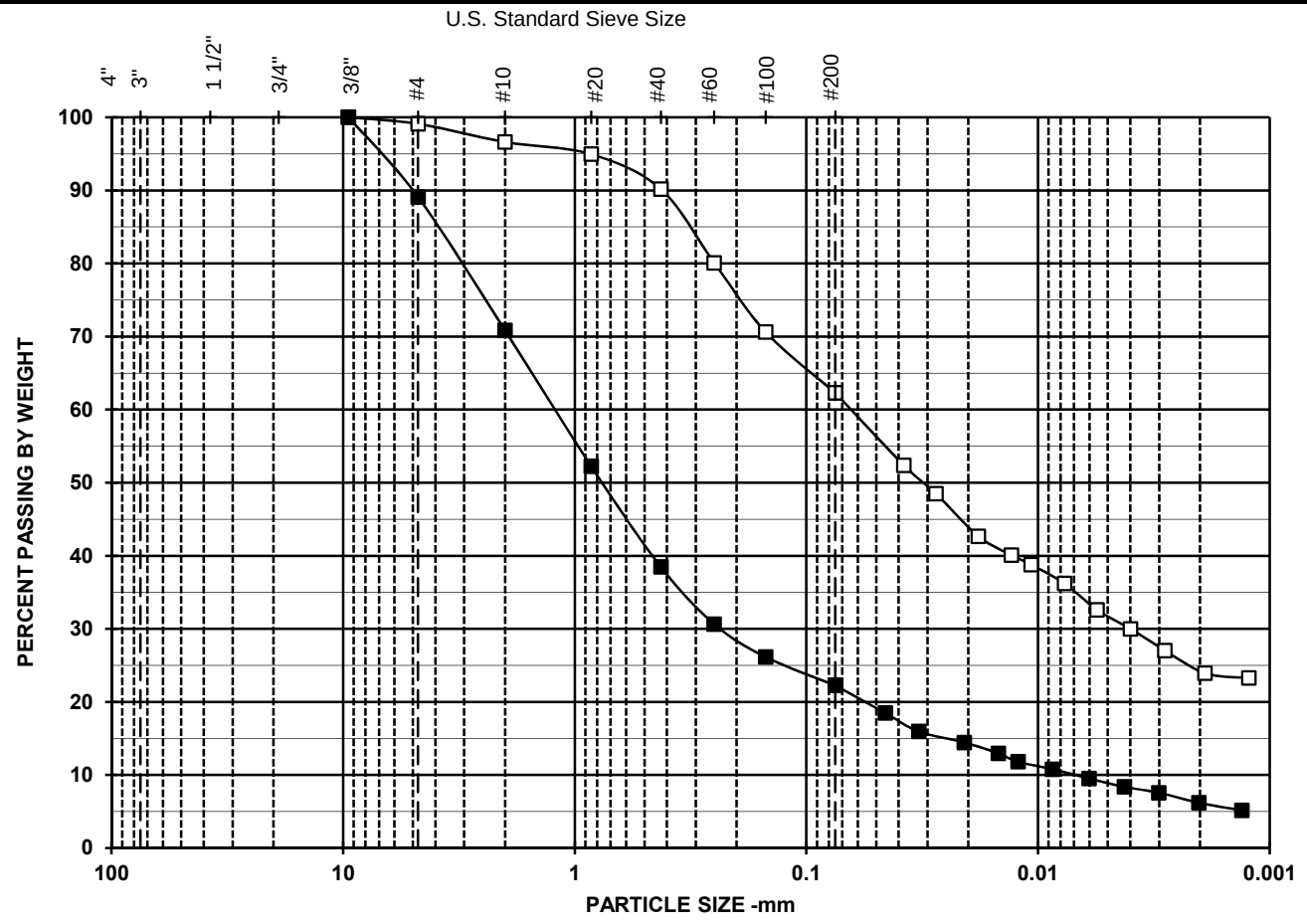
PARTICLE SIZE DISTRIBUTION

Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B010	NEW-B010	
Sample	S-7	S-13	
Depth	30-32	50-50.8	
% +3"	0.0	0.0	
% Gravel	0.9	10.9	
% SAND	36.8	66.8	
%C SAND	2.5	18.3	
%M SAND	6.5	32.3	
%F SAND	27.9	16.2	
% FINES	62.3	22.3	
% -2μ	24	6	
D_{100} (mm)	9.50	9.50	
D_{60} (mm)	0.07	1.33	
D_{30} (mm)	0.00	0.24	
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"			
3/8"	100.0	100.0	
4	99.1	89.1	
10	96.6	70.8	
20	95.0	52.2	
40	90.2	38.5	
60	80.1	30.6	
100	70.6	26.1	
200	62.3	22.3	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	21.0	49	16	33	CL	Brown , Sandy lean clay	9/2/2015
■	10.1				SC	Brown, Clayey sand	9/2/2015
○							

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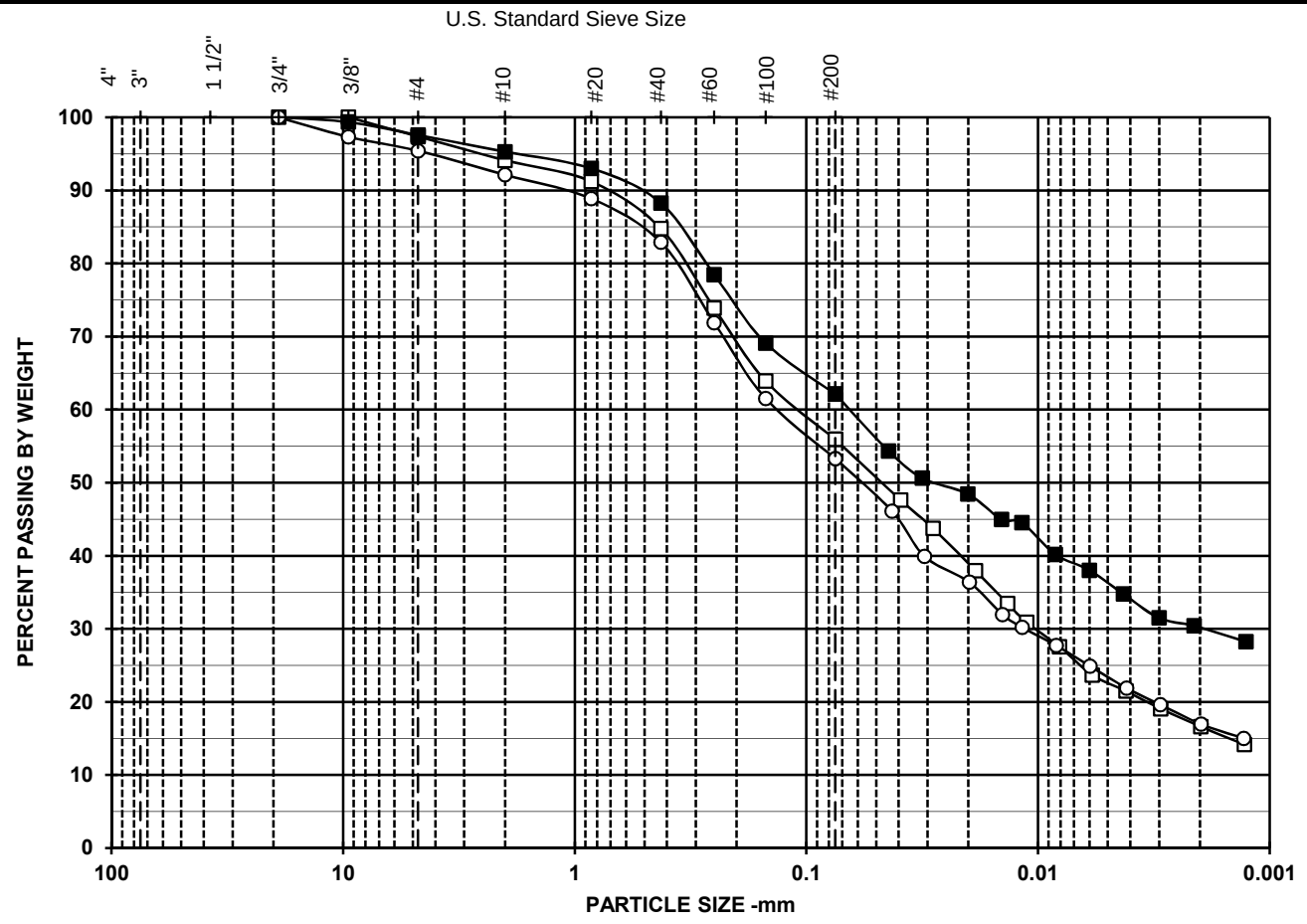
COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B012	NEW-B012	NEW-B012
Sample	S-11	ST-12C	S-18
Depth	40-42	46.4	75-77
% +3"	0.0	0.0	0.0
% Gravel	2.6	2.4	4.6
% SAND	41.5	35.5	42.1
%C SAND	3.3	2.3	3.3
%M SAND	9.3	7.0	9.2
%F SAND	28.8	26.1	29.6
% FINES	55.9	62.1	53.3
% -2μ	17	30	17
D_{100} (mm)	9.50	19.00	19.00
D_{60} (mm)	0.11	0.07	0.14
D_{30} (mm)	0.01	0.00	0.01
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"		100.0	100.0
3/8"	100.0	99.4	97.3
4	97.4	97.6	95.4
10	94.1	95.3	92.1
20	91.2	93.0	88.9
40	84.8	88.3	82.9
60	73.9	78.5	71.9
100	63.9	69.1	61.5
200	55.9	62.1	53.3

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	9.9				CL	Brown , Sandy lean clay	9/2/2015
■		43	14	29	CL	Brown, Sandy lean clay	9/23/2015
○	11.8	29	13	16	CL	Brown, Sandy lean clay	9/2/2015

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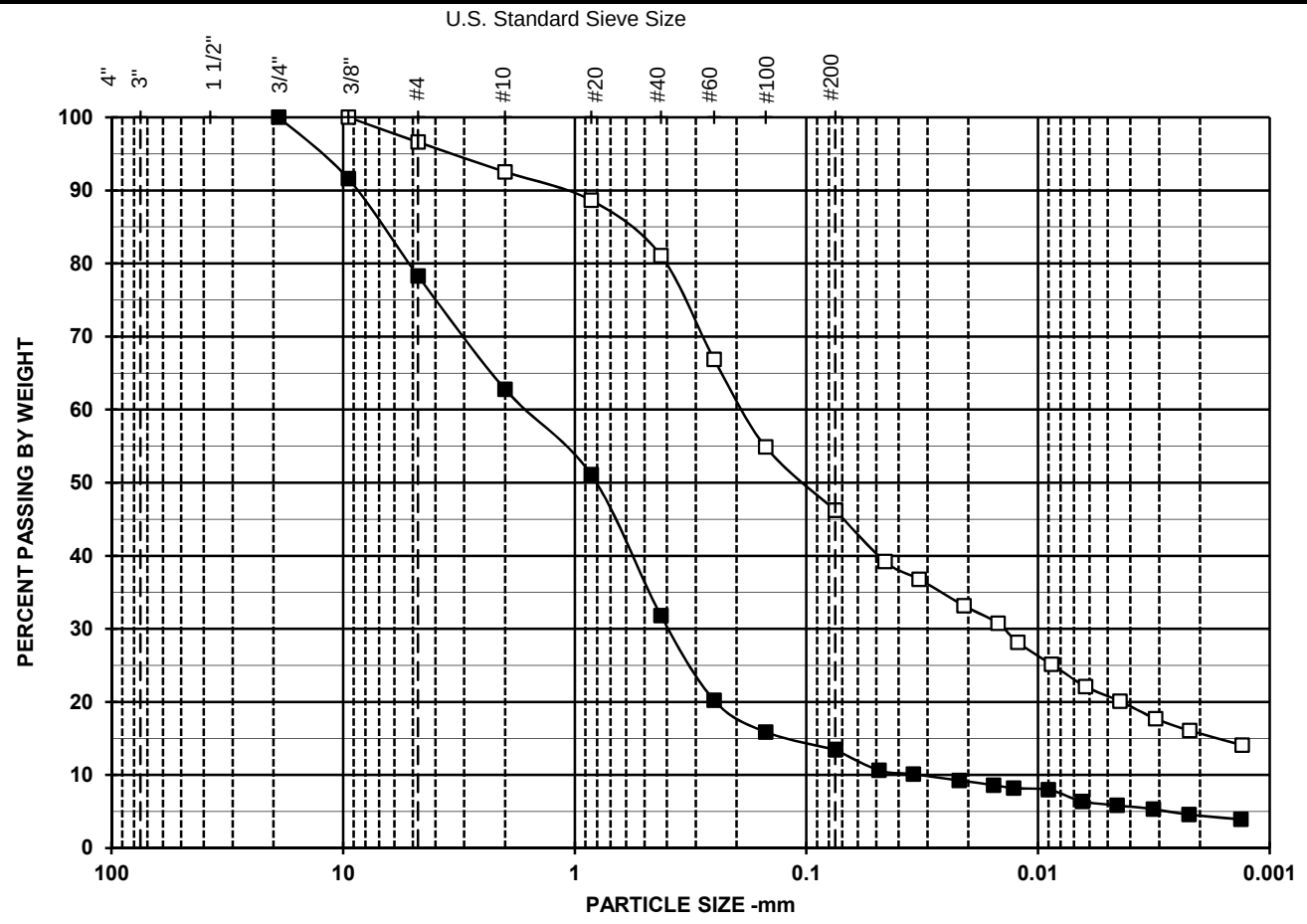
PARTICLE SIZE DISTRIBUTION

Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B014	NEW-B014	
Sample	ST-1B	ST-3C	
Depth	3.5	36.65	
% +3"	0.0	0.0	
% Gravel	3.4	21.7	
% SAND	50.4	64.8	
%C SAND	4.1	15.5	
%M SAND	11.5	31.0	
%F SAND	34.9	18.3	
% FINES	46.2	13.5	
% -2μ	16	4	
D_{100} (mm)	9.50	19.00	
D_{60} (mm)	0.19	1.73	
D_{30} (mm)	0.01	0.40	
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"		100.0	
3/8"	100.0	91.6	
4	96.6	78.3	
10	92.5	62.8	
20	88.7	51.1	
40	81.1	31.8	
60	66.9	20.2	
100	54.9	15.9	
200	46.2	13.5	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	9.5	28	13	15	SC	Orange brown, Clayey sand	9/18/2015
■		38	13	25	SC	Brown, Clayey sand with gravel	9/23/2015
○							

TerraSense, LLC	AECOM
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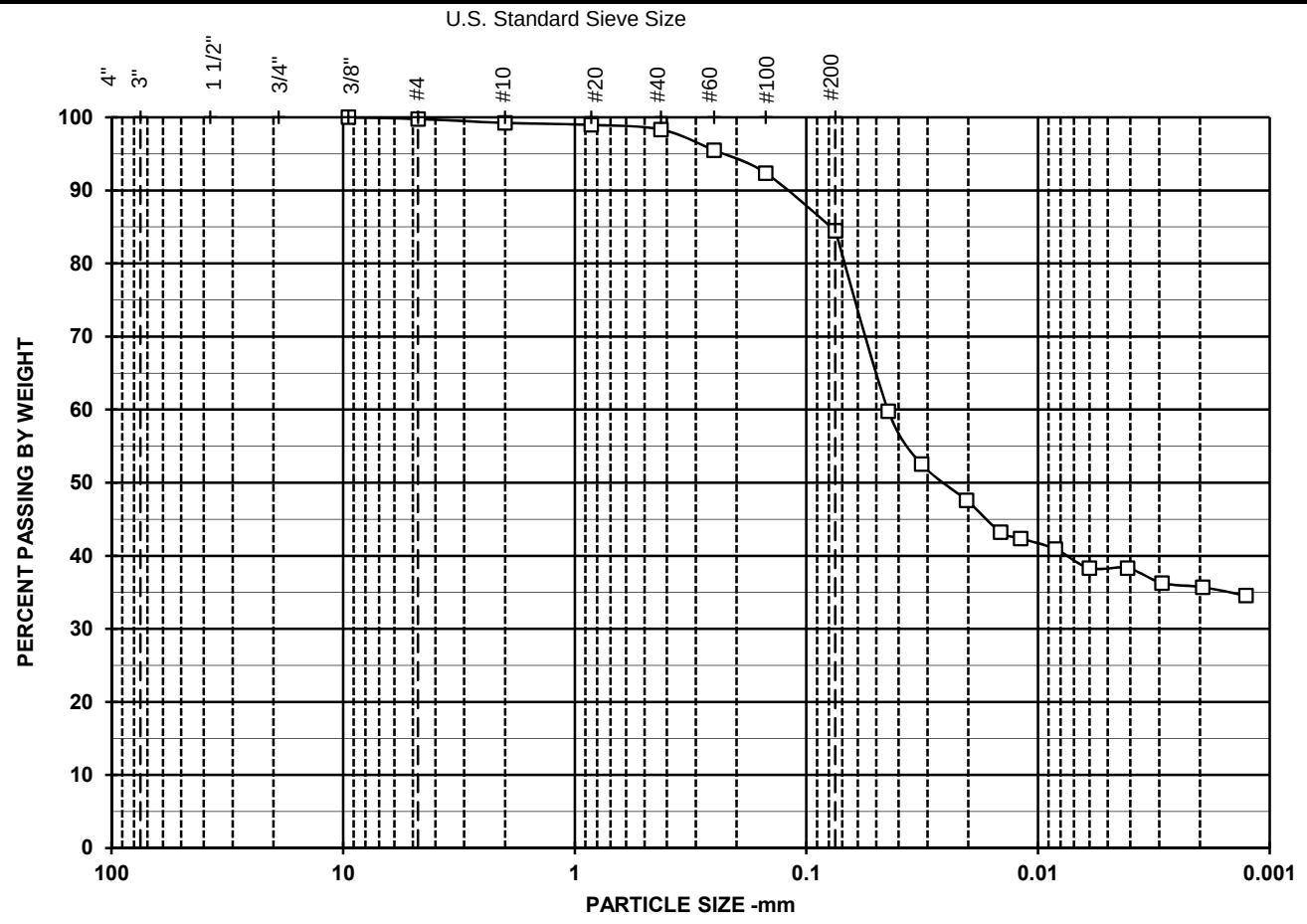
PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B015		
Sample	S-8		
Depth	35-37		
% +3"	0.0		
% Gravel	0.2		
% SAND	15.3		
%C SAND	0.5		
%M SAND	0.9		
%F SAND	13.8		
% FINES	84.5		
% -2μ	36		
D_{100} (mm)	9.50		
D_{60} (mm)	0.04		
D_{30} (mm)	0.00		
D_{10} (mm)			
Cc			
Cu			

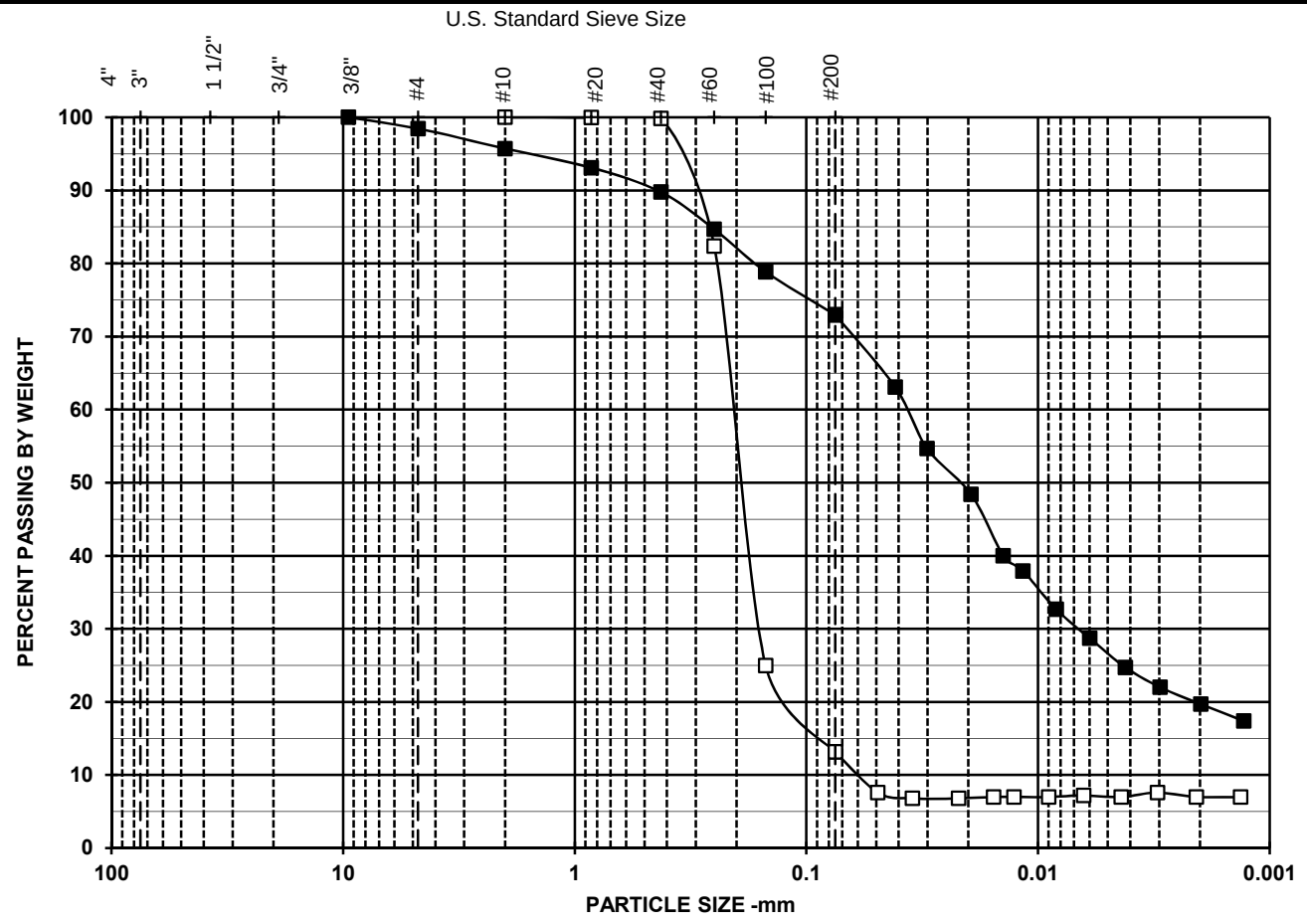
Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"			
3/8"	100.0		
4	99.8		
10	99.2		
20	99.0		
40	98.3		
60	95.5		
100	92.4		
200	84.5		

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□	21.5	46	14	32	CL	Brown , Lean clay with sand	9/2/2015
■							
○							

TerraSense, LLC	AECOM
T60428794	60428794-108

PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	



Symbol	□	■	○
Boring	NEW-B016	NEW-B016	
Sample	S-3B	S-6	
Depth	6.5-7	15-17	
% +3"	0.0	0.0	
% Gravel	0.0	1.6	
% SAND	86.8	25.4	
%C SAND	0.0	2.7	
%M SAND	0.2	5.9	
%F SAND	86.7	16.8	
% FINES	13.2	73.0	
% -2μ	7	20	
D_{100} (mm)	2.00	9.50	
D_{60} (mm)	0.21	0.04	
D_{30} (mm)	0.16	0.01	
D_{10} (mm)			
Cc			
Cu			

Particle Size	PERCENT FINER		
(Sieve #)	□	■	○
4"			
3"			
1 1/2"			
3/4"			
3/8"		100.0	
4		98.4	
10	100.0	95.7	
20	100.0	93.1	
40	99.8	89.8	
60	82.4	84.7	
100	25.0	78.9	
200	13.2	73.0	

SYMBOL	w (%)	LL	PL	PI	USCS	DESCRIPTION AND REMARKS	Date Tested
□					SM	Brown, Silty sand	9/1/2015
■	11.1	52	14	38	CH	Dark brown, Fat clay with sand	9/2/2015
○							

TerraSense, LLC	AECOM
T60428794	60428794-108

PARTICLE SIZE DISTRIBUTION
Dynegy CCR - Newton

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B003 | Test No.: P10611
Project Name: Dynegy CCR - Newton | SAMPLE: ST-3 | DEPTH (ft): 28.3
Specimen - Apparatus set-up - Test Information | Cell No. D | Apparatus No. 2 | Stage No.: 4

Preliminary Length/Area Calculations

Lo =	4.021	in	Lo=	10.212	cm
dLc=	0.057	in	Ao =	42.07	cm^2
Lc=	3.964	in	Vo =	429.65	cm^3
			Lc=	10.068	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	18.27	cm^3
			Vc =	411.38	cm^3
Sc =	0.246	cm^{-1}	Ac=	40.862	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or			
	x	with stones or		Stones with filter paper or			top + bottom
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination			
3) During saturation: Water flushed up sides of specimen to remove air			x	No		Yes	
4) During consolidation:	x	Top and bottom drainage or		Top		Bottom only	
5) Direction of permeant :	x	Up during or		Down during permeation			
6) Permeant: water used	x	Tap		Distilled			
or		Demineralized		0.005 N calcium sulfate (CaSO4)			

Equations Used
Kt = - 0.0000746 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3214

Consol Stage-Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	21.0	10/27/15	09	13	00	120.8	100.0	60.70	42.60	1.01	9.84E-08
final	21.2	10/27/15	09	51	00			58.18	43.40		9.51E-08
1	RT = 0.978	dT =		38.00 min		σ'_c =	3.0 ksf	0.187	0.185	io= 22.6	-1%
initial	21.2	10/27/15	09	52	00	120.8	100.0	59.07	43.10	1.05	1.01E-07
final	21.5	10/27/15	10	30	00			56.79	43.80		9.72E-08
2	RT = 0.971	dT =		38.00 min		σ'_c =	3.0 ksf	0.170	0.162	io= 19.9	1%
initial	21.5	10/27/15	10	31	00	120.8	100.0	58.80	43.20	1.00	1.03E-07
final	21.8	10/27/15	11	15	00			56.22	44.03		9.82E-08
3	RT = 0.964	dT =		44.00 min		σ'_c =	3.0 ksf	0.192	0.192	io= 19.5	2%
initial	21.8	10/27/15	11	16	00	120.8	100.0	58.70	43.23	1.00	1.01E-07
final	22.3	10/27/15	12	07	00			55.84	44.15		9.53E-08
4	RT = 0.954	dT =		51.00 min		σ'_c =	3.0 ksf	0.213	0.213	io= 19.3	-1%
initial											
final											
5											
initial											
final											
6											

TEST SUMMARY

Final Specimen and Test Conditions

Lc = 10.068 cm ε_{axial} = 1.4%
Ac = 41.331 cm^2
Vc= 416.10 cm^3 ε_{vol} = 3.2%
Sc = 0.244 cm^{-1} Sc = Lc / Ac , final

	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	21.21	126.4	104.3	91.3
PreTest	21.34	130.7	107.7	100.0

HYDRAULIC CONDUCTIVITY SUMMARY
Averages for trials: 1-4
ave K @ 20 ºC: **9.64E-08** cm/sec
(i_o)ave = 20.3

Tested By: BB Reviewed By: G. Thomas

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B004 | Test No.: P10610
Project Name: Dynegy CCR - Newton | SAMPLE: ST-12 | DEPTH (ft): 33.2
Specimen - Apparatus set-up - Test Information | Cell No. 6 | Apparatus No. 3 | Stage No.: 5

Preliminary Length/Area Calculations

Lo =	3.994	in	Lo=	10.145	cm
dLc=	0.058	in	Ao =	42.13	cm^2
Lc=	3.936	in	Vo =	427.40	cm^3
			Lc=	9.997	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	18.62	cm^3
			Vc =	408.78	cm^3
Sc =	0.245	cm^{-1}	Ac=	40.889	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or			
	x	with stones or		Stones with filter paper or			top + bottom
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination			
3) During saturation: Water flushed up sides of specimen to remove air			x	No		Yes	
4) During consolidation:	x	Top and bottom drainage or		Top		Bottom only	
5) Direction of permeant :	x	Up during or		Down during permeation			
6) Permeant: water used	x	Tap		Distilled			
or		Demineralized		0.005 N calcium sulfate (CaSO4)			

Equations Used
Kt = - 0.0000755 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3132

Consol Stage-Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	21.0	10/27/15	09	06	00	131.3	100.0	58.00	49.20	1.02	6.64E-06
final	21.0	10/27/15	09	08	00			54.56	50.26		6.41E-06
1	RT = 0.980	dT =		2.00 min		σ'_c =	4.5 ksf	0.257	0.253	io= 11.1	0%
initial	21.0	10/27/15	09	09	00	131.3	100.0	58.00	49.20	0.99	6.63E-06
final	21.0	10/27/15	09	12	00			53.58	50.60		6.40E-06
2	RT = 0.980	dT =		3.00 min		σ'_c =	4.5 ksf	0.330	0.334	io= 11.1	-1%
initial	21.0	10/27/15	09	13	00	131.3	100.0	58.00	49.20	1.00	6.65E-06
final	21.0	10/27/15	09	14	30			55.20	50.08		6.42E-06
3	RT = 0.980	dT =		1.50 min		σ'_c =	4.5 ksf	0.209	0.210	io= 11.1	0%
initial	21.0	10/27/15	09	16	00	131.3	100.0	58.00	49.20	0.97	6.76E-06
final	21.0	10/27/15	09	18	30			53.98	50.50		6.52E-06
4	RT = 0.980	dT =		2.50 min		σ'_c =	4.5 ksf	0.300	0.310	io= 11.1	1%
initial											
final											
5											
initial											
final											
6											

TEST SUMMARY

Final Specimen and Test Conditions

Lc =	9.997	cm	ε_{axial} =	1.5%	
Ac =	41.520	cm^2			
Vc=	415.09	cm^3	ε_{vol} =	2.9%	
Sc =	0.241	cm^{-1}	Sc = Lc / Ac , final		

	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	9.67	136.2	124.2	70.9
PreTest	12.18	143.5	127.9	100.0

HYDRAULIC CONDUCTIVITY SUMMARY
Averages for trials: 1-4
ave K @ 20 ºC: **6.44E-06** cm/sec
(i_o)ave = 11.1

Tested By: BB Reviewed By: G. Thomas

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B006 | Test No.: P10597
Project Name: Dynegy CCR - Newton | SAMPLE: ST-3 | DEPTH (ft): 31.25
Specimen - Apparatus set-up - Test Information | Cell No. D | Apparatus No. 1 | Stage No.: 5

Preliminary Length/Area Calculations

Lo =	3.986	in	Lo=	10.124	cm
dLc=	0.132	in	Ao =	41.97	cm^2
Lc=	3.854	in	Vo =	424.87	cm^3
			Lc=	9.789	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	42.21	cm^3
			Vc =	382.66	cm^3
Sc =	0.250	cm^{-1}	Ac=	39.091	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or			
	x	with stones or		Stones with filter paper or			top + bottom
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination			
3) During saturation: Water flushed up sides of specimen to remove air			x	No		Yes	
4) During consolidation:	x	Top and bottom drainage or		Top		Bottom only	
5) Direction of permeant :	x	Up during or		Down during permeation			
6) Permeant: water used	x	Tap		Distilled			
or		Demineralized		0.005 N calcium sulfate (CaSO4)			

Equations Used
Kt = - 0.0000757 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3127

Consol Stage-Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Permeability Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	22.7	10/7/15	09	32	00	130.0	80.0	55.90	38.12	0.98	1.95E-07
final	22.5	10/7/15	10	57	00			48.00	40.65		1.70E-07
1	RT = 0.941	dT =		85.00 min		σ'_c =	7.2 ksf	0.592	0.606	io= 22.8	5%
initial	22.6	10/7/15	11	52	00	130.0	80.0	55.90	38.10	0.99	1.86E-07
final	22.5	10/7/15	13	37	00			47.18	40.85		1.62E-07
2	RT = 0.942	dT =		105.00 min		σ'_c =	7.2 ksf	0.653	0.659	io= 22.9	0%
initial	22.5	10/7/15	13	39	00	130.0	80.0	56.20	38.00	1.01	1.82E-07
final	22.7	10/7/15	14	44	00			49.75	40.00		1.59E-07
3	RT = 0.941	dT =		65.00 min		σ'_c =	7.2 ksf	0.483	0.479	io= 23.4	-2%
initial	22.7	10/7/15	14	48	00	130.0	80.0	55.80	38.12	0.99	1.78E-07
final	22.8	10/7/15	17	24	00			45.44	41.40		1.55E-07
4	RT = 0.937	dT =		156.00 min		σ'_c =	7.2 ksf	0.776	0.786	io= 22.7	-4%
initial											
final											
5		dT =				σ'_c =					
initial											
final											
6		dT =				σ'_c =					

TEST SUMMARY
Final Specimen and Test Conditions

Lc =	9.789	cm	ε_{axial} =	3.3%	
Ac =	42.154	cm^2			
Vc=	412.65	cm^3	ε_{vol} =	2.9%	
Sc =	0.232	cm^{-1}	Sc = Lc / Ac , final		

	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	20.74	130.6	108.1	98.3
PreTest	19.44	133.0	111.3	100.0

HYDRAULIC CONDUCTIVITY SUMMARY
Averages for trials: 1-4
ave K @ 20 ºC: **1.62E-07** cm/sec
(i_o)ave = 22.9

Tested By: BB Reviewed By: G. Thomas

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B007 | Test No.: P10598
Project Name: Dynegy CCR - Newton | SAMPLE: ST-5A | DEPTH (ft): 50.3
Specimen - Apparatus set-up - Test Information | Cell No. 6 | Apparatus No. 2 | Stage No.: 5

Preliminary Length/Area Calculations

Lo =	3.981	in	Lo=	10.112	cm
dLc=	0.088	in	Ao =	42.06	cm^2
Lc=	3.893	in	Vo =	425.32	cm^3
			Lc=	9.888	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	28.21	cm^3
			Vc =	397.12	cm^3
Sc =	0.246	cm^{-1}	Ac=	40.161	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or			
	x	with stones or		Stones with filter paper or			top + bottom
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination			
3) During saturation: Water flushed up sides of specimen to remove air			x	No		Yes	
4) During consolidation:	x	Top and bottom drainage or		Top		Bottom only	
5) Direction of permeant :	x	Up during or		Down during permeation			
6) Permeant: water used	x	Tap		Distilled			
or		Demineralized		0.005 N calcium sulfate (CaSO4)			

Equations Used
Kt = - 0.0000746 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3214

Consol Stage- Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	22.8	10/8/15	09	06	00	132.0	80.0	60.40	42.75	1.02	4.30E-09
final	22.3	10/9/15	08	55	00			56.60	43.95		3.90E-09
1	RT = 0.942	dT =	1429.00 min			σ'_c =	7.5 ksf	0.283	0.278	io= 22.4	-24%
initial	22.3	10/9/15	08	59	00	132.0	80.0	60.75	42.65	0.99	5.83E-09
final	22.7	10/9/15	19	26	00			58.28	43.45		5.28E-09
2	RT = 0.943	dT =	627.00 min			σ'_c =	7.5 ksf	0.184	0.185	io= 23.0	3%
initial	22.7	10/9/15	19	31	00	132.0	80.0	60.30	42.80	1.02	5.81E-09
final	23.0	10/10/15	11	41	00			56.80	43.90		5.22E-09
3	RT = 0.935	dT =	970.00 min			σ'_c =	7.5 ksf	0.260	0.255	io= 22.2	2%
initial	23.1	10/10/15	12	10	00	132.0	80.0	60.35	42.70	0.98	5.99E-09
final	22.0	10/11/15	11	33	00			55.45	44.30		5.42E-09
4	RT = 0.942	dT =	1403.00 min			σ'_c =	7.5 ksf	0.365	0.370	io= 22.4	6%
initial	23.2	10/11/15	19	17	00	132.0	80.0	60.13	42.50	0.86	4.99E-09
final	22.9	10/13/15	16	42	00			53.15	45.10		4.46E-09
5	RT = 0.930	dT =	2725.00 min			σ'_c =	7.5 ksf	0.519	0.602	io= 22.4	-13%
initial	22.9	10/13/15	16	53	00	132.0	80.0	60.05	42.87	1.00	5.93E-09
final	22.4	10/14/15	08	45	00			56.61	43.98		5.36E-09
6	RT = 0.940	dT =	952.00 min			σ'_c =	7.5 ksf	0.256	0.257	io= 21.8	5%

TEST SUMMARY

Final Specimen and Test Conditions

Lc =	9.888	cm	ε_{axial} =	2.2%	
Ac =	41.793	cm^2			
Vc=	413.25	cm^3	ε_{vol} =	2.8%	
Sc =	0.237	cm^{-1}	Sc = Lc / Ac , final		

	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	16.26	137.1	117.9	99.6
PreTest	14.82	139.3	121.3	100.0

HYDRAULIC CONDUCTIVITY SUMMARY

Averages for trials: 2-6
ave K @ 20 ºC: **5.11E-09** cm/sec
(i_o)ave = 22.2

Tested By: BB Reviewed By: G. Thomas

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B012 | Test No.: P10609
Project Name: Dynegy CCR - Newton | SAMPLE: ST-7 | DEPTH (ft): 20.6
Specimen - Apparatus set-up - Test Information | Cell No. C | Apparatus No. 1 | Stage No.: 5

Preliminary Length/Area Calculations

Lo =	4.004	in	Lo=	10.171	cm
dLc=	0.045	in	Ao =	41.88	cm^2
Lc=	3.959	in	Vo =	425.95	cm^3
			Lc=	10.057	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	14.36	cm^3
			Vc =	411.59	cm^3
Sc =	0.246	cm^{-1}	Ac=	40.926	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or				
	x	with stones or		Stones with filter paper or		top + bottom		
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination				
3) During saturation: Water flushed up sides of specimen to remove ai			x	No		Yes		
4) During consolidation:	x	Top and bottom drainage or		Top		Bottom only		
5) Direction of permeant :	x	Up during or		Down during permeation				
6) Permeant: water used	x	Tap		Distilled				
or		Demineralized		0.005 N calcium sulfate (CaSO4)				

Equations Used
Kt = - 0.0000757 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3127

Consol Stage-Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	21.6	10/26/15	09	43	00	117.4	100.0	58.25	37.33	0.97	8.93E-09
final	22.5	10/26/15	12	19	00			57.10	37.70		8.38E-09
1	RT = 0.954	dT =		156.00 min		σ'_c =	2.5 ksf	0.086	0.089	io= 26.2	8%
initial	22.5	10/26/15	12	20	00	117.4	100.0	58.63	37.24	1.04	8.86E-09
final	23.6	10/26/15	14	37	00			57.60	37.55		8.11E-09
2	RT = 0.930	dT =		137.00 min		σ'_c =	2.5 ksf	0.077	0.074	io= 26.7	4%
initial	23.6	10/26/15	14	38	00	117.4	100.0	58.85	37.16	0.99	8.15E-09
final	23.5	10/26/15	18	00	00			57.45	37.60		7.36E-09
3	RT = 0.918	dT =		202.00 min		σ'_c =	2.5 ksf	0.105	0.105	io= 27.1	-5%
initial	23.5	10/26/15	18	03	00	117.4	100.0	59.00	37.19	1.02	7.74E-09
final	21.0	10/27/15	08	44	00			53.90	38.75		7.23E-09
4	RT = 0.949	dT =		881.00 min		σ'_c =	2.5 ksf	0.382	0.374	io= 27.3	-7%
initial											
final											
5											
initial											
final											
6											

TEST SUMMARY

Final Specimen and Test Conditions

Lc = 10.057 cm ε_{axial} = 1.1%
Ac = 41.598 cm^2
Vc= 418.35 cm^3 ε_{vol} = 1.8%
Sc = 0.242 cm^{-1} Sc = Lc / Ac , final

	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	13.28	137.1	121.0	88.9
PreTest	14.02	140.5	123.2	100.0

HYDRAULIC CONDUCTIVITY SUMMARY
Averages for trials: 1-4
ave K @ 20 ºC: **7.77E-09** cm/sec
(i_o)ave = 26.8

Tested By: BB Reviewed By: G. Thomas

PERMEABILITY TEST: FALLING HEAD - CONSTANT VOLUME U-TUBE
ASTM D 5084 - Method F

Project No.: T60428794 | BORING: NEW-B015 | Test No.: P10608
Project Name: Dynegy CCR - Newton | SAMPLE: ST-2A | DEPTH (ft): 25.45
Specimen - Apparatus set-up - Test Information | Cell No. C | Apparatus No. 3 | Stage No.: 2

Preliminary Length/Area Calculations

Lo =	4.012	in	Lo=	10.191	cm
dLc=	0.025	in	Ao =	42.03	cm^2
Lc=	3.987	in	Vo =	428.31	cm^3
			Lc=	10.127	cm
dVc = 3 Vo * (dLc/Lo)			dVc=	8.01	cm^3
			Vc =	420.30	cm^3
Sc =	0.244	cm^{-1}	Ac=	41.501	cm^2

1) Specimen Tested in :	x	Triaxial Cell or		Compaction Mold or			
	x	with stones or		Stones with filter paper or			top + bottom
2) Specimen orientation for:	x	Vertical or		Horizontal permeability determination			
3) During saturation: Water flushed up sides of specimen to remove air					x	No	Yes
4) During consolidation:	x	Top and bottom drainage or				Top	Bottom only
5) Direction of permeant :	x	Up during or		Down during permeation			
6) Permeant: water used	x	Tap		Distilled			
or		Demineralized		0.005 N calcium sulfate (CaSO4)			

Equations Used
Kt = - 0.0000755 * Sc/dT(min) * ln (ho/hf)
RT = (-0.02452*(ave. temp in C) + 1.495)
K @ 20 ºC = RT * Kt TubeC= 1.3132

Consol Stage-Trial No.	Temp. ºC	Date	Time hr	Time min	Time sec	Initial σ_c psi	Initial Ub psi	U-tube Reading Head (cm) (cc)	U-tube Reading Tail (cm) (cc)	Flow in/out gradient	Preliminary Final at 20ºC cm/sec Dev. from Ave.
initial	22.5	10/16/15	09	48	00	106.9	100.0	63.45	47.50	0.86	3.95E-09
final	24.0	10/16/15	16	24	00			62.46	47.86		3.57E-09
1	RT = 0.925	dT =		396.00 min		σ'_c =	1.0 ksf	0.074	0.086	io= 19.8	95%
initial	21.0	10/19/15	09	42	00	106.9	100.0	64.94	47.00	0.80	2.38E-09
final	22.5	10/19/15	17	53	00			64.10	47.33		2.24E-09
2	RT = 0.962	dT =		491.00 min		σ'_c =	1.0 ksf	0.063	0.079	io= 22.3	22%
initial	22.5	10/19/15	17	54	00	106.9	100.0	66.26	46.67	0.87	2.07E-09
final	22.0	10/20/15	08	42	00			64.84	47.18		1.92E-09
3	RT = 0.949	dT =		888.00 min		σ'_c =	1.0 ksf	0.106	0.122	io= 24.3	5%
initial	22.0	10/20/15	08	45	00	106.9	100.0	66.70	46.50	0.89	1.67E-09
final	23.1	10/20/15	17	04	00			66.02	46.74		1.54E-09
4	RT = 0.942	dT =		499.00 min		σ'_c =	1.0 ksf	0.051	0.057	io= 25.1	-16%
initial	23.1	10/20/15	17	07	00	106.9	100.0	66.82	46.46	1.02	1.76E-09
final	21.5	10/21/15	08	45	00			65.49	46.87		1.63E-09
5	RT = 0.948	dT =		938.00 min		σ'_c =	1.0 ksf	0.099	0.098	io= 25.3	-11%
initial											
final											
6		dT =				σ'_c =					

TEST SUMMARY

Final Specimen and Test Conditions

Lc =	10.127	cm	ε_{axial} =	0.6%	
Ac =	42.456	cm^2			
Vc=	429.98	cm^3	ε_{vol} =	-0.4%	
Sc =	0.239	cm^{-1}	Sc = Lc / Ac , final		

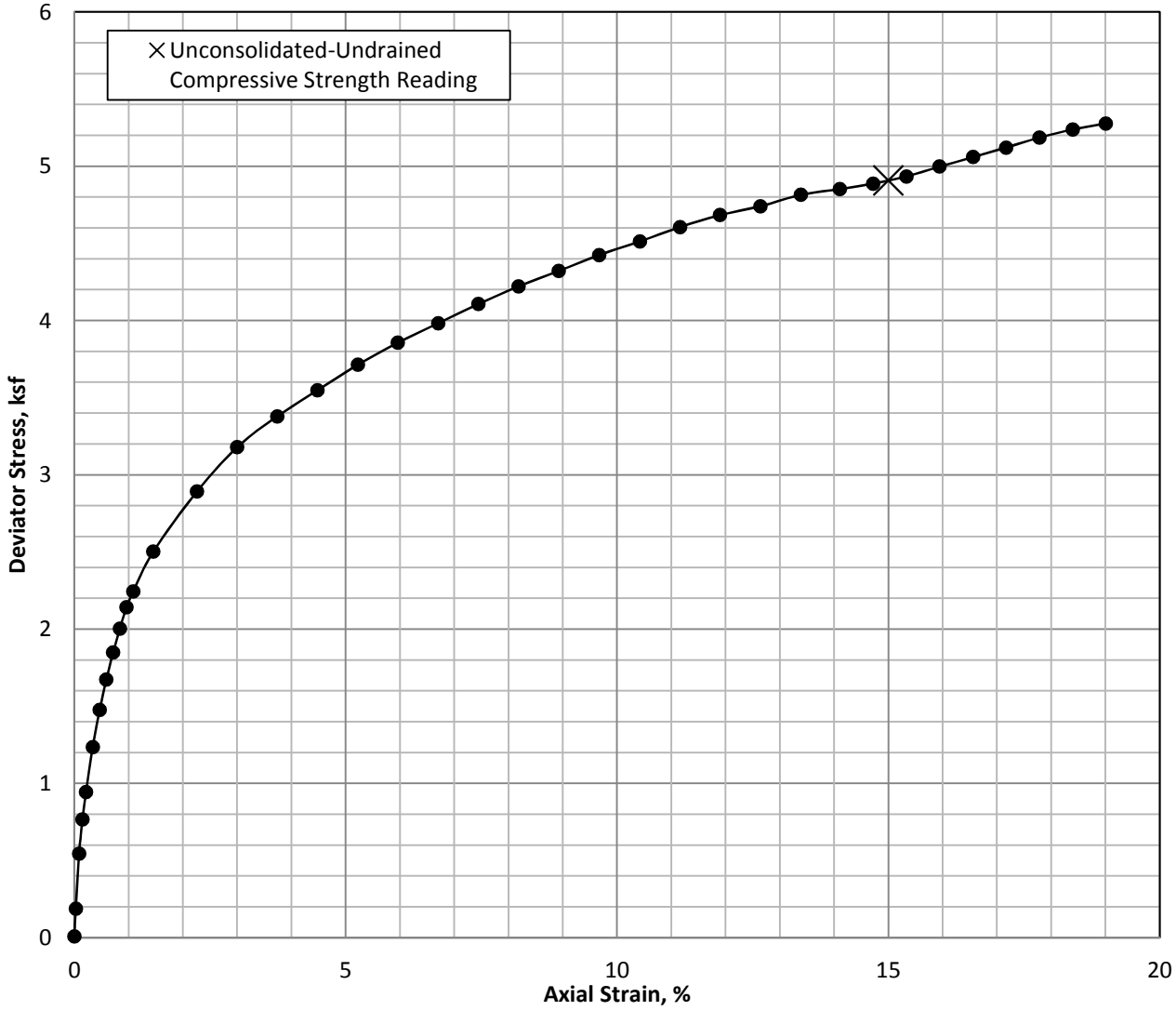
	w (%)	γ_τ (pcf)	γ_d (pcf)	S (%)
Initial	23.96	126.1	101.7	96.8
PreTest	24.99	126.6	101.3	100.0

HYDRAULIC CONDUCTIVITY SUMMARY
Averages for trials: 2-5
ave K @ 20 ºC: **1.83E-09** cm/sec
(i_o)ave = 24.2

Tested By: BB Reviewed By: G. Thomas

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

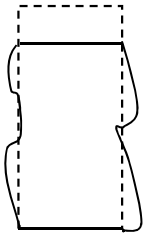
Sample Type: Intact tube sample

Description and/or Classification: CL, brown lean clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	19.4	130.9	109.7	0.56	94.8	5.999	2.880	2.1	43	26	2.74
4.0	19.4	132.2	110.8	0.54	97.5	5.979	2.870	2.1	17		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
4.91	2.455	15.0	0.74



FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

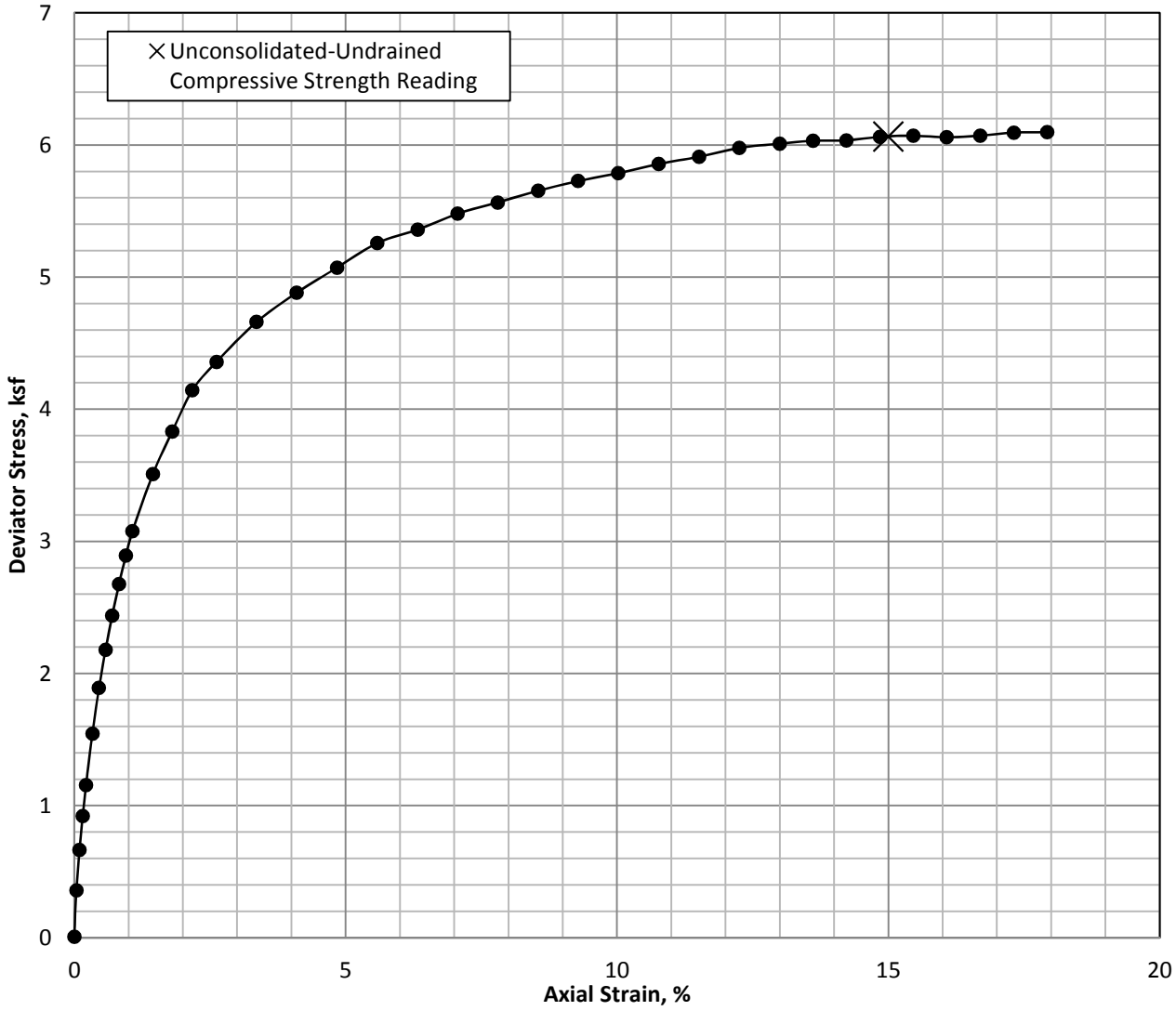
Tested by: BB Reviewed by: GET

Test Date: 10/23/2015 Review Date: 10/27/2015

AECOM **Project # 60428794-108**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST**
TerraSense, LLC **Project # T60428794**		**Boring: NEW-B003 Sample: ST-2** **Section: B Depth: 24.15 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

Sample Type: Intact tube sample

Description and/or Classification: CH, brown fat clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	21.1	129.2	106.7	0.60	96.0	6.014	2.881	2.1	55	39	2.74
3.0	21.1	130.0	107.3	0.59	97.5	6.002	2.875	2.1	16		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
6.06	3.03	15.0	0.74

FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

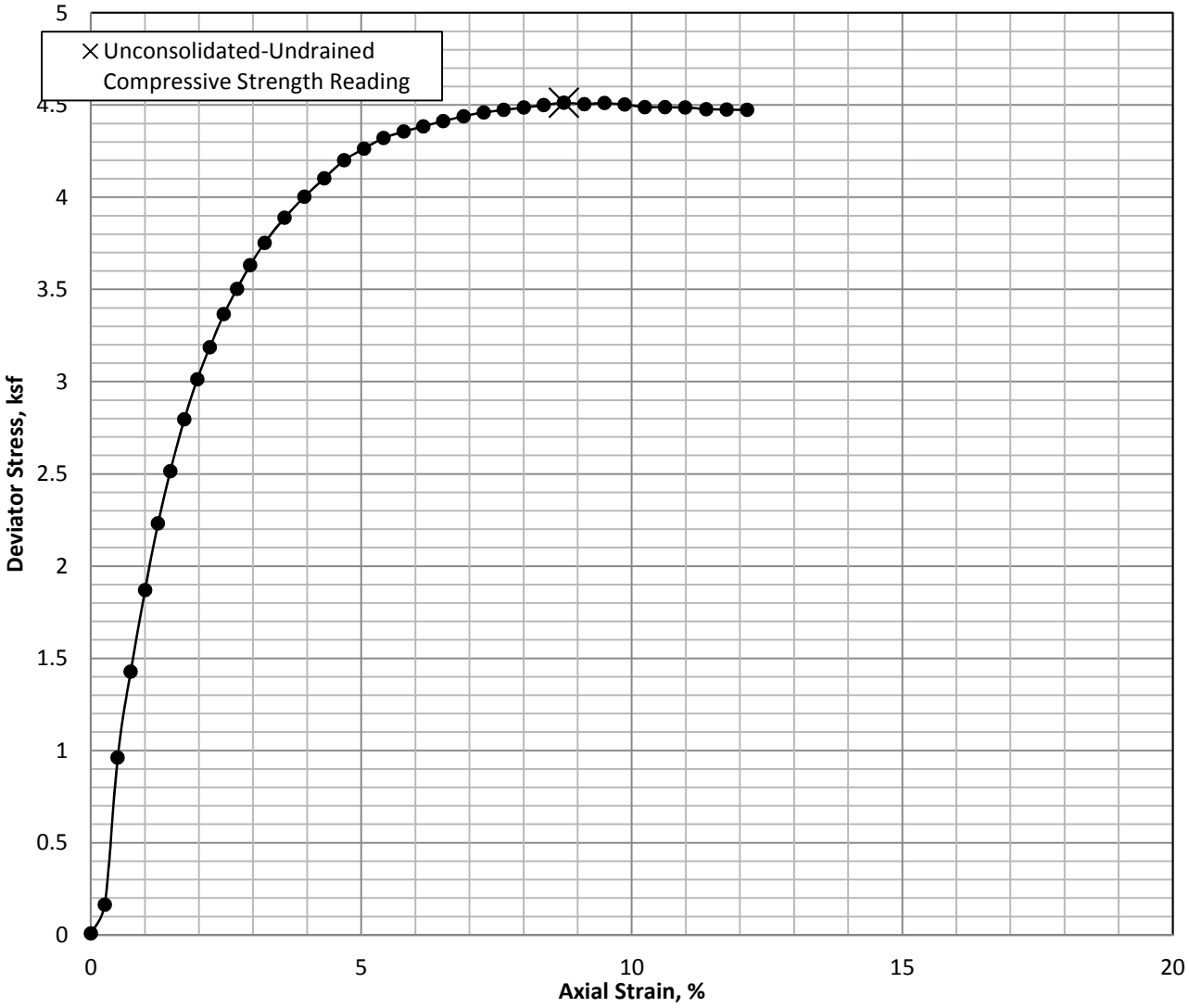
Tested by: BB Reviewed by: GET

Test Date: 10/23/2015 Review Date: 10/27/2015

AECOM **Project # 60428794-108** **TerraSense, LLC** **Project # T60428794**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST** **Boring: NEW-B003 Sample: ST-3** **Section: C Depth: 28.8 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

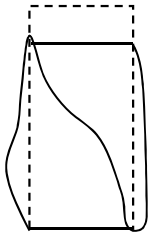
Sample Type: Intact tube sample

Description and/or Classification: CL, orange-brown clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	18.2	130.8	110.6	0.54	92.0	5.996	2.879	2.1	40	23	2.73
3.5	18.2	131.8	111.5	0.53	94.2	5.980	2.871	2.1	17		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
4.51	2.255	8.7	0.74



FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

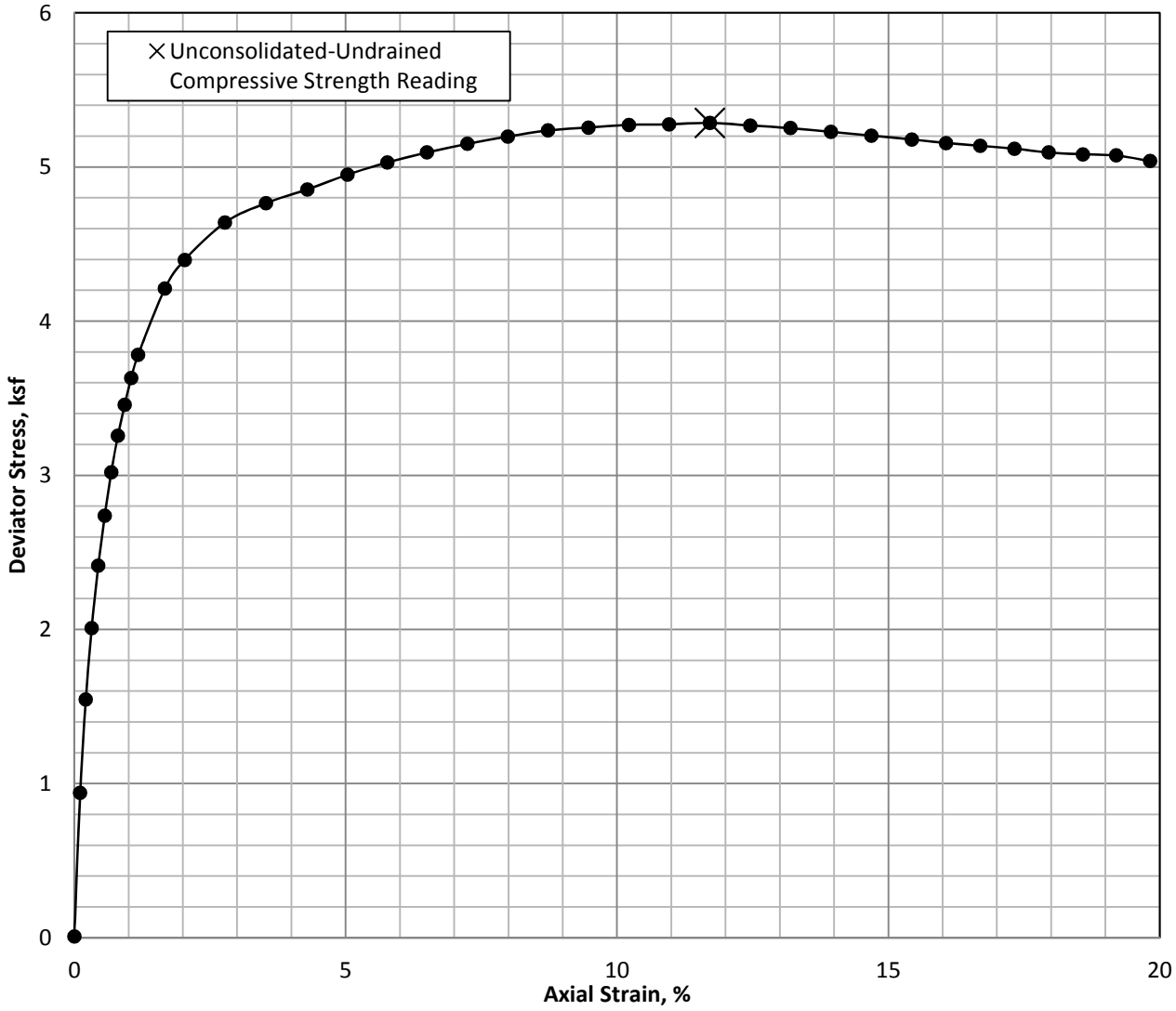
Tested by: BB Reviewed by: GET

Test Date: 10/28/2015 Review Date: 11/2/2015

AECOM **Project # 60428794-108** **TerraSense, LLC** **Project # T60428794**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST** **Boring: NEW-B006 Sample: ST-1** **Section: B Depth: 21.20 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

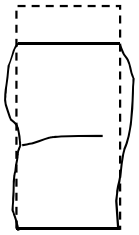
Sample Type: Intact tube sample

Description and/or Classification: CH, brown fat clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	21.5	132.0	108.6	0.61	98.9	5.987	2.877	2.1	52	40	2.80
6.0	21.5	133.0	109.4	0.60	100.9	5.972	2.870	2.1	12		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
5.29	2.645	11.7	0.74



FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

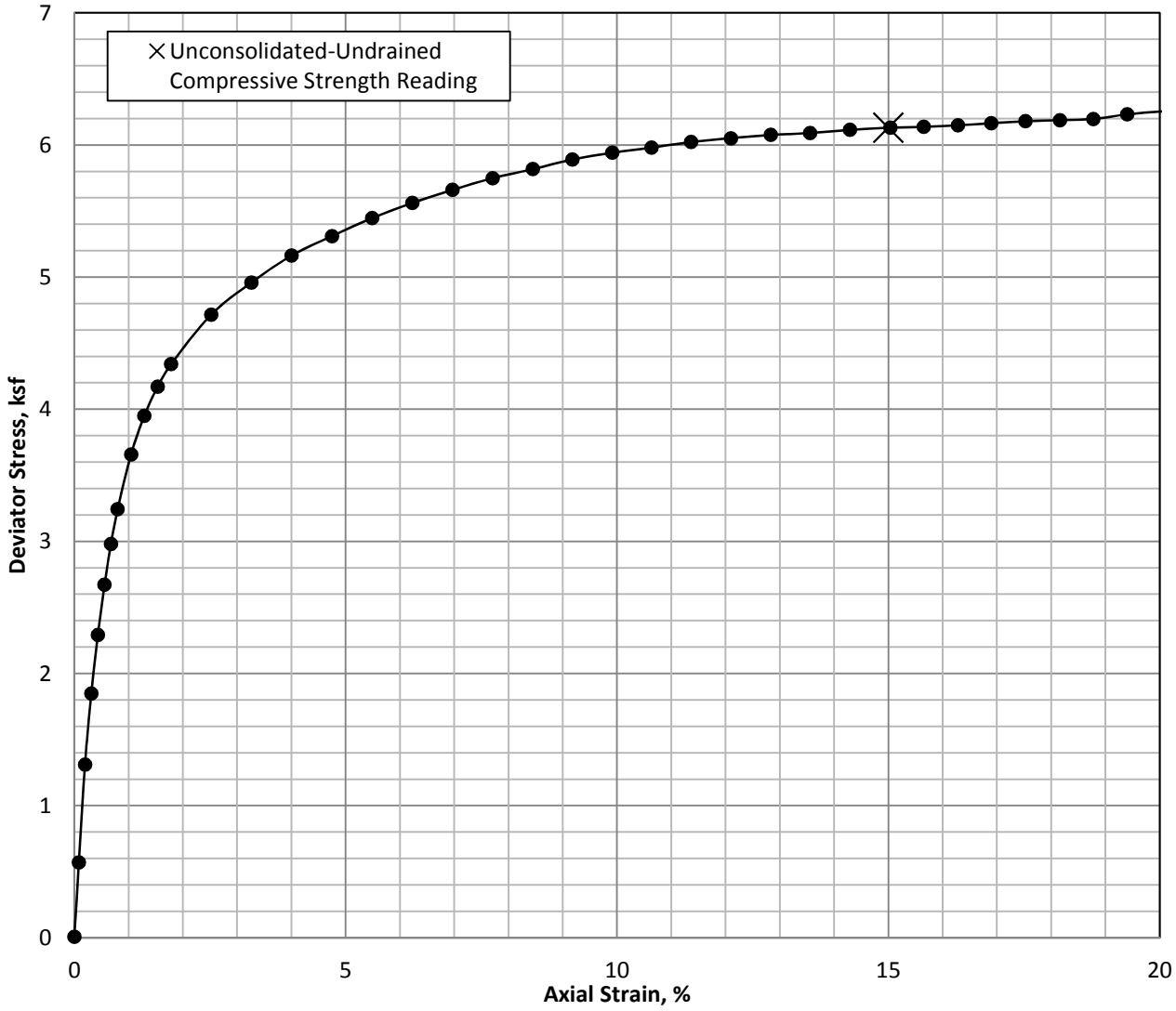
Tested by: BB Reviewed by: CMJ

Test Date: 10/15/2015 Review Date: 10/26/2015

AECOM **Project # 60428794-108** **TerraSense, LLC** **Project # T60428794**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST** **Boring: NEW-B007 Sample: ST-3C** **Section: Depth: 31.70 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

Sample Type: Intact tube sample

Description and/or Classification: CH, brown fat clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	16.7	136.3	116.8	0.46	98.2	5.986	2.882	2.1	50	37	2.74
2.5	16.7	136.7	117.2	0.46	99.3	5.979	2.878	2.1	13		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
6.13	3.065	15.0	0.74

FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

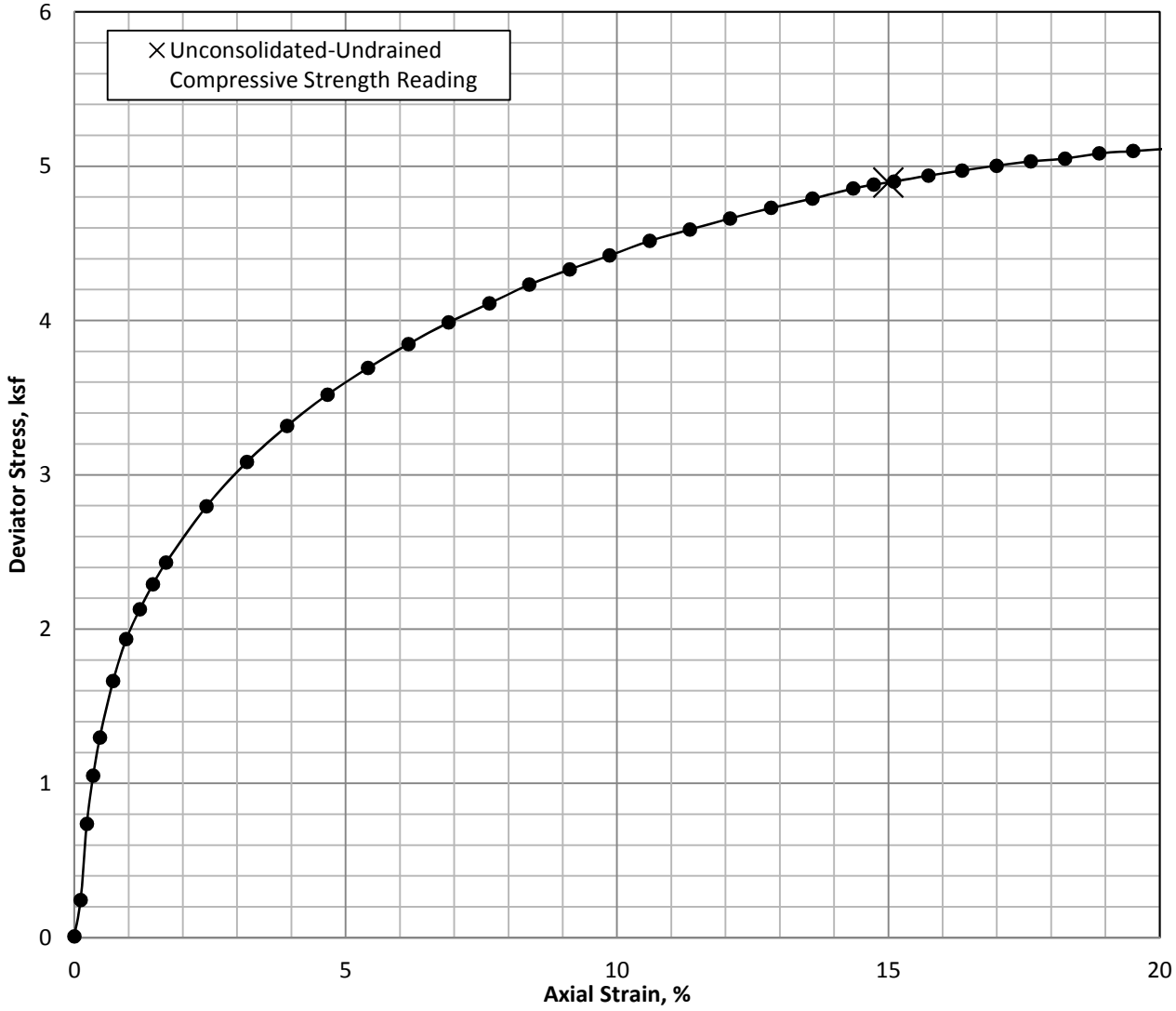
Tested by: BB Reviewed by: CMJ

Test Date: 10/15/2015 Review Date: 10/26/2015

AECOM **Project # 60428794-108**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST**
TerraSense, LLC **Project # T60428794**		**Boring: NEW-B008 Sample: ST-1C** **Section: Depth: 16.65 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

Sample Type: Intact tube sample

Description and/or Classification: CL, brown lean clay

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	19.0	132.3	111.2	0.52	98.6	5.982	2.874	2.1	47	32	2.71
2.0	19.0	132.7	111.6	0.52	99.6	5.975	2.870	2.1	15		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
4.9	2.45	15.0	0.75

FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

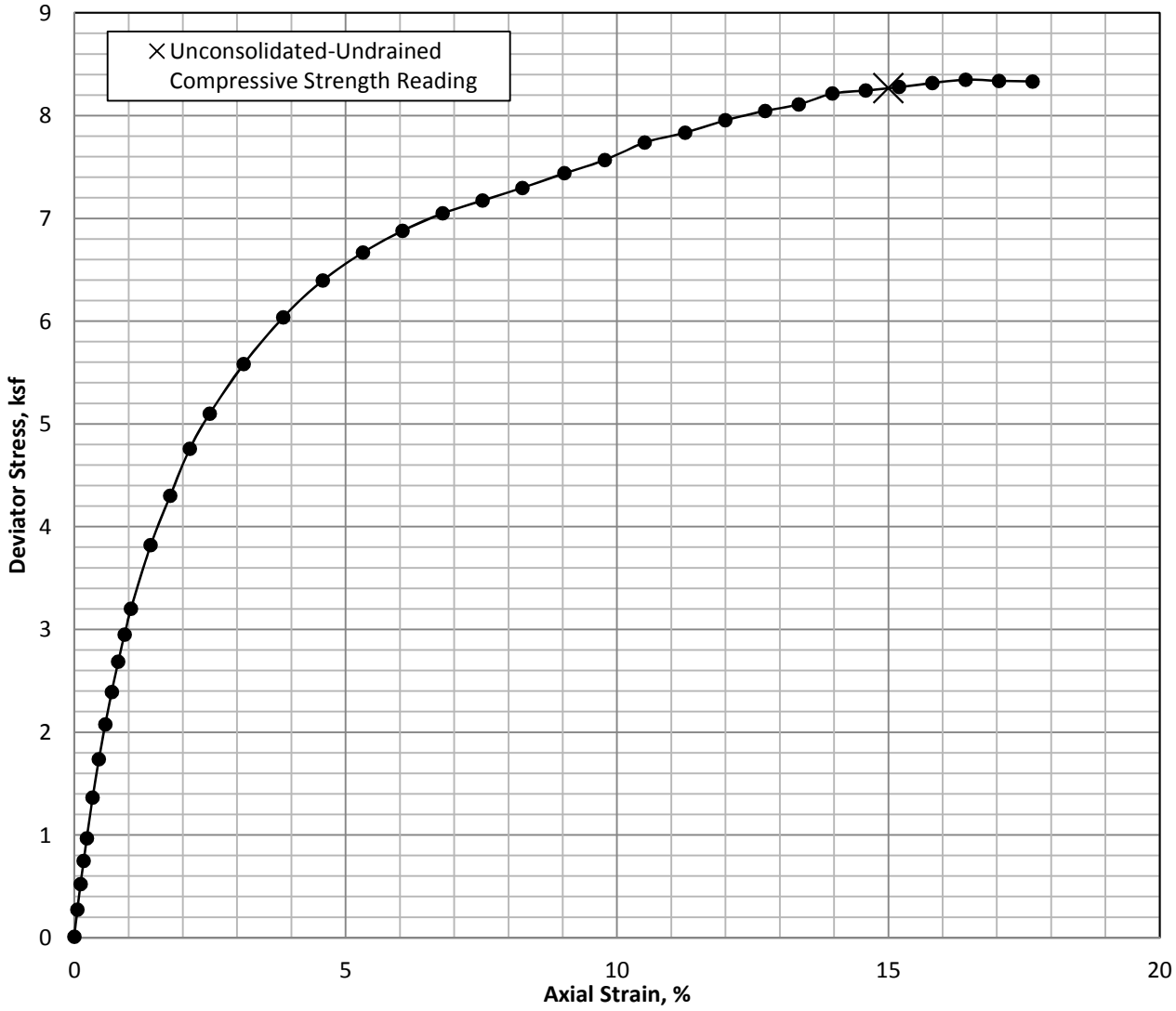
Tested by: BB Reviewed by: CMJ

Test Date: 10/15/2015 Review Date: 10/26/2015

AECOM **Project # 60428794-108**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST**
TerraSense, LLC **Project # T60428794**		**Boring: NEW-B009 Sample: ST-1B** **Section: Depth: 9.75 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

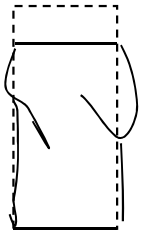
Sample Type: Intact tube sample

Description and/or Classification: CL, brown sandy clay, trace gravel

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	12.6	139.6	123.9	0.38	91.1	6.033	2.883	2.1	34	21	2.74
1.5	12.6	140.3	124.5	0.37	92.7	6.023	2.878	2.1	13		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
8.27	4.135	15.0	0.74



FAILURE SKETCH

Remarks and Notes:

(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

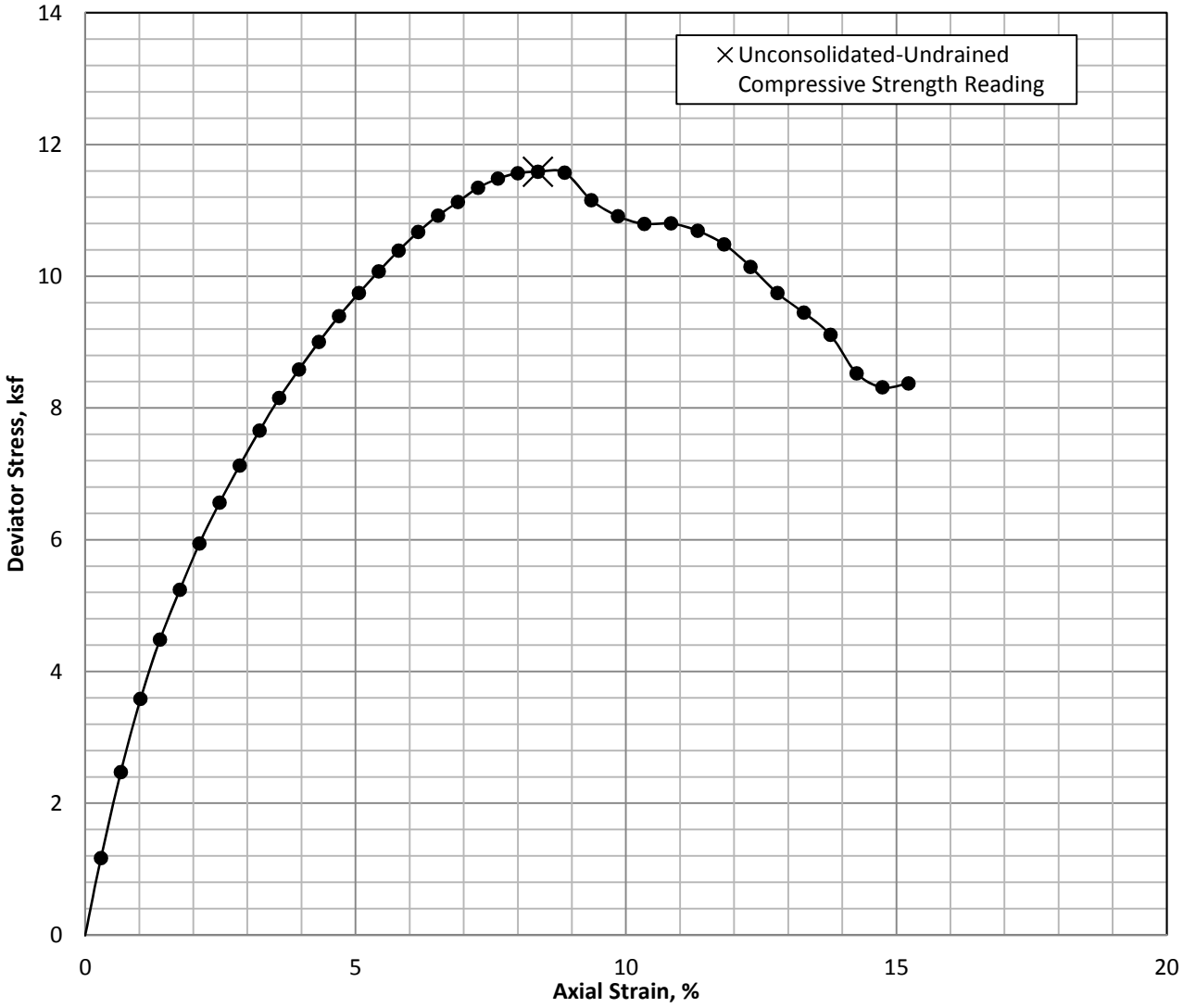
Tested by: BB Reviewed by: GET

Test Date: 10/23/2015 Review Date: 10/29/2015

AECOM **Project # 60428794-108**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST**
TerraSense, LLC **Project # T60428794**		**Boring: NEW-B012 Sample: ST-4** **Section: C Depth: 9.45 ft.**

Electronic Filing: Received, Clerk's Office 07/01/2024

UNCONSOLIDATED-UNDRAINED COMPRESSIVE STRENGTH TEST, ASTM METHOD D2850



Specimen and Material Property Information

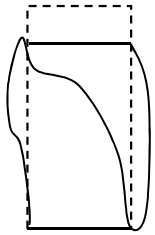
Sample Type: Intact tube sample

Description and/or Classification: SC, orange brown clayey sand

Cell Pressure (ksf)	Water (1) Content (%)	Wet Unit Weight (pcf)	Dry Unit (1) Weight (pcf)	Void Ratio (-)	Saturation (2) (%)	Length (inch)	Diameter (inch)	L/D (-)	LL/ PL (-)	PI (-)	Specific (2) Gravity (-)
0 (Initial)	9.5	142.7	130.3	0.31	84.3	6.025	2.886	2.1	28	15	2.73
0.5	9.5	142.9	130.4	0.31	84.7	6.023	2.885	2.1	13		

Failure Summary

U-U Compressive Strength (ksf)	U-U Shear Strength, s_u (ksf)	Strain to to Peak (%)	Strain Rate (%/min)
11.6	5.8	8.4	0.73



FAILURE SKETCH

Remarks and Notes:

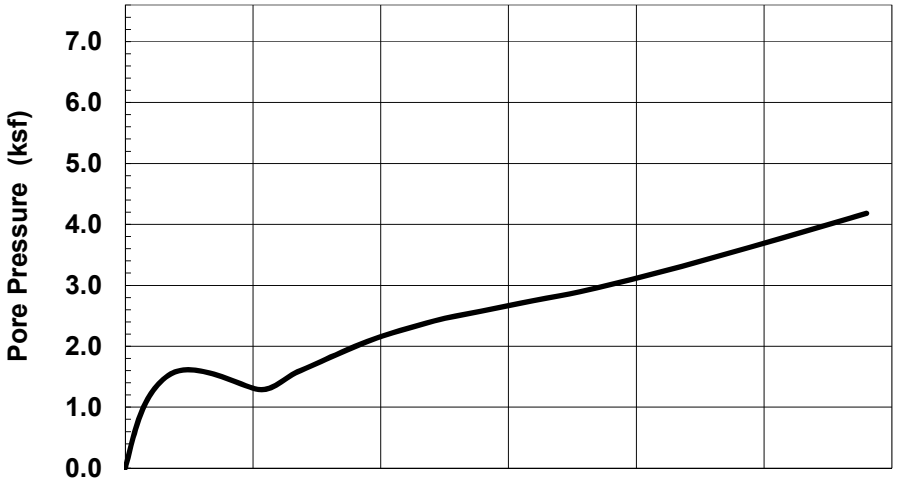
(1) Water Content determined after shear from partial specimen.

(2) Assumed specific gravity

Tested by: BB Reviewed by: GET

Test Date: 9/17/2015 Review Date: 10/27/2015

AECOM **Project # 60428794-108** **TerraSense, LLC** **Project # T60428794**	**Dynegy CCR - Newton**	**UNCONSOLIDATED-UNDRAINED COMPRESSION TEST** **Boring: NEW-B014 Sample: ST-1** **Section: B Depth: 3.50 ft.**



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST-5 Depth: 51.05 feet
Type: Intact tube sample
Description: CL, stiff brown clay, trace c-f sand, fine gravel
LL = 32 PL = 16 PI = 16

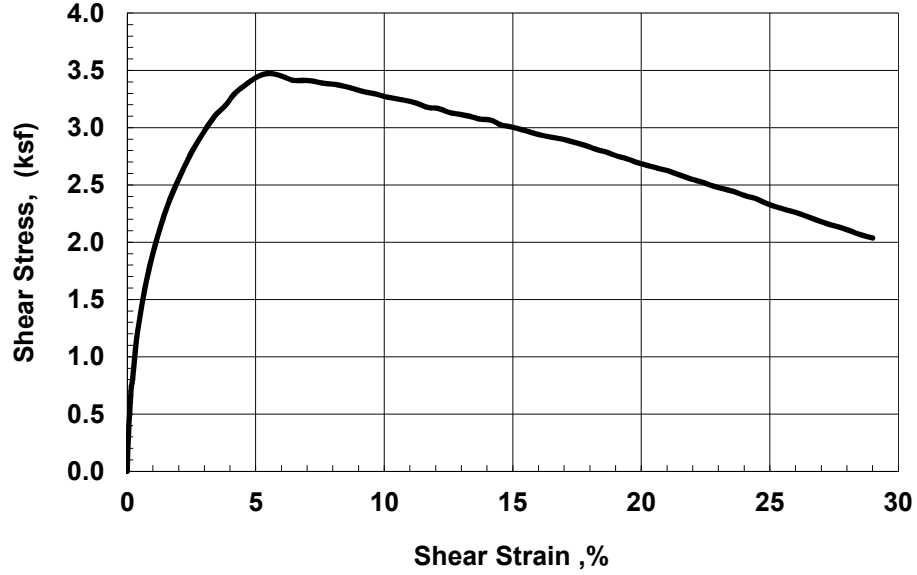
SPECIMEN INFORMATION (Initial)

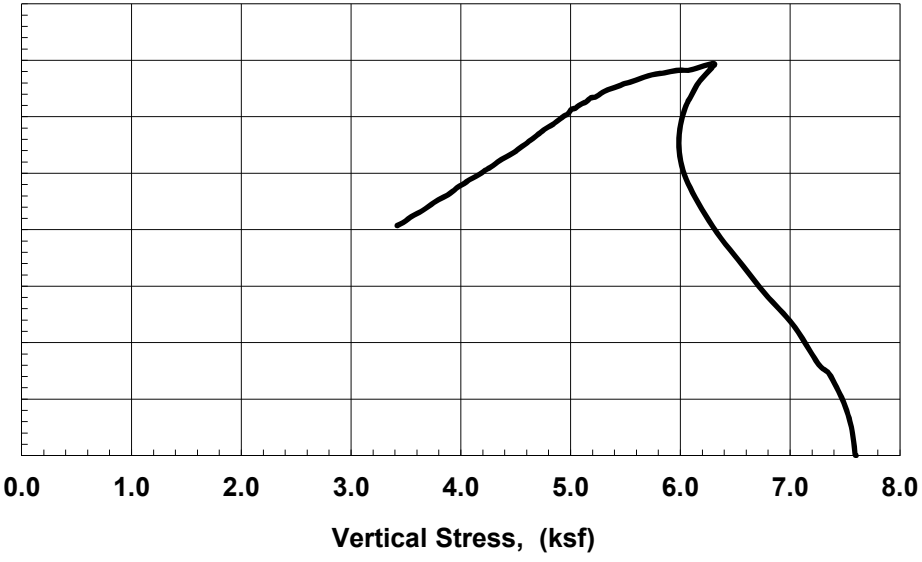
Height: 0.72 Diameter: 2.63 inch Area: 5.42 in²
Water Content: 13.9 % Total Unit Weight: 136.1 pcf

TEST SUMMARY

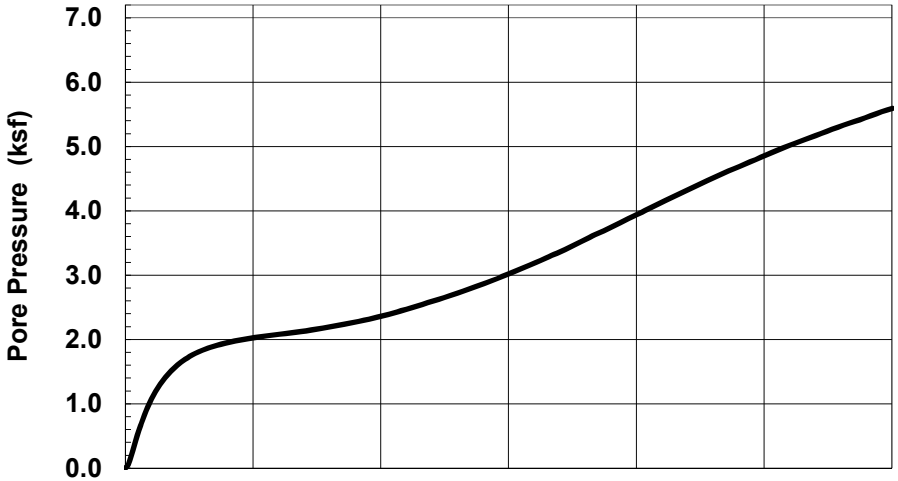
Vertical Consolidation Stress: 7.60 ksf OCR = 1.0
Water Content: 14.8 % Total Unit Weight: 139.9 pcf
Peak Shear Strength: 3.47 ksf @ 5.6 % Strain
Strain Rate: 0.064 %/min

REMARKS:





Test by: D Tso	Project No. T60428794	AECOM #60428794 Dynegy CCR - Newton	CONSTANT VOLUME	
Checked by: GET	**TerraSense, LLC**		DIRECT SIMPLE SHEAR Boring NEW-B007 Sample ST-5	October-15



SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-15 Depth: 61.45 feet
Type: Intact tube sample
Description: CL, brown clay
LL = 42 PL = 14 PI = 28

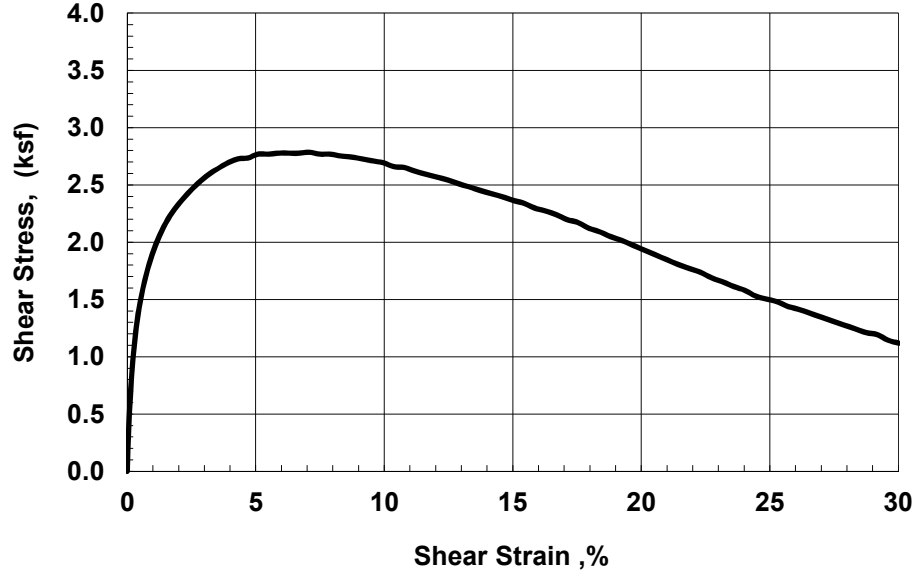
SPECIMEN INFORMATION (Initial)

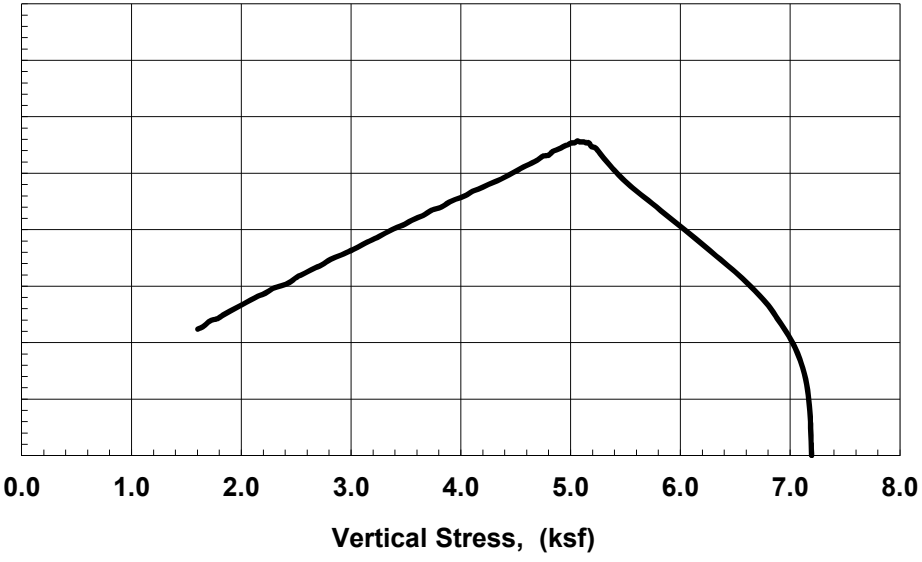
Height: 0.72 Diameter: 2.63 inch Area: 5.45 in²
Water Content: 12.8 % Total Unit Weight: 132.5 pcf

TEST SUMMARY

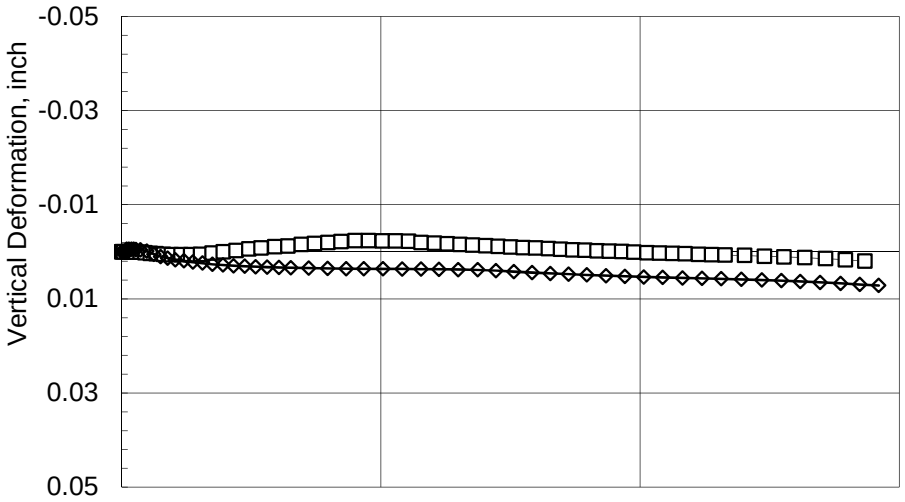
Vertical Consolidation Stress: 7.20 ksf OCR = 1.0
Water Content: 13.6 % Total Unit Weight: 138.6 pcf
Peak Shear Strength: 2.79 ksf @ 7.1 % Strain
Strain Rate: 0.067 %/min

REMARKS:





Test by: G. Thomas	Project No. T60428794	AECOM #60428794 Dynegy CCR - Newton	CONSTANT VOLUME	
Checked by: GET	**TerraSense, LLC**		DIRECT SIMPLE SHEAR Boring NEW-B012 Sample ST-15	October-15



SAMPLE INFORMATION

Boring: NEW-B006 Sample: ST- 4 Depth: 35-35.8 feet
Type: Intact tube sample
Description: CL, brown sandy clay

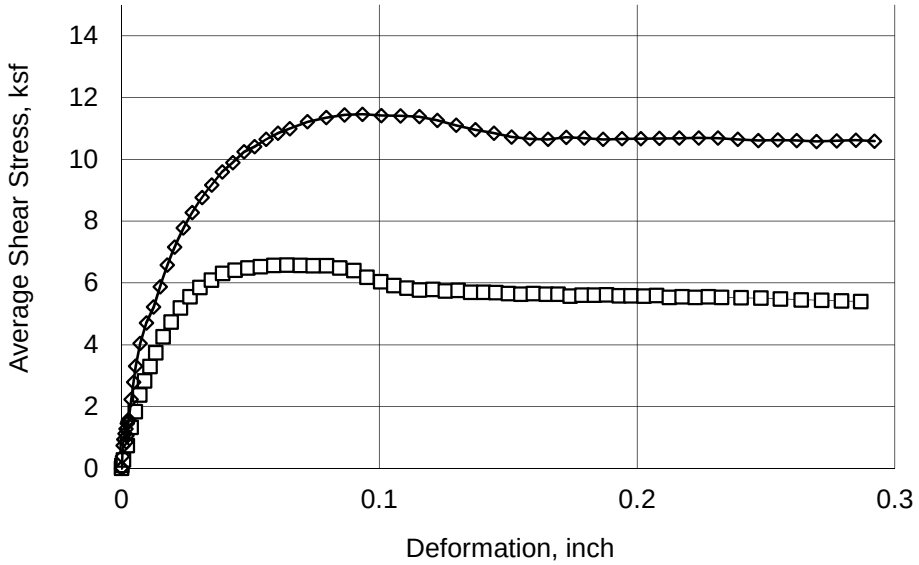
TEST INFORMATION

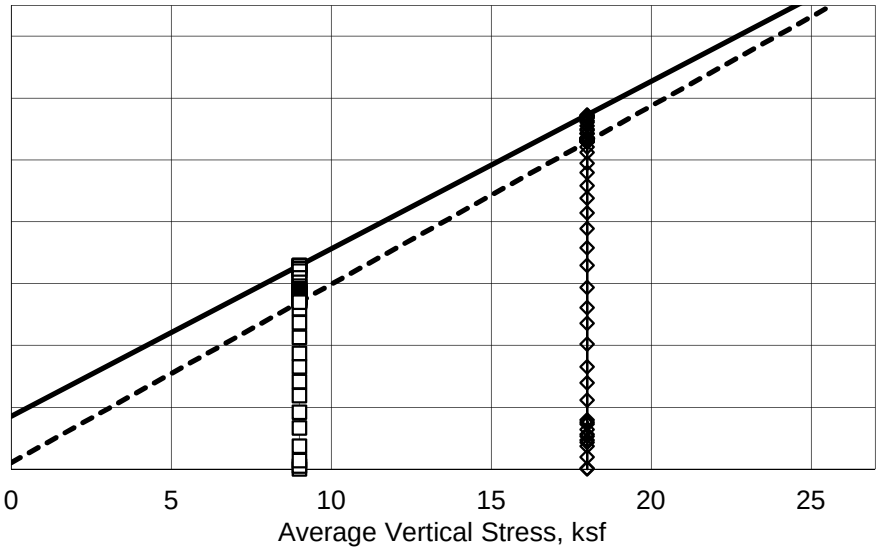
Test	Symbol	Vertical Stress (ksf)	Deformation Rate (inch/min.)
DS1619	□	9.0	0.0022
DS1617	◊	18.0	0.0020

TEST SUMMARY

Peak Effective Friction Angle: 28.4°, cohesion = 1.7ksf
Final Effective Friction Angle: 30.0°, cohesion = 0.2ksf

REMARKS:





Prepared by: MHC Checked by: GET	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **SERIES SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B006 Sample: ST- 4 Depth: 35-35.8	November 2015

STAGED DRAINED DIRECT SHEAR TEST SERIES

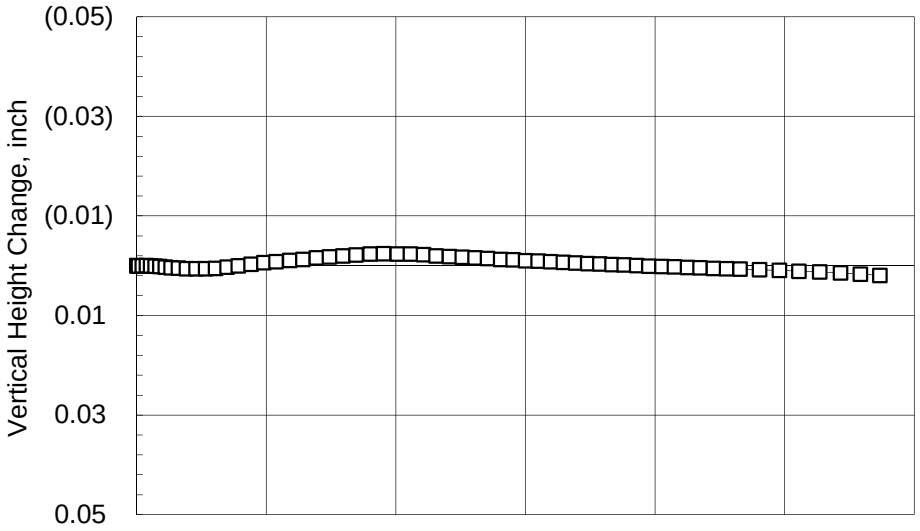
Boring No	Depth (ft)	w_o	γ_{to}	γ_{do}	$\sigma'_{v,c}$ (ksf)	Deformation rate (inch/min)	at Peak Shear Stress at High Deformation				Remarks
Sample/ Specimen	Test ID	w_c (estimated) (%)	γ_{tc} (estimated) (pcf)	γ_{dc} (estimated) (pcf)	$\varepsilon_{v,c}$ (%)	t_c (days)	ΔL (inch)	τ_h (ksf)	ε_v (%)	Φ' for c'=0	
NEW-B006	35.4	11.1	140.2	126.2	9.00	2.2E-3	0.06	6.58	-0.12	36.2	
ST- 4	DS1619	12.7	142.9	126.9	2.4	0.05	0.29	5.39	0.19	30.9	
NEW-B006	35.6	15.8	147.4	127.2	18.00	2.0E-3	0.09	11.46	0.36	32.5	
ST- 4	DS1617	12.4	148.1	131.7	27.0	0.16	0.29	10.59	0.71	30.5	

Description of Material Tested and Remarks	
DS1619	CL, brown sandy clay
DS1617	CL, brown sandy clay

Strength Envelope Summary			
Test Series	Failure Criterion	Φ' (degree)	c' (ksf)
1	1	28.4	1.7
	2	30.0	0.2
Failure Criterion		1. Peak shear stress 2. High deformation	

Prepared by: MHC
Checked by: GET

AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR SERIES SUMMARY**
TerraSense, LLC	T60428794	Boring: NEW-B006 Sample: ST- 4 Depth: 35-35.8 ft



SAMPLE INFORMATION

Boring: NEW-B006 Sample: ST- 4 Specimen: B Depth: 35.4 ft
Type: Intact tube sample

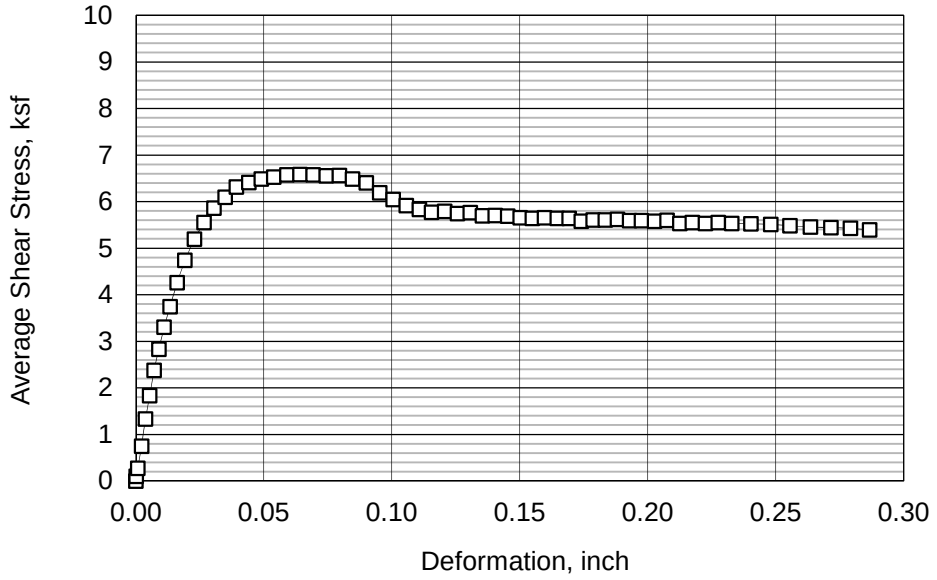
SPECIMEN INFORMATION (Initial)

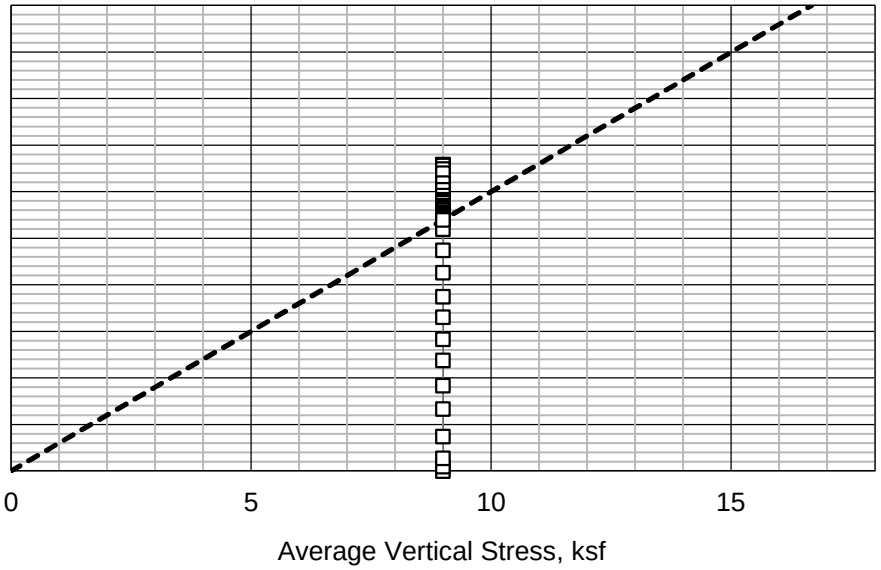
Description: CL, brown sandy clay
Height: 1.01 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 11.1 % Dry Unit Weight: 126.2 pcf

TEST SUMMARY

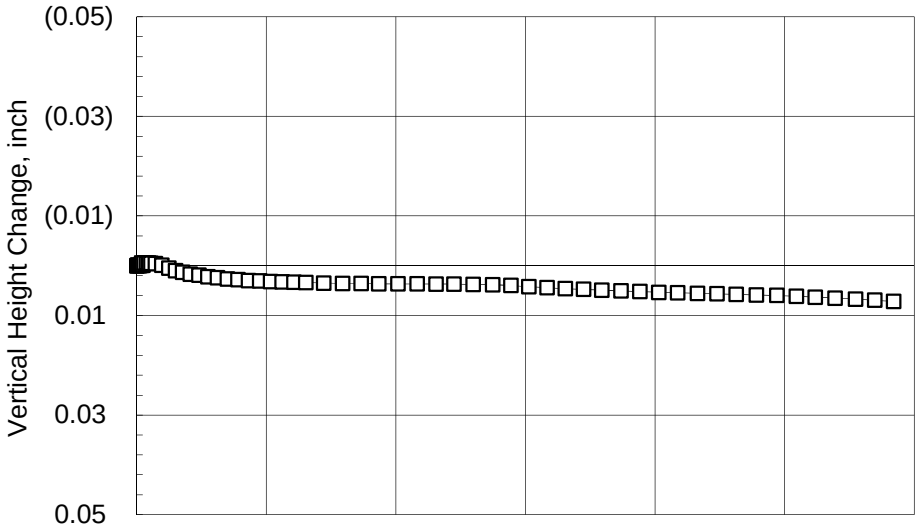
Vertical Consolidation Stress: 9.00 ksf
Water Content: 12.7 % Dry Unit Weight: 126.9 pcf
Deformation Rate: 0.00224 inch/min.
Peak Shear Strength: 6.58 ksf @ 0.06 inch deformation
Peak Effective Friction Angle: 36.2°, cohesion = 0.0ksf
Final Shear Strength: 5.39 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 30.9° (Shown)

REMARKS:





Prepared by: MHC Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B006 Sample: ST- 4 Specimen: B Depth: 35.4 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B006 Sample: ST- 4 Specimen: A Depth: 35.55 ft
Type: Intact tube sample

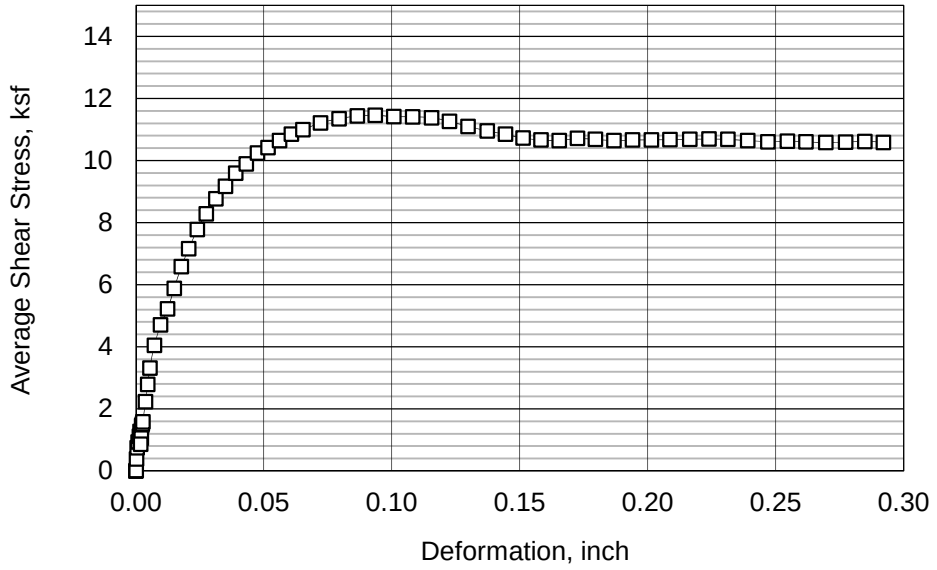
SPECIMEN INFORMATION (Initial)

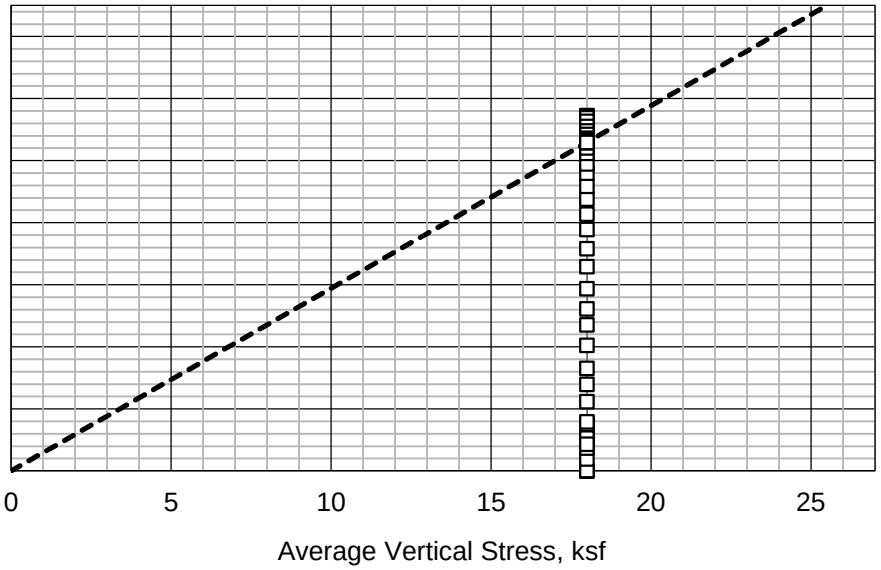
Description: CL, brown sandy clay
Height: 1.01 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 15.8 % Dry Unit Weight: 127.2 pcf

TEST SUMMARY

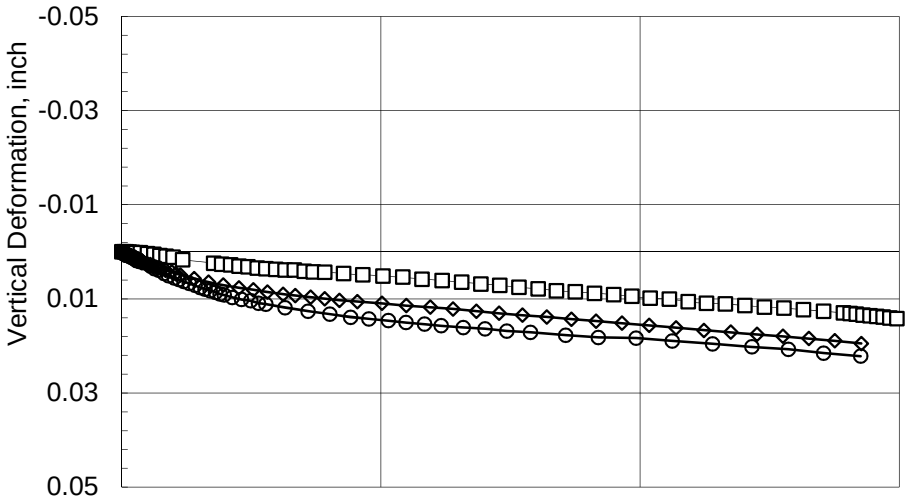
Vertical Consolidation Stress: 18.00 ksf
Water Content: 12.4 % Dry Unit Weight: 131.7 pcf
Deformation Rate: 0.00200 inch/min.
Peak Shear Strength: 11.46 ksf @ 0.09 inch deformation
Peak Effective Friction Angle: 32.5°, cohesion = 0.0ksf
Final Shear Strength: 10.59 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 30.5° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B006 Sample: ST- 4 Specimen: A Depth: 35.55 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST-4 Depth: 40-42 feet
Type: Intact tube sample
Description: CH, brown clay with sand

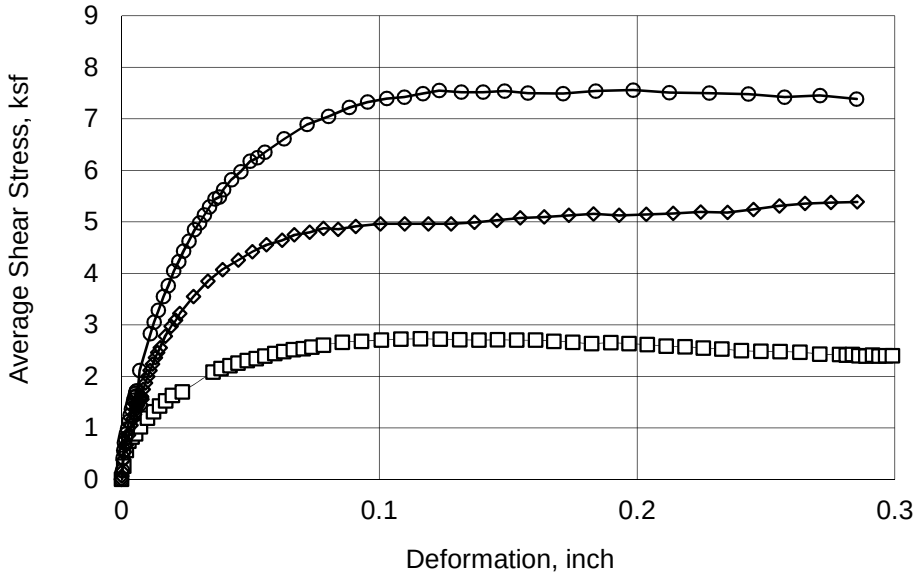
TEST INFORMATION

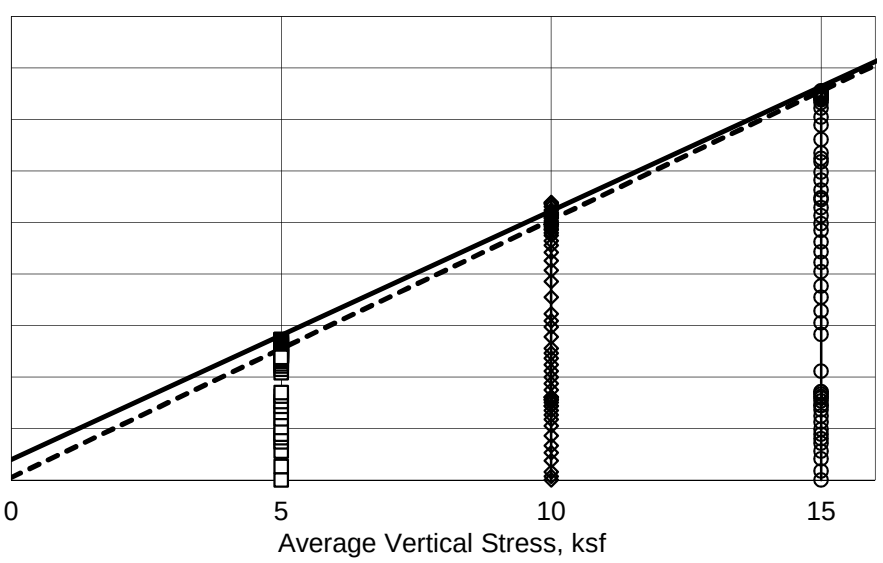
Test	Symbol	Vertical Stress (ksf)	Deformation Rate (inch/min.)
DS1620	□	5.0	0.0022
DS1621	◊	10.0	0.0002
DS1622	○	15.0	0.0001

TEST SUMMARY

Peak Effective Friction Angle: 25.8°, cohesion = 0.4ksf
Final Effective Friction Angle: 26.6°, cohesion = 0.1ksf

REMARKS:





Prepared by: MHC Checked by: GET	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **SERIES SUMMARY** Boring: NEW-B007 Sample: ST-4 Depth: 40-42	
	TerraSense, LLC	T60428794		November 2015

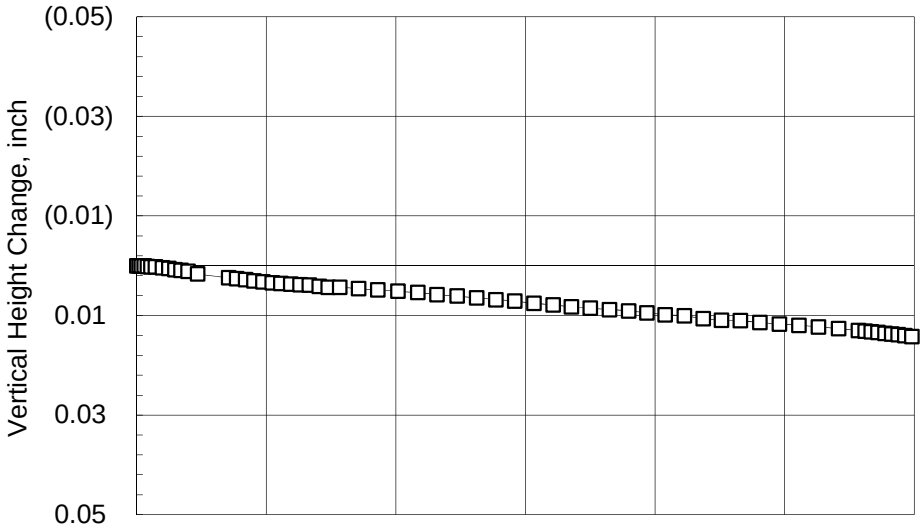
STAGED DRAINED DIRECT SHEAR TEST SERIES

Boring No	Depth (ft)	w_o	γ_{to}	γ_{do}	$\sigma'_{v,c}$ (ksf)	Deformation rate (inch/min)	at Peak Shear Stress at High Deformation				Remarks
Sample/ Specimen	Test ID	w_c (estimated) (%)	γ_{tc} (estimated) (pcf)	γ_{dc} (estimated) (pcf)	$\varepsilon_{v,c}$ (%)	t_c (days)	ΔL (inch)	τ_h (ksf)	ε_v (%)	Φ' for c'=0	
NEW-B007	41.0	17.5	129.9	110.5	5.00	2.2E-3	0.12	2.73	0.58	28.6	
ST-4	DS1620	18.6	131.8	111.1	2.9	1.69	0.30	2.38	1.45	25.5	
NEW-B007	41.3	14.7	128.7	112.2	10.00	1.8E-4	0.29	5.39	1.91	28.3	
ST- 4	DS1621	16.3	132.9	114.2	4.7	0.71	0.29	5.39	1.91	28.3	
NEW-B007	41.5	16.1	132.6	114.2	15.00	1.3E-4	0.20	7.56	1.83	26.7	
ST- 4	DS1622	14.8	138.9	121.0	8.5	0.78	0.29	7.38	2.21	26.2	

Description of Material Tested and Remarks	
DS1620	CH, brown clay with sand
DS1621	CH, brown clay with sand
DS1622	CH, brown clay with sand

Strength Envelope Summary			
Test Series	Failure Criterion	Φ' (degree)	c' (ksf)
1	1	25.8	0.4
	2	26.6	0.1
Failure Criterion		1. Peak shear stress 2. High deformation	

	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR SERIES SUMMARY**
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B007 Sample: ST-4 Depth: 40-42 ft



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST-4 Specimen: B Depth: 41 ft
Type: Intact tube sample

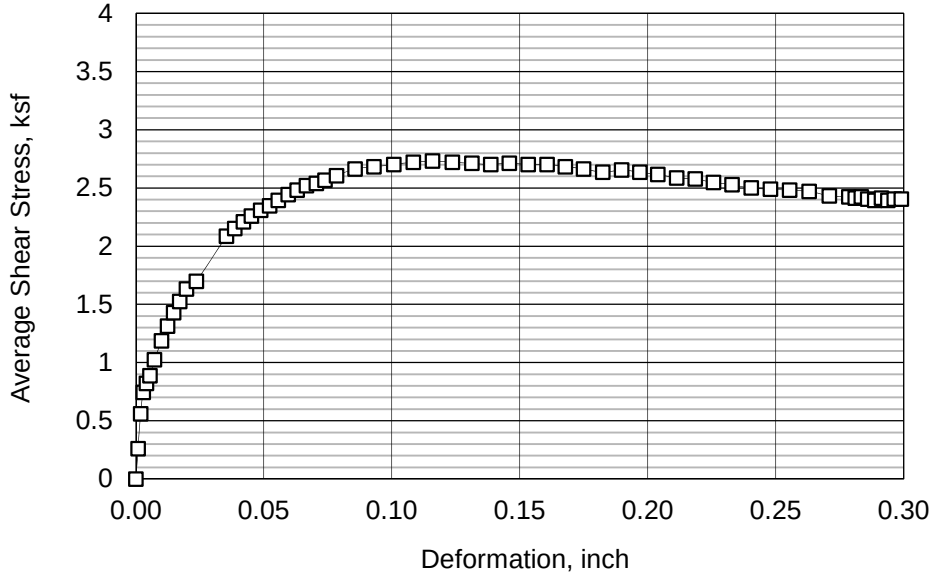
SPECIMEN INFORMATION (Initial)

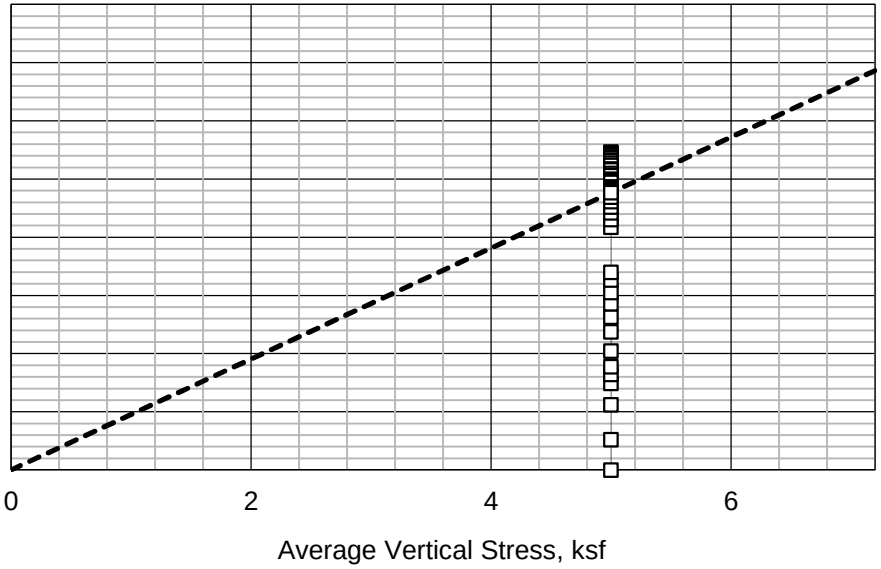
Description: CH, brown clay with sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 17.5 % Dry Unit Weight: 110.5 pcf

TEST SUMMARY

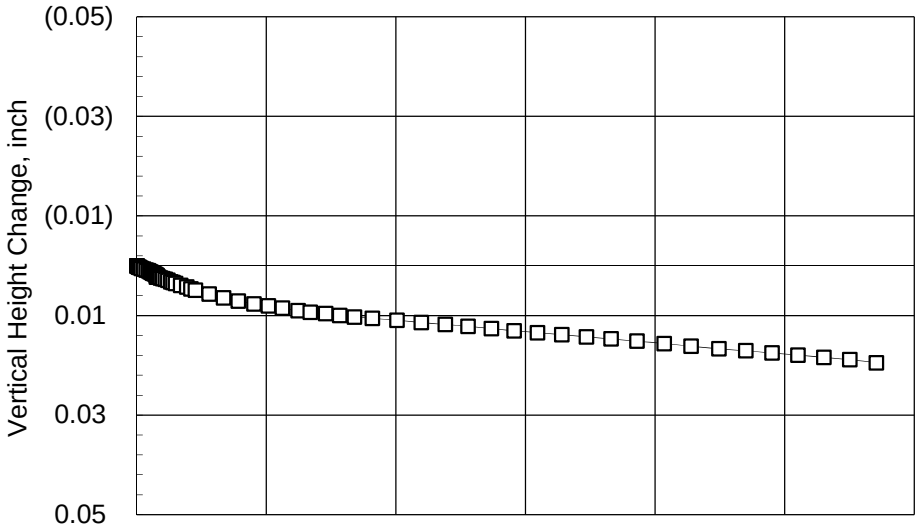
Vertical Consolidation Stress: 5.00 ksf
Water Content: 18.6 % Dry Unit Weight: 111.1 pcf
Deformation Rate: 0.00222 inch/min.
Peak Shear Strength: 2.73 ksf @ 0.12 inch deformation
Peak Effective Friction Angle: 28.6°, cohesion = 0.0ksf
Final Shear Strength: 2.38 ksf @ 0.30 inch deformation
Final Effective Friction Angle: 25.5° (Shown)

REMARKS:





Prepared by: MHC Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B007 Sample: ST-4 Specimen: B Depth: 41 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST- 4 Specimen: C Depth: 41.25 ft
Type: Intact tube sample

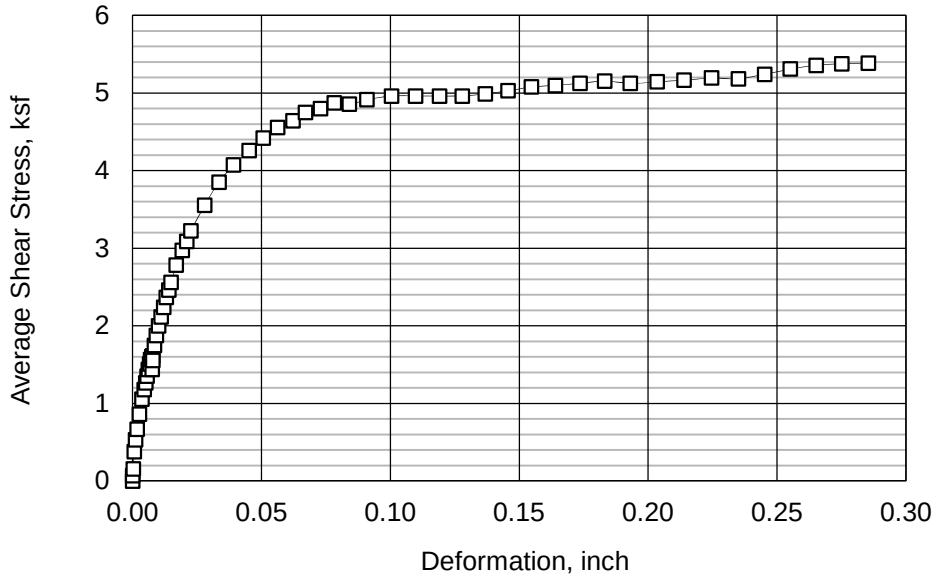
SPECIMEN INFORMATION (Initial)

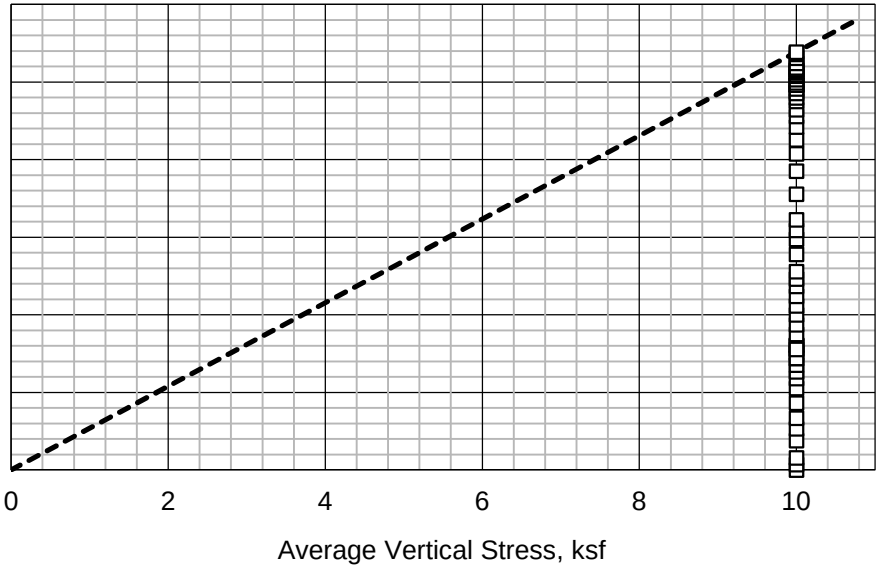
Description: CH, brown clay with sand
Height: 1.02 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 14.7 % Dry Unit Weight: 112.2 pcf

TEST SUMMARY

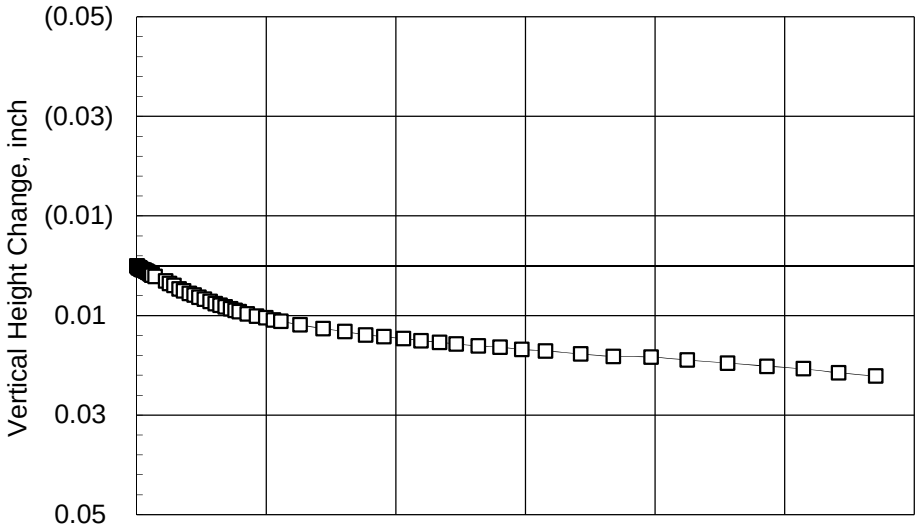
Vertical Consolidation Stress: 10.00 ksf
Water Content: 16.3 % Dry Unit Weight: 114.2 pcf
Deformation Rate: 0.00018 inch/min.
Peak Shear Strength: 5.39 ksf @ 0.29 inch deformation
Peak Effective Friction Angle: 28.3°, cohesion = 0.0ksf
Final Shear Strength: 5.39 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 28.3° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B007 Sample: ST- 4 Specimen: C Depth: 41.25 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST- 4 Specimen: D Depth: 41.45 ft
Type: Intact tube sample

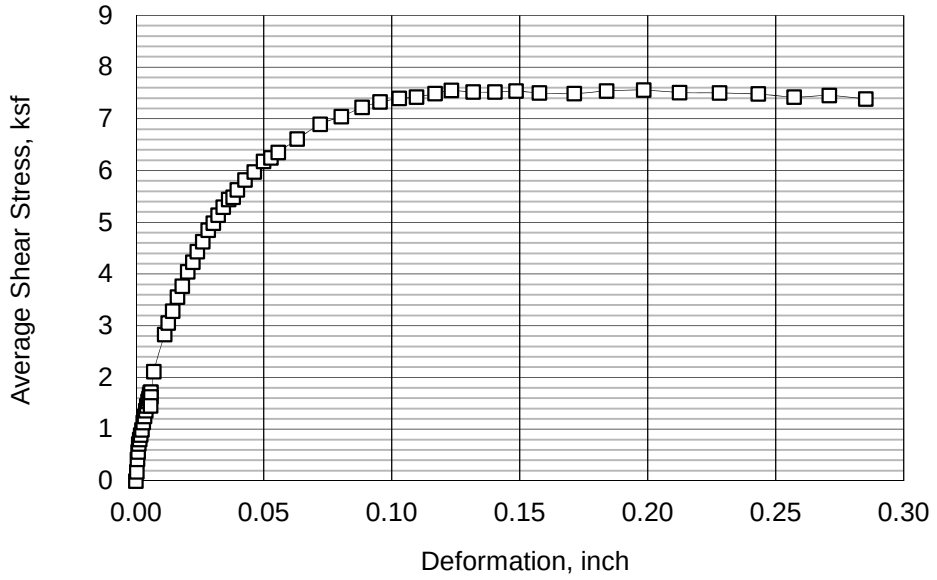
SPECIMEN INFORMATION (Initial)

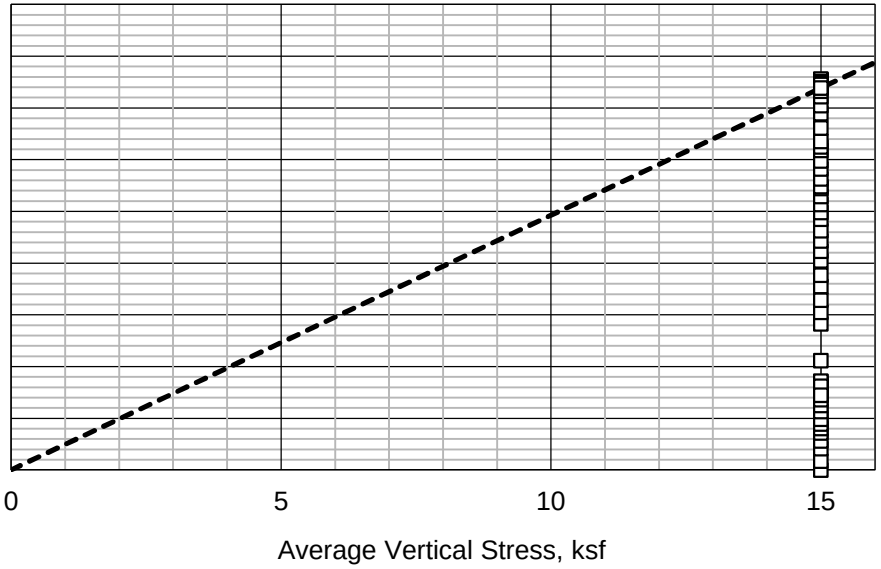
Description: CH, brown clay with sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 16.1 % Dry Unit Weight: 114.2 pcf

TEST SUMMARY

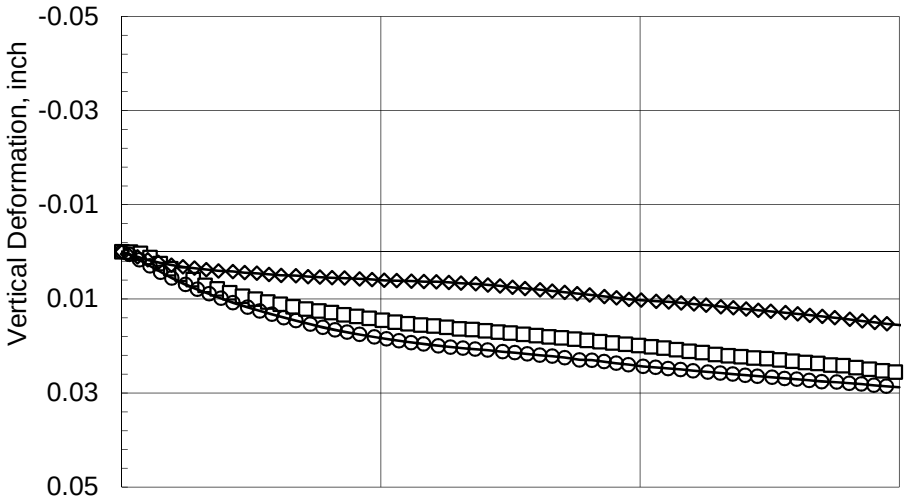
Vertical Consolidation Stress: 15.00 ksf
Water Content: 14.8 % Dry Unit Weight: 121.0 pcf
Deformation Rate: 0.00013 inch/min.
Peak Shear Strength: 7.56 ksf @ 0.20 inch deformation
Peak Effective Friction Angle: 26.7°, cohesion = 0.0ksf
Final Shear Strength: 7.38 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 26.2° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B007 Sample: ST- 4 Specimen: D Depth: 41.45 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B008 Sample: ST-2 Depth: 27.5-28.75 feet
Type: Intact tube sample
Description: CL, dark brown sandy clay with gravel

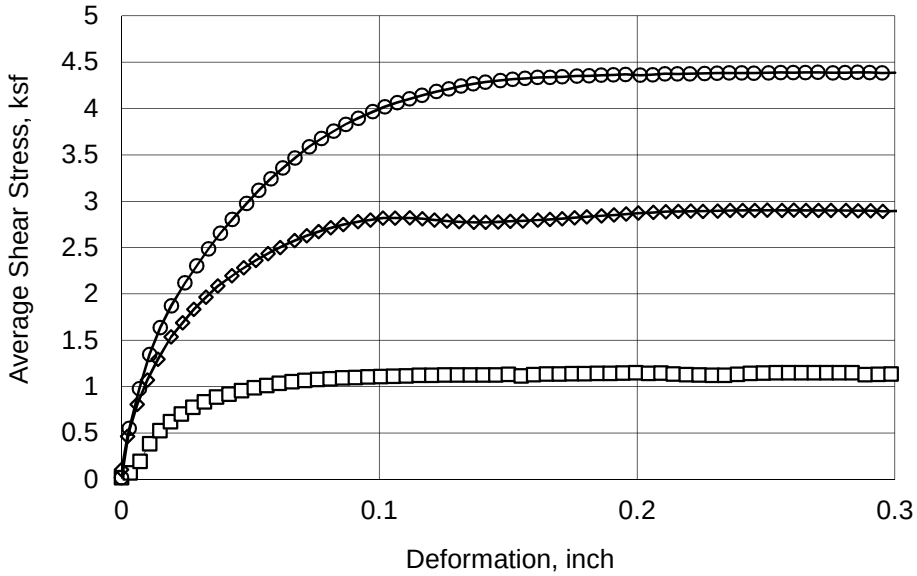
TEST INFORMATION

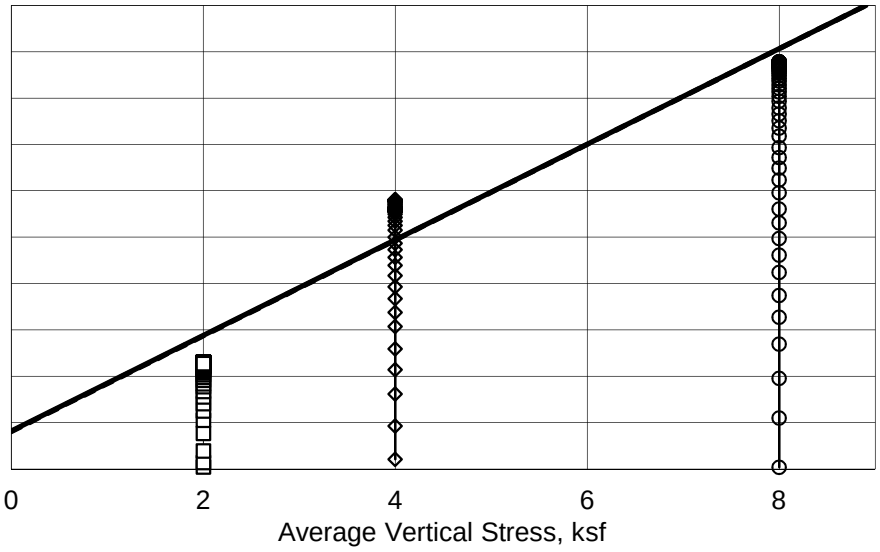
Test	Symbol	Vertical Stress (ksf)	Deformation Rate (inch/min.)
DS1624	□	2.0	0.0002
DS1626	◊	4.0	0.0002
DS1628	○	8.0	0.0002

TEST SUMMARY

Peak Effective Friction Angle: 27.3°, cohesion = 0.4ksf
Final Effective Friction Angle: 27.3°, cohesion = 0.4ksf

REMARKS:





AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **SERIES SUMMARY**	
TerraSense, LLC	T60428794	Boring: NEW-B008 Sample: ST-2 Depth: 27.5-28.75	November 2015

Prepared by: MHC
Checked by: GET

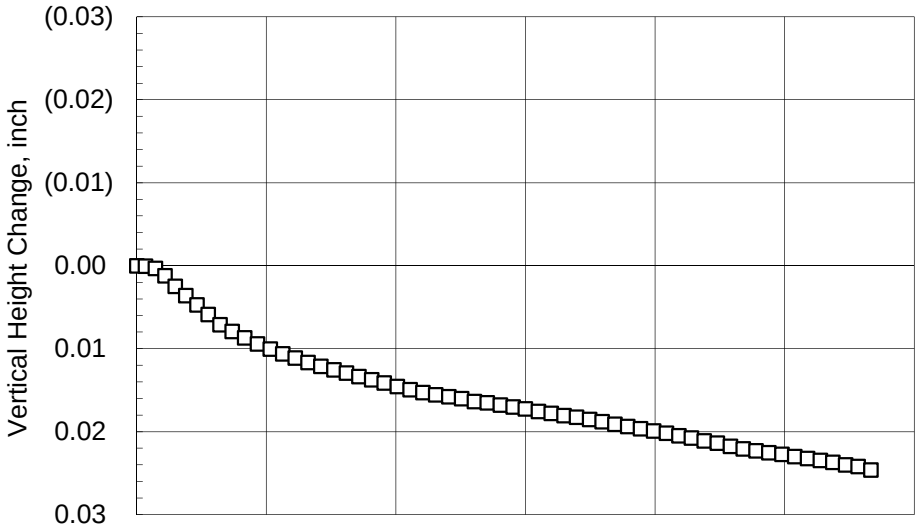
STAGED DRAINED DIRECT SHEAR TEST SERIES

Boring No	Depth (ft)	w_o	γ_{to}	γ_{do}	$\sigma'_{v,c}$ (ksf)	Deformation rate (inch/min)	at Peak Shear Stress at High Deformation				Remarks
Sample/ Specimen	Test ID	w_c (estimated) (%)	γ_{tc} (estimated) (pcf)	γ_{dc} (estimated) (pcf)	$\varepsilon_{v,c}$ (%)	t_c (days)	ΔL (inch)	τ_h (ksf)	ε_v (%)	Φ' for c'=0	
NEW-B008	27.7	20.3	122.5	101.8	2.00	1.9E-4	0.27	1.15	2.29	29.9	
ST-2	DS1624	20.9	126.7	104.8	4.0	0.33	0.28	1.15	2.34	29.9	
NEW-B008	28.0	14.4	133.8	117.0	4.00	1.9E-4	0.25	2.90	1.26	36.0	
ST-2	DS1626	19.3	143.5	120.3	4.4	0.67	0.29	2.90	1.46	35.9	
NEW-B008	28.4	16.4	133.2	114.5	8.00	1.9E-4	0.29	4.39	2.79	28.8	
ST-2	DS1628	18.2	141.6	119.9	7.2	0.67	0.29	4.39	2.79	28.8	

Description of Material Tested and Remarks	
DS1624	CL, dark brown sandy clay with gravel
DS1626	CL, dark brown sandy clay with gravel
DS1628	CL, dark brown clay with sand and gravel

Strength Envelope Summary			
Test Series	Failure Criterion	Φ' (degree)	c' (ksf)
1	1	27.3	0.4
	2	27.3	0.4
Failure Criterion		1. Peak shear stress 2. High deformation	

	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR SERIES SUMMARY**
Prepared by: MCH Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B008 Sample: ST-2 Depth: 27.5-28.75 ft



SAMPLE INFORMATION

Boring: NEW-B008 Sample: ST-2 Specimen: A Depth: 27.7 ft
Type: Intact tube sample

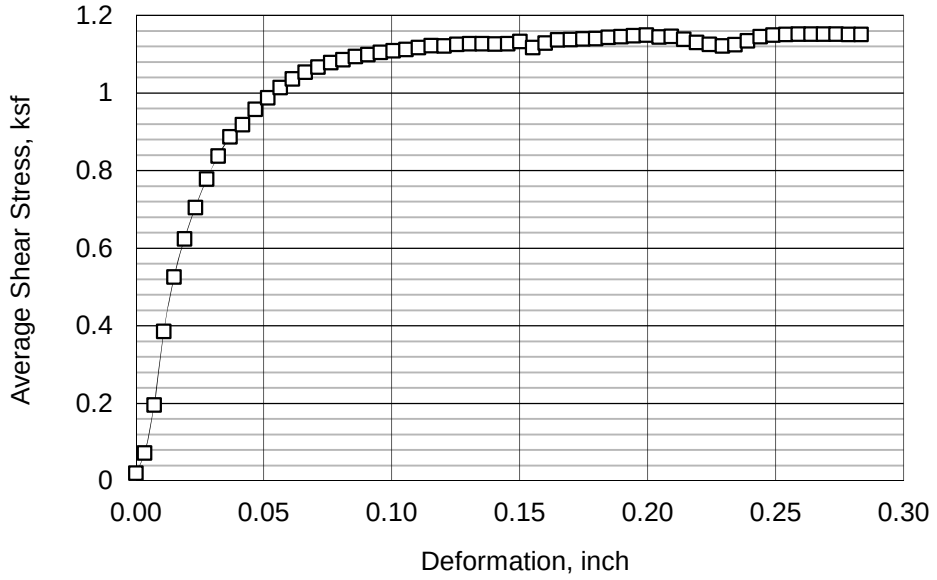
SPECIMEN INFORMATION (Initial)

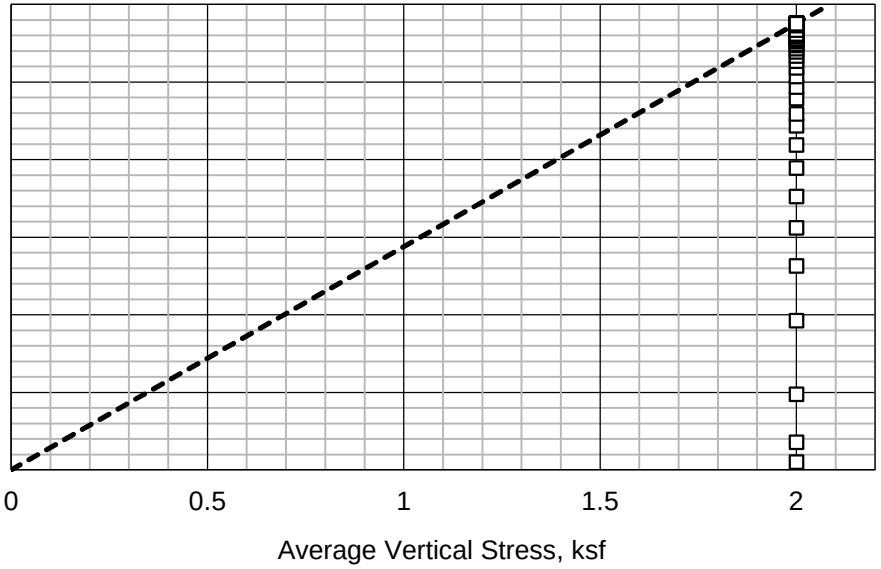
Description: CL, dark brown clay with sand and gravel
Height: 1.05 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 20.3 % Dry Unit Weight: 101.8 pcf

TEST SUMMARY

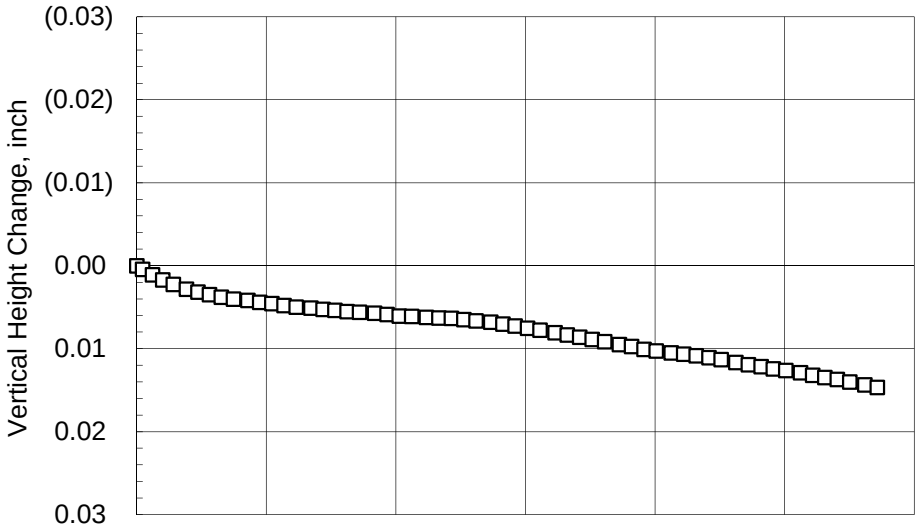
Vertical Consolidation Stress: 2.00 ksf
Water Content: 20.9 % Dry Unit Weight: 104.8 pcf
Deformation Rate: 0.00019 inch/min.
Peak Shear Strength: 1.15 ksf @ 0.27 inch deformation
Peak Effective Friction Angle: 29.9°, cohesion = 0.0 ksf
Final Shear Strength: 1.15 ksf @ 0.28 inch deformation
Final Effective Friction Angle: 29.9° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MCH Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B008 Sample: ST-2 Specimen: A Depth: 27.7 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B008 Sample: ST-2 Specimen: B Depth: 28 ft
Type: Intact tube sample

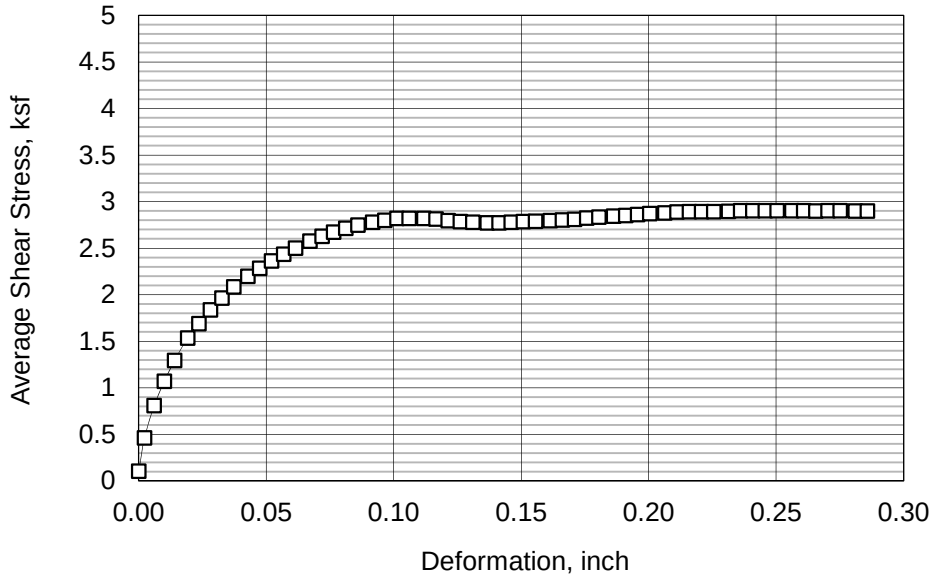
SPECIMEN INFORMATION (Initial)

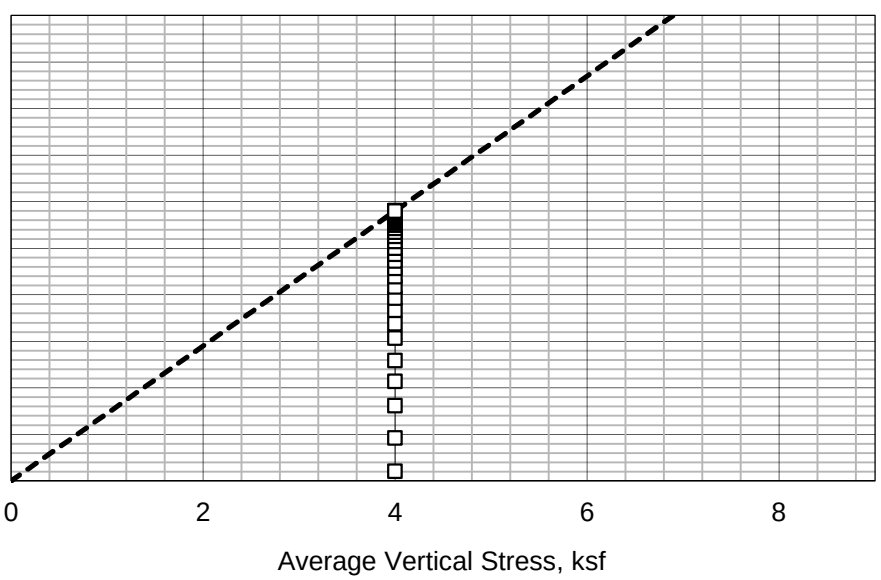
Description: CL, dark brown sandy clay with gravel
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 14.4 % Dry Unit Weight: 117.0 pcf

TEST SUMMARY

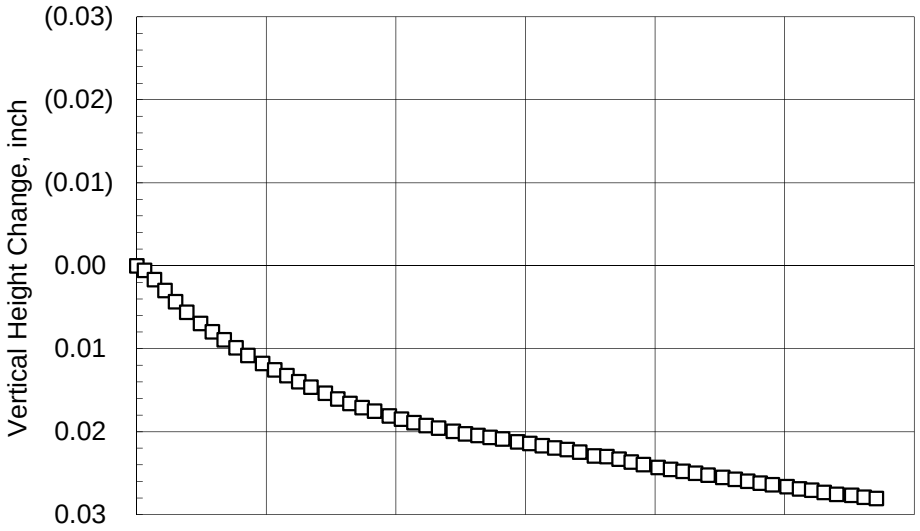
Vertical Consolidation Stress: 4.00 ksf
Water Content: 19.3 % Dry Unit Weight: 120.3 pcf
Deformation Rate: 0.00019 inch/min.
Peak Shear Strength: 2.90 ksf @ 0.25 inch deformation
Peak Effective Friction Angle: 36.0°, cohesion = 0.0 ksf
Final Shear Strength: 2.90 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 35.9° (Shown)

REMARKS:





Prepared by: MCH Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B008 Sample: ST-2 Specimen: B Depth: 28 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B008 Sample: ST-2 Specimen: C Depth: 28.4 ft
Type: Intact tube sample

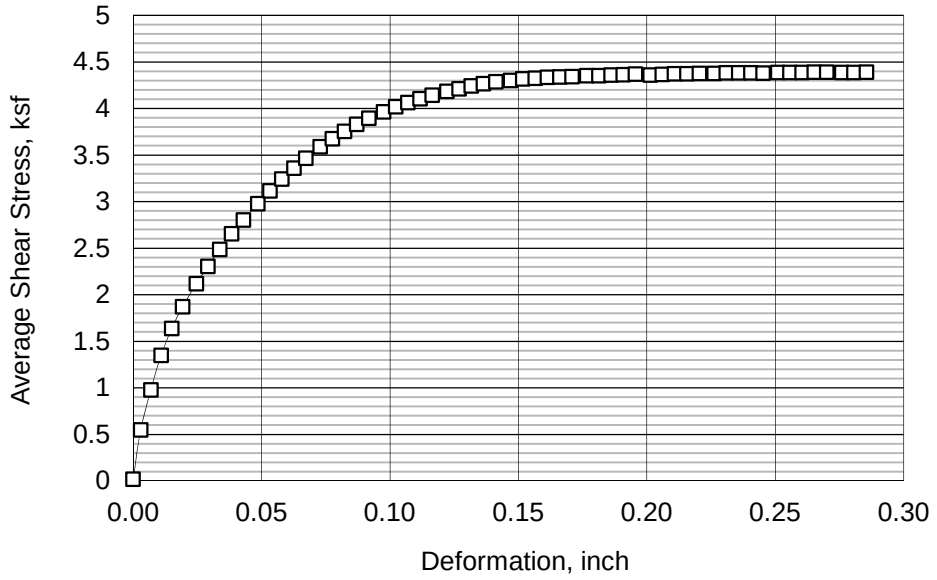
SPECIMEN INFORMATION (Initial)

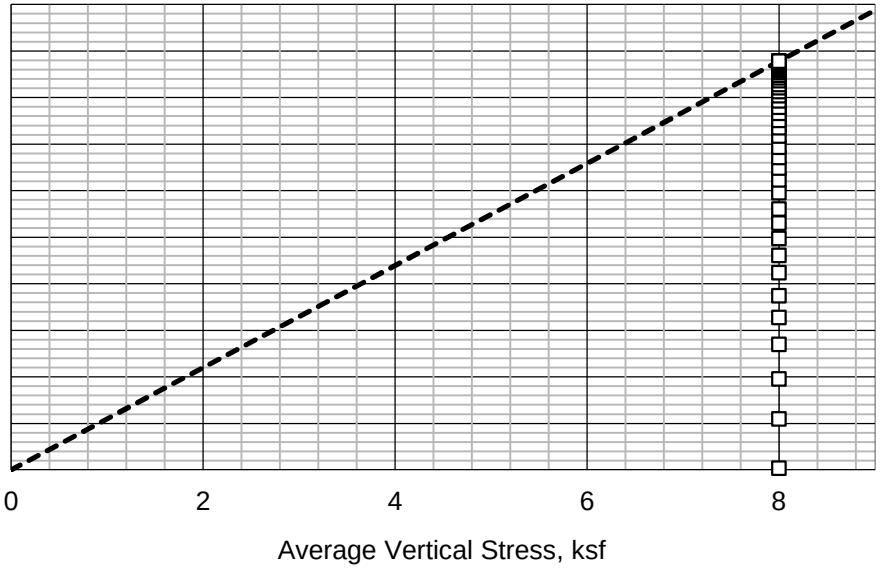
Description: CL, dark brown sandy clay with gravel
Height: 1.01 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 16.4 % Dry Unit Weight: 114.5 pcf

TEST SUMMARY

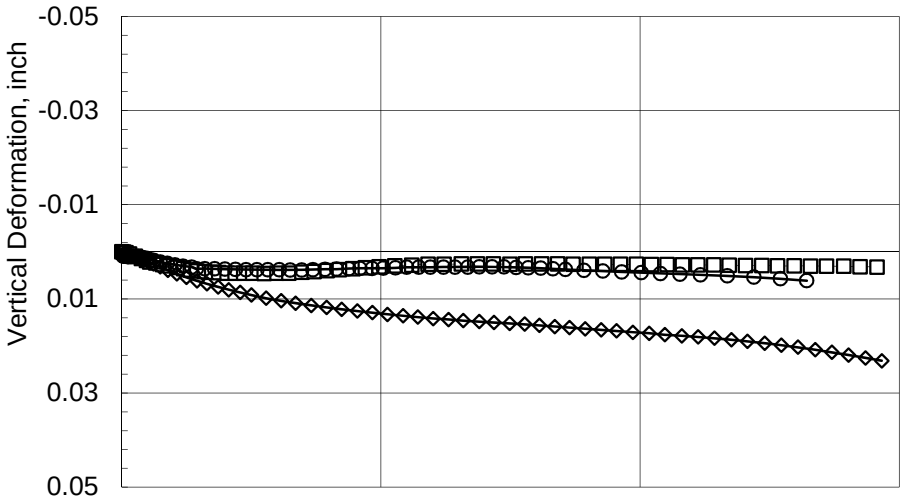
Vertical Consolidation Stress: 8.00 ksf
Water Content: 18.2 % Dry Unit Weight: 119.9 pcf
Deformation Rate: 0.00019 inch/min.
Peak Shear Strength: 4.39 ksf @ 0.29 inch deformation
Peak Effective Friction Angle: 28.8°, cohesion = 0.0 ksf
Final Shear Strength: 4.39 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 28.8° (Shown)

REMARKS:





Prepared by: MCH Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B008 Sample: ST-2 Specimen: C Depth: 28.4 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-19 A Depth: 80-82 feet
Type: Intact tube sample
Description: SC, brown clayey sand

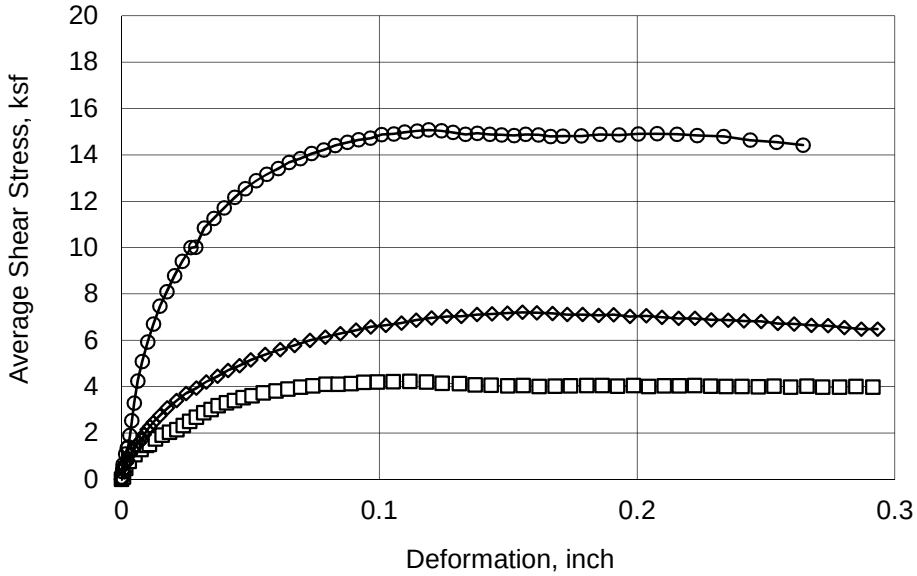
TEST INFORMATION

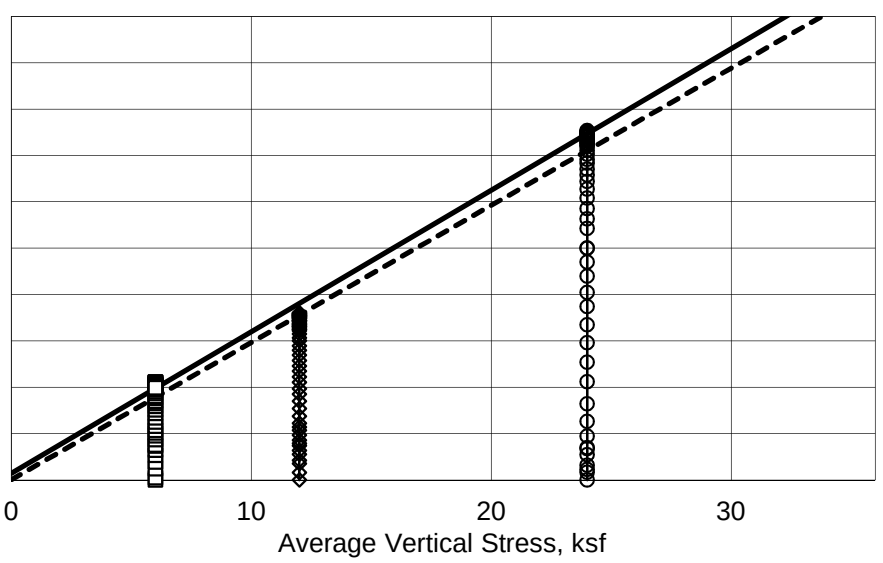
Test	Symbol	Vertical Stress (ksf)	Deformation Rate (inch/min.)
DS1611	□	6.0	0.0022
DS1613	◊	12.0	0.0021
DS1612	○	24.0	0.0017

TEST SUMMARY

Peak Effective Friction Angle: 31.4°, cohesion = 0.3ksf
Final Effective Friction Angle: 30.6°, cohesion = 0.0ksf

REMARKS:





Prepared by: MHC Checked by: GET	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **SERIES SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B012 Sample: ST-19 A Depth: 80-82	November 2015

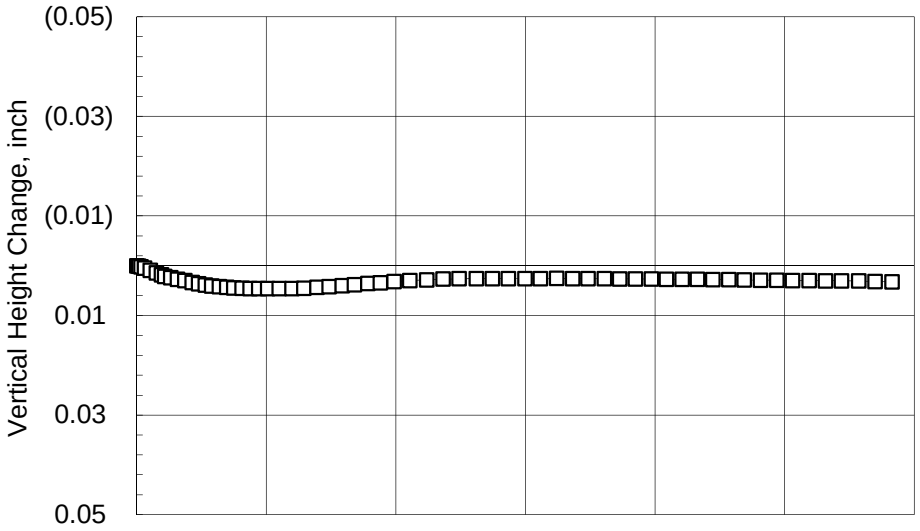
STAGED DRAINED DIRECT SHEAR TEST SERIES

Boring No	Depth (ft)	w_o	γ_{to}	γ_{do}	$\sigma'_{v,c}$ (ksf)	Deformation rate (inch/min)	at Peak Shear Stress at High Deformation				Remarks
Sample/ Specimen	Test ID	w_c (estimated) (%)	γ_{tc} (estimated) (pcf)	γ_{dc} (estimated) (pcf)	$\varepsilon_{v,c}$ (%)	t_c (days)	ΔL (inch)	τ_h (ksf)	ε_v (%)	Φ' for c'=0	
NEW-B012	81.1	11.2	136.8	122.9	6.00	2.2E-3	0.11	4.23	0.28	35.2	
ST-19 A	DS1611	12.1	140.7	125.5	4.4	0.06	0.29	3.98	0.32	33.5	
NEW-B012	81.8	16.9	130.5	111.7	12.00	2.1E-3	0.16	7.21	1.54	31.0	
ST-19	DS1613	16.7	136.2	116.7	8.6	1.81	0.29	6.49	2.32	28.4	
NEW-B012	81.5	10.5	139.2	126.0	24.00	1.7E-3	0.12	15.08	0.33	32.1	
ST-19	DS1612	10.9	145.6	131.3	14.6	0.13	0.26	14.42	0.61	31.0	

Description of Material Tested and Remarks	
DS1611	SC, brown clayey sand
DS1613	SC, brown clayey sand
DS1612	SC, brown clayey sand

Strength Envelope Summary			
Test Series	Failure Criterion	Φ' (degree)	c' (ksf)
1	1	31.4	0.3
	2	30.6	0.0
Failure Criterion		1. Peak shear stress 2. High deformation	

	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR SERIES SUMMARY**
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B012 Sample: ST-19 A Depth: 80-82 ft



SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-19 A Specimen: 1 Depth: 81.1 ft
Type: Intact tube sample

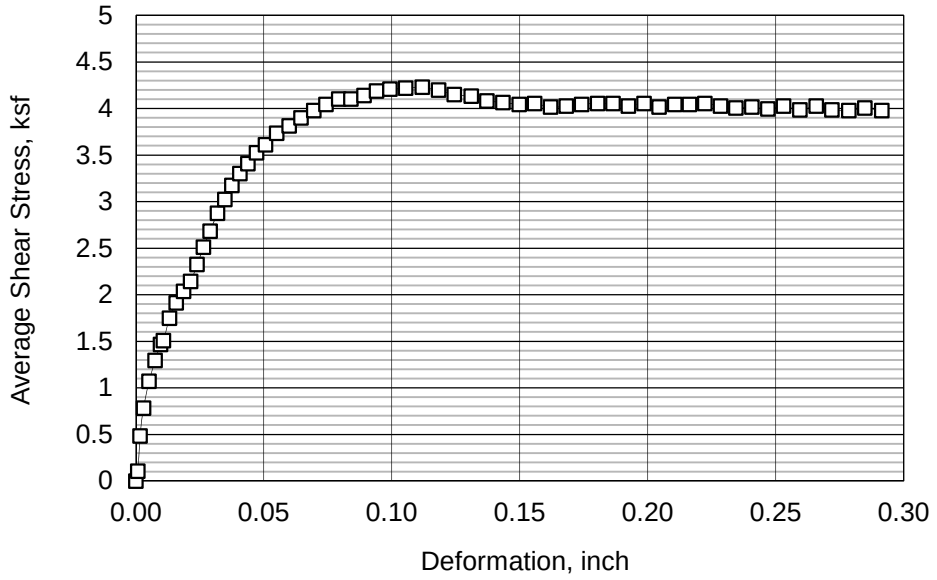
SPECIMEN INFORMATION (Initial)

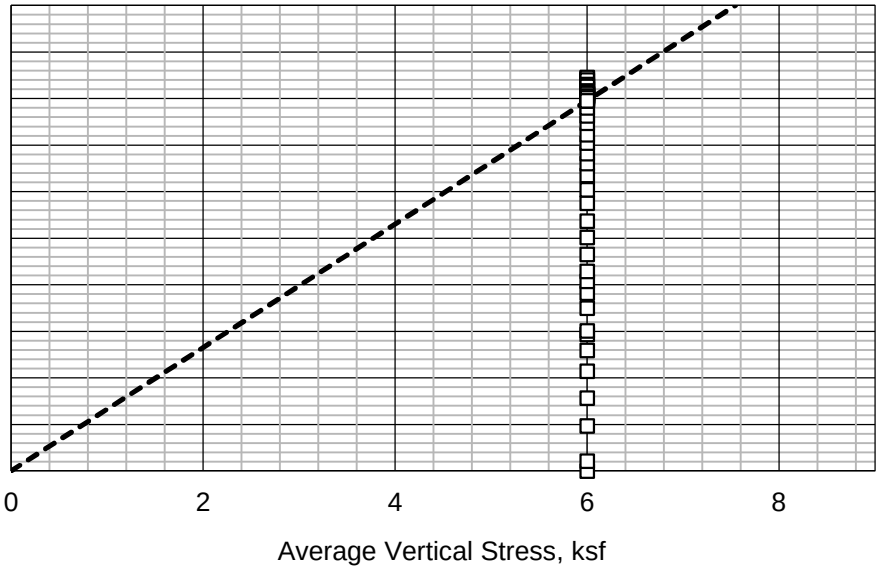
Description: SC, brown clayey sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 11.2 % Dry Unit Weight: 122.9 pcf

TEST SUMMARY

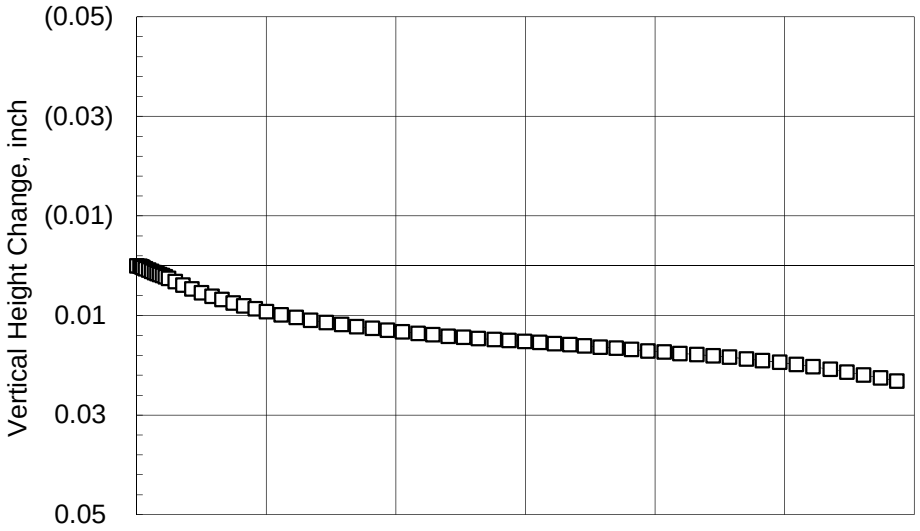
Vertical Consolidation Stress: 6.00 ksf
Water Content: 12.1 % Dry Unit Weight: 125.5 pcf
Deformation Rate: 0.00222 inch/min.
Peak Shear Strength: 4.23 ksf @ 0.11 inch deformation
Peak Effective Friction Angle: 35.2°, cohesion = 0.0ksf
Final Shear Strength: 3.98 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 33.5° (Shown)

REMARKS:





Prepared by: MHC Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B012 Sample: ST-19 A Specimen: 1 Depth: 81.1 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-19 Specimen: C Depth: 81.8 ft
Type: Intact tube sample

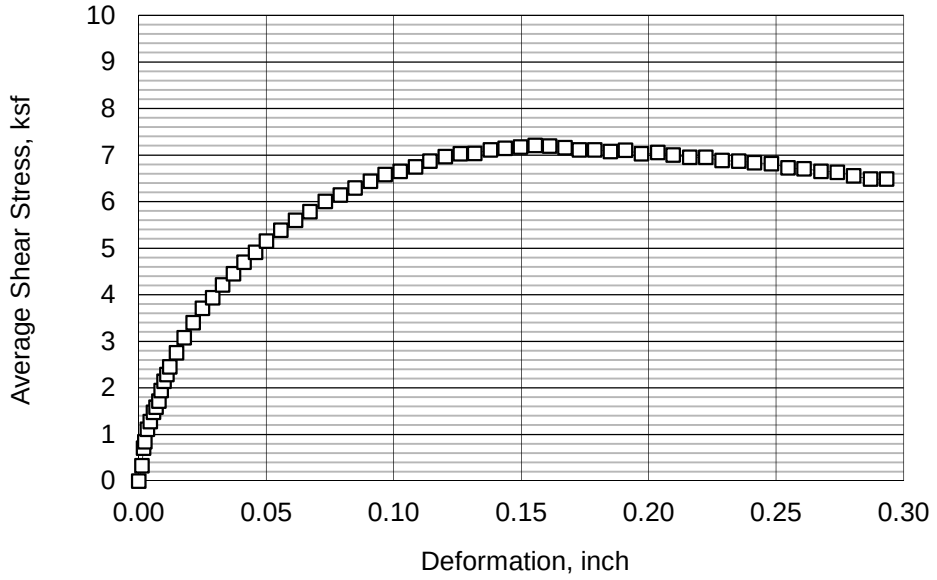
SPECIMEN INFORMATION (Initial)

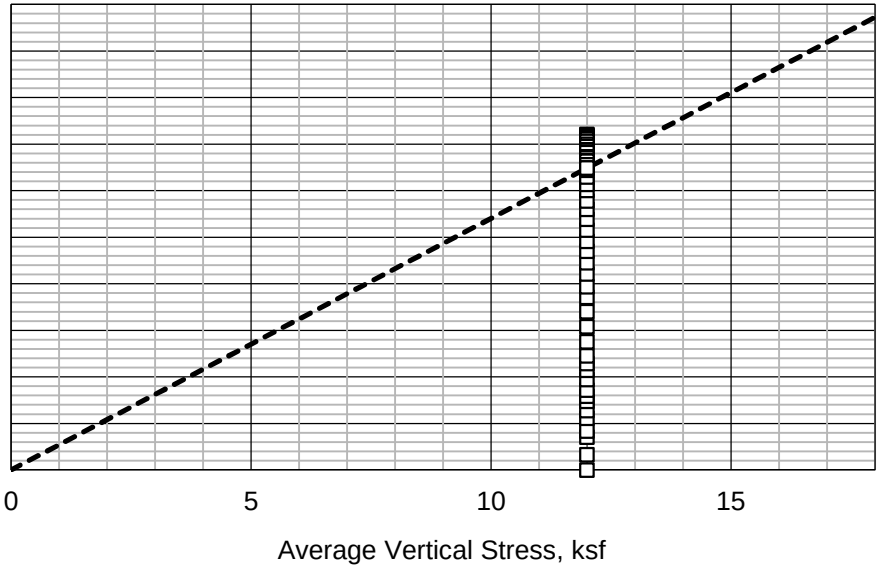
Description: SC, brown clayey sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 16.9 % Dry Unit Weight: 111.7 pcf

TEST SUMMARY

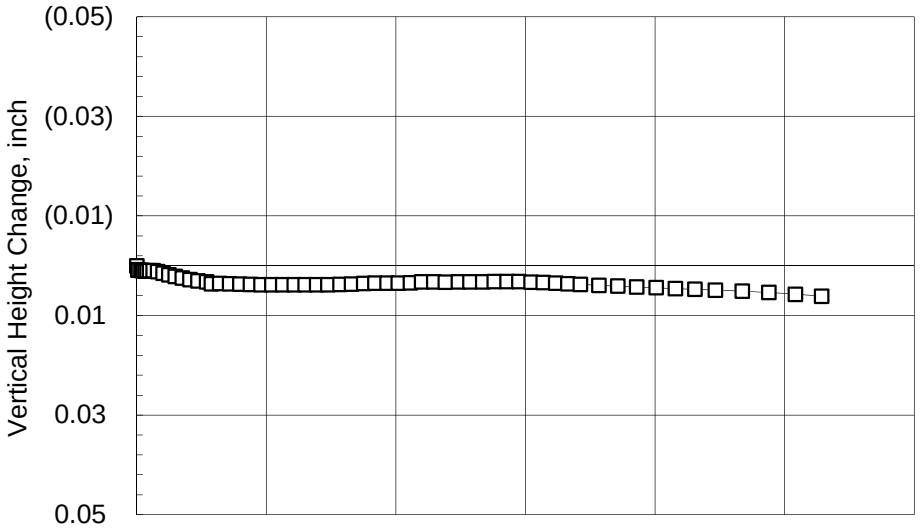
Vertical Consolidation Stress: 12.00 ksf
Water Content: 16.7 % Dry Unit Weight: 116.7 pcf
Deformation Rate: 0.00211 inch/min.
Peak Shear Strength: 7.21 ksf @ 0.16 inch deformation
Peak Effective Friction Angle: 31.0°, cohesion = 0.0ksf
Final Shear Strength: 6.49 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 28.4° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B012 Sample: ST-19 Specimen: C Depth: 81.8 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-19 Specimen: B Depth: 81.5 ft
Type: Intact tube sample

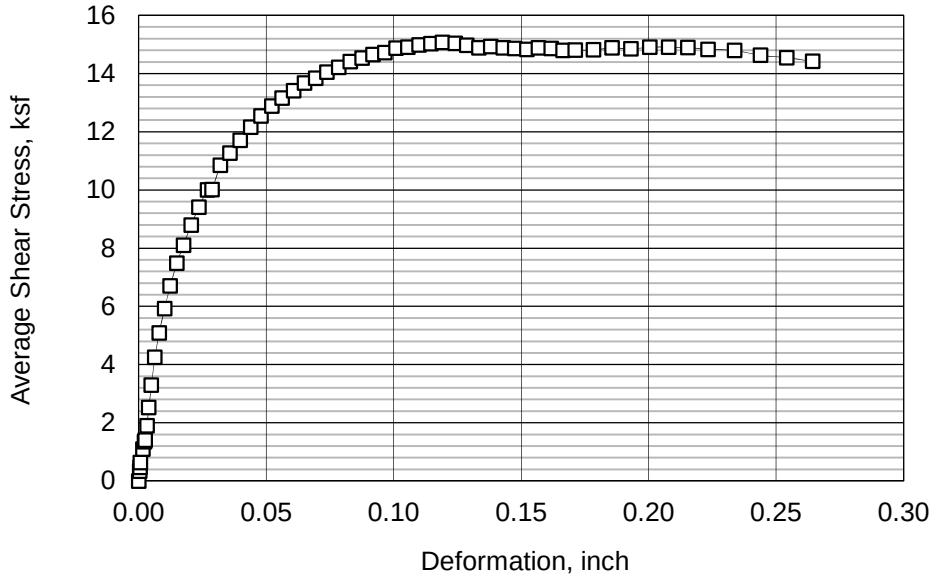
SPECIMEN INFORMATION (Initial)

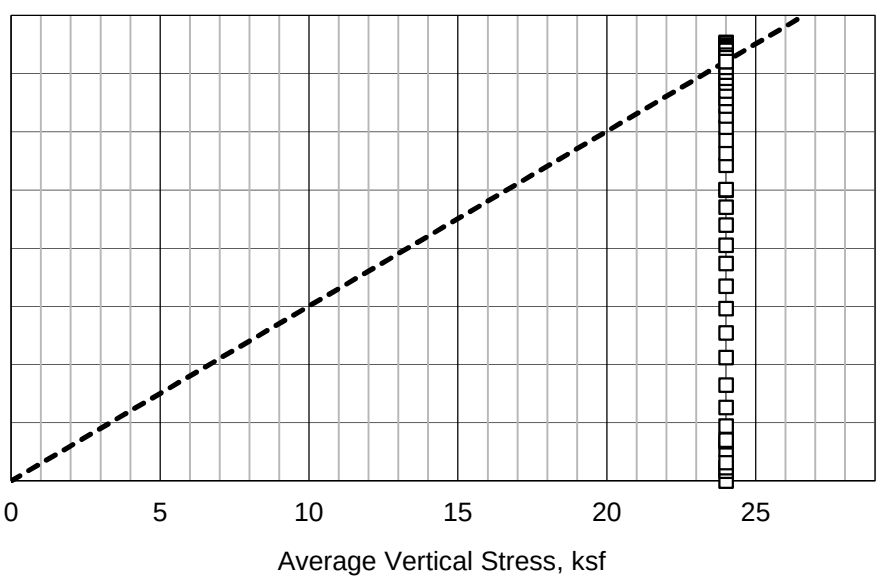
Description: SC, brown clayey sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 10.5 % Dry Unit Weight: 126.0 pcf

TEST SUMMARY

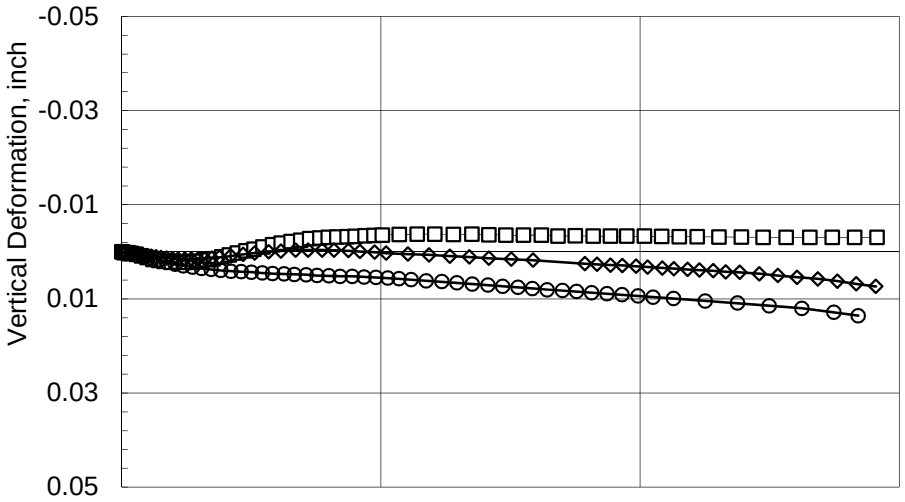
Vertical Consolidation Stress: 24.00 ksf
Water Content: 10.9 % Dry Unit Weight: 131.3 pcf
Deformation Rate: 0.00171 inch/min.
Peak Shear Strength: 15.08 ksf @ 0.12 inch deformation
Peak Effective Friction Angle: 32.1°, cohesion = 0.0ksf
Final Shear Strength: 14.42 ksf @ 0.26 inch deformation
Final Effective Friction Angle: 31.0° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B012 Sample: ST-19 Specimen: B Depth: 81.5 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B015 Sample: ST-3 Depth: 60-61.3 feet
Type: Intact tube sample
Description: CL, brown clay with sand and gravel

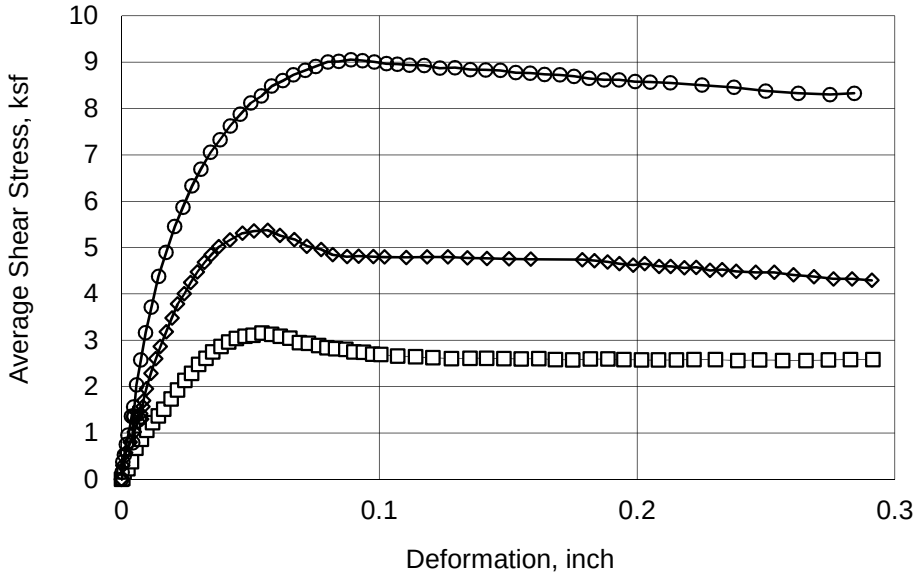
TEST INFORMATION

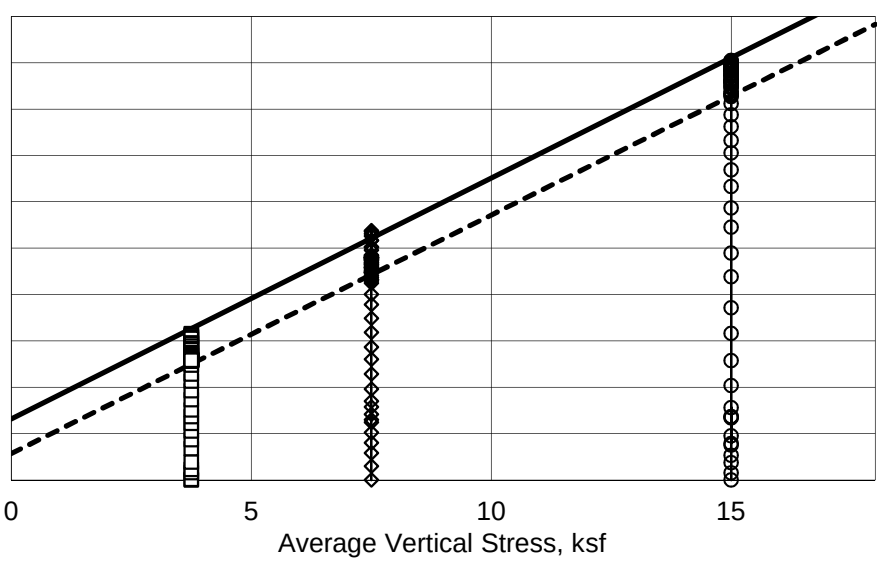
Test	Symbol	Vertical Stress (ksf)	Deformation Rate (inch/min.)
DS1623	□	3.8	0.0008
DS1625	◊	7.5	0.0008
DS1627	○	15.0	0.0007

TEST SUMMARY

Peak Effective Friction Angle: 27.4°, cohesion = 1.3ksf
Final Effective Friction Angle: 27.2°, cohesion = 0.6ksf

REMARKS:





Prepared by: MHC Checked by: GET	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **SERIES SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B015 Sample: ST-3 Depth: 60-61.3	November 2015

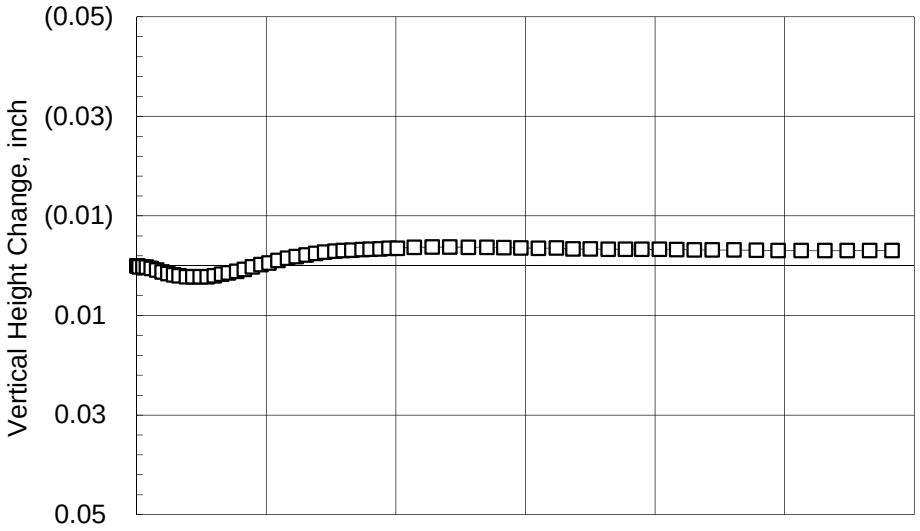
STAGED DRAINED DIRECT SHEAR TEST SERIES

Boring No	Depth (ft)	w_o	γ_{to}	γ_{do}	$\sigma'_{v,c}$ (ksf)	Deformation rate (inch/min)	at Peak Shear Stress at High Deformation				Remarks
Sample/ Specimen	Test ID	w_c (estimated) (%)	γ_{tc} (estimated) (pcf)	γ_{dc} (estimated) (pcf)	$\varepsilon_{v,c}$ (%)	t_c (days)	ΔL (inch)	τ_h (ksf)	ε_v (%)	Φ' for c'=0	
NEW-B015	60.4	11.2	139.6	125.5	3.75	8.2E-4	0.05	3.16	-0.10	40.1	
ST-3	DS1623	12.0	141.2	126.1	2.8	0.63	0.29	2.59	-0.30	34.6	
NEW-B015	60.8	11.9	140.2	125.3	7.50	7.8E-4	0.06	5.38	0.00	35.6	
ST-3	DS1625	13.3	142.1	125.5	2.7	0.24	0.29	4.29	0.73	29.8	
NEW-B015	61.1	12.7	139.8	124.1	15.00	6.6E-4	0.09	9.05	0.51	31.1	
ST-3	DS1627	12.0	141.4	126.2	4.9	1.08	0.28	8.33	1.33	29.0	

Description of Material Tested and Remarks	
DS1623	CL, brown clay with sand and gravel
DS1625	CL, brown clay with sand
DS1627	CL, brown clay with sand

Strength Envelope Summary			
Test Series	Failure Criterion	Φ' (degree)	c' (ksf)
1	1	27.4	1.3
	2	27.2	0.6
Failure Criterion		1. Peak shear stress 2. High deformation	

	AECOM #60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR SERIES SUMMARY**
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B015 Sample: ST-3 Depth: 60-61.3 ft



SAMPLE INFORMATION

Boring: NEW-B015 Sample: ST-3 Specimen: B Depth: 60.35 ft
Type: Intact tube sample

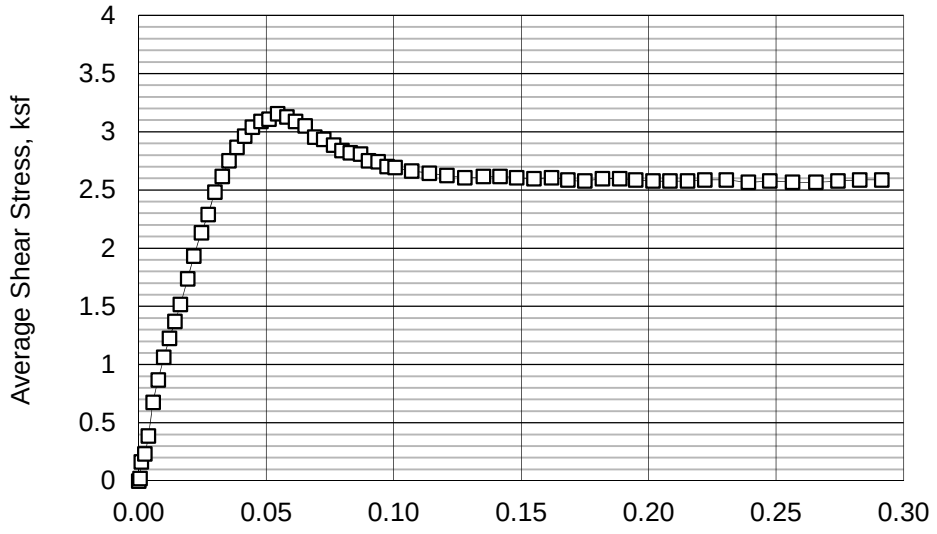
SPECIMEN INFORMATION (Initial)

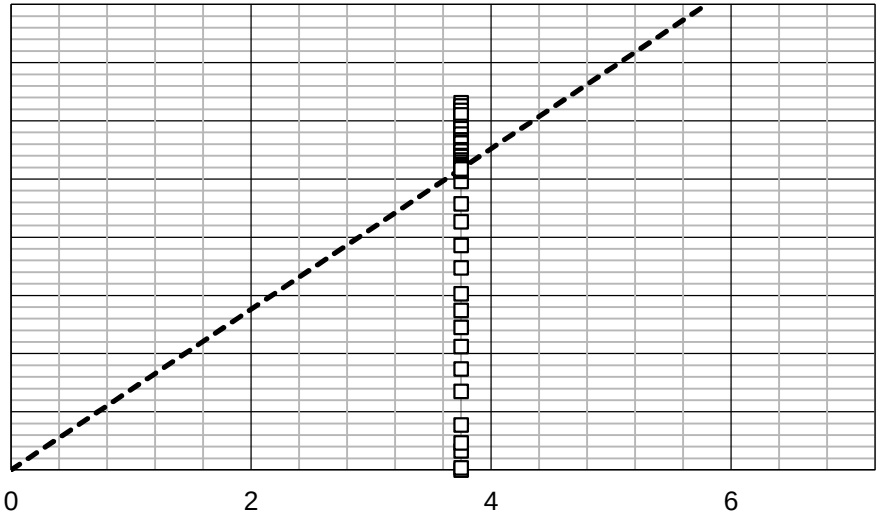
Description: CL, brown clay with sand and gravel
Height: 1.01 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 11.2 % Dry Unit Weight: 125.5 pcf

TEST SUMMARY

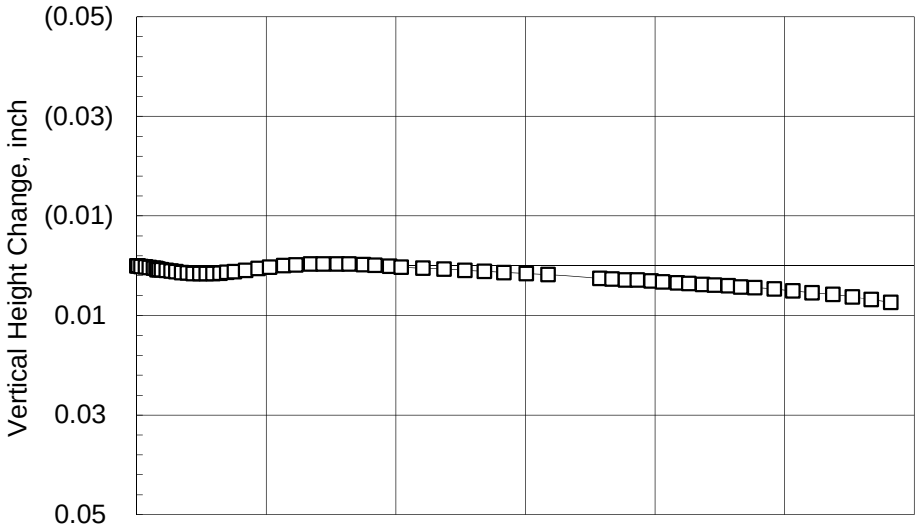
Vertical Consolidation Stress: 3.75 ksf
Water Content: 12.0 % Dry Unit Weight: 126.1 pcf
Deformation Rate: 0.00082 inch/min.
Peak Shear Strength: 3.16 ksf @ 0.05 inch deformation
Peak Effective Friction Angle: 40.1°, cohesion = 0.0ksf
Final Shear Strength: 2.59 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 34.6° (Shown)

REMARKS:





Prepared by: MHC Checked by: GET	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
	TerraSense, LLC	T60428794	Boring: NEW-B015 Sample: ST-3 Specimen: B Depth: 60.35 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B015 Sample: ST-3 Specimen: C Depth: 60.75 ft
Type: Intact tube sample

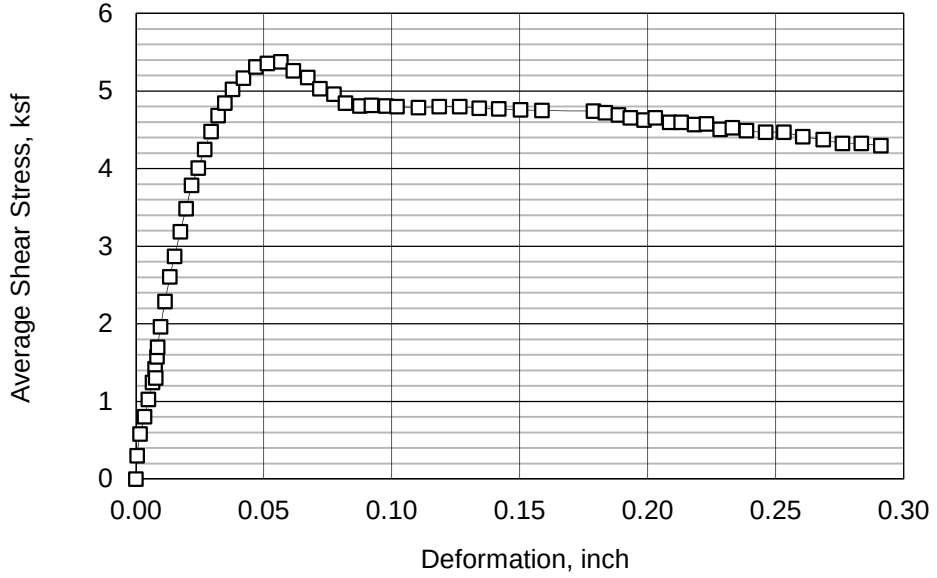
SPECIMEN INFORMATION (Initial)

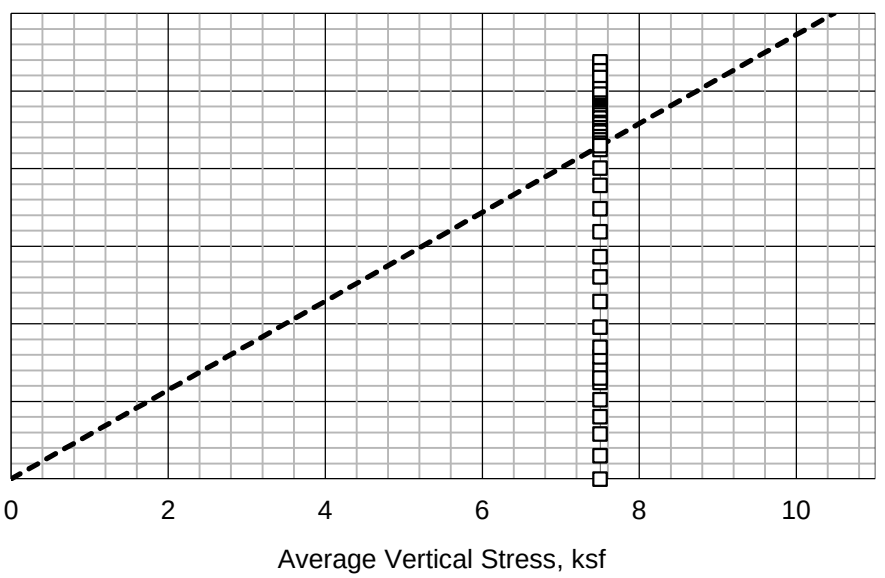
Description: CL, brown clay with sand
Height: 1.00 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 11.9 % Dry Unit Weight: 125.3 pcf

TEST SUMMARY

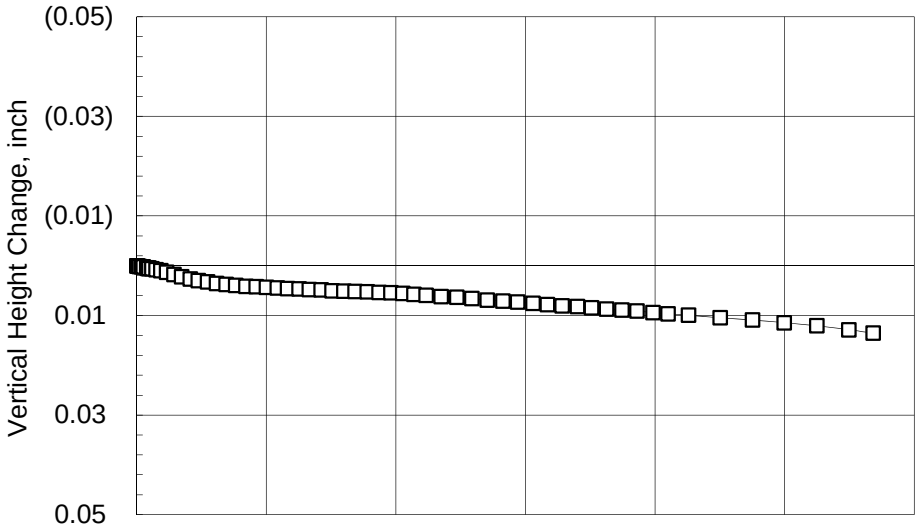
Vertical Consolidation Stress: 7.50 ksf
Water Content: 13.3 % Dry Unit Weight: 125.5 pcf
Deformation Rate: 0.00078 inch/min.
Peak Shear Strength: 5.38 ksf @ 0.06 inch deformation
Peak Effective Friction Angle: 35.6°, cohesion = 0.0ksf
Final Shear Strength: 4.29 ksf @ 0.29 inch deformation
Final Effective Friction Angle: 29.8° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B015 Sample: ST-3 Specimen: C Depth: 60.75 ft	November 15



SAMPLE INFORMATION

Boring: NEW-B015 Sample: ST-3 Specimen: D Depth: 61.05 ft
Type: Intact tube sample

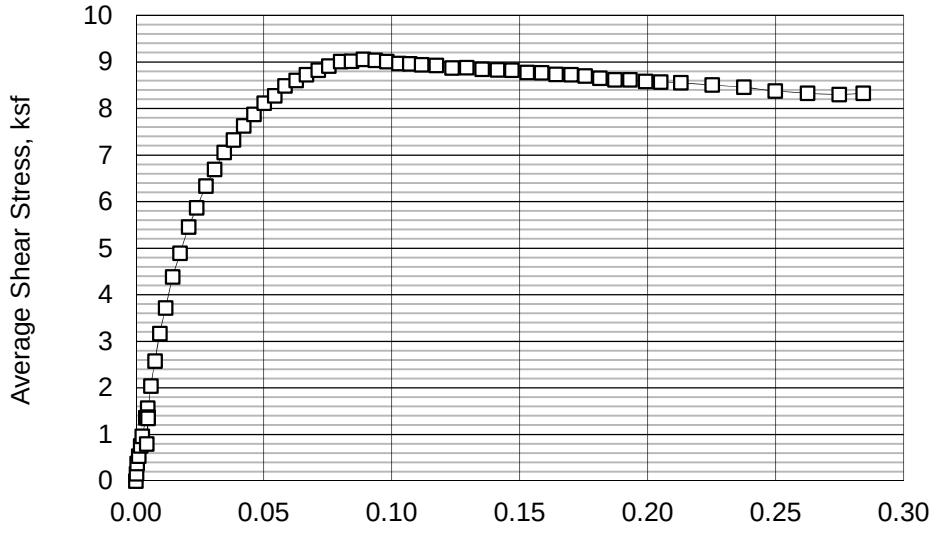
SPECIMEN INFORMATION (Initial)

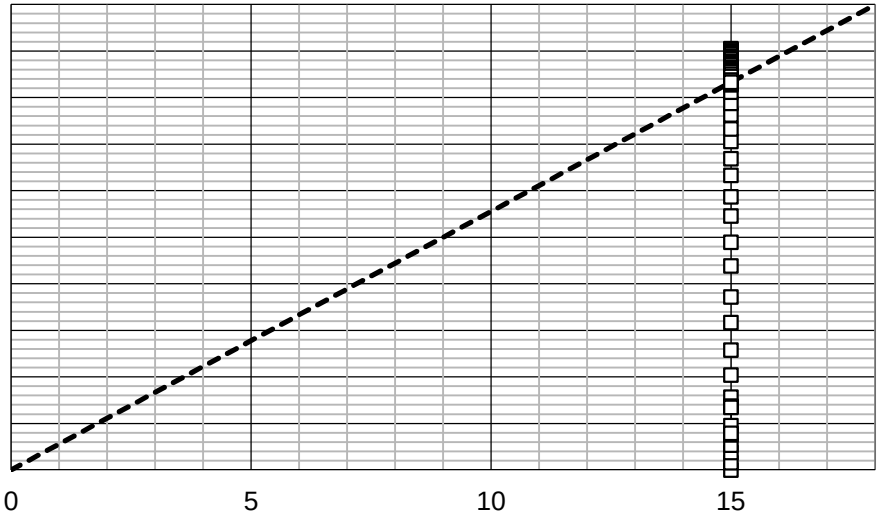
Description: CL, brown clay with sand
Height: 1.02 inch Diameter: 2.50 inch Area: 4.91 in²
Water Content: 12.7 % Dry Unit Weight: 124.1 pcf

TEST SUMMARY

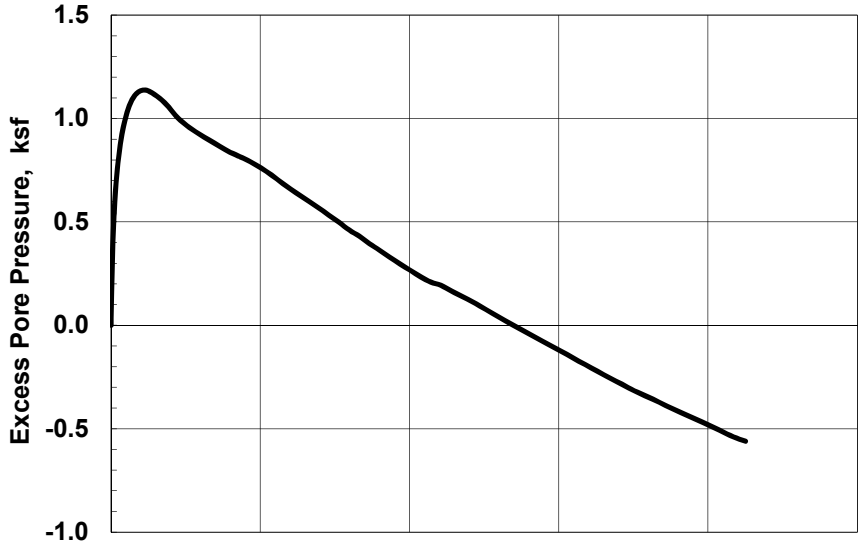
Vertical Consolidation Stress: 15.00 ksf
Water Content: 12.0 % Dry Unit Weight: 126.2 pcf
Deformation Rate: 0.00066 inch/min.
Peak Shear Strength: 9.05 ksf @ 0.09 inch deformation
Peak Effective Friction Angle: 31.1°, cohesion = 0.0ksf
Final Shear Strength: 8.33 ksf @ 0.28 inch deformation
Final Effective Friction Angle: 29.0° (Shown)

REMARKS:





	AECOM 60428794	Dynegy CCR - Newton	**DRAINED DIRECT SHEAR** **TEST SUMMARY**	
Prepared by: MHC Checked by: GET	**TerraSense, LLC**	T60428794	Boring: NEW-B015 Sample: ST-3 Specimen: D Depth: 61.05 ft	November 15

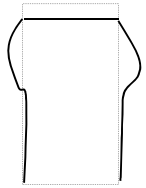


SAMPLE INFORMATION

Boring: NEW-B001 Sample: ST-5 Depth: 10.75 ft
Type: Intact tube sample
Description: CH, gray fat clay
LL = 50 PL = 14 PI = 36

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.88 inch Area: 6.51 in²
Water Content: 18.1 % Total Unit Weight: 132.6 pcf

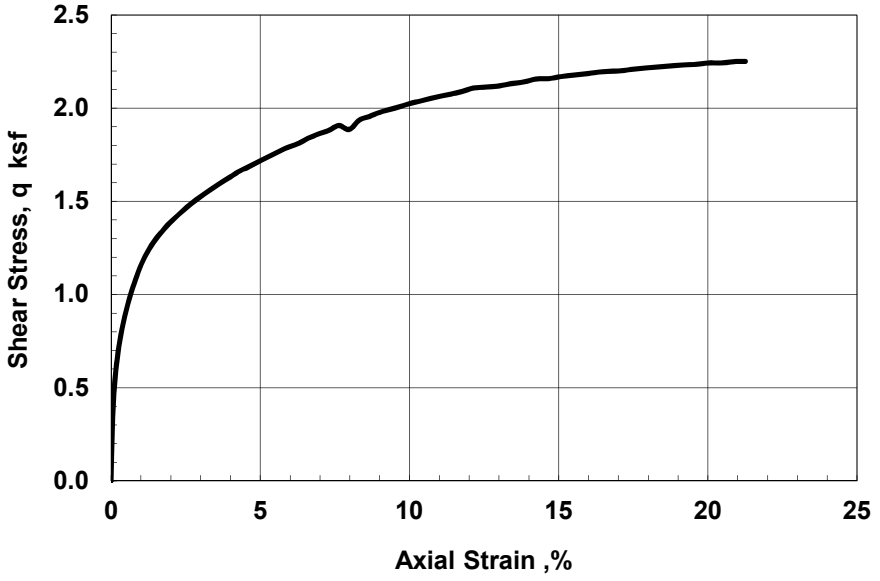


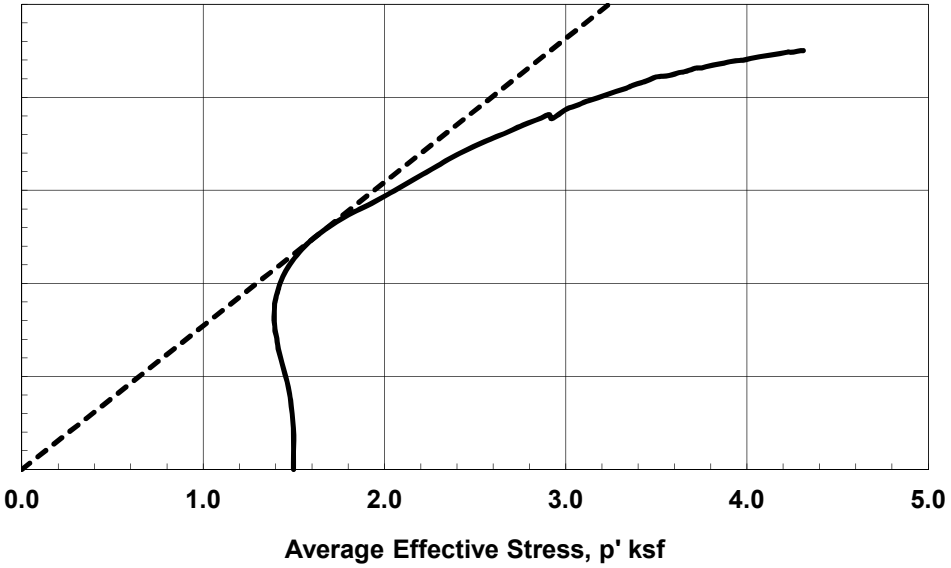
Failure Sketch

TEST SUMMARY

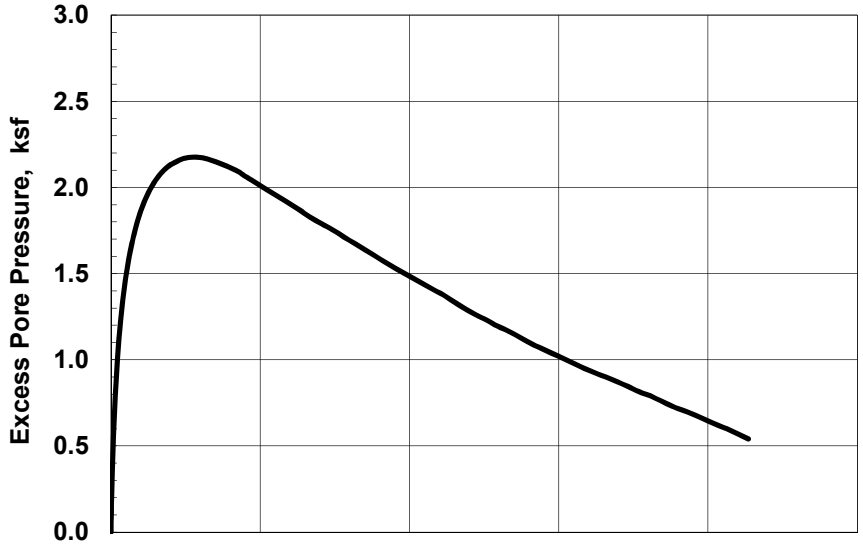
Consolidation Stresses: 1.50 ksf vertical, 1.50 ksf lateral
Water Content: 19.1 % Total Unit Weight: 133.4 pcf
B Coefficient: 99.6 Strain Rate: 0.021 %/min
Peak Shear Strength: 2.25 ksf @ 21.3 % Strain
Peak Effective Friction Angle: 50.5°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B001 Sample: ST-5 — November-15



SAMPLE INFORMATION

Boring: NEW-B001 Sample: ST-7B Depth: 21.1 ft
Type: Intact tube sample
Description: CL, gray brown sandy lean clay
LL = 49 PL = 13 PI = 36

SPECIMEN INFORMATION (Initial)

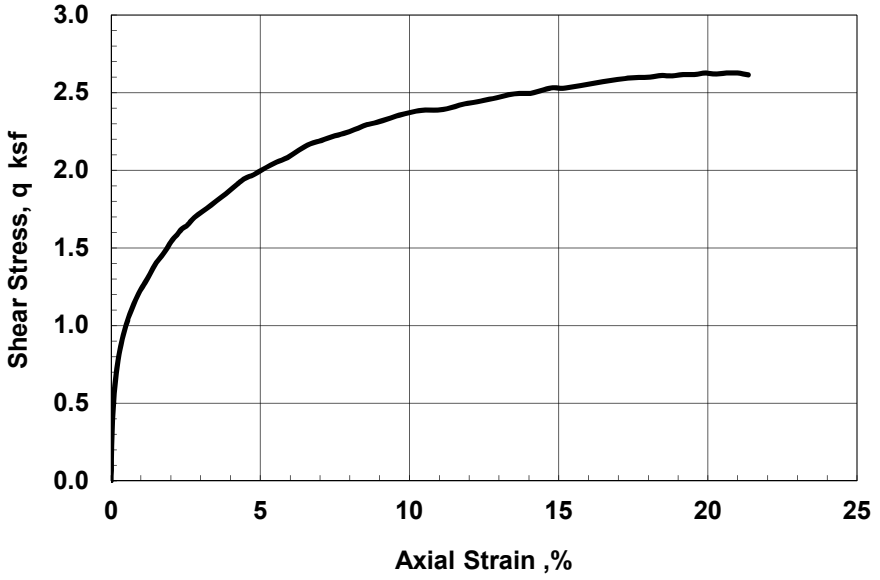
Height: 6.00 inch Diameter: 2.88 inch Area: 6.51 in²
Water Content: 16.2 % Total Unit Weight: 134.5 pcf

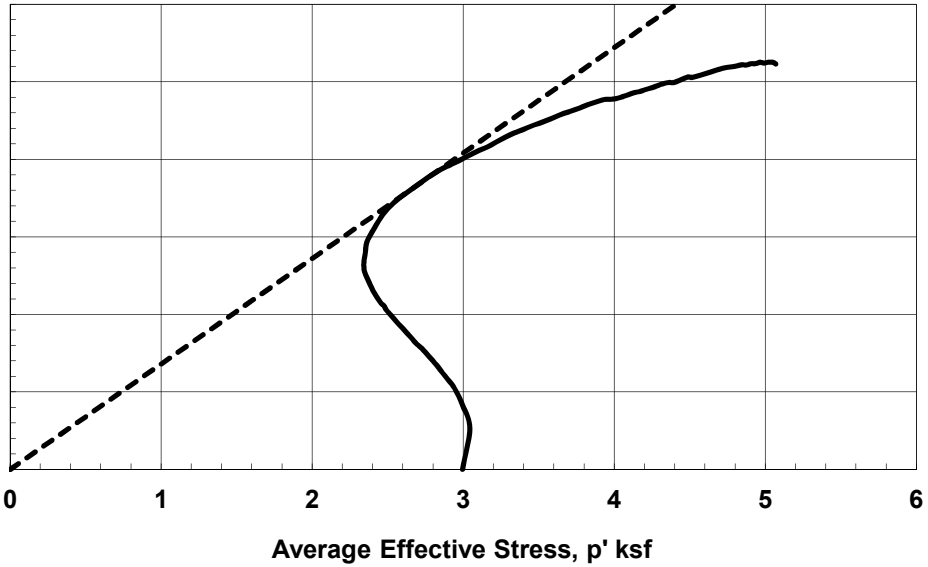
TEST SUMMARY

Consolidation Stresses: 3.00 ksf vertical, 3.00 ksf lateral
Water Content: 17.0 % Total Unit Weight: 136.5 pcf
B Coefficient: 99.14 Strain Rate: 0.023 %/min
Peak Shear Strength: 2.63 ksf @ 20.6 % Strain
Peak Effective Friction Angle: 42.9°

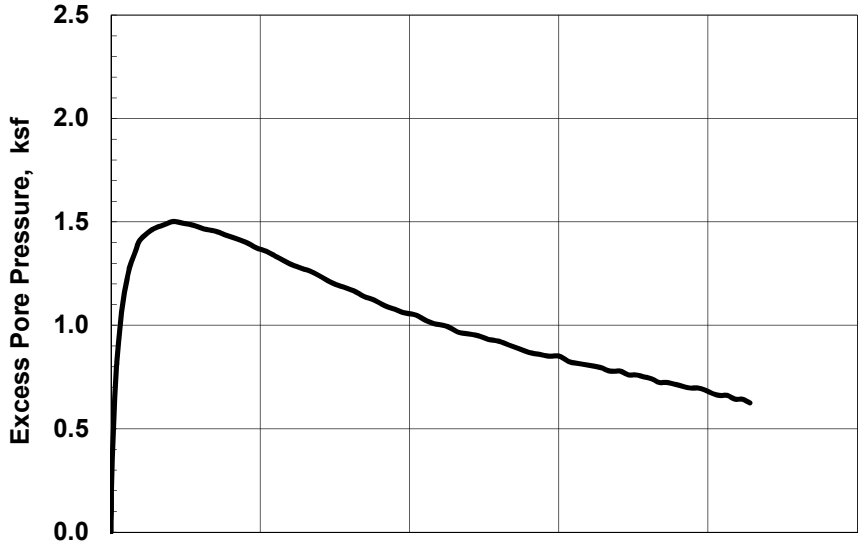
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B001 Sample: ST-7B	November-15



SAMPLE INFORMATION

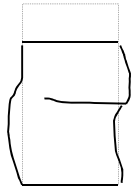
Boring: NEW-B003 Sample: ST-1C Depth: 15.35 ft
Type: Intact tube sample
Description: CH, gray brown fat clay with sand
LL = 59 PL = 15 PI = 44

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.87 inch Area: 6.49 in²
Water Content: 20.9 % Total Unit Weight: 129.5 pcf

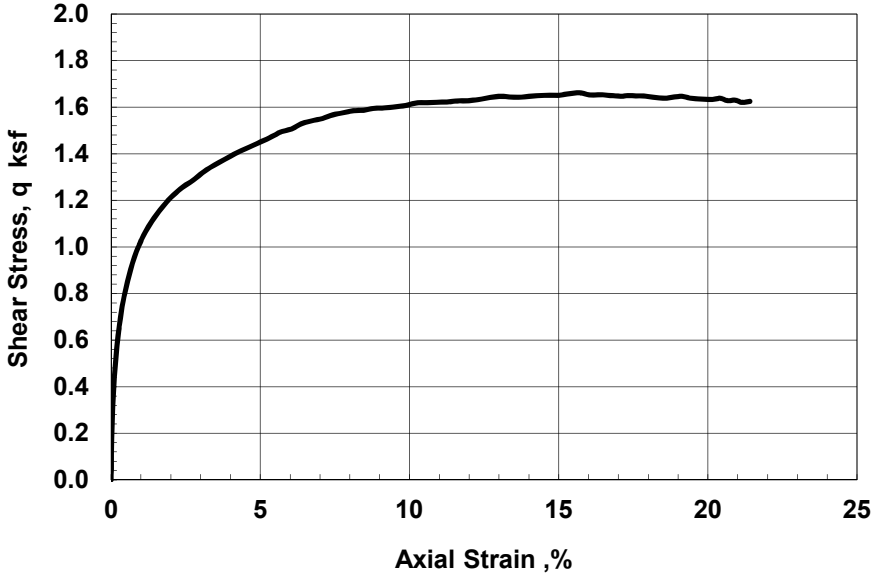
TEST SUMMARY

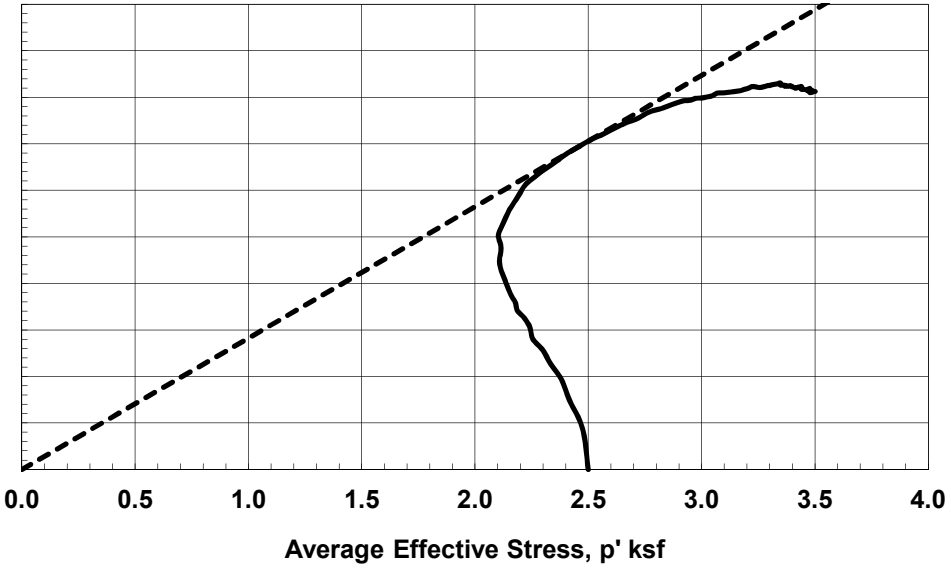
Consolidation Stresses: 2.50 ksf vertical, 2.50 ksf lateral
Water Content: 21.1 % Total Unit Weight: 131.8 pcf
B Coefficient: 99.52 Strain Rate: 0.021 %/min
Peak Shear Strength: 1.66 ksf @ 15.7 % Strain
Peak Effective Friction Angle: 34.4°



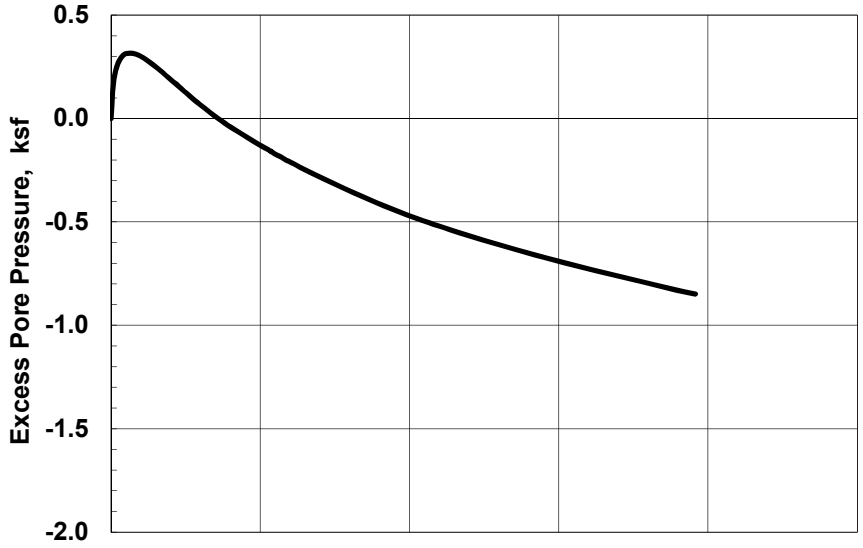
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B003 Sample: ST-1C	November-15



SAMPLE INFORMATION

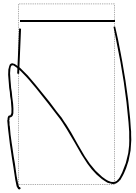
Boring: NEW-B004 Sample: ST-4 Depth: 9.5 ft
Type: Intact tube sample
Description: CH, gray fat clay with sand
LL = 50 PL = 13 PI = 37

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.88 inch Area: 6.52 in²
Water Content: 18.5 % Total Unit Weight: 131.3 pcf

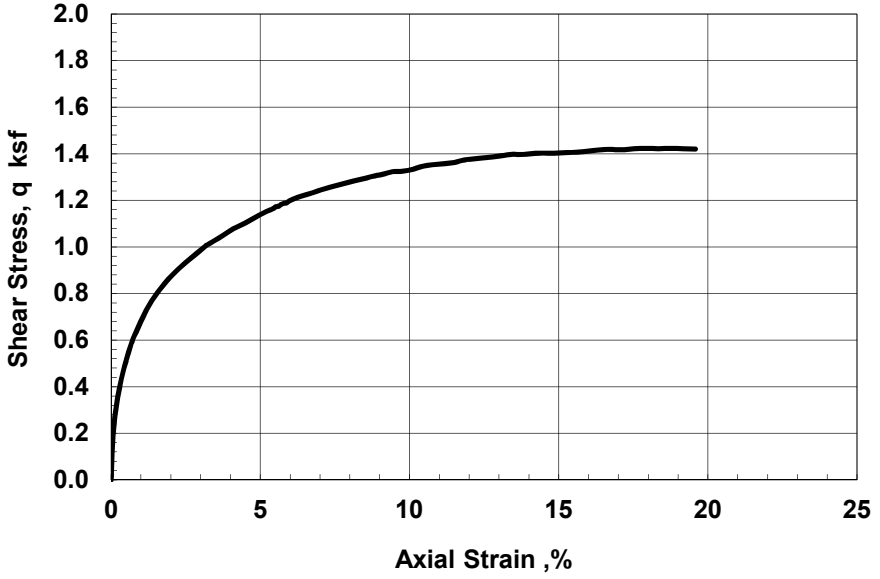
TEST SUMMARY

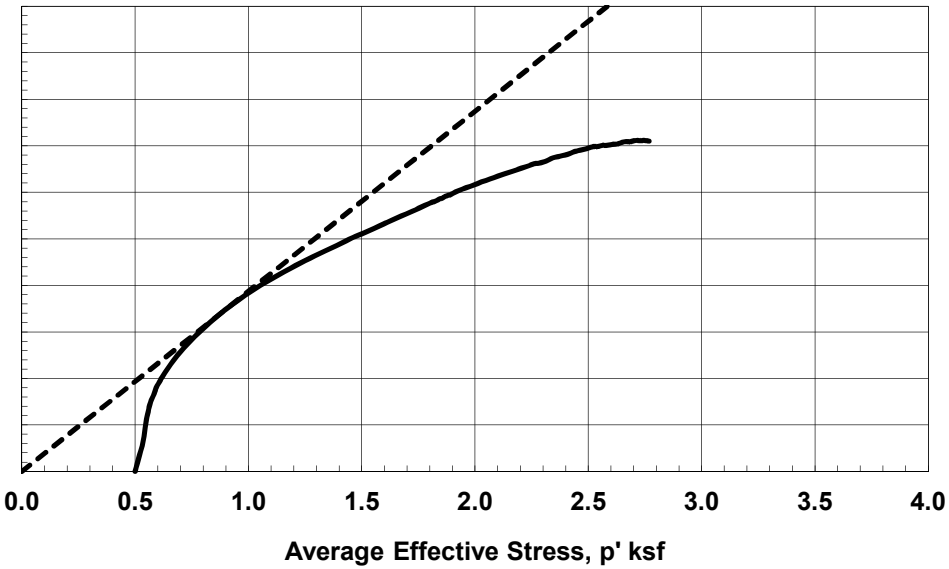
Consolidation Stresses: 0.50 ksf vertical, 0.50 ksf lateral
Water Content: 19.7 % Total Unit Weight: 132.6 pcf
B Coefficient: 99 Strain Rate: 0.022 %/min
Peak Shear Strength: 1.42 ksf @ 17.9 % Strain
Peak Effective Friction Angle: 50.7°



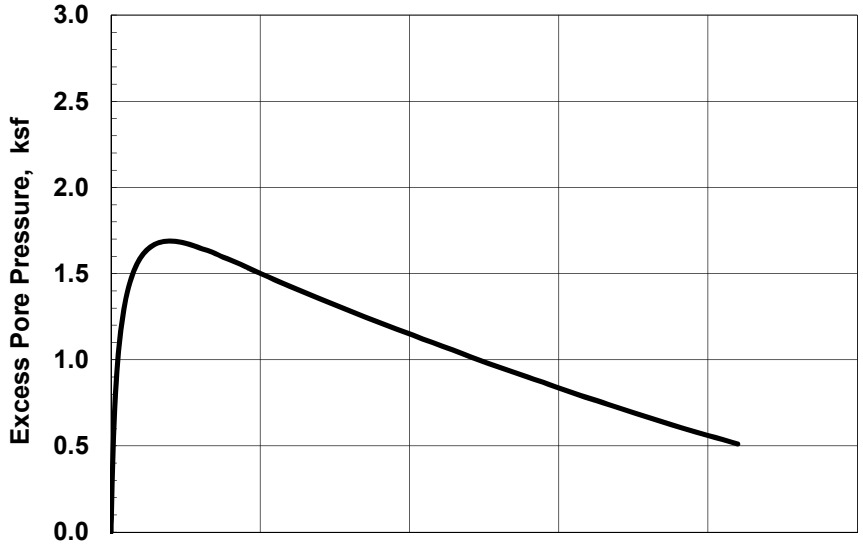
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B004 Sample: ST-4 — November-15

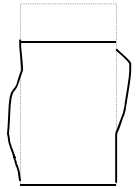


SAMPLE INFORMATION

Boring: NEW-B004 Sample: ST-7C Depth: 19.35 ft
Type: Intact tube sample
Description: CH, gray brown fat clay with sand
LL = 52 PL = 15 PI = 37

SPECIMEN INFORMATION (Initial)

Height: 6.01 inch Diameter: 2.88 inch Area: 6.50 in²
Water Content: 18.3 % Total Unit Weight: 128.5 pcf

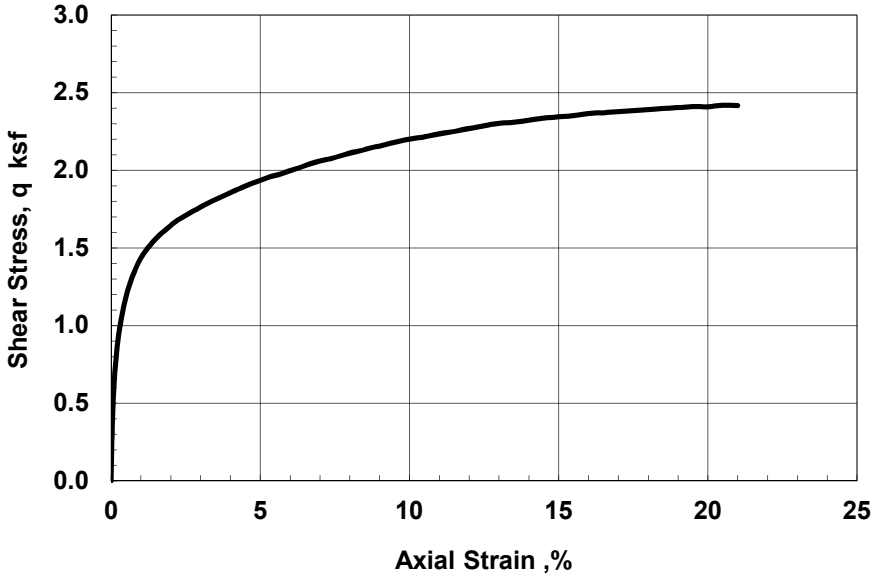


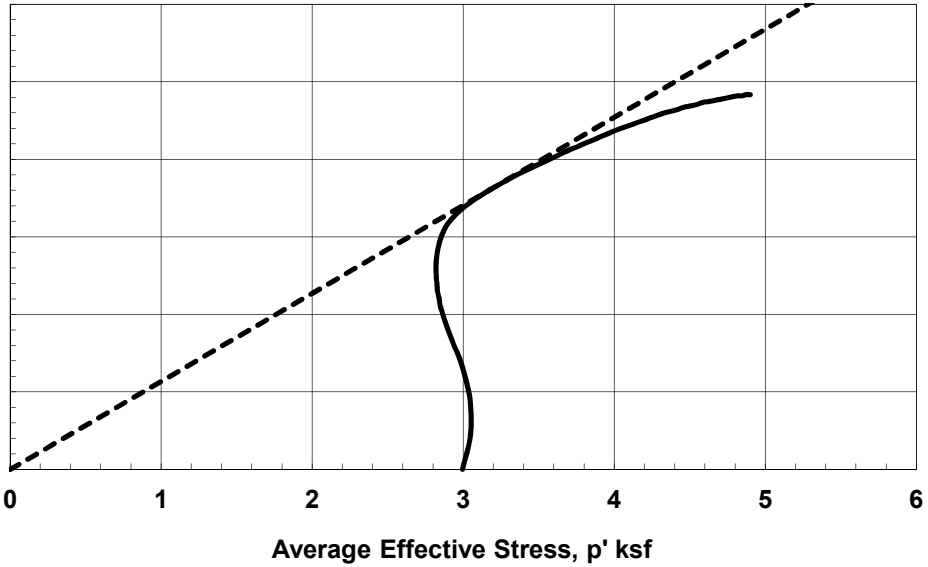
Failure Sketch

TEST SUMMARY

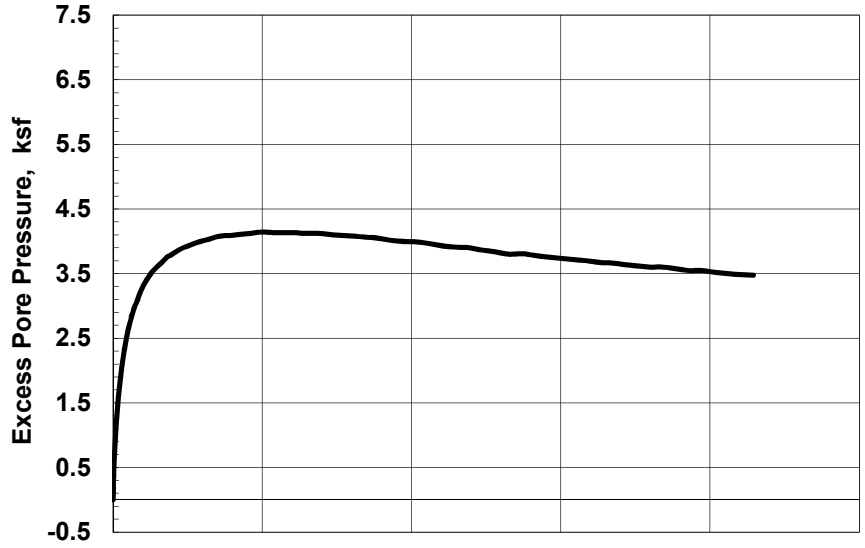
Consolidation Stresses: 3.00 ksf vertical, 3.00 ksf lateral
Water Content: 19.6 % Total Unit Weight: 133.7 pcf
B Coefficient: 99.56 Strain Rate: 0.021 %/min
Peak Shear Strength: 2.42 ksf @ 20.5 % Strain
Peak Effective Friction Angle: 34.6°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B004 Sample: ST-7C
			November-15



SAMPLE INFORMATION

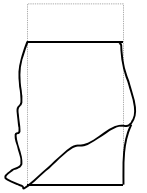
Boring: NEW-B006 Sample: ST-2 Depth: 26.75 ft
Type: Intact tube sample
Description: CL, gray sandy clay
LL = 44 PL = 12 PI = 32

SPECIMEN INFORMATION (Initial)

Height: 6.01 inch Diameter: 2.88 inch Area: 6.52 in²
Water Content: 19.7 % Total Unit Weight: 128.8 pcf

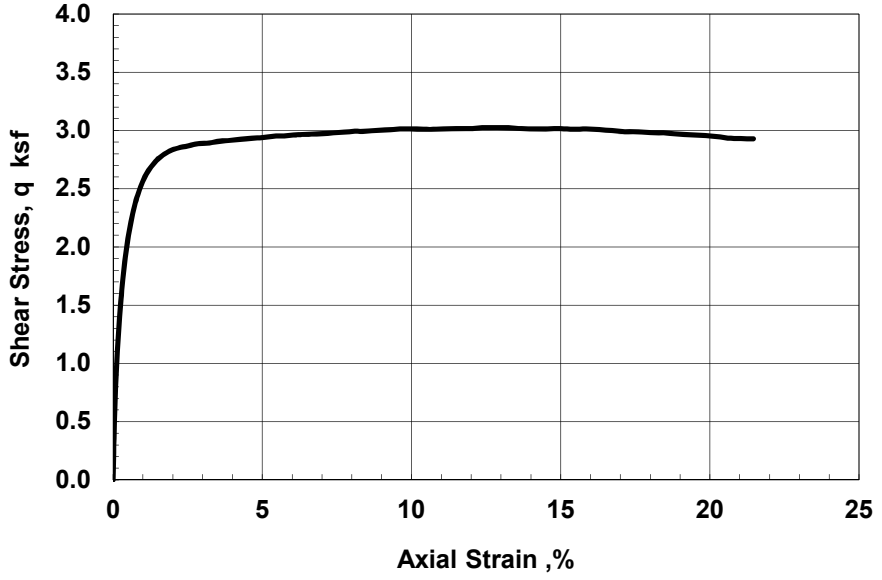
TEST SUMMARY

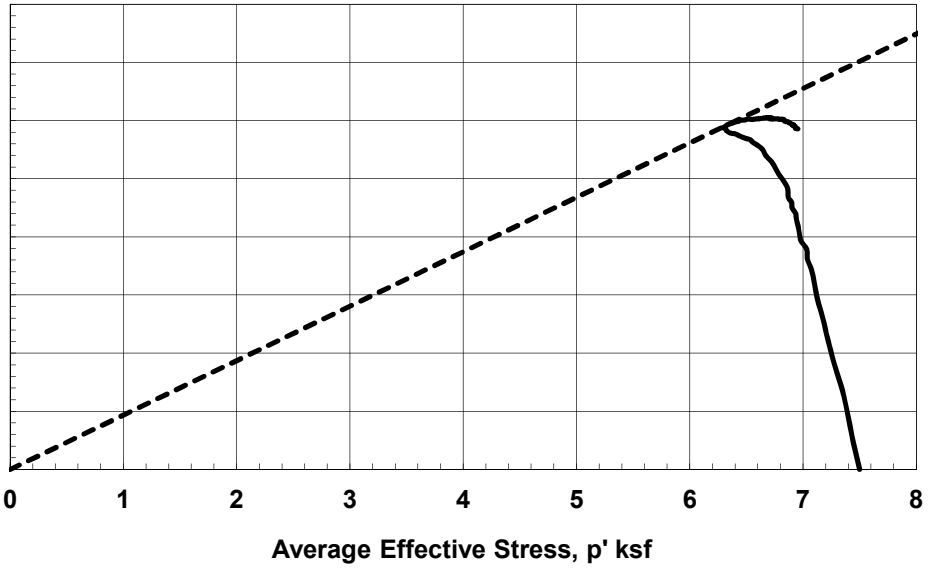
Consolidation Stresses: 7.50 ksf vertical, 7.50 ksf lateral
Water Content: 18.2 % Total Unit Weight: 134.6 pcf
B Coefficient: 97.7 Strain Rate: 0.022 %/min
Peak Shear Strength: 3.03 ksf @ 12.8 % Strain
Peak Effective Friction Angle: 27.9°



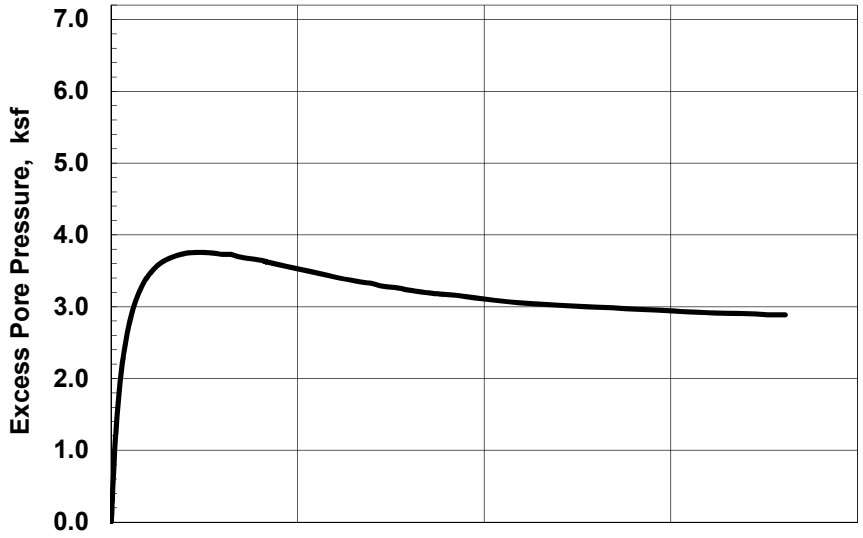
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B006 Sample: ST-2 — November-15

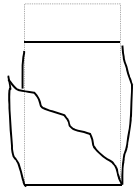


SAMPLE INFORMATION

Boring: NEW-B006 Sample: ST-3C Depth: 31.8 ft
Type: Intact tube sample
Description: CL, dark brown sandy lean clay
LL = 37 PL = 15 PI = 22

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.88 inch Area: 6.52 in²
Water Content: 18.3 % Total Unit Weight: 133.3 pcf

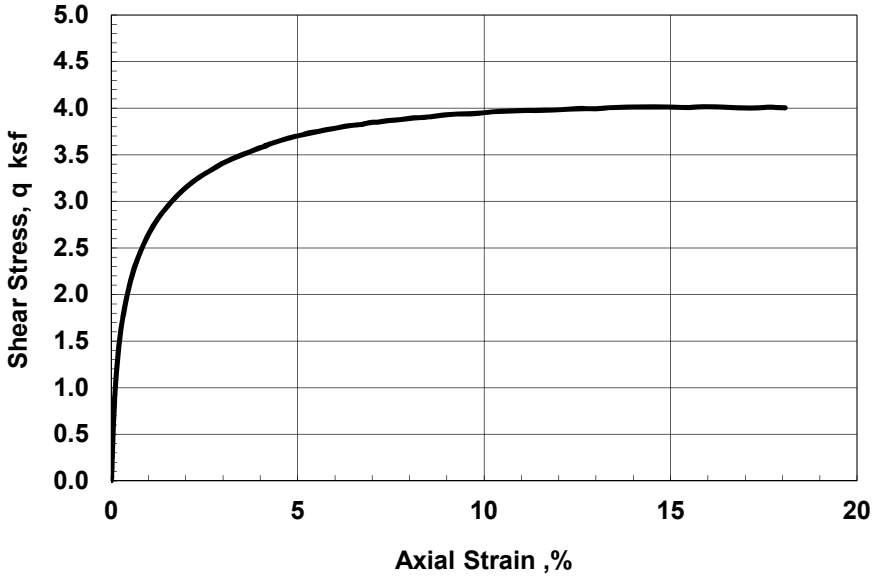


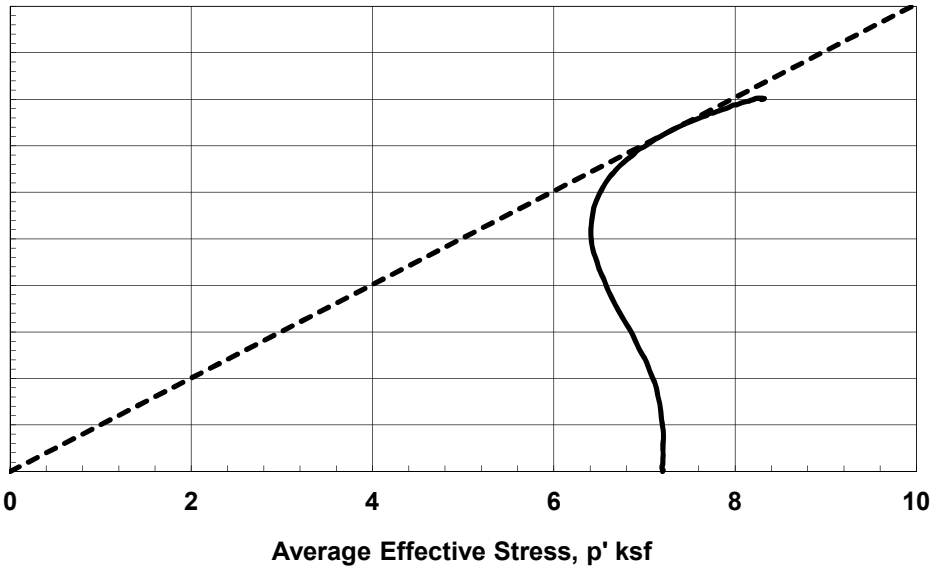
Failure Sketch

TEST SUMMARY

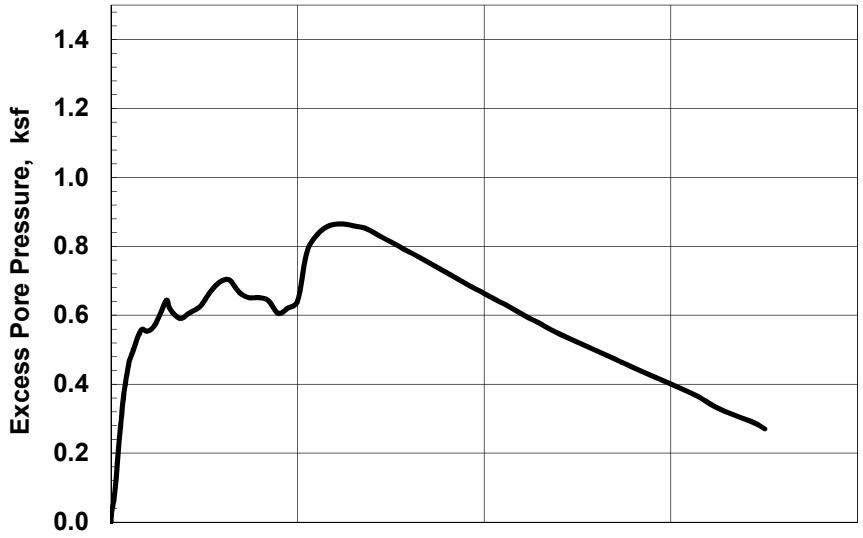
Consolidation Stresses: 7.20 ksf vertical, 7.20 ksf lateral
Water Content: 17.0 % Total Unit Weight: 138.2 pcf
B Coefficient: Strain Rate: 0.019 %/min
Peak Shear Strength: 4.01 ksf @ 14.8 % Strain
Peak Effective Friction Angle: 30.2°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B006 Sample: ST-3C — November-15

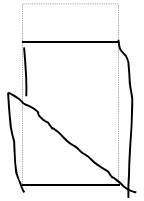


SAMPLE INFORMATION

Boring: NEW-C006 Sample: ST-1B Depth: 11.3 ft
Type: Intact tube sample
Description: CH, brown fat clay with sand
LL = 54 PL = 16 PI = 38

SPECIMEN INFORMATION (Initial)

Height: 6.03 inch Diameter: 2.87 inch Area: 6.48 in²
Water Content: 25.2 % Total Unit Weight: 124.1 pcf

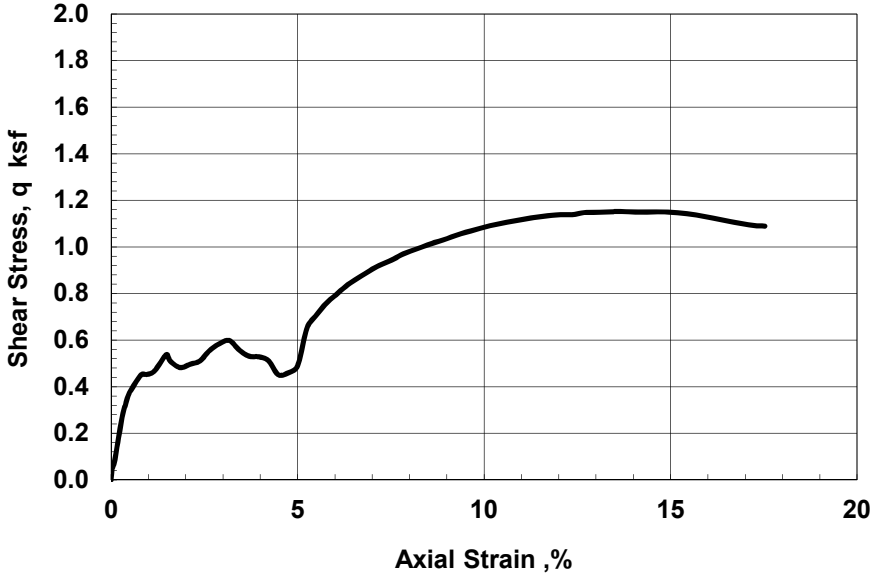


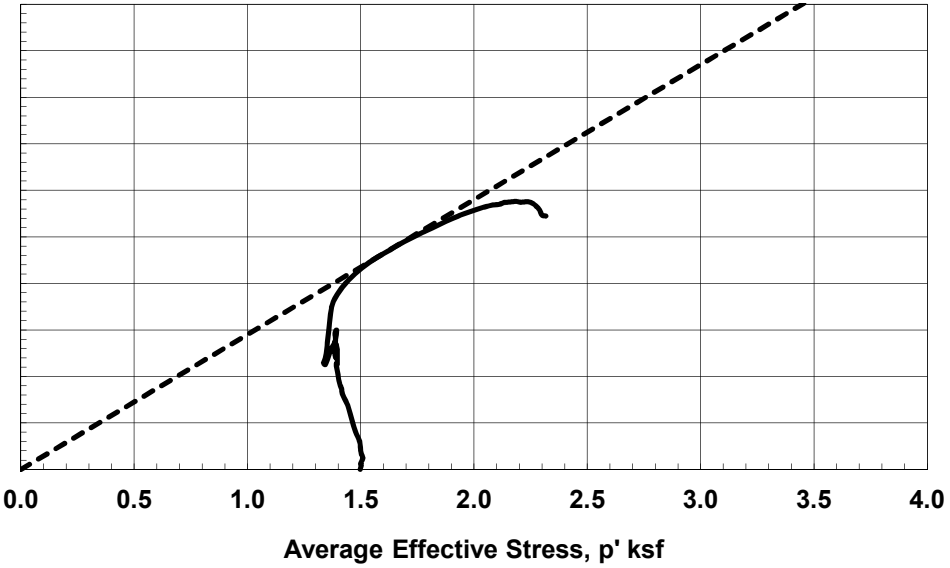
Failure Sketch

TEST SUMMARY

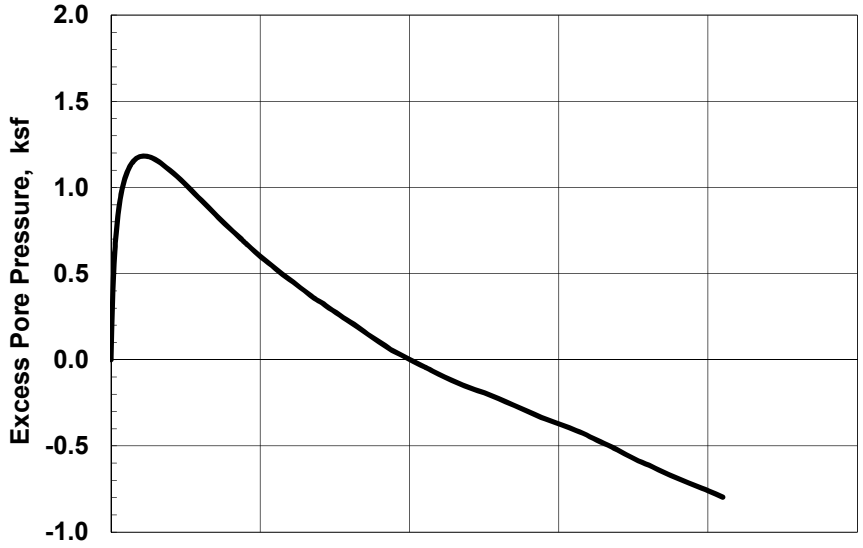
Consolidation Stresses: 1.50 ksf vertical, 1.50 ksf lateral
Water Content: 25.0 % Total Unit Weight: 127.5 pcf
B Coefficient: Strain Rate: 0.021 %/min
Peak Shear Strength: 1.15 ksf @ 13.7 % Strain
Peak Effective Friction Angle: 35.5°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-C006 Sample: ST-1B
			November-15



SAMPLE INFORMATION

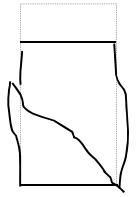
Boring: NEW-C006 Sample: ST-2B Depth: 13 ft
Type: Intact tube sample
Description: CH, brown fat clay
LL = 53 PL = 14 PI = 39

SPECIMEN INFORMATION (Initial)

Height: 6.02 inch Diameter: 2.88 inch Area: 6.49 in²
Water Content: 18.9 % Total Unit Weight: 131.5 pcf

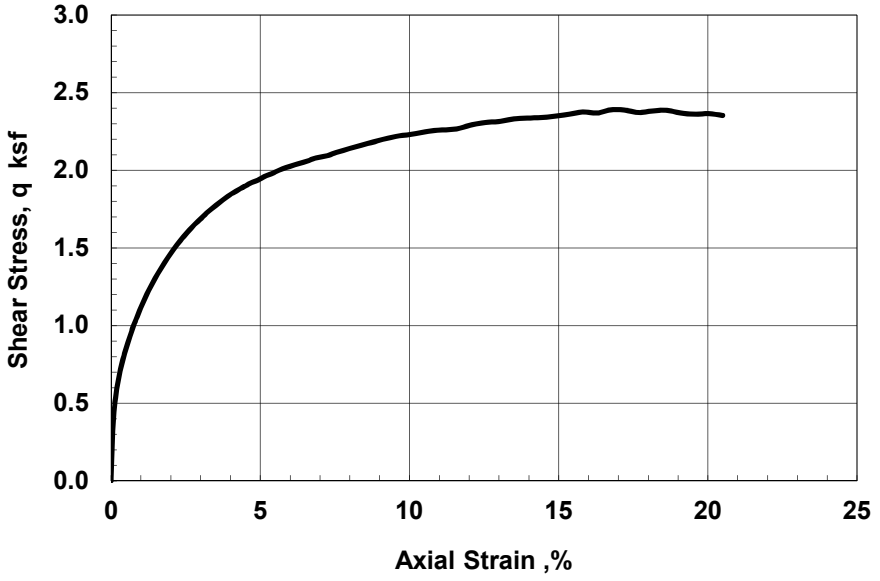
TEST SUMMARY

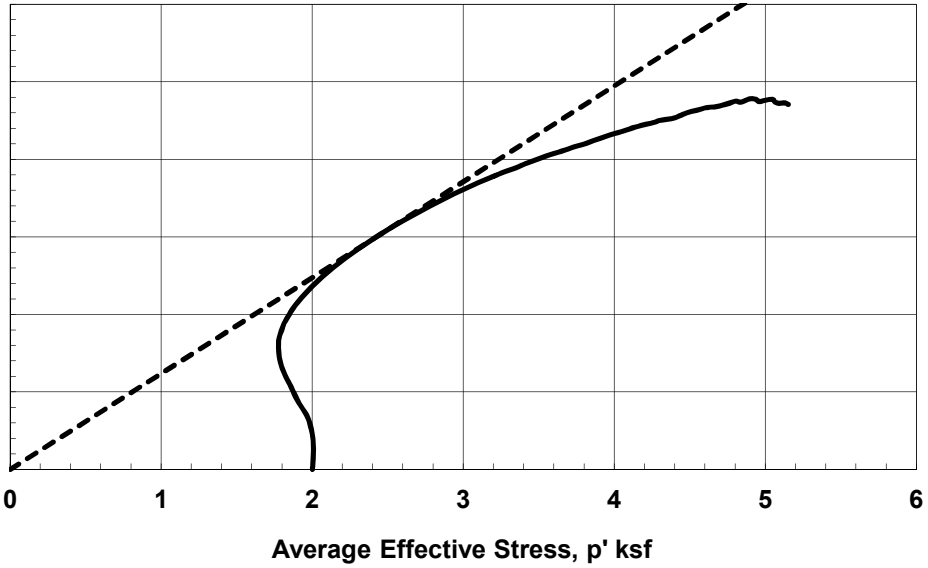
Consolidation Stresses: 2.00 ksf vertical, 2.00 ksf lateral
Water Content: 19.4 % Total Unit Weight: 134.0 pcf
B Coefficient: Strain Rate: 0.020 %/min
Peak Shear Strength: 2.39 ksf @ 16.7 % Strain
Peak Effective Friction Angle: 38.2°



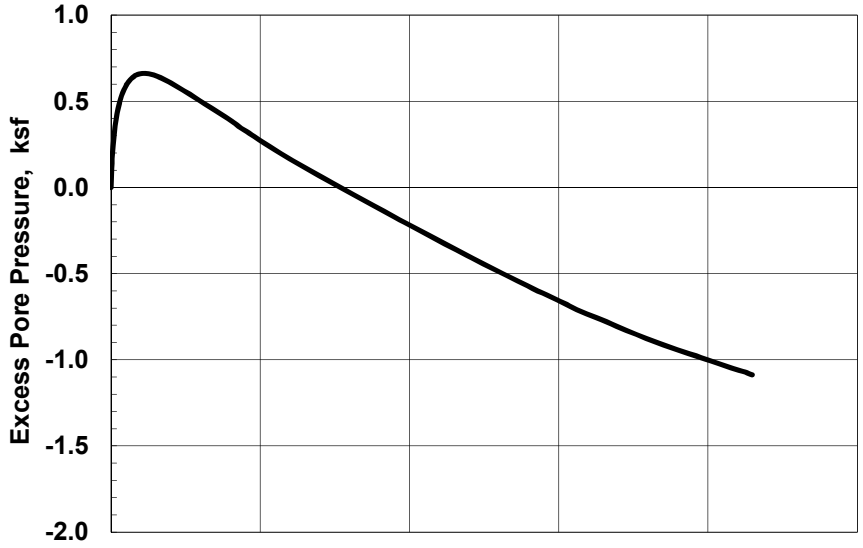
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-C006 Sample: ST-2B	November-15



SAMPLE INFORMATION

Boring: NEW-B007 Sample: ST-1C Depth: 11.55 ft
Type: Intact tube sample
Description: CL, brown lean clay with sand
LL = 38 PL = 14 PI = 24

SPECIMEN INFORMATION (Initial)

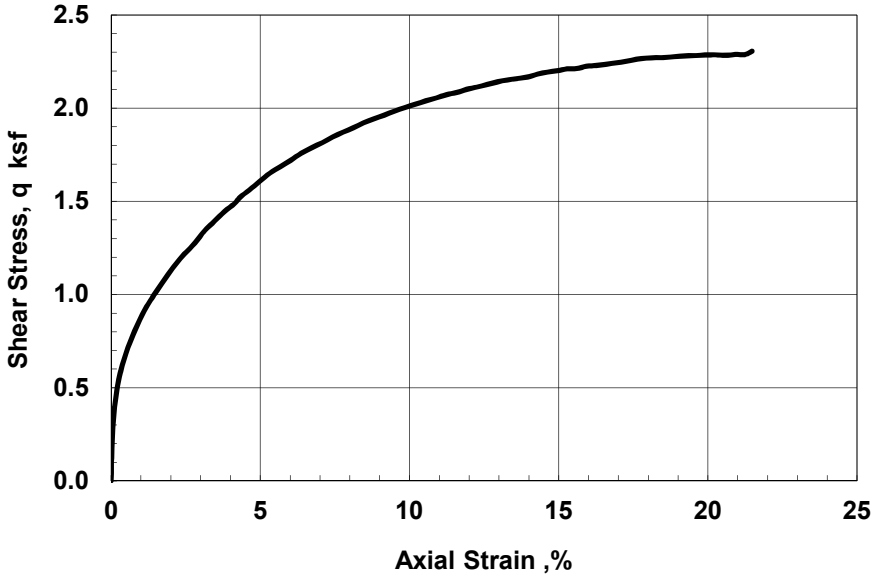
Height: 6.01 inch Diameter: 2.88 inch Area: 6.51 in²
Water Content: 15.4 % Total Unit Weight: 135.1 pcf

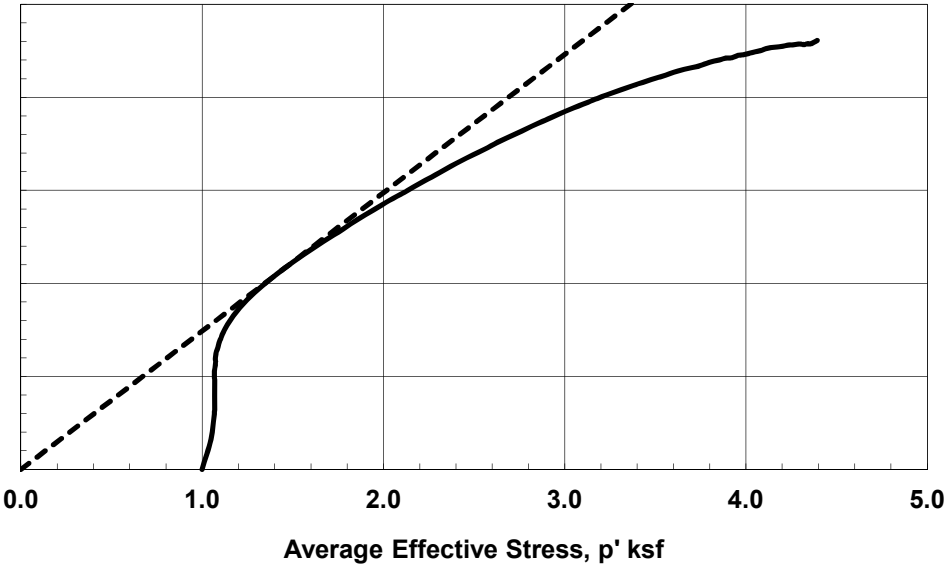
TEST SUMMARY

Consolidation Stresses: 1.00 ksf vertical, 1.00 ksf lateral
Water Content: 15.9 % Total Unit Weight: 137.7 pcf
B Coefficient: 99.2 Strain Rate: 0.021 %/min
Peak Shear Strength: 2.31 ksf @ 21.5 % Strain
Peak Effective Friction Angle: 48.0°

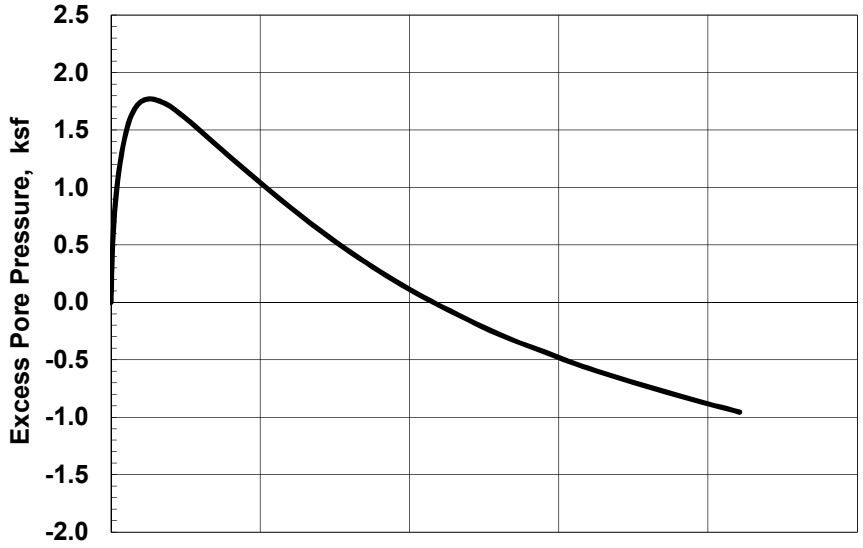
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B007 Sample: ST-1C	November-15



SAMPLE INFORMATION

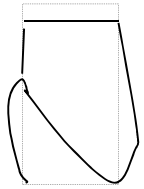
Boring: NEW-B007 Sample: ST-2 Depth: 21 ft
Type: Intact tube sample
Description: CL, brown sandy lean clay
LL = 30 PL = 13 PI = 17

SPECIMEN INFORMATION (Initial)

Height: 5.99 inch Diameter: 2.88 inch Area: 6.50 in²
Water Content: 12.1 % Total Unit Weight: 140.5 pcf

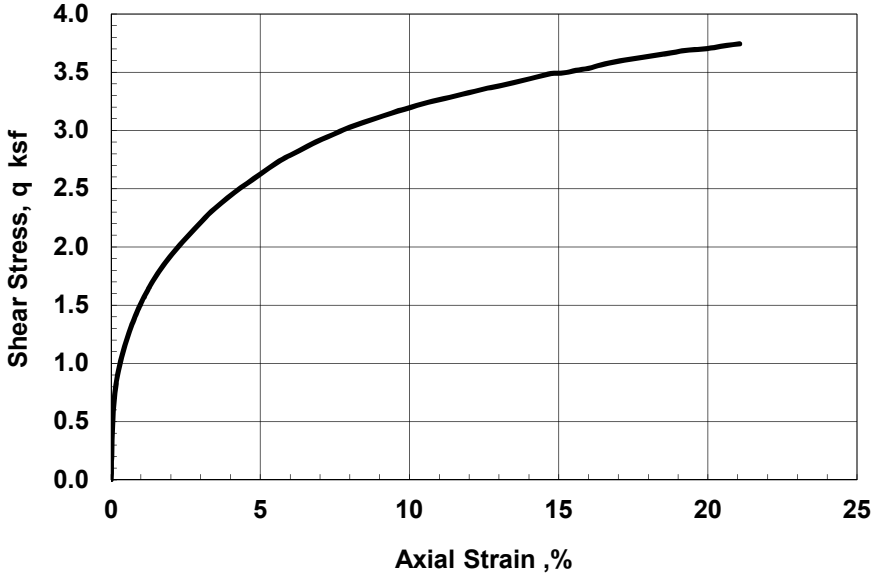
TEST SUMMARY

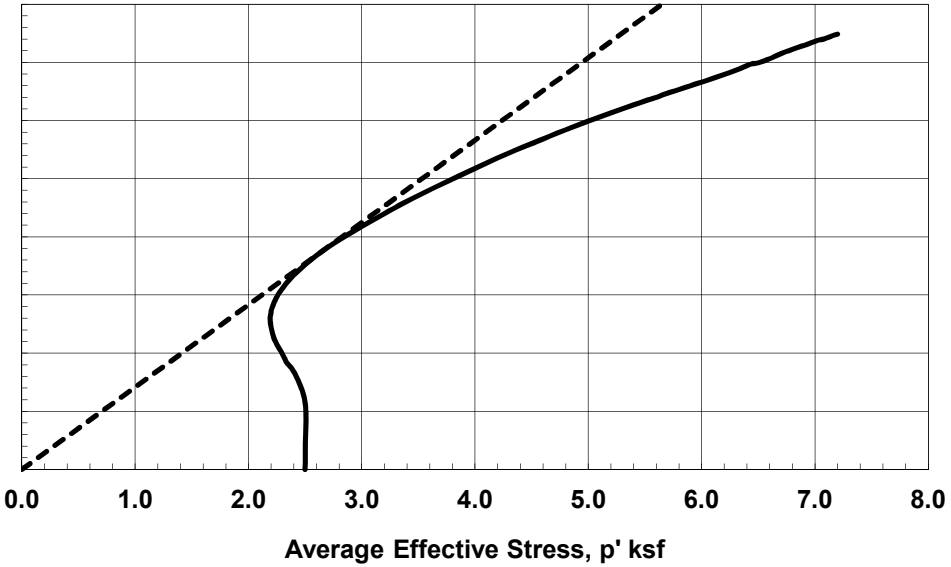
Consolidation Stresses: 2.50 ksf vertical, 2.50 ksf lateral
Water Content: 12.5 % Total Unit Weight: 142.9 pcf
B Coefficient: 99.62 Strain Rate: 0.021 %/min
Peak Shear Strength: 3.74 ksf @ 21.1 % Strain
Peak Effective Friction Angle: 45.1°



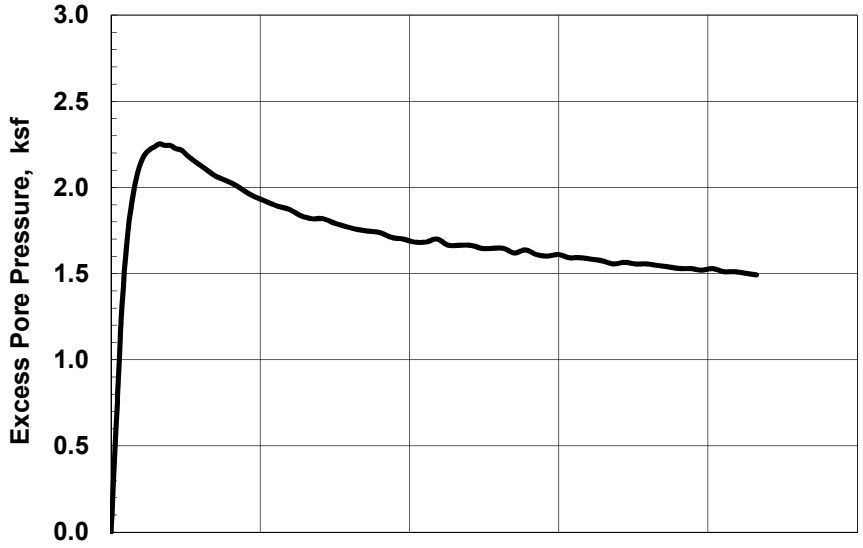
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B007 Sample: ST-2	November-15

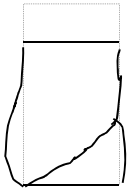


SAMPLE INFORMATION

Boring: NEW-B009 Sample: ST-2B Depth: 30 ft
Type: Intact tube sample
Description: CL, yellowish brown lean clay with sand
LL = 31 PL = 14 PI = 17

SPECIMEN INFORMATION (Initial)

Height: 5.96 inch Diameter: 2.89 inch Area: 6.55 in²
Water Content: 16.7 % Total Unit Weight: 132.6 pcf

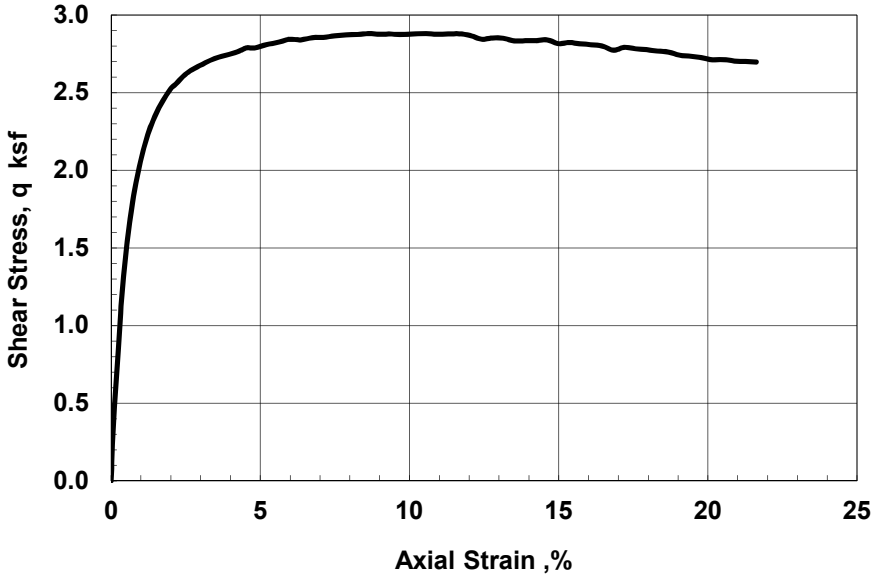


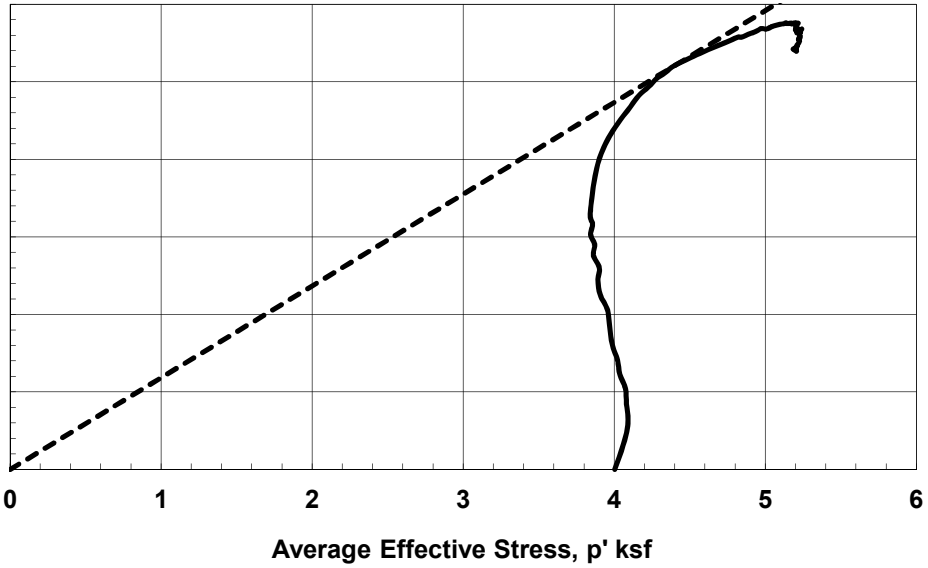
Failure Sketch

TEST SUMMARY

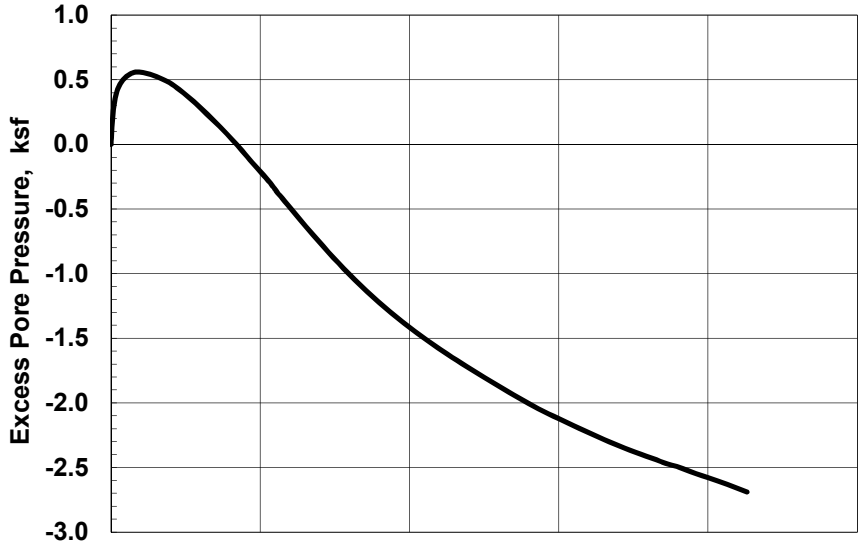
Consolidation Stresses: 4.00 ksf vertical, 4.00 ksf lateral
Water Content: 17.1 % Total Unit Weight: 136.8 pcf
B Coefficient: 98.02 Strain Rate: 0.023 %/min
Peak Shear Strength: 2.88 ksf @ 10.5 % Strain
Peak Effective Friction Angle: 36.3°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B009 Sample: ST-2B	November-15



SAMPLE INFORMATION

Boring: NEW-B010 Sample: ST-1C Depth: 6.3 ft
Type: Intact tube sample
Description: CL, brown lean clay with sand
LL = 24 PL = 13 PI = 11

SPECIMEN INFORMATION (Initial)

Height: 6.05 inch Diameter: 2.88 inch Area: 6.51 in²
Water Content: 10.2 % Total Unit Weight: 140.5 pcf

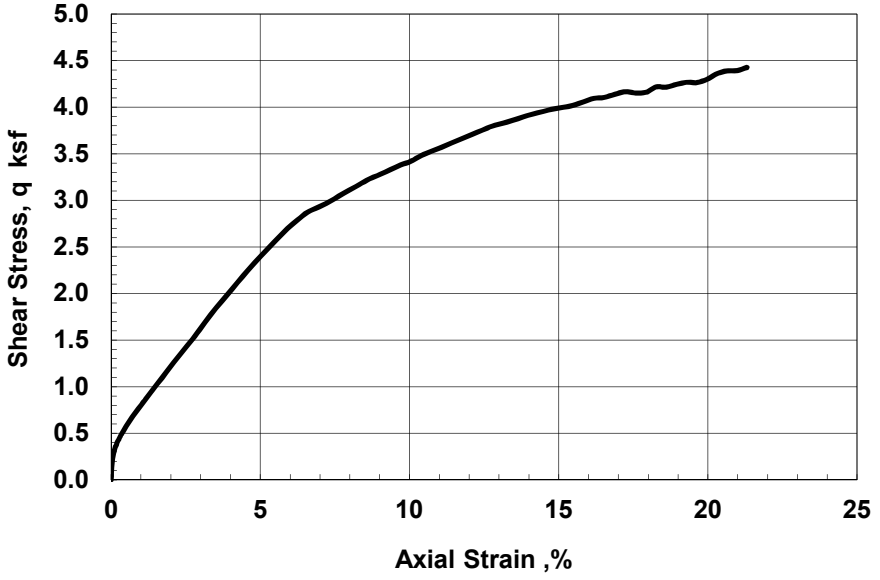
TEST SUMMARY

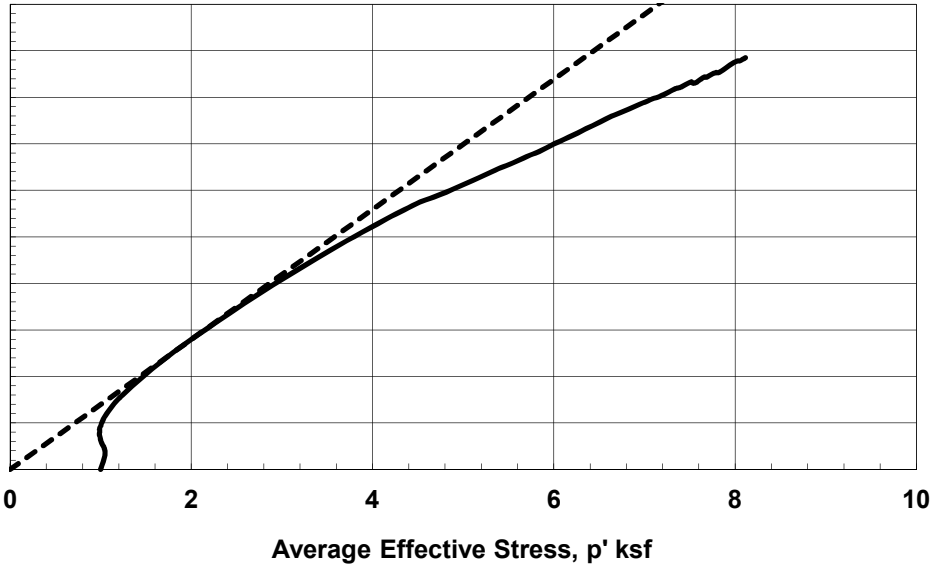
Consolidation Stresses: 1.00 ksf vertical, 1.00 ksf lateral
Water Content: 11.6 % Total Unit Weight: 145.2 pcf
B Coefficient: 98.32 Strain Rate: 0.021 %/min
Peak Shear Strength: 4.43 ksf @ 21.3 % Strain
Peak Effective Friction Angle: 44.4°



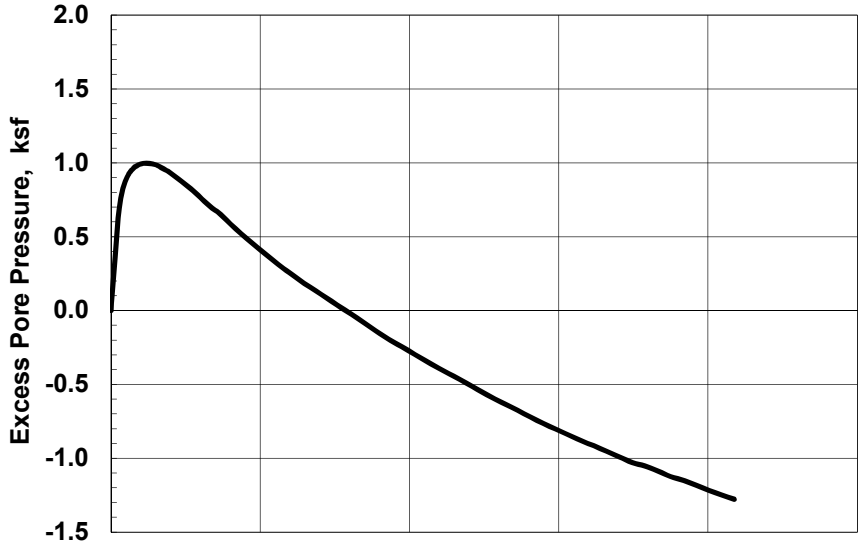
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B010 Sample: ST-1C
			November-15

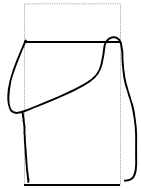


SAMPLE INFORMATION

Boring: NEW-B010 Sample: ST-2 Depth: 16.5 ft
Type: Intact tube sample
Description: CL, yellowish brown lean clay with sand, some m-f gravel
LL = 33 PL = 13 PI = 20

SPECIMEN INFORMATION (Initial)

Height: 6.02 inch Diameter: 2.88 inch Area: 6.53 in²
Water Content: 13.8 % Total Unit Weight: 137.3 pcf

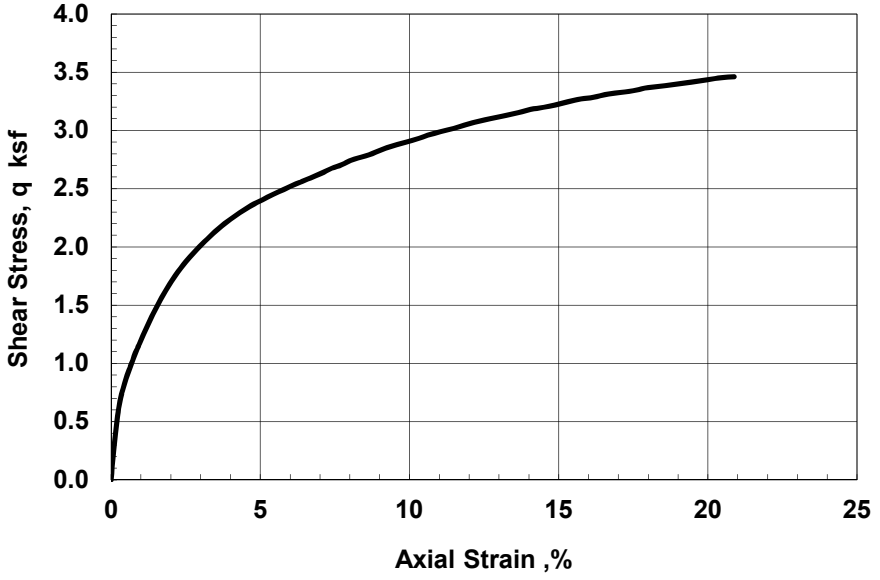


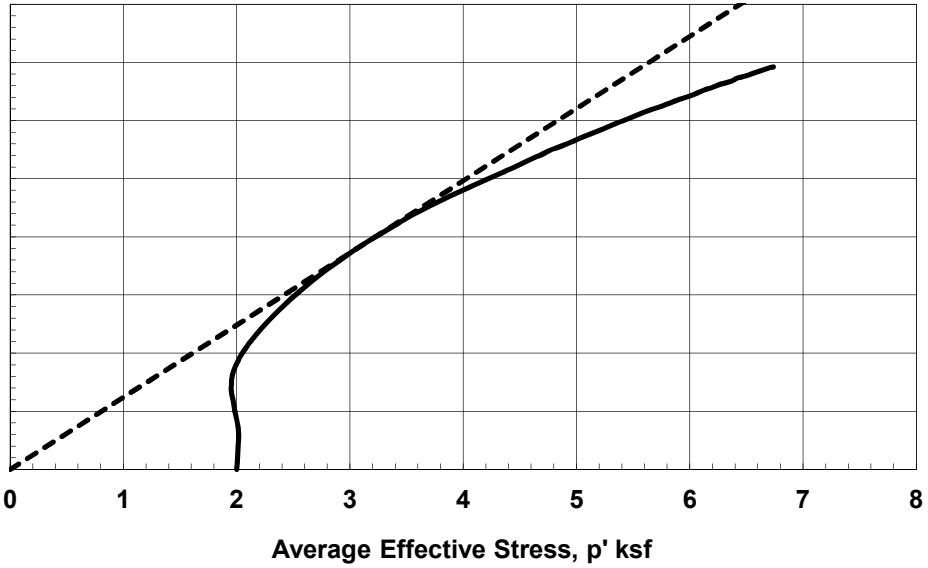
Failure Sketch

TEST SUMMARY

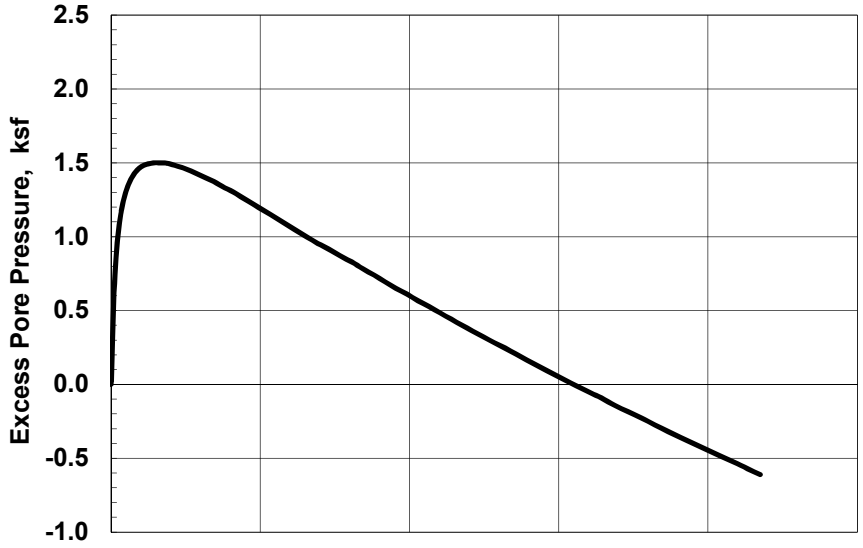
Consolidation Stresses: 2.00 ksf vertical, 2.00 ksf lateral
Water Content: 14.7 % Total Unit Weight: 139.5 pcf
B Coefficient: 99.6 Strain Rate: 0.022 %/min
Peak Shear Strength: 3.46 ksf @ 20.9 % Strain
Peak Effective Friction Angle: 38.4°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B010 Sample: ST-2 November-15



SAMPLE INFORMATION

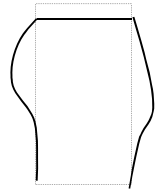
Boring: NEW-B012 Sample: ST-7 Depth: 21.15 ft
Type: Intact tube sample
Description: CL, brown sandy clay
LL = 35 PL = 13 PI = 22

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.88 inch Area: 6.52 in²
Water Content: 13.3 % Total Unit Weight: 138.4 pcf

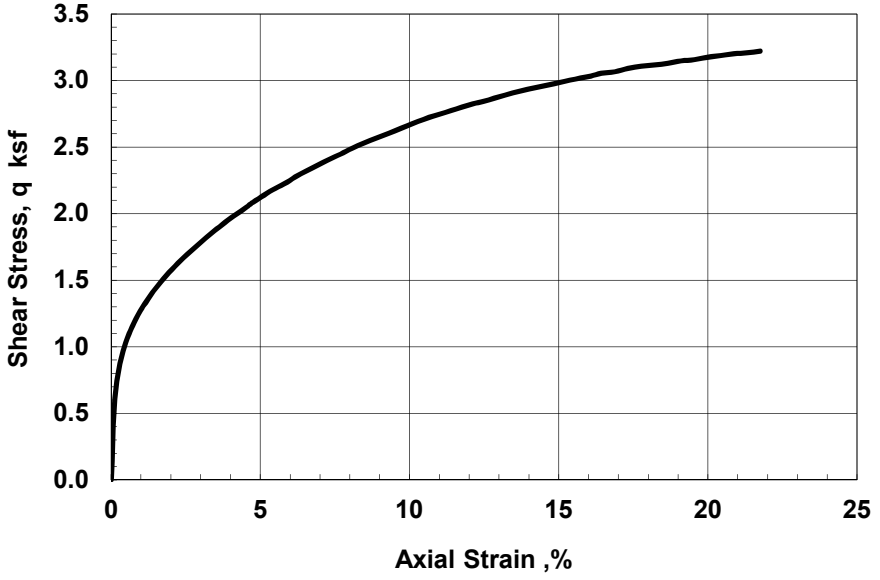
TEST SUMMARY

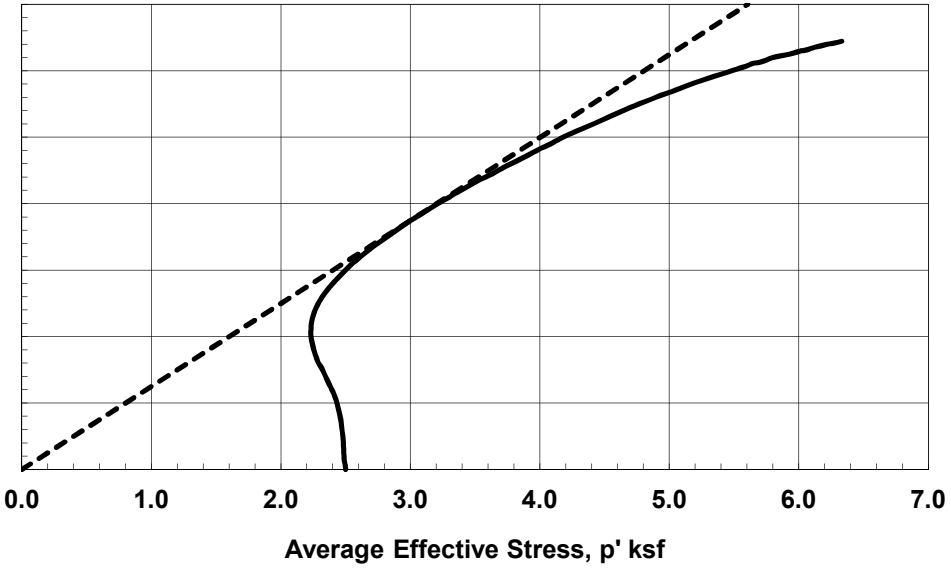
Consolidation Stresses: 2.50 ksf vertical, 2.50 ksf lateral
Water Content: 14.0 % Total Unit Weight: 140.6 pcf
B Coefficient: 97.9 Strain Rate: 0.023 %/min
Peak Shear Strength: 3.22 ksf @ 21.8 % Strain
Peak Effective Friction Angle: 38.6°



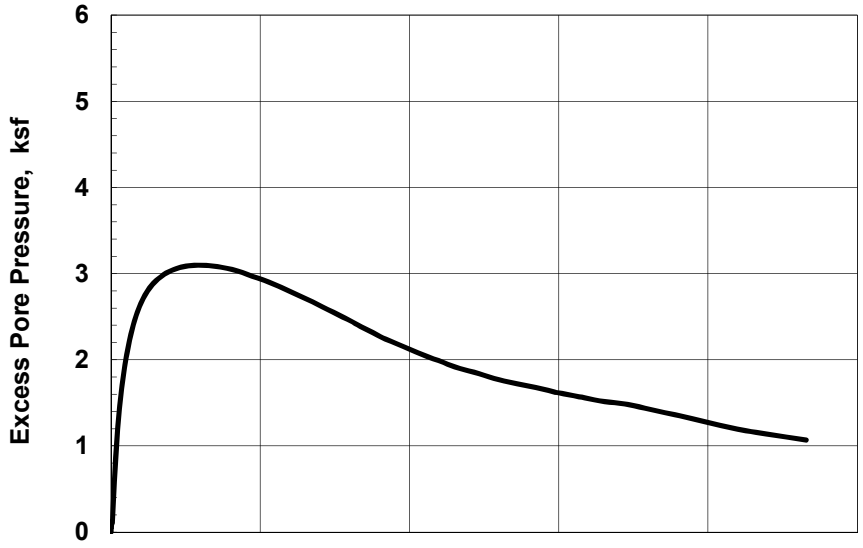
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B012 Sample: ST-7	November-15

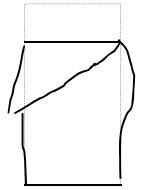


SAMPLE INFORMATION

Boring: NEW-B012 Sample: ST-12C Depth: 46.4 ft
Type: Intact tube sample
Description: CL, brown sandy lean clay
LL = 43 PL = 14 PI = 29

SPECIMEN INFORMATION (Initial)

Height: 6.04 inch Diameter: 2.88 inch Area: 6.52 in²
Water Content: 17.5 % Total Unit Weight: 133.6 pcf

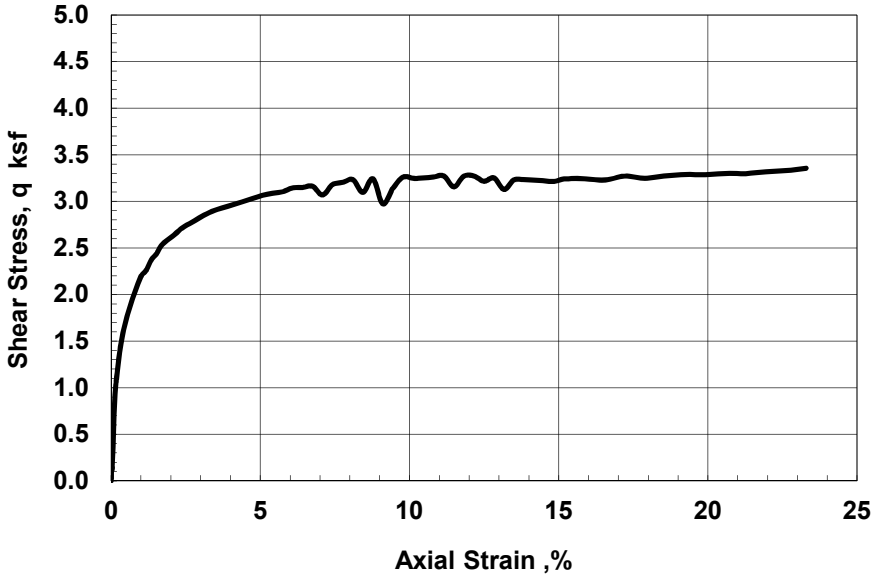


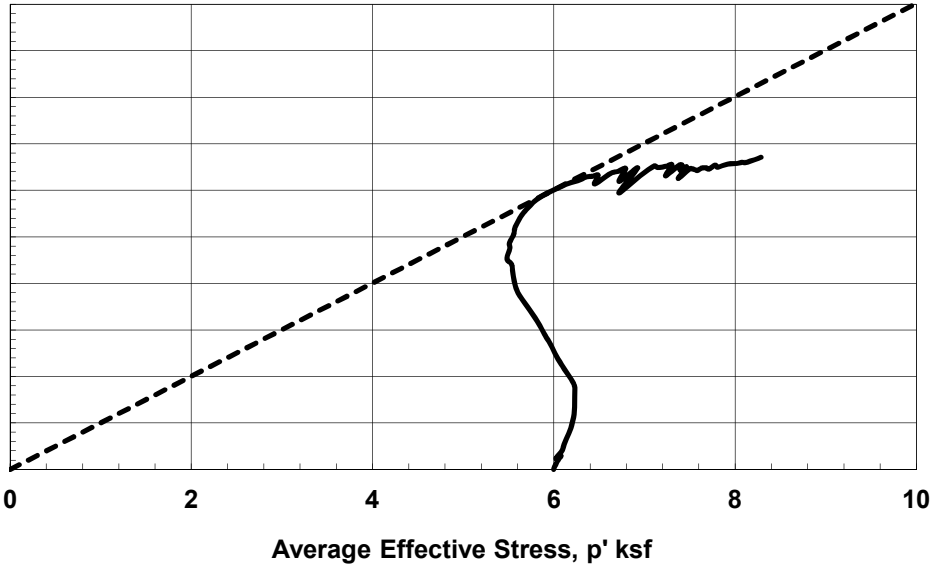
Failure Sketch

TEST SUMMARY

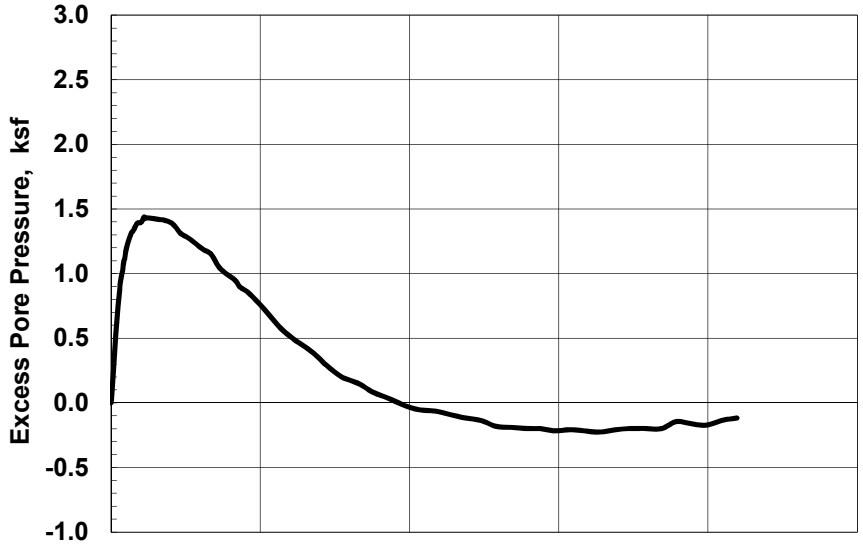
Consolidation Stresses: 6.00 ksf vertical, 6.00 ksf lateral
Water Content: 17.2 % Total Unit Weight: 137.3 pcf
B Coefficient: 96.31 Strain Rate: 0.021 %/min
Peak Shear Strength: 3.36 ksf @ 23.3 % Strain
Peak Effective Friction Angle: 30.1°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B012 Sample: ST-12C — November-15



SAMPLE INFORMATION

Boring: NEW-B014 Sample: ST-3C Depth: 36.65 ft
Type: Intact tube sample
Description: SC, brown clayey sand with gravel
LL = 38 PL = 13 PI = 25

SPECIMEN INFORMATION (Initial)

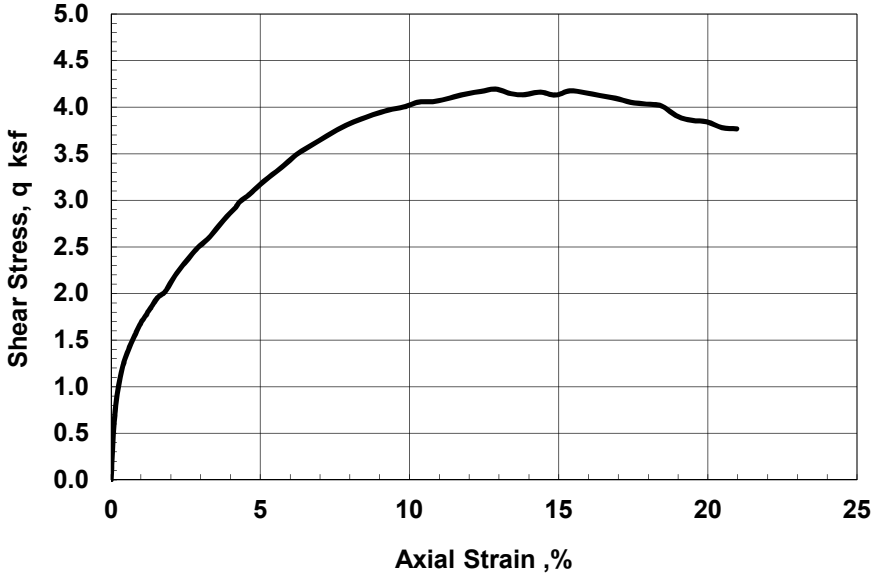
Height: 6.06 inch Diameter: 2.90 inch Area: 6.62 in²
Water Content: 16.3 % Total Unit Weight: 132.6 pcf

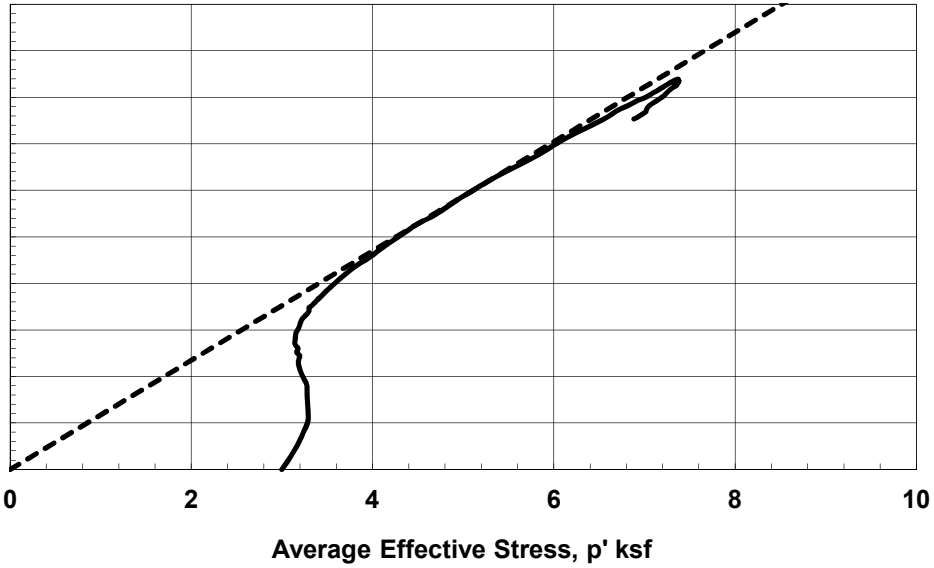
TEST SUMMARY

Consolidation Stresses: 3.00 ksf vertical, 3.00 ksf lateral
Water Content: 15.1 % Total Unit Weight: 134.8 pcf
B Coefficient: Strain Rate: 0.021 %/min
Peak Shear Strength: 4.19 ksf @ 12.9 % Strain
Peak Effective Friction Angle: 36.0°

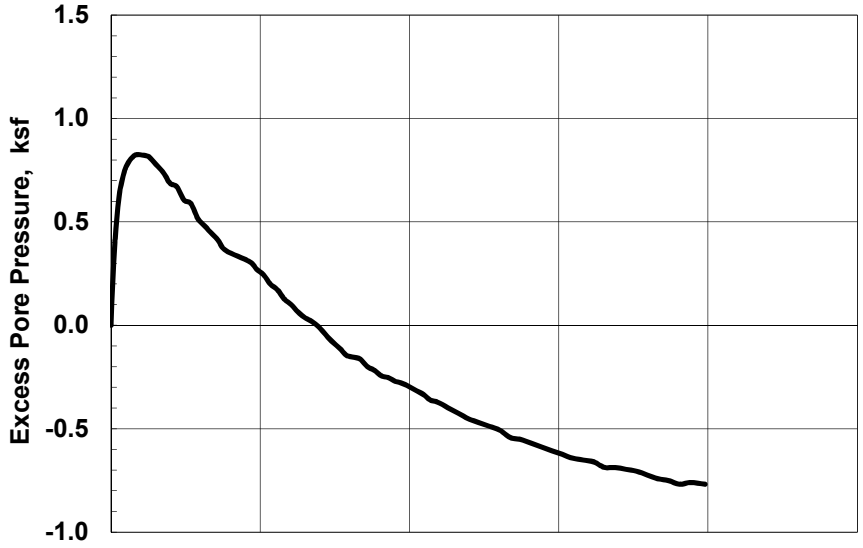
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B014 Sample: ST-3C
			November-15



SAMPLE INFORMATION

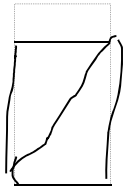
Boring: NEW-B015 Sample: ST-1B Depth: 10.95 ft
Type: Intact tube sample
Description: CH, gray brown fat clay
LL = 59 PL = 15 PI = 44

SPECIMEN INFORMATION (Initial)

Height: 6.02 inch Diameter: 2.89 inch Area: 6.56 in²
Water Content: 23.0 % Total Unit Weight: 126.0 pcf

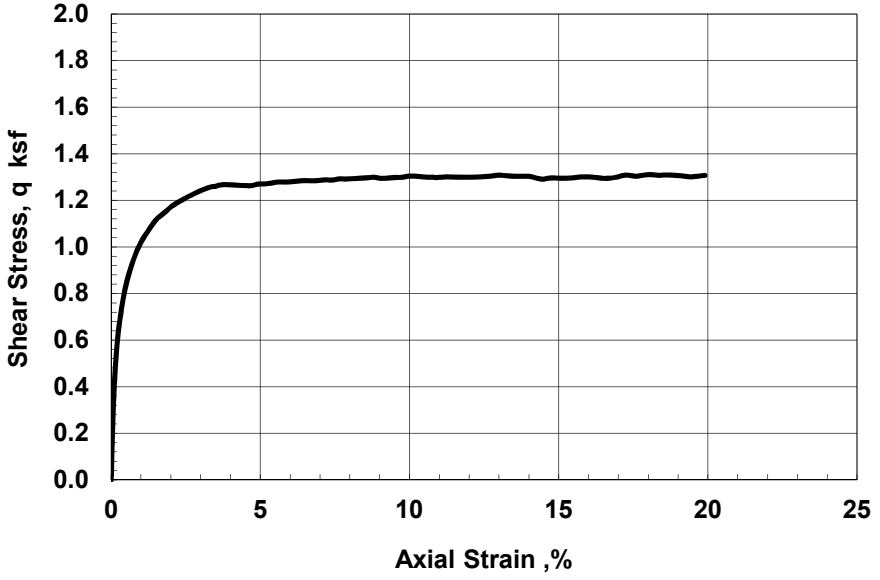
TEST SUMMARY

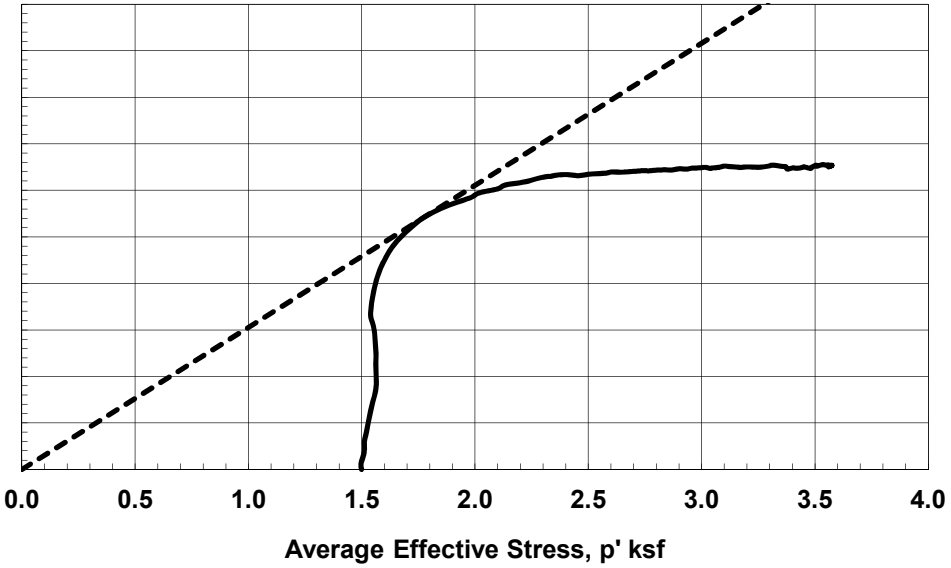
Consolidation Stresses: 1.50 ksf vertical, 1.50 ksf lateral
Water Content: 23.6 % Total Unit Weight: 128.1 pcf
B Coefficient: Strain Rate: 0.020 %/min
Peak Shear Strength: 1.31 ksf @ 18.0 % Strain
Peak Effective Friction Angle: 37.7°



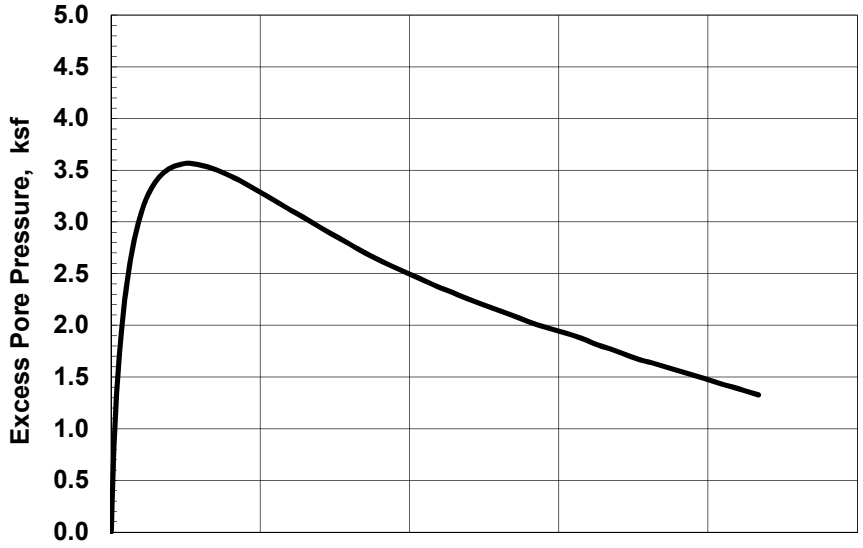
Failure Sketch

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B015 Sample: ST-1B
			November-15

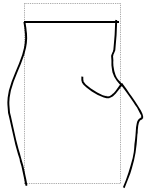


SAMPLE INFORMATION

Boring: NEW-B015 Sample: ST-2 Depth: 26 ft
Type: Intact tube sample
Description: CH, gray fat clay
LL = 52 PL = 15 PI = 37

SPECIMEN INFORMATION (Initial)

Height: 6.00 inch Diameter: 2.88 inch Area: 6.50 in²
Water Content: 19.5 % Total Unit Weight: 131.4 pcf

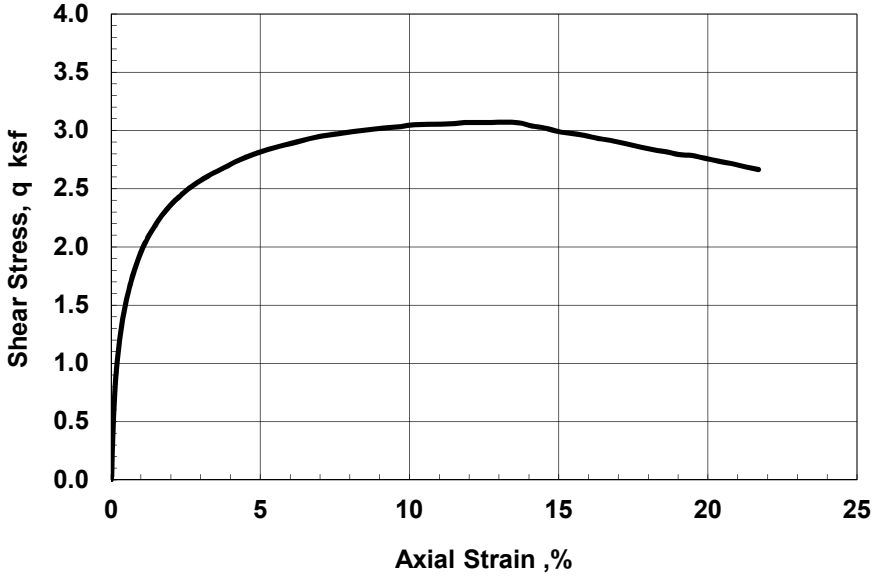


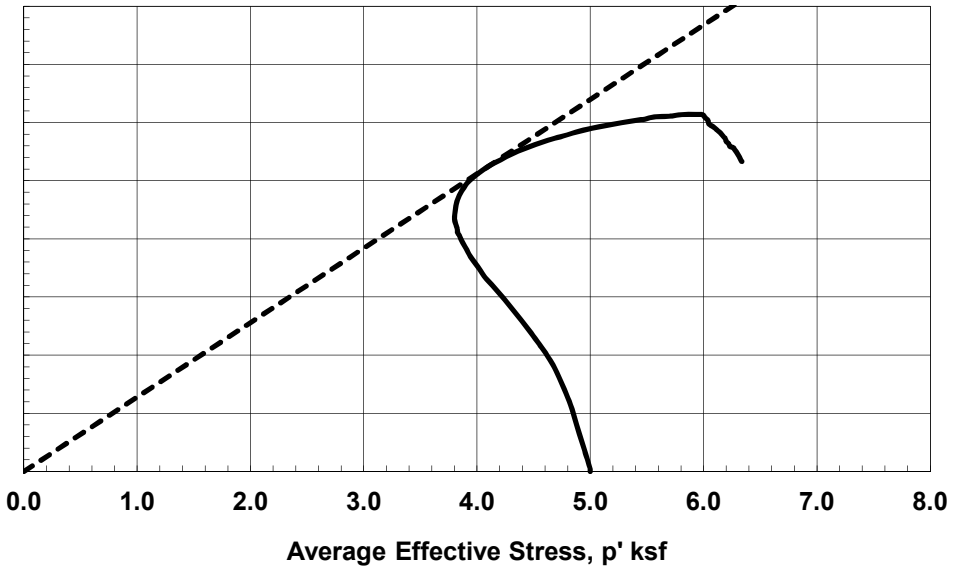
Failure Sketch

TEST SUMMARY

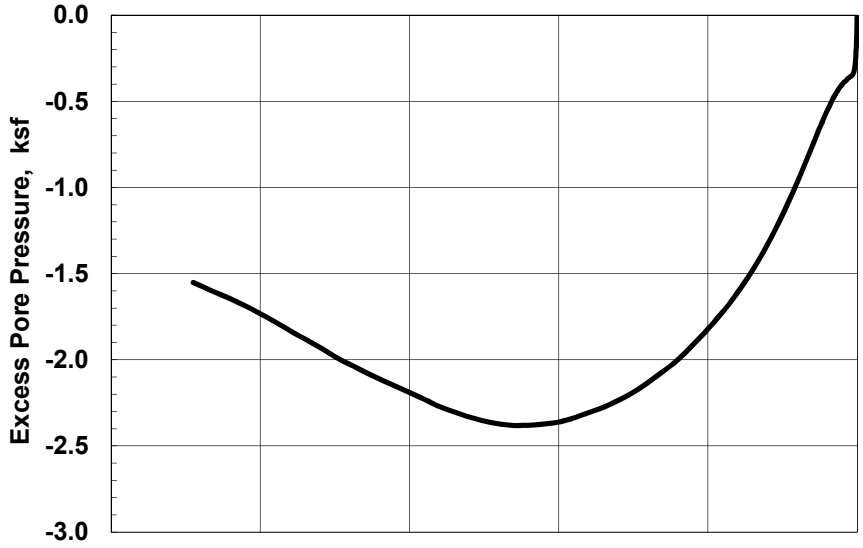
Consolidation Stresses: 5.00 ksf vertical, 5.00 ksf lateral
Water Content: 19.6 % Total Unit Weight: 132.8 pcf
B Coefficient: 99.27 Strain Rate: 0.023 %/min
Peak Shear Strength: 3.07 ksf @ 13.2 % Strain
Peak Effective Friction Angle: 39.8°

REMARKS:





Test by: BB	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL COMPRESSION with Pore Pressure Measurements
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B015 Sample: ST-2 — November-15



SAMPLE INFORMATION

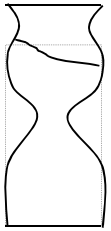
Boring: NEW-B014 Sample: ST-2 Depth: 15.85 ft
Type: Intact tube sample
Description: CL, gray clay, some f-c sand, trace gravel
LL = 31 PL = 14 PI = 17

SPECIMEN INFORMATION (Initial)

Height: 6.03 inch Diameter: 2.88 inch Area: 6.50 in²
Water Content: 12.2 % Total Unit Weight: 139.2 pcf

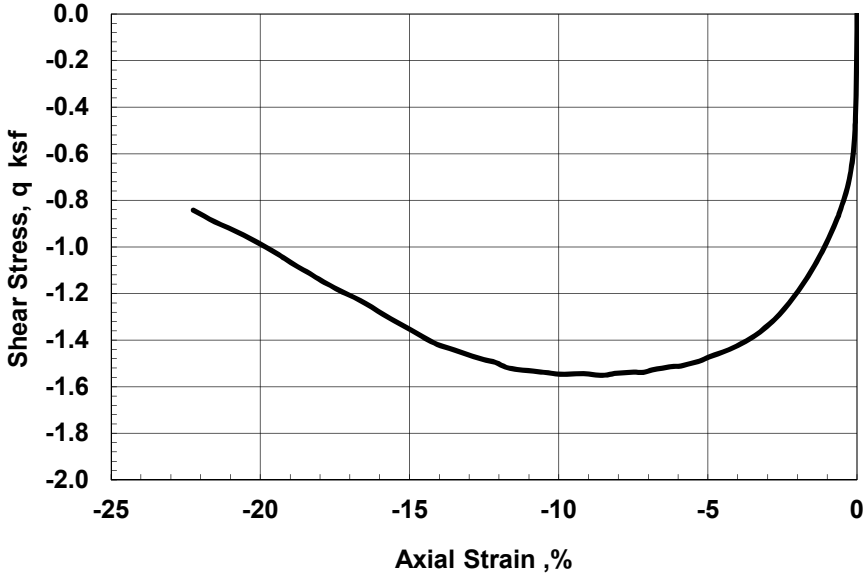
TEST SUMMARY

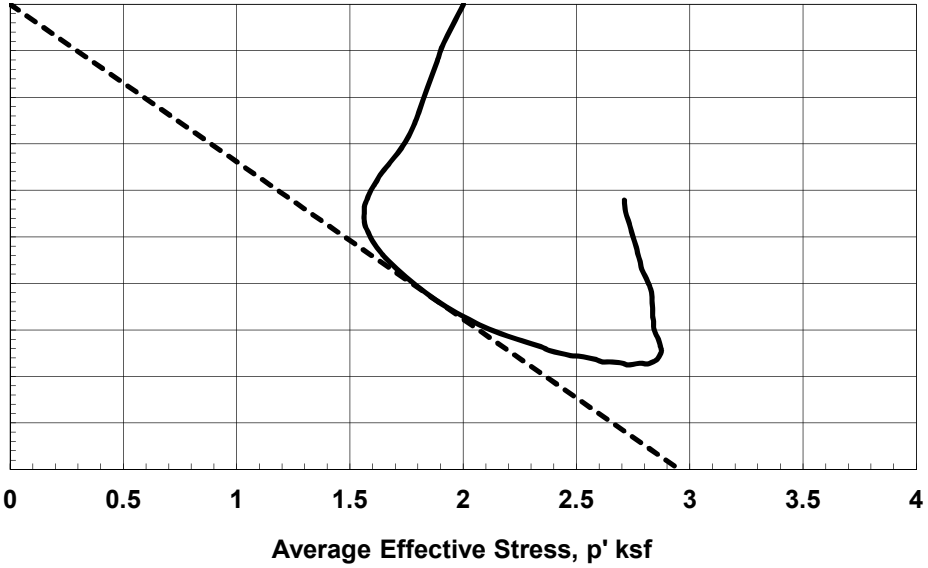
Consolidation Stresses: 2.00 ksf vertical, 2.00 ksf lateral
Water Content: 12.8 % Total Unit Weight: 142.5 pcf
B Coefficient: 98 Strain Rate: -0.020 %/min
Peak Shear Strength: -1.55 ksf @ -8.4 % Strain
Peak Effective Friction Angle: 42.6°



Failure Sketch

REMARKS:





Test by: GT	Project No. T60428794	AECOM Dynegy CCR - Newton	CONSOLIDATED UNDRAINED TRIAXIAL EXTENSION with Pore Pressure Measurements	
Checked by: GET	**TerraSense, LLC**		Boring: NEW-B014 Sample: ST-2	November-15

Electronic Filing: Received, Clerk's Office 07/01/2024

Appendix C

Hydraulic Conductivity/Slug Test Results

Appendix C - Table 1
Newton Power Station
Slug Test Results - Primary Ash Pond Wells (ID 501)
Hydrogeologic Monitoring Plan

Well ID	Slug In 1	Slug In 2	Slug In 3	Slug Out 1	Slug Out 2	Slug Out 3	Slug Out 4	MIN	MAX	GEOMEAN	Solution
APW2		4.41E-05		4.52E-05		3.45E-05		3.45E-05	4.52E-05	4.1E-05	Bouwer-Rice
APW3	8.44E-06			8.61E-06				8.44E-06	8.61E-06	8.5E-06	Bouwer-Rice
APW4	6.66E-06			5.14E-06				5.14E-06	6.66E-06	5.8E-06	Bouwer-Rice
APW5	5.66E-04	1.42E-03		1.54E-04	2.74E-04	2.56E-04		1.54E-04	1.42E-03	3.9E-04	Bouwer-Rice
APW6	1.64E-03	2.18E-03			2.09E-03	1.98E-03		1.64E-03	2.18E-03	2.0E-03	Bouwer-Rice
APW7	2.25E-03				3.24E-03	2.99E-03	2.75E-03	2.25E-03	3.24E-03	2.8E-03	Bouwer-Rice
APW8	6.60E-04	1.31E-03			1.06E-03	7.89E-04		6.60E-04	1.31E-03	9.2E-04	Bouwer-Rice
APW9	3.21E-03	3.28E-03		3.40E-03	3.00E-03			3.00E-03	3.40E-03	3.2E-03	Bouwer-Rice
APW10	5.27E-04	5.49E-04			5.73E-04	5.60E-04		5.27E-04	5.73E-04	5.5E-04	Bouwer-Rice

All slug test (i.e. hydraulic conductivity) results are in centimeters per second
Not Applicable

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Appendix C - Table 2
Newton Power Station
Slug Test Results - Landfill 2 CCR Wells (ID 502)
Hydrogeologic Monitoring Plan

Well ID	Slug In 1	Slug In 2	Slug In 3	Slug Out 1	Slug Out 2	Slug Out 3	MIN	MAX	GEOMEAN	Solution
G06D				3.92E-08			3.92E-08	3.92E-08	3.9E-08	Bouwer-Rice
G202	1.70E-02	1.43E-02			2.87E-02	2.33E-02	1.43E-02	2.87E-02	2.0E-02	Bouwer-Rice
G203	2.53E-02			2.42E-02	3.47E-02		2.42E-02	3.47E-02	2.8E-02	Bouwer-Rice
G208				1.32E-08			1.32E-08	1.32E-08	1.3E-08	Bouwer-Rice
G217D	2.27E-04	2.92E-04				3.03E-04	2.27E-04	3.03E-04	2.7E-04	Bouwer-Rice
G220				3.51E-07			3.51E-07	3.51E-07	3.5E-07	Bouwer-Rice
G222				1.54E-06			1.54E-06	1.54E-06	1.5E-06	Bouwer-Rice
G223	5.19E-05	2.50E-05		1.37E-05	1.79E-05		1.37E-05	5.19E-05	2.4E-05	Bouwer-Rice
G224	5.15E-02	1.90E-02	4.64E-02	4.31E-02		2.97E-02	1.90E-02	5.15E-02	3.6E-02	Bouwer-Rice

All slug test (i.e. hydraulic conductivity) results are in centimeters per second
Not Applicable

Natural Resource Technology
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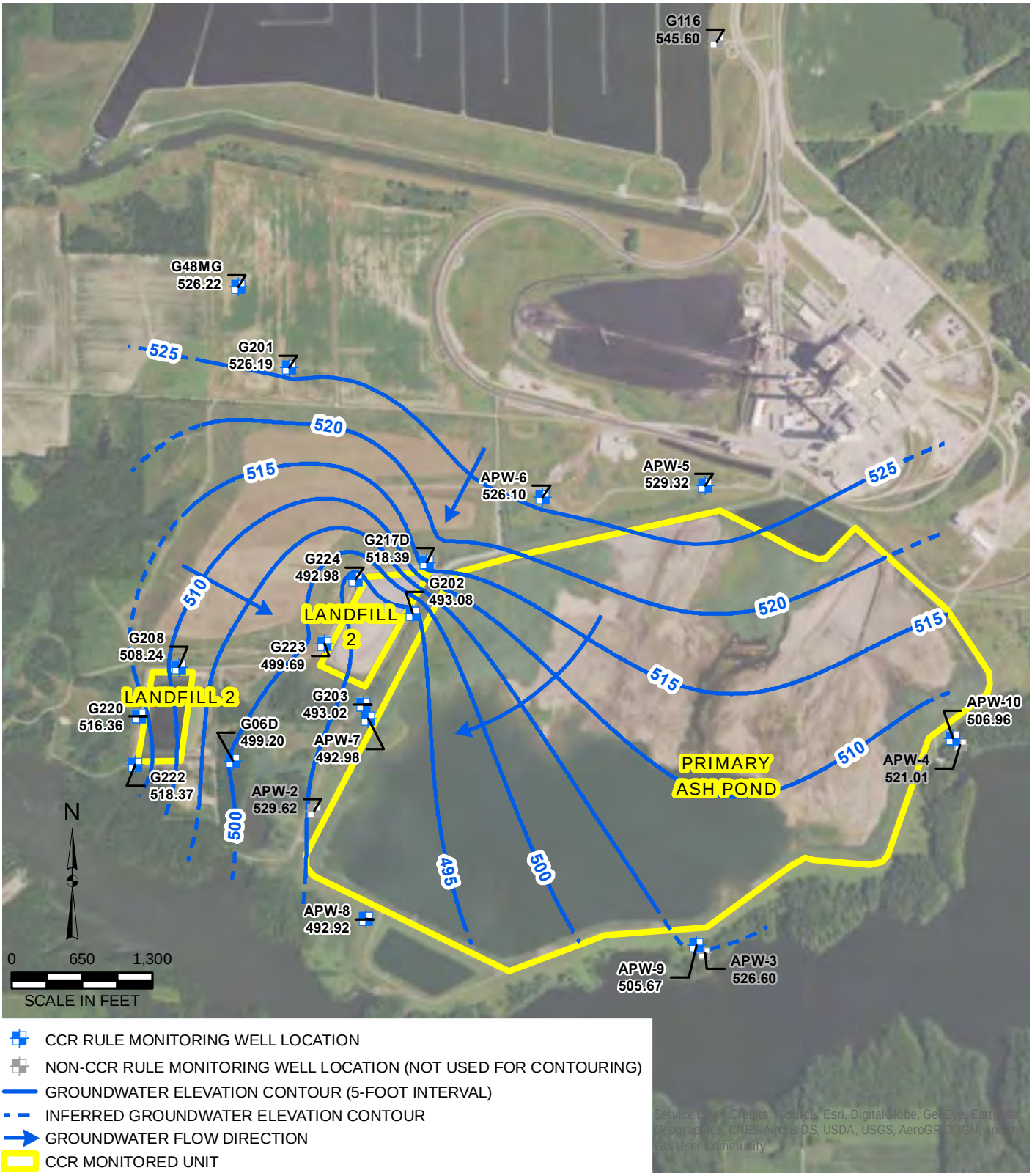
Appendix D

Groundwater Elevation Contour Maps

Electronic Filing: Received, Clerk's Office 07/01/2024



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DRAWN BY/DATE:
SDS 10/3/17
REVIEWED BY/DATE:
TBN 10/3/17
APPROVED BY/DATE:
SJC 10/3/17

GROUNDWATER ELEVATION CONTOUR MAP
ROUND 6: JANUARY 16, 2017

HYDROGEOLOGIC MONITORING PLAN
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

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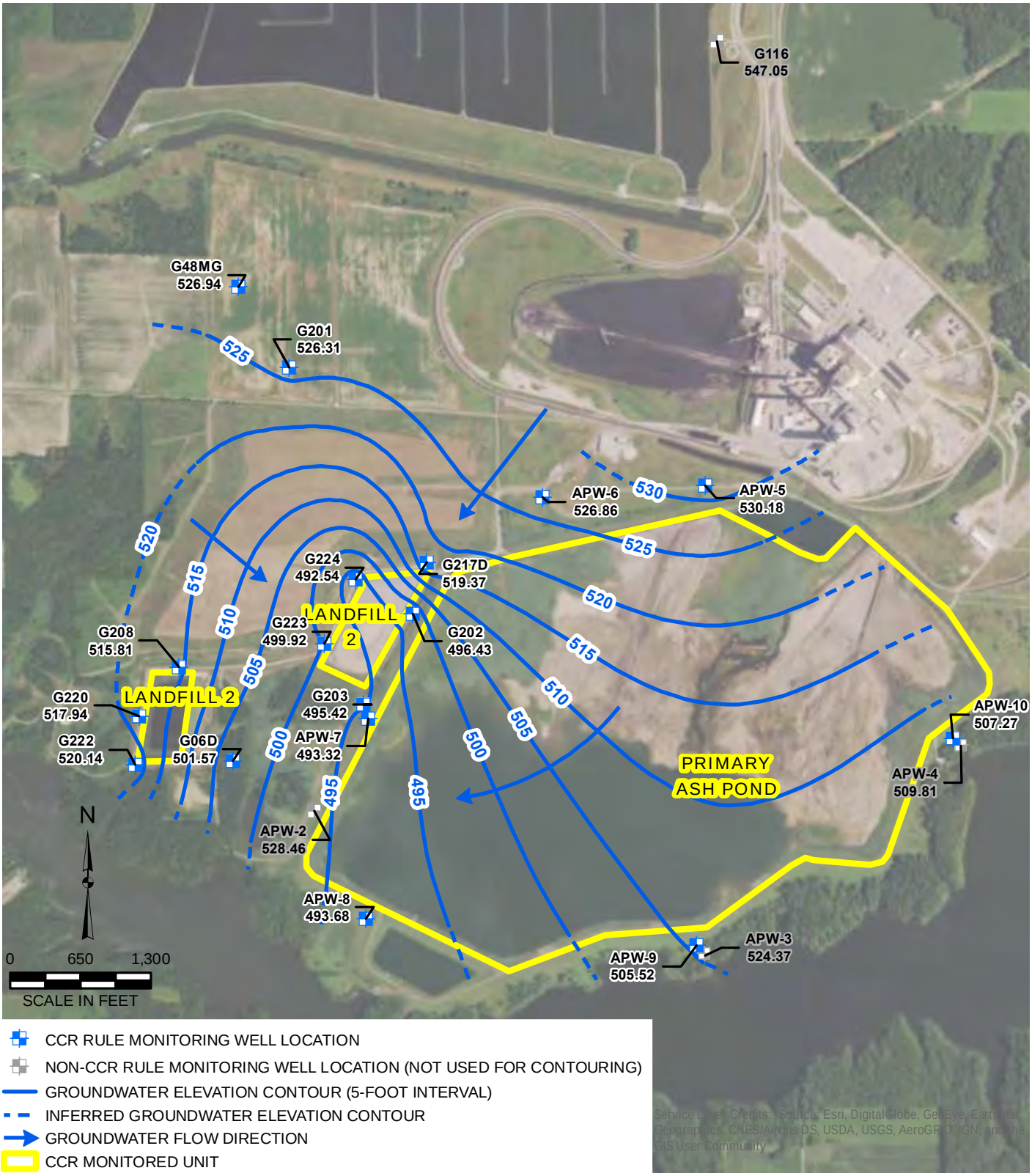
Electronic Filing: Received, Clerk's Office 07/01/2024



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DRAWN BY/DATE:
SDS 8/12/17
REVIEWED BY/DATE:
TBN 8/12/17
APPROVED BY/DATE:
JJW 8/30/17

GROUNDWATER ELEVATION CONTOUR MAP
ROUND 8: JUNE 12, 2017

HYDROGEOLOGIC MONITORING PLAN
NEWTON POWER STATION
NEWTON, ILLINOIS

PROJECT NO: 2285

FIGURE NO: 1

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OBG

THERE'S A WAY

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Appendix 3

Ramboll, 35 I.A.C. § 845.610(B)(3)(D) Groundwater Monitoring Data and Detected Exceedances; Quarter 2 2023; Primary Ash Pond, Newton Power Plant, Newton Illinois (August 7, 2023).

Electronic Filing: Received, Clerk's Office 07/01/2024

Luminant

Illinois Power Generating Company
1500 Eastport Plaza Drive
Collinsville, IL 62234

August 7, 2023
Illinois Environmental Protection Agency
DWPC – Permits MC#15
Attn: Part 845 Coal Combustion Residual Rule Submittal
1021 North Grand Avenue East
Springfield, IL 62794

Re: Newton Power Plant Primary Ash Pond; IEPA ID # W0798070001-01

Dear Mr. LeCrone:

In accordance with Title 35 of the Illinois Administrative Code (35 I.A.C.) Section (§) 845.610(b)(3)(D), Illinois Power Generating Company (IPGC) is submitting groundwater monitoring data for the Quarter 2 2023 sampling event at the Newton Power Plant Primary Ash Pond, identified by Illinois Environmental Protection Agency (IEPA) ID No. W0798070001-01. This data is being submitted and placed in the facility's operating record as required by 35 I.A.C. § 845.800(d)(15) within 60 days of receiving final laboratory analytical data. Results were compared with the groundwater protection standards (GWPSs) described in 35 I.A.C. § 845.600 to determine exceedances of the GWPS.

The date of this submittal is considered to be the date that exceedances of the GWPS were detected. This notification of exceedances of the GWPSs in 35 I.A.C. § 845.600 will be placed in the facility's operating record within 30 days as required by 35 I.A.C. § 845.800(d)(16). As allowed in 35 I.A.C. § 845.650(e), an alternate source demonstration (ASD) will be evaluated for the detected exceedances of the GWPS and, if successfully completed, the ASD will be submitted to IEPA within 60 days of this transmittal.

Sincerely,

Phil Morris, PE
Senior Director, Environmental

Enclosures

Groundwater Monitoring Data and Detected Exceedances, Quarter 2 2023, Primary Ash Pond, Newton Power Plant, Newton, Illinois

RAMBOLL

ENVIRONMENT & HEALTH

35 I.A.C. § 845.610(B)(3)(D) GROUNDWATER MONITORING DATA AND DETECTED EXCEEDANCES QUARTER 2 2023

PRIMARY ASH POND, NEWTON POWER PLANT, NEWTON, ILLINOIS

August 7, 2023

Samples were collected between April 25 and April 28, 2023 and analyzed for the parameters listed in Title 35 of the Illinois Administrative Code (35 I.A.C) Section (§) 845.600(a), calcium, and turbidity. Final laboratory analytical data were received on June 8, 2023.

The monitoring well locations are included in **Figure 1**. **Attachment A** summarizes the groundwater elevation data for the Quarter 2 2023 sampling event. **Table 1** is a summary of the field parameters and analytical results. **Attachment B** contains the associated laboratory analytical reports and field data sheets for the Quarter 2 2023 sampling event.

Statistical procedures used to evaluate groundwater results are provided in Appendix A of the Groundwater Monitoring Plan[1] provided in the operating permit application. In accordance with 35 I.A.C. § 845.610(b)(3)(B), the Quarter 2 2023 groundwater monitoring data were evaluated for statistically significant levels (SSLs) over background levels for the constituents listed in 35 I.A.C. § 845.600. **Attachment C** shows the statistically derived values compared to background levels.

In accordance with 35 I.A.C. § 845.610(b)(3)(C), the statistically derived values identified as Statistical Results in **Table 2** were compared with the groundwater protection standards (GWPSs) described in 35 I.A.C. § 845.600 to determine exceedances of the GWPS, as shown in **Table 2**. The date of this submittal is considered to be the date that the exceedances of the GPWS were detected.

As allowed in 35 I.A.C. § 845.650(e), an alternate source demonstration (ASD) will be evaluated for the detected exceedances of the GWPS and, if successfully completed, the ASD will be submitted to Illinois Environmental Protection Agency (IEPA) within 60 days of this transmittal.

TABLES

Table 1 Field Parameters and Analytical Results - Quarter 2, 2023
Table 2 Comparison of Statistical Results to GWPS - Quarter 2, 2023

FIGURES

Figure 1 Monitoring Well Location Map

ATTACHMENTS

Attachment A Groundwater Elevation Data - Quarter 2, 2023
Attachment B Laboratory Reports and Field Data Sheets - Quarter 2, 2023
Attachment C Comparison of Statistical Results to Background - Quarter 2, 2023

[1] Ramboll Americas Engineering Solutions, Inc. (Ramboll), 2021. *Groundwater Monitoring Plan. Primary Ash Pond. Newton Power Plant. Newton, Illinois. October 25, 2021.*

TABLES

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW05	Background	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW05	Background	E001	04/27/2023	Arsenic, total	0.0300	mg/L
APW05	Background	E001	04/27/2023	Barium, total	0.250	mg/L
APW05	Background	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW05	Background	E001	04/27/2023	Boron, total	0.0920	mg/L
APW05	Background	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW05	Background	E001	04/27/2023	Calcium, total	49.0	mg/L
APW05	Background	E001	04/27/2023	Chloride, total	46.0	mg/L
APW05	Background	E001	04/27/2023	Chromium, total	0.0037 J	mg/L
APW05	Background	E001	04/27/2023	Cobalt, total	0.00048 J	mg/L
APW05	Background	E001	04/27/2023	Dissolved Oxygen	18.0	mg/L
APW05	Background	E001	04/27/2023	Fluoride, total	0.498	mg/L
APW05	Background	E001	04/27/2023	Lead, total	0.00068 J	mg/L
APW05	Background	E001	04/27/2023	Lithium, total	0.0087 J	mg/L
APW05	Background	E001	04/27/2023	Mercury, total	0.00014 U	mg/L
APW05	Background	E001	04/27/2023	Molybdenum, total	0.00910	mg/L
APW05	Background	E001	04/27/2023	Oxidation Reduction Potential	-124	mV
APW05	Background	E001	04/27/2023	Radium 226 + Radium 228, total	0.841	pCi/L
APW05	Background	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW05	Background	E001	04/27/2023	Specific Conductance @ 25C (field)	819	micromhos/cm
APW05	Background	E001	04/27/2023	Sulfate, total	0.97 J	mg/L
APW05	Background	E001	04/27/2023	Temperature	14.5	degrees C
APW05	Background	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW05	Background	E001	04/27/2023	Total Dissolved Solids	560	mg/L
APW05	Background	E001	04/27/2023	Turbidity, field	40.1	NTU
APW05	Background	E001	04/27/2023	pH (field)	7.1	SU
APW06	Background	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW06	Background	E001	04/26/2023	Arsenic, total	0.00920	mg/L
APW06	Background	E001	04/26/2023	Barium, total	0.240	mg/L
APW06	Background	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L
APW06	Background	E001	04/26/2023	Boron, total	0.0870 J+	mg/L
APW06	Background	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW06	Background	E001	04/26/2023	Calcium, total	58.0	mg/L
APW06	Background	E001	04/26/2023	Chloride, total	26.0	mg/L
APW06	Background	E001	04/26/2023	Chromium, total	0.00790 J+	mg/L
APW06	Background	E001	04/26/2023	Cobalt, total	0.0011 J	mg/L
APW06	Background	E001	04/26/2023	Dissolved Oxygen	11.0	mg/L
APW06	Background	E001	04/26/2023	Fluoride, total	0.489	mg/L
APW06	Background	E001	04/26/2023	Lead, total	0.00170	mg/L
APW06	Background	E001	04/26/2023	Lithium, total	0.012 J	mg/L
APW06	Background	E001	04/26/2023	Mercury, total	0.00019 J	mg/L
APW06	Background	E001	04/26/2023	Molybdenum, total	0.00770	mg/L
APW06	Background	E001	04/26/2023	Oxidation Reduction Potential	-128	mV
APW06	Background	E001	04/26/2023	Radium 226 + Radium 228, total	1.20	pCi/L
APW06	Background	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW06	Background	E001	04/26/2023	Specific Conductance @ 25C (field)	796	micromhos/cm

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW06	Background	E001	04/26/2023	Sulfate, total	7.60	mg/L
APW06	Background	E001	04/26/2023	Temperature	17.6	degrees C
APW06	Background	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW06	Background	E001	04/26/2023	Total Dissolved Solids	500 J+	mg/L
APW06	Background	E001	04/26/2023	Turbidity, field	471	NTU
APW06	Background	E001	04/26/2023	pH (field)	7.3	SU
APW02	Compliance	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW02	Compliance	E001	04/27/2023	Arsenic, total	0.00140	mg/L
APW02	Compliance	E001	04/27/2023	Barium, total	0.0240	mg/L
APW02	Compliance	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW02	Compliance	E001	04/27/2023	Boron, total	0.120 J+	mg/L
APW02	Compliance	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW02	Compliance	E001	04/27/2023	Calcium, total	460	mg/L
APW02	Compliance	E001	04/27/2023	Chloride, total	110	mg/L
APW02	Compliance	E001	04/27/2023	Chromium, total	0.00400	mg/L
APW02	Compliance	E001	04/27/2023	Cobalt, total	0.0012 J	mg/L
APW02	Compliance	E001	04/27/2023	Dissolved Oxygen	1.20	mg/L
APW02	Compliance	E001	04/27/2023	Fluoride, total	0.172 J	mg/L
APW02	Compliance	E001	04/27/2023	Lead, total	0.00039 J	mg/L
APW02	Compliance	E001	04/27/2023	Lithium, total	0.0980	mg/L
APW02	Compliance	E001	04/27/2023	Mercury, total	0.00018 J	mg/L
APW02	Compliance	E001	04/27/2023	Molybdenum, total	0.00160	mg/L
APW02	Compliance	E001	04/27/2023	Oxidation Reduction Potential	80.8	mV
APW02	Compliance	E001	04/27/2023	Radium 226 + Radium 228, total	0.768	pCi/L
APW02	Compliance	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW02	Compliance	E001	04/27/2023	Specific Conductance @ 25C (field)	5,217	micromhos/cm
APW02	Compliance	E001	04/27/2023	Sulfate, total	3,100	mg/L
APW02	Compliance	E001	04/27/2023	Temperature	15.6	degrees C
APW02	Compliance	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW02	Compliance	E001	04/27/2023	Total Dissolved Solids	5,400	mg/L
APW02	Compliance	E001	04/27/2023	Turbidity, field	25.0	NTU
APW02	Compliance	E001	04/27/2023	pH (field)	6.7	SU
APW03	Compliance	E001	04/25/2023	Antimony, total	0.00043 U	mg/L
APW03	Compliance	E001	04/25/2023	Arsenic, total	0.00069 U	mg/L
APW03	Compliance	E001	04/25/2023	Barium, total	0.0780	mg/L
APW03	Compliance	E001	04/25/2023	Beryllium, total	0.00059 U	mg/L
APW03	Compliance	E001	04/25/2023	Boron, total	0.370	mg/L
APW03	Compliance	E001	04/25/2023	Cadmium, total	0.00074 U	mg/L
APW03	Compliance	E001	04/25/2023	Calcium, total	96.0	mg/L
APW03	Compliance	E001	04/25/2023	Chloride, total	6.90	mg/L
APW03	Compliance	E001	04/25/2023	Chromium, total	0.00720	mg/L
APW03	Compliance	E001	04/25/2023	Cobalt, total	0.00048 U	mg/L
APW03	Compliance	E001	04/25/2023	Dissolved Oxygen	2.20	mg/L
APW03	Compliance	E001	04/25/2023	Fluoride, total	0.04 U	mg/L
APW03	Compliance	E001	04/25/2023	Lead, total	0.00022 U	mg/L
APW03	Compliance	E001	04/25/2023	Lithium, total	0.01 J	mg/L

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW03	Compliance	E001	04/25/2023	Mercury, total	0.00014 U	mg/L
APW03	Compliance	E001	04/25/2023	Molybdenum, total	0.0008 J	mg/L
APW03	Compliance	E001	04/25/2023	Oxidation Reduction Potential	141	mV
APW03	Compliance	E001	04/25/2023	Radium 226 + Radium 228, total	1.02	pCi/L
APW03	Compliance	E001	04/25/2023	Selenium, total	0.00074 U	mg/L
APW03	Compliance	E001	04/25/2023	Specific Conductance @ 25C (field)	925	micromhos/cm
APW03	Compliance	E001	04/25/2023	Sulfate, total	120	mg/L
APW03	Compliance	E001	04/25/2023	Temperature	17.0	degrees C
APW03	Compliance	E001	04/25/2023	Thallium, total	0.00038 U	mg/L
APW03	Compliance	E001	04/25/2023	Total Dissolved Solids	740	mg/L
APW03	Compliance	E001	04/25/2023	Turbidity, field	0 U	NTU
APW03	Compliance	E001	04/25/2023	pH (field)	7.0	SU
APW04	Compliance	E001	04/25/2023	Antimony, total	0.00043 U	mg/L
APW04	Compliance	E001	04/25/2023	Arsenic, total	0.00089 J	mg/L
APW04	Compliance	E001	04/25/2023	Barium, total	0.0220	mg/L
APW04	Compliance	E001	04/25/2023	Beryllium, total	0.00059 U	mg/L
APW04	Compliance	E001	04/25/2023	Boron, total	0.0240	mg/L
APW04	Compliance	E001	04/25/2023	Cadmium, total	0.00074 U	mg/L
APW04	Compliance	E001	04/25/2023	Calcium, total	210	mg/L
APW04	Compliance	E001	04/25/2023	Chloride, total	34.0	mg/L
APW04	Compliance	E001	04/25/2023	Chromium, total	0.0440	mg/L
APW04	Compliance	E001	04/25/2023	Cobalt, total	0.00081 J	mg/L
APW04	Compliance	E001	04/25/2023	Dissolved Oxygen	0.930	mg/L
APW04	Compliance	E001	04/25/2023	Fluoride, total	0.051 J	mg/L
APW04	Compliance	E001	04/25/2023	Lead, total	0.00063 J	mg/L
APW04	Compliance	E001	04/25/2023	Lithium, total	0.018 J	mg/L
APW04	Compliance	E001	04/25/2023	Mercury, total	0.00014 U	mg/L
APW04	Compliance	E001	04/25/2023	Molybdenum, total	0.00180	mg/L
APW04	Compliance	E001	04/25/2023	Oxidation Reduction Potential	171	mV
APW04	Compliance	E001	04/25/2023	Radium 226 + Radium 228, total	1.00	pCi/L
APW04	Compliance	E001	04/25/2023	Selenium, total	0.00074 U	mg/L
APW04	Compliance	E001	04/25/2023	Specific Conductance @ 25C (field)	1,830	micromhos/cm
APW04	Compliance	E001	04/25/2023	Sulfate, total	840	mg/L
APW04	Compliance	E001	04/25/2023	Temperature	11.8	degrees C
APW04	Compliance	E001	04/25/2023	Thallium, total	0.00038 U	mg/L
APW04	Compliance	E001	04/25/2023	Total Dissolved Solids	1,800	mg/L
APW04	Compliance	E001	04/25/2023	Turbidity, field	178	NTU
APW04	Compliance	E001	04/25/2023	pH (field)	6.9	SU
APW05S	Compliance	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW05S	Compliance	E001	04/26/2023	Arsenic, total	0.00093 J	mg/L
APW05S	Compliance	E001	04/26/2023	Barium, total	0.0350	mg/L
APW05S	Compliance	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L
APW05S	Compliance	E001	04/26/2023	Boron, total	0.0540 J+	mg/L
APW05S	Compliance	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW05S	Compliance	E001	04/26/2023	Calcium, total	390	mg/L
APW05S	Compliance	E001	04/26/2023	Chloride, total	200	mg/L

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
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PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW05S	Compliance	E001	04/26/2023	Chromium, total	0.0031 J+	mg/L
APW05S	Compliance	E001	04/26/2023	Cobalt, total	0.00083 J	mg/L
APW05S	Compliance	E001	04/26/2023	Dissolved Oxygen	3.50	mg/L
APW05S	Compliance	E001	04/26/2023	Fluoride, total	0.365	mg/L
APW05S	Compliance	E001	04/26/2023	Lead, total	0.00022 J	mg/L
APW05S	Compliance	E001	04/26/2023	Lithium, total	0.0330	mg/L
APW05S	Compliance	E001	04/26/2023	Mercury, total	0.00014 U	mg/L
APW05S	Compliance	E001	04/26/2023	Molybdenum, total	0.00130	mg/L
APW05S	Compliance	E001	04/26/2023	Oxidation Reduction Potential	97.0	mV
APW05S	Compliance	E001	04/26/2023	Radium 226 + Radium 228, total	0.141	pCi/L
APW05S	Compliance	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW05S	Compliance	E001	04/26/2023	Specific Conductance @ 25C (field)	3,930	micromhos/cm
APW05S	Compliance	E001	04/26/2023	Sulfate, total	2,100	mg/L
APW05S	Compliance	E001	04/26/2023	Temperature	16.4	degrees C
APW05S	Compliance	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW05S	Compliance	E001	04/26/2023	Total Dissolved Solids	3,800 J+	mg/L
APW05S	Compliance	E001	04/26/2023	Turbidity, field	220	NTU
APW05S	Compliance	E001	04/26/2023	pH (field)	6.6	SU
APW07	Compliance	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW07	Compliance	E001	04/27/2023	Arsenic, total	0.0180	mg/L
APW07	Compliance	E001	04/27/2023	Barium, total	0.510	mg/L
APW07	Compliance	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW07	Compliance	E001	04/27/2023	Boron, total	0.0850 J+	mg/L
APW07	Compliance	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW07	Compliance	E001	04/27/2023	Calcium, total	100	mg/L
APW07	Compliance	E001	04/27/2023	Chloride, total	63.0	mg/L
APW07	Compliance	E001	04/27/2023	Chromium, total	0.0170	mg/L
APW07	Compliance	E001	04/27/2023	Cobalt, total	0.00360	mg/L
APW07	Compliance	E001	04/27/2023	Dissolved Oxygen	0.510	mg/L
APW07	Compliance	E001	04/27/2023	Fluoride, total	0.409	mg/L
APW07	Compliance	E001	04/27/2023	Lead, total	0.00550	mg/L
APW07	Compliance	E001	04/27/2023	Lithium, total	0.0058 J	mg/L
APW07	Compliance	E001	04/27/2023	Mercury, total	0.00014 U	mg/L
APW07	Compliance	E001	04/27/2023	Molybdenum, total	0.00340	mg/L
APW07	Compliance	E001	04/27/2023	Oxidation Reduction Potential	-116	mV
APW07	Compliance	E001	04/27/2023	Radium 226 + Radium 228, total	2.09	pCi/L
APW07	Compliance	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW07	Compliance	E001	04/27/2023	Specific Conductance @ 25C (field)	1,051	micromhos/cm
APW07	Compliance	E001	04/27/2023	Sulfate, total	14.0	mg/L
APW07	Compliance	E001	04/27/2023	Temperature	14.5	degrees C
APW07	Compliance	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW07	Compliance	E001	04/27/2023	Total Dissolved Solids	590	mg/L
APW07	Compliance	E001	04/27/2023	Turbidity, field	621	NTU
APW07	Compliance	E001	04/27/2023	pH (field)	7.4	SU
APW08	Compliance	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW08	Compliance	E001	04/26/2023	Arsenic, total	0.0260	mg/L

TABLE 1.
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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW08	Compliance	E001	04/26/2023	Barium, total	0.470	mg/L
APW08	Compliance	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L
APW08	Compliance	E001	04/26/2023	Boron, total	0.0870 J+	mg/L
APW08	Compliance	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW08	Compliance	E001	04/26/2023	Calcium, total	110	mg/L
APW08	Compliance	E001	04/26/2023	Chloride, total	58.0	mg/L
APW08	Compliance	E001	04/26/2023	Chromium, total	0.00760 J+	mg/L
APW08	Compliance	E001	04/26/2023	Cobalt, total	0.00220	mg/L
APW08	Compliance	E001	04/26/2023	Dissolved Oxygen	1.70	mg/L
APW08	Compliance	E001	04/26/2023	Fluoride, total	0.404	mg/L
APW08	Compliance	E001	04/26/2023	Lead, total	0.00330	mg/L
APW08	Compliance	E001	04/26/2023	Lithium, total	0.0057 J	mg/L
APW08	Compliance	E001	04/26/2023	Mercury, total	0.00015 J	mg/L
APW08	Compliance	E001	04/26/2023	Molybdenum, total	0.00440	mg/L
APW08	Compliance	E001	04/26/2023	Oxidation Reduction Potential	-118	mV
APW08	Compliance	E001	04/26/2023	Radium 226 + Radium 228, total	0.941	pCi/L
APW08	Compliance	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW08	Compliance	E001	04/26/2023	Specific Conductance @ 25C (field)	1,100	micromhos/cm
APW08	Compliance	E001	04/26/2023	Sulfate, total	48.0	mg/L
APW08	Compliance	E001	04/26/2023	Temperature	14.2	degrees C
APW08	Compliance	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW08	Compliance	E001	04/26/2023	Total Dissolved Solids	640 J+	mg/L
APW08	Compliance	E001	04/26/2023	Turbidity, field	17.7	NTU
APW08	Compliance	E001	04/26/2023	pH (field)	7.5	SU
APW09	Compliance	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW09	Compliance	E001	04/27/2023	Arsenic, total	0.0290	mg/L
APW09	Compliance	E001	04/27/2023	Barium, total	0.430	mg/L
APW09	Compliance	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW09	Compliance	E001	04/27/2023	Boron, total	0.0990 J+	mg/L
APW09	Compliance	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW09	Compliance	E001	04/27/2023	Calcium, total	76.0	mg/L
APW09	Compliance	E001	04/27/2023	Chloride, total	130	mg/L
APW09	Compliance	E001	04/27/2023	Chromium, total	0.00420	mg/L
APW09	Compliance	E001	04/27/2023	Cobalt, total	0.00068 J	mg/L
APW09	Compliance	E001	04/27/2023	Dissolved Oxygen	0.470	mg/L
APW09	Compliance	E001	04/27/2023	Fluoride, total	0.482	mg/L
APW09	Compliance	E001	04/27/2023	Lead, total	0.00130	mg/L
APW09	Compliance	E001	04/27/2023	Lithium, total	0.0072 J	mg/L
APW09	Compliance	E001	04/27/2023	Mercury, total	0.00014 U	mg/L
APW09	Compliance	E001	04/27/2023	Molybdenum, total	0.00390	mg/L
APW09	Compliance	E001	04/27/2023	Oxidation Reduction Potential	-137	mV
APW09	Compliance	E001	04/27/2023	Radium 226 + Radium 228, total	2.00	pCi/L
APW09	Compliance	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW09	Compliance	E001	04/27/2023	Specific Conductance @ 25C (field)	1,356	micromhos/cm
APW09	Compliance	E001	04/27/2023	Sulfate, total	9.40	mg/L
APW09	Compliance	E001	04/27/2023	Temperature	16.5	degrees C

TABLE 1.
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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW09	Compliance	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW09	Compliance	E001	04/27/2023	Total Dissolved Solids	840	mg/L
APW09	Compliance	E001	04/27/2023	Turbidity, field	117	NTU
APW09	Compliance	E001	04/27/2023	pH (field)	7.5	SU
APW10	Compliance	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW10	Compliance	E001	04/27/2023	Arsenic, total	0.00780	mg/L
APW10	Compliance	E001	04/27/2023	Barium, total	0.0260	mg/L
APW10	Compliance	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW10	Compliance	E001	04/27/2023	Boron, total	0.0770 J+	mg/L
APW10	Compliance	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW10	Compliance	E001	04/27/2023	Calcium, total	140	mg/L
APW10	Compliance	E001	04/27/2023	Chloride, total	46.0	mg/L
APW10	Compliance	E001	04/27/2023	Chromium, total	0.0028 U	mg/L
APW10	Compliance	E001	04/27/2023	Cobalt, total	0.00048 U	mg/L
APW10	Compliance	E001	04/27/2023	Dissolved Oxygen	3.40	mg/L
APW10	Compliance	E001	04/27/2023	Fluoride, total	0.217 J	mg/L
APW10	Compliance	E001	04/27/2023	Lead, total	0.00022 U	mg/L
APW10	Compliance	E001	04/27/2023	Lithium, total	0.018 J	mg/L
APW10	Compliance	E001	04/27/2023	Mercury, total	0.00014 U	mg/L
APW10	Compliance	E001	04/27/2023	Molybdenum, total	0.00650	mg/L
APW10	Compliance	E001	04/27/2023	Oxidation Reduction Potential	77.5	mV
APW10	Compliance	E001	04/27/2023	Radium 226 + Radium 228, total	0.316	pCi/L
APW10	Compliance	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW10	Compliance	E001	04/27/2023	Specific Conductance @ 25C (field)	1,461	micromhos/cm
APW10	Compliance	E001	04/27/2023	Sulfate, total	410	mg/L
APW10	Compliance	E001	04/27/2023	Temperature	15.1	degrees C
APW10	Compliance	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW10	Compliance	E001	04/27/2023	Total Dissolved Solids	1,100	mg/L
APW10	Compliance	E001	04/27/2023	Turbidity, field	0 U	NTU
APW10	Compliance	E001	04/27/2023	pH (field)	7.4	SU
APW11	Compliance	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW11	Compliance	E001	04/26/2023	Arsenic, total	0.00440	mg/L
APW11	Compliance	E001	04/26/2023	Barium, total	0.0430	mg/L
APW11	Compliance	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L
APW11	Compliance	E001	04/26/2023	Boron, total	0.0640 J+	mg/L
APW11	Compliance	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW11	Compliance	E001	04/26/2023	Calcium, total	120	mg/L
APW11	Compliance	E001	04/26/2023	Chloride, total	26.0	mg/L
APW11	Compliance	E001	04/26/2023	Chromium, total	0.00700 J+	mg/L
APW11	Compliance	E001	04/26/2023	Cobalt, total	0.00210	mg/L
APW11	Compliance	E001	04/26/2023	Dissolved Oxygen	0.640	mg/L
APW11	Compliance	E001	04/26/2023	Fluoride, total	0.283	mg/L
APW11	Compliance	E001	04/26/2023	Lead, total	0.00630	mg/L
APW11	Compliance	E001	04/26/2023	Lithium, total	0.0200	mg/L
APW11	Compliance	E001	04/26/2023	Mercury, total	0.00014 J	mg/L
APW11	Compliance	E001	04/26/2023	Molybdenum, total	0.00430	mg/L

TABLE 1.
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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW11	Compliance	E001	04/26/2023	Oxidation Reduction Potential	-17.8	mV
APW11	Compliance	E001	04/26/2023	Radium 226 + Radium 228, total	2.17 J	pCi/L
APW11	Compliance	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW11	Compliance	E001	04/26/2023	Specific Conductance @ 25C (field)	1,252	micromhos/cm
APW11	Compliance	E001	04/26/2023	Sulfate, total	260	mg/L
APW11	Compliance	E001	04/26/2023	Temperature	15.5	degrees C
APW11	Compliance	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW11	Compliance	E001	04/26/2023	Total Dissolved Solids	920 J+	mg/L
APW11	Compliance	E001	04/26/2023	Turbidity, field	446	NTU
APW11	Compliance	E001	04/26/2023	pH (field)	7.2	SU
APW12	Compliance	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW12	Compliance	E001	04/26/2023	Arsenic, total	0.00140	mg/L
APW12	Compliance	E001	04/26/2023	Barium, total	0.0280	mg/L
APW12	Compliance	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L
APW12	Compliance	E001	04/26/2023	Boron, total	0.440	mg/L
APW12	Compliance	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW12	Compliance	E001	04/26/2023	Calcium, total	230	mg/L
APW12	Compliance	E001	04/26/2023	Chloride, total	23.0	mg/L
APW12	Compliance	E001	04/26/2023	Chromium, total	0.003 U	mg/L
APW12	Compliance	E001	04/26/2023	Cobalt, total	0.0012 J	mg/L
APW12	Compliance	E001	04/26/2023	Dissolved Oxygen	0.980	mg/L
APW12	Compliance	E001	04/26/2023	Fluoride, total	0.04 U	mg/L
APW12	Compliance	E001	04/26/2023	Lead, total	0.00022 U	mg/L
APW12	Compliance	E001	04/26/2023	Lithium, total	0.0240	mg/L
APW12	Compliance	E001	04/26/2023	Mercury, total	0.00014 U	mg/L
APW12	Compliance	E001	04/26/2023	Molybdenum, total	0.00074 U	mg/L
APW12	Compliance	E001	04/26/2023	Oxidation Reduction Potential	107	mV
APW12	Compliance	E001	04/26/2023	Radium 226 + Radium 228, total	0.0586	pCi/L
APW12	Compliance	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW12	Compliance	E001	04/26/2023	Specific Conductance @ 25C (field)	1,831	micromhos/cm
APW12	Compliance	E001	04/26/2023	Sulfate, total	540	mg/L
APW12	Compliance	E001	04/26/2023	Temperature	14.6	degrees C
APW12	Compliance	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW12	Compliance	E001	04/26/2023	Total Dissolved Solids	1,500 J+	mg/L
APW12	Compliance	E001	04/26/2023	Turbidity, field	0.520	NTU
APW12	Compliance	E001	04/26/2023	pH (field)	6.5	SU
APW13	Compliance	E001	04/27/2023	Antimony, total	0.00043 U	mg/L
APW13	Compliance	E001	04/27/2023	Arsenic, total	0.00400	mg/L
APW13	Compliance	E001	04/27/2023	Barium, total	0.0500	mg/L
APW13	Compliance	E001	04/27/2023	Beryllium, total	0.00059 U	mg/L
APW13	Compliance	E001	04/27/2023	Boron, total	0.110 J+	mg/L
APW13	Compliance	E001	04/27/2023	Cadmium, total	0.00074 U	mg/L
APW13	Compliance	E001	04/27/2023	Calcium, total	120	mg/L
APW13	Compliance	E001	04/27/2023	Chloride, total	51.0	mg/L
APW13	Compliance	E001	04/27/2023	Chromium, total	0.0028 U	mg/L
APW13	Compliance	E001	04/27/2023	Cobalt, total	0.00048 U	mg/L

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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW13	Compliance	E001	04/27/2023	Dissolved Oxygen	1.60	mg/L
APW13	Compliance	E001	04/27/2023	Fluoride, total	0.394	mg/L
APW13	Compliance	E001	04/27/2023	Lead, total	0.00022 U	mg/L
APW13	Compliance	E001	04/27/2023	Lithium, total	0.0210	mg/L
APW13	Compliance	E001	04/27/2023	Mercury, total	0.00014 U	mg/L
APW13	Compliance	E001	04/27/2023	Molybdenum, total	0.00670	mg/L
APW13	Compliance	E001	04/27/2023	Oxidation Reduction Potential	-25.3	mV
APW13	Compliance	E001	04/27/2023	Radium 226 + Radium 228, total	0.651	pCi/L
APW13	Compliance	E001	04/27/2023	Selenium, total	0.00074 U	mg/L
APW13	Compliance	E001	04/27/2023	Specific Conductance @ 25C (field)	1,360	micromhos/cm
APW13	Compliance	E001	04/27/2023	Sulfate, total	250	mg/L
APW13	Compliance	E001	04/27/2023	Temperature	14.3	degrees C
APW13	Compliance	E001	04/27/2023	Thallium, total	0.00038 U	mg/L
APW13	Compliance	E001	04/27/2023	Total Dissolved Solids	940	mg/L
APW13	Compliance	E001	04/27/2023	Turbidity, field	0 U	NTU
APW13	Compliance	E001	04/27/2023	pH (field)	7.3	SU
APW14	Compliance	E001	04/28/2023	Antimony, total	0.00043 U	mg/L
APW14	Compliance	E001	04/28/2023	Arsenic, total	0.00550	mg/L
APW14	Compliance	E001	04/28/2023	Barium, total	0.0650	mg/L
APW14	Compliance	E001	04/28/2023	Beryllium, total	0.00059 U	mg/L
APW14	Compliance	E001	04/28/2023	Boron, total	0.100 J+	mg/L
APW14	Compliance	E001	04/28/2023	Cadmium, total	0.00074 U	mg/L
APW14	Compliance	E001	04/28/2023	Calcium, total	130	mg/L
APW14	Compliance	E001	04/28/2023	Chloride, total	46.0	mg/L
APW14	Compliance	E001	04/28/2023	Chromium, total	0.0028 U	mg/L
APW14	Compliance	E001	04/28/2023	Cobalt, total	0.00048 U	mg/L
APW14	Compliance	E001	04/28/2023	Dissolved Oxygen	1.20	mg/L
APW14	Compliance	E001	04/28/2023	Fluoride, total	0.243 J	mg/L
APW14	Compliance	E001	04/28/2023	Lead, total	0.00022 U	mg/L
APW14	Compliance	E001	04/28/2023	Lithium, total	0.016 J	mg/L
APW14	Compliance	E001	04/28/2023	Mercury, total	0.00014 U	mg/L
APW14	Compliance	E001	04/28/2023	Molybdenum, total	0.00400	mg/L
APW14	Compliance	E001	04/28/2023	Oxidation Reduction Potential	-95.0	mV
APW14	Compliance	E001	04/28/2023	Radium 226 + Radium 228, total	0.381 J	pCi/L
APW14	Compliance	E001	04/28/2023	Selenium, total	0.00074 U	mg/L
APW14	Compliance	E001	04/28/2023	Specific Conductance @ 25C (field)	1,480	micromhos/cm
APW14	Compliance	E001	04/28/2023	Sulfate, total	380	mg/L
APW14	Compliance	E001	04/28/2023	Temperature	14.8	degrees C
APW14	Compliance	E001	04/28/2023	Thallium, total	0.00038 U	mg/L
APW14	Compliance	E001	04/28/2023	Total Dissolved Solids	980	mg/L
APW14	Compliance	E001	04/28/2023	Turbidity, field	8.81	NTU
APW14	Compliance	E001	04/28/2023	pH (field)	7.3	SU
APW15	Compliance	E001	04/26/2023	Antimony, total	0.00043 U	mg/L
APW15	Compliance	E001	04/26/2023	Arsenic, total	0.0210	mg/L
APW15	Compliance	E001	04/26/2023	Barium, total	0.530	mg/L
APW15	Compliance	E001	04/26/2023	Beryllium, total	0.00059 U	mg/L

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
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NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW15	Compliance	E001	04/26/2023	Boron, total	0.130	mg/L
APW15	Compliance	E001	04/26/2023	Cadmium, total	0.00074 U	mg/L
APW15	Compliance	E001	04/26/2023	Calcium, total	91.0	mg/L
APW15	Compliance	E001	04/26/2023	Chloride, total	270	mg/L
APW15	Compliance	E001	04/26/2023	Chromium, total	0.00640 J+	mg/L
APW15	Compliance	E001	04/26/2023	Cobalt, total	0.0011 J	mg/L
APW15	Compliance	E001	04/26/2023	Dissolved Oxygen	0.320	mg/L
APW15	Compliance	E001	04/26/2023	Fluoride, total	0.402	mg/L
APW15	Compliance	E001	04/26/2023	Lead, total	0.00120	mg/L
APW15	Compliance	E001	04/26/2023	Lithium, total	0.0064 J	mg/L
APW15	Compliance	E001	04/26/2023	Mercury, total	0.00014 U	mg/L
APW15	Compliance	E001	04/26/2023	Molybdenum, total	0.00650	mg/L
APW15	Compliance	E001	04/26/2023	Oxidation Reduction Potential	-126	mV
APW15	Compliance	E001	04/26/2023	Radium 226 + Radium 228, total	1.97	pCi/L
APW15	Compliance	E001	04/26/2023	Selenium, total	0.00074 U	mg/L
APW15	Compliance	E001	04/26/2023	Specific Conductance @ 25C (field)	1,682	micromhos/cm
APW15	Compliance	E001	04/26/2023	Sulfate, total	0.4 J	mg/L
APW15	Compliance	E001	04/26/2023	Temperature	15.3	degrees C
APW15	Compliance	E001	04/26/2023	Thallium, total	0.00038 U	mg/L
APW15	Compliance	E001	04/26/2023	Total Dissolved Solids	1,100 J+	mg/L
APW15	Compliance	E001	04/26/2023	Turbidity, field	51.6	NTU
APW15	Compliance	E001	04/26/2023	pH (field)	7.2	SU
APW16	Compliance	E001	04/25/2023	Antimony, total	0.00043 U	mg/L
APW16	Compliance	E001	04/25/2023	Arsenic, total	0.0210	mg/L
APW16	Compliance	E001	04/25/2023	Barium, total	0.540	mg/L
APW16	Compliance	E001	04/25/2023	Beryllium, total	0.00059 U	mg/L
APW16	Compliance	E001	04/25/2023	Boron, total	0.130	mg/L
APW16	Compliance	E001	04/25/2023	Cadmium, total	0.00074 U	mg/L
APW16	Compliance	E001	04/25/2023	Calcium, total	96.0	mg/L
APW16	Compliance	E001	04/25/2023	Chloride, total	71.0	mg/L
APW16	Compliance	E001	04/25/2023	Chromium, total	0.0028 U	mg/L
APW16	Compliance	E001	04/25/2023	Cobalt, total	0.00048 U	mg/L
APW16	Compliance	E001	04/25/2023	Dissolved Oxygen	1.20	mg/L
APW16	Compliance	E001	04/25/2023	Fluoride, total	0.606	mg/L
APW16	Compliance	E001	04/25/2023	Lead, total	0.00036 J	mg/L
APW16	Compliance	E001	04/25/2023	Lithium, total	0.005 U	mg/L
APW16	Compliance	E001	04/25/2023	Mercury, total	0.00014 U	mg/L
APW16	Compliance	E001	04/25/2023	Molybdenum, total	0.00074 U	mg/L
APW16	Compliance	E001	04/25/2023	Oxidation Reduction Potential	-104	mV
APW16	Compliance	E001	04/25/2023	Radium 226 + Radium 228, total	2.05	pCi/L
APW16	Compliance	E001	04/25/2023	Selenium, total	0.00074 U	mg/L
APW16	Compliance	E001	04/25/2023	Specific Conductance @ 25C (field)	953	micromhos/cm
APW16	Compliance	E001	04/25/2023	Sulfate, total	0.65 J	mg/L
APW16	Compliance	E001	04/25/2023	Temperature	14.0	degrees C
APW16	Compliance	E001	04/25/2023	Thallium, total	0.00038 U	mg/L
APW16	Compliance	E001	04/25/2023	Total Dissolved Solids	800	mg/L

TABLE 1.
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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW16	Compliance	E001	04/25/2023	Turbidity, field	0.210	NTU
APW16	Compliance	E001	04/25/2023	pH (field)	7.7	SU
APW17	Compliance	E001	04/25/2023	Antimony, total	0.00043 U	mg/L
APW17	Compliance	E001	04/25/2023	Arsenic, total	0.0200	mg/L
APW17	Compliance	E001	04/25/2023	Barium, total	0.550	mg/L
APW17	Compliance	E001	04/25/2023	Beryllium, total	0.00059 U	mg/L
APW17	Compliance	E001	04/25/2023	Boron, total	0.0830	mg/L
APW17	Compliance	E001	04/25/2023	Cadmium, total	0.00074 U	mg/L
APW17	Compliance	E001	04/25/2023	Calcium, total	110	mg/L
APW17	Compliance	E001	04/25/2023	Chloride, total	56.0	mg/L
APW17	Compliance	E001	04/25/2023	Chromium, total	0.0028 U	mg/L
APW17	Compliance	E001	04/25/2023	Cobalt, total	0.00048 U	mg/L
APW17	Compliance	E001	04/25/2023	Dissolved Oxygen	1.20	mg/L
APW17	Compliance	E001	04/25/2023	Fluoride, total	0.483	mg/L
APW17	Compliance	E001	04/25/2023	Lead, total	0.00022 U	mg/L
APW17	Compliance	E001	04/25/2023	Lithium, total	0.005 U	mg/L
APW17	Compliance	E001	04/25/2023	Mercury, total	0.00014 U	mg/L
APW17	Compliance	E001	04/25/2023	Molybdenum, total	0.00530	mg/L
APW17	Compliance	E001	04/25/2023	Oxidation Reduction Potential	-97.2	mV
APW17	Compliance	E001	04/25/2023	Radium 226 + Radium 228, total	1.42	pCi/L
APW17	Compliance	E001	04/25/2023	Selenium, total	0.00074 U	mg/L
APW17	Compliance	E001	04/25/2023	Specific Conductance @ 25C (field)	1,162	micromhos/cm
APW17	Compliance	E001	04/25/2023	Sulfate, total	52.0	mg/L
APW17	Compliance	E001	04/25/2023	Temperature	15.2	degrees C
APW17	Compliance	E001	04/25/2023	Thallium, total	0.00038 U	mg/L
APW17	Compliance	E001	04/25/2023	Total Dissolved Solids	700	mg/L
APW17	Compliance	E001	04/25/2023	Turbidity, field	3.82	NTU
APW17	Compliance	E001	04/25/2023	pH (field)	7.6	SU
APW18	Compliance	E001	04/25/2023	Antimony, total	0.00043 U	mg/L
APW18	Compliance	E001	04/25/2023	Arsenic, total	0.00270	mg/L
APW18	Compliance	E001	04/25/2023	Barium, total	0.350	mg/L
APW18	Compliance	E001	04/25/2023	Beryllium, total	0.00059 U	mg/L
APW18	Compliance	E001	04/25/2023	Boron, total	0.100	mg/L
APW18	Compliance	E001	04/25/2023	Cadmium, total	0.00074 U	mg/L
APW18	Compliance	E001	04/25/2023	Calcium, total	75.0	mg/L
APW18	Compliance	E001	04/25/2023	Chloride, total	24.0	mg/L
APW18	Compliance	E001	04/25/2023	Chromium, total	0.0028 U	mg/L
APW18	Compliance	E001	04/25/2023	Cobalt, total	0.00048 U	mg/L
APW18	Compliance	E001	04/25/2023	Dissolved Oxygen	1.00	mg/L
APW18	Compliance	E001	04/25/2023	Fluoride, total	0.518	mg/L
APW18	Compliance	E001	04/25/2023	Lead, total	0.00022 U	mg/L
APW18	Compliance	E001	04/25/2023	Lithium, total	0.0052 J	mg/L
APW18	Compliance	E001	04/25/2023	Mercury, total	0.00014 U	mg/L
APW18	Compliance	E001	04/25/2023	Molybdenum, total	0.00290	mg/L
APW18	Compliance	E001	04/25/2023	Oxidation Reduction Potential	-137	mV
APW18	Compliance	E001	04/25/2023	Radium 226 + Radium 228, total	1.33	pCi/L

TABLE 1.
FIELD PARAMETERS AND ANALYTICAL RESULTS - QUARTER 2, 2023
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Well ID	Well Type	Event	Date	Parameter	Result	Unit
APW18	Compliance	E001	04/25/2023	Selenium, total	0.00074 U	mg/L
APW18	Compliance	E001	04/25/2023	Specific Conductance @ 25C (field)	1,012	micromhos/cm
APW18	Compliance	E001	04/25/2023	Sulfate, total	52.0	mg/L
APW18	Compliance	E001	04/25/2023	Temperature	15.2	degrees C
APW18	Compliance	E001	04/25/2023	Thallium, total	0.00038 U	mg/L
APW18	Compliance	E001	04/25/2023	Total Dissolved Solids	660	mg/L
APW18	Compliance	E001	04/25/2023	Turbidity, field	5.01	NTU
APW18	Compliance	E001	04/25/2023	pH (field)	7.8	SU

Notes:
C = Celsius
cm = centimeter
mg/L = milligrams per liter
mV = millivolts
NTU = Nephelometric Turbidity Units
pCi/L = picocuries per liter
SU = Standard Units
J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.
J+ = The result is an estimated quantity, but the result may be biased high.
U = The analyte was analyzed for, but was not detected above the level of the adjusted detection limit or quantitation limit, as appropriate.

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
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NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW02	UD	E001	Antimony, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW02	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/27/23	10	70	CI around median	0.001	0.059	Background	No Exceedance
APW02	UD	E001	Barium, total	mg/L	02/17/21 - 04/27/23	10	0	CB around linear reg	0.00275	2	Standard	No Exceedance
APW02	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW02	UD	E001	Boron, total	mg/L	02/17/21 - 04/27/23	10	0	CI around geomean	0.105	2	Standard	No Exceedance
APW02	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW02	UD	E001	Chloride, total	mg/L	02/17/21 - 04/27/23	10	0	CI around mean	100	200	Standard	No Exceedance
APW02	UD	E001	Chromium, total	mg/L	02/17/21 - 04/27/23	10	90	Most recent sample	0.004	0.1	Standard	No Exceedance
APW02	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW02	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.25	4	Standard	No Exceedance
APW02	UD	E001	Lead, total	mg/L	02/17/21 - 04/27/23	10	90	CI around median	0.001	0.0075	Standard	No Exceedance
APW02	UD	E001	Lithium, total	mg/L	02/17/21 - 04/27/23	10	0	CI around geomean	0.0888	0.04	Standard	Determined
APW02	UD	E001	Mercury, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW02	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/27/23	9	67	CI around median	0.001	0.1	Standard	No Exceedance
APW02	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/27/23	9	0	CI around mean	0.227	6.9	Background	No Exceedance
APW02	UD	E001	Selenium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW02	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/27/23	10	0	CI around median	2,900	400	Standard	Determined
APW02	UD	E001	Thallium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW02	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/27/23	16	0	CB around linear reg	5,180	1,200	Standard	Determined
APW02	UD	E001	pH (field)	SU	02/17/21 - 04/27/23	16	0	CI around mean	6.6/6.8	6.4/9	Background/Standard	No Exceedance
APW03	UD	E001	Antimony, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW03	UD	E001	Arsenic, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.059	Background	No Exceedance
APW03	UD	E001	Barium, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	0.0648	2	Standard	No Exceedance
APW03	UD	E001	Beryllium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW03	UD	E001	Boron, total	mg/L	02/18/21 - 04/25/23	10	0	CI around geomean	0.377	2	Standard	No Exceedance
APW03	UD	E001	Cadmium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW03	UD	E001	Chloride, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	7.35	200	Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
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NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW03	UD	E001	Chromium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.004	0.1	Standard	No Exceedance
APW03	UD	E001	Cobalt, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW03	UD	E001	Fluoride, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.25	4	Standard	No Exceedance
APW03	UD	E001	Lead, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.001	0.0075	Standard	No Exceedance
APW03	UD	E001	Lithium, total	mg/L	02/18/21 - 04/25/23	10	40	CI around median	0.02	0.04	Standard	No Exceedance
APW03	UD	E001	Mercury, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.0002	0.002	Standard	No Exceedance
APW03	UD	E001	Molybdenum, total	mg/L	02/18/21 - 04/25/23	9	11	CI around mean	0.000992	0.1	Standard	No Exceedance
APW03	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/25/23	9	0	CI around mean	0.123	6.9	Background	No Exceedance
APW03	UD	E001	Selenium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW03	UD	E001	Sulfate, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	139	400	Standard	No Exceedance
APW03	UD	E001	Thallium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW03	UD	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/25/23	16	0	CI around mean	628	1,200	Standard	No Exceedance
APW03	UD	E001	pH (field)	SU	02/18/21 - 04/25/23	16	0	CI around mean	6.8/7.2	6.4/9	Background/Standard	No Exceedance
APW04	UD	E001	Antimony, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW04	UD	E001	Arsenic, total	mg/L	02/18/21 - 04/25/23	10	40	CI around geomean	0.000941	0.059	Background	No Exceedance
APW04	UD	E001	Barium, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	0.0181	2	Standard	No Exceedance
APW04	UD	E001	Beryllium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW04	UD	E001	Boron, total	mg/L	02/18/21 - 04/25/23	10	0	CI around median	0.024	2	Standard	No Exceedance
APW04	UD	E001	Cadmium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.001	0.005	Standard	No Exceedance
APW04	UD	E001	Chloride, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	29.3	200	Standard	No Exceedance
APW04	UD	E001	Chromium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.004	0.1	Standard	No Exceedance
APW04	UD	E001	Cobalt, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW04	UD	E001	Fluoride, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.25	4	Standard	No Exceedance
APW04	UD	E001	Lead, total	mg/L	02/18/21 - 04/25/23	10	60	CI around median	0.001	0.0075	Standard	No Exceedance
APW04	UD	E001	Lithium, total	mg/L	02/18/21 - 04/25/23	10	30	CI around median	0.02	0.04	Standard	No Exceedance
APW04	UD	E001	Mercury, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.0002	0.002	Standard	No Exceedance
APW04	UD	E001	Molybdenum, total	mg/L	02/18/21 - 04/25/23	9	89	CI around median	0.001	0.1	Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW04	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/25/23	9	0	CI around mean	0.0207	6.9	Background	No Exceedance
APW04	UD	E001	Selenium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW04	UD	E001	Sulfate, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	844	400	Standard	Determined
APW04	UD	E001	Thallium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW04	UD	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/25/23	16	0	CI around mean	1,710	1,200	Standard	Determined
APW04	UD	E001	pH (field)	SU	02/18/21 - 04/25/23	16	0	CB around linear reg	6.9/8.0	6.4/9	Background/Standard	No Exceedance
APW05S	UD	E001	Antimony, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW05S	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/26/23	9	33	CI around mean	0.00105	0.059	Background	No Exceedance
APW05S	UD	E001	Barium, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	0.048	2	Standard	No Exceedance
APW05S	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW05S	UD	E001	Boron, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	0.04	2	Standard	No Exceedance
APW05S	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.001	0.005	Standard	No Exceedance
APW05S	UD	E001	Chloride, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	190	200	Standard	No Exceedance
APW05S	UD	E001	Chromium, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.004	0.1	Standard	No Exceedance
APW05S	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/26/23	9	33	CI around geomean	0.00185	0.006	Standard	No Exceedance
APW05S	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/26/23	9	0	CI around mean	0.349	4	Standard	No Exceedance
APW05S	UD	E001	Lead, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.001	0.0075	Standard	No Exceedance
APW05S	UD	E001	Lithium, total	mg/L	02/17/21 - 04/26/23	9	0	CI around geomean	0.0332	0.04	Standard	No Exceedance
APW05S	UD	E001	Mercury, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW05S	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/26/23	8	0	CB around linear reg	-0.000835	0.1	Standard	No Exceedance
APW05S	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/26/23	8	0	CI around geomean	0.128	6.9	Background	No Exceedance
APW05S	UD	E001	Selenium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW05S	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	640	400	Standard	Determined
APW05S	UD	E001	Thallium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW05S	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/26/23	9	0	CI around mean	3,450	1,200	Standard	Determined
APW05S	UD	E001	pH (field)	SU	02/17/21 - 04/26/23	9	0	CI around mean	6.7/7.0	6.4/9	Background/Standard	No Exceedance
APW07	UA	E001	Antimony, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.003	0.006	Standard	No Exceedance

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NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW07	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.0127	0.059	Background	No Exceedance
APW07	UA	E001	Barium, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.465	2	Standard	No Exceedance
APW07	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW07	UA	E001	Boron, total	mg/L	12/15/15 - 04/27/23	22	0	CB around T-S line	0.0841	2	Standard	No Exceedance
APW07	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW07	UA	E001	Chloride, total	mg/L	12/15/15 - 04/27/23	24	0	CB around T-S line	57.5	200	Standard	No Exceedance
APW07	UA	E001	Chromium, total	mg/L	12/15/15 - 04/27/23	12	75	CI around median	0.004	0.1	Standard	No Exceedance
APW07	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/27/23	11	82	CI around median	0.002	0.006	Standard	No Exceedance
APW07	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/27/23	22	4	CI around mean	0.36	4	Standard	No Exceedance
APW07	UA	E001	Lead, total	mg/L	12/15/15 - 04/27/23	12	58	CI around median	0.001	0.0075	Standard	No Exceedance
APW07	UA	E001	Lithium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.02	0.04	Standard	No Exceedance
APW07	UA	E001	Mercury, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW07	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/27/23	11	0	CB around linear reg	-0.00442	0.1	Standard	No Exceedance
APW07	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/27/23	12	0	CI around mean	1.31	6.9	Background	No Exceedance
APW07	UA	E001	Selenium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW07	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/27/23	23	17	CB around T-S line	6.15	400	Standard	No Exceedance
APW07	UA	E001	Thallium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW07	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/27/23	22	0	CI around mean	486	1,200	Standard	No Exceedance
APW07	UA	E001	pH (field)	SU	12/15/15 - 04/27/23	24	0	CI around mean	7.1/7.3	6.4/9	Background/Standard	No Exceedance
APW08	UA	E001	Antimony, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW08	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/26/23	12	0	CB around linear reg	0.0188	0.059	Background	No Exceedance
APW08	UA	E001	Barium, total	mg/L	12/15/15 - 04/26/23	12	0	CB around linear reg	0.444	2	Standard	No Exceedance
APW08	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW08	UA	E001	Boron, total	mg/L	12/15/15 - 04/26/23	22	0	CI around geomean	0.0816	2	Standard	No Exceedance
APW08	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW08	UA	E001	Chloride, total	mg/L	12/15/15 - 04/26/23	24	0	CI around mean	54.7	200	Standard	No Exceedance
APW08	UA	E001	Chromium, total	mg/L	12/15/15 - 04/26/23	12	58	CI around median	0.004	0.1	Standard	No Exceedance

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APW08	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/26/23	11	73	CI around median	0.002	0.006	Standard	No Exceedance
APW08	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/26/23	22	9	CI around median	0.373	4	Standard	No Exceedance
APW08	UA	E001	Lead, total	mg/L	12/15/15 - 04/26/23	12	50	CI around median	0.001	0.0075	Standard	No Exceedance
APW08	UA	E001	Lithium, total	mg/L	12/15/15 - 04/26/23	12	67	CI around median	0.01	0.04	Standard	No Exceedance
APW08	UA	E001	Mercury, total	mg/L	12/15/15 - 04/26/23	12	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW08	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/26/23	11	0	CI around mean	0.00453	0.1	Standard	No Exceedance
APW08	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/26/23	12	0	CI around mean	1.03	6.9	Background	No Exceedance
APW08	UA	E001	Selenium, total	mg/L	12/15/15 - 04/26/23	12	92	CI around median	0.001	0.05	Standard	No Exceedance
APW08	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/26/23	23	0	CB around linear reg	44	400	Standard	No Exceedance
APW08	UA	E001	Thallium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW08	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/26/23	22	0	CB around linear reg	592	1,200	Standard	No Exceedance
APW08	UA	E001	pH (field)	SU	12/15/15 - 04/26/23	25	0	CI around mean	7.2/7.4	6.4/9	Background/Standard	No Exceedance
APW09	UA	E001	Antimony, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW09	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.0223	0.059	Background	No Exceedance
APW09	UA	E001	Barium, total	mg/L	12/15/15 - 04/27/23	12	0	CI around mean	0.277	2	Standard	No Exceedance
APW09	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW09	UA	E001	Boron, total	mg/L	12/15/15 - 04/27/23	22	0	CB around T-S line	0.0809	2	Standard	No Exceedance
APW09	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW09	UA	E001	Chloride, total	mg/L	12/15/15 - 04/27/23	24	0	CI around median	95	200	Standard	No Exceedance
APW09	UA	E001	Chromium, total	mg/L	12/15/15 - 04/27/23	12	67	CB around T-S line	0.004	0.1	Standard	No Exceedance
APW09	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/27/23	11	91	CI around median	0.002	0.006	Standard	No Exceedance
APW09	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/27/23	22	4	CI around mean	0.438	4	Standard	No Exceedance
APW09	UA	E001	Lead, total	mg/L	12/15/15 - 04/27/23	12	50	CI around median	0.001	0.0075	Standard	No Exceedance
APW09	UA	E001	Lithium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.02	0.04	Standard	No Exceedance
APW09	UA	E001	Mercury, total	mg/L	12/15/15 - 04/27/23	12	83	CI around median	0.0002	0.002	Standard	No Exceedance
APW09	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/27/23	11	0	CB around linear reg	-0.00854	0.1	Standard	No Exceedance
APW09	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/27/23	12	0	CI around geomean	0.828	6.9	Background	No Exceedance

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Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW09	UA	E001	Selenium, total	mg/L	12/15/15 - 04/27/23	12	92	CI around median	0.001	0.05	Standard	No Exceedance
APW09	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/27/23	23	9	CI around geomean	4	400	Standard	No Exceedance
APW09	UA	E001	Thallium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW09	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/27/23	23	0	CB around T-S line	734	1,200	Standard	No Exceedance
APW09	UA	E001	pH (field)	SU	12/15/15 - 04/27/23	24	0	CI around median	7.4/7.5	6.4/9	Background/Standard	No Exceedance
APW10	UA	E001	Antimony, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW10	UA	E001	Arsenic, total	mg/L	12/16/15 - 04/27/23	14	0	CI around mean	0.0059	0.059	Background	No Exceedance
APW10	UA	E001	Barium, total	mg/L	12/16/15 - 04/27/23	14	0	CI around mean	0.0286	2	Standard	No Exceedance
APW10	UA	E001	Beryllium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW10	UA	E001	Boron, total	mg/L	12/16/15 - 04/27/23	24	0	CB around linear reg	0.0764	2	Standard	No Exceedance
APW10	UA	E001	Cadmium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW10	UA	E001	Chloride, total	mg/L	12/16/15 - 04/27/23	25	0	CI around mean	45.4	200	Standard	No Exceedance
APW10	UA	E001	Chromium, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.004	0.1	Standard	No Exceedance
APW10	UA	E001	Cobalt, total	mg/L	12/16/15 - 04/27/23	13	92	CI around median	0.002	0.006	Standard	No Exceedance
APW10	UA	E001	Fluoride, total	mg/L	12/16/15 - 04/27/23	24	21	CI around mean	0.298	4	Standard	No Exceedance
APW10	UA	E001	Lead, total	mg/L	12/16/15 - 04/27/23	14	86	CI around median	0.001	0.0075	Standard	No Exceedance
APW10	UA	E001	Lithium, total	mg/L	12/16/15 - 04/27/23	14	7	CB around linear reg	0.0132	0.04	Standard	No Exceedance
APW10	UA	E001	Mercury, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW10	UA	E001	Molybdenum, total	mg/L	12/16/15 - 04/27/23	13	0	CB around linear reg	0.00524	0.1	Standard	No Exceedance
APW10	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/16/15 - 04/27/23	14	0	CI around mean	0.442	6.9	Background	No Exceedance
APW10	UA	E001	Selenium, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW10	UA	E001	Sulfate, total	mg/L	12/16/15 - 04/27/23	25	0	CI around median	410	400	Standard	Determined
APW10	UA	E001	Thallium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW10	UA	E001	Total Dissolved Solids	mg/L	12/16/15 - 04/27/23	26	0	CB around linear reg	1,030	1,200	Standard	No Exceedance
APW10	UA	E001	pH (field)	SU	12/16/15 - 04/27/23	27	0	CB around linear reg	7.2/7.5	6.4/9	Background/Standard	No Exceedance
APW11	UA	E001	Antimony, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW11	UA	E001	Arsenic, total	mg/L	02/18/21 - 04/26/23	10	0	CI around mean	0.0015	0.059	Background	No Exceedance

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APW11	UA	E001	Barium, total	mg/L	02/18/21 - 04/26/23	10	0	CB around T-S line	-0.566	2	Standard	No Exceedance
APW11	UA	E001	Beryllium, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW11	UA	E001	Boron, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	0.063	2	Standard	No Exceedance
APW11	UA	E001	Cadmium, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW11	UA	E001	Chloride, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	26	200	Standard	No Exceedance
APW11	UA	E001	Chromium, total	mg/L	02/18/21 - 04/26/23	10	70	CI around median	0.004	0.1	Standard	No Exceedance
APW11	UA	E001	Cobalt, total	mg/L	02/18/21 - 04/26/23	10	70	CI around median	0.002	0.006	Standard	No Exceedance
APW11	UA	E001	Fluoride, total	mg/L	02/18/21 - 04/26/23	10	50	CI around geomean	0.245	4	Standard	No Exceedance
APW11	UA	E001	Lead, total	mg/L	02/18/21 - 04/26/23	10	60	CI around median	0.001	0.0075	Standard	No Exceedance
APW11	UA	E001	Lithium, total	mg/L	02/18/21 - 04/26/23	10	10	CI around mean	0.0175	0.04	Standard	No Exceedance
APW11	UA	E001	Mercury, total	mg/L	02/18/21 - 04/26/23	10	80	CI around median	0.0002	0.002	Standard	No Exceedance
APW11	UA	E001	Molybdenum, total	mg/L	02/18/21 - 04/26/23	9	0	CB around T-S line	-0.0661	0.1	Standard	No Exceedance
APW11	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/26/23	9	0	CI around mean	0.424	6.9	Background	No Exceedance
APW11	UA	E001	Selenium, total	mg/L	02/18/21 - 04/26/23	10	80	CI around median	0.001	0.05	Standard	No Exceedance
APW11	UA	E001	Sulfate, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	260	400	Standard	No Exceedance
APW11	UA	E001	Thallium, total	mg/L	02/18/21 - 04/26/23	10	90	CI around median	0.001	0.002	Standard	No Exceedance
APW11	UA	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/26/23	10	0	CI around mean	809	1,200	Standard	No Exceedance
APW11	UA	E001	pH (field)	SU	02/18/21 - 04/26/23	10	0	CI around median	6.6/7.2	6.4/9	Background/Standard	No Exceedance
APW12	UD	E001	Antimony, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW12	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	0.00155	0.059	Background	No Exceedance
APW12	UD	E001	Barium, total	mg/L	02/17/21 - 04/26/23	10	0	CB around linear reg	0.0133	2	Standard	No Exceedance
APW12	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW12	UD	E001	Boron, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	0.18	2	Standard	No Exceedance
APW12	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW12	UD	E001	Chloride, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	21.3	200	Standard	No Exceedance
APW12	UD	E001	Chromium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.004	0.1	Standard	No Exceedance
APW12	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/26/23	10	20	CB around linear reg	-0.00198	0.006	Standard	No Exceedance

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NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW12	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.25	4	Standard	No Exceedance
APW12	UD	E001	Lead, total	mg/L	02/17/21 - 04/26/23	10	90	CI around median	0.001	0.0075	Standard	No Exceedance
APW12	UD	E001	Lithium, total	mg/L	02/17/21 - 04/26/23	10	0	CI around geomean	0.0244	0.04	Standard	No Exceedance
APW12	UD	E001	Mercury, total	mg/L	02/17/21 - 04/26/23	10	90	CI around median	0.0002	0.002	Standard	No Exceedance
APW12	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/26/23	9	44	CI around geomean	0.000964	0.1	Standard	No Exceedance
APW12	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/26/23	9	0	CI around geomean	0.14	6.9	Background	No Exceedance
APW12	UD	E001	Selenium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW12	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	253	400	Standard	No Exceedance
APW12	UD	E001	Thallium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW12	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	1,160	1,200	Standard	No Exceedance
APW12	UD	E001	pH (field)	SU	02/17/21 - 04/26/23	10	0	CI around mean	6.2/6.6	6.4/9	Background/Standard	No Exceedance
APW13	UA	E001	Antimony, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW13	UA	E001	Arsenic, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.00314	0.059	Background	No Exceedance
APW13	UA	E001	Barium, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.05	2	Standard	No Exceedance
APW13	UA	E001	Beryllium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW13	UA	E001	Boron, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.105	2	Standard	No Exceedance
APW13	UA	E001	Cadmium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW13	UA	E001	Chloride, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	46.2	200	Standard	No Exceedance
APW13	UA	E001	Chromium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.004	0.1	Standard	No Exceedance
APW13	UA	E001	Cobalt, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW13	UA	E001	Fluoride, total	mg/L	02/22/21 - 04/27/23	10	10	CI around mean	0.285	4	Standard	No Exceedance
APW13	UA	E001	Lead, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.0075	Standard	No Exceedance
APW13	UA	E001	Lithium, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.0262	0.04	Standard	No Exceedance
APW13	UA	E001	Mercury, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW13	UA	E001	Molybdenum, total	mg/L	02/22/21 - 04/27/23	9	0	CB around linear reg	-0.00498	0.1	Standard	No Exceedance
APW13	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/22/21 - 04/27/23	9	0	CI around mean	0.245	6.9	Background	No Exceedance
APW13	UA	E001	Selenium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW13	UA	E001	Sulfate, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	210	400	Standard	No Exceedance
APW13	UA	E001	Thallium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW13	UA	E001	Total Dissolved Solids	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	801	1,200	Standard	No Exceedance
APW13	UA	E001	pH (field)	SU	02/22/21 - 04/27/23	10	0	CI around median	7.1/7.3	6.4/9	Background/Standard	No Exceedance
APW14	UA	E001	Antimony, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW14	UA	E001	Arsenic, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.00506	0.059	Background	No Exceedance
APW14	UA	E001	Barium, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.0752	2	Standard	No Exceedance
APW14	UA	E001	Beryllium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW14	UA	E001	Boron, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.0949	2	Standard	No Exceedance
APW14	UA	E001	Cadmium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW14	UA	E001	Chloride, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	41.8	200	Standard	No Exceedance
APW14	UA	E001	Chromium, total	mg/L	02/22/21 - 04/28/23	10	90	CI around median	0.004	0.1	Standard	No Exceedance
APW14	UA	E001	Cobalt, total	mg/L	02/22/21 - 04/28/23	10	90	CI around median	0.002	0.006	Standard	No Exceedance
APW14	UA	E001	Fluoride, total	mg/L	02/22/21 - 04/28/23	10	30	CI around mean	0.266	4	Standard	No Exceedance
APW14	UA	E001	Lead, total	mg/L	02/22/21 - 04/28/23	10	70	CI around median	0.001	0.0075	Standard	No Exceedance
APW14	UA	E001	Lithium, total	mg/L	02/22/21 - 04/28/23	10	20	CB around linear reg	-0.00217	0.04	Standard	No Exceedance
APW14	UA	E001	Mercury, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW14	UA	E001	Molybdenum, total	mg/L	02/22/21 - 04/28/23	9	0	CB around linear reg	-0.0066	0.1	Standard	No Exceedance
APW14	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/22/21 - 04/28/23	9	0	CI around mean	0.372	6.9	Background	No Exceedance
APW14	UA	E001	Selenium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW14	UA	E001	Sulfate, total	mg/L	02/22/21 - 04/28/23	10	0	CI around median	320	400	Standard	No Exceedance
APW14	UA	E001	Thallium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW14	UA	E001	Total Dissolved Solids	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	892	1,200	Standard	No Exceedance
APW14	UA	E001	pH (field)	SU	02/22/21 - 04/28/23	10	0	CI around median	7.3/7.5	6.4/9	Background/Standard	No Exceedance
APW15	UA	E001	Antimony, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW15	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.0166	0.059	Background	No Exceedance
APW15	UA	E001	Barium, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.559	2	Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW15	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW15	UA	E001	Boron, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.128	2	Standard	No Exceedance
APW15	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW15	UA	E001	Chloride, total	mg/L	02/23/21 - 04/26/23	10	0	CI around median	230	200	Standard	Determined
APW15	UA	E001	Chromium, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.004	0.1	Standard	No Exceedance
APW15	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.002	0.006	Standard	No Exceedance
APW15	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/26/23	10	0	CI around geomean	0.6	4	Standard	No Exceedance
APW15	UA	E001	Lead, total	mg/L	02/23/21 - 04/26/23	10	50	CI around median	0.001	0.0075	Standard	No Exceedance
APW15	UA	E001	Lithium, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.02	0.04	Standard	No Exceedance
APW15	UA	E001	Mercury, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW15	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/26/23	9	0	CI around mean	0.00846	0.1	Standard	No Exceedance
APW15	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/26/23	9	0	CI around mean	1.5	6.9	Background	No Exceedance
APW15	UA	E001	Selenium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW15	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	1	400	Standard	No Exceedance
APW15	UA	E001	Thallium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW15	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	1,020	1,200	Standard	No Exceedance
APW15	UA	E001	pH (field)	SU	02/23/21 - 04/26/23	10	0	CI around median	7.0/7.3	6.4/9	Background/Standard	No Exceedance
APW16	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW16	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.00767	0.059	Background	No Exceedance
APW16	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CB around linear reg	0.434	2	Standard	No Exceedance
APW16	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW16	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.128	2	Standard	No Exceedance
APW16	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW16	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	66.1	200	Standard	No Exceedance
APW16	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.004	0.1	Standard	No Exceedance
APW16	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW16	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.605	4	Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW16	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.0075	Standard	No Exceedance
APW16	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.04	Standard	No Exceedance
APW16	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW16	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	44	CB around linear reg	-0.00408	0.1	Standard	No Exceedance
APW16	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around geomean	1.22	6.9	Background	No Exceedance
APW16	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW16	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	1	400	Standard	No Exceedance
APW16	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW16	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around median	690	1,200	Standard	No Exceedance
APW16	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.2/7.6	6.4/9	Background/Standard	No Exceedance
APW17	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.003	0.006	Standard	No Exceedance
APW17	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	0	CB around linear reg	0.0181	0.059	Background	No Exceedance
APW17	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.565	2	Standard	No Exceedance
APW17	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.004	Standard	No Exceedance
APW17	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.0839	2	Standard	No Exceedance
APW17	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.005	Standard	No Exceedance
APW17	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	43.9	200	Standard	No Exceedance
APW17	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.004	0.1	Standard	No Exceedance
APW17	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.002	0.006	Standard	No Exceedance
APW17	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.394	4	Standard	No Exceedance
APW17	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.0075	Standard	No Exceedance
APW17	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.04	Standard	No Exceedance
APW17	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.0002	0.002	Standard	No Exceedance
APW17	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	0	CI around median	0.0048	0.1	Standard	No Exceedance
APW17	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around mean	0.644	6.9	Background	No Exceedance
APW17	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.05	Standard	No Exceedance
APW17	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	10	CI around mean	26.7	400	Standard	No Exceedance

TABLE 2.
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845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	GWPS	GWPS Source	Exceedance Type
APW17	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.002	Standard	No Exceedance
APW17	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	631	1,200	Standard	No Exceedance
APW17	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.3/7.6	6.4/9	Background/Standard	No Exceedance
APW18	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.003	0.006	Standard	No Exceedance
APW18	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	10	CI around mean	0.00144	0.059	Background	No Exceedance
APW18	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CI around median	0.33	2	Standard	No Exceedance
APW18	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.004	Standard	No Exceedance
APW18	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.103	2	Standard	No Exceedance
APW18	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.005	Standard	No Exceedance
APW18	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CB around T-S line	-243	200	Standard	No Exceedance
APW18	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	70	CI around median	0.004	0.1	Standard	No Exceedance
APW18	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	70	CI around median	0.002	0.006	Standard	No Exceedance
APW18	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.677	4	Standard	No Exceedance
APW18	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	50	CB around linear reg	-0.00473	0.0075	Standard	No Exceedance
APW18	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.04	Standard	No Exceedance
APW18	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.0002	0.002	Standard	No Exceedance
APW18	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	0	CB around linear reg	-0.0288	0.1	Standard	No Exceedance
APW18	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around mean	1.38	6.9	Background	No Exceedance
APW18	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.05	Standard	No Exceedance
APW18	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	20	CI around geomean	1.82	400	Standard	No Exceedance
APW18	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	80	CI around median	0.001	0.002	Standard	No Exceedance
APW18	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	508	1,200	Standard	No Exceedance
APW18	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.5/7.8	6.4/9	Background/Standard	No Exceedance

TABLE 2.
COMPARISON OF STATISTICAL RESULTS TO GWPS - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Notes:
Determined: An exceedance was determined upon without resampling
HSU = hydrostratigraphic unit:

- UA = Uppermost Aquifer
- UD = Upper Drift

mg/L = milligrams per liter
ND = non-detect
pCi/L = picocuries per liter
SU = standard units
Sample Count = number of samples from Sampled Date Range used to calculate the Statistical Result
Statistical Calculation = method used to calculate the statistical result:

- All ND - Last = All results were below the reporting limit, and the last determined reporting limit is shown
- CB around T-S line = Confidence band around Thiel-Sen line
- CB around linear reg = Confidence band around linear regression
- CI around geomean = Confidence interval around the geometric mean
- CI around mean = Confidence interval around the mean
- CI around median = Confidence interval around the median
- Most recent sample = Result for the most recently collected sample used due to insufficient data

Statistical Result = calculated in accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
For pH, the values presented are the lower / upper limits
GWPS = Groundwater Protection Standard
GWPS Source:

- Standard = standard specified in 35 I.A.C. § 845.600(a)(1)
- Background = background concentration (see cover page for additional information)

FIGURES

Electronic Filing: Received, Clerk's Office 07/01/2024



COMPLIANCE WELL
BACKGROUND WELL
STAFF GAUGE
REGULATED UNIT (SUBJECT UNIT)
SITE FEATURE
PROPERTY BOUNDARY

0 500 1,000
Feet

35 I.A.C. § 845 GROUNDWATER MONITORING WELL NETWORK

PRIMARY ASH POND
NEWTON POWER PLANT
NEWTON, ILLINOIS

FIGURE 1

RAMBOLL AMERICAS
ENGINEERING SOLUTIONS, INC.

RAMBOLL

Y:\Mapping\Projects\222285\MXD\845_Operating_Permit\Newton\CMP\Figure 2-1_Proposed Monitoring Well Network.mxd

PROJECT: 169000XXXX | DATED: 10/20/2021 | DESIGNER: STOLZSD

ATTACHMENTS

ATTACHMENT A
GROUNDWATER ELEVATION DATA
QUARTER 2 2023

ATTACHMENT A.
GROUNDWATER ELEVATION DATA - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	Well Type	Date	Depth to Groundwater (feet BMP)	Groundwater Elevation (feet NAVD88)
APW02	Compliance	04/24/2023	4.09	529.52
APW03	Compliance	04/24/2023	11.92	520.49
APW04	Compliance	04/24/2023	5.27	519.79
APW05	Background	04/24/2023	14.08	529.99
APW05S	Compliance	04/24/2023	11.78	532.16
APW06	Background	04/24/2023	19.17	526.90
APW07	Compliance	04/24/2023	46.18	492.19
APW08	Compliance	04/24/2023	36.99	490.80
APW09	Compliance	04/24/2023	26.55	504.97
APW10	Compliance	04/24/2023	17.60	506.65
APW11	Compliance	04/24/2023	24.26	514.37
APW12	Compliance	04/24/2023	14.59	531.70
APW13	Compliance	04/24/2023	32.00	505.99
APW14	Compliance	04/24/2023	20.89	505.40
APW15	Compliance	04/24/2023	21.51	503.18
APW16	Compliance	04/24/2023	40.22	490.96
APW17	Compliance	04/24/2023	41.16	491.36
APW18	Compliance	04/24/2023	51.91	491.36
XSG01	Water Level	04/24/2023	2.17	534.00
SG02	Water Level	04/24/2023	2.11	504.78

Notes:
BMP = below measuring point
NAVD88 = North American Vertical Datum of 1988

ATTACHMENT B
LABORATORY REPORTS AND FIELD DATA SHEETS
QUARTER 2 2023

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

June 07, 2023

Terry Hanratty
Vistra - Newton
Newton Energy Center 6725 N. 500th St
Newton, IL 62448

Dear Terry Hanratty:

Please find enclosed the analytical results for the sample(s) the laboratory received. All testing is performed according to our current TNI accreditations unless otherwise noted. This report cannot be reproduced, except in full, without the written permission of Pace Analytical Services, LLC.

If you have any questions regarding your report, please contact your project manager. Quality and timely data is of the utmost importance to us.

Pace Analytical Services appreciates the opportunity to provide you with analytical expertise. We are always trying to improve our customer service and we welcome you to contact the General Manager, Lisa Grant, with any feedback you have about your experience with our laboratory at 309-683-1764 or lisa.grant@pacelabs.com.

Sincerely,

Gail Schindler
Project Manager
(309) 692-9688 x1716
gail.schindler@pacelabs.com

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

SAMPLE RECEIPT CHECK LIST

Items not applicable will be marked as in compliance

Work Order GD04461

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
YES	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
YES	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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2231 W. Altorfer Drive
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(800)752-6651

Work Order GD04746

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
YES	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
YES	Short hold time analysis
YES	Current PDC COC submitted
YES	Case narrative provided

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Work Order GD04839

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
YES	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
YES	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
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(800)752-6651

Work Order GD04919

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
YES	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
YES	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04461-01
Name: APW03
Matrix: Ground Water - Grab

Sampled: 04/25/23 13:20
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	6.9	mg/L		04/26/23 20:03	1	1.0	04/26/23 20:03	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/26/23 20:03	1	0.250	04/26/23 20:03	CRD	EPA 300.0 REV 2.1
Sulfate	120	mg/L		04/26/23 20:21	25	25	04/26/23 20:21	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	11.94	Feet		04/25/23 13:20	1		04/25/23 13:20	FIELD	Field*
Dissolved oxygen, Field	2.2	mg/L		04/25/23 13:20	1		04/25/23 13:20	FIELD	Field*
Oxidation Reduction Potential	141	mV		04/25/23 13:20	1	-500	04/25/23 13:20	FIELD	Field*
pH, Field Measured	7.01	pH Units		04/25/23 13:20	1		04/25/23 13:20	FIELD	Field*
Specific Conductance, Field Measured	925.0	umhos/cm		04/25/23 13:20	1		04/25/23 13:20	FIELD	Field*
Temperature, Field Measured	17.0	°C		04/25/23 13:20	1		04/25/23 13:20	FIELD	Field*
Turbidity, Field Measured	< 0.00	NTU		04/25/23 13:20	1	0.00	04/25/23 13:20	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	390	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	740	mg/L		04/28/23 14:40	1	26	04/28/23 16:47	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/03/23 09:07	5	3.0	05/04/23 09:27	JMW	EPA 6020A
Arsenic	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Barium	78	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Boron	370	ug/L		05/03/23 09:07	5	10	05/05/23 08:18	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Calcium	96	mg/L		05/03/23 09:07	5	0.20	05/04/23 09:27	JMW	EPA 6020A
Chromium	7.2	ug/L		05/03/23 09:07	5	4.0	05/04/23 09:27	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/03/23 09:07	5	2.0	05/04/23 09:27	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Magnesium	58	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:27	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/03/23 09:07	5	0.20	05/05/23 08:18	JMW	EPA 6020A
Molybdenum	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Potassium	0.31	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:27	JMW	EPA 6020A

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2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04461-01
Name: APW03
Matrix: Ground Water - Grab

Sampled: 04/25/23 13:20
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Sodium	61	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:27	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:27	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/03/23 09:07	1	0.020	05/09/23 10:16	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04461-02
Name: APW04
Matrix: Ground Water - Grab

Sampled: 04/25/23 16:42
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	34	mg/L		04/26/23 20:57	10	10	04/26/23 20:57	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/26/23 20:39	1	0.250	04/26/23 20:39	CRD	EPA 300.0 REV 2.1
Sulfate	840	mg/L		04/26/23 21:51	100	100	04/26/23 21:51	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	5.1	Feet		04/25/23 16:42	1		04/25/23 16:42	FIELD	Field*
Dissolved oxygen, Field	0.93	mg/L		04/25/23 16:42	1		04/25/23 16:42	FIELD	Field*
Oxidation Reduction Potential	171	mV		04/25/23 16:42	1	-500	04/25/23 16:42	FIELD	Field*
pH, Field Measured	6.93	pH Units		04/25/23 16:42	1		04/25/23 16:42	FIELD	Field*
Specific Conductance, Field Measured	1830	umhos/cm		04/25/23 16:42	1		04/25/23 16:42	FIELD	Field*
Temperature, Field Measured	11.8	°C		04/25/23 16:42	1		04/25/23 16:42	FIELD	Field*
Turbidity, Field Measured	178	NTU		04/25/23 16:42	1	0.00	04/25/23 16:42	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	440	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	1800	mg/L		04/28/23 14:40	1	26	04/28/23 16:47	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/03/23 09:07	5	3.0	05/04/23 09:31	JMW	EPA 6020A
Arsenic	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Barium	22	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Boron	24	ug/L		05/03/23 09:07	5	10	05/05/23 08:21	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Calcium	210	mg/L		05/03/23 09:07	5	0.20	05/04/23 09:31	JMW	EPA 6020A
Chromium	44	ug/L		05/03/23 09:07	5	4.0	05/04/23 09:31	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/03/23 09:07	5	2.0	05/04/23 09:31	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Magnesium	170	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:31	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/03/23 09:07	5	0.20	05/05/23 08:21	JMW	EPA 6020A
Molybdenum	1.8	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Potassium	1.3	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:31	JMW	EPA 6020A

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2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04461-02
Name: APW04
Matrix: Ground Water - Grab

Sampled: 04/25/23 16:42
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Sodium	90	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:31	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:31	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/03/23 09:07	1	0.020	05/09/23 10:17	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04461-03
Name: APW16
Matrix: Ground Water - Grab

Sampled: 04/25/23 13:26
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	71	mg/L	Q4	04/26/23 23:03	10	10	04/26/23 23:03	CRD	EPA 300.0 REV 2.1
Fluoride	0.606	mg/L		04/26/23 22:09	1	0.250	04/26/23 22:09	CRD	EPA 300.0 REV 2.1
Sulfate	< 1.0	mg/L		04/26/23 22:09	1	1.0	04/26/23 22:09	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	40.15	Feet		04/25/23 13:26	1		04/25/23 13:26	FIELD	Field*
Dissolved oxygen, Field	1.2	mg/L		04/25/23 13:26	1		04/25/23 13:26	FIELD	Field*
Oxidation Reduction Potential	-104	mV		04/25/23 13:26	1	-500	04/25/23 13:26	FIELD	Field*
pH, Field Measured	7.65	pH Units		04/25/23 13:26	1		04/25/23 13:26	FIELD	Field*
Specific Conductance, Field Measured	953.0	umhos/cm		04/25/23 13:26	1		04/25/23 13:26	FIELD	Field*
Temperature, Field Measured	14.0	°C		04/25/23 13:26	1		04/25/23 13:26	FIELD	Field*
Turbidity, Field Measured	0.210	NTU		04/25/23 13:26	1	0.00	04/25/23 13:26	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	560	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	800	mg/L		04/28/23 14:40	1	26	04/28/23 16:47	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/03/23 09:07	5	3.0	05/04/23 09:34	JMW	EPA 6020A
Arsenic	21	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Barium	540	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Boron	130	ug/L		05/03/23 09:07	5	10	05/05/23 08:24	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Calcium	96	mg/L	Q4	05/03/23 09:07	5	0.20	05/04/23 09:34	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/03/23 09:07	5	4.0	05/04/23 09:34	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/03/23 09:07	5	2.0	05/04/23 09:34	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Magnesium	44	mg/L	Q4	05/03/23 09:07	5	0.10	05/04/23 09:34	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/03/23 09:07	5	0.20	05/05/23 08:24	JMW	EPA 6020A
Molybdenum	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Potassium	1.8	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:34	JMW	EPA 6020A

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2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04461-03
Name: APW16
Matrix: Ground Water - Grab

Sampled: 04/25/23 13:26
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Sodium	140	mg/L	Q4	05/03/23 09:07	5	0.10	05/04/23 09:34	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:34	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/03/23 09:07	1	0.020	05/09/23 10:19	TJJ	EPA 6010B

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Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04461-04
Name: APW17
Matrix: Ground Water - Grab

Sampled: 04/25/23 16:50
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	56	mg/L		04/26/23 23:40	10	10	04/26/23 23:40	CRD	EPA 300.0 REV 2.1
Fluoride	0.483	mg/L		04/26/23 23:22	1	0.250	04/26/23 23:22	CRD	EPA 300.0 REV 2.1
Sulfate	52	mg/L		04/26/23 23:40	10	10	04/26/23 23:40	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	41.09	Feet		04/25/23 16:50	1		04/25/23 16:50	FIELD	Field*
Dissolved oxygen, Field	1.2	mg/L		04/25/23 16:50	1		04/25/23 16:50	FIELD	Field*
Oxidation Reduction Potential	-97.2	mV		04/25/23 16:50	1	-500	04/25/23 16:50	FIELD	Field*
pH, Field Measured	7.62	pH Units		04/25/23 16:50	1		04/25/23 16:50	FIELD	Field*
Specific Conductance, Field Measured	1162	umhos/cm		04/25/23 16:50	1		04/25/23 16:50	FIELD	Field*
Temperature, Field Measured	15.2	°C		04/25/23 16:50	1		04/25/23 16:50	FIELD	Field*
Turbidity, Field Measured	3.82	NTU		04/25/23 16:50	1	0.00	04/25/23 16:50	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	450	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	700	mg/L		04/28/23 14:40	1	26	04/28/23 16:47	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/03/23 09:07	5	3.0	05/04/23 09:38	JMW	EPA 6020A
Arsenic	20	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Barium	550	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Boron	83	ug/L		05/03/23 09:07	5	10	05/05/23 08:27	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Calcium	110	mg/L		05/03/23 09:07	5	0.20	05/04/23 09:38	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/03/23 09:07	5	4.0	05/04/23 09:38	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/03/23 09:07	5	2.0	05/04/23 09:38	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Magnesium	47	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:38	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/03/23 09:07	5	0.20	05/05/23 08:27	JMW	EPA 6020A
Molybdenum	5.3	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Potassium	1.6	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:38	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04461-04
Name: APW17
Matrix: Ground Water - Grab

Sampled: 04/25/23 16:50
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Sodium	93	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:38	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:38	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/03/23 09:07	1	0.020	05/09/23 10:22	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04461-05
Name: APW18
Matrix: Ground Water - Grab

Sampled: 04/25/23 15:03
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	24	mg/L		04/27/23 00:16	10	10	04/27/23 00:16	CRD	EPA 300.0 REV 2.1
Fluoride	0.518	mg/L		04/26/23 23:58	1	0.250	04/26/23 23:58	CRD	EPA 300.0 REV 2.1
Sulfate	52	mg/L		04/27/23 00:16	10	10	04/27/23 00:16	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	51.63	Feet		04/25/23 15:03	1		04/25/23 15:03	FIELD	Field*
Dissolved oxygen, Field	1.0	mg/L		04/25/23 15:03	1		04/25/23 15:03	FIELD	Field*
Oxidation Reduction Potential	-137	mV		04/25/23 15:03	1	-500	04/25/23 15:03	FIELD	Field*
pH, Field Measured	7.78	pH Units		04/25/23 15:03	1		04/25/23 15:03	FIELD	Field*
Specific Conductance, Field Measured	1012	umhos/cm		04/25/23 15:03	1		04/25/23 15:03	FIELD	Field*
Temperature, Field Measured	15.2	°C		04/25/23 15:03	1		04/25/23 15:03	FIELD	Field*
Turbidity, Field Measured	5.01	NTU		04/25/23 15:03	1	0.00	04/25/23 15:03	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	440	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/04/23 10:11	1	10	05/04/23 10:11	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	660	mg/L		04/28/23 14:40	1	26	04/28/23 16:47	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/03/23 09:07	5	3.0	05/04/23 09:42	JMW	EPA 6020A
Arsenic	2.7	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Barium	350	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Boron	100	ug/L		05/03/23 09:07	5	10	05/05/23 08:30	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Calcium	75	mg/L		05/03/23 09:07	5	0.20	05/04/23 09:42	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/03/23 09:07	5	4.0	05/04/23 09:42	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/03/23 09:07	5	2.0	05/04/23 09:42	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Magnesium	40	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:42	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/03/23 09:07	5	0.20	05/05/23 08:30	JMW	EPA 6020A
Molybdenum	2.9	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Potassium	2.6	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:42	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04461-05
Name: APW18
Matrix: Ground Water - Grab

Sampled: 04/25/23 15:03
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Sodium	110	mg/L		05/03/23 09:07	5	0.10	05/04/23 09:42	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/03/23 09:07	5	1.0	05/04/23 09:42	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/03/23 09:07	1	0.020	05/09/23 10:23	TJJ	EPA 6010B

Sample: GD04461-27
Name: XSG01
Matrix: Ground Water

Sampled: 04/24/23 17:16
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Field - PIA									
Depth, From Measuring Point	5.34	Feet		04/24/23 17:16	1		04/24/23 17:16	FIELD	Field*

Sample: GD04461-28
Name: SG02
Matrix: Ground Water

Sampled: 04/24/23 14:44
Received: 04/26/23 14:08

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Field - PIA									
Depth, From Measuring Point	2.11	Feet		04/24/23 14:44	1		04/24/23 14:44	FIELD	Field*

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ANALYTICAL RESULTS

Sample: GD04746-02
Name: APW05S
Matrix: Ground Water - Grab

Sampled: 04/26/23 17:40
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	200	mg/L		04/29/23 21:22	100	100	04/29/23 21:22	CRD	EPA 300.0 REV 2.1
Sulfate	2100	mg/L		04/27/23 21:31	250	250	04/27/23 21:31	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	9.46	Feet		04/26/23 17:40	1		04/26/23 17:40	FIELD	Field*
Dissolved oxygen, Field	3.5	mg/L		04/26/23 17:40	1		04/26/23 17:40	FIELD	Field*
Oxidation Reduction Potential	97.0	mV		04/26/23 17:40	1	-500	04/26/23 17:40	FIELD	Field*
pH, Field Measured	6.60	pH Units		04/26/23 17:40	1		04/26/23 17:40	FIELD	Field*
Specific Conductance, Field Measured	3930	umhos/cm		04/26/23 17:40	1		04/26/23 17:40	FIELD	Field*
Temperature, Field Measured	16.4	°C		04/26/23 17:40	1		04/26/23 17:40	FIELD	Field*
Turbidity, Field Measured	220	NTU		04/26/23 17:40	1	0.00	04/26/23 17:40	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	520	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Fluoride	0.365	mg/L		05/05/23 16:50	1	0.250	05/05/23 16:50	TTH	SM 4500F C 1997
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	3800	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:20	JMW	EPA 6020A
Arsenic	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:33	JMW	EPA 6020A
Barium	35	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Boron	54	ug/L		05/04/23 09:03	5	10	05/09/23 07:20	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Calcium	390	mg/L	Q4	05/04/23 09:03	5	0.20	05/09/23 07:20	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:20	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:20	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Magnesium	300	mg/L	Q4	05/04/23 09:03	5	0.10	05/09/23 07:20	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:58	JMW	EPA 6020A
Molybdenum	1.3	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Potassium	1.8	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:20	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-02
Name: APW05S
Matrix: Ground Water - Grab

Sampled: 04/26/23 17:40
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Sodium	260	mg/L	Q4	05/04/23 09:03	5	0.10	05/09/23 07:20	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:20	JMW	EPA 6020A
Lithium	0.033	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:31	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04746-03
Name: APW06
Matrix: Ground Water - Grab

Sampled: 04/26/23 16:00
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	26	mg/L		04/27/23 22:07	10	10	04/27/23 22:07	CRD	EPA 300.0 REV 2.1
Fluoride	0.489	mg/L		04/27/23 21:49	1	0.250	04/27/23 21:49	CRD	EPA 300.0 REV 2.1
Sulfate	7.6	mg/L		04/27/23 21:49	1	1.0	04/27/23 21:49	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	19.33	Feet		04/26/23 16:00	1		04/26/23 16:00	FIELD	Field*
Dissolved oxygen, Field	11	mg/L		04/26/23 16:00	1		04/26/23 16:00	FIELD	Field*
Oxidation Reduction Potential	-128	mV		04/26/23 16:00	1	-500	04/26/23 16:00	FIELD	Field*
pH, Field Measured	7.35	pH Units		04/26/23 16:00	1		04/26/23 16:00	FIELD	Field*
Specific Conductance, Field Measured	796.0	umhos/cm		04/26/23 16:00	1		04/26/23 16:00	FIELD	Field*
Temperature, Field Measured	17.6	°C		04/26/23 16:00	1		04/26/23 16:00	FIELD	Field*
Turbidity, Field Measured	471	NTU		04/26/23 16:00	1	0.00	04/26/23 16:00	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	380	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	500	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:24	JMW	EPA 6020A
Arsenic	9.2	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:42	JMW	EPA 6020A
Barium	240	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Boron	87	ug/L		05/04/23 09:03	5	10	05/09/23 07:24	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Calcium	58	mg/L		05/04/23 09:03	5	0.20	05/09/23 07:24	JMW	EPA 6020A
Chromium	7.9	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:24	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:24	JMW	EPA 6020A
Lead	1.7	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Magnesium	27	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:24	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:24	JMW	EPA 6020A
Molybdenum	7.7	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Potassium	1.5	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:24	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-03
Name: APW06
Matrix: Ground Water - Grab

Sampled: 04/26/23 16:00
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Sodium	120	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:24	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:24	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:34	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04746-04
Name: APW08
Matrix: Ground Water - Grab

Sampled: 04/26/23 12:11
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	58	mg/L		04/27/23 22:43	10	10	04/27/23 22:43	CRD	EPA 300.0 REV 2.1
Fluoride	0.404	mg/L		04/27/23 22:25	1	0.250	04/27/23 22:25	CRD	EPA 300.0 REV 2.1
Sulfate	48	mg/L		04/27/23 22:43	10	10	04/27/23 22:43	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	37.56	Feet		04/26/23 12:11	1		04/26/23 12:11	FIELD	Field*
Dissolved oxygen, Field	1.7	mg/L		04/26/23 12:11	1		04/26/23 12:11	FIELD	Field*
Oxidation Reduction Potential	-118	mV		04/26/23 12:11	1	-500	04/26/23 12:11	FIELD	Field*
pH, Field Measured	7.52	pH Units		04/26/23 12:11	1		04/26/23 12:11	FIELD	Field*
Specific Conductance, Field Measured	1100	umhos/cm		04/26/23 12:11	1		04/26/23 12:11	FIELD	Field*
Temperature, Field Measured	14.2	°C		04/26/23 12:11	1		04/26/23 12:11	FIELD	Field*
Turbidity, Field Measured	17.7	NTU		04/26/23 12:11	1	0.00	04/26/23 12:11	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	410	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	640	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:27	JMW	EPA 6020A
Arsenic	26	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:45	JMW	EPA 6020A
Barium	470	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Boron	87	ug/L		05/04/23 09:03	5	10	05/09/23 07:27	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Calcium	110	mg/L		05/04/23 09:03	5	0.20	05/09/23 07:27	JMW	EPA 6020A
Chromium	7.6	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:27	JMW	EPA 6020A
Cobalt	2.2	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:27	JMW	EPA 6020A
Lead	3.3	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Magnesium	45	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:27	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:27	JMW	EPA 6020A
Molybdenum	4.4	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Potassium	2.0	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:27	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-04
Name: APW08
Matrix: Ground Water - Grab

Sampled: 04/26/23 12:11
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Sodium	91	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:27	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:27	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:35	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04746-05
Name: APW11
Matrix: Ground Water - Grab

Sampled: 04/26/23 15:43
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	26	mg/L		04/27/23 23:19	5	5.0	04/27/23 23:19	CRD	EPA 300.0 REV 2.1
Fluoride	0.283	mg/L		04/27/23 23:01	1	0.250	04/27/23 23:01	CRD	EPA 300.0 REV 2.1
Sulfate	260	mg/L		04/27/23 23:37	50	50	04/27/23 23:37	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	24.27	Feet		04/26/23 15:43	1		04/26/23 15:43	FIELD	Field*
Dissolved oxygen, Field	0.64	mg/L		04/26/23 15:43	1		04/26/23 15:43	FIELD	Field*
Oxidation Reduction Potential	-17.8	mV		04/26/23 15:43	1	-500	04/26/23 15:43	FIELD	Field*
pH, Field Measured	7.15	pH Units		04/26/23 15:43	1		04/26/23 15:43	FIELD	Field*
Specific Conductance, Field Measured	1252	umhos/cm		04/26/23 15:43	1		04/26/23 15:43	FIELD	Field*
Temperature, Field Measured	15.5	°C		04/26/23 15:43	1		04/26/23 15:43	FIELD	Field*
Turbidity, Field Measured	446	NTU		04/26/23 15:43	1	0.00	04/26/23 15:43	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	350	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	920	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:31	JMW	EPA 6020A
Arsenic	4.4	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:48	JMW	EPA 6020A
Barium	43	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Boron	64	ug/L		05/04/23 09:03	5	10	05/09/23 07:31	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Calcium	120	mg/L		05/04/23 09:03	5	0.20	05/09/23 07:31	JMW	EPA 6020A
Chromium	7.0	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:31	JMW	EPA 6020A
Cobalt	2.1	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:31	JMW	EPA 6020A
Lead	6.3	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Magnesium	57	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:31	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:31	JMW	EPA 6020A
Molybdenum	4.3	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Potassium	1.9	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:31	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-05
Name: APW11
Matrix: Ground Water - Grab

Sampled: 04/26/23 15:43
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Sodium	93	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:31	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:31	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:36	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04746-06
Name: APW12
Matrix: Ground Water - Grab

Sampled: 04/26/23 13:56
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	23	mg/L		04/28/23 00:13	5	5.0	04/28/23 00:13	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/28/23 00:13	1	0.250	04/28/23 00:13	CRD	EPA 300.0 REV 2.1
Sulfate	540	mg/L		04/29/23 21:58	100	100	04/29/23 21:58	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	14.56	Feet		04/26/23 13:56	1		04/26/23 13:56	FIELD	Field*
Dissolved oxygen, Field	0.98	mg/L		04/26/23 13:56	1		04/26/23 13:56	FIELD	Field*
Oxidation Reduction Potential	107	mV		04/26/23 13:56	1	-500	04/26/23 13:56	FIELD	Field*
pH, Field Measured	6.52	pH Units		04/26/23 13:56	1		04/26/23 13:56	FIELD	Field*
Specific Conductance, Field Measured	1831	umhos/cm		04/26/23 13:56	1		04/26/23 13:56	FIELD	Field*
Temperature, Field Measured	14.6	°C		04/26/23 13:56	1		04/26/23 13:56	FIELD	Field*
Turbidity, Field Measured	0.520	NTU		04/26/23 13:56	1	0.00	04/26/23 13:56	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	520	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	1500	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:35	JMW	EPA 6020A
Arsenic	1.4	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:50	JMW	EPA 6020A
Barium	28	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Boron	440	ug/L		05/04/23 09:03	5	10	05/09/23 07:35	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Calcium	230	mg/L		05/04/23 09:03	5	0.20	05/09/23 07:35	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:35	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:35	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Magnesium	110	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:35	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:35	JMW	EPA 6020A
Molybdenum	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Potassium	0.94	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:35	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-06
Name: APW12
Matrix: Ground Water - Grab

Sampled: 04/26/23 13:56
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Sodium	120	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:35	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:35	JMW	EPA 6020A
Lithium	0.024	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:38	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04746-07
Name: APW15
Matrix: Ground Water - Grab

Sampled: 04/26/23 17:23
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	270	mg/L		04/29/23 22:34	50	50	04/29/23 22:34	CRD	EPA 300.0 REV 2.1
Fluoride	0.402	mg/L		04/28/23 01:27	1	0.250	04/28/23 01:27	CRD	EPA 300.0 REV 2.1
Sulfate	< 1.0	mg/L		04/28/23 01:27	1	1.0	04/28/23 01:27	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	21.43	Feet		04/26/23 17:23	1		04/26/23 17:23	FIELD	Field*
Dissolved oxygen, Field	0.32	mg/L		04/26/23 17:23	1		04/26/23 17:23	FIELD	Field*
Oxidation Reduction Potential	-126	mV		04/26/23 17:23	1	-500	04/26/23 17:23	FIELD	Field*
pH, Field Measured	7.25	pH Units		04/26/23 17:23	1		04/26/23 17:23	FIELD	Field*
Specific Conductance, Field Measured	1682	umhos/cm		04/26/23 17:23	1		04/26/23 17:23	FIELD	Field*
Temperature, Field Measured	15.3	°C		04/26/23 17:23	1		04/26/23 17:23	FIELD	Field*
Turbidity, Field Measured	51.6	NTU		04/26/23 17:23	1	0.00	04/26/23 17:23	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	590	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/05/23 09:44	1	10	05/05/23 09:44	HRF	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	1100	mg/L		05/01/23 11:30	1	26	05/01/23 15:30	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/04/23 09:03	5	3.0	05/09/23 07:39	JMW	EPA 6020A
Arsenic	21	ug/L		05/04/23 09:03	5	1.0	05/10/23 07:53	JMW	EPA 6020A
Barium	530	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Boron	130	ug/L		05/04/23 09:03	5	10	05/09/23 07:39	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Calcium	91	mg/L		05/04/23 09:03	5	0.20	05/09/23 07:39	JMW	EPA 6020A
Chromium	6.4	ug/L		05/04/23 09:03	5	4.0	05/09/23 07:39	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/04/23 09:03	5	2.0	05/09/23 07:39	JMW	EPA 6020A
Lead	1.2	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Magnesium	38	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:39	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/04/23 09:03	5	0.20	05/09/23 07:39	JMW	EPA 6020A
Molybdenum	6.5	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Potassium	3.0	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:39	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04746-07
Name: APW15
Matrix: Ground Water - Grab

Sampled: 04/26/23 17:23
Received: 04/27/23 14:20

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Sodium	290	mg/L		05/04/23 09:03	5	0.10	05/09/23 07:39	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/04/23 09:03	5	1.0	05/09/23 07:39	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/04/23 09:03	1	0.020	05/09/23 10:39	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-03
Name: APW02
Matrix: Ground Water - Grab

Sampled: 04/27/23 12:17
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	110	mg/L		04/28/23 19:45	25	25	04/28/23 19:45	CRD	EPA 300.0 REV 2.1
Sulfate	3100	mg/L		04/28/23 20:03	500	500	04/28/23 20:03	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	3.72	Feet		04/27/23 12:17	1		04/27/23 12:17	FIELD	Field*
Dissolved oxygen, Field	1.2	mg/L		04/27/23 12:17	1		04/27/23 12:17	FIELD	Field*
Oxidation Reduction Potential	80.8	mV		04/27/23 12:17	1	-500	04/27/23 12:17	FIELD	Field*
pH, Field Measured	6.71	pH Units		04/27/23 12:17	1		04/27/23 12:17	FIELD	Field*
Specific Conductance, Field Measured	5217	umhos/cm		04/27/23 12:17	1		04/27/23 12:17	FIELD	Field*
Temperature, Field Measured	15.6	°C		04/27/23 12:17	1		04/27/23 12:17	FIELD	Field*
Turbidity, Field Measured	25.0	NTU		04/27/23 12:17	1	0.00	04/27/23 12:17	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	640	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Fluoride	< 0.250	mg/L		05/05/23 16:47	1	0.250	05/05/23 16:47	TTH	SM 4500F C 1997
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	5400	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 12:38	JMW	EPA 6020A
Arsenic	1.4	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:18	JMW	EPA 6020A
Barium	24	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:38	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:54	JMW	EPA 6020A
Boron	120	ug/L		05/08/23 09:07	5	10	05/09/23 09:54	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:38	JMW	EPA 6020A
Calcium	460	mg/L		05/08/23 09:07	5	0.20	05/09/23 09:54	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 09:54	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 09:54	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:54	JMW	EPA 6020A
Magnesium	430	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:54	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 12:38	JMW	EPA 6020A
Molybdenum	1.6	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:38	JMW	EPA 6020A
Potassium	5.8	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:54	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-03
Name: APW02
Matrix: Ground Water - Grab

Sampled: 04/27/23 12:17
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:54	JMW	EPA 6020A
Sodium	360	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:54	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:54	JMW	EPA 6020A
Lithium	0.098	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:47	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-04
Name: APW05
Matrix: Ground Water - Grab

Sampled: 04/27/23 12:40
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	46	mg/L	Q4	04/28/23 17:02	10	10	04/28/23 17:02	CRD	EPA 300.0 REV 2.1
Fluoride	0.498	mg/L		04/28/23 16:08	1	0.250	04/28/23 16:08	CRD	EPA 300.0 REV 2.1
Sulfate	< 1.0	mg/L		04/28/23 16:08	1	1.0	04/28/23 16:08	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	14.01	Feet		04/27/23 12:40	1		04/27/23 12:40	FIELD	Field*
Dissolved oxygen, Field	18	mg/L		04/27/23 12:40	1		04/27/23 12:40	FIELD	Field*
Oxidation Reduction Potential	-124	mV		04/27/23 12:40	1	-500	04/27/23 12:40	FIELD	Field*
pH, Field Measured	7.10	pH Units		04/27/23 12:40	1		04/27/23 12:40	FIELD	Field*
Specific Conductance, Field Measured	819.0	umhos/cm		04/27/23 12:40	1		04/27/23 12:40	FIELD	Field*
Temperature, Field Measured	14.5	°C		04/27/23 12:40	1		04/27/23 12:40	FIELD	Field*
Turbidity, Field Measured	40.1	NTU		04/27/23 12:40	1	0.00	04/27/23 12:40	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	480	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	560	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 12:42	JMW	EPA 6020A
Arsenic	30	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:21	JMW	EPA 6020A
Barium	250	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:42	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:58	JMW	EPA 6020A
Boron	92	ug/L		05/08/23 09:07	5	10	05/09/23 09:58	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:42	JMW	EPA 6020A
Calcium	49	mg/L		05/08/23 09:07	5	0.20	05/09/23 09:58	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 09:58	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 09:58	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:58	JMW	EPA 6020A
Magnesium	26	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:58	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 12:42	JMW	EPA 6020A
Molybdenum	9.1	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:42	JMW	EPA 6020A
Potassium	1.4	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:58	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-04
Name: APW05
Matrix: Ground Water - Grab

Sampled: 04/27/23 12:40
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:58	JMW	EPA 6020A
Sodium	130	mg/L		05/08/23 09:07	5	0.10	05/09/23 09:58	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 09:58	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:48	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-05
Name: APW07
Matrix: Ground Water - Grab

Sampled: 04/27/23 10:35
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	63	mg/L		04/28/23 17:38	10	10	04/28/23 17:38	CRD	EPA 300.0 REV 2.1
Fluoride	0.409	mg/L		04/28/23 17:20	1	0.250	04/28/23 17:20	CRD	EPA 300.0 REV 2.1
Sulfate	14	mg/L		04/28/23 17:38	10	10	04/28/23 17:38	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	46.59	Feet		04/27/23 10:35	1		04/27/23 10:35	FIELD	Field*
Dissolved oxygen, Field	0.51	mg/L		04/27/23 10:35	1		04/27/23 10:35	FIELD	Field*
Oxidation Reduction Potential	-116	mV		04/27/23 10:35	1	-500	04/27/23 10:35	FIELD	Field*
pH, Field Measured	7.39	pH Units		04/27/23 10:35	1		04/27/23 10:35	FIELD	Field*
Specific Conductance, Field Measured	1051	umhos/cm		04/27/23 10:35	1		04/27/23 10:35	FIELD	Field*
Temperature, Field Measured	14.5	°C		04/27/23 10:35	1		04/27/23 10:35	FIELD	Field*
Turbidity, Field Measured	621	NTU		04/27/23 10:35	1	0.00	04/27/23 10:35	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	500	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	590	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 12:46	JMW	EPA 6020A
Arsenic	18	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:24	JMW	EPA 6020A
Barium	510	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:46	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:02	JMW	EPA 6020A
Boron	85	ug/L		05/08/23 09:07	5	10	05/09/23 10:02	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:46	JMW	EPA 6020A
Calcium	100	mg/L		05/08/23 09:07	5	0.20	05/09/23 10:02	JMW	EPA 6020A
Chromium	17	ug/L		05/08/23 09:07	5	4.0	05/09/23 10:02	JMW	EPA 6020A
Cobalt	3.6	ug/L		05/08/23 09:07	5	2.0	05/09/23 10:02	JMW	EPA 6020A
Lead	5.5	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:02	JMW	EPA 6020A
Magnesium	40	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:02	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 12:46	JMW	EPA 6020A
Molybdenum	3.4	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:46	JMW	EPA 6020A
Potassium	2.5	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:02	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-05
Name: APW07
Matrix: Ground Water - Grab

Sampled: 04/27/23 10:35
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:02	JMW	EPA 6020A
Sodium	93	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:02	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:02	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:49	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-06
Name: APW09
Matrix: Ground Water - Grab

Sampled: 04/27/23 14:05
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	130	mg/L		04/28/23 19:09	25	25	04/28/23 19:09	CRD	EPA 300.0 REV 2.1
Fluoride	0.482	mg/L		04/28/23 17:57	1	0.250	04/28/23 17:57	CRD	EPA 300.0 REV 2.1
Sulfate	9.4	mg/L		04/28/23 18:51	5	5.0	04/28/23 18:51	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	26.56	Feet		04/27/23 14:05	1		04/27/23 14:05	FIELD	Field*
Dissolved oxygen, Field	0.47	mg/L		04/27/23 14:05	1		04/27/23 14:05	FIELD	Field*
Oxidation Reduction Potential	-137	mV		04/27/23 14:05	1	-500	04/27/23 14:05	FIELD	Field*
pH, Field Measured	7.53	pH Units		04/27/23 14:05	1		04/27/23 14:05	FIELD	Field*
Specific Conductance, Field Measured	1356	umhos/cm		04/27/23 14:05	1		04/27/23 14:05	FIELD	Field*
Temperature, Field Measured	16.5	°C		04/27/23 14:05	1		04/27/23 14:05	FIELD	Field*
Turbidity, Field Measured	117	NTU		04/27/23 14:05	1	0.00	04/27/23 14:05	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	600	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	840	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 12:50	JMW	EPA 6020A
Arsenic	29	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:27	JMW	EPA 6020A
Barium	430	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:50	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:06	JMW	EPA 6020A
Boron	99	ug/L		05/08/23 09:07	5	10	05/09/23 10:06	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:50	JMW	EPA 6020A
Calcium	76	mg/L		05/08/23 09:07	5	0.20	05/09/23 10:06	JMW	EPA 6020A
Chromium	4.2	ug/L		05/08/23 09:07	5	4.0	05/09/23 10:06	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 10:06	JMW	EPA 6020A
Lead	1.3	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:06	JMW	EPA 6020A
Magnesium	38	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:06	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 12:50	JMW	EPA 6020A
Molybdenum	3.9	ug/L		05/08/23 09:07	5	1.0	05/09/23 12:50	JMW	EPA 6020A
Potassium	1.7	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:06	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-06
Name: APW09
Matrix: Ground Water - Grab

Sampled: 04/27/23 14:05
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:06	JMW	EPA 6020A
Sodium	190	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:06	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:06	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:50	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-07
Name: APW10
Matrix: Ground Water - Grab

Sampled: 04/27/23 15:47
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	46	mg/L		04/29/23 13:25	10	10	04/29/23 13:25	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/29/23 13:07	1	0.250	04/29/23 13:07	CRD	EPA 300.0 REV 2.1
Sulfate	410	mg/L		04/29/23 13:43	100	100	04/29/23 13:43	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	17.53	Feet		04/27/23 15:47	1		04/27/23 15:47	FIELD	Field*
Dissolved oxygen, Field	3.4	mg/L		04/27/23 15:47	1		04/27/23 15:47	FIELD	Field*
Oxidation Reduction Potential	77.5	mV		04/27/23 15:47	1	-500	04/27/23 15:47	FIELD	Field*
pH, Field Measured	7.36	pH Units		04/27/23 15:47	1		04/27/23 15:47	FIELD	Field*
Specific Conductance, Field Measured	1461	umhos/cm		04/27/23 15:47	1		04/27/23 15:47	FIELD	Field*
Temperature, Field Measured	15.1	°C		04/27/23 15:47	1		04/27/23 15:47	FIELD	Field*
Turbidity, Field Measured	< 0.00	NTU		04/27/23 15:47	1	0.00	04/27/23 15:47	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	420	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	1100	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 13:09	JMW	EPA 6020A
Arsenic	7.8	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:30	JMW	EPA 6020A
Barium	26	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:09	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:10	JMW	EPA 6020A
Boron	77	ug/L		05/08/23 09:07	5	10	05/09/23 10:10	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:09	JMW	EPA 6020A
Calcium	140	mg/L		05/08/23 09:07	5	0.20	05/09/23 10:10	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 10:10	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 10:10	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:10	JMW	EPA 6020A
Magnesium	68	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:10	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 13:09	JMW	EPA 6020A
Molybdenum	6.5	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:09	JMW	EPA 6020A
Potassium	1.5	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:10	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-07
Name: APW10
Matrix: Ground Water - Grab

Sampled: 04/27/23 15:47
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:10	JMW	EPA 6020A
Sodium	120	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:10	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:10	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:52	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-08
Name: APW13
Matrix: Ground Water - Grab

Sampled: 04/27/23 17:16
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	51	mg/L		04/28/23 20:39	10	10	04/28/23 20:39	CRD	EPA 300.0 REV 2.1
Fluoride	0.394	mg/L		04/28/23 20:21	1	0.250	04/28/23 20:21	CRD	EPA 300.0 REV 2.1
Sulfate	250	mg/L		04/28/23 20:57	100	100	04/28/23 20:57	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	32.05	Feet		04/27/23 17:16	1		04/27/23 17:16	FIELD	Field*
Dissolved oxygen, Field	1.6	mg/L		04/27/23 17:16	1		04/27/23 17:16	FIELD	Field*
Oxidation Reduction Potential	-25.3	mV		04/27/23 17:16	1	-500	04/27/23 17:16	FIELD	Field*
pH, Field Measured	7.26	pH Units		04/27/23 17:16	1		04/27/23 17:16	FIELD	Field*
Specific Conductance, Field Measured	1360	umhos/cm		04/27/23 17:16	1		04/27/23 17:16	FIELD	Field*
Temperature, Field Measured	14.3	°C		04/27/23 17:16	1		04/27/23 17:16	FIELD	Field*
Turbidity, Field Measured	< 0.00	NTU		04/27/23 17:16	1	0.00	04/27/23 17:16	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	490	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	940	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 13:13	JMW	EPA 6020A
Arsenic	4.0	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:33	JMW	EPA 6020A
Barium	50	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:13	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:13	JMW	EPA 6020A
Boron	110	ug/L		05/08/23 09:07	5	10	05/09/23 10:13	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:13	JMW	EPA 6020A
Calcium	120	mg/L		05/08/23 09:07	5	0.20	05/09/23 10:13	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 10:13	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 10:13	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:13	JMW	EPA 6020A
Magnesium	61	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:13	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 13:13	JMW	EPA 6020A
Molybdenum	6.7	ug/L		05/08/23 09:07	5	1.0	05/09/23 13:13	JMW	EPA 6020A
Potassium	1.8	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:13	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-08
Name: APW13
Matrix: Ground Water - Grab

Sampled: 04/27/23 17:16
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:13	JMW	EPA 6020A
Sodium	120	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:13	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 10:13	JMW	EPA 6020A
Lithium	0.021	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:53	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04839-18
Name: XPW01
Matrix: Ground Water - Grab

Sampled: 04/27/23 14:07
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	8.1	mg/L		04/29/23 11:36	5	5.0	04/29/23 11:36	CRD	EPA 300.0 REV 2.1
Fluoride	5.34	mg/L		04/29/23 11:36	5	1.25	04/29/23 11:36	CRD	EPA 300.0 REV 2.1
Sulfate	2900	mg/L		05/04/23 21:21	1000	1000	05/04/23 21:21	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	11.06	Feet		04/27/23 14:07	1		04/27/23 14:07	FIELD	Field*
Dissolved oxygen, Field	4.3	mg/L		04/27/23 14:07	1		04/27/23 14:07	FIELD	Field*
Oxidation Reduction Potential	-379	mV		04/27/23 14:07	1	-500	04/27/23 14:07	FIELD	Field*
pH, Field Measured	12.2	pH Units		04/27/23 14:07	1		04/27/23 14:07	FIELD	Field*
Specific Conductance, Field Measured	10500	umhos/cm		04/27/23 14:07	1		04/27/23 14:07	FIELD	Field*
Temperature, Field Measured	18.4	°C		04/27/23 14:07	1		04/27/23 14:07	FIELD	Field*
Turbidity, Field Measured	>1000:	NTU		04/27/23 14:07	1	0.00	04/27/23 14:07	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	700	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	6900	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Boron	14000	ug/L		05/08/23 09:07	100	200	05/09/23 12:33	JMW	EPA 6020A
Calcium	36	mg/L		05/08/23 09:07	5	0.20	05/09/23 10:25	JMW	EPA 6020A
Magnesium	8.7	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:25	JMW	EPA 6020A
Potassium	47	mg/L		05/08/23 09:07	5	0.10	05/09/23 10:25	JMW	EPA 6020A
Sodium	2400	mg/L		05/08/23 09:07	100	2.0	05/09/23 12:33	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-19
Name: XPW02
Matrix: Ground Water - Grab

Sampled: 04/27/23 15:29
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	8.8	mg/L		04/29/23 12:12	1	1.0	04/29/23 12:12	CRD	EPA 300.0 REV 2.1
Fluoride	0.536	mg/L		04/29/23 12:12	1	0.250	04/29/23 12:12	CRD	EPA 300.0 REV 2.1
Sulfate	150	mg/L		04/29/23 12:48	25	25	04/29/23 12:48	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	7.39	Feet		04/27/23 15:29	1		04/27/23 15:29	FIELD	Field*
Dissolved oxygen, Field	4.8	mg/L		04/27/23 15:29	1		04/27/23 15:29	FIELD	Field*
Oxidation Reduction Potential	-237	mV		04/27/23 15:29	1	-500	04/27/23 15:29	FIELD	Field*
pH, Field Measured	9.58	pH Units		04/27/23 15:29	1		04/27/23 15:29	FIELD	Field*
Specific Conductance, Field Measured	400.0	umhos/cm		04/27/23 15:29	1		04/27/23 15:29	FIELD	Field*
Temperature, Field Measured	17.6	°C		04/27/23 15:29	1		04/27/23 15:29	FIELD	Field*
Turbidity, Field Measured	39.1	NTU		04/27/23 15:29	1	0.00	04/27/23 15:29	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	12	mg/L	M	05/08/23 16:02	1	10	05/08/23 16:02	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	35	mg/L		05/08/23 16:02	1	10	05/08/23 16:02	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	290	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Boron	2300	ug/L		05/08/23 09:07	5	10	05/09/23 13:28	JMW	EPA 6020A
Calcium	23	mg/L		05/08/23 09:07	5	0.20	05/09/23 13:28	JMW	EPA 6020A
Magnesium	0.19	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:28	JMW	EPA 6020A
Potassium	14	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:28	JMW	EPA 6020A
Sodium	64	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:28	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04839-20
Name: XPW03
Matrix: Ground Water - Grab

Sampled: 04/27/23 17:00
Received: 04/28/23 12:45

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	9.7	mg/L		04/29/23 15:49	5	5.0	04/29/23 15:49	CRD	EPA 300.0 REV 2.1
Fluoride	1.03	mg/L		04/29/23 15:31	1	0.250	04/29/23 15:31	CRD	EPA 300.0 REV 2.1
Sulfate	120	mg/L		04/29/23 16:07	25	25	04/29/23 16:07	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	10.81	Feet		04/27/23 17:00	1		04/27/23 17:00	FIELD	Field*
Dissolved oxygen, Field	0.70	mg/L		04/27/23 17:00	1		04/27/23 17:00	FIELD	Field*
Oxidation Reduction Potential	-273	mV		04/27/23 17:00	1	-500	04/27/23 17:00	FIELD	Field*
pH, Field Measured	11.5	pH Units		04/27/23 17:00	1		04/27/23 17:00	FIELD	Field*
Specific Conductance, Field Measured	1430	umhos/cm		04/27/23 17:00	1		04/27/23 17:00	FIELD	Field*
Temperature, Field Measured	17.1	°C		04/27/23 17:00	1		04/27/23 17:00	FIELD	Field*
Turbidity, Field Measured	119	NTU		04/27/23 17:00	1	0.00	04/27/23 17:00	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	< 10	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	200	mg/L		05/08/23 13:35	1	10	05/08/23 13:35	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	620	mg/L		05/02/23 12:44	1	26	05/03/23 11:06	HRF	SM 2540C
Total Metals - PIA									
Boron	1800	ug/L		05/08/23 09:07	5	10	05/09/23 13:32	JMW	EPA 6020A
Calcium	26	mg/L		05/08/23 09:07	5	0.20	05/09/23 13:32	JMW	EPA 6020A
Magnesium	0.69	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:32	JMW	EPA 6020A
Potassium	18	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:32	JMW	EPA 6020A
Sodium	190	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:32	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04919-02
Name: XPW04
Matrix: Ground Water - Grab

Sampled: 04/28/23 10:23
Received: 04/28/23 16:12

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	59	mg/L		04/29/23 17:45	10	10	04/29/23 17:45	CRD	EPA 300.0 REV 2.1
Sulfate	9500	mg/L		04/29/23 18:03	1000	1000	04/29/23 18:03	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	12.49	Feet		04/28/23 10:23	1		04/28/23 10:23	FIELD	Field*
Dissolved oxygen, Field	1.8	mg/L		04/28/23 10:23	1		04/28/23 10:23	FIELD	Field*
Oxidation Reduction Potential	-255	mV		04/28/23 10:23	1	-500	04/28/23 10:23	FIELD	Field*
pH, Field Measured	11.6	pH Units		04/28/23 10:23	1		04/28/23 10:23	FIELD	Field*
Specific Conductance, Field Measured	11900	umhos/cm		04/28/23 10:23	1		04/28/23 10:23	FIELD	Field*
Temperature, Field Measured	16.2	°C		04/28/23 10:23	1		04/28/23 10:23	FIELD	Field*
Turbidity, Field Measured	75.5	NTU		04/28/23 10:23	1	0.00	04/28/23 10:23	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	< 10	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	220	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Fluoride	0.985	mg/L		05/05/23 17:00	1	0.250	05/05/23 17:00	TTH	SM 4500F C 1997
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	14000	mg/L	H	05/05/23 17:14	1	51	05/08/23 10:59	CPS	SM 2540C
Total Metals - PIA									
Boron	4000	ug/L		05/08/23 09:07	5	10	05/09/23 13:40	JMW	EPA 6020A
Calcium	100	mg/L		05/08/23 09:07	5	0.20	05/09/23 13:40	JMW	EPA 6020A
Magnesium	0.50	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:40	JMW	EPA 6020A
Potassium	89	mg/L		05/08/23 09:07	5	0.10	05/09/23 13:40	JMW	EPA 6020A
Sodium	4700	mg/L		05/08/23 09:07	100	2.0	05/09/23 14:32	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04919-03
Name: APW14
Matrix: Ground Water - Grab

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	46	mg/L		04/29/23 18:39	10	10	04/29/23 18:39	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/29/23 18:21	1	0.250	04/29/23 18:21	CRD	EPA 300.0 REV 2.1
Sulfate	380	mg/L		04/29/23 18:57	50	50	04/29/23 18:57	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	20.72	Feet		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Dissolved oxygen, Field	1.2	mg/L		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Oxidation Reduction Potential	-95.0	mV		04/28/23 11:29	1	-500	04/28/23 11:29	FIELD	Field*
pH, Field Measured	7.34	pH Units		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Specific Conductance, Field Measured	1480	umhos/cm		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Temperature, Field Measured	14.8	°C		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Turbidity, Field Measured	8.81	NTU		04/28/23 11:29	1	0.00	04/28/23 11:29	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	460	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	980	mg/L		05/03/23 12:09	1	26	05/03/23 15:21	CPS	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 14:10	JMW	EPA 6020A
Arsenic	5.5	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:51	JMW	EPA 6020A
Barium	65	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Boron	100	ug/L		05/08/23 09:07	5	10	05/09/23 14:10	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Calcium	130	mg/L		05/08/23 09:07	5	0.20	05/09/23 14:10	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 14:10	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 14:10	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Magnesium	66	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:10	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 14:10	JMW	EPA 6020A
Molybdenum	4.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Potassium	1.6	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:10	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04919-03
Name: APW14
Matrix: Ground Water - Grab

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Sodium	130	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:10	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:10	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 10:54	TJJ	EPA 6010B

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ANALYTICAL RESULTS

Sample: GD04919-04
Name: APW14 DUP
Matrix: Ground Water - Grab

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Anions - PIA									
Chloride	48	mg/L	Q4	04/29/23 20:45	10	10	04/29/23 20:45	CRD	EPA 300.0 REV 2.1
Fluoride	< 0.250	mg/L		04/29/23 19:15	1	0.250	04/29/23 19:15	CRD	EPA 300.0 REV 2.1
Sulfate	370	mg/L	Q4	04/29/23 21:03	50	50	04/29/23 21:03	CRD	EPA 300.0 REV 2.1
Field - PIA									
Depth, From Measuring Point	20.72	Feet		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Dissolved oxygen, Field	1.2	mg/L		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Oxidation Reduction Potential	-95.0	mV		04/28/23 11:29	1	-500	04/28/23 11:29	FIELD	Field*
pH, Field Measured	7.34	pH Units		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Specific Conductance, Field Measured	1480	umhos/cm		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Temperature, Field Measured	14.8	°C		04/28/23 11:29	1		04/28/23 11:29	FIELD	Field*
Turbidity, Field Measured	8.81	NTU		04/28/23 11:29	1	0.00	04/28/23 11:29	FIELD	Field*
General Chemistry - PIA									
Alkalinity - bicarbonate as CaCO3	450	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Alkalinity - carbonate as CaCO3	< 10	mg/L		05/09/23 10:18	1	10	05/09/23 10:18	CPS	SM 2320B 1997*
Soluble General Chemistry - PIA									
Solids - total dissolved solids (TDS)	1000	mg/L		05/03/23 12:09	1	26	05/03/23 15:21	CPS	SM 2540C
Total Metals - PIA									
Antimony	< 3.0	ug/L		05/08/23 09:07	5	3.0	05/09/23 14:13	JMW	EPA 6020A
Arsenic	5.6	ug/L		05/08/23 09:07	5	1.0	05/10/23 09:54	JMW	EPA 6020A
Barium	64	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Beryllium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Boron	100	ug/L		05/08/23 09:07	5	10	05/09/23 14:13	JMW	EPA 6020A
Cadmium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Calcium	130	mg/L		05/08/23 09:07	5	0.20	05/09/23 14:13	JMW	EPA 6020A
Chromium	< 4.0	ug/L		05/08/23 09:07	5	4.0	05/09/23 14:13	JMW	EPA 6020A
Cobalt	< 2.0	ug/L		05/08/23 09:07	5	2.0	05/09/23 14:13	JMW	EPA 6020A
Lead	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Magnesium	65	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:13	JMW	EPA 6020A
Mercury	< 0.20	ug/L		05/08/23 09:07	5	0.20	05/09/23 14:13	JMW	EPA 6020A
Molybdenum	3.9	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Potassium	1.6	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:13	JMW	EPA 6020A

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ANALYTICAL RESULTS

Sample: GD04919-04
Name: APW14 DUP
Matrix: Ground Water - Grab

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Selenium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Sodium	130	mg/L		05/08/23 09:07	5	0.10	05/09/23 14:13	JMW	EPA 6020A
Thallium	< 1.0	ug/L		05/08/23 09:07	5	1.0	05/09/23 14:13	JMW	EPA 6020A
Lithium	< 0.020	mg/L		05/08/23 09:07	1	0.020	05/09/23 11:10	TJJ	EPA 6010B

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Batch B331846 - IC No Prep - EPA 300.0 REV 2.1									
Matrix Spike (B331846-MS2)	**Sample: GD04461-03**			Prepared & Analyzed: 04/26/23					
Chloride	1.0E9	mg/L	Q4	1.500	71	NR	80-120		
Fluoride	2.19	mg/L		1.500	0.606	106	80-120		
Sulfate	2.25	mg/L		1.500	0.650	107	80-120		
Matrix Spike Dup (B331846-MSD2)	**Sample: GD04461-03**			Prepared & Analyzed: 04/26/23					
Chloride	1.0E9	mg/L	Q4	1.500	71	NR	80-120	0	20
Fluoride	2.18	mg/L		1.500	0.606	105	80-120	0.2	20
Sulfate	2.25	mg/L		1.500	0.650	106	80-120	0.08	20
Batch B331995 - No Prep - SM 2540C									
Blank (B331995-BLK1)				Prepared & Analyzed: 04/28/23					
Solids - total dissolved solids (TDS)	< 17	mg/L							
LCS (B331995-BS1)				Prepared & Analyzed: 04/28/23					
Solids - total dissolved solids (TDS)	963	mg/L		1000		96	84.9-109		
Duplicate (B331995-DUP1)	**Sample: GD04461-03**			Prepared & Analyzed: 04/28/23					
Solids - total dissolved solids (TDS)	795	mg/L			795			0	5
Batch B332031 - IC No Prep - EPA 300.0 REV 2.1									
Matrix Spike (B332031-MS1)	**Sample: GD04839-04**			Prepared & Analyzed: 04/28/23					
Fluoride	2.01	mg/L		1.500	0.498	101	80-120		
Sulfate	2.58	mg/L		1.500	0.975	107	80-120		
Chloride	1.0E9	mg/L	Q4	1.500	46	NR	80-120		
Matrix Spike Dup (B332031-MSD1)	**Sample: GD04839-04**			Prepared & Analyzed: 04/28/23					
Fluoride	2.02	mg/L		1.500	0.498	101	80-120	0.6	20
Sulfate	2.58	mg/L		1.500	0.975	107	80-120	0.1	20
Chloride	1.0E9	mg/L	Q4	1.500	46	NR	80-120	0	20
Batch B332081 - No Prep - SM 2540C									
Blank (B332081-BLK1)				Prepared & Analyzed: 05/01/23					
Solids - total dissolved solids (TDS)	< 17	mg/L							
LCS (B332081-BS1)				Prepared & Analyzed: 05/01/23					
Solids - total dissolved solids (TDS)	947	mg/L		1000		95	84.9-109		
Duplicate (B332081-DUP2)	**Sample: GD04746-02**			Prepared & Analyzed: 05/01/23					
Solids - total dissolved solids (TDS)	3720	mg/L			3800			2	5
Batch B332085 - IC No Prep - EPA 300.0 REV 2.1									
Matrix Spike (B332085-MS1)	**Sample: GD04919-04**			Prepared & Analyzed: 04/29/23					
Sulfate	1.00E9	mg/L	Q4	1.500	370	NR	80-120		
Fluoride	1.70	mg/L		1.500	0.247	97	80-120		
Chloride	1.0E9	mg/L	Q4	1.500	48	NR	80-120		
Matrix Spike Dup (B332085-MSD1)	**Sample: GD04919-04**			Prepared & Analyzed: 04/29/23					
Fluoride	1.73	mg/L		1.500	0.247	99	80-120	2	20
Sulfate	1.00E9	mg/L	Q4	1.500	370	NR	80-120	0	20
Chloride	1.0E9	mg/L	Q4	1.500	48	NR	80-120	0	20
Batch B332218 - No Prep - SM 2540C									

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Blank (B332218-BLK1)				Prepared: 05/02/23 Analyzed: 05/03/23					
Solids - total dissolved solids (TDS)	< 17	mg/L							
LCS (B332218-BS1)				Prepared: 05/02/23 Analyzed: 05/03/23					
Solids - total dissolved solids (TDS)	1000	mg/L		1000		100	84.9-109		
Batch B332309 - SW 3015 - EPA 6010B									
Blank (B332309-BLK1)				Prepared: 05/03/23 Analyzed: 05/09/23					
Lithium	< 0.020	mg/L							
LCS (B332309-BS1)				Prepared: 05/03/23 Analyzed: 05/09/23					
Lithium	0.565	mg/L		0.5556		102	80-120		
Matrix Spike (B332309-MS1)	**Sample: GD04461-03**			Prepared: 05/03/23 Analyzed: 05/09/23					
Lithium	0.561	mg/L		0.5556	ND	101	75-125		
Matrix Spike Dup (B332309-MSD1)	**Sample: GD04461-03**			Prepared: 05/03/23 Analyzed: 05/09/23					
Lithium	0.543	mg/L		0.5556	ND	98	75-125	3	20
Batch B332309 - SW 3015 - EPA 6020A									
Blank (B332309-BLK1)				Prepared: 05/03/23 Analyzed: 05/04/23					
Antimony	< 3.0	ug/L							
Arsenic	< 1.0	ug/L							
Barium	< 1.0	ug/L							
Beryllium	< 1.0	ug/L							
Boron	< 10	ug/L							
Cadmium	< 1.0	ug/L							
Calcium	< 0.20	mg/L							
Chromium	< 4.0	ug/L							
Cobalt	< 2.0	ug/L							
Lead	< 1.0	ug/L							
Magnesium	< 0.10	mg/L							
Mercury	< 0.20	ug/L							
Molybdenum	< 1.0	ug/L							
Potassium	< 0.10	mg/L							
Selenium	< 1.0	ug/L							
Sodium	< 0.10	mg/L							
Thallium	< 1.0	ug/L							
LCS (B332309-BS1)				Prepared: 05/03/23 Analyzed: 05/04/23					
Antimony	539	ug/L		555.6		97	80-120		
Arsenic	538	ug/L		555.6		97	80-120		
Barium	540	ug/L		555.6		97	80-120		
Beryllium	557	ug/L		555.6		100	80-120		
Boron	568	ug/L		555.6		102	80-120		
Cadmium	529	ug/L		555.6		95	80-120		
Calcium	5.40	mg/L		5.556		97	80-120		
Chromium	582	ug/L		555.6		105	80-120		
Cobalt	576	ug/L		555.6		104	80-120		
Lead	557	ug/L		555.6		100	80-120		
Magnesium	5.64	mg/L		5.556		102	80-120		
Mercury	55.7	ug/L		55.56		100	80-120		
Molybdenum	527	ug/L		555.6		95	80-120		

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
LCS (B332309-BS1)				Prepared: 05/03/23 Analyzed: 05/04/23					
Potassium	5.54	mg/L		5.556		100	80-120		
Selenium	549	ug/L		555.6		99	80-120		
Sodium	5.54	mg/L		5.556		100	80-120		
Thallium	585	ug/L		555.6		105	80-120		
Matrix Spike (B332309-MS1)	**Sample: GD04461-03**			Prepared: 05/03/23 Analyzed: 05/04/23					
Antimony	530	ug/L		555.6	ND	95	75-125		
Arsenic	548	ug/L		555.6	21.0	95	75-125		
Barium	1070	ug/L		555.6	541	95	75-125		
Beryllium	550	ug/L		555.6	ND	99	75-125		
Boron	691	ug/L		555.6	129	101	75-125		
Cadmium	522	ug/L		555.6	ND	94	75-125		
Calcium	98.1	mg/L	Q4	5.556	96.3	32	75-125		
Chromium	562	ug/L		555.6	ND	101	75-125		
Cobalt	552	ug/L		555.6	ND	99	75-125		
Lead	531	ug/L		555.6	0.356	95	75-125		
Magnesium	47.9	mg/L	Q4	5.556	44.3	65	75-125		
Mercury	57.8	ug/L		55.56	ND	104	75-125		
Molybdenum	533	ug/L		555.6	ND	96	75-125		
Potassium	7.16	mg/L		5.556	1.80	97	75-125		
Selenium	543	ug/L		555.6	ND	98	75-125		
Sodium	144	mg/L	Q4	5.556	143	10	75-125		
Thallium	561	ug/L		555.6	ND	101	75-125		
Matrix Spike Dup (B332309-MSD1)	**Sample: GD04461-03**			Prepared: 05/03/23 Analyzed: 05/04/23					
Antimony	534	ug/L		555.6	ND	96	75-125	0.8	20
Arsenic	560	ug/L		555.6	21.0	97	75-125	2	20
Barium	1070	ug/L		555.6	541	96	75-125	0.2	20
Beryllium	561	ug/L		555.6	ND	101	75-125	2	20
Boron	707	ug/L		555.6	129	104	75-125	2	20
Cadmium	532	ug/L		555.6	ND	96	75-125	2	20
Calcium	100	mg/L	Q4	5.556	96.3	72	75-125	2	20
Chromium	575	ug/L		555.6	ND	103	75-125	2	20
Cobalt	566	ug/L		555.6	ND	102	75-125	2	20
Lead	536	ug/L		555.6	0.356	96	75-125	1	20
Magnesium	49.1	mg/L	Q4	5.556	44.3	87	75-125	2	20
Mercury	59.4	ug/L		55.56	ND	107	75-125	3	20
Molybdenum	542	ug/L		555.6	ND	98	75-125	2	20
Potassium	7.32	mg/L		5.556	1.80	99	75-125	2	20
Selenium	552	ug/L		555.6	ND	99	75-125	2	20
Sodium	147	mg/L	Q4	5.556	143	66	75-125	2	20
Thallium	565	ug/L		555.6	ND	102	75-125	0.8	20
Batch B332343 - No Prep - SM 2540C									
Blank (B332343-BLK1)				Prepared & Analyzed: 05/03/23					
Solids - total dissolved solids (TDS)	< 17	mg/L							
LCS (B332343-BS1)				Prepared & Analyzed: 05/03/23					
Solids - total dissolved solids (TDS)	950	mg/L		1000		95	84.9-109		

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Batch B332419 - SW 3015 - EPA 6010B									
Blank (B332419-BLK1)				Prepared: 05/04/23 Analyzed: 05/09/23					
Lithium	< 0.020	mg/L							
LCS (B332419-BS1)				Prepared: 05/04/23 Analyzed: 05/09/23					
Lithium	0.564	mg/L		0.5556		102	80-120		
Matrix Spike (B332419-MS1)	**Sample: GD04746-02**			Prepared: 05/04/23 Analyzed: 05/09/23					
Lithium	0.572	mg/L		0.5556	0.0326	97	75-125		
Matrix Spike Dup (B332419-MSD1)	**Sample: GD04746-02**			Prepared: 05/04/23 Analyzed: 05/09/23					
Lithium	0.575	mg/L		0.5556	0.0326	98	75-125	0.5	20
Batch B332419 - SW 3015 - EPA 6020A									
Blank (B332419-BLK1)				Prepared: 05/04/23 Analyzed: 05/09/23					
Antimony	< 3.0	ug/L							
Arsenic	< 1.0	ug/L							
Barium	< 1.0	ug/L							
Beryllium	< 1.0	ug/L							
Boron	< 10	ug/L							
Cadmium	< 1.0	ug/L							
Calcium	< 0.20	mg/L							
Chromium	< 4.0	ug/L							
Cobalt	< 2.0	ug/L							
Lead	< 1.0	ug/L							
Magnesium	< 0.10	mg/L							
Mercury	< 0.20	ug/L							
Molybdenum	< 1.0	ug/L							
Potassium	< 0.10	mg/L							
Selenium	< 1.0	ug/L							
Sodium	< 0.10	mg/L							
Thallium	< 1.0	ug/L							
LCS (B332419-BS1)				Prepared: 05/04/23 Analyzed: 05/09/23					
Antimony	546	ug/L		555.6		98	80-120		
Arsenic	608	ug/L		555.6		109	80-120		
Barium	548	ug/L		555.6		99	80-120		
Beryllium	549	ug/L		555.6		99	80-120		
Boron	548	ug/L		555.6		99	80-120		
Cadmium	547	ug/L		555.6		99	80-120		
Calcium	5.47	mg/L		5.556		98	80-120		
Chromium	578	ug/L		555.6		104	80-120		
Cobalt	558	ug/L		555.6		100	80-120		
Lead	555	ug/L		555.6		100	80-120		
Magnesium	5.53	mg/L		5.556		100	80-120		
Mercury	56.5	ug/L		55.56		102	80-120		
Molybdenum	532	ug/L		555.6		96	80-120		
Potassium	5.57	mg/L		5.556		100	80-120		
Selenium	562	ug/L		555.6		101	80-120		
Sodium	5.52	mg/L		5.556		99	80-120		
Thallium	550	ug/L		555.6		99	80-120		

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Matrix Spike (B332419-MS1)	**Sample: GD04746-02**			Prepared: 05/04/23 Analyzed: 05/09/23					
Antimony	523	ug/L		555.6	ND	94	75-125		
Arsenic	593	ug/L		555.6	0.933	107	75-125		
Barium	548	ug/L		555.6	34.8	92	75-125		
Beryllium	515	ug/L		555.6	ND	93	75-125		
Boron	577	ug/L		555.6	53.5	94	75-125		
Cadmium	518	ug/L		555.6	ND	93	75-125		
Calcium	379	mg/L	Q4	5.556	389	NR	75-125		
Chromium	538	ug/L		555.6	3.12	96	75-125		
Cobalt	518	ug/L		555.6	0.828	93	75-125		
Lead	509	ug/L		555.6	0.222	92	75-125		
Magnesium	285	mg/L	Q4	5.556	298	NR	75-125		
Mercury	56.8	ug/L		55.56	ND	102	75-125		
Molybdenum	527	ug/L		555.6	1.26	95	75-125		
Potassium	7.02	mg/L		5.556	1.83	94	75-125		
Selenium	544	ug/L		555.6	ND	98	75-125		
Sodium	248	mg/L	Q4	5.556	259	NR	75-125		
Thallium	509	ug/L		555.6	ND	92	75-125		
Matrix Spike Dup (B332419-MSD1)	**Sample: GD04746-02**			Prepared: 05/04/23 Analyzed: 05/09/23					
Antimony	522	ug/L		555.6	ND	94	75-125	0.2	20
Arsenic	592	ug/L		555.6	0.933	106	75-125	0.2	20
Barium	552	ug/L		555.6	34.8	93	75-125	0.6	20
Beryllium	523	ug/L		555.6	ND	94	75-125	2	20
Boron	586	ug/L		555.6	53.5	96	75-125	2	20
Cadmium	525	ug/L		555.6	ND	94	75-125	1	20
Calcium	385	mg/L	Q4	5.556	389	NR	75-125	2	20
Chromium	546	ug/L		555.6	3.12	98	75-125	1	20
Cobalt	530	ug/L		555.6	0.828	95	75-125	2	20
Lead	517	ug/L		555.6	0.222	93	75-125	1	20
Magnesium	290	mg/L	Q4	5.556	298	NR	75-125	2	20
Mercury	57.0	ug/L		55.56	ND	103	75-125	0.5	20
Molybdenum	534	ug/L		555.6	1.26	96	75-125	1	20
Potassium	7.12	mg/L		5.556	1.83	95	75-125	1	20
Selenium	554	ug/L		555.6	ND	100	75-125	2	20
Sodium	254	mg/L	Q4	5.556	259	NR	75-125	2	20
Thallium	517	ug/L		555.6	ND	93	75-125	2	20
Batch B332511 - No Prep - SM 2320B 1997									
Blank (B332511-BLK1)				Prepared & Analyzed: 05/04/23					
Alkalinity - carbonate as CaCO3	2.50	mg/L							
Alkalinity - bicarbonate as CaCO3	2.50	mg/L							
Blank (B332511-BLK2)				Prepared & Analyzed: 05/04/23					
Alkalinity - bicarbonate as CaCO3	2.50	mg/L							
Alkalinity - carbonate as CaCO3	2.50	mg/L							
Duplicate (B332511-DUP1)	**Sample: GD04461-03**			Prepared & Analyzed: 05/04/23					
Alkalinity - carbonate as CaCO3	< 10	mg/L			ND				10
Alkalinity - bicarbonate as CaCO3	600	mg/L			562			6	10
Duplicate (B332511-DUP2)	**Sample: GD04461-03**			Prepared & Analyzed: 05/04/23					

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
Duplicate (B332511-DUP2)	**Sample: GD04461-03**			Prepared & Analyzed: 05/04/23					
Alkalinity - carbonate as CaCO3	< 10	mg/L			ND				10
Alkalinity - bicarbonate as CaCO3	575	mg/L			562			2	10
Batch B332653 - No Prep - SM 4500F C 1997									
Matrix Spike (B332653-MS2)	**Sample: GD04746-02**			Prepared & Analyzed: 05/05/23					
Fluoride	1.38	mg/L		1.000	0.365	102	80-120		
Matrix Spike Dup (B332653-MSD2)	**Sample: GD04746-02**			Prepared & Analyzed: 05/05/23					
Fluoride	1.36	mg/L		1.000	0.365	99	80-120	2	20
Batch B332659 - No Prep - SM 2320B 1997									
Duplicate (B332659-DUP3)	**Sample: GD04746-02**			Prepared & Analyzed: 05/05/23					
Alkalinity - bicarbonate as CaCO3	525	mg/L			525			0	10
Alkalinity - carbonate as CaCO3	< 10	mg/L			ND				10
Batch B332663 - No Prep - SM 2540C									
Blank (B332663-BLK1)				Prepared: 05/05/23 Analyzed: 05/08/23					
Solids - total dissolved solids (TDS)	< 17	mg/L							
LCS (B332663-BS1)				Prepared: 05/05/23 Analyzed: 05/08/23					
Solids - total dissolved solids (TDS)	1010	mg/L		1000		101	84.9-109		
Batch B332692 - SW 3015 - EPA 6010B									
Blank (B332692-BLK1)				Prepared: 05/08/23 Analyzed: 05/09/23					
Lithium	< 0.020	mg/L							
LCS (B332692-BS1)				Prepared: 05/08/23 Analyzed: 05/09/23					
Lithium	0.558	mg/L		0.5556		100	80-120		
Batch B332692 - SW 3015 - EPA 6020A									
Blank (B332692-BLK1)				Prepared: 05/08/23 Analyzed: 05/09/23					
Antimony	< 3.0	ug/L							
Arsenic	< 1.0	ug/L							
Barium	< 1.0	ug/L							
Beryllium	< 1.0	ug/L							
Boron	< 10	ug/L							
Cadmium	< 1.0	ug/L							
Calcium	< 0.20	mg/L							
Chromium	< 4.0	ug/L							
Cobalt	< 2.0	ug/L							
Lead	< 1.0	ug/L							
Magnesium	< 0.10	mg/L							
Mercury	< 0.20	ug/L							
Molybdenum	< 1.0	ug/L							
Potassium	< 0.10	mg/L							
Selenium	< 1.0	ug/L							
Sodium	< 0.10	mg/L							
Thallium	< 1.0	ug/L							
LCS (B332692-BS1)				Prepared: 05/08/23 Analyzed: 05/09/23					
Antimony	512	ug/L		555.6		92	80-120		

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit
LCS (B332692-BS1)				Prepared: 05/08/23 Analyzed: 05/10/23					
Arsenic	595	ug/L		555.6		107	80-120		
Barium	527	ug/L		555.6		95	80-120		
Beryllium	534	ug/L		555.6		96	80-120		
Boron	531	ug/L		555.6		96	80-120		
Cadmium	525	ug/L		555.6		95	80-120		
Calcium	5.13	mg/L		5.556		92	80-120		
Chromium	545	ug/L		555.6		98	80-120		
Cobalt	542	ug/L		555.6		98	80-120		
Lead	523	ug/L		555.6		94	80-120		
Magnesium	5.36	mg/L		5.556		96	80-120		
Mercury	49.7	ug/L		55.56		89	80-120		
Molybdenum	510	ug/L		555.6		92	80-120		
Potassium	5.37	mg/L		5.556		97	80-120		
Selenium	535	ug/L		555.6		96	80-120		
Sodium	5.38	mg/L		5.556		97	80-120		
Thallium	520	ug/L		555.6		94	80-120		
Batch B332796 - No Prep - SM 2320B 1997									
Duplicate (B332796-DUP2)	**Sample: GD04839-07**			Prepared & Analyzed: 05/08/23					
Alkalinity - carbonate as CaCO3	< 10	mg/L			ND				10
Alkalinity - bicarbonate as CaCO3	438	mg/L			425			3	10
Batch B332797 - No Prep - SM 2320B 1997									
Duplicate (B332797-DUP1)	**Sample: GD04839-19**			Prepared & Analyzed: 05/08/23					
Alkalinity - bicarbonate as CaCO3	10.0	mg/L	M		12.5			22	10
Alkalinity - carbonate as CaCO3	35.0	mg/L			35.0			0	10

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NOTES

Specifications regarding method revisions, method modifications, and calculations used for analysis are available upon request. Please contact your project manager.

* Not a TNI accredited analyte

Certifications

CHI - McHenry, IL - 4314-A W. Crystal Lake Road, McHenry, IL 60050
TNI Accreditation for Drinking Water and Wastewater Fields of Testing through IL EPA Accreditation No. 100279
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory Registry No. 17556

PIA - Peoria, IL - 2231 W. Altorfer Drive, Peoria, IL 61615
TNI Accreditation for Drinking Water, Wastewater, Solid and Hazardous Material Fields of Testing through IL EPA Accreditation No. 100230
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory Registry No. 17553
Drinking Water Certifications/Accreditations: Iowa (240); Kansas (E-10338); Missouri (870)
Wastewater Certifications/Accreditations: Arkansas (88-0677); Iowa (240); Kansas (E-10338)
Solid and Hazardous Material Certifications/Accreditations: Arkansas (88-0677); Iowa (240); Kansas (E-10338)

SPMO - Springfield, MO - 1805 W Sunset Street, Springfield, MO 65807
USEPA DMR-QA Program

STL - Hazelwood, MO - 944 Anglum Rd, Hazelwood, MO 63042
TNI Accreditation for Wastewater, Solid and Hazardous Material Fields of Testing through KS KDHE Certification No. E-10389
TNI Accreditation for Wastewater, Solid and Hazardous Material Fields of Testing through IL EPA Accreditation No. - 200080
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory, Registry No. 171050
Missouri Department of Natural Resources - Certificate of Approval for Microbiological Laboratory Service - No. 1050

Qualifiers

H	Test performed after the expiration of the appropriate regulatory/advisory maximum allowable hold time.
M	Analyte failed to meet the required acceptance criteria for duplicate analysis.
Q4	The matrix spike recovery result is unusable since the analyte concentration in the sample is greater than four times the spike level. The associated blank spike was acceptable.

Gail J Schindler

Certified by: Gail Schindler, Project Manager

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GD04461
VMW 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N: NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213																						
2	NEW_A214																						
3	NEW_A215																						
4	NEW_APW02																						
5	NEW_APW03			4/25/23	1326		11	X	X	X													
6	NEW_APW04			4/25/23	1642		11	X	X	X													
7	NEW_APW05																						
8	NEW_APW05#S																						
9	NEW_APW06																						
10	NEW_APW07																						
11	NEW_APW08																						
12	NEW_APW09																						
13	NEW_APW10																						
14	NEW_APW11																						
15	NEW_APW12																						
16	NEW_APW13																						

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
NEW-23Q2 Rev 0		4/26/23	706		4-26-23	1020	
		4-26-23	1310		4-26-23	1330	15 / Y / N / Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY): 04/25/23

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

~~4-26 1020~~ ~~5-3-23~~
EMS 5-3-23

ATTACHMENT B.
845 QUARTERLY REPORT - QUARTER 2, 2023
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04461
Vmw 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

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Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_APW14																								
2	NEW_APW15																								
3	NEW_APW16			4/25/23	1326		22	X	X	X															
4	NEW_APW17			4/25/23	1650		11	X	X	X															
5	NEW_APW18			4/25/23	1503		11	X	X	X															
6	04/26/23 NEW_G104 + Dup			4/25/23	1652		8	X	X	X		X													
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106			4/25/23	1131		4	X	X	X		X													
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/26/23	0706		4-26-23	1020
		4-26-23	1310		4-26-23	1330

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
1.5	Y	N	Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Rinberton

SIGNATURE of SAMPLER:

DATE Signed (MM/DD/YY): 04/25/2023

ATTACHMENT B.
845 QUARTERLY REPORT - QUARTER 2, 2023
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04461
Vmw 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G114																								
2	NEW_G114&D			4/25/23	1804		2	X		X															
3	NEW_G115 DTW																								
4	NEW_G116																								
5	NEW_G117 DTW																								
6	NEW_G118																								
7	NEW_G119 DTW																								
8	NEW_G120 DTW																								
9	NEW_G125																								
10	NEW_G128																								
11	NEW_G130																								
12	NEW_G133																								
13	NEW_G136																								
14	NEW_G139																								
15	NEW_G141																								
16	NEW_G201			4/25/23	1527		4	X	X	X		X													

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	[signature]	4/26/23	0706	[signature]	4-26-23	1020
	[signature]	4-26-23	1330	[signature]	4-26-23	1330

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
1.5	Y	N	Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER: [signature]

DATE Signed (MM/DD/YY): 04/25/23

[signature] 4-26 1020

EMS 5-3-23

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04461-
Vmw 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:
Company: Vistra Corp
Address: 13498 E. 900th St
Email To: Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911 Fax:
Requested Due Date/TAT: 10 day

Section B Required Project Information:
Report To: Brian Voelker
Copy To: Jason Stuckey
Purchase Order No.:
Project Name:
Project Number: 2285

Section C Invoice Information:
Attention: Jason Stuckey
Company Name: Vistra Corp
Address: see Section A
Quote Reference:
Project Manager:
Profile #:

REGULATORY AGENCY
NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER
Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	0|S6|W|23 NEW_G202 - Duplicate			4/25/23	1208		8	X	X	X		X													
2	NEW_G217#S																								
3	NEW_G221																								
4	NEW_G225																								
5	NEW_G230																								
6	NEW_G231																								
7	NEW_G232																								
8	NEW_G233																								
9	NEW_G234			4/25/23	1542		11	X	X	X	X	X													
10	NEW_L1R_leachate																								
11	NEW_L201_leachate DTW																								
12	NEW_L202_leachate DTW																								
13	NEW_L203_leachate DTW																								
14	NEW_L204_leachate DTW																								
15	NEW_L205_leachate DTW																								
16	NEW_L301_leachate																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/26/23	0706		4-26-23	1020
		4-26-23	1330		4-26-23	1330

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Pemberton
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 04/25/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
15	Y	N	Y

EMS 5-3-23

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04461
VMW 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_LREP_leachate																								
2	NEW_MW34&D																								
3	NEW_MW35&D																								
4	NEW_MW43&D																								
5	NEW_MW46&D																								
6	NEW_R201			4/25/23	1424		4	X	X	X		X													
7	NEW_R202			4/25/23	1311		2	X	X	X		X													
8	NEW_R217&D						3	0	4/25																
9	NEW_R219																								
10	~~NEW_T101~~ EB-01 (04-25-23)			4/25/23	1715		9																		
11	NEW_T102																								
12	NEW_XPW01_pore																								
13	NEW_XPW02_pore																								
14	NEW_XPW03_pore																								
15	NEW_XPW04_pore																								
16	NEW_XSG01 - DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
NEW-23Q2 Rev 0		4/26/23	0706		4-26-23	1020	
		4-26-23	1330		4-26-23	1330	1.5 / Y / N / Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER: DATE Signed (MM/DD/YY): 04/25/23

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

EMS 5-3-23

Electronic Filing: Received, Clerk's Office 07/01/2024

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CHAIN-OF-CUSTODY / Analytical Request Document

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Page: 1 of 6

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213																								
2	NEW_A214																								
3	NEW_A215			4/26/23	1640		9	X	X	X	X	X													
4	NEW_APW02																								
5	NEW_APW03																								
6	NEW_APW04																								
7	NEW_APW05S 95 4-27-23			4/26/23	1740		11	X	X	X															
8	NEW_APW05#S																								
9	NEW_APW06			4/26/23	1600		11	X	X	X															
10	NEW_APW07																								
11	NEW_APW08			4/26/23	1211		11	X	X	X															
12	NEW_APW09																								
13	NEW_APW10																								
14	NEW_APW11			4/26/23	1543		11	X	X	X															
15	NEW_APW12			4/26/23	1356		11	X	X	X															
16	NEW_APW13																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph R Red	4/27/23	713	[signature]	4-27	1030
	[signature]	4-27	1426	[signature]	4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: [signature]

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.5	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

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Section A Required Client Information:

Company: Vistra Corp
Address: 13498 E. 900th St
Email To: Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911 Fax:
Requested Due Date/TAT: 10 day

Section B Required Project Information:

Report To: Brian Voelker
Copy To: Jason Stuckey
Purchase Order No.:
Project Name:
Project Number: 2285

Section C Invoice Information:

Attention: Jason Stuckey
Company Name: Vistra Corp
Address: see Section A
Quote Reference:
Project Manager:
Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Y/N	Analysis Test: NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_APW14																								
2	NEW_APW15			4/26/23	1723		11	X	X	X															
3	NEW_APW16																								
4	NEW_APW17																								
5	NEW_APW18																								
6	NEW_G104																								
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106																								
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS: **NEW-23Q2 Rev 0**

RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
Joseph R Reed	4/27/23	1030		4-27	1030
	4-27	1420		4/27/23	14:20

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: James David
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
5.0	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

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Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G114																								
2	NEW_G114&D																								
3	NEW_G115 DTW																								
4	NEW_G116																								
5	NEW_G117 DTW																								
6	NEW_G118																								
7	NEW_G119 DTW																								
8	NEW_G120 DTW																								
9	NEW_G125																								
10	NEW_G128 + dup 4-27-23			4/26/23	1500		12	X	X	X		X													
11	NEW_G130																								
12	NEW_G133			4/26/23	1609		6	X	X	X		X													
13	NEW_G136			4/26/23	1702		4	X	X	X		X													
14	NEW_G139																								
15	NEW_G141																								
16	NEW_G201																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph Rand	4/27/23	1030		4-27	1030
		4-27	1420		4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: James David

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.7	Y	Y	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N: NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G202																						
2	NEW_G217#S			4/26/23	1303		9	X	X	X	X	X												
3	NEW_G221																						
4	NEW_G225																						
5	NEW_G230			4/26/23	1151		9	X	X	X	X	X												
6	NEW_G231			4/26/23	1310		9	X	X	X	X	X												
7	NEW_G232			4/26/23	1416		9	X	X	X	X	X												
8	NEW_G233			4/26/23	1526		9	X	X	X	X	X												
9	NEW_G234																						
10	NEW_L1R_leachate																						
11	NEW_L201_leachate DTW																						
12	NEW_L202_leachate DTW																						
13	NEW_L203_leachate DTW																						
14	NEW_L204_leachate DTW																						
15	NEW_L205_leachate DTW																						
16	NEW_L301_leachate																						

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	James David	4/27/23	1030		4-27	1030
		4.27	1420		4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: James David

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.7	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_LREP_leachate																								
2	NEW_MW34&D																								
3	NEW_MW35&D																								
4	NEW_MW43&D																								
5	NEW_MW46&D																								
6	NEW_R201																								
7	NEW_R202																								
8	NEW_R217&D			4/26/23	1143		9	X	X	X	X	X													
9	NEW_R219																								
10	NEW_T101																								
11	NEW_T102																								
12	NEW_XPW01_pore																								
13	NEW_XPW02_pore																								
14	NEW_XPW03_pore																								
15	NEW_XPW04_pore																								
16	NEW_XSG01 - DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/27/23	1030		4-27	1030
		4-27	1420		4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: James David

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.7	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_YSG02 DW																								
2	NEW_YSW_S101			4/26/23	1803		9	X	X	X															
3	NEW_YSW_S102			4/26/23	1743		9	X	X	X															
4	4/26/23 EB-02			4/26/23	1630																				
5																									
6																									
7																									
8																									
9																									
10																									
11																									
12																									
13																									
14																									
15																									
16																									

Requested Analysis Filtered (Y/N)

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
NEW-23Q2 Rev 0	Joseph R Rod	4/27/23	1030		4-27	1020	
		4-27	1420		4/27/23	14:20	

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.7	Y	N	Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: James David

DATE Signed (MM/DD/YY): 4/26/23

courier

Electronic Filing: Received, Clerk's Office 07/01/2024

6D04839
gef

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213	WT	G	4/27/23	1209		9	X	X	X	X	X													
2	NEW_A214	WT	G	4/27/23	1432		9	X	X	X	X	X													
3	NEW_A215																								
4	NEW_APW02	WT	G	4/27/23	1217		11	X	X	X															
5	NEW_APW03																								
6	NEW_APW04																								
7	NEW_APW05	WT	G	4/27/23	1240		11	X	X	X															
8	NEW_APW05#S																								
9	NEW_APW06																								
10	NEW_APW07	WT	G	4/27/23	1035		11	X	X	X															
11	NEW_APW08																								
12	NEW_APW09	WT	G	4/27/23	1405		11	X	X	X															
13	NEW_APW10	WT	G	4/27/23	1547		11	X	X	X															
14	NEW_APW11																								
15	NEW_APW12																								
16	NEW_APW13	WT	G	4/27/23	1716		11	X	X	X															

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS: Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
NEW-23Q2 Rev 0		4/28/23	0705	Brenden Herron	4/28/23	0705	5.0		N	
	Brenden Herron	4/28/23	1245	Grace	4/28/23	1245		Y		Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER: [signature] DATE Signed (MM/DD/YY): 04/27/2023

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_APW14																								
2	NEW_APW15																								
3	NEW_APW16																								
4	NEW_APW17																								
5	NEW_APW18																								
6	NEW_G104																								
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105 + Dup	WT	G	4/27/23	1207		8	X	X	X	X														
10	NEW_G106																								
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
NEW-23Q2 Rev 0		4/28/23	0705	Brendan Heiman	4/28/23	0705	5		2	
	Brendan Heiman	4/28/23	1245		4/28/23	12:45	6	Y		Y
							Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Kemberen

SIGNATURE of SAMPLER: DATE Signed (MM/DD/YY): 04/27/23

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G114																							
2	NEW_G114&D																							
3	NEW_G115 DTW																							
4	NEW_G116																							
5	NEW_G117 DTW																							
6	NEW_G118																							
7	NEW_G119 DTW																							
8	NEW_G120 DTW																							
9	NEW_G125 + Dup	WT	G	4/27/23	1634		8	x	x	x					x									
10	NEW_G128																							
11	NEW_G130	WT	G	4/27/23	1020	6	6	x	x	x					x									
12	NEW_G133																							
13	NEW_G136																							
14	NEW_G139																							
15	NEW_G141	WT	G	4/27/23	1511		4	x	x	x					x									
16	NEW_G201																							

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
NEW-23Q2 Rev 0		4/28/23	0705	Brandon Hines	4/28/23	0705	0		3	
	Brandon Hines	4/28/23	1245		4/28/23	12:45	6	Y		Y

App 4/27/23

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Ambelerton
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 04/27/23

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G202																								
2	NEW_G217#S																								
3	NEW_G221	WT	G	4/27/23	1027		9	X	X	X	X	X													
4	NEW_G225	WT	G	4/27/23	1335		9	X	X	X	X	X													
5	NEW_G230																								
6	NEW_G231																								
7	NEW_G232																								
8	NEW_G233																								
9	NEW_G234																								
10	NEW_L1R_leachate	WT	G	4/27/23	1309		9	X	X	X															
11	NEW_L201_leachate DTW																								
12	NEW_L202_leachate DTW																								
13	NEW_L203_leachate DTW																								
14	NEW_L204_leachate DTW																								
15	NEW_L205_leachate DTW																								
16	NEW_L301_leachate																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/28/23	0705	Brandon Shannon	4/28/23	0705
	Brandon Shannon	4/28/23	1245		4/28/23	12:45

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Pemberton
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 04/27/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
6	Y		Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_LREP_leachate																								
2	NEW_MW34&D																								
3	NEW_MW35&D																								
4	NEW_MW43&D																								
5	NEW_MW46&D																								
6	NEW_R201																								
7	NEW_R202																								
8	NEW_R217&D																								
9	NEW_R219																								
10	NEW_T101	WT	G	4/27/23	1604		9	X	X	X															
11	NEW_T102																								
12	NEW_XPW01_pore	WT	G	4/27/23	1407		10	X	X	X															
13	NEW_XPW02_pore	WT	G	4/27/23	1529		10	X	X	X															
14	NEW_XPW03_pore	WT	G	4/27/23	1700		10	X	X	X															
15	~~NEW_XPW04_pore~~ EB-03	WT	G	4/27/23	1435		10	X	X	X															
16	NEW_XSG01 - DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/28/23	0705		4/28/23	0705
		4/28/23	1245		4/28/23	1245

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER: DATE Signed (MM/DD/YY): 04/27/23

SAMPLE CONDITIONS	Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
	0.5	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_LREP_leachate																							
2	NEW_MW34&D																							
3	NEW_MW35&D																							
4	NEW_MW43&D																							
5	NEW_MW46&D																							
6	NEW_R201																							
7	NEW_R202																							
8	NEW_R217&D																							
9	NEW_R219	WT	G	4/28/23	1134		9																	
10	NEW_T101																							
11	NEW_T102																							
12	NEW_XPW01_pore																							
13	NEW_XPW02_pore																							
14	NEW_XPW03_pore																							
15	NEW_XPW04_pore	WT	G	4/28/23	1023		10																	
16	NEW_XSG01 - DUP																							

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joe Reed	4/28/23			4/28/23	16:12

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Joe Reed
SIGNATURE of SAMPLER: Joe Reed
DATE Signed (MM/DD/YY): 4/28/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
F	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04919 gd

CHAIN-OF-CUSTODY / Analytical Request Document

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Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	GS 5-2-23 NEW_APW14 + dup	WT	G	4/28/23	1129		22																		
2	NEW_APW15																								
3	NEW_APW16																								
4	NEW_APW17																								
5	NEW_APW18																								
6	NEW_G104																								
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106																								
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
NEW-23Q2 Rev 0	Joseph R Reed	4/28/23	16 12	grace Just	4/28/23	16:12	4 / Y / 2 / Y

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Joe Reed

SIGNATURE of SAMPLER: Joseph R Reed

DATE Signed (MM/DD/YY): 4/28/23

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Page: 3 of 6

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_G114																								
2	NEW_G114&D																								
3	NEW_G115 DTW																								
4	NEW_G116	WT	G	4/28/23	1010		4																		
5	NEW_G117 DTW																								
6	GJS 6/6/23 NEW_G118 + DUP	WT	G	4/28/23	1004		4																		
7	NEW_G119 DTW																								
8	NEW_G120 DTW																								
9	NEW_G125																								
10	NEW_G128																								
11	NEW_G130																								
12	NEW_G133																								
13	NEW_G136																								
14	GJS 4/6/23 NEW_G139 + DUP	WT	G	4/28/23	1128		8																		
15	NEW_G141																								
16	~~NEW_G201~~ EB-04	WT	G	4/28/23	1200		2																		

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph R Reed	4/28/23	1612	Grace [signature]	4/28/23	16:12

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
4.4	Y	2	Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Joe Reed

SIGNATURE of SAMPLER: Joseph R Reed

DATE Signed (MM/DD/YY): 4/28/23

SAR-3: Depth to Groundwater Measurements
Plant: NEWTON POWER PLANT
Event: PRIMARY ASH POND
NEW 2302
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
A207	NEW_A207	4/24/23	1541	X	36.00	NA	NA	NA	JMD	
A213	NEW_A213		1544	X	18.63				KL	
A214	NEW_A214		1531	X	40.90				KL	
A215	NEW_A215		1527	X	44.03				KL	
G06D	NEW_G006&D		1459	X	28.92				JMD	
G104	NEW_G104		1804	X	4.51				JMD	
G104D	NEW_G104&D		1810	X	50.37				JMD	TD = 89.31
G104S	NEW_G104#S		1806	X	4.68				JMD	TD = 26.04
G105	NEW_G105		1833	X	7.10				JMD	TD = 26.20
G106	NEW_G106		1857	X	20.37				AP	
G109	NEW_G109		1647	X	5.11				JMD	TD = 24.97
G111	NEW_G111		1815	X	5.97				JMD	TD = 22.75
G112	NEW_G112		1823	X	4.38				JMD	TD = 24.62
G113	NEW_G113		1908	X	17.09				JMD	TD = 33.33
G114	NEW_G114		1723	X	13.45				JR	
G114D	NEW_G114&D		1556	X	42.69				JR	
G115	NEW_G115		1612	X	4.04				JR	No Lock, no pump
G116	NEW_G116		1933	X	6.00				JMD	
G117	NEW_G117		1845	X	7.08				JMD	TD = 21.90
G118	NEW_G118		1608	X	6.32				JMD	TD = 22.59
G119	NEW_G119		1654	X	4.10				JMD	TD = 23.85
G120	NEW_G120		1632	X	7.33				JMD	TD = 23.38
G125	NEW_G125		1457 JMD 4/24	X	2.84 JMD 4/24				KL	
G128	NEW_G128		~~1531/1511~~	X	~~19.75~~ 3.96				JMD	
G130	NEW_G130		1704	X	4.34				JMD	TD = 22.69
G133	NEW_G133		1658	X	8.84				JMD	TD = 27.32
G136	NEW_G136		1643	X	6.69				JMD	TD = 22.20
G139	NEW_G139		1639	X	6.15				JMD	TD = 23.05
G141	NEW_G141		1515	X	10.99				JMD	TD = 25.16
G201	NEW_G201		1742	X	17.50				JMD	
G202	NEW_G202		1828	X	47.84				JMD	

Electronic Filing: Received, Clerk's Office 07/01/2024

SAR-3: Depth to Groundwater Measurements
Plant: NEWTON POWER PLANT
Event: PRIMARY ASH POND
NEW 2023 2

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
G203	NEW_G203	4/24/23	1536	X	41.39	NA	NA	NA	JR	No lock
G208	NEW_G208	"	1534	X	24.02	"	"	"	JMD	
G217S	NEW_G217#S	"	1439	X	6.20	"	"	"	KL	
G218	NEW_G218	"	1839	X	19.78	"	"	"	JMD	
G220	NEW_G220	"	1525	X	17.03	"	"	"	JMD	
G221	NEW_G221	"	1521	X	21.34	"	"	"	JMD	
G222	NEW_G222	"	1518	X	15.13	"	"	"	JMD	
G223	NEW_G223	"	1515	X	33.13	"	"	"	KL	Well has incorrect sign, says G233
G224	NEW_G224	"	1503	X	42.56	"	"	"	KL	
G225	NEW_G225	"	1511	X	7.27	"	"	"	JMD	TD= 24.99
G230	NEW_G230	"	1500	X	47.99	"	"	"	JR	
G231	NEW_G231	"	1504	X	47.36	"	"	"	JR	
G232	NEW_G232	"	1509	X	45.73	"	"	"	JR	
G233	NEW_G233	"	1516	X	41.67	"	"	"	JR	
G234	NEW_G234	"	1532	X	43.18	"	"	"	JR	
G48MG	NEW_G048MG	"	1826	X	18.99	"	"	"	JR	TD = 80.07
L1R	NEW_L1R_leachate	"	1716	X	52.80	"	"	"	KL	
L201	NEW_L201_leachate	"	1720	X	13.30	"	"	"	KL	Dry
L202	NEW_L202_leachate	"	1643	X	15.30	"	"	"	KL	Dry
L203	NEW_L203_leachate	"	1650	X	9.60	"	"	"	KL	Dry
L204	NEW_L204_leachate	"	1709	X	15.42	"	"	"	KL	
L205	NEW_L205_leachate	"	1701	X	0.97	"	"	"	KL	
L301	NEW_L301_leachate	"	NA	X	NA	"	"	"	JMD	No depth to measure
L302	NEW_L302_leachate	"	NA	X	NA	"	"	"	JMD	Not a well
M25-1	NEW_M25-1	"	1556	X	2.15	"	"	"	KL	
M25-2	NEW_M25-2	"	1557	X	1.42	"	"	"	KL	
M25-3	NEW_M25-3	"	1558	X	1.63	"	"	"	KL	
M25-4	NEW_M25-4	"	1559	X	2.43	"	"	"	KL	
M25-5	NEW_M25-5	"	1601	X	5.67	"	"	"	KL	
M25-6	NEW_M25-6	"	1602	X	12.28	"	"	"	KL	
M25-7	NEW_M25-7	"	1602	X	18.52	"	"	"	KL	

SAR-3: Depth to Groundwater Measurements
Plant: NEWTON POWER PLANT
Event: PRIMARY ASH POND
NEW-2302
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
M26-1	NEW_M26-1	4/24/23	1806	X	2.80	NA	NA	NA	KL	
M26-2	NEW_M26-2		1807	X	23.02				KL	
M26-3	NEW_M26-3		1808	X	23.19				KL	
M26-4	NEW_M26-4		1809	X	NA				KL	Obstruction in well at depth 1.17'
M26-5	NEW_M26-5		1810	X	1.22				KL	
M26-6	NEW_M26-6		1811	X	1.21				KL	
M26-7	NEW_M26-7		1812	X	40.76				KL	
MW31S	NEW_MW31#S		19:35	X	6.00				JMD	TD = 18.69
MW33S	NEW_MW33#S		1600	X	8.32				AP	TD = 29.59
MW34D	NEW_MW34&D		1655	X	14.85				AP	TD = 58.73, unable to close casing
MW35D	NEW_MW35&D		1438	X	26.24				AP	TD = 53.73
MW35S	NEW_MW35#S		1737	X	2.99				JMD	TD = 16.28
MW36S	NEW_MW36#S		1623	X	3.35				AP	TD = 15.49
MW43D	NEW_MW43&D		1812	X	5.73				AP	TD = 40.80
MW46D	NEW_MW46&D		1619	X	16.82				JR	
MW48S	NEW_MW48#S		1833	X	3.52				JR	13.49 = TD
R201	NEW_R201		1445	X	47.56				JR	
R202	NEW_R202		1912	X	47.55					
R216	NEW_R216		1455	X	43.33				KL	
R217D	NEW_R217&D		1444	X	19.15				KL	
R219	NEW_R219		1528	X	20.08				JMD	
T101	NEW_T101		1700	X	5.84				JR	
T102	NEW_T102		1712	X	6.00				JR	
APW02	NEW_APW02				X	21521987				
APW03	NEW_APW03				X	21521988				
APW04	NEW_APW04				X	21503517				
APW05	NEW_APW05				X	21615053				
APW05S	NEW_APW05#S				X	21503536				
APW06	NEW_APW06				X	21615054				
APW07	NEW_APW07				X	21615033				
APW08	NEW_APW08				X	21615032				

Electronic Filing: Received, Clerk's Office 07/01/2024

SAR-3: Depth to Groundwater Measurements
Plant: Newton
Event: NEW 2023 1

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
APW09	NEW_APW09				X	21522025	NA	NA		
APW10	NEW_APW10				X	21558058				
APW11	NEW_APW11				X	21558059				
APW12	NEW_APW12				X	21503535				
APW13	NEW_APW13				X	21522024				
APW14	NEW_APW14				X	21522035				
APW15	NEW_APW15				X	21522034				
APW16	NEW_APW16				X	21522033				
APW17	NEW_APW17				X	21522023				
APW18	NEW_APW18				X	21522026				
SG02	NEW_YSG02	4/24/23	1444	2.11	X	TBD			AP	
XPW01	NEW_XPW01_pore				X	21503518				
XPW02	NEW_XPW02_pore				X	21522010				
XPW03	NEW_XPW03_pore				X	21503520				
XPW04	NEW_XPW04_pore				X	21503519				
XSG01	NEW_XSG01	4/24/23	1716	534	X	TBD			AP	Staff gauge says 534
MW31D		4/24/23	1936	8.64						TD = 43.20
MW32S			1545	4.93						TD = 22.20
MW32D			1536	15.55						TD = 63.12
MW33D			1557	12.30						TD = 51.71
MW34S			1659	3.58						TD = 18.66
MW36D			1618	7.52						TD = 35.07
MW43S			1812	4.79						TD = 16.54
MW46S			1623	4.28						
MW48D			1831	4.98						TD = 41.54

Lake Levels
4/26/23 11:02 2.15'
4/26/23 8:11 2.19'
4/27/23 17:00 2.20'
4/28/23 7:58 2.17'
5/1/23 15:36 2.05'

GW08 - well removed Jan 2023

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW02 **Purge Method:** Submersible pump

Date: 4/27/23 Start Time: 1056 Finish/Sample Time: 1217

Well Depth (Bottom) From MP: 24.03 ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 3.72 ft Total Purge Volume: 4 Gal (L)

Total Drawdown: 3.11 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1118	6.83	100	6.72	5213.3	15.55	80.6	1.23	24.51
2	1120	6.83	100	6.72	5216.1	15.58	80.7	1.23	23.97
3	1121	6.83	100	6.71	5217.2	15.62	80.8	1.23	25.04
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	/	
Casing locked/secure	/	
Well cap fits securely.	/	
Good seal/drainage	/	
Well has weep holes	/	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40 mL H2S04
1	P 1000 mL
0.165 ppm	Soluble Iron +2

Comments APW02 next to APW07. HOBO connect S/Ns 21615523 and 21615614
FDTW = 6.83

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW03 **Purge Method:** non dedicated pump

Date: 4/25/23 Start Time: 1145 Finish/Sample Time: 1320

Well Depth (Bottom) From MP: 23.47 ft Min. Purge Volume: 2 Gal / (L)

Depth to Water From MP: 11.94 ft Total Purge Volume: 2 Gal / (L)

Total Drawdown: 0.65 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1223	11.34	100	7.02	925	16.94	141	2.50	0.0
2	1224	11.39	100	7.01	925	16.91	140	2.45	0.0
3	1225	11.41	100	7.01	925	16.97	140	2.32	0.0
4	1226	11.47	100	7.01	925	16.97	141	2.25	0.0
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☒ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250~~ mL) 1000mL
1	2.5 L

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P,500mL)
3	4 V 40mL H_2SO_4

Comments 0.106 ppm Soluble iron +2 Final DTW 12.59 AL

Transducer S/N - 216155 24

Sampler's Signature: for Joe Reed

Electronic Filing: Received, Clerk's Office 07/01/2024
NEWTON

WELL/SAMPLE POINT APW04 **Purge Method:** Submersible pump

Date: 4/25/23 Start Time: 1450 Finish/Sample Time: 1642

Well Depth (Bottom) From MP: ~~22.63~~ ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 5.10 ft Total Purge Volume: 2.1 Gal / L

Total Drawdown: 6.21 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1528	9.16	100	6.93	1830	11.79	172	0.93	203
2	1529	9.17	100	6.93	1830	11.79	172	0.93	204
3	1530	9.18	100	6.93	1830	11.79	171	0.93	178
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☐ None ☒ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250~~ mL) 1000 mL
1	2.5 L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500~~ mL) 1000 mL
3	TOC

Comments S/n 21615483 0.155 ppm soluble iron +2

Sampler's Signature: Joseph R Rad

End DTW 11.31

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW-058 (MW) **Purge Method:** Bladder pump/low flow

Date: 4/27/23 Start Time: 1110 JR Finish/Sample Time: 1240

Well Depth (Bottom) From MP: NM ft pump Min. Purge Volume: 2 Gal / L

Depth to Water From MP: 14.01 ft Total Purge Volume: 2.3 Gal / L

End DTW 14.05 ft

Total Drawdown: 0.04 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1149	14.05	100	7.06	824	14.55	-120	17.70	30.0
2	1150	14.05	100	7.08	822	14.50	-122	17.78	36.0
3	1151	14.05	100	7.10	819	14.51	-124	17.70	40.1
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☐ None ☒ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, [redacted] mL) S/1000mL
1	2.5L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2SO4)
1	General (P, [redacted] mL) S/1000mL
3	TOC 40mL

Comments S/n - 21629308 Dis. Iron $^{+2}$ = 1.151 ppm

Sampler's Signature: Joseph R Reed

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW05S (UA) **Purge Method:** Submersible pump

Date: 4/26/23 Start Time: 1633 Finish/Sample Time: 1740

Well Depth (Bottom) From MP: 23.24 ft Min. Purge Volume: 2 Gal / L

Depth to Water From MP: 9.46 ft Total Purge Volume: 2.3 Gal / L

End DTW 10.23

Total Drawdown: 0.77 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1655	10.17	100	6.64	3940	16.35	101	3.61	225
2	56	10.17	100	6.62	3940	16.36	100	3.58	230
3	57	10.17	100	6.60	3930	16.35	97	3.53	220
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☐ None ☒ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, 250 mL)
1	2.5L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500mL~~) 1000mL
3	TOC 40mL

Comments S/N-21615502 Disolved Iron^{+2} = 0.259 ppm

Sampler's Signature: Joseph R Reed

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW06 **Purge Method:** Submersible pump

Date: 4/26/23 Start Time: 1443 Finish/Sample Time: 1600

Well Depth (Bottom) From MP: 75.75 ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 19.33 ft Total Purge Volume: 2.3 Gal / L

End DTW 19.45

Total Drawdown: 0.12 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1510	19.45	100	7.36	795	17.55	-126	10.71	400
2	1511	19.45	100	7.35	797	17.55	-128	10.70	436
3	1512	19.45	100	7.35	796	17.55	-128	10.71	471
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☐ None ☐ Slight ☒ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250~~mL) 1000 mL
1	2.5 L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500~~mL) 1000mL
3	40mL TOC

Comments Disolved Iron #2 = 0.904 ppm
S/N- 216 29309

Sampler's Signature: Joseph R Reed

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW07 **Purge Method:** Submersible pump

Date: 4/27/23 Start Time: 0919 Finish/Sample Time: 1035

Well Depth (Bottom) From MP: 85.77 ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 46.59 ft Total Purge Volume: 7 Gal (L)

Total Drawdown: 0.00 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	0946	46.59	100	7.39	1050.9	14.41	-117.0	0.47	625.73
2	0947	46.59	100	7.40	1051.9	14.46	-117.0	0.48	648.42
3	0949	46.59	100	7.39	1050.7	14.50	-115.6	0.51	620.77
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☐ None ☑ Slight ☐ Mod. ☐ Strong

Color ☐ None ☐ Slight ☑ Mod. ☐ Strong

Turb: ☐ None ☐ Slight ☑ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	/	
Casing locked/secure	/	
Well cap fits securely.	/	
Good seal/drainage	/	
Well has weep holes	/	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40mL H2SO4
1	P 1000 mL
1.103 ppm	Soluble Iron $^{+2}$

Comments HOBO connect SN 21629296
Dedicated pump wasn't working properly. It discharges all the water in the tubing and then air. Pulled pump and used portable pump.

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW08 **Purge Method:** Dedicated pump

Date: 4/26/23 Start Time: 1048 Finish/Sample Time: 1211

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2.4 Gal (L)

Depth to Water From MP: 37.56 ft Total Purge Volume: 2.4 Gal (L)

Total Drawdown: 0.00 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1110	37.56	100	7.52	1105.4	14.24	-118.1	1.63	14.80
2	1111	37.56	100	7.53	1115.9	14.27	-117.2	1.67	16.76
3	1113	37.56	100	7.52	1100.0	14.23	-118.0	1.66	17.73
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☐ None ☑ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 1000 mL
1	P 2.5L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40mL H2SO4
1	P 1000 mL
2.641 ppm	Soluble Iron +2

Comments HOBO correct SN 21629295

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW09 **Purge Method:** Submersible pump

Date: 4/27/23 Start Time: 1240 Finish/Sample Time: 1405

Well Depth (Bottom) From MP: 57.97 ft Min. Purge Volume: 2 Gal / (L)

Depth to Water From MP: 26.56 ft Total Purge Volume: 6 Gal / (L)

Total Drawdown: 0.00 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1304	26.56	100	7.53	1357.2	16.47	-134.6	0.53	93.33
2	1306	26.56	100	7.53	1357.4	16.51	-134.0	0.50	100.42
3	1307	26.56	100	7.53	1356.5	16.54	-137.0	0.47	116.74
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquaroll 600

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☐ None ☒ Slight ☐ Mod. ☐ Strong

Turb: ☐ None ☐ Slight ☒ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	/	
Casing locked/secure	/	
Well cap fits securely.	/	
Good seal/drainage	/	
Well has weep holes	/	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40 ml H2SO4
1	P 1000 mL
2.279 ppm	Soluble Iron +2

Comments APW09 next to APW03. HOBOconnect SNs 21615616 and 21615524
Dedicated pump isn't pumping water at all. Pulled pump and used portable pump

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW10 **Purge Method:** Dedicated pump

Date: 4/27/23 Start Time: 1420 Finish/Sample Time: 1547

Well Depth (Bottom) From MP: 48.55 ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 17.53 ft Total Purge Volume: 2.3 Gal (L)

Total Drawdown: 0.11 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1442	17.59	100	7.36	1463.9	15.14	77.4	3.38	0.00
2	1443	17.59	100	7.36	1466.9	15.17	77.5	3.37	0.00
3	1445	17.59	100	7.36	1461.2	15.13	77.5	3.39	0.00
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.		✓
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40 mL H2SO4
1	P 1000 mL
0.025 ppm	Soluble Iron +2

Comments APW10 reset to APW04. HOBO connect SNs 21615483 and 21615555
Top 3 feet of pump tubing is folded in well. Needs to be cut off and reattached to wellhead adapter. Folded tubing has caused holes and leaks.

Sampler's Signature:

FDTW = 17.64'

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW11 **Purge Method:** Dedicated pump

Date: 4/26/23 Start Time: 1406 Finish/Sample Time: 1543

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 24.27 ft Total Purge Volume: 2.3 Gal (L)

Total Drawdown: 0.09 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1432	24.32	100	7.14	1253.8	15.52	-13.8	0.67	471.71
2	1433	24.32	100	7.14	1252.4	15.56	-15.5	0.66	456.53
3	1435	24.32	100	7.15	1252.5	15.51	-17.8	0.64	445.59
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☐ None ☐ Slight ☑ Mod. ☐ Strong

Turb: ☐ None ☐ Slight ☑ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 1000mL
1	P 2.5L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40mL H2SO4
1	P 1000mL
0.721 ppm	Soluble Iron +2

Comments HOBO connect SN 21615556
Final DTW = 24.36

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024
NEWTON

WELL/SAMPLE POINT APW12 **Purge Method:** Dedicated pump

Date: 4/26/23 Start Time: 1229 Finish/Sample Time: 1356

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal /(L)

Depth to Water From MP: 14.56 ft Total Purge Volume: 2.3 Gal /(L)

Total Drawdown: 0.02 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1252	14.58	100	6.51	1817.1	14.64	109.5	1.04	1.02
2	1253	14.58	100	6.52	1817.1	14.66	108.7	1.02	0.62
3	1255	14.58	100	6.52	1831.4	14.65	107.4	0.98	0.52
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 1000mL
1	P 2.5L HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40mL H2SO4
1	P 1000mL
0.107 ppm	Soluble Iron +2

3rd 4/26

Comments HOBO connect SN 21615501

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW13 **Purge Method:** Dedicated pump

Date: 4/27/23 Start Time: 1554 Finish/Sample Time: 1716

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal /(L)

Depth to Water From MP: 32.05 ft Total Purge Volume: 2.3 Gal /(L)

Total Drawdown: 0.10 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1616	32.15	100	7.26	1376.7	14.29	-22.8	1.58	0.00
2	1617	32.15	100	7.26	1377.2	14.33	-24.1	1.61	0.00
3	1619	32.15	100	7.26	1360.1	14.28	-25.3	1.63	0.00
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40 mL H2S04
1	P 1000 mL
1.316 ppm	Soluble Iron+2

Comments HOBOconnect SN 21615615

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW14 **Purge Method:** Dedicated pump

Date: 4/28/23 Start Time: 0908 Finish/Sample Time: 2nd 4/28 ~~0~~ 1129

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal / (L)

Depth to Water From MP: 20.72 ft Total Purge Volume: 2.4 Gal / (L)

Total Drawdown: 0.08 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	0930	20.76	100	7.35	1481.3	14.87	-93.3	1.28	12.43
2	0931	20.76	100	7.34	1473.8	14.85	-94.0	1.25	6.05
3	0933	20.76	100	7.34	1480.5	14.84	-95.0	1.22	8.81
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	/	
Casing locked/secure	/	
Well cap fits securely.	/	
Good seal/drainage	/	
Well has weep holes	/	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3 + 3 dup	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1 + 1 dup	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1 + 1 dup	P 2.5 L HNO3
1 + 1 dup	P 1000 mL

Filtered	
Qty	Bottles
1 + 1 dup	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3 + 3 dup	AV 40 mL H2SO4
1 + 1 dup	P 1000 mL
3.827 ppm	Soluble Iron **

Comments HOBO connect SN 21615626
Field dup
FDTH: 20.80

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW15 **Purge Method:** Dedicated pump

Date: 4/26/23 Start Time: 1601 Finish/Sample Time: 1723

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 21.43 ft Total Purge Volume: 2.3 Gal (L)

Total Drawdown: 0.72 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1623	22.05	100	7.26	1694.5	15.26	-125.3	0.34	63.37
2	1625	22.05	100	7.25	1658.2	15.28	-125.5	0.33	56.78
3	1626	22.05	100	7.25	1682.1	15.32	-125.6	0.32	51.55
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☐ None ☒ Slight ☐ Mod. ☐ Strong

Color ☐ None ☐ Slight ☒ Mod. ☐ Strong

Turb: ☐ None ☐ Slight ☒ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 1000 mL
1	P 2.5 HNO3

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40 mL H2SO4
1	P 1000 mL
Overread	Soluble Iron ++

>6 ppm

Comments HOBO connect SN 21615625 Soluble Iron ++ reading was over the limit of 6 ppm
Final DTW = 22.15'

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT APW16 **Purge Method:** Dedicated pump

Date: 4/25/23 Start Time: 1108 Finish/Sample Time: 1326

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 40.15 ft Total Purge Volume: 2 Gal (L)

Total Drawdown: 0.00 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1137	40.15	100	7.64	947.82	14.10	-100.7	1.24	0.78
2	1138	40.15	100	7.65	949.58	14.04	-102.3	1.21	0.02
3	1140	40.15	100	7.65	953.00	14.04	-103.5	1.20	0.21
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☐ None ☑ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
6	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
2	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
2	General (P, 250 mL) 1000 mL
1	P 2.5L HNO3
1	P 1000mL HNO3

Filtered	
Qty	Bottles
2	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
6	AV 40mL H2SO4
2	P 1000mL
2.271 ppm	Soluble Iron FD

Comments HOBO connect SN 21615624
MS/MSD

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024 NEWTON

WELL/SAMPLE POINT APW17 **Purge Method:** Dedicated Pump

Date: 4/25/23 Start Time: 1527 Finish/Sample Time: 1650

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2.2 Gal (L)

Depth to Water From MP: 41.09 ft Total Purge Volume: 2.2 Gal (L)

Total Drawdown: 0.00 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1552	41.09	100	7.62	1161.9	15.13	-95.4	1.24	3.04
2	1553	41.09	100	7.62	1161.8	15.14	-96.3	1.22	2.84
3	1555	41.09	100	7.62	1162.3	15.17	-97.2	1.20	3.82
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☐ None ☑ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	/	
Casing locked/secure	/	
Well cap fits securely.	/	
Good seal/drainage	/	
Well has weep holes	/	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	4V 40mL H2S04
1	P 1000 mL
1.933 ppm	Soluble Iron ++

Comments APW17 next to APW02. HOBOconnect SNs 21615523 and 21615614

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT APW18 **Purge Method:** Dedicated pump

Date: 4/25/23 Start Time: 1340 Finish/Sample Time: 1503

Well Depth (Bottom) From MP: NM ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 51.63 ft Total Purge Volume: 2 Gal (L)

Total Drawdown: 0.00 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1405	51.63	100	7.77	1019.1	15.20	-134.0	1.10	10.57
2	1406	51.63	100	7.77	1015.5	15.17	-135.3	1.07	6.27
3	1408	51.63	100	7.78	1012.4	15.18	-136.7	1.05	5.01
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Aquatroll 600

Sample Appearance:

Odor: ☑ None ☐ Slight ☐ Mod. ☐ Strong

Color ☑ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☑ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	✓	
Casing locked/secure	✓	
Well cap fits securely.	✓	
Good seal/drainage	✓	
Well has weep holes	✓	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
	General (P, 250 mL)
1	P 2.5L HNO3
1	P 1000 mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
	General (P,500mL)
3	AV 40mL H2SO4
1	P 1000 mL
1.328 ppm	Soluble Iron +2

Comments HOBO connect SN 21615617

Sampler's Signature:

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT XPW01 **Purge Method:** Bladder Pump / low flow

Date: 4/27/23 Start Time: 1300 Finish/Sample Time: 1407

Well Depth (Bottom) From MP: 17.47 ft Min. Purge Volume: 2 Gal (V)

Depth to Water From MP: 11.06 ft Total Purge Volume: 2.3 Gal (L)

End DTW 11.07

Total Drawdown: 0.01 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1326	11.07	100	12.20	10500	18.54	-378	4.43	>1000
2	1327	11.07	100	12.20	10500	18.40	-378	4.36	>1000
3	1328	11.07	100	12.19	10500	18.38	-379	4.27	>1000
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☐ None ☐ Slight ☐ Mod. ☒ Strong

Turb: ☐ None ☐ Slight ☐ Mod ☒ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250~~ mL) 1000mL (B)

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500~~mL) (B) 1000mL
3	TOC 40mL

Comments S/N – 21615484 Dis. $Iron^{+2}$ = 0.508 ppm

Sampler's Signature: Joseph R Reed

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT XPW02 **Purge Method:** Bladder pump / low flow

Date: 4/27/23 Start Time: 1413 Finish/Sample Time: 1529

Well Depth (Bottom) From MP: 16.49 ft Min. Purge Volume: 2 Gal (L)

Depth to Water From MP: 7.39 ft Total Purge Volume: 2.3 Gal (L)

End DTW 7.39

Total Drawdown: 0.0 ft

Reading	Time	Depth	Flow Rate	pH	Spec Cond	Temp	ORP	DO	Turb
(Units)		(ft.)	(mL/min)	(s.u.)	(umhos/cm)	(deg C)	(mV)	(mg/L)	(NTU)
1	1443	7.45	100	9.59	400	17.55	-236	4.86	40.8
2	1444	7.45	100	9.58	400	17.56	-235	4.80	43.1
3	1445	7.45	100	9.58	400	17.56	-237	4.80	39.1
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☐ None ☒ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☒ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3 + JR	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250mL~~ 1000mL)

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500mL~~ 1000mL)
3	TOC 40mL

Comments S/n - 21615544 Dis. Iron $^{+2}$ = 0.163 ppm

Sampler's Signature: Joseph R Rad

Electronic Filing: Received, Clerk's Office 07/01/2024

WELL/SAMPLE POINT XPW03 **Purge Method:** Bladder pump / low flow

Date: 4/27/23 Start Time: 1546 Finish/Sample Time: 1700

Well Depth (Bottom) From MP: 20.43 ft Min. Purge Volume: 2.0 Gal / L

Depth to Water From MP: 10.81 ft Total Purge Volume: 2.3 Gal / L

End DTW 10.81 ft

Total Drawdown: 0.0 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	1620	10.81	100	11.51	1440	17.16	-272	0.69	146
2	1621	10.81	100	11.51	1440	17.13	-272	0.72	132
3	1622	10.81	100	11.51	1430	17.09	-273	0.70	119
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Horiba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☒ None ☐ Slight ☐ Mod. ☐ Strong

Turb: ☒ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250 mL~~) 1000 mL (2)

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P, ~~500mL~~) 1000 mL (2)
3	TOC 49 mL

Comments S/N 21615486 D.S. Iron $^{+2}$ = 0.127 ppm

Sampler's Signature: Joseph R Rad

Electronic Filing: Received, Clerk's Office 07/01/2024

NEWTON

WELL/SAMPLE POINT XPW04 **Purge Method:** Bladder Pump/Low Flow

Date: 4/28/23 Start Time: 918 Finish/Sample Time: 1023

Well Depth (Bottom) From MP: 20.40 ft Min. Purge Volume: 2.0 Gal (L)

Depth to Water From MP: 12.49 ft Total Purge Volume: 2.3 Gal (L)

End DTW 12.50

Total Drawdown: 0.01 ft

Reading (Units)	Time	Depth (ft.)	Flow Rate (mL/min)	pH (s.u.)	Spec Cond (umhos/cm)	Temp (deg C)	ORP (mV)	DO (mg/L)	Turb (NTU)
1	939	12.50	100	11.59	11900	12.21	-246	1.99	88.4
2	940	12.50	100	11.59	11900	16.19	-251	1.85	75.0
3	941	12.50	100	11.59	11900	16.20	-255	1.78	75.5
4									
5									
Stabilization	NA	NA	NA	± 0.2	± 3%	± 0.2	± 20	± 10% or 0.2	NA

Field Meter: Hor.Ba

Sample Appearance:

Odor: ☒ None ☐ Slight ☐ Mod. ☐ Strong

Color ☐ None ☒ Slight ☐ Mod. ☐ Strong

Turb: ☒ None ☐ Slight ☐ Mod ☐ Strong

Well Integrity	Yes	No
Well has ID sign	X	
Casing locked/secure	X	
Well cap fits securely.	X	
Good seal/drainage	X	
Well has weep holes	X	

BOTTLE INFORMATION:

Unfiltered	
Qty	Bottles
	VOAs (C,V, 40mL, HCL)
	VOAS (C,V, 40mL)
	Organics (A,G,U 1000mL)
	Organics (A,G,U 500mL)
3	TOC (A,V 40mL, H2SO4)
	TOX (A,G 250mL, H2SO4)
1	Metals (P,250mL, HNO3)
	Cyanide (P, 250mL, NaOH)
	Phenols (A,G,250mL, H2SO4)
1	General (P, ~~250~~mL) 1000mL

Filtered	
Qty	Bottles
1	Metals (P,250mL, HNO3)
	Ammonia (P,250mL, H2S04)
1	General (P ~~500~~mL) 1000mL
3	TOC 40mL

Comments S/N - 21615485 Dis. Iron = 0.367 ppm

Sampler's Signature: Joseph R Rad

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	JD	Location:	Vistra Newton
Weather:	43-62°F p.cloudy wind W 5-10mph	Environment:	grass, dirt rock roads

Multiparameter Water Meter	Make: Aquatroll	Model: 600	Serial Number: 762215		
Water Level Meter	Make: Heron	Model: Dipper-T	Serial Number: 3717-T		

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.11	s.u.	±0.1 s.u.	Fail	Yes	4.06	MSI	L344-09	12/14/2023
pH 7.00a	6.86	s.u.	±0.1 s.u.	Fail	Yes	7.06	MSI	L343-07	12/9/2023
pH 10.00a	9.89	s.u.	±0.1 s.u.	Fail	Yes	10.08	MSI	M082-04	3/25/2024
SC Zero (DI)	12.13	µS/cm	0<25 µS/cm	Pass	No	NA	Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2023.0	µS/cm	±5%	Pass	No	NA	Geotech	2GE1442	May-23
ORP	244.3	mV	±15 mV	Pass	No	NA	InSitu	2G1762	Jun-23
DO (Zero pt)	0.08	mg/L	±0.1	Pass	No	NA	Macron	#000228049	8/26/2025
DO (Saturated)	90.87	%	97-100%	Fail	Yes	99.73	Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.00	NTU	<2 NTU	Pass	No	NA	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 10:16			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.08	s.u.	±0.15 s.u.	Pass	NA	Geotech	2GC243	Mar-24
pH 7.00b	7.07	s.u.	±0.15 s.u.	Pass	NA	Geotech	2GC931	Mar-24
pH 10.00b	10.07	s.u.	±0.15 s.u.	Pass	NA	Geotech	2GE820	May-24
SC 1000	965.05	µS/cm	±5%	Pass	NA	Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1731			
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.07	s.u.	±0.1 s.u.	pass	No	NA	MSI	L315-04	11/22/2023
pH 7.00a	7.07	s.u.	±0.1 s.u.	pass	No	NA	MSI	L172-33	6/23/2023
pH 10.00a	10.10	s.u.	±0.1 s.u.	pass	No	NA	MSI	L354-22	1/5/2024
SC 1000	969.37	µS/cm	±5%	pass	No	NA	Ricca	2108D48	Jul-23
DO (Zero pt)	0.07	mg/L	±0.1 mg/L	pass	No	NA	Macron	#000228049	8/26/2025
Turbidity (DI)	0.00	NTU	<2 NTU	pass	No	NA	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/25/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Kyle Lane	Location:	Newton Power
Weather:	46° to 65° cloudy	Environment:	Dry
Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number: VL9KJ9HR
Water Level Meter	Make: Huron	Model: water tape	Serial Number: 19FF2111192HB

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.01	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L344-09	12/14/2023
pH 7.00a	6.97	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.01	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	25.00	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1994	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	238	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.08	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	97.48	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.84	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)

Time: 10:21

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.00	s.u.	±0.15 s.u.		NA	Geotech	2GC243	Mar-24
pH 7.00b	7.00	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.91	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	978	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
pH 7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time: 17:45

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a	4.07	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L315-04	11/22/2023
7.00a	6.94	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a	9.97	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1016	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.00	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	1.80	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4-25-23

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	Joe Reed	Location:	Newton Power Station
Weather:	40-65° Mostly sunny wind 5-10 mph	Environment:	Grassy, gravel road

Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number: U4U1EVTF		
Water Level Meter	Make: Heron	Model: Dipper T	Serial Number: 19FF220213ML		

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.02	s.u.	±0.1 s.u.	P	Y		MSI	L344-09	12/14/2023
pH 7.00a	7.04	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.05	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	8	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2050	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	244	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.05	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	97.8	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.0	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

12.64°C

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 1010			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.07	s.u.	±0.15 s.u.	P	N/A	Geotech	2GC243	Mar-24
pH 7.00b	6.97	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.95	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1010	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1815				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.05	s.u.	±0.1 s.u.	P	N		MSI	L315-04	11/22/2023
pH 7.00a	7.04	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.06	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1010	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.05	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.5	NTU	<2 NTU				Race Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	Joseph R Reed	Date:	4/25/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Amar Rembelton	Location:	Newton
Weather:	45°-63°F cloudy wind SE 3mph	Environment:	grass, dirt, woods

Multiparameter Water Meter	Make: AT	Model: 600	Serial Number:	762193	
Water Level Meter	Make: Heron	Model: Dipper i	Serial Number:	115F220930SMC	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.09	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L344-09	12/14/2023
pH 7.00a	7.08	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L343-07	12/9/2023
pH 10.00a	10.08	s.u.	±0.1 s.u.	P	NO	N/A	MSI	M082-04	3/25/2024
SC Zero (DI)	21.07	µS/cm	0<25 µS/cm	P	NO	N/A	Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2044.7	µS/cm	±5%	P	NO	N/A	Geotech	2GE1442	May-23
ORP	236.9	mV	±15 mV	P	NO	N/A	InSitu	2G1762	Jun-23
DO (Zero pt)	0.08	mg/L	±0.1	P	NO	N/A	Macron	#000228049	8/26/2025
DO (Saturated)	83.74	%	97-100%	P	yes	~~1000~~ 100	Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	2.72	NTU	<2 NTU	P	yes	0.00	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

App 4/25/23 242 @ 15rc

ICV (Initial Calibration Verification)					Time: 0915				
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?		Manufacturer	Lot#	Exp.
pH 4.00b	4.09	s.u.	±0.15 s.u.	P	N/A		Geotech	2GC243	Mar-24
pH 7.00b	6.93	s.u.	±0.15 s.u.	P	N/A		Geotech	2GC931	Mar-24
pH 10.00b	10.01	s.u.	±0.15 s.u.	P	N/A		Geotech	2GE820	May-24
SC 1000	986.46	µS/cm	±5%	P	N/A		Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1831				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.08	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L315-04	11/22/2023
pH 7.00a	7.08	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L172-33	6/23/2023
pH 10.00a	10.07	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L354-22	1/5/2024
SC 1000	1024	µS/cm	±5%	P	NO	N/A	Ricca	2108D48	Jul-23
DO (Zero pt)	0.09	mg/L	±0.1 mg/L	P	NO	N/A	Macron	#000228049	8/26/2025
Turbidity (DI)	1.81	NTU	<2 NTU	P	NO	N/A	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:		Date:	4/25/2023

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	JD	Location:	Vistra Newton
Weather:	42-62°F partly sunny wind NW 5mph	Environment:	grassy

Multiparameter Water Meter	Make: Aquatroll	Model: 600	Serial Number:	762215	
Water Level Meter	Make: Heron	Model: Dipper-T	Serial Number:	3717-T	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	3.98	s.u.	±0.1 s.u.	pass	No	NA	MSI	L344-09	12/14/2023
pH 7.00a	7.06	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L343-07	12/9/2024
pH 10.00a	10.07	s.u.	±0.1 s.u.	↓	↓	↓	MSI	M082-04	3/25/2024
SC Zero (DI)	14.62	µS/cm	0<25 µS/cm	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1937.2	µS/cm	±5%	↓	↓	↓	Geotech	2GE1442	May-23
ORP	252.0	mV	±15 mV	↓	↓	↓	InSitu	2G1762	Jun-23
DO (Zero pt)	0.05	mg/L	±0.1	↓	↓	↓	Macron	#000228049	8/26/2025
DO (Saturated)	98.13	%	97-100%	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 0916			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.07	s.u.	±0.15 s.u.	pass	NA	Geotech	2GC243	Mar-24
pH 7.00b	6.91	s.u.	±0.15 s.u.	↓	↓	Geotech	2GC931	Mar-24
pH 10.00b	9.92	s.u.	±0.15 s.u.	↓	↓	Geotech	2GE820	May-24
SC 1000	981.01	µS/cm	±5%	↓	↓	Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1740				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.03	s.u.	±0.1 s.u.	pass	No	NA	MSI	L315-04	11/22/2023
pH 7.00a	7.07	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L172-33	6/23/2023
pH 10.00a	10.02	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L354-22	1/5/2024
SC 1000	955.42	µS/cm	±5%	↓	↓	↓	Ricca	2108D48	Jul-23
DO (Zero pt)	0.09	mg/L	±0.1 mg/L	↓	↓	↓	Macron	#000228049	8/26/2025
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/26/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Aaron Pemberton	Location:	Newton
Weather:	52°-63°F Sunny Wind NE 5mph	Environment:	grass, dirt
Multiparameter Water Meter	Make: AT	Model: 600	Serial Number: 762193
Water Level Meter	Make: Heron	Model: Dipper T	Serial Number: 11ff2209305ML

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.05	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L344-09	12/14/2023
pH 7.00a	7.04	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.04	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	3.93	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2025.1	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	240.0	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.08	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	97.6	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	1.15	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

236 @ 20°C

ICV (Initial Calibration Verification)					Time: 0952			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.06	s.u.	±0.15 s.u.	P	N/A	Geotech	2GC243	Mar-24
pH 7.00b	6.89	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	10.00	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1088.10	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1720				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.07	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L315-04	11/22/2023
pH 7.00a	7.02	s.u.	±0.1 s.u.	P			MSI	L172-33	6/23/2023
pH 10.00a	10.05	s.u.	±0.1 s.u.	P			MSI	L354-22	1/5/2024
SC 1000	1099.72	µS/cm	±5%	P			Ricca	2108D48	Jul-23
DO (Zero pt)	0.09	mg/L	±0.1 mg/L	P			Macron	#000228049	8/26/2025
Turbidity (DI)	1.03	NTU	<2 NTU	P			Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/26/2023

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Kyle Lane	Location:	Newton Power
Weather:	41° to 63° Sunny cloudy	Environment:	Dry

Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number:	419KJ9Ha	
Water Level Meter	Make: Heron	Model: Water tape	Serial Number:	19FF2111192HB	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.00	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L344-09	12/14/2023
pH 7.00a	6.81	s.u.	±0.1 s.u.	F	7.00	7.00	MSI	L343-07	12/9/2023
pH 10.00a	10.09	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	M082-04	3/25/2024
SC Zero (DI)	13.00	µS/cm	0<25 µS/cm	P	N/a	N/a	Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1790	µS/cm	±5%	F	2000	2,000	Geotech	2GE1442	May-23
ORP	243	mV	±15 mV	P	N/a	N/a	InSitu	2G1762	Jun-23
DO (Zero pt)	0.65	mg/L	±0.1	P	N/a	N/a	Macron	#000228049	8/26/2025
DO (Saturated)	97.46	%	97-100%	P	N/a	N/a	Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	1.90	NTU	<2 NTU	P	N/a	N/a	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 10:04			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	3.95	s.u.	±0.15 s.u.	P	N/a	Geotech	2GC243	Mar-24
pH 7.00b	7.00	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	10.13	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	990	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
pH 7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 18:48				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a	4.08	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L315-04	11/22/2023
7.00a	7.01	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a	10.03	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1049	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.07	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	1.40	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	Kyle Lane	Date:	4-26-2023

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Joe Reed	Location:	Newton Power
Weather:	54-63° sunny w 4-7mph	Environment:	Dusty road / grass

Multiparameter Water Meter	Make: Horiba	Model: U5000	Serial Number:	U4U1FVTF	
Water Level Meter	Make: Heron	Model: Dipper-T	Serial Number:	3717-T	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	3.99	s.u.	±0.1 s.u.	P	Y		MSI	L344-09	12/14/2023
pH 7.00a	7.01	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	9.99	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	5	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2010	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	235	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.04	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	99.1	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.40	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

19.25°C

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 1236			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.00	s.u.	±0.15 s.u.	P	N	Geotech	2GC243	Mar-24
pH 7.00b	6.95	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.97	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1030	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1858				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.03	s.u.	±0.1 s.u.	P	N		MSI	L315-04	11/22/2023
pH 7.00a	7.05	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.03	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1010	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.05	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.6	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	Joseph R Reed	Date:	4/26/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Aaron Pemberton	Location:	Newton
Weather:	64°F Cloudy wind NE 7mph	Environment:	grass, dirt, woods

Multiparameter Water Meter	Make: AT	Model: 600	Serial Number: 762193
Water Level Meter	Make: Heron	Model: Dipper T	Serial Number: 11FF220930SMC

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.04	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L344-09	12/14/2023
pH 7.00a	7.02	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.06	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	3.52	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2022.2	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	239	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.09	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	98.72	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.00	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

242 @ 15°C

ICV (Initial Calibration Verification)

Time: 0903

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.01	s.u.	±0.15 s.u.	P	N/A	Geotech	2GC243	Mar-24
pH 7.00b	6.89	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	10.04	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	994.75	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time: 1200

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.08	s.u.	±0.1 s.u.	P	NO	N/A	MSI	L315-04	11/22/2023
pH 7.00a	7.06	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.03	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	995.1	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.09	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.00	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/27/2023

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Joe Reed	Location:	Newton
Weather:	50-69° partcloudy windy mph	Environment:	Dusty grassy
Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number: U4U1FVTF
Water Level Meter	Make: Heron	Model: Dipper	Serial Number: 19FF2111192HB

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.00	s.u.	±0.1 s.u.	P	N		MSI	L344-09	12/14/2023
pH 7.00a	6.99	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.00	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	0.5	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2010	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	234	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.05	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	98.1	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.0	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification) — Time:

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.00	s.u.	±0.15 s.u.	P	N	Geotech	2GC243	Mar-24
pH 7.00b	7.01	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	10.02	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1010	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification): — Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.02	s.u.	±0.1 s.u.	P	N		MSI	L315-04	11/22/2023
pH 7.00a	7.01	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.00	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1020	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.05	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.0	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification): — Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature: Joe Reed — Date: 4/27/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	JD	Location:	Vistra Newton
Weather:	40-69°F wind NE 5mph	Environment:	grassy, rock road

Multiparameter Water Meter	Make: Aquatroll	Model: 600	Serial Number:	762215	
Water Level Meter	Make: Heron	Model: Dipper-T	Serial Number:	3717-T	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.04	s.u.	±0.1 s.u.	Pass	No	NA	MSI	L344-09	12/14/2023
pH 7.00a	7.01	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L343-07	12/9/2023
pH 10.00a	10.01	s.u.	±0.1 s.u.	↓	↓	↓	MSI	M082-04	3/25/2024
SC Zero (DI)	7.25	µS/cm	0<25 µS/cm	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1914.8	µS/cm	±5%	↓	↓	↓	Geotech	2GE1442	May-23
ORP	255.8	mV	±15 mV	↓	↓	↓	InSitu	2G1762	Jun-23
DO (Zero pt)	0.07	mg/L	±0.1	↓	↓	↓	Macron	#000228049	8/26/2025
DO (Saturated)	97.49	%	97-100%	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 0849			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.10	s.u.	±0.15 s.u.	Pass	NA	Geotech	2GC243	Mar-24
pH 7.00b	6.92	s.u.	±0.15 s.u.	↓	↓	Geotech	2GC931	Mar-24
pH 10.00b	9.94	s.u.	±0.15 s.u.	↓	↓	Geotech	2GE820	May-24
SC 1000	962.41	µS/cm	±5%	↓	↓	Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1739				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.05	s.u.	±0.1 s.u.	Pass	No	NA	MSI	L315-04	11/22/2023
pH 7.00a	7.06	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L172-33	6/23/2023
pH 10.00a	10.05	s.u.	±0.1 s.u.	↓	↓	↓	MSI	L354-22	1/5/2024
SC 1000	965.34	µS/cm	±5%	↓	↓	↓	Ricca	2108D48	Jul-23
DO (Zero pt)	0.06	mg/L	±0.1 mg/L	↓	↓	↓	Macron	#000228049	8/26/2025
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/27/23

Electronic Filing: Received, Clerk's Office 07/01/2024

Multiparameter Meter Field Calibration Checklist

Field Personnel:	Kyle Lane	Location:	Newton Power
Weather:	45° to 70° Sunny	Environment:	Dry

Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number:	9L9KJ4Ha	
Water Level Meter	Make: Heron	Model: Water tape	Serial Number:	IIFF209305 Mi	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.00	s.u.	±0.1 s.u.	P	N/A	N/A	MSI	L344-09	12/14/2023
pH 7.00a	7.00	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.01	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	12.14	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1978	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	241	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.06	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	97.49	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	1.30	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)

Time: 08:47

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.01	s.u.	±0.15 s.u.	P	N/a	Geotech	2GC243	Mar-24
pH 7.00b	6.98	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.91	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	968 4.68	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
pH 7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time: 12:34

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a	4.03	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L315-04	11/22/2023
7.00a	7.02	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a	10.07	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1020	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.00	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	1.10	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	Kyle Lane	Date:	4-27-23

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	Kyle Lane	Location:	Newton Power
Weather:	56° to 70° sunny	Environment:	Wet

Multiparameter Water Meter	Make: Horiba	Model: U-5100	Serial Number:	YL 9KJ9Ha	
Water Level Meter	Make: Heron	Model: Water tape	Serial Number:	19FF22013ML	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.35	s.u.	±0.1 s.u.	F	Y	4.00	MSI	L344-09	12/14/2023
pH 7.00a	6.96	s.u.	±0.1 s.u.	P	N/a	N/a	MSI	L343-07	12/9/2023
pH 10.00a	10.00	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	20.10	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1,978	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	215	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.00	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	98.00	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	1.60	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification) — Time: 08:45

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	3.98	s.u.	±0.15 s.u.	P	N/a	Geotech	2GC243	Mar-24
pH 7.00b	6.87	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.96	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	960	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification): — Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
pH 7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification): — Time: 12:04

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a	4.02	s.u.	±0.1 s.u.	P	N/a	N/A	MSI	L315-04	11/22/2023
7.00a	6.98	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a	9.92	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1,030	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.00	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	1.30	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4-28-23

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	Aaron Pemberton	Location:	Newton
Weather:	55°-61°F sunny winds NNW	Environment:	grass, gravel, dirt
Multiparameter Water Meter	Make: AT	Model: 600	Serial Number: 762193
Water Level Meter	Make: Heron	Model: Dipper T	Serial Number: 11FF220930SML

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.07	s.u.	±0.1 s.u.	P	NO	NA	MSI	L344-09	12/14/2023
pH 7.00a	7.06	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.02	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	21.21	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2024.1	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	237.1	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.09	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	101.8	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	1.03	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

242 @ 15°C

ICV (Initial Calibration Verification)					Time: 0829			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.04	s.u.	±0.15 s.u.	P	NA	Geotech	2GC243	Mar-24
pH 7.00b	6.92	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.98	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1089.19	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
pH 7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/28/2023

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	JD	Location:	Vistra Newton
Weather:	52-70°F p.sunny wind NE 10mph	Environment:	grassy

Multiparameter Water Meter	Make: Aquatroll	Model: 600	Serial Number: 762215		
Water Level Meter	Make: Heron	Model: Dipper-T	Serial Number: 3717-T		

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.07	s.u.	±0.1 s.u.	pass	No	NA	MSI	L344-09	12/14/2023
pH 7.00a	7.05	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.02	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	19.34	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	1982.7	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	250.9	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.06	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	99.48	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)					Time: 0845			
Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.10	s.u.	±0.15 s.u.	pass	NA	Geotech	2GC243	Mar-24
pH 7.00b	6.89	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.92	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	954.22	µS/cm	±5%	↓	↓	Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time: 1200				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.09	s.u.	±0.1 s.u.	pass	No	NA	MSI	L315-04	11/22/2023
pH 7.00a	7.05	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.03	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	969.19	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.07	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.00	NTU	<2 NTU	↓	↓	↓	Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):					Time:				
Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	[signature]	Date:	4/28/23

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Multiparameter Meter Field Calibration Checklist

Field Personnel:	Joe Reed	Location:	Newton Power
Weather:	56-74 partcloudy wind 10mph	Environment:	grassy

Multiparameter Water Meter	Make: Horiba	Model: U-5000	Serial Number:	U4UIFVTF	
Water Level Meter	Make: Heron	Model: Dipper T	Serial Number:	9FF2202131ML	

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.00	s.u.	±0.1 s.u.	P	N		MSI	L344-09	12/14/2023
pH 7.00a	6.99	s.u.	±0.1 s.u.				MSI	L343-07	12/9/2023
pH 10.00a	10.00	s.u.	±0.1 s.u.				MSI	M082-04	3/25/2024
SC Zero (DI)	10	µS/cm	0<25 µS/cm				Pace Labs	N/A (DI)	N/A (DI)
SC 2000	2010	µS/cm	±5%				Geotech	2GE1442	May-23
ORP	240	mV	±15 mV				InSitu	2G1762	Jun-23
DO (Zero pt)	0.05	mg/L	±0.1				Macron	#000228049	8/26/2025
DO (Saturated)	99.3	%	97-100%				Pace Labs	N/A (DI)	N/A (DI)
Turbidity (DI)	0.0	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

ICV (Initial Calibration Verification)

Time: 830

Buffer	Check Value	Units	Range	Pass/Fail	Action Taken?	Manufacturer	Lot#	Exp.
pH 4.00b	4.02	s.u.	±0.15 s.u.	P	N	Geotech	2GC243	Mar-24
pH 7.00b	6.99	s.u.	±0.15 s.u.			Geotech	2GC931	Mar-24
pH 10.00b	9.99	s.u.	±0.15 s.u.			Geotech	2GE820	May-24
SC 1000	1011	µS/cm	±5%			Ricca	4205H64	May-24

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time: 1217

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
pH 4.00a	4.03	s.u.	±0.1 s.u.	P	N		MSI	L315-04	11/22/2023
pH 7.00a	7.01	s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
pH 10.00a	10.01	s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000	1020	µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)	0.05	mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)	0.0	NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Approx. every 4 hrs, unless only one well

CCV (Continued Calibration Verification):

Time:

Buffer	Check Value	Units	Range	Pass/Fail	Calibrate?	Adjusted Reading	Manufacturer	Lot#	Exp.
4.00a		s.u.	±0.1 s.u.				MSI	L315-04	11/22/2023
7.00a		s.u.	±0.1 s.u.				MSI	L172-33	6/23/2023
10.00a		s.u.	±0.1 s.u.				MSI	L354-22	1/5/2024
SC 1000		µS/cm	±5%				Ricca	2108D48	Jul-23
DO (Zero pt)		mg/L	±0.1 mg/L				Macron	#000228049	8/26/2025
Turbidity (DI)		NTU	<2 NTU				Pace Labs	N/A (DI)	N/A (DI)

Comments:

Signature:	Joseph E Reed	Date:	4/28/23

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

June 08, 2023

Terry Hanratty
Vistra - Newton
Newton Energy Center 6725 N. 500th St
Newton, IL 62448

Dear Terry Hanratty:

Please find enclosed the analytical results for the sample(s) the laboratory received. All testing is performed according to our current TNI accreditations unless otherwise noted. This report cannot be reproduced, except in full, without the written permission of Pace Analytical Services, LLC.

If you have any questions regarding your report, please contact your project manager. Quality and timely data is of the utmost importance to us.

Pace Analytical Services appreciates the opportunity to provide you with analytical expertise. We are always trying to improve our customer service and we welcome you to contact the General Manager, Lisa Grant, with any feedback you have about your experience with our laboratory at 309-683-1764 or lisa.grant@pacelabs.com.

Sincerely,

Gail Schindler
Project Manager
(309) 692-9688 x1716
gail.schindler@pacelabs.com

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

SAMPLE RECEIPT CHECK LIST

Items not applicable will be marked as in compliance

Work Order GD04486

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
NO	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
NO	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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2231 W. Altorfer Drive
Peoria, IL 61615
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Work Order GD04770

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
NO	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
NO	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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Peoria, IL 61615
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Work Order GD04853

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
NO	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
NO	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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Peoria, IL 61615
(800)752-6651

Work Order GD04926

YES	Samples received within temperature compliance when applicable
YES	COC present upon sample receipt
YES	COC completed & legible
YES	Sampler name & signature present
YES	Unique sample IDs assigned
YES	Sample collection location recorded
YES	Date & time collected recorded on COC
YES	Relinquished by client signature on COC
YES	COC & labels match
YES	Sample labels are legible
YES	Appropriate bottle(s) received
YES	Sufficient sample volume received
YES	Sample containers received undamaged
NO	Zero headspace, <6 mm present in VOA vials
NO	Trip blank(s) received
YES	All non-field analyses received within holding times
NO	Short hold time analysis
YES	Current PDC COC submitted
NO	Case narrative provided

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2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

ANALYTICAL RESULTS

Sample: GD04486-01 **Sampled:** 04/25/23 13:20
Name: APW03 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.02	pCi/L			1	0.598	05/19/23 14:32		904.0 903.0

Sample: GD04486-02 **Sampled:** 04/25/23 16:42
Name: APW04 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1	pCi/L			1	0.518	05/19/23 14:32		904.0 903.0

Sample: GD04486-03 **Sampled:** 04/25/23 13:26
Name: APW16 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	2.05	pCi/L			1	0.472	05/19/23 14:32		904.0 903.0

Sample: GD04486-04 **Sampled:** 04/25/23 16:50
Name: APW17 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.42	pCi/L			1	0.493	05/19/23 14:32		904.0 903.0

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Peoria, IL 61615
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ANALYTICAL RESULTS

Sample: GD04486-05 **Sampled:** 04/25/23 15:03
Name: APW18 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.33	pCi/L			1	0.476	05/19/23 14:32		904.0 903.0

Sample: GD04486-06 **Sampled:** 04/25/23 17:15
Name: EB-01 **Received:** 04/26/23 13:30
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.426 J	pCi/L			1	0.652	05/19/23 14:32		904.0 903.0

Sample: GD04770-01 **Sampled:** 04/26/23 17:40
Name: APW05S **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.141 U	pCi/L			1	0.784	05/31/23 08:55		904.0 903.0

Sample: GD04770-02 **Sampled:** 04/26/23 16:00
Name: APW06 **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.2	pCi/L			1	0.686	05/31/23 08:55		904.0 903.0

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ANALYTICAL RESULTS

Sample: GD04770-03 **Sampled:** 04/26/23 12:11
Name: APW08 **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.941	pCi/L			1	0.628	05/31/23 08:55		904.0 903.0

Sample: GD04770-04 **Sampled:** 04/26/23 15:43
Name: APW11 **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	2.17	pCi/L			1	0.566	05/31/23 08:55		904.0 903.0

Sample: GD04770-05 **Sampled:** 04/26/23 13:56
Name: APW12 **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.0586 U	pCi/L			1	0.697	05/31/23 08:55		904.0 903.0

Sample: GD04770-06 **Sampled:** 04/26/23 17:23
Name: APW15 **Received:** 04/27/23 14:20
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.97	pCi/L			1	0.696	05/31/23 08:55		904.0 903.0

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ANALYTICAL RESULTS

Sample: GD04770-07 **Sampled:** 04/26/23 16:30
Name: EB-02 **Received:** 04/27/23 14:20
Matrix: Ground Water - Equipment Blank

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.142 U	pCi/L			1	0.528	05/31/23 08:55		904.0 903.0

Sample: GD04853-01 **Sampled:** 04/27/23 12:17
Name: APW02 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.768	pCi/L			1	0.551	05/19/23 14:32		904.0 903.0

Sample: GD04853-02 **Sampled:** 04/27/23 12:40
Name: APW05 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.841	pCi/L			1	0.471	05/19/23 14:32		904.0 903.0

Sample: GD04853-03 **Sampled:** 04/27/23 10:35
Name: APW07 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	2.09	pCi/L			1	0.546	05/19/23 14:32		904.0 903.0

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ANALYTICAL RESULTS

Sample: GD04853-04 **Sampled:** 04/27/23 14:05
Name: APW09 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	2	pCi/L			1	0.449	05/19/23 14:32		904.0 903.0

Sample: GD04853-05 **Sampled:** 04/27/23 15:47
Name: APW10 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.316 J	pCi/L			1	0.562	05/19/23 14:32		904.0 903.0

Sample: GD04853-06 **Sampled:** 04/27/23 17:16
Name: APW13 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.651	pCi/L			1	0.485	05/19/23 14:32		904.0 903.0

Sample: GD04853-07 **Sampled:** 04/27/23 14:35
Name: EB-03 **Received:** 04/28/23 12:45
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.418 J	pCi/L			1	0.513	05/19/23 14:32		904.0 903.0

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ANALYTICAL RESULTS

Sample: GD04926-01
Name: APW14
Alias: NEW_811_502

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	0.381 J	pCi/L			1	0.465	05/24/23 00:32		904.0 903.0

Sample: GD04926-02
Name: APW14 DUP
Alias: NEW_811_502

Sampled: 04/28/23 11:29
Received: 04/28/23 16:12
Matrix: Ground Water - Grab

Parameter	Result	Unit	Qualifier	Prepared	Dilution	MRL	Analyzed	Analyst	Method
Miscellaneous - Pace Analytical - Mt Juliet, Tn									
Rad 226 and 228-Subcontract	1.71	pCi/L			1	0.584	05/31/23 08:55		904.0 903.0

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QC SAMPLE RESULTS

Parameter	Result	Unit	Qual	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit

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Pace Analytical Services, LLC
2231 W. Altorfer Drive
Peoria, IL 61615
(800)752-6651

NOTES

Specifications regarding method revisions, method modifications, and calculations used for analysis are available upon request. Please contact your project manager.

* Not a TNI accredited analyte

Certifications

CHI - McHenry, IL - 4314-A W. Crystal Lake Road, McHenry, IL 60050
TNI Accreditation for Drinking Water and Wastewater Fields of Testing through IL EPA Accreditation No. 100279
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory Registry No. 17556

PIA - Peoria, IL - 2231 W. Altorfer Drive, Peoria, IL 61615
TNI Accreditation for Drinking Water, Wastewater, Solid and Hazardous Material Fields of Testing through IL EPA Accreditation No. 100230
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory Registry No. 17553
Drinking Water Certifications/Accreditations: Iowa (240); Kansas (E-10338); Missouri (870)
Wastewater Certifications/Accreditations: Arkansas (88-0677); Iowa (240); Kansas (E-10338)
Solid and Hazardous Material Certifications/Accreditations: Arkansas (88-0677); Iowa (240); Kansas (E-10338)

SPMO - Springfield, MO - 1805 W Sunset Street, Springfield, MO 65807
USEPA DMR-QA Program

STL - Hazelwood, MO - 944 Anglum Rd, Hazelwood, MO 63042
TNI Accreditation for Wastewater, Solid and Hazardous Material Fields of Testing through KS KDHE Certification No. E-10389
TNI Accreditation for Wastewater, Solid and Hazardous Material Fields of Testing through IL EPA Accreditation No. - 200080
Illinois Department of Public Health Bacterial Analysis in Drinking Water Approved Laboratory, Registry No. 171050
Missouri Department of Natural Resources - Certificate of Approval for Microbiological Laboratory Service - No. 1050

Gail J Schindler

Certified by: Gail Schindler, Project Manager

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Pace Analytical

ANALYTICAL REPORT

June 01, 2023

Pace IR - Peoria, IL

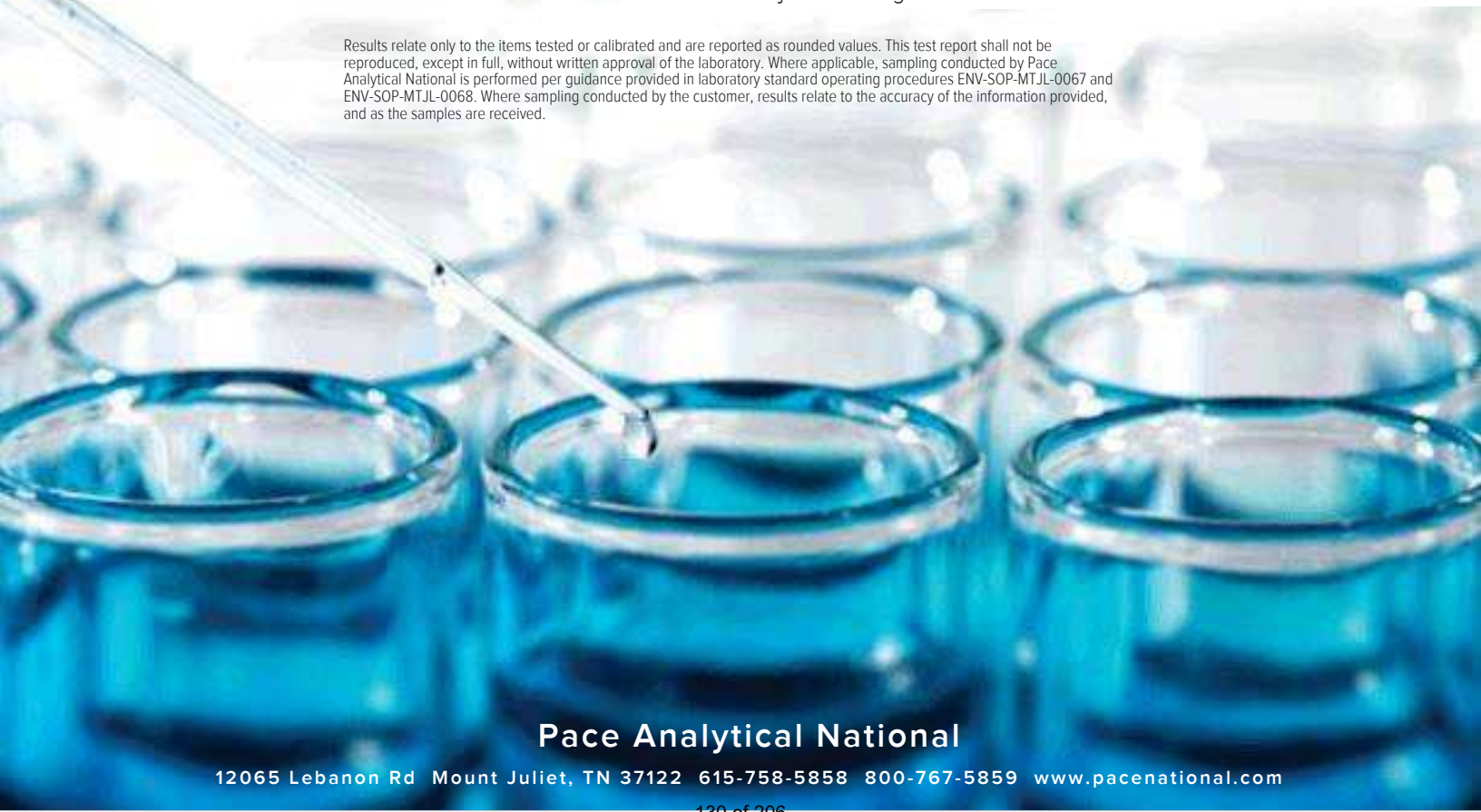
Sample Delivery Group:	L1611854
Samples Received:	05/03/2023
Project Number:	GD04486
Description:	Vistra-Newton
Site:	001
Report To:	Gail Schindler 2231 W. Altorfer Drive Peoria, IL 61615

Entire Report Reviewed By:

Haley Torrence

Haley Torrence
Project Manager

Results relate only to the items tested or calibrated and are reported as rounded values. This test report shall not be reproduced, except in full, without written approval of the laboratory. Where applicable, sampling conducted by Pace Analytical National is performed per guidance provided in laboratory standard operating procedures ENV-SOP-MTJL-0067 and ENV-SOP-MTJL-0068. Where sampling conducted by the customer, results relate to the accuracy of the information provided, and as the samples are received.



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APW03 L1611854-01 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 13:20	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	RRE	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RRE	Mt. Juliet, TN

APW04 L1611854-02 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 16:42	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW16 L1611854-03 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 13:26	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW17 L1611854-04 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 16:50	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW18 L1611854-05 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 15:03	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

EB-01 L1611854-06 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/25/23 17:15	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

CASE NARRATIVE

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All sample aliquots were received at the correct temperature, in the proper containers, with the appropriate preservatives, and within method specified holding times, unless qualified or notated within the report. Where applicable, all MDL (LOD) and RDL (LOQ) values reported for environmental samples have been corrected for the dilution factor used in the analysis. All radiochemical sample results for solids are reported on a dry weight basis with the exception of tritium, carbon-14 and radon, unless wet weight was requested by the client. All Method and Batch Quality Control are within established criteria except where addressed in this case narrative, a non-conformance form or properly qualified within the sample results. By my digital signature below, I affirm to the best of my knowledge, all problems/anomalies observed by the laboratory as having the potential to affect the quality of the data have been identified by the laboratory, and no information or data have been knowingly withheld that would affect the quality of the data.

Haley Torrence

Haley Torrence
Project Manager

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APW03 SAMPLE RESULTS - 01 L1611854

Collected date/time: 04/25/23 13:27

Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.267	J	0.241	0.432	05/19/2023 14:32	WG2061003
(T) Barium	*109*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*90.0*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.02		0.551	0.598	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.754		0.496	0.414	05/18/2023 18:05	WG2058951
(T) Barium-133	*39.3*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.543		0.253	0.444	05/19/2023 14:32	WG2061003
(T) Barium	*109*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*112*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.00		0.379	0.518	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.462		0.282	0.266	05/18/2023 18:05	WG2058951
(T) Barium-133	*95.1*			*30.0-143*	*05/18/2023 18:05*	WG2058951

APW16 SAMPLE RESULTS - 03 L1611854

Collected date/time: 04/25/23 13:22

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	1.28		0.264	0.442	05/19/2023 14:32	WG2061003
(T) Barium	*118*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*105*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	2.05		0.408	0.472	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.774		0.311	0.166	05/18/2023 18:05	WG2058951
(T) Barium-133	*91.0*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.696		0.244	0.423	05/19/2023 14:32	WG2061003
(T) Barium	*110*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*100*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.42		0.417	0.493	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.725		0.338	0.254	05/18/2023 18:05	WG2058951
(T) Barium-133	*87.1*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.515		0.238	0.417	05/19/2023 14:32	WG2061003
(T) Barium	*108*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*94.8*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.33		0.413	0.476	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.819		0.338	0.230	05/18/2023 18:05	WG2058951
(T) Barium-133	*118*			*30.0-143*	*05/18/2023 18:05*	WG2058951

EB-01 SAMPLE RESULTS - 06
Collected date/time: 04/25/23 17:15 L1611854

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	-0.653	U	0.262	0.500	05/19/2023 14:32	WG2061003
(T) Barium	*105*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*114*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.426	J	0.434	0.652	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.426		0.346	0.419	05/18/2023 18:05	WG2058951
(T) Barium-133	*89.5*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Method Blank (MB)

(MB) R3929806-1 05/19/23 14:32

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-228	-0.357	U	0.173	0.324
(T) Barium	*108*		*108*	
(T) Yttrium	*101*		*101*	

L1611854-01 Original Sample (OS) • Duplicate (DUP)

(OS) L1611854-01 05/19/23 14:32 • (DUP) R3929806-5 05/19/23 14:32

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-228	0.267	0.241	0.432	-0.527	0.396	0.432	1	200	1.71	U	20	3
(T) Barium	*109*			*114*	*114*							
(T) Yttrium	*90.0*			*116*	*116*							

Laboratory Control Sample (LCS)

(LCS) R3929806-2 05/19/23 14:32

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-228	5.00	4.97	99.4	80.0-120	
(T) Barium			*116*		
(T) Yttrium			*112*		

L1606733-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1606733-01 05/19/23 14:32 • (MS) R3929806-3 05/19/23 14:32 • (MSD) R3929806-4 05/19/23 14:32

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-228	10.0	0.855	10.4	10.0	95.1	91.7	1	70.0-130			3.34		20
(T) Barium		*121*			*120*	*116*							
(T) Yttrium		*108*			*111*	*98.4*							

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Method Blank (MB)

(MB) R3927911-5 05/18/23 18:22

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-226	-0.0127	U	0.0290	0.0632
(T) Barium-133	*74.5*		*74.5*	

L1611860-01 Original Sample (OS) • Duplicate (DUP)

(OS) L1611860-01 05/18/23 18:05 • (DUP) R3927911-4 05/18/23 18:05

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-226	0.688	0.371	0.320	0.0912	0.205	0.320	1	153	1.41	U	20	3
(T) Barium-133	*85.0*			*87.1*	*87.1*							

Laboratory Control Sample (LCS)

(LCS) R3927911-1 05/18/23 18:05

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-226	5.01	5.13	102	80.0-120	
(T) Barium-133			*77.2*		

L1611860-07 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1611860-07 05/18/23 18:05 • (MS) R3927911-2 05/18/23 18:05 • (MSD) R3927911-3 05/18/23 18:05

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-226	20.0	0.0721	19.7	19.7	98.2	97.9	1	75.0-125			0.305		20
(T) Barium-133		*79.2*			*84.7*	*72.7*							

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Guide to Reading and Understanding Your Laboratory Report

The information below is designed to better explain the various terms used in your report of analytical results from the Laboratory. This is not intended as a comprehensive explanation, and if you have additional questions please contact your project representative.

Results Disclaimer - Information that may be provided by the customer, and contained within this report, include Permit Limits, Project Name, Sample ID, Sample Matrix, Sample Preservation, Field Blanks, Field Spikes, Field Duplicates, On-Site Data, Sampling Collection Dates/Times, and Sampling Location. Results relate to the accuracy of this information provided, and as the samples are received.

Abbreviations and Definitions

MDA	Minimum Detectable Activity.
Rec.	Recovery.
RER	Replicate Error Ratio.
RPD	Relative Percent Difference.
SDG	Sample Delivery Group.
(T)	Tracer - A radioisotope of known concentration added to a solution of chemically equivalent radioisotopes at a known concentration to assist in monitoring the yield of the chemical separation.
Analyte	The name of the particular compound or analysis performed. Some Analyses and Methods will have multiple analytes reported.
Dilution	If the sample matrix contains an interfering material, the sample preparation volume or weight values differ from the standard, or if concentrations of analytes in the sample are higher than the highest limit of concentration that the laboratory can accurately report, the sample may be diluted for analysis. If a value different than 1 is used in this field, the result reported has already been corrected for this factor.
Limits	These are the target % recovery ranges or % difference value that the laboratory has historically determined as normal for the method and analyte being reported. Successful QC Sample analysis will target all analytes recovered or duplicated within these ranges.
Original Sample	The non-spiked sample in the prep batch used to determine the Relative Percent Difference (RPD) from a quality control sample. The Original Sample may not be included within the reported SDG.
Qualifier	This column provides a letter and/or number designation that corresponds to additional information concerning the result reported. If a Qualifier is present, a definition per Qualifier is provided within the Glossary and Definitions page and potentially a discussion of possible implications of the Qualifier in the Case Narrative if applicable.
Result	The actual analytical final result (corrected for any sample specific characteristics) reported for your sample. If there was no measurable result returned for a specific analyte, the result in this column may state “ND” (Not Detected) or “BDL” (Below Detectable Levels). The information in the results column should always be accompanied by either an MDL (Method Detection Limit) or RDL (Reporting Detection Limit) that defines the lowest value that the laboratory could detect or report for this analyte.
Uncertainty (Radiochemistry)	Confidence level of 2 sigma.
Case Narrative (Cn)	A brief discussion about the included sample results, including a discussion of any non-conformances to protocol observed either at sample receipt by the laboratory from the field or during the analytical process. If present, there will be a section in the Case Narrative to discuss the meaning of any data qualifiers used in the report.
Quality Control Summary (Qc)	This section of the report includes the results of the laboratory quality control analyses required by procedure or analytical methods to assist in evaluating the validity of the results reported for your samples. These analyses are not being performed on your samples typically, but on laboratory generated material.
Sample Chain of Custody (Sc)	This is the document created in the field when your samples were initially collected. This is used to verify the time and date of collection, the person collecting the samples, and the analyses that the laboratory is requested to perform. This chain of custody also documents all persons (excluding commercial shippers) that have had control or possession of the samples from the time of collection until delivery to the laboratory for analysis.
Sample Results (Sr)	This section of your report will provide the results of all testing performed on your samples. These results are provided by sample ID and are separated by the analyses performed on each sample. The header line of each analysis section for each sample will provide the name and method number for the analysis reported.
Sample Summary (Ss)	This section of the Analytical Report defines the specific analyses performed for each sample ID, including the dates and times of preparation and/or analysis.

Qualifier	Description
J	The identification of the analyte is acceptable; the reported value is an estimate.
U	Below Detectable Limits: Indicates that the analyte was not detected.

ACCREDITATIONS & LOCATIONS
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Pace Analytical National 12065 Lebanon Rd Mount Juliet, TN 37122

Alabama	40660	Nebraska	NE-OS-15-05
Alaska	17-026	Nevada	TN000032021-1
Arizona	AZ0612	New Hampshire	2975
Arkansas	88-0469	New Jersey–NELAP	TN002
California	2932	New Mexico [1]	TN00003
Colorado	TN00003	New York	11742
Connecticut	PH-0197	North Carolina	Env375
Florida	E87487	North Carolina [1]	DW21704
Georgia	NELAP	North Carolina [3]	41
Georgia [1]	923	North Dakota	R-140
Idaho	TN00003	Ohio–VAP	CL0069
Illinois	200008	Oklahoma	9915
Indiana	C-TN-01	Oregon	TN200002
Iowa	364	Pennsylvania	68-02979
Kansas	E-10277	Rhode Island	LAO00356
Kentucky [1 6]	KY90010	South Carolina	84004002
Kentucky [2]	16	South Dakota	n/a
Louisiana	AI30792	Tennessee [1 4]	2006
Louisiana	LA018	Texas	T104704245-20-18
Maine	TN00003	Texas [5]	LAB0152
Maryland	324	Utah	TN000032021-11
Massachusetts	M-TN003	Vermont	VT2006
Michigan	9958	Virginia	110033
Minnesota	047-999-395	Washington	C847
Mississippi	TN00003	West Virginia	233
Missouri	340	Wisconsin	998093910
Montana	CERT0086	Wyoming	A2LA
A2LA – ISO 17025	1461.01	AIHA-LAP,LLC EMLAP	100789
A2LA – ISO 17025 [5]	1461.02	DOD	1461.01
Canada	1461.01	USDA	P330-15-00234
EPA–Crypto	TN00003		

[1] Drinking Water [2] Underground Storage Tanks [3] Aquatic Toxicity [4] Chemical/Microbiological [5] Mold [6] Wastewater n/a Accreditation not applicable

* Not all certifications held by the laboratory are applicable to the results reported in the attached report.

* Accreditation is only applicable to the test methods specified on each scope of accreditation held by Pace Analytical.

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A133

Internal Transfer Chain of Custody

Pace Analytical®
www.pacelabs.com

State of Origin: IL
Cert. Needed: [X] YES [ ] NO

GD04486 **Workorder Name:** VISTRA - NEWTON

Owner Received Date: 4/26/2023

Results Requ By: 5/15/2023

Report To:	Subcontract To:
Gail Schindler Pace Analytical - IL/MO 2231 W. Altorfer Drive Peoria, IL 61615 800-752-6651	Pace Analytical - Mt Juliet 12065 Lebanon Rd Mt Juliet TN 37122

Item	Sample ID	Sample Type	Collect Date/Time	Lab ID	Matrix	Preserved Containers	Requested Analysis: Radium 226	Requested Analysis: Radium 228	LAB USE ONLY
1	APW03	GRAB	4/25/2023 13:20	GD04486-01	GW		X	X	-01
2	APW04	GRAB	4/25/2023 16:42	GD04486-02	GW		X	X	-02
3	APW16	GRAB	4/25/2023 13:26	GD04486-03	GW		X	X	-03
4	APW17	GRAB	4/25/2023 16:50	GD04486-04	GW		X	X	-04
5	APW18	GRAB	4/25/2023 15:03	GD04486-05	GW		X	X	-05
6	EB-01	GRAB	4/25/2023 17:15	GD04486-06	DI		X	X	-06

L161854

Transfers	3/14/2023 14:31	Date/Time	Received By	Date/Time	Comments
1	Camden Bennett	5-2-23 14:42	Hayley Robertson	5/3/23 0900	Needs 226, 228 and combined Include QC summary and edd 10 day TAT
2					
3					

HR 5/3

Cooler Temperature on Receipt _____ °C	Custody Seal Y or N	Received on Ice Y or N	Sample Intact Y or N

***In order to maintain client confidentiality, location/name of the sampling site, sampler's name and signature may not be provided on this COC document. This chain of custody is considered complete as is since this information is available in the owner laboratory.

FMT-ALL-C-002rev.00 24March2009

Sample Receipt Checklist

COC Seal Present/Intact:	Y N	If Applicable	
COC Signed/Accurate:	Y N	VOA Zero Headspace:	Y N
Bottles arrive intact:	Y N	Pres.Correct/Check:	Y N
Correct bottles used:	Y N		
Sufficient volume sent:	Y N		
RAD Screen <0.5 mR/hr:	Y N		

17.7±0=17.7 NS AG

6319597 8519

L1611851

Pace Analytical
www.pacelabs.com

Ship to :
Pace Analytical Services, LLC
12065 Lebanon Rd
Mt Juliet TN 37122

(615)758-5858

INTER_LABORATORY WORK ORDER # GD04486
(To be complete by sending lab)

Sending Project No:	GD04486
Receiving Project No:	
Check Box for Consolidated Invoice:	
Date Prepared:	5/2/2023
REQUESTED COMPLETION DATE:	5/15/2023

Sending Region	IR72-IL/MO	Sending Project Mgr.	Gail Schindler
Receiving Region	MT JULIET	External Client	VISTRA - NEWTON
State of Sample Origin	IL	QC Deliverable	**STD Report**

All questions should be addressed to sending project manager.

Requested Reportable Units _____ Report Wet or Dry Weight? _____ Cert Needed: IL

WORK REQUESTED						
Method Description	**Container Type**	**Quantity of**	**Preservative**	**Quantity of**	**Unit Price**	**Amount**
Radium 226		6		6	$100.00	$600.00
Radium 228		6		6	$100.00	$600.00
		1		1		$0.00
					TOTAL	$1,200.00

Special Requirements: Report as 226, 228 & combined 226/228. Include QC summary & edd

Receiving Reqion Department	Acctg. Code	Totals from above	Revenue Allocation	
			Receiving Region (80%)	Client Services Dept.
radiological	38	$1,200.00	$960.00	$240.00
		TOTAL	$960.00	$240.00

* Custom Revenue Allocation

FOR ANALYTICAL WORK COMPLETED THIS SECTION ALSO

Return Samples to Sending Region: [ ] Yes [X] No

CONFIRMATION OF WORK COMPLETED

Date Completed: _____ Receiving Project Manager: _____

Original sent to the receiving lab - Copy kept at the sending lab.

When work completed: Original sent to the ABM at the receiving laboratory. Copies are made to corporate as needed.

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Pace Analytical

ANALYTICAL REPORT

June 06, 2023

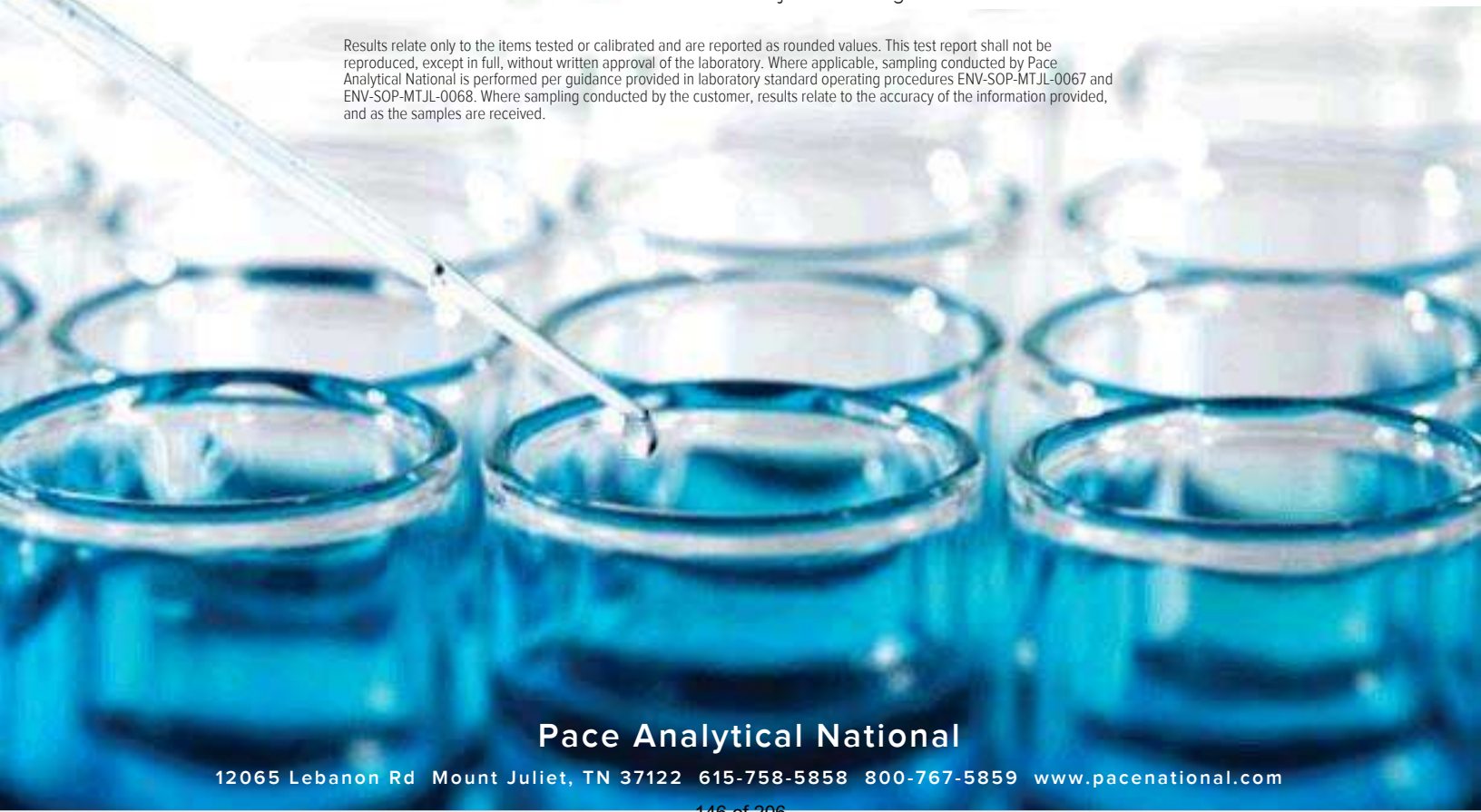
Pace IR - Peoria, IL

Sample Delivery Group:	L1611866
Samples Received:	05/03/2023
Project Number:	GD04770
Description:	Vistra-Newton
Site:	001
Report To:	Gail Schindler
	2231 W. Altorfer Drive
	Peoria, IL 61615

Entire Report Reviewed By: Haley Torrence

Haley Torrence
Project Manager

Results relate only to the items tested or calibrated and are reported as rounded values. This test report shall not be reproduced, except in full, without written approval of the laboratory. Where applicable, sampling conducted by Pace Analytical National is performed per guidance provided in laboratory standard operating procedures ENV-SOP-MTJL-0067 and ENV-SOP-MTJL-0068. Where sampling conducted by the customer, results relate to the accuracy of the information provided, and as the samples are received.



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APW05S L1611866-01 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 17:40	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

APW06 L1611866-02 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 16:00	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RRE	Mt. Juliet, TN

APW08 L1611866-03 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 12:11	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

APW11 L1611866-04 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 15:43	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

APW12 L1611866-05 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 13:56	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

APW15 L1611866-06 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/26/23 17:23	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

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SAMPLE SUMMARY

EB-02 L1611866-07 Non-Potable Water

Collected by	Collected date/time	Received date/time
	04/26/23 16:30	05/03/23 09:00

Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 13:18	RGT	Mt. Juliet, TN

CASE NARRATIVE

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All sample aliquots were received at the correct temperature, in the proper containers, with the appropriate preservatives, and within method specified holding times, unless qualified or notated within the report. Where applicable, all MDL (LOD) and RDL (LOQ) values reported for environmental samples have been corrected for the dilution factor used in the analysis. All radiochemical sample results for solids are reported on a dry weight basis with the exception of tritium, carbon-14 and radon, unless wet weight was requested by the client. All Method and Batch Quality Control are within established criteria except where addressed in this case narrative, a non-conformance form or properly qualified within the sample results. By my digital signature below, I affirm to the best of my knowledge, all problems/anomalies observed by the laboratory as having the potential to affect the quality of the data have been identified by the laboratory, and no information or data have been knowingly withheld that would affect the quality of the data.

Haley Torrence

Haley Torrence
Project Manager

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	-1.07	U	0.400	0.755	05/31/2023 08:55	WG2061735
(T) Barium	*80.2*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*88.7*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.141	U	0.430	0.784	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.141	J	0.159	0.210	05/24/2023 13:18	WG2058953
(T) Barium-133	*101*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.574	J	0.336	0.595	05/31/2023 08:55	WG2061735
(T) Barium	*78.6*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*127*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.20		0.487	0.686	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.621		0.353	0.342	05/24/2023 13:18	WG2058953
(T) Barium-133	*96.0*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.337	J	0.293	0.524	05/31/2023 08:55	WG2061735
(T) Barium	*93.7*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*88.5*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.941		0.456	0.628	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.604		0.349	0.346	05/24/2023 13:18	WG2058953
(T) Barium-133	*84.4*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	1.64		0.303	0.496	05/31/2023 08:55	WG2061735
(T) Barium	*78.2*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*95.5*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	2.17		0.424	0.566	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.530		0.296	0.273	05/24/2023 13:18	WG2058953
(T) Barium-133	*101*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	-1.05	U	0.345	0.659	05/31/2023 08:55	WG2061735
(T) Barium	*85.3*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*127*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.0586	U	0.369	0.697	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.0586	U	0.131	0.226	05/24/2023 13:18	WG2058953
(T) Barium-133	*97.0*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	1.38		0.390	0.665	05/31/2023 08:55	WG2061735
(T) Barium	*78.6*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*83.7*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.97		0.488	0.696	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.586		0.294	0.207	05/24/2023 13:18	WG2058953
(T) Barium-133	*98.0*			*30.0-143*	*05/24/2023 13:18*	WG2058953

EB-02 SAMPLE RESULTS - 07

Collected date/time: 04/26/23 16:10 L1611866

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	-0.0858	U	0.272	0.502	05/31/2023 08:55	WG2061735
(T) Barium	*82.0*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*139*	C1		*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.142	U	0.306	0.528	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.142	J	0.140	0.163	05/24/2023 13:18	WG2058953
(T) Barium-133	*100*			*30.0-143*	*05/24/2023 13:18*	WG2058953

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WG2061939

QUALITY CONTROL SUMMARY

Radiochemistry by Method 904/9320

Method Blank (MB)

(MB) R3932968-2 05/31/23 08:55

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-228	0.510		0.175	0.303
(T) Barium	*80.6*		*80.6*	
(T) Yttrium	*117*		*117*	

L1611866-05 Original Sample (OS) • Duplicate (DUP)

(OS) L1611866-05 05/31/23 08:55 • (DUP) R3932968-5 05/31/23 08:55

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-228	-1.05	0.345	0.659	-1.23	0.448	0.659	1	0.000	0.313	U	20	3
(T) Barium	*85.3*			*81.0*	*81.0*							
(T) Yttrium	*127*			*143*	*143*					C1		

Laboratory Control Sample (LCS)

(LCS) R3932968-1 05/26/23 09:50

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-228	5.00	5.89	118	80.0-120	
(T) Barium			*94.2*		
(T) Yttrium			*74.8*		

L1607413-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1607413-01 05/31/23 08:55 • (MS) R3932968-3 05/31/23 08:55 • (MSD) R3932968-4 05/31/23 08:55

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-228	10.0	4.03	11.0	11.8	69.2	77.2	1	70.0-130	J6		7.05		20
(T) Barium		*80.5*			*88.9*	*84.4*							
(T) Yttrium		*87.6*			*117*	*116*							

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WG2058993

Radiochemistry by Method SW7500Ra B M

QUALITY CONTROL SUMMARY

L1611866-01,02,03,04,05,06,07

Method Blank (MB)

(MB) R3929001-1 05/24/23 00:32

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-226	-0.0131	U	0.0300	0.0654
(T) Barium-133	*72.0*		*72.0*	

L1611866-07 Original Sample (OS) • Duplicate (DUP)

(OS) L1611866-07 05/24/23 13:18 • (DUP) R3929001-5 05/24/23 13:18

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-226	0.142	0.140	0.163	0.130	0.254	0.163	1	8.91	0.0417	U	20	3
(T) Barium-133	*100*			*83.2*	*83.2*							

Laboratory Control Sample (LCS)

(LCS) R3929001-2 05/24/23 13:18

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-226	5.01	5.10	102	80.0-120	
(T) Barium-133			*94.0*		

L1611864-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1611864-01 05/24/23 00:32 • (MS) R3929001-3 05/24/23 13:18 • (MSD) R3929001-4 05/24/23 13:18

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-226	20.0	0.153	19.5	18.2	96.6	90.2	1	75.0-125			6.74		20
(T) Barium-133		*99.5*			*97.5*	*94.4*							

Cp
Tc
Ss
Cn
Sr
Qc
Gl
Al
Sc

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Guide to Reading and Understanding Your Laboratory Report

The information below is designed to better explain the various terms used in your report of analytical results from the Laboratory. This is not intended as a comprehensive explanation, and if you have additional questions please contact your project representative.

Results Disclaimer - Information that may be provided by the customer, and contained within this report, include Permit Limits, Project Name, Sample ID, Sample Matrix, Sample Preservation, Field Blanks, Field Spikes, Field Duplicates, On-Site Data, Sampling Collection Dates/Times, and Sampling Location. Results relate to the accuracy of this information provided, and as the samples are received.

Abbreviations and Definitions

MDA	Minimum Detectable Activity.
Rec.	Recovery.
RER	Replicate Error Ratio.
RPD	Relative Percent Difference.
SDG	Sample Delivery Group.
(T)	Tracer - A radioisotope of known concentration added to a solution of chemically equivalent radioisotopes at a known concentration to assist in monitoring the yield of the chemical separation.
Analyte	The name of the particular compound or analysis performed. Some Analyses and Methods will have multiple analytes reported.
Dilution	If the sample matrix contains an interfering material, the sample preparation volume or weight values differ from the standard, or if concentrations of analytes in the sample are higher than the highest limit of concentration that the laboratory can accurately report, the sample may be diluted for analysis. If a value different than 1 is used in this field, the result reported has already been corrected for this factor.
Limits	These are the target % recovery ranges or % difference value that the laboratory has historically determined as normal for the method and analyte being reported. Successful QC Sample analysis will target all analytes recovered or duplicated within these ranges.
Original Sample	The non-spiked sample in the prep batch used to determine the Relative Percent Difference (RPD) from a quality control sample. The Original Sample may not be included within the reported SDG.
Qualifier	This column provides a letter and/or number designation that corresponds to additional information concerning the result reported. If a Qualifier is present, a definition per Qualifier is provided within the Glossary and Definitions page and potentially a discussion of possible implications of the Qualifier in the Case Narrative if applicable.
Result	The actual analytical final result (corrected for any sample specific characteristics) reported for your sample. If there was no measurable result returned for a specific analyte, the result in this column may state “ND” (Not Detected) or “BDL” (Below Detectable Levels). The information in the results column should always be accompanied by either an MDL (Method Detection Limit) or RDL (Reporting Detection Limit) that defines the lowest value that the laboratory could detect or report for this analyte.
Uncertainty (Radiochemistry)	Confidence level of 2 sigma.
Case Narrative (Cn)	A brief discussion about the included sample results, including a discussion of any non-conformances to protocol observed either at sample receipt by the laboratory from the field or during the analytical process. If present, there will be a section in the Case Narrative to discuss the meaning of any data qualifiers used in the report.
Quality Control Summary (Qc)	This section of the report includes the results of the laboratory quality control analyses required by procedure or analytical methods to assist in evaluating the validity of the results reported for your samples. These analyses are not being performed on your samples typically, but on laboratory generated material.
Sample Chain of Custody (Sc)	This is the document created in the field when your samples were initially collected. This is used to verify the time and date of collection, the person collecting the samples, and the analyses that the laboratory is requested to perform. This chain of custody also documents all persons (excluding commercial shippers) that have had control or possession of the samples from the time of collection until delivery to the laboratory for analysis.
Sample Results (Sr)	This section of your report will provide the results of all testing performed on your samples. These results are provided by sample ID and are separated by the analyses performed on each sample. The header line of each analysis section for each sample will provide the name and method number for the analysis reported.
Sample Summary (Ss)	This section of the Analytical Report defines the specific analyses performed for each sample ID, including the dates and times of preparation and/or analysis.

Qualifier Description

C1	Tracer recovery limits have been exceeded; values are outside upper control limits.
J	The identification of the analyte is acceptable; the reported value is an estimate.
J6	The sample matrix interfered with the ability to make any accurate determination; spike value is low.
U	Below Detectable Limits: Indicates that the analyte was not detected.

ACCREDITATIONS & LOCATIONS

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Pace Analytical National 12065 Lebanon Rd Mount Juliet, TN 37122

Alabama	40660	Nebraska	NE-OS-15-05
Alaska	17-026	Nevada	TN000032021-1
Arizona	AZ0612	New Hampshire	2975
Arkansas	88-0469	New Jersey–NELAP	TN002
California	2932	New Mexico [1]	TN00003
Colorado	TN00003	New York	11742
Connecticut	PH-0197	North Carolina	Env375
Florida	E87487	North Carolina [1]	DW21704
Georgia	NELAP	North Carolina [3]	41
Georgia [1]	923	North Dakota	R-140
Idaho	TN00003	Ohio–VAP	CL0069
Illinois	200008	Oklahoma	9915
Indiana	C-TN-01	Oregon	TN200002
Iowa	364	Pennsylvania	68-02979
Kansas	E-10277	Rhode Island	LAO000356
Kentucky [1 6]	KY90010	South Carolina	84004002
Kentucky [2]	16	South Dakota	n/a
Louisiana	AI30792	Tennessee [1 4]	2006
Louisiana	LA018	Texas	T104704245-20-18
Maine	TN00003	Texas [5]	LAB0152
Maryland	324	Utah	TN000032021-11
Massachusetts	M-TN003	Vermont	VT2006
Michigan	9958	Virginia	110033
Minnesota	047-999-395	Washington	C847
Mississippi	TN00003	West Virginia	233
Missouri	340	Wisconsin	998093910
Montana	CERT0086	Wyoming	A2LA
A2LA – ISO 17025	1461.01	AIHA-LAP,LLC EMLAP	100789
A2LA – ISO 17025 [5]	1461.02	DOD	1461.01
Canada	1461.01	USDA	P330-15-00234
EPA–Crypto	TN00003		

[1] Drinking Water [2] Underground Storage Tanks [3] Aquatic Toxicity [4] Chemical/Microbiological [5] Mold [6] Wastewater n/a Accreditation not applicable

* Not all certifications held by the laboratory are applicable to the results reported in the attached report.

* Accreditation is only applicable to the test methods specified on each scope of accreditation held by Pace Analytical.

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Internal Transfer Chain of Custody

Pace Analytical® A130

State of Origin: IL
Cert. Needed: [X] YES [ ] NO

GD04770 Workorder Name: VISTRA - NEWTON Owner Received Date: 4/27/2023 Results Requ By: 5/15/2023

Report To:	Subcontract To:
Gail Schindler Pace Analytical - IL/MO 2231 W. Altorfer Drive Peoria, IL 61615 800-752-6651	Pace Analytical - Mt Juliet 12065 Lebanon Rd Mt Juliet TN 37122

Requested Analysis

Item	Sample ID	Sample Type	Collect Date/Time	Lab ID	Matrix	Preserved Containers	Radium 226	Radium 228	LAB USE ONLY
1	APW05s	GRAB	4/26/2023 17:40	GD04770-01	GW		X	X	-01
2	APW06	GRAB	4/26/2023 16:00	GD04770-02	GW		X	X	-02
3	APW08	GRAB	4/26/2023 12:11	GD04770-03	GW		X	X	-03
4	APW11	GRAB	4/26/2023 15:43	GD04770-04	GW		X	X	-04
5	APW12	GRAB	4/26/2023 13:56	GD04770-05	GW		X	X	-05
6	APW15	GRAB	4/26/2023 17:23	GD04770-06	GW		X	X	-06
7	EB-02	GRAB	4/26/2023 16:30	GD04770-07	DI		X	X	-07

4611866

Transfers	3/14/2023 14:31	Date/Time	Reveived By	Date/Time	Comments
1	Camden Bennett	5-2-23 14:42	Harley Rentz	5/3/23 0900	Needs 226, 228 and combined
2					Include QC summary and edd
3					10 day TAT

Cooler Temperature on Receipt _____ °C | Custody Seal Y or N | Received on Ice Y or N | Sample Intact Y or N

***In order to maintain client confidentiality, location/name of the sampling site, sampler's name and signature may not be provided on this COC document.
This chain of custody is considered complete as is since this information is available in the owner laboratory.

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Sample Receipt Checklist
COC Seal Present/Intact: Y N
COC Signed/Accurate: Y N
Bottles arrive intact: Y N
Correct bottles used: Y N
Sufficient volume sent: Y N
RAD Screen <0.5 mR/hr: Y N
If Applicable
VOA Zero Headspace: Y N
Pres.Correct/Check: Y N

18.8±0=18.8 NS A7

6319 5997 8493

4611866

Pace Analytical®
www.pacelabs.com

Ship to :
Pace Analytical Services, LLC
12065 Lebanon Rd
Mt Juliet TN 37122

(615)758-5858

INTER_LABORATORY WORK ORDER # GD04770
(To be complete by sending lab)

Sending Project No:	GD04770
Receiving Project No:	
Check Box for Consolidated Invoice:	
Date Prepared:	5/2/2023
REQUESTED COMPLETION DATE:	5/15/2023

Sending Region	IR72-IL/MO	Sending Project Mgr.	Gail Schindler
Receiving Region	MT JULIET	External Client	VISTRA - NEWTON
State of Sample Origin	IL	QC Deliverable	**STD Report**

All questions should be addressed to sending project manager.

Requested Reportable Units _____ Report Wet or Dry Weight? _____ Cert Needed: IL

WORK REQUESTED

Method Description	Container Type	Quantity of	Preservative	Quantity of	Unit Price	Amount
Radium 226		7		7	$100.00	$700.00
Radium 228		7		7	$100.00	$700.00
		1		1		$0.00
					TOTAL	$1,400.00

Special Requirements: Report as 226, 228 & combined 226/228. Include QC summary & edd

Receiving Region Department	Acctg. Code	Totals from above	Revenue Allocation	
			Receiving Region (80%)	Client Services Dept.
radiological	38	$1,400.00	$1,120.00	$280.00
		TOTAL	$1,120.00	$280.00

* Custom Revenue Allocation

FOR ANALYTICAL WORK COMPLETED THIS SECTION ALSO

Return Samples to Sending Region: [ ] Yes [X] No

CONFIRMATION OF WORK COMPLETED

Date Completed: _____ Receiving Project Manager: _____

Original sent to the receiving lab - Copy kept at the sending lab.
When work completed: Original sent to the ABM at the receiving laboratory. Copies are made to corporate as needed.

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ATTACHMENT B.
845 QUARTERLY REPORT - QUARTER 2, 2023
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

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Pace Analytical®

ANALYTICAL REPORT

May 26, 2023

Pace IR - Peoria, IL

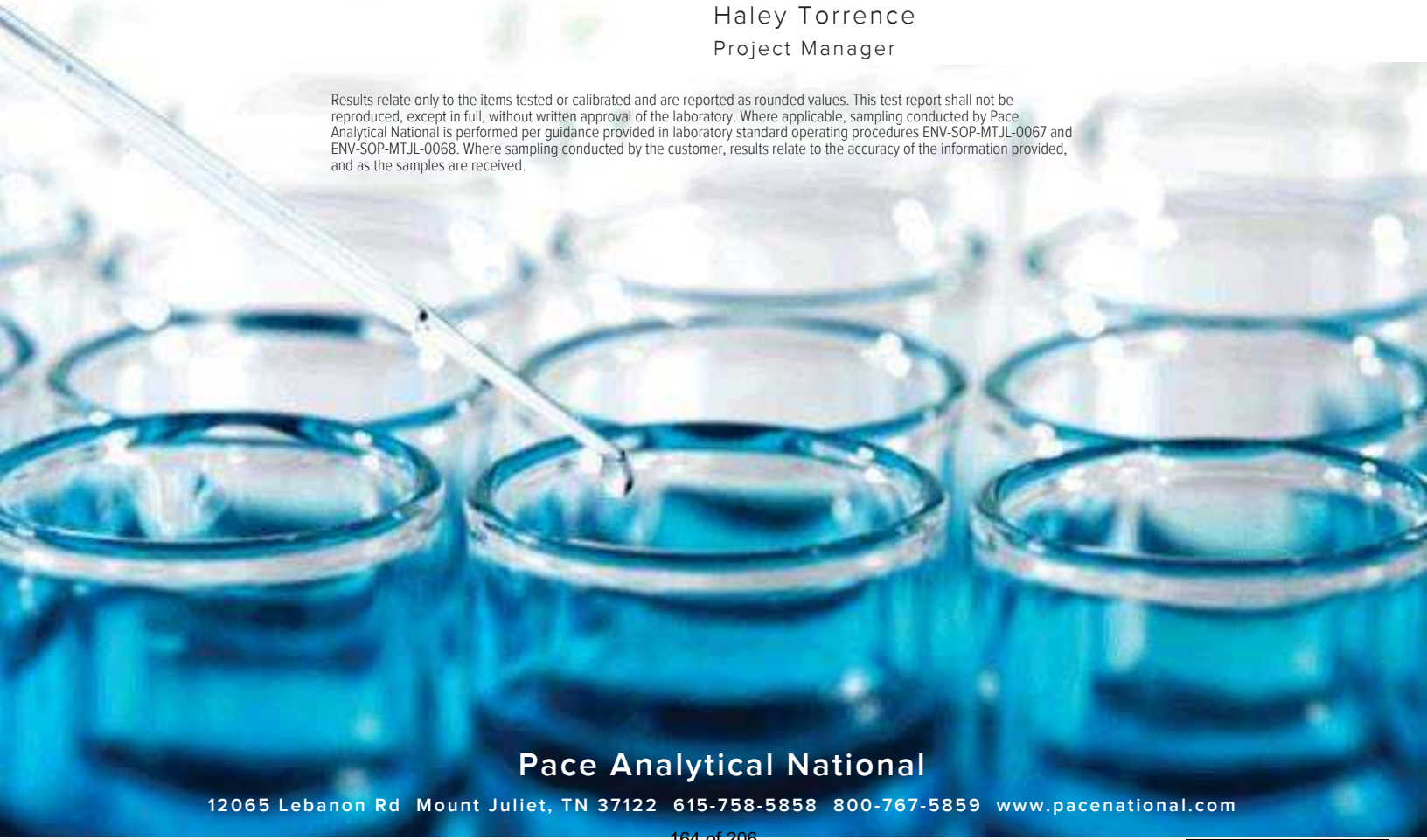
Sample Delivery Group:	L1611860
Samples Received:	05/03/2023
Project Number:	GD04853
Description:	Vistra-Newton
Site:	001
Report To:	Gail Schindler 2231 W. Altorfer Drive Peoria, IL 61615

Entire Report Reviewed By:

Haley Torrence

Haley Torrence
Project Manager

Results relate only to the items tested or calibrated and are reported as rounded values. This test report shall not be reproduced, except in full, without written approval of the laboratory. Where applicable, sampling conducted by Pace Analytical National is performed per guidance provided in laboratory standard operating procedures ENV-SOP-MTJL-0067 and ENV-SOP-MTJL-0068. Where sampling conducted by the customer, results relate to the accuracy of the information provided, and as the samples are received.



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APW02 L1611860-01 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 12:17	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW05 L1611860-02 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 12:40	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW07 L1611860-03 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 10:35	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW09 L1611860-04 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 14:05	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW10 L1611860-05 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 15:47	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

APW13 L1611860-06 Non-Potable Water

			Collected by	Collected date/time	Received date/time	
				04/27/23 17:16	05/03/23 09:00	
Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

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SAMPLE SUMMARY

EB-03 L1611860-07 Non-Potable Water

Collected by	Collected date/time	Received date/time
	04/27/23 14:35	05/03/23 09:00

Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058951	1	05/17/23 16:27	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058951	1	05/17/23 16:27	05/18/23 18:05	RGT	Mt. Juliet, TN

CASE NARRATIVE

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All sample aliquots were received at the correct temperature, in the proper containers, with the appropriate preservatives, and within method specified holding times, unless qualified or notated within the report. Where applicable, all MDL (LOD) and RDL (LOQ) values reported for environmental samples have been corrected for the dilution factor used in the analysis. All radiochemical sample results for solids are reported on a dry weight basis with the exception of tritium, carbon-14 and radon, unless wet weight was requested by the client. All Method and Batch Quality Control are within established criteria except where addressed in this case narrative, a non-conformance form or properly qualified within the sample results. By my digital signature below, I affirm to the best of my knowledge, all problems/anomalies observed by the laboratory as having the potential to affect the quality of the data have been identified by the laboratory, and no information or data have been knowingly withheld that would affect the quality of the data.

Haley Torrence
Project Manager

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.0802	U	0.245	0.448	05/19/2023 14:32	WG2061003
(T) Barium	*106*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*127*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.768		0.445	0.551	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.688		0.371	0.320	05/18/2023 18:05	WG2058951
(T) Barium-133	*85.0*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.606		0.211	0.365	05/19/2023 14:32	WG2061003
(T) Barium	*118*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*114*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.841		0.314	0.471	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.236	J	0.233	0.298	05/18/2023 18:05	WG2058951
(T) Barium-133	*99.0*			*30.0-143*	*05/18/2023 18:05*	WG2058951

APW07 SAMPLE RESULTS - 03 L1611860

Collected date/time: 04/27/23 10:45

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	1.07		0.274	0.467	05/19/2023 14:32	WG2061003
(T) Barium	*110*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*109*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	2.09		0.488	0.546	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	1.02		0.404	0.282	05/18/2023 18:05	WG2058951
(T) Barium-133	*91.3*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.920		0.237	0.402	05/19/2023 14:32	WG2061003
(T) Barium	*125*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*119*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	2.00		0.465	0.449	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	1.08		0.400	0.199	05/18/2023 18:05	WG2058951
(T) Barium-133	*96.8*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	-0.384	U	0.250	0.469	05/19/2023 14:32	WG2061003
(T) Barium	*108*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*107*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.316	J	0.360	0.562	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.316		0.259	0.310	05/18/2023 18:05	WG2058951
(T) Barium-133	*92.1*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.413	J	0.242	0.430	05/19/2023 14:32	WG2061003
(T) Barium	*95.4*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*111*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.651		0.314	0.485	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.238		0.200	0.225	05/18/2023 18:05	WG2058951
(T) Barium-133	*83.9*			*30.0-143*	*05/18/2023 18:05*	WG2058951

EB-03 SAMPLE RESULTS - 07

Collected date/time: 04/27/23 14:15 L1611860

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.346	J	0.218	0.389	05/19/2023 14:32	WG2061003
(T) Barium	*116*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*113*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.418	J	0.292	0.513	05/19/2023 14:32	WG2058951

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.0721	U	0.195	0.334	05/18/2023 18:05	WG2058951
(T) Barium-133	*79.2*			*30.0-143*	*05/18/2023 18:05*	WG2058951

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WG2064093

QUALITY CONTROL SUMMARY

Radiochemistry by Method 904.0/9320

Method Blank (MB)

(MB) R3929806-1 05/19/23 14:32

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-228	-0.357	U	0.173	0.324
(T) Barium	*108*		*108*	
(T) Yttrium	*101*		*101*	

L1611854-01 Original Sample (OS) • Duplicate (DUP)

(OS) L1611854-01 05/19/23 14:32 • (DUP) R3929806-5 05/19/23 14:32

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-228	0.267	0.241	0.432	-0.527	0.396	0.432	1	200	1.71	U	20	3
(T) Barium	*109*			*114*	*114*							
(T) Yttrium	*90.0*			*116*	*116*							

Laboratory Control Sample (LCS)

(LCS) R3929806-2 05/19/23 14:32

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-228	5.00	4.97	99.4	80.0-120	
(T) Barium			*116*		
(T) Yttrium			*112*		

L1606733-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1606733-01 05/19/23 14:32 • (MS) R3929806-3 05/19/23 14:32 • (MSD) R3929806-4 05/19/23 14:32

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-228	10.0	0.855	10.4	10.0	95.1	91.7	1	70.0-130			3.34		20
(T) Barium		*121*			*120*	*116*							
(T) Yttrium		*108*			*111*	*98.4*							

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Method Blank (MB)

(MB) R3927911-5 05/18/23 18:22

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-226	-0.0127	U	0.0290	0.0632
(T) Barium-133	*74.5*		*74.5*	

L1611860-01 Original Sample (OS) • Duplicate (DUP)

(OS) L1611860-01 05/18/23 18:05 • (DUP) R3927911-4 05/18/23 18:05

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-226	0.688	0.371	0.320	0.0912	0.205	0.320	1	153	1.41	U	20	3
(T) Barium-133	*85.0*			*87.1*	*87.1*							

Laboratory Control Sample (LCS)

(LCS) R3927911-1 05/18/23 18:05

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-226	5.01	5.13	102	80.0-120	
(T) Barium-133			*77.2*		

L1611860-07 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1611860-07 05/18/23 18:05 • (MS) R3927911-2 05/18/23 18:05 • (MSD) R3927911-3 05/18/23 18:05

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-226	20.0	0.0721	19.7	19.7	98.2	97.9	1	75.0-125			0.305		20
(T) Barium-133		*79.2*			*84.7*	*72.7*							

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Guide to Reading and Understanding Your Laboratory Report

The information below is designed to better explain the various terms used in your report of analytical results from the Laboratory. This is not intended as a comprehensive explanation, and if you have additional questions please contact your project representative.

Results Disclaimer - Information that may be provided by the customer, and contained within this report, include Permit Limits, Project Name, Sample ID, Sample Matrix, Sample Preservation, Field Blanks, Field Spikes, Field Duplicates, On-Site Data, Sampling Collection Dates/Times, and Sampling Location. Results relate to the accuracy of this information provided, and as the samples are received.

Abbreviations and Definitions

MDA	Minimum Detectable Activity.
Rec.	Recovery.
RER	Replicate Error Ratio.
RPD	Relative Percent Difference.
SDG	Sample Delivery Group.
(T)	Tracer - A radioisotope of known concentration added to a solution of chemically equivalent radioisotopes at a known concentration to assist in monitoring the yield of the chemical separation.
Analyte	The name of the particular compound or analysis performed. Some Analyses and Methods will have multiple analytes reported.
Dilution	If the sample matrix contains an interfering material, the sample preparation volume or weight values differ from the standard, or if concentrations of analytes in the sample are higher than the highest limit of concentration that the laboratory can accurately report, the sample may be diluted for analysis. If a value different than 1 is used in this field, the result reported has already been corrected for this factor.
Limits	These are the target % recovery ranges or % difference value that the laboratory has historically determined as normal for the method and analyte being reported. Successful QC Sample analysis will target all analytes recovered or duplicated within these ranges.
Original Sample	The non-spiked sample in the prep batch used to determine the Relative Percent Difference (RPD) from a quality control sample. The Original Sample may not be included within the reported SDG.
Qualifier	This column provides a letter and/or number designation that corresponds to additional information concerning the result reported. If a Qualifier is present, a definition per Qualifier is provided within the Glossary and Definitions page and potentially a discussion of possible implications of the Qualifier in the Case Narrative if applicable.
Result	The actual analytical final result (corrected for any sample specific characteristics) reported for your sample. If there was no measurable result returned for a specific analyte, the result in this column may state “ND” (Not Detected) or “BDL” (Below Detectable Levels). The information in the results column should always be accompanied by either an MDL (Method Detection Limit) or RDL (Reporting Detection Limit) that defines the lowest value that the laboratory could detect or report for this analyte.
Uncertainty (Radiochemistry)	Confidence level of 2 sigma.
Case Narrative (Cn)	A brief discussion about the included sample results, including a discussion of any non-conformances to protocol observed either at sample receipt by the laboratory from the field or during the analytical process. If present, there will be a section in the Case Narrative to discuss the meaning of any data qualifiers used in the report.
Quality Control Summary (Qc)	This section of the report includes the results of the laboratory quality control analyses required by procedure or analytical methods to assist in evaluating the validity of the results reported for your samples. These analyses are not being performed on your samples typically, but on laboratory generated material.
Sample Chain of Custody (Sc)	This is the document created in the field when your samples were initially collected. This is used to verify the time and date of collection, the person collecting the samples, and the analyses that the laboratory is requested to perform. This chain of custody also documents all persons (excluding commercial shippers) that have had control or possession of the samples from the time of collection until delivery to the laboratory for analysis.
Sample Results (Sr)	This section of your report will provide the results of all testing performed on your samples. These results are provided by sample ID and are separated by the analyses performed on each sample. The header line of each analysis section for each sample will provide the name and method number for the analysis reported.
Sample Summary (Ss)	This section of the Analytical Report defines the specific analyses performed for each sample ID, including the dates and times of preparation and/or analysis.

Qualifier	Description
J	The identification of the analyte is acceptable; the reported value is an estimate.
U	Below Detectable Limits: Indicates that the analyte was not detected.

ACCREDITATIONS & LOCATIONS
Electronic Filing: Received, Clerk's Office 07/01/2024

Pace Analytical National 12065 Lebanon Rd Mount Juliet, TN 37122

Alabama	40660	Nebraska	NE-OS-15-05
Alaska	17-026	Nevada	TN000032021-1
Arizona	AZ0612	New Hampshire	2975
Arkansas	88-0469	New Jersey–NELAP	TN002
California	2932	New Mexico [1]	TN00003
Colorado	TN00003	New York	11742
Connecticut	PH-0197	North Carolina	Env375
Florida	E87487	North Carolina [1]	DW21704
Georgia	NELAP	North Carolina [3]	41
Georgia [1]	923	North Dakota	R-140
Idaho	TN00003	Ohio–VAP	CL0069
Illinois	200008	Oklahoma	9915
Indiana	C-TN-01	Oregon	TN200002
Iowa	364	Pennsylvania	68-02979
Kansas	E-10277	Rhode Island	LAO000356
Kentucky [1 6]	KY90010	South Carolina	84004002
Kentucky [2]	16	South Dakota	n/a
Louisiana	AI30792	Tennessee [1 4]	2006
Louisiana	LA018	Texas	T104704245-20-18
Maine	TN00003	Texas [5]	LAB0152
Maryland	324	Utah	TN000032021-11
Massachusetts	M-TN003	Vermont	VT2006
Michigan	9958	Virginia	110033
Minnesota	047-999-395	Washington	C847
Mississippi	TN00003	West Virginia	233
Missouri	340	Wisconsin	998093910
Montana	CERT0086	Wyoming	A2LA
A2LA – ISO 17025	1461.01	AIHA-LAP,LLC EMLAP	100789
A2LA – ISO 17025 [5]	1461.02	DOD	1461.01
Canada	1461.01	USDA	P330-15-00234
EPA–Crypto	TN00003		

[1] Drinking Water [2] Underground Storage Tanks [3] Aquatic Toxicity [4] Chemical/Microbiological [5] Mold [6] Wastewater n/a Accreditation not applicable

* Not all certifications held by the laboratory are applicable to the results reported in the attached report.

* Accreditation is only applicable to the test methods specified on each scope of accreditation held by Pace Analytical.

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A132

Internal Transfer Chain of Custody

Pace Analytical®
www.pacelabs.com

State of Origin: IL
Cert. Needed: [X] YES [ ] NO

GD04853 **Workorder Name:** VISTRA - NEWTON **Owner Received Date:** 4/28/2023 **Results Requ By:** 5/15/2023

Report To:	Subcontract To:
Gail Schindler Pace Analytical - IL/MO 2231 W. Altorfer Drive Peoria, IL 61615 800-752-6651	Pace Analytical - Mt Juliet 12065 Lebanon Rd Mt Juliet TN 37122

Item	Sample ID	Sample Type	Collect Date/Time	Lab ID	Matrix	Preserved Containers	Requested Analysis: Radium 226	Requested Analysis: Radium 228	LAB USE ONLY
1	APW02	GRAB	4/27/2023 12:17	GD04853-01	GW		X	X	-01
2	APW05	GRAB	4/27/2023 12:40	GD04853-02	GW		X	X	-02
3	APW07	GRAB	4/27/2023 10:35	GD04853-03	GW		X	X	-03
4	APW09	GRAB	4/27/2023 14:05	GD04853-04	GW		X	X	-04
5	APW10	GRAB	4/27/2023 15:47	GD04853-05	GW		X	X	-05
6	APW13	GRAB	4/27/2023 17:16	GD04853-06	GW		X	X	-06
7	EB-03	GRAB	4/27/2023 14:35	GD04853-07	DI		X	X	-07

U1d8160 LAB USE ONLY

Transfers		Date/Time	Received By	Date/Time	Comments
1	Camden Bennett	5-2-23 14:42	Harley Balutar	5/3/23 0900	Needs 226, 228 and combined Include QC summary and edd 10 day TAT
2					
3					

Cooler Temperature on Receipt _____ °C | **Custody Seal** Y or N | **Received on Ice** Y or N | **Sample Intact** Y or N

***In order to maintain client confidentiality, location/name of the sampling site, sampler's name and signature may not be provided on this COC document.
This chain of custody is considered complete as is since this information is available in the owner laboratory.

Sample Receipt Checklist
COC Seal Present/Intact: Y N
COC Signed/Accurate: Y N
Bottles arrive intact: Y N
Correct bottles used: Y N
Sufficient volume sent: Y N
RAD Screen <0.5 mR/hr: Y N
If Applicable
VOA Zero Headspace: Y N
Pres.Correct/Check: Y N

16.5±0=16.5 NS A7

6319 5997 8530

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L1618160

Pace Analytical
www.pacelabs.com

Ship to :
Pace Analytical Services, LLC
12065 Lebanon Rd
Mt Juliet TN 37122

(615)758-5858

INTER_LABORATORY WORK ORDER # GD4853
(To be complete by sending lab)

Sending Project No:	GD4853
Receiving Project No:	
Check Box for Consolidated Invoice:	
Date Prepared:	5/2/2023
REQUESTED COMPLETION DATE:	5/15/2023

Sending Region	IR72-IL/MO	Sending Project Mgr.	Gail Schindler
Receiving Region	MT JULIET	External Client	VISTRA - NEWTON
State of Sample Origin	IL	QC Deliverable	**STD Report**

All questions should be addressed to sending project manager.

Requested Reportable Units _____ Report Wet or Dry Weight? _____ Cert Needed: IL

WORK REQUESTED						
Method Description	**Container Type**	**Quantity of**	**Preservative**	**Quantity of**	**Unit Price**	**Amount**
Radium 226		7		7	$100.00	$700.00
Radium 228		7		7	$100.00	$700.00
		1		1		$0.00
					TOTAL	$1,400.00

Special Requirements: Report as 226, 228 & combined 226/228. Include QC summary & edd

Receiving Reqion Department	Acctg. Code	Totals from above	Revenue Allocation	
			Receiving Region (80%)	Client Services Dept.
radiological	38	$1,400.00	$1,120.00	$280.00
		TOTAL	$1,120.00	$280.00

* Custom Revenue Allocation

FOR ANALYTICAL WORK COMPLETED THIS SECTION ALSO

Return Samples to Sending Region: [ ] Yes [X] No

CONFIRMATION OF WORK COMPLETED

Date Completed: _____ Receiving Project Manager: _____

Original sent to the receiving lab - Copy kept at the sending lab.
When work completed: Original sent to the ABM at the receiving laboratory. Copies are made to corporate as needed.

FMT-ALL-C-001 rev.00 24March2009 Page 1 of 1

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Pace Analytical

ANALYTICAL REPORT

June 06, 2023

Pace IR - Peoria, IL

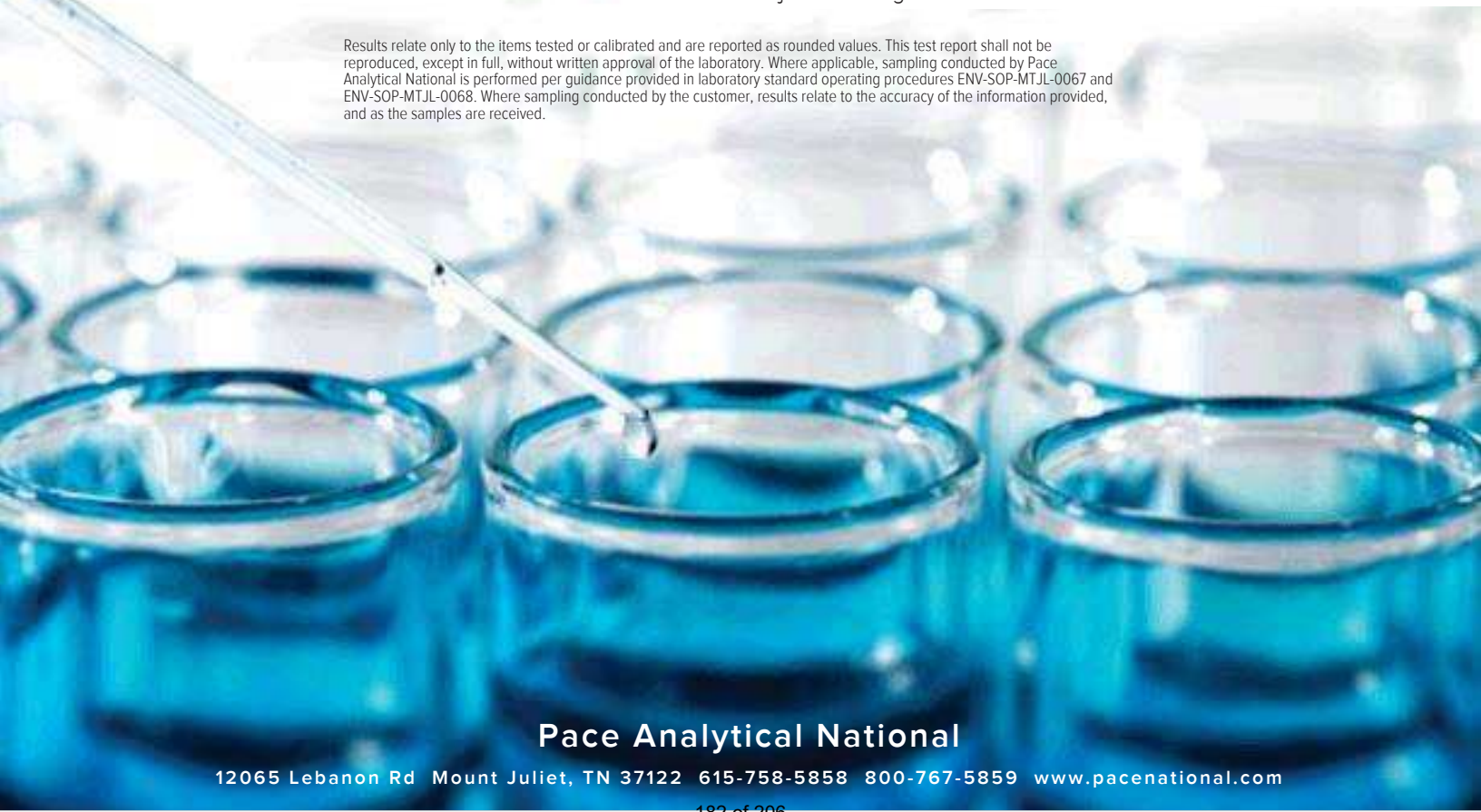
Sample Delivery Group:	L1611864
Samples Received:	05/03/2023
Project Number:	GD04926
Description:	Vistra-Newton
Site:	001
Report To:	Gail Schindler
	2231 W. Altorfer Drive
	Peoria, IL 61615

Entire Report Reviewed By:

Haley Torrence

Haley Torrence
Project Manager

Results relate only to the items tested or calibrated and are reported as rounded values. This test report shall not be reproduced, except in full, without written approval of the laboratory. Where applicable, sampling conducted by Pace Analytical National is performed per guidance provided in laboratory standard operating procedures ENV-SOP-MTJL-0067 and ENV-SOP-MTJL-0068. Where sampling conducted by the customer, results relate to the accuracy of the information provided, and as the samples are received.



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SAMPLE SUMMARY

APW14 L1611864-01 Non-Potable Water

Collected by	Collected date/time	Received date/time
	04/28/23 11:29	05/03/23 09:00

Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061003	1	05/16/23 23:23	05/19/23 14:32	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/24/23 00:32	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 00:32	RGT	Mt. Juliet, TN

APW14 DUP L1611864-02 Non-Potable Water

Collected by	Collected date/time	Received date/time
	04/28/23 11:29	05/03/23 09:00

Method	Batch	Dilution	Preparation date/time	Analysis date/time	Analyst	Location
Radiochemistry by Method 904/9320	WG2061735	1	05/17/23 20:19	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method Calculation	WG2058953	1	05/22/23 11:11	05/31/23 08:55	SNR	Mt. Juliet, TN
Radiochemistry by Method SM7500Ra B M	WG2058953	1	05/22/23 11:11	05/24/23 00:32	RGT	Mt. Juliet, TN

CASE NARRATIVE

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All sample aliquots were received at the correct temperature, in the proper containers, with the appropriate preservatives, and within method specified holding times, unless qualified or notated within the report. Where applicable, all MDL (LOD) and RDL (LOQ) values reported for environmental samples have been corrected for the dilution factor used in the analysis. All radiochemical sample results for solids are reported on a dry weight basis with the exception of tritium, carbon-14 and radon, unless wet weight was requested by the client. All Method and Batch Quality Control are within established criteria except where addressed in this case narrative, a non-conformance form or properly qualified within the sample results. By my digital signature below, I affirm to the best of my knowledge, all problems/anomalies observed by the laboratory as having the potential to affect the quality of the data have been identified by the laboratory, and no information or data have been knowingly withheld that would affect the quality of the data.



Haley Torrence
Project Manager

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Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	0.228	J	0.217	0.391	05/19/2023 14:32	WG2061003
(T) Barium	*109*			*30.0-143*	*05/19/2023 14:32*	WG2061003
(T) Yttrium	*108*			*30.0-136*	*05/19/2023 14:32*	WG2061003

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	0.381	J	0.285	0.465	05/24/2023 00:32	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.153	J	0.184	0.252	05/24/2023 00:32	WG2058953
(T) Barium-133	*99.5*			*30.0-143*	*05/24/2023 00:32*	WG2058953

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APW14 DUP SAMPLE RESULTS - 02

Collected date/time: 04/28/23 11:21 L1611864

Radiochemistry by Method 904/9320

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-228	1.28		0.291	0.489	05/31/2023 08:55	WG2061735
(T) Barium	*77.9*			*30.0-143*	*05/31/2023 08:55*	WG2061735
(T) Yttrium	*123*			*30.0-136*	*05/31/2023 08:55*	WG2061735

Radiochemistry by Method Calculation

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
Combined Radium	1.71		0.417	0.584	05/31/2023 08:55	WG2058953

Radiochemistry by Method SM7500Ra B M

Analyte	Result pCi/l	Qualifier	Uncertainty + / -	MDA pCi/l	Analysis Date date / time	Batch
RADIUM-226	0.433		0.299	0.319	05/24/2023 00:32	WG2058953
(T) Barium-133	*96.7*			*30.0-143*	*05/24/2023 00:32*	WG2058953

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Method Blank (MB)

(MB) R3929806-1 05/19/23 14:32

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-228	-0.357	U	0.173	0.324
(T) Barium	*108*		*108*	
(T) Yttrium	*101*		*101*	

L1611854-01 Original Sample (OS) • Duplicate (DUP)

(OS) L1611854-01 05/19/23 14:32 • (DUP) R3929806-5 05/19/23 14:32

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-228	0.267	0.241	0.432	-0.527	0.396	0.432	1	200	1.71	U	20	3
(T) Barium	*109*			*114*	*114*							
(T) Yttrium	*90.0*			*116*	*116*							

Laboratory Control Sample (LCS)

(LCS) R3929806-2 05/19/23 14:32

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-228	5.00	4.97	99.4	80.0-120	
(T) Barium			*116*		
(T) Yttrium			*112*		

L1606733-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1606733-01 05/19/23 14:32 • (MS) R3929806-3 05/19/23 14:32 • (MSD) R3929806-4 05/19/23 14:32

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-228	10.0	0.855	10.4	10.0	95.1	91.7	1	70.0-130			3.34		20
(T) Barium		*121*			*120*	*116*							
(T) Yttrium		*108*			*111*	*98.4*							

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Method Blank (MB)

(MB) R3932968-2 05/31/23 08:55

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / -	MB MDA pCi/l
Radium-228	0.510		0.175	0.303
(T) Barium	*80.6*		*80.6*	
(T) Yttrium	*117*		*117*	

L1611866-05 Original Sample (OS) • Duplicate (DUP)

(OS) L1611866-05 05/31/23 08:55 • (DUP) R3932968-5 05/31/23 08:55

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-228	-1.05	0.345	0.659	-1.23	0.448	0.659	1	0.000	0.313	U	20	3
(T) Barium	*85.3*			*81.0*	*81.0*							
(T) Yttrium	*127*			*143*	*143*					C1		

Laboratory Control Sample (LCS)

(LCS) R3932968-1 05/26/23 09:50

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-228	5.00	5.89	118	80.0-120	
(T) Barium			*94.2*		
(T) Yttrium			*74.8*		

L1607413-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1607413-01 05/31/23 08:55 • (MS) R3932968-3 05/31/23 08:55 • (MSD) R3932968-4 05/31/23 08:55

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-228	10.0	4.03	11.0	11.8	69.2	77.2	1	70.0-130	J6		7.05		20
(T) Barium		*80.5*			*88.9*	*84.4*							
(T) Yttrium		*87.6*			*117*	*116*							

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Method Blank (MB)

(MB) R3929001-1 05/24/23 00:32

Analyte	MB Result pCi/l	MB Qualifier	MB Uncertainty + / - pCi/l	MB MDA pCi/l
Radium-226	-0.0131	U	0.0300	0.0654
(T) Barium-133	*72.0*		*72.0*	

L1611866-07 Original Sample (OS) • Duplicate (DUP)

(OS) L1611866-07 05/24/23 13:18 • (DUP) R3929001-5 05/24/23 13:18

Analyte	Original Result pCi/l	Original Uncertainty + / -	Original MDA pCi/l	DUP Result pCi/l	DUP Uncertainty + / -	DUP MDA pCi/l	Dilution	DUP RPD %	DUP RER	DUP Qualifier	DUP RPD Limits %	DUP RER Limit
Radium-226	0.142	0.140	0.163	0.130	0.254	0.163	1	8.91	0.0417	U	20	3
(T) Barium-133	*100*			*83.2*	*83.2*							

Laboratory Control Sample (LCS)

(LCS) R3929001-2 05/24/23 13:18

Analyte	Spike Amount pCi/l	LCS Result pCi/l	LCS Rec. %	Rec. Limits %	LCS Qualifier
Radium-226	5.01	5.10	102	80.0-120	
(T) Barium-133			*94.0*		

L1611864-01 Original Sample (OS) • Matrix Spike (MS) • Matrix Spike Duplicate (MSD)

(OS) L1611864-01 05/24/23 00:32 • (MS) R3929001-3 05/24/23 13:18 • (MSD) R3929001-4 05/24/23 13:18

Analyte	Spike Amount pCi/l	Original Result pCi/l	MS Result pCi/l	MSD Result pCi/l	MS Rec. %	MSD Rec. %	Dilution	Rec. Limits %	MS Qualifier	MSD Qualifier	RPD %	MS RER	RPD Limits %
Radium-226	20.0	0.153	19.5	18.2	96.6	90.2	1	75.0-125			6.74		20
(T) Barium-133		*99.5*			*97.5*	*94.4*							

1 Cp
2 Tc
3 Ss
4 Cn
5 Sr
6 Qc
7 Gl
8 Al
9 Sc

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Guide to Reading and Understanding Your Laboratory Report

The information below is designed to better explain the various terms used in your report of analytical results from the Laboratory. This is not intended as a comprehensive explanation, and if you have additional questions please contact your project representative.

Results Disclaimer - Information that may be provided by the customer, and contained within this report, include Permit Limits, Project Name, Sample ID, Sample Matrix, Sample Preservation, Field Blanks, Field Spikes, Field Duplicates, On-Site Data, Sampling Collection Dates/Times, and Sampling Location. Results relate to the accuracy of this information provided, and as the samples are received.

Abbreviations and Definitions

MDA	Minimum Detectable Activity.
Rec.	Recovery.
RER	Replicate Error Ratio.
RPD	Relative Percent Difference.
SDG	Sample Delivery Group.
(T)	Tracer - A radioisotope of known concentration added to a solution of chemically equivalent radioisotopes at a known concentration to assist in monitoring the yield of the chemical separation.
Analyte	The name of the particular compound or analysis performed. Some Analyses and Methods will have multiple analytes reported.
Dilution	If the sample matrix contains an interfering material, the sample preparation volume or weight values differ from the standard, or if concentrations of analytes in the sample are higher than the highest limit of concentration that the laboratory can accurately report, the sample may be diluted for analysis. If a value different than 1 is used in this field, the result reported has already been corrected for this factor.
Limits	These are the target % recovery ranges or % difference value that the laboratory has historically determined as normal for the method and analyte being reported. Successful QC Sample analysis will target all analytes recovered or duplicated within these ranges.
Original Sample	The non-spiked sample in the prep batch used to determine the Relative Percent Difference (RPD) from a quality control sample. The Original Sample may not be included within the reported SDG.
Qualifier	This column provides a letter and/or number designation that corresponds to additional information concerning the result reported. If a Qualifier is present, a definition per Qualifier is provided within the Glossary and Definitions page and potentially a discussion of possible implications of the Qualifier in the Case Narrative if applicable.
Result	The actual analytical final result (corrected for any sample specific characteristics) reported for your sample. If there was no measurable result returned for a specific analyte, the result in this column may state “ND” (Not Detected) or “BDL” (Below Detectable Levels). The information in the results column should always be accompanied by either an MDL (Method Detection Limit) or RDL (Reporting Detection Limit) that defines the lowest value that the laboratory could detect or report for this analyte.
Uncertainty (Radiochemistry)	Confidence level of 2 sigma.
Case Narrative (Cn)	A brief discussion about the included sample results, including a discussion of any non-conformances to protocol observed either at sample receipt by the laboratory from the field or during the analytical process. If present, there will be a section in the Case Narrative to discuss the meaning of any data qualifiers used in the report.
Quality Control Summary (Qc)	This section of the report includes the results of the laboratory quality control analyses required by procedure or analytical methods to assist in evaluating the validity of the results reported for your samples. These analyses are not being performed on your samples typically, but on laboratory generated material.
Sample Chain of Custody (Sc)	This is the document created in the field when your samples were initially collected. This is used to verify the time and date of collection, the person collecting the samples, and the analyses that the laboratory is requested to perform. This chain of custody also documents all persons (excluding commercial shippers) that have had control or possession of the samples from the time of collection until delivery to the laboratory for analysis.
Sample Results (Sr)	This section of your report will provide the results of all testing performed on your samples. These results are provided by sample ID and are separated by the analyses performed on each sample. The header line of each analysis section for each sample will provide the name and method number for the analysis reported.
Sample Summary (Ss)	This section of the Analytical Report defines the specific analyses performed for each sample ID, including the dates and times of preparation and/or analysis.

Qualifier	Description
C1	Tracer recovery limits have been exceeded; values are outside upper control limits.
J	The identification of the analyte is acceptable; the reported value is an estimate.
J6	The sample matrix interfered with the ability to make any accurate determination; spike value is low.
U	Below Detectable Limits: Indicates that the analyte was not detected.

ACCREDITATIONS & LOCATIONS
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Pace Analytical National 12065 Lebanon Rd Mount Juliet, TN 37122

Alabama	40660	Nebraska	NE-OS-15-05
Alaska	17-026	Nevada	TN000032021-1
Arizona	AZ0612	New Hampshire	2975
Arkansas	88-0469	New Jersey–NELAP	TN002
California	2932	New Mexico [1]	TN00003
Colorado	TN00003	New York	11742
Connecticut	PH-0197	North Carolina	Env375
Florida	E87487	North Carolina [1]	DW21704
Georgia	NELAP	North Carolina [3]	41
Georgia [1]	923	North Dakota	R-140
Idaho	TN00003	Ohio–VAP	CL0069
Illinois	200008	Oklahoma	9915
Indiana	C-TN-01	Oregon	TN200002
Iowa	364	Pennsylvania	68-02979
Kansas	E-10277	Rhode Island	LAO000356
Kentucky [1 6]	KY90010	South Carolina	84004002
Kentucky [2]	16	South Dakota	n/a
Louisiana	AI30792	Tennessee [1 4]	2006
Louisiana	LA018	Texas	T104704245-20-18
Maine	TN00003	Texas [5]	LAB0152
Maryland	324	Utah	TN000032021-11
Massachusetts	M-TN003	Vermont	VT2006
Michigan	9958	Virginia	110033
Minnesota	047-999-395	Washington	C847
Mississippi	TN00003	West Virginia	233
Missouri	340	Wisconsin	998093910
Montana	CERT0086	Wyoming	A2LA
A2LA – ISO 17025	1461.01	AIHA-LAP,LLC EMLAP	100789
A2LA – ISO 17025 [5]	1461.02	DOD	1461.01
Canada	1461.01	USDA	P330-15-00234
EPA–Crypto	TN00003		

[1] Drinking Water [2] Underground Storage Tanks [3] Aquatic Toxicity [4] Chemical/Microbiological [5] Mold [6] Wastewater n/a Accreditation not applicable

* Not all certifications held by the laboratory are applicable to the results reported in the attached report.

* Accreditation is only applicable to the test methods specified on each scope of accreditation held by Pace Analytical.

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A131

Internal Transfer Chain of Custody

Pace Analytical
www.pacelabs.com

State of Origin: IL
Cert. Needed: [X] YES [ ] NO

GD04926 **Workorder Name:** VISTRA - NEWTON

Owner Received Date: 4/29/2023

Results Requ By: 5/15/2023

Report To:	Subcontract To:
Gail Schindler Pace Analytical - IL/MO 2231 W. Altorfer Drive Peoria, IL 61615 800-752-6651	Pace Analytical - Mt Juliet 12065 Lebanon Rd Mt Juliet TN 37122

Item	Sample ID	Sample Type	Collect Date/Time	Lab ID	Matrix	Preserved Containers	Requested Analysis: Radium 226	Requested Analysis: Radium 228	LAB USE ONLY
1	APW14	GRAB	4/28/2023 11:29	GD04926-01	GW		X	X	4618164
2	APW14 DUP	GRAB	4/28/2023 11:29	GD04926-02	GW		X	X	

Transfers	3/14/2023 14:31	Date/Time	Received By	Date/Time	Comments
1	Camden Bennett	5-2-23 14:42	Hanley Baltz	5/3/23 0900	Needs 226, 228 and combined Include QC summary and edd 10 day TAT
2					
3					

Cooler Temperature on Receipt _____ °C | **Custody Seal** Y or N | **Received on Ice** Y or N | **Sample Intact** Y or N

***In order to maintain client confidentiality, location/name of the sampling site, sampler's name and signature may not be provided on this COC document.
This chain of custody is considered complete as is since this information is available in the owner laboratory.

Sample Receipt Checklist

		If Applicable	
COC Seal Present/Intact:	Y N	VOA Zero Headspace:	Y N
COC Signed/Accurate:	Y N	Pres.Correct/Check:	Y N
Bottles arrive intact:	Y N		
Correct bottles used:	Y N		
Sufficient volume sent:	Y N		
RAD Screen <0.5 mR/hr:	Y N		

18.8 ± 0 = 18.8 NS AT

6319 5997 8493

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L1618864

Pace Analytical
www.pacelabs.com

Ship to :
Pace Analytical Services, LLC
12065 Lebanon Rd
Mt Juliet TN 37122

(615)758-5858

INTER_LABORATORY WORK ORDER # GD04926
(To be complete by sending lab)

Sending Project No:	GD04926
Receiving Project No:	
Check Box for Consolidated Invoice:	
Date Prepared:	5/2/2023
REQUESTED COMPLETION DATE:	5/15/2023

Sending Region	IR72-IL/MO	Sending Project Mgr.	Gail Schindler
Receiving Region	MT JULIET	External Client	VISTRA - NEWTON
State of Sample Origin	IL	QC Deliverable	**STD Report**

All questions should be addressed to sending project manager.

Requested Reportable Units _____ Report Wet or Dry Weight? _____ Cert Needed: IL

WORK REQUESTED						
Method Description	**Container Type**	**Quantity of**	**Preservative**	**Quantity of**	**Unit Price**	**Amount**
Radium 226		2		2	$100.00	$200.00
Radium 228		2		2	$100.00	$200.00
		1		1		$0.00
					TOTAL	$400.00

Special Requirements: Report as 226, 228 & combined 226/228. Include QC summary & edd

Receiving Region Department	Acctg. Code	Totals from above	Revenue Allocation	
			Receiving Region (80%)	Client Services Dept.
radiological	38	$400.00	$320.00	$80.00
* Custom Revenue Allocation		TOTAL	$320.00	$80.00

FOR ANALYTICAL WORK COMPLETED THIS SECTION ALSO

Return Samples to Sending Region: [ ] Yes [X] No

CONFIRMATION OF WORK COMPLETED

Date Completed: _____ Receiving Project Manager: _____

Original sent to the receiving lab - Copy kept at the sending lab.
When work completed: Original sent to the ABM at the receiving laboratory. Copies are made to corporate as needed.

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~~GD04461~~ VMW
GD04486
VMW 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test ↓ Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213																								
2	NEW_A214																								
3	NEW_A215																								
4	NEW_APW02																								
5	NEW_APW03			4/25/23	1326		11	X	X	X															
6	NEW_APW04			4/25/23	1642		11	X	X	X															
7	NEW_APW05																								
8	NEW_APW05#S																								
9	NEW_APW06																								
10	NEW_APW07																								
11	NEW_APW08																								
12	NEW_APW09																								
13	NEW_APW10																								
14	NEW_APW11																								
15	NEW_APW12																								
16	NEW_APW13																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS			
NEW-23Q2 Rev 0		4/26/23	1706		4-26-23	1020				
		4-26-23	1330		4-26-23	1330	1.5	Y	N	Y

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Pemberton
SIGNATURE of SAMPLER: DATE Signed (MM/DD/YY): 04/25/23

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

~~4-26~~ ~~1020~~ EMS 5-3-23

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GD04486
VMW 4-26-23

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company: Vistra Corp
Address: 13498 E. 900th St
Email To: Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911 Fax:
Requested Due Date/TAT: 10 day

Section B Required Project Information:

Report To: Brian Voelker
Copy To: Jason Stuckey
Purchase Order No.:
Project Name:
Project Number: 2285

Section C Invoice Information:

Attention: Jason Stuckey
Company Name: Vistra Corp
Address: see Section A
Quote Reference:
Project Manager:
Profile #:

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_APW14																								
2	NEW_APW15																								
3	NEW_APW16			4/25/23	1326		22	X	X	X															
4	NEW_APW17			4/25/23	1650		11	X	X	X															
5	NEW_APW18			4/25/23	1503		11	X	X	X															
6	NEW_G104			4/25/23	1652		8	X	X	X	X														
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106			4/25/23	1131		4	X	X	X	X														
11	9/26/23 ~~NEW_G108~~ EB-01			4/25/23	1715																				
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

Requested Analysis Filtered (Y/N)

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0		4/26/23	0706		4-26-23	1020
		4-26-23	1330		4-26-23	1330

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Robertson
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 04/25/2023

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
1.5	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

6D04746 ge

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Page: 1 of 6

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213																								
2	NEW_A214																								
3	NEW_A215			4/26/23	1640		9	X	X	X	X	X													
4	NEW_APW02																								
5	NEW_APW03																								
6	NEW_APW04																								
7	NEW_APW05S 95 4-27-23			4/26/23	1740		11	X	X	X															
8	NEW_APW05#S																								
9	NEW_APW06			4/26/23	1600		11	X	X	X															
10	NEW_APW07																								
11	NEW_APW08			4/26/23	1211		11	X	X	X															
12	NEW_APW09																								
13	NEW_APW10																								
14	NEW_APW11			4/26/23	1543		11	X	X	X															
15	NEW_APW12			4/26/23	1356		11	X	X	X															
16	NEW_APW13																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph R Red	4/27/23	713	[signature]	4-27	1030
	[signature]	4-27	1426	[signature]	4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: [signature]

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.5	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Requested Analysis Filtered (Y/N) Y/N	Analysis Test ↓ NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_APW14																								
2	NEW_APW15			4/26/23	1723		11	X	X	X															
3	NEW_APW16																								
4	NEW_APW17																								
5	NEW_APW18																								
6	NEW_G104																								
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106																								
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph R Reed	4/27/23	1030		4-27	1030
		4-27	1420		4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: James David

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS			
Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.5	Y	N	Y

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_YSG02 DTW																								
2	NEW_YSW_S101			4/26/23	1803		9	X	X	X															
3	NEW_YSW_S102			4/26/23	1743		9	X	X	X															
4	6/6/23 EB-02			4/26/23	1630																				
5																									
6																									
7																									
8																									
9																									
10																									
11																									
12																									
13																									
14																									
15																									
16																									

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	Joseph R Reed	4/27/23	1030	[signature]	4-27	1030
	[signature]	4-27	1420	[signature]	4/27/23	14:20

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: James David

SIGNATURE of SAMPLER: [signature]

DATE Signed (MM/DD/YY): 4/26/23

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
0.7	Y	N	Y

courier

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04853-07

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_A213	WT	G	4/27/23	1209		9	X	X	X	X	X													
2	NEW_A214	WT	G	4/27/23	1432		9	X	X	X	X	X													
3	NEW_A215																								
4	NEW_APW02	WT	G	4/27/23	1217		11	X	X	X															
5	NEW_APW03																								
6	NEW_APW04																								
7	NEW_APW05	WT	G	4/27/23	1240		11	X	X	X															
8	NEW_APW05#S																								
9	NEW_APW06																								
10	NEW_APW07	WT	G	4/27/23	1035		11	X	X	X															
11	NEW_APW08																								
12	NEW_APW09	WT	G	4/27/23	1405		11	X	X	X															
13	NEW_APW10	WT	G	4/27/23	1547		11	X	X	X															
14	NEW_APW11																								
15	NEW_APW12																								
16	NEW_APW13	WT	G	4/27/23	1716		11	X	X	X															

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS: Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
NEW-23Q2 Rev 0		4/28/23	0705		4/28/23	0705	5.0		N	
		4/28/23	1245		4/28/23	12:45		T		Y

SAMPLER NAME AND SIGNATURE
PRINT Name of SAMPLER: Aaron Pemberton
SIGNATURE of SAMPLER:
DATE Signed (MM/DD/YY): 04/27/2023

Electronic Filing: Received, Clerk's Office 07/01/2024

CHAIN-OF-CUSTODY / Analytical Request Document

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Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone:	(217) 753-8911
Fax:	
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES | GROUND WATER | DRINKING WATER
UST | RCRA | OTHER

Site Location STATE: IL

Section D Required Client Information

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

SAMPLE ID (A-Z, 0-9 / ,-) Sample IDs MUST BE UNIQUE

Requested Analysis Filtered (Y/N)

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test (Y/N)	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	NEW_LREP_leachate																								
2	NEW_MW34&D																								
3	NEW_MW35&D																								
4	NEW_MW43&D																								
5	NEW_MW46&D																								
6	NEW_R201																								
7	NEW_R202																								
8	NEW_R217&D																								
9	NEW_R219																								
10	NEW_T101	WT	G	4/27/23	1604		9	X	X	X															
11	NEW_T102																								
12	NEW_XPW01_pore	WT	G	4/27/23	1407		10	X	X	X															
13	NEW_XPW02_pore	WT	G	4/27/23	1529		10	X	X	X															
14	NEW_XPW03_pore	WT	G	4/27/23	1700		10	X	X	X															
15	5-2-23 ~~NEW_XPW04_pore~~ EB-03	WT	G	4/27/23	1435		10	X	X	X															
16	NEW_XSG01 - DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME
NEW-23Q2 Rev 0	[signature]	4/28/23	0705	Brendan Glenn	4/28/23	0705
	Brendan Glenn	4/28/23	1245	[signature]	4/28/23	12:45

SAMPLE CONDITIONS

Temp in °C	Received on Ice (Y/N)	Custody Sealed Cooler (Y/N)	Samples Intact (Y/N)
5.0	Y	N	Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Aaron Pemberton

SIGNATURE of SAMPLER: [signature]

DATE Signed (MM/DD/YY): 04/27/23

Electronic Filing: Received, Clerk's Office 07/01/2024

GD04926

gdf

CHAIN-OF-CUSTODY / Analytical Request Document

The Chain-of-Custody is a LEGAL DOCUMENT. All relevant fields must be completed accurately.

Section A Required Client Information:

Company:	Vistra Corp
Address:	13498 E. 900th St
Email To:	Brian.Voelker@VistraCorp.com
Phone: (217) 753-8911	Fax:
Requested Due Date/TAT:	10 day

Section B Required Project Information:

Report To:	Brian Voelker
Copy To:	Jason Stuckey
Purchase Order No.:	
Project Name:	
Project Number:	2285

Section C Invoice Information:

Attention:	Jason Stuckey
Company Name:	Vistra Corp
Address:	see Section A
Quote Reference:	
Project Manager:	
Profile #:	

REGULATORY AGENCY

NPDES GROUND WATER DRINKING WATER
UST RCRA OTHER

Site Location STATE: IL

Section D Required Client Information

SAMPLE ID
(A-Z, 0-9 / ,-)
Sample IDs MUST BE UNIQUE

Valid Matrix Codes

MATRIX	CODE
DRINKING WATER	DW
WATER	WT
WASTE WATER	WW
PRODUCT	P
SOIL/SOLID	SL
OIL	OL
WIPE	WP
AIR	AR
OTHER	OT
TISSUE	TS

ITEM #	SAMPLE ID	MATRIX CODE (see valid codes to left)	SAMPLE TYPE (G=GRAB C=COMP)	COLLECTED DATE	COLLECTED TIME	SAMPLE TEMP AT COLLECTION	# OF CONTAINERS	Preservatives: Unpreserved	H_2SO_4	HNO_3	HCl	NaOH	$Na_2S_2O_3$	Methanol	Other	Analysis Test Y/N	NEW_257_501	NEW_257_502	NEW_811_502	NEW_811_503	NEW_845_501	NEW_NPDES_501	NEW_SUP_000	Residual Chlorine (Y/N)	Project No./ Lab I.D.
1	0/S 5-2-23 NEW_APW14 + dup	WT	G	4/28/23	1129		22																		
2	NEW_APW15																								
3	NEW_APW16																								
4	NEW_APW17																								
5	NEW_APW18																								
6	NEW_G104																								
7	NEW_G104#S DTW																								
8	NEW_G104&D																								
9	NEW_G105																								
10	NEW_G106																								
11	NEW_G108																								
12	NEW_G109 DTW																								
13	NEW_G110 DTW																								
14	NEW_G111 DTW																								
15	NEW_G112 DTW																								
16	NEW_G113 DTW																								

ADDITIONAL COMMENTS	RELINQUISHED BY / AFFILIATION	DATE	TIME	ACCEPTED BY / AFFILIATION	DATE	TIME	SAMPLE CONDITIONS
NEW-23Q2 Rev 0	Joseph R Reed	4/28/23	16:12		4/28/23	16:12	4 / Y / 2 / Y

SAMPLER NAME AND SIGNATURE

PRINT Name of SAMPLER: Joe Reed

SIGNATURE of SAMPLER: Joseph R Reed

DATE Signed (MM/DD/YY): 4/28/23

Temp in °C | Received on Ice (Y/N) | Custody Sealed Cooler (Y/N) | Samples Intact (Y/N)

SAR-3: Depth to Groundwater Measurements
Plant: NEWTON POWER PLANT
Event: PRIMARY ASH POND
NEW 2302
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
A207	NEW_A207	4/24/23	1541	x	36.00	NA	NA	NA	JMD	
A213	NEW_A213		1544	x	18.63				KL	
A214	NEW_A214		1531	x	40.90				KL	
A215	NEW_A215		1527	x	44.03				KL	
G06D	NEW_G006&D		1459	x	28.92				JMD	
G104	NEW_G104		1804	x	4.51				JMD	
G104D	NEW_G104&D		1810	x	50.37				JMD	TD = 89.31
G104S	NEW_G104#S		1806	x	4.68				JMD	TD = 26.04
G105	NEW_G105		1833	x	7.10				JMD	TD = 26.20
G106	NEW_G106		1857	x	20.37				AP	
G109	NEW_G109		1647	x	5.11				JMD	TD = 24.97
G111	NEW_G111		1815	x	5.97				JMD	TD = 22.75
G112	NEW_G112		1823	x	4.38				JMD	TD = 24.62
G113	NEW_G113		1908	x	17.09				JMD	TD = 33.33
G114	NEW_G114		1723	x	13.45				JR	
G114D	NEW_G114&D		1556	x	42.69				JR	
G115	NEW_G115		1612	x	4.04				JR	No Lock, no pump
G116	NEW_G116		1933	x	6.00				JMD	
G117	NEW_G117		1845	x	7.08				JMD	TD = 21.90
G118	NEW_G118		1608	x	6.32				JMD	TD = 22.59
G119	NEW_G119		1654	x	4.10				JMD	TD = 23.85
G120	NEW_G120		1632	x	7.33				JMD	TD = 23.38
G125	NEW_G125		1457	x	2.84				KL	
G128	NEW_G128		~~1531~~ JMD 4/24 1511	x	~~19.75~~ JMD 4/24 3.96				JMD	
G130	NEW_G130		1704	x	4.34				JMD	TD = 22.69
G133	NEW_G133		1658	x	8.84				JMD	TD = 27.32
G136	NEW_G136		1643	x	6.69				JMD	TD = 22.20
G139	NEW_G139		1639	x	6.15				JMD	TD = 23.05
G141	NEW_G141		1515	x	10.99				JMD	TD = 25.16
G201	NEW_G201		1742	x	17.50				JMD	
G202	NEW_G202		1828	x	47.84				JMD	

Electronic Filing: Received, Clerk's Office 07/01/2024

SAR-3: Depth to Groundwater Measurements
Plant: NEWTON POWER PLANT
Unit: PRIMARY ASH POND
Event: NEW CCR

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
G203	NEW_G203	4/24/23	1536	x	41.39	NA	NA	NA	JR	No lock
G208	NEW_G208		1534	x	24.02				JMD	
G217S	NEW_G217#S		1439	x	6.20				KL	
G218	NEW_G218		1839	x	19.78				JMD	
G220	NEW_G220		1525	x	17.03				JMD	
G221	NEW_G221		1521	x	21.34				JMD	
G222	NEW_G222		1518	x	15.13				JMD	
G223	NEW_G223		1515	x	33.13				KL	Well has incorrect sign, says G233
G224	NEW_G224		1503	x	42.56				KL	
G225	NEW_G225		1511	x	7.27				JMD	TD= 24.99
G230	NEW_G230		1500	x	47.99				JR	
G231	NEW_G231		1504	x	47.36				JR	
G232	NEW_G232		1509	x	45.73				JR	
G233	NEW_G233		1516	x	41.67				JR	
G234	NEW_G234		1532	x	43.18				JR	
G48MG	NEW_G048MG		1826	x	18.99				JR	TD= 80.07
L1R	NEW_L1R_leachate		1716	x	52.80				KL	
L201	NEW_L201_leachate		1720	x	13.30				KL	Dry
L202	NEW_L202_leachate		1643	x	15.30				KL	Dry
L203	NEW_L203_leachate		1650	x	9.60				KL	Dry
L204	NEW_L204_leachate		1709	x	15.42				KL	
L205	NEW_L205_leachate		1701	x	0.97				KL	
L301	NEW_L301_leachate		NA	x	NA				JMD	No depth to measure
L302	NEW_L302_leachate		NA	x	NA				JMD	Not a well
M25-1	NEW_M25-1		1556	x	2.15				KL	
M25-2	NEW_M25-2		1557	x	1.42				KL	
M25-3	NEW_M25-3		1558	x	1.63				KL	
M25-4	NEW_M25-4		1559	x	2.43				KL	
M25-5	NEW_M25-5		1601	x	5.67				KL	
M25-6	NEW_M25-6		1602	x	12.28				KL	
M25-7	NEW_M25-7		1602	x	18.52				KL	

SAR-3: Depth to Groundwater Measurements
Plant: NEW
Event: NEW 2302

NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Electronic Filing: Received, Clerk's Office 07/01/2024

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
M26-1	NEW_M26-1	4/24/23	1806	X	2.80	NA	NA	NA	KL	
M26-2	NEW_M26-2		1807	X	23.02				KL	
M26-3	NEW_M26-3		1808	X	23.19				KL	
M26-4	NEW_M26-4		1809	X	NA				KL	Obstruction in well at depth 1.17'
M26-5	NEW_M26-5		1810	X	1.22				KL	
M26-6	NEW_M26-6		1811	X	1.21				KL	
M26-7	NEW_M26-7		1812	X	40.76				KL	
MW31S	NEW_MW31#S		19:35	X	6.00				JMD	TD = 18.69
MW33S	NEW_MW33#S		1600	X	8.32				AP	TD = 29.59
MW34D	NEW_MW34&D		1655	X	14.85				AP	TD = 58.73, unable to close casing
MW35D	NEW_MW35&D		1438	X	26.24				AP	TD = 53.73
MW35S	NEW_MW35#S		1737	X	2.99				JMD	TD = 16.28
MW36S	NEW_MW36#S		1623	X	3.35				AP	TD = 15.49
MW43D	NEW_MW43&D		1812	X	5.73				AP	TD = 40.80
MW46D	NEW_MW46&D		1619	X	16.82				JR	
MW48S	NEW_MW48#S		1833	X	3.52				JR	13.49 = TD
R201	NEW_R201		1445	X	47.56				JR	
R202	NEW_R202		1912	X	47.55					
R216	NEW_R216		1455	X	43.33				KL	
R217D	NEW_R217&D		1444	X	19.15				KL	
R219	NEW_R219		1528	X	20.08				JMD	
T101	NEW_T101		1700	X	5.84				JR	
T102	NEW_T102		1712	X	6.00				JR	
APW02	NEW_APW02				X	21521987				
APW03	NEW_APW03				X	21521988				
APW04	NEW_APW04				X	21503517				
APW05	NEW_APW05				X	21615053				
APW05S	NEW_APW05#S				X	21503536				
APW06	NEW_APW06				X	21615054				
APW07	NEW_APW07				X	21615033				
APW08	NEW_APW08				X	21615032				

SAR-3: DUNYON POWER PLANT
Plant: NEW
Event: NEWTON, IL

Groundwater Measurements

Electronic Filing: Received, Clerk's Office 07/01/2024

Well	Unique ID	Date	Time	Depth to Water, ft bmp		Transducer			Initials	Notes
				Manual	Transducer	Serial No.	Batt %	DL		
APW09	NEW_APW09				X	21522025	NA	NA		
APW10	NEW_APW10				X	21558058				
APW11	NEW_APW11				X	21558059				
APW12	NEW_APW12				X	21503535				
APW13	NEW_APW13				X	21522024				
APW14	NEW_APW14				X	21522035				
APW15	NEW_APW15				X	21522034				
APW16	NEW_APW16				X	21522033				
APW17	NEW_APW17				X	21522023				
APW18	NEW_APW18				X	21522026				
SG02	NEW_YSG02	4/24/23	1444	2.11	X	TBD			AP	
XPW01	NEW_XPW01_pore				X	21503518				
XPW02	NEW_XPW02_pore				X	21522010				
XPW03	NEW_XPW03_pore				X	21503520				
XPW04	NEW_XPW04_pore				X	21503519				
XSG01	NEW_XSG01	4/24/23	1716	534	X	TBD			AP	Staff gauge says 534
MW31D		4/24/23	1936	8.64						TD = 43.20
MW32S			1545	4.93						TD = 22.20
MW32D			1536	15.55						TD = 63.12
MW33D			1557	12.30						TD = 51.71
MW34S			1659	3.58						TD = 18.66
MW36D			1618	7.52						TD = 35.07
MW43S			1812	4.79						TD = 16.54
MW46S			1623	4.28						
MW48D			1831	4.98						TD = 41.54

Lake Levels

4/25/23 11:02 2.15'
4/26/23 8:11 2.19'
4/27/23 17:00 2.20'
4/28/23 7:58 2.17'
5/1/23 15:36 2.05'

G108 - well removed Jan 2023

Electronic Filing: Received, Clerk's Office 07/01/2024

ATTACHMENT C
COMPARISON OF STATISTICAL RESULTS TO BACKGROUND
QUARTER 2 2023

ATTACHMENT C.
COMPARISON OF STATISTICAL RESULTS TO BACKGROUND - QUARTER 2, 2023
845 QUARTERLY REPORT
NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW02	UD	E001	Antimony, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.003	0.003
APW02	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/27/23	10	70	CI around median	0.001	0.059
APW02	UD	E001	Barium, total	mg/L	02/17/21 - 04/27/23	10	0	CB around linear reg	0.00275	0.3
APW02	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW02	UD	E001	Boron, total	mg/L	02/17/21 - 04/27/23	10	0	CI around geomean	0.105	0.26
APW02	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW02	UD	E001	Chloride, total	mg/L	02/17/21 - 04/27/23	10	0	CI around mean	100	52
APW02	UD	E001	Chromium, total	mg/L	02/17/21 - 04/27/23	10	90	Most recent sample	0.004	0.011
APW02	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.002	0.0043
APW02	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.25	0.633
APW02	UD	E001	Lead, total	mg/L	02/17/21 - 04/27/23	10	90	CI around median	0.001	0.0074
APW02	UD	E001	Lithium, total	mg/L	02/17/21 - 04/27/23	10	0	CI around geomean	0.0888	0.03
APW02	UD	E001	Mercury, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.0002	0.0002
APW02	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/27/23	9	67	CI around median	0.001	0.018
APW02	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/27/23	9	0	CI around mean	0.227	6.9
APW02	UD	E001	Selenium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW02	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/27/23	10	0	CI around median	2,900	35.84
APW02	UD	E001	Thallium, total	mg/L	02/17/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW02	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/27/23	16	0	CB around linear reg	5,180	628
APW02	UD	E001	pH (field)	SU	02/17/21 - 04/27/23	16	0	CI around mean	6.6/6.8	6.4/7.8
APW03	UD	E001	Antimony, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.003	0.003
APW03	UD	E001	Arsenic, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.059
APW03	UD	E001	Barium, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	0.0648	0.3
APW03	UD	E001	Beryllium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW03	UD	E001	Boron, total	mg/L	02/18/21 - 04/25/23	10	0	CI around geomean	0.377	0.26
APW03	UD	E001	Cadmium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW03	UD	E001	Chloride, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	7.35	52

ATTACHMENT C.
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NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW03	UD	E001	Chromium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.004	0.011
APW03	UD	E001	Cobalt, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.002	0.0043
APW03	UD	E001	Fluoride, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.25	0.633
APW03	UD	E001	Lead, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.001	0.0074
APW03	UD	E001	Lithium, total	mg/L	02/18/21 - 04/25/23	10	40	CI around median	0.02	0.03
APW03	UD	E001	Mercury, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.0002	0.0002
APW03	UD	E001	Molybdenum, total	mg/L	02/18/21 - 04/25/23	9	11	CI around mean	0.000992	0.018
APW03	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/25/23	9	0	CI around mean	0.123	6.9
APW03	UD	E001	Selenium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW03	UD	E001	Sulfate, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	139	35.84
APW03	UD	E001	Thallium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW03	UD	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/25/23	16	0	CI around mean	628	628
APW03	UD	E001	pH (field)	SU	02/18/21 - 04/25/23	16	0	CI around mean	6.8/7.2	6.4/7.8
APW04	UD	E001	Antimony, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.003	0.003
APW04	UD	E001	Arsenic, total	mg/L	02/18/21 - 04/25/23	10	40	CI around geomean	0.000941	0.059
APW04	UD	E001	Barium, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	0.0181	0.3
APW04	UD	E001	Beryllium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW04	UD	E001	Boron, total	mg/L	02/18/21 - 04/25/23	10	0	CI around median	0.024	0.26
APW04	UD	E001	Cadmium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.001	0.001
APW04	UD	E001	Chloride, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	29.3	52
APW04	UD	E001	Chromium, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.004	0.011
APW04	UD	E001	Cobalt, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.002	0.0043
APW04	UD	E001	Fluoride, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.25	0.633
APW04	UD	E001	Lead, total	mg/L	02/18/21 - 04/25/23	10	60	CI around median	0.001	0.0074
APW04	UD	E001	Lithium, total	mg/L	02/18/21 - 04/25/23	10	30	CI around median	0.02	0.03
APW04	UD	E001	Mercury, total	mg/L	02/18/21 - 04/25/23	10	90	CI around median	0.0002	0.0002
APW04	UD	E001	Molybdenum, total	mg/L	02/18/21 - 04/25/23	9	89	CI around median	0.001	0.018

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PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW04	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/25/23	9	0	CI around mean	0.0207	6.9
APW04	UD	E001	Selenium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW04	UD	E001	Sulfate, total	mg/L	02/18/21 - 04/25/23	10	0	CI around mean	844	35.84
APW04	UD	E001	Thallium, total	mg/L	02/18/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW04	UD	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/25/23	16	0	CI around mean	1,710	628
APW04	UD	E001	pH (field)	SU	02/18/21 - 04/25/23	16	0	CB around linear reg	6.9/8.0	6.4/7.8
APW05S	UD	E001	Antimony, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.003	0.003
APW05S	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/26/23	9	33	CI around mean	0.00105	0.059
APW05S	UD	E001	Barium, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	0.048	0.3
APW05S	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.001
APW05S	UD	E001	Boron, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	0.04	0.26
APW05S	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.001	0.001
APW05S	UD	E001	Chloride, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	190	52
APW05S	UD	E001	Chromium, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.004	0.011
APW05S	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/26/23	9	33	CI around geomean	0.00185	0.0043
APW05S	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/26/23	9	0	CI around mean	0.349	0.633
APW05S	UD	E001	Lead, total	mg/L	02/17/21 - 04/26/23	9	89	CI around median	0.001	0.0074
APW05S	UD	E001	Lithium, total	mg/L	02/17/21 - 04/26/23	9	0	CI around geomean	0.0332	0.03
APW05S	UD	E001	Mercury, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.0002	0.0002
APW05S	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/26/23	8	0	CB around linear reg	-0.000835	0.018
APW05S	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/26/23	8	0	CI around geomean	0.128	6.9
APW05S	UD	E001	Selenium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.001
APW05S	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/26/23	9	0	CI around median	640	35.84
APW05S	UD	E001	Thallium, total	mg/L	02/17/21 - 04/26/23	9	100	All ND - Last	0.001	0.001
APW05S	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/26/23	9	0	CI around mean	3,450	628
APW05S	UD	E001	pH (field)	SU	02/17/21 - 04/26/23	9	0	CI around mean	6.7/7.0	6.4/7.8
APW07	UA	E001	Antimony, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.003	0.003

ATTACHMENT C.
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NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW07	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.0127	0.059
APW07	UA	E001	Barium, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.465	0.3
APW07	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW07	UA	E001	Boron, total	mg/L	12/15/15 - 04/27/23	22	0	CB around T-S line	0.0841	0.26
APW07	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW07	UA	E001	Chloride, total	mg/L	12/15/15 - 04/27/23	24	0	CB around T-S line	57.5	52
APW07	UA	E001	Chromium, total	mg/L	12/15/15 - 04/27/23	12	75	CI around median	0.004	0.011
APW07	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/27/23	11	82	CI around median	0.002	0.0043
APW07	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/27/23	22	4	CI around mean	0.36	0.633
APW07	UA	E001	Lead, total	mg/L	12/15/15 - 04/27/23	12	58	CI around median	0.001	0.0074
APW07	UA	E001	Lithium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.02	0.03
APW07	UA	E001	Mercury, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.0002	0.0002
APW07	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/27/23	11	0	CB around linear reg	-0.00442	0.018
APW07	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/27/23	12	0	CI around mean	1.31	6.9
APW07	UA	E001	Selenium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.001	0.001
APW07	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/27/23	23	17	CB around T-S line	6.15	35.84
APW07	UA	E001	Thallium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW07	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/27/23	22	0	CI around mean	486	628
APW07	UA	E001	pH (field)	SU	12/15/15 - 04/27/23	24	0	CI around mean	7.1/7.3	6.4/7.8
APW08	UA	E001	Antimony, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.003	0.003
APW08	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/26/23	12	0	CB around linear reg	0.0188	0.059
APW08	UA	E001	Barium, total	mg/L	12/15/15 - 04/26/23	12	0	CB around linear reg	0.444	0.3
APW08	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.001
APW08	UA	E001	Boron, total	mg/L	12/15/15 - 04/26/23	22	0	CI around geomean	0.0816	0.26
APW08	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.001
APW08	UA	E001	Chloride, total	mg/L	12/15/15 - 04/26/23	24	0	CI around mean	54.7	52
APW08	UA	E001	Chromium, total	mg/L	12/15/15 - 04/26/23	12	58	CI around median	0.004	0.011

ATTACHMENT C.
COMPARISON OF STATISTICAL RESULTS TO BACKGROUND - QUARTER 2, 2023
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NEWTON POWER PLANT
PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW08	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/26/23	11	73	CI around median	0.002	0.0043
APW08	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/26/23	22	9	CI around median	0.373	0.633
APW08	UA	E001	Lead, total	mg/L	12/15/15 - 04/26/23	12	50	CI around median	0.001	0.0074
APW08	UA	E001	Lithium, total	mg/L	12/15/15 - 04/26/23	12	67	CI around median	0.01	0.03
APW08	UA	E001	Mercury, total	mg/L	12/15/15 - 04/26/23	12	100	All ND - Last	0.0002	0.0002
APW08	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/26/23	11	0	CI around mean	0.00453	0.018
APW08	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/26/23	12	0	CI around mean	1.03	6.9
APW08	UA	E001	Selenium, total	mg/L	12/15/15 - 04/26/23	12	92	CI around median	0.001	0.001
APW08	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/26/23	23	0	CB around linear reg	44	35.84
APW08	UA	E001	Thallium, total	mg/L	12/15/15 - 04/26/23	11	100	All ND - Last	0.001	0.001
APW08	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/26/23	22	0	CB around linear reg	592	628
APW08	UA	E001	pH (field)	SU	12/15/15 - 04/26/23	25	0	CI around mean	7.2/7.4	6.4/7.8
APW09	UA	E001	Antimony, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.003	0.003
APW09	UA	E001	Arsenic, total	mg/L	12/15/15 - 04/27/23	12	0	CB around linear reg	0.0223	0.059
APW09	UA	E001	Barium, total	mg/L	12/15/15 - 04/27/23	12	0	CI around mean	0.277	0.3
APW09	UA	E001	Beryllium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW09	UA	E001	Boron, total	mg/L	12/15/15 - 04/27/23	22	0	CB around T-S line	0.0809	0.26
APW09	UA	E001	Cadmium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW09	UA	E001	Chloride, total	mg/L	12/15/15 - 04/27/23	24	0	CI around median	95	52
APW09	UA	E001	Chromium, total	mg/L	12/15/15 - 04/27/23	12	67	CB around T-S line	0.004	0.011
APW09	UA	E001	Cobalt, total	mg/L	12/15/15 - 04/27/23	11	91	CI around median	0.002	0.0043
APW09	UA	E001	Fluoride, total	mg/L	12/15/15 - 04/27/23	22	4	CI around mean	0.438	0.633
APW09	UA	E001	Lead, total	mg/L	12/15/15 - 04/27/23	12	50	CI around median	0.001	0.0074
APW09	UA	E001	Lithium, total	mg/L	12/15/15 - 04/27/23	12	100	All ND - Last	0.02	0.03
APW09	UA	E001	Mercury, total	mg/L	12/15/15 - 04/27/23	12	83	CI around median	0.0002	0.0002
APW09	UA	E001	Molybdenum, total	mg/L	12/15/15 - 04/27/23	11	0	CB around linear reg	-0.00854	0.018
APW09	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/15/15 - 04/27/23	12	0	CI around geomean	0.828	6.9

ATTACHMENT C.
COMPARISON OF STATISTICAL RESULTS TO BACKGROUND - QUARTER 2, 2023
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APW09	UA	E001	Selenium, total	mg/L	12/15/15 - 04/27/23	12	92	CI around median	0.001	0.001
APW09	UA	E001	Sulfate, total	mg/L	12/15/15 - 04/27/23	23	9	CI around geomean	4	35.84
APW09	UA	E001	Thallium, total	mg/L	12/15/15 - 04/27/23	11	100	All ND - Last	0.001	0.001
APW09	UA	E001	Total Dissolved Solids	mg/L	12/15/15 - 04/27/23	23	0	CB around T-S line	734	628
APW09	UA	E001	pH (field)	SU	12/15/15 - 04/27/23	24	0	CI around median	7.4/7.5	6.4/7.8
APW10	UA	E001	Antimony, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.003	0.003
APW10	UA	E001	Arsenic, total	mg/L	12/16/15 - 04/27/23	14	0	CI around mean	0.0059	0.059
APW10	UA	E001	Barium, total	mg/L	12/16/15 - 04/27/23	14	0	CI around mean	0.0286	0.3
APW10	UA	E001	Beryllium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.001
APW10	UA	E001	Boron, total	mg/L	12/16/15 - 04/27/23	24	0	CB around linear reg	0.0764	0.26
APW10	UA	E001	Cadmium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.001
APW10	UA	E001	Chloride, total	mg/L	12/16/15 - 04/27/23	25	0	CI around mean	45.4	52
APW10	UA	E001	Chromium, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.004	0.011
APW10	UA	E001	Cobalt, total	mg/L	12/16/15 - 04/27/23	13	92	CI around median	0.002	0.0043
APW10	UA	E001	Fluoride, total	mg/L	12/16/15 - 04/27/23	24	21	CI around mean	0.298	0.633
APW10	UA	E001	Lead, total	mg/L	12/16/15 - 04/27/23	14	86	CI around median	0.001	0.0074
APW10	UA	E001	Lithium, total	mg/L	12/16/15 - 04/27/23	14	7	CB around linear reg	0.0132	0.03
APW10	UA	E001	Mercury, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.0002	0.0002
APW10	UA	E001	Molybdenum, total	mg/L	12/16/15 - 04/27/23	13	0	CB around linear reg	0.00524	0.018
APW10	UA	E001	Radium 226 + Radium 228, total	pCi/L	12/16/15 - 04/27/23	14	0	CI around mean	0.442	6.9
APW10	UA	E001	Selenium, total	mg/L	12/16/15 - 04/27/23	14	100	All ND - Last	0.001	0.001
APW10	UA	E001	Sulfate, total	mg/L	12/16/15 - 04/27/23	25	0	CI around median	410	35.84
APW10	UA	E001	Thallium, total	mg/L	12/16/15 - 04/27/23	13	100	All ND - Last	0.001	0.001
APW10	UA	E001	Total Dissolved Solids	mg/L	12/16/15 - 04/27/23	26	0	CB around linear reg	1,030	628
APW10	UA	E001	pH (field)	SU	12/16/15 - 04/27/23	27	0	CB around linear reg	7.2/7.5	6.4/7.8
APW11	UA	E001	Antimony, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.003	0.003
APW11	UA	E001	Arsenic, total	mg/L	02/18/21 - 04/26/23	10	0	CI around mean	0.0015	0.059

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APW11	UA	E001	Barium, total	mg/L	02/18/21 - 04/26/23	10	0	CB around T-S line	-0.566	0.3
APW11	UA	E001	Beryllium, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW11	UA	E001	Boron, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	0.063	0.26
APW11	UA	E001	Cadmium, total	mg/L	02/18/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW11	UA	E001	Chloride, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	26	52
APW11	UA	E001	Chromium, total	mg/L	02/18/21 - 04/26/23	10	70	CI around median	0.004	0.011
APW11	UA	E001	Cobalt, total	mg/L	02/18/21 - 04/26/23	10	70	CI around median	0.002	0.0043
APW11	UA	E001	Fluoride, total	mg/L	02/18/21 - 04/26/23	10	50	CI around geomean	0.245	0.633
APW11	UA	E001	Lead, total	mg/L	02/18/21 - 04/26/23	10	60	CI around median	0.001	0.0074
APW11	UA	E001	Lithium, total	mg/L	02/18/21 - 04/26/23	10	10	CI around mean	0.0175	0.03
APW11	UA	E001	Mercury, total	mg/L	02/18/21 - 04/26/23	10	80	CI around median	0.0002	0.0002
APW11	UA	E001	Molybdenum, total	mg/L	02/18/21 - 04/26/23	9	0	CB around T-S line	-0.0661	0.018
APW11	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/18/21 - 04/26/23	9	0	CI around mean	0.424	6.9
APW11	UA	E001	Selenium, total	mg/L	02/18/21 - 04/26/23	10	80	CI around median	0.001	0.001
APW11	UA	E001	Sulfate, total	mg/L	02/18/21 - 04/26/23	10	0	CI around median	260	35.84
APW11	UA	E001	Thallium, total	mg/L	02/18/21 - 04/26/23	10	90	CI around median	0.001	0.001
APW11	UA	E001	Total Dissolved Solids	mg/L	02/18/21 - 04/26/23	10	0	CI around mean	809	628
APW11	UA	E001	pH (field)	SU	02/18/21 - 04/26/23	10	0	CI around median	6.6/7.2	6.4/7.8
APW12	UD	E001	Antimony, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.003	0.003
APW12	UD	E001	Arsenic, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	0.00155	0.059
APW12	UD	E001	Barium, total	mg/L	02/17/21 - 04/26/23	10	0	CB around linear reg	0.0133	0.3
APW12	UD	E001	Beryllium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW12	UD	E001	Boron, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	0.18	0.26
APW12	UD	E001	Cadmium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW12	UD	E001	Chloride, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	21.3	52
APW12	UD	E001	Chromium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.004	0.011
APW12	UD	E001	Cobalt, total	mg/L	02/17/21 - 04/26/23	10	20	CB around linear reg	-0.00198	0.0043

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APW12	UD	E001	Fluoride, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.25	0.633
APW12	UD	E001	Lead, total	mg/L	02/17/21 - 04/26/23	10	90	CI around median	0.001	0.0074
APW12	UD	E001	Lithium, total	mg/L	02/17/21 - 04/26/23	10	0	CI around geomean	0.0244	0.03
APW12	UD	E001	Mercury, total	mg/L	02/17/21 - 04/26/23	10	90	CI around median	0.0002	0.0002
APW12	UD	E001	Molybdenum, total	mg/L	02/17/21 - 04/26/23	9	44	CI around geomean	0.000964	0.018
APW12	UD	E001	Radium 226 + Radium 228, total	pCi/L	02/17/21 - 04/26/23	9	0	CI around geomean	0.14	6.9
APW12	UD	E001	Selenium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW12	UD	E001	Sulfate, total	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	253	35.84
APW12	UD	E001	Thallium, total	mg/L	02/17/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW12	UD	E001	Total Dissolved Solids	mg/L	02/17/21 - 04/26/23	10	0	CI around mean	1,160	628
APW12	UD	E001	pH (field)	SU	02/17/21 - 04/26/23	10	0	CI around mean	6.2/6.6	6.4/7.8
APW13	UA	E001	Antimony, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.003	0.003
APW13	UA	E001	Arsenic, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.00314	0.059
APW13	UA	E001	Barium, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.05	0.3
APW13	UA	E001	Beryllium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW13	UA	E001	Boron, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.105	0.26
APW13	UA	E001	Cadmium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW13	UA	E001	Chloride, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	46.2	52
APW13	UA	E001	Chromium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.004	0.011
APW13	UA	E001	Cobalt, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.002	0.0043
APW13	UA	E001	Fluoride, total	mg/L	02/22/21 - 04/27/23	10	10	CI around mean	0.285	0.633
APW13	UA	E001	Lead, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.0074
APW13	UA	E001	Lithium, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	0.0262	0.03
APW13	UA	E001	Mercury, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.0002	0.0002
APW13	UA	E001	Molybdenum, total	mg/L	02/22/21 - 04/27/23	9	0	CB around linear reg	-0.00498	0.018
APW13	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/22/21 - 04/27/23	9	0	CI around mean	0.245	6.9
APW13	UA	E001	Selenium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.001

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APW13	UA	E001	Sulfate, total	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	210	35.84
APW13	UA	E001	Thallium, total	mg/L	02/22/21 - 04/27/23	10	100	All ND - Last	0.001	0.001
APW13	UA	E001	Total Dissolved Solids	mg/L	02/22/21 - 04/27/23	10	0	CI around mean	801	628
APW13	UA	E001	pH (field)	SU	02/22/21 - 04/27/23	10	0	CI around median	7.1/7.3	6.4/7.8
APW14	UA	E001	Antimony, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.003	0.003
APW14	UA	E001	Arsenic, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.00506	0.059
APW14	UA	E001	Barium, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.0752	0.3
APW14	UA	E001	Beryllium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.001
APW14	UA	E001	Boron, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	0.0949	0.26
APW14	UA	E001	Cadmium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.001
APW14	UA	E001	Chloride, total	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	41.8	52
APW14	UA	E001	Chromium, total	mg/L	02/22/21 - 04/28/23	10	90	CI around median	0.004	0.011
APW14	UA	E001	Cobalt, total	mg/L	02/22/21 - 04/28/23	10	90	CI around median	0.002	0.0043
APW14	UA	E001	Fluoride, total	mg/L	02/22/21 - 04/28/23	10	30	CI around mean	0.266	0.633
APW14	UA	E001	Lead, total	mg/L	02/22/21 - 04/28/23	10	70	CI around median	0.001	0.0074
APW14	UA	E001	Lithium, total	mg/L	02/22/21 - 04/28/23	10	20	CB around linear reg	-0.00217	0.03
APW14	UA	E001	Mercury, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.0002	0.0002
APW14	UA	E001	Molybdenum, total	mg/L	02/22/21 - 04/28/23	9	0	CB around linear reg	-0.0066	0.018
APW14	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/22/21 - 04/28/23	9	0	CI around mean	0.372	6.9
APW14	UA	E001	Selenium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.001
APW14	UA	E001	Sulfate, total	mg/L	02/22/21 - 04/28/23	10	0	CI around median	320	35.84
APW14	UA	E001	Thallium, total	mg/L	02/22/21 - 04/28/23	10	100	All ND - Last	0.001	0.001
APW14	UA	E001	Total Dissolved Solids	mg/L	02/22/21 - 04/28/23	10	0	CI around mean	892	628
APW14	UA	E001	pH (field)	SU	02/22/21 - 04/28/23	10	0	CI around median	7.3/7.5	6.4/7.8
APW15	UA	E001	Antimony, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.003	0.003
APW15	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.0166	0.059
APW15	UA	E001	Barium, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.559	0.3

ATTACHMENT C.
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APW15	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW15	UA	E001	Boron, total	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	0.128	0.26
APW15	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW15	UA	E001	Chloride, total	mg/L	02/23/21 - 04/26/23	10	0	CI around median	230	52
APW15	UA	E001	Chromium, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.004	0.011
APW15	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.002	0.0043
APW15	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/26/23	10	0	CI around geomean	0.6	0.633
APW15	UA	E001	Lead, total	mg/L	02/23/21 - 04/26/23	10	50	CI around median	0.001	0.0074
APW15	UA	E001	Lithium, total	mg/L	02/23/21 - 04/26/23	10	80	CI around median	0.02	0.03
APW15	UA	E001	Mercury, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.0002	0.0002
APW15	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/26/23	9	0	CI around mean	0.00846	0.018
APW15	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/26/23	9	0	CI around mean	1.5	6.9
APW15	UA	E001	Selenium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW15	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	1	35.84
APW15	UA	E001	Thallium, total	mg/L	02/23/21 - 04/26/23	10	100	All ND - Last	0.001	0.001
APW15	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/26/23	10	0	CI around mean	1,020	628
APW15	UA	E001	pH (field)	SU	02/23/21 - 04/26/23	10	0	CI around median	7.0/7.3	6.4/7.8
APW16	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.003	0.003
APW16	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.00767	0.059
APW16	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CB around linear reg	0.434	0.3
APW16	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW16	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.128	0.26
APW16	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW16	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	66.1	52
APW16	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.004	0.011
APW16	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.002	0.0043
APW16	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.605	0.633

ATTACHMENT C.
COMPARISON OF STATISTICAL RESULTS TO BACKGROUND - QUARTER 2, 2023
845 QUARTERLY REPORT
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PRIMARY ASH POND
NEWTON, IL

Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW16	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.0074
APW16	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.03
APW16	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.0002	0.0002
APW16	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	44	CB around linear reg	-0.00408	0.018
APW16	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around geomean	1.22	6.9
APW16	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW16	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	1	35.84
APW16	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW16	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around median	690	628
APW16	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.2/7.6	6.4/7.8
APW17	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.003	0.003
APW17	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	0	CB around linear reg	0.0181	0.059
APW17	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.565	0.3
APW17	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW17	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.0839	0.26
APW17	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW17	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	43.9	52
APW17	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.004	0.011
APW17	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.002	0.0043
APW17	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.394	0.633
APW17	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.0074
APW17	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.03
APW17	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.0002	0.0002
APW17	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	0	CI around median	0.0048	0.018
APW17	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around mean	0.644	6.9
APW17	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW17	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	10	CI around mean	26.7	35.84

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Well ID	HSU	Event	Parameter	Units	Date Range	Sample Count	Percent ND	Statistical Calculation	Statistical Result	Background
APW17	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.001	0.001
APW17	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	631	628
APW17	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.3/7.6	6.4/7.8
APW18	UA	E001	Antimony, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.003	0.003
APW18	UA	E001	Arsenic, total	mg/L	02/23/21 - 04/25/23	10	10	CI around mean	0.00144	0.059
APW18	UA	E001	Barium, total	mg/L	02/23/21 - 04/25/23	10	0	CI around median	0.33	0.3
APW18	UA	E001	Beryllium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.001
APW18	UA	E001	Boron, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.103	0.26
APW18	UA	E001	Cadmium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.001
APW18	UA	E001	Chloride, total	mg/L	02/23/21 - 04/25/23	10	0	CB around T-S line	-243	52
APW18	UA	E001	Chromium, total	mg/L	02/23/21 - 04/25/23	10	70	CI around median	0.004	0.011
APW18	UA	E001	Cobalt, total	mg/L	02/23/21 - 04/25/23	10	70	CI around median	0.002	0.0043
APW18	UA	E001	Fluoride, total	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	0.677	0.633
APW18	UA	E001	Lead, total	mg/L	02/23/21 - 04/25/23	10	50	CB around linear reg	-0.00473	0.0074
APW18	UA	E001	Lithium, total	mg/L	02/23/21 - 04/25/23	10	100	All ND - Last	0.02	0.03
APW18	UA	E001	Mercury, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.0002	0.0002
APW18	UA	E001	Molybdenum, total	mg/L	02/23/21 - 04/25/23	9	0	CB around linear reg	-0.0288	0.018
APW18	UA	E001	Radium 226 + Radium 228, total	pCi/L	02/23/21 - 04/25/23	9	0	CI around mean	1.38	6.9
APW18	UA	E001	Selenium, total	mg/L	02/23/21 - 04/25/23	10	90	CI around median	0.001	0.001
APW18	UA	E001	Sulfate, total	mg/L	02/23/21 - 04/25/23	10	20	CI around geomean	1.82	35.84
APW18	UA	E001	Thallium, total	mg/L	02/23/21 - 04/25/23	10	80	CI around median	0.001	0.001
APW18	UA	E001	Total Dissolved Solids	mg/L	02/23/21 - 04/25/23	10	0	CI around mean	508	628
APW18	UA	E001	pH (field)	SU	02/23/21 - 04/25/23	10	0	CI around mean	7.5/7.8	6.4/7.8

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Notes:
Lower Confidence Limit (LCL) or Upper Confidence Limit (UCL) exceeded the statistical background value
HSU = hydrostratigraphic unit:

UA = Uppermost Aquifer

UD = Upper Drift

mg/L = milligrams per liter
ND = non-detect
pCi/L = picocuries per liter
SU = standard units
Sample Count = number of samples from Sampled Date Range used to calculate the Statistical Result
Statistical Calculation = method used to calculate the statistical result:

All ND - Last = All results were below the reporting limit, and the last determined reporting limit is shown

CB around T-S line = Confidence band around Thiel-Sen line

CB around linear reg = Confidence band around linear regression

CI around geomean = Confidence interval around the geometric mean

CI around mean = Confidence interval around the mean

CI around median = Confidence interval around the median

Most recent sample = Result for the most recently collected sample used due to insufficient data

Statistical Result = calculated in accordance with Statistical Analysis Plan using constituent concentrations observed at monitoring well during all sampling events within the specified date range
For pH, the values presented are the lower / upper limits of the background determination

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Appendix 4

Rapps Engineering and Applied Science (Rapps), 1997. Hydrogeologic Investigation and Groundwater Monitoring, CIPS – Newton Power Station Landfill, Jasper County, Illinois, in Newton Power Station Landfill, Application for Landfill Permit.

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5.0 HYDROGEOLOGIC CONSIDERATIONS

An assessment of hydrogeologic conditions at the landfill site has been prepared in conjunction with this application. The results of the hydrogeologic investigation and the proposed groundwater monitoring program are contained in Appendix 5.0, (Application Volume III). The required groundwater impact assessment is contained in Appendix 5.1, (Application Volume IV).

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VOLUME III
APPENDIX 5.0

HYDROGEOLOGIC INVESTIGATION AND GROUNDWATER MONITORING PROGRAM CIPS - NEWTON POWERSTATION LANDFILL JASPER COUNTY, ILLINOIS

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1.0 INTRODUCTION

1.1 PURPOSE

This hydrogeologic investigation has been completed to characterize the geology and hydrogeology of the proposed Central Illinois Public Service Company (CIPS) Newton Power Station Landfill (Figure 1-1). Currently, a stabilized scrubber sludge landfill (IEPA Site Code #0798080002) is located on the property of the Newton Power Station. The existing landfill has been permitted to close as a Subpart D Facility by September 1997. This investigation presents site-specific data obtained through the completion of approximately 40 borings, 20 monitoring wells, a literature review of existing regional information, and an evaluation of sub-surface data from nearby residential wells. The hydrogeologic investigation demonstrates site suitability for use as a solid waste disposal facility, and was performed in accordance with the requirements of 35 Illinois Administration Code (IAC) Parts 811 and 814.

1.2 SITE LOCATION

The subject facility is situated within CIPS-Newton Power Station property located near Newton, Illinois, in the southwestern portion of Jasper County adjacent to Newton Lake. The site is located in the northwest quarter of Section 26 and the northeast quarter of Section 27, Township 6 North, Range 8 East of the third principal meridian in Jasper County, Illinois. Approximately 40 acres of the site will be used primarily for coal combustion waste disposal. Bordering the site to the south is the Newton Lake Fish and Wildlife Preserve. The Jasper County Prairie Chicken Sanctuary is located to the east of the CIPS property.

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2.0 PHYSICAL ENVIRONMENTAL SETTING

The environmental setting of Jasper County is discussed in this section in order to emphasize the characteristics of the subject site and surrounding area that may affect the potential for contaminant migration from the proposed waste disposal facility.

2.1 CLIMATE

Jasper County has a humid and temperate climate with a normal annual total precipitation of approximately 40 inches. Approximately two-thirds of the precipitation falls from April through September and is produced primarily by thunderstorms, with May having the highest average monthly precipitation. The average annual snowfall for the study area is approximately 15 inches. Figure 2-1 shows the average annual precipitation, snowfall and two-year, 24-hour rainfall for the area.

Evapotranspiration is the sum of water lost from the soil through evaporation and water consumed by vegetation (i.e. transpiration). The Army Corps of Engineers has estimated the average potential evapotranspiration in the Jasper County area to be greater than 30 inches per year (Figure 2-2). Evaporation is directly dependent upon air temperature and absolute humidity, as well as wind intensity. Transpiration, the uptake of water by plants, is dependent upon the type, size, and density of vegetation. The majority of evapotranspiration in humid, temperate climates occurs in the spring and summer, decreasing dramatically in the fall. Evapotranspiration is negligible during the winter (Fetter, 1988).

2.2 PHYSIOGRAPHY

Jasper County is located in the southeastern portion of central Illinois. The subject site as well as all of Jasper County, is located within the Springfield Plain of the Till Plains Section of the Central Lowlands Province (Figure 2-3). The Springfield Plain physiographic province is comprised largely of Illinoian glacial drift (Willman et al., 1975). The region is characterized by relatively flat to gently rolling topography. The uppermost geologic materials consist primarily of unconsolidated eolian, slopewash and fluvial deposits underlain by superglacial and subglacial deposits associated with recent glaciations. The topography of these materials is a function of the underlying bedrock surface on which the materials were deposited, and eolian and fluvial processes which

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have been in effect from their deposition to the present.

The Embarras River and its tributaries drain much of the county and eventually flow into the Wabash River. The southwestern portion of the county, including the subject site, lies within the Little Wabash River Basin (Figure 2-4). Therefore, all surface drainage from the property discharges to the Little Wabash River, which then flows into the Wabash River.

The highest point in Jasper County is at Island Grove at an elevation of 624 feet msl. The lowest elevation, 440 ft msl, is located at the point on the Crawford County line which is intersected by the Embarras River. With a total relief of only 184 feet, the surface features of Jasper County are nominal and reflect the moderate amount of erosional modification to the post-glacial topographic surface.

2.3 GEOLOGY

In general, the geology of Jasper County is characterized by unconsolidated Quaternary deposits overlying Pennsylvanian bedrock. The following subsections provide specific information regarding the thickness and composition of geologic formations in the vicinity of the subject facility.

2.3.1 Bedrock Geology

Figure 2-5 shows the generalized stratigraphic column for the area. Jasper County lies north of the center of the Illinois Basin, which is a "spoon-shaped structure" that trends north-northwest to south-southeast. In Jasper County, approximately 11,000 feet of Paleozoic rocks overlie the Precambrian surface. The Clay City Anticline, which trends north-northeast to south-southwest is located in the eastern portion of Jasper County (Figure 2-6).

The uppermost bedrock in Jasper County is predominantly composed of shales with minor sandstones, underclays, and coals of the Pennsylvanian System (Figure 2-7). The average thickness of the Pennsylvanian System in Jasper County is approximately 2000 feet, but is as little as 900 feet thick in the northeastern part of the county (Figure 2-8). The uppermost bedrock at the subject location and throughout Jasper County consists of limestones and shales of the Mattoon Formation. In Jasper County, the Mattoon Formation ranges from zero to 600 feet in thickness. Figure 2-9 shows that at the subject

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location the thickness of the Mattoon Formation is approximately 600 feet (Willman et al., 1975). Underlying the Mattoon Formation in Jasper County are the Bond and Modesto Formations of the Pennsylvanian System.

Bedrock surface topography in Jasper County is generally characterized by a gentle sloping from northeast to southwest. Bedrock surface elevations range from approximately 400 feet msl to greater than 600 feet msl in Jasper County (Figure 2-10). At the subject location the upper bedrock surface lies at approximately 400 to 450 feet msl.

2.3.2 Quaternary Geology

The Quaternary System includes all unconsolidated sediments, both glacial and non-glacial, that overlie the bedrock. Figure 2-11 shows a general stratigraphic classification of Pleistocene deposits in Illinois. Most of the Quaternary sediments in Jasper County were deposited during two distinct stages of glaciation - the Kansan Stage and the Illinoian Stage (Figure 2-12). Minor deposition also occurred during the Wisconsinan Interglacial Stage, as well as the Recent Stage. Glacial till can be described as an unstratified, poorly-sorted mixture of sand, silt, and clay with some pebbles and cobbles.

The Sangamonian Interglacial Stage includes the period between the Illinoian and Wisconsinan Stages, and is represented as a soil that occurs between Illinoian Age tills and Wisconsinan Age deposits. The Sangamonian Interglacial Stage is characterized by weathering and the accumulation of organic debris on the surface of the Illinoian till. The Wisconsinan Stage is represented in Jasper County by a thin veneer of loess that is widespread and overlies the Illinoian deposits.

The glacial deposits in Jasper County range in thickness from less than 50 feet to greater than 100 feet where drift overlies bedrock valleys (Figure 2-13). The major Quaternary formations present at or near the surface of the subject location are described below.

2.3.2.1 **Banner Formation.** The Banner Formation of the Kansan Stage rests on the bedrock of the Mattoon Formation and underlies the Illinoian deposits at the subject location. This formation consists of clay, till, and sand, and frequently contains wood fragments (Piskin and Bergstrom, 1975). The Banner Formation is present at the subject location and consists of a silty clay till with traces of sand and gravel.

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2.3.2.2 Yarmouth Soil. The Yarmouth Soil of the Yarmouthian Interglacial Stage is described as a weathering interval and organic accumulation separating the Kansan and Illinoian deposits (Willman et al., 1975). The Yarmouth soil does not appear to be present at the site as it was likely removed during advance of the ice sheet(s) during the Illinoian Stage.

2.3.2.3 Glasford Formation. The Glasford Formation of the Liman Substage of the Illinoian Stage is the predominant formation of glacial deposits throughout Jasper County, including the subject location. This formation consists of glacial tills and intercalated outwash deposits of silt, sand, and gravel. The glaciation which formed the deposits of the Glasford Formation represent the southernmost glaciation in the northern hemisphere (Willman and Frye, 1970).

Eight till members of the Glasford Formation have been differentiated on the basis of texture and mineral content. Four members of the Glasford Formation encountered at the subject site consist of the *Smithboro Till Member*, the *Mulberry Grove Member*, the *Vandalia Till Member*, and the *Hagarstown Member*, all of which can be traced throughout much of central and southern Illinois. The Smithboro Till Member underlies the Mulberry Grove Member and can be described as a gray, compact, silty till (Willman et al., 1975). At the subject location the Smithboro Till has a thickness of approximately fifteen feet. Immediately overlying the Smithboro Till Member is the Mulberry Grove Member. The Mulberry Grove is described as a calcareous gray silt with some fine sand and ranges in thickness from three to five feet at the subject location. The Mulberry Grove Member is missing at several locations on the subject property, and varies significantly in texture in borings. Overlying the Mulberry Grove Member is the Vandalia Till Member which can be described as a sandy till that contains thin lenses of silt, sand, and gravel (Willman et al., 1975). Above the Vandalia Till Member lies the Hagarstown Member. Willman et al, 1975, describes the Hagarstown Member as a gravelly till that consists of poorly-sorted gravel, well-sorted gravel, and sand.

2.3.2.4 Sangamon Soil. The Sangamon Soil formed in the Sangamonian interglacial period between the Wisconsinan and Illinoian glacial periods. The Sangamon Soil at the subject location consists of a light brown to gray, silty, sandy clay with some organic material and a trace of pebbles.

2.3.2.5 Peoria Loess. The Peoria Loess of the Woodfordian Substage of the Wisconsinan

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Stage is a wind-blown light yellow to gray silt, often sandy, that is distinguishable from other underlying loess deposits based on its low plasticity. The Peoria Loess is the only Wisconsinan deposit present in Jasper County because the Woodfordian Glaciation covered much of northeastern and east-central Illinois, but did not reach southeastern Illinois and Jasper County. The Peoria Loess can be found in upland areas and along valley walls in most of Illinois outside of the Woodfordian glaciation (Willman et al., 1975).

2.3.2.6 Cahokia Alluvium. The Cahokia Alluvium of the Holocene Stage consists of recent alluvial material found in the floodplains and bottomlands associated with streams and rivers. It is formed in part by the erosion of upland loess and till deposits and thus has a relatively high silt content. The Cahokia Alluvium can be described as poorly sorted silt, clay, and silty sand and locally contains sand and gravel lenses (Willman et al., 1975).

2.3.2.7 Peyton Colluvium. The Peyton Colluvium of the Holocene Stage is a recent slope-wash deposit. Willman et al., 1975 describes the Peyton Colluvium as a poorly-sorted deposit that accumulates on lower slopes and their bases through creep, slopewash, and mudflow.

2.4 SOILS

According to the Soil Survey of Jasper County, Illinois (US Dept. of Agriculture Soil Conservation Service), soil in the vicinity of the subject site consists of two different soil associations. The eastern portion of the site contains soils from the Cisne-Hoyleton-Darmstadt Association, and the Bluford-Wynoose-Atlas Association is located in the western portions of the subject site. A map of the soil associations in Jasper County is included as Figure 2-14.

The Cisne-Hoyleton-Darmstadt Association is found in nearly flat to gently sloping areas that are poorly drained. The soils in this association are silty soils that formed in the loess and underlying glacial deposits. The Bluford-Wynoose-Atlas Association is found in nearly flat to sloping areas that are somewhat poorly drained. The soils in this association are also formed in loess or glacial till. Both soil associations are generally found in upland areas.

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2.5 HYDROGEOLOGY

Potable groundwater supplies in Jasper County can be obtained from either unconsolidated glacial sediments or the underlying Pennsylvanian bedrock. Potable water wells located within glacial deposits in Jasper County typically do not yield enough water for industrial or municipal use. Larger groundwater supplies are usually available from the underlying Pennsylvanian sandstones and limestones. However, glacial deposits generally provide enough water for rural, residential water supplies. Additional groundwater supplies in Jasper County are located within the thick sand and gravel deposits associated with buried bedrock valleys. However, sand and gravel deposits associated with bedrock valleys are not known to exist in the immediate vicinity of the subject site. Discontinuous sand and gravel deposits within the glacial till generally contain water, however these deposits do not constitute a major source of potable groundwater in Jasper County.

Figure 2-15 shows wells within the sand and gravel aquifers present in the bedrock valleys in southwestern Jasper County that have a reasonable chance of obtaining yields of 20 gallons per minute or more. The above referenced figure also illustrates the potential of wells within the sandstone and limestone aquifers near the subject site that have a small chance of obtaining yields of 10 gallons per minute or more.

Included as Attachment A are available Illinois State Geological Survey (ISGS) completion records of potable water wells within a one-mile radius of the subject site. Figure 2-16 is a water well location map delineating water wells located near the subject site, including those wells within a one-mile radius. According to the available ISGS well completion records, nine wells exist within a one-mile radius of the subject site. A further eight wells are located outside this one-mile radius and are also included in Attachment A.

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3.0 HYDROGEOLOGIC INVESTIGATION

3.1 FIELD STUDIES

Approximately 40 exploratory borings and 20 monitoring wells have been completed at the subject site to date. These were completed in a series of five episodes conducted since 1973. Boring logs for the exploratory episodes can be found in Attachment B. Groundwater monitoring well as-built diagrams can be found in Attachment C. Figure 3-1 illustrates the locations of all borings and monitoring wells.

3.2 FINDINGS

The geology of the subject site is characteristic of Jasper County and is similar to that discussed in Section 2.3, with between 100 and 120 feet of Quaternary sediments overlying Pennsylvanian bedrock. The thickness of Quaternary sediments was approximated through site boring logs (see Attachment B).

3.2.1 Bedrock Geology

Pennsylvanian bedrock consists mainly of shales with interbedded sandstones, siltstones, limestones, underclays, and coals. The uppermost bedrock unit at the subject site, as well as most of Jasper County, consists of the Mattoon Formation of the McLeansboro Group of the Pennsylvanian System. The bedrock surface at the subject site ranges in elevation from approximately 423 to 443 feet msl for a total bedrock relief of approximately 20 feet. Numerous deep site borings were completed to bedrock to determine thickness of unconsolidated materials as well as verify upper bedrock lithology. The average thickness of the Mattoon Formation and the Pennsylvanian System in Jasper County is approximately 600 and 2000 feet, respectively (Willman, et. al., 1975).

3.2.2 Quaternary Geology

Unconsolidated deposits at the subject site range in age from Illinoian to Recent, with approximately 100 feet of Quaternary deposits overlying bedrock. In order to establish site stratigraphy and variation of Quaternary deposits, soil borings taken during the past five-phase sub-surface investigations were utilized to create geologic cross sections. In general, the soil borings encountered the following materials, from oldest to youngest: the Banner Formation, the Smithboro Till Member, Mulberry Grove Member, Vandalia

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Till Member, Hagarstown Member, Cahokia Alluvium, Peyton Colluvium, Sangamon Soil and Peoria Loess. Figures 3-3, 3-4, 3-5, and 3-6 are cross sections of the unconsolidated deposits at the subject site. Figure 3-2 is the cross section key. Grain-size distribution results for most of the Quaternary sediments can be found in Attachment D.

Banner Formation: Overlying the Pennsylvanian shale is Kansan till of the Banner Formation. At the subject site, the Banner Formation is approximately 20 to 30 feet thick, and consists of greenish-gray moist silty clay with a trace of sand.

Smithboro Till Member: Overlying the Banner Formation is the Smithboro Till Member of the Glasford Formation. The Smithboro Till Member is approximately 10 to 20 feet thick. Site borings describe the Smithboro Till Member as a gray silty clay with traces of sand and gravel. The Smithboro Till Member is softer, more silty, and is higher in expandable clay mineral clay content than the overlying Vandalia Till (Willman and Frye, 1970).

Mulberry Grove Member: The Mulberry Grove Member is approximately three to five feet thick at the subject site and consists mostly of a gray sandy silt. This unit was deposited in temporary glacial lakes that formed between advancements and retreats of ice sheets that deposited the Vandalia and Smithboro Till Members. Locally, thin sandy layers are present which are indicative of near-shore (beach) environments.

Vandalia Till Member: Site borings describe the Vandalia Till Member as a gray, silty to sandy clay till, with traces of sand and gravel within the matrix. Grain-size distribution analyses completed by Professional Service Industries, Inc., (PSI) show that the Vandalia Till Member varies from 27-32% sand, 42-46% silt, and 26-27% clay. The Vandalia Till is approximately 20 to 60 feet thick at the subject site.

Hagarstown Till Member: Where present, the Hagarstown Member is underlain by the Vandalia Till and overlain by the Sangamon Soil. The contact between the Hagarstown Till and underlying Vandalia Till Member fluctuates between approximately 532 feet to 510 feet msl at the site. The Hagarstown Member is associated with the Vandalia Till, but is less compact, contains less clay sized material and is, therefore, much more permeable. This unit was derived as superglacial sediment thrust to the surface of the ice sheet, and deposited as the glacier melted (Jacobs and Lineback, 1969). At the subject site, the Hagarstown Member varies in thickness from 3 to 24 feet and can be described as a

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reddish-brown silty clay with some sand and gravel. Most of the Hagarstown Member has been highly weathered due to infiltration of oxygenated rainwater.

Sangamon Soil: The Sangamon Soil is present in all borings throughout the subject site. The Sangamon Soil formed as a result of weathering of the upper portion of the Hagarstown Member during the interglacial period between the Illinoian and Wisconsinan glacial stages. The Sangamon Soil ranges in thickness from 2.5 to 5.5 feet, and is described in site borings as a light-brown to light gray silty clay.

Peoria Loess: The Peoria Loess is a wind-blown silt deposit of Woodfordian age that occurs in upland areas and along valley walls in most areas of Illinois outside of Woodfordian Glaciation. It is distinguished from other loessal deposits by its low plasticity. At the subject facility it ranges in thickness from three to nine feet and consists of a brown, mottled gray silty clay.

Peyton Colluvium: This material consists of slope wash deposits that are derived from upland areas at the subject site. The colluvium is a poorly-sorted mixture that consists primarily of silt but also contains sand and clay in smaller amounts. Locally, the Peyton Colluvium can be found on slopes and sides of intermittent streams and drainageways. Where present, the Peyton Colluvium has an approximate maximum thickness of 10 feet.

Cahokia Alluvium: The Cahokia Alluvium consists of recent stream derived deposits typically found in floodplains and channels of rivers and streams. Willman et al., 1975, describes the Cahokia Alluvium as a poorly sorted silt, clay, and silty sand. Locally the Cahokia Alluvium may contain lenses of sand and gravel. On site the Cahokia Alluvium can be found at the base of intermittent streams and drainageways. Where present, the Cahokia Alluvium has an approximate maximum thickness of 10 feet.

3.2.3 Hydrostratigraphic Units

Based on stratigraphic position and hydraulic characteristics, four distinct hydrostratigraphic units have been identified at the subject site. The upper hydrostratigraphic unit, referred to hereafter as the Upper Drift, consists of the combined Peoria Loess, Sangamon Soil, Hagarstown Member, Peyton Colluvium and Cahokia Alluvium (where present). Below the Upper Drift lies the Vandalia Till, which will be referred to as the Vandalia Till Aquitard. Underneath the Vandalia Till Aquitard lies the Mulberry Grove Member, which will be referred to as the Uppermost Aquifer. The lower

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hydrostratigraphic unit which consists of the combined Smithboro Till Member and Banner Formation will be referred to hereafter as the Lower Drift Aquitard. Figures 3-7, 3-8 and 3-9 illustrate the depth to top of the uppermost aquifer, elevation of the top of the uppermost aquifer and elevation of the top of the Vandalia Till Aquitard, respectively.

3.2.4 Hydraulic Conductivity

Seventeen hydraulic conductivity tests were performed at the subject site, both as in-situ field tests and laboratory analyses of site boring samples. The Hvorslev bail-down method was used in determining in-situ field permeabilities for monitoring wells G104D, G105, G106, G115, G116, G119, G139, G201, G203, G204, G205 and G207. Laboratory derived permeability values for borings B-141, B-142 and B-143 were determined using falling head permeameter methods. Table 3-1 lists the wells/borings tested and the conductivity results for the corresponding geologic interval. Results of laboratory and field permeability tests are included in Volume III, Attachment E.

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TABLE 3-1
LABORATORY AND IN-SITU HYDRAULIC CONDUCTIVITY TESTS

WELL/BORING	TESTED INTERVAL	HYDRAULIC CONDUCTIVITY (CM/SEC)	GEOLOGIC UNIT MONITORED
G105	11-26 ft	2.39×10^{-6} (F)	Upper Drift
G106	21-36 ft	7.53×10^{-6} (F)	Upper Drift
G115	8-18 ft	1.42×10^{-5} (F)	Upper Drift
G116	10-20 ft	3.09×10^{-5} (F)	Upper Drift
G119	10-20 ft	6.10×10^{-5} (F)	Upper Drift
G139	10-20 ft	5.14×10^{-5} (F)	Upper Drift
G201	57-67 ft	1.58×10^{-4} (F)	Uppermost Aquifer
G203	60-70 ft	5.14×10^{-3} (F)	Uppermost Aquifer
G204	55.5-64.5 ft	5.99×10^{-3} (F)	Uppermost Aquifer
G205	67-80 ft	2.54×10^{-6} (F)	Uppermost Aquifer
G207	57-70 ft	7.19×10^{-5} (F)	Uppermost Aquifer
B-141 (R)	20-25 ft	1.69×10^{-8} (L)	Vandalia Till Aquitard
B-141	27-28.5 ft	6.34×10^{-9} (L)	Vandalia Till Aquitard
B-142	27.5-30 ft	9.25×10^{-9} (L)	Vandalia Till Aquitard
B-142 (R)	28-32 ft	2.11×10^{-8} (L)	Vandalia Till Aquitard
B-143	21-22.5 ft	9.55×10^{-9} (L)	Vandalia Till Aquitard
G104D	79-87 ft	1.4×10^{-7} (F)	Lower Drift Aquitard

(F) From in-situ field test
(L) From laboratory analysis of site boring samples
(R) Re-molded Sample

Table 3-2 lists the number of tests, range of hydraulic conductivities (K), and the mean K for each hydrostratigraphic unit.

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TABLE 3-2
MEAN HYDRAULIC CONDUCTIVITY (K) VALUES

GEOLOGIC UNIT	# OF VALUES	K RANGE LOW/HIGH (CM/SEC)	MEAN K (CM/SEC)
Upper Drift	6	2.39×10^{-6}/6.10×10^{-3}	2.79×10^{-5}
Re-molded Vandalia Till	2	1.69×10^{-8}/2.11×10^{-8}	1.9×10^{-8}
Vandalia Till	3	9.55×10^{-9}/6.34×10^{-8}	8.38×10^{-9}
Uppermost Aquifer	5	2.54×10^{-6}/5.99×10^{-3}	2.27×10^{-3}
Lower Drift Aquitard	1	1.4×10^{-7}	NA

3.2.5 Field Hydraulic Conductivity Test Methodology

In-situ field conductivity tests were performed using the Hvsorlev bail-down method (Fetter, 1988). This versatile field method is applicable to confined or unconfined conditions. Additionally, both fully and partially penetrating wells can be evaluated as results are only indicative of the screened formation and not the degree of penetration.

A typical field conductivity test consists of the following steps:

1) Measure the depth-to-water from the top of the riser using an electronic water level indicator. Calculate the elevation (above mean sea level) of the static water level using the surveyed top of riser elevation.

2) Depending upon the estimated conductivity of the screened formation, bail (remove) a sufficient amount of water from the well to induce a change in the hydraulic head.

3) Immediately after bailing a sufficient amount of water, measure recovering water levels at timed intervals until levels reach at least 75 percent recovery.

4) The time-drawdown data are plotted as a semilog plot of h/h_o versus time, where

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h is the recovering water level at time t, and h_o is the initial water level (after bailing) at time t=0.

5) If the length of the piezometer is more than eight times the length of the well screen, the following formula applies:

$$K = \frac{r^2 \ln(L/R)}{2LT_o}$$

where:
K = horizontal hydraulic conductivity of the screened interval (in/sec),
r = radius of the well screen (in),
R = radius of well screen (in) for relatively high conductivity materials (> 10^{-4} cm/sec),
= radius of sand pack (in) for relatively low conductivity materials (< 10^{-4} cm/sec),
L = length of well screen (in) for relatively high conductivity materials (> 10^{-4} cm/sec),
= length of sand pack for relatively low conductivity materials (< 10^{-4} cm/sec),
T_o = elapsed time it takes for the water level to rise to 37 percent of the initial change.

3.2.6 Groundwater Flow

Groundwater elevations in the Upper Drift and Uppermost Aquifer were determined from top-of-casing elevation and depth-to-groundwater measurements. Water levels in the Upper Drift range from 512.35 ft msl to 541.51 ft msl (Figure 3-10), groundwater elevations in the Uppermost Aquifer range from 476.85 ft msl to 516.99 ft msl (Figure 3-11). Table 3-3 summarizes groundwater elevations determined from December 1996, January 1997 and February 1997 field measurements.

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TABLE 3-3
GROUNDWATER ELEVATIONS

WELL	UNIT	GROUNDWATER ELEVATIONS		
		12/24/96	01/21/97	02/18/97
G105	Upper Drift	523.82	531.96	NM
G106	Upper Drift	512.35	513.31	NM
G107S	Upper Drift	525.06	NM	NM
G107	Upper Drift	524.92	526.37	NM
G108	Upper Drift	528.12	530.26	NM
G109	Upper Drift	527.92	531.24	NM
G110	Upper Drift	538.41	539.43	NM
G111	Upper Drift	541.51	542.47	NM
G112	Upper Drift	536.46	536.41	NM
G113	Upper Drift	532.90	535.68	NM
G114R	Upper Drift	535.88	539.18	NM
G115	Upper Drift	535.53	538.07	NM
G117	Upper Drift	523.46	523.88	NM
G118	Upper Drift	520.56	525.23	NM
G119	Upper Drift	534.16	534.87	NM
G120	Upper Drift	534.96	535.69	NM
G125A	Upper Drift	518.08	519.25	NM
G130	Upper Drift	529.27	527.17	NM
G133	Upper Drift	535.02	534.87	NM
G136	Upper Drift	532.41	533.46	NM
G139	Upper Drift	529.09	537.76	NM
G201	Uppermost Aquifer	476.85	476.69	477.33
G202	Uppermost Aquifer	493.89	494.10	494.74
G203	Uppermost Aquifer	493.08	494.21	494.83
G204	Vandalia Till Aquitard	516.90	522.17	NM
G205*	Uppermost Aquifer	NM	NM	516.99
G207*	Uppermost Aquifer	NM	NM	494.68

* Wells were not installed before December 1996. NM - Not Measured

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In general, groundwater flow in the Upper Drift is highly localized due to surface interactions and tends to converge along southward dipping drainageways. Groundwater flow in the Uppermost Aquifer is northward, probably as a result of recharge from Newton Lake which lies on the southernmost edge of the site.

The hydraulic gradients at the site were determined from groundwater elevations. The following equation was used:

$$i = \frac{dh}{dl}$$

where: i = hydraulic gradient (unitless)
dh = difference in hydraulic head, and,
dl = horizontal distance between points

Using the above equation, an average horizontal hydraulic gradient was calculated for the Uppermost Aquifer. A hydraulic head difference of 39.66 ft exists between G205 (516.99 ft msl) and G201 (477.33 ft msl) with a horizontal distance of approximately 4200 ft. The approximate hydraulic gradient is therefore 0.0094 ft/ft using February 1997 data.

A vertical gradient exists across the Vandalia Till Aquitard which is based on the head level differences between the Upper Drift and the Uppermost Aquifer. A mean hydraulic head difference of 23.5 ft was calculated for the Upper Drift (523 ft msl) and Uppermost Aquifer (501.5 ft msl). The Vandalia Till Aquitard has an approximate thickness of 39.5 ft. Dividing the mean hydraulic head difference (21.5 ft) by the mean thickness of the Vandalia Till Aquitard yields a vertical gradient of 0.544 ft/ft.

3.3 SEALING OF BORINGS AND MONITORING WELLS

To date, there have been five boring and monitoring well installation events at the subject site. These activities have been conducted by Sergeant and Lundy, Hanson Engineers Inc. (HEI) and RAPPS. More than 40 borings and 20 plus wells have been completed during the above episodes. Previous borings conducted by Sergeant and Lundy and HEI were sealed using techniques available at that time. This typically entailed backfilling the borings with the cuttings. Previous boring and monitoring well

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installations conducted by RAPPS have been sealed and abandoned in accordance with Illinois Department of Public Health (IDPH) procedures. The most recent boring and monitoring well installation events conducted by RAPPS took place in October and December 1996. Table 3-4 is a listing of the status of all the completed borings and wells at the CIPS-Newton facility.

TABLE 3-4
STATUS OF ALL COMPLETED BORINGS AND WELLS

BORING/WELL	COMPLETION DATE	DATE SEALED	DEPTH (FT)	STATUS
G101	1979	10/21/91	34	SEALED
G102	1979	10/21/91	22.5	SEALED
G103	1979	10/21/91	22.5	SEALED
G104		NA		CURRENT WELL
G104S	12/17/93	NA	23.2	CURRENT WELL
G104D	12/17/93	NA	87.0	CURRENT WELL
G105	08/01/90	NA	26.0	CURRENT WELL
G106	08/01/90	NA	36.0	CURRENT WELL
G107	08/02/90	NA	33.5	CURRENT WELL
G107S	02/23/94	NA	6.0	CURRENT WELL
G108	12/27/93	NA	20.0	CURRENT WELL
G109	12/20/93	NA	22.0	CURRENT WELL
G110	12/20/93	NA	22.5	CURRENT WELL
G111	12/29/93	NA	20.0	CURRENT WELL
G112	12/27/93	NA	22.0	CURRENT WELL
G113	12/29/93	NA	32.0	CURRENT WELL
G114	02/24/94	10/96	16.0	SEALED
G115	02/22/94	NA	18.0	CURRENT WELL
G116	02/23/94	NA	20.0	CURRENT WELL
PHS	12/28/93	10/96	40.0	SEALED
PHD	12/28/93	10/96	54.5	SEALED

TABLE 3-4
STATUS OF ALL COMPLETED BORINGS AND WELLS

B117	07/26/95	07/95	70.0	SEALED
G117	07/26/95	NA	18.5	CURRENT WELL
B118	07/28/95	07/95	65.0	SEALED
G118	07/28/95	NA	19.0	CURRENT WELL
G119	07/25/95	NA	21.5	CURRENT WELL
G120	07/27/95	NA	20.0	CURRENT WELL
G125A	07/25/95	NA	20.0	CURRENT WELL
G128	07/24/95	NA	35.0	CURRENT WELL
G130	07/27/95	NA	19.0	CURRENT WELL
G133	07/25/95	NA	25.0	CURRENT WELL
G136	07/27/95	NA	20.0	CURRENT WELL
G139	07/26/95	NA	20.0	CURRENT WELL
B141	10/11/96	10/96	25.0	SEALED
B142	10/14/96	10/96	35.0	SEALED
B143	10/11/96	10/96	21.0	SEALED
B144	10/11/96	10/96	18.0	SEALED
G114R	10/7/96	NA	48.0	CURRENT WELL
G121	10/14/96	NA	25.0	CURRENT WELL
G201	10/10/96	NA	70.0	CURRENT WELL
G202	10/16/96	NA	75.0	CURRENT WELL
G203	10/15/96	NA	73.0	CURRENT WELL
G204	10/22/96	NA	75.0	CURRENT WELL
G205	01/28/97	NA	80.0	CURRENT WELL
B206	02/03/97	12/96	90.0	SEALED
G207	01/31/97	NA	70.0	CURRENT WELL
L1	10/31/96	NA	60.0	CURRENT WELL

NA = NOT APPLICABLE, COMPLETED AS WELL

The October 1996 event consisted of nine borings and one well abandonment. Four of the nine borings were completed as wells (G201, G202, G203 and G204), and well G114

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was abandoned. The borings and well G114 were sealed to the surface with cement-bentonite grout. The December 1996 event consisted of three borings (B205, B206 and B207), in which two of the three borings were completed as wells (G205 and G207). Boring B206 was sealed to the surface with cement-bentonite grout. Completed boring sealing forms have been included in Attachment B.

Future adjustments to the proposed monitoring network may require the abandonment of currently used wells. Also, additional subsurface borings at the site may necessitate proper sealing. This is required in accordance with IAC Section 811.316. All abandoned borings and monitoring wells will be sealed in such a manner that the sealing material reaches the bottom of the boring without separation or dilution of the material in accordance with the following requirements.

a) *Non-fractured/Consolidated Formations.* Wells finished in consolidated sandstone or any other water bearing consolidated formation will be sealed by filling the well with disinfected pea gravel or limestone chips to within ten feet below the top of the water bearing formation or within ten feet of the casing, whichever is less. A cement/bentonite slurry containing a 20:1 to 60:1 ratio by dry weight, or pure bentonite, shall be placed for a minimum of twenty feet above this point. An impervious material shall be used to fill the upper part of the well to the surface.

b) *Fractured Formations.* Wells finished in fractured formations will be sealed by filling with disinfected pea gravel or limestone chips to within ten feet below the top of the water bearing formation or to within ten feet below the bottom of the casing, whichever is less. A cement/bentonite slurry containing a 20:1 to 60:1 ratio by dry weight, or pure bentonite, shall be placed for a minimum of twenty feet above this point. An impervious material shall be used to fill the upper part of the well to the surface.

c) *Unconsolidated Formations.* If the water bearing strata consists of coarse gravel and producing wells are present nearby, the well will be sealed by filling with disinfected pea gravel or limestone chips to ten feet below the top of the water bearing strata. A cement/bentonite slurry containing a 20:1 to 60:1 ratio by dry weight, or pure bentonite, shall be placed for a minimum of twenty feet above this point. An impervious material shall be used to fill the remaining upper part of the well to the surface. Abandoned wells finished only in unconsolidated strata near ground surface may be sealed by completely filling with concrete, cement, grout, neat cement or impervious material.

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d) *Multiple Water Bearing Formations.* Wells finished in more than one water bearing strata require that each water bearing strata be sealed separately in the manner described earlier, depending upon the type of strata encountered. A cement/bentonite seal containing a 20:1 to 60:1 ratio by dry weight, or pure bentonite, shall be placed a minimum of ten feet above and below all water bearing strata except where artesian wells and artesian strata are present. Disinfected pea gravel or limestone chips will be placed in each water bearing strata between seals. In the case of an overpressured formation that produces an upflow of water into the overlying strata, a pressure seal will be required to shut off the upflow while the seal is placed and allowed to set. Impervious material will be used to fill all other parts of the well between plugs and the upper seals and the upper part of the well to the surface.

e) *Artesian Wells.* A cement retainer shall be used with pressure grouting equipment to install the grout. A cement/bentonite seal containing a 20:1 to 60:1 ratio by dry weight shall be placed for a minimum of ten feet below and ten feet above the water bearing strata. An impervious material will be placed to fill the upper part of the well to ground surface.

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4.0 GROUNDWATER CLASSIFICATION

Groundwater quality regulations 35 Illinois Administrative Code (IAC) 620 establish numerical standards and a classification system for groundwater. Groundwater quality standards may vary according to the class. Therefore, it is necessary to classify the groundwater in order to identify the appropriate numerical standard with which to compare analytical data from groundwater monitoring wells.

Groundwater in Illinois is designated as one of four classes or as a groundwater management zone (GMZ). Groundwater quality standards are dependent upon groundwater classification. Under these classifications, Class I is a potable resource groundwater. Generally, groundwater in Illinois is considered to be Class I unless otherwise demonstrated. Class II is a general resource groundwater and has less stringent or equivalent standards relative to Class I standards. Class III groundwater is a special resource groundwater including groundwater that is irreplaceable or vital to a particular sensitive ecological system. Class IV groundwater is other groundwater that includes groundwater within a previously mined area, and within the zone of attenuation of a landfill as provided by 35 IAC Sections 811 and 814. Within any class of groundwater, a groundwater management zone (a three-dimensional region containing groundwater that is being managed to mitigate impairment caused by the release of contaminants from the site) may be established. Groundwater in the zone of attenuation at the proposed Phase II landfill is Class IV.

Groundwater in the Upper Drift and the Vandalia Till Aquitard is Class II, while groundwater in the Uppermost Aquifer is Class I. The following discussion further explains and justifies the classification of groundwater at the subject site. Criteria and their applicability to the Newton Power Station Landfill are summarized in Table 4-1.

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TABLE 4-1
SUMMARY OF EVALUATION OF CRITERIA FOR CLASS I GROUNDWATER

CRITERIA:	UPPER DRIFT	VANDALIA TILL AQUITARD	UPPERMOST AQUIFER
SECTION 620.210(a) Groundwater 10 feet or more below the land surface and within:	YES	YES	YES
(1) The minimum setback zone of a well which serves as a possible potable water supply and to the bottom of such wells; or	NO	NO	NO
(2) unconsolidated sand and gravel, gravel or sand and gravel which is 5 ft or more in thickness and that contains 12 percent or less of fines; or	NO	NO	YES
(3) sandstone which is 10 ft or more in thickness, or fractured carbonate which is 15 feet or more in thickness; or	N/A	N/A	N/A
(4) Any geologic material which is capable of a: (B) hydraulic conductivity of 1×10^{-4} cm/sec or greater.	NO	NO	YES
SECTION 620.220(b) Any groundwater which is determined by the Board pursuant to petition procedures set forth in Section 620.260, to be capable of potable use.	NO	NO	NO
RESULT	CLASS II	CLASS II	CLASS I

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4.1 CLASS I AND II GROUNDWATER

According to IAC Section 620.210, groundwater is classified as Class I (Potable Resource Groundwater) if the following criteria are satisfied:

> *SECTION 620.210 (a): "Groundwater located 10 feet or more below the land surface and within:"*

Since all groundwater in the Upper Drift, Vandalia Till and Uppermost Aquifer lies 10 feet or more below the land surface, groundwater in these formations could be Class I if any of the criteria below are also satisfied.

> *SECTION 620.210 (a)(1): "and within the minimum setback zone of a well which serves as a potable water supply and to the bottom of such well;"*

The minimum setback zone for all potable wells in the State of Illinois is a 200 foot radius except for those that are used by the facility in question. There are no potable water supply wells near the current or future disposal areas on the subject property.

> *SECTION 620.210 (a)(2): "and within unconsolidated sand, gravel or sand and gravel which is 5 feet or more in thickness and that contains 12 percent or less of fines (i.e. fines which pass through a No. 200 sieve tested according to ASTM Standard Practice D2488-84, incorporated by reference at Section 620.215);"*

Based on available boring logs, there are no significant sand and gravel lenses in the Upper Drift or Vandalia Till Aquitard. Therefore, groundwater in the Upper Drift and Vandalia Till Aquitard would not be classified as Class I due to this criterion. However, given that in places the Uppermost Aquifer consists of sand or sand or gravel up to 5 feet in thickness, groundwater in this unit is classified as Class I due to this criterion.

> *SECTION 620.210 (a)(3): "and within sandstone which is 10 feet or more in thickness, or fractured carbonate which is 15 feet or more in thickness;"*

This criterion does not pertain to groundwater in either the Upper Drift or Vandalia Till Aquitard.

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SECTION 620.210 (a)(4): "and within any geologic material which is capable of a:

(A) Sustained groundwater yield, from up to a 12 inch borehole, of 150 gallons per day or more from a thickness of 15 feet or less; or

(B) Hydraulic conductivity of 1 x 10^{-3} cm/sec or greater using permeameter, slug test or pump test methods or their equivalent."

In order to evaluate SECTION 620.210 (a)(4)(A), PUMPWIN was used to calculate whether a well installed in a water-bearing formation can sustain an extraction rate of 150 gallons per day. These calculations require certain known values (aquifer thickness, hydraulic conductivity) and radius of pumping well to estimate water level drawdown in an extraction well following a specified period of time. The numerical model is not sensitive to radius of influence. Since groundwater in the Uppermost Aquifer is Class I due to SECTION 620.210 (a)(2), evaluation of this criterion was not performed for the Uppermost Aquifer.

However, evaluation of this criterion was performed on the Upper Drift and Vandalia Till Aquitard using PUMPWIN. This model can be used to calculate the drawdown in a hypothetical well finished in a formation with certain hydrogeologic properties and pumped at a specified rate for a specified duration. For evaluation of the Upper Drift, the following input parameters were used:

1) a thickness of 15 feet;
2) a hydraulic conductivity value of 2.79 x 10^{-5}cm/sec;
3) a radius of influence of 100 ft; and
4) a 12 inch diameter borehole (well).

Mean hydraulic conductivity was used to provide the most accurate estimates of drawdown at the hypothetical well. See Section 3.2.4 for a discussion of hydraulic conductivity at the site. The model input and results are included in Attachment F. In summary, the model shows the maximum sustainable yield for the hypothetical well is less than 15 gpm. Thus, groundwater in the Upper Drift is Class II. Because the hydraulic conductivity of the Vandalia Till Aquitard is considerably less than that of the Upper Drift, sustainable yield from the Vandalia Till Aquitard is considerably less,

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therefore, groundwater in both the Upper Drift and Vandalia Till Aquitard is Class II.

The determination of whether SECTION 620.210 (a)(4)(B) is met for groundwater in the Upper Drift and Vandalia Till Aquitard can be based on available hydraulic conductivity test results. These results are summarized in Table 3-2. The results of hydraulic conductivity tests performed on all monitoring wells finished in the Upper Drift and Vandalia Till Aquitard indicate that the hydraulic conductivity is substantially less than 1 x 10^{-4} cm/sec. Therefore, groundwater in both units could not be classified as Class I according to this criterion.

> *SECTION 620.210 (b): "Any groundwater which is determined by the Board pursuant to petition procedures set forth in Section 620.260, to be capable of potable use."*

No groundwater in the vicinity of the site has been classified by the Board pursuant to Section 620.260. Therefore the groundwater at the site would not be classified as Class I due to this criterion.

4.2 SUMMARY

Based on the available information and applicable regulations, groundwater in the vicinity of the subject facility is one of the three classes. Groundwater within the zone of attenuation of the proposed landfill is Class IV. Elsewhere at the site, groundwater in both the Upper Drift and Vandalia Till Aquitard is Class II and groundwater in the Uppermost Aquifer is Class I.

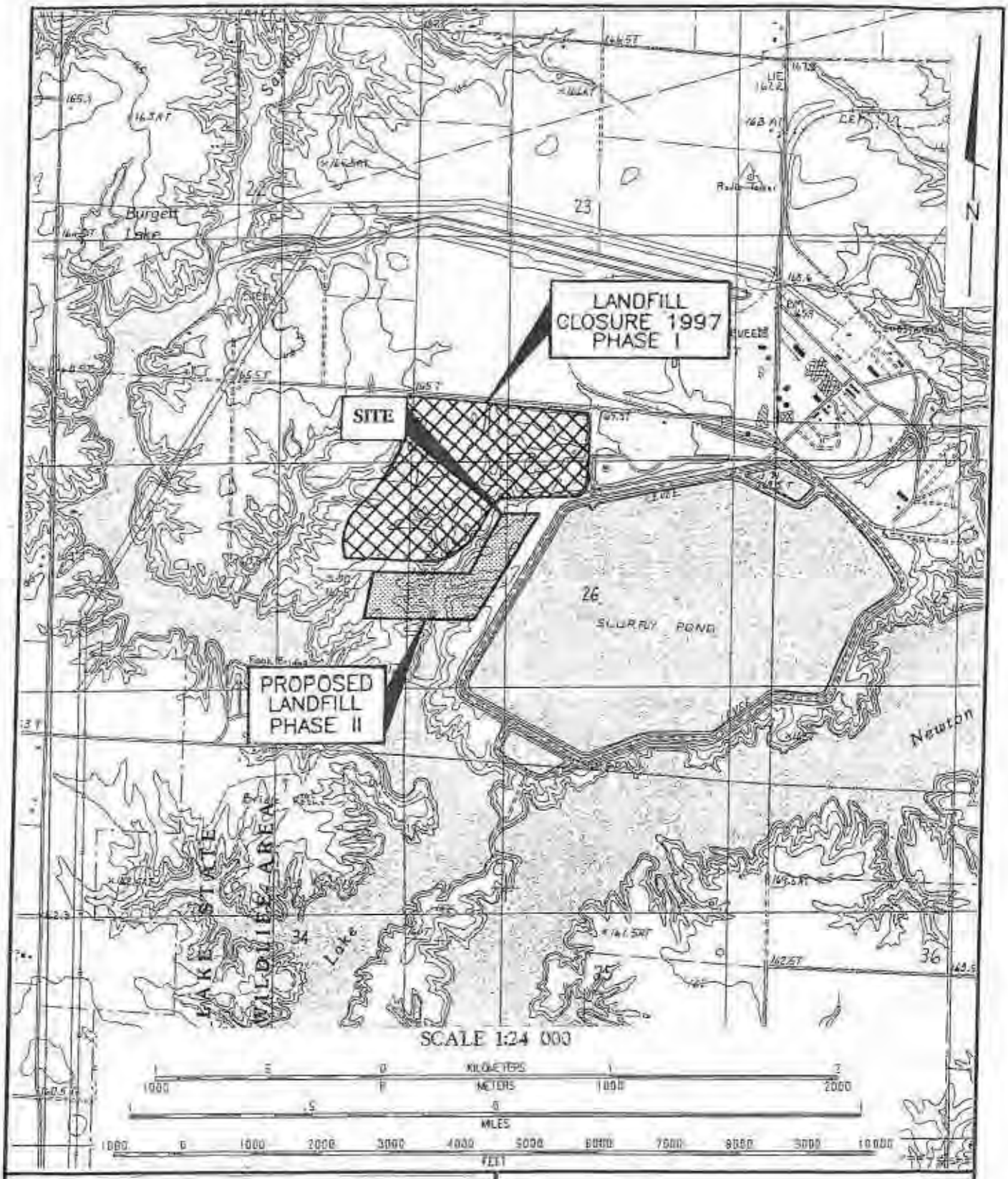

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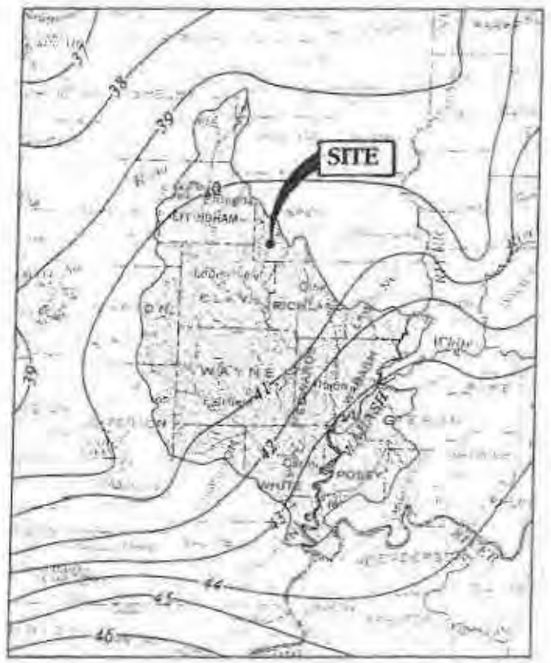
FIGURE 1-1

SITE LOCATION MAP

NEWTON POWER STATION LANDFILL

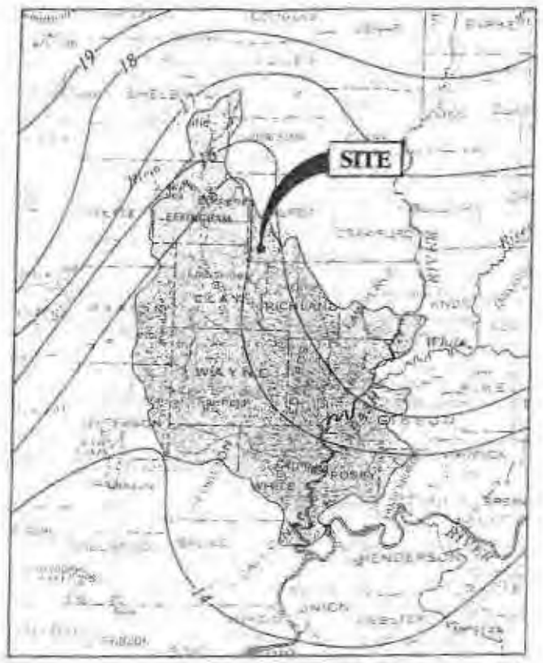
CENTRAL ILLINOIS PUBLIC SERVICE CO.

NEWTON, ILLINOIS



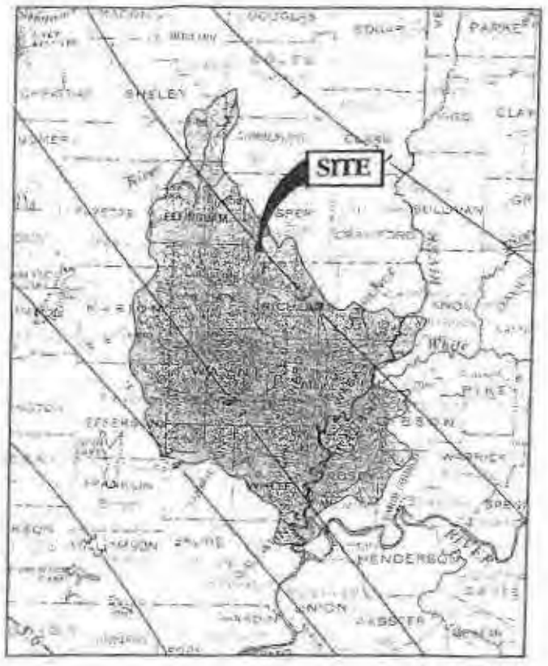
Hershfield, 1961

Figure 7.0-1 Average annual precipitation, in inches.



Dawes and Terstriep, 1966

Figure 7.0-2 Average annual snowfall, in inches.



Hershfield, 1961

Figure 7.0-3 Two-year, 24-hour rainfall, in inches.

SOURCE: E.E. ZUEHLS, "HYDROLOGY OF AREA 31, EASTERN REGION, INTERIOR COAL PROVINCE, ILLINOIS & INDIANA," 1987.

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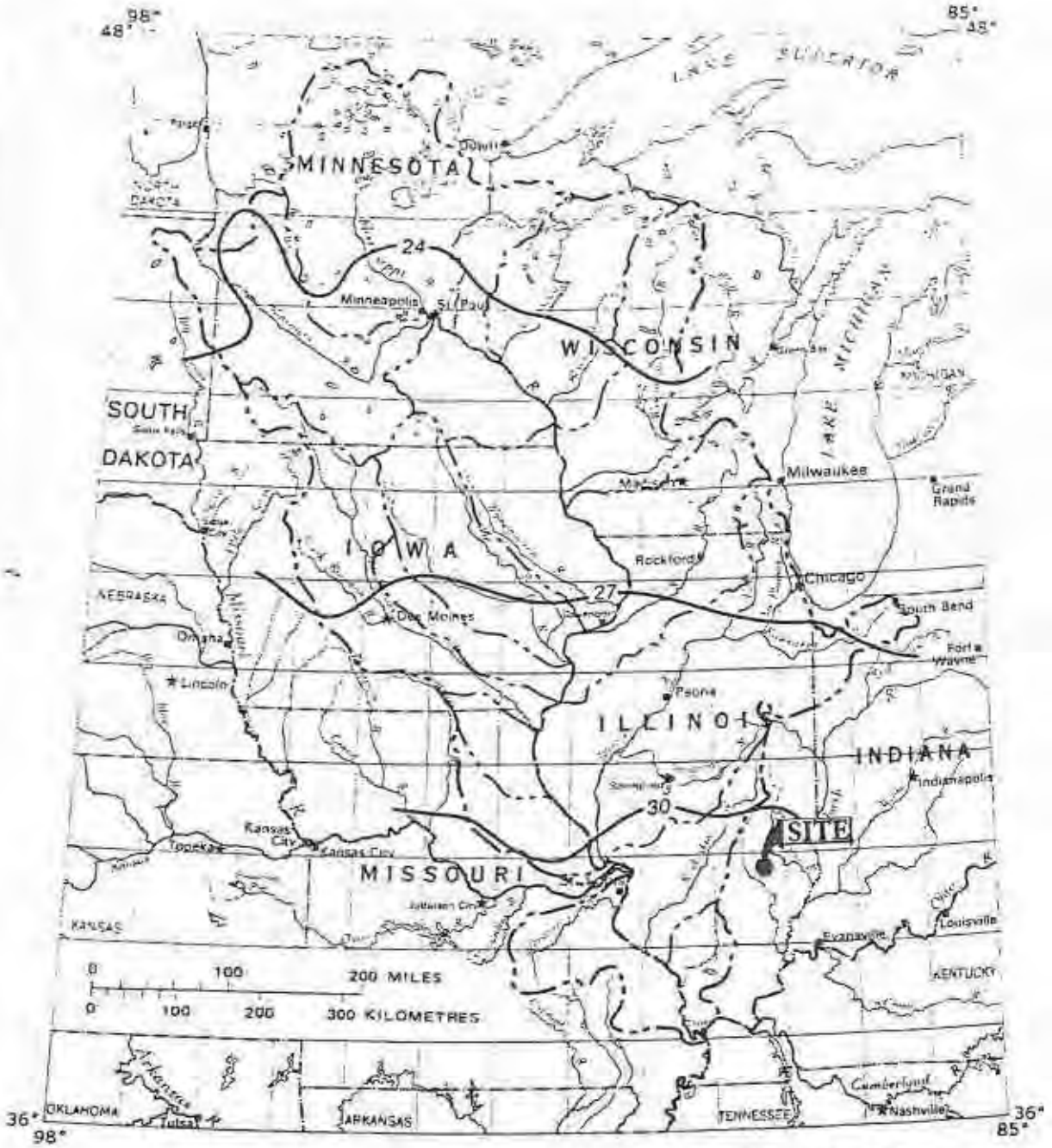
FIGURE 2-1
AVERAGE ANNUAL PRECIPITATION AND SNOWFALL
CIPS NEWTON POWER STATION
JASPER COUNTY, ILLINOIS



(Source is U.S. Army Corps of Engineers, 1970b.)

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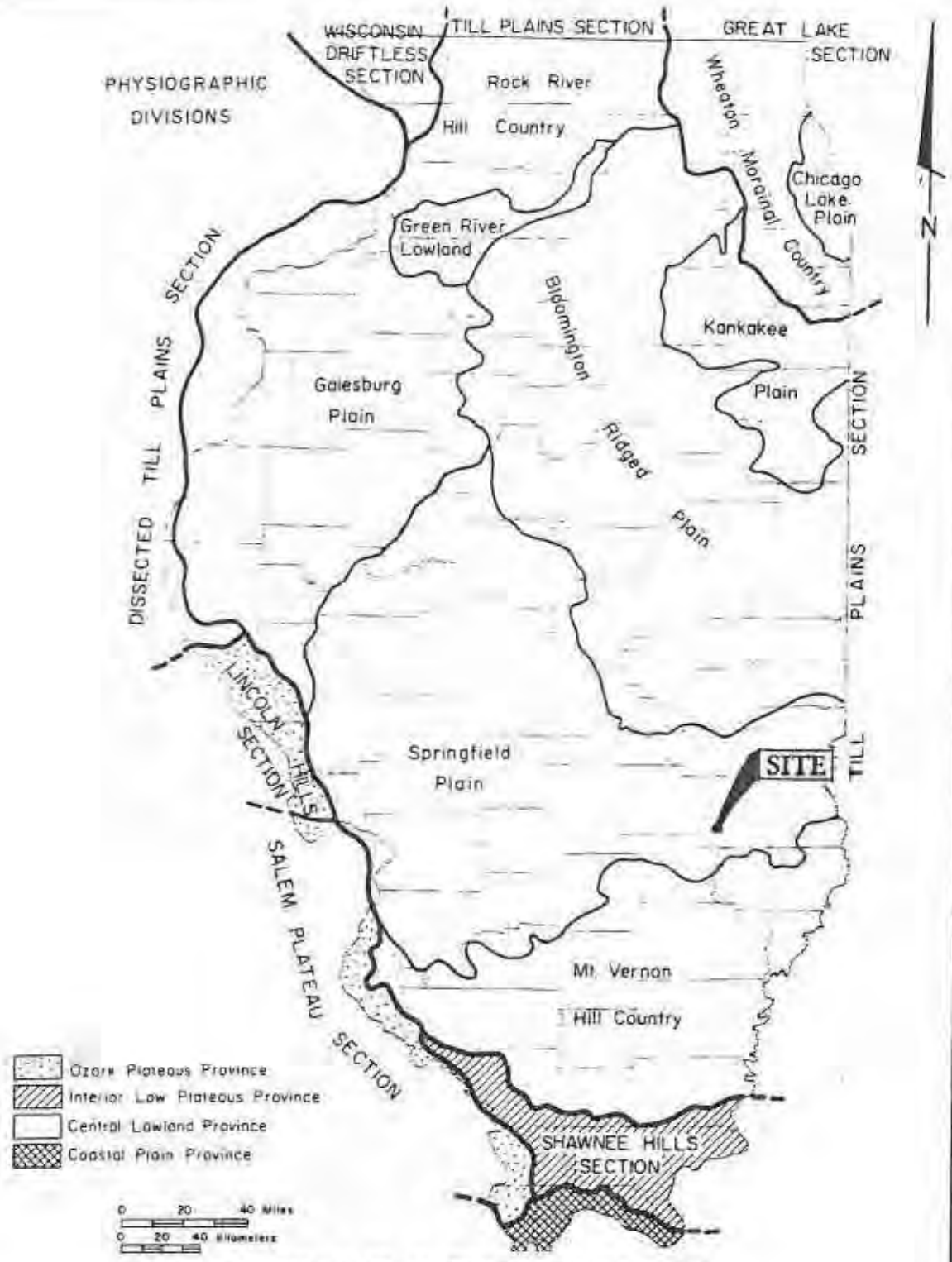
FIGURE 2-2
AVERAGE ANNUAL EVAPOTRANSPIRATION
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



SOURCE: WILLMAN, ET. AL., "HANDBOOK OF ILLINOIS STRATIGRAPHY," ISGS, 1975.

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FIGURE 2-3
PHYSIOGRAPHIC DIVISIONS OF ILLINOIS
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



SOURCE: E.E. ZUEHLS, "HYDROLOGY OF AREA 31, EASTERN REGION, INTERIOR COAL PROVINCE, ILLINOIS & INDIANA," 1987.

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FIGURE 2-4
LITTLE WABASH RIVER BASIN
CIPS NEWTON POWER STATION
JASPER COUNTY, ILLINOIS

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Stage	Deposits	Grain size	Clay mineralogy (< 2μ)	Carbonate mineralogy (< 2μ)
RECENT	Alluvium	Generally fine grained	No data	Leached
	Accretion-gleys	Clay rich	Rich in expandable clay minerals	Leached
	Lacustrine	Silt and clay	Rich in expandable clay minerals	Leached
WISCONSINAN	Peoria Loess	Silt	Variable, but generally rich in expandable clay minerals	Mostly thin and leached
	Roxana Silt	Sandy	Rich in expandable clay minerals	Leached
	Accretion-gleys	Clay rich	Rich in expandable clay minerals	Leached
	Lacustrine	Silt, clay, gyttja (organic-rich mud)	Variable	Partly calcareous
	Valley train	Fine- to coarse-grained outwash	No data	No data
SANGAMONIAN	Lacustrine (?)	Silt, clay, gyttja (?)	Rich in illite	Calcareous
	Accretion-gleys	Clay rich	Rich in expandable clay minerals	Leached
ILLINOIAN	Hagarstown beds	Well sorted gravel, sand, poorly sorted gravel, gravelly till	Rich in illite where unweathered	Dolomite usually more than calcite; mostly leached where thin
	Vandalia till (some sand and gravel)	Sandy (43 ± 10%* sand, 38± 10% silt, 19± 5% clay)	Rich in illite, poor in expandable clay minerals	Dolomite usually more than calcite
	Mulberry Grove silt (some sand and gravel)	Variable	No data	No data
	Smithboro till (little sand and gravel)	Silty (25± 7% sand, 49± 7% silt, 26± 7% clay)	More expandable clay minerals than other tills	More dolomite than calcite, but lower in total carbonate than other tills
YARMOUTHIAN	Buried soil (no deposits)			
KANSAN	Till	Somewhat sandy (33± 6% sand, 42 ± 10% silt, 25± 5% clay)	Rich in illite, poor in expandable clay minerals	Calcite about twice dolomite

*Mean percent ± 2 standard deviations

SOURCE: ISGS CIRCULAR 442

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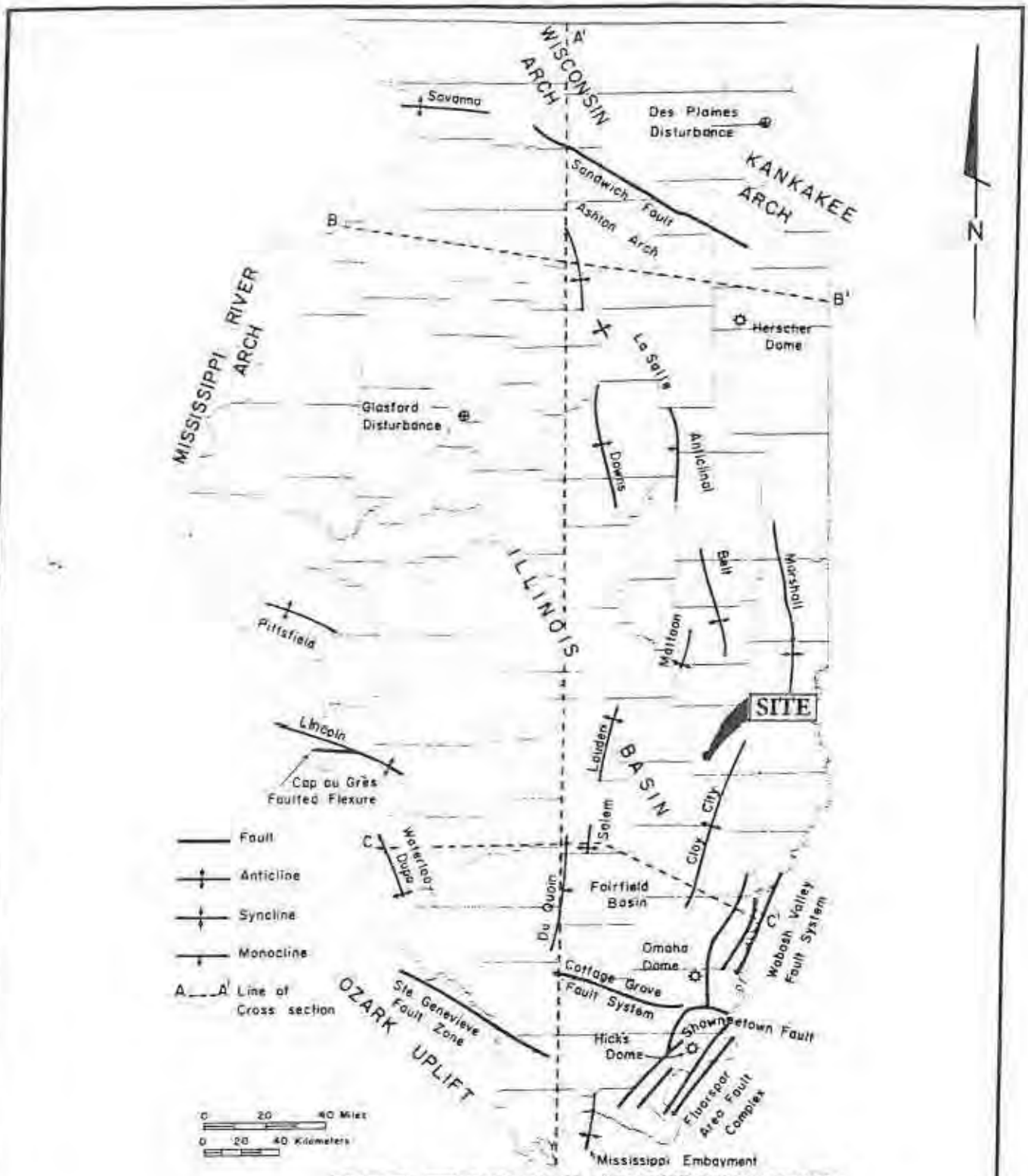
FIGURE 2-5
GENERALIZED STRATIGRAPHIC COLUMN
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



SOURCE: WILLMAN, ET. AL., "HANDBOOK OF ILLINOIS STRATIGRAPHY," ISGS, 1975.

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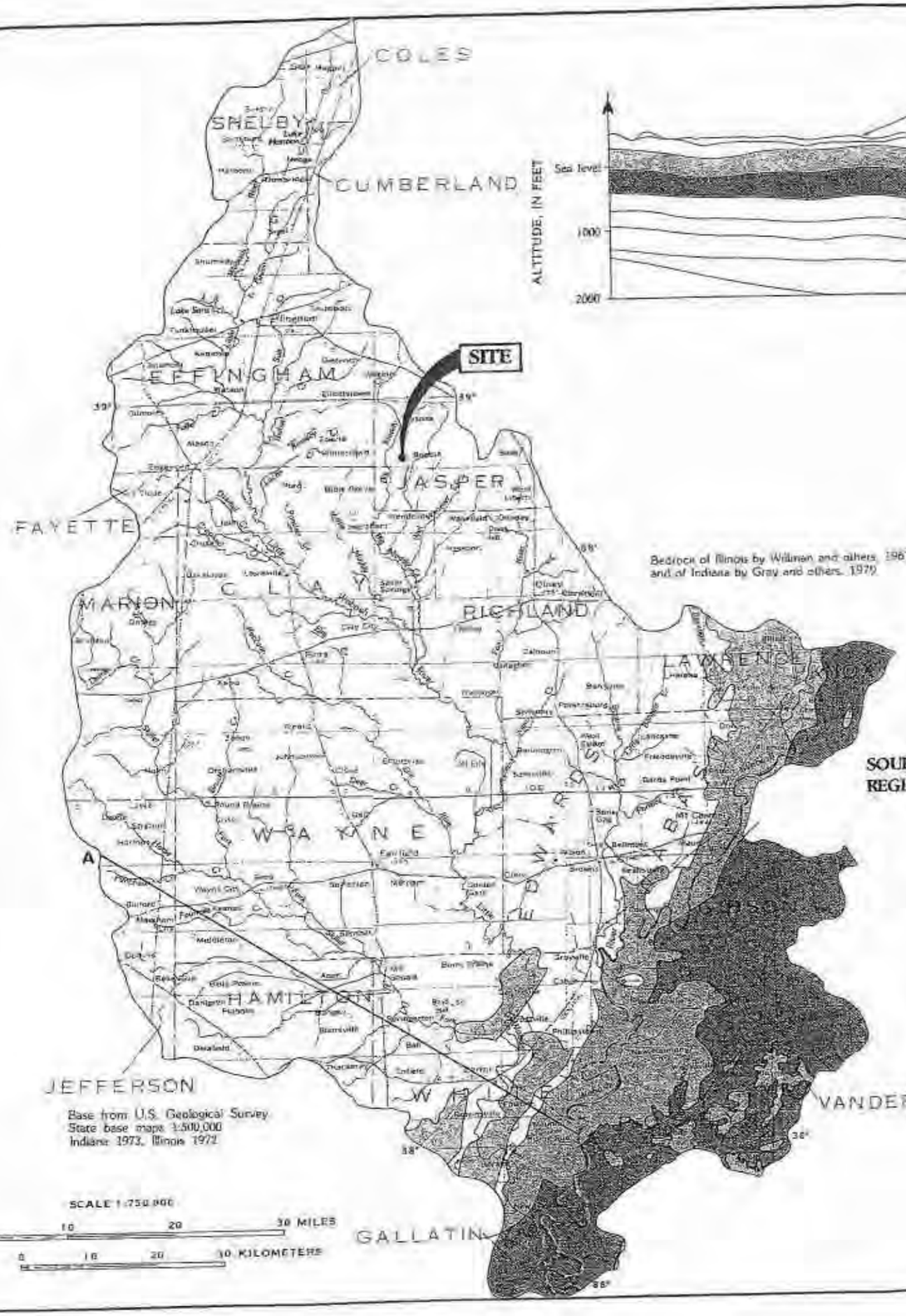
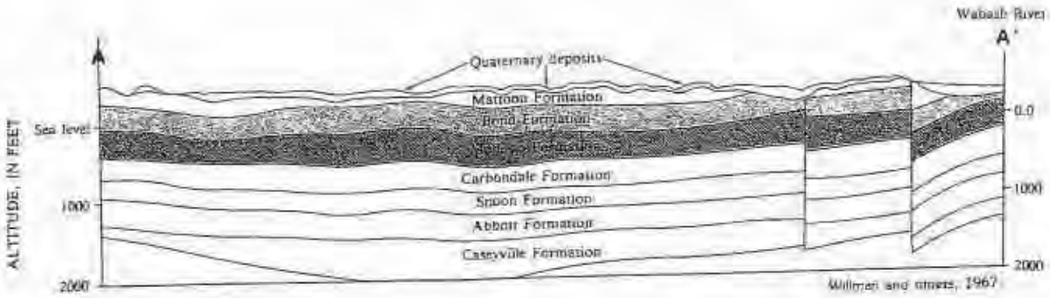
FIGURE 2-6
PRINCIPAL GEOLOGIC STRUCTURES OF ILLINOIS
CIPS NEWTON POWER STATION
JASPER COUNTY, ILLINOIS





Bedrock of Illinois by Willman and others, 1967 and of Indiana by Gray and others, 1979

EXPLANATION

PENNSYLVANIAN SYSTEM
McLeansboro Group

ILLINOIS	INDIANA
Mattoon Formation	Mattoon Formation
Bond Formation	Bond Formation
Modesto Formation	Patoka and Shelburn Formation

SOURCE: E.E. ZUEHLS, "HYDROLOGY OF AREA 31, EASTERN REGION, INTERIOR COAL PROVINCE, ILLINOIS & INDIANA," 1987.

Modified from Gray and others, 1970, and Patton, 1956, and Willman and others, 1975, P. 167, 171.
The stratigraphic nomenclature follows the usage of the Illinois State Geological Survey and the Indiana Geological Survey and differs somewhat from the usage of the U.S. Geological Survey.

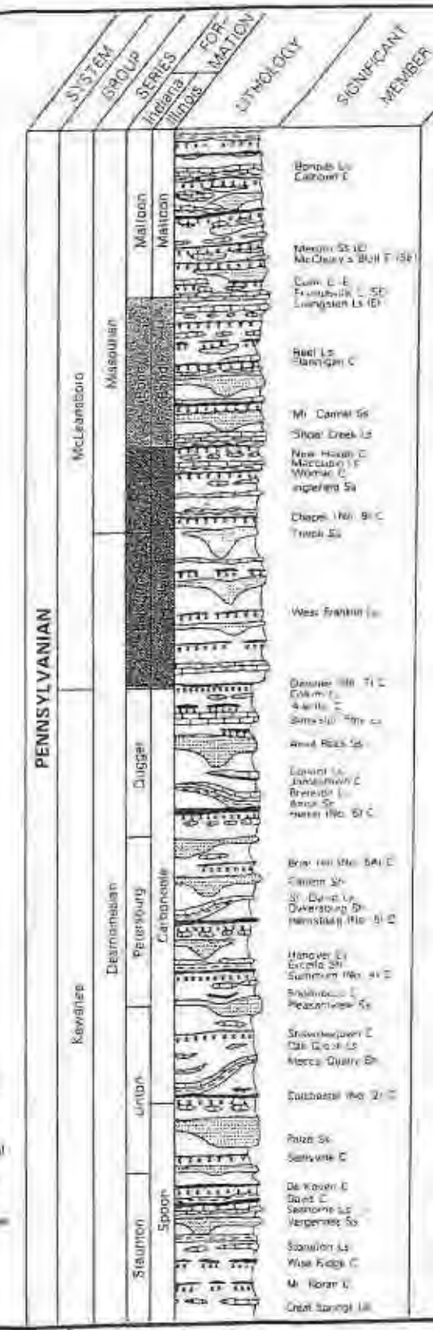


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FIGURE 2-7
BEDROCK GEOLOGIC MAP
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

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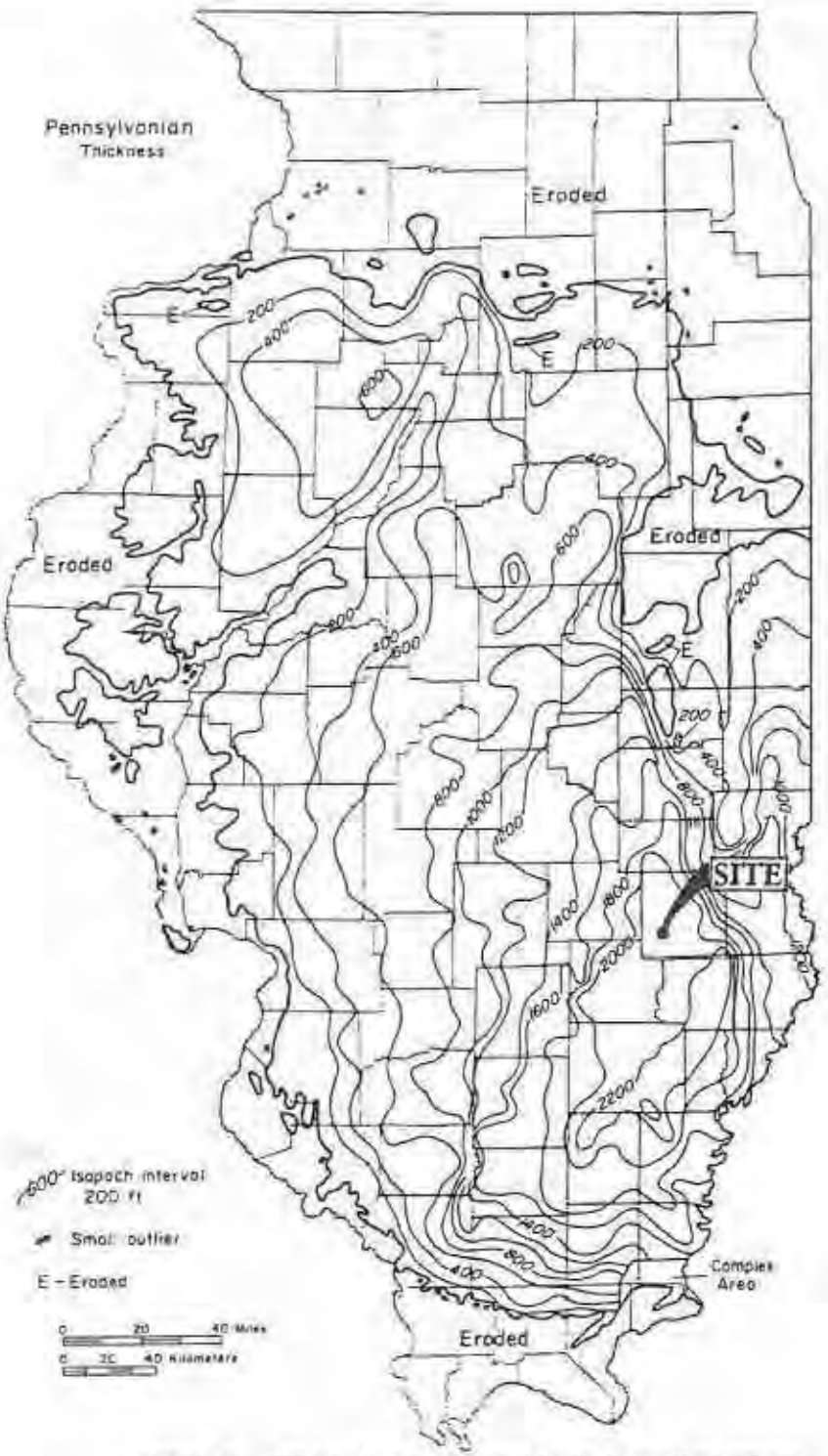

SOURCE: WILLMAN, ET. AL., "HANDBOOK OF ILLINOIS STRATIGRAPHY," ISGS, 1975.

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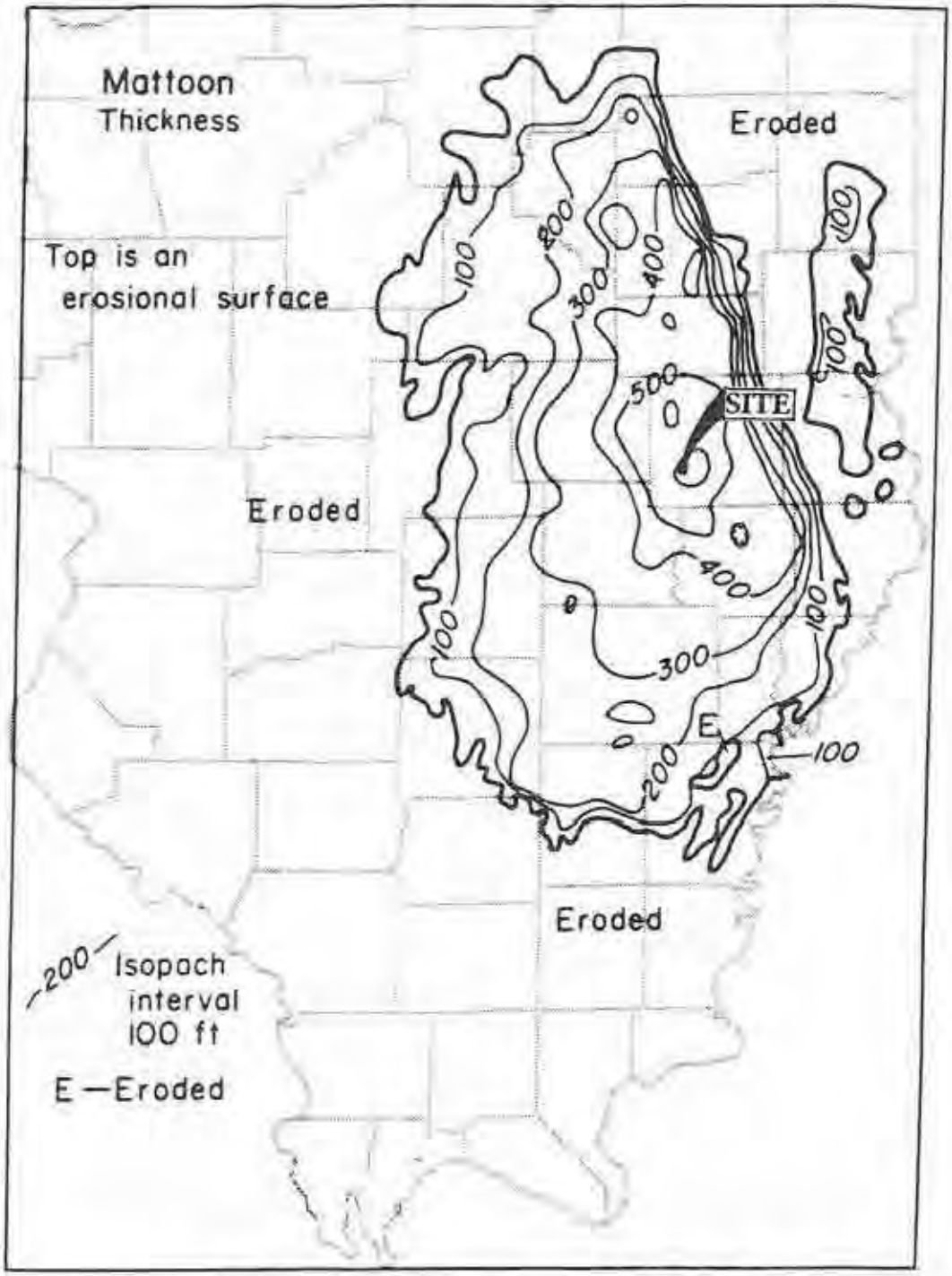
FIGURE 2-8
THICKNESS OF THE PENNSYLVANIAN SYSTEM
CIPS NEWTON POWER STATION
JASPER COUNTY, ILLINOIS



SOURCE: WILLMAN, ET. AL., "HANDBOOK OF ILLINOIS STRATIGRAPHY," ISGS, 1975.

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FIGURE 2-9
THICKNESS OF THE MATTOON FORMATION
CIPS NEWTON POWER STATION
JASPER COUNTY, ILLINOIS

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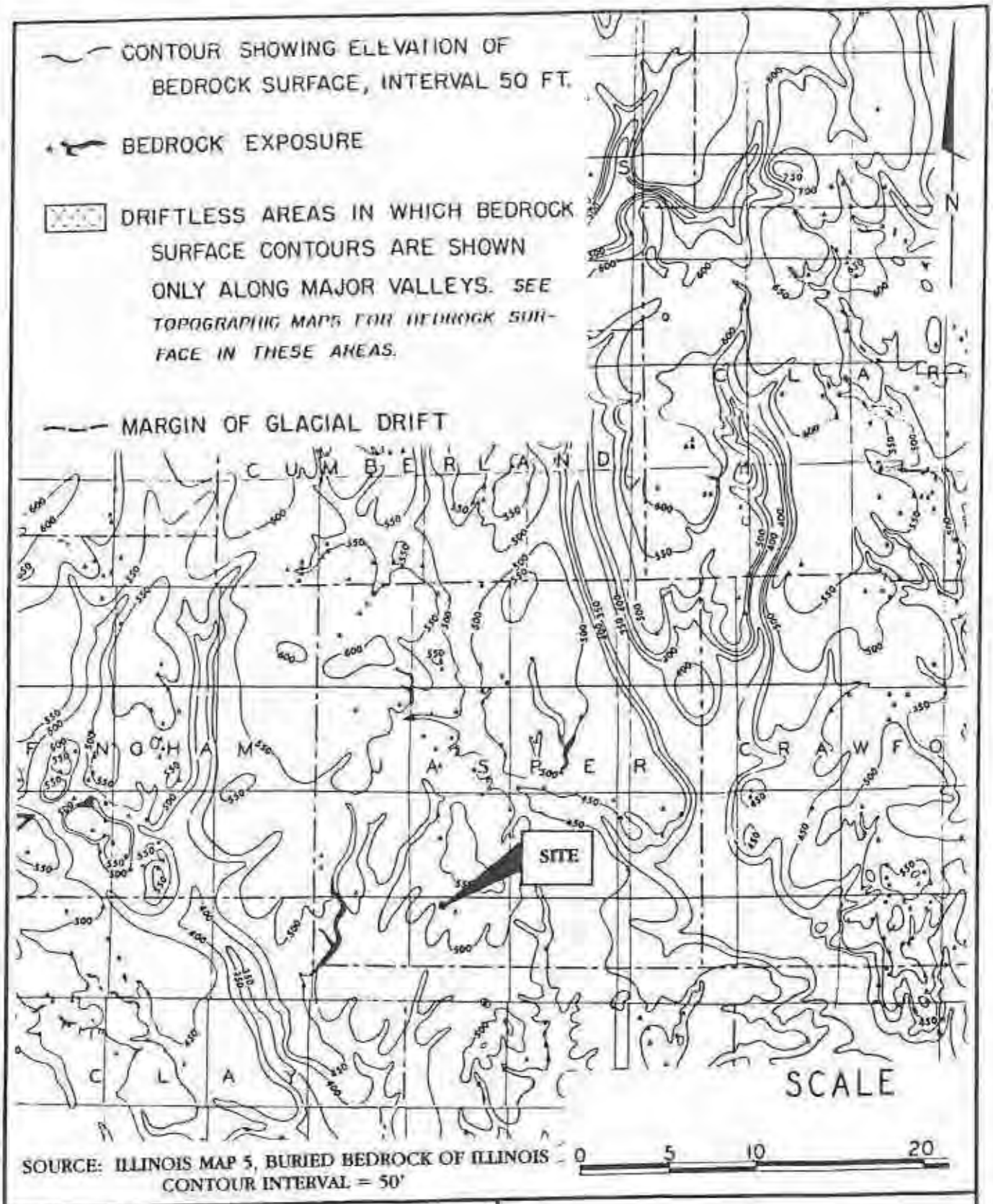

SOURCE: ILLINOIS MAP 5, BURIED BEDROCK OF ILLINOIS
CONTOUR INTERVAL = 50'

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FIGURE 2-10
BEDROCK SURFACE TOPOGRAPHY
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

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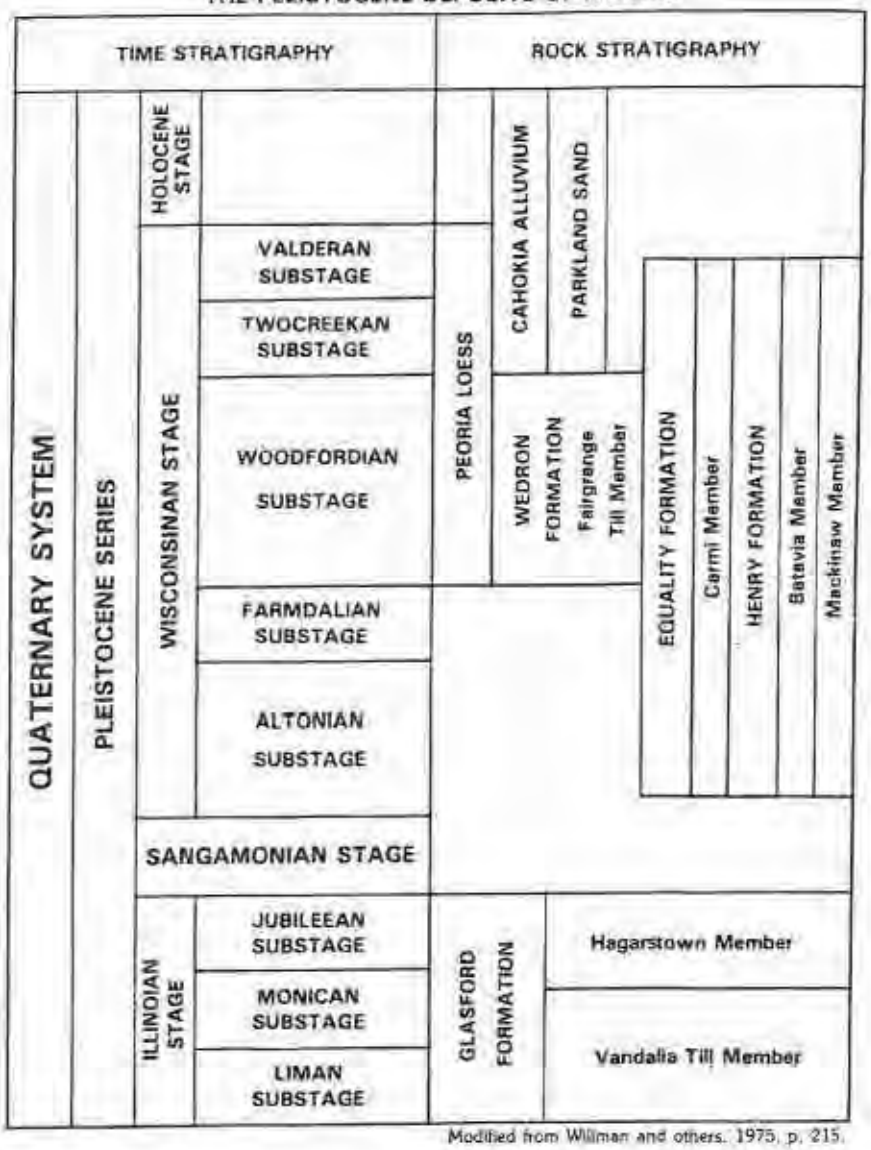
STRATIGRAPHIC CLASSIFICATION OF
THE PLEISTOCENE DEPOSITS OF ILLINOIS



Modified from Willman and others, 1975, p. 215.

SOURCE: E.E. ZUEHLS, "HYDROLOGY OF AREA 31, EASTERN REGION, INTERIOR COAL PROVINCE, ILLINOIS & INDIANA," 1987.

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FIGURE 2-11
QUATERNARY STRATIGRAPHY
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

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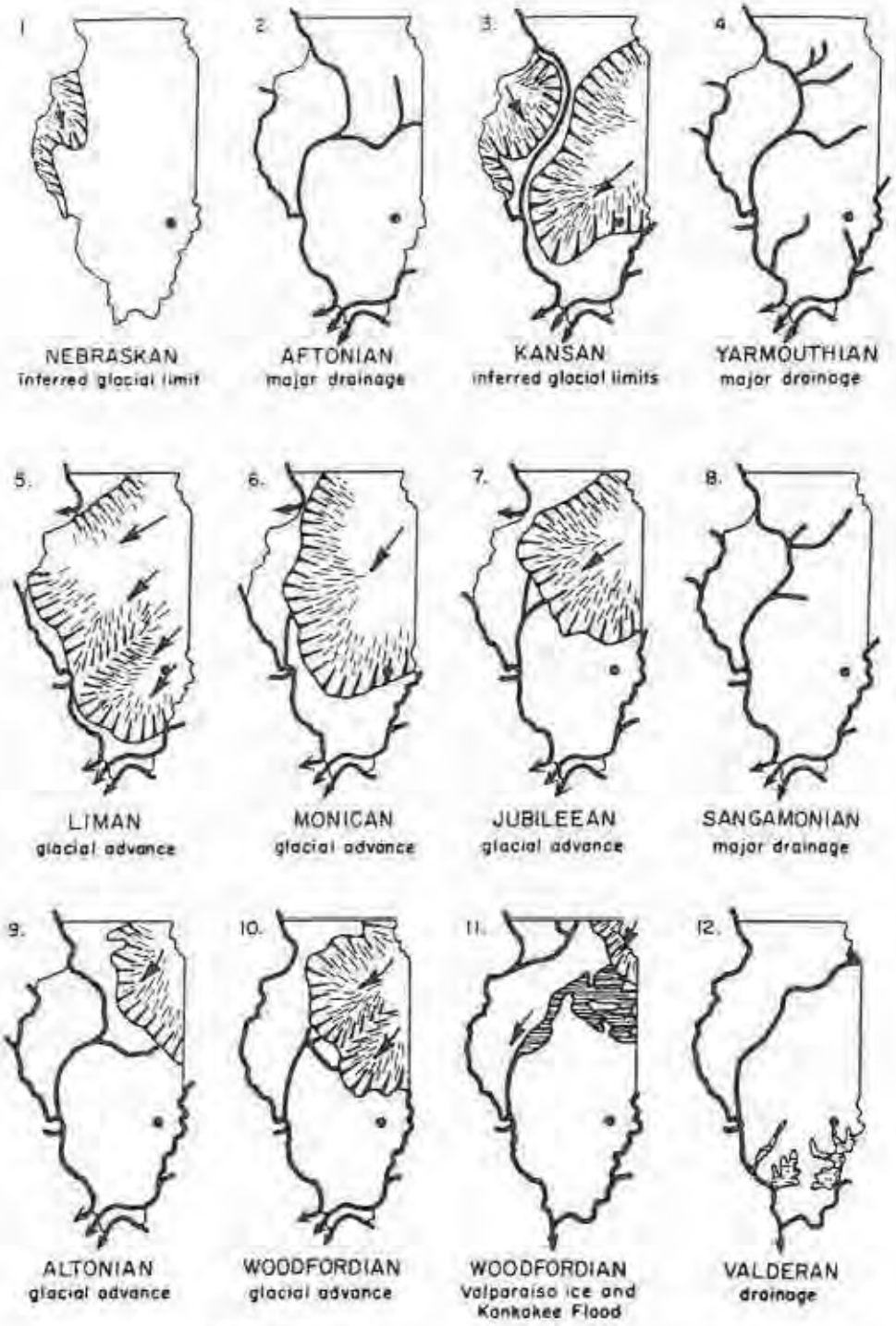

e - SITE LOCATION IN ILLINOIS

SOURCE:
WILLMAN, H.B. & J.C. FRYE, 1970,
"PLEISTOCENE STRATIGRAPHY OF ILLINOIS",
ILLINOIS STATE GEOLOGICAL SURVEY, BULLETIN 94,
URBANA, ILLINOIS

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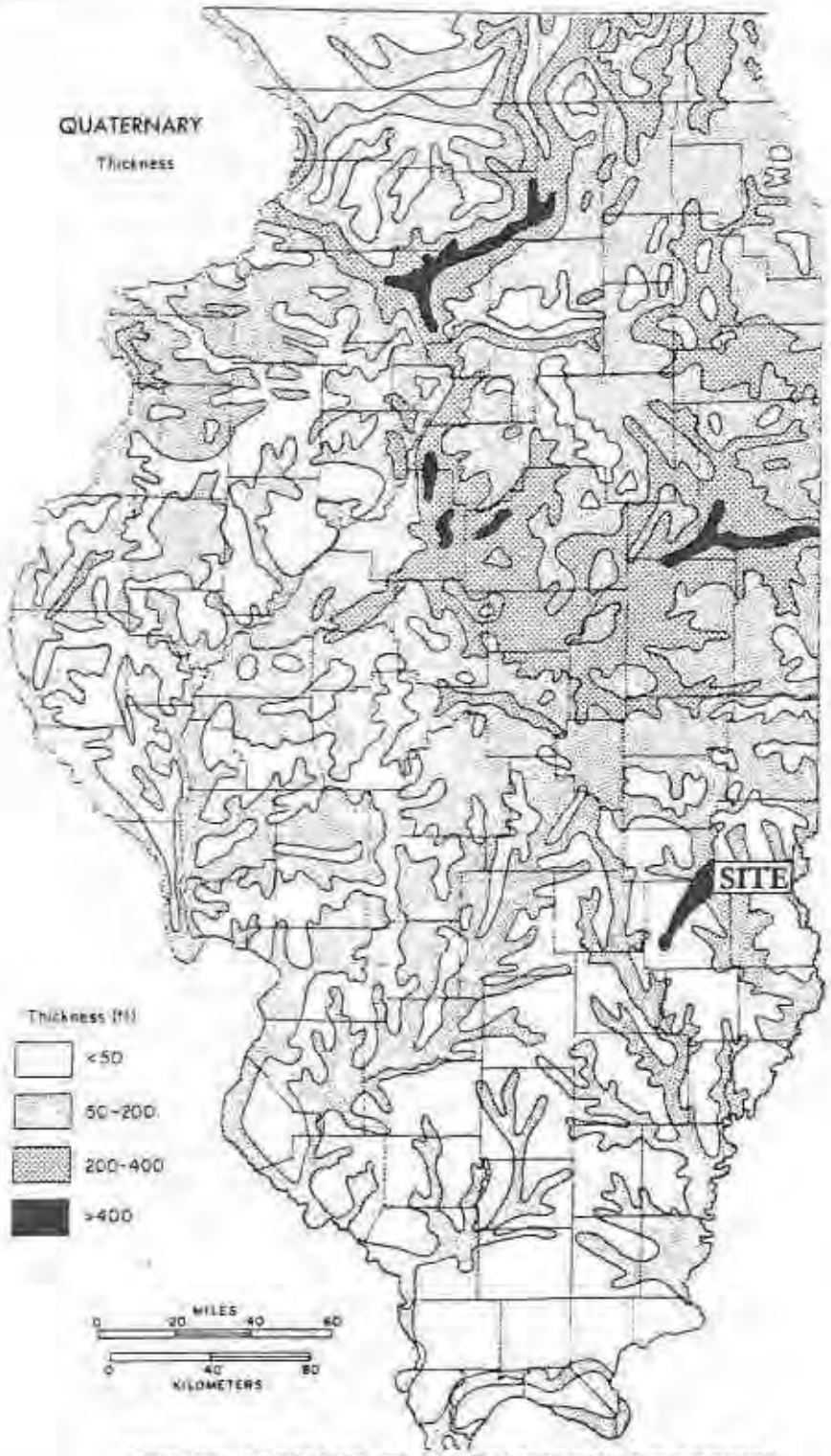
FIGURE 2-12
GLACIAL STAGES OF ILLINOIS
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



SOURCE: WILLMAN, ET. AL., "HANDBOOK OF ILLINOIS STRATIGRAPHY," ISGS, 1975.

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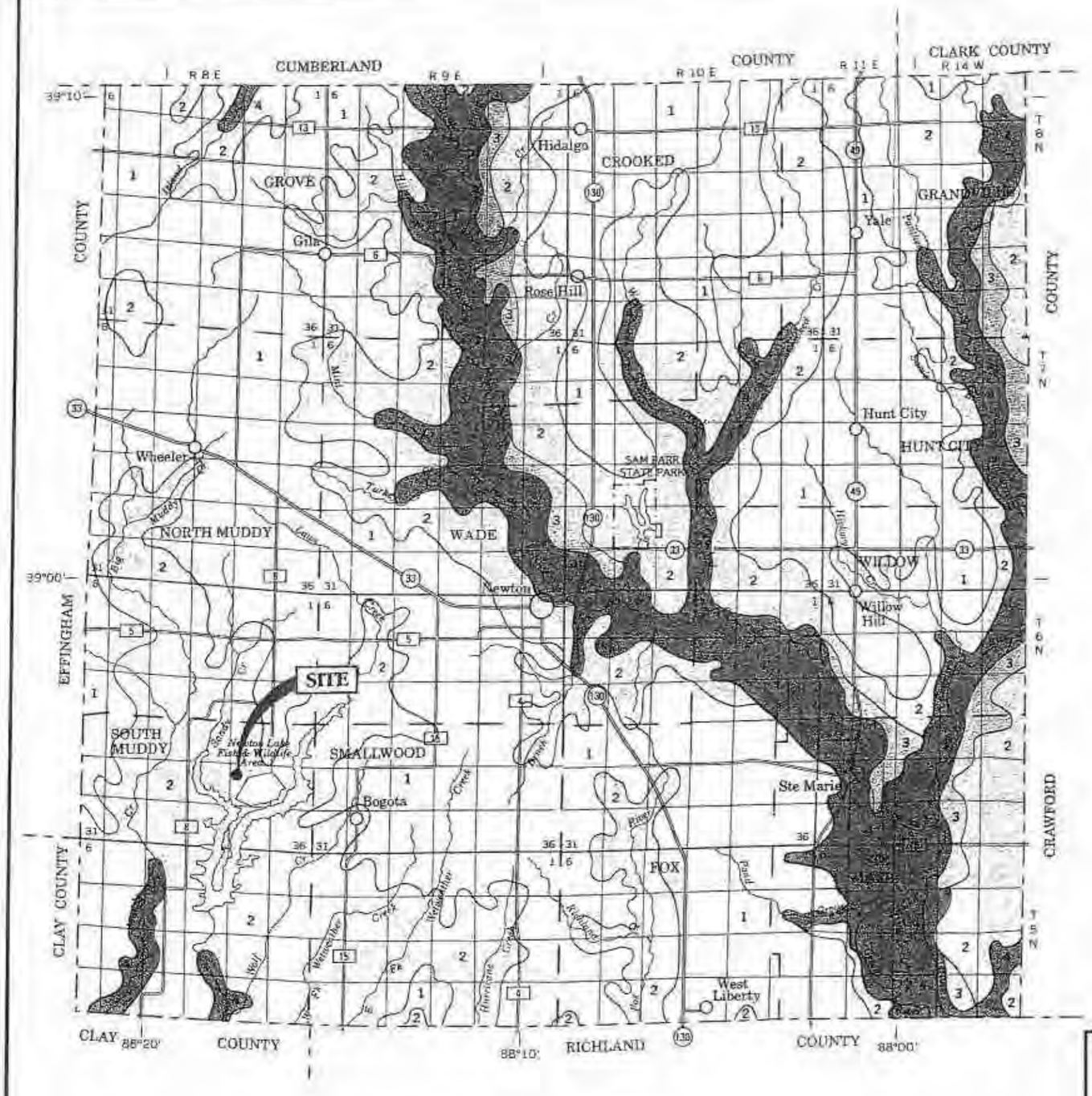
FIGURE 2-13
THICKNESS OF QUATERNARY DEPOSITS
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



SOIL LEGEND*

1 — CISNE-HOYLETON-DARMSTADT ASSOCIATION: Nearly level to gently sloping, poorly drained and somewhat poorly drained, silty soils formed in loess and the underlying sediments; on uplands

2 — BLUFORD-WYNOOSE-ATLAS ASSOCIATION: Nearly level to strongly sloping, somewhat poorly drained and poorly drained, silty soils formed in loess and the underlying sediments or in glacial till; on uplands

3 — THEBES-ALVIN ASSOCIATION: Gently sloping to steep, well drained, silty and loamy soils formed in loess and the underlying sandy material or in loamy and sandy material; on terraces and uplands

WAKELAND-PETROLIA ASSOCIATION: Nearly level, somewhat poorly drained and poorly drained, silty soils formed in alluvium, on flood plains

*Unless otherwise indicated, the texture terms in the descriptive headings refer to the surface layer of the major soils in the associations.

Compiled 1991

SECTIONALIZED TOWNSHIP

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ILLINOIS AGRICULTURAL EXPERIMENT STATION

GENERAL SOIL MAP

JASPER COUNTY, ILLINOIS

Scale 1:190,080

1 0 1 2 3 Mi

1 0 3 5 Km

Each area outlined on this map consists of more than one kind of soil. The map is thus meant for general planning rather than a basis for decisions on the use of specific tracts.

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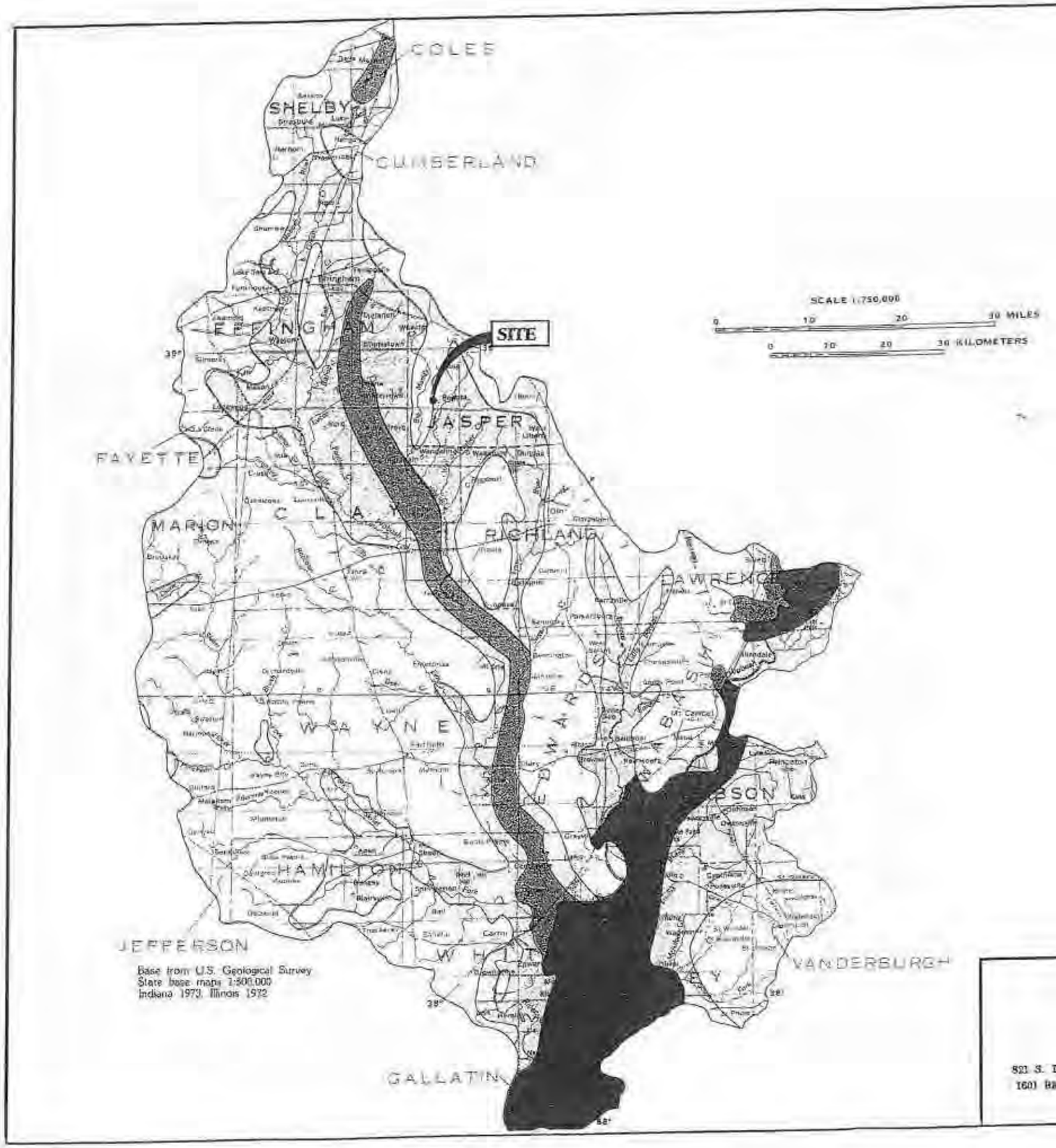
FIGURE 2-14
SOIL ASSOCIATIONS OF JASPER COUNTY
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



Base from U.S. Geological Survey
State base maps 1:500,000
Indiana 1973, Illinois 1972

EXPLANATION

SAND AND GRAVEL AQUIFERS WHERE CHANCES ARE GOOD FOR OBTAINING WELLS WITH YIELDS OF:

- **500 gallons per minute or more**
- **100 gallons per minute or more**
- **20 gallons per minute or more**

SANDSTONE AND LIMESTONE AQUIFERS WHERE CHANCES ARE POOR FOR OBTAINING WELLS WITH YIELDS OF:

- **10 gallons per minute or more**

(from Smith and Stall, 1975; Berbert and Heckard, 1966)

SOURCE: E.E. ZUEHLS, "HYDROLOGY OF AREA 31, EASTERN REGION, INTERIOR COAL PROVINCE, ILLINOIS & INDIANA," 1987.

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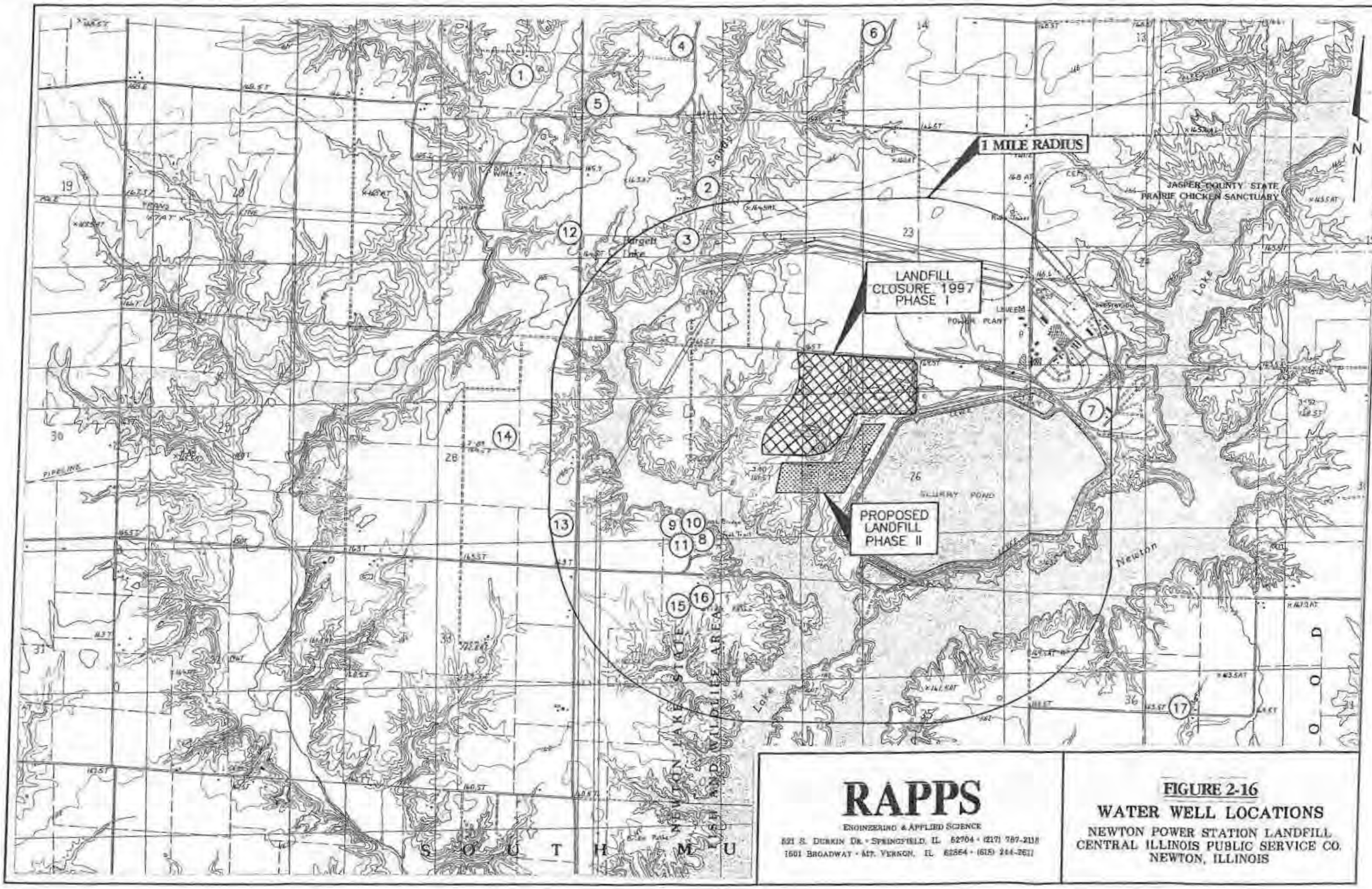
FIGURE 2-15
GROUNDWATER WELL-YIELD POTENTIAL
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS



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1601 BROADWAY • MT. VERNON, IL. 62864 • (618) 244-2611

FIGURE 2-16

WATER WELL LOCATIONS

NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA96083\FIGURES\BMWLOCTN

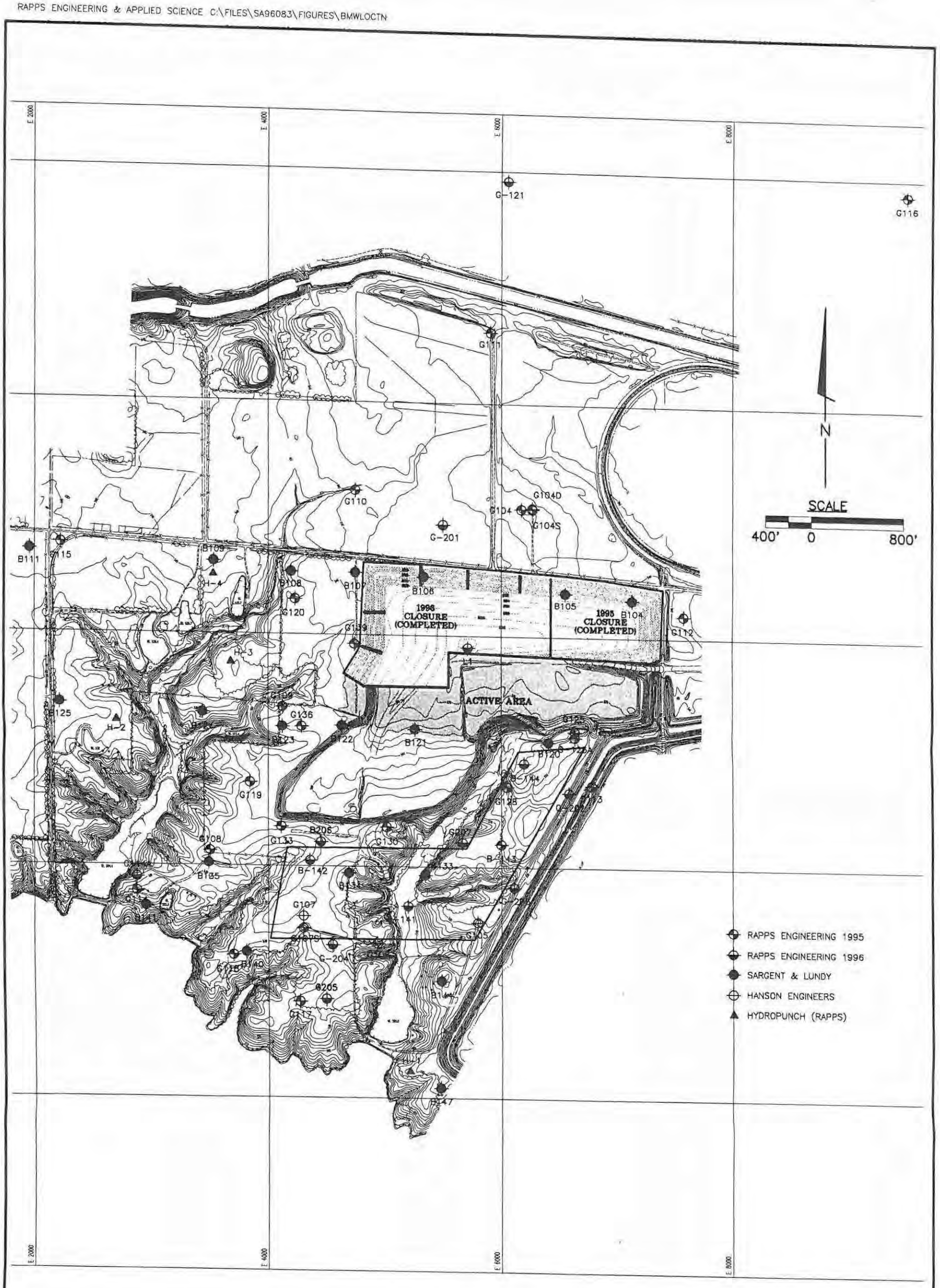

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FIGURE 3-1

BORING & MONITORING WELL LOCATIONS

NEWTON POWER STATION LANDFILL

CENTRAL ILLINOIS PUBLIC SERVICE

NEWTON, ILLINOIS

RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA96083\FIGURES\XSECKEY

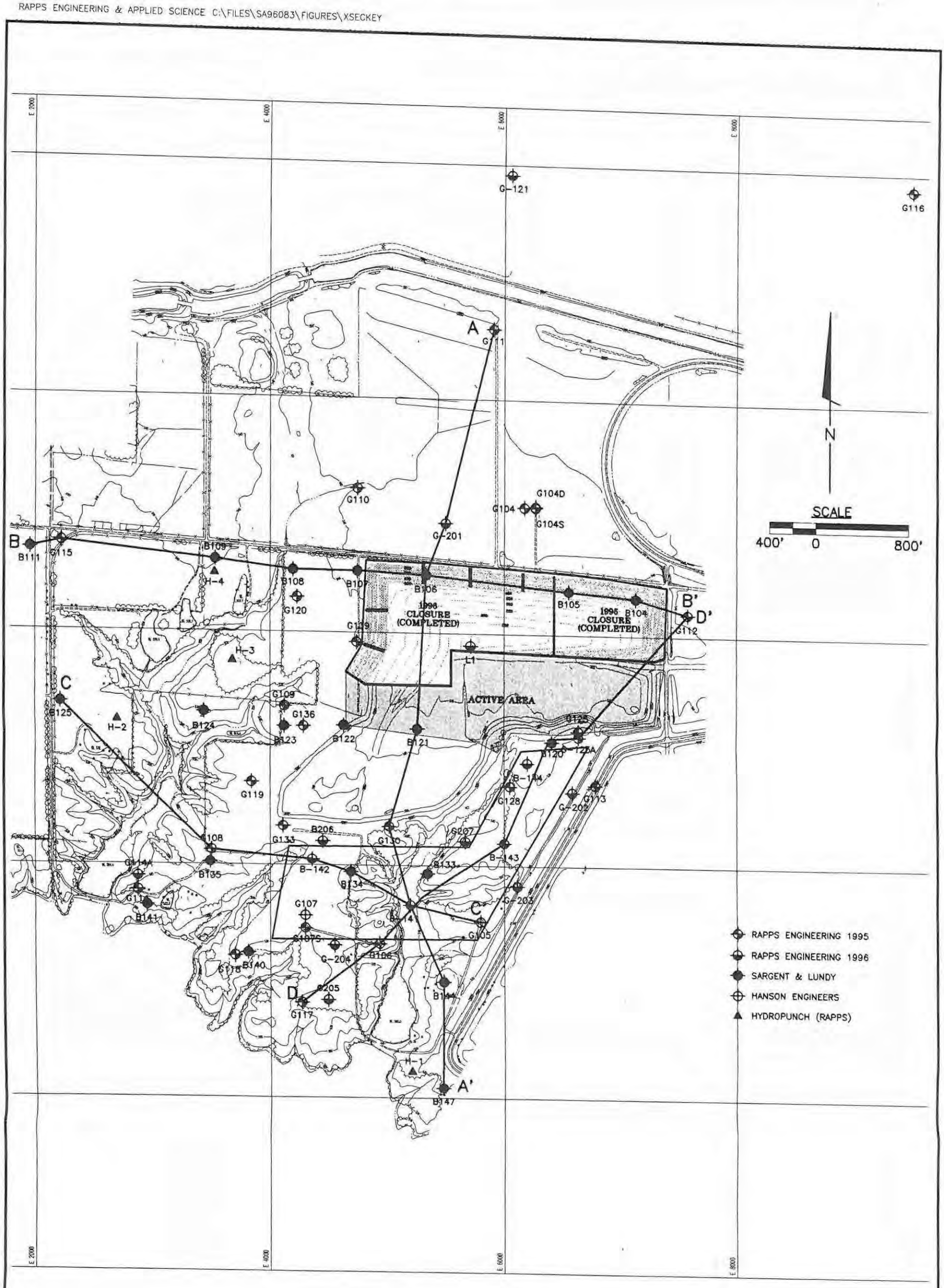

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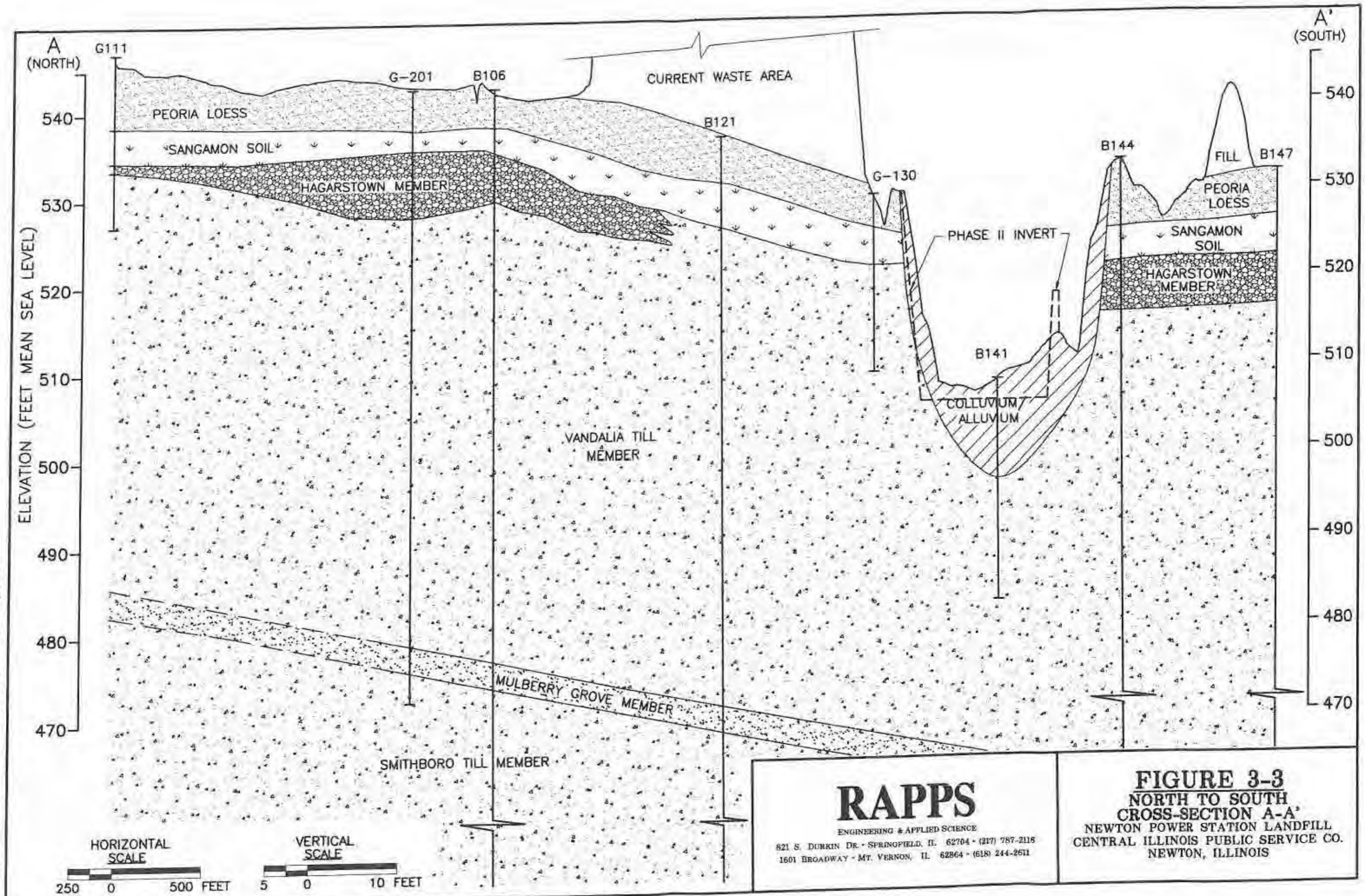
FIGURE 3-2
CROSS SECTION KEY
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS



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RAPPS

ENGINEERING & APPLIED SCIENCE

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FIGURE 3-3

NORTH TO SOUTH
CROSS-SECTION A-A'
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

B (WEST)

B' (EAST)

ELEVATION (FEET MEAN SEA LEVEL)

550
540
530
520
510
500
490
480
470
460

B111 G115 B109 B108 B107 B106 B105 B104 G112

ALLUVIUM/ COLLUVIUM

EXISTING WASTE AREA

PEORIA LOESS

SANGAMON SOIL

HAGARSTOWN MEMBER

VANDALIA TILL MEMBER

MULBERRY GROVE MEMBER

SMITHBORO TILL MEMBER

HORIZONTAL SCALE
250 0 500 FEET

VERTICAL SCALE
5 0 10 FEET

FIGURE 3-4
WEST TO EAST CROSS SECTION B-B'
CIPS NEWTON
CIPS
NEWTON LANDFILL

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1601 BROADWAY • MT. VERNON, IL 62864 (618) 244-2611

RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA9B083\SHEETS\SEC_B-B'

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RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA9606B\SHEETS\SEC_C-C

C (WEST)

C' (EAST)

ELEVATION (FEET MEAN SEA LEVEL)

470 480 490 500 510 520 530 540 550

HORIZONTAL SCALE
250 0 500 FEET

VERTICAL SCALE
5 0 10 FEET

B125
G108
B142
B134
B141
G105

ALLUVIUM/ COLLUVIUM
PEORIA LOESS
SANGAMON SOIL
HAGARSTOWN MEMBER
VANDALIA TILL MEMBER
MULBERRY GROVE MEMBER
SMITHBORO TILL MEMBER

PHASE II INVERT

RAPPS
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1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

FIGURE 3-5
WEST TO EAST
CROSS SECTION C-C'
NEWTON LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

D
(SOUTHWEST)

D'
(NORTHEAST)

ELEVATION (FEET MEAN SEA LEVEL)

550
540
530
520
510
500
490
480
470
460

EXISTING WASTE AREA

PHASE II INVERT

G117
G106
G112
G125A
B120
B141
B143

ALLUVIUM/ COLLUVIUM

PEORIA LOESS

SANGAMON SOIL

HAGARSTOWN MEMBER

VANDALIA TILL MEMBER

MULBERRY GROVE MEMBER

SMITHBORO TILL MEMBER

HORIZONTAL SCALE
250 0 500 FEET

VERTICAL SCALE
5 0 10 FEET

FIGURE 3-6
SOUTHWET TO NORTHEAST CROSS SECTION D-D'
CIPS NEWTON
CIPS
NEWTON LANDFILL

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RAPPS ENGINEERING & APPLIED SCIENCE D:\FILES\SA960831\SHEETS\SEC_D-D'

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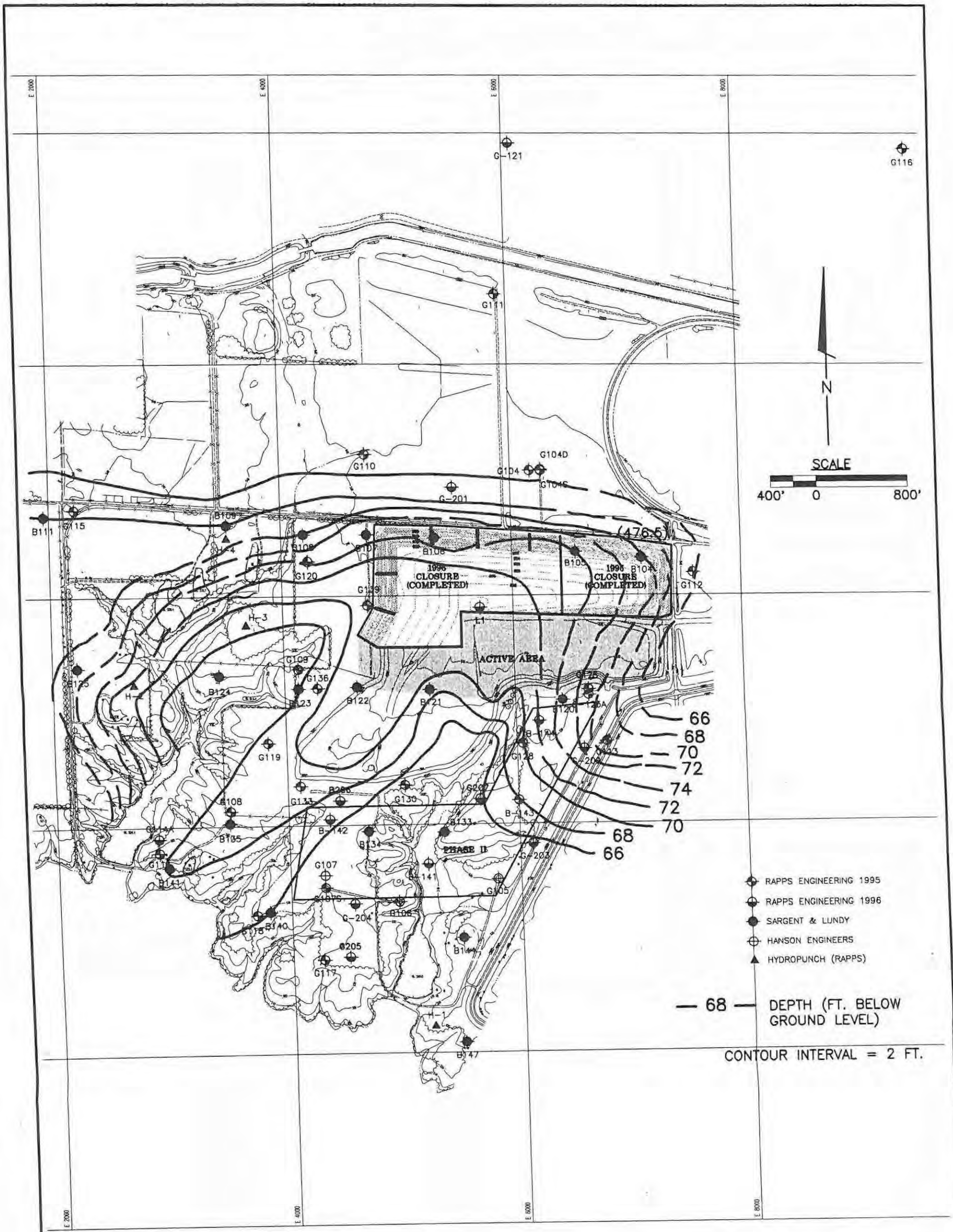

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FIGURE 3-7
DEPTH TO THE BASE OF THE UPPERMOST AQUIFER
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

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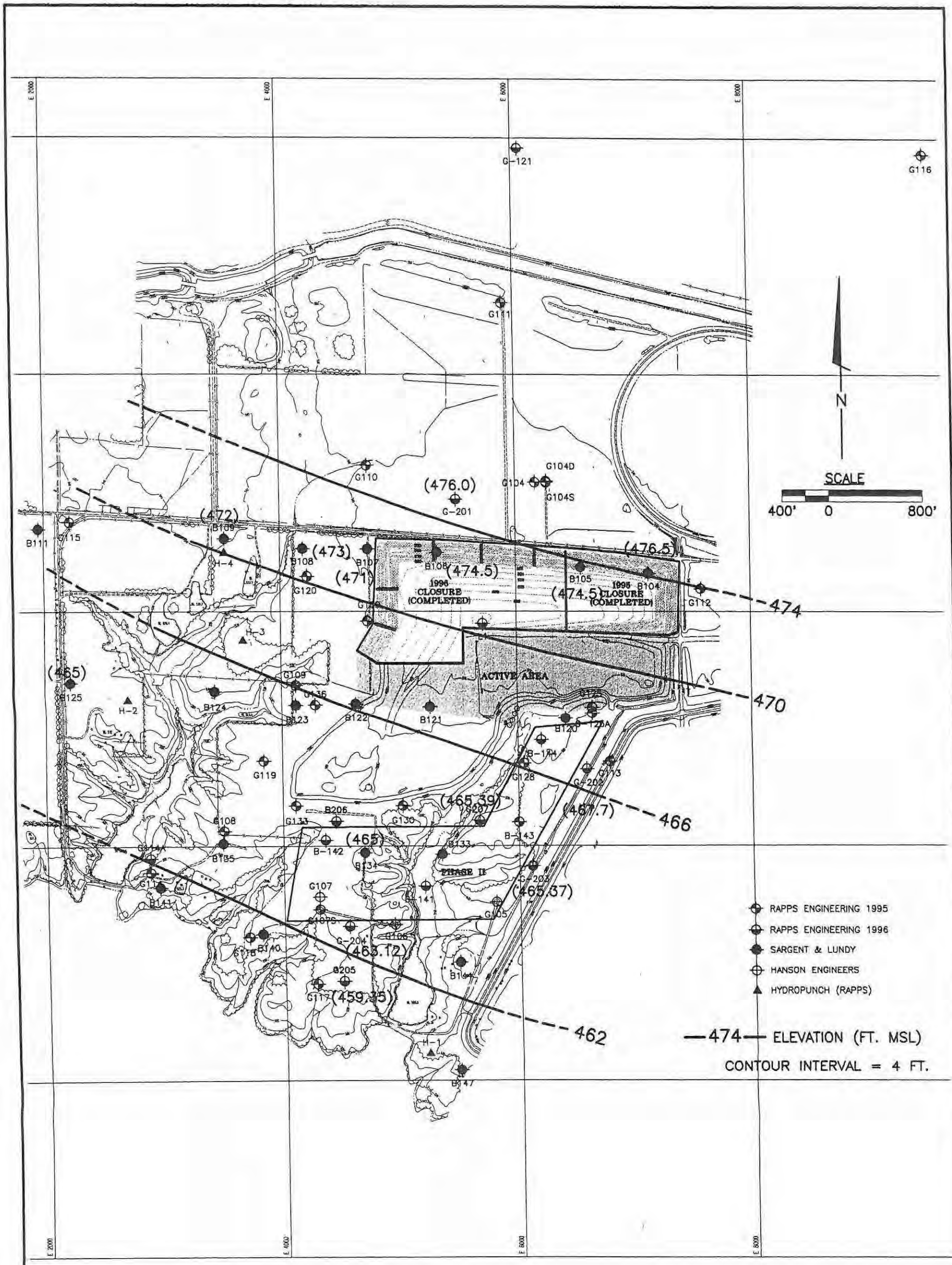

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FIGURE 3-8
ELEVATION OF THE TOP OF THE UPPERMOST AQUIFER
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

RAPPS ENGINEERING & APPLIED SCIENCE C:\FILES\SA96083\FIGURES\3-9

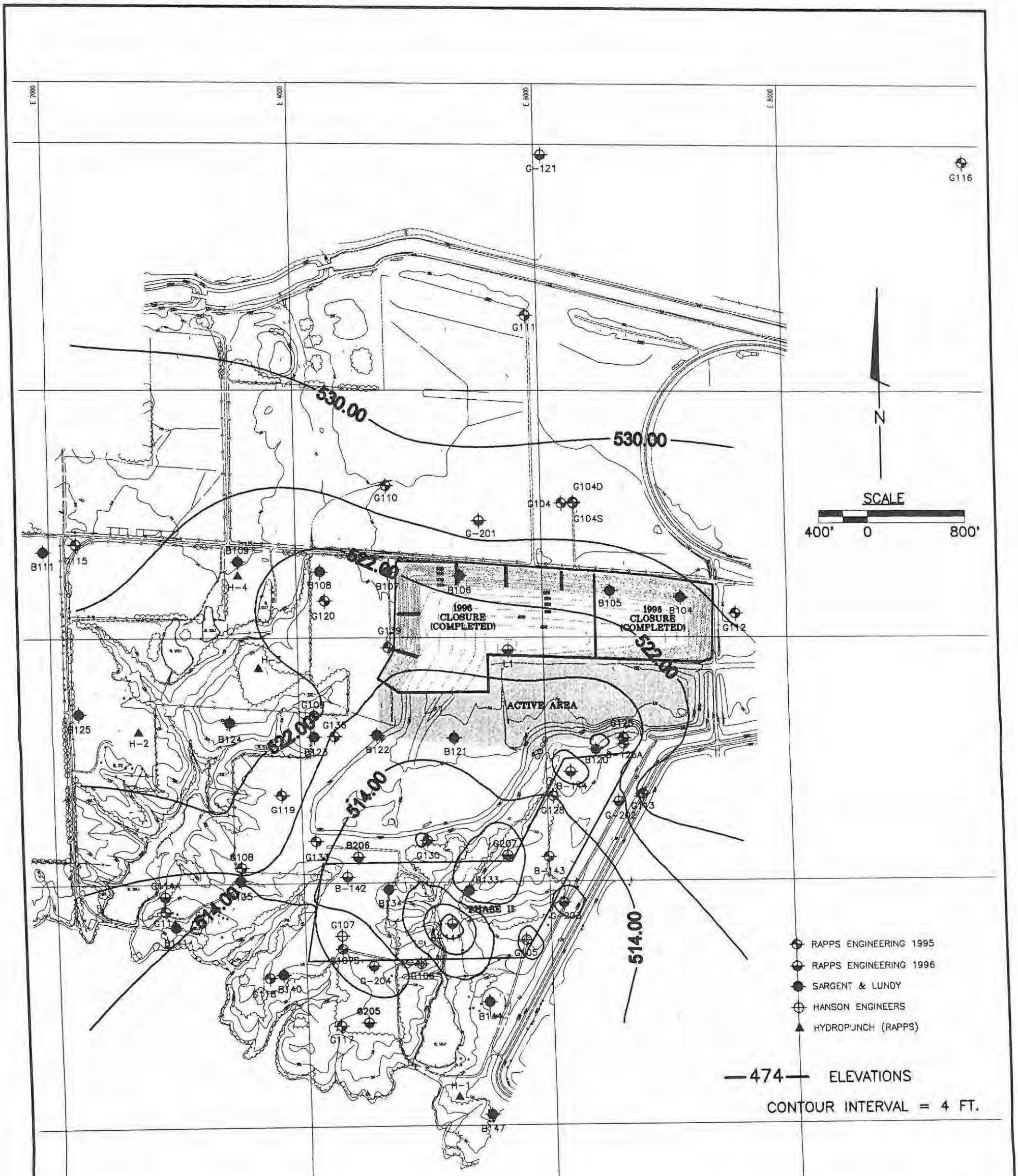

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FIGURE 3-9

ELEVATION OF THE TOP OF THE VANDALIA TILL AQUITARD

NEWTON POWER STATION LANDFILL

CENTRAL ILLINOIS PUBLIC SERVICE

NEWTON, ILLINOIS

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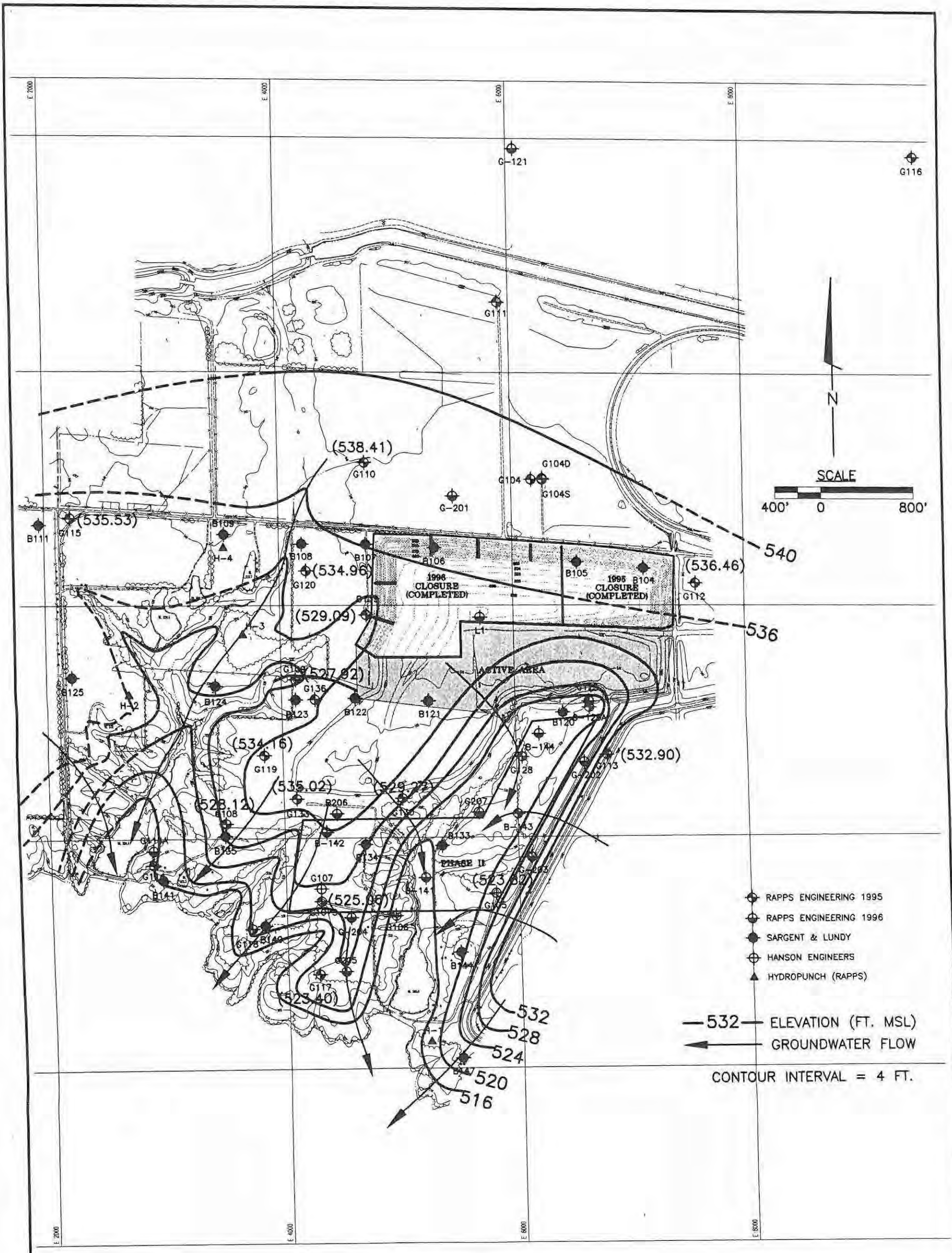

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FIGURE 3-10A
GW FLOW IN UPPER DRIFT UNIT (DECEMBER 1996)
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

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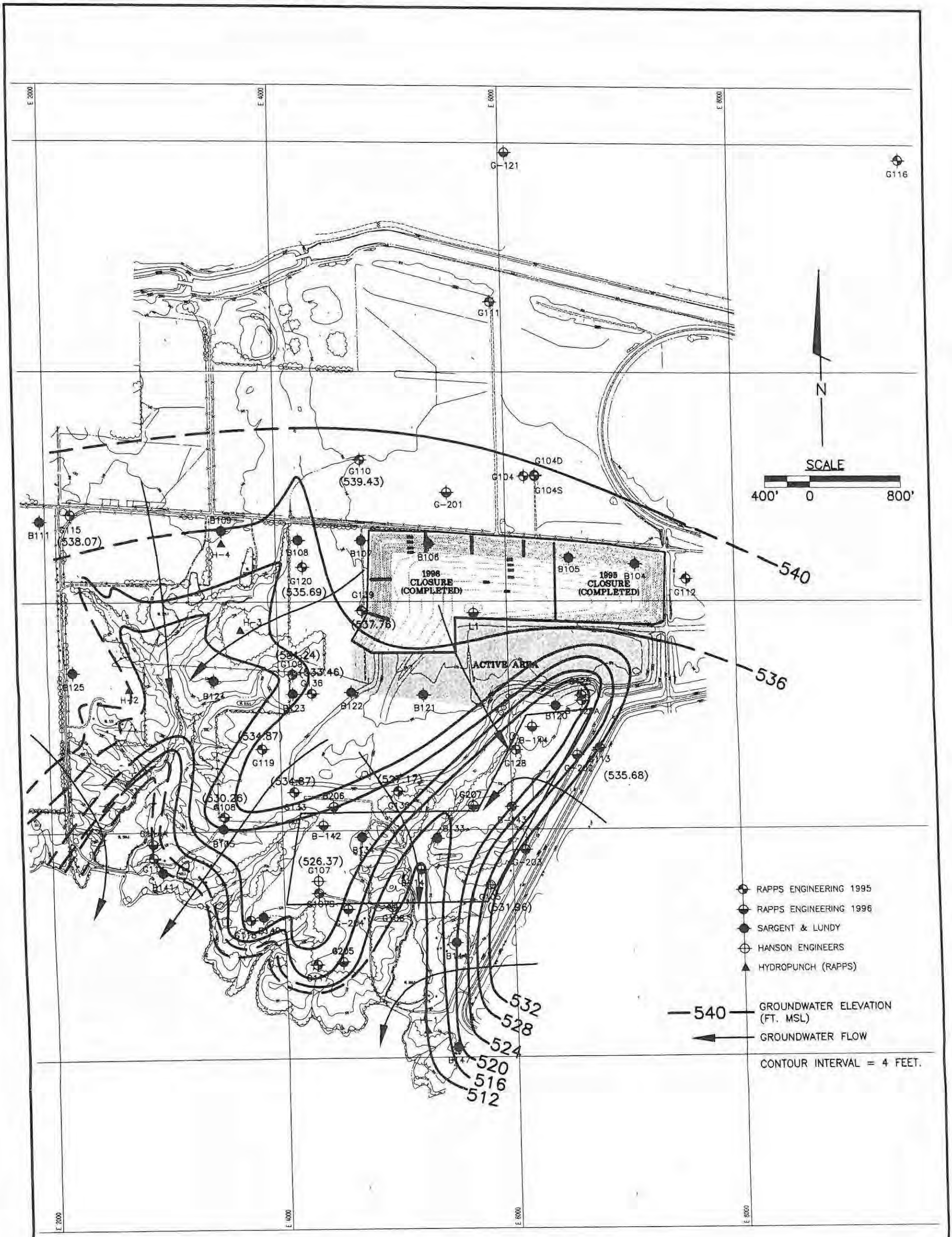

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1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

FIGURE 3-10B
GW FLOW IN UPPER DRIFT UNIT (JANUARY 1997)
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

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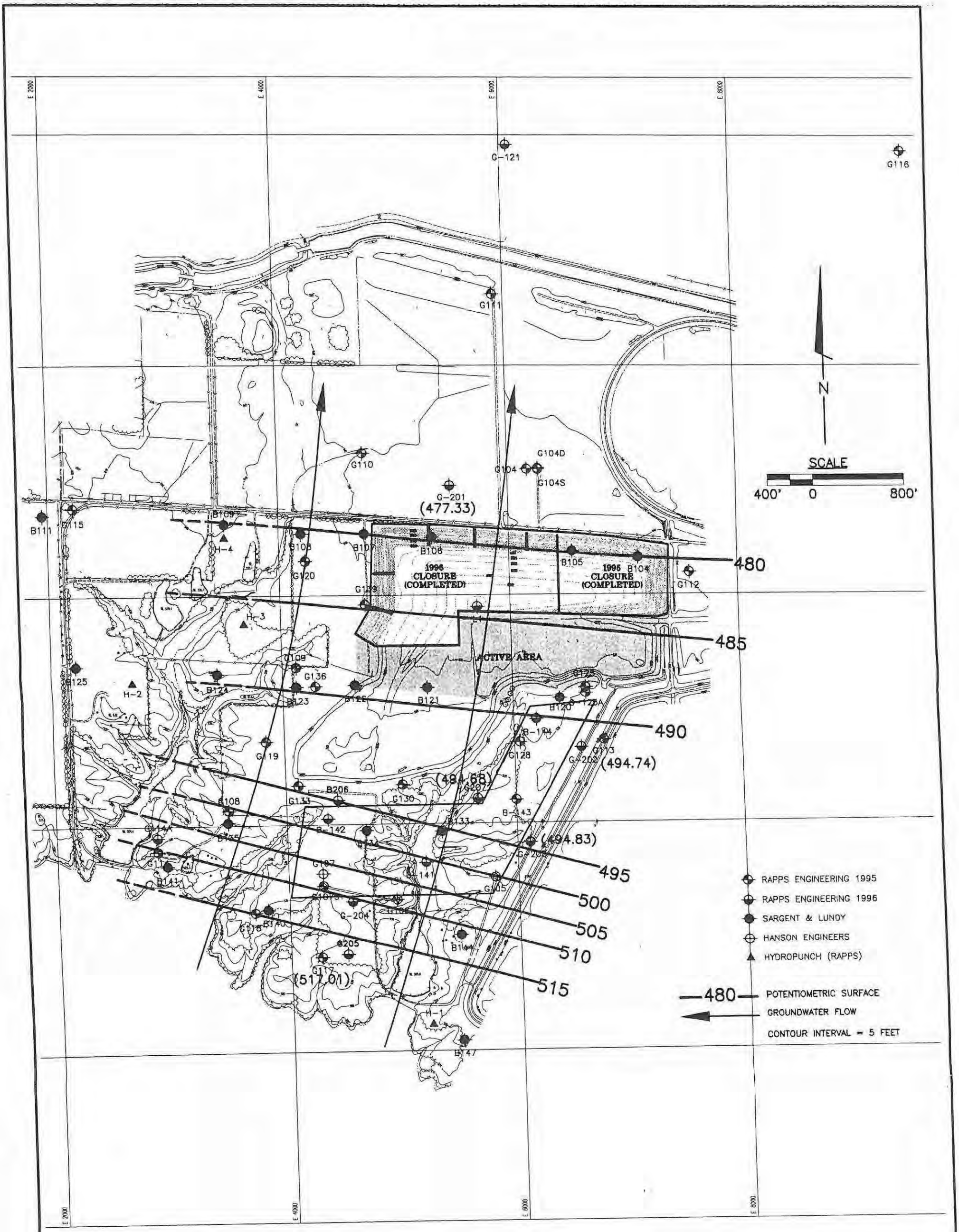

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FIGURE 3-11A
GW FLOW IN UPPERMOST AQUIFER (FEBRUARY 1997)
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

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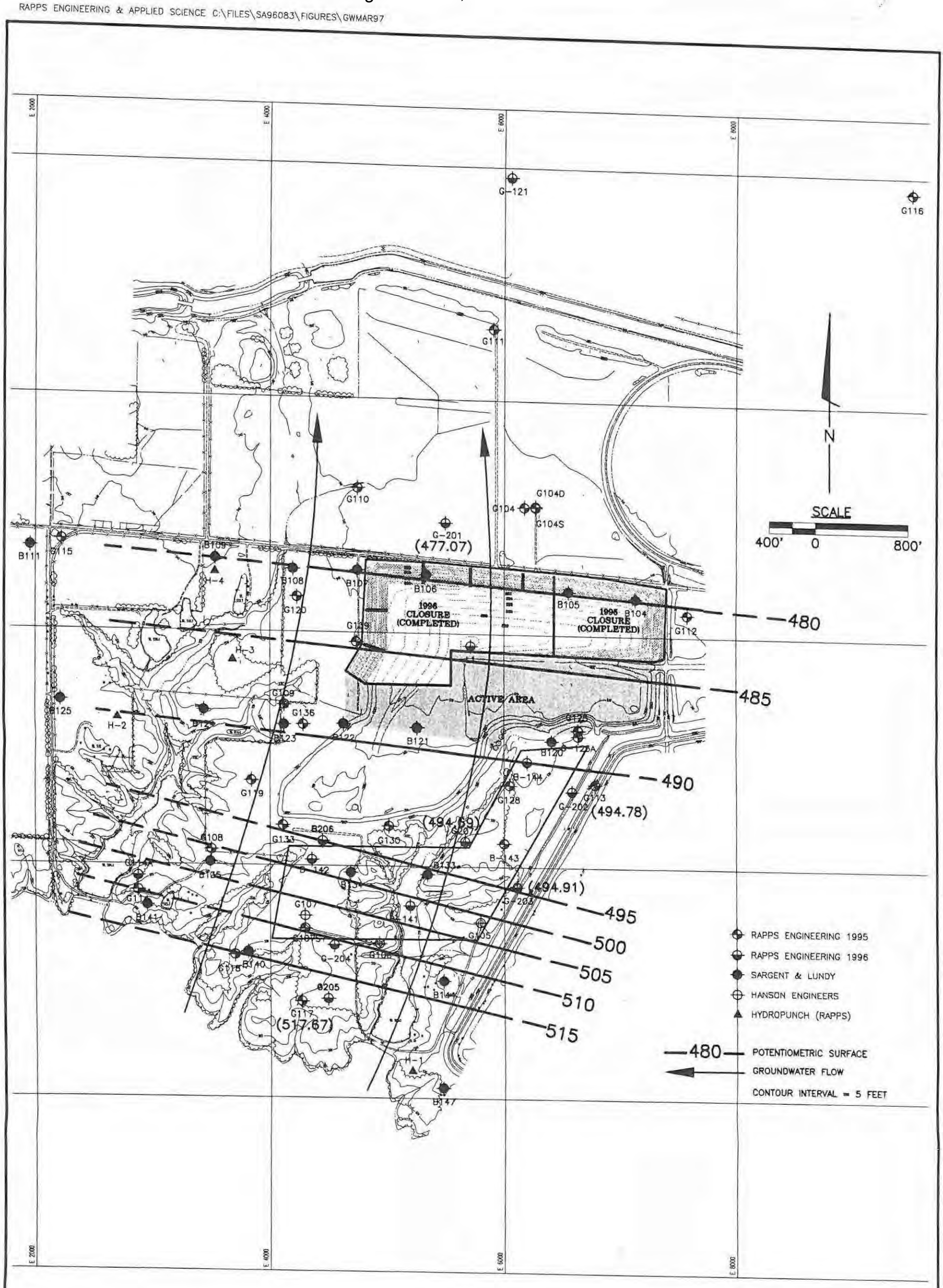

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FIGURE 3-11B
GW FLOW IN UPPERMOST AQUIFER (MARCH 1997)
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE
NEWTON, ILLINOIS

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ATTACHMENT A

LOCAL WATER WELL RECORDS

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(1)

GEOLOGICAL AND WATER SURVEYS WELL RECORD

10. Property owner Finn, Philip Well No. _____
Address R.R. #1 Wheeler IL
Driller Kohnen, Clarence License No. 102-0304
11. Permit No. 100072 Date 06/11/81
12. Water from clay-sand 13. County Jasper
at depth 20 to 21 ft.
14. Screen: Diam. _____ in.
Length: _____ ft. Slot _____
Sec. 21
Twp. 6 N
Rge. 8 E
Elev. _____

126' S 131' E NWc SE NW NE

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (ft)	To (ft)
36	CONCRETE	-1	34

16. Size hole below casing: _____ in.
17. Static level _____ ft. below casing top which is _____ ft. above ground level. Pumping level _____ ft. when pumping at _____ gpm for _____ hours.

18. Formations passed through	Thickness	Bottom
top soil	1	1
brown clay	12	13
brown sandy clay	7	20
brown sand	1	21
gray & brown hardpan	6	27
gray hardpan	7	34

Jasper 12-079-24277-00 21-06N-08E

(4)

GEOLOGICAL AND WATER SURVEYS WELL RECORD

Completed 12-8-75

10. Property owner Paul Moore Well No. _____
Address R.R. # 4, Newton, Illinois
Driller Clarence Kohnen License No. 102-30
11. Permit No. 76089 Date August 14, 1975
12. Water from Yellow Sand 13. County Jasper
Formation
at depth 14 to 15 ft.
14. Screen: Diam. _____ in.
Length: _____ ft. Slot _____
Sec. 22
Twp. 6N
Rge. 8E
Elev. ?

SHOW LOCATION IN SECTION PLAT
109'NL, 117'EL, NE NE NW (permit)

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
36	Concrete Pipe	32	0+1

16. Size Hole below casing: _____ in.
17. Static level _____ ft. below casing top which is _____ ft. above ground level. Pumping level _____ ft. when pumping at _____ gpm for _____ hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Top Soil	2	2
Yellow Sandy Clay	12	14
Yellow Sand	1	15
Yellow Clay	17	32

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED _____ DATE Feb. 10, 1976

JASPER

COUNTY No. 24277

22-6N-8E

(3)

GEOLOGICAL AND WATER SURVEYS WELL RECORD

10. Property owner Johnson, Mike Well No. _____
Address R.R. #1 P.O. Box #164 Wheeler IL
Driller Hacker, Tim License No. 092-6477
11. Permit No. 021586 Date 03/06/92
12. Water from _____ 13. County Jasper
at depth _____ to _____ ft.
14. Screen: Diam. _____ in.
Length: _____ ft. Slot _____
Sec. 22
Twp. 6 N
Rge. 8 E
Elev. _____

SE SE SW

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (ft)	To (ft)

16. Size hole below casing: _____ in.
17. Static level _____ ft. below casing top which is _____ ft. above ground level. Pumping level _____ ft. when pumping at _____ gpm for _____ hours.

18. Formations passed through	Thickness	Bottom
clay top soil	4	4
sandy clay	12	16
soft brown sandstone	6	22
hard gray clay	27	49
muddy sand & gravel	6	55
hard gray clay	20	75
muddy sand & gravel	3	78
hard gray clay	14	92
shale	11	103

Household - Private

Jasper 12-079-24855-00 22-06N-08E

(3)

18. Formations passed through (continued)	Thickness	Bottom
black shale	1	104
shale	14	118
coal	1	119
shale	21	140

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GEOL[illegible] AND WATER SURVEYS [illegible]

Completed 8-31-78

(5)

10. Property owner Fred Miller Well No. _____
Address Rt. #1; Willow Hill, IL
Driller Clarence Kohnen License No. 102-30
11. Permit No. 77998 Date August 9, 1978
12. Water from sandy clay (Formation) 13. County Jasper
at depth 15 to 18 ft.
14. Screen: Diam. _____ in.
Length: _____ ft. Slot _____
Sec. 22
Twp. 6n
Rge. 8e
Elev. x

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
36	Concrete pipe	0+1	42

SHOW LOCATION IN SECTION PLAT
104'NL 109'WL
SW NW (permit)

16. Size Hole below casing: _____ in.
17. Static level _____ ft. below casing top which is _____ ft. above ground level. Pumping level _____ ft. when pumping at _____ gpm for _____ hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Top soil	1	1
Yellow clay	14	15
Yellow sandy clay	3	18
Blue clay	24	42

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED Clarence Kohnen DATE Sept 13, 1978

JASPER mlc COUNTY No 22902 22-6N-8E

[illegible] SURVEYS [illegible]

Completed 7-18-77

(6)

10. Property owner Bernard Marshall Well No. _____
Address R. R. #4; Newton, IL
Driller Clarence Kohnen License No. 102-30
11. Permit No. 61756 Date June 7, 1977
12. Water from sandy clay (Formation) 13. County Jasper
at depth 30 to 31 ft.
14. Screen: Diam. _____ in.
Length: _____ ft. Slot _____
Sec. 23
Twp. 6N
Rge. 8E
Elev. x

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
36	Concrete pipe	0+1	40

SHOW LOCATION IN SECTION PLAT
110'NL 121'WL
NE NW
(permit)

16. Size Hole below casing: _____ in.
17. Static level _____ ft. below casing top which is _____ ft. above ground level. Pumping level _____ ft. when pumping at _____ gpm for _____ hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Top soil	1	1
Yellow clay	8	9
Yellow sandy clay	23	32
Gray sandy clay	8	40

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED Clarence Kohnen DATE July 25, 1977

JASPER mlc COUNTY No 22903 23-6N-8E

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(8)

LOG OF WATER WELL

Property owner C. I. P. S. Well No. 2

Drilled by E. C. BAKER & SONS, INC. Year 1978

Formations passed through	Thickness	Depth of Bottom
YELLOW CLAY HARD	20	20
YELLOW & BLUE CLAY HARD	10	30
HARD BLUE CLAY SIGN OF WATER	25	55
SOFT GRAVELY CLAY	7	62
HARD BLUE CLAY	3	65
S.S. # 61751(0 - 65' COUNTY No. 22747		
Received 9-25-78		

[Continue on back if necessary]

Finished in ____ at ____ to ____ ft.

Cased with ____ inch ____ from 0 to ____ ft.

and ____ inch ____ from ____ to ____ ft.

Size hole below casing ____ inch. Static level from surf. ____ ft.

Tested capacity ____ gal. per min. Temperature ____ °F.

Water lowered to ____ ft. ____ in. in ____ hrs. ____ min.

Length of test ____ hrs. ____ min. Screen ____

Slot ____ Diam. ____ Length ____ Bottom set at ____ ft.

[Show location in Section Plat]

Township name SOUTH MUDDY Elev. ____ Sec. 27

Description of location 2700' E. & 300' N. OF SW CORNER Twp. 6N Rge. 8E

Signed EARL BAKER JR. 300' N. OF TRAILER ST. County JASPER

JASPER

Copy for Illinois State Geological Survey Index: 27-6N-8E

(9)

LOG OF WATER WELL

Property owner C. I. P. S. Well No. 3

Drilled by E. C. BAKER & SONS, INC. Year 1978

Formations passed through	Thickness	Depth of Bottom
GRAY CLAY	5	5
YELLOW CLAY	10	15
BLUE CLAY	8	23
ROCK (BOULDER)		
S.S. # 61752(0-28' COUNTY No. 22748		
Received 9-25-78		

[Continue on back if necessary]

Finished in ____ at ____ to ____ ft.

Cased with ____ inch ____ from 0 to ____ ft.

and ____ inch ____ from ____ to ____ ft.

Size hole below casing ____ inch. Static level from surf. ____ ft.

Tested capacity ____ gal. per min. Temperature ____ °F.

Water lowered to ____ ft. ____ in. in ____ hrs. ____ min.

Length of test ____ hrs. ____ min. Screen ____

Slot ____ Diam. ____ Length ____ Bottom set at ____ ft.

[Show location in Section Plat]

Township name SOUTH MUDDY Elev. ____ Sec. 27

Description of location 2500' E. & 600' N. OF SW CORNER Twp. 6N Rge. 8E

Signed EARL BAKER, JR. County JASPER

JASPER

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(10)

LOG OF WATER WELL

Property owner C. I. P. S. Well No. 4

Drilled by E. C. BAKER & SONS, INC. Year 1978

Formations passed through	Thickness	Depth of Bottom
GRAY CLAY	10	10
YELLOW CLAY	15	25
GREEN DIRTY SAND	5	30
HARD BLUE SANDY CLAY	35	65

S.S. #61753(0-60') COUNTY No. 22747

Received 9-25-78

[Continue on back if necessary]

Finished in ____ at ____ to ____ ft.

Cased with ____ inch ____ from 0 to ____ ft.

and ____ inch ____ from ____ to ____ ft.

Size hole below casing ____ inch. Static level from surf. ____ ft.

Tested capacity ____ gal. per min. Temperature ____ °F.

Water lowered to ____ ft. ____ in. in ____ hrs. ____ min.

Length of test ____ hrs. ____ min. Screen ____

Slot ____ Diam. ____ Length ____ Bottom set at ____ ft.

[Show location in Section Plat]

Township name SOUTH MUDDY Elev. ____ Sec. 27

Description of location 2525' E. & 600' N. OF SW CORNER Twp. 6N

Rge. 8E

Signed EARL BAKER, JR. County JASPER

20' E. OF #3 30' S. 25' E. OF STA 5200

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(11)

LOG OF WATER WELL

Property owner C. I. P. S. Well No. 5

Drilled by E. C. BAKER & SONS, INC. Year 1978

Formations passed through	Thickness	Depth of Bottom
YELLOW CLAY	5	5
BLUE CLAY	25	30
GREEN SANDY CLAY	10	40
BLUE GRAVELY ~~SH~~ CLAY	13 ~~20~~	53
GREENISH BLUE SAND	2	55
HARD GREEN CLAY X/GRAVEL	7	62
SHALE HARD	1	63

S.S. # 61754(0-63')

Received 9-25-78 COUNTY No. 22748

[Continue on back if necessary]

Finished in ____ at ____ to ____ ft.

Cased with ____ inch ____ from 0 to ____ ft.

and ____ inch ____ from ____ to ____ ft.

Size hole below casing ____ inch. Static level from surf. ____ ft.

Tested capacity ____ gal. per min. Temperature ____ °F.

Water lowered to ____ ft. ____ in. in ____ hrs. ____ min.

Length of test ____ hrs. ____ min. Screen ____

Slot ____ Diam. ____ Length ____ Bottom set at ____ ft.

[Show location in Section Plat]

Township name SOUTH MUDDY Elev. ____ Sec. 27

Description of location 2500' E. & 1200' N. OF SW CORNER Twp. 6N

Rge. 8E

Signed EARL BAKER JR. County JASPER

JASPER ON ROAD BY LAKE 60' S. OF HIGH WATER

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(12)

GEOLOGICAL AND WATER SURVEYS WELL RECORD

10. Property owner Johnson, Donald Well No. #1
Address R.R. #1 Newton IL
Driller Green, William E. License No. 102-3316
11. Permit No. 020174 Date 04/19/91
12. Water from sand gravel 13. County Jasper
at depth 21 to 24 ft. Sec. 21
14. Screen: Diam. ____ in. Twp. 6 N
Length: ____ ft. Slot ____ Rge. 8 E
Elev. ____

15. Casing and Liner Pipe NE NE SE

Diam. (in.)	Kind and Weight	From (ft)	To (ft)
30	CONCRETE	11	25

16. Size hole below casing: ____ in.
17. Static level 5 ft. below casing top which is 2 ft. above ground level. Pumping level ____ ft. when pumping at ____ gpm for ____ hours.

18. Formations passed through	Thickness	Bottom
top soil	1	1
red sandy clay	20	21
yellow sand & gravel	3	24
dark gray shale	1	25

Household - Private

Jasper 12-079-24817-00 21-06N-08E

GEOLOGICAL WATER SURVEYS WATER WELL RECORD

Completed 10-1-68

(13)

10. Dept. Mines and Minerals permit No. NF 4772 Year 1968
11. Property owner Lawrence Cochran Well No. ____
Address R.R. #1 Newton Ill.
Driller C. Kohnen License No. 92-326
12. Water from sand (Formation) 13. County Jasper
at depth 14 to 15 ft. Sec. 28
14. Screen: Diam. ____ in. Twp. 6N
Length: ____ ft. Slot ____ Rng. 8E
Elev. ____

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
26	Concrete	26	0

SHOW LOCATION IN SECTION PLAT
115' SL, 132' EL of SE (permit)

16. Size Hole below casing: ____ in.
17. Static level ____ ft. below casing top which is ____ ft. above ground level. Pumping level ____ ft. when pumping at ____ gpm for ____ hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
brown top soil	1/2	1/2
brown clay	10 1/2	11
yellow sandy clay	3	14
brown sand	1	15
brown clay	11	26
(CONTINUE ON SEPARATE SHEET IF NECESSARY)		

SIGNED C. Kohnen DATE 10 4/68

COUNTY No. 2224

JASPER 28-6N-8E

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GEO. ... AL AND WATER SURVEYS ... CIPS AND DEPTH OF ... Completed 9-27-78

(16)

10. Property owner CONSERVATION Well No. 1
Address SPRINGFIELD, IL.
Driller E. C. BAKER & SONS, INC. License No. 92.62
11. Permit No. 79078 Date SEPT. 6, 1978
12. Water from DRIFT (Formation) 13. County JASPER
at depth 21 to 78 ft.
14. Screen: Diam. ____ in.
Length: ____ ft. Slot ____
Sec. 34
Twp. 6N
Rge. 8E
Elev. ____

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
6" ID	SCH. 40, 19#, .280 WALL		
	BLK STEEL PIPE	+2.6	-21.0
36" ID	CONCRETE PIPE	-21.0	-78.0

SHOW LOCATION IN SECTION PLAT
100' NL
2540' EL
NE (permit)

16. Size Hole below casing: ____ in.
17. Static level ____ ft. below casing top which is ____ ft. above ground level. Pumping level ____ ft. when pumping at ____ gpm for ____ hours. 750 TO 1000 GPD ESTIMATED

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
SOIL	3	3
YELLOW CLAY	9	12
YELLOW SANDY CLAY (WATER)	1	~~12~~ 13
YELLOW HARDPAN	7	20
GLACIAL DRIFT	32 ~~8~~	52
GRAY SAND (WATER)	6	58
GLACIAL DRIFT	14	72
SAND (WATER)	3	75
GLACIAL DRIFT	3	78

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED VERNON A. BAKER DATE SEPT. 27, 1978

COUNTY No. 22906

JASPER 34-6N-8E

... STATE OFFICE ... SPRINGFIELD, ... WATER SURVEYS SECTION. BE SURE TO

(17)

GEOLOGICAL AND WATER SURVEYS WELL RECORD
Completed 5-4-74

10. Property owner Ernest E. Crouse Well No. ____
Address R.P.# 1 Box 202 Newton, Illinois
Driller Clarence Kohnen License No. 92-326
11. Permit No. 21736 Date Nov. 5, 1973
12. Water from Yellow Sandy Clay (Formation) 13. County Jasper
at depth 15 to 18 ft.
14. Screen: Diam. ____ in.
Length: ____ ft. Slot ____
Sec. 36
Twp. 6 N
Rge. 8 E
Elev. X

15. Casing and Liner Pipe

Diam. (in.)	Kind and Weight	From (Ft.)	To (Ft.)
36"	Concrete Pipe	30	0+1

SHOW LOCATION IN SECTION PLAT
79'NL 87'WL of NE NW SE (permit)

16. Size Hole below casing: ____ in.
17. Static level ____ ft. below casing top which is ____ ft. above ground level. Pumping level ____ ft. when pumping at ____ gpm for ____ hours.

18. FORMATIONS PASSED THROUGH	THICKNESS	DEPTH OF BOTTOM
Top Soil Brown	1	1
Yellow Clay	14	15
Yellow Sandy Clay	3	18
Blue Clay	12	30

(CONTINUE ON SEPARATE SHEET IF NECESSARY)

SIGNED C. Kohnen DATE 5/14/74

COUNTY No. 22503

JASPER 36-6N-8E

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ATTACHMENT B

BORING LOGS, BORING SEALING FORMS AND IEPA WELL COMPLETION REPORTS

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RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY — Date July 5, 19 73 — Job No. [illegible]
Location of Borings NEWTON, ILLINOIS — PROPOSED POWER PLANT

All borings are plotted to a scale of 1" = 5' fr. using ELEVATIONS AS FURNISHED as a fixed datum.

	No. 101		No. 102	
	GROUND SURFACE		GROUND SURFACE	
	ELEV. 542.5'	0.0'	ELEV. 541.3'	0.
	BROWN MOIST SILTY TOP SOIL	1.0'	BROWN MOIST VERY FINE SANDY SILT TOP SOIL	1
540	BROWN & GREY MOIST SILTY CLAY	8	BROWN & GREY MOIST SILTY CLAY TR. SAND	8
535		7.0'		6
	BROWN MOIST TO DAMP SILT	45	BROWN & GREY MOIST SILT	31
530	SOME CLAY & SAND TR. GRAVEL & ROCK FRAGMENTS	60/7	SOME CLAY W/SAND	12.
		16.0'	BROWN WET VERY FINE TO MED. SAND SOME SILT	60/5 13.
525	BROWN WET FINE TO COURSE SAND	18.0'		
		38	BROWN & GREY MOIST TO DAMP VERY COMPACT SAND TR. GRAVEL	60/6
520	GREY MOIST CLAYEY SILT TR. SAND & GRAVEL	100/4		22.
				43
515		27.0'	GREY MOIST SILT SOME CLAY & SAND TR. GRAVEL	
		21		38
510		41		45
505		42		38. 73
500	BROWN & GREY MOIST CLAYEY SILT TR. SAND	48	BROWN & GREY MOIST CLAYEY SILT SOME SAND TR. GRAVEL	55
495		39		73
490		52.0'		52.
		72		73
		55		55
480	GREY WET COMPACT FINE TO COURSE SAND SOME GRAVEL W/SILT	45	GREY MOIST SILT SOME CLAY & SAND TR. GRAVEL	48

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470

465

GREY COMPACT SILT SOME CLAY & SAND TR. GRAVEL

455

450

BROWN & GREY COMPACT SILT W/SHALE

445

GREY VERY HARD SHALE

440

BORING ADVANCED BY AUGER & ROTARY WASH METHOD.
WATER ENCOUNTERED @ 15.0' TO 18.0'.
USED 40.0' OF BX CASING.

435

430

425

420

415

49

78.5'

53

62

53

92.0'

67/10

97.8'

100/2 100.0'

60/4

56

51

45

GREY MOIST SILT SOME CLAY W/SAND & GRAVEL

49

60

61

10

68

52

GREY MOIST FINE SANDY SILT TR. CLAY & FRAGMENTS & GRAVEL

27

100/1

11

13

DRY VERY COMPACT SILTY SHALE

BORING ADVANCED BY AUGER & ROTARY WASH METHOD.
WATER ENCOUNTERED @ 12.0' TO 13.0'.
USED 40.0' OF BX CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot using 140-lb weight falling 30 inches.

Total Footage 200.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet ____ of ____

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY

Location of Borings NEWTON, ILLINOIS

Date JULY 3, 19 71 Job No. 18-212-11

PROPOSED POWER PLANT

All borings are plotted to a scale of 1" = 5' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

	No. 103		No. 104	
	GROUND SURFACE		GROUND SURFACE	
	ELEV. 541.0'	0.0'	ELEV. 540.4'	0
	BROWN DAMP SILTY TOP SOIL	1.0'	BROWN VERY MOIST SILTY TOP SOIL	1
540				
	BROWN & GREY MOIST CLAYEY	9		11
535	SILT SOME SAND TR. GRAVEL		BROWN & GREY MOIST SILTY	
		10	CLAY TR. SAND	11
530		11.0'		
	BROWN WET SILTY FINE SAND	10		52 14
525		16.5'		
		47	GREY MOIST SILT SOME CLAY	
			& SAND TR. GRAVEL	44
520				
		40		84 24
515				
		42		57
510	GREY MOIST SILT		GREY MOIST CLAYEY SILT	
		37	SOME SAND TR. GRAVEL	
	SOME CLAY &			43
505				
	SAND TR. GRAVEL	74		
				45 41
500				
		63	GREENISH GREY MOIST CLAY	
			SOME SILT TR. SANDSEAM	14
495				47
		60		89
490				
		39	BROWN & GREY MOIST CLAYEY	
			SILT SOME SAND TR. GRAVEL	53
		44		66
480				
		63.0'		6
	GREY WET COMPACT FINE TO COARSE SAND SOME SILT	66/9	WET SILT W/COMPACT SAND & GRAVEL	64/6
		66.0'		

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470			49
		60/7	
465	GREY COMPACT SILT SOME		61
	CLAY & SAND TR. GRAVEL	50	
460			104
		44	
455			38
		40	
450			37
		57	GREY MOIST SILT SOME SAND
445			& CLAY TR. GRAVEL 35
		35	
440			28
		27	
435			33
		30	
30		11?.?'	32
	GREENISH GREY MOIST SILT	36	
425	TR. CLAY VERY FINE SAND		29
		52 120.0'	
420	BORING ADVANCED BY AUGER & ROTARY WASH METHOD. WATER ENCOUNTERED @ 13.0'. USED 40.0' OF 8X CASING.		56
			BORING ADVANCED BY AUGER & ROTARY WASH METHOD. WATER ENCOUNTERED @ 18.0'. USED 40.0' OF 8X CASING.
415			

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR – NUMBER OF BLOWS
DENOMINATOR – PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 240.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet ___ of ___

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY

Location of Borings NEWTON, ILLINOIS

Date JULY 17, 19 73 Job No. CR-21241-

PROPOSED POWER PLANT ADDITION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 105

545	GROUND SURFACE		
	ELEV. 544.4'		0.0'
	BROWN MOIST SILTY TOP SOIL		0.8'
540	BROWN & GREY MOIST SILTY	9	
	CLAY TR. SAND		
535		8	
			12.0'
530	GREY & BROWN MOIST COMPACT SILT W/SAND TR. GRAVEL & CLAY	60/5	
			16.0'
	GREY MOIST SILT SOME	60/4	
520	CLAY & SAND TR. GRAVEL		
		79	26.5'
515	BROWN & GREY MOIST SILT & CLAY TR. SAND & GRAVEL	16	
			32.0'
510		60'	
	GREY MOIST SILT SOME SAND		
505		34	
	& CLAY TR. GRAVEL		
500		32	
			48.0'
	GREY WET FINE TO COURSE SAND	80/5	
490	SOME GRAVEL W/VERY COMPACT SILT	60/4	
			56.0'
485		31	

No. 106

GROUND SURFACE		
ELEV. 542.5'		0.
BROWN & GREY DRY TO	9	
MOIST SILT SOME		
CLAY TR. SAND	7	
		13.
	65/8	
	68/9	
	47	
	29	
	28	
BROWN W/GREY COMPACT		
	31	
SILT, SAND,		
	35	
SOME CLAY,		
	37	
TR. GRAVEL		
	39	

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480	GREY MOIST SILT [illegible]	[illegible]	
	SAND TR. GRAVEL & SANDSTONE		
475	GRAVEL OR FRAGMENTS	21	
470		28	
465		26	81.5'
460		57	
455		34	
450		69	
	GREY MOIST COMPACT CLAYEY		
445	SILT SOME SAND TR. GRAVEL	20	
	& SANDSTONE FRAGMENTS		
440		29	
435		36	
430		30	
425		46	120.0'

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12' TO 14.0'.

USED 40.0' OF BX CASING.

	46	
	31	
	26	
		77
	32	
BROWN & GREY MOIST		
CLAYEY SILT	27	
TR. SAND & GRAVEL	29	
		92
GREY MOIST SILT SOME	28	
CLAY TR. SAND & GRAVEL		98
GREY MOIST FINE TO COURSE SANDY SILT TR. GRAVEL	47	10[illegible]
GREY MOIST SILT SOME	24	
CLAY, SAND TR. GRAVEL		
	22	
		11[illegible]
GREY MOIST VERY FINE	60	
SANDY SILT TR. CLAY		
	48	12

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12.0'.

USED 40.0' OF BX CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS

NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 240.0'
Foreman A. ANDERSON
Classification by /FOREMAN
Sheet ___ of ___

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY — Date JULY 23, 19 73 — Job No. CB-21241-K
ation of Borings NEWTON, ILLINOIS — PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 107

545	GROUND SURFACE		
	ELEV. 541.3'		0.0
540	BROWN & GREY DAMP TO	10	
535	MOIST SILT, SOME		
	CLAY, TR. SAND	11	
530			11.5'
		63	
525			
		48	
520			
		67/7	
515			
		42	
510	BROWN & GREY		
		53	
505	MOIST COMPACT		
		62	
500	SILT SOME CLAY,		
		60	
	SAND, TR. GRAVEL		
		92/4	
490			

No. 108

GROUND SURFACE		
ELEV. 536.8'		0.
BROWN MOIST SILTY TOP SOIL		2.
	20	
BROWN & GREY MOIST		
	17	
SILT W/SAND		
	63	
SOME CLAY TR. GRAVEL		
	46	
	71	
		26
	60	
GREY MOIST SILT SOME		
CLAY - SAND TR. GRAVEL	67	
		38
	40	
GREY MOIST SILT SOME		
	37	
CLAY TR. SAND & GRAVEL		

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485		50	33
480		49	33
475		48	75/9
		67.0'	
470		80/5	VERY COMPACT FINE TO 75/9
	GREY CEMENTED		
465	SAND, GRAVEL,	42	COURSE SILTY SAND 100/5
	SILT, CLAY		
460		63	W/GRAVEL SEAM 72
		82.0'	
455	GREY MOIST SILT, SOME	50	74
	CLAY W/SAND & GRAVEL		
450		42	47
		91.0'	
445		40	GREY COMPACT SILT & 59
	GREY MOIST SILT		CLAY W/FINE SAND
440	SOME CLAY,	35	50
435	SAND, TR. GRAVEL	38	TR. GRAVEL 68/9
430		35	73
		117.0'	DARK GREY HARD SLATE & SHALE
425	GREY SANDY SILT - CLAY	67/10	GREY VERY HARD SHALE 100/1
		116.0'	
	GREY MOIST SILT SOME CLAY,		BORING ADVANCED BY AUGER TO 40.0'. NO WATER ENCOUNTERED WHILE AUGERING.
	SAND TR. GRAVEL		
420		47 120.0'	USED 40.0' OF 8x CASING.
	BORING ADVANCED BY AUGER TO 40.0'. WATER ENCOUNTERED @ 17.0'.		
	USED 40.0' OF 8x CASING.		

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive

Total Footage 230.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet of

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RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY — Date JULY 30, 1973 — Job No. 67-21241-
Location of Borings NEWTON, ILLINOIS — PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' fr. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 109

GROUND SURFACE

ELEV. 540.7'
BROWN DRY SILTY TOP SOIL — 0.2' — 1.0'

BROWN & GREY DAMP TO MOIST CLAYEY SILT SOME SAND TR. GRAVEL — 14 — 11 — 13.2'

BROWN MOIST COMPACT FINE TO COURSE SANDY SILT SOME CLAY TR. GRAVEL — 41 — 62/11 — 70/6 — 27.0'

GREY MOIST COMPACT SILT SOME CLAY, SAND TR. GRAVEL — 64 — 33.5'

GREY VERY COMPACT SILT — 65/5 — 36.0'

62/10

GREY MOIST COMPACT SILT SOME CLAY — 65/11 — 65 — 51

SAND TR. GRAVEL — 42

No. 110

GROUND SURFACE

ELEV. 538.1'
BROWN MOIST SILTY TOP SOIL

BROWN & GREY MOIST CLAYEY SILT TR. SAND — 11 — 9

BROWN & GREY MOIST COMPACT SILT SOME CLAY, SAND TR. GRAVEL — 68/11 — 81 — 75

GREY MOIST — 65/11 — 62

SILT SOME CLAY, SAND TR. GRAVEL — 56 — 53 — 42 — 53

GREY MOIST SILT SEAM — 5

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475

69.0'

69

GREY WET COMPACT FINE

TO COURSE SAND W/SILT 66/11

465 & SMALL GRAVEL TR.

100/10

460 LARGE GRAVEL OR COBBLES

93.5'

56

455

GREY MOIST SILT SOME

CLAY W/FINE TO COURSE 32

450 SAND TR. LARGE GRAVEL

SEAM OR COBBLES 93.0'

445 30

37

440 GREY MOIST

36

CLAYEY SILT

36

430

SOME SAND

39

425

TR. GRAVEL

27 120.0'

420

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12.0'.

USED 40.0' OF 8X CASING.

415

GREY MOIST CLAYEY SILT

08/11

SOME CLAY W/SAND

TR. GRAVEL 36

72.0

GREY MOIST FINE TO COURSE 52

SAND, GRAVEL & SILT

78.0

46

29

GREY MOIST

36

SILT SOME

33

CLAY, SAND

25

TR. GRAVEL

104.

GREY MOIST SILTY SAND 30

106.

GREY MOIST SILTY CLAY SOME 31

SAND TR. GRAVEL

34

118

GREY MOIST SANDY
SILT W/GRAVEL 75/10 120

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12.5'.

USED 40.0' OF 8X CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 240.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet ____ of ____

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY
Location of Borings NEWTON, ILLINOIS

Date AUGUST 7, 1973 Job No. 73-2124-1
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 5' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 111

GROUND SURFACE

ELEV. 539.6'

LIGHT BROWN SILTY TOP SOIL — 0.0' / 1.0'

535

BROWN & GREY MOIST CLAYEY SILT SOME SAND TR. GRAVEL — 10

530 — 10

12.5'

525 — 53

520 — 61/5

BROWN & GREY COMPACT SILT SOME CLAY, SAND, TR. GRAVEL — 75/10

510 — 46

32.0'

505 — 60

500 — 57

495 — 54

GREY MOIST SILT SOME CLAY, SAND, TR. GRAVEL — 68

490

485 — 43

480 — 43

475

No. 112

GROUND SURFACE

ELEV. 530.3'

BROWN & GREY DAMP TO MOIST SILT — 11

BROWN & GREY MOIST SILT SOME CLAY, SAND, TR. GRAVEL — 29

BROWN TR. GREY VERY COMPACT SILT, SAND, & GRAVEL — 66/10

BROWN WET SAND SEAM — 53

71

GREY MOIST SILT SOME CLAY, SAND, TR. GRAVEL — 50

62/9

W/SILTY SAND SEAM — 63

49

23

19

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		31	
470			68.0'
		75/6	
	GREY DAMP VERY COMPACT		
465	SILTY SAND		
		69/6	
			76.2'
460			
		32	
455	GREY MOIST SILT SOME		
		25	
	CLAY, SAND, TR. GRAVEL		
450			
		32	
445			
	MOIST GRAVEL SEAM W/	77/6	94.1'
	SILTY SAND		96.5'
440			
	GREY MOIST SILTY CLAY,	28	
435	SAND, TR. GRAVEL		
		32	
430			108.0'
	GREY VERY COMPACT SILTY SAND TR. GRAVEL	62/2	
			112.0'
425			
	GREY MOIST SILTY CLAY	37	
	SOME SAND TR. GRAVEL		
420			
		33	120.0'

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12.0'.

415 USED 40.0' OF 8X CASING.

	GREY MOIST SILTY		
	CLAY SOME SAND	20	
	TR. GRAVEL		
		23	
		25	
		64/6	
	GREY MOIST COMPACT		
	SILTY SAND	62/7	
		38	
	GREY MOIST SILTY CLAY	34	
	TR. SAND & GRAVEL	30	
		19	
		23	
	DARK GREY HARD SHALEY COAL	100/3	

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 19.0'.

USED 40.0' OF 8X CASING.
GAS ENCOUNTERED BEFORE DRIVING LAST SAMPLE. WATER WAS BLOWN OUT OF THE HOLE & THE GAS CONTINUED TO BLOW FOR 35 MINUTES.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling [illegible]

Total Footage 230.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet [illegible] of [illegible]

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY
ion of Borings NEWTON, ILLINOIS

Date SEPTEMBER 24, 19 73 Job No. CB-21241-KC
PROPOSED POWER PLANT EXPANSION

ings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 119

GROUND SURFACE
ELEV. 538.6'

0.0'		
0.9'	LIGHT GREY SILTY-TOP SOIL	
		16
	BROWN, GREY, CLAYEY SILT SOME SAND & GRAVEL	8
		27
		40
22.0'		
22.9'	GRAVEL - COBBLE	31
		26
	BROWN, GREY, SILTY CLAY	32
		25
		50
	TR. SAND & GRAVEL	44
		49
		36
		34

No. 120

GROUND SURFACE
ELEV. 527.5'

0.0		
0.6	LIGHT GREY SILTY TOP SOIL	
	LIGHT BROWN & GREY CLAYEY SILT	10
7.5		
	GREY & BROWN SANDY CLAY	8
12.5		
	GREY SANDY SILT SOME GRAVEL	36
19.4'		
		60/7
	COMPACT SANDY SILT SOME GRAVEL	60/7
29.1'		
30.0'	COURSE SAND & GRAVEL	41
		42
	GREY SILTY CLAY TR.	25
		28
	SAND & GRAVEL	50

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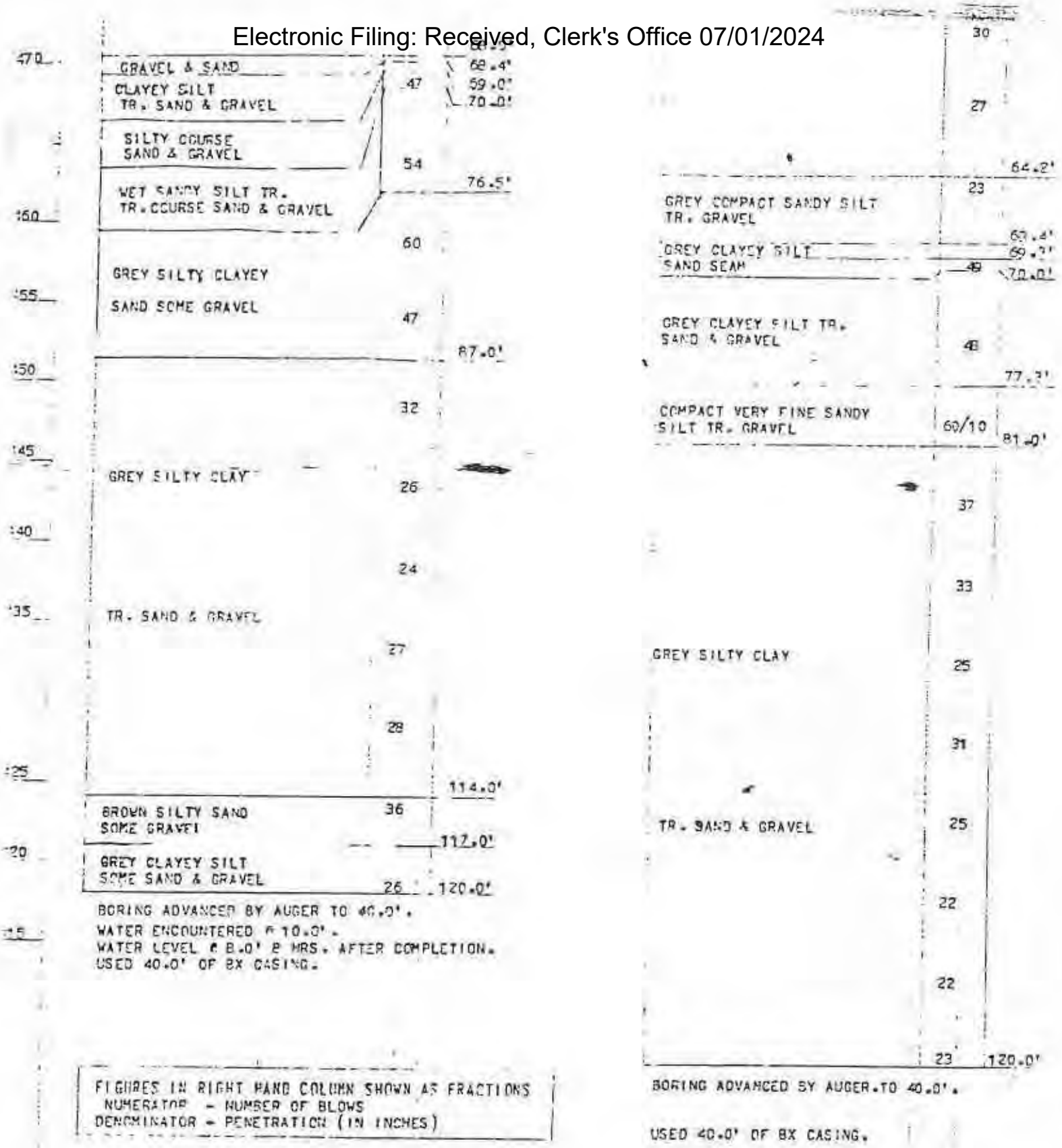

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 10.0'.
WATER LEVEL @ 8.0' @ HRS. AFTER COMPLETION.
USED 40.0' OF 8X CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

BORING ADVANCED BY AUGER TO 40.0'.

USED 40.0' OF 8X CASING.

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 ins.

Total Footage 240.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet ____ of ____

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TEST BORING REPORT

RAYMOND

CONCRETE PILE DIVISION

To SARGENT & LUNDY Date JULY 23, 19 73 Job No. 73-2124

Location of Borings NEWTON, ILLINOIS PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 5' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 121

540	GROUND SURFACE		
	ELEV. 536.6'		0.0'
535	BROWN & GREY DRY TO MOIST SILT W/CLAY	14	
	TR. SAND	11	
525			13.0'
		65/9	
520	BROWN & GREY MOIST COMPACT SILT SOME	66/8	
515	CLAY, SAND TR. GRAVEL	73/5	
510			28.0'
		53	
505	GREY MOIST SILT	53	
500	SOME CLAY, SAND	53	
	TR. GRAVEL	51	
490			47.2'
		42	

No. 122

GROUND SURFACE		
ELEV. 539.1'		
BROWN MOIST SILTY TOP SOIL		
BROWN & GREY MOIST CLAYEY SILT & SAND	10	
TR. GRAVEL	10	
BROWN & GREY MOIST COMPACT SILT SOME SAND	58	
TR. CLAY & GRAVEL	66/9	
	44	
GREY MOIST	49	
SILT SOME	60	
CLAY - SAND	67	
TR. GRAVEL	63	
	50	

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480	GREY SILT SILT-	12	GREY DAMP COMPACT SILT
			74/6
	CLAY, SOME SAND	40	6
475			GREY MOIST SILT SOME 52
		35	CLAY, SAND TR. GRAVEL
	TR. GRAVEL &		& GRAVEL SEAMS OR COBBLES
470			46
		39	7
	SAND-SEAMS		
465			GREY MOIST FINE TO
			38
		39	COURSE SAND, GRAVEL
		76.0'	& SILT
460			57 8
	GREY MOIST FINE TO COURSE	45	
	SAND W/GRAVEL & SILT TR.		GREY MOIST
455	CLAY	82.0'	23
		36	
	GREY MOIST CLAYEY SILT,		CLAYEY SILT
450			25
	SAND, TR. GRAVEL	29	
445			SOME SAND
		92.5'	32
		73/7	
	GREY COMPACT FINE W/ TR.		
0	COURSE SAND		(COMPACT SILT SEAM W/SAND) 63
	& GRAVEL	35	TR. GRAVEL
435		102.0'	28
		31	
430			
			26
	GREY MOIST SILT-CLAY	29	11
425			
	SOME SAND TR. GRAVEL		GREY MOIST COMPACT 64/7
		27	SILT W/SAND
420			TR. CLAY
		27 120.0'	55 12
415	BORING ADVANCED BY AUGER TO 40.0'. WATER ENCOUNTERED @ 12.0'.		BORING ADVANCED BY AUGER TO 40.0'. WATER ENCOUNTERED @ 11.0'.
	USED 40.0' OF BX CASING.		USED 40.0' OF BX CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 240.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet _____ of _____

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY — Date MARCH 22, 19 74 — Job No. CE-21241-X

Location of Borings NEWTON, ILLINOIS — PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 5' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 123

GROUND SURFACE

ELEV. 535.0'

GREY SILTY TOP SOIL — 0.0' — 0.8'

BROWN COMPACT SANDY SILTY CLAY — 13

SAND & GRAVEL — 6.0' — 7.0'

BROWN SANDY CLAYEY SILT

GREY SANDY CLAYEY SILT — 37 — 9.4' — 11.0'

20

GREY SANDY SILTY

22

CLAY TR. GRAVEL

32

SAND & GRAVEL — 27.0' — 28.0'

36

GREY SANDY SILTY

CLAY TR. GRAVEL — 34

36

SAND & GRAVEL SEAM — 42.0' — 43.9'

47

31

18

21

No. 124

GROUND SURFACE

ELEV. 531.2'

GREY SILTY TOP SOIL — 0.

BROWN & GREY CLAY TR. SILT

14 — 5.

BROWN SANDY SILTY CLAY — 14

13.

BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL — 60

17.

SAND & GRAVEL — 18.

BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL — 60/8

23.

SAND & GRAVEL — 23.

60/11

BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL — 60

34.

51

60

39

31

GREY SANDY SILTY — 33

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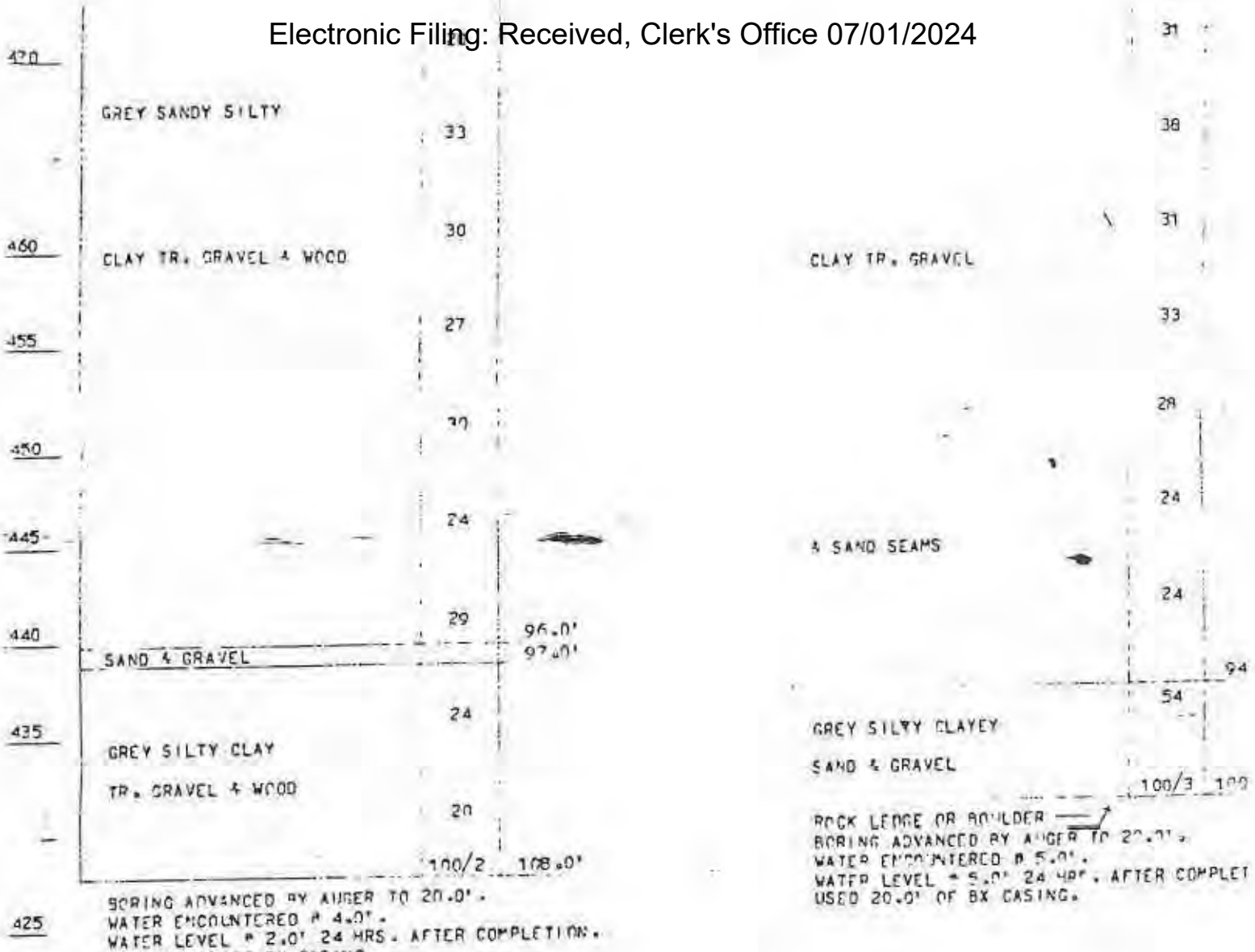

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 208.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet ___ of ___

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RAYMOND
CONCRETE PILE DIVISION

ARGENT & LUNDY
Location of Borings NEWTON, ILLINOIS

Date AUGUST 7, 1973 Job No. CR-21241-KC
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 125

GROUND SURFACE
ELEV. 538.2'
BROWN MOIST SILTY TOP SOIL — 0.0' / 0.7'

BROWN & GREY MOIST SILT	16	
TR. CLAY & SAND	14	
		12.0'
	39	
BROWN W/TR. GREY MOIST	68/10"	
SILT SOME CLAY,	62/9	
W/SAND, TR. GRAVEL	70/10	
	59	34.5'
GREY MOIST COMPACT SILT VERY FINE SAND SEAM		36.0'
	42	
GREY MOIST SILT SOME		
	47	
CLAY W/ SAND TR. GRAVEL		
	42	
		53.5'
VERY COMPACT SILT, FINE TO COURSE SAND & GRAVEL	100/1	56.0'
	44	

No. 126

GROUND SURFACE
ELEV. 532.9'
BROWN DRY SILTY TOP SOIL — 0.0' / 0.7'

BROWN & GREY MOIST CLAYEY SILT SOME SAND TR. GRAVEL	12	
	12	
		13.0
BROWN & GREY DAMP COMPACT SILT SOME SAND TR. GRAVEL	51	
		19.0
BROWN WET COMPACT SAND SEAM	68	20.0
BROWN MOIST SILT, SAND, TR. GRAVEL & CLAY	66	
		27.5
	43	
GREY MOIST SILT SOME CLAY,	40	
SAND, TR. GRAVEL	44	
	47	
		46.5
	46	
GREY MOIST SILT SOME CLAY,	74/5	

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	GREY MOIST CLAY & SILT	33	
	SOME SAND TR. GRAVEL	32	
		33	
		26	
			88.5'
	MOIST COMPACT FINE TO COURSE SILTY SAND & GRAVEL SEAM	70	89.0'
	GREY MOIST SILTY CLAY	29	
	SOME SAND TR. GRAVEL	28	
		42	104.5'
	MOIST FINE TO COURSE SANDY SILT TR. GRAVEL SEAM		105.5'
	GREY MOIST CLAY W/SILT TR. SAND & GRAVEL	30	112.0'
	BROWN & GREY MOIST SOFT SHALEY CLAY	36	116.0'
	GREY DAMP COMPACT SHALE	100/1	120.0'

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 12.0'.

USED 40.0' OF 8X CASING.

		45
		55.
		35
	GREY MOIST SILTY CLAY	
	SOME SAND TR. GRAVEL	40
		32
		81.
	GREY MOIST FINE TO COURSE SAND, GRAVEL, & SILT	61
		40
		90.
	GREY MOIST SILT, CLAY, SAND, TR. GRAVEL	93.
	GREY MOIST SHALE	100/3
		95.

BORING ADVANCED BY AUGER TO 40.0'.
WATER ENCOUNTERED @ 19.0'.

USED 40.0' OF 8X CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 215.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet ___ of ___

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RAYMOND
CONCRETE PILE DIVISION

SARGENT & LUNDY
Location of Borings NEWTON, ILLINOIS

Date NOVEMBER 15, 1972 Job No. CR-21241-KC
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 132

No. 132-A

GROUND SURFACE

535	ELEV. 535.0'		0.0'
	LIGHT GREY SILTY TOP SOIL		0.9'
530		15	
	LIGHT BROWN & GREY		
525	SANDY SILT TR. GRAVEL	15	
520		42	
515		56	20.0'
	COMPACT FINE SAND SEAM		23.0'
	GRAVEL		24.1'
510		50	
	LIGHT GREY SANDY CLAYEY		
	SILT TR. GRAVEL	53	
505			32.0'
	BOULDER ENCOUNTERED 32.0'.		
	BORING OFFSET 40.0' EAST TO		
500	CONTINUE - SEE 132A.		
	BORING ADVANCED BY AUGER TO 32.0'.		
	WATER ENCOUNTERED @ 15.0'.		
	WATER LEVEL @ 11.0' 24 HRS. AFTER COMPLETION.		
	USED 35.0' OF BX CASING.		
495	USED 20.0' OF NX CASING.		
490			
48[illegible]			
480			

GROUND SURFACE

	ELEV. 535.0'		0.
	SEE BORING 132		
			32
	GRAVEL SEAM		3[illegible]
		42	
	GREY CLAYEY SANDY		
	SILT TR. GRAVEL	49	
			4[illegible]
	SAND SEAM		4[illegible]
		60/10	
		52	
		45	
	GREY SANDY CLAYEY		

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475		48
470		47
	SILT TR. GRAVEL	
465		41
460		42
	SAND & GRAVEL SEAM	160/1
455	SHELL OR BOULDER	

BORING ADVANCED BY FLIGHT TO 35.0'.
WATER ENCOUNTERED @ 1[illegible].
WATER LEVEL [illegible] ON COMPLETION.
USED 35.0' OF BX CASING, 30.0' OF NX CASING & DRILLING MUD.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140 lb. weight falling 30 inches.

Total Footage 100.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet ___ of ___

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY — Date MARCH 25, 1974 — Job No. CP-21241-
Location of Borings NEWTON, ILLINOIS — PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 133
(OFF-SET 50.0' SOUTHWEST - ELEVATION 20.0' LOWER)

535

GROUND SURFACE

530 — ELEV. 520.5'
LIGHT GREY TOP SOIL — 0.0'
0.0'

12

525 — BROWN & GREY CLAYEY SILT

9

520 — 11.0'
SAND & GRAVEL — 11.5'

BROWN SANDY CLAYEY
515 — SILT TR. GRAVEL
19
17.0'
FINE SAND & SMALL
TO MED. GRAVEL — 19.5'
31

510 — GREY SANDY SILTY
CLAY TR. GRAVEL — 22.0'
SAND & GRAVEL — 22.5'

57

505

47

500

GREY SANDY SILTY

60/9

495

CLAY TR. GRAVEL

490 — 60/4

60/10

485

48.0'

4

480 — COMPACT SAND &
SOME GRAVEL

53.0'

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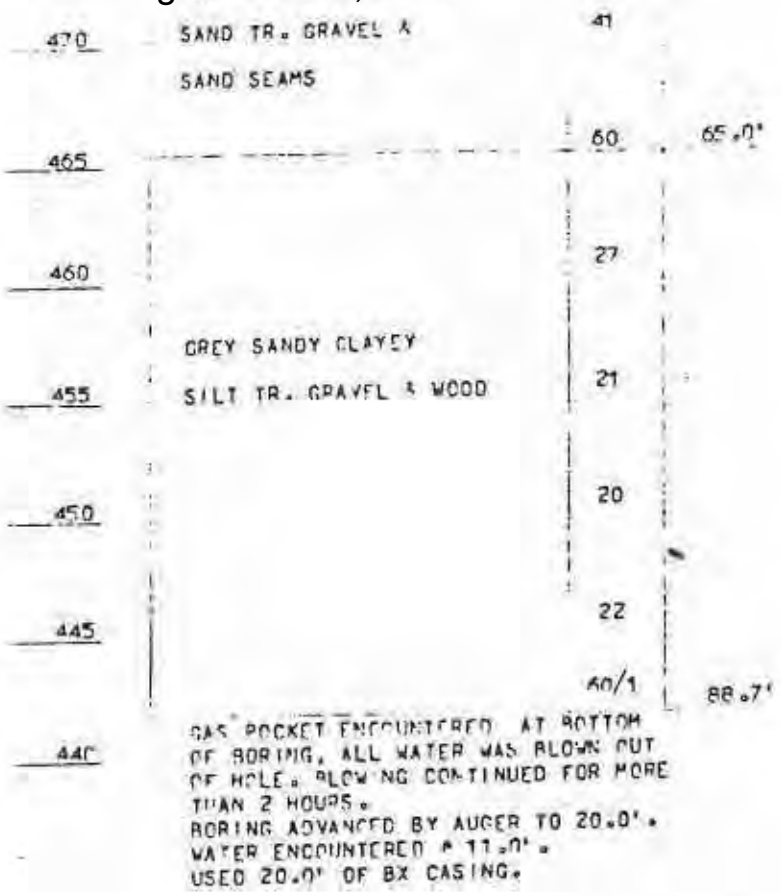

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY
Location of Borings NEWTON, ILLINOIS
Date JANUARY 11, 19 74 Job No. CB-21241
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 134

GROUND SURFACE
ELEV. 527.1'
GREY SILTY TOP SOIL 0.0' – 0.8'
BROWN CLAYEY SILT 26
7.0'
BROWN & GREY SANDY CLAY 10
FINE SAND & SMALL TO MEDIUM GRAVEL 49 15.3'
BROWN SILTY CLAYEY SILT TR. GRAVEL 17.3'
BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL 50/10 19.0'
COMPACT SANDY GRAVEL 50/8 23.0'
25.0'
GREY SANDY CLAYEY SILT TR. GRAVEL

No. 135

GROUND SURFACE
ELEV. 525.6'
GREY SILTY TOP SOIL 16
BROWN CLAYEY SANDY 8
SILT TR. GRAVEL 30
COMPACT FINE SAND & SMALL TO MEDIUM GRAVEL 42 20
22
BROWN COMPACT SANDY SILT TR. GRAVEL 50/6
60/10 30
COMPACT SANDY CLAYEY SILT TR. GRAVEL 34
42
GREY COMPACT SANDY CLAYEY SILT TR. GRAVEL 37.
28
26
32
28
GREY SANDY
26

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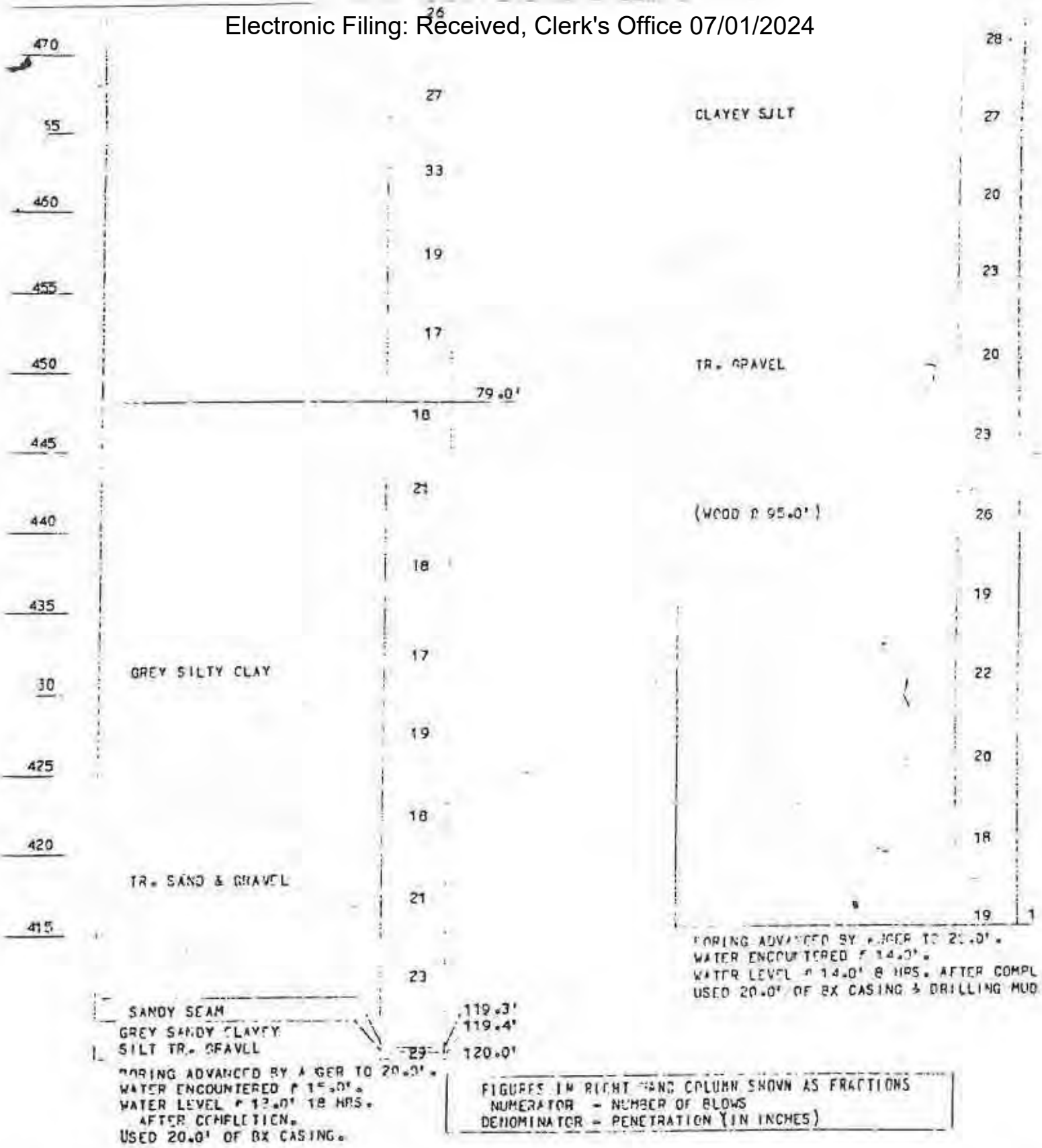

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RAYMOND CONCRETE PILE DIVISION

To SARGENT & LUNDY Date AUGUST 13, 1973 Job No. CR-21241-X

Location of Borings NEWTON, ILLINOIS PROPOSED POWER PLANT EXPANSION

I borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 136

Elev.	Description	Blows	Depth
535	GROUND SURFACE		
	ELEV. 532.4'		0.0'
	BROWN DRY SILTY TOP SOIL		0.8'
530		14	
	BROWN MOIST SILT SOME		
525	CLAY TR. SAND & GRAVEL		
		11	
520			13.5'
		43	
	BROWN & GREY MOIST COMPACT		
	SILT SOME CLAY, SAND,	60/8	
510	TR. GRAVEL		
		32	
505			27.0'
		38	
500			
	GREY MOIST SILT SOME	47	
495	CLAY, SAND, TR. GRAVEL		
		47	
490			
		40	
485			
		40	
			52.5'
		44	
475	GREY MOIST SILTY CLAY		
		36	

No. 138

Description	Blows	Depth
GROUND SURFACE		
ELEV. 534.6'		0
LIGHT GREY SILTY TOP SOIL		0
	23	
LIGHT BROWN SANDY CLAYEY		
SILT TR. GRAVEL	10	
		14
SAND & GRAVEL SEAM	18	14
LIGHT BROWN SANDY CLAYEY		
SILT TR. GRAVEL		17
SAND & GRAVEL SEAM		17
LIGHT BROWN SANDY CLAYEY		
SILT TR. GRAVEL	17	16
SAND & GRAVEL SEAM		19
LIGHT BROWN SANDY		
CLAYEY SILT		24
SAND & GRAVEL SEAM	26	25
LIGHT BROWN SANDY		
	27	
CLAYEY SILT TR. GRAVEL		
		30
	24	
	30	
	38	
GREY SANDY CLAYEY SILT	37	
TR. GRAVEL	28	
		50
SHALE SEAM	50	50
GREY SANDY CLAYEY		

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465			57
		44	
460	GREY MOIST FINE TO COURSE SAND W/SILT & SMALL GRAVEL		GREY SANDY CLAYEY 33
		69/11	
455		77.5'	36
		34	SILT TR. GRAVEL
450	GREY MOIST SILTY CLAY SOME SAND TR. GRAVEL		22
		29	
445		88.0'	27
	GREY MOIST SILT SOME CLAY, SAND, TR. GRAVEL	62/10 90.8'	
440	DARK GREY MOIST SHALE		29
		100/3 95.0'	
435	BORING ADVANCED BY AUGER TO 40.0'. WATER ENCOUNTERED @ 23.0'. USED 40.0' OF BX CASING.		24
430			31
425			24
420			12
415			300/1

SHALE, ROCK OR BOULDER

BORING ADVANCED BY AUGER TO 30.0'.
WATER ENCOUNTERED @ 10.0'.

USED 30.0' OF BX CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 214.0'
Foreman A. ANDERSON
Classification by FOREMAN
Sheet _____ of _____

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CONCRETE FIELD DIVISION

To SARGENT & LUNCY Date FEBRUARY 14, 1974 Job No. CB-21241-KC

Location of Borings NEWTON, ILLINOIS PROPOSED POWER PLANT EXPANSION

borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 140

GROUND SURFACE

530 ELEV. 529.1' 0.0'

LIGHT BREY SILTY TOP SOIL 0.8'

525 BROWN SILTY CLAY

TR. SAND

520 10.0'

SAND & GRAVEL 12.0'

515 BROWN FINE SAND & SILT

18.5'

BROWN SANDY CLAYEY

SILT TR. GRAVEL

505 26.0'

SAND & GRAVEL SEAM 27.0'

500

GREY SILTY CLAY

TR. SAND & GRAVEL

495 37.0'

490 DARK GREY SILTY

CLAY TR. GRAVEL

485 46.0'

SAND & SMALL TO MED. GRAVEL 47.0'

480

GREY SANDY CLAYEY

SILT TR. GRAVEL

56.0'

BOULDER ENCOUNTERED, COULD NOT PENETRATE, OFFSET 5.0' WEST SEE BORING 140-A.

475

BORING ADVANCED BY AUGER TO 20.0'.

WATER ENCOUNTERED @ 10.0'.

WATER LEVEL @ 10.0' 8 HRS. AFTER COMPLETION.

No. 140-A

GROUND SURFACE

ELEV. 529.1' 0.0

14

9

43

OVERBURDEN 40

SEE BORING 140 60/11

20

26

27

25

45

30 56.

23

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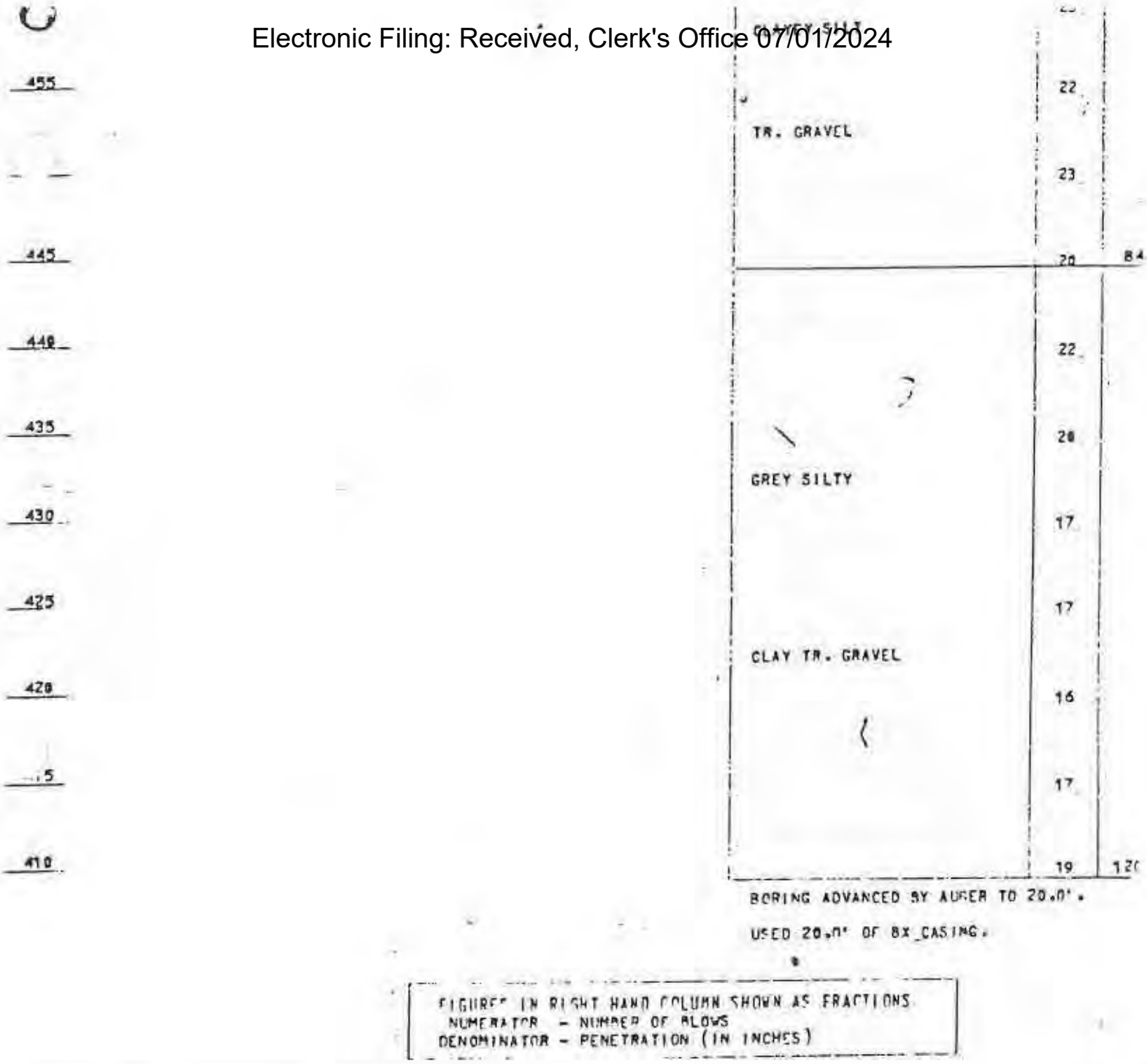

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

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TEST BORING REPORT

RAYMOND

CONCRETE PILE DIVISION

To SARGENT & LUNDY
...tion of Borings NEWTON, ILLINOIS

Date FEBRUARY 14, 19 74 Job No. CB-21741-K
PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 141

GROUND SURFACE

Elev.	Description	Blows	Depth
525	ELEV. 524.5'		0.0'
	LIGHT GREY SILTY TOP SOIL		0.5'
520	BROWN CLAYEY SILT	20	
515		9	11.3'
	FINE SAND & SMALL TO MEDIUM GRAVEL		11.5'
510	BROWN CLAYEY SANDY SILT	43	14.5'
	BROWN SANDY SILT		15.0'
505	BROWN COMPACT SANDY CLAYEY SILT TR. GRAVEL	60/6	
500		44	27.0'
	SMALL TO MED. GRAVEL & SAND		27.9'
495	BROWN SANDY SILTY CLAY TR. GRAVEL	36	32.0'
	SMALL TO MED. GRAVEL & SAND		33.1'
490	BROWN SANDY SILTY CLAY	34	34.4'
485		38	
480	GREY SANDY	47	
475	CLAYEY SILT	55	
470	TR. GRAVEL	47	
465		35	

No. 142

GROUND SURFACE

Description	Blows	Depth
ELEV. 534.8'		0
GREY SILTY TOP SOIL		0
BROWN & GREY SILTY CLAY	6	
	14	11
FINE SAND & GRAVEL		11
BROWN & GREY SILTY CLAY	22	16.
SAND & GRAVEL		18.
BROWN COMPACT FINE SAND	60/9	22.
FINE TO COURSE SAND & MED. TO LARGE GRAVEL	60/11	25.
	60	
GREY COMPACT SANDY CLAYEY SILT TR. GRAVEL SOME	60/11	
	38	
SAND SEAMS	39	48.
	43	
BROWN & GREY SANDY SILTY CLAY TR. GRAVEL	51	56.
GREY COMPACT SANDY CLAYEY SILT TR. GRAVEL		57.
FINE SAND & SMALL TO MED. GRAVEL SEAM	41	58.
	43	
GREY COMPACT	44	

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5	SAND & SMALL TO MED. GRAVEL	60/9	68.3' 69.0'	37
	LIGHT GREY SANDY CLAYEY SILT TR. GRAVEL			
450		60/8	74.0'	41
	COMPACT SANDY SILT			
445	TR. GRAVEL & CLAY	60/7		37
			83.0'	
440		21		34
435	GREY SILTY	25		36
430	CLAY TR. SAND	24		30
425	& GRAVEL	20		29
	(TR. WOOD)	23		26
415		21		24
410			114.0'	
	BLACK SILTY SAND & WOOD	60/11		
	SHALE OR BOULDER	60/1	116.0'	
405	BORING ADVANCED BY AUGER. WATER ENCOUNTERED @ 15.0'. WATER LEVEL @ 13.0' 24 HRS. AFTER COMPLETION. USED 20.0' OF BX CASING.			

				8
	GREY SANDY SILTY CLAY TR. GRAVEL			
	SAND & GRAVEL			9
	GREY SILTY CLAY TR. GRAVEL			106
	SAND & GRAVEL			108
	GREY SANDY SILTY CLAY TR. GRAVEL			120
	BORING ADVANCED BY AUGER TO 20.0'. WATER ENCOUNTERED @ 16.0'. WATER LEVEL @ 10.0' 24 HRS. AFTER COMPLETION. USED 20.0' OF BX CASING.			

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 230.0'
Foreman A. KENNERLY
Classification by FOREMAN
Sheet of

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TEST BORING REPORT

RAYMOND
CONCRETE PILE DIVISION

To SARGENT & LUNDY Date NOVEMBER 8, 19 73 Job No. CB-2124

Location of Borings NEWTON, ILLINOIS PROPOSED POWER PLANT EXPANSION

All borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 143

535	GROUND SURFACE	
	ELEV. 533.2'	0.0'
	LIGHT GREY SILTY TOP SOIL	0.8'
530		22
	LIGHT BROWN CLAYEY	
525	SILT TR. SAND & GRAVEL	17
		12.4'
520	SAND & GRAVEL SEAM	12.9'
		60/9
	LIGHT BROWN CLAYEY SILT	
515	TR. SAND & GRAVEL	60/7
		22.1'
510		60/6
505		37
500		50
495		
	GREY SANDY CLAYEY	50
490		38
485	SILT TR. GRAVEL	41
480		44
475		

No. 144

GROUND SURFACE	
ELEV. 535.7'	
LIGHT GREY SILTY TOP SOIL	3
LIGHT BROWN CLAYEY	16
SANDY SILT TR. GRAVEL	12
SAND & GRAVEL	50
BROWN CLAYEY SANDY	
SILT TR. GRAVEL	60/8
COMPACT SANDY CLAYEY	
SILT TR. GRAVEL	60/11
	40
	47
GREY SANDY CLAYEY	
SILT TR. GRAVEL	60
WOOD	35
	34
	31
LIGHT GREY SANDY	
	30

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470			CLAYEY SILT TR. GRAVEL	26
	(64.0' - WOOD)	45 - 65.0'		
				36
		60/7		7
			SAND & GRAVEL	7
460				33
		27	GREY SANDY CLAYEY SILT TR. GRAVEL	
				60 PC
455			FINE SAND & GRAVEL TR. CLAY	
		24		60/1 84
450			SHALE OR BOULDER ?	
		19	BORING ADVANCED BY AUGER TO 20.0'. WATER ENCOUNTERED @ 17.0'.	
	GREY CLAYEY		USED 20.0' OF 8X CASING.	
445				
		27		
440	SILT TR.			
		15		
435				
		30		
	SAND & GRAVEL			
430				
		20		
25				
		22		
20				
		24		
5				
		28	120.0'	

BORING ADVANCED BY AUGER TO 30.0'.

USED 30.0' OF 8X CASING.

FIGURES IN RIGHT HAND COLUMN SHOWN AS FRACTIONS
NUMERATOR - NUMBER OF BLOWS
DENOMINATOR - PENETRATION (IN INCHES)

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings were made, or as noted. Porosity of the soil strata, variations of rainfall, site topography, etc., may cause changes in those levels.

Figures in right hand column indicate number of blows required to drive 2" O.D. sampling pipe one foot, using 140-lb. weight falling 30 inches.

Total Footage 204.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet ___ of ___

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TEST BORING REPORT

RAYMOND

CONCRETE PILE DIVISION

ARGENT & LUNDY

Location of Borings: NEWTON, ILLINOIS

Date: OCTOBER 25, 1973 Job No. CP-2124n-KC

PROPOSED POWER PLANT EXPANSION

11 borings are plotted to a scale of 1" = 8' ft. using ELEVATIONS AS FURNISHED as a fixed datum.

No. 147

GROUND SURFACE

ELEV. 531.6'

LIGHT GREY SILTY TOP SOIL 0.0' – 0.8'

530

22

525 LIGHT BROWN CLAYEY

20

SILT TR. SAND & GRAVEL

520

50

515 18.3'

60/7

510

COMPACT SANDY CLAYEY 60/6

505

SILT TR. GRAVEL 56

500

24 34.1'

495 LIGHT GREY SANDY CLAYEY

SILT TR. GRAVEL

COMPACT SANDY SILT W/WOOD 60/10 38.0' – 40.0'

490

50

485

40

480 LIGHT GREY SANDY CLAYEY

SILT TR. GRAVEL 54

475

42

470

No. 148

GROUND SURFACE

ELEV. 528.9'

LT. GREY SILTY TOP SOIL 0.0' – 0.8'

22

LIGHT BROWN CLAYEY SILT 12

40

18.5

GRY COMPACT CLAYEY SILT TR. SAND 60/7 20.2

BROWN SANDY CLAYEY 60/11

SILT TR. GRAVEL

41

34.2

SAND SEAM 60 – 34.4

37

45

52

GREY SILTY CLAY

38

41

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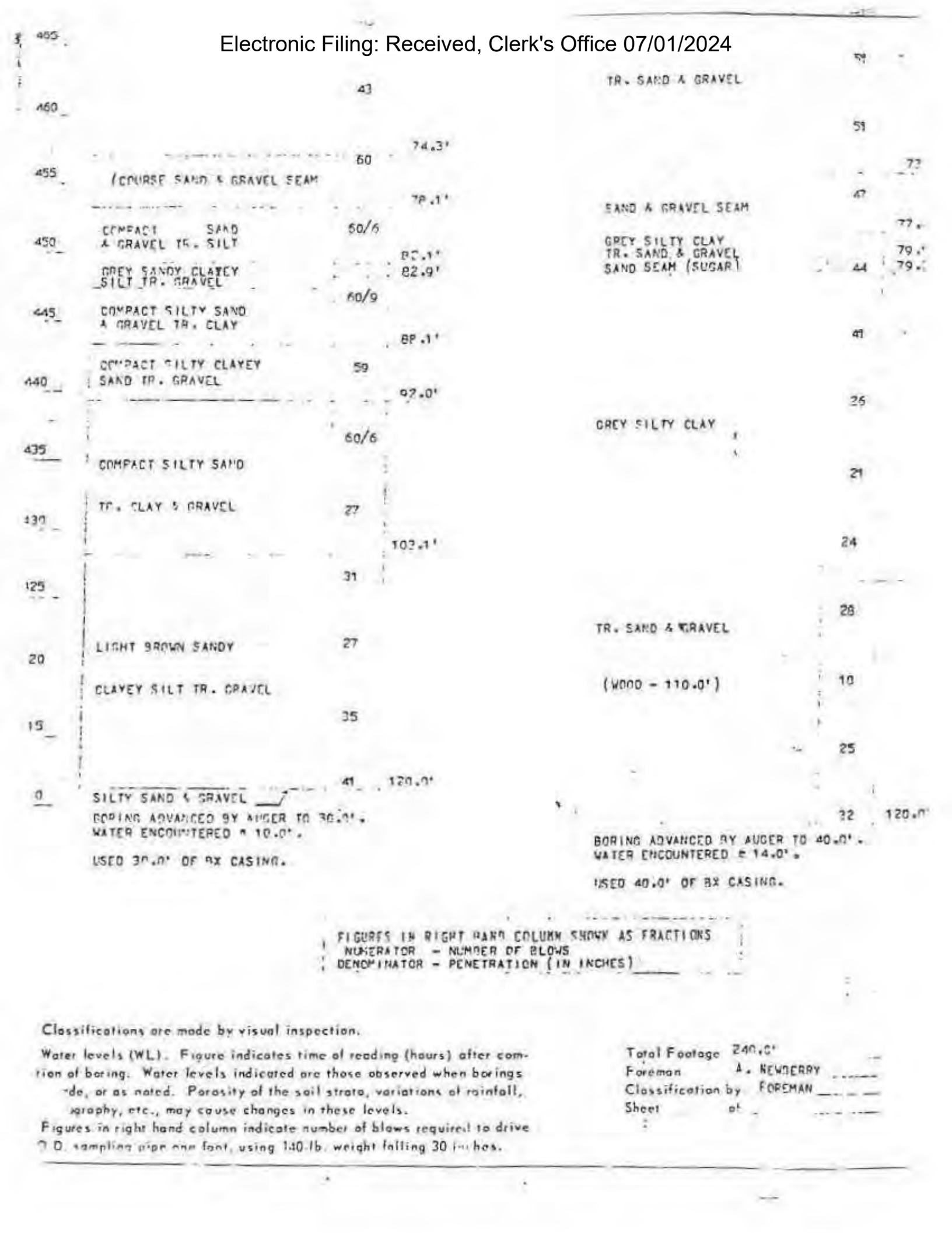

Classifications are made by visual inspection.

Water levels (WL). Figure indicates time of reading (hours) after completion of boring. Water levels indicated are those observed when borings made, or as noted. Porosity of the soil strata, variations of rainfall, topography, etc., may cause changes in these levels.

Figures in right hand column indicate number of blows required to drive O.D. sampling pipe one foot, using 140 lb. weight falling 30 inches.

Total Footage 240.0'
Foreman A. NEWBERRY
Classification by FOREMAN
Sheet of

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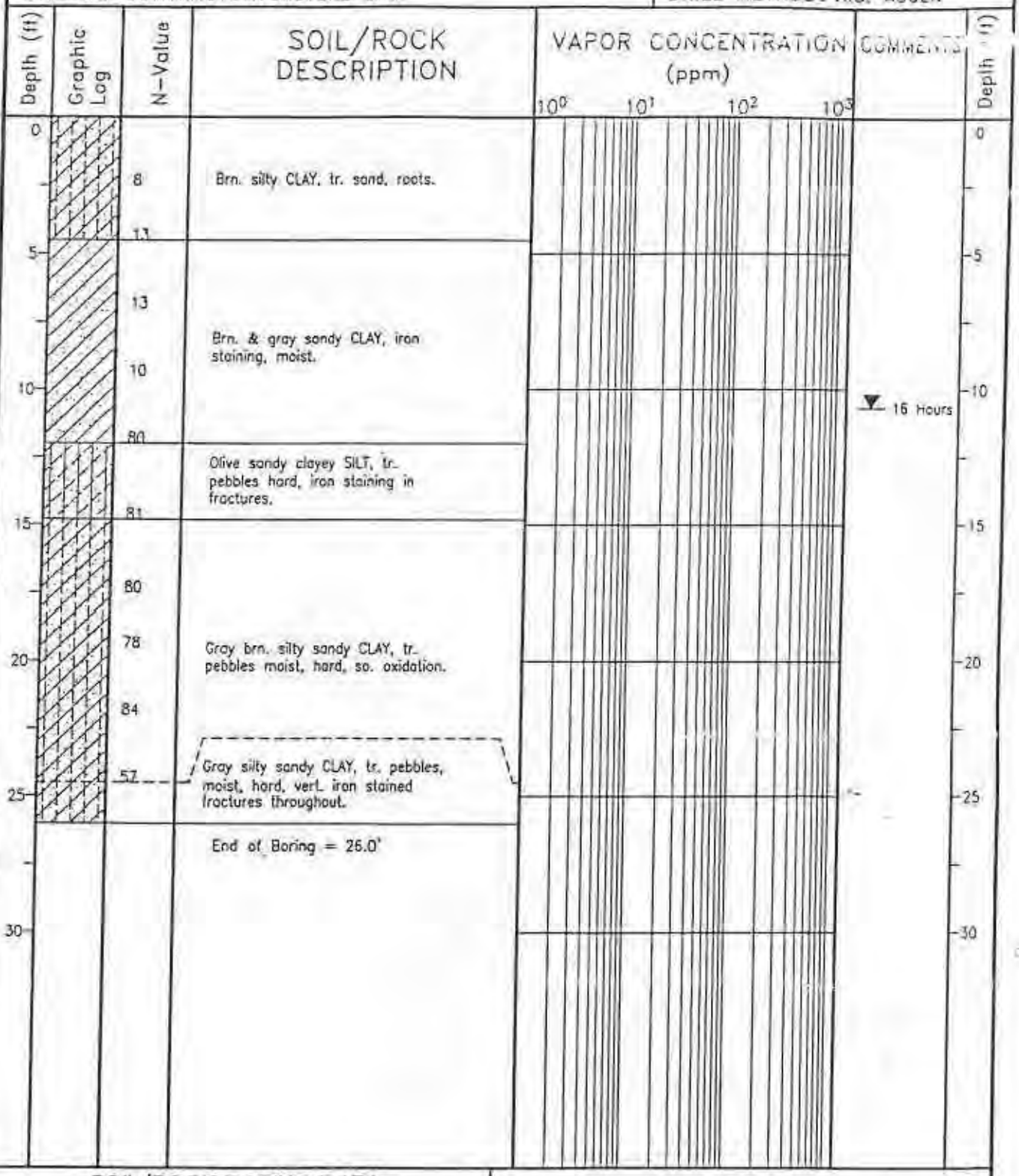
CIPS NEWTON POWER STATION	BORING G-105	SHEET 1 of 1
DATE STARTED 7/31/90	DATE COMPLETED 8/1/90	LOGGED BY RAB	SURFACE EL. 530.5
DRILLING CONTRACTOR: BROTCKE ENG.	DRILL METHOD: H.S. AUGER



SOIL/ROCK BORING DATA

HANSON ENGINEERS

PAC REVIEWED 11-19-90 DATE

RKC APPROVED 11-19-90 DATE

CIPS
NEWTON POWER STATION
NEWTON, ILLINOIS

JOB NO. 89S5008A

Electronic Filing: Received, Clerk's Office 07/01/2024

CIPS NEWTON POWER STATION	BORING G-106	SHEET 1 of 1
DATE STARTED 8/1/90	DATE COMPLETED 8/1/90	LOGGED BY RAB	SURFACE EL. 529.0
DRILLING CONTRACTOR: BROTCKE ENG.	DRILL METHOD: H.S. AUGER

Depth (ft)	Graphic Log	N-Value	SOIL/ROCK DESCRIPTION
0		22	Brn. clayey SILT, tr. roots, blocky, dry.
		20	Brn. sandy silty CLAY, tr. pebbles, sl. moist, blocky.
		18	
		33	Mottled gray & brn. silty sandy CLAY, tr. pebbles, moist.
10		50	Brn. sandy CLAY, tr. pebbles, vert. med. sand filled fract., so. mn & iron oxid., moist.
		72	
		50	Brn. coarse SAND.
		80	
20		43	Gray brn. sandy silty CLAY, tr. pebbles, coal frag., oxid. vert. fract., hard.
		59	
		45	
		9	Gray coarse – v. coarse SAND.
			Gray sandy silty CLAY, tr. pebbles, moist.
		63	
30			Coarse – v. coarse SAND grading downward to gravel.
		35	
		33	Gray sandy silty CLAY, tr. pebbles, unweathered.
			End of Boring = 36.0'
40			

VAPOR CONCENTRATION (ppm)

10^0 10^1 10^2 10^3

COMMENTS

SOIL/ROCK BORING DATA

HANSON ENGINEERS

PAC 11-9-90
REVIEWED DATE

RJC 11-19-90
APPROVED DATE

CIPS
NEWTON POWER STATION
NEWTON, ILLINOIS

JOB NO. 89S5008A

Electronic Filing: Received, Clerk's Office 07/01/2024

CIPS NEWTON POWER STATION	BORING G-107	SHEET 1 of 1
DATE STARTED 8/2/90	DATE COMPLETED 8/2/90	LOGGED BY RAB	SURFACE EL. 531.0
DRILLING CONTRACTOR: BROTCKE ENG.		DRILL METHOD: H.S. AUGER

Depth (ft)	Graphic Log	N-Value	SOIL/ROCK DESCRIPTION
0		11	Mottled gray & brn. CLAY, tr. f. sand & pebbles, blocky, moist.
5			
10		16	
		18	
15		28	Brn. CLAY, blocky, moist (root size wood frag.).
		46	Brn & gray sandy silty CLAY, tr. pebbles, coal frags., sl. iron stain, fractured, hard.
20		54	
		51	
25		42	
		26	Dk. gray CLAY, moist.
30		22	Gray sandy silty CLAY, tr. pebbles, moist.
35			End of Boring = 33.5'

VAPOR CONCENTRATION (ppm): 10^0 10^1 10^2 10^3

COMMENTS: ▽

Depth (ft): 0, 5, 10, 15, 20, 25, 30, 35

SOIL/ROCK BORING DATA

HANSON ENGINEERS INCORPORATED

PAC REVIEWED 11/19/90 DATE

RKC APPROVED 11-19-90 DATE

CIPS
NEWTON POWER STATION
NEWTON, ILLINOIS

JOB NO. 89S5008A

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW104S
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 548.06
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-17-93 Completed: 12-17-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	See boring log for MW104D, which is located approximately 10 feet north of MW104S									0
5										5
10										10
15										15
20										20
25	END OF BORING @ 23.2 FT. (Auger Refusal)									25
30										30

Water Level 6.34 after 24 days

Note: Refer to Standard Legend Sheet

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW104D
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev.: 547.76
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-15-93 Completed: 12-17-93

DEPTH	Material Description Classification System_____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu tsf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Light brown & gray mottled silty clay w/few small pebbles 1/8"-1/4" dia., some organics, moist, some iron oxide staining	1	24" SPLIT SPOONS	100						0
		2		100		2.0		N=4,9,9,11		
5		3		100		1.4		N=4,5,6,7		5
		4		100		0.1		N=4,5,5,9		
		5		100		1.0		N=6,9,10,11		
10	Light brown & gray mottled fine sand w/little clay, grading to coarse sand	6		100		0		N=4,5,7,8		10
		7		100		>5		N=3,4,31,42		
	Gray silt w/little clay & sand	8		75		>5		N=29,64,100/5"		
15										15
	Gray pebbly clay, dense, pebbles 1/8" - 1/4" dia.	9		40				N=40/6", 100/3"		
		10		25				N=100/6"		
20		11		25				N=100/6"		20
		12		40				N=25, 60/4"		
25		13		40				N=19, 60/4"		25
		14		40				N=43, 60/4"		
	Gray silty fine sand; moist									
	Gray pebbly clay, dense, pebbles 1/8" - 1/4" dia.	15		40				N=27, 50/5"		
30										30

Water Level 62.58 after 24 days

Note: Refer to Standard Legend Sheet.

Electronic Filing: Received, Clerk's Office 07/01/2024

RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW104D (cont.)
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 547.76
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-15-93 Completed: 12-17-93

DEPTH	Material Description (Classification System: _____)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	% Moist	Comments	WELL	DEPTH
30	Gray pebbly clay, dense, pebbles 1/8"-1/4" dia.	16	24" SPLIT SPOONS	75				N=21,42,60/5"		30
		17		75		>5		N=19,33,60/6"		
35		18		25				N=60/5"		35
	Gray coarse sand & gravel									
	Gray pebbly clay, dense, pebbles 1/8"-1/4" dia.	19		50		>5		N=15, 60/6"		
		20		50				N=17, 60/6"		
40		21		50				N=17, 62/6"		40
		22		50				N=23, 60/5"		
45		23		50				N=17, 58/6"		45
		24		75		4.0		N=12,19,59/6		
		25		50				N=50,100/6"		
50		26		75		3.0		N=13,24,58/6"		50
		27		50		>5		N=20,50/6"		
55		28		50		>5		N=20,60/5"		55
		29		75				N=17,32,66/6"		
		30		75		>5		N=17,22,50/6"		
60										60

Water Level 62.58 after 24 days

Note: Refer to Standard Legend Sheet

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW104D (cont.)
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 547.76
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-15-93 Completed: 12-17-93

DEPTH	Material Description Classification System: _____	Sampling Tube No.	Type	% Rec.	Tests OVM (ppm)	Qu t/sf PEN	% Moist	Comments	WELL	DEPTH
60	Gray pebbly clay, dense, pebbles 1/8" - 1/4" dia.	31	24" SPLIT SPOONS	75		3.0		N=20,37,70/6"		60
		32		50				N=20, 52/6"		
65		33		100				N=11,26,32,60/6"		65
		34		100		3.0		N=11,19,40,44		
70										70
75										75
		35		100				N=8,16,18,25		
80								Driller noted increasing auger resistance @ 80.5'		80
	Dark brown-gray clay w/ abundant wood chips. Some wood chips up to 1" long. Few angular chips of limestone.									
85										85
	END OF BORING @ 87.0 FT. (Auger Refusal)	36		100				N=15,28,38,48		
90										90

Water Level 62.58 after 24 days

Note: Refer to Standard Legend Sheet

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE • SPRINGFIELD IL 62704 • (217)787-2198

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: G107s

Drilling Firm: FOX DRILLING COMPANY Drilling Method: HSA 8" O.D. Surface Elev. 531.28

Logged By: D. VANDERLINDEN Checked By: _____ Date Started: 2-23-94 Completed: 2-23-94

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	See boring log for G107D, which is located approximately 6 feet west of G107s.		24" SPLIT SPOONS							0
5	END OF BORING @ 6.0 FT.									5
10										10
15										15
20										20
25										25
30										30

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW108
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 535.85
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-27-93 Completed: 12-27-93

DEPTH	Material Description (Classification System: _____)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Light brown sandy silty clay	1	24" SPLIT SPOONS	100				N=3,3,3,3		0
	Mottled light brown & gray silty clay with iron oxidation, trace small pebbles	2		100				N=5,6,6,7		
5		3		100		1.5		N=6,10,12,12		5
		4		100						
	Light brown sandy silty clay with iron oxidation, organics, coal fragments, few pebbles 1/8"-1/4" dia., firm	5		100		4.5				
10		6		100		0.5				10
	Well-sorted light brown medium sand, little clay	7		100				N=12,27,38,47		
15	Gray silty sandy clay, fractured, with iron oxidation staining, dense, few pebbles 1/8"-1/4" dia., becoming unweathered at 18 feet	8		25		>5		N=50/5"		15
		9		50						
		10		50						
20	END OF BORING @ 20 FT. (Auger Refusal)									20
25										25
30										30

Water Level 5.49 after 34 days

Note: Refer to Standard Legend Sheet.

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW109
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 535.62
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-20-93 Completed: 12-20-93

DEPTH	Material Description (Classification System: _____)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu 1/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Light brown silty clay	1	24" SPLIT SPOONS	100				N=2,4,6,8		0
	Light brown–gray mottled silty clay w/few small pebbles 1/8"–1/4" dia., abundant roots. Some iron oxidation. Thin (1/4"–1/2") sand seams.	2		100		1.75		N=8,9,9,10		
5		3		100		2.0		N=5,7,9,12		5
	Reprecipitated calcite deposited within fractures at 6'.	4		100		1.75				
		5		100		3.0		N=5,6,8,12		
10		6		100				N=8,10,24,32		10
	Gray very sandy clay					>5				
	Brown sandy, silty clay w/ 1/8"–1/4" dia. pebbles. Iron oxidation and secondary manganese deposited in fractures.	7		100		>5		N=10,42,70/6"		
15	Brown & gray mottled pebbly clay, dense, fractured. Pebbles up to 3/4" dia.									15
20	END OF BORING @ 22 FT, SPOON DRIVEN TO 24.0 FT.	8		100		>5		N=15,20,26,66		20
	Hard gray pebbly till, fractured.					>5		N=40,32,60/5"		
		9		75						
25										25
30										30

Water Level 5.64 after 27 days

Note: Refer to Standard Legend Sheet

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW110

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 540.57

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-20-93 Completed: 12-20-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Mottled light gray & brown clayey silt with iron oxidation, organics grading to sandy clay at 4 feet.	1	24" SPLIT SPOONS	100				N=4,4,4,4		0
		2		100		2.75		N=12,12,13,14		
5		3		100		1.3		N=4,5,7,8		5
		4		100		1.5		N=5,6,7,9		
	Mottled light gray & brown clay with angular pebbles, iron oxide nodules, carbonized wood chips	5		100		1.3		N=4,5,6,7		
10		6		100		0.5		N=3,4,5,12		10
	Gray pebbly clay, dense. Pebbles 1/8"-1/4" dia.	7		75		>5		N=16,42,60/5"		
15										15
20		8		25				N=42,60/3"		20
	END OF BORING @ 22.5 FT. (Auger Refusal)									
25										25
30										30

Water Level 5.58 after 27 days

Note: Refer to Standard Legend Sheet.

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW111

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 547.27

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-29-93 Completed: 12-29-93

DEPTH	Material Description Classification System_____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Bottom ash	1	24" SPLIT SPOONS	100						0
	Mottled light brown & gray silty clay, few pebbles <1/16" dia	2		100						
5		3		100						5
		4		100						
		5		100						
10	Reddish-Orange to light brown silty clay, some organics	6		100						10
	Light brown clayey sand, wet	7		100						
	Light brown pebbly clay, 1/8"-1/4" dia.									
15	Gray pebbly clay, dense. Pebbles 1/8" - 1/4" dia.	8		50				N=60/6" from 12.5' to 20'		15
20	END OF BORING @ 20 FT. (Auger Refusal)									20
25										25
30										30

Water Level 7.92 after 36 days

Note: Refer to Standard Legend Sheet

Sheet 1 of 1

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW112

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 542.55

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-27-93 Completed: 12-27-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Light brown silty clay	1	24" SPLIT SPOONS	100						0
	Mottled light brown & gray silty clay with iron oxidation, organics, Coal fragments at 3 feet.	2		100						
5		3		100						5
	Dark gray silty, sandy clay, soft with trace pebbles 1/8" dia.	4		100						
		5		100						
10		6		100						10
	Gray, poorly-sorted medium-coarse grained sand with some clay & pebbles 1/8" -1/4" dia.	7		100						
	Reddish-orange well-sorted fine sand	8		100						
15										15
	Gray silty sandy clay, fractured with iron oxidation, dense, few pebbles 1/8" - 1/4" dia.									
20										20
	END OF BORING @ 22 FT. (Auger Refusal)									
25										25
30										30

Water Level 7.97 after 34 days

Note: Refer to Standard Legend Sheet.

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW113

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 551.07

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-29-93 Completed: 12-29-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	0-10 feet not sampled, levee was being penetrated.									0
10	Light brown to gray mottled silty clay with some organics	1	24" SPLIT SPOONS	100						10
		2		100						
15	Light gray very silty clay, no pebbles	3		100						15
	Mottled light brown to gray silty clay with some organics, trace pebbles 1/4" dia.	4		100						
		5		100						
20		6		100						20
	Reddish-orange silty clay with pebbles 1/8"-1/4" dia., some organics	7		100						
25		8		50				N = 60/6"		25
	Light brown silty clay with some pebbles 1/8"-1/4" dia.									
	Gray silty sandy clay, fractured with iron oxidation, dense, few pebbles 1/8"-1/4" dia.									
30										30

Water Level 20.10 after 36 days

Note: Refer to Standard Legend Sheet.

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW113 (cont.)
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 551.07
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-29-93 Completed: 12-29-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
30	Gray silty sandy clay, fractured with iron oxidation, dense, few pebbles 1/8"-1/4" dia.									30
	END OF BORING @ 32 FEET.									
35										35
40										40
45										45
50										50
55										55
60										60

Water Level 20.10' after 36 days

Note: Refer to Standard Legend Sheet

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW114

Drilling Firm: FOX DRILLING COMPANY Drilling Method: HSA 8" O.D. Surface Elev. 543.51

Logged By: D. VANDERLINDEN Checked By: _____ Date Started: 2-24-94 Completed: 2-24-94

DEPTH	Material Description Classification System:	Sampling Tube No.	Type	% Rec.	Tests OVM (ppm)	Qu t/sf PEN	% Moist	Comments	WELL	DEPTH
0	Brown silty clay with trace pebbles up to 1/8" dia., some organics, moist	1	24" SPLIT SPOONS	50						0
	Gray mottled sandy clay, roots up to 2" long, trace pebbles up to 1/8" dia. iron oxide staining present	2		50						
5	Brown & gray mottled sandy clay, more pebbles, consisting of mostly 1/16-1/4" dia., some up to 1" dia. yellow staining at 5 feet, becomes very firm at approx. 6 feet	3		100						5
	Brown & gray mottled sandy clay, slightly fractured with secondary manganese along fractures, very firm, pebbles <1/2" dia.	4		100						
		5		100						
10	Light brown weathered pebbly clay, pebbles 1/8" to 1/4" dia., some up to 1" dia., very firm, fractured	6		100						10
	Gray unweathered pebbly clay, pebbles 1/8" to 1/4" dia., very firm, fractured	7		100						
15	Coarse, brown sand	8		100						15
	Gray unweathered pebbly clay, pebbles 1/8" to 1/4" dia., very firm, fractured									
	END OF BORING @ 16 FT.									
20										20
25										25
30										30

Water Level 8 1/2' after 0 days

Note: Refer to Standard Legend Sheet.

Sheet 1 of 1

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2357 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW115

Drilling Firm: FOX DRILLING COMPANY Drilling Method: HSA 8" O.D. Surface Elev. 540.59

Logged By: D. VANDERLINDEN Checked By: _____ Date Started: 2-22-94 Completed: 2-22-94

DEPTH	Material Description (Classification System: _____)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu tsf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Light gray silty clay, moist	1	24" SPLIT SPOONS	50						0
	Light gray mottled silty clay, iron oxidation stains present, firm, somewhat moist, trace pebbles less than 1/16" dia. some organics.	2		100						
5	Organics & iron oxidation stains more prevalent at approx. 10 ft.	3		100						5
		4		100				Roots found at 6 ft., 8" long, 1/4" dia. in center of sample		
		5								
10		6								10
	Light gray pebbly sandy clay, less organics, most pebbles 1/8"-1/4" dia. few >3/8" dia.	7								
15	Dense, gray clay, pebbles 1/16"-1/2" dia., fractured, secondary manganese present along fracture planes	8						N>100/6"		15
		9								
	END OF BORING @ 18 FT.									
20										20
25										25
30										30

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet.

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ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: MW116

Drilling Firm: FOX DRILLING COMPANY Drilling Method: HSA 8" O.D. Surface Elev. 551.16

Logged By: D. VANDERLINDEN Checked By: _____ Date Started: 2-23-94 Completed: 2-23-94

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0	Coarse gravel (Fill)	1	24" SPLIT SPOONS							0
	Gray-green silty clay, mottled, pebbles up to 1/8" dia. Becomes moist at 4 ft.	2								
5	Gray silt 2" thick (Fill)	3								5
	Light gray mottled silty clay, iron oxidation stains present, firm, somewhat moist, trace pebbles >1/16" dia.	4								
	Light gray sandy clay, some organics and iron oxidation staining, pebbles up to 1/4" dia., few 3/4" dia. pebbles. Grading to brown and becoming fractured at 12 ft.	5								
10		6								10
		7								
15	Weathered brown sandy clay, moist, numerous pebbles 1/8" to 1/4" dia.	8								15
		9								
	Dense gray clay, pebbles 1/8" to 1/4" dia.	10								
20	END OF BORING @ 20 FT									20
25										25
30										30

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet.

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ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: PIIS

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 570.61

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-28-93 Completed: 12-28-93

DEPTH	Material Description Classification System_____	Sampling Tube No.	Sampling Type	Sampling % Rec.	Tests OVM (ppm)	Tests Qu t/sf PEN	Tests % Moist	Comments	WELL	DEPTH
0	Piezometer PIIS was installed with the same boring for PIID. Bottom of screen of PIIS was set within waste at a depth of 40 feet.		24" SPLIT SPOONS							0
5										5
10										10
15										15
20										20
25										25
30										30

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet.

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2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: PIIS (cont.)

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 570.61

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-28-93 Completed: 12-28-93

DEPTH	Material Description Classification System_____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
30										30
35										35
40										40
45										45
50										50
55										55
60										60

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet

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ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: PIID

Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 570.61

Logged By: B. KIMPEL Checked By: _____ Date Started: 12-28-93 Completed: 12-28-93

DEPTH	Material Description Classification System: _____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
0			24" SPLIT SPOONS					Samples not collected from 0 to 30 feet.		0
5										5
10										10
15										15
20										20
25										25
30										30

Water Level _____ after _____ days

Note: Refer to Standard Legend Sheet

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ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS NEWTON POWER STATION Project: HYDROGEOLOGIC INVESTIGATION Boring No: PIID (cont.)
Drilling Firm: FOX DRILLING COMPANY Drilling Method: ROTARY, 8" O.D. Surface Elev. 570.61
Logged By: B. KIMPEL Checked By: _____ Date Started: 12-28-93 Completed: 12-28-93

DEPTH	Material Description Classification System_____	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: % Moist	Comments	WELL	DEPTH
30								PIIS Screen		30
35										35
40	Waste							Driller noted change in auger resistance at 42 feet.		40
45	Light brown sandy clay with some 1/4" – 1/2" pebbles, dense	1		100				Driller noted change in auger resistance at 47 feet.		45
50	Gray pebbly clay, dense, pebbles 1/8" – 1/4" dia.	2		25				N = 70/6"		50
55	END OF BORING @ 54.5 FT. (Auger Refusal)	3		25				PIIS Screen N = 60/6"		55
60										60

Water Level _____ after _____ days Note: Refer to Standard Legend Sheet. Sheet 2 of 2

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G114R

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 532.66

Logged By: MSS Checked By: Date Started: 10–7–96 Completed: 10–7–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0										0
5	Blind drill to 15.0' Boring log G114 2/24/94									5
10										10
15		1	5.0' CME continuous sampler	100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry			15
20	Gray silty CLAY (ML–CL) w/pebbles	2		80		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry			20
25		3		100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry			25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5775.46, E 2873.52

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G114R
Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 532.66
Logged By: MSS Checked By: Date Started: 10-7-96 Completed: 10-7-96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	30.5									30
	Gray sandy SILT (SM-ML)					4.5+				
	32.0					4.5+	dry			
		4	5.0' CME continuous sampler	100		4.5+				
						4.5+	dry			
35						4.5+				35
						2.75				
		5		80		4.5+	moist			
						4.5+				
						4.5+	dry			
	Gray silty CLAY (ML-CL) w/pebbles					4.5+				
40						4.5+		Note:		40
						4.5+	dry	Very hard		
		6		80		4.5+		Slow drilling		
						4.5+	dry			
						4.5+				
45										45
		7		40		4.5+				
						4.5+	dry			
	Auger Refusal @ 48.0'									
50										50
55										55
60										60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5775.46, E 2873.52

Sheet 2 of 2

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G117

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3-1/2" ID HSA Surface Elev. 530.41

Logged By: MSS Checked By: _____ Date Started: 7-26-95 Completed: 7-26-95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	No Recovery	1	5.0' CME continuous sampler	0						0
5	5.0									5
	Light brown, mottled gray clayey SILT(ML), w/trace pebbles increasing in depth	2		100		3.5 4.0		Sample A: 6.5'-7.5'		
10	12.5	3		80		4.0 0.5 3.5				10
	Brown medium grained SAND (SM) w/silt 13.0									
	Brown, silty CLAY (CL-ML) w/pebbles & sand 15.0									
15	No recovery	4		20				Very weathered till		15
	Brown, sandy SILT (ML-SM) w/clay 20.0									
20	Light brown, mottled gray silty CLAY (CL), w/sand	5		100		>4.5 4.5 4.5 >4.5		Sample B: 20'-21'		20
	24.5									
25	Grayish brown, silty CLAY (CL) w/sand 26.0	6		100		>4.5 2.0 3.0 >4.5 >4.5		Sample C: 28'-29' Sample D: 29'-30'		25
	Dark gray, silty CLAY (CL), w/pebbles									
30										30

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2119

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G117

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3–1/2" ID HSA Surface Elev. 530.41

Logged By: MSS Checked By: Date Started: 7–26–95 Completed: 7–26–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
30	Dark gray silty CLAY (CL) w/pebbles	7	5.0' CME continuous sampler	100		>4.5		Sample E: 30'–31'		30
	32.5 Brown silty SAND (SM), w/gravel 33.0					>4.5				
						>4.5				
						>4.5				
35		8		100		>4.5				35
						>4.5				
						3.0				
						4.0				
40						4.0				40
		9		100		4.0				
						3.0				
						3.0		Sample F: 43'–44'		
						3.0		Sample G: 44'–45'		
45						>4.5		Sample H: 45'–46'		45
	Dark gray silty CLAY (CL) w/pebbles					>4.5				
		10		100		>4.5				
						4.0				
						>4.5				
50						3.0				50
		11		60		3.0				
55						>4.5				55
						4.5				
		12		100		4.0				
						3.0				
						4.5				
60						>4.5				60

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ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2181

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G117

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3-1/2" ID HSA Surface Elev. 530.41

Logged By: MSS Checked By: _____ Date Started: 7-26-95 Completed: 7-26-95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Dark gray, silty CLAY (CL) w/pebbles	13	5.0' CME continuous sampler	100		>4.5 >4.5 >4.5 >4.5 3.0		Sample I: 62'-63' Sample J: 63'-64' Sample K: 64'-65'		60
65	65.0 Gray silty SAND (SM), medium grained, w/gravel									65
	67.0 Gray silty CLAY (CL) w/trace course sand & pebbles	14		100		3.0 3.0 3.0				
70	End Of Boring @70.0'									70
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

Sheet 3 of 3

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2116

Client: CIPS-NEWTON Project: DEEP BORING Boring No: G118

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3-1/2" ID HSA Surface Elev. 529.50

Logged By: MSS Checked By: Date Started: 7-28-95 Completed: 7-28-95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu 1/st PEN	Tests: Moist	Comments	Well	DEPTH
0	Brown, mottled gray silty CLAY (CL)	1	5.0' CME continuous sampler	60		4.5 3.0 3.0		Dry		0
5		2		60				Sample 1: 7.0'-8.0' Sample 2: 8.0'-9.0' Sample 3: 9.0'-10.0'		5
10	10.0 Gray, mottled brown silty CLAY (CL) w/trace coarse sand	3		80		1.5 1.5 3.0 2.5		Wet		10
	14.5 Gray-brown silty CLAY (CL) w/trace sand									
15	15.0 No recovery	4		20						15
	19.0 Gray-brown, med. grained SAND (SW)									
20	20.0 No recovery	5		25						20
	23.5 Brown silty CLAY (CL) w/trace sand									
25	25.5 Gray silty CLAY (CL) w/trace coarse sand & pebbles	6		95		3.75 3.75 3.5 >4.5		Sample 4: 28.0'-29.0' Sample 5: 29.0'-30.0'		25
30										30

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2166

Client: CIPS–NEWTON Project: DEEP BORING Boring No: G118

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3–1/2" ID HSA Surface Elev. 529.50

Logged By: MSS Checked By: Date Started: 7–28–95 Completed: 7–28–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well
30	Gray silty CLAY (CL) w/trace coarse sand & pebbles	7	5.0' CME continuous sampler	80		3.0 3.0 3.5 2.0		Sample 6: 30.0'–31.0'	
	34.0								
35	Bluish–green silty CLAY (CL) w/coarse sand 35.0								
	Dark gray silty CLAY (CL) w/trace coarse sand & pebbles	8		100		3.5 3.5 3.5 3.5			
40		9		100		>4.5 >4.5 >4.5 4.5 4.5			
	45.0								
45	No recovery	10		0					
50		11		30					
	54.5								
55	Dark gray silty CLAY (CL) w/trace coarse sand & pebbles	12		80		4.5 4.5 4.0 3.0		Sample 7: 57.0'–58.0' Sample 8: 58.0'–59.0' Sample 9: 59.0'–60.0'	
	59.0								
60	Gray–green silty CLAY (CL) 59.3								

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: DEEP BORING Boring No: G118

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3–1/2" ID HSA Surface Elev. 529.50

Logged By: MSS Checked By: _____ Date Started: 7–28–95 Completed: 7–28–95

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray med. grained SAND (SM) w/silt	13	5.0' CME continuous sampler	100		3.5 3.5 3.5 3.0 3.5				60
65	End Of Boring @65.0'									65
70										70
75										75
80										80
85								Note: Well G118 is located 5.0 feet west		85
90										90

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ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G119

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: SPLIT SPOON Surface Elev. 535.44

Logged By: MSS Checked By: Date Started: 7-25-95 Completed: 7-25-95

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVN (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Blind 5.0	1	2-1/2' split spoon sampler							0
5	Gray, mottled brown silty CLAY (CL), w/trace sand 6.5 Blind 10.0									5
10	Gray, mottled brown silty CLAY (CL) w/pebbles 11.0 Brown, mottled gray silty CLAY (CL) w/pebbles 11.5 Blind 12.5	2								10
	Gray-brown silty CLAY (CL), w/trace sand 14.0	3								
15	Blind 15.0 Brown gray silty CLAY (CL) w/trace sand 16.5	4								15
	Blind 17.5 Brown sandy SILT (ML-SM) 18.0	5								
20	Brown silty CLAY (CL), w/trace coarse sand 19.0 Blind 20.0	6								20
	Brown silty CLAY (CL), w/trace coarse sand 21.5 End Of Boring @21.5'							NOTE: Blow counts not recorded		
25										25
30										30

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ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G120

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.63

Logged By: MSS Checked By: _____ Date Started: 7–27–95 Completed: 7–27–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Brown clayey SILT (ML), w/trace sand	1	5.0' CME continuous sampler	90		3.0 3.0 3.0 3.0		Blocky Sample: 4.0'–5.0'		0
5	Grayish–brown, silty CLAY (CL), w/pebbles, oxidized 8.5	2		100		2.5 2.5 2.5 2.5		Sample: 9.0'–10.0'		5
10	Gray, mottled brown, silty CLAY (CL) w/pebbles & sand 11.0	3		95		1.0 0.0 1.0 >4.5		Oxidation streaking		10
15	Brown silty SAND (SM), medium grained 11.4 Brown silty CLAY (CL), with sand & pebbles & gravel at depth, oxidized 16.5	4		90				Sample: 18.0'–19.0'		15
20	Brown silty SAND (SM), coarse–medium 18.0 Brown silty CLAY (CL–ML), w/sand End Of Boring @ 20.0'									20
25										25
30										30

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ENGINEERING and APPLIED SCIENCE
821 S.DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G125

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev.

Logged By: MSS Checked By: Date Started: 7–25–95 Completed: 7–25–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Brown, silty CLAY, (CL) w/ few pebbles	1	5.0' CME continuous sampler	90		>4.5 >4.5 >4.5		Dry		0
5	Brown mottled gray silty CLAY, (CL) with pebbles & trace sand	2		60		3.5 >4.5 >4.5		Dry weathered		5
10	11.0									10
	Brown sandy SILT, (SM–ML) with pebbles 11.5	3		90		3.5 >4.5		Moist weathered		
	Gray mottled brown silty CLAY, (CL) with pebbles 14.0					>4.5				
	Brown coarse SAND & PEBBLES (SP) w/silt 15.0					0				
15	Brown silty SAND (SM), med. to coarse grain 15.5							Wet sand		15
	No recovery	4		5						
20	End of Boring @20'							Soft drilling, blow in @18.3'		20
25										25
30										30

Sheet 1 of 1

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ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G128

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4" ID HSA Surface Elev. 534.71

Logged By: MSS Checked By: Date Started: 7–24–95 Completed: 7–24–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Topsoil 0.5									0
	Light brown, mottled gray CLAY (CL) w/silt & pebbles	1	5.0' CME continuous sampler	80		>4.5				
5	7.0	2		90				Wet		5
	Reddish–brown silty CLAY (CL–SC) w/sand & pebbles 10.0									
10	Brown silty CLAY (CL) w/pebbles 12.0	3		95		>4.5				10
	Gray mottled brown silty CLAY (CL) w/pebbles & some sand					>4.5				
	17.4					>4.5				
15	Brown medium grained SAND (SW) 18.0	4		100		>4.5				15
						2.5				
						1.0				
						>4.5				
20	Brown mottled gray silty CLAY (CL) 21.5					>4.5		Hard, very weathered		20
		5		100		>4.5				
	Dark gray silty CLAY (CL) w/alot of pebbles					>4.5				
25		6		100		>4.5				25
						>4.5				
30										30

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ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G128

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 534.71

Logged By: MSS Checked By: Date Started: 7-24-95 Completed: 7-24-95

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	Dark gray silty CLAY (CL), w/alot of pebbles	7	5.0' CME continuous sampler	100		>4.5 >4.5				30
35	35.0 End Of Boring @35.0'									35
40										40
45										45
50										50
55										55
60										60

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ENGINEERING and APPLIED SCIENCE
821 S DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G130

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3–1/2" ID HSA Surface Elev. 529.40

Logged By: MSS Checked By: _____ Date Started: 7–27–95 Completed: 7–27–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Brown clayey SILT (ML) 1.0					1.25		Organic material		0
	Gray mottled brown, silty CLAY (CL–ML) 5.0	1	5.0' CME continuous sampler	60		1.25 2.5				
5	Gray mottled brown sandy SILT (ML–SM) w/some coarse sand 7.0	2		95		3.0 3.0				5
	Brown sandy SILT (ML–SM) w/pebbles & gravel 8.0					3.0 2.5				
10	Gray mottled brown silty CLAY (CL–ML) w/alot of sand & pebbles 10.0					1.0				10
	Gray sandy SILT (ML–SM) 13.0	3		60		1.0 1.0 3.5 3.5		Wet		
15	Brown silty CLAY (CL) w/pebbles, interspaced with gray to med. gray SAND lenses 18.5	4		60		3.5 3.5		Oxidation planes		15
	Brown–gray silty CLAY (CL) blocky & hard					>4.5				
20	End Of Boring @ 20.0'									20
25										25
30										30

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ENGINEERING and APPLIED SCIENCE

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821 S.DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G133

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3-1/2" ID HSA Surface Elev. 535.36

Logged By: MSS Checked By: Date Started: 7-25-95 Completed: 7-25-95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Gray clayey SILT (ML) w/sand 1.0	1	5.0' CME continuous sampler	90		3.5 2.5 3.5				0
5	Brown, mottled gray, clayey SILT (ML) with trace sand increasing in depth	2		95		2.0 2.0 3.0 2.0		Moist, free water in sample		5
10	13.0	3		95		1.0 1.0 2.0 2.5		Very wet		10
15	Brown, sandy SILT (ML-SM) w/pebbles 16.0	4		100		2.0 >4.5 >4.5 >4.5				15
	Brown, sandy SILT (ML) w/pebbles 16.6									
	Grayish brown, clayey SILT (ML) w/trace coarse sand 19.5							Very wet		
20	Brown SAND (SM) w/silt, med. grained 20.0					>4.5				20
	Brown, silty CLAY (CL) w/trace coarse sand	5		100		>4.5 >4.5 >4.5		Wet		
25	End of Boring @25'							Dry		25
30										30

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ENGINEERING and APPLIED SCIENCE
821 S.DURKIN DR. - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G136

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 3–1/2" ID HSA Surface Elev. 537.08

Logged By: MSS Checked By: _____ Date Started: 7–27–95 Completed: 7–27–95

DEPTH	Material Description Classification System UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu tsf PEN	Tests: Moist	Comments	WL	DEPTH
0	No Recovery	1	5.0' CME continuous sampler	0						0
5	Gray, mottled brown, silty CLAY with trace sand	2		100						5
	9.0									
10	Brown, silty CLAY (CL) w/trace sand									10
	10.0									
	No recovery	3		50						
	12.5									
	Gray silty SAND (SM)									
	13.5									
15	Gray–brown silty CLAY (CL–ML) with coarse sand									15
	16.0									
	Brown silty CLAY (CL) with coarse sand	4		80						
	17.5									
	Gray–brown silty CLAY (CL) with trace sand									
	19.5									
20	Brown silty coarse SAND (SM) with pebbles									20
	End of Boring @20'									
25										25
30										30

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BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S.DURKIN DR. - SPRINGFIELD, IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G139

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: SPLIT SPOON Surface Elev. 539.68

Logged By: MSS Checked By: _____ Date Started: 7–25–95 Completed: 7–26–95

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Blind 3.5	1	2-1/2' split spoon sampler							0
	Brown clayey SILT (SM) 4.0							Dry		
5	Gray, mottled brown silty CLAY (CL) w/trace sand 5.0									5
	Blind 8.5									
	Brown, mottled gray silty CLAY (CL) w/trace sand 10.0	2								
10	Blind 11.0									10
	Brown, mottled gray silty CLAY (CL) 12.5	3						Oxidation present		
	Blind 13.5									
	Brown SAND (SM) w/silt, med. grained 15.0	4						Wet		
15	Blind 16.0									15
	No recovery 18.5	5								
	Blind 19.5	6						Wet		
20	Brown SAND (SM) w/silt, med. grained									20
	Grayish Brown clayey SILT w/sand 20.0									
	End of Boring @20'									
25										25
30										30

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BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G121

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 544.69

Logged By: MSS Checked By: _____ Date Started: 10–14–96 Completed: 10–14–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Light grayish Brown, silty CLAY (OH) w/ red streaking 2.0	1	5.0' CME continuous sampler	60		3.0 3.25 4.5	dry dry	weathered		0
5	Gray, w/reddish brown streaking silty CLAY (MH–OH) w/trace fine sand 10.0	2		05		1.25	moist	very soft		5
10	Brownish Gray, silty CLAY (MH–OH) w/sand and trace pebbles 13.0	3		100		0.75 1.0 0.75 3.5 4.5+	moist moist moist	very soft		10
	Brownish Gray, coarse sandy silt (SM) w/pebbles 13.5									
15	Gray silty CLAY (ML–CL) w/pebbles 17.0	4		80		4.5+ 4.5+ 0.0 1.0	dry dry wet			15
	Gray gravelly CLAY (GC) w/sand and silt 19.0									
20	Gray silty SAND (SM), grading from medium to fine grain 21.0	5		90		2.0 4.5+ 4.5+ 4.5+ 4.0	wet wet moist			20
	Gray silty CLAY (ML–CL) w/pebbles 23.0									
	Gray fine SAND & SILT (SM)									
25	End Of Boring @ 25.0'									25
										30

Level NA of NA hrs.
Level NA of NA hrs.

N 1915.30, E 606.02

Sheet 1 of 1

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RAPPS

BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G125a

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 535.53

Logged By: MSS Checked By: _____ Date Started: 10–17–96 Completed: 10–21–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Blind drill As G125 (7/25/96)	1	5.0' CME continuous sampler	0						0
5.0										
5		2		60		3.5 3.5 4.5	dry dry			5
10	Brown, mottled gray silty CLAY (MH–CH) w/pebbles & sand	3		20		3.5	dry			10
15		4		60		3.5 3.5 3.5 4.5+	dry moist			15
18.0										
20	Brown silty CLAY (MH–CH) w/pebbles & trace sand	5		60		4.5+ 4.5+ 3.5	wet wet			20
22.0										
25	Gray silty CLAY (ML–CL) w/pebbles	6		80		4.5+ 4.5+ 4.5+ NA 4.5+	wet wet			25
28.0										
	Gray silty fine SAND (SM) 28.8									
	Gray silty CLAY (ML–CL) w/pebbles									
30	End of Boring @30'									30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 7126.62, E 6640.64

Sheet 1 of 1

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G201

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 542.45

Logged By: MSS Checked By: _____ Date Started: 10–8–96 Completed: 10–10–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Brown, mottled gray silty CLAY (OH) w/trace pebbles	1	5.0' CME continuous sampler	80		1.5 1.5 3.25 3.75	dry	Fractured		0
4.5										
5	Gray to tan clayey SILT (MH)	2		100		1.75				5
5.0										
	Brown, w/reddish streaking silty CLAY (CH)					1.25	dry			
6.7										
	Gray, mottled brown silty CLAY (CH) w/trace sand & pebbles					1.50 1.50 1.75	moist			
10.2										10
	Reddish brown, silty CLAY (CL) w/pebbles	3		95		1.75	wet			
13.0						2.25 2.75	moist			
	Reddish brown silty SAND (SP–SM) w/pebbles					0.75 0.75	wet			
15.0								Blocky Structure		15
	Gray silty CLAY (ML–CL) w/pebbles	4		100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry			
		5		100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry			20
		6		50		4.5+ 4.5+	dry			25
27.5										
	Gray SAND (SM) fine to coarse grain w/silt & trace pebbles					NA NA	wet	Blow–in: Tried to flush hole. Redrilled w/plug.		30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 8947.43, E 5499.92

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G201

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 542.45

Logged By: MSS Checked By: _____ Date Started: 10–8–96 Completed: 10–8–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
30	Gray SAND (SM) fine to coarse grain w/silt & trace pebbles	7	5.0' CME continuous sampler	40		NA NA NA 4.5+	wet wet			30
	33.0									
	Gray GRAVEL (GL) w/sand & silt									
	33.4									
35	Gray silty CLAY (ML–CL) w/pebbles	8		60		4.5+ 4.5+ 4.5+	moist moist			35
	40.0									
40	No recovery	9		00		NA		Very hard Firm.		40
	45.0									
45	Gray silty CLAY (ML–CL) w/pebbles	10		90		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	moist moist			45
50		11		100		4.5+ 3.0 3.0 3.0 3.0	moist moist			50
	54.1									
55	Gray–brown silty CLAY (ML–CL) w/pebbles									55
	55.0									
	Gray–brown silty CLAY (ML–CL) w/pebbles	12		100		4.0 4.5 4.0 4.0 4.5+	moist moist			
60										60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 8947.43, E 5499.92

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G201

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 542.45

Logged By: MSS Checked By: _____ Date Started: 10–8–96 Completed: 10–8–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles					4.5				60
	63.0	13	5.0' CME continuous sampler	75		4.5	moist			
						4.5				
	Gray fine grain sandy SILT (SM–ML) w/trace pebbles					3.0	wet			
65	65.5							Note: 63.5' to 65.0' split spoon to open augers 30/120/150 blow count.		65
	Gray fine grain SAND–SILT (SM) w/trace pebbles	14		90		3.0	wet			
						3.0				
						3.0	wet			
70	End Of Boring @70.0'					3.0				70
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 8947.43, E 5499.92

Sheet 3 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: Date Started: 10–16–96 Completed: 10–16–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Fill Material: Drilled through built drilling pad	1	5.0' CME continuous sampler	0		NA	NA			0
5		2		0		NA	NA			5
10	10.0									10
	Brown–gray silty SAND (SM) w/clay & trace pebbles	3		30		NA	moist			
	12.5					0.25				
	Brown–clayey SILT (ML) w/ sand & pebbles					NA	wet			
15	16.5									15
	Gray silty CLAY (ML–CL) w/pebbles	4		30		NA	moist	Very weathered		
	18.0					NA				
	Brown coarse SAND (SM) w/silt					NA	moist			
20	20.8									20
	Gray silty CLAY (ML–CL) w/pebbles	5		60		4.5+	dry			
						4.5+				
						4.5+				
25		6		100		4.5+	moist			25
						4.5+				
						4.5+	moist			
30						4.5+				30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

Sheet 1 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD, IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: Date Started: 10-8-96 Completed: 10-8-96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
30	Gray silty CLAY (ML-CL) w/pebbles 31.3	7	5.0' CME continuous sampler	100		4.5+				30
	Brownish Gray CLAY (CH) w/silt 32.3					4.5+	moist			
	Gray silty CLAY (ML-CL) w/pebbles					3.0	wet			
						4.5+	moist			
35	36.0					4.5+				35
	Gray silty SAND (SM) 36.5	8		100		4.5+				
						NA	wet			
						4.5+	moist			
40	Gray silty CLAY (ML-CL) w/pebbles					4.5+				40
		9		90		4.5+	moist			
						4.5+				
						4.5+	moist			
45						4.5+				45
		10		100		3.75	moist			
						4.5+				
						4.5+	moist			
50						4.5+				50
		11		100		4.5+	moist			
						4.5+				
						4.5+	moist			
55						4.5+				55
		12		100		4.5+	moist			
						4.5+				
60						4.5+				60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G202

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 537.24

Logged By: MSS Checked By: Date Started: 10–16–96 Completed: 10–16–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles					4.5+				60
	61.4					4.5+	wet			
	Gray GRAVEL (GM) w/silt	13	5.0' CME continuous sampler	100		4.5+				
	62.0					4.5+	wet			
	Gray silty CLAY (ML–CL) w/pebbles					4.5+				
65						4.5+	wet			65
		14		100		4.5+				
						4.5+	wet			
	69.5									
70	Gray fine sandy SILT (SM)					NA		Blind drill: Augers plugged w/SILT–SAND		70
	End Of Boring @70.0'									
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6649.68, E 6587.20

Sheet 3 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2181

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: Date Started: 10–15–96 Completed: 10–15–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Tan, mottled reddish clayey SILT (MH)	1	5.0' CME continuous sampler	75		4.5+ 4.5+ 4.0 2.75	dry moist	Very soft		0
3.5										
5	Gray, mottled brown silty CLAY (MH–CH) w/trace coarse sand & pebbles	2		100		1.75 1.0 0.75 1.75 2.5	moist moist			5
10		3		60		NA NA 2.5 2.75	dry dry			10
11.5	Brown silty clay (CL–ML) w/coarse sand & pebbles									
15		4		70		NA NA NA NA	dry dry			15
20										20
21.5	Brown SAND (SM) w/silt, poorly sorted	5		70		4.0 4.0 NA 4.5+	dry dry			
23.0	Gray, mottled brown silty CLAY (CL) w/pebbles									25
25		6		95		4.5+ 4.5+ 4.25 4.5 4.5+	moist dry			
28.0	Gray silty CLAY (CL–ML) w/pebbles									
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2158

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: _____ Date Started: 10–15–96 Completed: 10–15–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	WL	DEPTH
30	Gray silty CLAY (ML–CL) w/pebbles	7	5.0' CME continuous sampler	100		4.5+ 4.5+ 4.5+ 4.5	dry dry			30
	33.2 Gray fine grain SAND (SM) w/silt 34.5									
35	Brownish gray silty CLAY (CL) w/pebbles 36.5	8		100		4.0 4.5 4.5+ 4.5	dry dry			35
40	Gray silty CLAY (ML–CL) w/pebbles	9		100		4.5+ 4.5+ 4.5+ 4.5+	dry dry			40
45		10		100		4.5+ 4.5+ 4.5+ 4.5+	dry dry			45
50		11		100		4.5+ 4.5+ 4.5+ 4.5+	moist moist			50
55	57.5 Gray fine SAND (SM) w/silt 58.0	12		100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	moist moist			55
60	Gray silty CLAY (ML–CL) w/pebbles									60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

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RAPPS — BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G203

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.97

Logged By: MSS Checked By: _____ Date Started: 10–15–96 Completed: 10–15–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles	13	5.0' CME continuous sampler	100		4.5+				60
						4.5+	moist			
						4.0				
						4.5	moist			
65						4.5+				65
	65.6									
	Gray fine SAND (SM) w/silt 66.4					3.0	wet			
	Gray fine SAND–SILT (SM) w/trace gravel	14		80		4.0	wet			
70	70.0					NA				70
	Blind Drill: Auger plugged & redrilled to 73.0'									
	End Of Boring @73.0'									
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5821.29, E 6113.10

Sheet 3 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G204

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 531.34

Logged By: MSS Checked By: Date Started: 10–21–96 Completed: 10–22–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0	Whitish Tan clayey SILT (OL) w/organics, very weathered					4.25				0
	2.0	1	5.0' CME continuous sampler	100		NA	dry	weathered		
	Brownish Gray clay SILT (OL) less weathered					4.5				
	4.5					3.25	dry			
5	Brown silty CLAY (CL) w/trace sand					3.75				5
						1.0	moist			
	no recovery	2		10		NA				
						NA				
10	Reddish Brown clayey SILT (MH) w/sand					1.5	moist	soft		10
	12.1	3		100		1.5				
						0.5	moist			
						1.5				
15						3.25	moist			15
	Brown silty CLAY (CH) w/pebbles					2.5	moist			
		4		100		2.5				
						2.5	moist			
	20.0					2.5				
20						2.75				20
		5		100		2.5	moist	friable (soft & sticky)		
						2.5	moist			
25	Brown silty CLAY (CH) w/pebbles and gravel					3.0	dry			25
		6		100		2.75		weathered		
						3.75	dry			
30	29.8									30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5310.25, E 4549.88

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G204

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 531.34

Logged By: MSS Checked By: Date Started: 10–21–96 Completed: 10–22–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
30										30
		7	5.0' CME continuous sampler	60		3.5		weathered		
						4.5+	dry			
						4.5+	dry			
						4.5+				
35	Gray silty CLAY (ML–CL) w/pebbles									35
		8		100		4.5+				
						4.5+	moist			
						4.5+				
						4.5+	moist			
						4.5+				
40	40.4									40
	Gray coarse SAND(SM) w/silt 40.6									
		9		100		3.5				
						4.5	moist			
						3.25				
						4.25	moist			
						4.0				
45										45
		10		100		4.5+				
						4.5+	moist			
						4.5+				
	Gray silty CLAY (ML–CL) w/pebbles					3.75	moist			
						3.75				
50										50
		11		100		3.5				
						4.0	moist			
						4.5+				
						4.5+	moist			
						4.5+				
55	55.9									55
	Gray sandy SILT (SM) 56.2									
	Gray SILT–CLAY (ML) w/fine sand	12		100		4.0				
						4.5+	moist			
						4.5+				
	59.0					4.0	moist			
	Gray silty SAND (SM) w/pebbles					NA				
60	60.5									60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5310.25, E 4549.88

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G204

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 531.34

Logged By: MSS Checked By: _____ Date Started: 10–21–96 Completed: 10–22–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	We	DEPTH
60	Gray silty CLAY (ML–CL) w/pebbles	13	5.0' CME continuous sampler	100		4.5+ 4.5+ 4.5+ 4.5 4.5+	moist moist			60
65		14		100		4.5+ 4.5+ 4.0 2.5 2.5	wet wet			65
	68.2									
70	Gray silty CLAY (ML–CL) w/pebbles	15		100		2.5 3.0 2.75 3.0	wet wet	very soft, wet		70
75	End of Boring @ 75.0'									75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5310.25, E 4549.88

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2367 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G205

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8–3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1–27–97 Completed: 1–28–97

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0										0
5										5
10	Blind drill to 45'									10
15										15
20										20
25										25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6214.32, E 5669.05

Sheet 1 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G205

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8-3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1-27-97 Completed: 1-28-97

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30										30
35	Blind drill to 45'									35
40										40
45						>4.5				45
						>4.5	moist			
		10	5.0' CME continuous sampler	100		>4.5		Vandalia Till Member		
						>4.5	moist			
50	Med gray silty clay, some sand & gravel (Vandalia Till)					>4.5				50
						>4.5	moist			
		11		100		>4.5				
						>4.5	moist			
55						>4.5				55
						>4.5	moist			
		12		100		>4.5				
						>4.5	moist			
60						>4.5				60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6214.32, E 5669.05

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2158

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G205

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8–3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1–27–97 Completed: 1–28–97

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	same as above Trace large gravel	13	5.0' CME continuous sampler	100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			60
65		14		100		>4.5 >4.5 >4.5 >4.5 >4.5	wet wet			65
70	Some thin silt lenses @ 72.5' & 73.8'	15		100		>4.5 >4.5 3.0 >4.5 >4.5	moist wet moist			70
75	2.5' of med. gray, silt/sand from 75' to 77.5'	16		80		– 3.0 >4.5	wet	Mulberry Grove Member		75
	Med. gray silty clay, tr. sand & gravel					>4.5 >4.5	moist	Smithboro Till Member		
80	End of Boring @ 80.0'									80
85	Well completed in boring Screened 80'–70' Sand 80'–67' Bentonite Seal 67'–64' Cement/Bentonite 64'–3.5' Cement 3.5'–0'									85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6214.32, E 5669.05

Sheet 3 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: B206

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8-3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1-31-97 Completed: 2-3-97

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
0										0
5										5
10										10
	Blind drill to 55'									
15										15
20										20
25										25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N , E

Sheet 1 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DUKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: B206

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8–3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1–31–97 Completed: 2–03–97

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30										30
35	Blind drill to 55'									35
40										40
45										45
50										50
55	Med. gray silty clay (till) tr. sand & gravel	12	5.0' CME	100		>4.5 >4.5 >4.5 >4.5 >4.5	 moist moist 	Vandalia Till Member		55
60										60

Water Level NA of NA hrs. N , E Sheet 2 of 3
Water Level NA of NA hrs.

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: B206

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8–3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1–31–97 Completed: 2–3–97

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	We-ll	DEPTH
60	same as above	13	5.0' CME continuous sampler	100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist	Mulberry Grove Member —?— —?— Smithboro Till Member		60
65		14		100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			65
70		15		100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			70
75		16		100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			75
80		17		100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			80
85		18		100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			85
90	End of Boring @ 90.0' Boring sealed to surface with 20:1 cement/bentonite grout									90

Water Level NA of NA hrs. N , E Sheet 3 of 3
Water Level NA of NA hrs.

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G207

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8-3/4" ID HSA Surface Elev. _____

Logged By: AMC Checked By: AMC Date Started: 1-29-97 Completed: 1-31-97

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	We l	DEPTH
0										0
5										5
10										10
	Blind drill to 57'									
15										15
20										20
25										25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 4841.43, E 4649.02

Sheet 1 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: G207

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8-3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1-29-97 Completed: 1-31-97

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30										30
35	Blind drill to 57'									35
40										40
45										45
50										50
55										55
60	Med gray silty clay, trace sand & gravel	12	5.0' CME	100		>4.5 >4.5 >4.5	moist	Vandalia Till Member		60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 4841.43, E 4649.02

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
821 S. DURKIN DRIVE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: G207

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 8–3/4" ID HSA Surface Elev.

Logged By: AMC Checked By: AMC Date Started: 1–29–97 Completed: 1–31–97

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
60	same as above Trace large gravel	13	5.0' CME continuous sampler	100		>4.5 >4.5 >4.5 >4.5 >4.5	moist moist			60
65		14		60		>4.5 2.0 >4.5	moist wet	Vandalia Till Member		65
	Lt. gray silt/sand; thin laminate alternating light/dark layers							Mulberry Grove Member		
	Med. gray silty clay, tr. sand/gravel							Smithboro Till Member		
70	End of Boring @ 70.0'									70
	Well completed in boring Screened 70'–60' Sand 70'–57' Bentonite Seal 57'–54' Cement/Bentonite 54'–3.5' Cement 3.5'–0'									
75										75
80										80
85										85
90										90

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 484143. E 4649.02

Sheet 3 of 3

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: LEACHATE WELL Boring No: L1

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 593.70

Logged By: MSS Checked By: _____ Date Started: 10–31–96 Completed: 10–31–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Cover material	1	5.0' CME continuous sampler	75						0
3.0										
5		2		100						5
10		3		60						10
15	Blind drill through ash	4		70						15
20		5		70						20
25		6		95						25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 7897.63, E 5714.80

Sheet 1 of 2

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2181

Client: CIPS-NEWTON Project: LEACHATE WELL Boring No: L1

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 593.70

Logged By: MSS Checked By: Date Started: 10-31-96 Completed: 10-31-96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: OVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	Blind drill through ash									30
35										35
40		6	5.0' CME continuous sampler	100		NA	dry			40
45		7		100		NA	dry			45
50		8		80		NA	moist / wet			50
55	54.5 Black-gray ASH-SOIL mixture 55.5									55
	Brown, mottled gray silty CLAY w/trace sand & organics	9		100		NA	wet / wet			
60	End of Boring @60.0'									60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 7897.63. E 5714.80

Sheet 2 of 2

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2198

Client: CIPS–NEWTON Project: WELL INSTALLATION Boring No: B141

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 507.99

Logged By: MSS Checked By: Date Started: 10–11–96 Completed: 10–11–96

DEPTH	Material Description (Classification System: UNIFIED)	Sampling: Tube No.	Type	% Rec.	Tests: OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Grayish Brown silty CLAY (OH) w/trace sand	1	5.0' CME continuous sampler	80		4.5+	dry	Very weathered		0
						4.5+				
						4.5+	dry			
5						4.5+				5
	Gray–Green SILT (ML–OL) w/clay & trace fine sand in thin lenses	2		80		2.75	moist			
						2.75	moist			
						3.25	moist			
10	10.8									10
	Brown SAND (SM) medium grain w/silt 11.2	3		100		4.5+				
						4.5+	moist			
	Brown, reddish oxidation silty CLAY (ML–CL) w/trace sand					4.5+				
						4.5+	moist			
15						4.5+				15
	16.8									
		4		100		4.5+	moist			
						3.5				
						3.25	moist			
						3.75				
						4.0	moist			
20	Gray silty CLAY (ML–CL) w/pebbles & trace sand							Sample: 22.0' to 23.5' 23.5' to 25.0'		20
		5		100		4.5				
						4.5+	moist			
						4.5+				
						4.5+	moist			
						4.5+				
25	End of Boring @25'							Note: Shelby tube 25' to 26' and 27' to 28.5'		25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 5653.02, E 5198.79

Sheet 1 of 1

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: GEOTECH BORING Boring No: B142

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.38

Logged By: MSS Checked By: Date Started: 10–14–96 Completed: 10–14–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0										0
		1	5.0' CME continuous sampler	45		1.75	dry	sample 3.0' to 4.0'		
						3.25	moist	sample 4.0' to 5.5'		
5	Light Brown, mottled gray clayey SILT (ML) w/trace sand									5
		2		20		2.5	moist			
10										10
	11.5	3		70		4.5+				
	Brown, mottled gray silty CLAY (ML–CL) w/pebbles & thin lenses of fine sand					4.5+				
						4.5+	dry	weathered		
15						4.5+				15
	17.1	4		80		4.5+	dry			
	Brown, fine to very fine sand (SW–SM) w/silt 18.2					4.5+	moist			
	Brown, mottled gray silty CLAY (ML–CL) w/pebbles, blocky, very weathered					4.5+	dry			
20	20.4							weathered–stained		20
	Brown clayey SILT (ML) w/trace of fine sand					2.75				
	22.2	5		80		2.25	moist			
						3.0				
	Gray, mottled brown silty CLAY (ML–CL) w/pebbles					4.5+	moist			
25										25
	26.5					7.5	moist	sample 26.5' to 28.0'		
						4.5		sample 28.0' to 29.5'		
	Gray silty CLAY (ML–CL) w/pebbles	6		100		4.0	moist			
						4.5				
30						4.5+	dry	Bulk sample 28.0' to 32.0'		30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6047.33, E 4357.20

Sheet 1 of 2

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: GEOTECH BORING Boring No: B142

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 530.38

Logged By: MSS Checked By: _____ Date Started: 10–14–96 Completed: 10–14–96

DEPTH	Material Description Classification System: UNIFIED	Sampling: Tube No.	Sampling: Type	Sampling: % Rec.	Tests: DVM (ppm)	Tests: Qu t/sf PEN	Tests: Moist	Comments	Well	DEPTH
30	Gray silty CLAY (ML–CL) w/pebbles					4.5 4.0	dry			30
	32.5 Gray SAND–SILT(SM), poorly sorted	7	5.0' CME continuous sampler	90		4.0	moist			
	33.5 Gray silty CLAY(ML–CL) w/pebbles					1.0 4.5+	dry			
35	End Of Boring @ 35.0'									35
40										40
45										45
50										50
55										55
60										60

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6047.33, E 4357.20

Sheet 2 of 2

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2357 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS–NEWTON Project: GEOTECH BORINGS Boring No: B143

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4–1/4 ID HSA Surface Elev. 515.16

Logged By: MSS Checked By: Date Started: 10–11–96 Completed: 10–11–96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well
0	Brown silty CLAY (ML–CL) w/sand & pebbles	1	5.0' CME continuous sampler	100		2.0 4.5 4.5+ 4.5+ 4.5+	dry dry	Sample: 3.0' to 4.5'	
4.8									
5	Gray silty CLAY (ML–CL) w/pebbles	2		100		4.5+ 4.5+ 4.5+ 4.5+	dry dry		
10.3									
10	Gray, fine sandy SILT (SM) w/pebbles	3		60		NA NA NA 4.5+	dry	Very friable	
13.3									
15	Gray silty CLAY (ML–CL) w/pebbles	4		100		4.5+ 4.5+ 4.5+ 4.5+ 4.5+	dry dry	Sample: 15.5' to 17.0' 17.0' to 18.5'	
20.0									
20	No Sample: Auger for shelby tube	5		NA		NA	NA		
	End of Boring @21'							Shelby tube: 21.0' to 22.5'	
25									
30									

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6199.38, E 6001.14

Sheet 1 of 1

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RAPPS BORING LOG

ENGINEERING and APPLIED SCIENCE
2387 WEST MONROE - SPRINGFIELD IL 62704 - (217)787-2118

Client: CIPS-NEWTON Project: WELL INSTALLATION Boring No: B144

Drilling Firm: PROFESSIONAL SERVICE IND. Drilling Method: 4-1/4 ID HSA Surface Elev. 522.81

Logged By: MSS Checked By: _____ Date Started: 10-11-96 Completed: 10-11-96

DEPTH	Material Description (Classification System: UNIFIED)	Tube No.	Type	% Rec.	OVM (ppm)	Qu t/sf PEN	Moist	Comments	Well	DEPTH
0	Brown, mottled gray clayey SILT (ML) w/pebbles	1	5.0' CME continuous sampler	95		1.5 4.5+ 4.5+ 4.5+ 4.5+	dry dry	soft Sample: 3.0' to 4.0' 4.0' to 5.2'		0
4.7										
5	Brown silty CLAY(ML-CL) w/pebbles	2		100		NA NA NA 4.5+ 4.5+	dry dry dry	Extremely weathered		5
10.8										
10	Gray, mottled brown silty CLAY (ML-CL) w/pebbles	3		95		4.5+ 4.5+ 4.5+ 4.5+	dry dry dry			10
14.3										
15	Gray silty CLAY (ML-CL) w/pebbles	4		100		4.5+ 4.5+ 4.5+	dry	Sample: 15.0' to 18.0'		15
	End of Boring @18'							Shelby tube: 18.0' to 19.5'		
20										20
25										25
30										30

Water Level NA of NA hrs.
Water Level NA of NA hrs.

N 6898.61, E 6199.24

Sheet 1 of 1

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW104S

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 9090.65 Easting 6268.54

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/17/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/17/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags ____ lbs. per bag ____

Amount of bentonite: # of bags ____ lbs. per bag ____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags ____ lbs. per bag ____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags ____ lbs. per bag ____

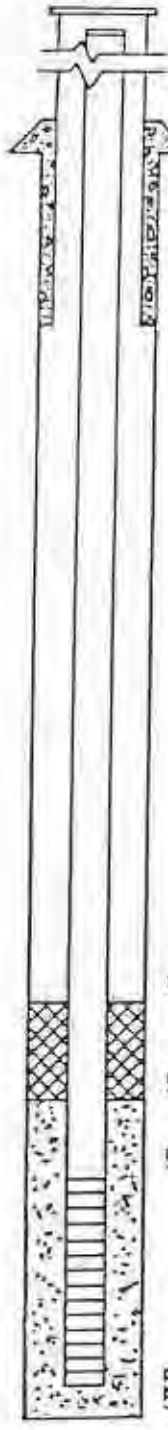
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements to .01 ft. (where applicable)

Riser pipe length	14.93 feet
Protective casing length	5.0 feet
Screen length	10.2 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



550.49 ____ MSL Top of Protective Casing

____ MSL Top of Riser Pipe

2.43 ft. Casing Stickup

548.06 ____ MSL Ground Surface

545.56 2.5 ft. Top of annular sealant

541.06 7.0 ft. Top of Seal

____ 2.5 ft. Total Seal Interval

538.56 9.5 ft. Top of Sand

535.56 12.5 ft. Top of Screen

____ 10.2 ft. Total Screen Interval

525.36 22.7 ft. Bottom of Screen

524.86 23.2 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: ____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW104D

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 9099.28 Easting 6268.56

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/15/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/17/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

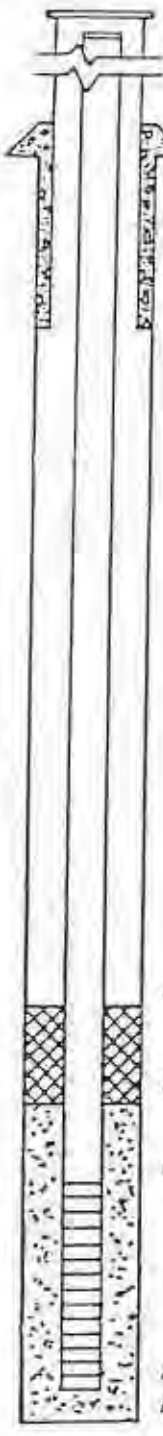
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	83.87 feet
Protective casing length	5.0 feet
Screen length	5.0 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



550.13 — MSL Top of Protective Casing

— 547.76 — MSL Top of Riser Pipe

2.37 ft. Casing Stickup

547.76 — MSL Ground Surface

545.26 2.5 ft. Top of annular sealant

472.76 75.0 ft. Top of Seal

— 4.0 ft. Total Seal Interval

468.76 79.0 ft. Top of Sand

466.26 81.5 ft. Top of Screen

— 5.0 ft. Total Screen Interval

461.26 86.5 ft. Bottom of Screen

460.76 87.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW107S

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 5453.55 Easting 4300.89

Drilling Contractor: Fox Drilling Company Date Drilled Start: 2/23/94

Driller: _____ Geologist: D. VanderLinden Date Completed: 2/23/94

Drilling Method: HSA 8 inch O.D. Drilling Fluids (type): none

Annular Space Details

Type of Surface Seal: Concrete

Type of Annular Sealant: Portland Cement

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: _____

Amount of Sand: # of bags _____ lbs. per bag _____

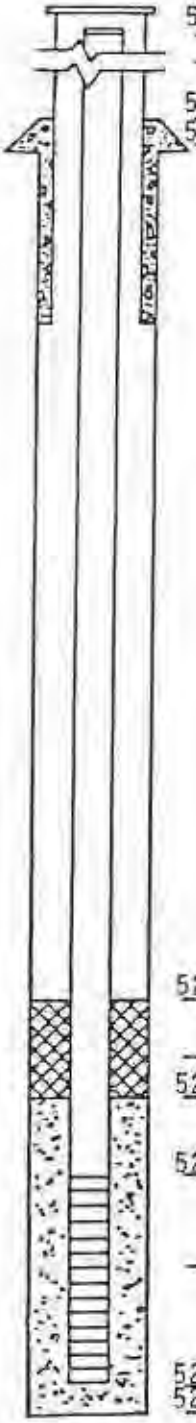
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements to .01 ft. (where applicable)

Riser pipe length	7.02feet
Protective casing length	5.0 feet
Screen length	0.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
% of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



533.30 — MSL Top of Protective Casing

— 2.02 ft. MSL Top of Riser Pipe

ft. Casing Stickup

531.28 — MSL Ground Surface

530.28 1.0 ft. Top of annular sealant

528.28 3.0 ft. Top of Seal

— 1.0 ft. Total Seal Interval

527.28 4.0 ft. Top of Sand

526.28 5.0 ft. Top of Screen

— 0.5 ft. Total Screen Interval

525.78 5.5 ft. Bottom of Screen

525.28 6.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley IL registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW108

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 6127.33 Easting 3501.84

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/27/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/27/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

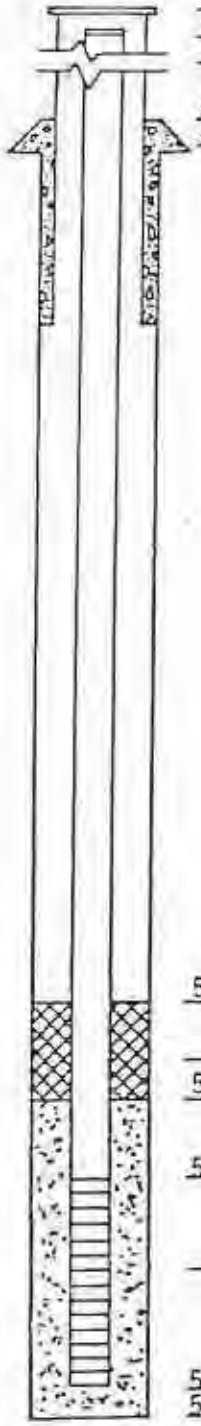
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	12.26 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



538.11 MSL Top of Protective Casing

MSL Top of Riser Pipe

2.26 ft. Casing Stickup

535.85 MSL Ground Surface

533.35 2.5 ft. Top of annular sealant

529.35 6.5 ft. Top of Seal

2.0 ft. Total Seal Interval

527.35 8.5 ft. Top of Sand

525.85 10.0 ft. Top of Screen

9.5 ft. Total Screen Interval

516.35 19.5 ft. Bottom of Screen

515.85 20.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW109

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 7369.79 Easting 4123.10

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/20/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/20/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

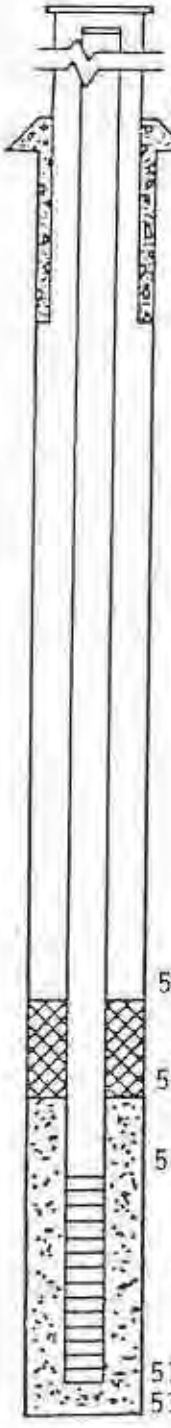
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	14.02feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



537.64 — MSL Top of Protective Casing

537.64 — MSL Top of Riser Pipe

2.02 ft. Casing Stickup

535.62 — MSL Ground Surface

533.12 2.5 ft. Top of annular sealant

529.62 6.0 ft. Top of Seal

3.0 ft. Total Seal Interval

526.62 9.0 ft. Top of Sand

523.62 12.0 ft. Top of Screen

9.5 ft. Total Screen Interval

514.12 21.5 ft. Bottom of Screen

513.62 22.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois En... Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW110

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 9232.71 Easting 4746.19

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/20/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/20/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags ____ lbs. per bag ____

Amount of bentonite: # of bags ____ lbs. per bag ____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags ____ lbs. per bag ____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags ____ lbs. per bag ____

Well Construction Materials

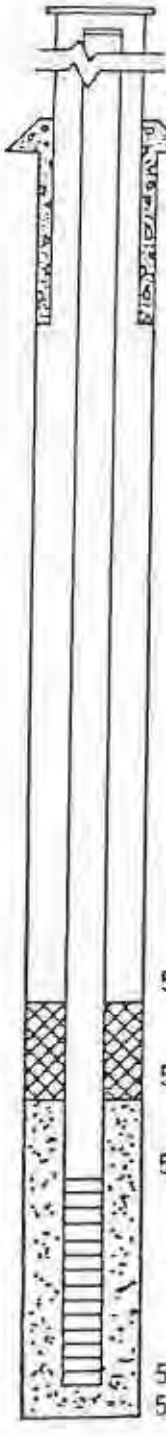
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	14.34 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



542.91 ____ MSL Top of Protective Casing

____ MSL Top of Riser Pipe

____ 2.34 ft. Casing Stickup

540.57 ____ MSL Ground Surface

538.07 2.5 ft. Top of annular sealant

534.57 6.0 ft. Top of Seal

____ 3.0 ft. Total Seal Interval

531.57 9.0 ft. Top of Sand

528.57 12.0 ft. Top of Screen

____ 9.5 ft. Total Screen Interval

518.57 22.0 ft. Bottom of Screen

518.07 22.5 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley IL registration #: ____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: 0798080002 County: Jasper Well #: MW11

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 10605.40 Easting 5908.12

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/29/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/29/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

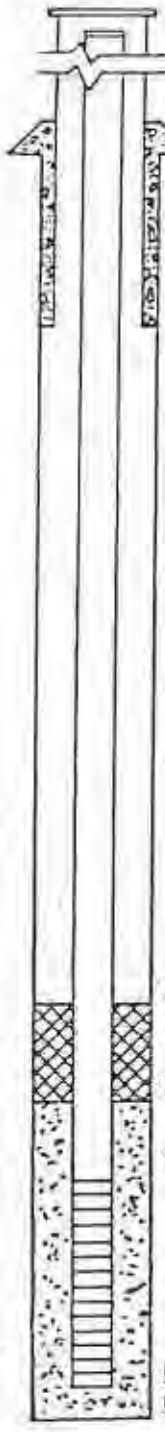
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	12.54 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



549.81	____	MSL Top of Protective Casing
____	2.54	MSL Top of Riser Pipe / ft. Casing Stickup
547.27	____	MSL Ground Surface
544.77	2.5	ft. Top of annular sealant
542.27	5.0	ft. Top of Seal
____	3.0	ft. Total Seal Interval
539.27	8.0	ft. Top of Sand
537.27	10.0	ft. Top of Screen
____	9.5	ft. Total Screen Interval
527.77	19.5	ft. Bottom of Screen
527.27	20.0	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW112

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 8194.01 Easting 7578.76

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/27/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/27/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

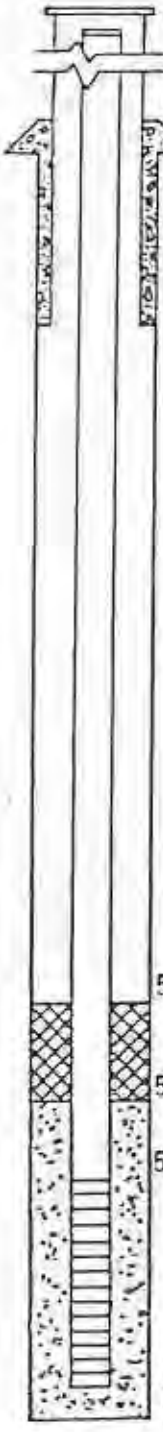
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	14.3 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



544.85	____	MSL Top of Protective Casing
____	____	MSL Top of Riser Pipe
____	2.3	ft. Casing Stickup
542.55	____	MSL Ground Surface
540.05	2.5	ft. Top of annular sealant
535.55	7.0	ft. Top of Seal
____	3.0	ft. Total Seal Interval
532.55	10.0	ft. Top of Sand
530.55	12.0	ft. Top of Screen
____	9.5	ft. Total Screen Interval
521.05	21.5	ft. Bottom of Screen
520.55	22.0	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley IL registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW113

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 6714.47 Easting 6785.56

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/29/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/29/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: 5% bentonite grout

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

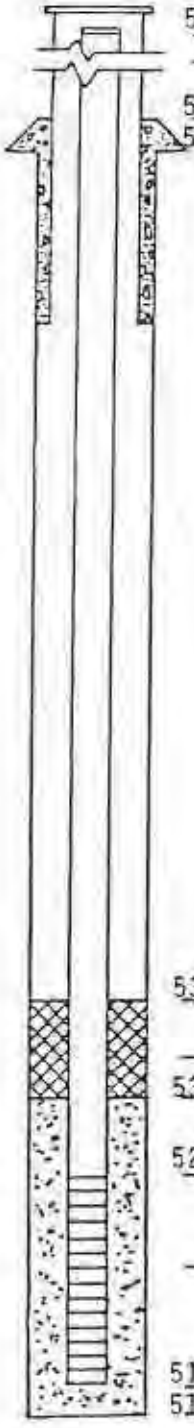
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft (where applicable)

Riser pipe length	24.45 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



553.52 ____ MSL Top of Protective Casing

____ 2.45 ft. Casing Stickup

551.07 ____ MSL Ground Surface

548.57 2.5 ft. Top of annular sealant

537.07 14.0 ft. Top of Seal

____ 3.0 ft. Total Seal Interval

534.07 17.0 ft. Top of Sand

529.07 22.0 ft. Top of Screen

____ 9.5 ft. Total Screen Interval

519.57 31.5 ft. Bottom of Screen

519.07 32.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW114

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 5771.96 Easting 2876.58

Drilling Contractor: Fox Drilling Company Date Drilled Start: 2/24/94

Driller: _____ Geologist: D. VanderLinden Date Completed: 2/24/94

Drilling Method: HSA 8 inch O.D. Drilling Fluids (type): none

Annular Space Details

Type of Surface Seal: Concrete

Type of Annular Sealant: Portland Cement

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: _____

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

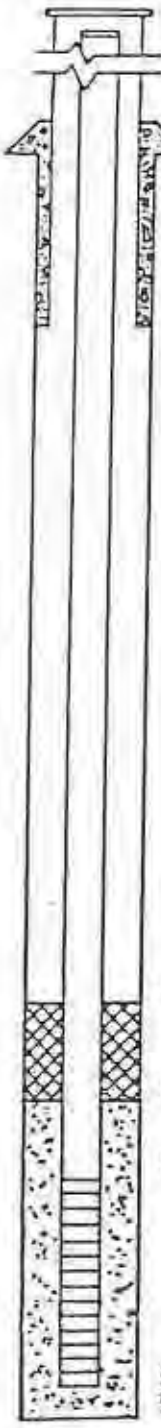
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	8.06 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
% of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



545.57 ____ MSL Top of Protective Casing

____ 2.06 MSL Top of Riser Pipe / ft. Casing Stickup

543.51 ____ MSL Ground Surface

542.51 1.0 ft. Top of annular sealant

540.51 3.0 ft. Top of Seal

____ 2.0 ft. Total Seal Interval

538.51 5.0 ft. Top of Sand

537.51 6.0 ft. Top of Screen

____ 9.5 ft. Total Screen Interval

528.01 15.5 ft. Bottom of Screen

527.51 16.0 ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: MW115

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 8756.61 Easting 2221.99

Drilling Contractor: Fox Drilling Company Date Drilled Start: 2/22/94

Driller: _____ Geologist: D. VanderLinden Date Completed: 2/22/94

Drilling Method: HSA 8 inch O.D. Drilling Fluids (type): none

Annular Space Details

Type of Surface Seal: Concrete

Type of Annular Sealant: Portland Cement

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: _____

Amount of Sand: # of bags _____ lbs. per bag _____

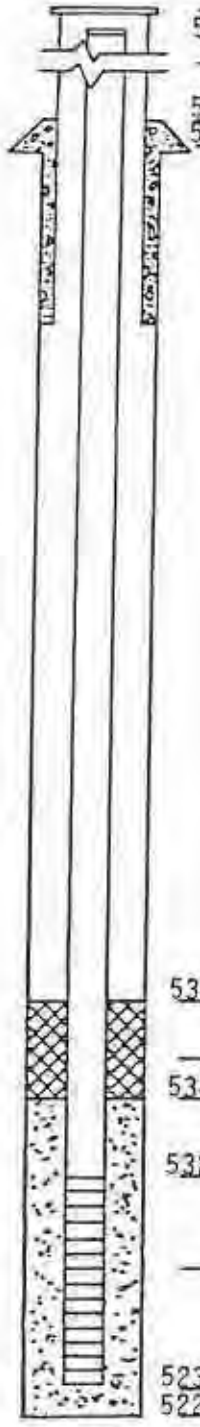
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements to .01 ft. (where applicable)

Riser pipe length	10.03 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
% of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



____	____	MSL Top of Protective Casing
542.62	____	MSL Top of Riser Pipe
____	2.03	ft. Casing Stickup
540.59	____	MSL Ground Surface
539.59	1.0	ft. Top of annular sealant
537.59	3.0	ft. Top of Seal
____	3.0	ft. Total Seal Interval
534.59	6.0	ft. Top of Sand
532.59	8.0	ft. Top of Screen
____	9.5	ft. Total Screen Interval
523.09	17.5	ft. Bottom of Screen
522.59	18.0	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well: MW 116

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 11867.07 Easting 9516.19

Drilling Contractor: Fox Drilling Company Date Drilled Start: 2/23/94

Driller: _____ Geologist: D. VanderLinden Date Completed: 2/23/94

Drilling Method: HSA 8 inch O.D. Drilling Fluids (type): none

Annular Space Details

Type of Surface Seal: Concrete

Type of Annular Sealant: Portland Cement

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: _____

Amount of Sand: # of bags _____ lbs. per bag _____

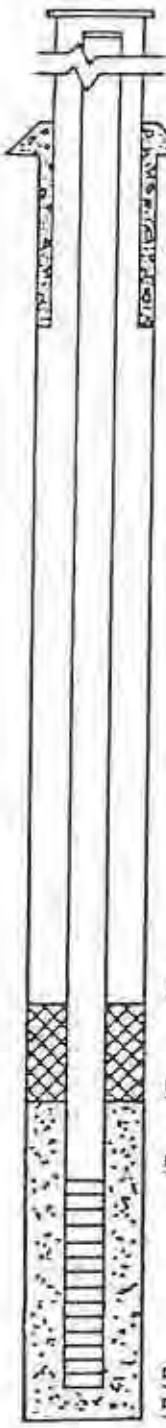
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements to .01 ft. (where applicable)

Riser pipe length	12.27 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
% of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



_____	_____	MSL Top of Protective Casing
553.43	_____	MSL Top of Riser Pipe
_____	2.27	ft. Casing Stickup
551.16	_____	MSL Ground Surface
550.16	1.0	ft. Top of annular sealant
546.16	5.0	ft. Top of Seal
_____	3.0	ft. Total Seal Interval
543.16	8.0	ft. Top of Sand
541.16	10.0	ft. Top of Screen
_____	9.5	ft. Total Screen Interval
531.66	19.5	ft. Bottom of Screen
531.16	20.0	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley IL registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: 0798080002 County: Jasper Well #: PII S

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 7367.47 Easting 6214.74

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/28/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/28/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: bentonite chips

Amount of cement: # of bags ____ lbs. per bag ____

Amount of bentonite: # of bags ____ lbs. per bag ____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags ____ lbs. per bag ____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags ____ lbs. per bag ____

Well Construction Materials

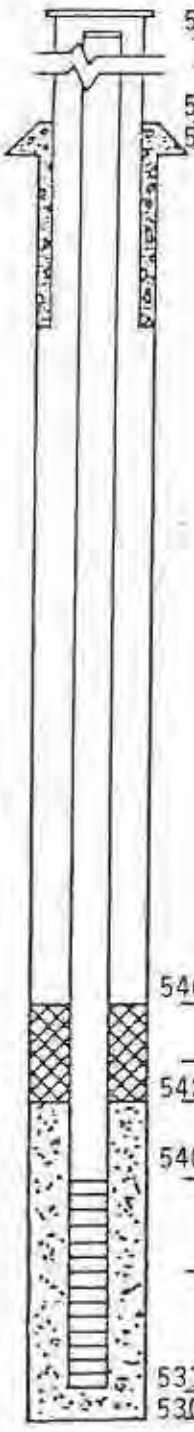
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	31.48 feet
Protective casing length	5.0 feet
Screen length	9.5 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



572.09	____	MSL Top of Protective Casing
		MSL Top of Riser Pipe
____	1.48	ft. Casing Stickup
570.61	____	MSL Ground Surface
568.11	2.5	ft. Top of annular sealant
546.61	24.0	ft. Top of Seal
____	4.0	ft. Total Seal Interval
542.61	28.0	ft. Top of Sand
540.61	30.0	ft. Top of Screen
____	9.5	ft. Total Screen Interval
531.11	39.5	ft. Bottom of Screen
530.61	40.0	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley IL registration #: ____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Water Well Completion Report

Site #: 0798080002 County: Jasper Well #: PII D

Site Name: CIPS Newton Power Plant Grid Coordinate: Northing 7367.47 Easting 6214.74

Drilling Contractor: Fox Drilling Company Date Drilled Start: 12/28/93

Driller: Tom Dychas Geologist: B. Kimpel Date Completed: 12/28/93

Drilling Method: Rotary Drilling, 8 inch O.D. Drilling Fluids (type): None

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: bentonite chips

Amount of cement: # of bags _____ lbs. per bag _____

Amount of bentonite: # of bags _____ lbs. per bag _____

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag _____

Type of Sand Pack: very coarse sand

Source of Sand: Global Drilling Supplies

Amount of Sand: # of bags _____ lbs. per bag _____

Well Construction Materials

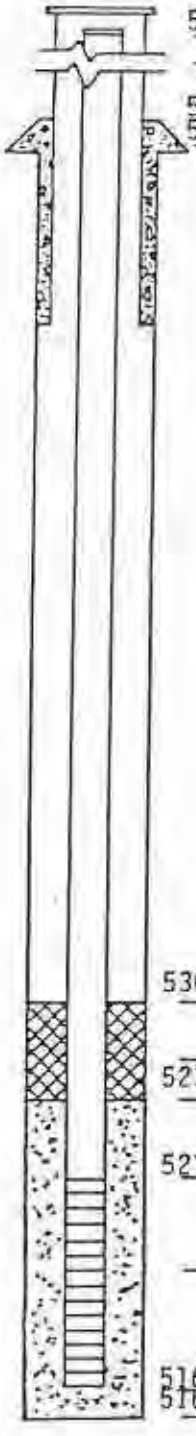
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch.40	
Riser pipe below w.t.			Sch.40	
Screen			Sch.40	
Coupling joint screen to riser				
Protective casing				steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	50.43 feet
Protective casing length	5.0 feet
Screen length	5.0 feet
Bottom of screen to end cap	0.5 feet
Top of screen to first joint	0.5 feet
Total length of casing	NA
Screen slot size	0.010 slot
# of openings in screen	13/inch
Diameter of borehole (in)	8 inches
ID of riser pipe (in)	2 inches

Elevations — .01 ft.



572.04	____	MSL Top of Protective Casing
____	____	MSL Top of Riser Pipe
____	1.43	ft. Casing Stickup
570.61	____	MSL Ground Surface
568.11	2.5	ft. Top of annular seslant
530.61	40.0	ft. Top of Seal
____	7.0	ft. Total Seal Interval
523.61	47.0	ft. Top of Sand
521.61	49.0	ft. Top of Screen
____	5.0	ft. Total Screen Interval
516.61	54.0	ft. Bottom of Screen
516.11	54.5	ft. Bottom of Borehole

Completed by: D. VanderLinden Surveyed by: Ron Whaley Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Site # ILD 0 [illegible] 6105

Site Name Scrubber Sludge Landfill — Grid Coordinate (Plant) Northing 509.28N Easting 6321.64W

Drilling Contractor Broecke Engineering — Date Drilled Start 7/31/90

Driller Mike Foppy — Geologist Rich Boyer (HEI) — Date Completed 8/1/90

Drilling Method 4¼" ID, 8" OD Hollow Stem Augers — Drilling Fluids (type) None

Annular Space Details

Type of Surface Seal Cement/Bentonite Grout

Type of Annular Sealant Cement/Bentonite Grout

Amount of cement # of bags 2 lbs. per bag 94

Amount of bentonite # of bags 0.1 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet) ¼" pellets

Amount of bentonite # of Bags 2 lbs. per bag 50

Type of Sand Pack Silica Sand

Source of Sand Meramec WB-35

Amount of Sand # of bags 5.25 lbs. per bag 94

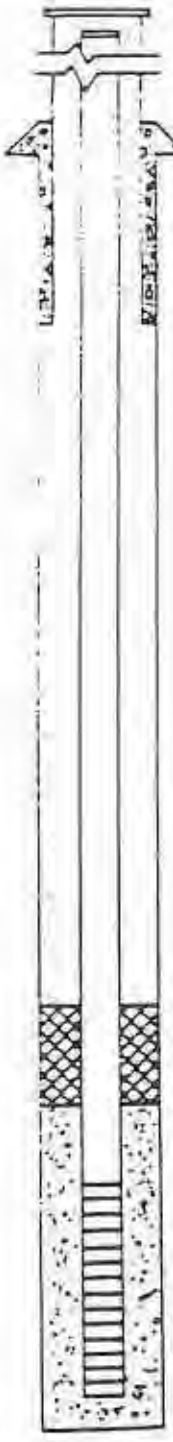
Well Construction Materials

	Stainless Steel (Specify Type)	Teflon (Specify Type)	PVC (Specify Type Schedule 40)	Other (Specify Type)
Riser coupling joint			X	
Riser pipe above w.t.			2" ID	
Riser pipe below w.t.			2" ID	
Screen			0.01"	
Coupling joint screen to riser			X	
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	11.3
Protective casing length	5.0
Screen length	15.1
Bottom of screen to end cap	0
Top of screen to first joint	10
Total length of casing	26.4
Screen slot size	0.01"
# of openings in screen	0.125" spacing
Diameter of borehole (in)	8"
ID of riser pipe (in)	2



Elevations — .01 ft.

532.90 MSL Top of Protective Casing

532.78 MSL Top of Riser Pipe

2.28 ft. Casing Stickup

530.50 MSL Ground Surface

530.50 ft. Top of annular seal

526.48 ft. Top of Seal

3.00 ft. Total Seal Interval

523.48 ft. Top of Sand

521.48 ft. Top of Screen

15.10 ft. Total Screen Interval

506.38 ft. Bottom of Screen

504.88 ft. Bottom of Borehole

Completed by Robert Coules (HEI) Surveyed by Herb Williams (HEI) Ill. registration # 035-002385

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # ILD 0774808008 County Gallatin Log # G106

Site Name Scrubber Sludge Landfill — Grid Coordinate (PLANT) Northing 983.42N Easting 7065.61W

Drilling Contractor Broecke Engineering — Date Drilled Start 8/1/90

Driller Mike Foppy — Geologist Rich Boyer CHEI — Date Completed 8/1/90

Drilling Method 4½" ID, 8" OD Hollow Stem Augers — Drilling Fluids (type) None

Annular Space Details

Type of Surface Seal: Cement/Bentonite Grout

Type of Annular Sealant: Cement/Bentonite Grout

Amount of cement # of bags 3 lbs. per bag 94

Amount of bentonite # of bags 0.28 lbs. per bag 50

Type of Bentonite Seal, Granular, Pellet: ¼" pellets

Amount of bentonite # of Bags 2 lbs. per bag 50

Type of Sand Pack: Silica Sand

Source of Sand: Meramec WB-25

Amount of Sand # of bags 3 lbs. per bag 94

Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type Schedule 40	Other Specify Type
Riser coupling joint			X	
Riser pipe above w.t.			2" ID	
Riser pipe below w.t.			2" ID	
Screen			0.01"	
Coupling joint screen to riser			X	
Protective casing				Steel

Measurements

to 01 ft. (where applicable)

Riser pipe length	21.5
Protective casing length	5.0
Screen length	14.9
Bottom of screen to end cap	0
Top of screen to first joint	10
Total length of casing	36.4
Screen slot size	0.01"
# of openings in screen	0.125" spacing
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.

530.87 MSL Top of Protective Casing

530.86 MSL Top of Riser Pipe

1.86 ft. Casing Stickup

529.00 MSL Ground Surface

529.00 ft. Top of annular seal



515.76 ft. Top of Seal

3.20 ft. Total Seal Interval

512.56 ft. Top of Sand

509.36 ft. Top of Screen

14.90 ft. Total Screen Interval

494.46 ft. Bottom of Screen

492.56 ft. Bottom of Borehole

Completed by Robert Cowles (CHEI) Surveyed by Herb Williams (CHEI) Ill. registration # 035-00238

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # ILD [illegible] County [illegible] Well # G107

Site Name Scrubber Sludge Landfill PLANT Grid Coordinate Northing 1526.89 N Easting 7427.29 W

Drilling Contractor Broecke Engineering Date Drilled Start 8/2/90

Driller Mike Foppy Geologist Rich Boyer (HEI) Date Completed 8/2/90

Drilling Method 4¼" ID, 8" OD Hollow Stem Augers Drilling Fluids (type) None

Annular Space Details

Type of Surface Seal Cement/Bentonite Grout

Type of Annular Sealant Cement/Bentonite Grout

Amount of cement # of bags 3 lbs. per bag 94

Amount of bentonite # of bags 0.36 lbs. per bag 50

Type of Bentonite Seal Granular Pellets ¼" pellets

Amount of bentonite # of Bags 2 lbs. per bag 50

Type of Sand Pack Silica Sand

Source of Sand Meramec WB-35

Amount of Sand # of bags 6 lbs. per bag 94

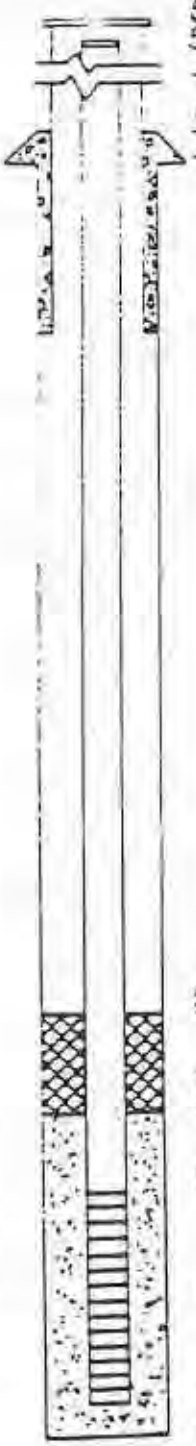
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type Schedule 40	Other Specify Type
Riser coupling joint			X	
Riser pipe above w.t.			2" ID	
Riser pipe below w.t.			2" ID	
Screen			0.01"	
Coupling joint screen to riser			X	
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	19.0
Protective casing length	5.0
Screen length	15.0
Bottom of screen to end cap	0
Top of screen to first joint	10
Total length of casing	34.0
Screen slot size	0.01"
# of openings in screen	0.125" spacing
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

533.30 MSL Top of Protective Casing
533.25 MSL Top of Riser Pipe
2.25 ft. Casing Stickup

531.00 MSL Ground Surface
531.00 ft. Top of annular sealant

519.75 ft. Top of Seal
3.50 ft. Total Seal Interval
516.25 ft. Top of Sand

514.25 ft. Top of Screen

15.00 ft. Total Screen Interval

499.25 ft. Bottom of Screen
497.45 ft. Bottom of Borehole

Completed by Robert Cowles (HEI) Surveyed by Herb Williams (HEI) Ill. registration # 035-002383

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # _____ County Jasper Well # G117

Site Name Newton Power Station Landfill Grid Coordinate: Northing 4801.06 Easting 4264.14

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/26/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/26/95

Drilling Method: 3¼" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

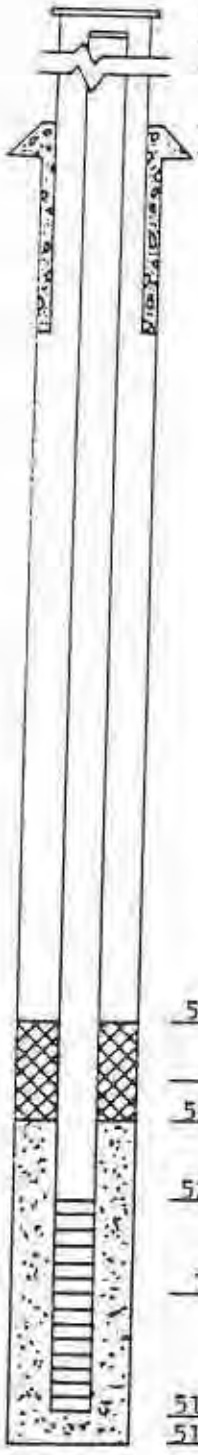
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements to .01 ft. (where applicable)

Riser pipe length	11.87 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



533	98	MSL Top of Protective Ca
533	98	MSL Top of Riser Pipe
3	57	ft. Casing Stickup
530	41	MSL Ground Surface
___	___	ft. Top of annular sealant
523	61	ft. Top of Seal
0	40	ft. Total Seal Interval
523	21	ft. Top of Sand
522	11	ft. Top of Screen
10	00	ft. Total Screen Interval
512	11	ft. Bottom of Screen
511	91	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # _____ County Jasper Well # G118

Site Name Newton Power Station Landfill Grid Coordinate Northing 5232.17 Easting 3694.90

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start 07/28/95

Driller: _____ Geologist Mike Summers Date Completed 07/28/95

Drilling Method: 3¼" HSA Drilling Fluids (type) N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

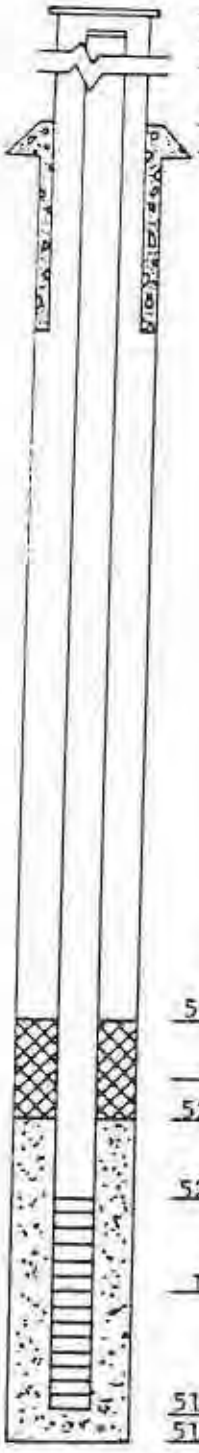
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	13.18 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



		MSL Top of Protective Cr
533	68	MSL Top of Riser Pipe
4	18	ft. Casing Stickup
529	50	MSL Ground Surface
		ft. Top of annular sealan
522	00	ft. Top of Seal
0	50	ft. Total Seal Interval
521	50	ft. Top of Sand
520	50	ft. Top of Screen
10	00	ft. Total Screen Interval
510	50	ft. Bottom of Screen
510	50	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G119

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6717.47 Easting 3843.26

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/25/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/25/95

Drilling Method: 3¼" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags _____ lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

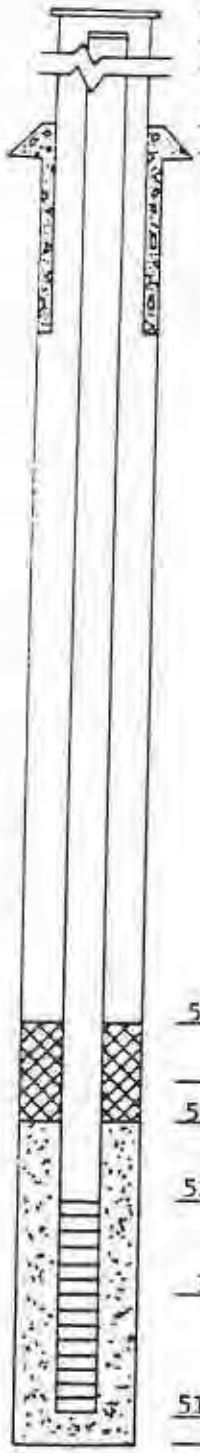
Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements to .01 ft. (where applicable)

Riser pipe length	13.13 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

538	57	MSL Top of Protective Ca
		MSL Top of Riser Pipe
3	13	ft. Casing Stickup
535	44	MSL Ground Surface
____	____	ft. Top of annular sealant
528	14	ft. Top of Seal
0	50	ft. Total Seal Interval
527	64	ft. Top of Sand
525	44	ft. Top of Screen
10	00	ft. Total Screen Interval
515	44	ft. Bottom of Screen
____	____	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G120

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 8299.8 Easting 4230.37

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/27/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/27/95

Drilling Method: 3¼" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

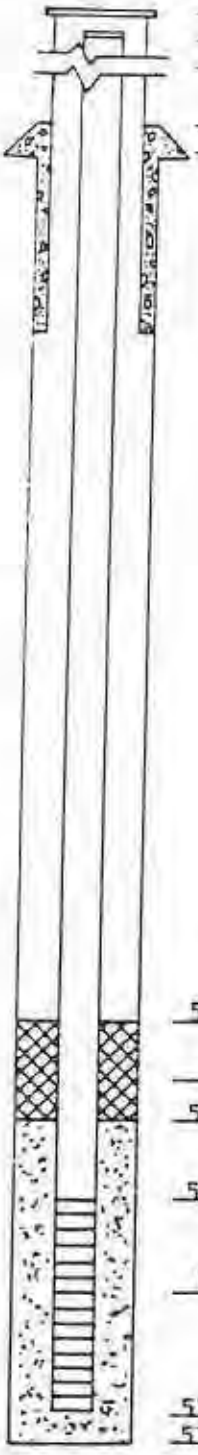
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	13.94 Ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



541	57	MSL Top of Protective Ca
3	94	MSL Top of Riser Pipe ft. Casing Stickup
537	63	MSL Ground Surface
____	____	ft. Top of annular sealant
530	13	ft. Top of Seal
0	50	ft. Total Seal Interval
529	63	ft. Top of Sand
527	63	ft. Top of Screen
10	00	ft. Total Screen Interval
517	63	ft. Bottom of Screen
517	63	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G128

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6698.06 Easting 6049.09

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/24/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/24/95

Drilling Method: 3¼" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 7 lbs. per bag 100

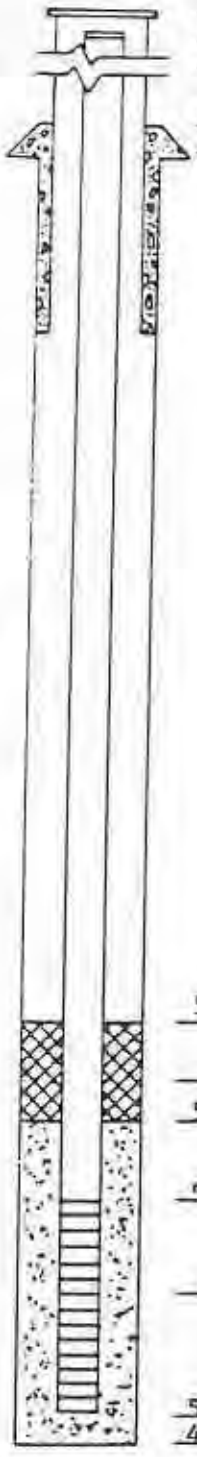
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	20.45 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

____	____	MSL Top of Protective Cas
538	16	MSL Top of Riser Pipe
3	45	ft. Casing Stickup
534	71	MSL Ground Surface
____	____	ft. Top of annular sealant
521	21	ft. Top of Seal
0	50	ft. Total Seal Interval
520	71	ft. Top of Sand
517	71	ft. Top of Screen
10	00	ft. Total Screen Interval
507	71	ft. Bottom of Screen
499	71	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G130

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6340.44 Easting 5017.07

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/27/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/27/95

Drilling Method: 3¼" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

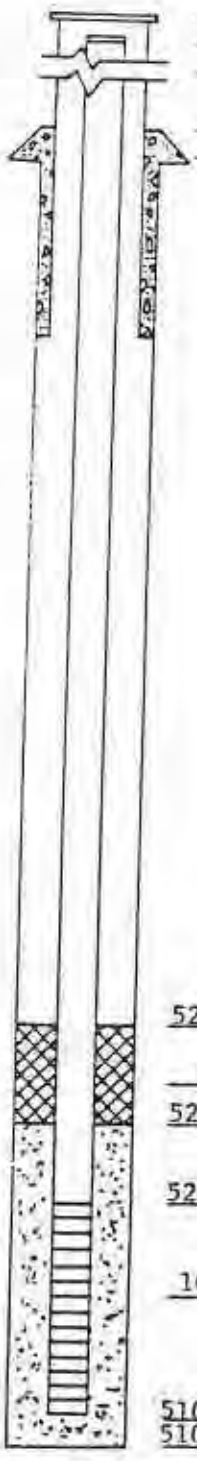
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	13.05 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



533	45	MSL Top of Protective Ca
4	05	MSL Top of Riser Pipe
		ft. Casing Stickup
529	40	MSL Ground Surface
		ft. Top of annular sealant
522	40	ft. Top of Seal
0	30	ft. Total Seal Interval
522	10	ft. Top of Sand
520	40	ft. Top of Screen
10	00	ft. Total Screen Interval
510	40	ft. Bottom of Screen
510	40	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # _____ County Jasper Well # G133

Site Name: Newton Power Station Landfill Grid Coordinate Northing 6339.97 Easting 4111.01

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/25/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/25/95

Drilling Method: 3½" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

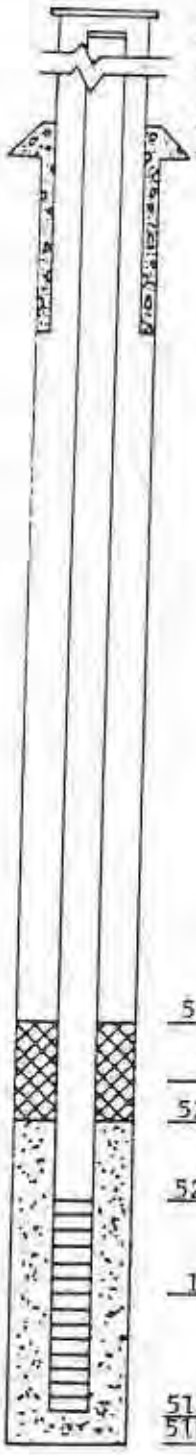
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	18.27 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2



Elevations — .01 ft.

____	____	MSL Top of Protective Cas
538	63	MSL Top of Riser Pipe
3	27	ft. Casing Stickup
535	36	MSL Ground Surface
____	____	ft. Top of annular sealant
523	36	ft. Top of Seal
0	50	ft. Total Seal Interval
522	86	ft. Top of Sand
520	36	ft. Top of Screen
10	00	ft. Total Screen Interval
510	36	ft. Bottom of Screen
510	36	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G136

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 7200.23 Easting 4285.93

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/27/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/27/95

Drilling Method: 3½" HSA Drilling Fluids (type): _____

Annular Space Details

Type of Surface Seal: portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

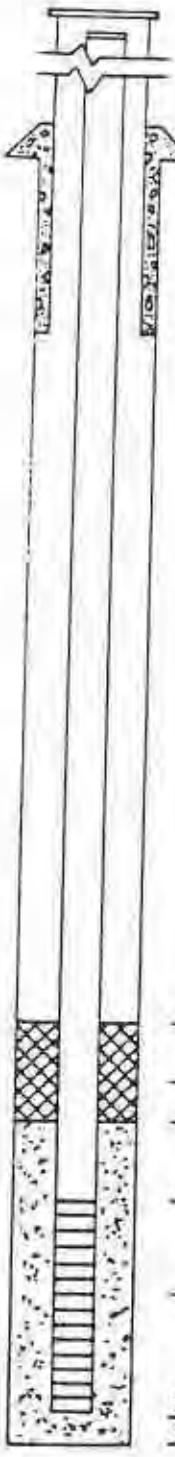
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	12.73 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



540	31	MSL Top of Protective Ca
3	23	MSL Top of Riser Pipe / ft. Casing Stickup
537	08	MSL Ground Surface
____	____	ft. Top of annular sealant
530	08	ft. Top of Seal
0	40	ft. Total Seal Interval
529	68	ft. Top of Sand
527	58	ft. Top of Screen
10	00	ft. Total Screen Interval
517	58	ft. Bottom of Screen
517	08	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # _____ County Jasper Well # G139

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 7920.15 Easting 4739.21

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 07/25/95

Driller: _____ Geologist: Mike Summers Date Completed: 07/26/95

Drilling Method: 3½" HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 96

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 5 lbs. per bag 100

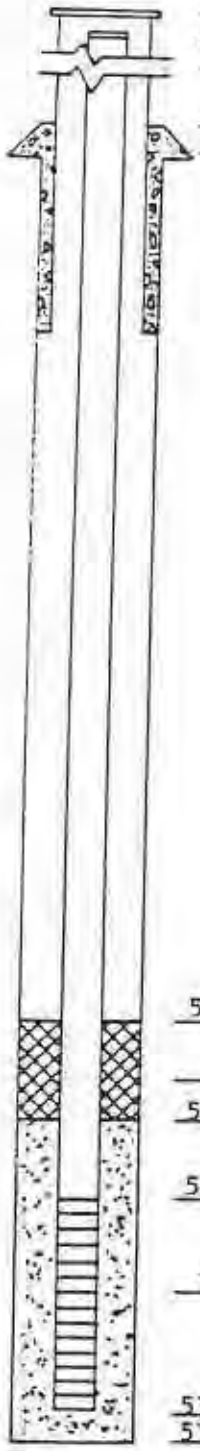
Well Construction Materials

	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements to .01 ft. (where applicable)

Riser pipe length	13.66 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	0.010
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



543	34	MSL Top of Protective Ca
3	66	MSL Top of Riser Pipe
		ft. Casing Stickup
539	68	MSL Ground Surface
____	____	ft. Top of annular sealant
535	18	ft. Top of Seal
0	50	ft. Total Seal Interval
534	68	ft. Top of Sand
529	68	ft. Top of Screen
10	00	ft. Total Screen Interval
519	68	ft. Bottom of Screen
519	68	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois E[illegible] Well Completion Report

Site #: _____ County Jasper Well # G114R

Site Name: Newton Power Station Landfill Grid Coordinate Northing 5775.46 Easting 2873.52

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/07/96

Driller: _____ Geologist Mike Summers Date Completed: 10/07/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 4 lbs. per bag 94

Amount of bentonite: # of bags 2/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1.5 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 7.5 lbs. per bag 100

Well Construction Materials

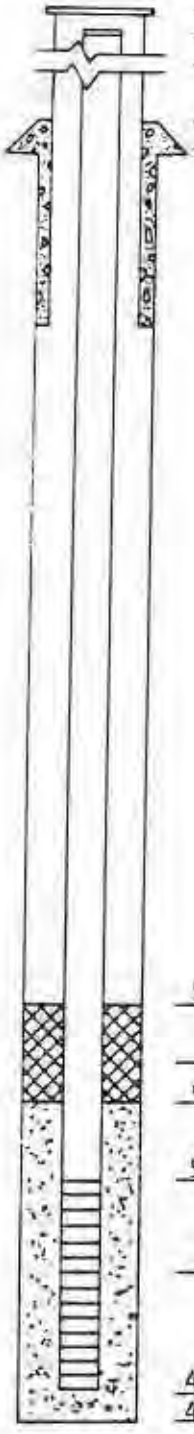
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen		Sch 40		
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	26.75 ft.
Protective casing length	
Screen length	20.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



_____	_____	MSL Top of Protective Casing
535	41	MSL Top of Riser Pipe
2	75	ft. Casing Stickup
532	66	MSL Ground Surface
_____	_____	ft. Top of annular sealant
514	16	ft. Top of Seal
3	00	ft. Total Seal Interval
511	16	ft. Top of Sand
508	66	ft. Top of Screen
20	00	ft. Total Screen Interval
488	66	ft. Bottom of Screen
488	66	ft. Bottom of Borehole

Completed by _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: _____ County: Jasper Well #: G125A

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 7177.73 Easting 6640.64

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/17/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/21/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 94

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1/4 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

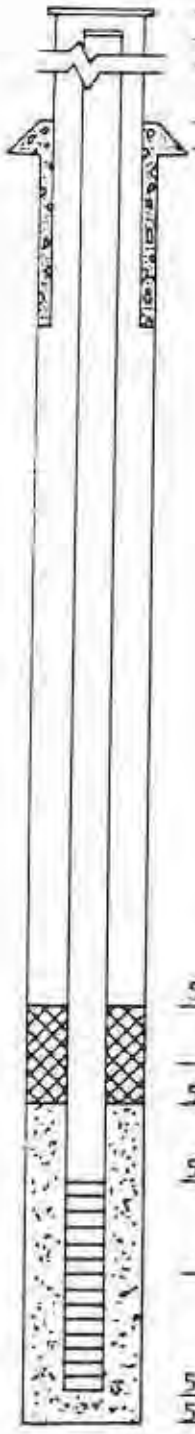
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	12.66 ft.
Protective casing length	
Screen length	10.00 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



538	19	MSL Top of Protective Casin
538	19	MSL Top of Riser Pipe
2	66	ft. Casing Stickup
535	53	MSL Ground Surface
____	____	ft. Top of annular sealant
528	03	ft. Top of Seal
0	.5	ft. Total Seal Interval
527	53	ft. Top of Sand
525	53	ft. Top of Screen
10	00	ft. Total Screen Interval
515	53	ft. Bottom of Screen
515	53	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: _____ County: Jasper Well #: G201

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 8947.43 Easting 5499.92

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/08/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/10/96

Drilling Method: 4½" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 12 lbs. per bag 94

Amount of bentonite: # of bags 1 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 3.5 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 5 lbs. per bag 100

Well Construction Materials

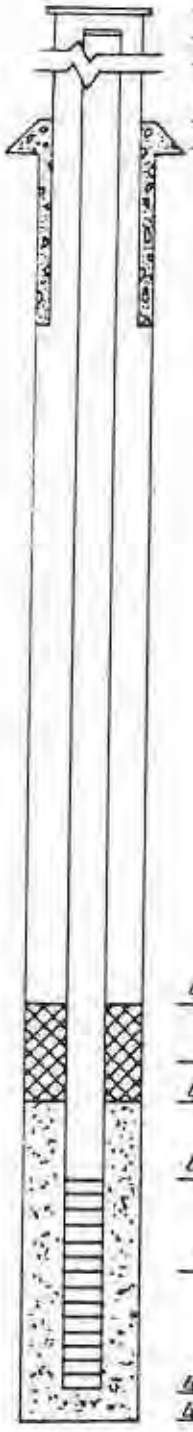
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	59.52 ft.
Protective casing length	
Screen length	10.00 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



____	____	MSL Top of Protective Casing
544	97	MSL Top of Riser Pipe
2	52	ft. Casing Stickup
542	45	MSL Ground Surface
____	____	ft. Top of annular sealant
492	95	ft. Top of Seal
5	50	ft. Total Seal Interval
487	45	ft. Top of Sand
485	45	ft. Top of Screen
10	00	ft. Total Screen Interval
475	45	ft. Bottom of Screen
473	45	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency

Well Completion Report

Site # _____ County Jasper Well # G202

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6649.68 Easting 6587.20

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/16/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/16/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 14 lbs. per bag 94

Amount of bentonite: # of bags 1.5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 12.5 lbs. per bag 100

Well Construction Materials

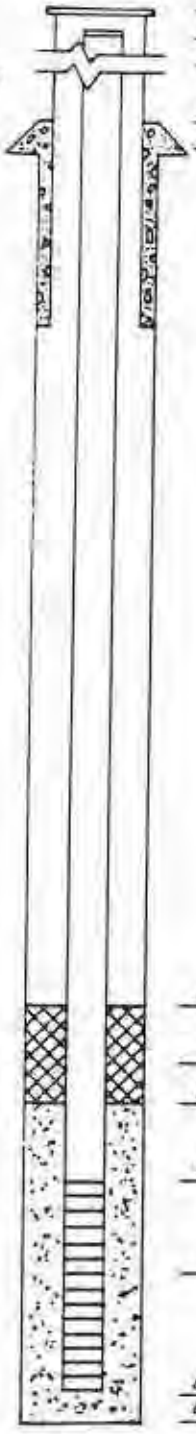
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.				
Riser pipe below w.t.				
Screen				
Coupling joint screen to riser				
Protective casing				

Measurements

to .01 ft. (where applicable)

Riser pipe length	66.78 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



____	____	MSL Top of Protective Casing
540	02	MSL Top of Riser Pipe
2	78	ft. Casing Stickup
537	24	MSL Ground Surface
____	____	ft. Top of annular sealant
479	24	ft. Top of Seal
2	50	ft. Total Seal Interval
476	74	ft. Top of Sand
473	24	ft. Top of Screen
10	00	ft. Total Screen Interval
463	24	ft. Bottom of Screen
463	24	ft. Bottom of Borehole

Completed by _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — **Well Completion Report**

Site #: _____ County: Jasper Well #: G203

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 5821.29 Easting 6113.10

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/15/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/15/96

Drilling Method: 4½" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 10 lbs. per bag 94

Amount of bentonite: # of bags 1 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 8 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 13.5 lbs. per bag 100

Well Construction Materials

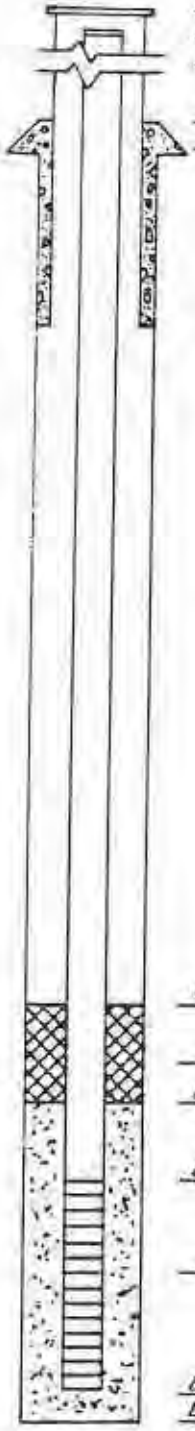
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	65.22 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



533	69	MSL Top of Protective Casing
		MSL Top of Riser Pipe
2	72	ft. Casing Stickup
530	97	MSL Ground Surface
		ft. Top of annular sealant
487	97	ft. Top of Seal
16	50	ft. Total Seal Interval
471	47	ft. Top of Sand
468	47	ft. Top of Screen
10	00	ft. Total Screen Interval
458	47	ft. Bottom of Screen
458	47	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G204

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 5210.25 Easting 4549.88

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/21/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/22/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 12 lbs. per bag 100

Amount of bentonite: # of bags 1 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 2 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 12.5 lbs. per bag 100

Well Construction Materials

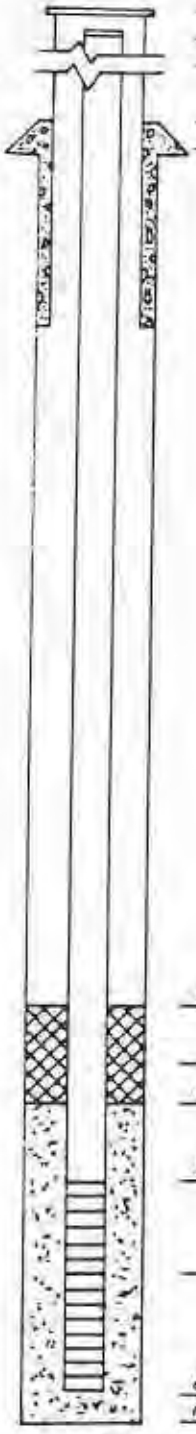
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	56.75 ft.
Protective casing length	
Screen length	10.00 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



533	59	MSL Top of Protective Casing
533	59	MSL Top of Riser Pipe
2	25	ft. Casing Stickup
531	34	MSL Ground Surface
____	____	ft. Top of annular sealant
483	34	ft. Top of Seal
4	00	ft. Total Seal Interval
479	34	ft. Top of Sand
476	84	ft. Top of Screen
10	00	ft. Total Screen Interval
466	84	ft. Bottom of Screen
466	84	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois [illegible] Well Completion Report

Site #: _____ County Jasper Well # G205

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 6214.32 Easting 5669.05

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 01/27/97

Driller: _____ Geologist Al Curtiss Date Completed: 01/28/97

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type) N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 12 lbs. per bag 96

Amount of bentonite: # of bags 1.5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1.5 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: Best Sand

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

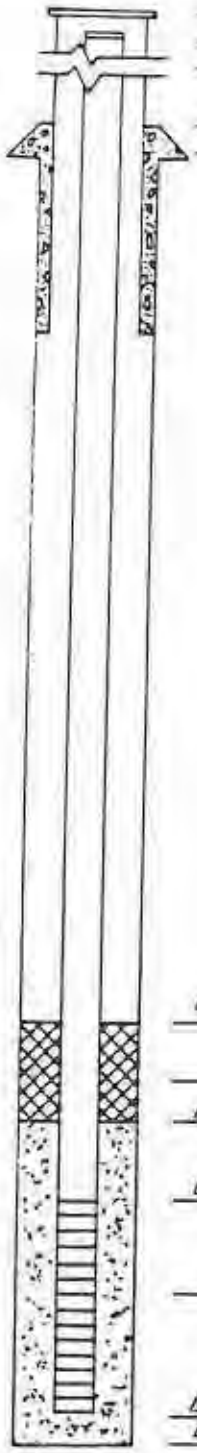
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	72.13 ft.
Protective casing length	
Screen length	10.00 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



537	01	MSL Top of Protective Cas
2	63	MSL Top of Riser Pipe ft. Casing Stickup
534	38	MSL Ground Surface
____	____	ft. Top of annular sealant
470	38	ft. Top of Seal
3	00	ft. Total Seal Interval
467	38	ft. Top of Sand
464	88	ft. Top of Screen
10	00	ft. Total Screen Interval
454	88	ft. Bottom of Screen
454	38	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site # _____ County Jasper Well # G207

Site Name: Newton Power Station Landfill Grid Coordinate Northing 6214.32 Easting 5669.05

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: _____

Driller: _____ Geologist: Al Curtiss Date Completed: _____

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 12 lbs. per bag 96

Amount of bentonite: # of bags 1.5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 1.5 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: Best Sand

Amount of Sand: # of bags 4 lbs. per bag 100

Well Construction Materials

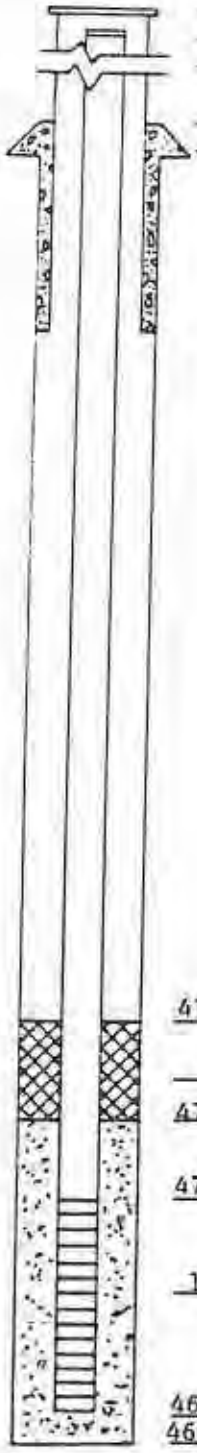
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen		Type 304		
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	64.25 ft.
Protective casing length	
Screen length	10.00 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



537	75	MSL Top of Protective Cas
537	75	MSL Top of Riser Pipe
2	75	ft. Casing Stickup
533	00	MSL Ground Surface
____	____	ft. Top of annular sealant
479	00	ft. Top of Seal
3	00	ft. Total Seal Interval
476	00	ft. Top of Sand
473	50	ft. Top of Screen
10	00	ft. Total Screen Interval
463	50	ft. Bottom of Screen
463	00	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration # _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Water Well Completion Report

Site #: _____ County: Jasper Well #: 1.1

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 7897.63 Easting 5714.80

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/31/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/31/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 4 lbs. per bag 94

Amount of bentonite: # of bags 2/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 2 lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 12/5 lbs. per bag 100

Well Construction Materials

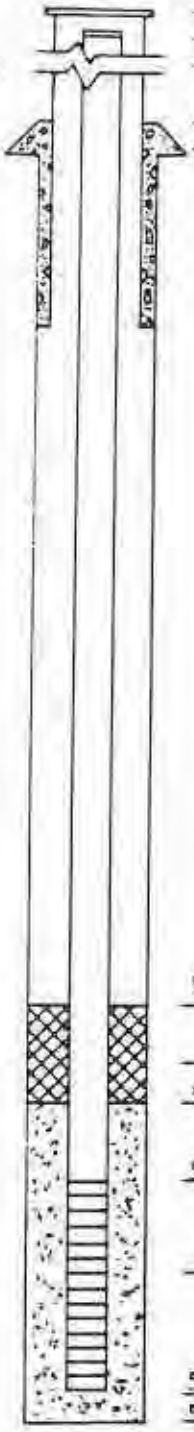
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type 304			
Screen	Type 304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	46.92 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
# of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



597	12	MSL Top of Protective Casing
597	12	MSL Top of Riser Pipe
3	42	ft. Casing Stickup
593	70	MSL Ground Surface
___	___	ft. Top of annular sealant
580	70	ft. Top of Seal
4	00	ft. Total Seal Interval
576	70	ft. Top of Sand
550	20	ft. Top of Screen
10	00	ft. Total Screen Interval
540	20	ft. Bottom of Screen
540	20	ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

Illinois Environmental Protection Agency — Well Completion Report

Site #: _____ County: Jasper Well #: G121

Site Name: Newton Power Station Landfill Grid Coordinate: Northing 11915.30 Easting 6061.02

Drilling Contractor: Professional Service Industries, Inc. Date Drilled Start: 10/31/96

Driller: _____ Geologist: Mike Summers Date Completed: 10/31/96

Drilling Method: 4¼" I.D. HSA Drilling Fluids (type): N/A

Annular Space Details

Type of Surface Seal: Portland Cement

Type of Annular Sealant: Cement/Bentonite Grout (20:1)

Amount of cement: # of bags 2 lbs. per bag 94

Amount of bentonite: # of bags 1/5 lbs. per bag 50

Type of Bentonite Seal (Granular, Pellet): Pellet

Amount of bentonite: # of Bags 2½ lbs. per bag 50

Type of Sand Pack: Silica

Source of Sand: _____

Amount of Sand: # of bags 13 lbs. per bag 100

Well Construction Materials

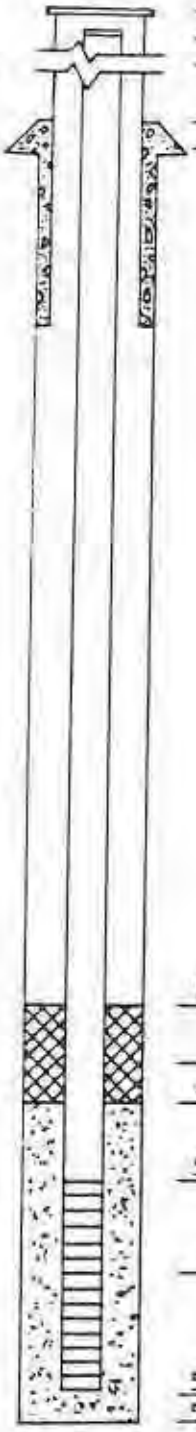
	Stainless Steel Specify Type	Teflon Specify Type	PVC Specify Type	Other Specify Type
Riser coupling joint				
Riser pipe above w.t.			Sch 40	
Riser pipe below w.t.	Type304			
Screen	Type304			
Coupling joint screen to riser				
Protective casing				Steel

Measurements

to .01 ft. (where applicable)

Riser pipe length	18.26 ft.
Protective casing length	
Screen length	10.0 ft.
Bottom of screen to end cap	
Top of screen to first joint	
Total length of casing	
Screen slot size	.010 in.
% of openings in screen	
Diameter of borehole (in)	8
ID of riser pipe (in)	2

Elevations — .01 ft.



_____ _____ MSL Top of Protective Casing

_____ _____ MSL Top of Riser Pipe

_____ _____ ft. Casing Stickup

_____ _____ MSL Ground Surface

_____ _____ ft. Top of annular sealant

537 19 ft. Top of Seal

4 5 ft. Total Seal Interval

532 69 ft. Top of Sand

529 69 ft. Top of Screen

10 00 ft. Total Screen Interval

519 69 ft. Bottom of Screen

519 69 ft. Bottom of Borehole

Completed by: _____ Surveyed by: _____ Ill. registration #: _____

Electronic Filing: Received, Clerk's Office 07/01/2024

WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address - Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter _____

3. Year Drilled 1994

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled X Other _____

6. Total Depth 16 Diameter (inches) 8

7. Formation clear of obstruction X yes _____ no

8. DETAILS OF PLUGGING

   Filled with 20:1 Cement-Bentonite Grout (cement or other materials) from 16 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed X Yes _____ No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day 7 Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI (Name) — N/A (Complete License Number)

    408 North Street (Address) — Springfield (City) — IL/62704 (State/Zip)

Printed by Authority of the State of Illinois
P.O. #534070 4M 4/94

This State Agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center.

IL 482-0631

Electronic Filing: Received, Clerk's Office 07/01/2024

WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

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1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ Newton Jasper
   Address - Lot Number / City / County

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter _____

3. Year Drilled 1993

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled X Other _____

6. Total Depth 40.0 Diameter (inches) 8

7. Formation clear of obstruction X yes _____ no

8. DETAILS OF PLUGGING

   Filled with 20:1 Cement-Bentonite Grout (cement or other materials) from 40 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed X Yes _____ No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day _____ Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

PSI (Name)		Complete License Number
408 North Street (Address)	Springfield (City)	IL/62704 (State/Zip)

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

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1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address – Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1993

4. Drilling Permit No.(and date, if known) _____

5. Type of Well: Bored _____ Drilled X Other _____

6. Total Depth 54.5 Diameter (inches) 8

7. Formation clear of obstruction X yes _____ no

8. DETAILS OF PLUGGING

   Filled with 20:1 Cement-Bentonite Grout (cement or other materials) from 54.5 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed X Yes _____ No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day _____ Year 1996

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI (Name) _____ (Complete License Number)

    408 North Street (Address) Springfield (City) IL/62704 (State/Zip)

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P.O. #534070 4M 4/94

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address – Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter _____

3. Year Drilled 1995

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 70.0 Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 Cement-Bentonite Grout (cement or other materials) from 70 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month July Day _____ Year 1995.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI (Name) _____ Complete License Number

    408 North Street (Address) Springfield (City) IL/62704 (State/Zip)

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P.O. #534070 4M 4/94

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ Newton _____ Jasper
   Address - Lot Number / City / County

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1995

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 65.0 Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 Cement-Bentonite Grout (cement or other materials) from 65 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month July Day _____ Year 1995.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI — _____
    Name — Complete License Number
    408 North Street — Springfield — IL/62704
    Address — City — State/Zip

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P.O. #534070 4M 4/94

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IL 482-0631

WATER WELL SEALING FORM

Electronic Filing: Received, Clerk's Office 07/01/2024

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address - Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter _____

3. Year Drilled 1996

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 25 ft. Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 cement-bentonite grout (cement or other materials) from 25 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day 11 Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI (Name) — N/A (Complete License Number)

    408 North Street (Address) — Springfield (City) — IL/62704 (State/Zip)

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P.O. #534070 4M 4/94

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IL 482-0631

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

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1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address - Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1996

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 35 ft. Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 cement-bentonite grout (cement or other materials) from 35 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day 14 Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI (Name) — N/A (Complete License Number)

    408 North Street (Address) — Springfield (City) — IL/62704 (State/Zip)

Printed by Authority of the State of Illinois
P.O. #534070 4M 4/94

This State Agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center.

IL 482-0631

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ Newton Jasper
   Address – Lot Number / City / County

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1996

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 21 ft. Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 cement-bentonite grout (cement or other materials) from 21 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day 11 Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

    PSI — N/A
    Name — Complete License Number

    408 North Street — Springfield — IL/62704
    Address — City — State/Zip

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P.O. #534070 4M 4/94

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WATER WELL SEALING FORM

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ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

TYPE OR PRESS FIRMLY — RETURN ALL COPIES TO IDPH

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ (Address - Lot Number) Newton (City) Jasper (County)

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1996

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 18 ft. Diameter (inches) 8

7 Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 cement-bentonite grout (cement or other materials) from 18 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD

   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month October Day 11 Year 1996.

11. Licensed water well driller or other person approved by the Department performing well sealing:

PSI (Name)	N/A (Complete License Number)
408 North Street (Address)	Springfield (City)
	IL/62704 (State/Zip)

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P.O. #534070 4M 4/94

This State Agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center.

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WATER WELL SEALING FORM

ILLINOIS DEPARTMENT OF PUBLIC HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
525 WEST JEFFERSON STREET
SPRINGFIELD, ILLINOIS 62761

RETURN ALL COPIES TO IDPH

TYPE OR PRESS FIRMLY

This form shall be submitted to this Department not more than 30 days after a potable water well, boring or monitoring well is sealed. Such wells are to be sealed not more than 30 days after they are abandoned in accordance with the sealing requirements in the Water Well Construction Code.

1. Ownership (Name of Controlling Party) Central Illinois Public Service

2. Well Location: _____ Newton _____ Jasper
   Address - Lot Number / City / County

   General Description: Section 26/27 Township 6N (N)(S) Range 8E (E)(W)
   _____ Quarter of the _____ Quarter of the _____ Quarter

3. Year Drilled 1996

4. Drilling Permit No.(and date, if known) N/A

5. Type of Well: Bored _____ Drilled _____ Other Boring

6. Total Depth 90 Diameter (inches) 8

7. Formation clear of obstruction _____ yes N/A no

8. DETAILS OF PLUGGING

   Filled with 20:1 cement-bentonite grout (cement or other materials) from 90 to 0 ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

   Filled with _____ from _____ to _____ ft.

   Kind of plug _____ from _____ to _____ ft.

9. CASING RECORD
   Upper 3 feet of casing removed _____ Yes N/A No

   If well casing consists of brick, stone, concrete blocks, porous tile, or other porous material, casing was removed to a depth of 3 feet below the surface _____ Yes _____ No.

10. Date well was sealed: Month January Day 29 Year 1997.

11. Licensed water well driller or other person approved by the Department performing well sealing:

PSI	N/A
Name	Complete License Number
408 North Street	Springfield / IL/62704
Address	City / State/Zip

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P.O. #534070 4M 4/94

This State Agency is requesting disclosure of information that is necessary to accomplish the statutory purpose as outlined under Public Act 85-0863. Disclosure of this information is mandatory. This form has been approved by the Forms Management Center.

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ATTACHMENT C

MONITORING WELL AS-BUILT DIAGRAMS

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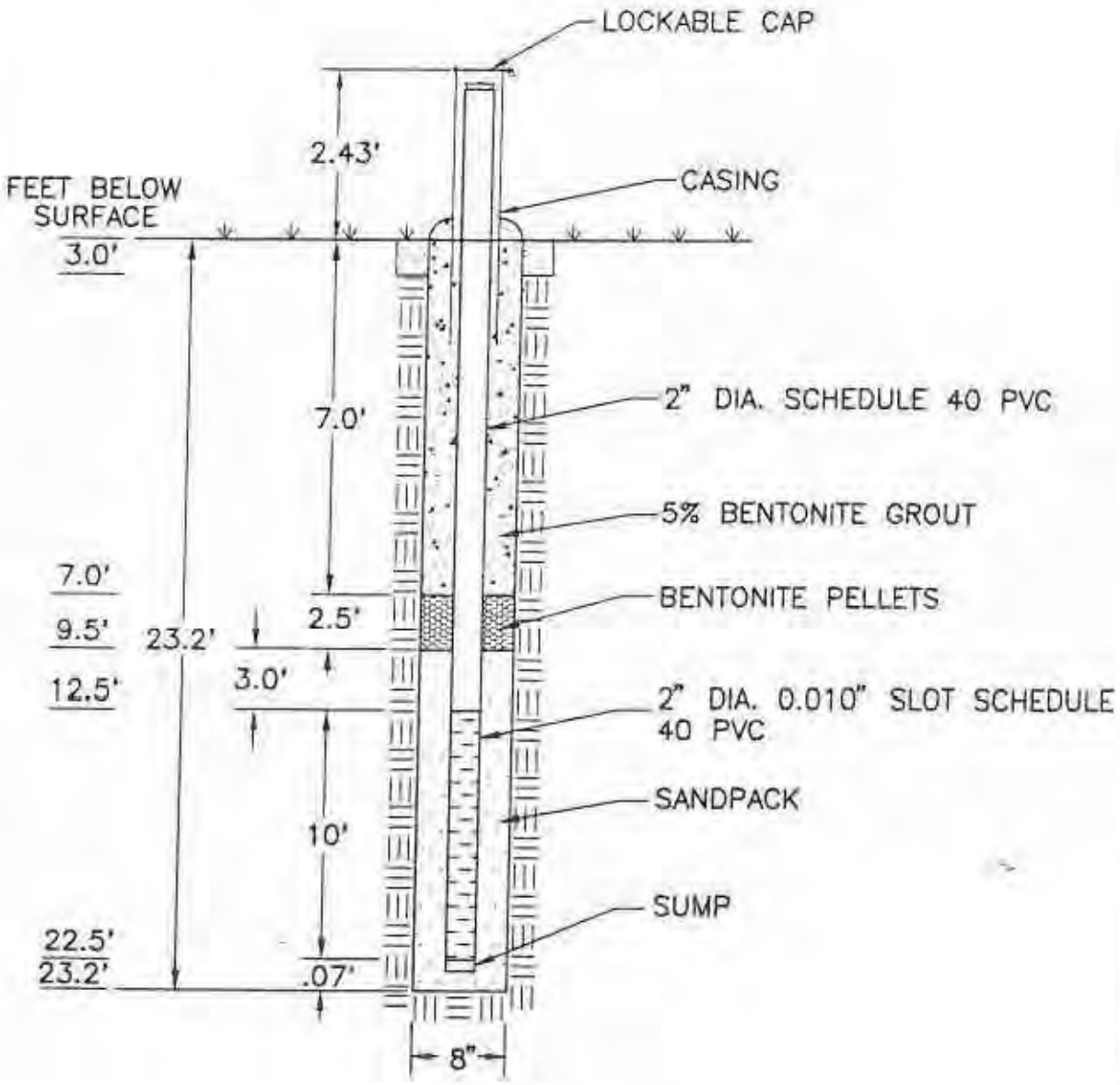
AS-BUILT MONITORING WELL DIAGRAM
MW104S



NOT TO SCALE

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. · SPRINGFIELD, IL 62704 · (217) 787-2118
1601 BROADWAY · MT. VERNON, IL 62864 · (618) 244-2611

AS-BUILT MONITORING WELL DIAGRAM MW104S

C.I.P.S.
NEWTON, ILLINOIS

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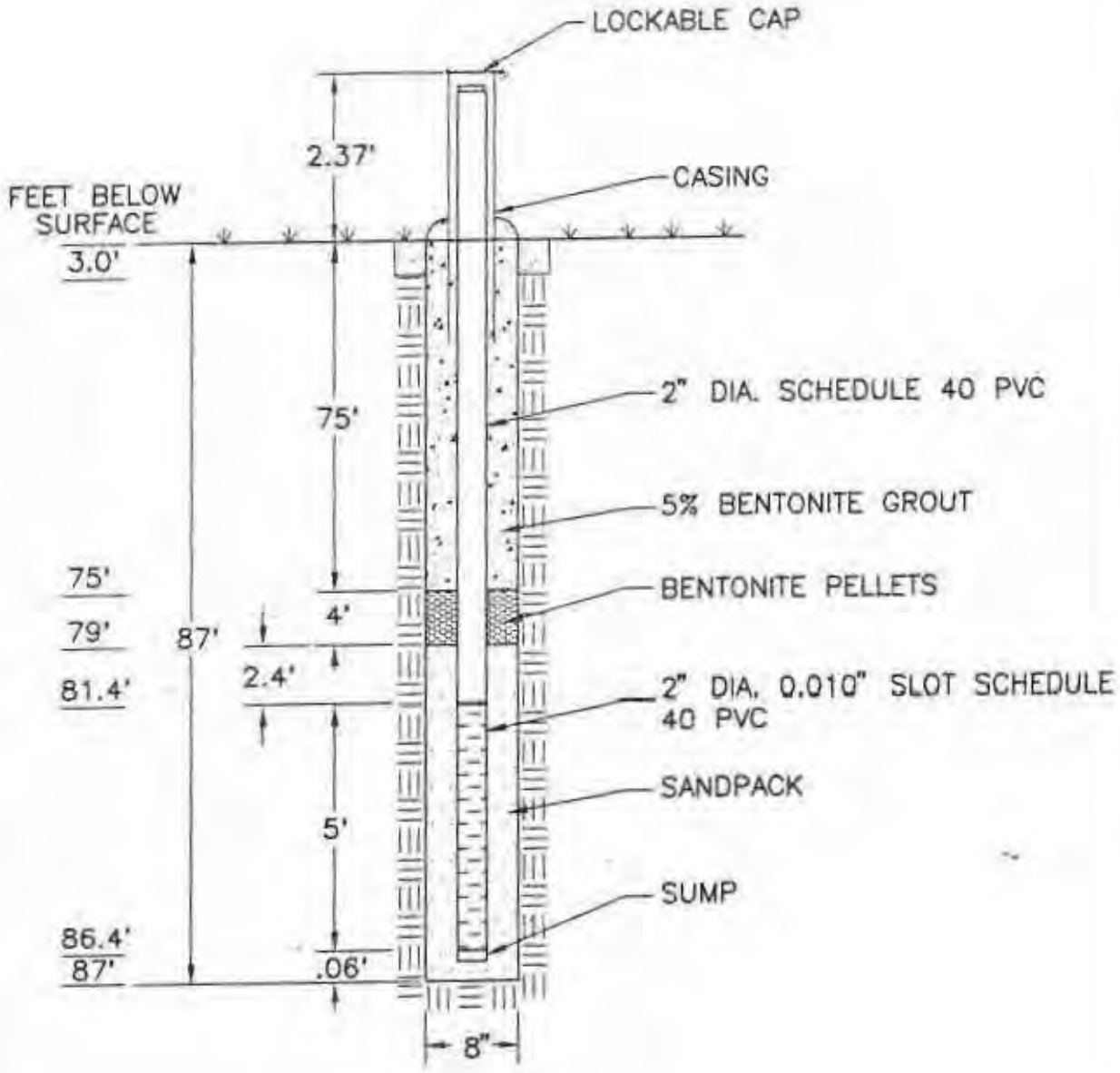
AS-BUILT MONITORING WELL DIAGRAM
MW104D



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AS-BUILT MONITORING WELL DIAGRAM MW104D

C.I.P.S.
NEWTON, ILLINOIS

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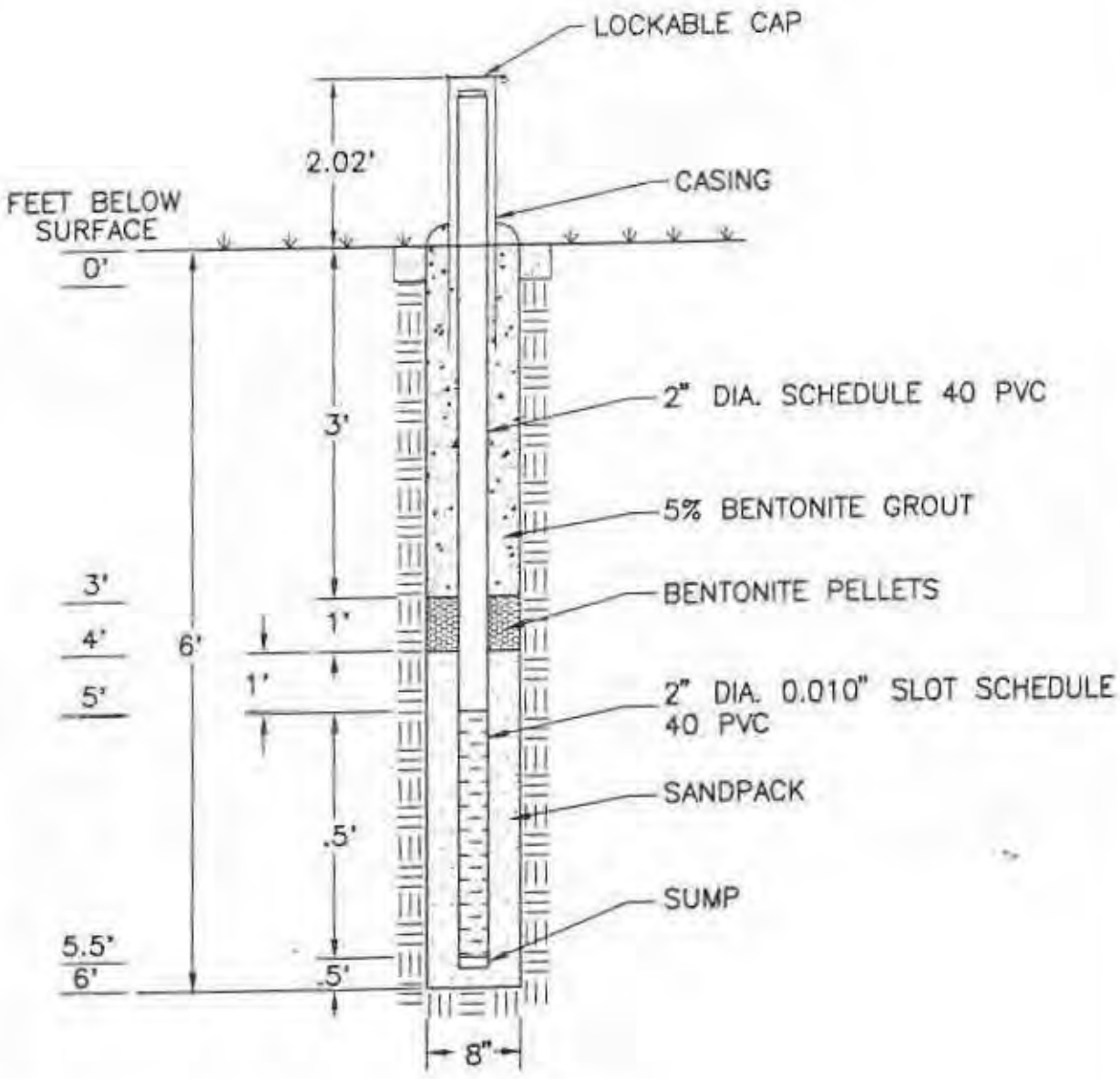
AS-BUILT MONITORING WELL DIAGRAM
G107S



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AS-BUILT MONITORING WELL DIAGRAM G107S

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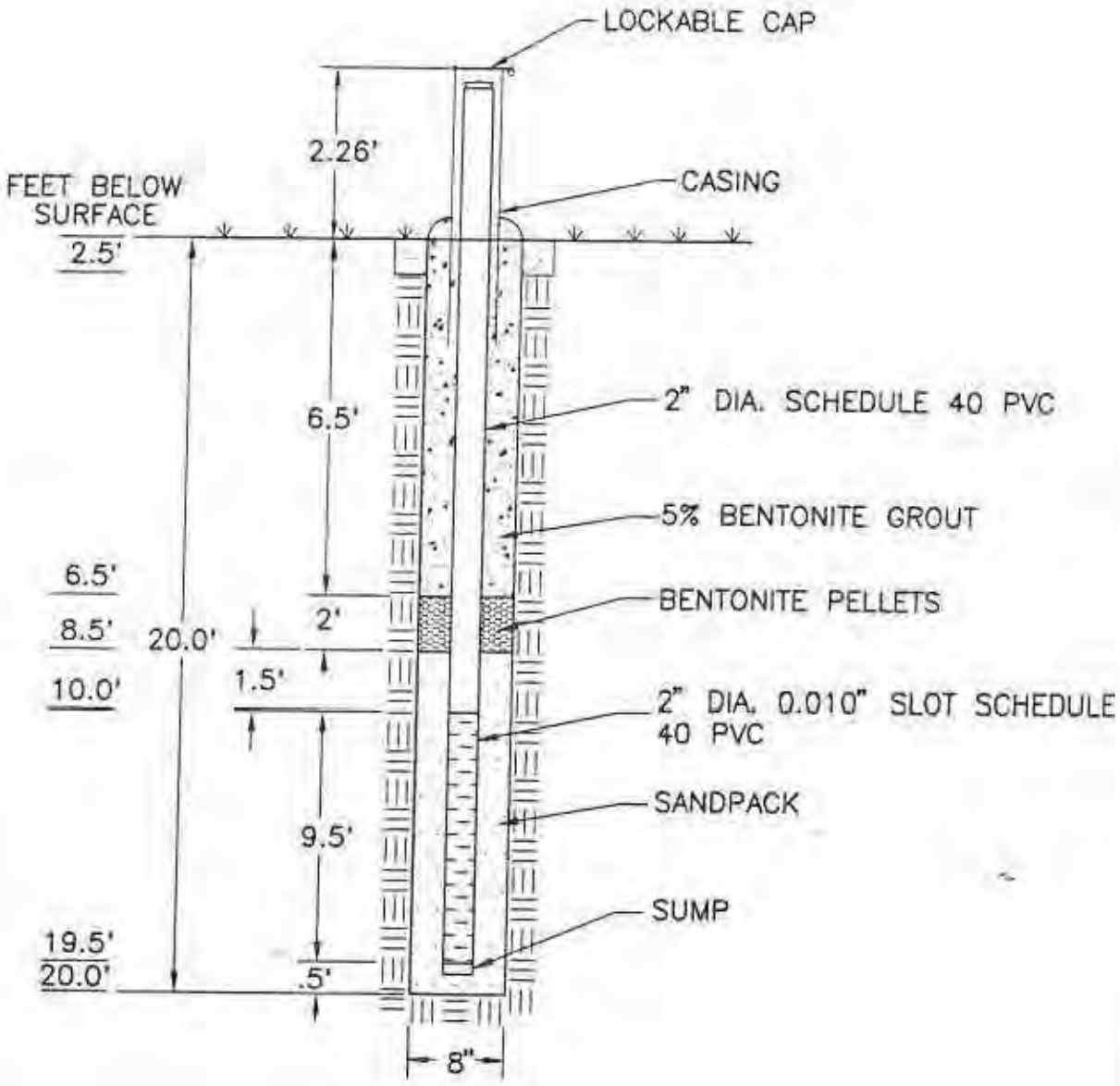
AS-BUILT MONITORING WELL DIAGRAM
MW108



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AS-BUILT MONITORING WELL DIAGRAM MW108

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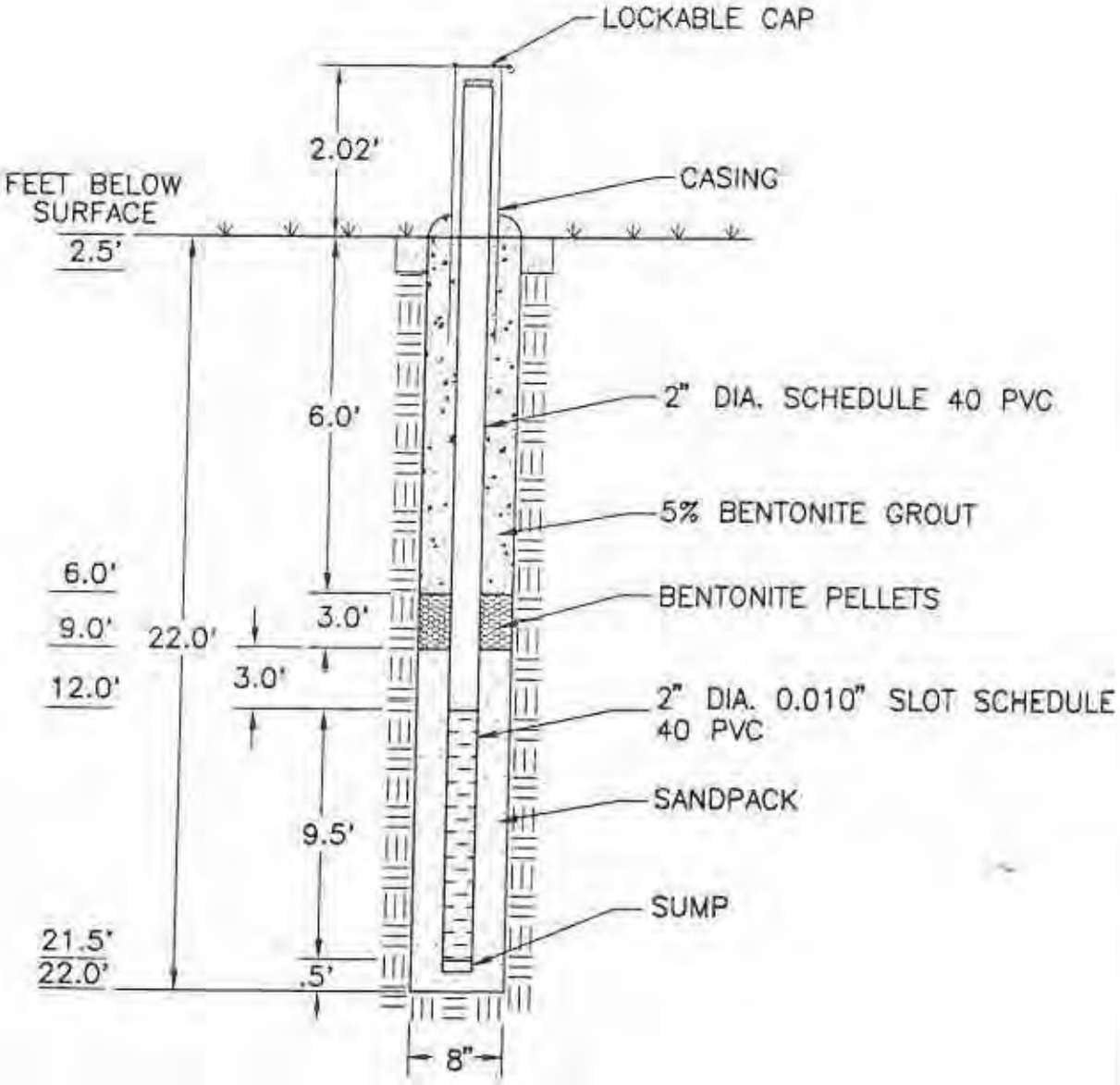
AS-BUILT MONITORING WELL DIAGRAM
MW109



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AS-BUILT MONITORING WELL DIAGRAM MW109

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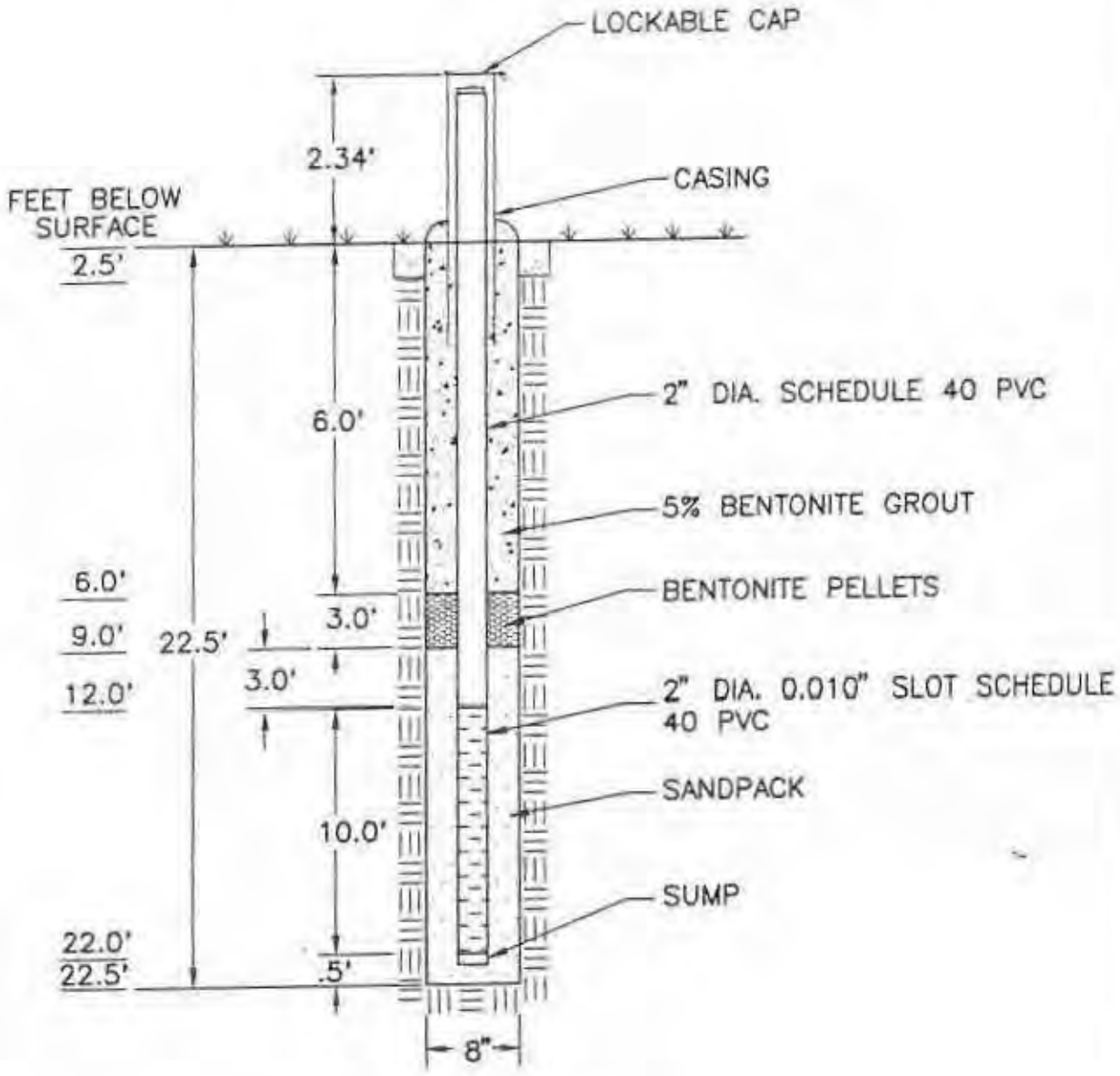
MW110



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AS-BUILT MONITORING WELL DIAGRAM MW110

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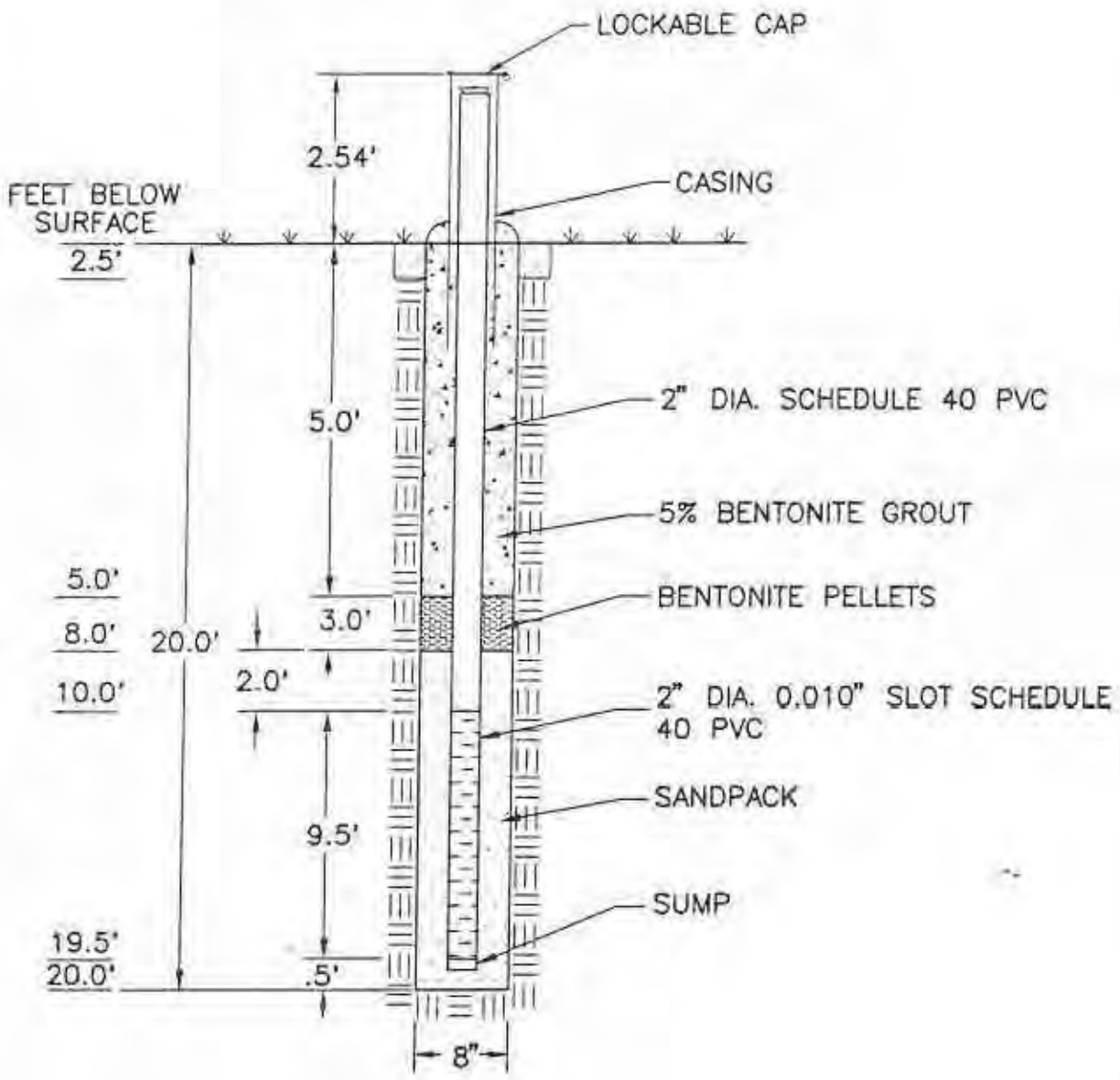
MW111



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AS-BUILT MONITORING WELL DIAGRAM MW111

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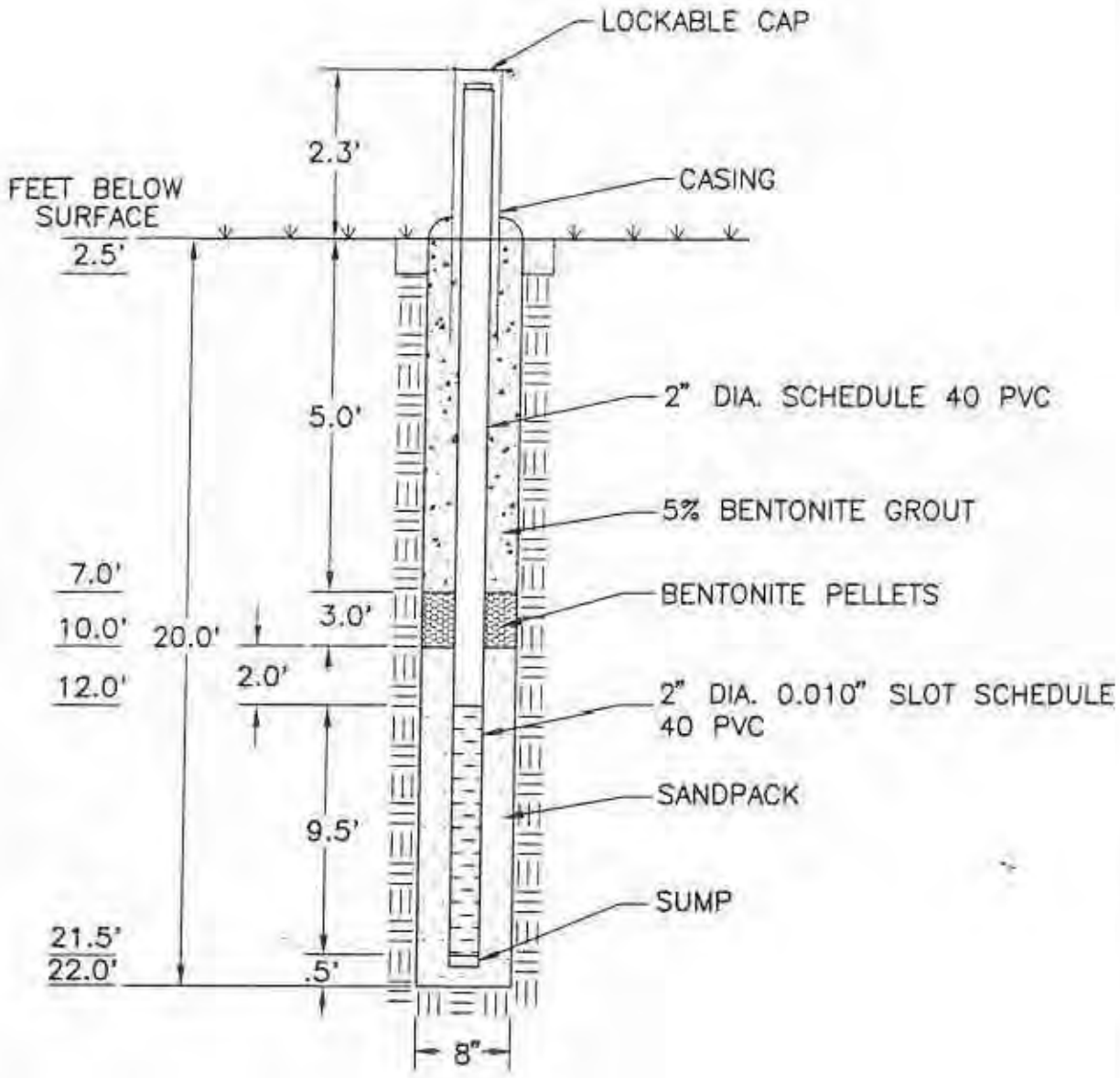
AS-BUILT MONITORING WELL DIAGRAM

MW112



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AS-BUILT MONITORING WELL DIAGRAM MW112

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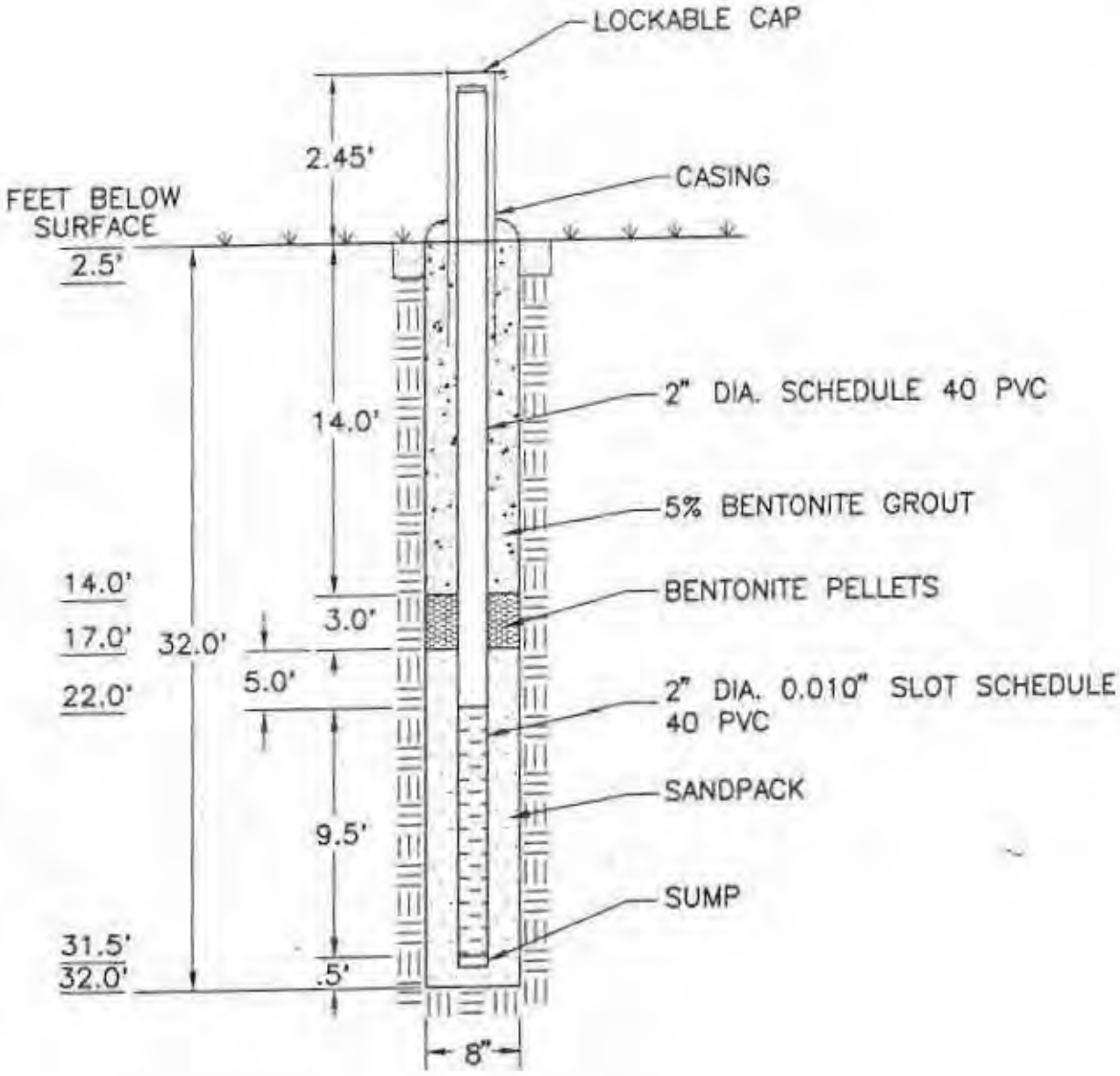
AS-BUILT MONITORING WELL DIAGRAM

MW113



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AS-BUILT MONITORING WELL DIAGRAM MW113

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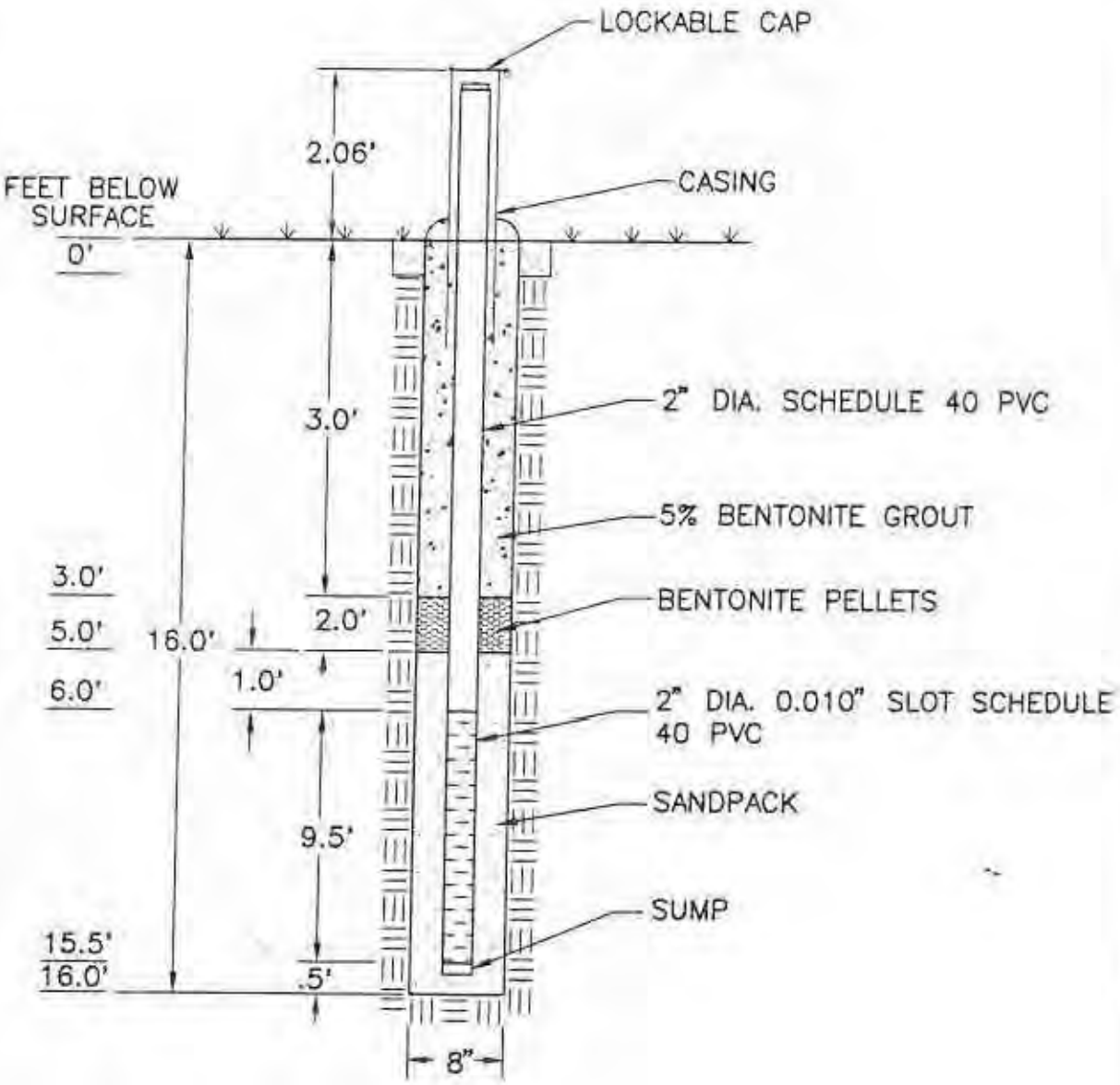
MW114



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AS-BUILT MONITORING WELL DIAGRAM MW114

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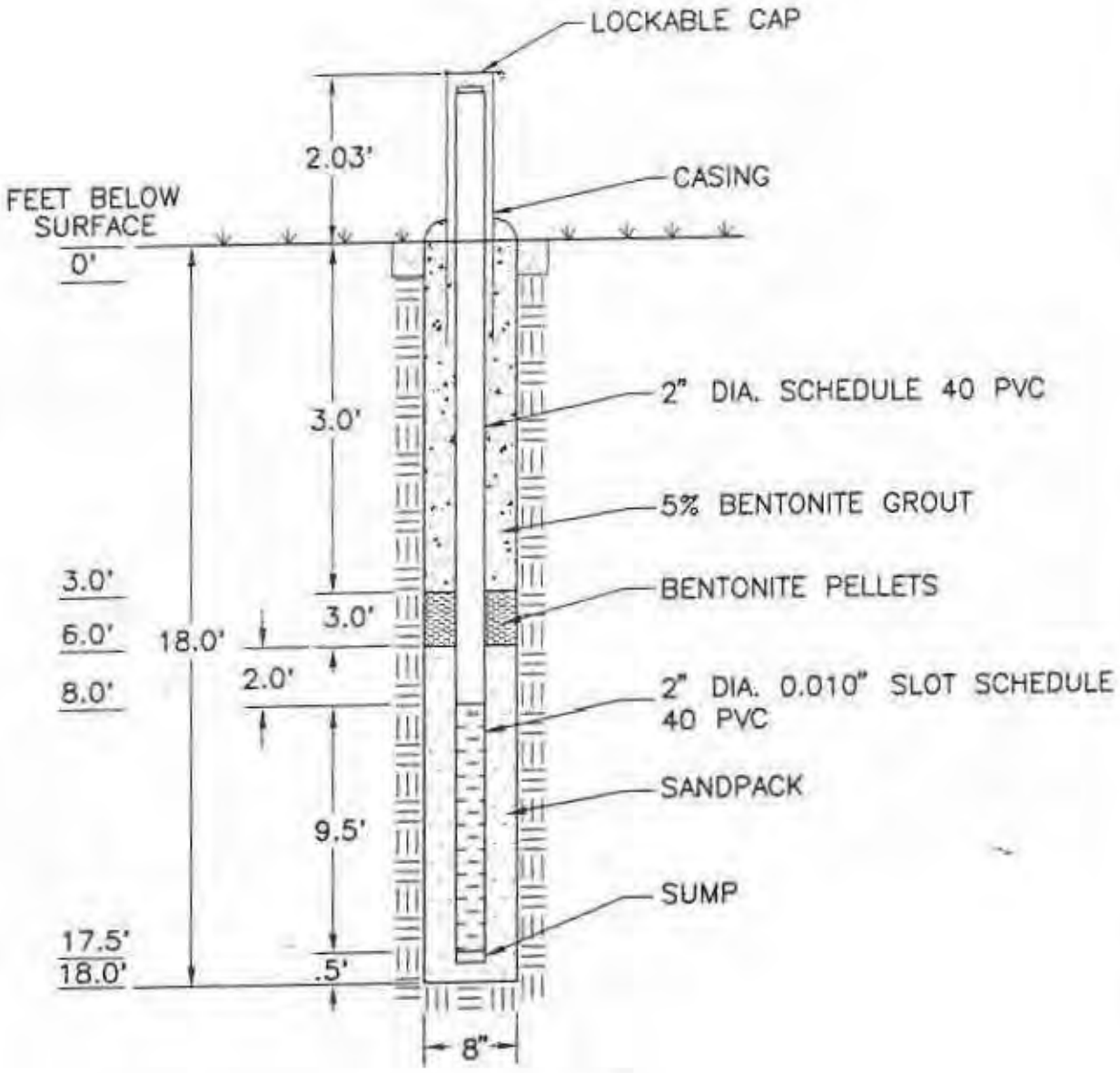
MW115



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AS-BUILT MONITORING WELL DIAGRAM MW115

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NEWTON, ILLINOIS

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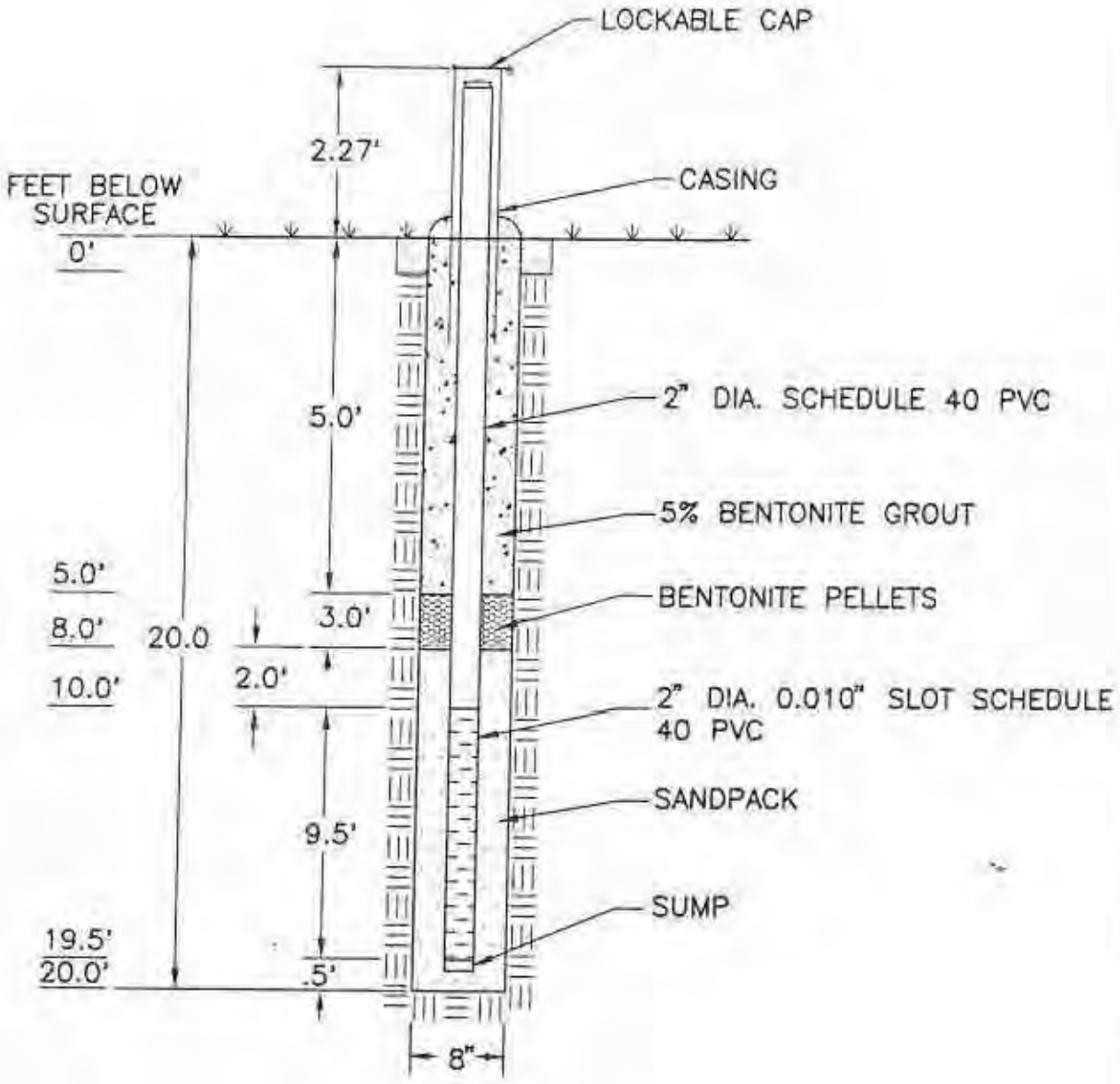
AS-BUILT MONITORING WELL DIAGRAM
MW116



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ENGINEERING & APPLIED SCIENCE
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AS-BUILT MONITORING WELL DIAGRAM MW116

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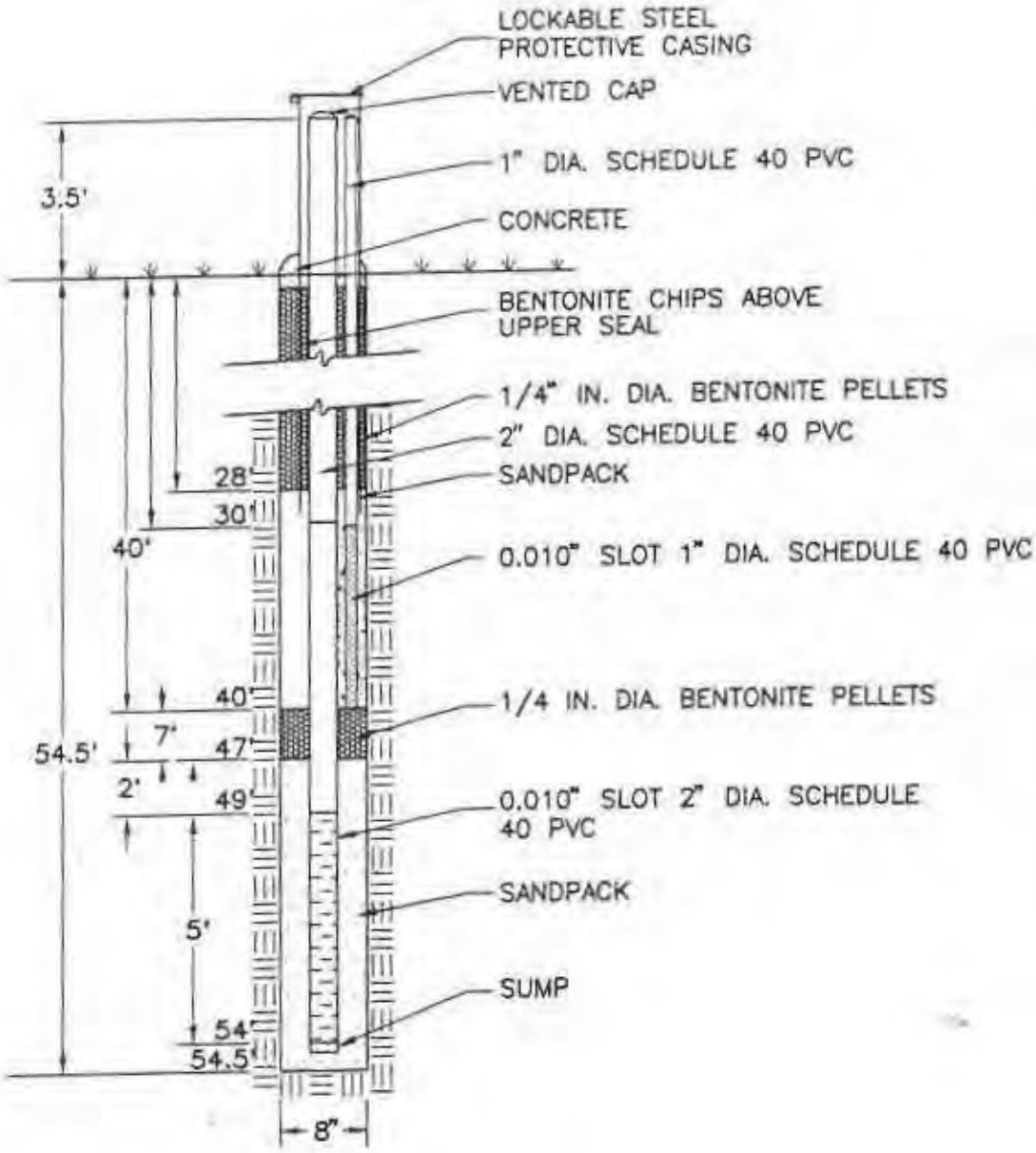

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RAPPS

ENGINEERING & APPLIED SCIENCE
2387 WEST MONROE
SPRINGFIELD IL 62704 · (217) 787-2118

AS-BUILT MONITORING WELL DIAGRAM PIIS & PIID

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NEWTON, ILLINOIS

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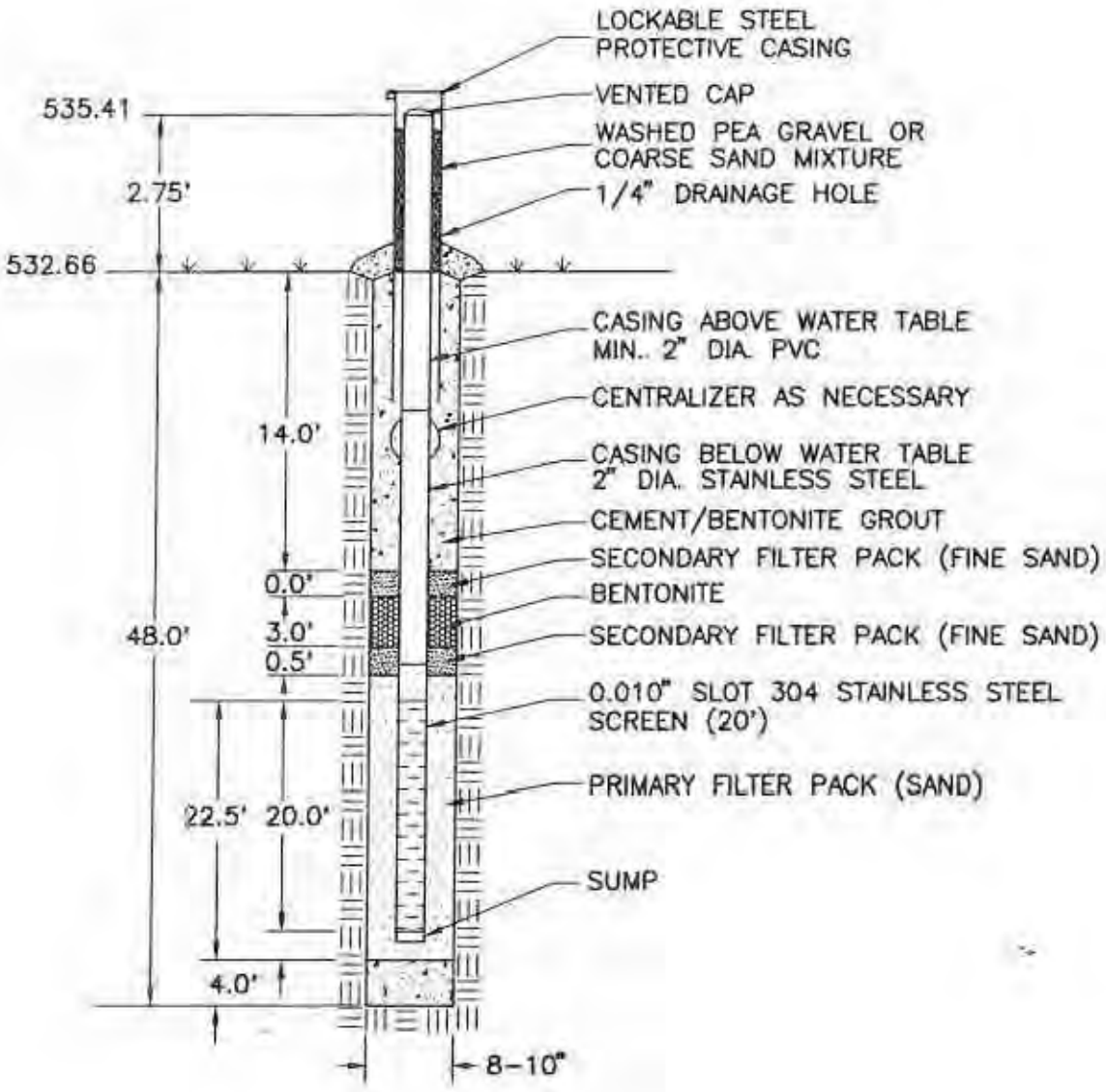

N: 5775.46 / E: 2873.52

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G114R
MONITORING WELL AS-BUILT DIAGRAM

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JASPER COUNTY, ILLINOIS

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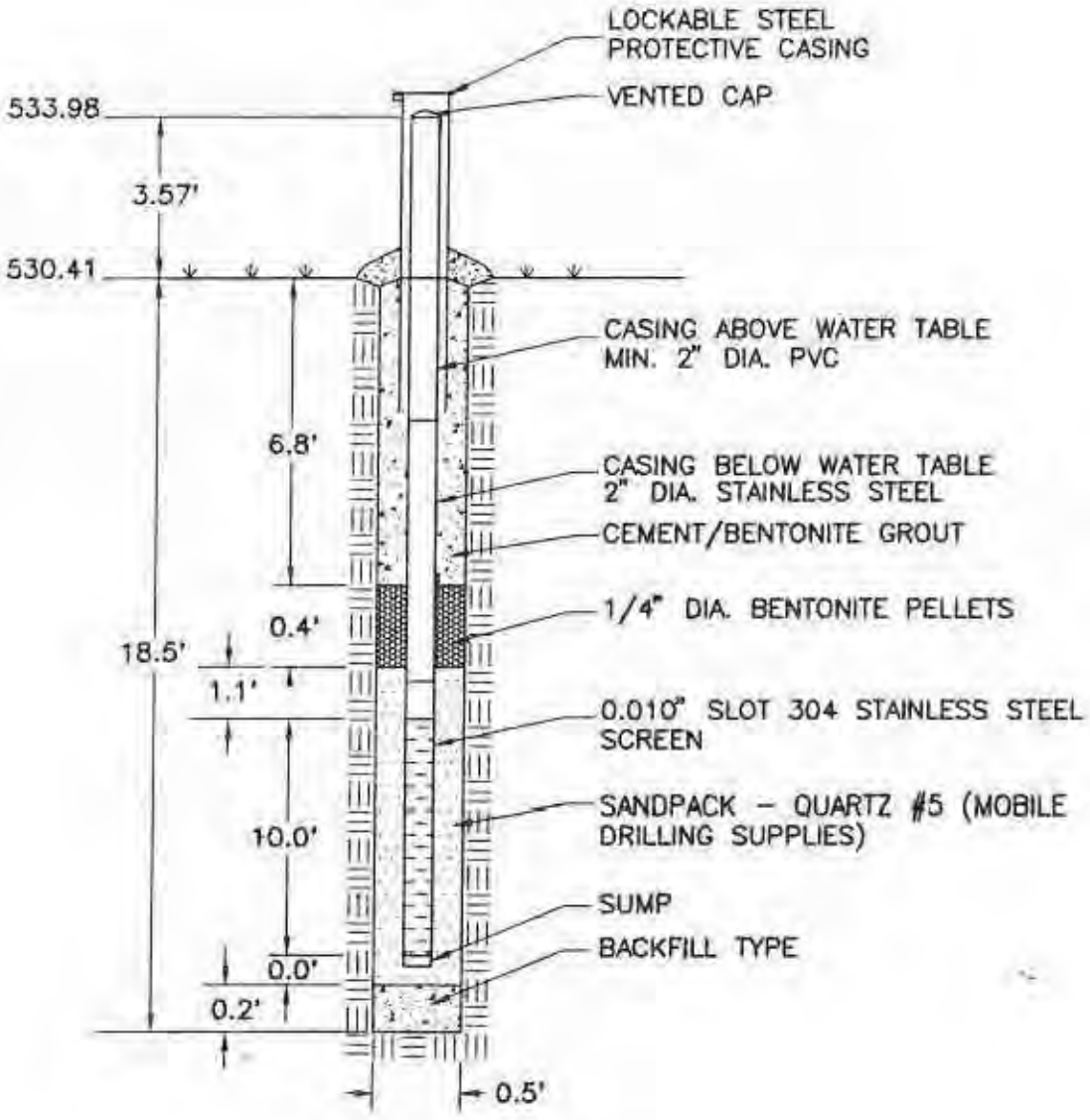

N: 4801.06 / E: 4264.14

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G117
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

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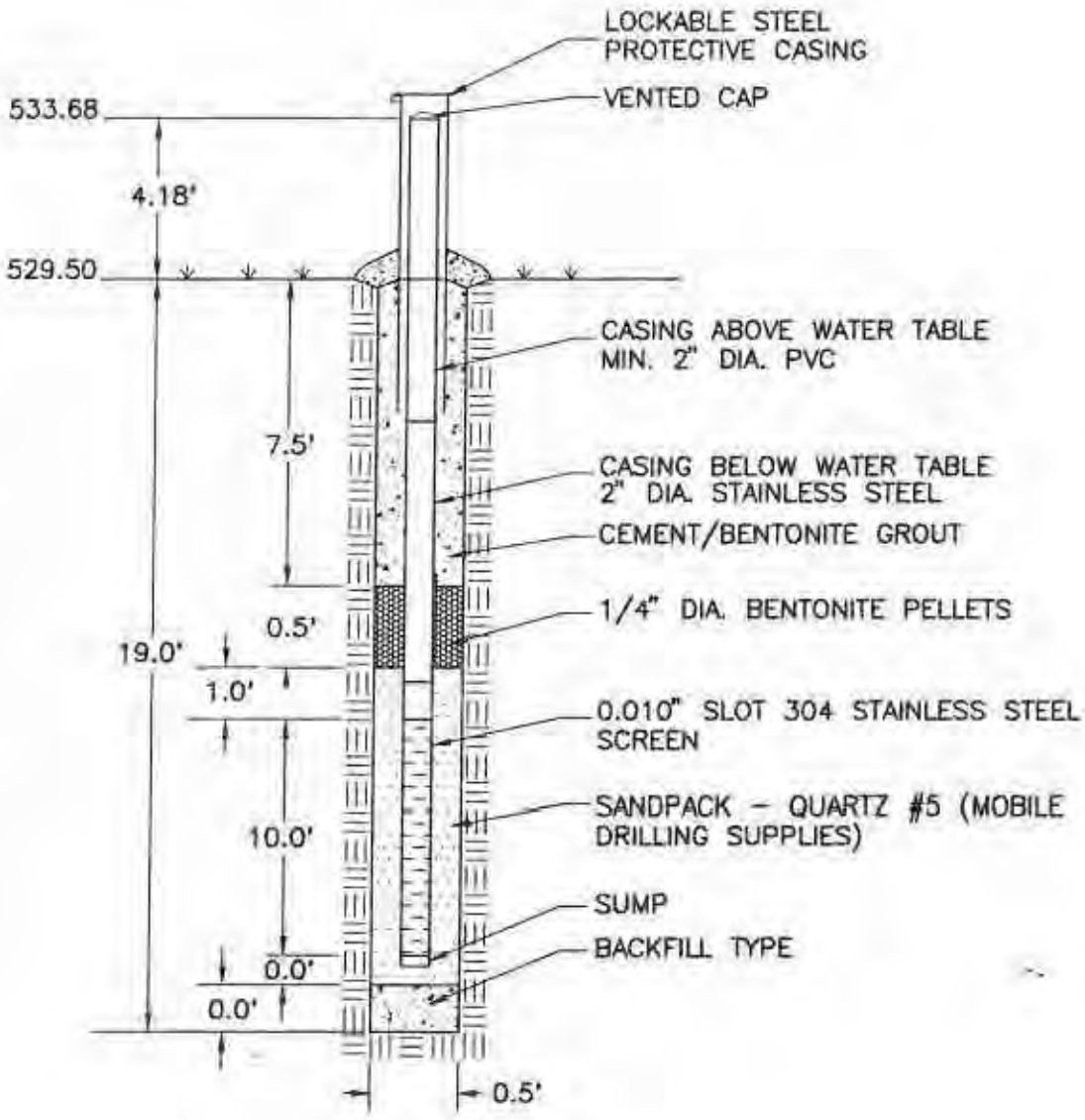

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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G118
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

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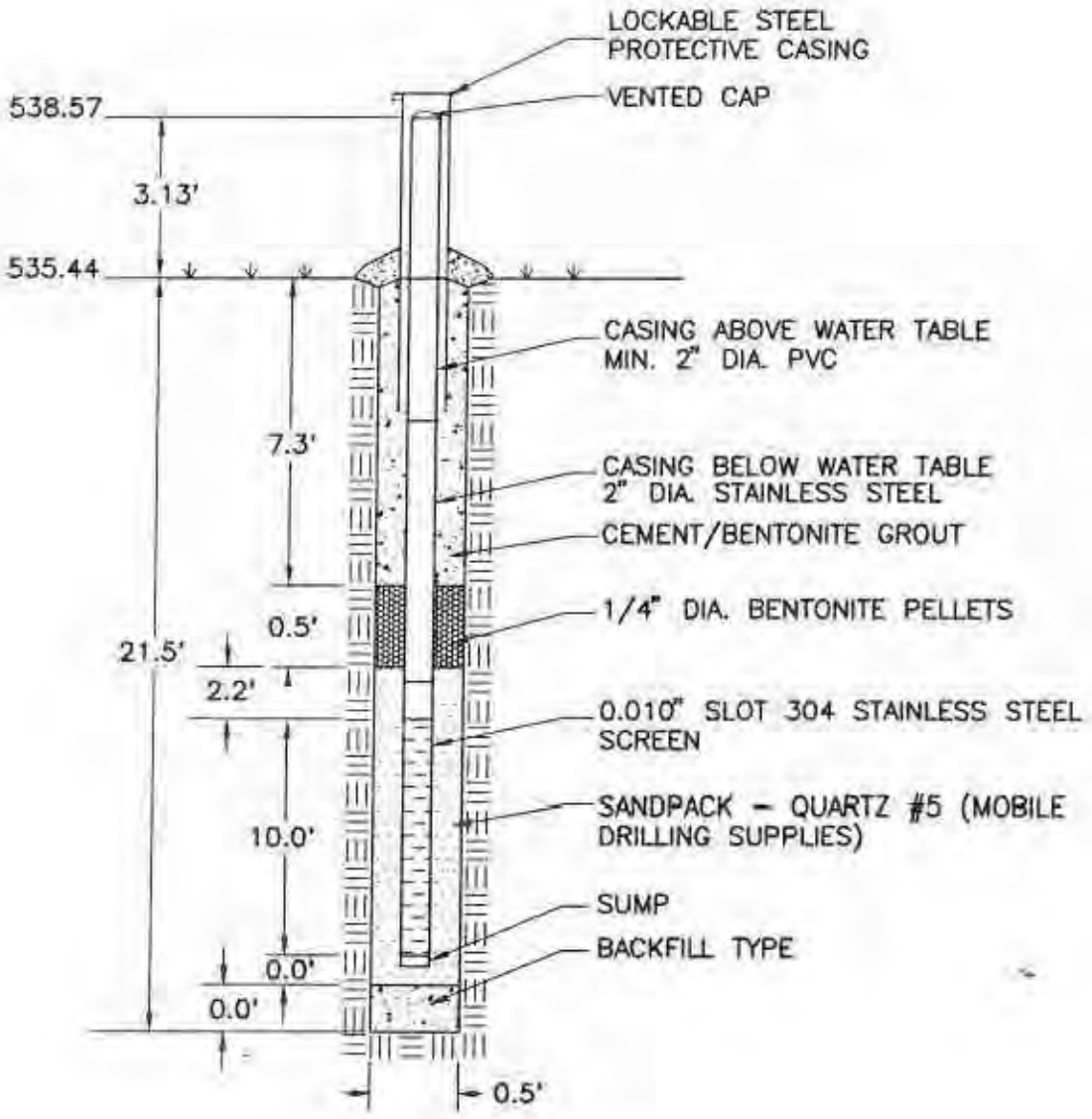

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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G119
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

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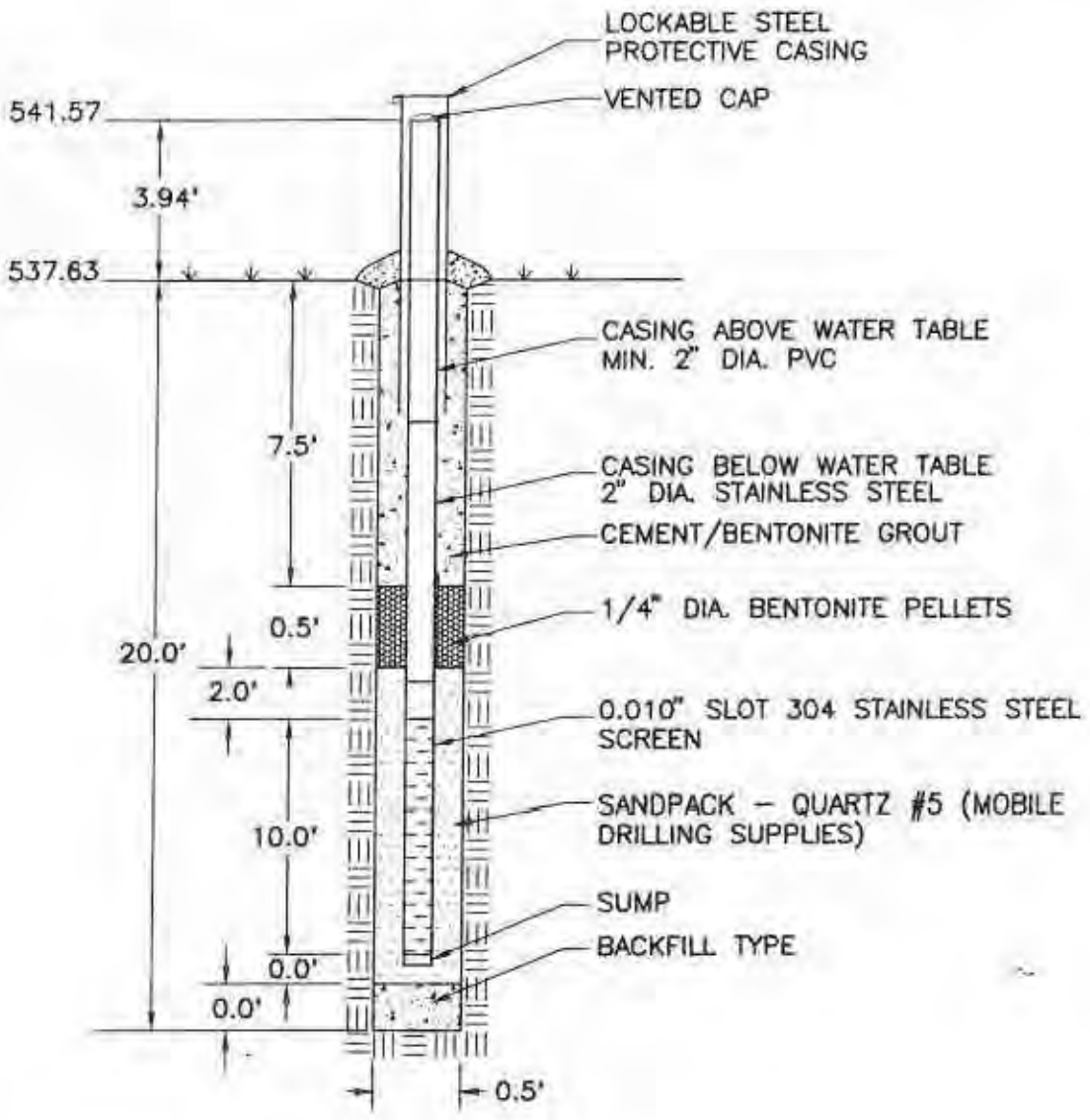

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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL. 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL. 62864 • (618) 244-2611

G120
MONITORING WELL AS-BUILT DIAGRAM

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JASPER COUNTY, ILLINOIS

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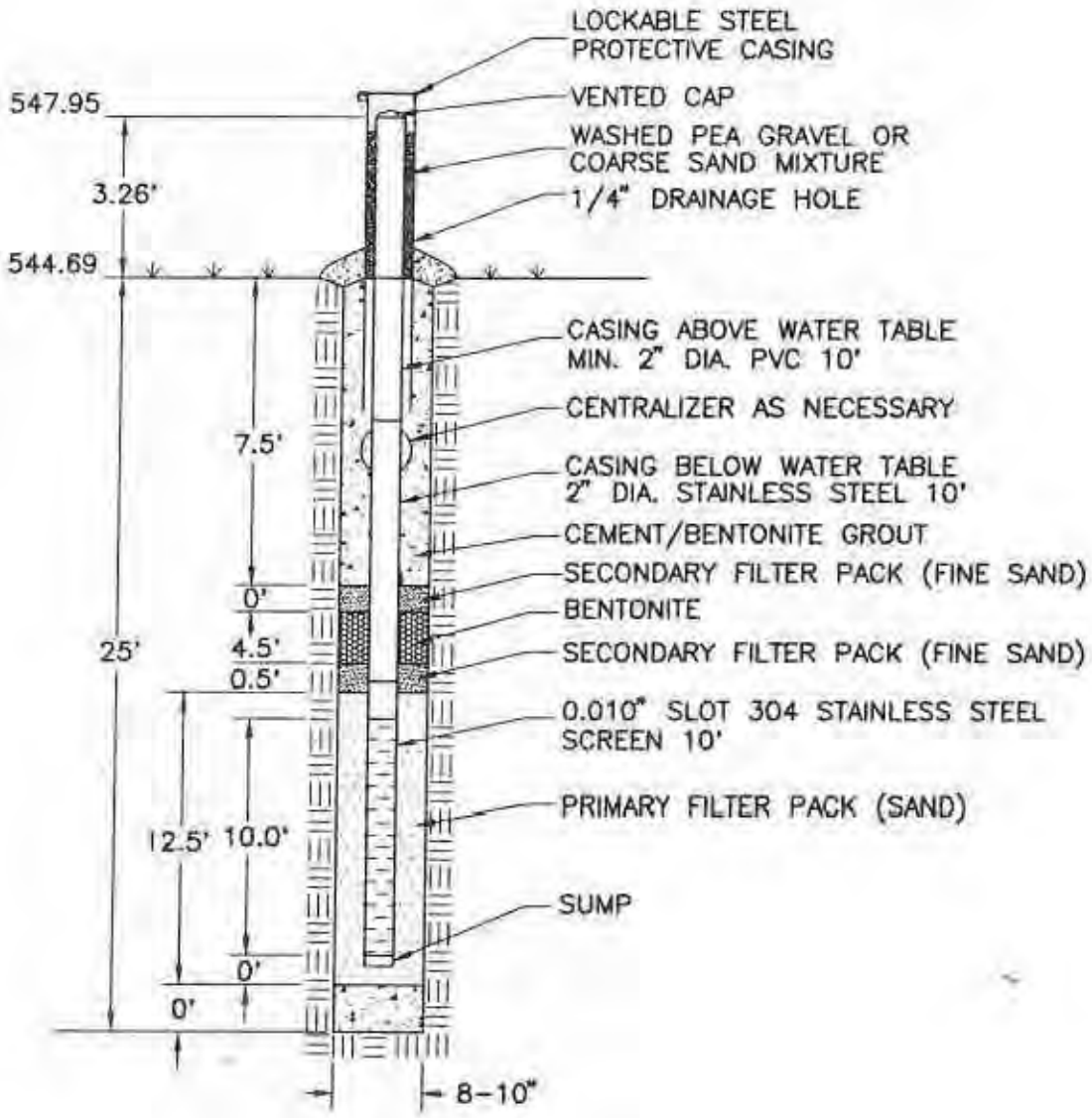

N: 11915.30 / E: 6061.02

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY - MT. VERNON, IL 62864 • (618) 244-2611

G121
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

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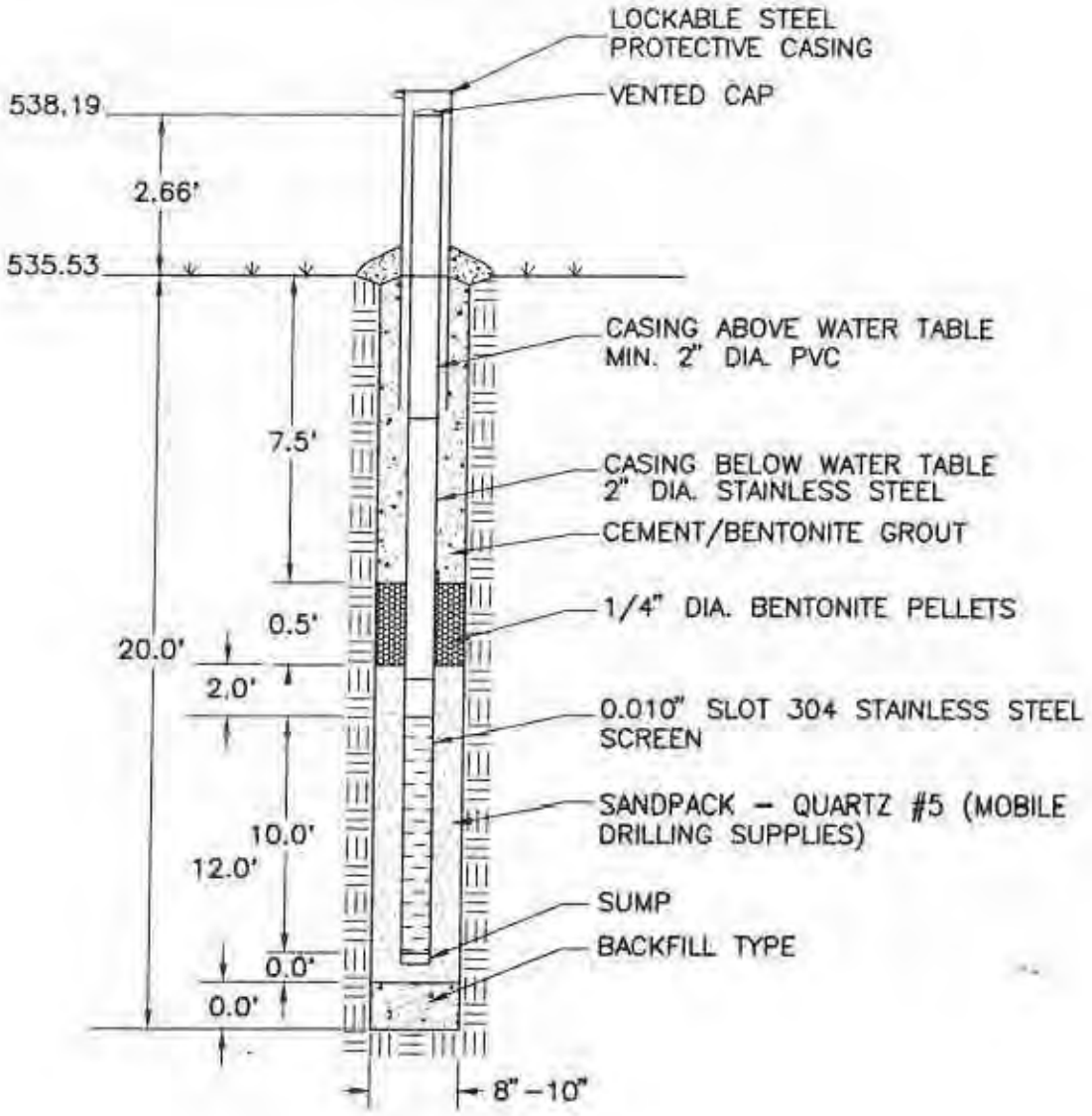

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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2116
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G125A
MONITORING WELL AS-BUILT DIAGRAM

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JASPER COUNTY, ILLINOIS

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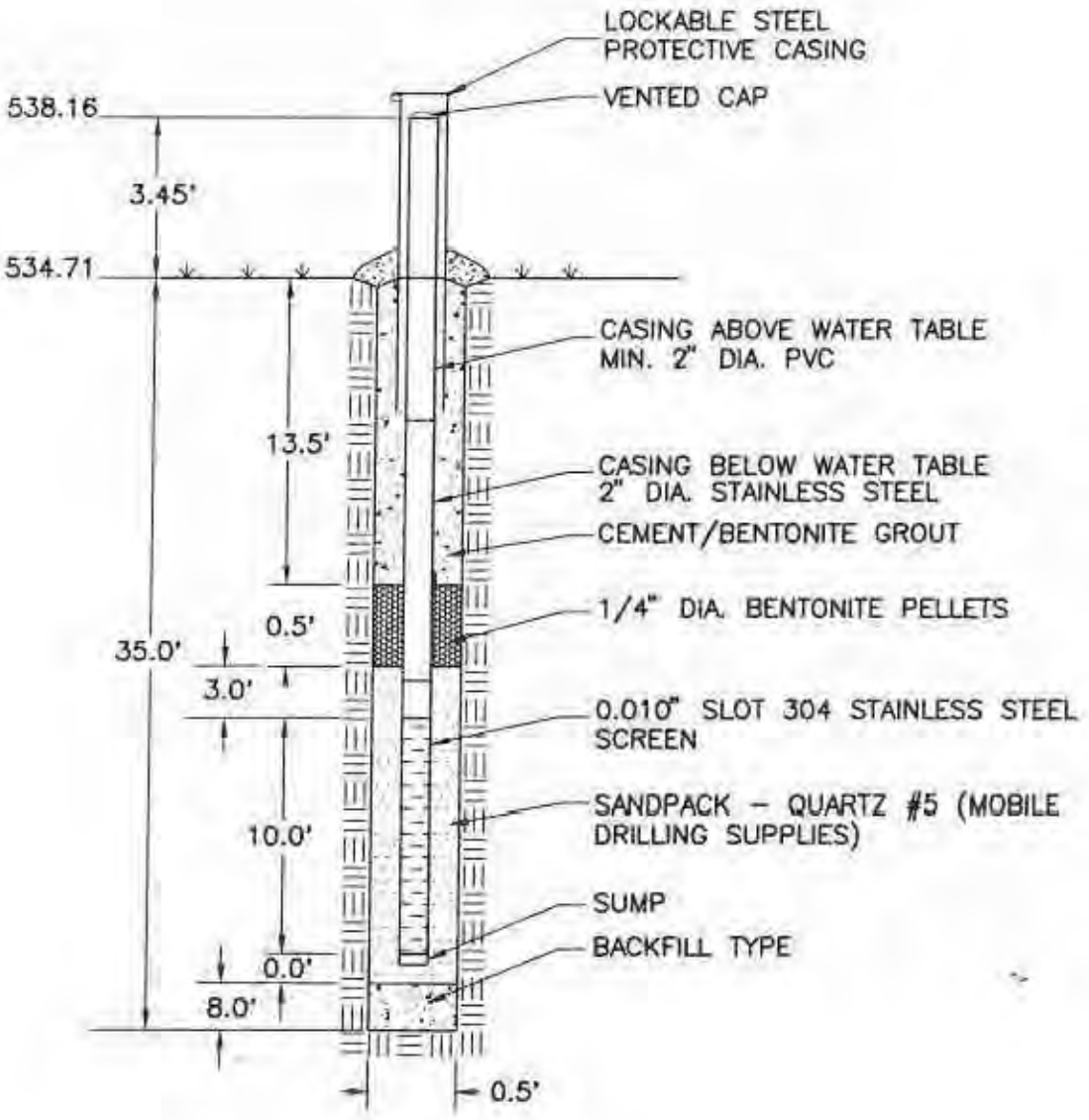

N: 6698.06 / E: 6049.09

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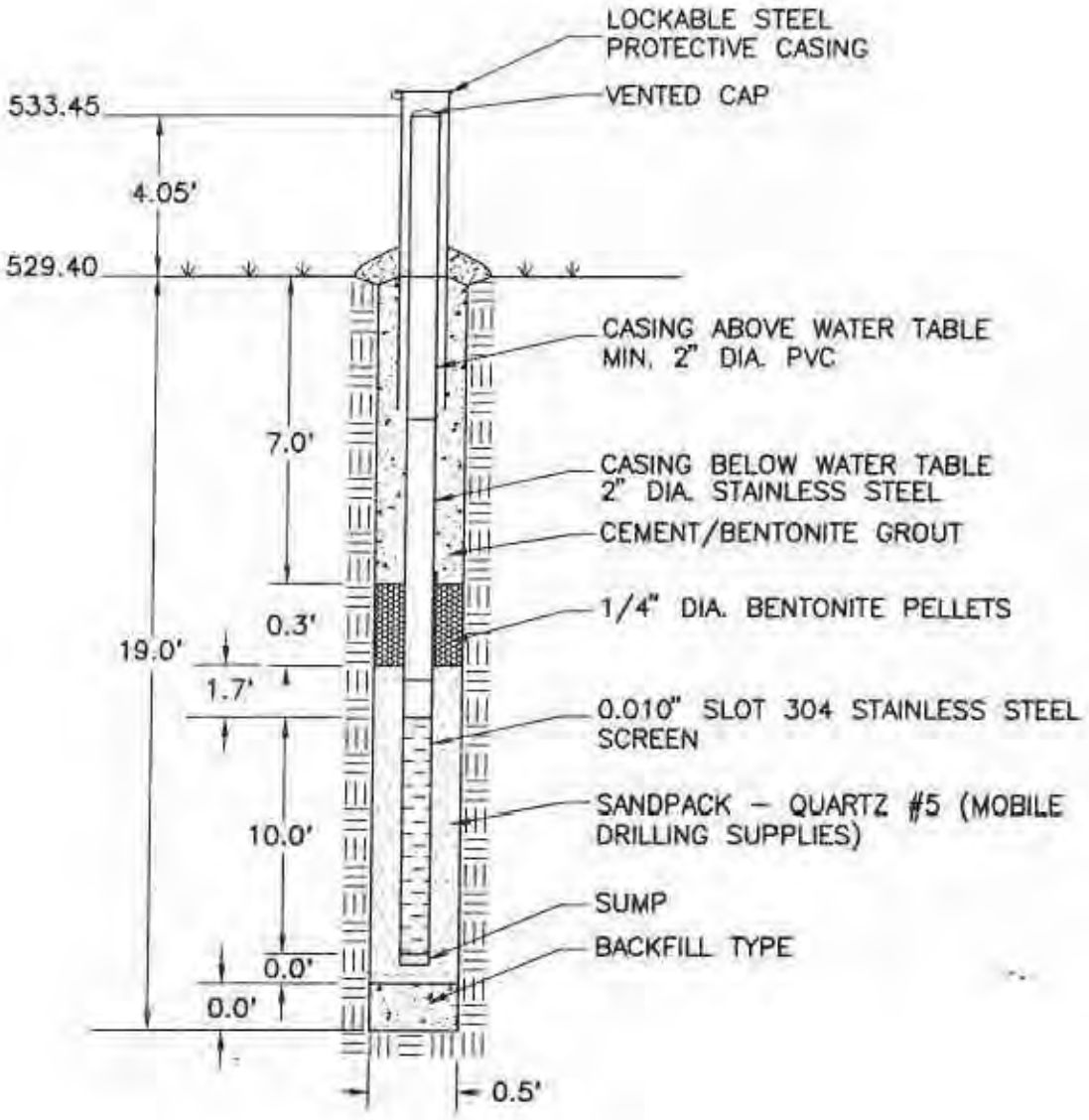
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G128
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 6340.44 / E: 5017.07

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821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
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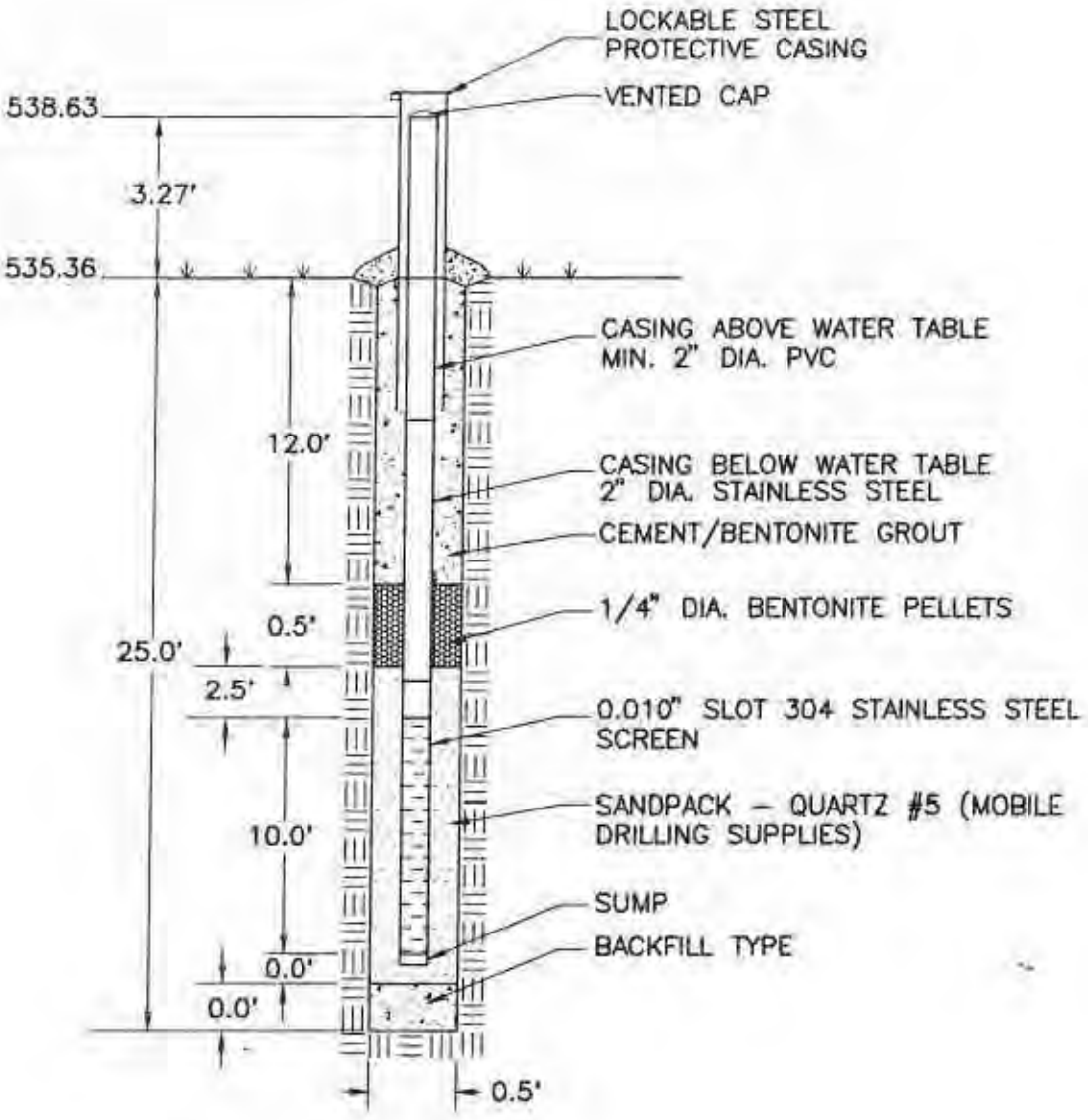
G130
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 6339.97 / E: 4111.01

RAPPS
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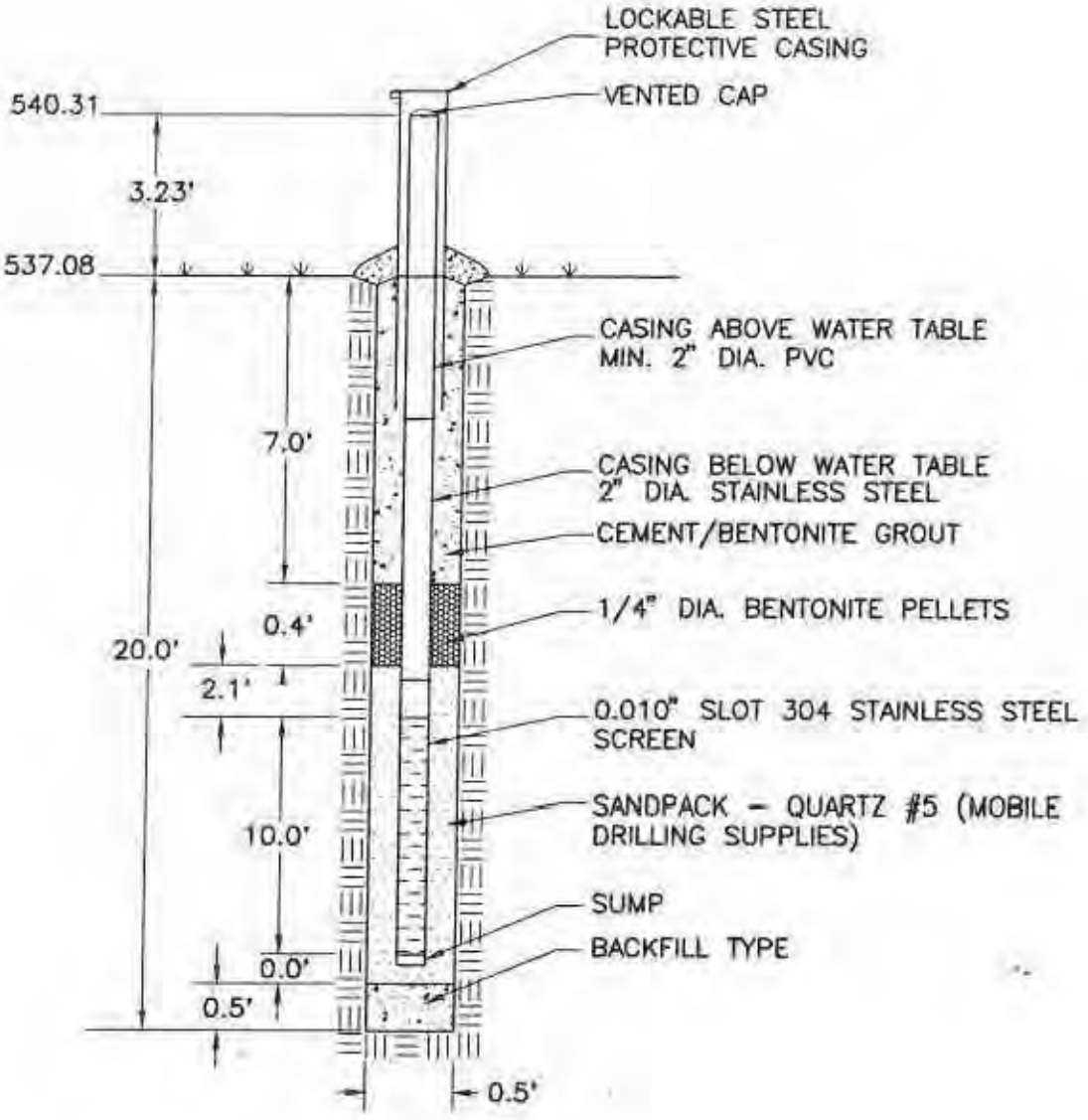
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G133
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 7200.23 / E: 4285.93

RAPPS
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821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
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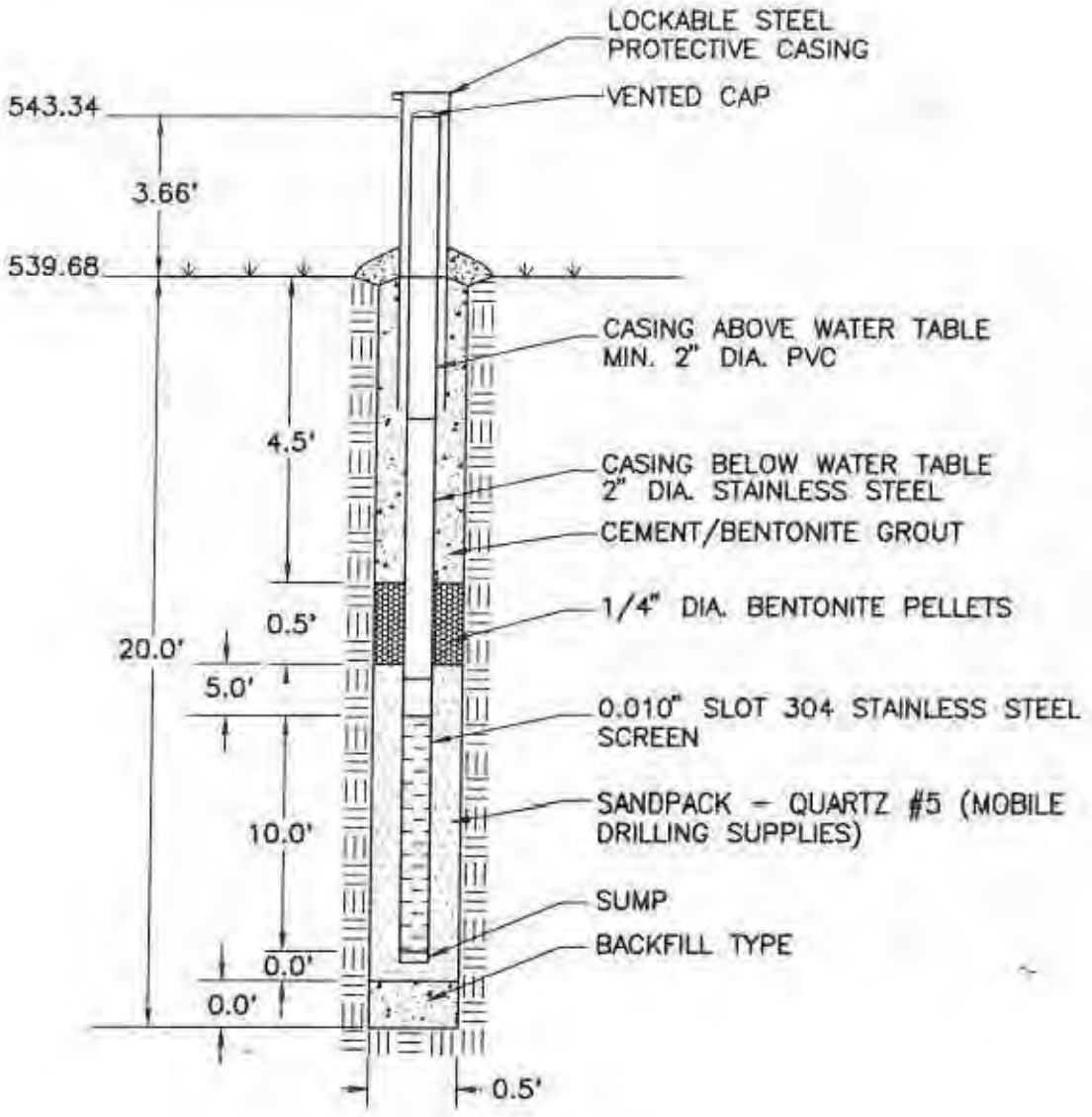
G136
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2318
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G139
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

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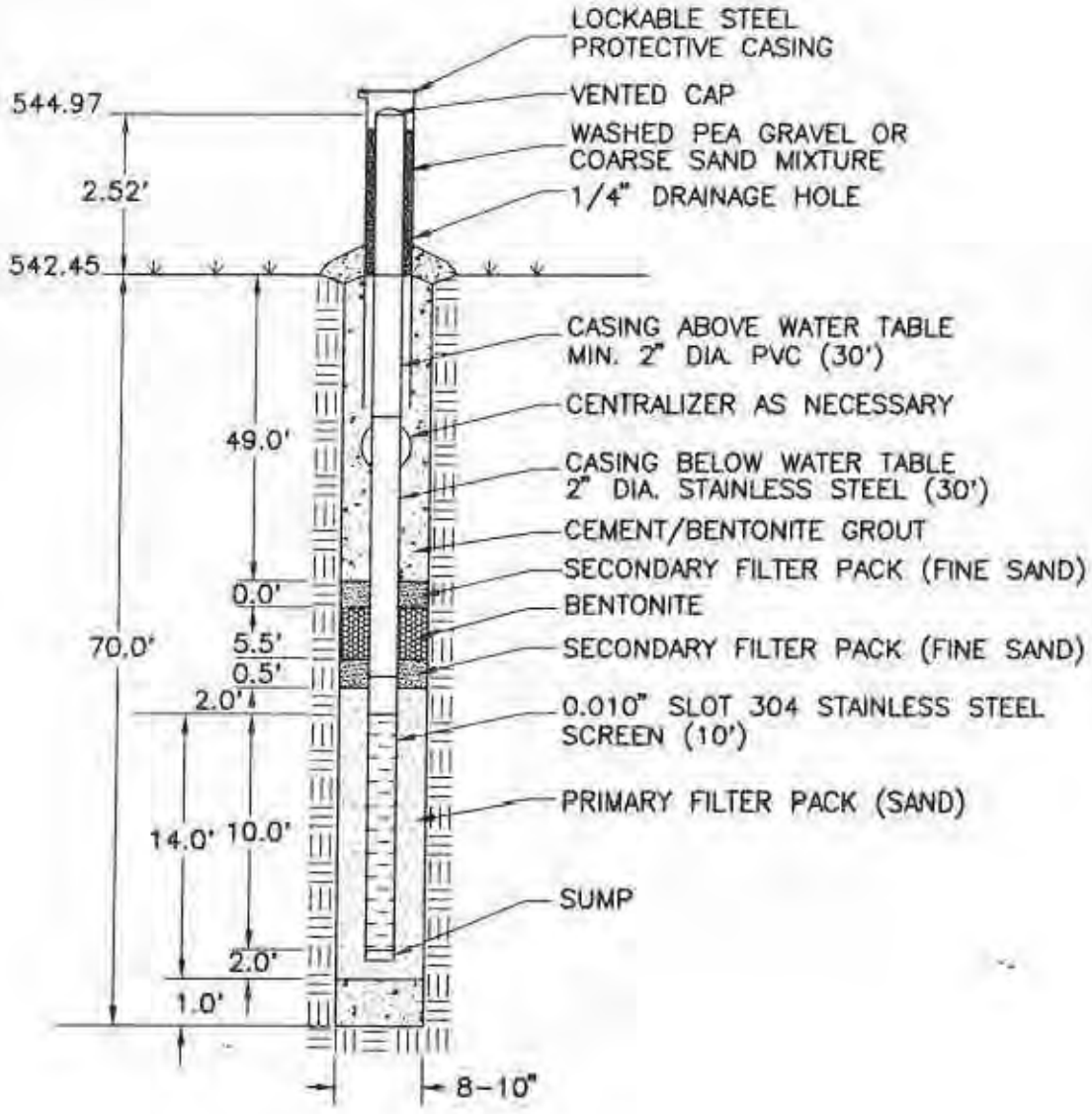


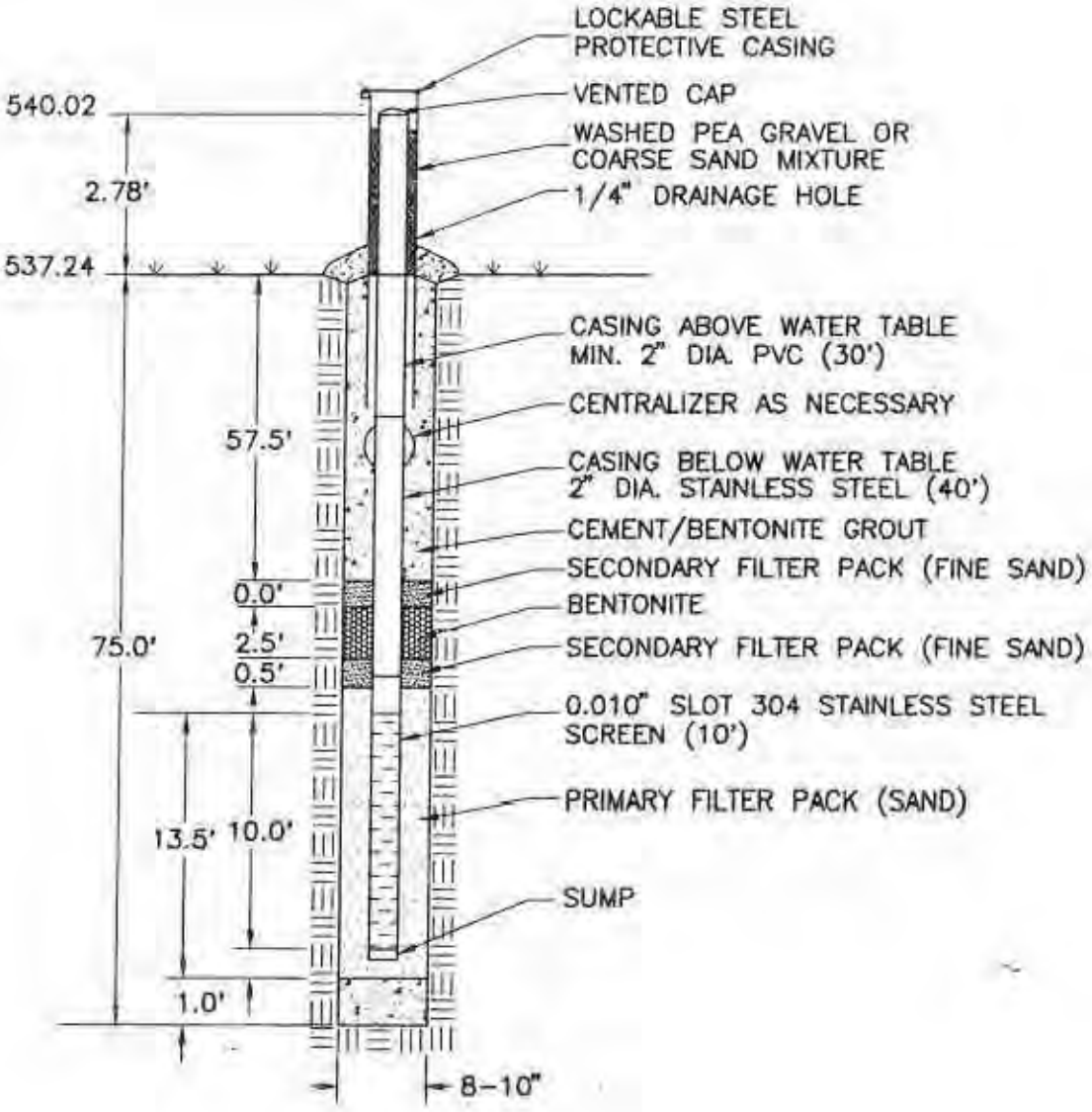
N: 8947.43 / E: 5499.92

RAPPS
ENGINEERING & APPLIED SCIENCE
521 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G201
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 6649.68 / E: 6587.20

RAPPS
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521 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
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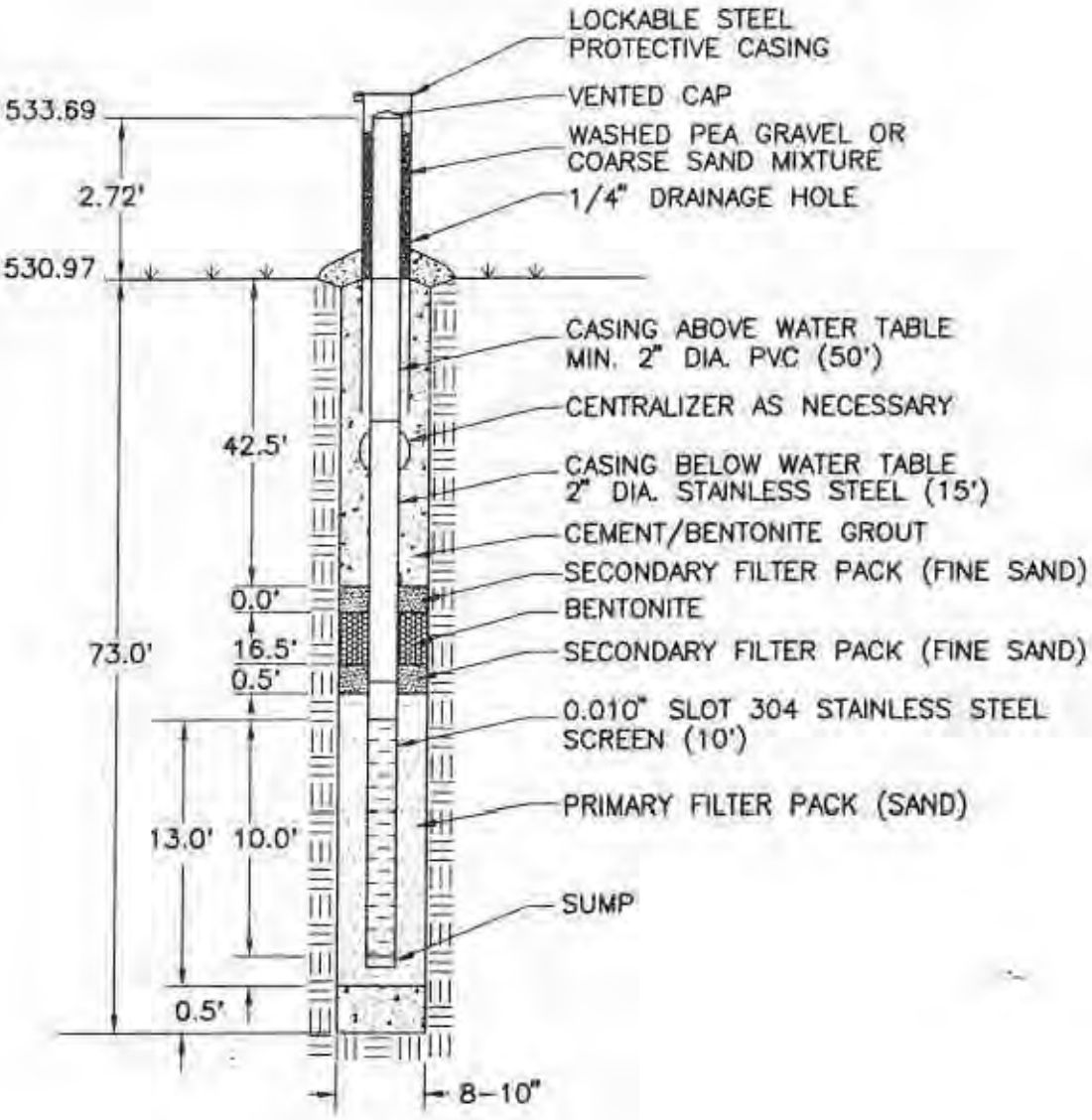
G202
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 5821.29 / E: 6113.10

RAPPS
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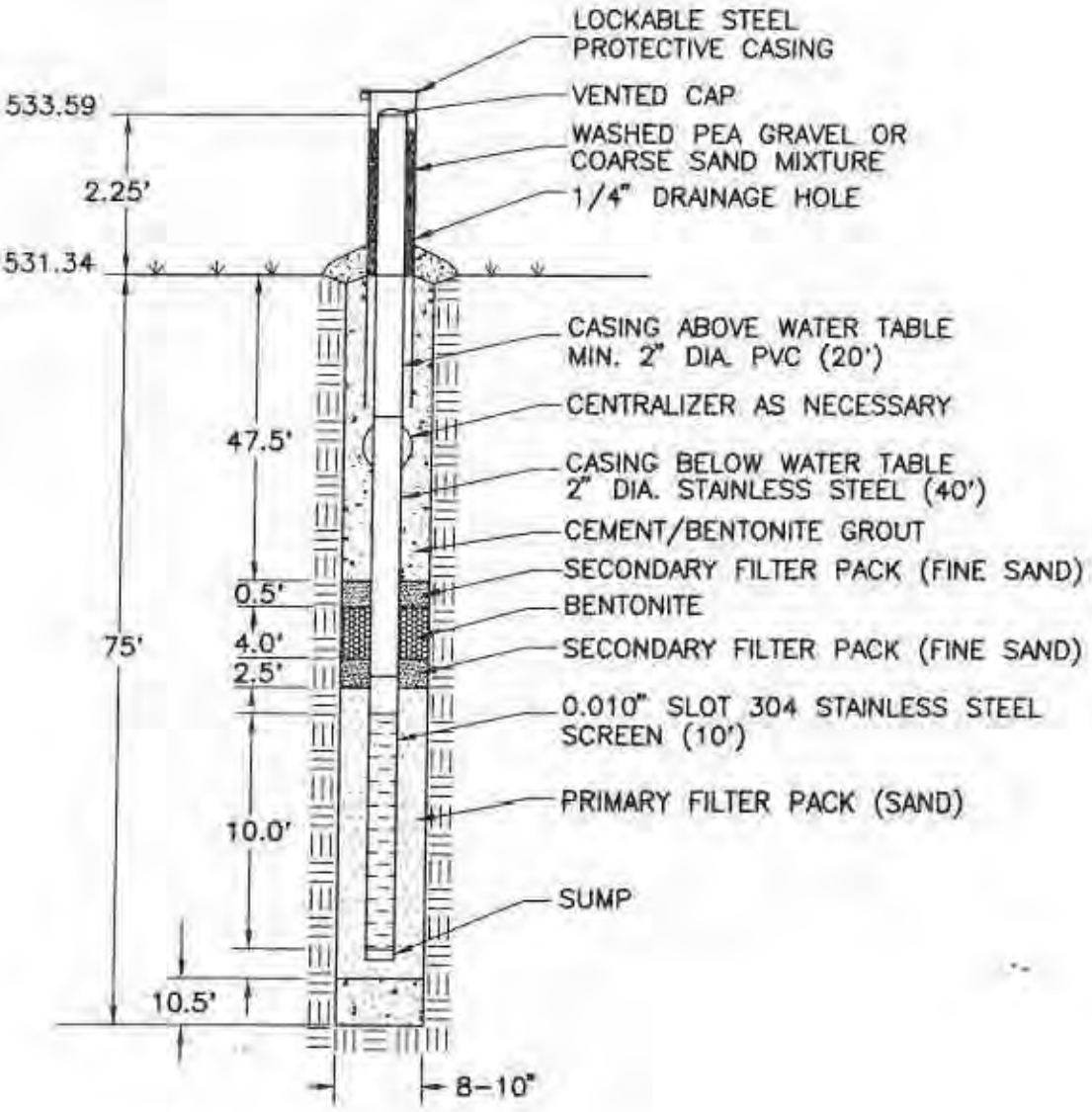
G203
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, LANDFILL

Electronic Filing: Received, Clerk's Office 07/01/2024



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RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
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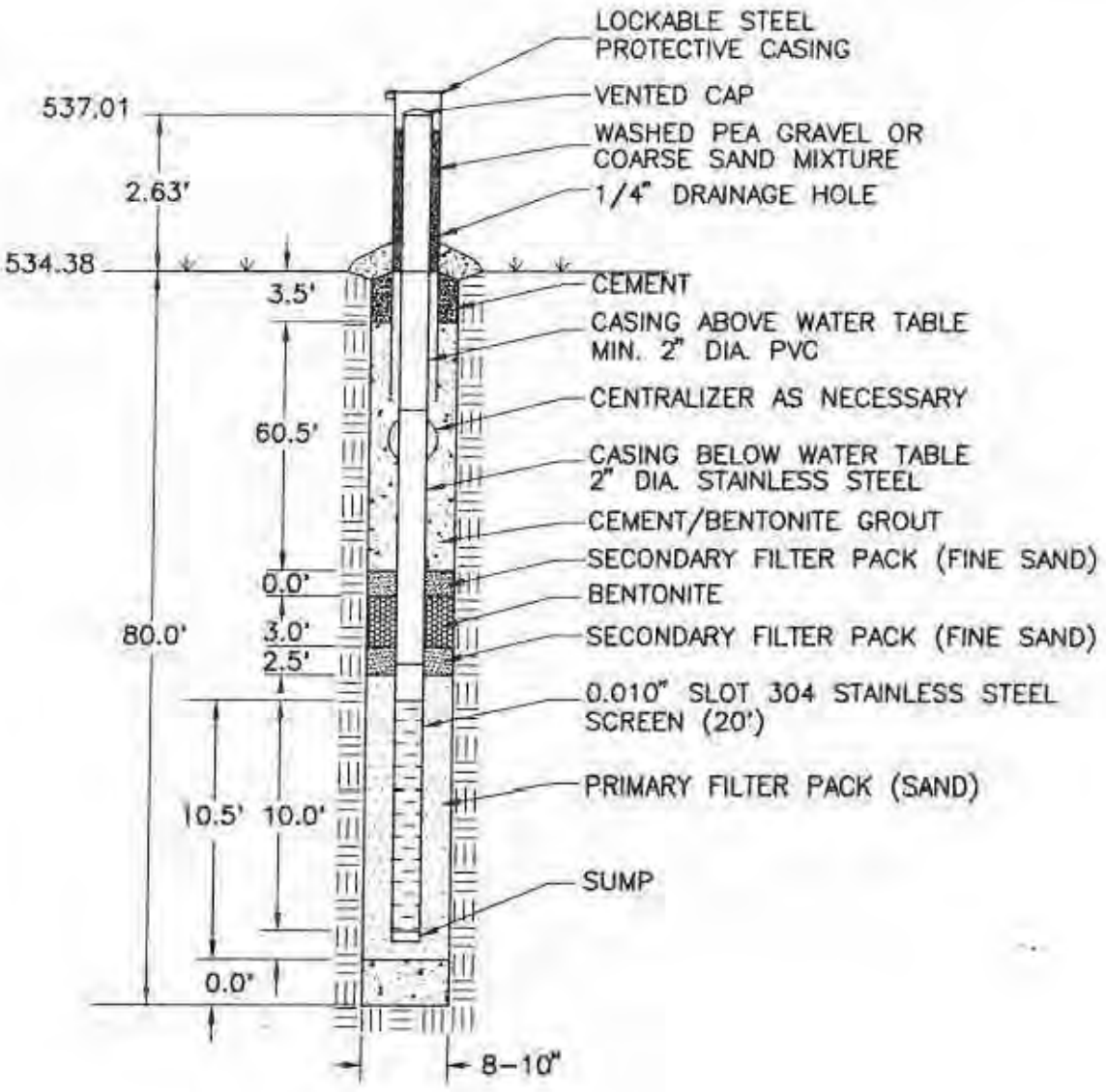
G204
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



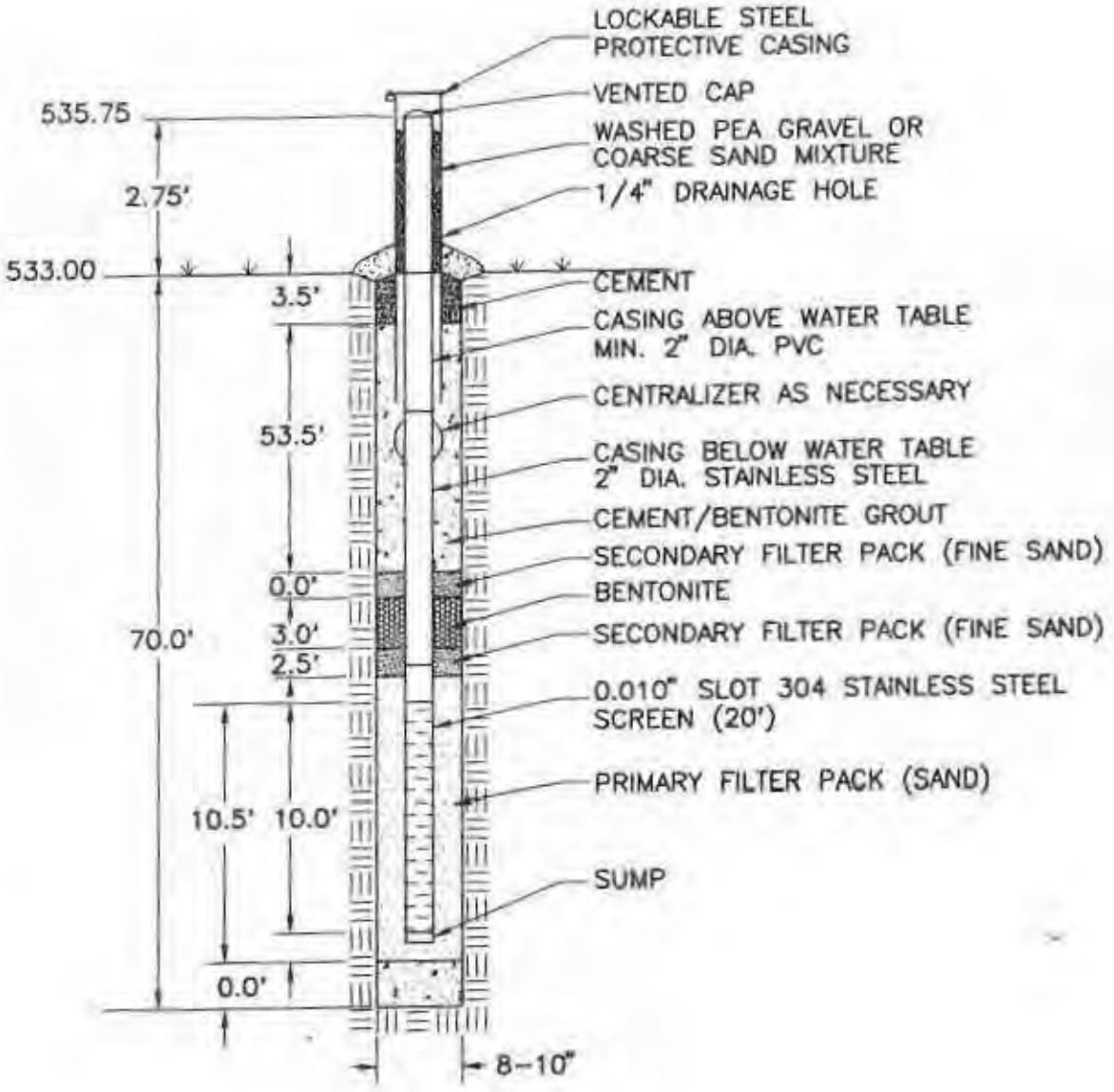
N: 4841.43 / E: 4649.02

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G205
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



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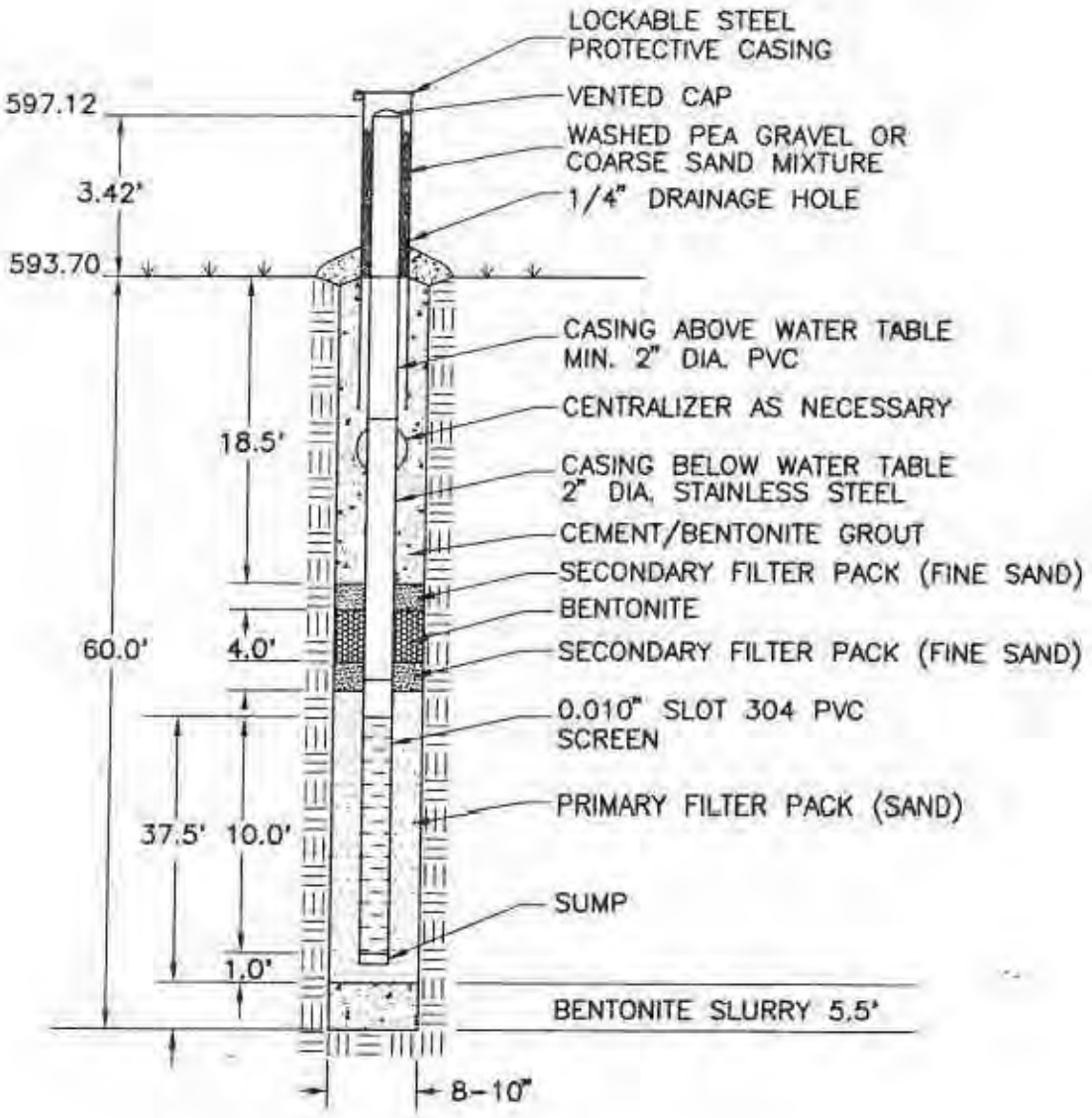
RAPPS
ENGINEERING & APPLIED SCIENCE
621 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
1601 BROADWAY • MT. VERNON, IL 62864 • (618) 244-2611

G207
MONITORING WELL AS-BUILT DIAGRAM

CIPS-NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024



N: 7897.63 / E: 5714.80

RAPPS
ENGINEERING & APPLIED SCIENCE
821 S. DURKIN DR. • SPRINGFIELD, IL 62704 • (217) 787-2118
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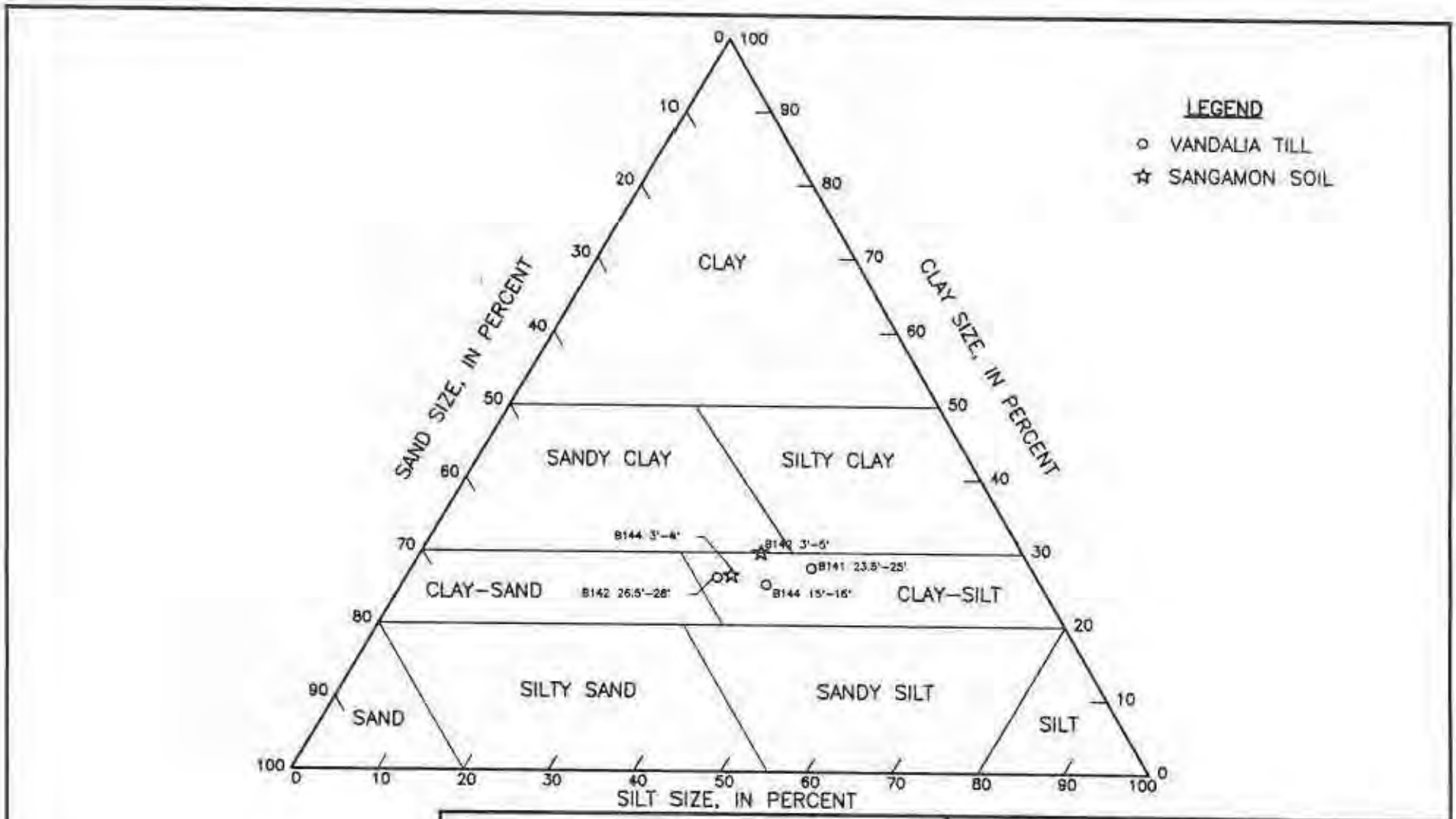
L1
MONITORING WELL AS-BUILT DIAGRAM

CIPS NEWTON LANDFILL
JASPER COUNTY, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024

ATTACHMENT D

GRAIN-SIZE DISTRIBUTION ANALYSIS



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ENGINEERING & APPLIED SCIENCE
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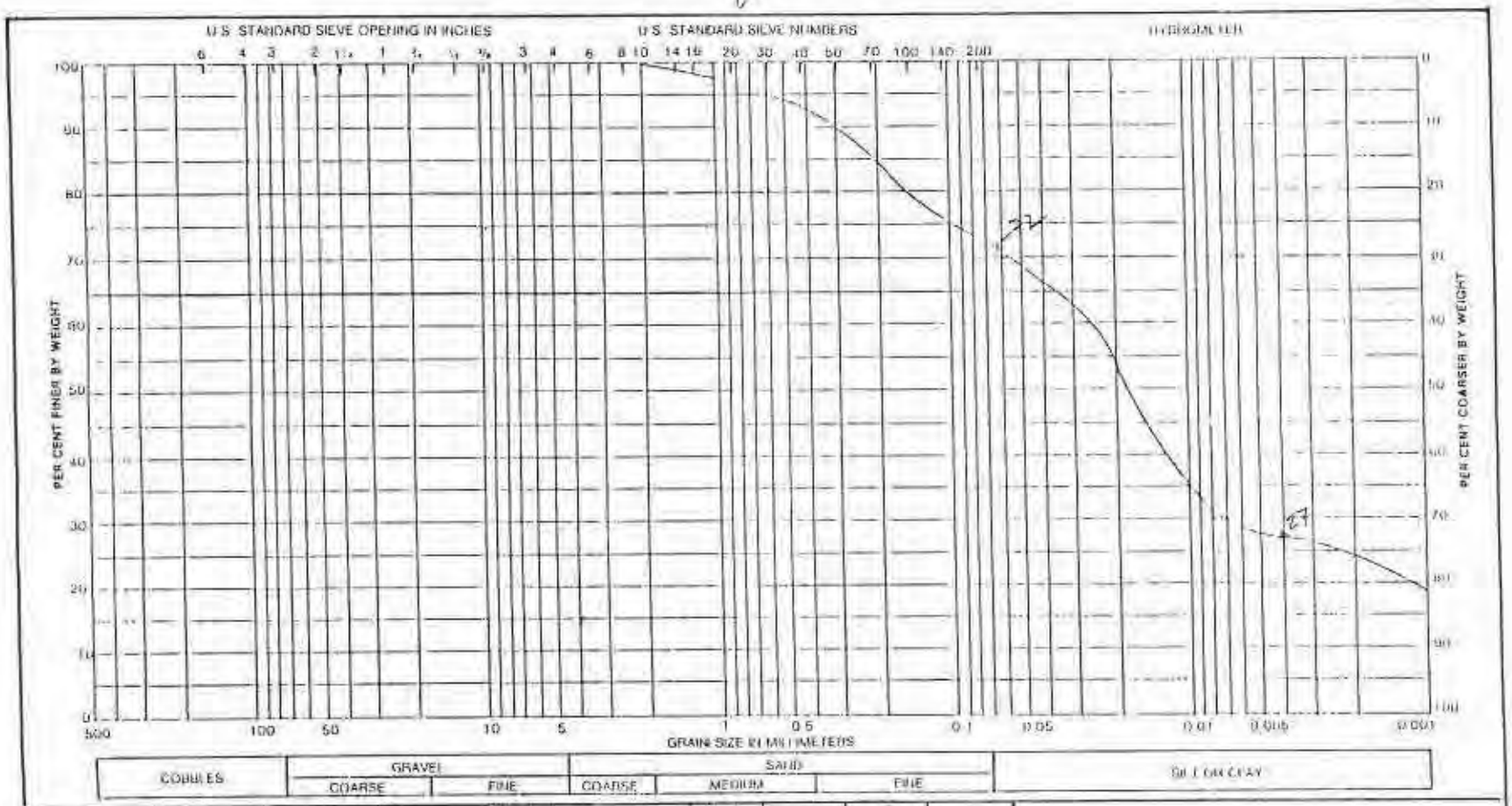
ATTACHMENT D
GRAIN SIZE DISTRIBUTION ANALYSIS
NEWTON POWER STATION LANDFILL
CENTRAL ILLINOIS PUBLIC SERVICE CO.
NEWTON, ILLINOIS

Electronic Filing: Received, Clerk's Office 07/01/2024

28% Sand
45% Silt
27% Clay



Boring No.	Sample No.	Elev. or Depth	Classification	Nat'l w %	LL	PL	PI
B141		23.5' to 25'	Clayey silt, gray some sand, fine to medium				

REPORT OF SOIL ANALYSIS

Project: NEWTON POWER STATION LANDFILL
CIPS NEWTON POWER PLANT

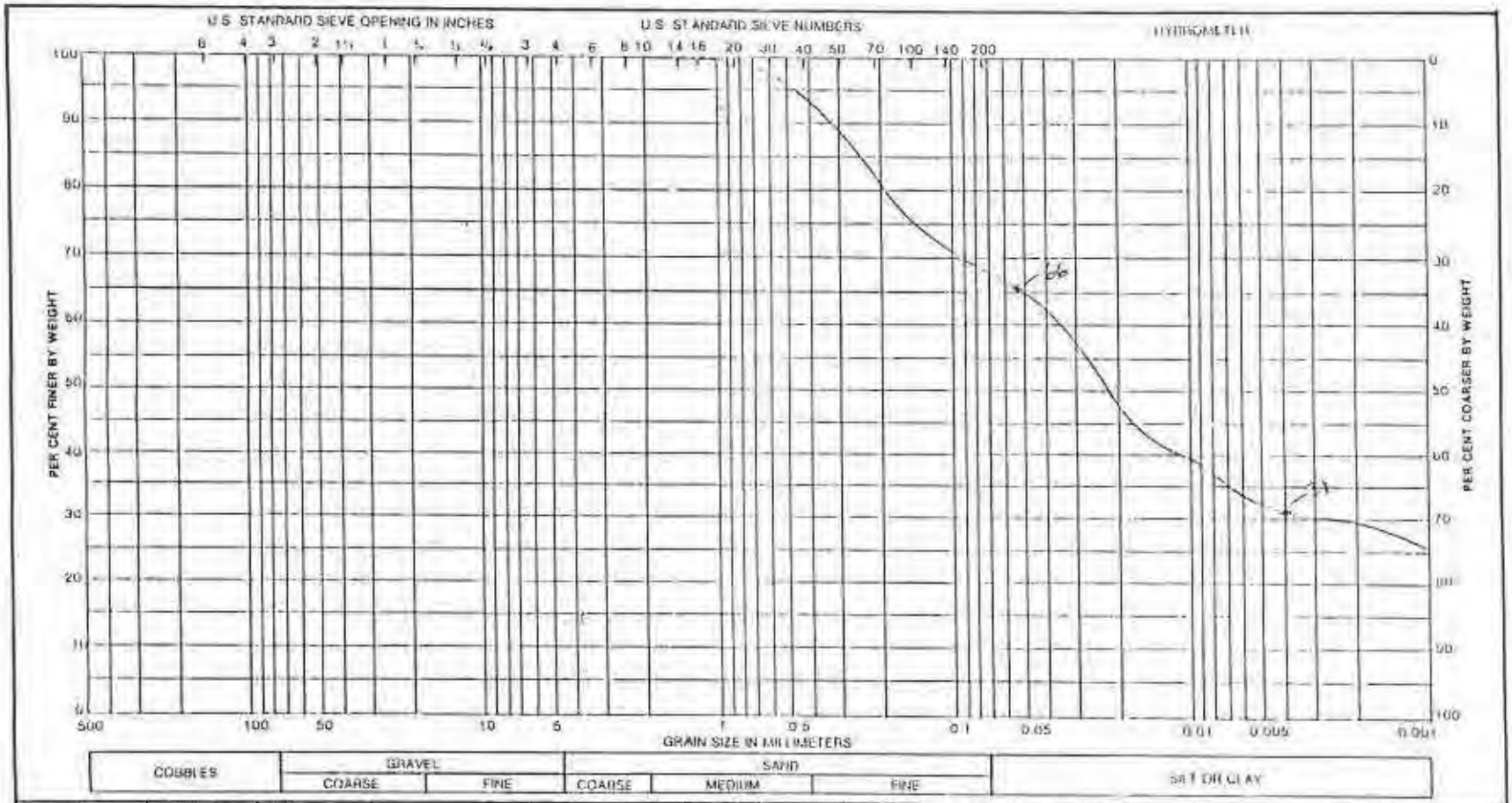
File No: 020-60146-01

Date: November 5, 1996

6812M

Electronic Filing: Received, Clerk's Office 07/01/2024

31% Sand
25% Silt
31% Clay



Boring No.	Sample No.	Elev. or Depth	Classification	Nat'l w %	LL	PL	PI
B142		3' to 5'	Clayey silt, brown, some sand, fine to medium				

REPORT OF SOIL ANALYSIS

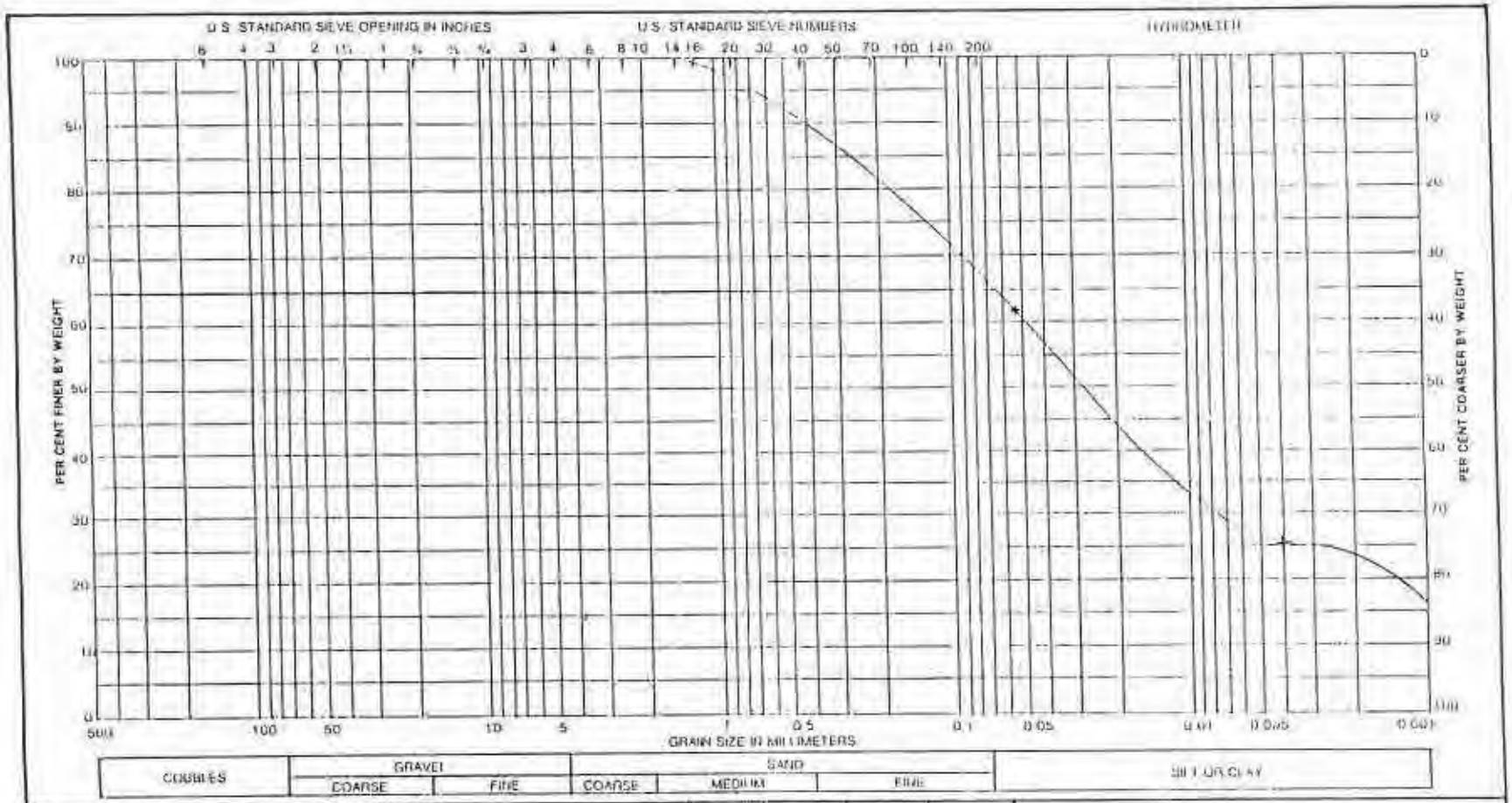
Project: NEWTON POWER STATION LANDFILL
CIPS NEWTON POWER STATION

File No. 020-60146-03

Date: November 5, 1996

6812M

38% Sand
36% Silt
26% Clay



Boring No	Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI
B142		26.5' to 28'	Clayey silt, gray, some sand, fine to medium				

REPORT OF SOIL ANALYSIS

Project: NEWTON POWER STATION LANDFILL
CIPS NEWTON POWER STATION

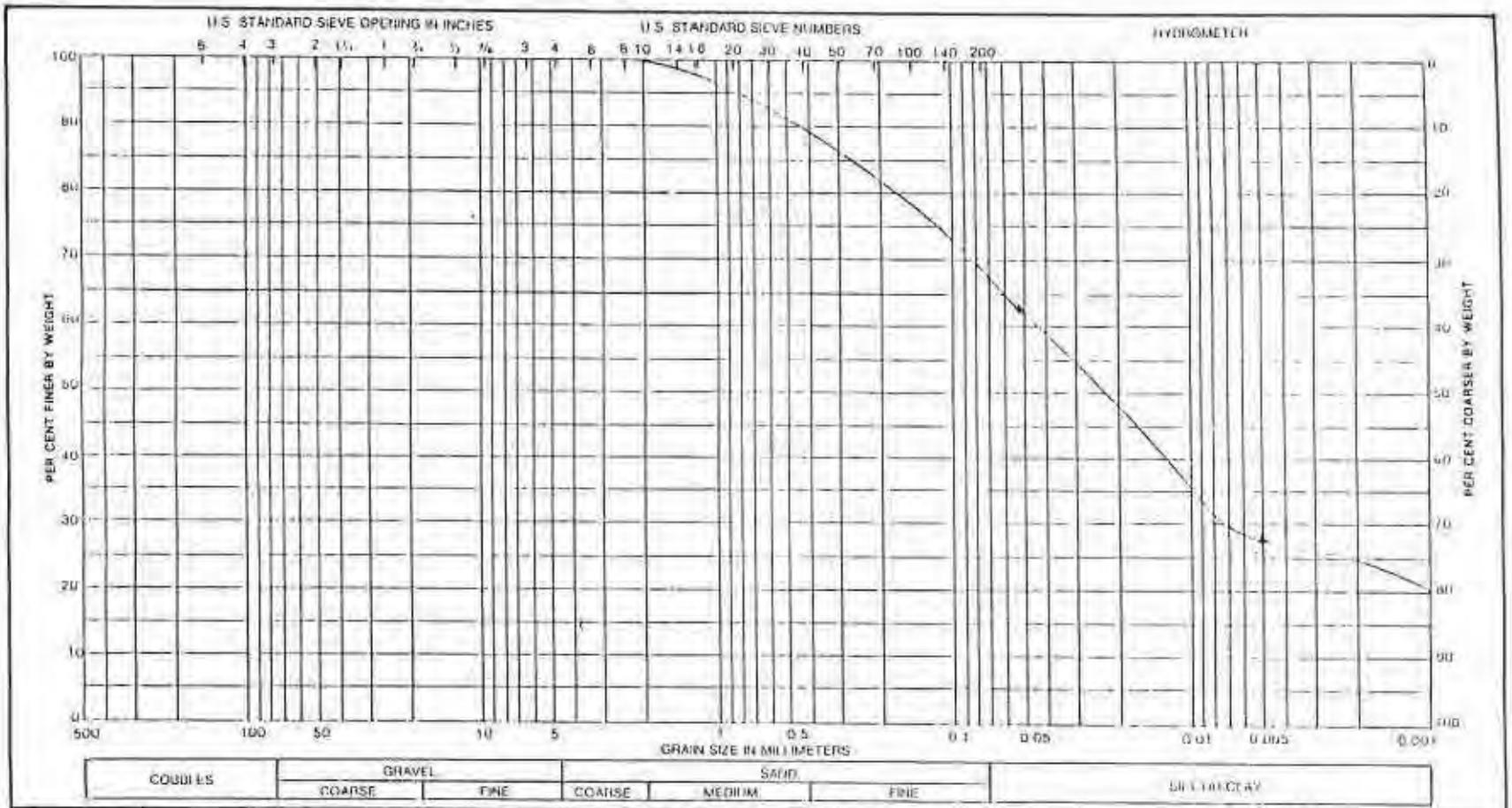
File No: 020-60146-04

Date: November 5, 1996

6812M

Electronic Filing: Received, Clerk's Office 07/01/2024

37% Sand
36% Silt
27% Clay ✓



Boring No.	Sample No.	Elev. or Depth	Classification	Nat. w %	LL	PL	PI
B144		3' to 4'	Clayey silt, brown some sand, fine to medium				

REPORT OF SOIL ANALYSIS

Project: NEWTON POWER STATION LANDFILL
CIPS NEWTON POWER STATION

Proj. No. 020-60146-08

Date: November 5, 1996

6812M

Electronic Filing: Received, Clerk's Office 07/01/2024

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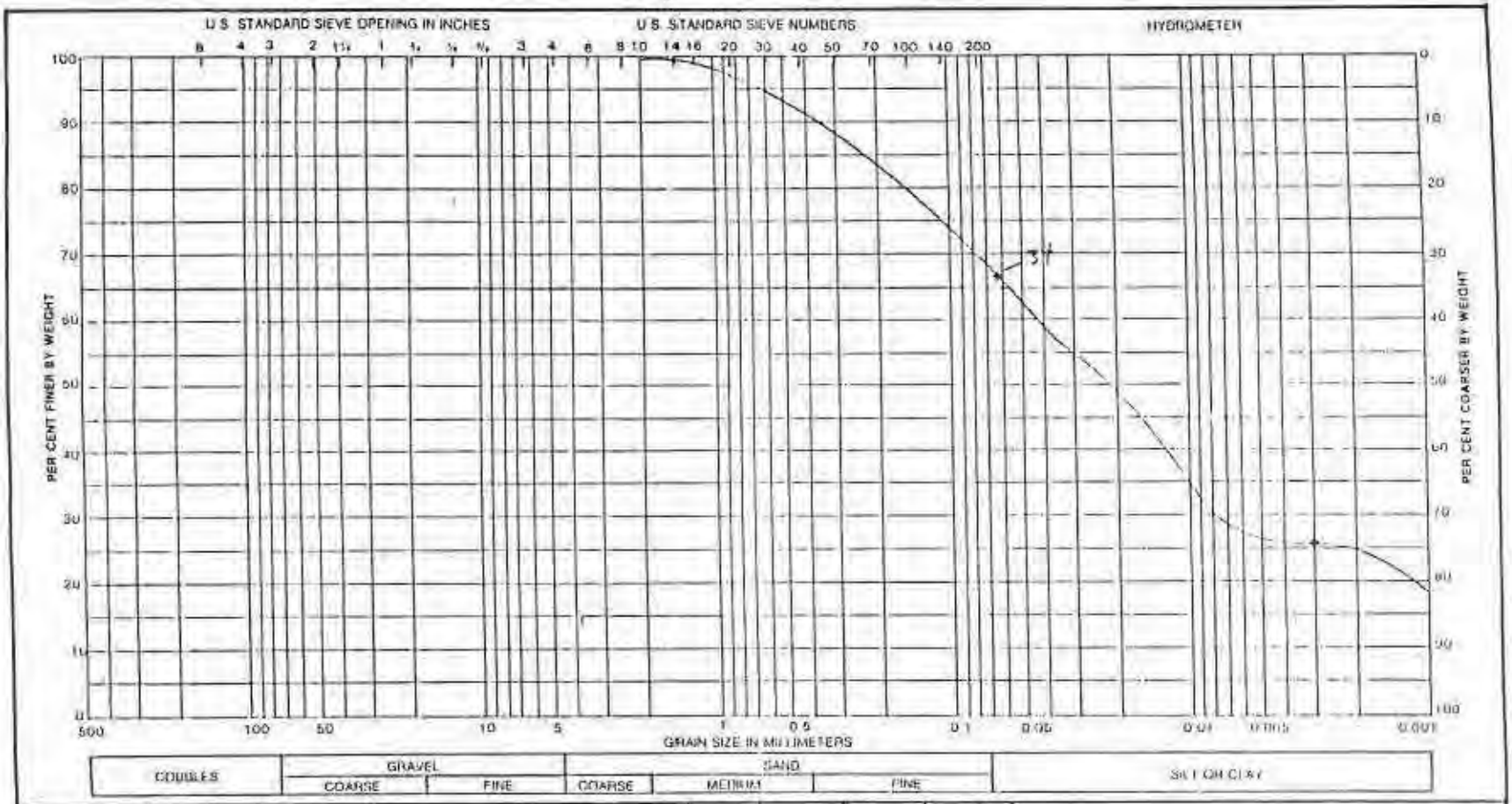
34% Sand
40% Silt
26% Clay



Boring No.	Sample No.	Elev. or Depth	Classification	Nat. w %	LL	PL	PI
B144		15' to 16'	Clayey silt, brown, some sand, fine to medium				

REPORT OF SOIL ANALYSIS

Project: NEWTON POWER STATION LANDFILL
CIPS NEWTON POWER STATION

File No. 020--60146-09

Date: November 5, 1996

6812M

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ATTACHMENT E

HYDRAULIC CONDUCTIVITY CALCULATIONS
AND
LABORATORY PERMEABILITY RESULTS

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SKS ENGINEERS, INC.

CONSULTING ENGINEERS

2930 N. MARTIN LUTHER KING, JR. DRIVE • DECATUR, ILLINOIS 62526 • 217-877-2100 • FAX 217-877-4816

CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

STRUCTURAL ENGINEERING

LAND SURVEYING

SUBSURFACE INVESTIGATIONS

ENVIRONMENTAL INVESTIGATIONS

CONSTRUCTION QUALITY CONTROL

SOILS / MATERIALS TESTING

November 22, 1996

SKS No. 19-66398-6

Mr. James E. Conlon
RAPPS Engineering & Applied Science
PO Box 7349
Springfield, IL 62791-7349

RE: Newton Power Station Landfill
Soil Testing

Dear Mr. Conlon:

Enclosed are the soil tests for the referenced project. Please use these to replace the ones sent previously.

If you have any questions or comments please call.

Sincerely,
SKS ENGINEERS, INC.

By: _____
Jerrel L. Shaffer, P.E.

JLS/mah
Enc.

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SKS ENGINEERS, INC.
CONSULTING ENGINEERS
2900 N. MARTIN LUTHER KING, JR. DRIVE
DECATUR, ILLINOIS 62526

SOIL CLASSIFICATION AND ENGINEERING PROPERTIES

PROJECT: Newton Power Plant

JOB NO. I9-66398-6

DATE: November 22, 1996

BORING/SAMPLE NO'S.	B-141	B-141	B-142	B-142	B-143
DEPTH/ELEVATION	20' - 25'	27' - 28.5'	27.5' - 30'	28' - 32'	21' - 22.5'
SOIL PARTICLE SIZES					
GRAVEL; %					
SAND; %					
coarse %					
medium %					
fine %					
FINES; %					
silt %					
clay %					
PLASTICITY CHARACTERISTICS					
MOISTURE CONTENT %					
LIQUID LIMIT					
PLASTIC LIMIT					
PLASTICITY INDEX					
CLASSIFICATION					
USCS	CL	CL	CL	CL	CL
POROSITY %	27.37	24.65	25.05	28.28	24.17
ENGINEERING PROPERTIES					
MAX. DRY DENSITY; pcf	126.3				
OPT. MOISTURE CONTENT; %	9.9				
TEST DENSITY; pcf	120.1	124.6	124.1	118.6	125.4
PERMEABILITY, cm/sec	1.69×10^{-8}	6.34×10^{-9}	9.25×10^{-9}	2.11×10^{-8}	9.55×10^{-9}

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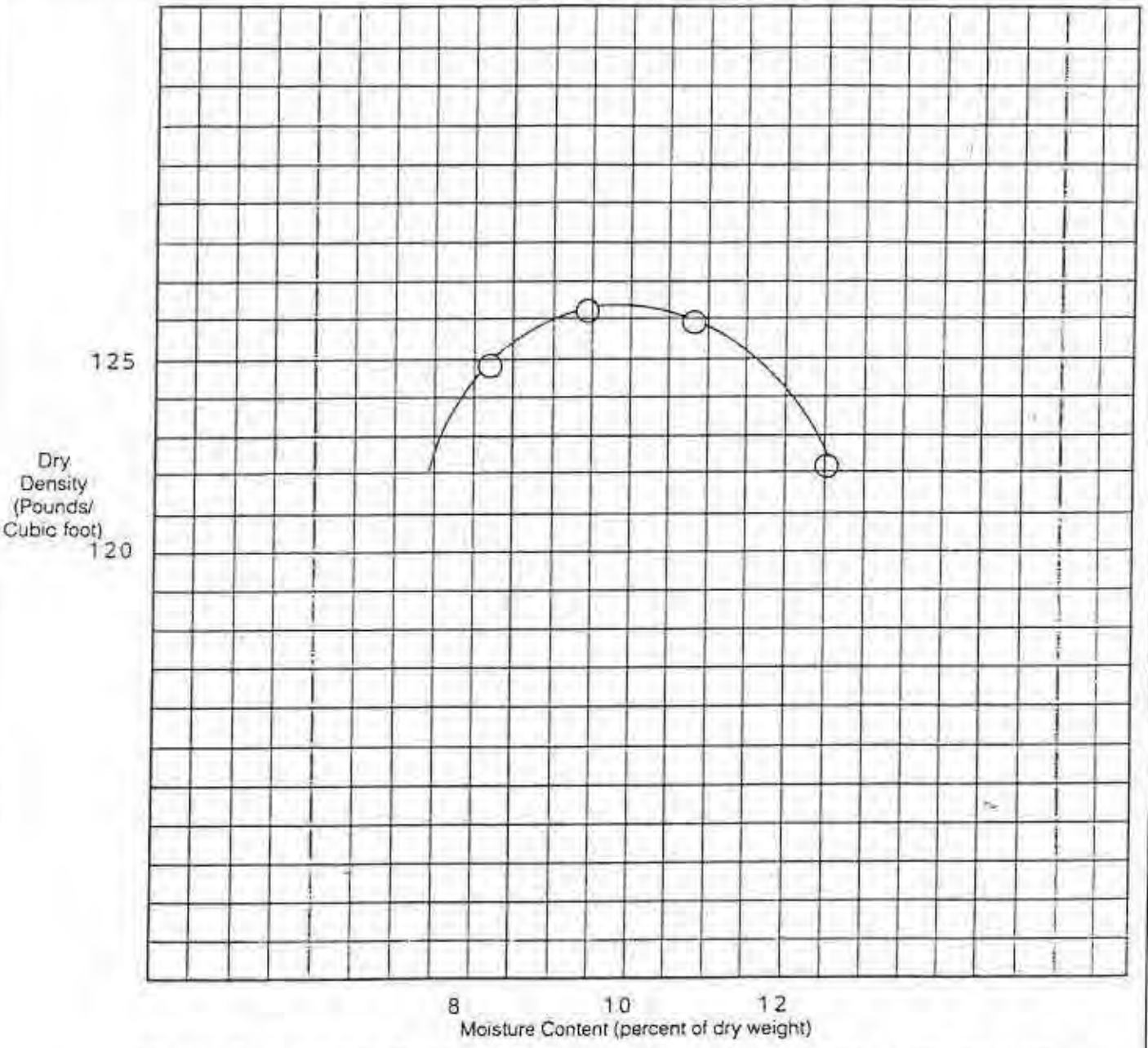
Project Number 66398

MOISTURE DENSITY RELATIONSHIP

Date 11-3-96

Test Method ASTM D-698

Source B-141 20' - 25'



Maximum Dry Density (Lbs./Cu.Ft.) 126.3

Optimum Moisture Content (%) 9.9

Type of Material: Gray, low-medium plasticity silty clay, trace sand, trace gravel

CIPS-Newton Power Station Landfill
RAPPS

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DECATUR, ILLINOIS 62526

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PERMEABILITY & CLASSIFICATION TEST RESULTS

PROJECT: NEWTON POWER STATION — DATE: November 22, 1996
LANDFILL — PROJECT NO.: 66398
CLIENT: RAPPS — REPORT NO: 66398-1
Sheet 1 of 5

SAMPLE IDENTIFICATION: B-141 — DEPTH/ELEV: 20' - 25'

CLASSIFICATION; USCS:

DESCRIPTION: Gray, medium plasticity, SILTY CLAY, trace sand, trace gravel

SOIL PARTICLE SIZES

GRAVEL %:	SAND %:	SILT %:	CLAY %:	*

NATURAL MOISTURE %: 12.2 — DENSITY;lb/ft3 NATURAL: 0.0
LIQUID LIMIT : — MAX. DRY;lb/ft3: 126.3 REMOLDED: 120.1
PLASTICITY INDEX : — PROCTOR;DEG OF COMPACTION (D698): 95.1

PERMEABILITY (k), cm/sec: 1.69E-8 **

PERMEABILITY TEST DETAILS

SAMPLES OBTAINED BY: CLIENT — TYPE OF SAMPLE: REMOLDED

SPECIMEN DATA

DIAMETER;cm:	7.264	INITIAL DENSITY;pcf:	134.8
LENGTH;cm:	7.442	DRY UNIT DENSITY;pcf:	120.1
AREA;cm2:	41.45	INITIAL MOISTURE; %:	12.2
VOLUME;cm3:	308.5	FINAL MOISTURE; %:	
INITIAL SATURATION; %:	23.46	FLOW ORIENTATION:	-V

TEST APPARATUS: GEOTEST

TEST PRESSURES

CELL/CONFINING; psi:	30.0
SAMPLE BACK PRESSURE;psi:	25.0
DRIVING PRESSURE; psi:	2.0

HYDRAULIC GRADIENT: 18.9

PERMEANT LIQUID: 0.005 N CaSO4

TIME OF TEST; SATURATION: 40.5 Hrs — PERMEABILITY: 170.0 Hrs
FLOW THRU SPECIMEN; TOTAL: 13.41 ml — PERMEABILITY TEST: 8.23 ml
TEMPERATURE CORRECTION; TEMPERATURE: 20.6 C — FACTOR: 0.986

REMARKS:

* Percentage of silt and clay fractions is based on 0.002mm as the division between the fractions (Unified Soil Classification System)

** Hydraulic conductivity test conducted in accordance with ASTM D 5084-90 unless noted otherwise. E-8 equals 10 to the minus 8 (exponent); cm3 equals cubic centimeters; The 2 in H2O is a subscript.

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PERMEABILITY & CLASSIFICATION TEST RESULTS

PROJECT: NEWTON POWER STATION — DATE: November 22, 1996
LANDFILL — PROJECT NO.: 66398
CLIENT: RAPPS — REPORT NO: 66398-1
Sheet 1 of 5

SAMPLE IDENTIFICATION: B-142 — DEPTH/ELEV: 28' - 32'

CLASSIFICATION; USCS:

DESCRIPTION: Gray, medium plasticity, SILTY CLAY, trace sand, trace gravel

SOIL PARTICLE SIZES

GRAVEL %:	SAND %:	SILT %:	CLAY %:	*

NATURAL MOISTURE %: 12.5 — DENSITY;lb/ft3 NATURAL: 0.0
LIQUID LIMIT : — MAX. DRY;lb/ft3: 126.3 REMOLDED: 118.6
PLASTICITY INDEX : — PROCTOR;DEG OF COMPACTION (D698): 93.9

PERMEABILITY (k), cm/sec: 2.11E-8 **

PERMEABILITY TEST DETAILS

SAMPLES OBTAINED BY: CLIENT — TYPE OF SAMPLE: REMOLDED

SPECIMEN DATA

DIAMETER;cm:	7.264	INITIAL DENSITY;pcf:	133.4
LENGTH;cm:	7.595	DRY UNIT DENSITY;pcf:	118.6
AREA;cm2:	41.45	INITIAL MOISTURE; %:	12.5
VOLUME;cm3:	314.8	FINAL MOISTURE; %:	12.7
INITIAL SATURATION; %:	23.79	FLOW ORIENTATION:	-V

TEST APPARATUS: GEOTEST

TEST PRESSURES

CELL/CONFINING; psi:	30.0		
SAMPLE BACK PRESSURE;psi:	25.0		
DRIVING PRESSURE; psi:	2.0	HYDRAULIC GRADIENT:	18.5

PERMEANT LIQUID: 0.005 N CaSO4

TIME OF TEST; SATURATION: 19.7 Hrs — PERMEABILITY: 167.5 Hrs
FLOW THRU SPECIMEN; TOTAL: 10.81 ml — PERMEABILITY TEST: 10.10 ml
TEMPERATURE CORRECTION; TEMPERATURE: 21.46 C — FACTOR: 0.966

REMARKS:

* Percentage of silt and clay fractions is based on 0.002mm as the division between the fractions (Unified Soil Classification System)

** Hydraulic conductivity test conducted in accordance with ASTM D 5084-90 unless noted otherwise. E-8 equals 10 to the minus 8 (exponent); cm3 equals cubic centimeters; The 2 in H2O is a subscript.

Electronic Filing: Received, Clerk's Office 07/01/2024

SKS ENGINEERS, INC.

CONSULTING ENGINEERS

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PERMEABILITY & CLASSIFICATION TEST RESULTS

PROJECT: NEWTON POWER STATION — DATE: November 10, 1996

LANDFILL — PROJECT NO.: 66398

CLIENT: RAPPS — REPORT NO: 66398-1

SAMPLE IDENTIFICATION: B-141 — DEPTH/ELEV: 27' - 28.5

CLASSIFICATION; USCS:

DESCRIPTION: Gray, medium plasticity, SILTY CLAY, trace sand, trace gravel

SOIL PARTICLE SIZES

GRAVEL %:	SAND %:	SILT %:	CLAY %:	*

NATURAL MOISTURE %: 13.0 — DENSITY;lb/ft3 NATURAL: 124.6

LIQUID LIMIT : — MAX. DRY;lb/ft3: — REMOLDED: 0.0

PLASTICITY INDEX : — PROCTOR;DEG OF COMPACTION (D698):

PERMEABILITY (k), cm/sec: 6.34E-9 **

PERMEABILITY TEST DETAILS

SAMPLES OBTAINED BY: CLIENT — TYPE OF SAMPLE: 3" THIN-WALL TUBE

SPECIMEN DATA

DIAMETER;cm:	7.264	INITIAL DENSITY;pcf:	140.8
LENGTH;cm:	7.188	DRY UNIT DENSITY;pcf:	124.6
AREA;cm2:	41.45	INITIAL MOISTURE; %:	13.0
VOLUME;cm3:	297.9	FINAL MOISTURE; %:	13.8
INITIAL SATURATION; %:	26.01	FLOW ORIENTATION:	-V

TEST APPARATUS: GEOTEST

TEST PRESSURES

CELL/CONFINING; psi:	30.0
SAMPLE BACK PRESSURE;psi:	25.0
DRIVING PRESSURE; psi:	2.0

HYDRAULIC GRADIENT: 19.6

PERMEANT LIQUID: 0.005 N CaSO4

TIME OF TEST; SATURATION: 115.2 Hrs — PERMEABILITY: 167.0 Hrs

FLOW THRU SPECIMEN; TOTAL: 6.98 ml — PERMEABILITY TEST: 3.24 ml

TEMPERATURE CORRECTION; TEMPERATURE: 22.06 C — FACTOR: 0.953

REMARKS:

* Percentage of silt and clay fractions is based on 0.002mm as the division between the fractions (Unified Soil Classification System)

** Hydraulic conductivity test conducted in accordance with ASTM D 5084-90 unless noted otherwise. E-8 equals 10 to the minus 8 (exponent); cm3 equals cubic centimeters; The 2 in H2O is a subscript.

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PERMEABILITY & CLASSIFICATION TEST RESULTS

PROJECT: NEWTON POWER STATION — DATE: November 10, 1996
LANDFILL — PROJECT NO.: 66398
CLIENT: RAPPS — REPORT NO: 66398-1

SAMPLE IDENTIFICATION: B-142 — DEPTH/ELEV: 27.5' - 30

CLASSIFICATION; USCS:

DESCRIPTION: Gray, medium plasticity, SILTY CLAY, trace sand, trace gravel

SOIL PARTICLE SIZES

GRAVEL %:	SAND %:	SILT %:	CLAY %:	*

NATURAL MOISTURE %: 11.9 — DENSITY;lb/ft3 NATURAL: 124.1
LIQUID LIMIT : — MAX. DRY;lb/ft3: — REMOLDED: 0.0
PLASTICITY INDEX : — PROCTOR;DEG OF COMPACTION (D698):

PERMEABILITY (k), cm/sec: 9.25E-9 **

PERMEABILITY TEST DETAILS

SAMPLES OBTAINED BY: CLIENT — TYPE OF SAMPLE: 3" THIN-WALL TUBE

SPECIMEN DATA

DIAMETER;cm:	7.264	INITIAL DENSITY;pcf:	138.9
LENGTH;cm:	7.696	DRY UNIT DENSITY;pcf:	124.1
AREA;cm2:	41.45	INITIAL MOISTURE; %:	11.9
VOLUME;cm3:	319.0	FINAL MOISTURE; %:	12.9
INITIAL SATURATION; %:	23.69	FLOW ORIENTATION:	-V

TEST APPARATUS: GEOTEST

TEST PRESSURES

CELL/CONFINING; psi:	30.0
SAMPLE BACK PRESSURE;psi:	25.0
DRIVING PRESSURE; psi:	2.0

HYDRAULIC GRADIENT: 18.3

PERMEANT LIQUID: 0.005 N CaSO4

TIME OF TEST; SATURATION: 115.2 Hrs — PERMEABILITY: 167.0 Hrs
FLOW THRU SPECIMEN; TOTAL: 9.41 ml — PERMEABILITY TEST: 4.42 ml
TEMPERATURE CORRECTION; TEMPERATURE: 22.06 C — FACTOR: 0.953

REMARKS:

* Percentage of silt and clay fractions is based on 0.002mm as the division between the fractions (Unified Soil Classification System)

** Hydraulic conductivity test conducted in accordance with ASTM D 5084-90 unless noted otherwise. E-8 equals 10 to the minus 8 (exponent); cm3 equals cubic centimeters; The 2 in H2O is a subscript.

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PERMEABILITY & CLASSIFICATION TEST RESULTS

PROJECT: NEWTON POWER STATION — DATE: November 10, 1996
LANDFILL — PROJECT NO.: 66398
CLIENT: RAPP — REPORT NO: 66398-1
Sheet 3 of 3

SAMPLE IDENTIFICATION: B-143 — DEPTH/ELEV: 21' - 22.5

CLASSIFICATION; USCS:

DESCRIPTION: Gray, Silty Clay, trace sand, trace gravel

SOIL PARTICLE SIZES

GRAVEL %:	SAND %:	SILT %:	CLAY %:	*

NATURAL MOISTURE %: 11.4	DENSITY;lb/ft3	NATURAL:	125.4
LIQUID LIMIT :	MAX. DRY;lb/ft3:	REMOLDED:	0.0
PLASTICITY INDEX :	PROCTOR;DEG OF COMPACTION (D698):		

PERMEABILITY (k), cm/sec: 9.55E-9 **

PERMEABILITY TEST DETAILS

SAMPLES OBTAINED BY: CLIENT — TYPE OF SAMPLE: 3" THIN-WALL TUBE

SPECIMEN DATA

DIAMETER;cm:	7.264	INITIAL DENSITY;pcf:	139.7
LENGTH;cm:	7.595	DRY UNIT DENSITY;pcf:	125.4
AREA;cm2:	41.45	INITIAL MOISTURE; %:	11.4
VOLUME;cm3:	314.8	FINAL MOISTURE; %:	14.3
INITIAL SATURATION; %:	22.89	FLOW ORIENTATION:	-V

TEST APPARATUS: GEOTEST

TEST PRESSURES

CELL/CONFINING; psi:	30.0	
SAMPLE BACK PRESSURE;psi:	25.0	
DRIVING PRESSURE; psi:	2.0	HYDRAULIC GRADIENT: 18.5

PERMEANT LIQUID: 0.005 N CaSO4

TIME OF TEST; SATURATION:	73.4 Hrs	PERMEABILITY:	117.0 Hrs
FLOW THRU SPECIMEN; TOTAL:	6.40 ml	PERMEABILITY TEST:	3.27 ml
TEMPERATURE CORRECTION; TEMPERATURE:	22.4 C	FACTOR:	0.944

REMARKS:

* Percentage of silt and clay fractions is based on 0.002mm as the division between the fractions (Unified Soil Classification System)

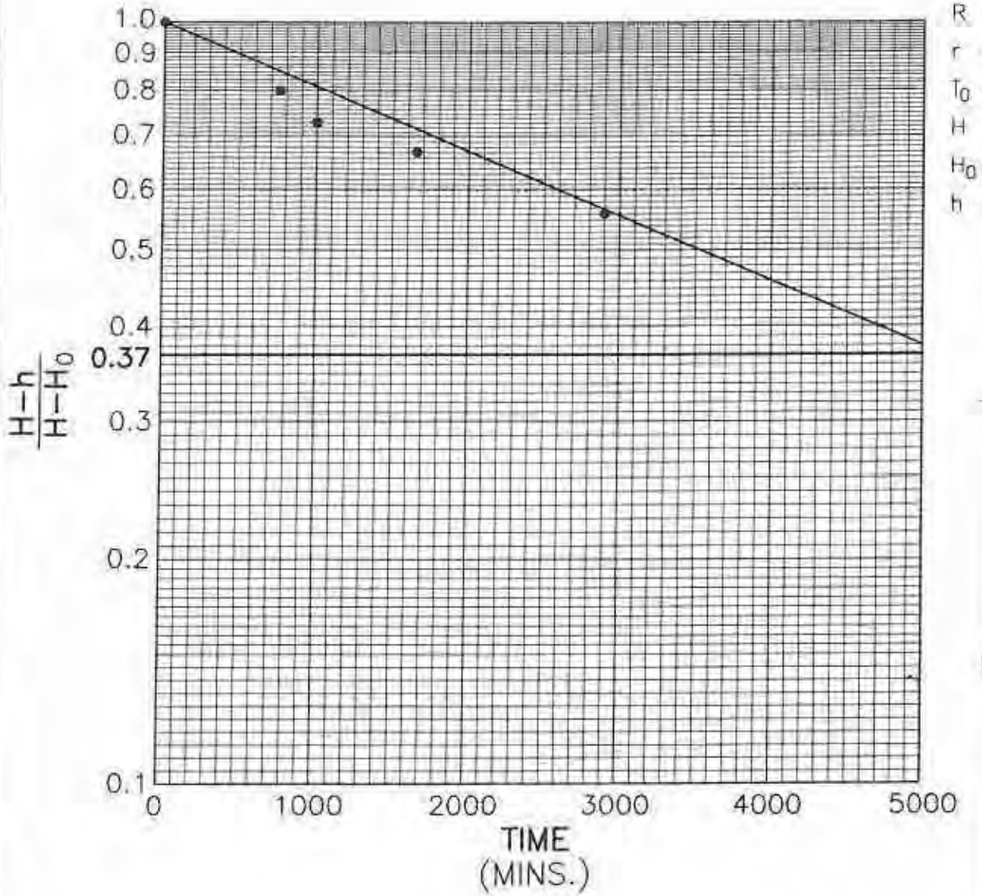
** Hydraulic conductivity test conducted in accordance with ASTM D 5084-90 unless noted otherwise. E-8 equals 10 to the minus 8 (exponent); cm3 equals cubic centimeters; The 2 in H2O is a subscript.

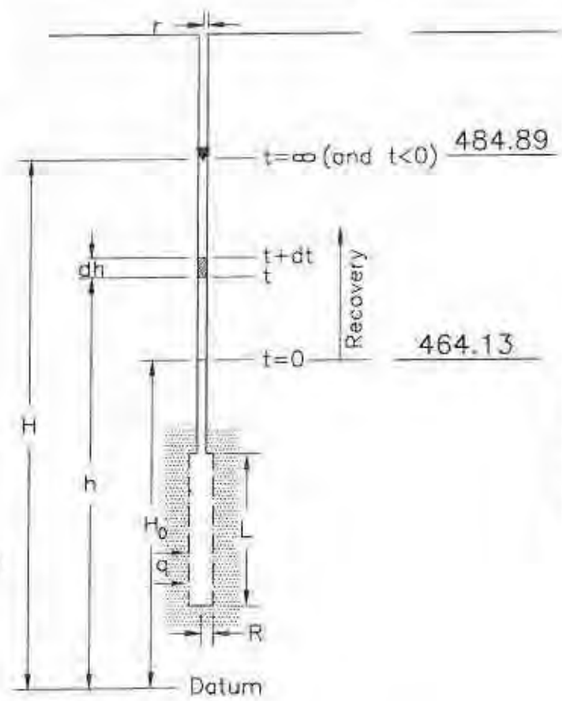
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ LT_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 484.89 H_0= 464.13 H−H_0= 20.76

TIME	DEPTH TO WATER	h	H−h	(H−h)/(H−H_0)
200	16.04	465.75	19.14	0.92
740	13.51	468.28	16.61	0.80
1000	12.06	469.73	15.16	0.73
1650	9.50	469.99	13.90	0.67
2880	8.665	473.13	11.76	0.57

SOLUTION

$$K = \frac{(1)^2 \ln(96/4)}{2\ (96)(5000)}$$

$$K = \frac{3.18}{960{,}000}$$

$K = 3.31 \times 10^{-6}$ in./min.

$K = 1.4 \times 10^{-7}$ cm./sec.

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G104D
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HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
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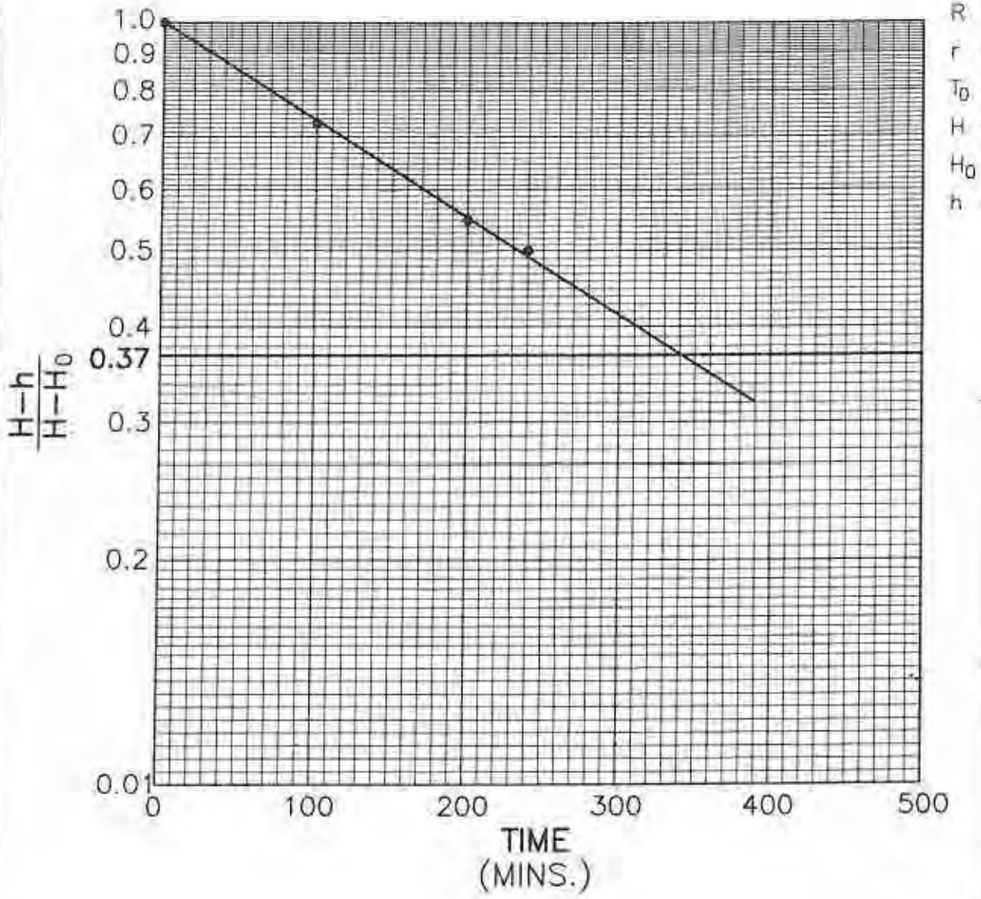
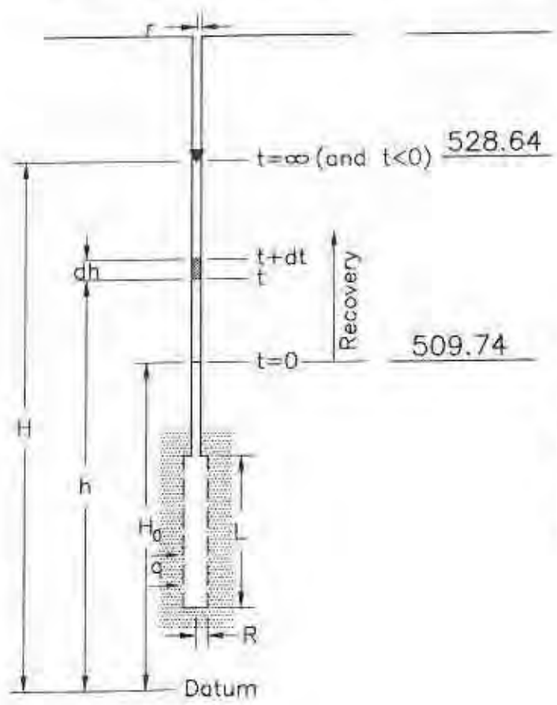
- h = Groundwater elevation at a given time (msl)





H= 528.64 H_0= 509.74 $H-H_0$= 18.9

TIME	DEPTH TO WATER	h	H−h	(H−h)/(H−H0)
0	23.21	509.74	18.90	1.00
50	17.94	515.01	13.63	0.72
100	14.78	518.17	10.47	0.55
120	13.80	519.15	9.49	0.50

SOLUTION

$$K = \frac{(1)^2 \ln(204/4)}{2\ (204)(170)}$$

$$K = \frac{3.93}{69.360}$$

$K = 5.66 \times 10^{-5}$ in./min.

$K = 2.39 \times 10^{-6}$ cm./sec.

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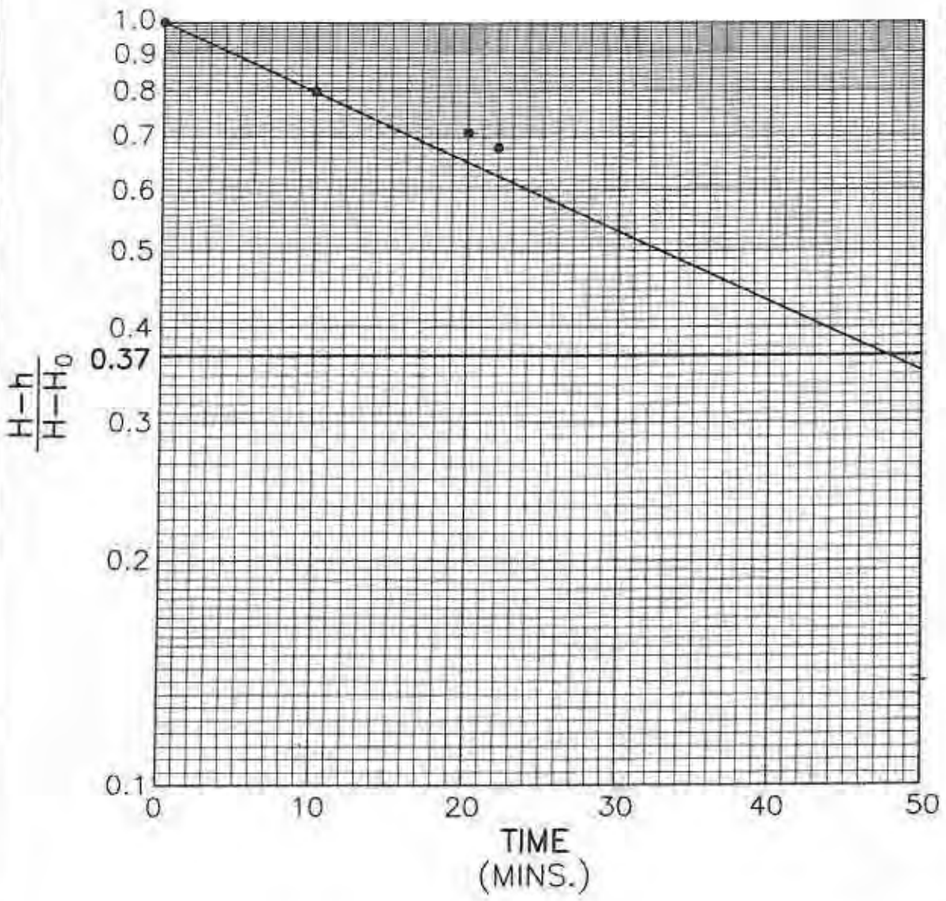
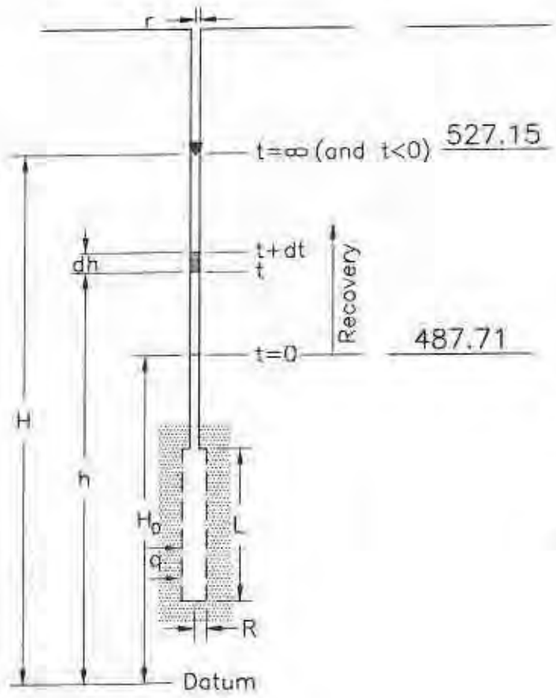
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 527.15 H_0= 487.71 $H-H_0$= 39.44

TIME	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0	43.16	487.71	39.44	1.00
10	35.23	495.64	31.51	0.80
20	31.63	499.24	27.91	0.71
22	30.52	500.35	26.80	0.68

SOLUTION

$$K = \frac{(1)^2 \ln(204/4)}{2\ (240)(48)}$$

$$K = \frac{4.1}{23{,}040}$$

$K = 1.78 \times 10^{-4}$ in./min.

$K = 7.53 \times 10^{-6}$ cm./sec.

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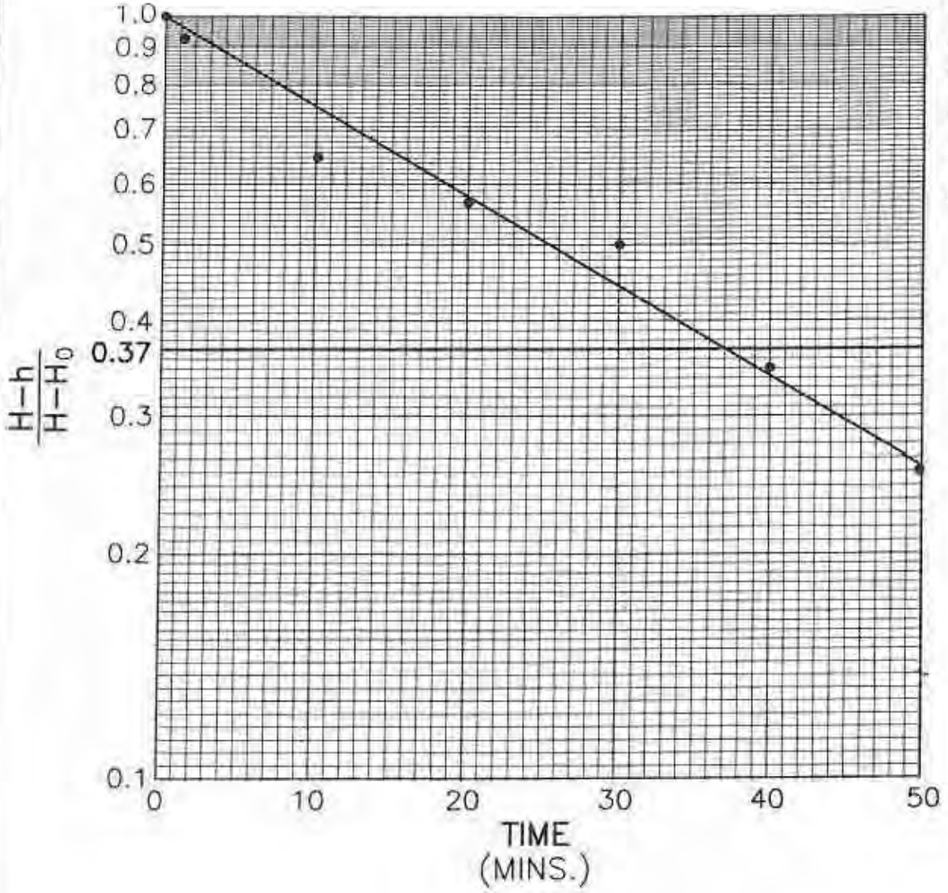
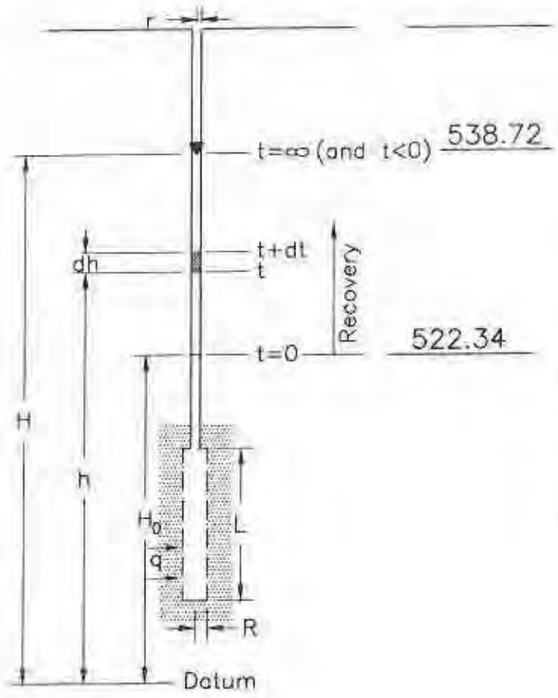
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ LT_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 538.72 H_0= 522.34 $H-H_0$= 16.38

TIME	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0	20.27	522.35	20.27	1.00
10	14.53	528.09	10.63	0.65
20	13.17	529.45	9.27	0.57
30	12.01	530.61	8.11	0.50
40	9.63	532.99	5.73	0.35
50	8.12	534.50	4.22	0.26

SOLUTION

$$K = \frac{(1)^2 \ln(144/4)}{2\ (144)(37)}$$

$$K = \frac{1^2\ (3.58)}{10{,}656}$$

$K = 3.35 \times 10^{-4}$ in./min.

$K = 1.42 \times 10^{-5}$ cm./sec.

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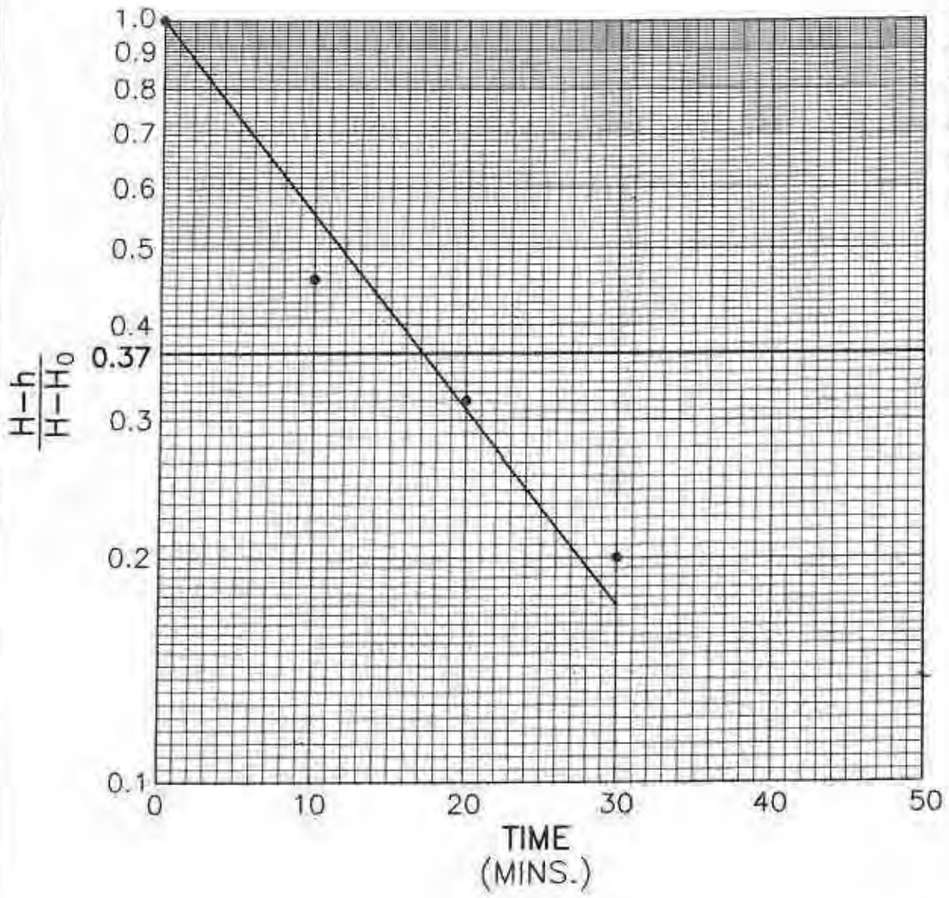
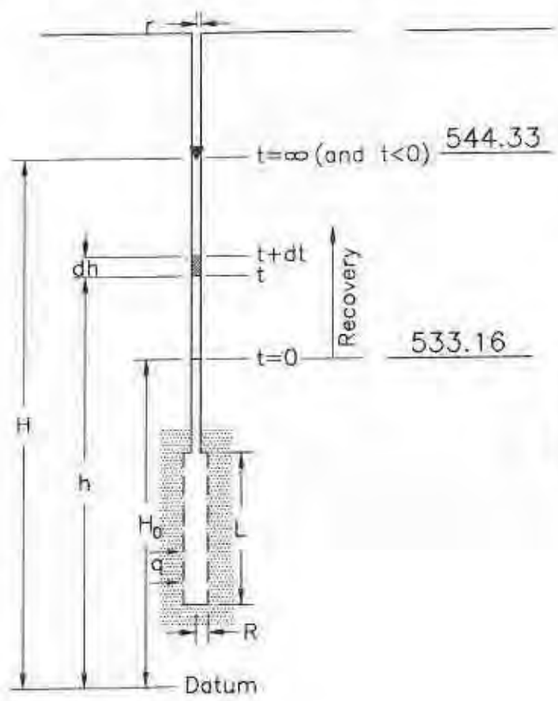
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ LT_0}$$

WHERE:

K = Hydraulic conductivity (in/sec)
L = Piezometer intake length (in)
R = Piezometer intake radius (in)
r = Riser radius (in)
T_0 = Basic time lag (min)
H = Static groundwater elevation (msl)
H_0 = Initial groundwater elevation (msl)
h = Groundwater elevation at a given time (msl)





H= 544.33 H_0= 533.16 $H-H_0$= 11.17

TIME	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0	20.27	533.16	11.17	1.00
10	14.28	539.15	5.18	0.46
20	12.64	540.79	3.54	0.32
30	11.32	542.11	2.22	0.20

SOLUTION

$$K = \frac{(1)^2 \ln(144/4)}{2\ (144)(17)}$$

$$K = \frac{1^2\ (3.58)}{4896}$$

$K = 7.31 \times 10^{-4}$ in./min.

$K = 3.09 \times 10^{-5}$ cm./sec.

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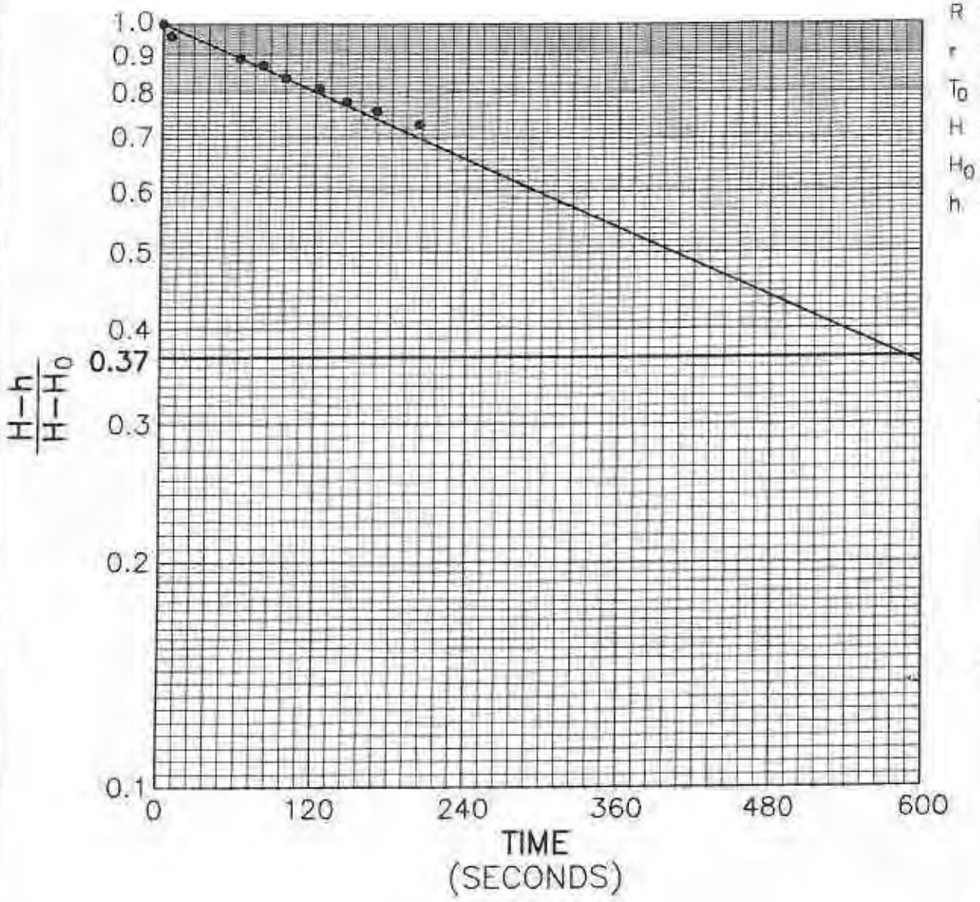
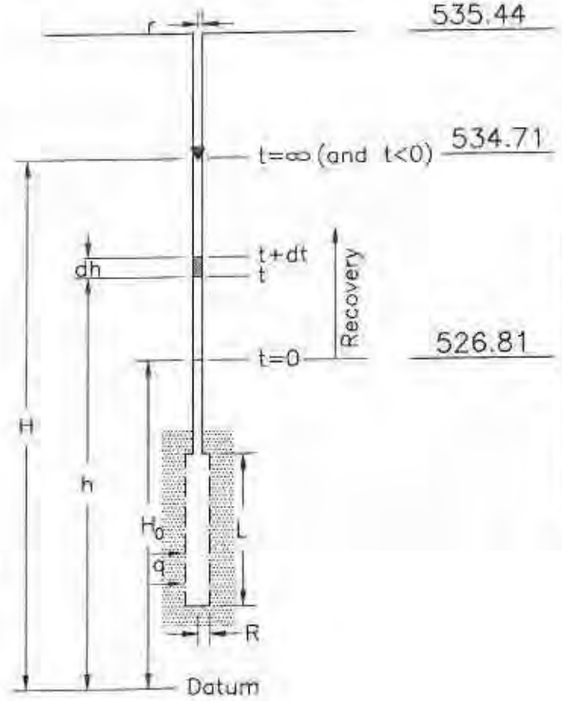
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 534.71 H_0= 526.81 $H-H_0$= 7.9

TIME (MIN.)	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0 sec	7.9	526.81	7.9	1.00
6 sec	7.6	527.11	7.6	0.96
63 sec	7.0	527.71	7.0	0.89
79 sec	6.8	527.91	6.8	0.86
95 sec	6.6	528.11	6.6	0.84
122 sec	6.4	528.31	6.4	0.81
145 sec	6.2	528.51	6.2	0.78
171 sec	6.0	528.71	6.0	0.76
201 sec	5.8	528.91	5.8	0.73

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(590)}$$

$$K = \frac{3.40}{141{,}600}$$

$K = 2.40 \times 10^{-5}$ in./sec.

$K = 6.10 \times 10^{-5}$ cm./sec.

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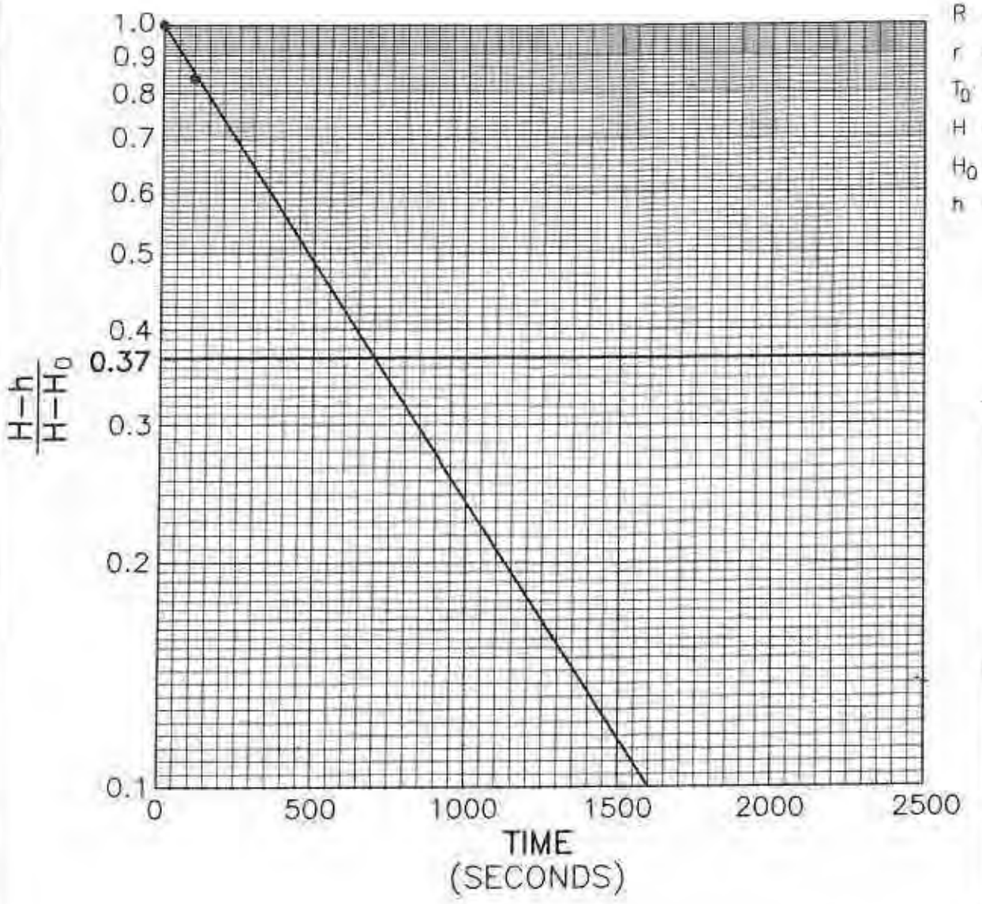
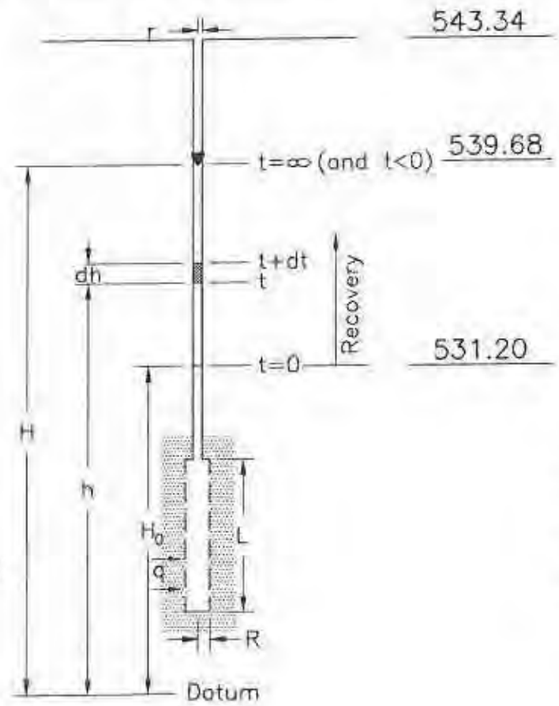
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

K = Hydraulic conductivity (in/sec)
L = Piezometer intake length (in)
R = Piezometer intake radius (in)
r = Riser radius (in)
T_0 = Basic time lag (min)
H = Static groundwater elevation (msl)
H_0 = Initial groundwater elevation (msl)
h = Groundwater elevation at a given time (msl)





H= 538.2 H_0= 531.2 H-H_0= 7.0

TIME (MIN.)	DEPTH TO WATER	h	H-h	$\frac{H-h}{H-H_0}$
0 sec	7.0	531.2	7.0	1.00
7 sec	6.7	531.5	6.7	0.96
19 sec	6.5	531.7	6.5	0.93
28 sec	6.4	531.8	6.4	0.91
48 sec	6.2	532.0	6.2	0.89
63 sec	6.1	532.1	6.1	0.87
82 sec	6.0	532.2	6.0	0.85
108 sec	5.9	532.3	5.9	0.84

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(700)}$$

$$K = \frac{3.40}{168{,}000}$$

$K = 2.02 \times 10^{-5}$ in./sec.

$K = 5.14 \times 10^{-5}$ cm./sec.

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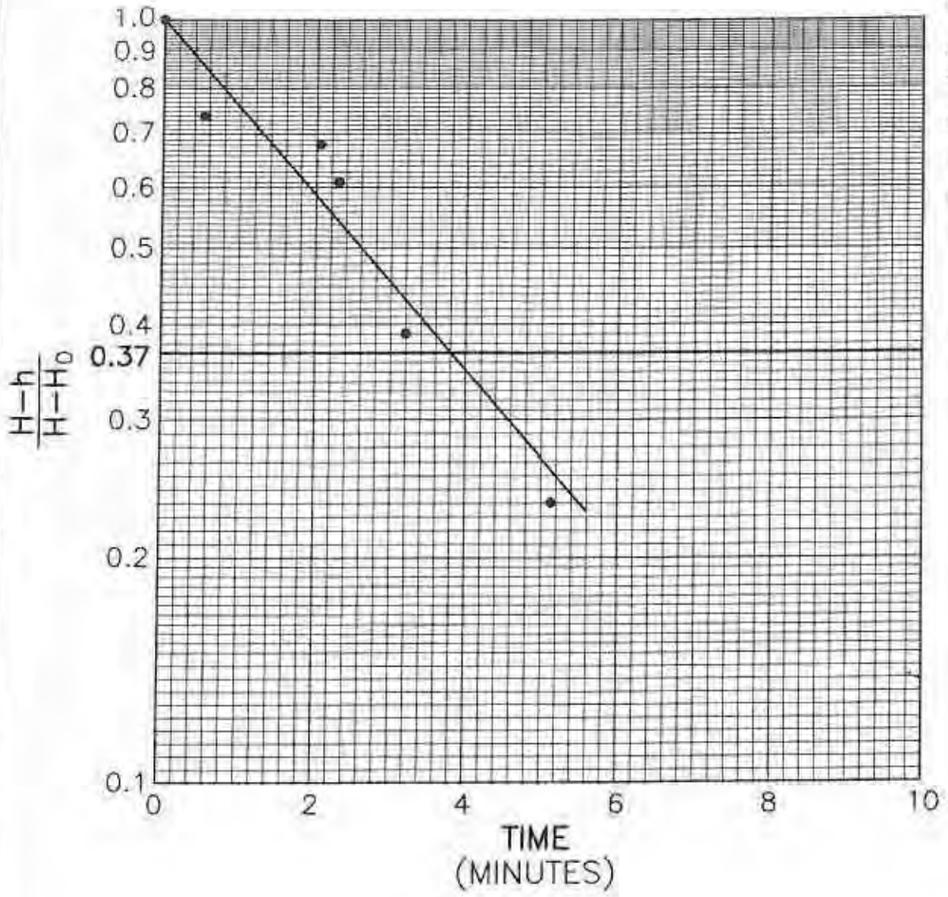
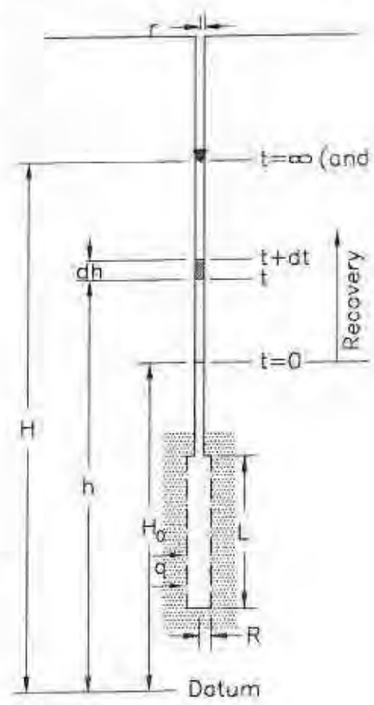
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

K = Hydraulic conductivity (in/sec)
L = Piezometer intake length (in)
R = Piezometer intake radius (in)
r = Riser radius (in)
T_0 = Basic time lag (min)
H = Static groundwater elevation (msl)
H_0 = Initial groundwater elevation (msl)
h = Groundwater elevation at a given time (msl)





H= 476.99 H_0= 475.64 $H-H_0$= 1.35

TIME (MIN.)	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0 min	69.33	475.64	1.35	1.00
0:58 min	69.00	475.97	1.02	0.75
2:05 min	68.90	476.07	0.92	0.68
2:30 min	68.80	476.17	0.82	0.61
3:20 min	68.50	476.47	0.52	0.39
5:10 min	68.30	476.67	0.32	0.24

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(3.8)}$$

$$K = \frac{3.40}{912}$$

$K = 3.7 \times 10^{-3}$ in./min.

$K = 1.58 \times 10^{-4}$ cm./sec.

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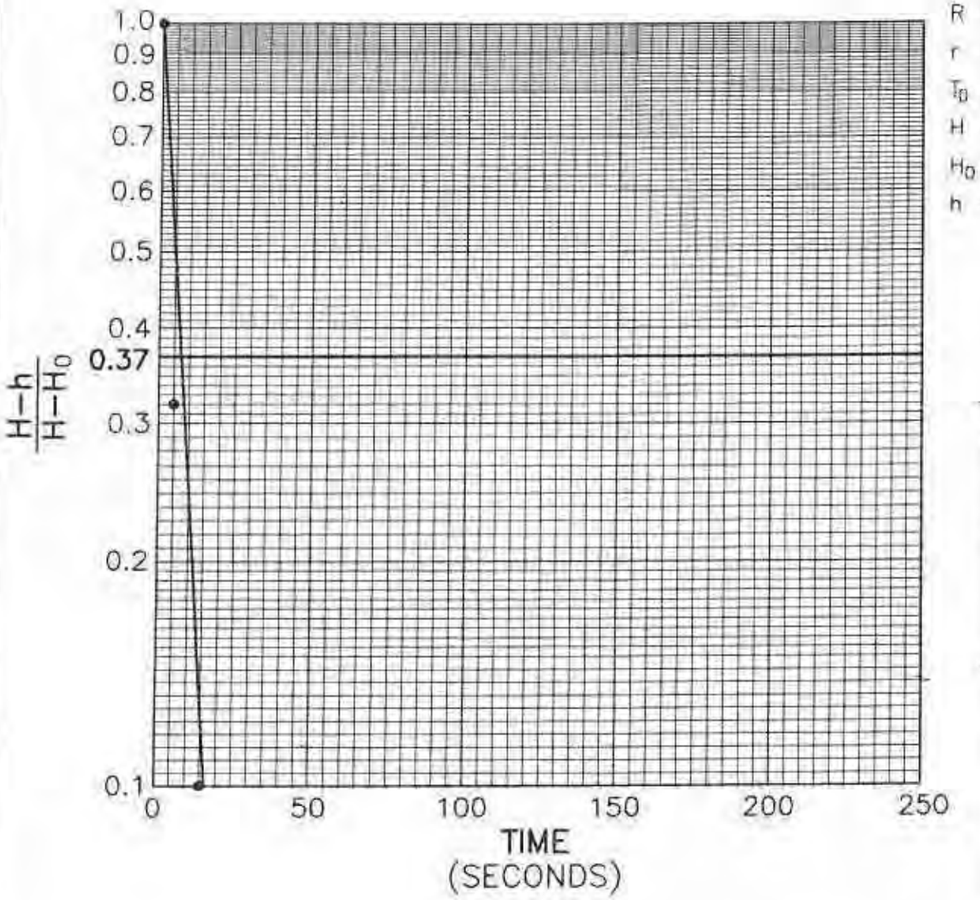
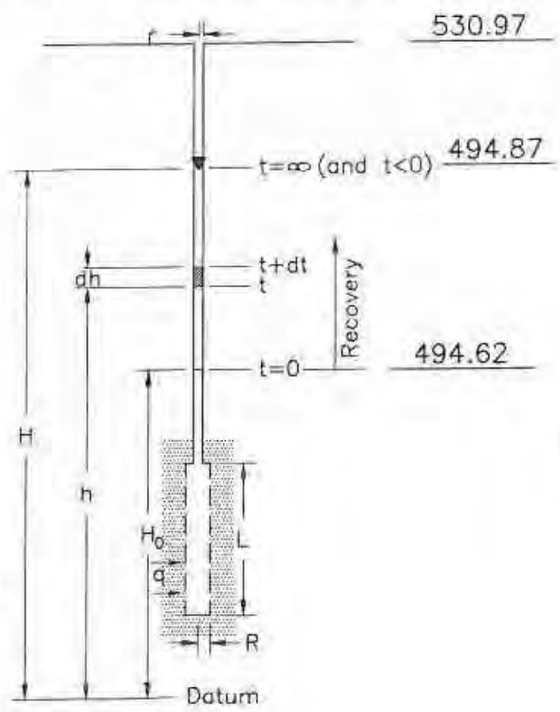
$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

K = Hydraulic conductivity (in/sec)
L = Piezometer intake length (in)
R = Piezometer intake radius (in)
r = Riser radius (in)
T_0 = Basic time lag (min)
H = Static groundwater elevation (msl)
H_0 = Initial groundwater elevation (msl)
h = Groundwater elevation at a given time (msl)





H= 494.87 H_0= 494.62 $H-H_0$= 0.25

TIME (MIN.)	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0 sec	39.07	494.62	0.25	1.00
5 sec	38.90	494.79	0.08	0.32
10 sec	38.85	494.84	0.03	0.12
14 sec	38.82	494.87	0.00	0.00

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(7)}$$

$$K = \frac{3.40}{1680}$$

K= 0.002 in./sec.

K= 5.14×10^{-3} cm./sec.

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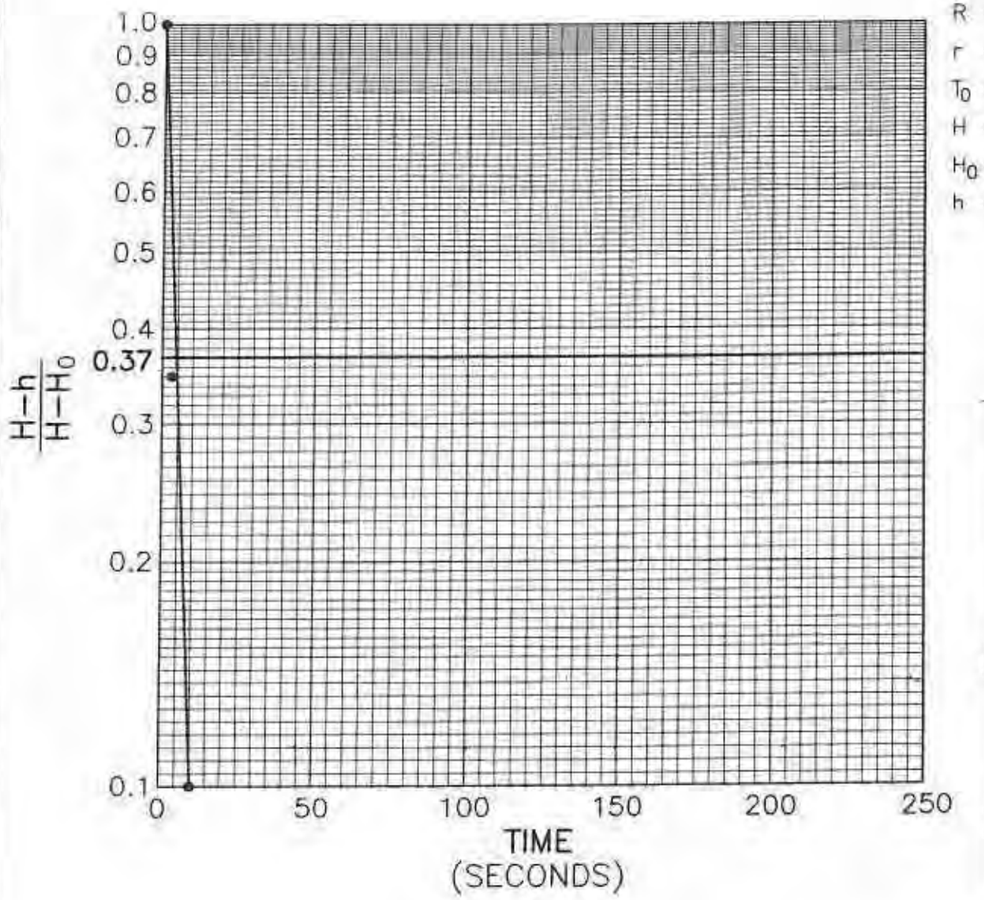
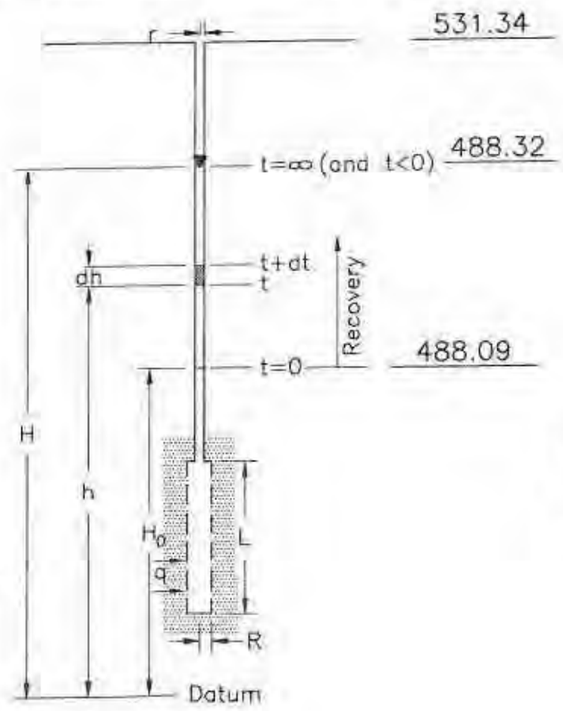
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ L T_0}$$

WHERE:

K = Hydraulic conductivity (in/sec)
L = Piezometer intake length (in)
R = Piezometer intake radius (in)
r = Riser radius (in)
T_0 = Basic time lag (min)
H = Static groundwater elevation (msl)
H_0 = Initial groundwater elevation (msl)
h = Groundwater elevation at a given time (msl)





H= 488.32 H_0= 488.09 $H-H_0$= 0.23

TIME (SEC.)	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0	45.50	488.09	0.23	1.00
4	45.35	488.24	0.08	0.35
7	45.30	488.29	0.03	0.13
10	45.27	488.32	0.00	0.00

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(6)}$$

$$K = \frac{3.40}{1440}$$

K= 0.0024 in./sec.

K= 5.99×10^{-3} cm./sec.

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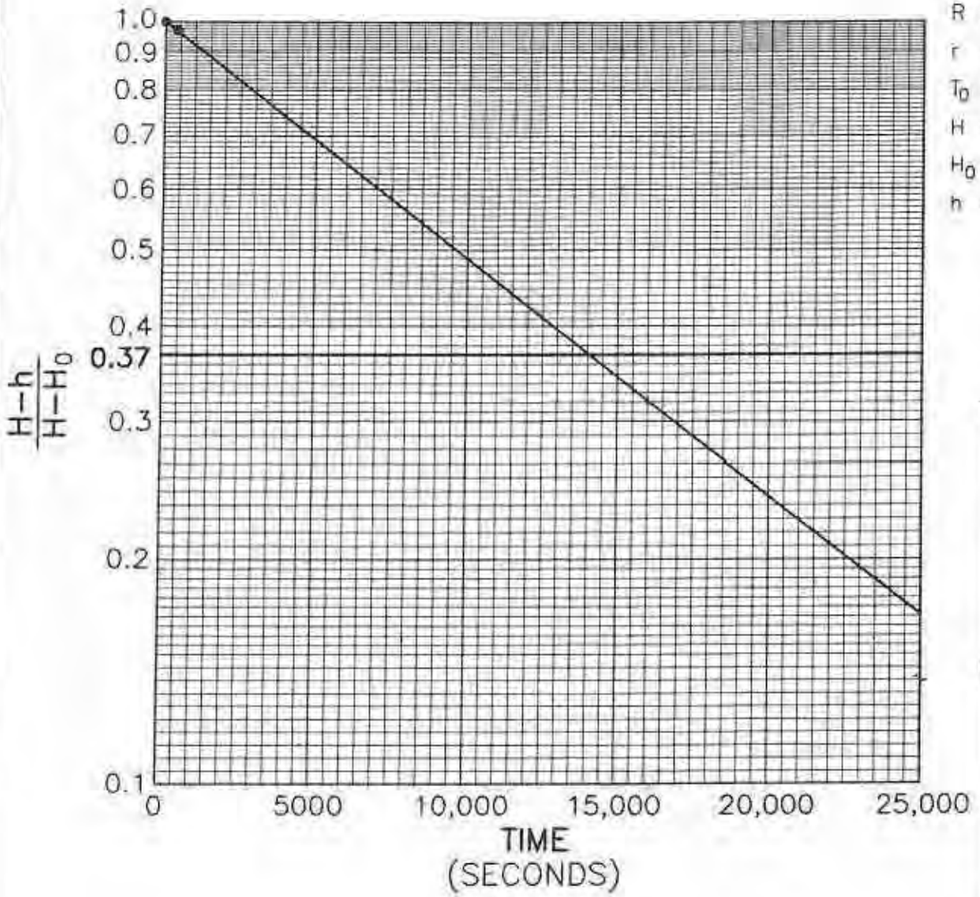
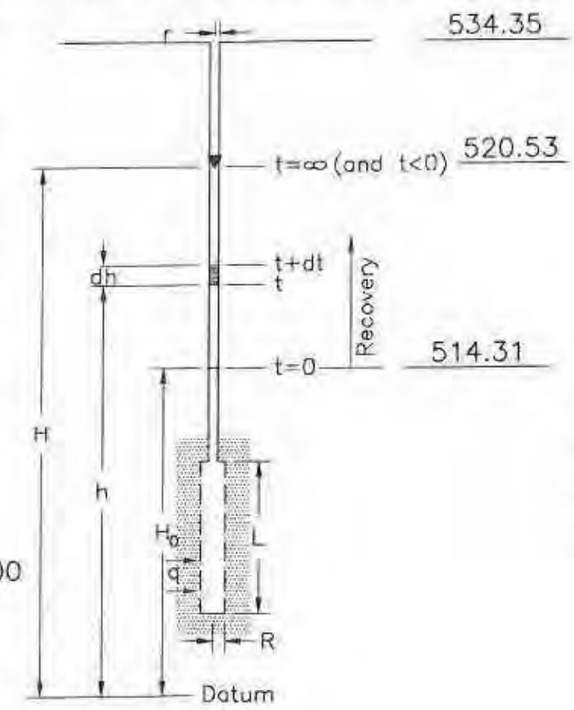
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ LT_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 520.53 H_0= 514.31 $H-H_0$= 0.22

TIME (SEC.)	DEPTH TO WATER	h	H−h	$\frac{H-h}{H-H_0}$
0	20.04	514.31	6.22	1.00
60	19.95	514.40	6.13	0.99
120	19.93	514.42	6.11	0.98
300	19.91	514.44	6.09	0.97

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(14{,}000)}$$

$$K = \frac{3.40}{3{,}360{,}000}$$

$K = 1 \times 10^{-6}$ in./sec.

$K = 2.54 \times 10^{-6}$ cm./sec.

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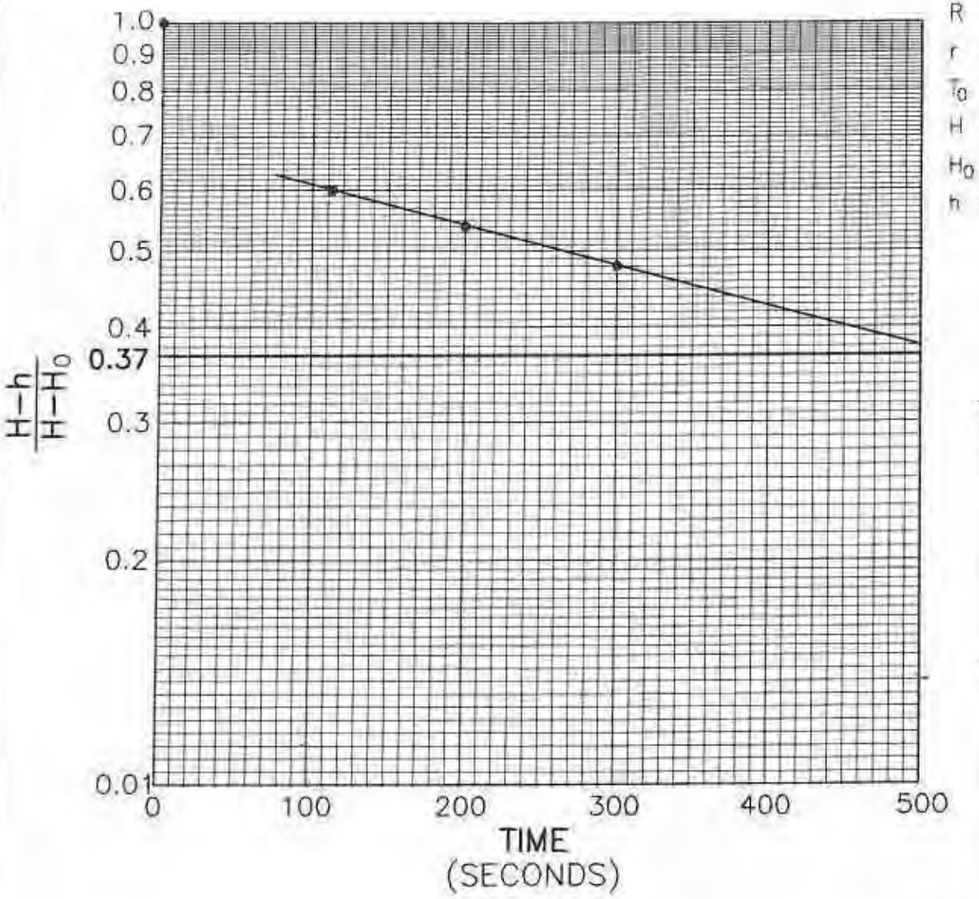
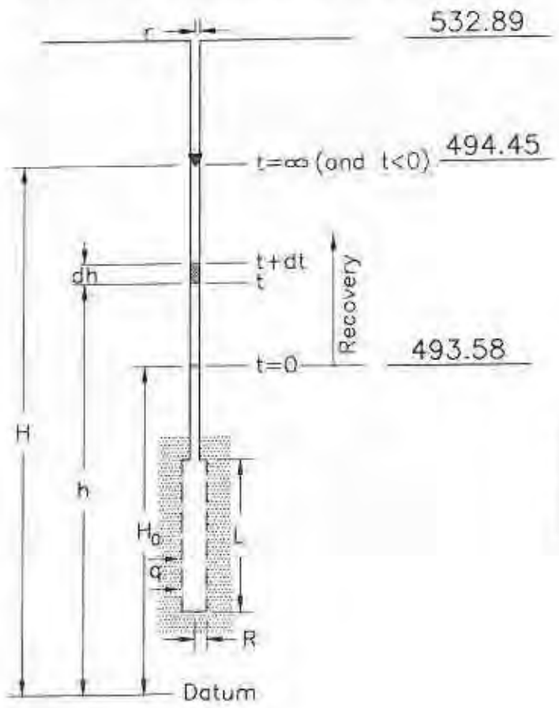
HVORSLEV PIEZOMETER TEST CALCULATIONS

$$K = \frac{r^2 \ln(L/R)}{2\ LT_0}$$

WHERE:

- K = Hydraulic conductivity (in/sec)
- L = Piezometer intake length (in)
- R = Piezometer intake radius (in)
- r = Riser radius (in)
- T_0 = Basic time lag (min)
- H = Static groundwater elevation (msl)
- H_0 = Initial groundwater elevation (msl)
- h = Groundwater elevation at a given time (msl)





H= 494.45 H_0= 493.58 $H-H_0$= 0.87

TIME (SEC.)	DEPTH TO WATER	h	H-h	$\frac{H-h}{H-H_0}$
0	29.31	493.58	0.87	1.00
125	38.96	493.93	0.52	0.60
200	38.91	493.98	0.47	0.54
300	38.86	494.03	0.42	0.48

SOLUTION

$$K = \frac{(1)^2 \ln(120/4)}{2\ (120)(500)}$$

$$K = \frac{3.40}{120{,}000}$$

$K = 2.83 \times 10^{-5}$ in./sec.

$K = 7.19 \times 10^{-5}$ cm./sec.

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ATTACHMENT F

PUMPWIN RESULTS

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ABOUT THE MODEL

This program solves the Dupuit-Forchheimer Equation and the Gravity Drainage Equation to determine the maximum sustainable pumping rate of a fully-penetrating well and the maximum drawdown in an unconfined aquifer. The theoretical model was confirmed using a physical model (Gefell et al., 1994, GROUNDWATER, Vol 32, No. 3) which evaluated the 3 geometric parameters that control maximum water-table drawdown: (1) effective radius of pumping well; (2) initial saturated thickness of the aquifer; and (3) the radius of influence. Of these, the effective radius of the pumping well has the greatest effect with the radius of influence having the least effect on maximum water-table drawdown and sustainable yield.

Flow to the pumping well is governed by the Dupuit-Forchheimer Equation which, taken to the extreme, suggests that maximum steady-state flow rate to the well would occur with no remaining saturated thickness adjacent to the pumping well. To compensate for this, the gravity Drainage Equation evaluates flow into the well, where the well is fully dewatered, and the seepage face drains water away from the aquifer creating a cone of depression. Maximum sustainable pumping rates and drawdowns are determined by extrapolation of the point where the two equation curves intersect to the y and x axes where drawdown and yield are plotted. Essentially, the model assumes that the well is dewatered, but the aquifer adjacent to the well is only partially dewatered to an extent determined by aquifer characteristics. The physical model confirmed that maximum water-table drawdowns and pumping rates occurred when the well was completely dewatered, an inherent feature of the theoretical model. Furthermore, maximum water-table drawdowns observed in test wells of varying diameters agreed with theoretical results to within three percent.

The following assumptions are made in using this model; (1) fully-penetrating pumping well; (2) homogeneous and isotropic water-table aquifer; (3) steady-state drawdown; (4) steady-state, laminar flow; and (5) no reharge due to infiltration.

MODEL RESULTS

Input: Hydraulic conductivity (Ft/Day) = .079
Radius of Pumping Well (Ft) = 1
Aquifer Thickness (Ft) = 15
Radius of Influence (Ft) = 100

Output: Maximum Drawdown in Aquifer adjacent to Dewatered Well (Ft) = 3.914166

Maximum Sustainable Pumping Rate (Gpd) = 41.14214

Because this material cannot sustain a yield of 150 gallons per day from a 12-inch borehole from a thickness of 15 ft. or less, it does not meet the requirements of Class I: Potable Resource Groundwater as presented in 35 IAC 620.210 (a)(4)(A).

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Appendix 5

Cartwright, K., 1970. Groundwater discharge in the Illinois Basin as suggested by temperature anomalies. Water Resources Research 6, No. 3: 912-918.

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Groundwater Discharge in the Illinois Basin as Suggested by Temperature Anomalies

KEROS CARTWRIGHT

Illinois State Geological Survey, Urbana, Illinois 61801

Abstract. Areas where ground water in the Illinois basin is moving vertically should be reflected by temperature anomalies. To test this hypothesis, an isothermal map for a depth of 500 feet was constructed, based on bottom hole temperatures of deep wells. This map was compared with a theoretical isothermal map for a depth of 500 feet that was made by projecting temperature gradients (calculated from the thermal conductivities of the rock) downward from the surface where mean annual air temperatures were known. The residual temperature map that was made on the basis of this comparison (calculated minus observed temperature) shows several warm and cool anomalies that are postulated to be discharge and recharge areas, respectively. Analysis of the curvature of the earth's thermal profile calculated for the basin suggests that approximately 59,000 acre-feet of ground water per year are discharged upward from the deep rocks in the Illinois basin. This figure is of the same magnitude as an estimated excessive groundwater discharge into the region's streams of 43,000 acre-feet, based on comparison of unit-area discharge of streams in the basin with streams in similar areas outside the basin. From a simplified model of the basin, a groundwater inflow of about 36,500 acre-feet from the surrounding highlands is estimated. A significant portion of this discharge must be through fracture zones associated with faults and anticlines in the basin, inasmuch as this amount of flow would require that the shales have a vertical permeability from one to three orders of magnitude higher than is generally observed. One such discharge area in southwestern Illinois is suggested by field data.

INTRODUCTION

Movement of ground water within the lithosphere has long been known to affect the flux of heat within the earth. *Van Orstrand* [1934] suggested that the movement of ground water caused variations in the geothermal gradient in the Salt Creek oil field, Wyoming. The effect of groundwater movement is significant because the natural heat flux density from the earth is small.

Stallman [1960] presented the basic equation for the simultaneous transfer of heat and water within the earth and suggested they might be used to measure the rates of groundwater movement. *Bredehoeft and Papadopulos* [1965] and *Stallman* [1965] presented solutions of the basic equations applied to the vertical movement of water for certain boundary conditions. The Bredehoeft and Papadopulos solution is used in this paper to estimate the quantity of ground water discharge from the Illinois basin.

The general differential equation for simultaneous nonsteady flow of heat and fluid through fully saturated, isotropic, homogeneous, porous medium was developed [*Stallman*, 1960] from consideration of a unit volume of the medium. The equation is

$$\frac{\delta^2 T}{\delta x^2} + \frac{\delta^2 T}{\delta y^2} + \frac{\delta^2 T}{\delta z^2} - \frac{c_w \rho_w}{k} \left[\frac{\delta(v_x T)}{\delta x} + \frac{\delta(v_y T)}{\delta y} + \frac{\delta(v_z T)}{\delta z} \right] = \frac{c\rho}{k} \frac{\delta T}{\delta t} \quad (1)$$

where

- v, velocity of fluid flow; direction of flow specified by subscripts x, y, z;
- T, temperature at any point at time t;
- t, time since flow started;
- c, specific heat of rock fluid complex;
- c_w, specific heat of fluid;
- ρ, density of rock fluid complex;
- ρ_w, density of fluid;
- k, thermal conductivity of rock fluid complex;
- x,y,z, Cartesian coordinates.

For steady one-dimensional (vertical) flow of

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heat and fluid, equation 1 according to *Bredehoeft and Papadopulos* [1965] becomes

$$k\frac{\delta^2 T}{\delta z^2} - v_s c_w \rho_w \frac{\delta T}{\delta z} = 0 \qquad (2)$$

which when solved subject to the boundary conditions

$$T_s = T_0 \text{ at } z = 0 \qquad (3)$$

$$T_s = T_L \text{ at } z = L \qquad (4)$$

where T_s is the temperature measurement at any depth z, T_0 is the uppermost temperature measurement, T_L is the lowermost temperature measurement, and L is the length of vertical section over which temperature is measured, yields

$$\frac{(T_s - T_0)}{(TL - T_0)} = f(\beta, z/L) \qquad (5)$$

where

$$f(\beta, z/_L) = \frac{[\exp(\beta z/L) - 1]}{[\exp(\beta) - 1]} \qquad (6)$$

and

$$\beta = \frac{c_w \rho_w v_s L}{k} \qquad (7)$$

β is a dimensionless parameter that is positive or negative depending on whether v_s is downward or upward. *Bredehoeft and Papadopulos* [1965] presented a table and type curves for the solution of equation 6.

ILLINOIS BASIN

The Illinois basin is an oval-shaped structural and topographic depression with over 9000 feet of maximum relief in the granite basement [*Bell et al.*, 1964] and 1000 feet maximum topographic relief. Definition of the exact limits of the basin vary. However, at its broadest defined limits the basin extends from the Ozark uplift on the southwest to the Cincinnati and Kankakee arches on the east and northeast.

Very little is known of the distribution of hydrostatic head within the rocks of the basin. The difference in head between the rocks on the periphery of the basin and the water table at the center is 100 to at least 500 feet [*Bredehoeft et al.*, 1963]. Theoretical analyses by *Toth* [1963] and *Freeze and Witherspoon* [1966; 1967; 1968], and work by *Hitchon* [1969] in the Western Canadian sedimentary basin suggest that basins of this general shape should be discharging water upward from the deep, basin-wide flow system.

A mechanism for the concentration of the highly saline brine found in the basin was suggested by *Bredehoeft et al.* [1963]. The character and origin of these brines were further discussed in a series of papers by *Clayton et al.* [1966] and *Graf et al.* [1965; 1966]. The consensus of these studies is that the water in the deep formations of the basin is in motion and that some upward discharge of ground water is taking place through the clay shales that act as an osmotic membrane.

This study estimates the quantity of water being discharged, and where and how the major portion of discharge may be taking place. Most, if not all, of the fluid being discharged is in areas of high vertical permeability associated with the structural features of the basin.

TEMPERATURE ANOMALY

To test the hypothesis of upward flow of water and its effect on the geothermal gradients, an isothermal map for a depth of 500 feet was constructed from recorded bottom hole temperatures of deep wells. The wells are not evenly distributed throughout the mapped area (Figure 1). The first six wells (maximum of two per section where many datum points are available) for each Congressional township were selected from the mineral resource records of the Illinois State Geological Survey. Only wells over 1000-feet deep were chosen and records of obviously poor quality were eliminated from the sample. About 2000 well records were used. The temperature at 500 feet was calculated for each well by assuming that a linear gradient existed between the bottom hole temperature and the mean annual air temperature [*Jones*, 1966]. The mean of the temperature at 500 feet for all the selected wells was calculated for each township and plotted as a single point in the township. The inaccuracies of this type of temperature data are well known, but the fairly high degree of internal consistency in the data suggests the approach is valid.

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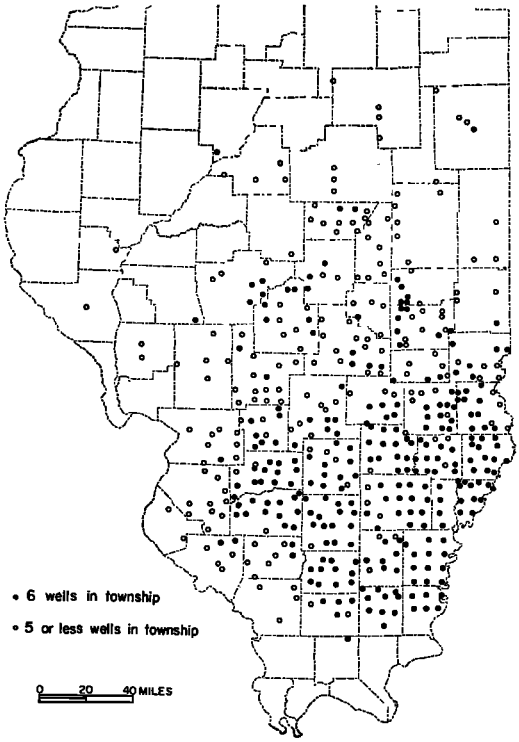

Fig. 1. Distribution of deep wells used in compiling isothermal map for 500-foot depth.

The resulting isothermal map (Figure 2) is a reasonable representation of the distribution of temperatures at the 500-foot depth. Two striking features appear on the map: (1) a general decrease in temperature from south to north reflects the trend of the mean annual air temperatures, and (2) the warm areas generally coincide with anticlinal areas and fault zones in the Illinois basin, which are also the principal oil producing areas in the state.

A theoretical isothermal map for the 500-foot depth was prepared (Figure 3) for comparison with the map based on well temperatures. For the theoretical map, temperatures at the 500-foot depth were calculated by estimating temperature gradients (based on assumed thermal conductivities of the rocks and geothermal gradient given below), and projecting the gradients downward from the surface where mean annual air temperatures were known. The air temperature data were from weather stations in the state [*Jones*, 1966]. The following thermal conductivities and geothermal gradients were used [*Cartwright*, 1968]:

Glacial sediments	0.0025 cgs units (cal/cm sec °C)
Pennsylvanian rocks	0.005 cgs units
Deep carbonate rocks	0.007 cgs units (and 1°F per 100 ft temperature gradient)

The thickness of the glacial drift in wide areas around the various weather stations was averaged.

A residual map (Figure 4) was then made to show the difference between the two isothermal maps by subtracting the observed temperature data from the calculated temperature data. The warm (negative) areas were assumed to be zones of upward movement (discharge) of water from deep aquifers in the basin, and the cool (positive) areas are zones of downward movement (recharge). Temperature anomalies in the northern third of the map probably are of little significance inasmuch as the data are sparse, and the thickness

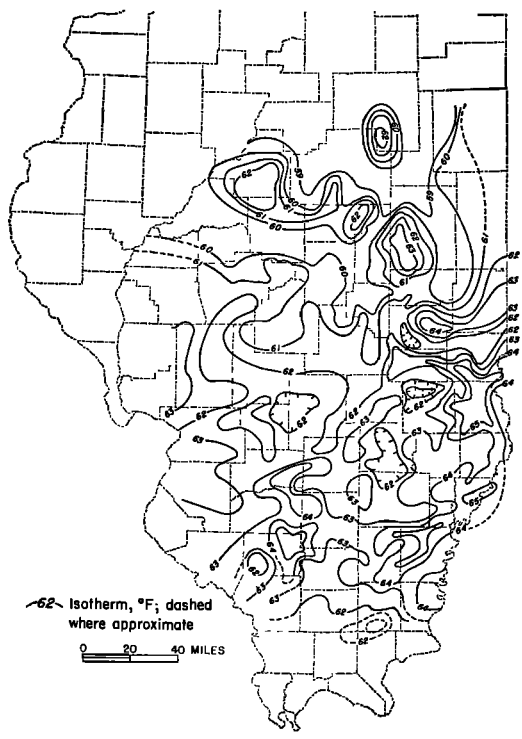

Fig. 2. Isothermal map for the 500-foot depth, based on temperature data from deep wells.

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of glacial drift, which has the greatest effect on the calculated temperature values, varies greatly. The Mahomet buried bedrock valley [*Horberg*, 1950], for instance, which contains 300 to 400 feet of fill, is reflected on the map as a cool area. This could be the result of the permeable drift's acting as a recharge zone, but it is probably due to not taking the effect of the thick drift when the temperature was calculated completely into account.

The residual map (Figure 4) also reflects some of the structural features of the area. The Wabash valley fault zone and the DuQuoin-Louden anticlinal belt are anomalously warm and probably are the principal discharge areas. In the latter area, saline waters too brackish for human consumption immediately underlie the water table. The area along the Shawnee hills to the south and the Mississippi river area to the west are both cool areas, and data suggest that recharge is probably occurring.

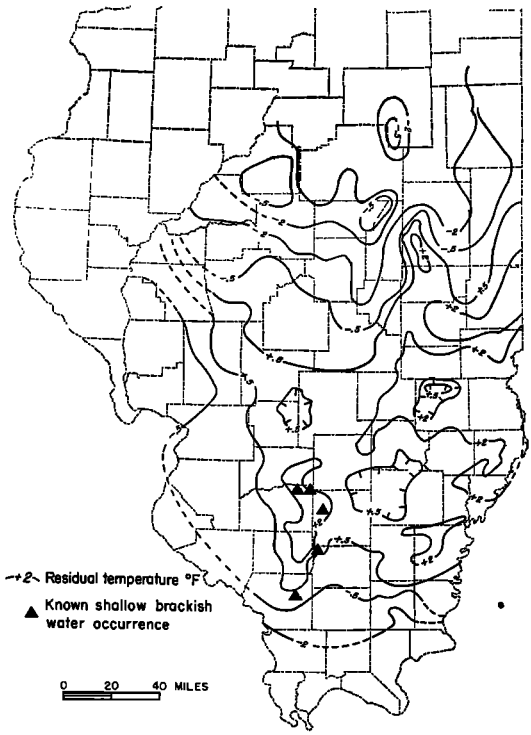

Fig. 4. Residual temperature map (calculated temperature minus observed temperature), showing anomalously warm (positive) and cool (negative) areas.

VOLUME OF DISCHARGE

The mean velocity of upward movement of water in the Illinois basin was calculated from the temperature data with equation 5. The average temperature in the warm discharge areas was determined at intervals of 300 feet for depths between 500 and 3500 feet, the range of depth that includes most oil wells in Illinois. At each 300-foot interval all points that fell within 50 feet of that depth were averaged to obtain a single value. The temperatures for 500 and 800 feet were determined by an upward extrapolation of the temperature data. The plotted temperature curve (Figure 5) compared with the type curves of *Bredehoeft and Papadopulos* [1965] yielded a velocity of 0.16×10^{-8} feet per second. The very small velocity can be detected because of the relatively large vertical distance over which the temperature is observed.

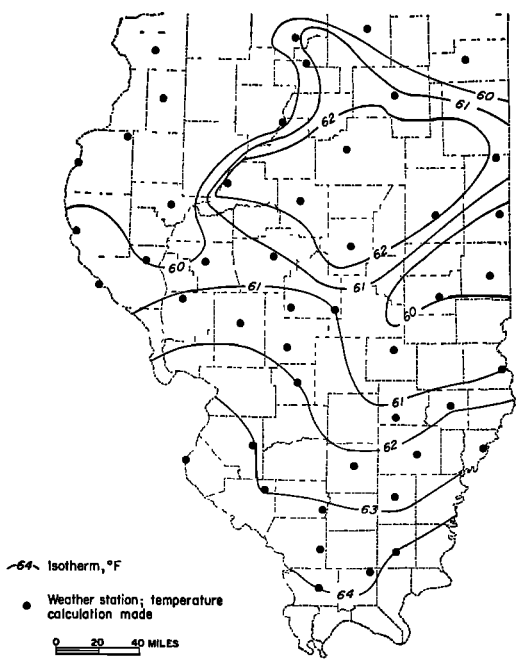

Fig. 3. Isothermal map calculated for 500-foot depth on basis of mean annual surface temperatures and thermal conductivity of the rocks.

Most of the discharge probably takes place in the anomalously warm areas within a radius of 100 miles from the center of the basin. This is approximately 1800 square miles. The quantity of water discharged was calculated by using

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$$Q = V_s A \quad (8)$$

where Q is the quantity of fluid discharge per unit of time, V_s is the velocity of fluid flow (upward), and A is the area over which discharge takes place. The discharge amounts to 59,000 acre-feet per year.

The quantity of water flowing into the Illinois basin was estimated by using the simplest model of *Bredehoeft et al.* [1963], which assumes the change of head over distance is linear (2.8×10^{-4} feet per feet). According to the model, all the water would pass through the sandstone aquifers (principally the Mt. Simon, St. Peter, Chesterian, and basal Pennsylvanian), which were assumed to average 3000 feet thick and have the permeability of the Mt. Simon sandstone of northern Illinois (1.34 feet per day according to *Walton and Csallany* [1962]). The discharge would be equal to the water that passes into the basin through the circumference of a circle with a radius of 100 miles, the center of which is the center of the basin. From this model it was calculated that 36,500 acre-feet of water per year moves into the basin.

Streams and rivers presently draining the central part of the Illinois basin have a normal annual groundwater runoff of about 2,670,000 acre-feet per year [*Walton*, 1965] exclusive of flow in the Wabash River which crosses the eastern part of the basin. The 59,000 acre-feet of discharge from the deeper rocks of the basin is only 2.2% of the total groundwater runoff, and only 0.7% of the total average stream discharge of 8.26 million acre-feet per year [*Mitchell*, 1957].

To determine whether streams of the Illinois basin have different discharge characteristics,

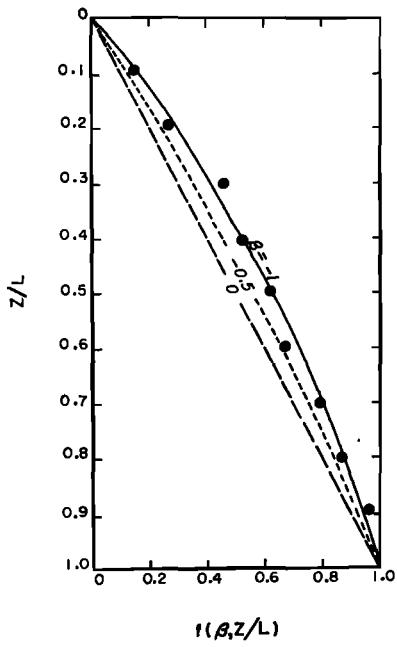

Fig. 5. Temperature profile (dots) in the Illinois basin compared with type curves of *Bredehoeft and Papadopulos* [1965]. The depth and temperatures of the profile are plotted as the ratios

$$\frac{Z - Z_0}{L} \quad \text{and} \quad \frac{T_s - T_0}{T_L - T_0} \quad \text{(equation 5)}$$

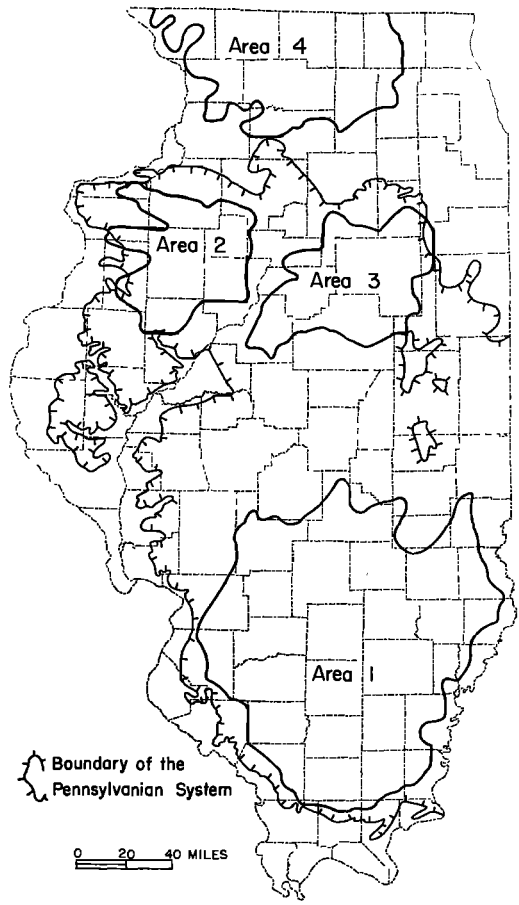

Fig. 6. Drainage areas studied for comparison of the groundwater discharge characteristics between years of normal and below normal precipitation.

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TABLE 1. Average Annual Groundwater Runoff

Region	Precipitation, inches	Runoff in Year of Normal Precipitation, cfs/mi²	Runoff in Year of Below Normal Precipitation, cfs/mi²	Percent of Below Normal Year's to Normal Year's Runoff	Area of Drainage Basin, mi²
1	35 to 45	0.19	0.11	57.9	10,161
		0.23*	0.14	60.9	6,609
2	34 to 37	0.19	0.09	44.3	4,731
3	33 to 37	0.16	0.06	37.5	2,984
4	33 to 34	0.31	0.21	67.7	9,663

* Stream with high drought period flow only.

a comparison was made of the annual groundwater runoff or base flow of streams, for four regions of the state [*Walton*, 1965]. The regions are shown in Figure 6. Region 1 is the area where discharge from the Illinois basin occurs. Regions 1, 2, and 3 are geologically similar and contain generally thin glacial tills [*Piskin and Bergstrom*, 1967] overlying rocks of the Pennsylvanian system, principally shale. Region 4 is different and has generally thin glacial tills overlying permeable Ordovician and Silurian carbonates. The evapotranspiration in the four regions varies in a pattern similar to the variation in precipitation [*Jones*, 1966] (Table 1). The variability in precipitation is slightly greater in region 1 than in the other three areas [*Huff and Changnon*, 1963].

The figures in the table suggest that the groundwater runoff characteristics of region 1 resemble those of region 4 rather than those of regions 2 and 3, even though region 1 is more similar geologically to the latter two.

Region 1 had a higher groundwater runoff in drought years in comparison to the other three regions and at least part of it must be discharge of deep basin waters. All areas except region 1 have 0.10 cfs/mi² differences between below-normal and normal years; area 1 has only a 0.08 cfs difference or a 0.09 cfs difference if we consider only streams with more than 55% of below-normal to normal discharge. This may be merely fortuitous; nevertheless, I assumed that the 0.01 cfs extra groundwater runoff of the streams with high flow during drought years is the result of discharge of water from the deep basin groundwater flow system. This amounts to 43,000 acre-feet of water per year.

If the shale of the Illinois basin has the same permeability of 0.13×10^{-4} feet per day found in the Ordovician shales of northern Illinois [*Walton*, 1960] and 100 feet of hydraulic head, the possible leakage upward would be only 2000 acre-feet per year. Thus, possibly as much as 95% of the discharge must be moving upward through vertical fractures. Concentration of fractures are present within the main structural features of the basin and therefore saline water discharges in the area of these features.

Regions where naturally brackish water is encountered immediately below the water table are shown on Figure 4. Brackish water also is found elsewhere, but from data presently available, it cannot be determined with certainty whether those occurrences are natural or related to the activities of man. The brackish water occurs within the areas of anomalously warm temperatures (Figure 4) near the main structural features of the basin. Furthermore, the anomalously cool area along the southern edge of the map coincides with the region of recharge to the thick basal Pennsylvanian sandstones that dip steeply toward the center of the basin.

DISCUSSION

Hydrogeologists working in the Illinois basin area have long believed that ground water is circulating in the basin. Lack of data on the fluid potentials in the water transmitting zone has necessitated reliance on chemical data and the theoretical explanation of these data. Theoretical calculations supported by chemical data suggest hydrodynamic rather than hydrostatic conditions. This paper further corroborates this hypothesis, and suggests that the quantity of

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groundwater discharge is about 40,000 to 60,000 acre-feet per year.

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Appendix 6

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The Sources, Distribution, and Trends of Chloride in the Waters of Illinois

Walton R. Kelly, Samuel V. Panno, Keith Hackley

March 2012



Illinois State Water Survey
Prairie Research Institute
University of Illinois at Urbana-Champaign

Champaign, Illinois



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The Sources, Distribution, and Trends of Chloride in the Waters of Illinois

Walton R. Kelly
Illinois State Water Survey

Samuel V. Panno
Illinois State Geological Survey

Keith Hackley
Illinois State Geological Survey

Prairie Research Institute
University of Illinois at Urbana-Champaign

March 2012

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Abstract

Chloride (Cl^-) is a major anion found in all natural waters. It occurs naturally and is also a relatively minor contaminant. Chloride concentrations in Illinois range from less than 0.1 milligrams per liter (mg/L) in precipitation to close to 100,000 mg/L in Paleozoic brines. Chloride is non-toxic to humans, although there is a secondary drinking water standard of 250 mg/L. It is, however, deleterious to some plants and aquatic biota, thus the Illinois Environmental Protection Agency (IEPA) has set an acute standard of 500 mg/L for surface waters in Illinois. Chloride is also a very corrosive agent, and elevated levels pose a threat to infrastructure, such as road beds, bridges, and industrial pipes.

Some streams and aquifers in Illinois have naturally elevated Cl^- concentrations due to surface or near-surface discharge of Paleozoic brines. Of greater concern to water resources in Illinois are anthropogenic sources of Cl^-, including road salt runoff, sewage, water conditioning salts, and fertilizer. Chloride concentrations are elevated in most water bodies in the Chicago region, primarily due to road salt runoff. Concentrations have been increasing since approximately the 1960s, and in general, concentrations continue to increase. These elevated Cl^- concentrations may pose a risk to infrastructure as well as aquatic to ecosystems.

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Introduction

Chloride (Cl^-) is a naturally occurring major anion found in all natural waters. Chloride behaves as a conservative ion in most aqueous environments, meaning its movement is not retarded by the interaction of water with soils, sediments, and rocks. As such, it can be used as an indicator of other types of contamination. Anomalously high concentrations can act as an "advance warning" of the presence of other more toxic contaminants. Concentrations of Cl^- in natural waters can range from less than 1 milligram per liter (mg/L) in rainfall and some freshwater aquifers to greater than 100,000 mg/L for very old groundwaters within deep intracratonic basins (Graf et al., 1966; Psenner, 1989). Its concentration in precipitation in mid-continental regions (far from oceans and other salt sources) is almost always less than 1 mg/L, and often less than 0.1 mg/L (NADP, 2011). Upon contacting land surface, Cl^- concentrations in water increase as a result of interaction with soils, rocks, and biota (waste products), as well as the effects of evaporation. Chloride is the most abundant ion in seawater, with a concentration greater than 19,000 mg/L (Stumm and Morgan, 1996). Extremely elevated levels of Cl^- in surface water are generally due to significant evaporation (e.g., the Dead Sea has a Cl^- concentration > 230,000 mg/L).

Chloride is non-toxic to humans, but elevated levels make water unpotable due to the salty taste. In the U.S., there is a secondary (non-enforced) drinking water standard of 250 mg/L, but in areas of the world with water scarcities, drinking water can have considerably greater concentrations of Cl^-. Chloride is corrosive to steel, thus it may corrode pipes in water treatment and industrial plants. Because it imparts a salty taste to water and is corrosive, elevated Cl^- levels in drinking water supplies can lead to increased treatment costs. Elevated Cl^- in surface water has been linked to damage of terrestrial and aquatic plants and aquatic animals at concentrations as low as 210 mg/L (Environment Canada, 2001; Hart et al., 1991; Kaushal et al., 2005; Wilcox, 1986). The U.S. Environmental Protection Agency (USEPA) recommends a chronic criterion for aquatic life of a four-day average Cl^-concentration of 230 mg/L with an occurrence interval of once every three years (USEPA, 1988). The recommended acute criterion is 860 mg/L, which relates to a one-hour average concentration with a recurrence interval of less than once every three years. The Illinois EPA (IEPA) uses an acute criterion of 500 mg/L, but there is no chronic standard. The government of British Columbia has proposed a lower maximum Cl^- concentration of 600 mg/L and a 30-day average concentration of 150 mg/L to protect freshwater life (Nagpal et al., 2003). Increased Cl^- concentrations in some environments have killed off native vegetation and allowed invasive salt-tolerant species to thrive (Panno et al., 1999).

The objective of this report is to characterize the sources, distribution, and trends of Cl^- in the waters of Illinois, including rainwater, lakes, rivers and streams, groundwater, and wetlands.

Acknowledgements

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Natural Sources of Chloride

Precipitation

Chloride in precipitation and dry deposition originates from marine aerosols or volcanic gases. Naturally-occurring Cl^- concentrations in rainwater and snowmelt can be several mg/L near the coastal regions of the U.S. due to the contribution of seawater aerosols (Figure 1). Chloride concentrations in mid-continental regions are much lower. Concentrations in Illinois are typically less than 0.1 mg/L (NADP, 2011).

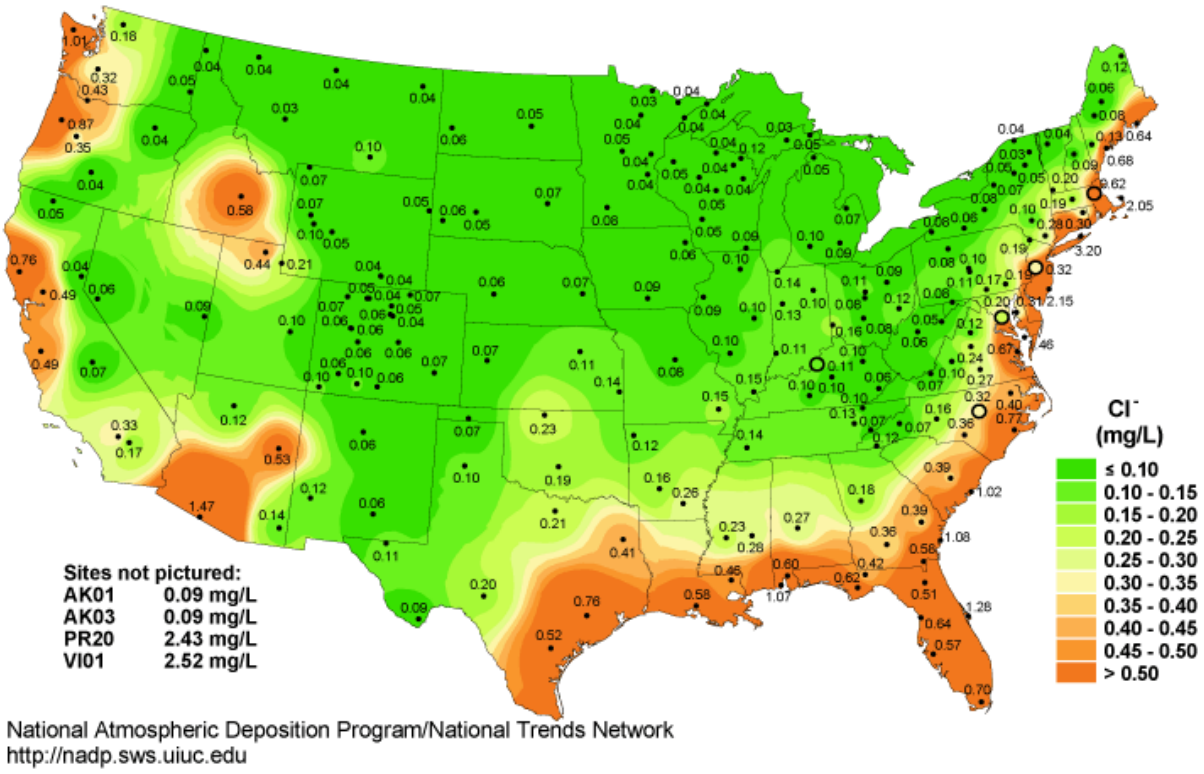

Figure 1. Chloride concentrations in U.S. precipitation for 2009. Map from NADP, 2011.

Rock-Water Interactions

Once rainwater and snow fall to the ground, evaporation and evapotranspiration tend to concentrate the Cl^- in soil water to levels ten or more times their original concentration. Rock-water interactions such as mineral dissolution and desorption within the soil zone and groundwater can further increase Cl^- concentrations.

The largest source of Cl^- in the Earth's crust is the mineral halite (NaCl) in evaporate deposits, which formed over geologic time by the evaporation of seawater. Chloride is also found in other less common salts (e.g., potassium chloride [KCl] and calcium chloride [$CaCl_2$]) associated with these evaporite deposits. Because halite and other chloride salts are extremely soluble, they are not found in areas where there is active circulation of fresh water. There are no known halite deposits in Illinois, although there is evidence from breciated limestone that evaporates may have existed in the geologic past (Willman et al., 1975). Chloride is found in small amounts (1000 to 10,000 parts per million [ppm]) in some silicate and phosphate minerals, including biotite, amphibole, apatite, sodalite, and scapolite (Kamineni, 1987), but these are not common minerals in the sedimentary rocks and sediments of Illinois. Chloride is a minor constituent of sedimentary rocks such as limestone, sandstone, and shale (as well as granitic rocks), but typically at low concentrations. Krauskopf (1979) reported typical Cl^- concentrations of 150, 10, and 200 ppm for limestone, sandstone, and shale, respectively. Chloride is also present within some minerals as fluid inclusions and can have very high concentrations comparable to those of a concentrated brine; however, fluid inclusions are typically very small (a few microns in diameter) and impart very little Cl^- to circulating groundwater. Because of the lack of appreciable amounts of Cl^- in rocks and sediments of Illinois, soils, sediments, and rocks in the shallow subsurface in Illinois would not be expected to have appreciable amounts of naturally-occurring Cl^-.

There are, however, natural brines in Paleozoic sedimentary formations of the Illinois Basin that underlie the southern two-thirds of the state (Figure 2). Meents et al. (1952) sampled over 700 oil field brines in the oil-producing regions of Illinois, primarily in the southeastern quadrant of the state; more than 80 percent of the samples had Cl^- concentrations greater than that of seawater, with a high of ~95,000 mg/L. Panno et al. (2006) summarized data from several studies in the Illinois Basin, and calculated a median Cl^- concentration of 64,600 mg/L, about three times the concentration in seawater.

Naturally saline groundwater in Illinois is very old. The chemical and isotopic compositions of brines in the Illinois Basin suggest they were formed as a result of the partial evaporation of seawater short of the precipitation of halite (Walter et al., 1990; Stueber and Walter, 1991; Kesler et al., 1995). Deeper groundwater in Precambrian granitic bedrock is even more saline, intensified by very long-term rock-water interactions at much warmer conditions than those encountered nearer the surface. Groundwater in the deeper parts of the Paleozoic and crystalline basement bedrock of the Illinois Basin is typically a hypersaline, calcium (Ca)-sodium (Na)-Cl-type brine with total dissolved solids (TDS) concentrations greater than 100,000 to over 250,000 mg/L (Horita, 2005).

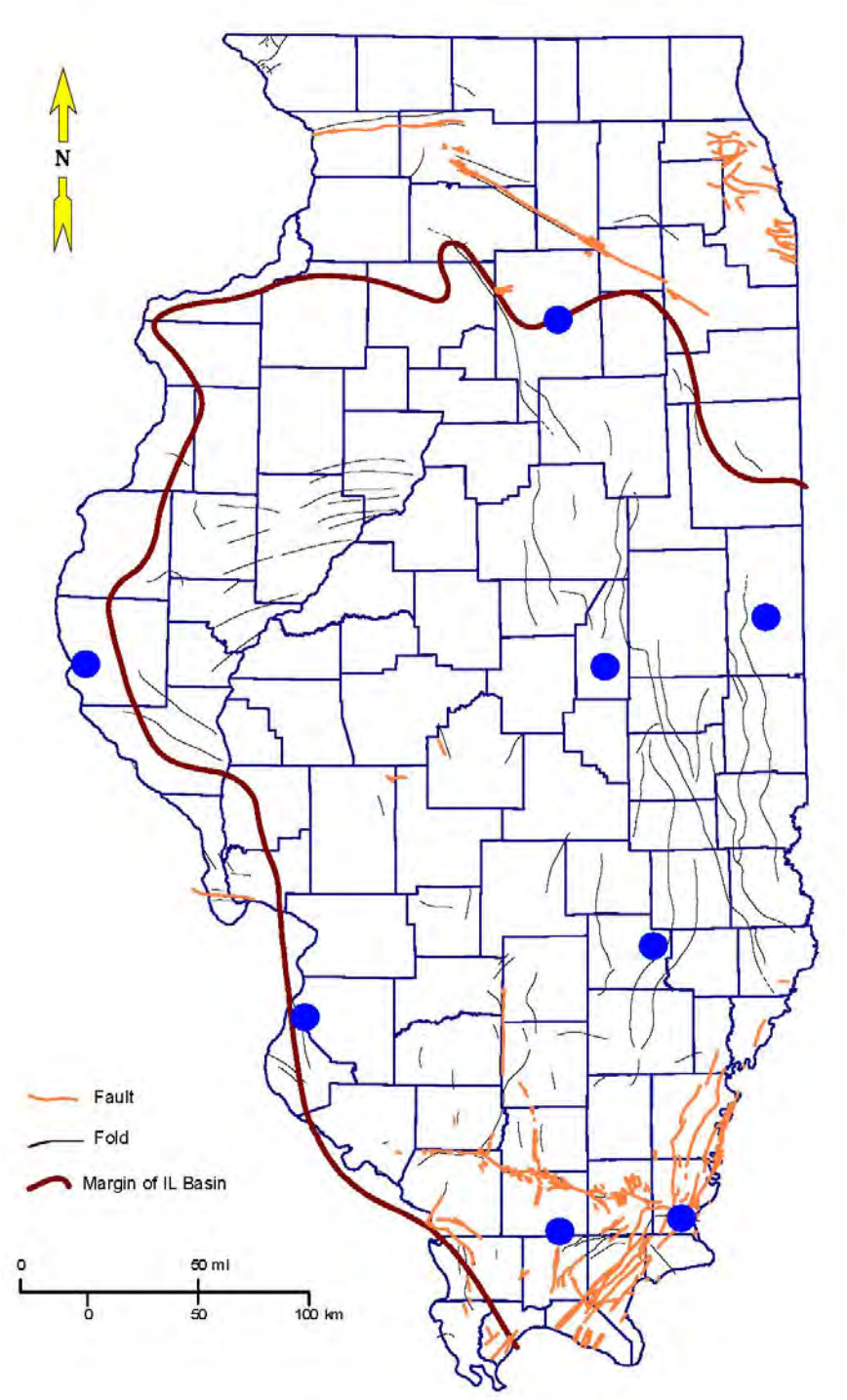

Figure 2. Illinois Basin. Blue circles indicate location of saline springs. Figure from Panno et al. (in preparation).

Saline groundwater in Illinois is under pressure, and at many locations it discharges into shallower aquifers or at the land surface as saline springs (Bartow et al., 1909; Willman et al., 1975; Cartwright, 1970; Panno et al., 1994, 2006). Bedrock discharge into the Mahomet Aquifer in Piatt County in east-central Illinois increases the Cl^- concentration from less than 10 mg/L to concentrations as high as 500 mg/L (Hackley et al., 2010). Thirteen samples of brine-affected groundwater collected by Panno et al. (2006), primarily in the southern part of the state, had a median Cl^- concentration of 474 mg/L. In some parts of Illinois, especially in the south, these deep brines discharge to surface waters, increasing the natural Cl^- concentration. For example, the North Fork of the Saline River in southeastern Illinois, named for its natural saltiness, had a median Cl^- concentration of 109 mg/L between 1978 and 1997 (USGS, 2009).

Background Chloride Concentrations

Despite the existence of saline seeps in Illinois, the vast majority of groundwater has relatively low concentrations of Cl^-, especially in major aquifers. In a study of shallow groundwater (< 100 meters) in northern Illinois, Panno et al. (2006) determined that Cl^- concentrations in shallow aquifers ranged from less than 1 to 15 mg/L. They suggested that concentrations greater than 15 mg/L indicated contamination from human sources. This threshold is probably similar (or lower) for aquifers in the rest of Illinois as well, where urbanization is less (Panno et al., 2005). Prior to human alterations to the landscape, almost all water discharging to surface streams in Illinois passed through the subsurface (i.e., groundwater), and a large majority still does. Thus pristine surface waters in Illinois should have Cl^- concentrations < 15 mg/L. Lusk Creek, for example, which flows through the undeveloped Shawnee National Forest in southern Illinois, had a median Cl^- concentration of 2.3 mg/L between 1978 and 1997 (USGS, 2009).

Anthropogenic Sources

Schlesinger (2004) estimated that more than 140 teragrams (140 trillion kilograms) of Cl^- are annually cycled through various reservoirs on Earth, almost all of it due to human activities. Anthropogenic sources include human sewage, livestock waste, water conditioning salt, synthetic fertilizer (primarily KCl), brine disposal pits associated with oil fields, chemical and other industries, and, in snowy climes, road salt runoff. From a volume standpoint, the most important anthropogenic sources of Cl^- to waters in Illinois are fertilizer, road salt, water conditioning salt, sewage, and livestock waste (Table 1). Chloride concentrations for potential contamination sources of Cl^- in Illinois are shown in Table 2. Once in groundwater, Cl^- and other contaminants can persist for many years if travel times are slow. For example, Howard et al. (1993) estimated that if road salting was stopped immediately in the Toronto area, it would be decades before the Cl^- concentrations returned to pre-1960 levels in shallow groundwater. In rural areas, agricultural sources of Cl^- are of greater importance. Oil field-related contamination problems have occurred primarily in the southern two-thirds of Illinois.

Table 1. Annual Chloride Fluxes in Illinois

Source	*Flux (metric tons)*
Treated Wastewater	
MWRDGC	175,000
Remainder of state	125,000
Atmospheric	18,000
Road Salt	471,000
Water Conditioning Salt	135,000
Fertilizer (KCl)	373,000
Livestock	139,000
Lake Michigan withdrawals	34,000
Groundwater withdrawals	
Public supply wells	12,500
Industrial/commercial	5,300
Irrigation	10,000
Oil-Field Brines	23,000

Note: The treated wastewater fluxes do not include road salt inputs.

Table 2. Chloride Concentrations (mg/L) for Potential Sources in Illinois

Sample Type	*Location*	*Min*	*Median*	*Max*	*Reference*
Tile Drain	Ludlow	10.3	14.5	17.8	Kelly et al. (2010)
	Champaign	23.1	25.4	36.5	Panno et al. (2005)
Treated Wastewater	Stickney (2000-2008)	26.3	145	1,481	MWRDGC
Road Salt Runoff	Willow Springs		8,930		Kelly et al. (2010)
	Pekin		1,572		Kelly et al. (2010)
Agricultural Soil Water	Central Illinois	16.2	17.5	20.8	W. Kelly (unpublished data)
Natural Brine	Central Illinois		6,517		Panno et al. (2006)
	SW Illinois		8,080		Panno et al. (2006)
Illinois Basin Brine		557	64,600	125,000	Panno et al. (2006)
Livestock Manure	Central Illinois	440	847	1,980	Panno et al. (2006)
Septic System Discharge	SW Illinois	20.8	91	5,620	Panno et al. (septic paper)
Landfill Leachate		198	1,284	6,170	Panno et al. (2006)

Human Waste

The median Cl^- concentration in treated wastewater (TWW) discharging from the Stickney wastewater treatment plant (WWTP) in Chicago (the largest in the U.S.) between 2000 and 2008 was 145 mg/L (based on weekly sampling) (MWRDGC, 2010) (Table 2). Kelly et al. (2010) got similar results in samples collected on three dates between 2003 and 2005 from two Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) WWTPs (Stickney and Calumet); they reported a median Cl^- concentration of 141 mg/L. Kelly et al. (2010) also collected samples from the Peoria WWTP, which had Cl^- concentrations that ranged from 113 to 291 mg/L. TWW is generally discharged directly into surface waterways in Illinois.

Livestock Waste

Animal waste contains elevated concentrations of Cl^-; Panno et al. (2006) measured levels as high as 1980 mg/L (Table 2). Because of this, even relatively small concentrations of livestock can create a local problem for shallow groundwater. Large confined animal feeding operations, which can concentrate thousands of animals in a relatively small area, have the potential to produce more widespread contamination of shallow groundwater, streams, and rivers (Wing et al., 2002; Showers et al., 2008).

Road Deicers

The chemical industry and governmental departments handling road ice control are the major importers and consumers of halite in the U.S., accounting for about three-fourths of its total use (Kostick, 2008). Road salt has been linked to groundwater degradation in many urban and roadside areas in snowy climes (Amrhein et al., 1992; Bester et al., 2006; Howard and Haynes, 1993; Huling and Hollocher, 1972; Pilon and Howard, 1987; Williams et al., 2000b). Significant application of road salt began after World War II and accelerated rapidly from the 1960s (Figure 3) (Salt Institute, 2009). Chloride concentrations have been increasing in surface waters and groundwater in urban regions of the northern United States and Canada since the 1960s, primarily due to road salt runoff (Godwin et al., 2003; Howard and Haynes, 1993; Kaushal et al., 2005; Kelly, 2008; Novotny et al., 2009; Kelly et al., 2010).

Two road salt runoff samples collected by Kelly et al. (2010) dripping off road bridges in Pekin and Willow Springs, IL, had very high concentrations of Cl^-: 1572 and 8930 mg/L, respectively (Table 2). Chloride concentrations in road salt runoff samples are extremely variable due to variability in application rates, snowfall amounts, melting rates, etc.; the values measured by Kelly et al. (2010) fall within the range of values reported by others (Amrhein et al., 1992; Environment Canada, 2001; Greb et al., 2000; Pilon and Howard, 1987). Road salt also can increase Cl^- concentrations in precipitation. For example, Williams et al. (2000a) characterized road salt aerosol in suburban areas west and south of Chicago, and measured Cl^- concentrations up to 9.4 mg/L in samples collected after snow events. They also found that Cl^- concentrations in snow samples decreased exponentially with distance from major highways.

Road salt runoff that recharges the soil zone and shallow groundwater can produce very high concentrations of Cl^-. Kelly and Roadcap (1994) measured Cl^- concentrations in excess of 1,000 mg/L in several shallow (< 25 ft; 7.6 m) monitoring wells installed along the uncurbed Interstate 94 in south Chicago, including two exceeding 3,500 mg/L.

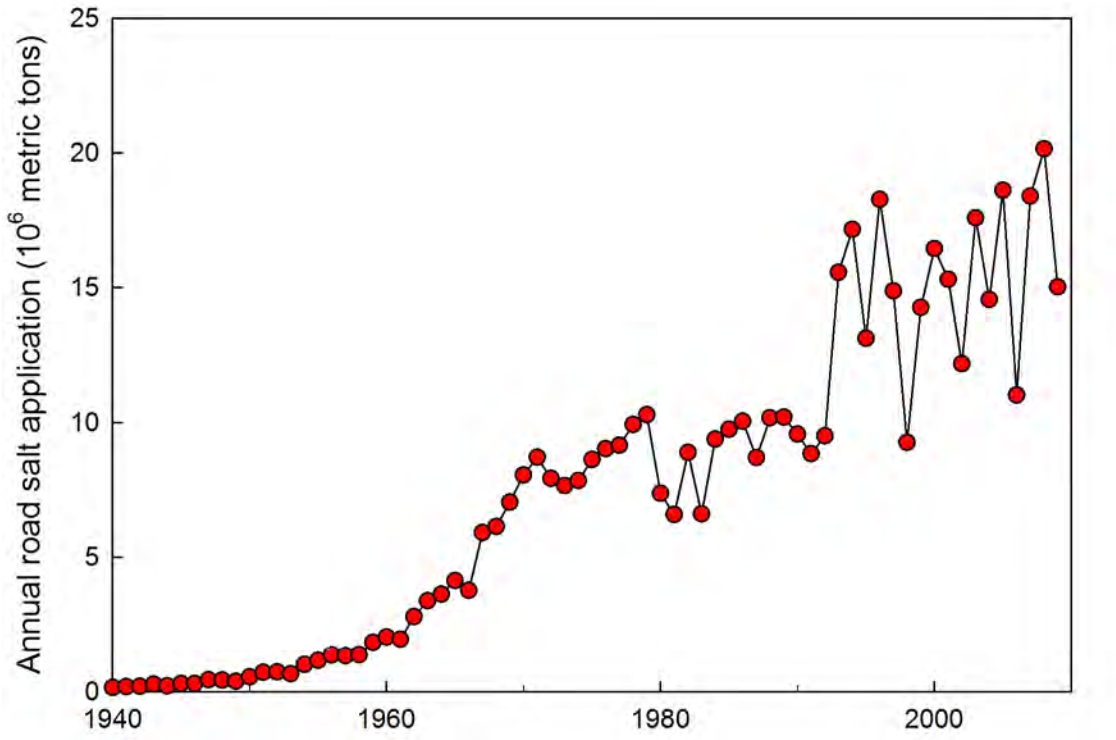

Figure 3. Yearly U.S. highway salt sales. Data from Salt Institute, 2011.

Water Conditioning Salts

In-home water treatment, specifically water softening, typically uses NaCl to recharge ion exchange columns in order to reduce hardness (Ca + Mg) by replacement with Na. For a family of three or four with moderately hard water, the recommended amount of NaCl for water softening is between 1.8 and 2.7 kilograms per day, or 600 to nearly 1000 kg of NaCl per year (Panno et al., 2005, 2007). If a household uses on-site wastewater treatment, the Cl^- is discharged to the shallow groundwater system via the leach field. If the household is connected to a community waste treatment facility, the Cl^- (which is not removed in the treatment process) is generally discharged to streams or rivers.

KCl Fertilizer

Illinois is a major producer of row crops, primarily corn and soybeans. KCl is the most commonly available potassium (K) fertilizer and usually the cheapest, thus it is widely applied in Illinois. Because it is spread over large areas (i.e., non-point source), its impact on soil water and

groundwater quality is less than more concentrated Cl^- applications, such as road salt. In much of Illinois, agricultural fields are tiled to facilitate drainage of soils, and these drain tiles are the major source of water to many streams in Illinois. Panno et al. (2005) and Kelly et al. (2010) collected samples from several tile drains in east-central Illinois, which represent shallow groundwater beneath row crop areas. Chloride concentrations in these tile drain samples ranged from 10 to 37 mg/L (Table 2). This is also approximately the same concentration range found in soil water in agricultural fields in central Illinois (W. Kelly, unpublished data).

Municipal Landfills

Panno et al. (2006) measured Cl^- concentrations in municipal landfill leachate as high as 6,170 mg/L. Roy (1994) reported the greatest Cl^- concentration recorded in municipal landfill leachate to be 27,100 mg/L. Potential sources of Cl^- in landfills include food scraps and pet wastes. Chloride concentrations in landfills are not static, but decrease with the age of the landfill (McGinley and Kmet, 1984; Ham, 1980; Lu et al., 1985). Farquhar (1989) reported that Cl^- concentrations in municipal landfill leachate tend to decrease asymptotically with time, with concentrations 1,000–3,000 mg/L during the first five years, 500–2,000 mg/L during years 5 to 10, 100–500 mg/L during years 10 to 20, and < 100 mg/L after that.

Oil and Gas Exploitation

Leakage of brine-holding ponds associated with oil wells has locally contaminated groundwater with high TDS waters in southeastern Illinois. Hensel and McKenna (1989) installed shallow monitoring wells around two brine-holding ponds in Clay County and measured Cl^- concentrations over 10,000 mg/L in several samples. They identified 384 holding ponds in their study area (~300 mi^2 in southeastern Clay County), so the potential for widespread groundwater contamination is significant and hundreds of acres of farm land were reported to have been made unsuitable for crops due to brine leakage and spillage. However, Hensel and McKenna (1989) found no widespread degradation of groundwater resources in the area.

Identification of Sources of Chloride

There are various methods for determining the source(s) of Cl^- in individual water samples, one of the best being halide ratios. In a recent investigation, Panno et al. (2006) collected more than 100 samples from various Cl^- sources (primarily in Illinois) and, by plotting Cl^- and bromide (Br^-) data on a Cl^- vs. Cl/Br diagram, were able to define domains that distinguish among the sources (Figure 4). TWW can plot outside the septic effluent source domain because there are often multiple sources of Cl^- in TWW. Chicago and many of its suburbs have combined sewers (sewage and storm water), and an average of about 30 percent of the water entering the Stickney WWTP is from storm runoff (J. Wasik, MWRDGC, December 1, 2006, personal communication). The highest Cl/Br ratios in TWW measured by Kelly et al. (2010) were during the winter, which was due to a dominant road salt component.

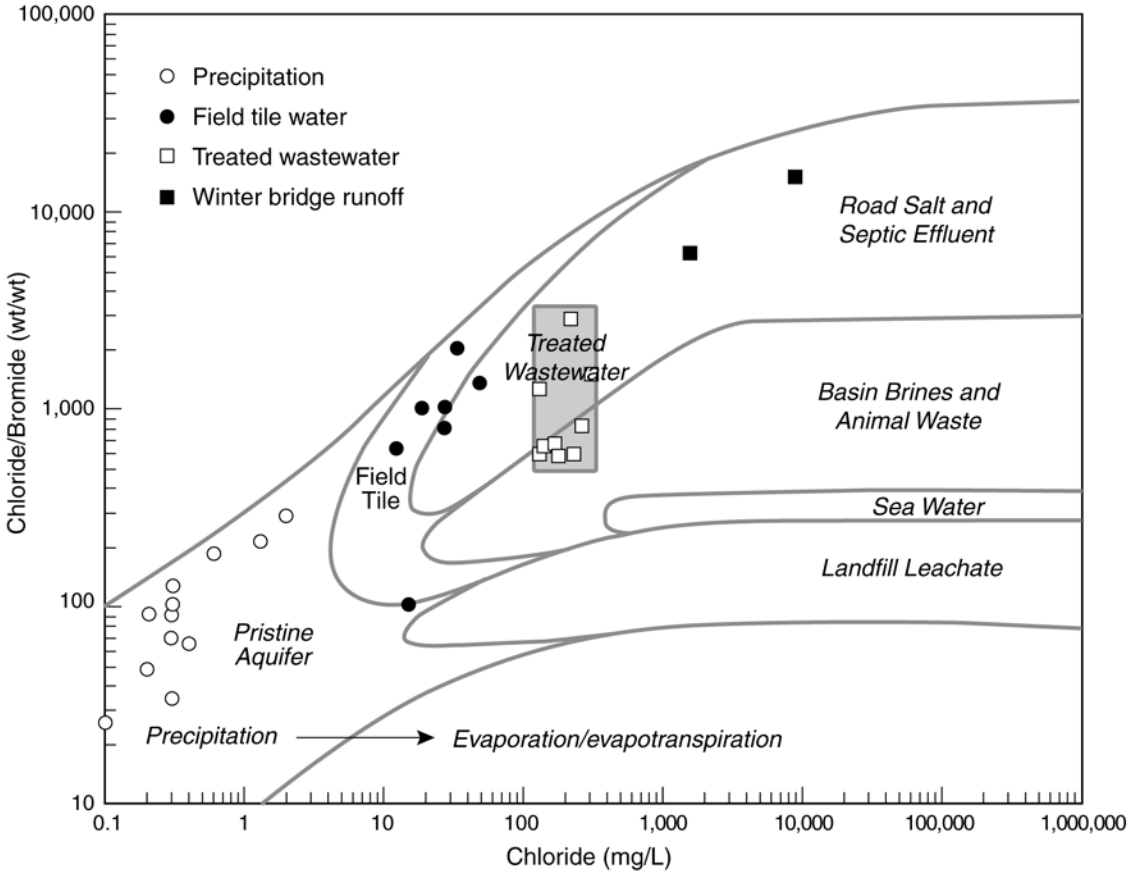

Figure 4. Cl/Br vs. Cl^- plot showing source domains (Kelly et al., 2010)

Annual Fluxes of Chloride in Illinois

The estimated annual flux of Cl^- in Illinois from various sources was determined using the methods of Kelly et al. (2010) (Table 2). They found that Cl^- in the Illinois River Basin was predominantly from road salt, TWW, and KCl fertilizer. An accurate estimate of how much road salt is applied in an average winter is difficult, due to the large number of government agencies and private entities that apply salt to roads and parking lots. Friederici (2004) and Keseley (2006) reported more than 250,000 metric tons of road salt is applied annually in the Chicago metropolitan region, but this is almost certainly an underestimate. Probably the best method for estimating road salt applications is to use road salt sales reported by the Salt Institute (Salt Institute, 2009) as a proxy. Using additional state data from Richter and Kreitler (1993) and Panno et al. (2005), Kelly et al. (2010) estimated that an annual average of 471,000 metric tons of road salt (equivalent to ~283,000 metric tons of Cl^-) were used in Illinois for the years 2002 to 2005, mostly in the Chicago region. Average annual road salt sales have increased since 2005, so the amount of road salt applied in Illinois has undoubtedly increased as well. The amount applied in a particular year generally depends on how much snow and ice fall during winter.

The Cl^- flux for TWW from the Chicago region can be calculated from WWTP discharge and Cl^- concentration data reported by MWRDGC (MWRDGC, 2010), but this calculation is complicated by multiple sources in TWW and the potential for "double counting" of sources. In addition to human waste, TWW includes industrial effluent, water conditioning salt, and road salt, as well as Cl^- present in drinking water sources.

Chloride fluxes from the Chicago WWTPs were calculated using Cohn's equation (Kelly et al., 2010). Road salt contributions were removed from the WWTP loads by assuming that there was no road salt in TWW from May to October. Chloride loads during these months were divided by monthly discharges, and it was assumed that the same load per discharge ratio for non-road salt sources occurred between November and April. The remaining chloride loads between November and April (which varied between 17 percent and 50 percent of the total monthly load) were assumed to come from road salt and were removed from the TWW load calculations.

The seven MWRDGC plants account for almost 60 percent of the TWW discharged to surface water bodies in Illinois. To calculate the Cl^- flux for the remaining TWW, it was assumed that the effluent Cl^- concentration was the same as for the MWRDGC plants, resulting in a flux of 125,000 metric tons.

Human waste actually accounts for a small percentage of Cl^- in TWW. Adult humans excrete between 110 and 250 millimoles of Cl^- per day (3,900–8,860 mg day) (WebMD, 2011). Assuming 5,500 mg of Cl^- per day, a typical value for urine production (1.25 L/day), and a 2010 population of 12.83 million, results in about 32,000 metric tons of Cl^- from human urine annually in Illinois. Another approach taken by Mullaney et al. (2009) is to use per capita salt consumption based on the recommended daily adult sodium intake of 2,300 mg/d, which would include about 3,547 mg of Cl^-. A person on this diet would consume, and release, about 1.3 kg of Cl^- per year, which would be released by wastewater discharge. This would produce almost 17,000 metric tons of Cl^- in Illinois per year. Either estimate represents less than 10 percent of the Cl^- in TWW.

Chloride from water conditioning salt was also estimated from salt sales data. Between 2005 and 2008, approximately 3.2 million metric tons of salt (predominantly NaCl) was sold for water conditioning in the U.S. (Salt Institute, 2009). Assuming that water conditioning salt use was distributed equally across the U.S. based on population, approximately 135,000 metric tons of Cl^- is annually consumed in Illinois by water conditioning.

About 80 percent of corn fields and 30 percent of soybean fields in Illinois receive potassium chloride (KCl) annually (USDA, 2008). The amount of KCl applied in Illinois was estimated from state fertilizer sales data (USDA, 2008). Between 2005 and 2007, an average of 373,000 metric tons of Cl^- from KCl were purchased per year in Illinois.

Between 2005 and 2008, there were approximately 4.23 million pigs and 1.28 million cattle in Illinois (Illinois Agricultural Statistics Service, 2009). A pig produces about 3 gallons of waste a day and a cow produces 14 gal/day. Using Cl^- concentrations of 3,680 mg/L and 3,000 mg/L for pigs and cows, respectively (DeRouchey et al., 2003; Lengemann et al., 1952), an annual total of 139,000 metric tons of Cl^- was calculated to come from livestock.

For Cl^- from precipitation, a Cl^- concentration of 0.12 mg/L and an average annual precipitation of 102 centimeters (cm) were assumed (NAPD, 2011). This gives approximately 18,000 metric tons of Cl^-.

One source of Cl^- that may be overlooked is water extracted from Lake Michigan and groundwater for drinking, industrial, and agricultural purposes. Chicago and many of the inner suburbs obtain drinking water from Lake Michigan, which has a Cl^- concentration of approximately 12 mg/L. Because most of the water Illinois takes from Lake Michigan is discharged outside the Great Lakes Basin, Illinois is limited by U.S. Supreme Court decree to 3,200 cubic feet per second (cfs) (~2,900 billion L/yr) of water from the lake. Assuming Illinois diverts all of this each year, approximately 34,000 metric tons of Cl^- is removed from the lake. Most of this eventually finds its way into wastewater, which would be included in the TWW Cl^- flux, and eventually is discharged down the Illinois River.

Approximately 1,180 million gallons (4,470 million L) of groundwater are withdrawn daily in Illinois (Kenny et al., 2009). About 507 million gallons per day (mgd) (1,920 million L/day) are used for drinking and other household uses, 517 mgd for agriculture (irrigation and livestock), 128 mgd by industrial and commercial applications, 15.5 mgd by mining, and 7.2 mgd for thermoelectric. Most extracted groundwater is not returned to the ground, but eventually finds its way to surface waters. In communities with sewers, most drinking water eventually finds its way into wastewater, which is then discharged to surface streams and rivers, eventually leaving the state. For homes and businesses with private wells and on-site sewage treatment (i.e., septic systems), extracted groundwater is discharged at or just below the ground surface, and most does not recharge underlying aquifers but is either evapotranspired or discharged to nearby streams or other surface waters. The same is true for irrigation water.

Groundwater withdrawal data are available for many public water supply wells and industrial/commercial wells. Of the top 200 pumped public water supply wells, 176 have been sampled sometime in the past 20 years, and the Cl^- concentration and withdrawal data from 2008 were used to calculate the mass of Cl^- removed. In order to not include potential surface contamination sources in shallow wells, it was assumed that the background Cl^- concentration was 15 mg/L in all wells ≤ 250 feet deep. These results were then used to estimate Cl^- fluxes

from the other approximately 2,500 public water supply wells for which we have withdrawal data. It was estimated that approximately 12,500 metric tons of Cl^- was extracted from public supply wells.

Sample results were available only for 13 of the top 200 industrial/commercial wells. For 184 of the other 187 wells, samples from a well located near to and at a similar depth to the well in question were found, and the Cl^- concentration from that well was used to calculate Cl^- fluxes. Using these data and the assumption that the background Cl^- concentration was 15 mg/L in all wells ≤ 250 feet deep gives an estimate of approximately 5,300 metric tons of Cl^- extracted annually from industrial/commercial wells.

In 2005, the U.S. Geological Survey estimated that approximately 479 million gallons of water were pumped from irrigation wells in Illinois (USGS, 2009). Withdrawal data from individual irrigation wells are lacking in Illinois. Because most irrigation wells are finished in relatively shallow sand and gravel aquifers, it was assumed that the Cl^- concentration was 15 mg/L. This gives a Cl^- flux of approximately 10,000 metric tons from irrigation wells.

It is difficult to get accurate estimates of how much water is withdrawn for oil and gas production. The most recent and most reliable estimates are from the 1980s, when Kirk (1987) reported that 25.5 million gallons per day (~9.3 billion gallons annually) were withdrawn. Almost all of this is reinjected for secondary oil and gas recovery. However, some of this brine was temporarily stored in ponds at the surface, and leakage to surface and shallow subsurface environments has been reported (Hensel and McKenna, 1989). Using the median concentration of 64,600 mg/L reported by Panno et al. (2006), and assuming leakage of 1 percent of the withdrawn brine, gives an annual Cl^- flux of approximately 23,000 metric tons.

Distribution and Trends in Chloride Concentrations in Waters of Illinois

Recent research has suggested that Cl^- concentrations in many water bodies in Illinois are changing (e.g., Kelly [2008] and Kelly et al. [in press]), thus any report on the distribution of Cl^- is a "snapshot in time," subject to change. This is especially true for rivers and shallow groundwater in urban and urbanizing areas, most notably the Chicago region. In order to fully understand the distribution of Cl^- in the waters of Illinois, a discussion of temporal trends must also be included. Trends in Cl^- concentrations in surface water and groundwater can reveal much about the origin, evolution, character, and movement of its sources. Such information is critical to predicting future changes in Cl^- concentrations.

Lakes

As mentioned previously, Lake Michigan currently has an average Cl^- concentration of 12 mg/L, its highest historical level. Concentrations have been slowly increasing since the late 1800s, due to human inputs to the lake (Chapra et al., 2009), with an increase of about 3 mg/L since the 1980s (USEPA, 2011a) (Figure 5). While the increase seems small, it represents an additional annual load of approximately 600,000 metric tons of Cl^- to Lake Michigan.

Natural lakes in Illinois are primarily found in the northern part of the state, especially Lake and McHenry Counties. Most lakes in downstate Illinois are reservoirs created by the

damming of streams and rivers. Their Cl^- concentrations are similar to those found in their stream or river supplies, potentially increasing in summer if there is significant evaporation.

Many lakes in Lake County have been monitored between April and October for dissolved solids since the late 1980s by the Lake County Health Department (LCHD). Chloride concentrations have been routinely monitored only since 2005, but specific conductance, which is highly correlated with Cl^- concentrations, has been monitored from the beginning. Specific conductance values have been increasing with time in most of these lakes (Figure 6). In 2010, the median Cl^- concentration in the 22 lakes being monitored by LCHD was 112 mg/L, with highest concentrations usually measured in the first sample collected (May). Between 2005 and 2010, Cl^- concentrations have generally dropped in many of these lakes, which has been attributed to dilution during the relatively wet summers in recent years (Figure 7) (M. Adams, LCHD, pers. comm.). There is anecdotal evidence that the increasing TDS levels in lakes at golf courses has forced their abandonment as sources of irrigation water due to the deleterious effects on turf. This in turn has led to drilling of new wells, increasing the amount extracted from aquifers in Lake County.

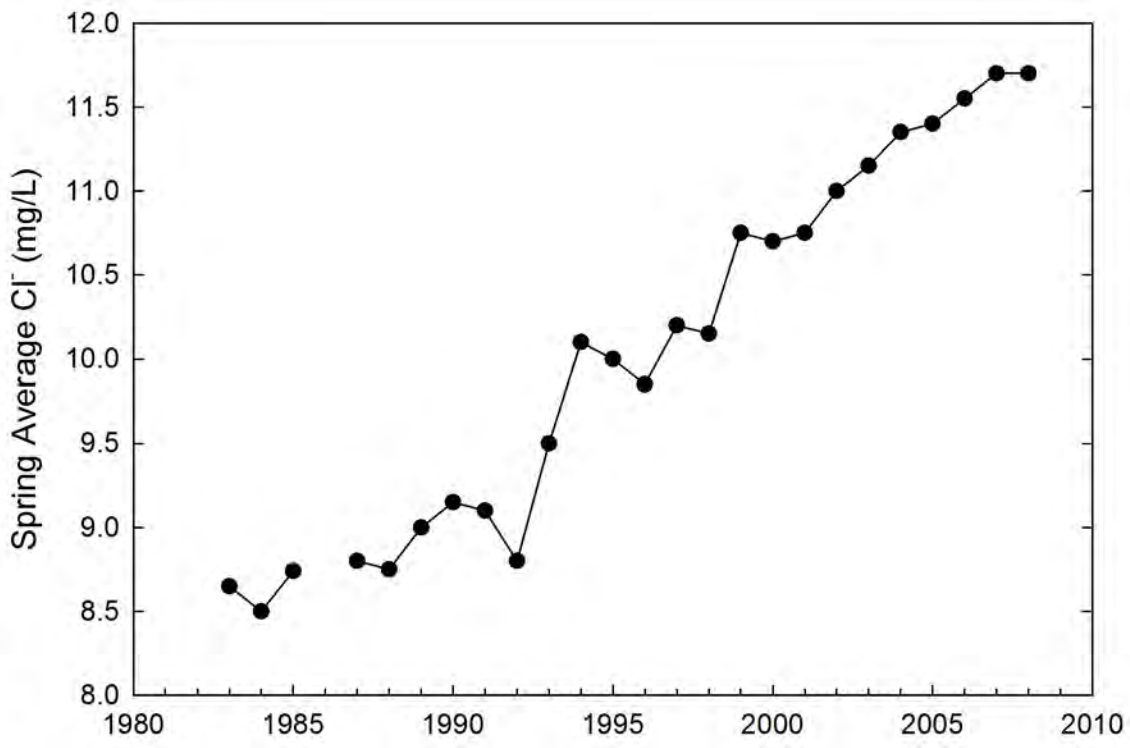

Figure 5. Chloride concentrations in Lake Michigan. Data from USEPA, 2011.

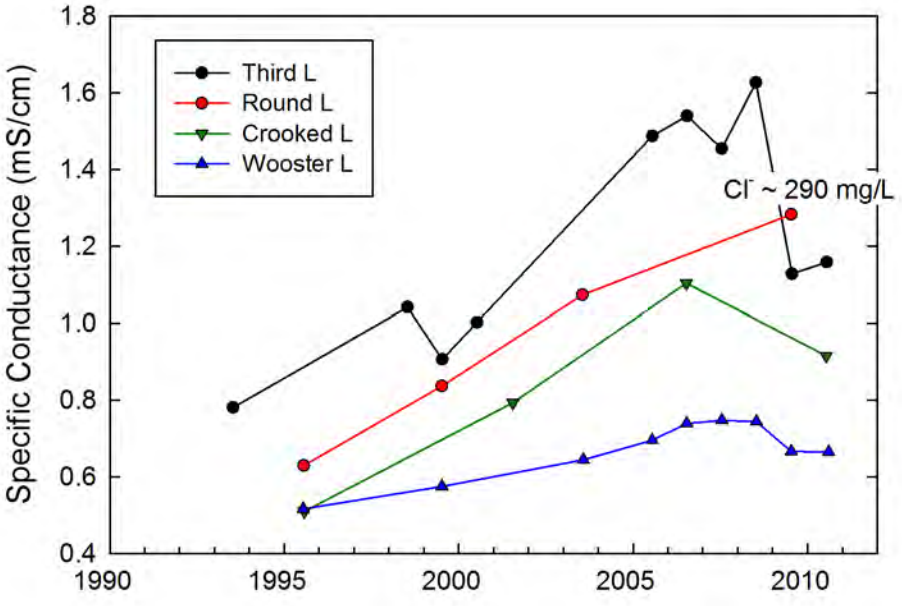

Figure 6. Annual median specific conductance values in selected lakes in Lake County. The chloride concentration for the most recent sample from Crooked Lake is reported. Data from Lake County Health Department.

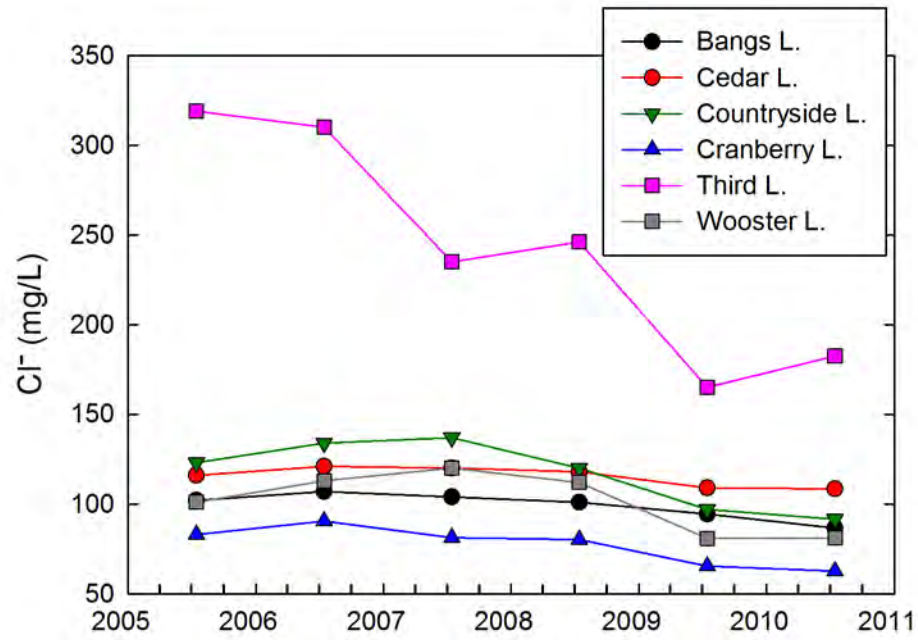

Figure 7. Chloride concentrations in selected lakes in Lake County. Data from Lake County Health Department.

Rivers and Streams

Water quality data for streams and rivers in Illinois are available from several agencies, including the ISWS, USGS, MWRDGC, and IEPA. Chloride concentrations in streams in Illinois are highest in the Chicago region and lowest in streams in forested watersheds in far southern Illinois. The USGS has historical data from a number of streams and rivers throughout Illinois. A comparison of data sets from a time period with the greatest overlap of data (1990–1992) indicates that downstate rivers draining primarily agricultural watersheds (Kankakee, Spoon, La Moine) had median Cl^- concentrations < 30 mg/L (Table 3 and Figure 8). Even though the North Fork of the Saline River drains an agricultural watershed, it has natural sources of Cl^- (geological brine discharge) and thus had a significantly higher median Cl^- concentration (86 mg/L). The Sangamon River, which has several large cities in its watershed (Bloomington-Normal, Decatur, Springfield), had a median concentration (34 mg/L at its most downstream station, Oakford) higher than rivers draining primarily agricultural land. The Fox River, which drains some of the western suburbs of the Chicago region and receives TWW, had an even higher median concentration (70 mg/L at its most downstream station, Dayton). Major Chicago waterways, including the Des Plaines River and the Chicago Sanitary & Ship Canal (CSSC), had median values > 90 mg/L. The median Cl^- concentration in the Illinois River, which receives water from tributaries in the Chicago region as well as down-state, is > 60 mg/L at Peoria and upstream, dropping to around 50 mg/L near its discharge to the Mississippi. Figure 9 shows that there are large annual variations in Cl^- concentrations in rivers throughout Illinois.

The MWRDGC has been monitoring water quality monthly at surface water stations in the Chicago region since 1975, primarily in Cook County but also at a few stations in DuPage and Will Counties (Figure 10). Forty-one stations have been monitored relatively continuously since 1975, with more than 30 others having a shorter period of record. Median Cl^- concentrations in 2008 were > 150 mg/L at about 80 percent of the stations (Figure 11 and Table 4). The highest values tended to be in the smallest streams in northern Cook County, including Higgins Creek, Salt Creek, and Buffalo Creek, as well as the North Branch of the Chicago River. The stream with the lowest values appears to be the North Shore Channel, which receives significant flow from Lake Michigan.

The presence of trends in Cl^- concentrations were determined using Kendall's tau test at the 95 percent confidence level, and annual rates of change were estimated by calculating slope coefficients (β_1) on 5-point running medians (Helsel and Hirsch, 2002). Rivers draining the Chicago region, including the Illinois River, have increasing trends in Cl^- concentrations. Of the 41 stations monitored by MWRDGC since 1975, 35 had statistically significant positive trends in Cl^- concentrations, with a median increase of 2.7 mg/L per year (Table 5). Five stations had increases of greater than 5 mg/L/yr; two of these stations were in the North Branch of the Chicago River. Of a total of 78 USGS stations tested throughout the entire state, 36 had significant positive trends in Cl^- concentrations, and 10 had significant negative trends (Table 6). The positive stations included almost all the Chicago region rivers and canals (Des Plaines River, Fox River, Chicago River, Addison Creek, CSSC), as well as a number of down-state rivers, including the Kankakee, Rock, and Sangamon Rivers. All of the Illinois River stations, as well as those on the Mississippi and Ohio, had positive trends. The stations with negative trends were scattered throughout the state.

Table 3. Median Cl^- Values (mg/L) for Rivers in Illinois for Water Years 1991–1992 at USGS stations. For Rivers with More Than One Station (Ordered from Upstream to Downstream)

River	*Location*	*Station*	*Median*		*River*	*Location*	*Station*	*Median*
Big Muddy	Murphysboro	5599500	31		La Moine	Colmar	5585000	17
Cache	Forman	3612000	10		Little Wabash	Effingham	3378635	30
Cal Sag Channel	Sag Bridge	5536700	105		Little Wabash	Carmi	3381495	34
Casey Fork	Mt Vernon	5595830	67		Lusk Ck	Eddyville	3384450	2.3
CSSC	Romeoville	5536995	109		Md Fk Vermilion	Oakwood	3336645	24
CSSC	Lockport	5537000	91		N Branch Chicago	Deerfield	5534500	131
Crab Orchard Ck	Carbondale	5598245	13		N Branch Chicago	Niles	5536000	146
Des Plaines	Riverside	5532500	158		N Fork Saline	Texas City	3382325	86
Des Plaines	Joliet	5537980	99		Pecatonica	Freeport	5435500	20
Embarras	Camargo	3343395	30		Richland Ck	Hecker	5595200	65
Embarras	Diona	3344000	29		Rock	Rockton	5437500	24
Embarras	Billett	3346550	30		Rock	Como	5443500	38
Fox	Channel Lk	5546700	65		S Fork Saline	Crab Orchard	3382055	32
Fox	S Elgin	5551000	75		S Fork Saline	Carrier Mills	3382100	19
Fox	Montgomery	5551540	85		Saline Branch	Mayview	3337700	51
Fox	Dayton	5552500	70		Salt Fork	St Joseph	3336900	39
Green	Geneseo	5447500	25		Sangamon	Allerton Park	5572125	44
Illinois	Marseilles	5543500	63		Sangamon	Oakford	5583000	34
Illinois	Peoria	5559900	59		Sangamon S Fork	Kincaid	5575500	50
Illinois	Valley City	5586100	52		Spoon	Seville	5570000	31
Iroquois	Chebanse	5526000	40		Sugar Ck (Saline)	Stonefort	3382090	5.9
Kankakee	Wilmington	5527500	27		Sugar Ck (Lk Springfield)	Springfield	5576250	56
Kaskaskia	Cooks Mills	5591200	33		Sugar Ck (Salt Ck)	Hartsburg	5581500	48
Kaskaskia	Venedy Station	5594100	27		Thorn Ck	Thornton	5536275	130
Kishwaukee	Perryville	5440000	43					

Table 4. Median Cl^- Values (mg/L) for 2008 at River Stations Monitored by MWRDGC

Station	*River*	*Location*	*Cl^-*		*Station*	*River*	*Location*	*Cl^-*
12	Buffalo Ck	Lake-Cook Rd	286		34	N Br Chicago	Dempster St	231
43	Cal-Sag Channel	Rte 83	186		37	N Br Chicago	Wilson Ave	166
58	Cal-Sag Channel	Ashland Ave	176		46	N Br Chicago	Grand Ave	159
59	Cal-Sag Channel	Cicero Ave	173		73	N Br Chicago	Diversey Ave	159
49	Calumet	Ewing St	33.5		96	N Br Chicago	Albany Ave	236
55	Calumet	130th St	156		104	N Br Chicago	Glenview Rd	204
74	Calumet	Lake Shore Dr	45.5		31	N Br Chicago (Md Fk)	Lake-Cook Rd	277
100	Chicago	Wells St	105		103	N Br Chicago (W Fk)	Golf Rd	288
40	CSSC	Damen Ave	143		106	N Br Chicago (W Fk)	Dundee Rd	350
41	CSSC	Harlem Ave	175		35	N Shore Channel	Central Ave	21.5
42	CSSC	Rte 83	169		36	N Shore Channel	Touhy Ave	135
48	CSSC	Stephen St	167		101	N Shore Channel	Foster Ave	140
75	CSSC	Cicero	169		102	N Shore Channel	Oakton Ave	72.0
92	CSSC	Lockport	162		39	S Br Chicago	Madison St	134
13	Des Plaines	Lake-Cook Rd	182		108	S Br Chicago	Loomis St	136
17	Des Plaines	Oakton St	196		99	S Br Chicago (S Fk)	Archer Ave	170
19	Des Plaines	Belmont Ave	196		18	Salt Ck	Devon Ave	241
20	Des Plaines	Roosevelt Rd	195		24	Salt Ck	Wolf Rd	252
22	Des Plaines	Ogden Ave	197		79	Salt Ck	Higgins Rd	388
23	Des Plaines	Willow Springs Rd	209		80	Salt Ck	Arlington Hts Rd	235
29	Des Plaines	Stephen St	198		90	Salt Ck	Rte 19	252
91	Des Plaines	Material Service Rd	193		109	Salt Ck	Brookfield Ave	256
86	Grand Calumet	Burnham Ave	138		32	Skokie	Lake-Cook Rd	247
77	Higgins Ck	Elmhurst Rd	452		105	Skokie	W Frontage Rd	181
78	Higgins Ck	Wille Rd	187		54	Thorn Ck	Joe Orr Rd	160
52	Little Calumet	Wentworth Ave	168		97	Thorn Ck	170th St	182
56	Little Calumet	Indiana Ave	172		64	W Br DuPage	Lake St	168
57	Little Calumet	Ashland Ave	191		89	W Br DuPage	Walnut Ln	151
76	Little Calumet	Halsted Ave	170		110	W Br DuPage	Springinsguth Rd	297
					50	Wolf Lake	127th St	64.9

Table 5. Trends Determined by Kendall Tau Statistic and β_1 Values (Reported as Yearly Change in Cl^-) for MWRDGC Stations with Monitoring Data from 1975 to 2008. Kendall Tau Significance Determined at 95% Confidence Level. β_1 Values Reported for All Data (total) as Well as Seasonally.

		Kendall Tau	β_1 (mg/L/yr)				
Station	*River*	*Significant?*	*Total*	*Jan-Mar*	*Apr-Jun*	*Jul-Sep*	*Oct-Dec*
12	Buffalo Creek	Y	5.8	13.2	6.9	1.4	3.0
13	Des Plaines R	Y	3.4	6.9	3.4	2.1	2.0
17	Des Plaines R	Y	3.8	8.2	3.9	2.6	2.7
18	Salt Creek	Y	2.1	6.7	6.4	-0.1	-1.2
19	Des Plaines R	Y	3.7	8.2	3.4	1.6	2.8
20	Des Plaines R	Y	4.1	8.6	3.7	2.2	3.0
22	Des Plaines R	Y	3.3	2.6	3.8	1.2	1.2
23	Des Plaines R	Y	3.4	8.9	4.0	1.1	2.0
24	Salt Creek	N					
29	Des Plaines R	Y	3.3	8.7	3.8	1.0	1.5
31	N Branch Chicago R (Md Fk)	Y	5.2	7.1	5.9	4.8	3.5
32	Skokie R	Y	4.6	5.5	6.3	4.3	3.5
34	N Branch Chicago R	Y	5.5	9.7	6.3	3.5	3.9
35	N Shore Channel	Y	0.17	5.4	2.0	-0.3	0.3
36	N Shore Channel	Y	1.9	5.2	2.1	0.9	2.7
37	N Branch Chicago R	Y	2.7	6.8	2.9	1.3	3.4
39	S Branch Chicago R	Y	2.6	6.4	2.5	0.5	3.0
40	CSSC	Y	2.7	6.4	2.7	0.4	3.2
41	CSSC	Y	2.5	5.2	2.2	1.0	4.2
42	CSSC	Y	2.7	7.0	2.4	1.1	2.3
43	Cal-Sag Channel	Y	1.4	5.2	1.8	0.1	0.0
46	N Branch Chicago R	Y	2.7	6.8	3.2	1.4	2.7
48	CSSC	Y	2.4	5.2	2.5	0.9	1.9
49	Calumet R	Y	0.76	1.7	0.5	-0.1	0.8
50	Wolf Lake	Y	0.51	0.4	0.7	0.6	0.4
52	Little Calumet R	Y	1.9	3.6	2.5	0.4	0.5
54	Thorn Creek	Y*	-4.8	-1.3	-2.8	-6.1	-7.7
55	Calumet R	N					
56	Little Calumet R	N					
57	Little Calumet R	Y	0.07	5.2	1.8	-2.3	-2.5
58	Cal-Sag Channel	Y	1.2	5.0	0.9	-0.1	1.4
59	Cal-Sag Channel	Y	1.2	4.3	1.8	-0.2	0.2
64	W Branch DuPage R	Y	-0.93	4.4	1.7	-2.2	-3.1
73	N Branch Chicago R	Y	2.5	6.7	2.5	1.0	2.6
74	Chicago R	Y	1.1	6.0	2.7	0.0	1.4
75	CSSC	Y	2.9	7.0	1.5	0.6	3.3
76	Little Calumet R	Y	1.4	4.7	10.1	0.6	1.4
78	Higgins Creek	Y	1.6	3.8	9.9	1.0	1.4
79	Salt Creek	Y	7.3	15.9	6.4	5.8	4.6
80	Salt Creek	Y	2.0	6.6	2.3	0.3	-0.6
90	Salt Creek	Y	6.8	12.8	11.1	4.4	3.7

* Negative trend.

Table 6. Trends Determined by Kendall Tau Statistic and β_1 Values (Reported as Yearly Change in Cl^-, mg/L/yr) for USGS Stations. Data Start in 1984, and End between 1997 and 2008. Kendall Tau Significance Determined at 95% Confidence.

Station	*River*	*KT sign.*	β_1		*Station*	*River*	*KT sign.*	β_1
5532000	Addison Creek	Y	9.33		3384450	Lusk Creek	N	
5599500	Big Muddy	N			3336645	Middle Fork Vermilion	N	
3378000	Bonpas Creek	Y*	-1.08		7022000	Mississippi	Y	0.21
3612000	Cache	Y*	0.07		5587455	Mississippi	Y	0.48
5536700	Cal Sag Channel	N			5534500	N Branch Chicago	Y	7.13
5595830	Casey Fork	N			5536000	N Branch Chicago	Y	5.74
5598245	Crab Orchard Creek	N			3346000	N Fork Embarras	Y*	-2.00
5593520	Crooked Creek	Y*	-3.17		3382325	N Fork Saline	N	
5537000	CSSC	Y	3.84		3338780	N Fork Vermilion	Y*	-0.29
5536995	CSSC	Y	5.64		3612500	Ohio	Y	0.23
5528000	Des Plaines	Y	6.00		5435500	Pecatonica	Y*	-0.15
5529000	Des Plaines	Y	6.03		5550500	Poplar Creek	Y	14.2
5532500	Des Plaines	Y	2.11		5595200	Richland Creek	Y	0.99
5537980	Des Plaines	N			5437500	Rock	Y	1.00
5540500	DuPage	Y*	-2.63		5443500	Rock	Y	0.99
3344000	Embarras	N			5446500	Rock	Y	0.98
3345500	Embarras	Y*	-0.40		3337700	Saline Branch	Y	1.63
3343395	Embarras	N			5531500	Salt Creek	N	
3346550	Embarras	N			3336900	Salt Fork	N	
5551000	Fox	Y	5.89		5576500	Sangamon	N	
5551540	Fox	Y	7.11		5583000	Sangamon	Y	0.58
5552500	Fox	Y	1.76		5572000	Sangamon	N	
5550000	Fox	Y	5.56		5573540	Sangamon	N	
5546700	Fox	Y	2.94		5572125	Sangamon	N	
5447500	Green	N			3382100	S Fork Saline	N	
5539000	Hickory Creek	Y	6.52		3382055	S Fork Saline	N	
5543500	Illinois	Y	1.24		5575500	S Fork Sangamon	N	
5559900	Illinois	Y	2.54		3380500	Skillet Fork	N	
5586100	Illinois	Y	0.90		5594450	Silver Creek	Y	2.04
5526000	Iroquois	Y	0.32		5594800	Silver Creek	N	
5520500	Kankakee	Y	0.36		3382090	Sugar Creek	Y*	-0.59
5527500	Kankakee	Y	0.07		5576250	Sugar Creek	Y	2.53
5594100	Kaskaskia	N			5581500	Sugar Creek	Y	1.18
5592500	Kaskaskia	Y*	-2.08		5536275	Thorn Creek	N	
5591200	Kaskaskia	Y	1.68		3339000	Vermilion	N	
5440000	Kishwuakee	Y	0.98		5539900	W Branch DuPage	Y	4.23
5584500	La Moine	N			5540095	W Branch DuPage	N	
5585000	La Moine	N						
3378635	Little Wabash	N						
3379500	Little Wabash	N						
3381495	Little Wabash	N						

* Negative trend.

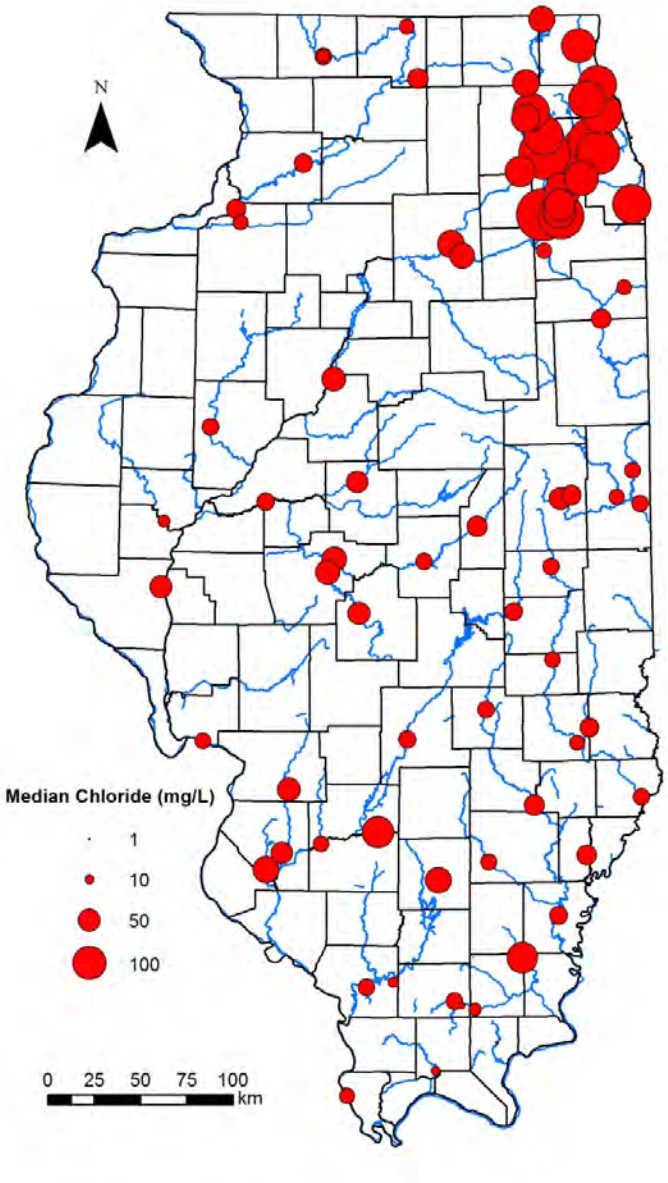

Figure 8. Median Cl^- values in streams and rivers of Illinois for the Water Years 1991-1992 for USGS monitoring stations

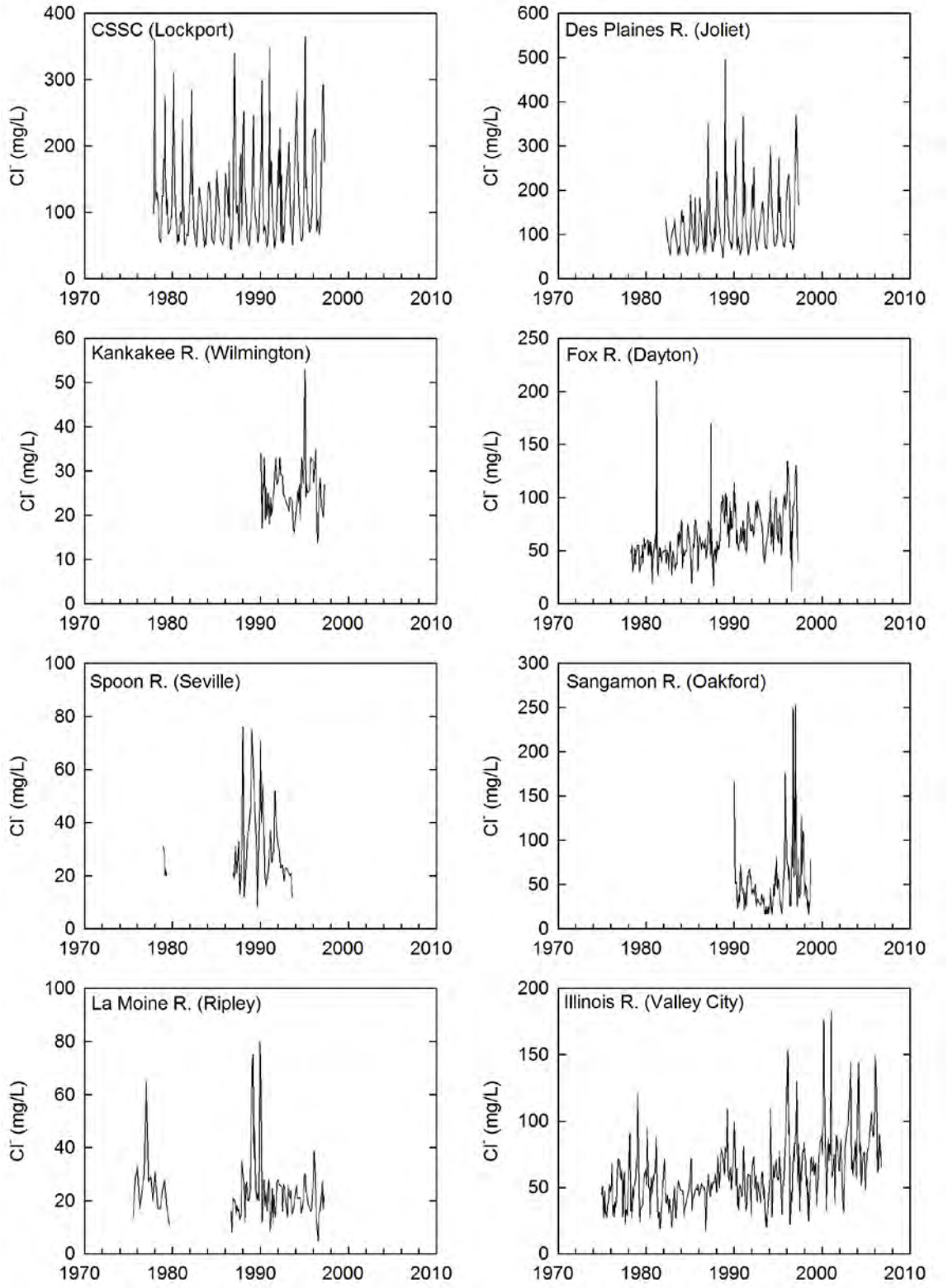

Figure 9. Chloride concentrations at selected USGS monitoring stations in Illinois

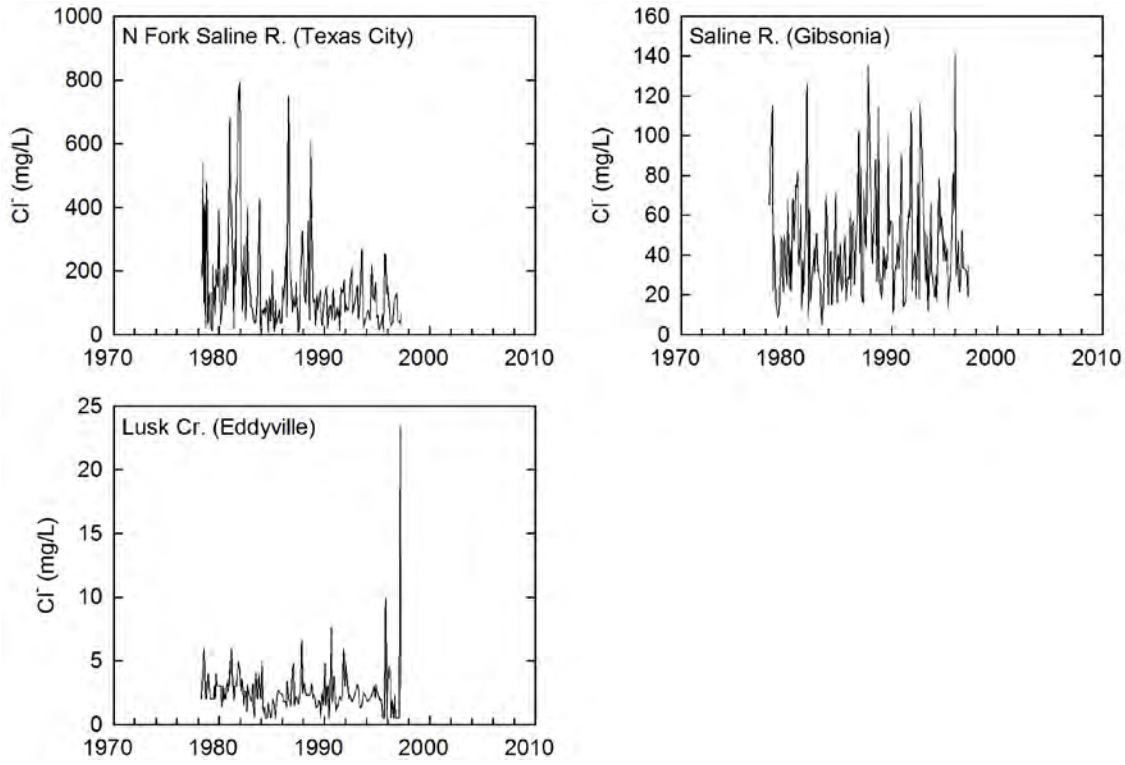

Figure 9. Continued

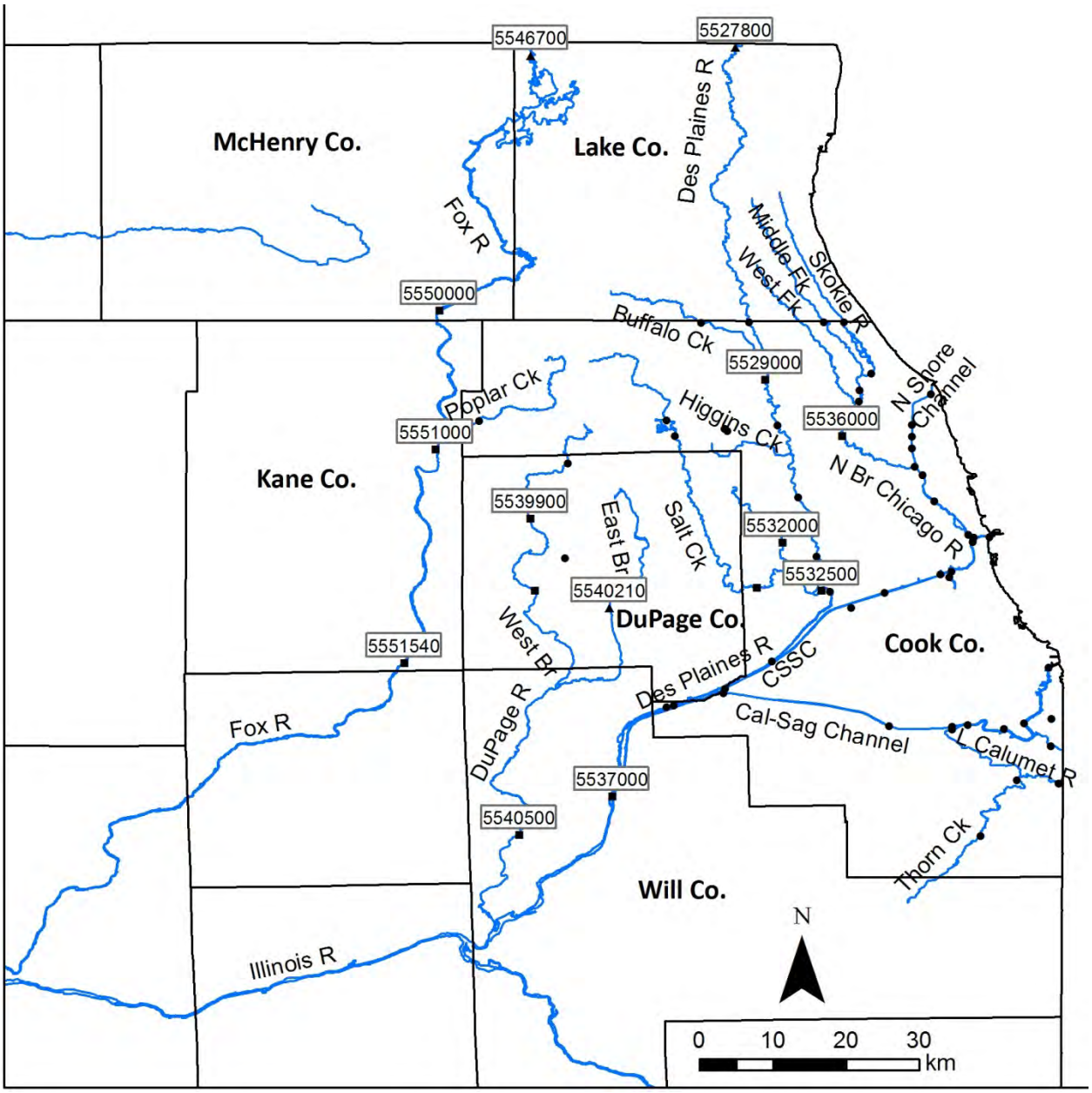

Figure 10. MWRDGC and USGS surface water monitoring stations evaluated in this study. Seven-digit numbers are USGS stations.

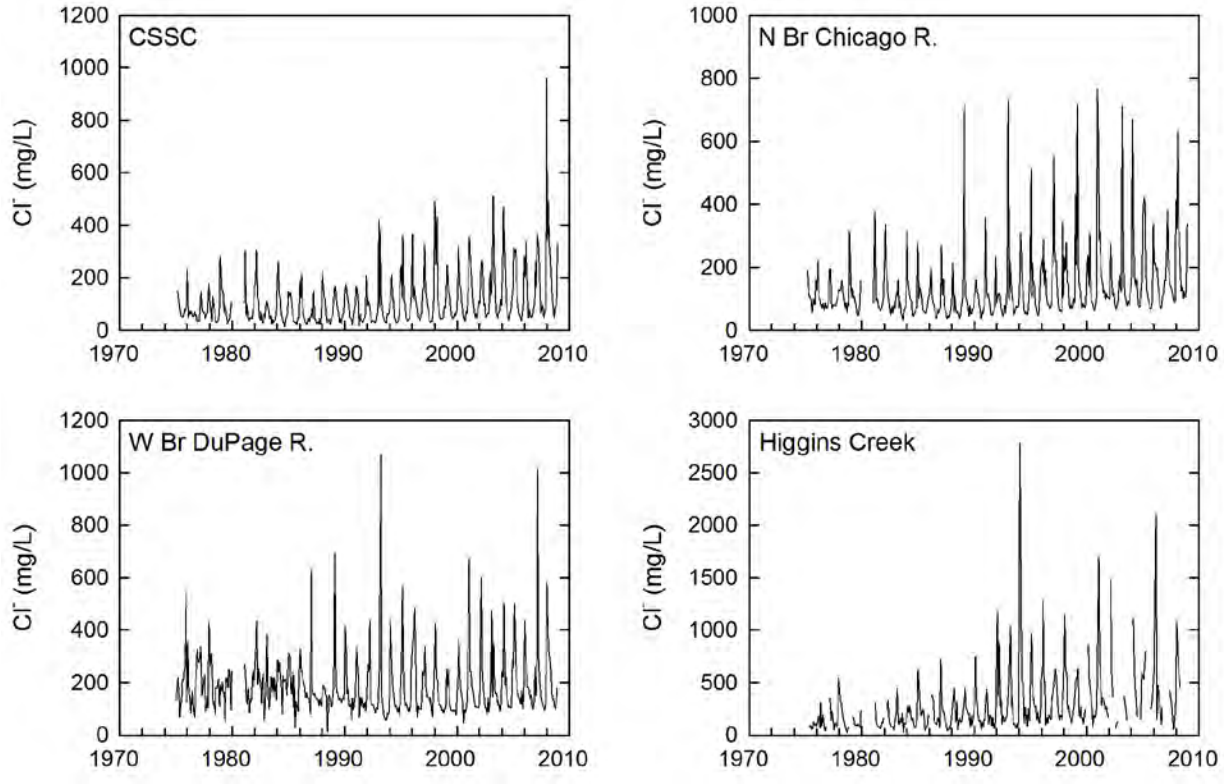

Figure 11. Chloride concentrations at selected MWRDGC monitoring stations in the Chicago region

There are clear seasonal differences in Cl^- concentrations for rivers where concentrations are increasing, with highest values between January and March (Figure 12). At 97 percent of the MWRDGC stations, the largest Cl^- concentrations were in the winter (January–March). At 83 percent of these stations, the winter concentrations were significantly greater (determined by ANOVA on ranks) than each of the other three seasons, and for 16 percent of these stations, concentrations were significantly greater than two of the other seasons. The spring months (April–June) generally had the second highest concentrations (88 percent of the stations), and for 53 percent of these stations spring concentrations were significantly greater than fall or summer. Concentrations were usually lowest in the summer (88 percent of stations). This seasonality is obviously due to road salt runoff. In snowy winters, large applications of NaCl produce Cl^- concentrations and loads in streams and rivers considerably higher than in winters with low snowfalls (Figure 13). It should be noted that during the months when Cl^- concentrations are lowest in the Chicago region (July–October), concentrations still are typically greater than 100 mg/L.

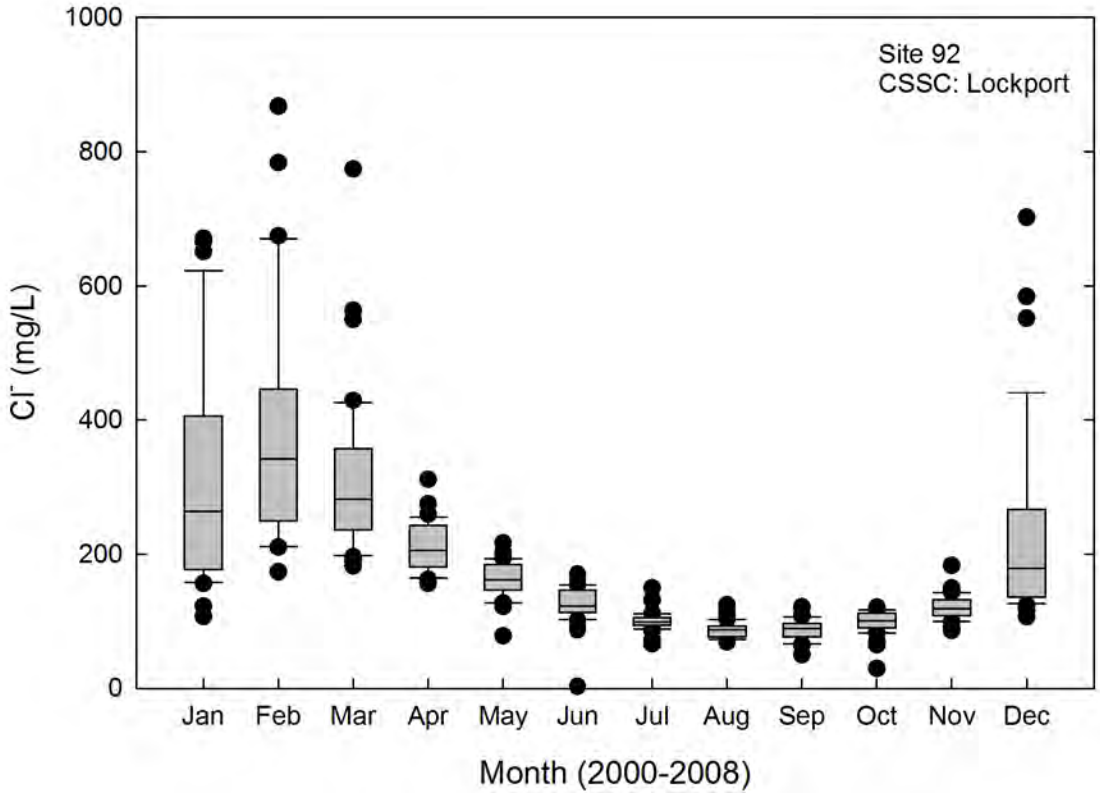

Figure 12. Chloride concentrations by month for MWRDGC station 92 (CSSC at Lockport) between 2000 and 2008. The site was sampled weekly.

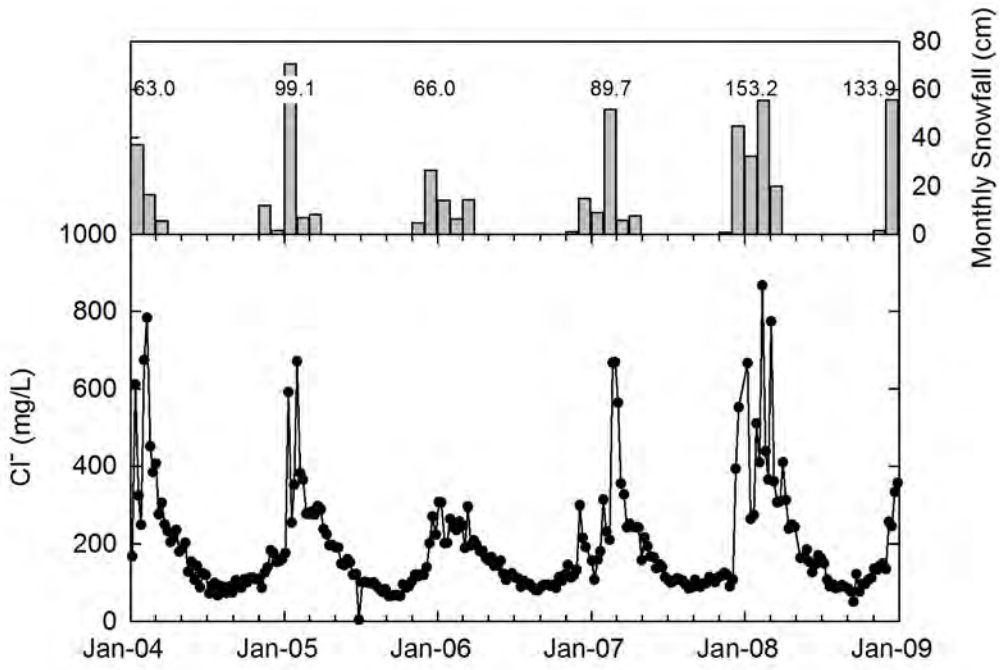

Figure 13. Chloride concentrations at MWRDGC station 92 on the CSSC at Lockport, IL, and monthly snowfall totals in Chicago (winter totals shown above bar). Snowfall data from NOAA, 2010.

Increasing trends in Cl^- concentrations are observed in all seasons at the MWRDGC stations, with the rates of increase following the same seasonal pattern as the concentration data, i.e., greatest increases in the winter and smallest in the summer (Figure 14 and Table 5). This is additional evidence that increases in Cl^- concentrations are the result of road salt runoff.

Rivers outside the Chicago region tended to have different seasonal patterns. Chloride concentrations in the Fox River were significantly lower between April and June than for both autumn and winter samples, and in the Sangamon River, concentrations were significantly lower between April and June than in all other seasons. For both these rivers, the highest Cl^- concentrations were typically measured between October and December. This may be due to leaching of fertilizer, which is typically applied in Illinois in the autumn after harvest. There were no significant seasonal differences for the Kankakee, Spoon, and La Moine Rivers.

Kelly et al. (2010) reported that chloride concentrations were significantly higher when river discharge was low, regardless of season. The USGS data sets showed the influence of discharge on Cl^- concentrations (Figure 15). For every station except CSSC reported by Kelly et al. (2010), Cl^- concentrations at low discharge (bottom 25th percentile) were significantly greater than at high (top 25th percentile) and intermediate (middle 50th percentile) discharges, and concentrations at intermediate discharge were almost always significantly greater than at high discharge. For CSSC, Cl^- concentrations at low discharge were significantly greater than at intermediate discharge.

For the most part, discharge from tributaries to the Illinois River downstream of Chicago dilutes the concentrations of Cl^- and other ions originating from TWW and road salt. Road salt inputs are seasonally variable, with fluxes highest in the winter and early spring; the flux of contaminants from TWW should be less seasonally affected. Thus when the Illinois River discharge is low, there is less dilution of TWW downstream of Chicago. Therefore, Cl^-, which is elevated in TWW, becomes relatively elevated in the river because there is less dilution by downstream tributaries. This relationship can be seen in Figure 16, which shows the fraction of the Cl^- load at Peoria attributable to the load in the CSSC as a function of river discharge at Peoria. When discharge is low, it is not uncommon for more than 60 percent of the Cl^- load at Peoria to be attributable to what is coming out of the CSSC, which is predominantly TWW.

The longest record of data is the Illinois River at Peoria, which indicates that Cl^- concentrations have been steadily increasing since the 1960s (Figure 17). The annual increase since 1960 (from β_1 calculation) is 1.0 mg/L per year (mg/L/yr), and 3.1 mg/L/yr since 1990. Concentrations are highest in the winter and early spring months, and the variability in concentrations during these months has been increasing. The overall temporal increase in Cl^- concentrations is mostly due to increases during January through April; concentrations have increased at rates greater than 4.0 mg/L/yr in all these months since 1990. However, there were positive trends in all months except June, indicating that increases in Cl^- concentrations are due to factors other than just direct road salt runoff. Shallow groundwater in much of the Chicago region has elevated Cl^- due to road salt (Kelly, 2008), and most of this groundwater discharges to tributaries of the Illinois Waterway throughout the year, not just in winter. In addition, the increasing population and concomitant increase in residential acreage and sewage in the Chicago region is likely increasing the Cl^- load to the Illinois Waterway via TWW discharge. The influence of river discharge on Cl^- concentrations can also be seen in Figure 17. Concentrations were relatively low during flood years (e.g., 1972, 1993), and relatively high during droughts (1963–1964, 1977, 1980, 1988–1989).

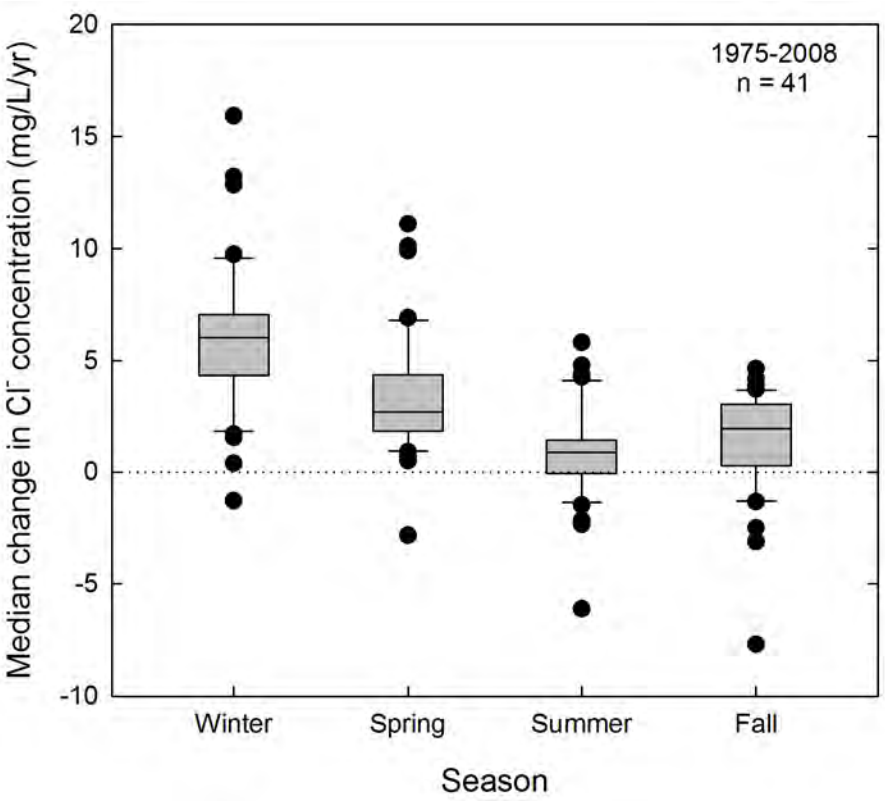

Figure 14. Box and whisker plot of median changes in chloride concentrations for 41 MWRDGC stations monitored between 1975 and 2008, divided by season. Changes calculated from slope statistic ($^2_1$) for linear regressions. Changes were significantly greater for winter compared to all other seasons, and for spring compared to summer and fall (ANOVA on ranks).

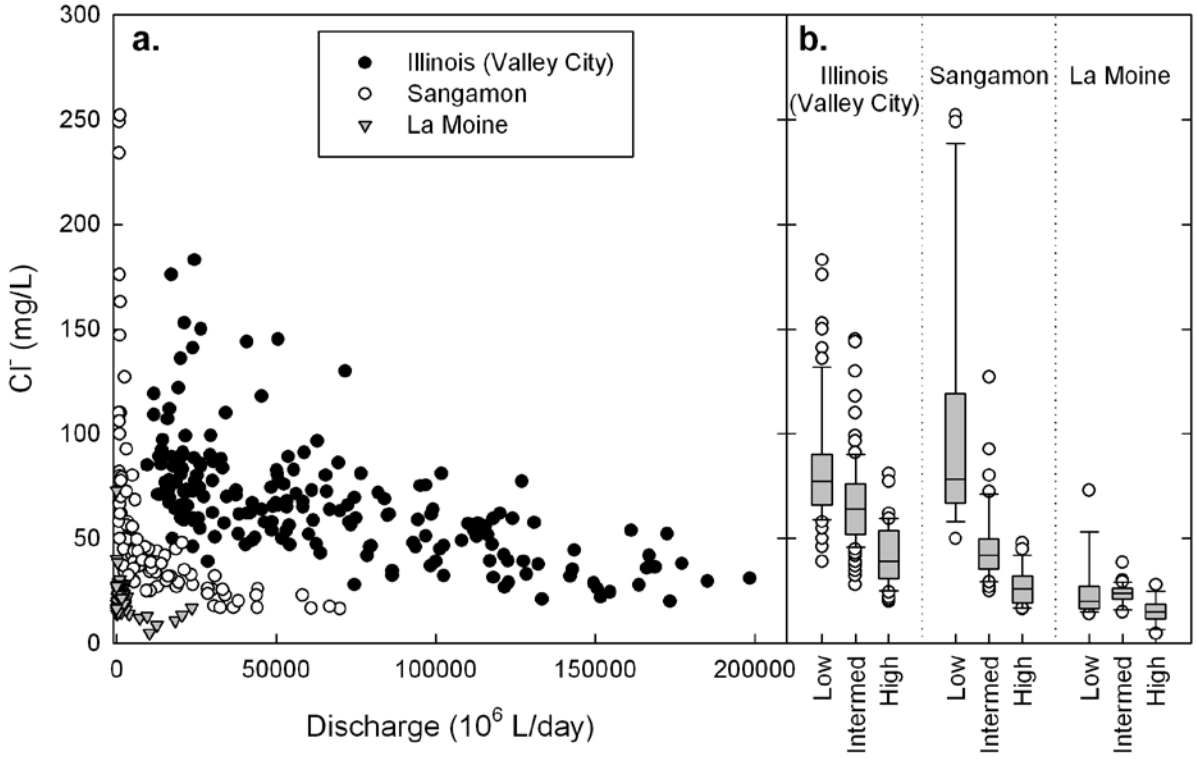

Figure 15. (a) Chloride concentration as a function of discharge for the Illinois River (Valley City), Sangamon River (Oakford), and La Moine River (Ripley). (b) Box plots showing same data as a function of river discharge category; circles are all outliers (< 10%, > 90%). Figure from Kelly et al. (2010), data from USGS (2008).

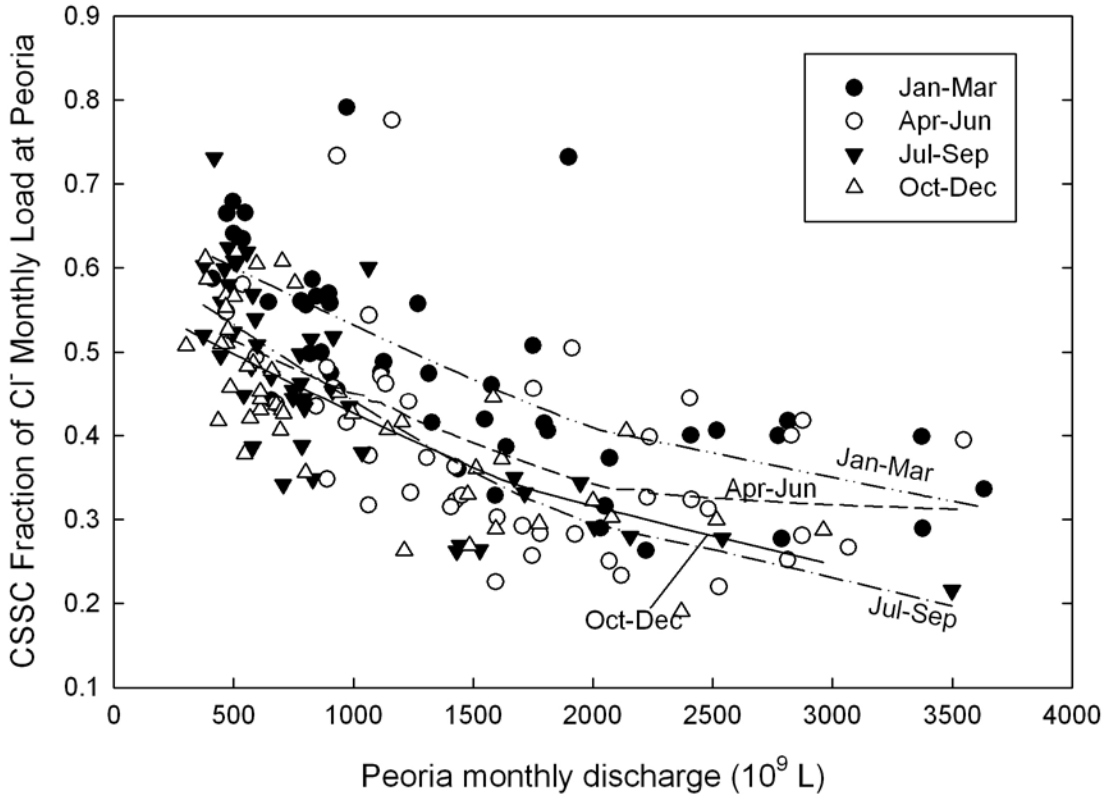

Figure 16. Fractions of the chloride monthly loads in the Illinois River at Peoria that can be attributable to discharge from the CSSC (Romeoville) as a function of monthly discharge at Peoria (1987–2001) Lines are smoothed regressions using LOWESS. Figure from Kelly et al. (2010), data from USGS (2008).

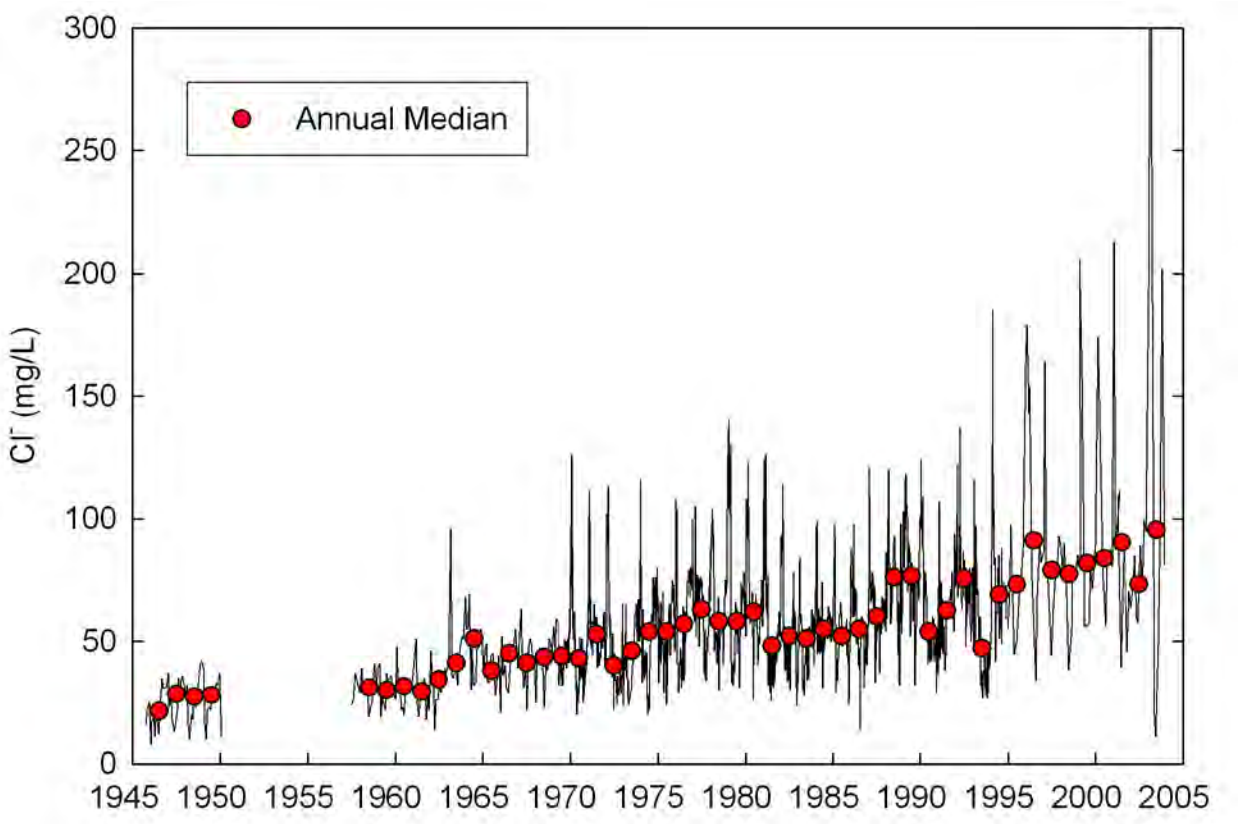

Figure 17. Chloride concentrations in Illinois River at Peoria. Data from ISWS and USGS.

Groundwater

In this report, we use the hydrostratigraphic nomenclature developed by Meyer et al. (2009) to differentiate among aquifers in Illinois. In most of the state, the aquifers closest to the land surface are Quaternary in age. These are composed of unconsolidated sands and gravels deposited by glacial and alluvial processes. Bedrock aquifers in Illinois are all sedimentary rocks (sandstones and carbonates) of Paleozoic age, the youngest being Pennsylvanian and the oldest Cambrian. We divided the bedrock aquifers into three groups (Figure 18), from youngest to oldest: (1) the upper bedrock unit, primarily sandstones of Pennsylvanian and Mississippian age; (2) the Silurian-Devonian carbonate unit, primarily fractured dolomites; and (3) the Cambrian-Ordovician aquifers, which are primarily sandstones. The Cambrian-Ordovician group comprises several aquifers, but because wells are commonly open to more than one of these aquifers, we chose to group them together.

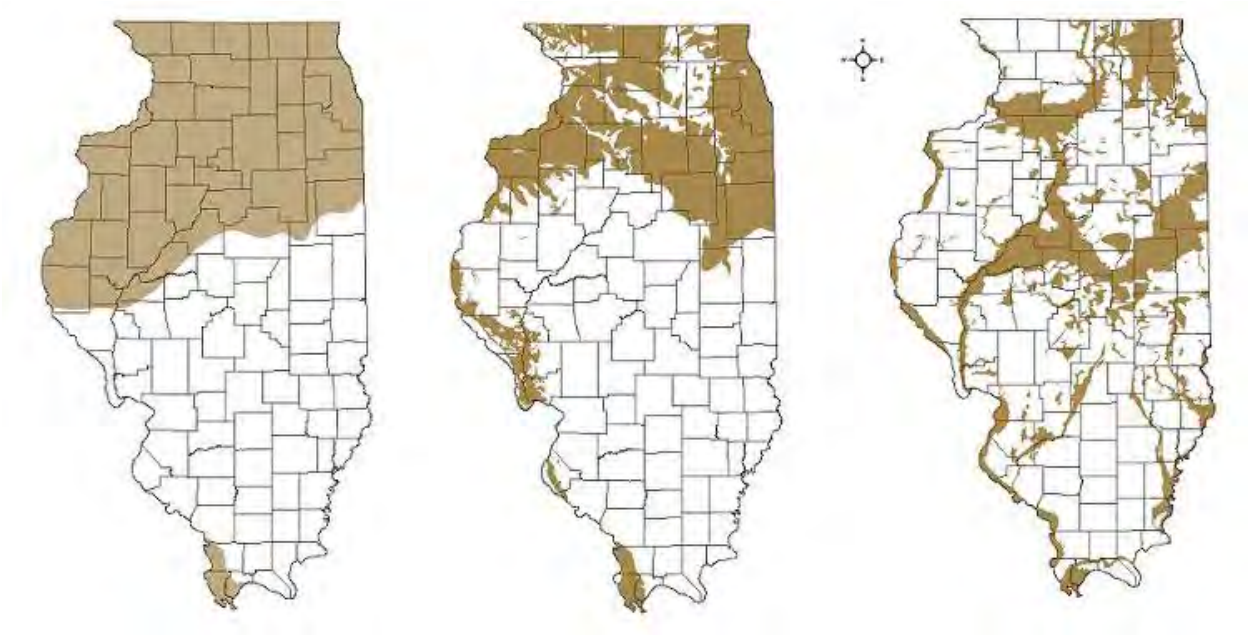

Figure 18. Extents of principal aquifer systems in Illinois (a) Cambrian-Ordovician bedrock; (b) shallow bedrock (Silurian-Pennsylvanian); (c) unconsolidated

Quaternary Aquifers

Sand and gravel Quaternary aquifers are found throughout Illinois (Figure 18c). Alluvial aquifers are found in river valleys; most aquifers in the southern third of Illinois are of this type. Glacial aquifers include buried bedrock valleys filled with sand and gravels and sand and gravel lenses within till deposits. The largest buried bedrock valley aquifer is the Mahomet Aquifer in central Illinois, and other major glacial aquifers are found in the northern half of the state. Chloride concentrations vary greatly in these aquifers (Figure 19).

In the Mahomet Aquifer (Figure 20), chloride concentrations are extremely low in the eastern part of the aquifer, and are < 1 mg/L in parts of Champaign County. Hackley et al. (2010) suggested that recharge from glacial meltwaters recharging the Mahomet aquifer in Champaign County near the end of the Wisconsin Glacial Episode (about 11,500 years BP) leached the fine sediments and sand and gravel of the recharge zone and the aquifer. This resulted in the anomalously low Cl^- concentrations. Near the border between Champaign and Piatt Counties, Cl^- concentrations abruptly increase, due to discharge of brine from Pennsylvanian bedrock. Concentrations then decrease gradually to the west due to dilution. In the western region of the Mahomet aquifer (Piatt, Macon, and DeWitt Counties) where Cl^- concentrations are highest, concentrations along the bedrock valley walls tend to be higher than in the central, thalweg part of the valley. This is likely due to proximity to bedrock discharge along the valley walls and greater dilution in the thalweg. The Mahomet is confined through most of its central and eastern extent, thus surface activities generally do not impact its water quality. In the Sankoty-Mahomet section (Mason and western Tazewell Counties), the Sankoty-Mahomet is unconfined and

surface activities can impact water quality. Elevated Cl^- concentrations in the East Peoria and Pekin regions are probably due to road salt runoff in those urban areas.

Other buried bedrock valley aquifers in Illinois include the Mackinaw and Princeton bedrock valleys northwest of the Mahomet Aquifer. Chloride concentrations are generally low in these aquifers. Burch (2004) reported a median Cl^- concentration of 10.8 mg/L (N = 30) in samples from the Princeton bedrock valley, which included several samples impacted by road salt runoff.

Chloride concentrations in glacial aquifers within till deposits vary greatly. For example, the Glasford Aquifer in central Illinois has Cl^- concentrations ranging from < 1 to about 100 mg/L. Sand and gravel aquifers in northeastern Illinois have been heavily impacted by human activities, with the most obvious sign being increasing Cl^- concentrations. Kelly (2008) showed that Cl^- concentrations in shallow groundwater in the Chicago region have been increasing since the 1960s when road salt began being used in earnest. Over half of the public supply wells finished in sand and gravel aquifers have statistically significant increasing trends in Cl^- concentrations. Widespread sampling of shallow aquifers (< 250 feet deep) in Kane County in 2003 indicated the role of urbanization on shallow groundwater quality (Kelly, 2005). Chloride concentrations were significantly higher in the eastern urban corridor compared with the remainder of the county, which was primarily rural (Figure 21). Figure 21 clearly shows that urban land use increases Cl^- concentrations but rural land uses do not.

Mullaney et al. (2009) reported on Cl^- in unconsolidated glacial aquifers of the U.S. and found that land use significantly affected Cl^- concentrations. Shallow monitoring wells in urban areas had significantly greater Cl^- concentrations (median = 46 mg/L, n = 317) than in agricultural areas (median = 12 mg/L, n = 430), and both were significantly higher than wells in forested areas (median = 2.9 mg/L, n = 50). Their source analysis suggested that Cl^- in urban settings was dominated by deicing and/or water softening salt.

Chloride concentrations in alluvial aquifers in southern Illinois are generally low (< 30 mg/L), with a few exceptions. The Rock River valley in Rockford has higher Cl^- concentrations (generally > 50 mg/L), reflecting greater urbanization and heavier amounts of snow and thus road salt runoff. Chloride concentrations also are higher in the American Bottoms area across the Mississippi River from St. Louis, again reflecting the large degree of urbanization. In areas where there are no aquifers, primarily the southern half of Illinois, large-diameter dug and bored wells are used. These wells are vulnerable to surface contamination. Chloride concentrations in these areas vary widely, probably reflecting the local land use activities that impact the wells.

An important control on Cl^- concentrations in Quaternary aquifers is depth. In general, the shallower the aquifer, the more vulnerable it is to surface-derived contamination. Figure 22 shows Cl^- concentrations for wells 50 feet or less. In contrast, Figure 23 shows Cl^- concentrations for wells greater than 250 feet. Figure 24 shows a box-and-whisker diagram of Cl^- concentrations as a function of depth. Results from ANOVA testing indicated that Cl^- concentrations in each depth range were significantly greater than all deeper groups.

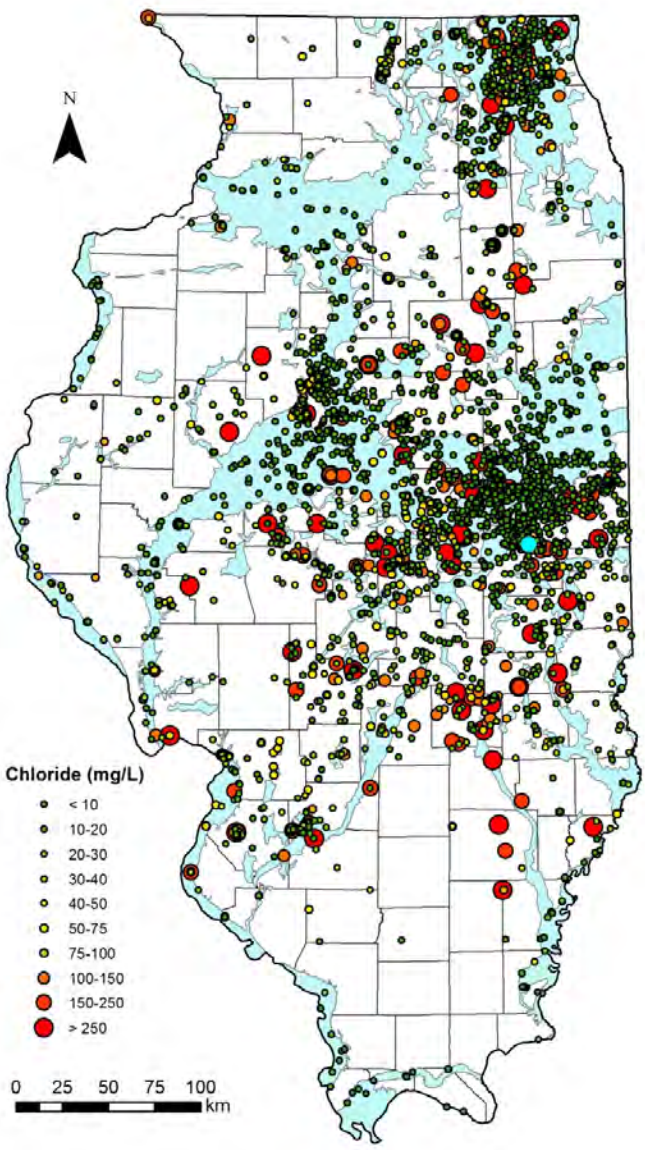

Figure 19. Chloride concentrations in wells open to Quaternary sand-and-gravel aquifers. Locations of significant Quaternary sand-and-gravel aquifers indicated by light blue.

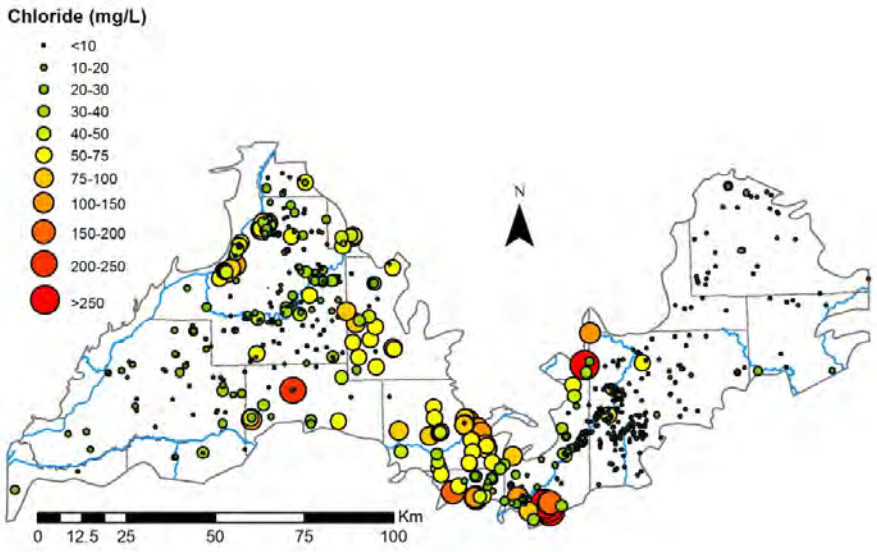

Figure 20. Chloride concentrations in the Mahomet Aquifer

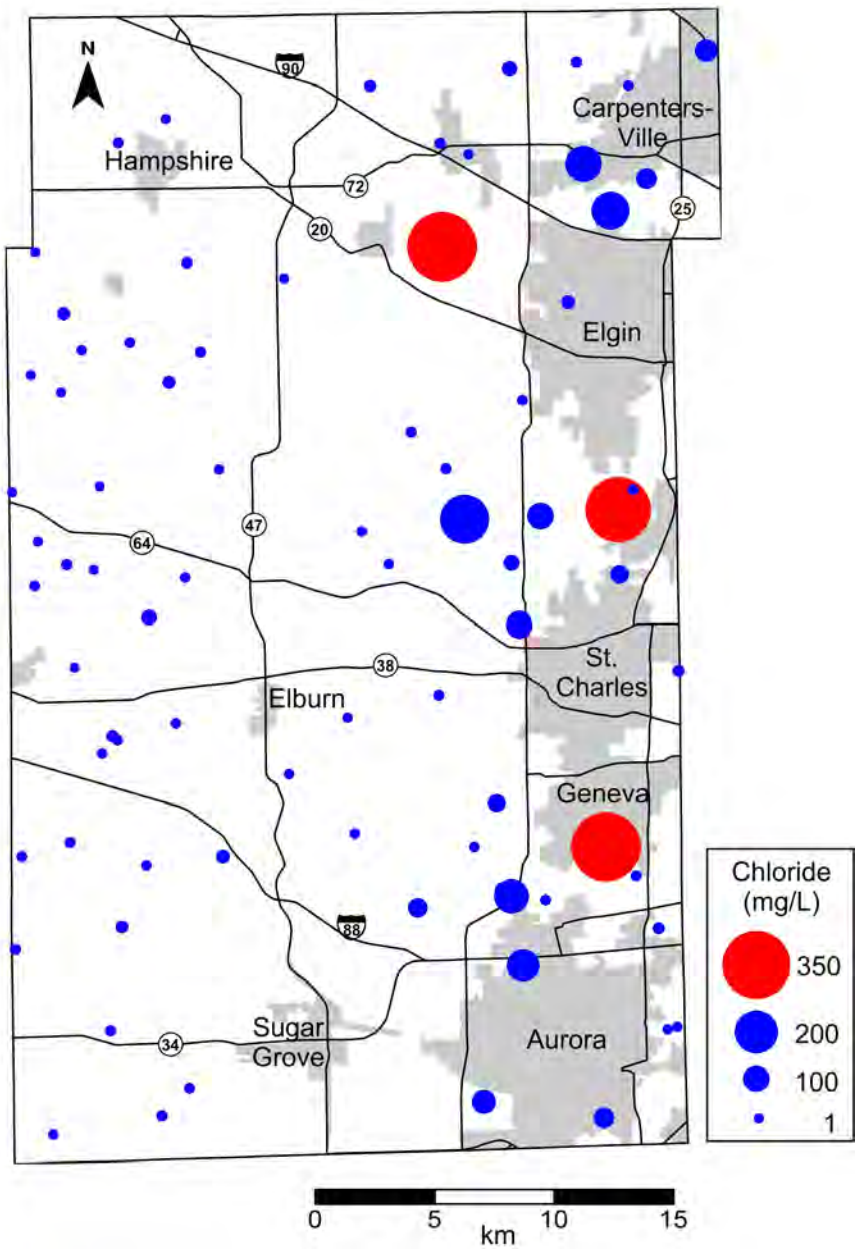

Figure 21. Chloride concentrations in samples collected from shallow wells (< 250 feet) in Kane County in 2003. Size of circle represents Cl^- concentration, with red circles indicating values > 250 mg/L. Gray areas represent municipalities. Major roads shown. Figure from Kelly, 2005.

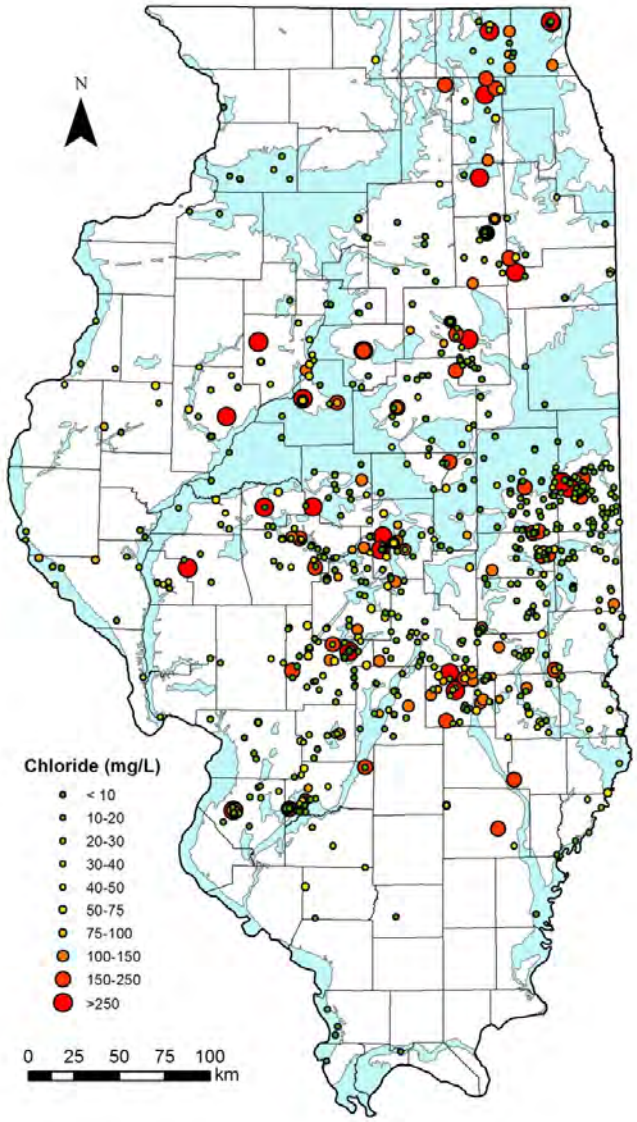

Figure 22. Chloride concentrations in wells 50 feet deep or less open to Quaternary sand-and-gravel aquifers. Locations of significant Quaternary sand-and-gravel aquifers indicated by light blue.

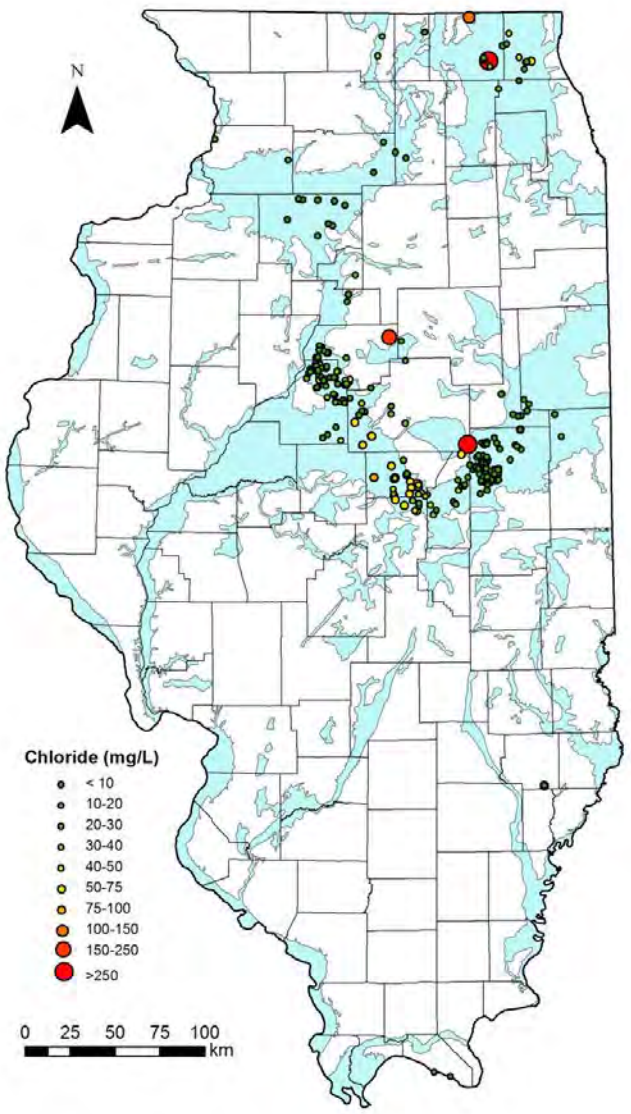

Figure 23. Chloride concentrations in wells equal to or greater than 250 feet open to Quaternary sand-and-gravel aquifers. Locations of significant Quaternary sand-and-gravel aquifers indicated by light blue.

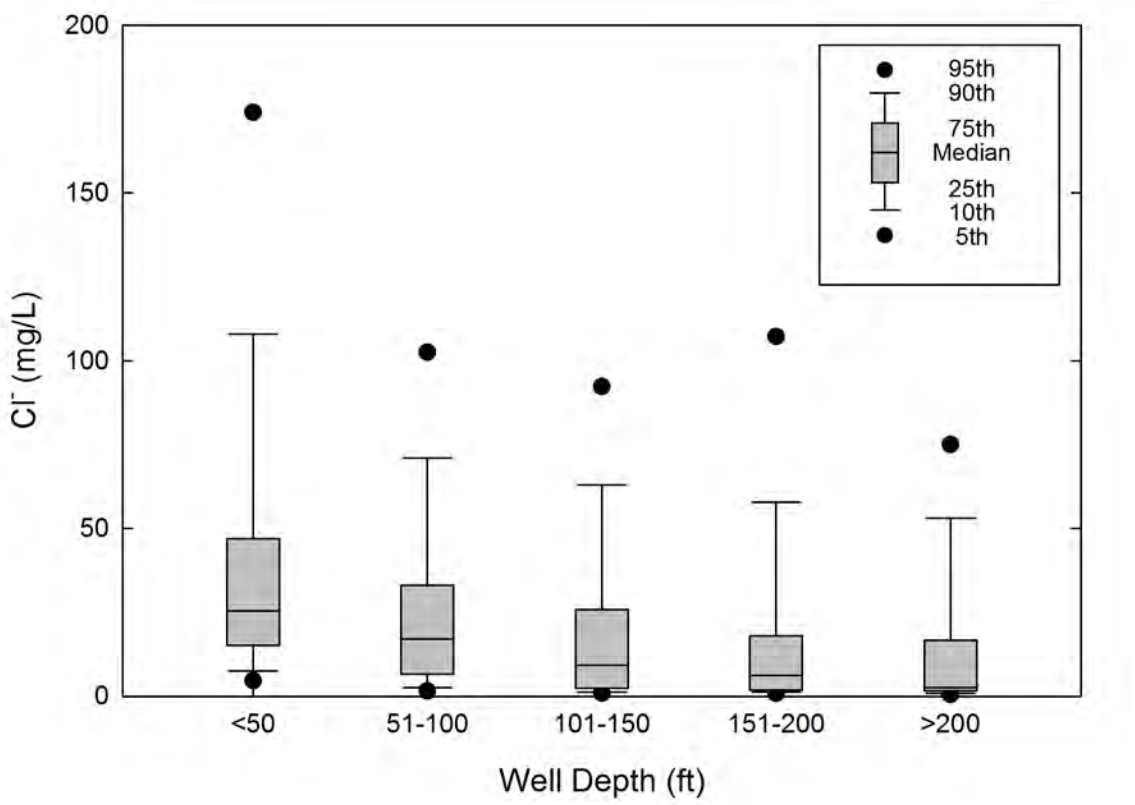

Figure 24. Box-and-whisker diagram for Cl^- concentrations in Quaternary aquifers in Illinois as a function of well depth. Concentrations are significantly greater for each depth group compared to all deeper groups.

Bedrock Aquifers

Bedrock aquifers in Illinois are found in the northern third of the state and along the Mississippi River (Figure 18). Aquifers in the upper bedrock unit are used in the southern two-thirds of Illinois. Chloride concentrations vary widely (Figures 25 and 26), and primarily appear to be a function of depth, i.e., the deeper the well, the higher the concentration (Figure 27). Very high concentrations are likely primarily due to natural sources, i.e., recharge from brines; Pennsylvanian formations are the primary oil producing units in Illinois. Some of these wells may also be exhibiting contamination from leaky brine holding ponds commonly associated with oil drilling activities (Hensel and McKenna, 1989). In the sinkhole plain of southwestern Illinois (Monroe, Randolph, and St. Clair Counties), Mississippian limestones exhibit karst features (sinkholes, caves). These aquifers are extremely vulnerable to surface contamination, but Cl^- is not an important contaminant in this primarily rural region.

Devonian and Silurian Age aquifers are important aquifers in Illinois, heavily used in northeastern and northwestern Illinois (Figure 26). They are primarily of carbonate lithology, the most productive being fractured dolomites. The heaviest use of these aquifers is in the Chicago

region, in DuPage, northern Will, southern and western Cook, and western Lake Counties. These bedrock units dip towards the south, and Cl^- concentrations are significantly greater in areas where the Devonian-Silurian aquifers are deeper (Figures 26 and 27). In northeastern Illinois, the tops of the bedrock aquifers are often in contact with sand and gravel glacial units. Wells are often screened in this interval due to its large hydraulic conductivity. These Silurian bedrock aquifers also show the increasing trend in Cl^- concentrations seen in the sand and gravel aquifers due to road salt runoff (Kelly, 2008). More than half of public supply wells finished in these aquifers tested by Kelly (2008) have statistically significant increasing trends in Cl^- concentrations.

The oldest aquifers in Illinois are found in the northern third of the state and are Cambrian and Ordovician aged. These aquifers are primarily sandstones and are heavily used in the northern part of Illinois, especially centered around Joliet and Aurora south and west of Chicago, respectively. In general, the salinity of water in the Cambrian-Ordovician aquifers is lowest in north-central and northwestern Illinois where the Ancell Aquifer outcrops at the surface and recharge is occurring (Figure 28). Salinity generally increases to the east and south in the direction of flow and stratigraphic dip. Below a latitude of about 40° the water in these aquifers is unpotable due to high TDS levels. Chloride concentrations tend to increase with well depth (Figure 29).

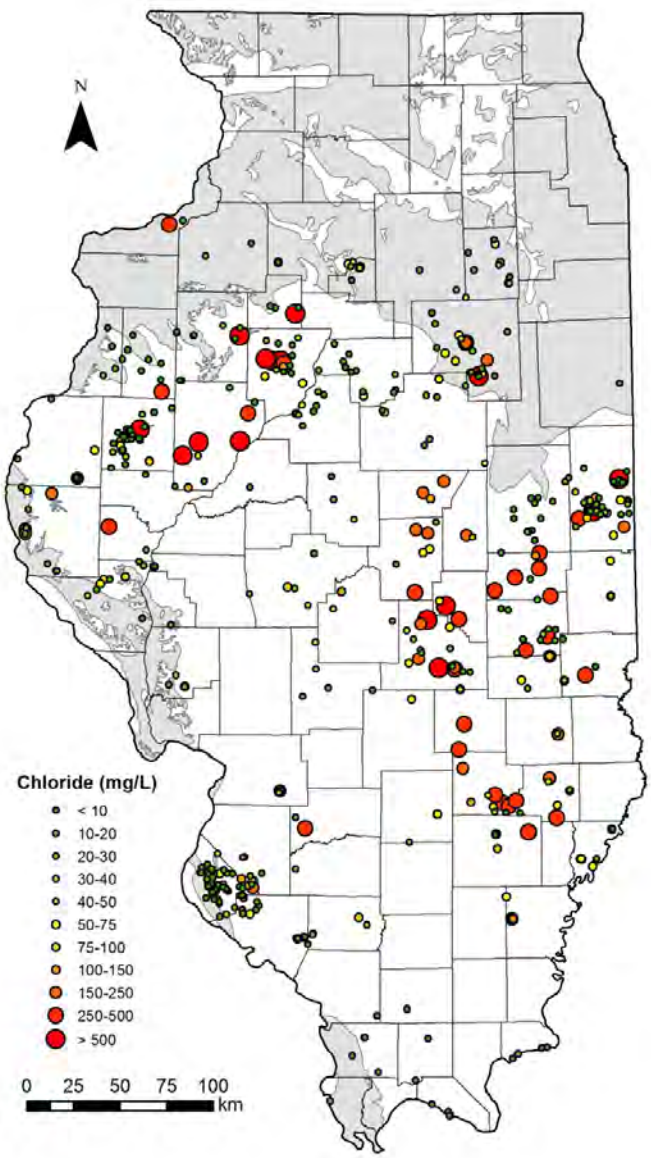

Figure 25. Chloride concentrations in wells open to upper bedrock aquifers (Pennsylvanian-Mississippian). Extent of Silurian-Pennsylvanian aquifers indicated by gray.

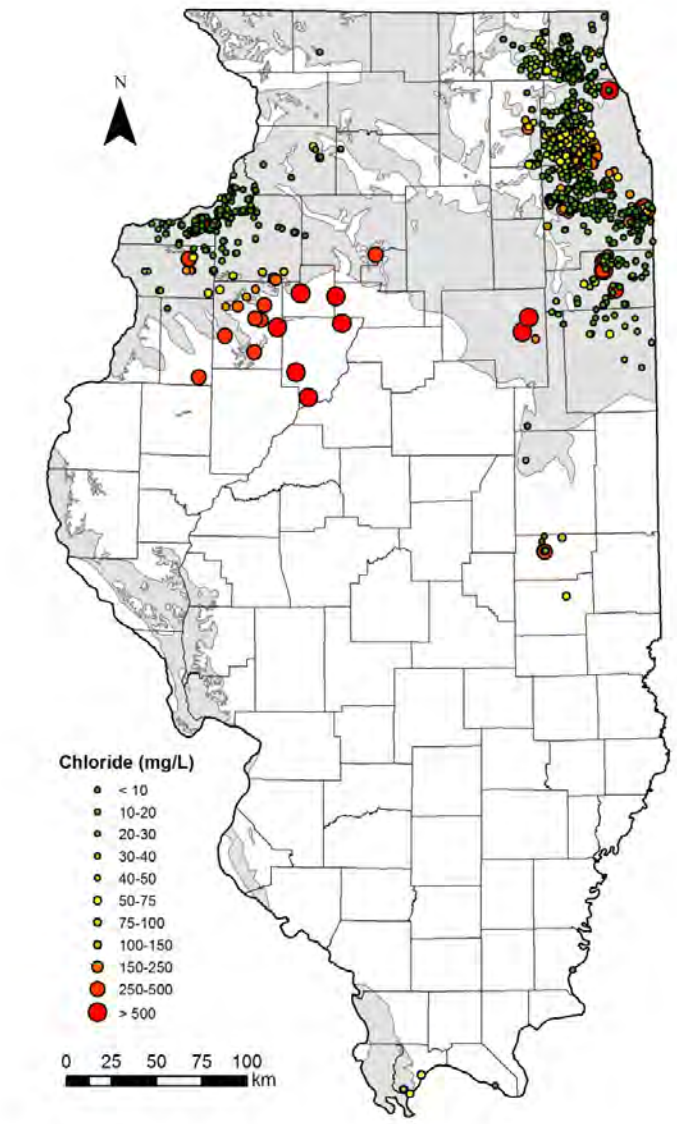

Figure 26. Chloride concentrations in wells open to Devonian-Silurian bedrock aquifers. Extent of Silurian-Pennsylvanian aquifers indicated by gray.

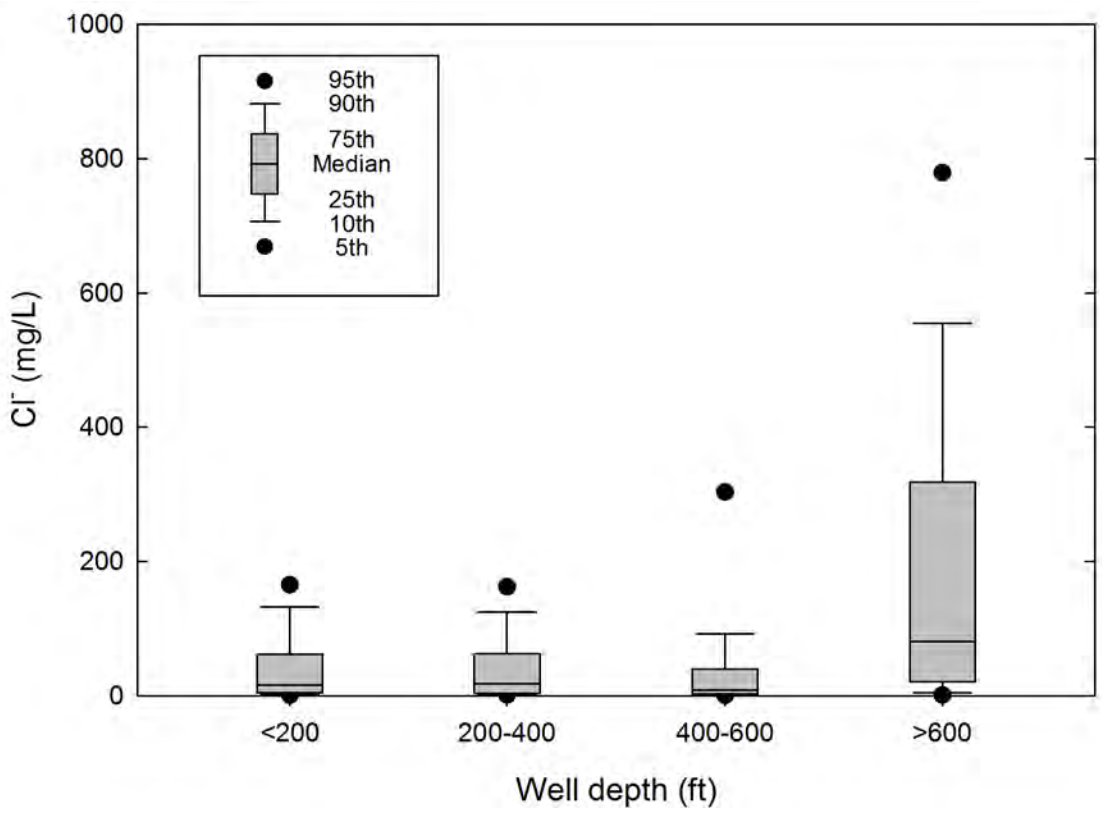

Figure 27. Chloride concentrations as a function of depth for wells completed in Silurian-Devonian bedrock aquifers. The deepest group has significantly greater concentrations than all three shallower groups (ANOVA on ranks).

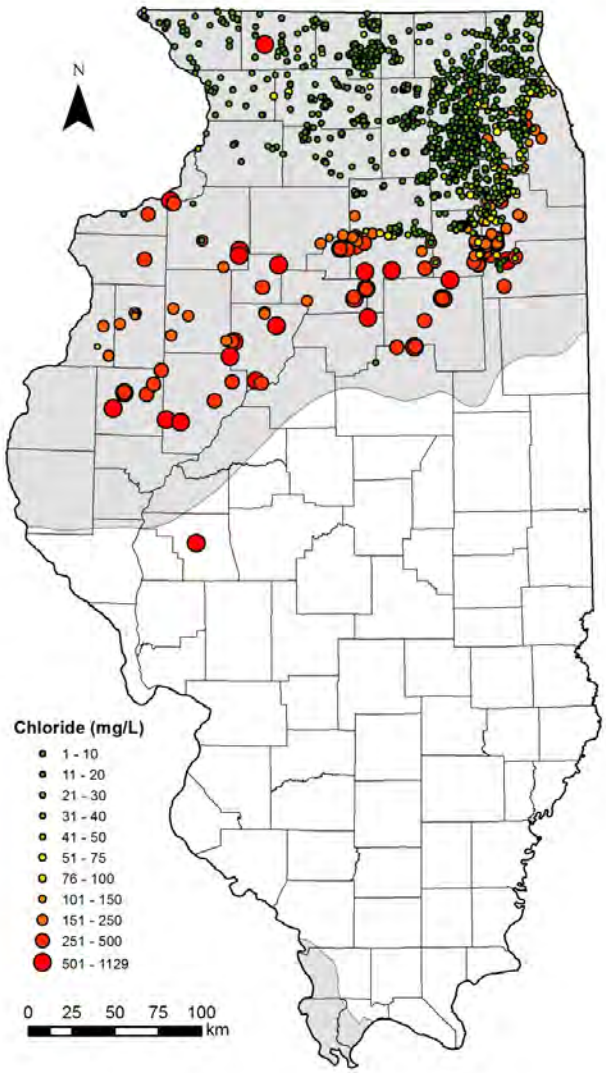

Figure 28. Chloride concentrations in wells open to Cambrian-Ordovician aquifers. Extent of Cambrian-Ordovician aquifers indicated by gray.

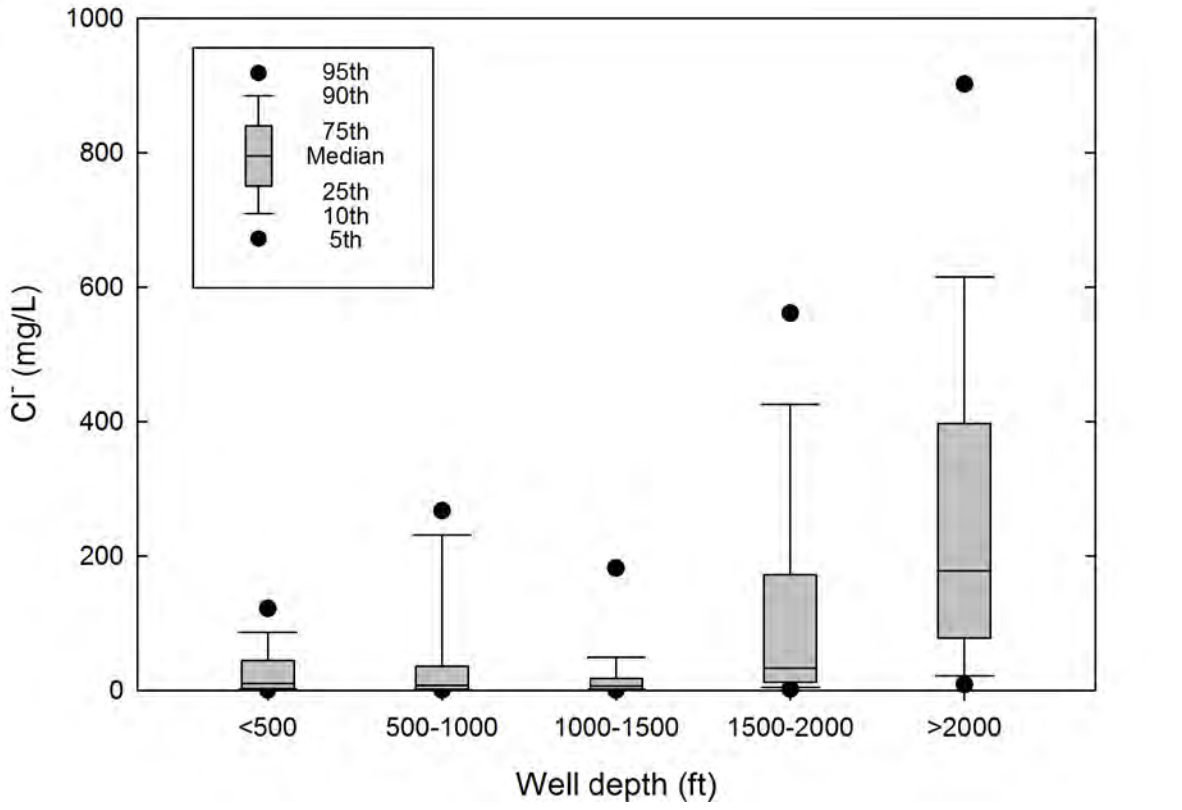

Figure 29. Chloride concentrations as a function of depth for wells completed in Cambrian-Ordovician bedrock aquifers. The two deepest groups have significantly greater concentrations than all three shallower groups (ANOVA on ranks).

Saline Springs

Panno et al. (2010) reported that there are about 30 saline springs throughout the Illinois Basin (most of which are in Illinois) that are coincident with geologic structures within and at the margins of the basin (Figure 2). Saline springs in Illinois have been identified by others (i.e., Bartow et al., 1909; Willman and Payne 1941; Panno et al., 1994, 2006, 2011). Discharge of saline groundwater may be found along the LaSalle Anticlinorium in the form of shallow wells, salt marshes, and springs at Starved Rock, Matheson, and Kickapoo Creek State Parks, and as bedrock seeps into the Mahomet aquifer in east central Illinois (Panno et al., 1994, 2006). Similar saline springs are found in southern Illinois along the Rough Creek-Shawneetown Fault Zone near Equality, and many of these sites are historic in that they were used by Native Americans and early settlers as a source of salt for meat preservation and other uses (Panno et al., 2006, 2010). Chloride concentrations in these springs can range from several hundred to greater than 30,000 mg/L in the case of the Vermilion Salines in Kickapoo Creek State Park (Panno et al., ISGS, unpublished data). The sources of these saline springs range from Cambrian- to Pennsylvanian-age formations (Panno et al., 2010).

Trend Analysis

Shallow aquifers in northeastern Illinois have been heavily impacted by human activities, with the most obvious sign being increasing Cl^- concentrations. Kelly (2008) showed that Cl^- concentrations in shallow groundwater in the Chicago region have been increasing since the 1960s. Over half of the shallow (< 200 ft; 60 m) public supply wells evaluated (N = 239) had statistically significant increasing trends in Cl^- concentrations, and there did not appear to be a leveling off of trends for the most recent samples (1990–2005).

Chloride concentrations have been increasing in shallow aquifers since the 1950s–1960s (Figure 30). The median Cl^- concentration steadily increased from 6 mg/L prior to 1950 to nearly 20 mg/L in samples from 1990 to 2005, and each time period had significantly greater concentrations than the previous time period except for the 1990–2005 group compared to the 1980s. The spread in concentrations has also been increasing, indicating spatial variability in sources of Cl^- contamination. Chloride had greater concentrations in the shallower (< 100 ft) wells than the deeper (100–200 ft) ones for all date groupings (Figure 31). These differences were statistically significant at most time periods for Cl^-. Concentration trends were generally the same for both the shallower and deeper wells. There were increasing trends for Cl^- concentrations for both shallower and deeper wells, with the median concentration increasing from 8 to 36 mg/L in the shallower wells and from 5 to 17 mg/L in the deeper wells from prior to 1950s–1960s to 1990–2005.

For individual counties, the greatest temporal changes for Cl^- were generally found in the western counties, DuPage, Kane, McHenry, and, to a lesser extent, Will County to the south (Figure 31) (Kelly, 2008). In DuPage County, the median values of all major ions tended to increase, especially Cl^-, which increased from 4 mg/L prior to 1950 to 101 mg/L in the 1990s and later, an increase of more than 2500 percent. Chloride in Cook County was highest in the 1990–2005 data group, but there was little change in the previous groups. No significant change occurred in Cl^- concentrations in Lake County during the entire time span.

Kelly (2008) reported there were significant temporal increases in Cl^- concentrations for the majority of the municipal wells tested (55 percent), and significant positive slope values were calculated for 57 percent of the wells (Figure 32). Chloride trends varied spatially; Lake and Cook Counties had relatively low percentages of wells with increasing Cl^- trends (39 to 45 percent) and slope values, while DuPage, Kane, and McHenry Counties had much higher percentages of wells with positive trends (55 to 71 percent) and slope values. Almost half (112 of 239) of the individual public supply wells tested had at least one sample collected between 1990 and 2005. The same trends for Cl^- were observed for the wells with the most recent data compared to the entire group of wells, suggesting that there has not been a leveling off in Cl^- concentrations in the 1990s or later (Kelly, 2008).

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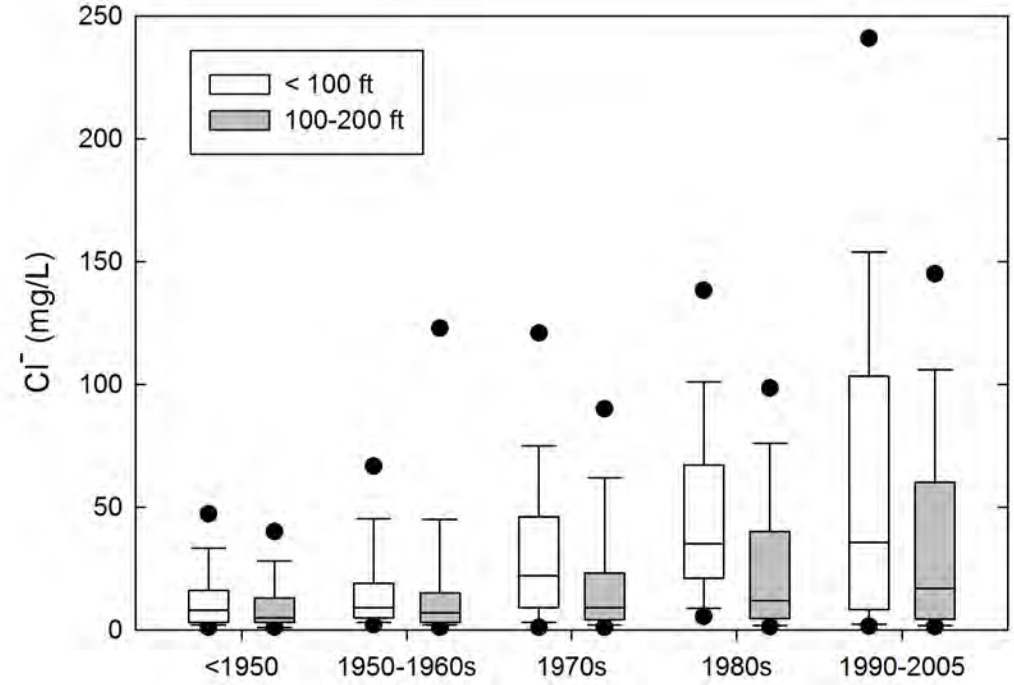

Figure 30. Box plots of Cl^- concentrations in shallow aquifers in the Chicago region. Circles show 5th and 95th percentile data. Figure from Kelly (2008).

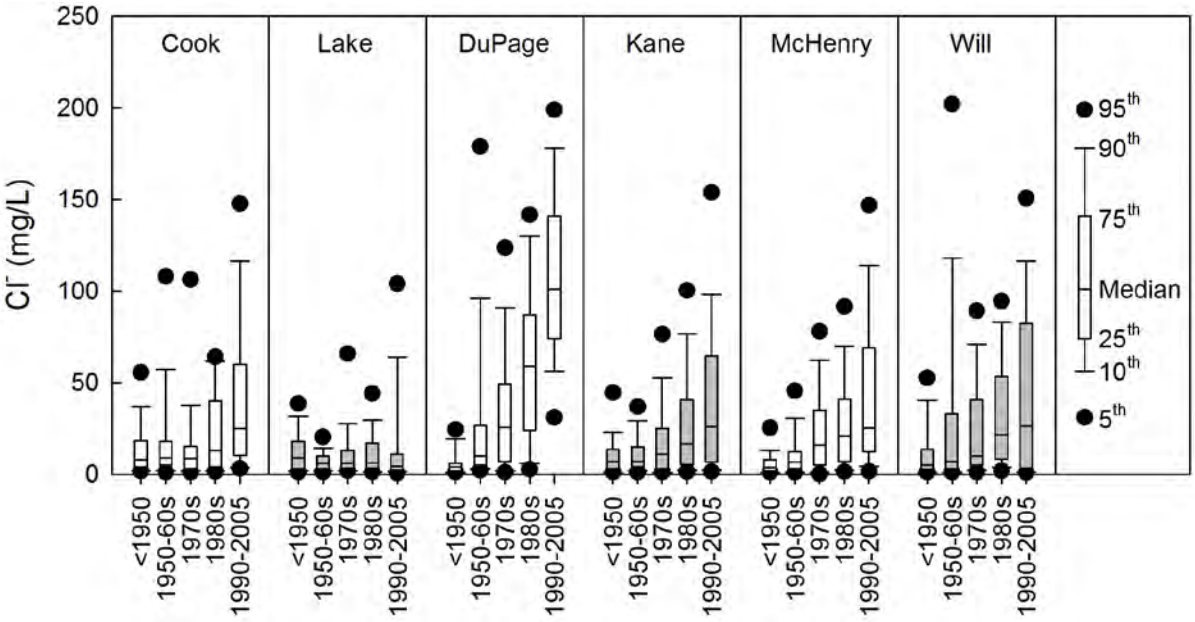

Figure 31. Box plots of Cl^- concentrations in shallow aquifers in the Chicago region by county. Figure from Kelly, 2008.

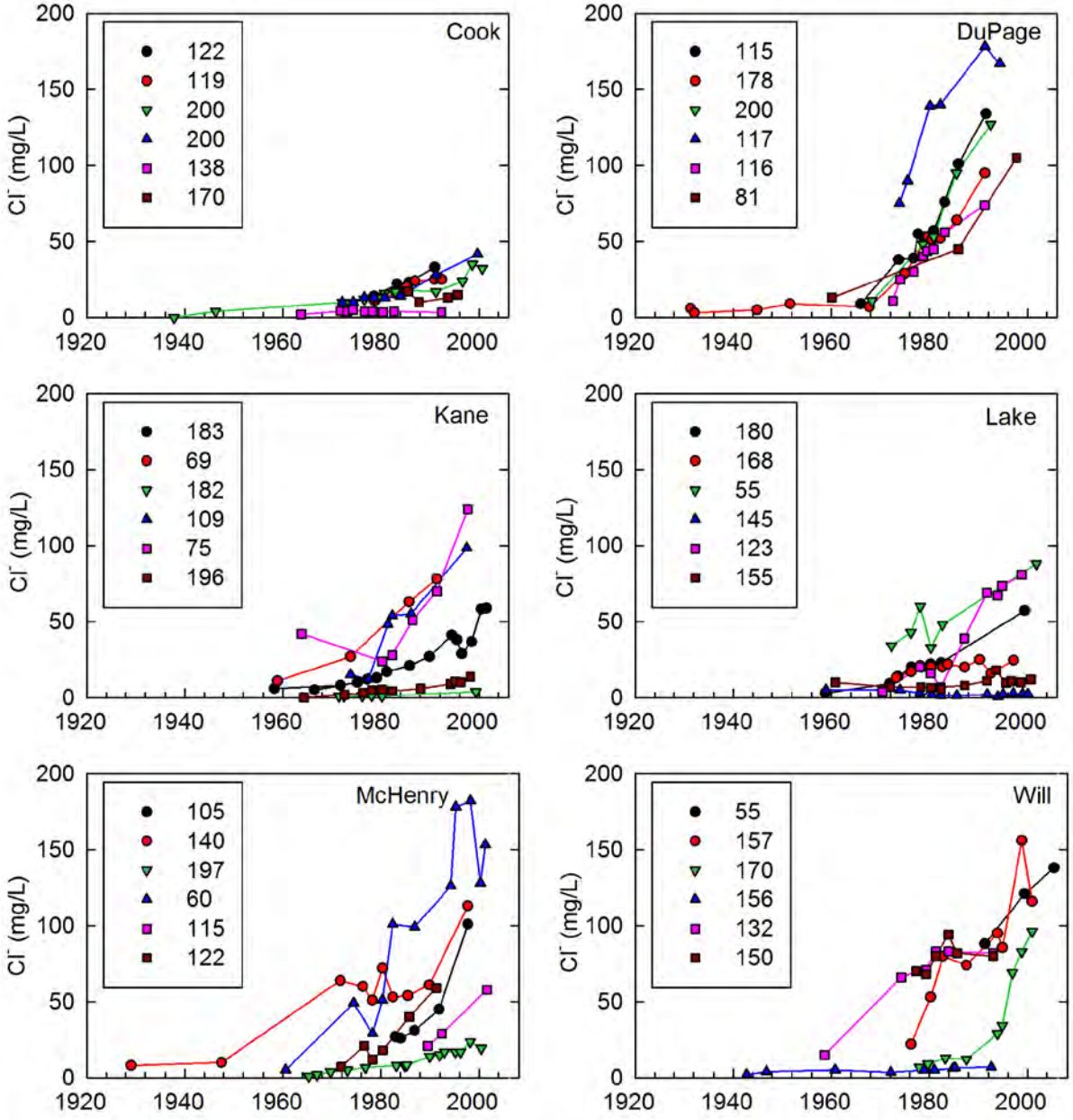

Figure 32. Chloride concentrations as a function of time for selected public supply wells in the Chicago region. Well depths (feet) in legends. Figure from Kelly, 2008.

Wetlands

Wetlands are defined as lands that transition between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water (U.S. Fish and Wildlife, 2011). Wetland substrates can be either predominantly undrained hydric soils or nonsoils that are saturated or covered by shallow water at some time during the growing season. Wetland types found in Illinois include marshes, swamps, bogs, and fens (USEPA, 2011b). Water quality in wetlands should generally reflect their source water, whether it is shallow groundwater or surface runoff, but land use activities adjacent to wetlands can strongly influence concentrations of Cl^- and other aqueous species within the wetlands.

There have been few published studies that include water quality data, and specifically Cl^-, for wetlands in Illinois. There are some published data for fens and bogs in northeastern Illinois. Fens are essentially springs that receive a very hard Ca-HCO_3-type groundwater, while bogs receive surface water from more dilute runoff. Both types of wetlands are common in northeastern Illinois. Fens at Sterne's Woods State Natural Area near Crystal Lake and South Elgin Fen near South Elgin were found to be contaminated with road salt and septic effluent (Panno et al., 1999, 2006). One part of a fen at Sterne's Woods that was reported to be in near pristine condition had Cl^- concentrations between 8.8 and 44 mg/L. Two other fens affected by septic effluent and road salt had Cl^- concentrations as high as 339 mg/L and 283 mg/L, respectively. Septic effluent and road salt discharged into South Elgin Fen increased the Cl^- concentration to 116 mg/L (Panno et al., 2005). In cases where septic effluent discharged into fens, the diverse fen-wetland vegetation was replaced by a more salt-tolerant monoculture of cattails (*Typhaangustifolia*). Panno et al. (1999) reported that fen vegetation diversity was profoundly reduced when Cl^- concentrations exceeded 45 mg/L. Road salt runoff has reduced plant diversity in wetlands of northern Illinois, where very high Cl^- concentrations have produced wetlands that can only support cattails and other halophilic vegetation (e.g., *Phragmitesaustralis*).

Discussion and Conclusions

Prior to major settlements in Illinois, Cl^- concentrations in most shallow groundwater and rivers and streams were very low, probably < 10 mg/L, and in many cases much lower. The exceptions were areas where natural brines in Paleozoic sedimentary rocks discharged at or near the land surface. There were numerous saline springs that were exploited by Native Americans and early settlers for making salt. There are numerous streams and rivers in Illinois with names such as Salt Creek or Saline Branch, named because of the discharge of saline water in or near these streams.

Once Illinois became settled as the population grew, contamination of water began. Chloride was not an important component of contamination sources in the 19th century, with the possible exception of livestock waste. It wasn't until around the middle of the 20th century that the important sources of Cl^- contamination, i.e., water conditioning salt, KCl fertilizer, and road deicers, began to be used in large amounts in Illinois. Since that time, there has been an increase

in Cl^- concentrations in many water bodies in Illinois, and there does not yet appear to be any slackening in its increase in groundwater or surface waters (Kelly, 2008; Kelly et al., in press).

One of the most likely results of increasing Cl^- concentrations in surface waters is degradation of aquatic biota. We are unaware of any systematic studies of the effects of elevated levels of Cl^- on aquatic biota in the Chicago area, but it seems certain that there would be negative effects. Corsi et al. (2010) reported that seven of 13 streams in the Milwaukee, WI, area exhibited toxicity to water fleas (*Ceriodaphniadubia*) and fathead minnows (*Pimephalespromelas*) due to road salt runoff. They measured very high Cl^- concentrations in some of the streams (commonly > 1,000 mg/L and up to 7,730 mg/L).While these are higher than typically found in stations monitored in Chicago, some of the smaller streams occasionally had Cl^- concentrations > 1,000 mg/L, and smaller streams that are unmonitored undoubtedly experience even higher concentrations.

Chicago, many of its suburbs, and many other cities in Illinois have combined sewer systems, with storm water runoff being collected and treated at WWTPs. A large percentage of road salt runoff in the most urban parts of the Chicago region thus does not enter shallow groundwater but is diverted to streams and rivers in discharge from WWTPs. The rapid transfer of saline snow melt to streams and rivers in Chicago produces very high Cl^- concentrations in the winter. However, some road salt runoff ends up in the soil zone and shallow groundwater, and this could represent a relatively long-term source of Cl^- and other ions to surface water.

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Appendix 7

**Lineback, J., 1979. Quaternary Deposits of Illinois:
Illinois State Geological Survey map, scale 1:500,000**

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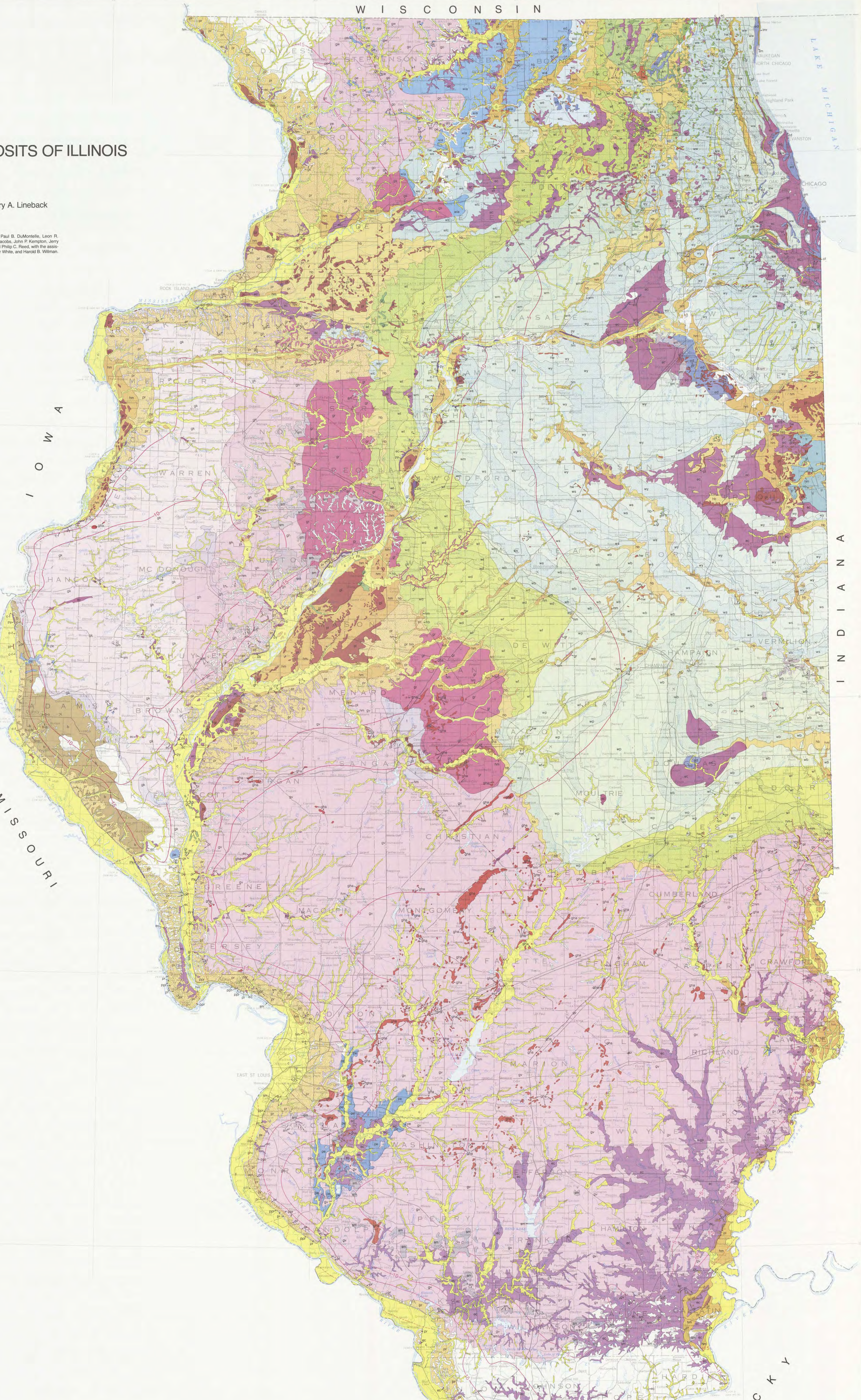
INSTITUTE OF NATURAL RESOURCES
STATE OF ILLINOIS
ILLINOIS STATE GEOLOGICAL SURVEY
Jack A. Simon, Chief
Urbana, 1979

QUATERNARY DEPOSITS OF ILLINOIS

Compiled by Jerry A. Lineback

From maps prepared in 1975 by Paul B. DuMontelle, Leon R. Follmer, David L. Gross, Alan M. Jacobs, John P. Kempton, Jerry A. Lineback, E. Donald McKay, and Philip C. Reed, with the assistance of Herbert D. Glass, W. Arthur White, and Harold B. Willman.



EXPLANATION

Because many of the areas mapped are small, the conventional symbols for Quaternary units are abbreviated. Q for Quaternary is omitted.

SYSTEM — SERIES — STAGE — SUBSTAGE

QUATERNARY — PLEISTOCENE

HOLOCENE

sm — **Surface Mines**

Includes coal strip mines; rock quarries; clay, sand, or gravel pits; and other excavated areas, including those where the mixed fill of bedrock or Quaternary deposits was replaced or disturbed. Also includes areas of man-made fill in areas formerly covered by Lake Michigan or Lake Calumet in northeastern Illinois and by causeways in Rend Lake and Carlyle Lake in southern Illinois. Many small areas are not shown.

WISCONSINAN and HOLOCENE — WOODFORDIAN, TWOCREEKAN, VALDERAN, and younger

c — **Cahokia Alluvium**

Deposits in floodplains and channels of modern rivers and streams; mostly poorly sorted sand, silt, or clay containing local deposits of sandy gravel; in many places overlies well-sorted glacial outwash of the Henry Formation.

c-f — **Alluvial-fan facies of Cahokia Alluvium**

Fan-shaped deposits of poorly sorted sand and silt at the mouths of tributary streams along the Illinois and Mississippi Rivers.

Lake Michigan Formation

Lacustrine sediments and beach deposits of modern lakes.

lmr — **Ravinia Sand Member of Lake Michigan Formation**

Sand on modern beaches; map shows only areas along major beaches of Lake Michigan such as those near Illinois Beach State Park.

py — **Peyton Colluvium**

Narrow deposits of largely unsorted debris that resulted from creep and slopewash and accumulated on and at the base of river bluffs. May include some areas where materials were deposited by slumps or landslides (Lacon Formation).

pl — **Parkland Sand**

Windblown sand; well-sorted, medium-grained sand in dunes and thick sheet deposits between dunes.

gl — **Grayslake Peat**

Peat, muck, and marl; dominantly organic deposits that are interbedded with silt and clay in some places. Mostly found in glacial lake basins; locally in lake basins on floodplains of major rivers.

WISCONSINAN — ALTONIAN, FARMDALIAN, WOODFORDIAN, TWOCREEKAN, and VALDERAN

Equality Formation

Lake deposits; offshore deposits of silt and clay; sand facies near shorelines. Deposits in older lakes have a thin to medium cover of silt (Richland Loess or Peoria Loess).

ec — **Carmi Member of Equality Formation**

Largely quiet-water lake sediments dominated by well-bedded silt and some clay; includes sediment of proglacial lakes and slack-water lakes in valleys tributary to major river valleys. Where thin and discontinuous, generally covers more than 25 percent of the area mapped.

ed — **Dolton Member of Equality Formation**

Largely shallow-water, nearshore lake sediments in beaches, bars, spits, and deltas; includes some former lakes that contain coarse-grained deposits; dominantly medium-grained sand; some gravel along beaches; contains beds of silt where gradational with the Carmi Member.

Henry Formation

Sand and gravel; generally well sorted; local minor beds of silt; glacial outwash in outwash plains, valley trains, and ice-contact deposits; generally has a thin cover of silt (Richland Loess or Peoria Loess).

hm — **Mackinaw Member of Henry Formation**

Sand and gravel; generally well sorted and well bedded; deposits in valleys; mostly glacial outwash in former valley trains and terrace remnants of former valley trains.

hb — **Batavia Member of Henry Formation**

Sand and gravel; well-sorted deposits of glacial meltwater in outwash plains and fans on uplands.

hw — **Wasco Member of Henry Formation**

Sand and gravel; unevenly sorted; irregularly bedded lenses of silt and till; glacial ice-contact deposits in kames, eskers, and kame terraces.

WISCONSINAN

pr — **Peoria Loess and Roxana Silt**

Windblown silt more than 20 feet (6 m) thick on uplands; local lenses of fine-grained sand. Combined thickness of Peoria and Roxana (outside the limit of Wisconsinan glaciation) shown by 15-foot (4.5-m), 10-foot (3.0-m), and 5-foot (1.5-m) contour lines. Thicknesses are averages for undisturbed uplands. The thickness of the Peoria Loess on Altonian drift and the thickness of the Richland Loess within the areas of Woodfordian drift are also shown by the contours.

ppr — **Peyton Colluvium, Peoria Loess, and Roxana Silt**

A complex deposit of silt more than 20 feet (6 m) thick on steep slopes along the bluffs of the Mississippi River in the St. Louis area. A colluvial mixture of Peoria and Roxana formed by creep and slopewash.

WOODFORDIAN

Wedron Formation

Mostly glacial till with lenses and beds of sand, gravel, and silt; includes all tills of Woodfordian age in the Lake Michigan and Green Bay Lobes; surface often mantled with silt (Richland Loess).

Ground moraine

Solid colors indicate ground moraine including areas of generally low relief underlain by tills that lie between the morainic ridges.

Moraine

Overprinted pattern indicates moraines associated with the till members; generally continuous curvilinear areas that have elevated hummocky topography and local deposits of sand, gravel, and peat in addition to till.

ww, wy, ws — **Wadsworth Till Member of Wedron Formation / Yorkville Till Member of Wedron Formation / Snider Till Member of Wedron Formation**

Mostly gray clayey and silty clayey till. The Wadsworth contains few pebbles and cobbles and is more clayey near Lake Michigan than till to the south and west. Local lenses of sand and silt. Where the intervening Haeger Till Member is absent, it is difficult to distinguish the Wadsworth from the Yorkville, and the boundary is placed at the front of the Valparaiso Morainic System. The Yorkville is a gray or greenish-gray, very clayey till overlain in some places by extensive glacial lake deposits. The Snider is a gray silty clayey till that has a coarse blocky structure.

wh — **Haeger Till Member of Wedron Formation**

Sandy and gravelly till, commonly thin, over thick deposits of sand and gravel outwash that are included in the member; present only in northeastern Illinois.

wm, wb, wp — **Malden Till Member of Wedron Formation / Batestown Till Member of Wedron Formation / Piatt Till Member of Wedron Formation**

Gray silty till that oxidizes to olive brown; some sandy till and lenses of sand and gravel. The Malden is a gray silty till that oxidizes to olive brown; local lenses of sand and gravel. The Batestown is a gray silty till that oxidizes to olive brown; recognized in east-central Illinois only. The Piatt includes sandy and silty gray till.

Continued in next column

QUATERNARY — PLEISTOCENE — WISCONSINAN — WOODFORDIAN (Continued)

wt, wd, wt-a, wf — **Tiskilwa Till Member of Wedron Formation / Ablation drift of Tiskilwa Till Member / Delavan Till Member of Wedron Formation / Fairgrange Till Member of Wedron Formation**

Pink, pinkish-gray, gray, brown, and reddish-brown silty and sandy till; lenses of silt, sand, and gravel in some places. The Tiskilwa is generally sandy and silty till that is pinkish- or reddish-brown; includes yellow-gray to pinkish-gray sandy ablation drift (Gilberts Drift) in a small area in northeastern Illinois. The Delavan is gray to pinkish-gray sandy to silty till. The Fairgrange is pink, reddish-brown, and brownish-gray sandy till in east-central Illinois.

wlc, we — **Lee Center Till Member of Wedron Formation / Esmond Till Member of Wedron Formation**

Gray silty to clayey till in the Green River Sublobe of the Lake Michigan Lobe in northwestern Illinois; generally thin and discontinuous; includes areas of bedrock and older drift. The Lee Center is a gray clayey till. The Esmond is a gray till, silty in the upper part and silty clay till in the lower part.

Trafalgar Formation (of Indiana)

Mostly till; some associated sand and gravel. An extension of Erie or Saginaw Lobe drift into Illinois; overlies part of the Yorkville Till Member of the Wedron Formation.

tr — **Unnamed till member of Trafalgar Formation (of Indiana)**

Mostly yellow-gray sandy and silty till; the Iroquois Drift.

ALTONIAN

Winnebago Formation

Till with interbedded silt, peat, and gravel; present at surface in northwestern and central northern Illinois; separated from the Wedron Formation by the Robein Silt and Morton Loess. Generally covered by thin to medium layers of silt (Peoria Loess).

wic — **Capron Till Member of Winnebago Formation**

Pink sandy till in upper part, silty in lower part; mapped in central northern Illinois only.

wia — **Argyle Till Member of Winnebago Formation**

A very sandy, gravelly, pinkish-tan or salmon till; may include older tills with similar composition; present in central northern Illinois.

ILLINOIAN — LIMAN, MONICAN, and JUBILEEAN

t — **Teneriffe Silt**

Mostly silt and clayey silt with beds of sand or clay deposited in large proglacial lakes associated with several Illinoian glaciers; may contain some outwash, sheetwash, and eolian deposits. Generally has prominent Sangamon Soil at top of deposits and is overlain by a moderate thickness of silt (Peoria Loess and Roxana Silt).

pe — **Pearl Formation**

Sand, gravel, and some silt in outwash plains and valley-train deposits of Illinoian glaciers; largely preserved as small terrace remnants along major drainageways in central and western Illinois and as extensive remnants along the lower Kaskaskia River Valley in southern Illinois. Generally has prominent Sangamon Soil at top of deposits and is overlain by moderate to thick silt (Peoria Loess and Roxana Silt).

Glasford Formation

Till with interbedded sand and gravel and surficial clay, silt, sand, and gravel deposits. The Glasford is the most widespread glacial formation in Illinois. The Glasford is divided into several members; generally has prominent Sangamon Soil at top of deposits and is overlain by moderate to great thickness of silt (Peoria Loess and Roxana Silt).

Ground moraine

Solid colors indicate Illinoian ground moraine.

Moraine

Small moraines of the Illinoian present in some places are indicated by the overprint pattern. The moraines consist of subdued, rounded ridges of till and some outwash sands and gravels.

gha — **Hagarstown Member of Glasford Formation**

Mostly well-sorted and well-bedded sand and gravel, cemented in some places; till in places; in kames, eskers, and crevasse fillings; kames may contain large thrust blocks of older till or bedrock. Commonly overlies the Vandalia Till Member, but similar deposits overlying older and younger tills are mapped as the Hagarstown Member also; includes the "ridged drift" of the Kaskaskia Basin, elongate sand-and-gravel-cored ridges in south-central Illinois.

JUBILEEAN

gr, gs — **Radnor Till Member of Glasford Formation / Sterling Till Member of Glasford Formation**

Mostly gray compact silty till with a little gravel, sand, and silt in some places.

MONICAN

gw, gv, go, gh — **Winslow Till Member of Glasford Formation / Ogle Till Member of Glasford Formation / Vandalia Till Member of Glasford Formation / Hulick Till Member of Glasford Formation**

Compact, hard, silty, sandy, and clayey till and intercalated sand and gravel. The Winslow is dark-gray clayey till in northwestern Illinois, related to the Ogle, but more clayey; thin with many small outcrops of underlying bedrock included. The Ogle is thin and discontinuous, tan to grayish-brown sandy till; many small outcrops of underlying bedrock or areas of bedrock covered by thin silt included; probably related to the Hulick. The Hulick and Vandalia are hard, compact sandy till with sand and gravel; mapped as Hulick west of the Illinois River and Vandalia east of the Illinois River; gradational to silty till in southern Illinois.

LIMAN

gk — **Kellerville Till Member of Glasford Formation**

Brown and gray silty till with discontinuous sand and gravel beds; mineralogically intermediate between western Banner Formation tills and the Vandalia-Hulick; may include some older tills of similar composition in extreme western Illinois; mapped only west of the Illinois River; small areas of stratigraphically equivalent Smithboro Till Member in southern Illinois may be included in the Vandalia.

KANSAN

b, b-o — **Banner Formation / Banner Formation outwash facies**

Mostly till, but includes small areas of outwash sands and gravels and lacustrine silt and clay. Sand and gravel facies (b-o) in terrace remnants along tributaries to the Mississippi. Mapped where not overlain by Illinoian deposits in western Illinois and in other scattered locations where it crops out from under Illinoian drift; generally has Yarmouth Soil or combined Yarmouth and Sangamon Soil at the top of deposit and is overlain by thick deposits of silt (Peoria Loess and Roxana Silt). As mapped, Banner Formation may actually include deposits of several pre-Illinoian glaciations.

TERTIARY-QUATERNARY — PLIOCENE-PLEISTOCENE

mg — **Mounds Gravel**

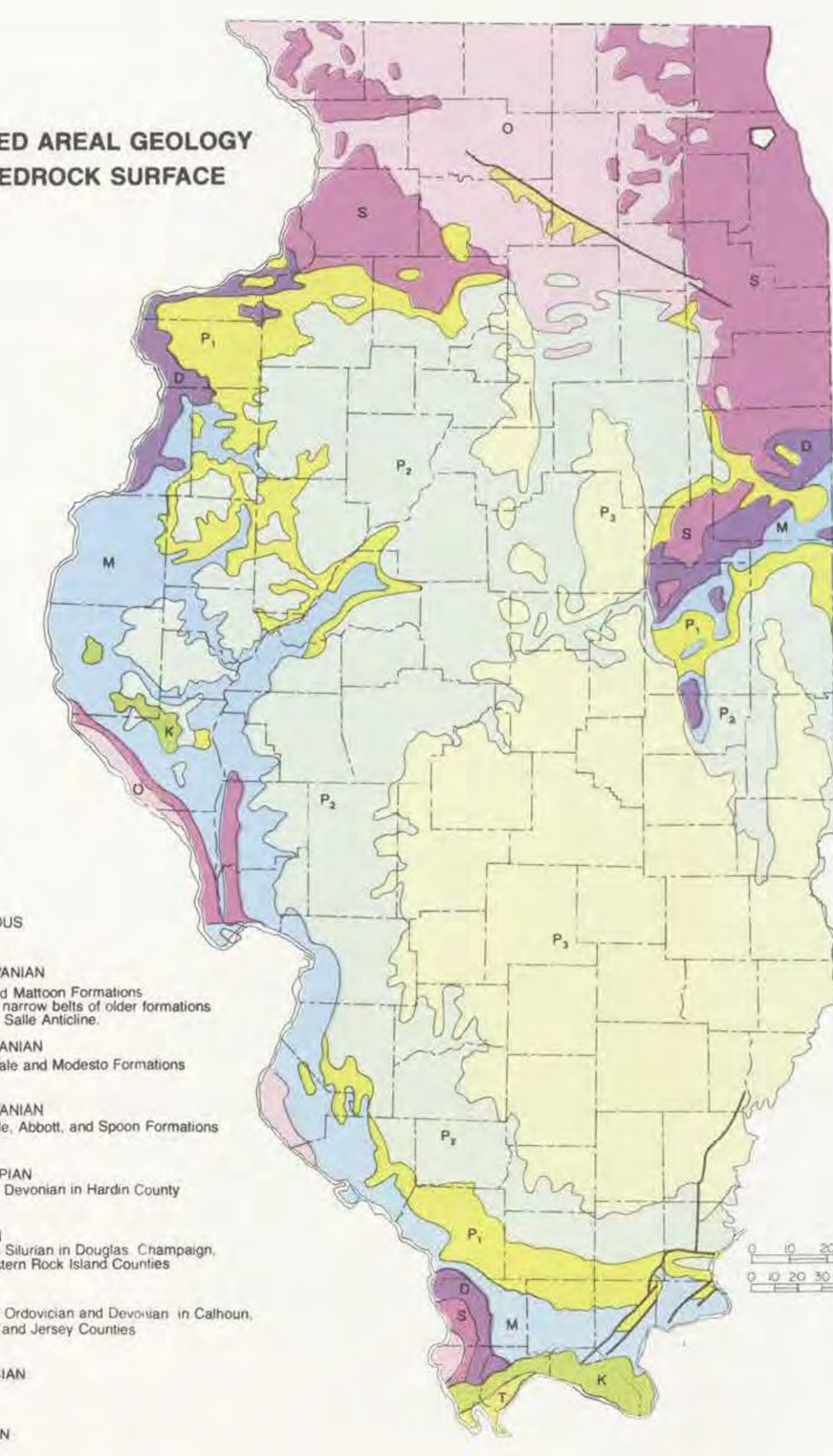
Mostly gravel on uplands; brown chert pebbles; high remnants of former terrace levels believed to be of Pliocene-Pleistocene age; does not contain materials characteristic of glacial deposits; mapped only in extreme southern Illinois. Similar gravel, the Grover Gravel, is present in areas too small to map in western Illinois (Calhoun County); generally overlain by moderate to thick silt (Peoria Loess and Roxana Silt).

White areas on map indicate that rocks older than Pliocene are present at or near the surface; for bedrock units, see inset bedrock map or refer to Willman and others (1967), *Geologic Map of Illinois* (1:500,000).

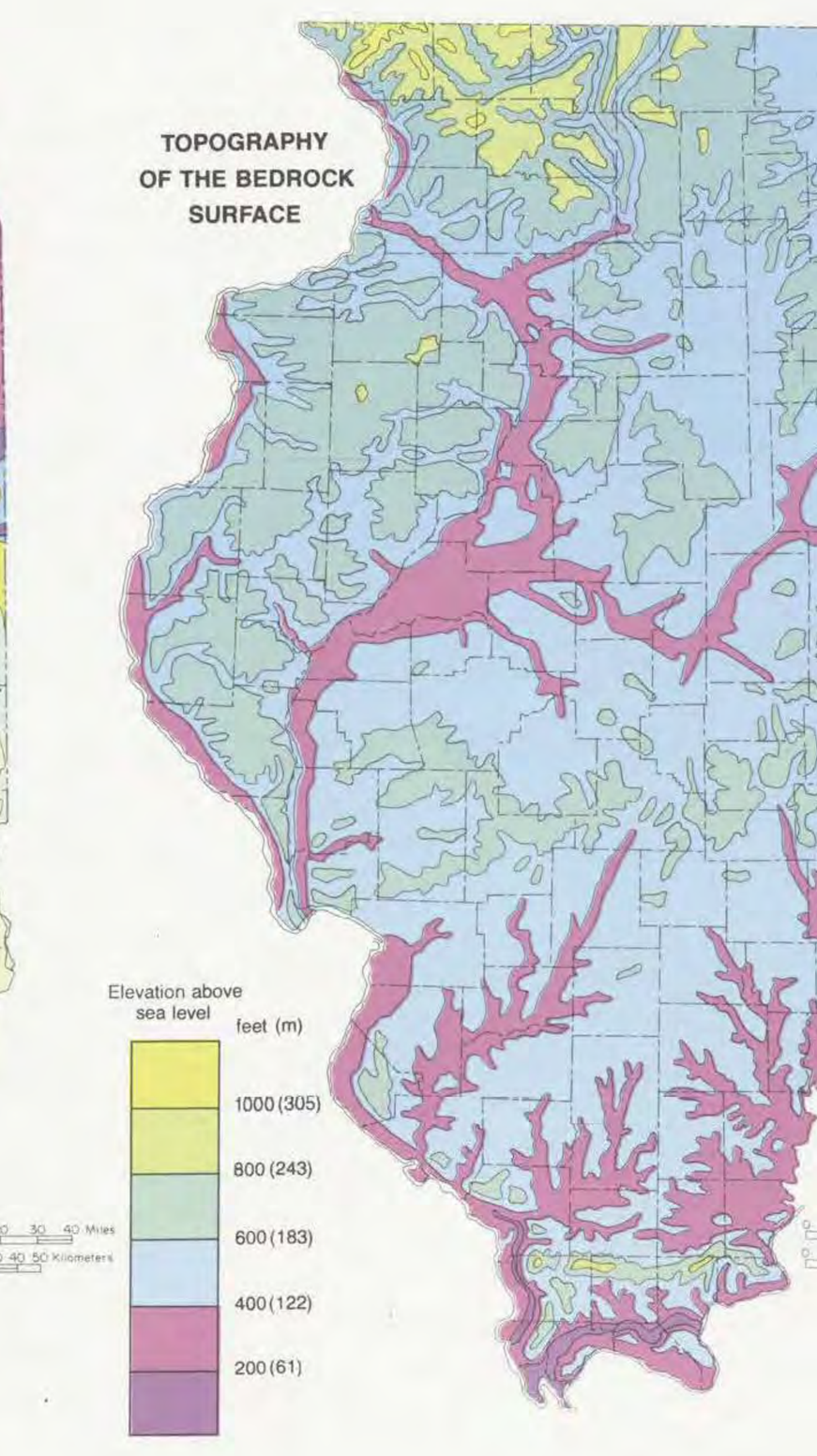
5 — Thickness of loess; contour interval, 5 feet (1.5 m)

Inferred limit of glaciation

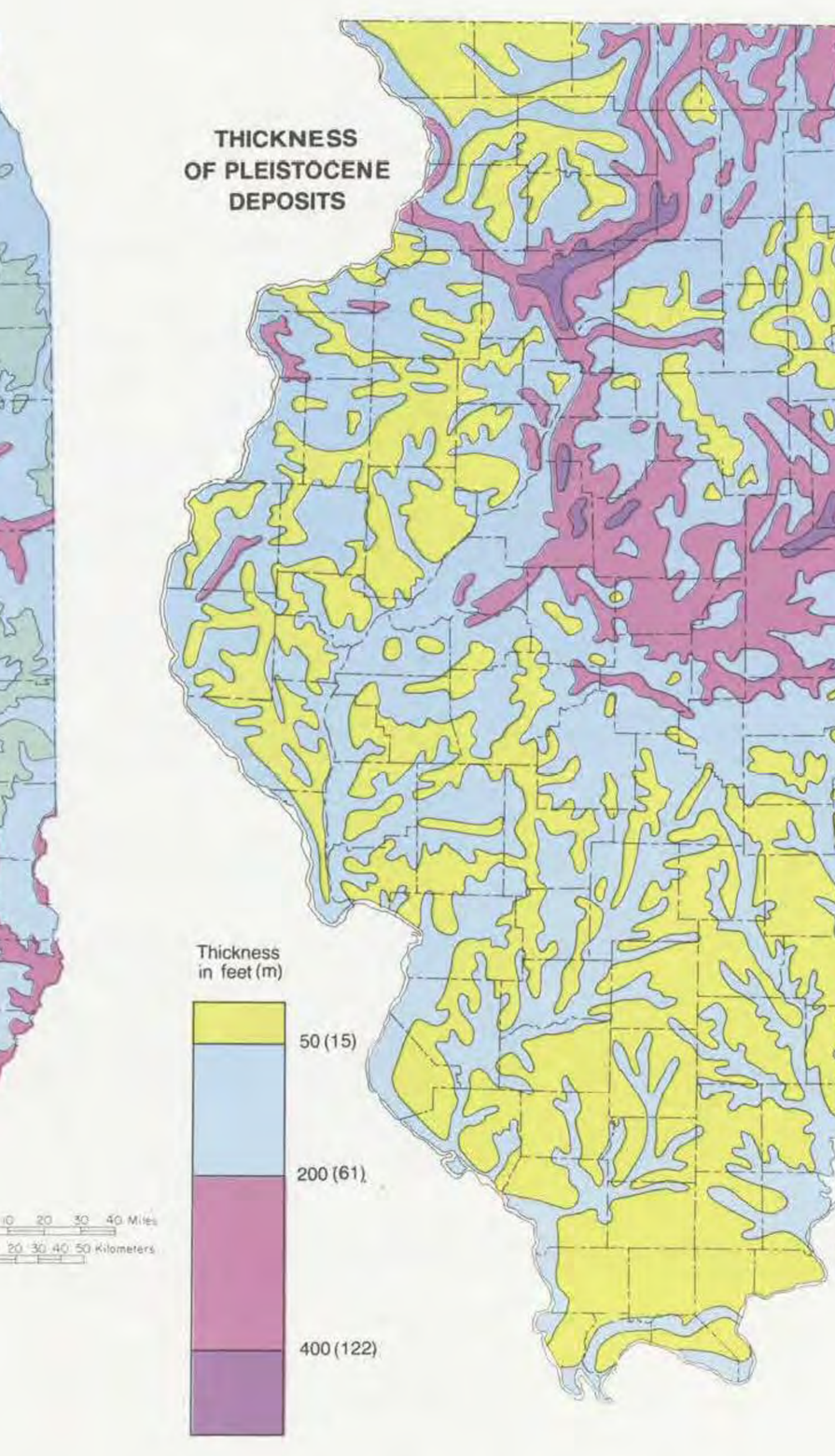
GENERALIZED AREAL GEOLOGY OF THE BEDROCK SURFACE



TOPOGRAPHY OF THE BEDROCK SURFACE



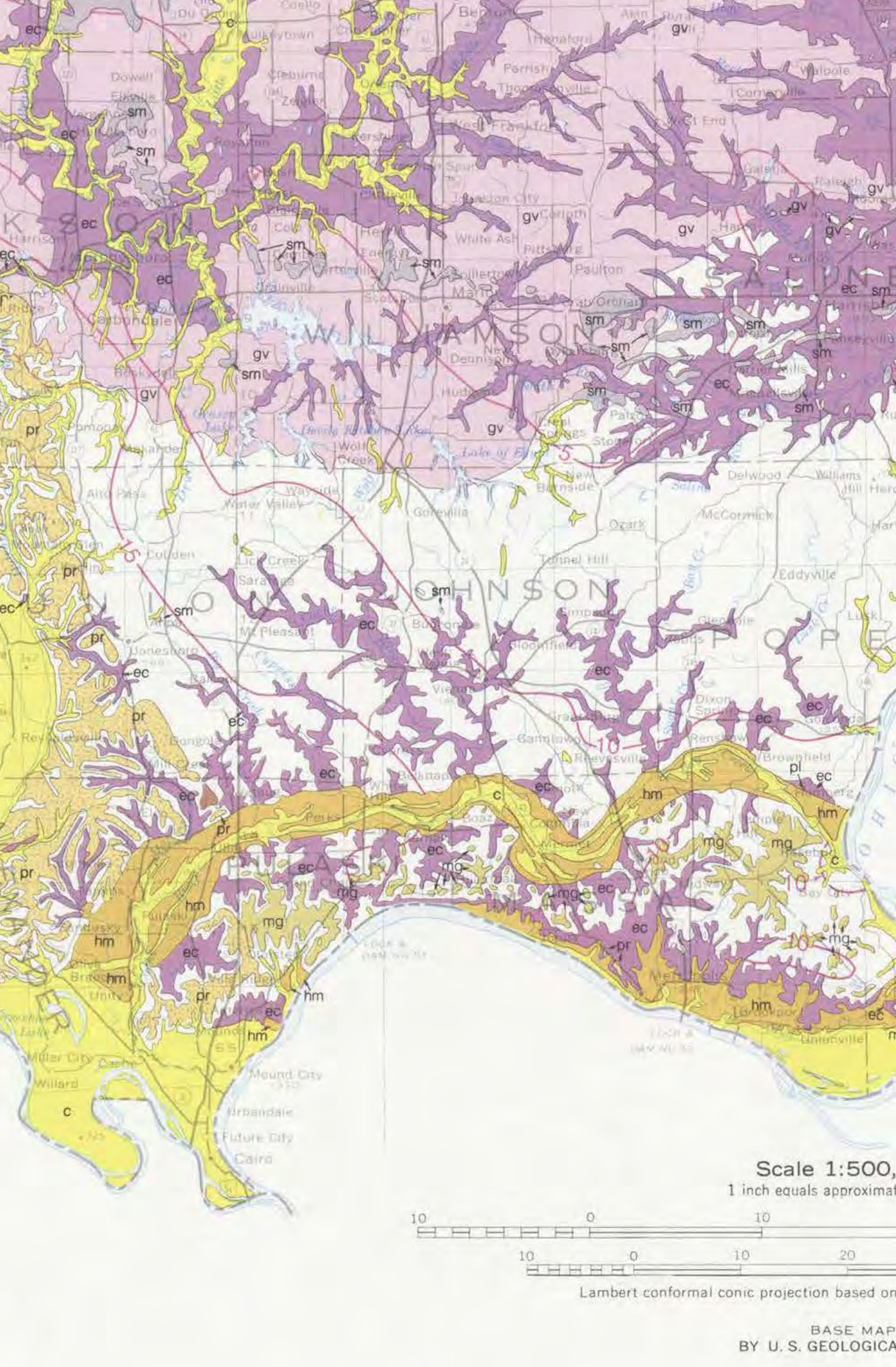
THICKNESS OF PLEISTOCENE DEPOSITS



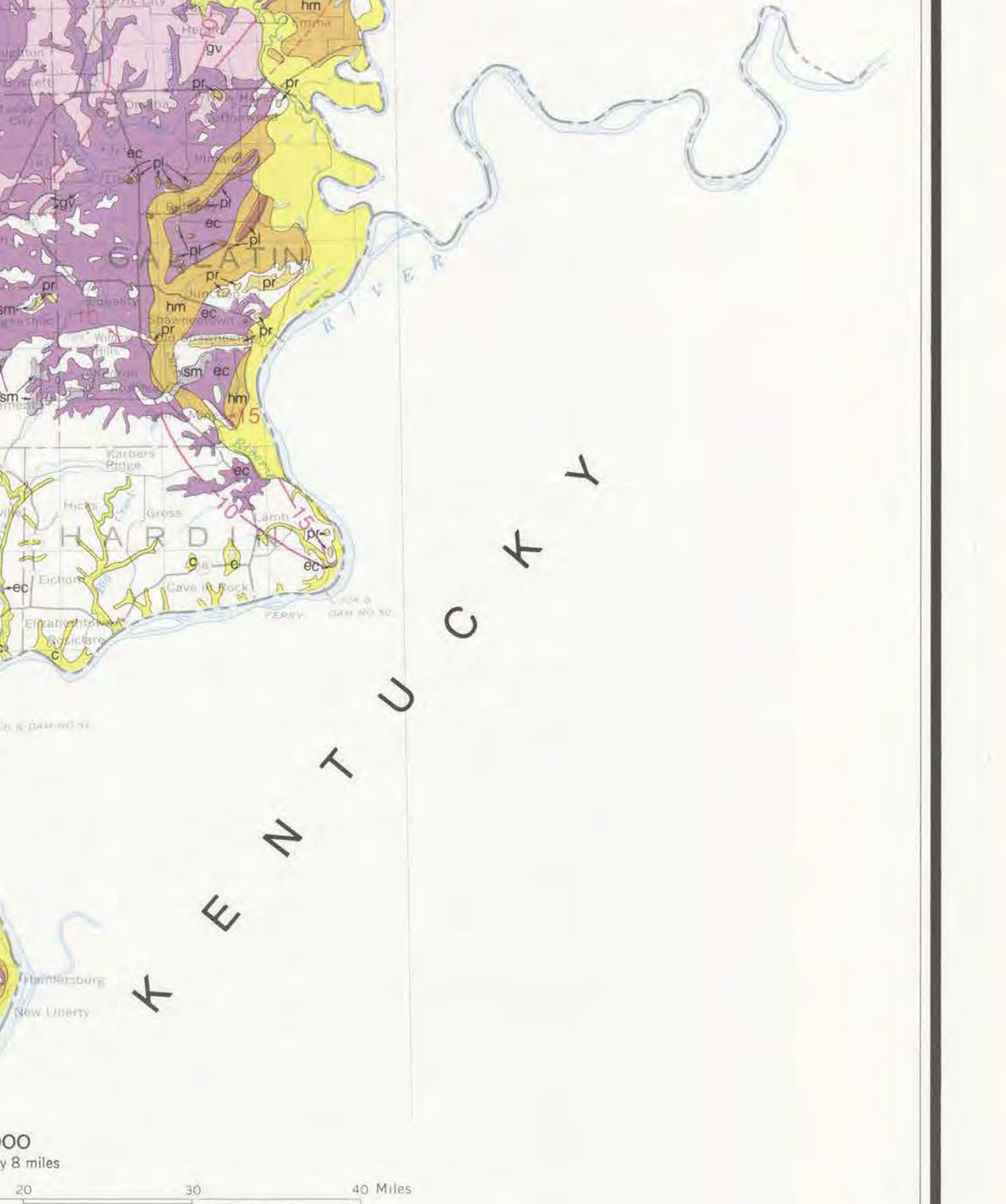
STRATIGRAPHIC CLASSIFICATIONS OF THE PLEISTOCENE DEPOSITS OF ILLINOIS

TIME STRATIGRAPHY	ROCK STRATIGRAPHY	SOIL STRATIGRAPHY
QUATERNARY SYSTEM — PLEISTOCENE SERIES — HOLOCENE STAGE	Lake Michigan Fm.: Ravinia Sand Member, Waukegan M., Lake Forest M., Winnetka M., Sheboygan M., Wilmette Bed, South Haven M.; Cahokia Alluvium; Parkland Sand; Grayslake Peat; Lacon Formation; Peyton Colluvium	Modern Soil
WISCONSINAN STAGE — VALDERAN SUBSTAGE	Peoria Loess; Richland Loess	
WISCONSINAN STAGE — TWOCREEKAN SUBSTAGE		
WISCONSINAN STAGE — WOODFORDIAN SUBSTAGE	Peoria Loess; Richland Loess; Morton Loess; Wedron Fm.: Wadsworth Till Member, Haeger Till Member, Yorkville Till Member, Malden Till Member, Tiskilwa Till Member, Delavan Till Member, Lee Center Till Member, Esmond Till Member; Trafalgar Fm.: Snider Till M., Batestown T.M., Piatt Till Member, Fairgrange T.M., Oakland Till M.; Equality Formation (Carmi and Dolton Members); Henry Formation (Batavia, Mackinaw, and Wasco Members)	Jules Soil
WISCONSINAN STAGE — FARMDALIAN SUBSTAGE	Robein Silt; Peddicord Formation	Farmdale Soil
WISCONSINAN STAGE — ALTONIAN SUBSTAGE	Roxana Silt: Meadow Loess M., McDonough Loess M., Markham Silt M.; Winnebago Fm.: Capron Till Member, Plano Silt Member, Argyle Till Member	Pleasant Grove Soil; Chapin Soil
SANGAMONIAN STAGE	Berry Clay Member	Sangamon Soil
ILLINOIAN STAGE — JUBILEEAN SUBSTAGE	Loveland Silt; Teneriffe Silt; Glasford Formation: Radnor T.M., Sterling T.M., Hagarstown M., Toulon M., Roby Silt M.; Pearl Fm.	
ILLINOIAN STAGE — MONICAN SUBSTAGE	Glasford Formation: Winslow T.M., Hulick T.M., Ogle T.M., Vandalia T.M., Duncan Mills M., Mulberry Grove M.	
ILLINOIAN STAGE — LIMAN SUBSTAGE	Petersburg Silt; Glasford Formation: Kellerville T.M., Smithboro T.M.	Pike Soil
YARMOUTHIAN STAGE	Lierle Clay Member	Yarmouth Soil
KANSAN STAGE	Banner Fm.: Tilton T.M., Hillery T.M., Harmattan T.M., Belgium Member, Hegeler T.M., Harkness Silt M., Sankoty Sand M., Mahomet Sand M.	
AFTONIAN STAGE		Afton Soil
NEBRASKAN STAGE	Enion Formation; Mounds Gravel; Grover Gravel	

DIAGRAMMATIC CROSS SECTION SHOWING THE RELATIONS OF FORMATIONS AND MEMBERS OF WISCONSINAN AGE IN NORTHERN AND WESTERN ILLINOIS



DIAGRAMMATIC CROSS SECTION SHOWING THE RELATIONS OF FORMATIONS AND MEMBERS OF ILLINOIAN AGE IN WESTERN ILLINOIS



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Appendix 8

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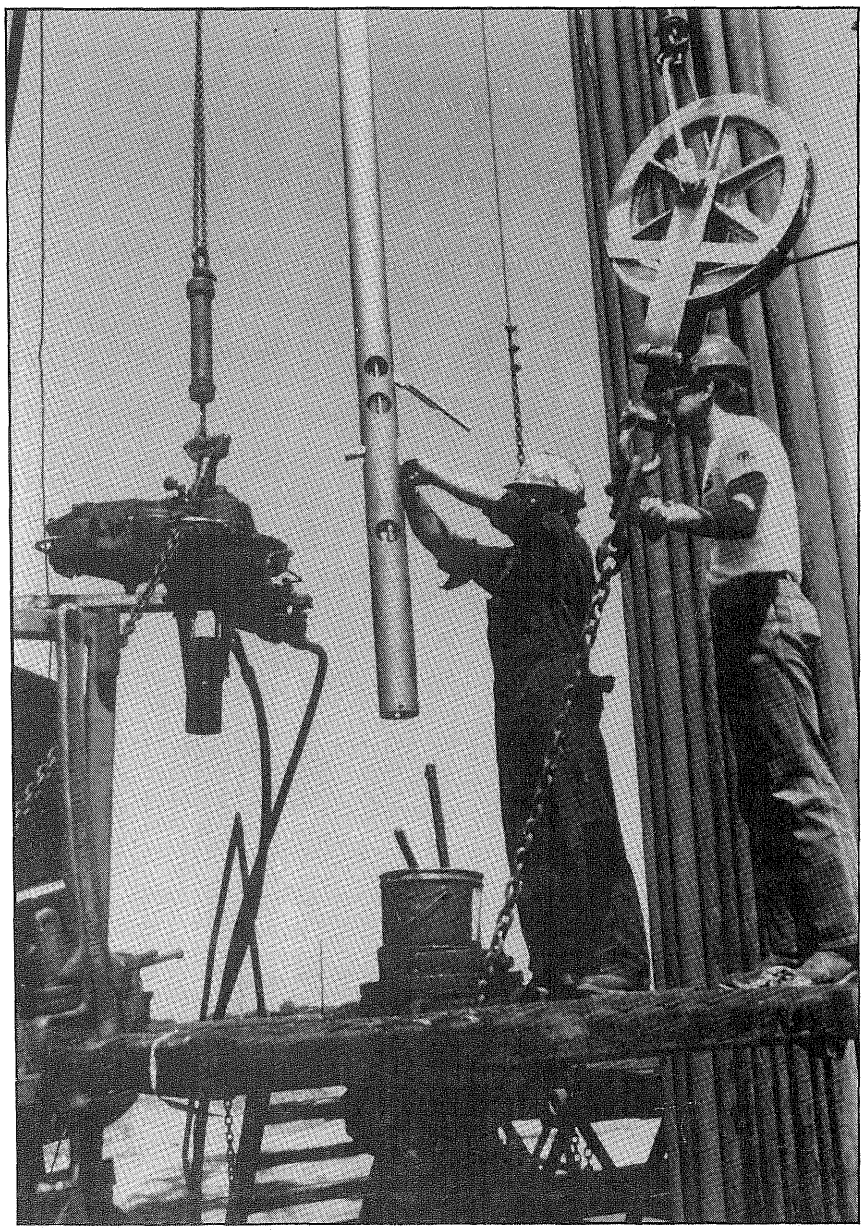
Edward Mehnert, Craig R. Gendron, and Ross D. Brower



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INVESTIGATION OF THE HYDRAULIC EFFECTS OF DEEP-WELL INJECTION OF INDUSTRIAL WASTES

Edward Mehnert, Craig R. Gendron, and Ross D. Brower
Illinois State Geological Survey

Final Report

Prepared for

United States Environmental Protection Agency
Office of Drinking Water
David Morganwalp, Project Officer
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Department of Energy and Natural Resources
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ILLINOIS STATE GEOLOGICAL SURVEY
Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

HAZARDOUS WASTE RESEARCH AND INFORMATION CENTER
One East Hazelwood Drive
Champaign, Illinois 61820

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ABSTRACT

A numerical modeling study was conducted to investigate the hydraulic effects of liquid waste injection on an injection system. The site investigated was a chemical refinery with an operational Class I well and an observation well, both completed in Devonian limestone. Input data for the model were obtained from available records and field investigations.

The regional geologic investigation indicated that the injection system (defined here as the injection zone and its associated confining units) was laterally continuous. The hydraulic response of the injection system was numerically modeled under two injection scenarios: average historical injection rate and maximum average permitted rate. For both scenarios, pressure buildup from waste injection during the simulated 30-year injection and 30-year postinjection periods did not approach the pressure calculated to be necessary to initiate or propagate fractures in the injection system. Therefore, injected waste would be contained, and waste injection at this site and for the scenarios modeled would not endanger human health or the environment.

This analysis assumes that hydraulic conductivity remains constant; however, the formation of brucite within the injection zone may invalidate this assumption and the preceding analysis. Brucite formation within the injection zone requires additional study.

The model was also used to investigate the response of the injection system when a hypothetical conduit was introduced. This hypothetical conduit connected the uppermost injection zone with an overlying aquifer. Differences in head buildup were not monitorable in the injection well or in an observation well completed in the injection zone. Monitorable head differences were observed only in the overlying aquifer, when the hydraulic conductivity of the hypothetical conduit was greater than or equal to 1×10^{-10} m^2.

EXECUTIVE SUMMARY

Concern over the potential for groundwater contamination from waste injection prompted a multi-faceted research effort funded by the U.S. Environmental Protection Agency (USEPA) and industry. The research will provide the USEPA with data needed to determine if underground injection of hazardous waste endangers human health or the environment. One facet of this research effort was an investigation of the hydraulic effects of deep-well injection on the injection system.

The injection system includes the geologic units constituting the injection zone and the upper and lower confining units. The site of this investigation was a chemical refinery in Illinois that has an operational injection well and an observation well completed in Devonian limestone.

Data Collection and Analysis

Before numerical modeling could be conducted, a hydrogeologic description of the site was developed from available records and geophysical logs. Numerous records and logs were available from oil- and gas-related tests and wells within a 10-mile radius of the site. Logs and records for on-site wells were also used.

In addition, hydraulic tests and geophysical logs were run to obtain detailed hydrogeologic data on the injection system. Two hydraulic tests were run in the injection well: a continuous spinner flowmeter survey and a 15-day injection test. Sidewall cores were also retrieved from the injection well. The following geophysical logs were run in the observation well: Compensated Neutron Log, Borehole Compensated Sonic Log, Minilog, Dual Induction Spherically Focused Log, and Gamma Ray Log.

Although analyses of the data from these logs and tests yielded much information concerning the hydrogeologic character of the injection system, there was one discrepancy—the results of the spinner flowmeter indicated that the waste was flowing through different zones of the injection system than had been theorized from the results of geophysical logging. To clarify this discrepancy, we conducted additional analyses (x-ray diffraction and scanning electron microscopy). The discrepancy can be explained briefly as follows. Because of its high pH, the injected wastewater reacts with the Mg^{2+} present in the injection zones or in solution, forming brucite ($Mg[OH]_2$). Brucite accumulation reduces the permeability of the injection zone. Greater amounts of brucite apparently formed in the injection zones where the flow of fluid was greater; thus the zones with higher permeability were affected first. Additional work beyond the scope of this project is needed to verify the brucite-formation hypothesis. Also, the long-term effect of this decrease in permeability on injectivity needs to be investigated.

Numerical Modeling

Site Analysis

A description of the regional and site-specific stratigraphy, structural geology, and hydrogeology of the injection system was generated from a review of available data and the field work conducted during this project. This description formed the basis of input for the numerical model. Model input also included data on the physical and chemical characteristics of the injected wastewater and the native brine in the injection system.

These data were employed as input data for a three-dimensional groundwater flow model (HST3D). Before the effects of various injection scenarios were evaluated, HST3D was verified with respect to two analytical solutions and calibrated by the use of data collected during a 2-week injection test. Both verification and calibration were considered satisfactory.

Once calibrated, the model was used to predict the effects of various injection scenarios. The effect of long-term injection was investigated at two constant injection rates—the average historical rate (1.15×10^{-2} m^3/sec) and the maximum average rate permitted under Class I regulations (2.21×10^{-2} m^3/sec). With both scenarios, significant head buildup was observed at the injection well and radially from it. During the simulated 30-year injection period, steady state was approached but not obtained for both injection scenarios. During the subsequent 30-year postinjection period, dropoff in head buildup was fairly rapid, falling to half in less than 2,000 hours for both scenarios. The maximum hydraulic pressures at the bottom of the well and at the base of the upper confining unit were significantly lower than the pressures calculated to initiate hydraulic fracturing. A fracture gradient of 1.5×10^4 Pa/m (Pascals/meter) (0.65 psi/ft) was used to calculate the hydraulic fracture pressures.

The regional and site-specific geological analysis revealed the continuity of the stratigraphy and qualitative permeability on a regional basis. The numerical modeling indicated that injection pressures were lower than calculated pressures required to initiate hydraulic fracturing. Therefore, from a hydraulic viewpoint, waste injected into this injection system would be contained, and waste injection at this site and for the scenarios modeled would be considered protective of human health and the environment.

These results were based on an assumption that the permeability remains constant. If the hypothesis concerning the formation of brucite is correct, its formation may reduce the permeability of the injection zones and invalidate this analysis. Any reduction in permeability of the injection zones will probably increase the hydraulic pressure resulting from waste injection if the injection rate remains constant. In such a situation, hydraulic fracturing may be of concern. Because of the potential ramifications, formation of brucite within the injection zone requires additional geochemical analysis.

Effects of Hypothetical Conduit

The model was also used to investigate the hydraulic response of the injection system to the introduction of a hypothetical conduit. The conduit, a microannulus (0.01 m wide) at the injection well, hydraulically connects the uppermost injection zone and an aquifer immediately overlying the upper confining unit. To determine the impact of the microannulus, the head buildup with the microannulus present was compared with the buildup from runs with the microannulus not present. Differences in head buildup at selected positions and for certain times were computed. Differences in the head buildup were considered unmonitorable at the injection well and the observation well. The difference in head buildup in the overlying aquifer was monitorable only when the microannulus had a hydraulic conductivity greater than or equal to 1.00×10^{-10} m^2. The head buildup in the overlying aquifer is a function of its hydraulic conductivity, the hydraulic conductivity of the microannulus, and the radial distance from the microannulus. Thus for the scenario modeled, leakage via a microannulus could not be hydraulically monitored by use of the injection well or an observation well completed within the injection zone. This leakage was monitorable only through the use of an observation well in the overlying aquifer.

GLOSSARY

AIF	aquifer influence boundary
b	thickness
DOW	Devonian Observation Well
GL	ground level
HST3D	Heat and Solute Transport Model
ISGS	Illinois State Geological Survey
k	permeability
K	hydraulic conductivity
KB	Kelly Bushing
m	modulus of shear for the medium
Pa	Pascals
POR	porosity
psi	pounds per square inch
q	pumping rate
S	storativity
SEM	scanning electron microscopy
SWIFT	Sandia Waste Isolation Flow and Transport Model
SWIP	Survey Waste Isolation Program
T	transmissivity
TDS	total dissolved solids
USDW	underground sources of drinking water
USEPA	United States Environmental Protection Agency
WDW2	Waste Disposal Well 2
α	matrix compressibility
β	fluid compressibility
Δh	head buildup
ρ	fluid density
μ	fluid viscosity

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1. INTRODUCTION

Background

Liquid waste is disposed of through underground injection by pumping the waste into or allowing it to flow through a specially designed and monitored well. Developed by the petroleum industry in the 1930s as a method for brine disposal, the technique was adapted by other industries in the 1950s for the disposal of industrial waste streams. As regulations for the disposal of waste into landfills and surface waters became more stringent, the volume of waste disposed of by underground injection increased.

Regulatory agencies have classified injection wells according to the purpose of the wells and the proximity of injection reservoirs to the lowermost underground source of drinking water (USDW). The five classes of injection wells are:

Class I — wells used to inject hazardous and nonhazardous wastes below the lowermost USDW (this report is concerned with this class of wells).

Class II — wells associated with the production and storage of oil and gas below the lowermost USDW.

Class III — wells used in special process (mining) operations to inject fluid above, into, or below an USDW.

Class IV — wells used to inject hazardous waste into or above an USDW (this class of wells is currently banned).

Class V — wells used to inject all other wastes into or above an USDW.

According to the U.S. Environmental Protection Agency (USEPA), there were 429 Class I injection wells active in 1986 (USEPA 1986). Although the volume of waste disposed of nationwide via these wells is difficult to estimate, accurate figures are available from some states. In Illinois, nine Class I wells were used in 1984 to dispose of 310 million gallons of waste (Brower et al. 1989).

With the promulgation of the Hazardous and Solid Waste Amendments of 1984, the level of interest in underground injection increased tremendously. Provisions of the act mandated that the administrator of USEPA determine if underground injection is a threat to human health and the environment for the period the waste remains hazardous. If underground injection is found to be hazardous to human health and the environment, or if the determination is not made by the Congressionally mandated date, all underground injection will be banned. Some environmental groups want situations detailed in which underground injection has endangered or may endanger human health or the environment.

The USEPA developed an extensive research agenda to examine pertinent issues. The USEPA has funded to date one or more projects in each of the following areas: identification and classification of Class I well failures; techniques to detect abandoned wells; monitoring of various aspects of the well; flow and transport modeling of various injection scenarios; geochemical modeling of injected waste, injection formation, and brine; and hydrogeologic characterization of important injection formations and associated confining formations. Industry also has conducted research into pertinent topics of underground injection.

In this project, a numerical model was used to investigate the hydraulic effects of waste injection on the geologic reservoir. The site of the investigation is a chemical refinery located near Marshall, Illinois, in north-central Clark County (fig. 1). The chemical company used the injection well

to dispose of alkaline (pH>12) waste. An observation well, which is completed in the same formation as the injection well, is located 506 meters north of the injection well.

Purpose

The primary purpose of this project was to investigate the pressure response (flow modeling) of an actual injection formation and its associated confining formations due to waste injection via a Class I well. Modeling of solute transport was not investigated here but was addressed by other researchers sponsored by USEPA and industry. Flow modeling requires detailed characterization of the site hydrogeology, so this project bridged two areas of concern—flow modeling and hydrogeologic characterization. In addition, the effectiveness of pressure-monitoring systems to detect movement of fluid beyond the injection formation was evaluated.

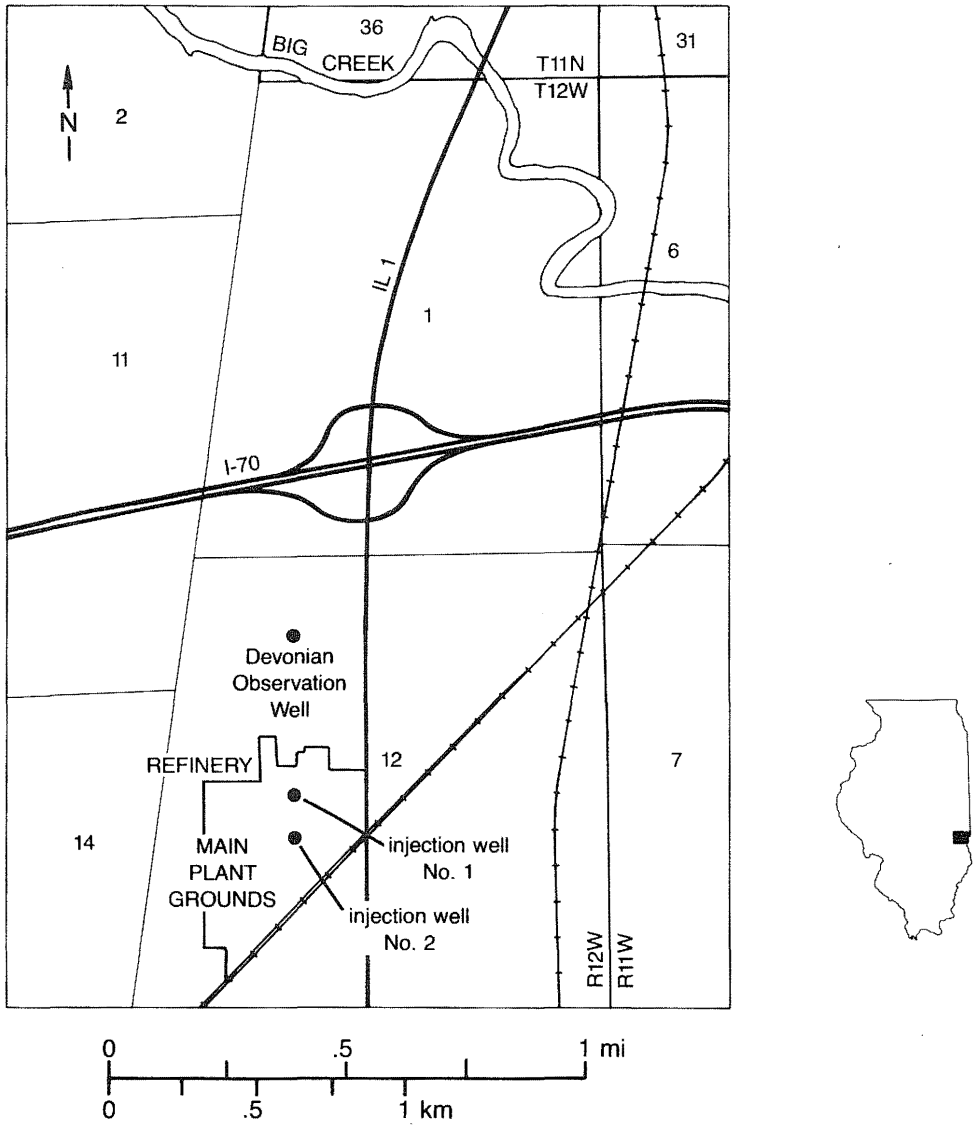

Figure 1 Location of investigation site.

2. GEOLOGY OF THE INJECTION SYSTEM

The geologic environment of an injection well site controls many aspects of the disposal operation and the fate of the injected wastes. This section includes a summary of the regional geology and hydrogeology of the units involved with the deep-well injection operation. The geologic setting is described within the context of the regional geology to show regional trends and the degree of uniformity in geologic conditions.

Only those aspects of geology pertinent to underground injection are described. The major emphasis is on the hydrogeology of the confining units and the injection interval, specifically, the hydrogeology of the upper confining unit (New Albany Group), the lower confining unit (Maquoketa Group), and the injection interval (Hunton Supergroup). The Borden Siltstone, which overlies the New Albany Group, acts as an additional confining zone.

Overview of Geologic Conditions Affecting Waste Injection

The principal geologic factors for the regional evaluation are those affecting (1) the capacity of geologic units in the injection system to accept and confine injected waste, (2) the chemical interaction of the waste with injection system components, (3) the generation of dislocations that developed during the forming of structural features or seismic events, and (4) the use of subsurface space and commercial grade resources in the area of disposal influence.

In this section we have focused on the broader regional issues that relate to local geologic conditions. Broadly defined lithologic units form a key component of the regional discussion. These units have been described in the literature, and the uniformity of their general geologic conditions and structural trends have been established by oil, gas, water, and mineral resource exploration activities in the region.

The character and trends of the regional geology have been determined from data gathered from key well records, reports, and publications. This information reveals the distribution of aquifers that meet regulatory requirements for Class I injection, i.e., aquifers that contain saline water (>10,000 mg/L total dissolved solids [TDS]) and that have confining intervals capable of protecting all USDW from contamination by injection activities. Injection is limited to selected aquifers in the southern two-thirds of Illinois, including the Hunton Supergroup and the Salem Limestone, which have been used for disposal at the study site. Injection system response to waste injection is primarily controlled by porosity and permeability characteristics, which can be directly related regionally to specific geologic units.

Porosity and permeability develop during sedimentation processes and are modified by other geologic processes. Thus porosity and permeability have a general relationship with specific lithologies. Each geologic unit in the region exhibits a range of values and areal trends. The sedimentary geologic units in east-central Illinois exhibit relatively uniform characteristics over large areas; however, both vertical and radial trends are noted within each unit. Similar patterns can also be expected within the subdivisions of each unit, but determining this would require a detailed study of subsurface records.

The lithology of the geologic units forming the injection system plays an important role in the chemical interaction between the injected waste and injection system. Chemical interaction between injected waste and the injection system can affect flow conditions (porosity and permeability) and under certain disposal conditions can compromise the integrity of the confining intervals. However, beneficial interactions may also occur that would improve flow conditions, involve retention of some waste components near the well, and provide treatment for selected, undesirable components in the waste.

This discussion focuses on the general regional characteristics of principal geologic units and relates these characteristics to hydrogeologic parameters for characterizing flow in the injection system. An effective evaluation by numerical modeling requires that the hydrogeologic character of the geologic units accepting and retaining injected waste be predictable and relatively uniform throughout the area influenced by injection. A more detailed description of the character and radial uniformity of the units in the injection system is presented in chapter 3.

General Geologic Setting

The geologic framework of Illinois in which deep-well disposal is practiced can be described as a sequence of areally extensive sedimentary rock units deposited in a large midcontinent basin known as the Illinois Basin. The study site, in the east-central part of the basin, is immediately east of the axis of the Marshall-Sidell Syncline and about 14 miles east of the La Salle Anticlinal Belt, the most dominant structural feature in the area. Figure 2 shows the generalized geology of the bedrock surface in Illinois. Generalized geologic cross sections of Illinois are depicted in figure 3. Figure 4 provides a generalized geologic column and comments on the stratigraphy, lithology, hydrogeology, and groundwater geochemistry of the geologic units associated with or protected from waste injection. Additional details on geologic units covered in this report are available in the *Handbook for Illinois Stratigraphy* (Willman et al. 1975), the *Bibliography of Illinois Geology* (Willman et al. 1968) and reports prepared by Brower et al. (1989), Cluff et al. (1981), Gray et al. (1979), and Piskin and Bergstrom (1975).

In Illinois, lithologies range from very fine- to coarse-grained clastics, a variety of carbonates, and a few evaporites and organics. Relatively uniform lithologic characteristics exist on a regional basis within individual units as a whole and within the subdivisions of each unit.

Many processes have been involved in forming, altering, and structurally readjusting these units from the time of deposition to the present day. Sedimentary deposition began early in the Paleozoic Era on the eroded surface of igneous and metamorphic rock of the Precambrian basement complex. Deposition and some erosion continued throughout the Paleozoic. Several episodes of deposition in the Mesozoic and Cenozoic Eras produced nonlithified sedimentary units. The present-day landscape has developed principally on these nonlithified sediments. Marine carbonate and clastic lithologies are dominant in the Paleozoic units, but terrestrial clastics and some organic deposits are present in the upper part of the Paleozoic (Mississippian and Pennsylvanian Systems).

The thickness of the sedimentary sequence in Illinois ranges from approximately 2,000 feet northwest of Rockford to more than 20,000 feet in the southeastern corner of the state, the deepest part of the Illinois Basin (Sargent and Buschbach 1985). In the project area, the total thickness of the sedimentary units is approximately 8,500 feet. Lithologies include dolomite, limestone, sandstone, siltstone, shale, and some coal and evaporite. The stratigraphic column in figure 4 provides a summary of the typical sedimentary sequence in the Illinois Basin. Widespread carbonate lithologies are dominant in the lower part of the Paleozoic, and a few sandstones and some shales are interbedded with these carbonates. Most of the carbonates become sandy to the north, and a few grade into sandstones in the far northern part of the state. Greater variations in regional lithology exist in the upper part of the Devonian through the middle part of the Mississippian. Cyclic deposits of fine-grained clastics (shales and siltstones), some carbonates, and some coarse-grained clastics (sandstones) accumulated in the upper part of the Mississippian and in all of the Pennsylvanian as numerous sea-level oscillations shifted shorelines across shallow-marine and flat-lowland terrestrial environments.

The study site is in the Marshall-Sidell Syncline (see fig. 5), a broad structural feature of low relief between the La Salle Anticlinal Belt, about 14 miles to the west, and the Kankakee Arch more than 90 miles to the northeast. These two structures are reflected in the distribution of the boundaries of the geologic units exposed at the bedrock surface (fig. 2). The regional dip of the units in the study area is to the southwest from the Kankakee Arch and into the Illinois Basin, but

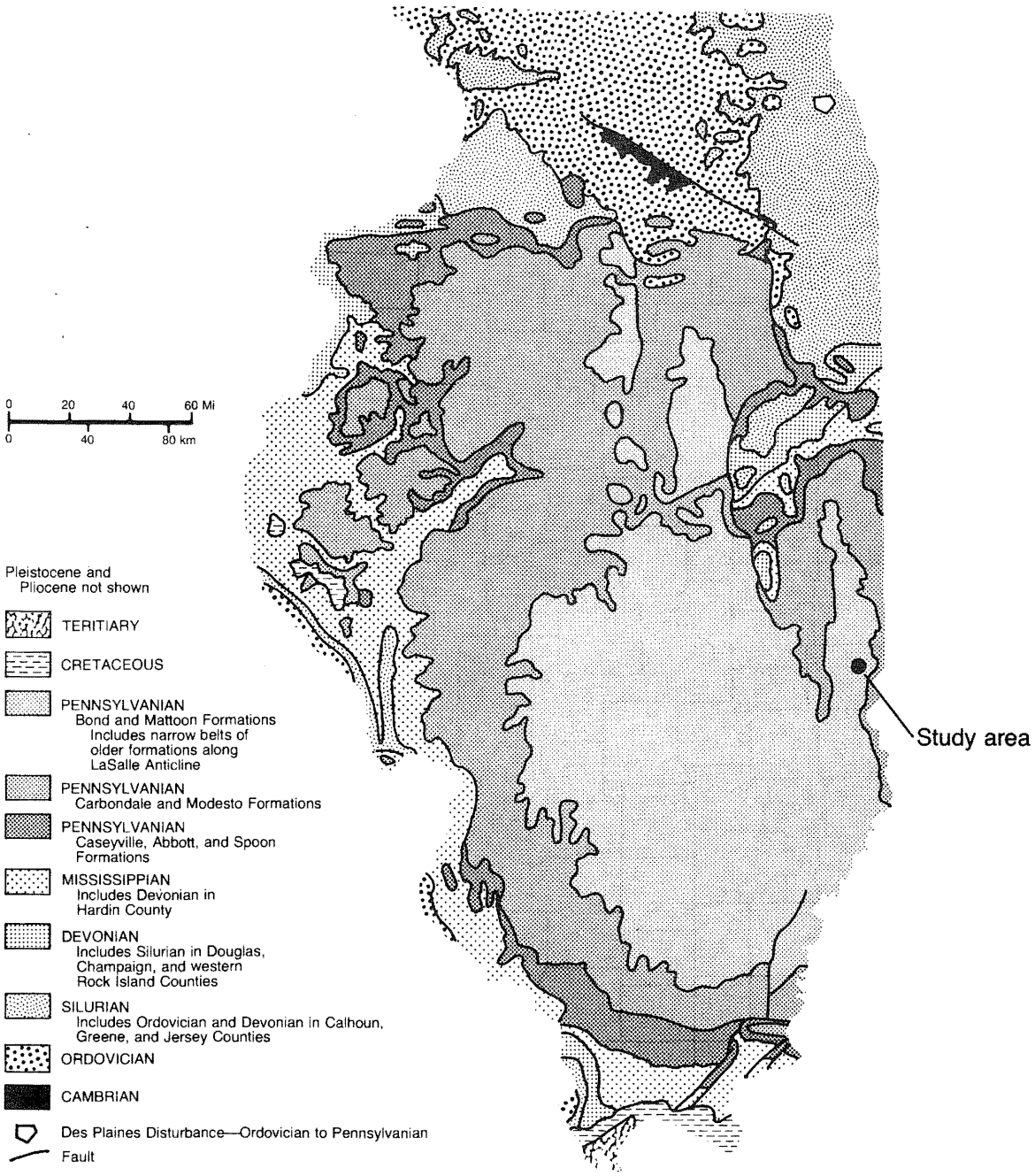

Figure 2 Generalized areal geology of the bedrock surface (from Willman and Frye 1970).

boundaries of the geologic units exposed at the bedrock surface (fig. 2). The regional dip of the units in the study area is to the southwest from the Kankakee Arch and into the Illinois Basin, but locally the units dip gently in a south-to-southwesterly direction toward the axial trend of the Marshall-Sidell Syncline.

Waste Injection Potential in Illinois

Some sequences of Paleozoic units possess sufficient porosity, permeability, and confinement to accept and retain wastes injected at moderate to high injection rates. Criteria for acceptable injec-

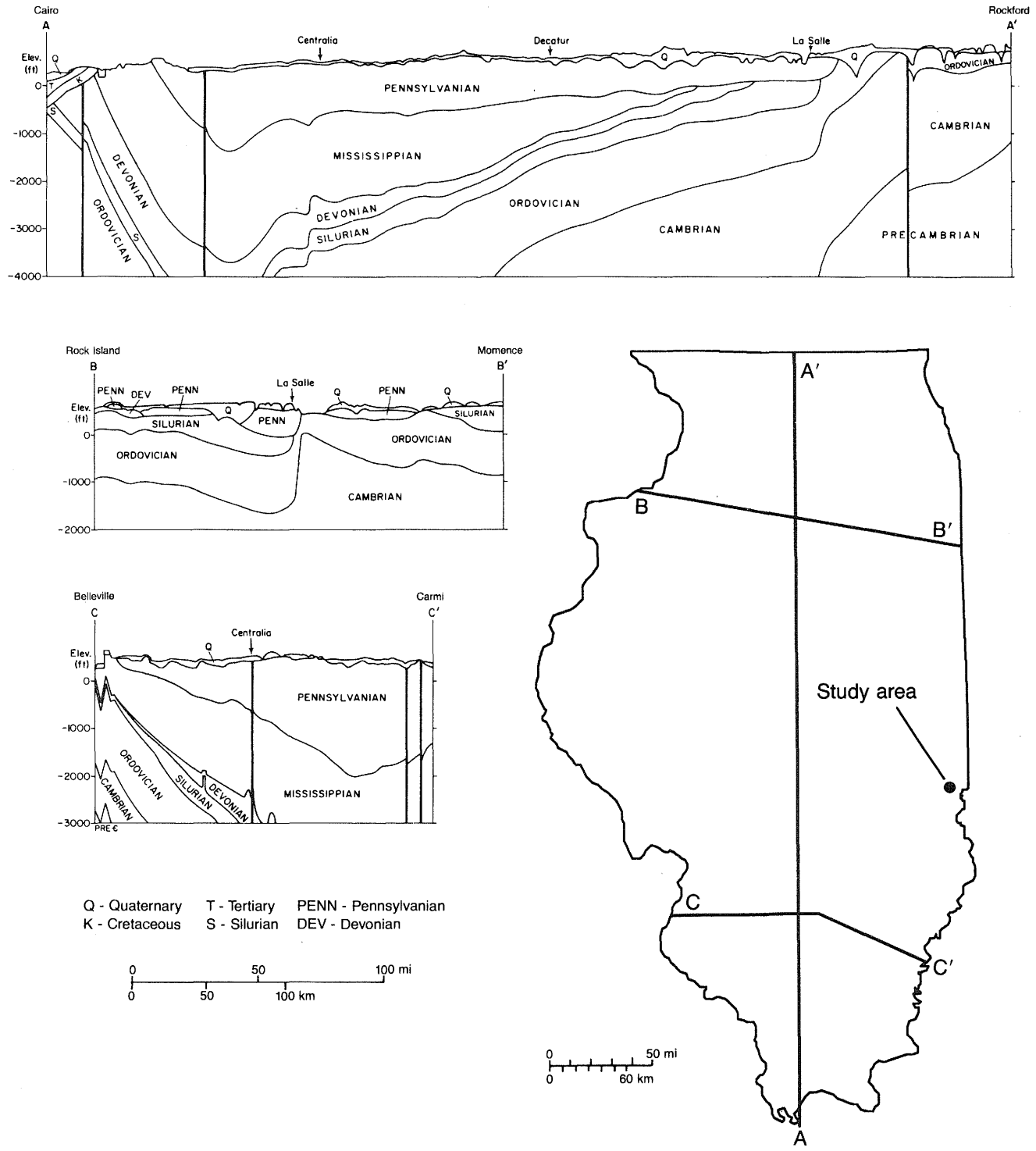

Figure 3 Generalized statewide cross sections of Illinois (from Willman et al. 1975).

Protection Act (Title 35, Illinois Administrative Code). Within Illinois, the base of the USDW ranges in depth from 500 to slightly more than 3,000 feet. All units below the lowermost USDW contain groundwater with a TDS content exceeding 10,000 mg/L (milligrams/liter). Injection is feasible only in portions of Cambrian through basal Pennsylvanian units that meet the criteria for waste injection established in the Illinois Environmental Protection Act.

In the study area, the base of the USDW has been established at a depth of about 500 feet (Piskin 1986). In the immediate vicinity of the study site, significant injection potential for the Salem and Hunton carbonate units has been proved by oil exploration and waste-injection testing conducted to a depth of 6,000 feet. Recently, injection has been limited to the Devonian portion of the Hunton. Very limited groundwater supplies have been obtained from the uppermost part of the Pennsylvanian bedrock. The City of Marshall obtains a moderate to large water supply from a shallow sand and gravel aquifer in the nearby valley of Big Creek.

Seismic Activity in Illinois

Earthquake waves traveling through earth materials can affect deep-well disposal systems. Earthquakes are infrequent in Illinois, and most have been low to moderate in magnitude and intensity (fig. 7). Several earthquakes of low-to-moderate magnitude recently occurred in the vicinity of the Wabash Valley Fault System, which extends northward into Edwards and Wabash Counties from southeastern Illinois (fig. 5). The largest earthquakes affecting Illinois in recorded history occurred near New Madrid, Missouri, in 1811 and 1812 (Heigold 1968, 1972). Although faulting is reported in other areas of Illinois, field studies and drilling records available to the Illinois State Geological Survey indicate that no faults are mapped at the surface or known to have occurred in the subsurface in the vicinity of the study area.

The greatest likelihood for major damage from earthquakes exists in 14 southern Illinois counties (figs. 6 and 7). This region of the state is in Area 3 on the Seismic Risk Map (fig. 6) compiled by Algermissen (1969). The project site is near the southern margin of Area 1, the area in which the damage expectancy from potential earthquakes is rated as minor.

Subsurface Resources

Subsurface resources in Illinois exclusive of groundwater resources include mineral deposits, hydrocarbon deposits, and subsurface storage space. Many of the geologic units containing subsurface resources also qualify as potential disposal horizons. The regulations for deep-well disposal require a review of all subsurface resources of commercial value in order to reduce the potential for conflicts between injection and resource extraction.

Oil and limited natural gas resources have been exploited in numerous permeable units above the St. Peter Sandstone. Oil production is mainly associated with Mississippian units; however, significant production has come from other Paleozoic units. The petroleum-producing regions in Illinois are confined to the Illinois Basin (fig. 8). Wells drilled for production provide valuable information about subsurface conditions; however, if not properly sealed, these wells can be potential avenues for fluid movement into overlying geologic units.

Oil has been produced in the Weaver Field about 9 miles to the east-southeast of the study area and in several small fields on the La Salle Anticlinal Belt, more than 14 miles to the west. Exploratory wells have been drilled throughout the vicinity of the study site; a few of these wells are within the 2.5-mile area of review of the disposal well. No commercial oil pools have been reported in the Marshall-Sidell Syncline in the vicinity of the study site.

Coal deposits are more widespread than petroleum deposits in the Pennsylvanian units, and multiple coal deposits are often found where Pennsylvanian units are present. Although more than 50 potential coal horizons have been found in Illinois, only a few are thick enough for commercial development. The coals in the project area tend to be relatively thin and deeply buried. Most coal deposits mined in Illinois are shallow (less than 500 ft) and lie within units designated as USDW.

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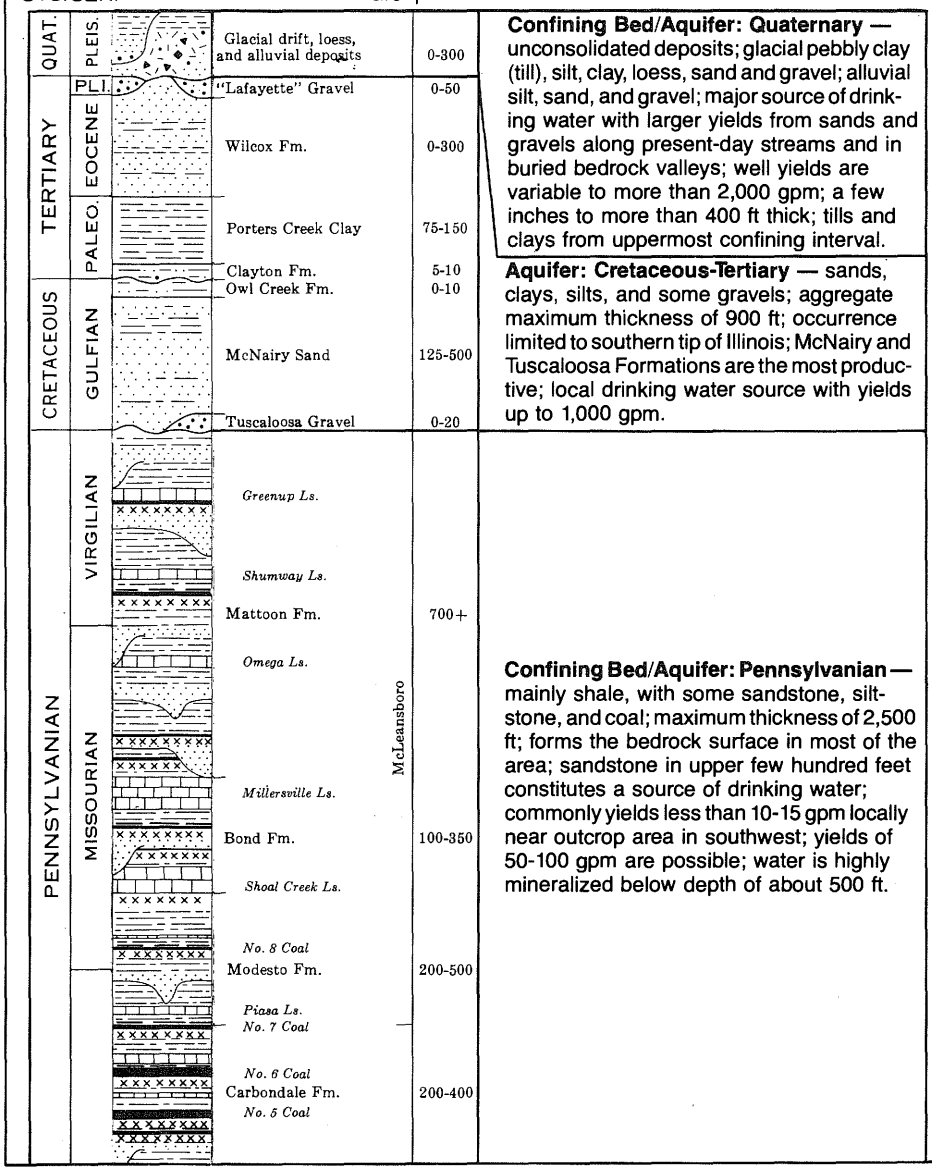
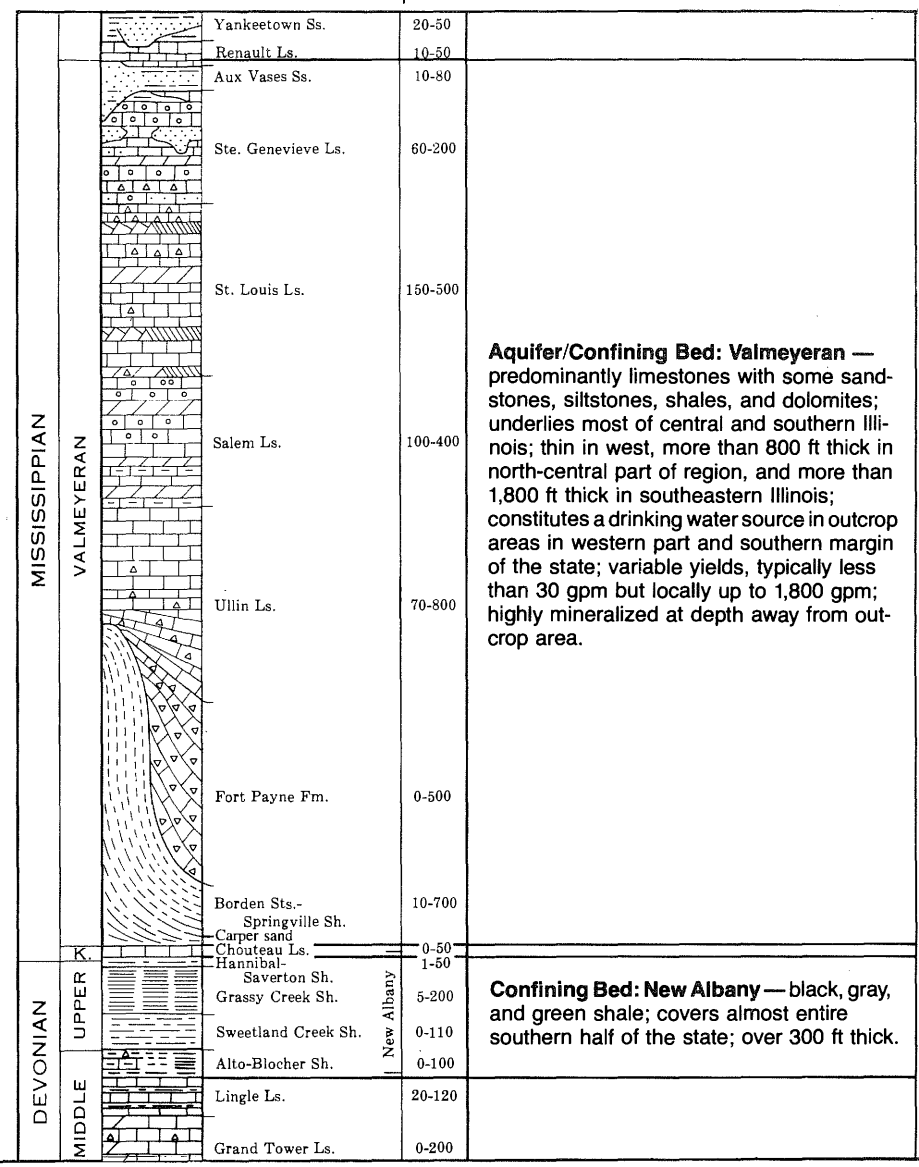
Rock Units and Their Hydrogeologic Roles

Southern Illinois





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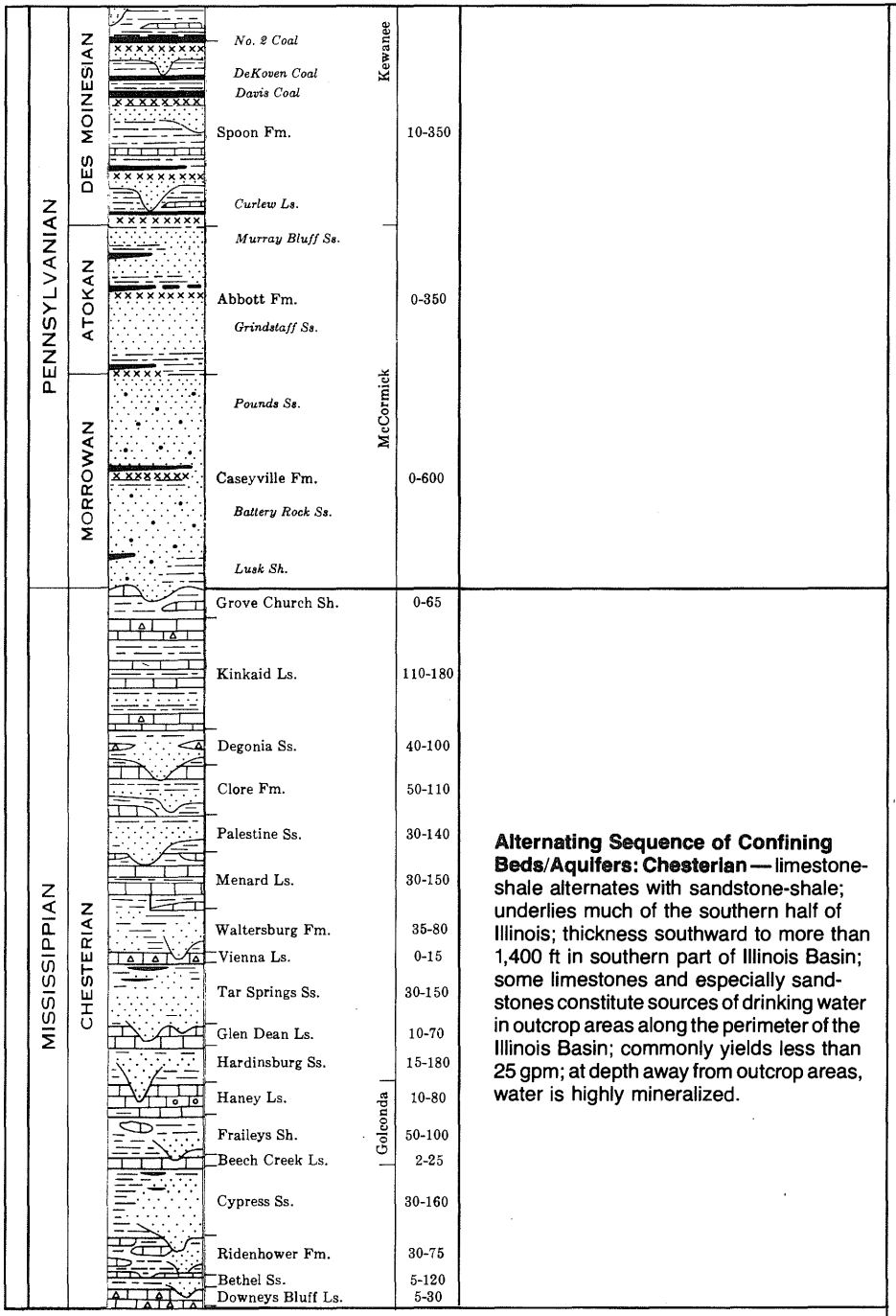

Alternating Sequence of Confining Beds/Aquifers: Chesterian — limestone-shale alternates with sandstone-shale; underlies much of the southern half of Illinois; thickness southward to more than 1,400 ft in southern part of Illinois Basin; some limestones and especially sandstones constitute sources of drinking water in outcrop areas along the perimeter of the Illinois Basin; commonly yields less than 25 gpm; at depth away from outcrop areas, water is highly mineralized.

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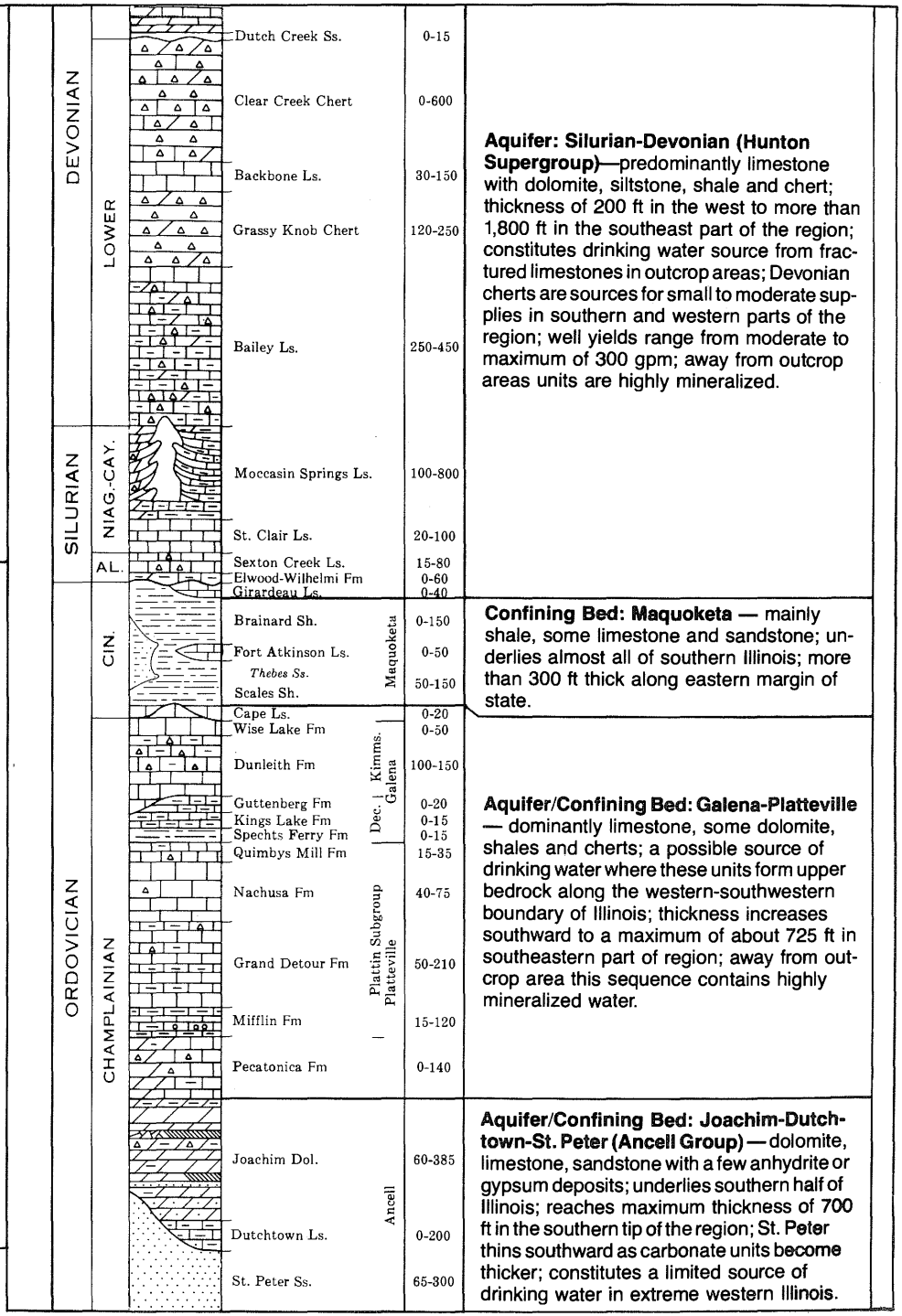

Aquifer: Silurian-Devonian (Hunton Supergroup)—predominantly limestone with dolomite, siltstone, shale and chert; thickness of 200 ft in the west to more than 1,800 ft in the southeast part of the region; constitutes drinking water source from fractured limestones in outcrop areas; Devonian cherts are sources for small to moderate supplies in southern and western parts of the region; well yields range from moderate to maximum of 300 gpm; away from outcrop areas units are highly mineralized.

Confining Bed: Maquoketa — mainly shale, some limestone and sandstone; underlies almost all of southern Illinois; more than 300 ft thick along eastern margin of state.

Aquifer/Confining Bed: Galena-Platteville — dominantly limestone, some dolomite, shales and cherts; a possible source of drinking water where these units form upper bedrock along the western-southwestern boundary of Illinois; thickness increases southward to a maximum of about 725 ft in southeastern part of region; away from outcrop area this sequence contains highly mineralized water.

Aquifer/Confining Bed: Joachim-Dutchtown-St. Peter (Ancell Group) — dolomite, limestone, sandstone with a few anhydrite or gypsum deposits; underlies southern half of Illinois; reaches maximum thickness of 700 ft in the southern tip of the region; St. Peter thins southward as carbonate units become thicker; constitutes a limited source of drinking water in extreme western Illinois.

Figure 4 Description of rock units and their hydrogeologic roles (Brower et al 1989).

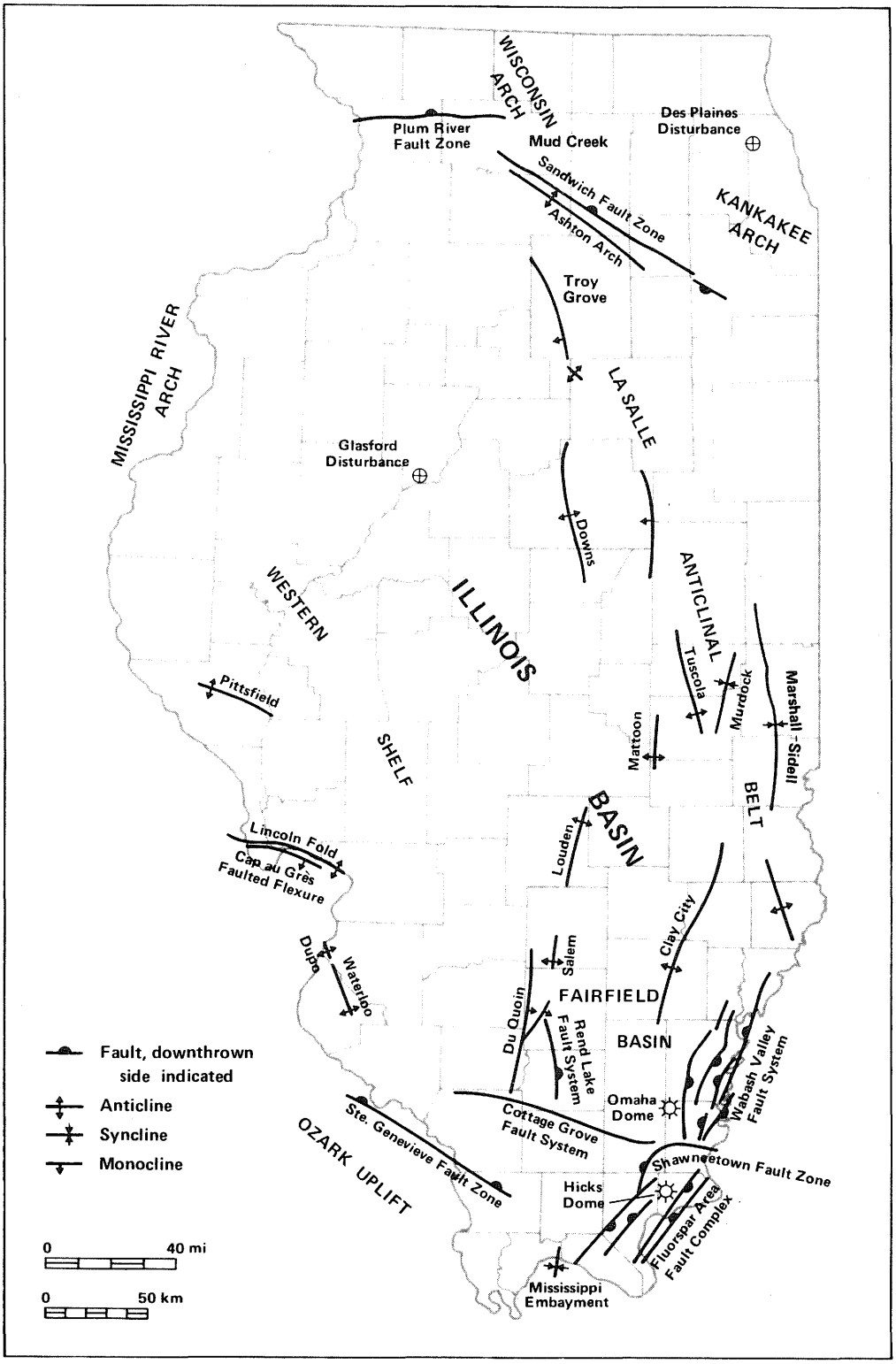

Figure 5 Geologic structures in Illinois (compiled by J. Treworgy 1979).

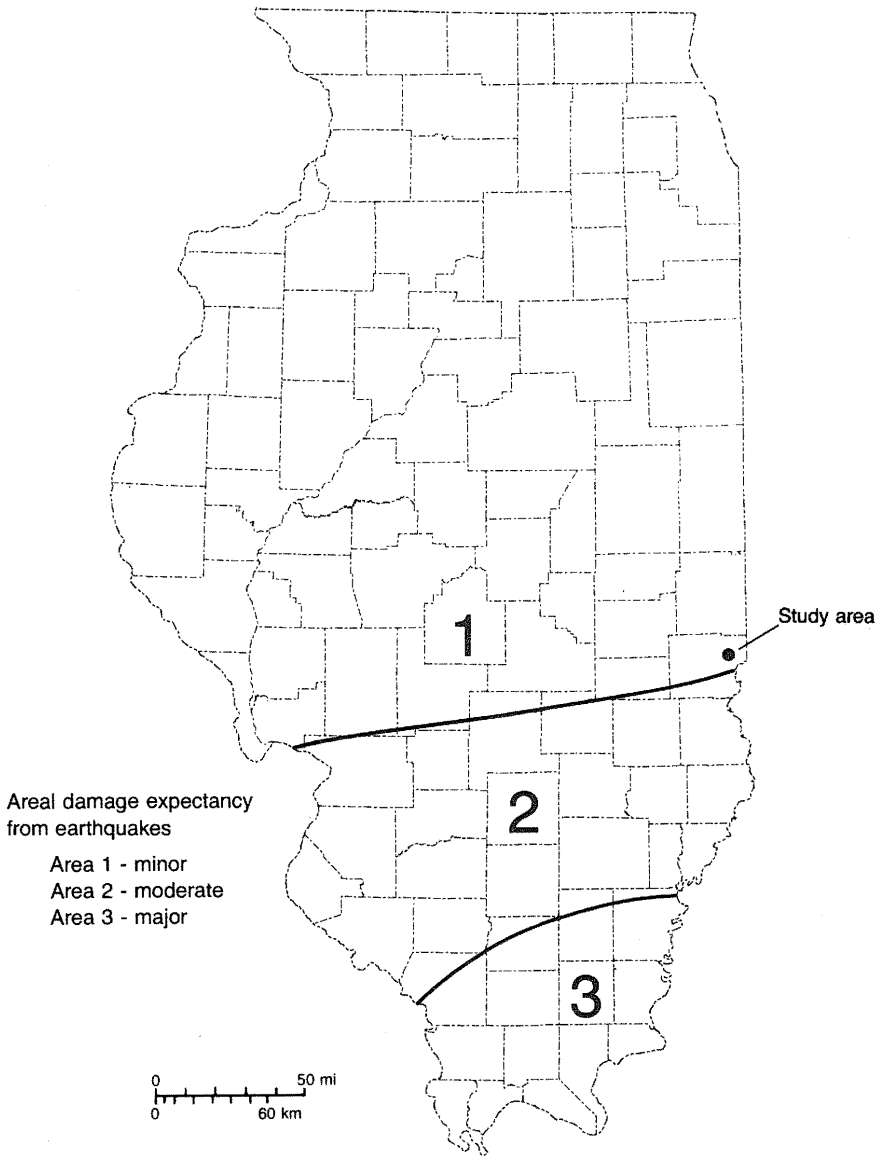

Figure 6 Seismic risk map for Illinois (after Algermissen 1969).

Other mineral resources, including building stone, agricultural lime, clay, sand, sand and gravel, metals, fluorite, barite, and tripoli, have been mined commercially throughout Illinois (Samson 1983, 1989). Most of the mining operations are at or near the land surface. Only limited surface mining (for aggregate and stone) has been done near the study area, and apparently neither the mining nor the injection operations have affected each other.

Natural gas storage fields in aquifers having localized structural closure features are scattered throughout the state. Three storage fields are located about 10 miles north and northeast of the study site (fig. 9). Aquifers of sandstone and limestone strata of Cambrian through Pennsylvanian age have been used for storage. Drilling and testing records from the Nevins, State Line, and Elbridge storage facilities have provided much useful information about subsurface geologic and

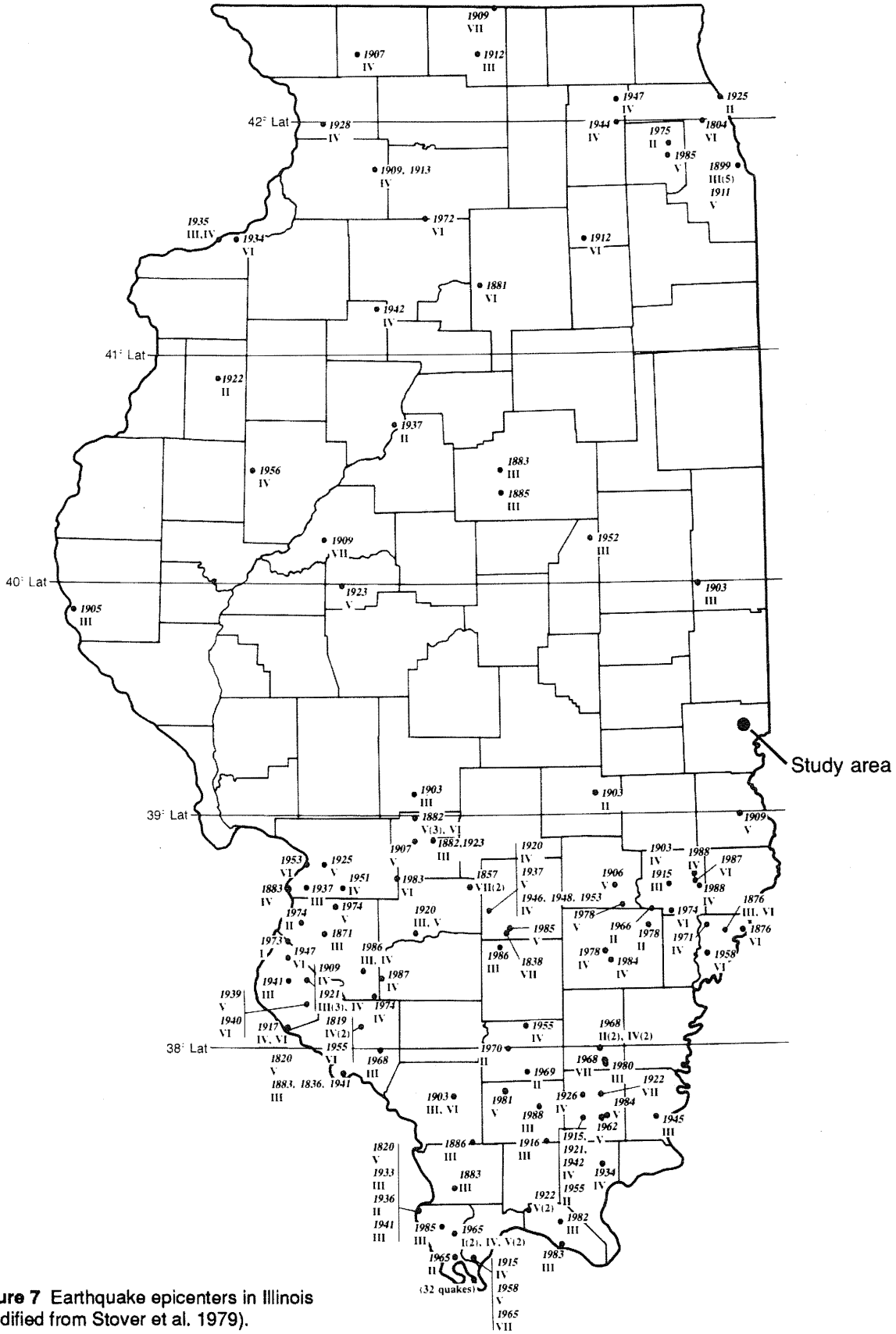

Figure 7 Earthquake epicenters in Illinois (modified from Stover et al. 1979).

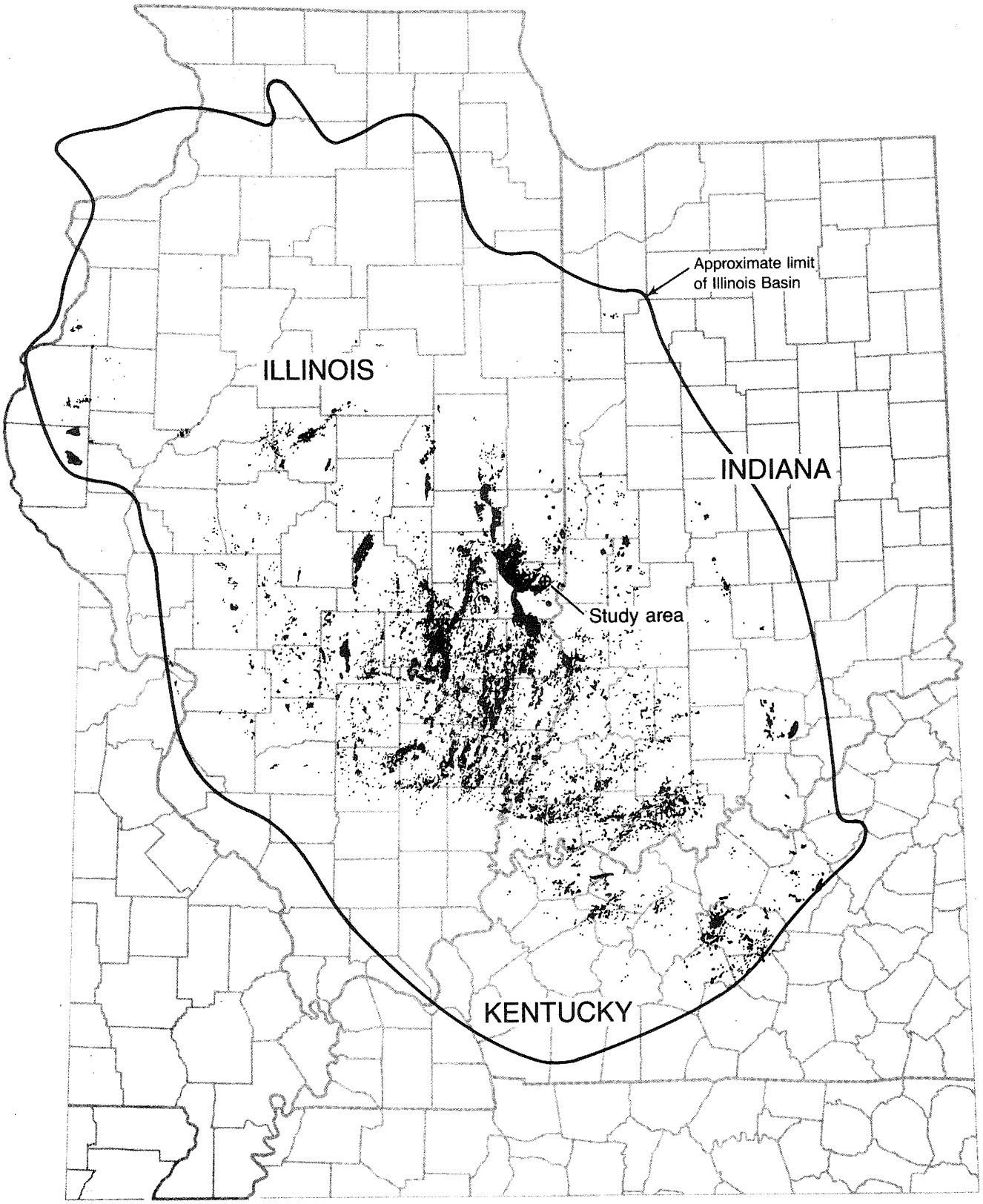

Figure 8 Oil and gas fields of the Illinois Basin (from Leighton et al. in press).

hydrogeologic conditions at the study site. Injection activities in the nearby natural gas storage fields and at the study site do not appear to affect each other significantly, although both utilize the same units of the Hunton.

Regional Geology and Hydrogeology

The units that are part of the injection system and are penetrated by the disposal well include the basal confining interval (Maquoketa Group), the injection interval (Hunton carbonate sequence), and the upper confining interval (New Albany shale sequence). Additional impermeable units and some aquifers lie between the upper confining interval and land surface. The first significant aquifer above the injection interval is the Salem Limestone.

Waste Disposal Well 2 (WDW2) was originally drilled to 6,000 feet (Eminence-Potosi Dolomites). It was plugged back into the uppermost unit of the Silurian limestone part of the Hunton because the immediately overlying Devonian limestone was the deepest, most receptive injection interval available.

Ordovician System

Ordovician strata (fig. 4) range in thickness from 700 feet (in northern Illinois) to more than 6,000 feet (in southern Illinois). The thickness increases gradually toward the south. Dolomites and limestones are the predominant lithologies; however, several distinct sandstones are found in the lower (Gunter and New Richmond Sandstones) and middle (St. Peter Sandstone) parts of the Ordovician. A thick shale-shaly carbonate sequence (Maquoketa Group) forms the upper part of the Ordovician. Many of the units below the Maquoketa are relatively impermeable and act as aquitards. The St. Peter Sandstone, a thin (50-ft), fine-grained, low-permeability sandstone in Clark County, is the first significant aquifer below the Hunton injection interval.

Maquoketa Group (Lower Confining Unit)

The Maquoketa Group (fig. 4) consists of two shale units and an interbedded shaly limestone-dolomite unit. The thickness of the Maquoketa ranges from approximately 150 feet in the western part of the state, where the top is eroded, to nearly 300 feet along the eastern edge of the state (fig. 10). In the vicinity of Marshall, the Maquoketa is less than 300 feet thick.

Hydrologic Characteristics of the Ordovician System

In northern Illinois, carbonate units of the Ordovician that are at or near land surface have moderate to relatively low permeabilities. As the burial depth of these units increases toward the south, the permeabilities of the units generally decrease. Carbonate units lying below freshwater zones (groundwater with less than 10,000 mg/L TDS) are essentially aquitards. Figure 11 shows the basal position of USDW in a north-south cross section from Rockford to Cairo. The southward-pointing tongue of USDW in the Ordovician lies in the St. Peter Sandstone. The TDS level of the St. Peter in the Marshall area is greater than 50,000 mg/L (Meents 1952).

Porosities in carbonate units in the southern half of the state are generally less than 10 percent; permeabilities in the more permeable units rarely exceed 1 to 30 millidarcys (Ford et al. 1981, Mast 1967). Porosities and permeabilities across vertical sections of the St. Peter are quite variable. The more permeable horizons measured in northern Illinois had porosities ranging from 12 to 17 percent and permeabilities ranging from 25 to 250 millidarcys. In the south, where the St. Peter is thinner, finer-grained, and more shaly, porosity and permeability values can be expected to be smaller. The shale units in the Maquoketa Group are expected to be very tight (<1 millidarcy).

Hunton Supergroup (Injection Interval)

The limestone and dolomite units of the Silurian and Devonian Systems have similar lithologic and hydrogeologic characteristics and thus are considered one large unit, the Hunton Supergroup. The thickness of the Hunton ranges from a featheredge along the Mississippi River to more than 1,800 feet near the southern tip of the state. Figure 12 shows the thickness and dis-

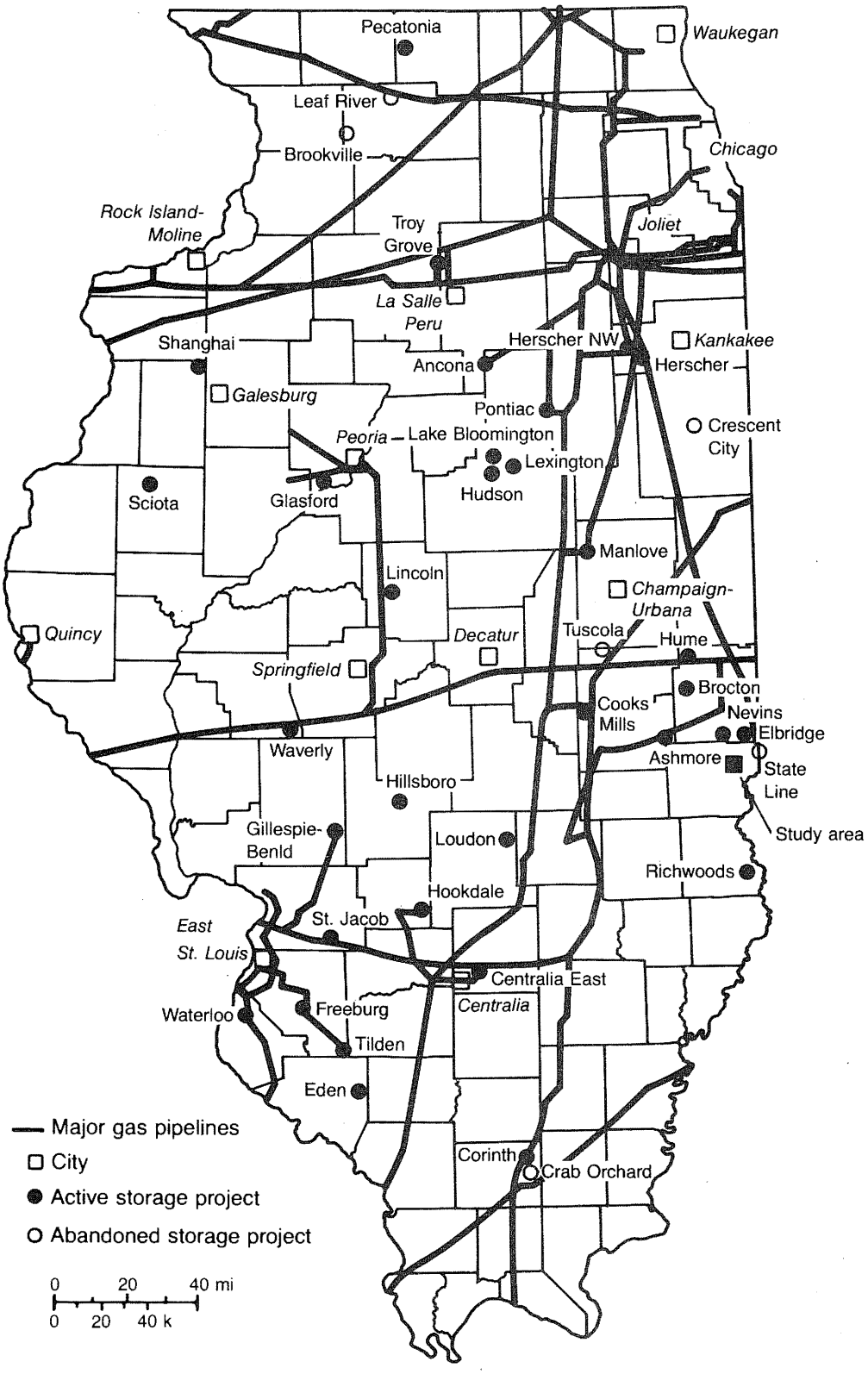

Figure 9 Location of underground gas storage projects in Illinois (after Buschbach and Bond 1974).

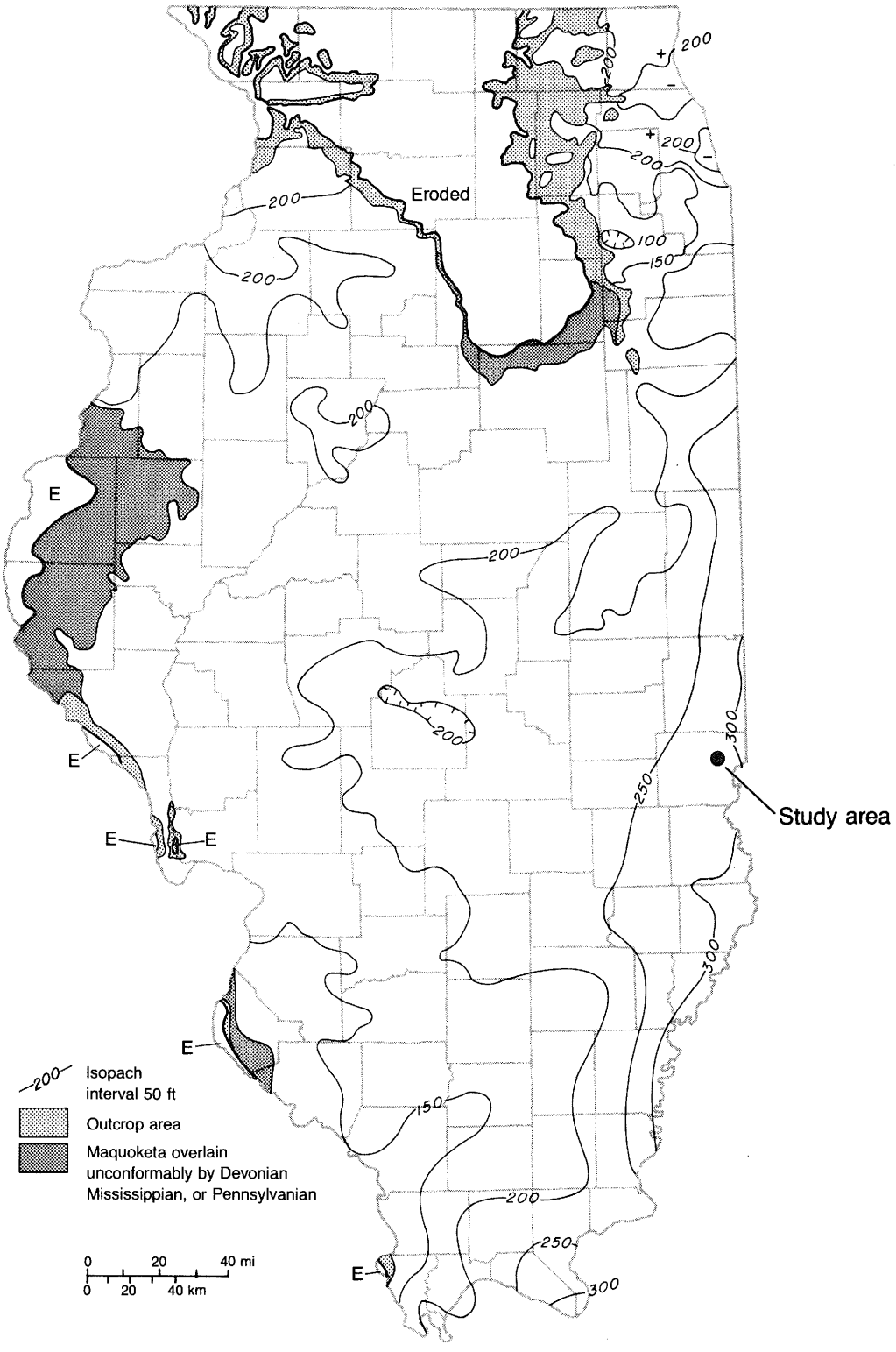

Figure 10 Generalized thickness and distribution of the Maquoketa Group (after Willman et al. 1975).

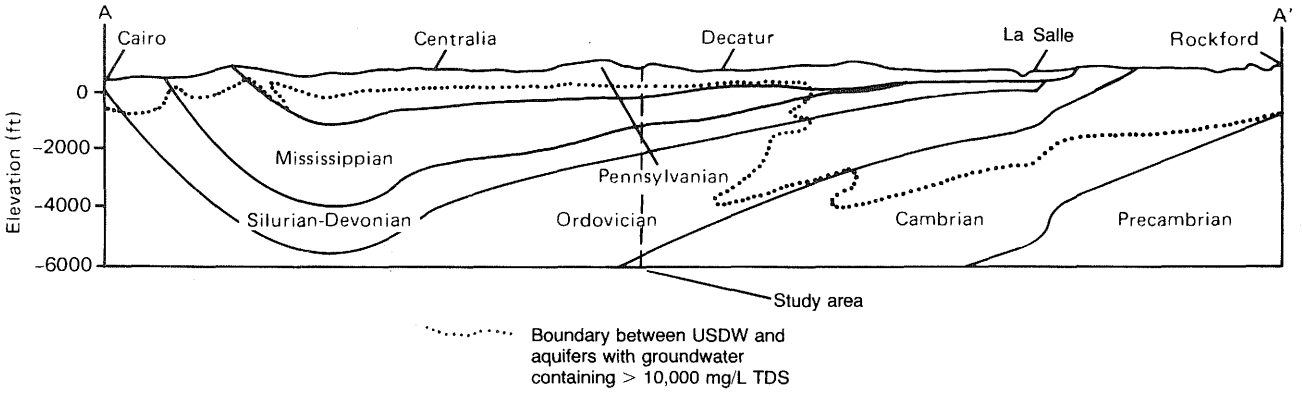

Figure 11 Cross section from Cairo to Rockford (see fig. 3) showing the position of base of the USDW (Brower et al. 1989).

tribution of this unit. Note that erosion has truncated the Hunton in a large area in the northern third of the state. Near the project site the Hunton is about 800 feet; its upper 350 feet includes units of the Devonian System.

Silurian Part of Hunton Supergroup

The Silurian consists of Alexandrian (lower part) and Niagaran (middle part) units and thickens eastward from an erosional featheredge in western Illinois to more than 700 feet in the east-central part of the state. In places, pinnacle reefs may increase the thickness to 1,000 feet. Units of the Cayugan (upper part) are thin or missing in Illinois. The Niagaran, the principal unit of the Silurian, consists of three dominant carbonate facies: shaly dolomite in the south, intermediate-purity carbonate in the north-central and northeast, and relatively high-purity carbonate in the northwest. Reefs are found throughout the Silurian units, and those in the southern part of the state (particularly in the southwestern part) may be oil-bearing (Whitaker 1988).

The uppermost Silurian unit in the study area is the Moccasin Springs Formation (fig. 4). The Moccasin Springs consists mostly of red (or red-and-gray-mottled), very silty, argillaceous limestone and calcareous siltstone; shale is common near the top. The Moccasin Springs contains numerous reefs, dominantly limestone, which have well-defined flank structures. The Moccasin Springs is commonly 160 to 200 feet thick and is more than 160 feet thick in the study area.

Devonian Part of the Hunton Supergroup

The Devonian part of the Hunton is composed of a basal sequence of four cherty limestones (including the Bailey Limestone) and an upper sequence of two limestones (the Grand Tower Limestone and the Lingle Formation). The Bailey Limestone is a silty, cherty, thin-bedded, hard limestone that begins along a southwesterly trending featheredge in central Illinois. Southeast of Marshall, additional cherty carbonate units were successively deposited above the Bailey. The combined thickness of these units reaches 1,200 feet in the southern part of the state. The Bailey is 144 feet thick in the Marshall area. The overlying Grand Tower Limestone and Lingle Formation begin along a southwesterly trending featheredge 75 miles northwest of Marshall and thicken southward to more than 400 feet in Gallatin County. Near Marshall, these two units have a total thickness of 96 feet; the Lingle is 22 feet thick.

Hydrogeology of the Hunton Supergroup

Fresh water is found at or near the surface in the Hunton in the northern half of the state and along the margins of the Illinois Basin. Well yields vary, depending mostly on the degree of fracture development. Variations in primary porosity and permeability can be related to lithology, which exerts some control on the degree of fracture development. Fracture development is greatest near the surface and generally decreases as depth of burial increases, particularly where the Hunton is overlain by impermeable shale units of the New Albany and Pennsylvanian.

The boundary marking the base of USDW in the Hunton is shown in figure 12. Typically, groundwater mineralization increases rapidly southward from this boundary. However, in Clark County the rate of increase in the TDS of the brine is relatively lower southwest of the USDW boundary, resulting in a TDS content of approximately 16,000 mg/L in the permeable Devonian units. Increased groundwater circulation in units with higher permeabilities allows less mineralized water to advance greater distances downdip (Brower et al. 1989). Other examples of this phenomenon are shown in figure 11; tongues of fresher water in the St. Peter Sandstone (Ordovician), the Ironton-Galesville Sandstone (Cambrian), and in certain shallow units (Silurian through basal Pennsylvanian near Cairo) move downdip into the Illinois Basin (Student et al. 1981). In the deeper parts of the basin, the mineral content of groundwater in the Hunton may reach from 150,000 to more than 200,000 mg/L TDS (Graf et al. 1966).

Drilling records and testing for the region show that the Lingle, portions of the Grand Tower, and a major part of the Silurian are relatively tight. The Bailey and several horizons in the Grand Tower and the Silurian have significant zones of permeability. Selected intervals of higher permeability in the Bailey have been used for disposal at the study site.

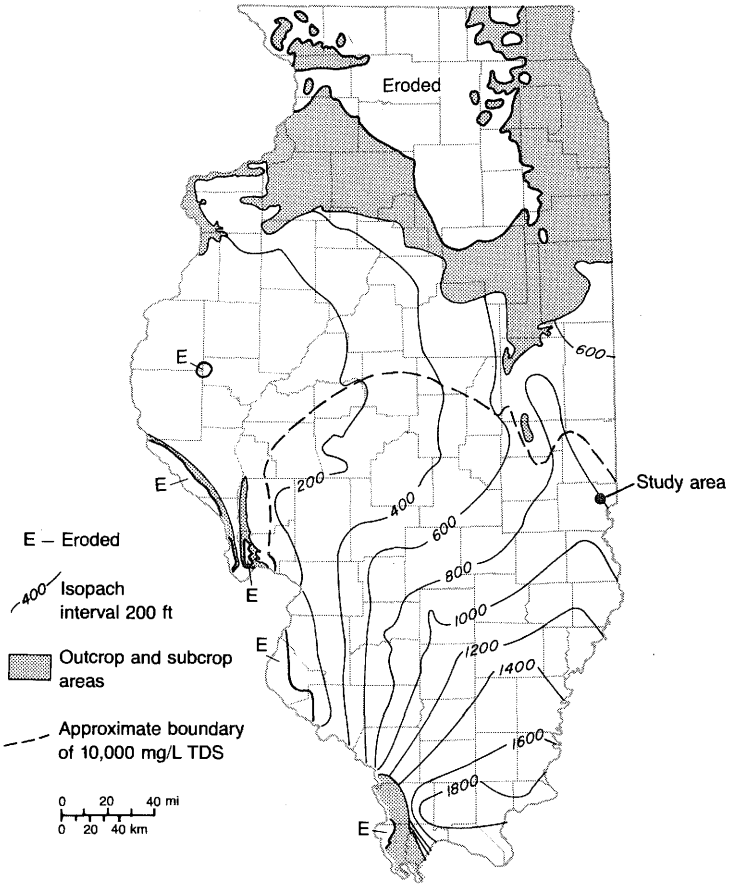

Figure 12 Generalized thickness and distribution of the Hunton Supergroup (after Willman et al. 1975) and the TDS boundary for USDW (Brower et al. 1989).

Porosity and permeability data obtained from tests run on samples collected from oil exploratory and gas storage wells scattered around the state show a mean porosity of 13 percent and a mean permeability of 40 millidarcys (Mast 1967). These data included values obtained from units in the Galena Group. Ford et al. (1981) reported porosity values of 12 to 19.5 percent and permeability values of 50 to 300 millidarcys for 269 wells completed in Devonian carbonate reservoirs of Illinois.

Evaluation of geophysical logs and sample cuttings conducted during the course of this study and for related studies of the disposal wells indicated that discrete, areally extensive horizons having high, moderate, and low permeabilities occur in the Bailey. Pore sizes range from 5 microns (μm) to over 300 (average range, 10 to 25 μm), and the pores have a fair degree of interconnection.

New Albany Group

Sedimentation during Late Devonian and Kinderhookian (Mississippian) time produced widespread accumulation of black, gray, and green shales and some limestones and siltstones. The rock units that accumulated during this time attained a total thickness of 100 to 450 feet through central and southeastern Illinois (fig. 13). Cluff et al. (1981) identified three formations present in east-central Illinois. The Blocher Shale, the basal unit, appears several miles west of the study area and thickens toward the southeast. The Blocher consists of calcareous-to-dolomitic, pyritic shale that is rich in organic matter. The Blocher is overlain with the Sweetland Creek Shale, which thickens from about 50 feet at an erosional cutoff in the central part of the state to more than 350 feet in Hardin County in southern Illinois. The Sweetland Creek is dark gray (in some places, green) and has poorly developed, laminated bedding. The unit is similar in

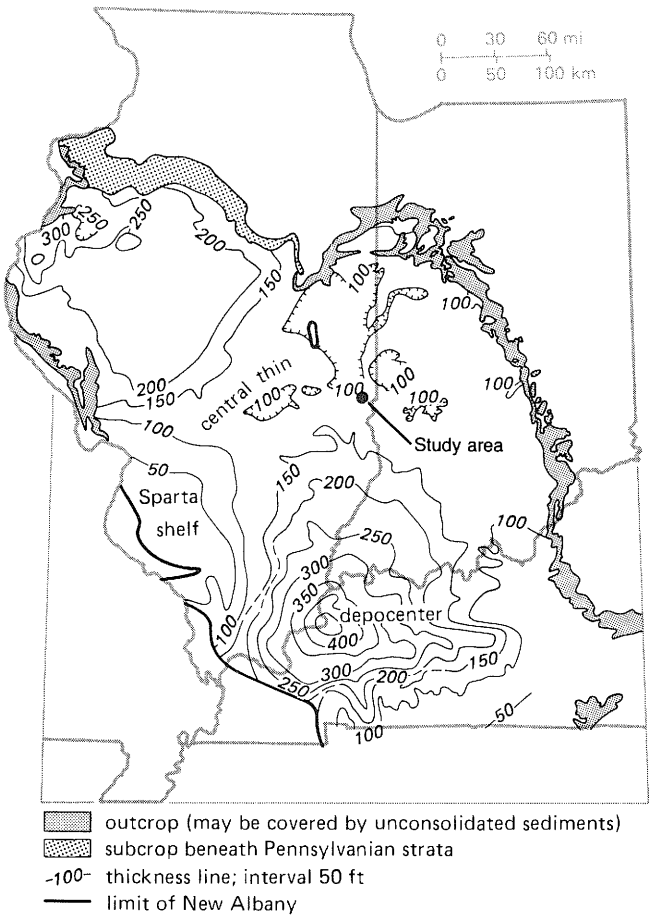

Figure 13 Generalized thickness and distribution of the New Albany Group (after Cluff et al. 1981).

appearance to both the Blocher and the overlying Hannibal Shale, but has widely traceable key beds. The overlying Hannibal Shale or its equivalent is less than 10 feet thick and indistinctly bedded. These formations are not differentiated at the study site.

Hydrogeology of the New Albany Group

The units of this group are very tight and therefore serve as an upper confining interval for the Hunton Supergroup. Natural gas storage fields completed in the Hunton utilize the low porosity and very low permeability of these units to retain gas in the underlying storage reservoirs (Buschbach and Bond 1974). The shale units in this group have essentially no water- or oil-yielding potential.

Mississippian Units

Mississippian units cover the southern two-thirds of the state and reach a maximum thickness of 3,300 feet in Williamson and Saline Counties (fig. 14). The widespread, thin, irregularly bedded Chouteau Limestone (Buschbach 1952) rests on the top of the New Albany and marks the base of three simultaneously deposited units: (1) the deltaic, tongue-shaped Borden Siltstone trending southwesterly across the state from the west-central part of Indiana; (2) the Burlington-Keokuk Limestones to the northwest; and (3) the Fort Payne Formation and Ullin Limestone to the southeast. The Borden consists of siltstone, some silty shale, and a few beds of fine sandstone and coarse siltstone. The "Carper sand" is present in places near the base of the Borden. The Ullin or its equivalent overlaps the top of the Borden with 150 feet of limestone and some shale in the Marshall area. Widespread limestone units, including the Salem, St. Louis, and Ste. Genevieve Limestones, accumulated between the Borden and the overlying alternating sequences of shale-limestone and shale-sandstone units that were deposited during Chesterian time.

The Mississippian section above the Chouteau is approximately 1,200 feet thick in the Marshall area and includes 450 feet of Borden Siltstone. The "Carper sand" is approximately 20 feet thick and lies very near the base of the Borden.

Hydrogeologic Conditions in the Mississippian

Mississippian units are used extensively for small (and some moderate) water supplies in and near outcrop areas. Most wells are finished at shallow depths, typically less than 300 to 500 feet. Groundwater mineralization increases rapidly with increasing depth of burial and in a down-dip direction toward the Illinois Basin (Meents 1952).

The Borden Siltstone is a thick unit of very low-permeability material that provides confinement in addition to the New Albany Group, the primary confining unit of the Hunton injection interval. The "Carper sand" provides the first somewhat permeable horizon above the top of the Hunton. Several thin, fine-grained sandstones also lie near the top of the Borden. Available porosity logs suggest that porosities of about 8 to 12 percent can be expected in these sandstones. At the study site, the Salem Limestone is the first overlying aquifer having significant permeability; it has been used for waste injection in the past. The measured static water level in the Salem is about 50 feet lower than the water level in the Bailey. The mineral content of the Salem and the Bailey in the Marshall area is similar (about 15,000 to 16,000 mg/L TDS). The groundwater in these units has an anomalously low mineral content, which appears to be related to the relatively high porosity and permeability of these units. Figures 12 and 14 show the location of the USDW boundary in Hunton and Mississippian units. The less permeable units of the Mississippian, particularly those in the upper part, contain groundwater with a much higher mineral content.

Pennsylvanian Units

The bedrock surface in the southern two-thirds of the state has been formed on Pennsylvanian units. Shale and clay units (more than 50% of the total thickness), sandstones and siltstones (more than 25%), limestones (less than 10%), and coals comprise more than 500 distinguishable units. Pennsylvanian strata reach a maximum thickness of 2,500 feet in the south-central part of the basin. Sandstones are interbedded with the shale throughout the Pennsylvanian but are most

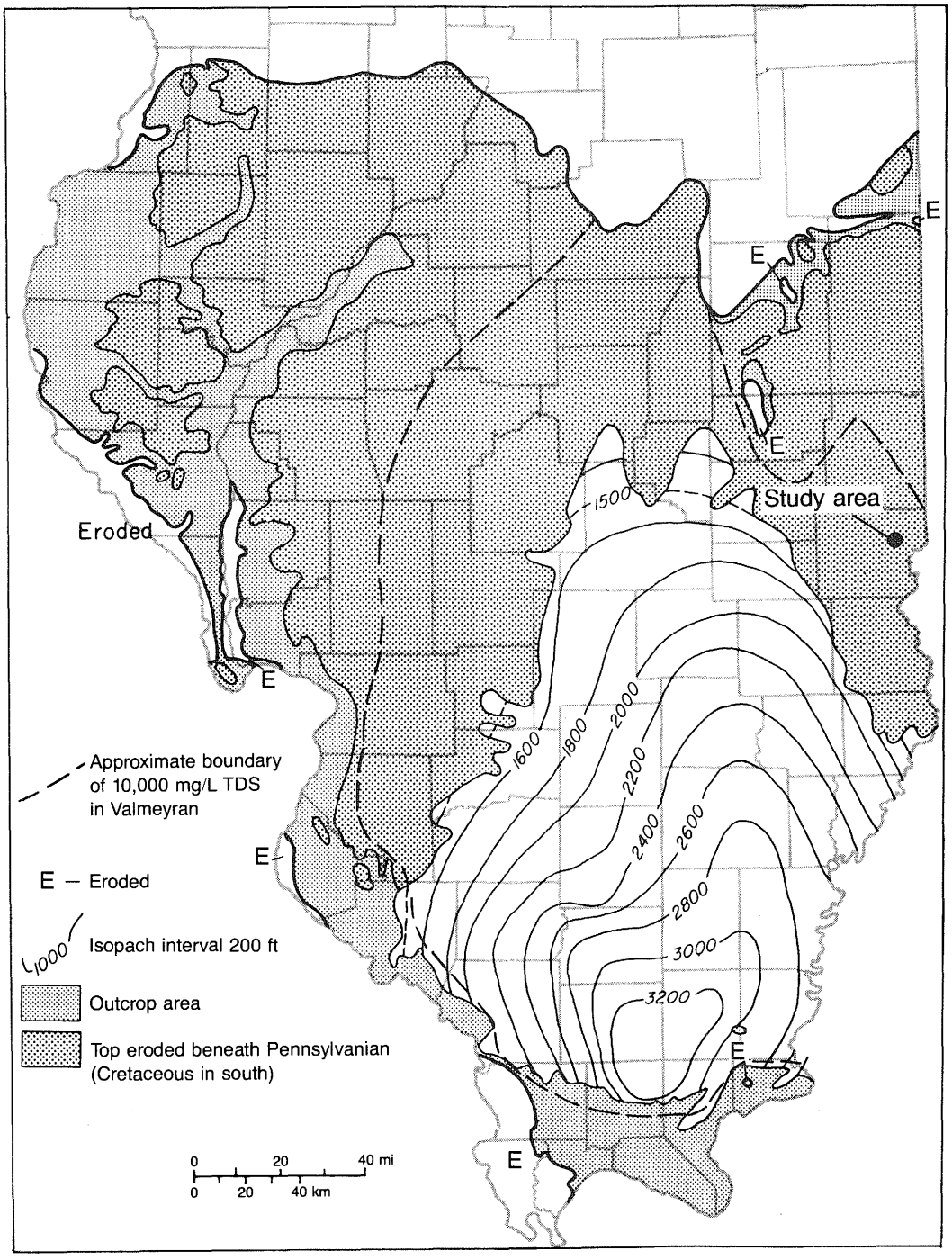

Figure 14 Generalized thickness and distribution of the Mississippian System (after Willman et al. 1975) and the TDS boundary for USDW (Brower et al. 1989).

abundant in the lower two of seven formations. Limestones are more abundant in the second formation from the top, and the most well-developed coal units are in the middle (fourth) formation.

In the Marshall area, the Pennsylvanian is about 1,050 feet thick. The thicker sandstones are found near the base of the Pennsylvanian. Coal units are present but thin. The more prominent coals occur below a depth of 400 feet.

Hydrogeologic Conditions in the Pennsylvanian Units

Fresh water exists in the upper 300 to 500 feet of the Pennsylvanian units and is a principal source for low-volume water supplies where no potential for supply exists in overlying glacial deposits. Near the margins of the basal formations, the more permeable sandstones contain fresh water to depths of more than 1,000 feet. In the Marshall area, mineralization of groundwater increases rapidly below depths of 50 to 75 feet, and water wells rarely penetrate to depths below 100 to 200 feet. The base of USDW is estimated from geophysical logs to lie about 500 feet below the surface (Piskin 1986).

Sandstones in the upper three-fourths of the Pennsylvanian are thin and widely spaced and yield very little water. The basal sandstones in the Marshall area may yield up to 20 gpm; however, water from these sandstones has a very high mineral content (38,000 mg/L TDS) (ISGS UIC files).

Porosity and permeability values measured from cores and wells collected from or finished in all types of Pennsylvanian units range from 9 to 25 percent and 10 to 10,000 millidarcys (Ford et al. 1981). Porosities measured in oil-producing sandstones are relatively uniform, averaging 17 to 20 percent (Whiting et al. 1964). Whiting also reported permeabilities of 100 to 400 millidarcys, which decrease as depth of burial increases.

Quaternary System

Glacial deposits consisting of loess, silt, clay, till, sand, and gravel cover a large part of the bedrock surface of Illinois. In the Marshall area, the drift is less than 10 to 50 feet thick in the upland areas and up to 30 to 100 feet thick in the larger stream valleys. Peoria Loess (2 to 6 ft thick) and Roxana Silt (0 to 3 ft thick) mantle the Glasford Formation (clay, sand, and till, 0 to >21 ft thick) on the upland. The Banner Formation (clay and till 0 to >20 ft) underlies Glasford Formation till where thicker drift is present in the upland areas (ISGS UIC files 1981). Cahokia Alluvium (silt, sand, and clay) overlies Henry Formation (outwash sand and gravel up to 70 ft thick) in the valley of Big Creek. Very limited to small water supplies are available from the upland glacial deposits. Moderate to large water supplies are available along some segments of Big Creek valley. Marshall obtains its water supply from the Henry Formation, about 2.25 miles east of the study site.

3. HYDROGEOLOGIC INVESTIGATION OF THE INJECTION SYSTEM

This chapter briefly discusses techniques used to collect and analyze hydrogeologic data. Details of the techniques and analyses are in appendices A and B. Specifically, stratigraphic correlations within the injection system from regional (5 to 10 miles) and local (3 miles) perspectives are discussed, along with methods used to collect additional data from the site of the injection well. These methods include geophysical logging, sidewall coring and associated analysis, and hydraulic testing. A hydrogeologic description of the injection system at the site is also given.

Stratigraphic and Structural Definition of the Injection System

The injection system consists of the geologic materials constituting the injection zone and its associated upper and lower confining units. To evaluate the confining and injection potential for the Devonian injection system, data were collected from wells in three gas storage fields (Nevins, Elbridge, and State Line), wells within 5 to 10 miles from the project site, and wells within 3 miles of the site (see figure 15 and table 1). The gas storage fields are approximately 9 miles northeast of Velsicol's Waste Disposal Well 2 (WDW2). Data from these wells were used to correlate hydrogeologic units within the injection system and to construct a structure map of the top of the Lingle Formation. The injection interval for WDW2 lies within the Devonian limestone sequence, immediately below the Lingle and Grand Tower Formations.

Each of the three gas storage fields utilizes a domal structure with closure to concentrate and store the gas. Each domal structure was formed by the deposition of Devonian- and Silurian-age shelf facies sediments over Silurian-age reef facies sediments.

Although this type of structure is not present in the area immediately surrounding the Velsicol plant, the general stratigraphic relationship of the rock units near the storage fields and those near the disposal well was shown to be consistent. Inferences were then made regarding data from the gas storage fields to the disposal well at Velsicol.

Geophysical logs from wells at a 5- to 10-mile radius from the plant were used to correlate stratigraphy and to give a regional picture of the configuration of the injection system. Geophysical logs from wells within 3 miles of the injection well were used to construct a structure map consistent with regional data.

Stratigraphic Description of the Injection System

The stratigraphy of the injection system includes the Silurian-age Moccasin Springs Formation at the base through the Grassy Creek Shale, the uppermost Devonian unit of the New Albany Group. Figure 16 is a geologic column showing the stratigraphic position and hydrogeologic characteristics of these units at the waste disposal well studied. Much of the strata information is from Willman et al. (1975). Additional data were obtained for the Middle Devonian strata from North (1969) and for the strata of the New Albany Group from Cluff et al. (1981).

The Devonian strata comprise three series—the Lower, Middle, and Upper. The Bailey Limestone, basal unit of the Lower Devonian Series, is dominantly gray to greenish gray, silty, cherty, thin-bedded, very hard limestone. Some beds are argillaceous. The chert, black to dark gray, occurs in bands up to 2 feet thick. An upper zone, 0 to 100 feet thick, is limestone that is pure, white, coarsely crystalline, and only slightly cherty.

A major unconformity occurs at the Lower and Middle Devonian interface. The basal formation of the Middle Devonian Series is the Grand Tower Limestone, which is mostly coarse-grained, light gray, medium- to thick-bedded, cross-bedded, pure, fossiliferous limestone. It also contains lithographic limestone, which becomes more abundant upward. One member differentiated at the study site is the Tioga Bentonite Bed, which is found 10 to 30 feet from the top of the Grand

Table 1 Wells used in study

Well No.	Name	Location
3	Richard Lindley #1	29-11N-10W
4	Thomas Coats #2	31-10N-13W
5	C. A. Pence #1	31-10N-13W
6	Burger #1	23-10N-13W
7	H. O. Coldren #1	4-11N-11W
8	A. Kannmacher #1	24-10N-13W
9	Clifford I Morgan, et al. #1	4-11N-11W
10	Gus Birchfield #1	24-10N-13W
12	Frank Morgan, et. al. #1	19-10N-13W
13	S. M. Scholfield #1	6-11N-11W
14	Birchfield-Shumaker Comm. #1	34-11N-11W
15	Boyd #1	5-11N-14W
17	Smitley #1	7-11N-11W
19	F. Kuhn #1	8-11N-11W
21	D. M. Davison #1	8-11N-11W
23	Eugene Chenowith #1-A	9-11N-11W
25	Alfred Seidel #1	15-10N-11W
26	Russel Higginbottom, et. al. #1	34-10N-12W
27	E. P. Daly #1	8-11N-14W
28	E. F. Newman, et. al. #1	30-10N-13W
29	Ella Mae Young #1	19-10N-13W
30	Ormal Higginbotham #1	22-11N-13W
33	Fraker #1	16-11N-11W
35	Lickert #1	16-11N-11W
36	Guinnip-Keyes Comm. #1	10-11N-12W
37	Southerland Comm. #1	16-11N-11W
39	Southerland #2	16-11N-11W
43	Gunder #1	19-11N-11W
45	Monk #1	21-11N-11W
48	WDW1	12-11N-12W
49	DOW	12-11N-12W
50	Redman #1	5-11N-14W
51	Mary E. Kendall #1	22-11N-11W
52	G. and E. Herrington #1	8-11N-10W
53	Frank Morgan #2	24-10N-14W
54	WDW2	12-11N-12W
55	J. C. Yeley #1	27-12N-11W
56	Elbridge #1 (gas storage)	2-12N-11W
57	Nevins #6 (gas storage)	5-12N-11W
58	State Line #1 (gas storage)	28-12N-10W
61	Hall #1	1-11N-12W
69	Alton Blankenship #1	16-11N-12W
77	Bays #1	21-11N-12W
79	Anna Brosman #1	21-11N-12W
81	Minnie L. Jackson #1	21-11N-12W
85	John W. Dawson #1	22-11N-12W
87	Frahm-Cole-Lee Comm. #1	28-11N-12W
103	Glen Morgan #1	21-11N-12W
111	Waller Comm. #1	21-11N-11W

Tower. The Tioga is a greenish to brownish gray shale that contains biotite flakes and an abundance of silicate minerals that distinguish it from other shales. The Tioga generally is only 1 to 2 inches thick, but it may be 6 to 8 inches thick.

The Lingle Formation overlies the Grand Tower and is more argillaceous, darker, and finer-grained than the Grand Tower. At the study site, the Lingle is composed of two members, the Howardton Limestone Member and the Tripp Limestone Member. Howardton, the basal member, is gray, fine-grained, slightly silty, argillaceous limestone, most of which has thin, shaly partings. The Tripp is heterogeneous, containing limestone, dolomite, chert, siltstone, and shale. It is largely cherty, argillaceous, silty limestone, but beds of shale are abundant near its base and top. The New Albany Group overlies the Lingle Formation. The Devonian portion of this group includes the Blocher, Selmier (Sweetland Creek), and Grassy Creek Shales. These units were not

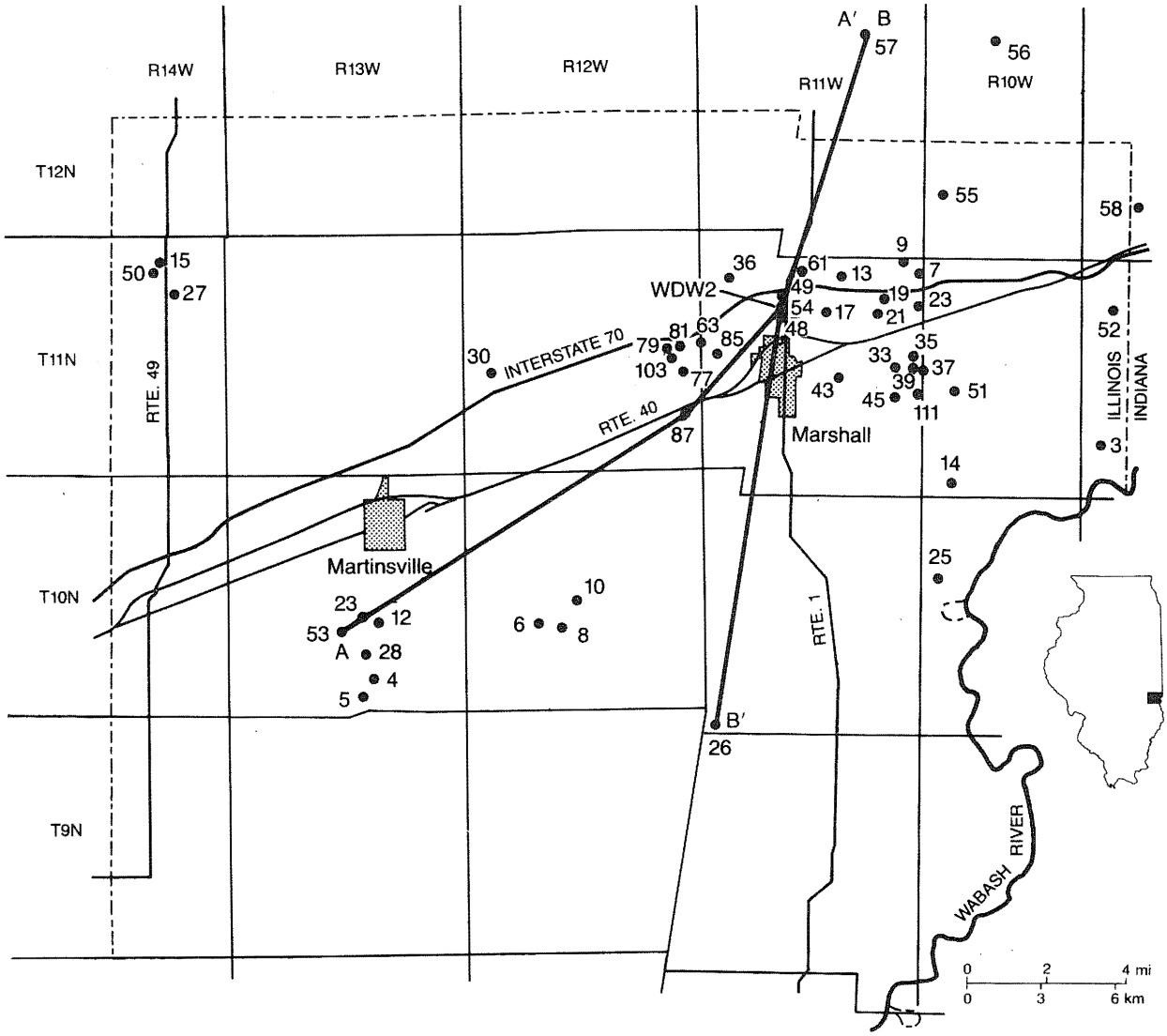

Figure 15 Well locations. Cross sections for A-A′ and B-B′ appear in figures 17, 18, and 19.

differentiated at the study site. The Blocher is the basal formation of the New Albany Group and is a calcareous or dolomitic black shale. The Blocher is the only shale in the New Albany containing much calcite.

The Selmier Shale Member overlies the Blocher and consists of greenish gray, dolomitic, bioturbated mudstone at the top that grades downward through an interbedded zone to black dolomitic laminated shale at the base. North (1969) placed these same units in the Sweetland Creek Member. The Selmier is conformably overlain by the Grassy Creek Shale Member.

The Grassy Creek is the uppermost Devonian unit of the New Albany Group and consists of brownish black to grayish black, finely laminated, pyritic, carbonaceous shale.

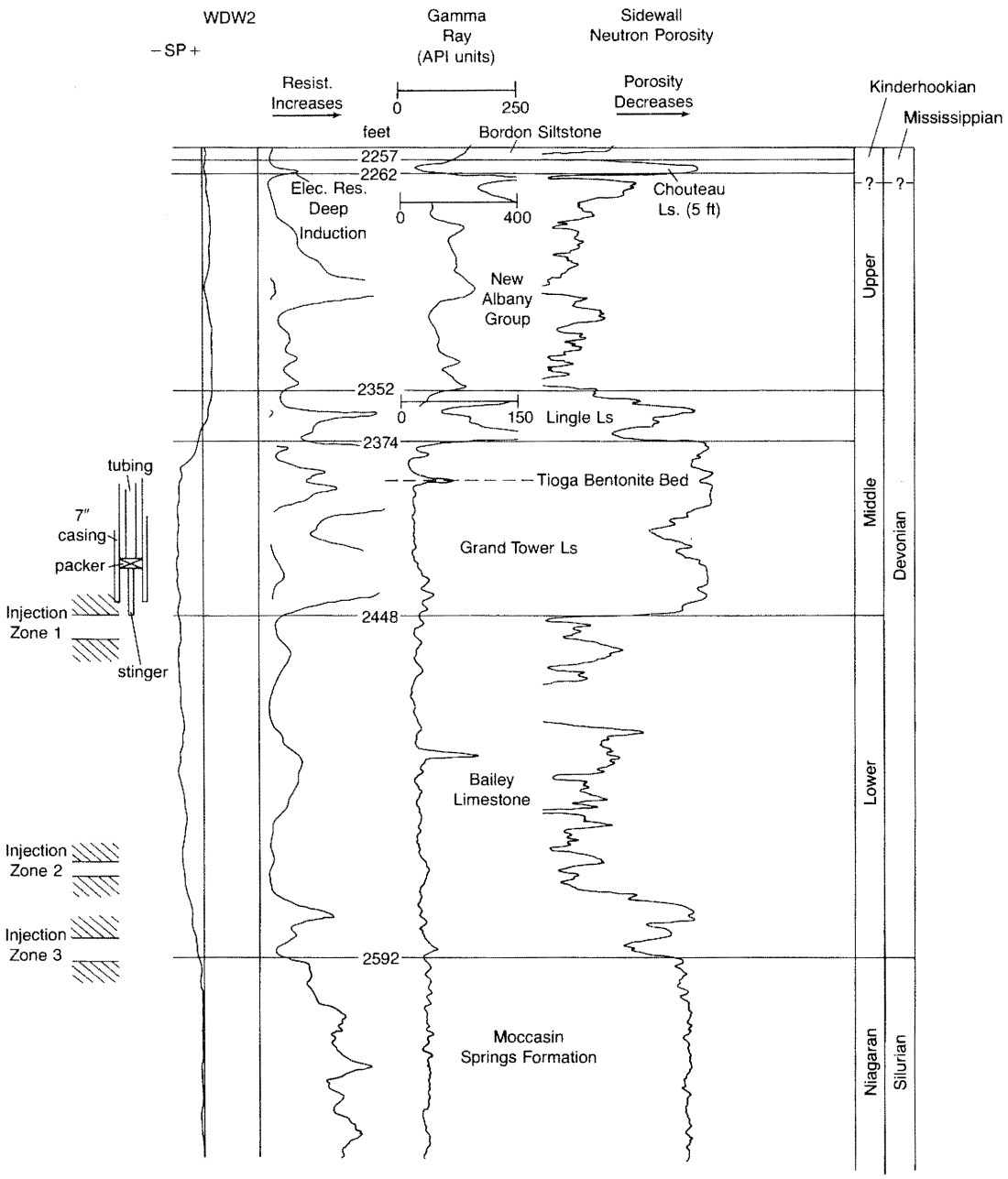

Figure 16 Geologic column for the injection system at Waste Disposal Well 2 (WDW2).

Geophysical Log Correlations

Figures 17, 18, and 19 illustrate the stratigraphic continuity of the hydrogeologic units within the injection system and the base of the New Albany Group within a 10-mile radius of WDW2. Figure 17 shows a southwest-northeast cross section based on resistivity logs, Induction Electric Logs (IEL), and Electric Logs (EL). Figure 18 is also a southwest-northeast cross section, but it is based on qualitative permeability log (Minilog) responses. Figure 19 shows a north-south cross section that is based on resistivity logs. Qualitative permeability logs were not available for all wells along this cross section.

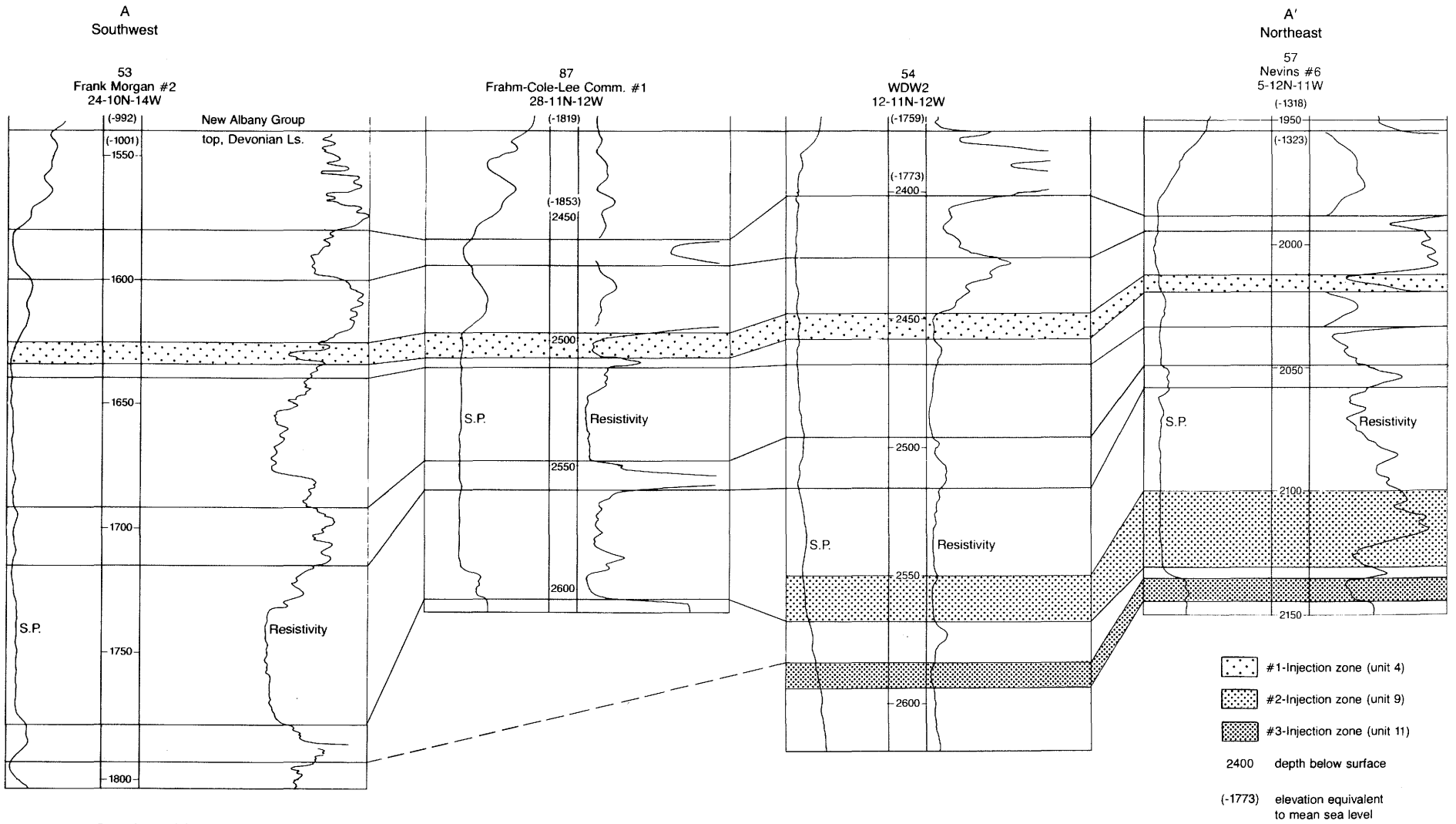

Figure 17 Stratigraphic correlation utilizing resistivity logs for southwest-northeast cross section.

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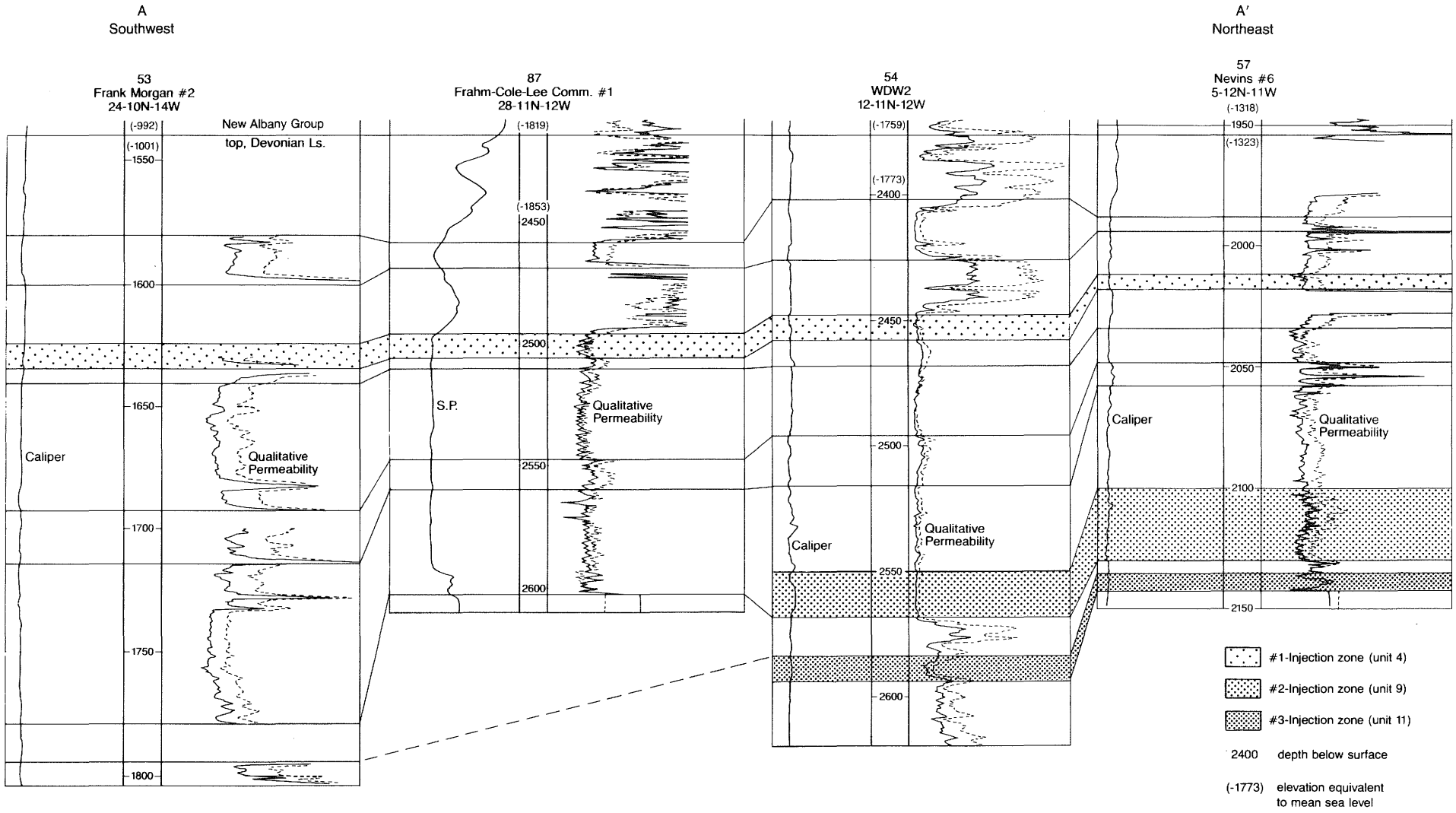

Figure 18 Qualitative permeability correlation utilizing permeability indicator logs for southwest-northeast cross section.

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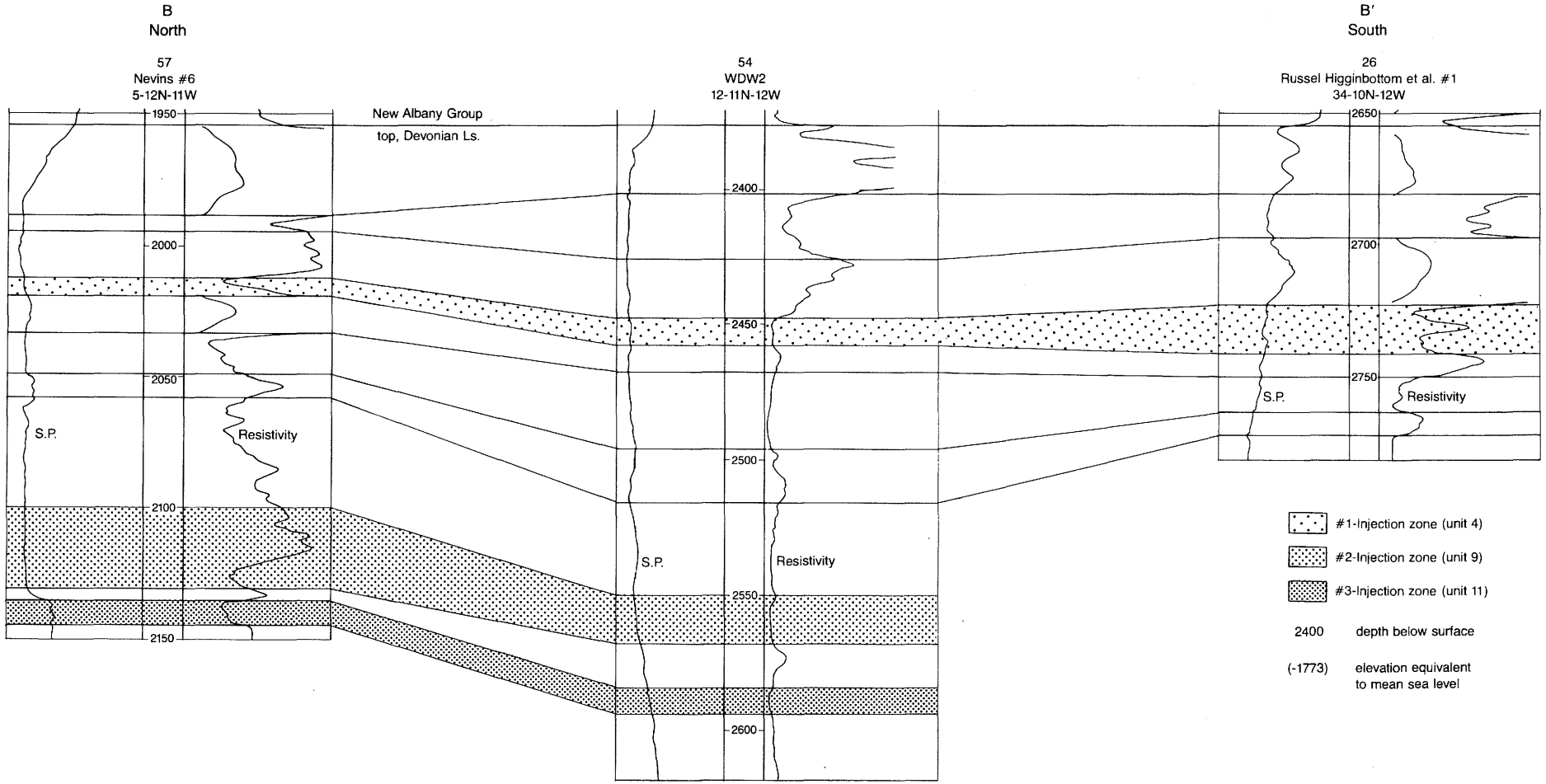

Figure 19 Stratigraphic correlation utilizing resistivity logs for north-south cross section.

The data presented in figures 17 and 19 show the hydrogeologic units within the injection system to be laterally continuous across the study area with one exception. Likewise, the continuity of the qualitative permeability of these units is inferred from figure 18. On the basis of resistivity and qualitative permeability logs, injection zone no. 2 could not be differentiated from the overlying unit in some wells in the study area. These unit designations are not included in these cross sections.

Nevertheless, the stratigraphic and qualitative permeability continuity of the Devonian limestone and the New Albany shale between the wells at Velsicol and the wells in the gas storage fields can be inferred; thus, continuity of quantitative permeability can be inferred. Analysis of core retrieved from WDW2 provided quantitative permeability data for the various hydrogeologic units. The quantitative permeability data obtained from wells at the three gas storage field wells are summarized later in this chapter (see Hydrogeology of the Site, p. 40).

A structure map of the top of the Lingle Formation was constructed (fig. 20) using information from wells within a 3-mile radius of Velsicol.

Stratigraphic and Structural Characterization

On the basis of correlations between the disposal well at Velsicol and the wells within a 5- to 10-mile radius of the plant, both the upper and lower confining units and the injection zones appear to be continuous across the study area. Although information about the thickness of the lower confining unit is limited, figures 17, 18, and 19 clearly show its stratigraphic location.

The analysis of available geophysical logs for regional hydrogeology of the injection system is summarized in figure 21. A confining unit is distinguished from an "impermeable" unit by its position with respect to the permeable units. Confining units lie directly above the uppermost perme-

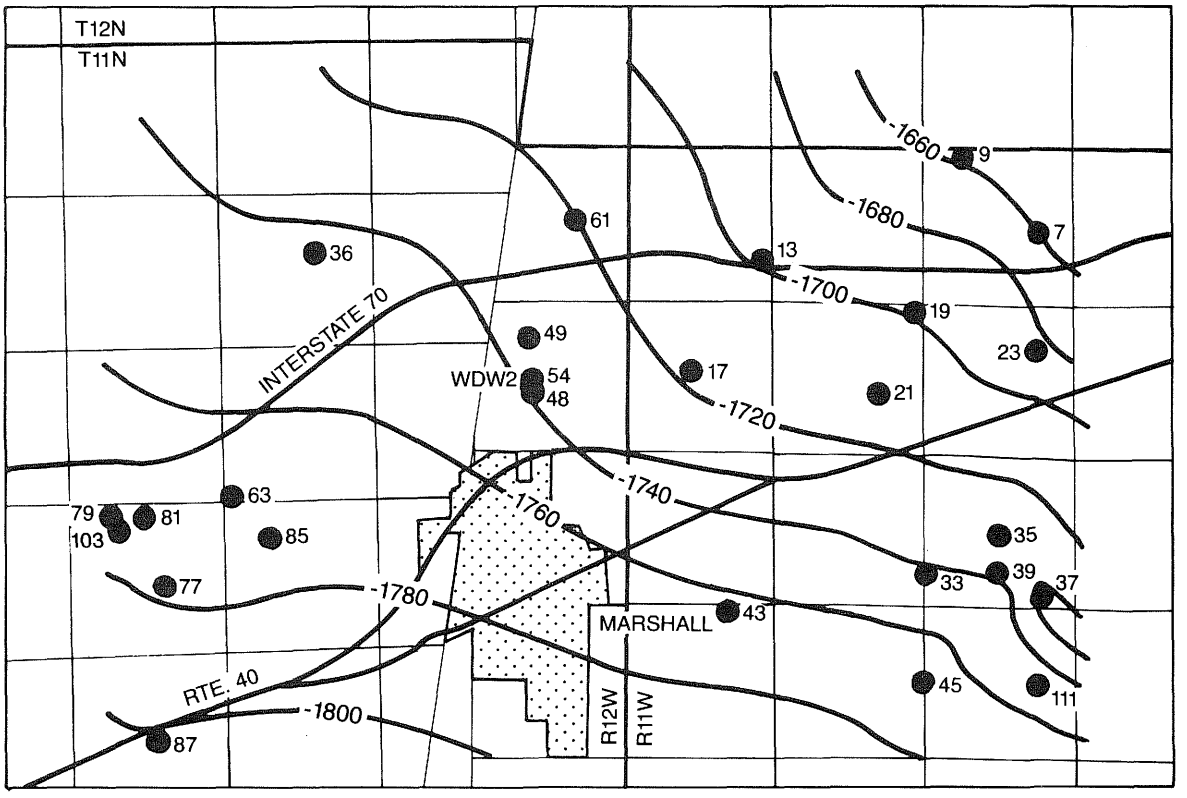

Figure 20 Structure contour map of the top of the Lingle Formation in the vicinity of the Velsicol plant.

able unit or directly below the lowermost permeable unit; impermeable units lie between permeable units. For permitting purposes, the upper confining unit includes the base of the New Albany shale and 26 feet of the Lingle Formation and Grand Tower Formation. Thickness variations for this section of the upper Devonian limestone are limited to about ±8 feet over the 10-mile region of investigation. In terms of the hydraulic confinement of the injection interval, the upper confining unit is composed of Grand Tower Limestone. Its thickness is approximately 74 feet at WDW2.

For permitting purposes, the Maquoketa shale is considered the lower confining unit. In terms of hydraulic confinement, the lower confining unit consists of the Moccasin Springs Limestone. Its total thickness could not be determined in this study because of limited data, but it is at least 160 feet thick at WDW2, based on available geophysical log data.

It is evident from figure 20 that the structure in the Velsicol plant area is generally flat with a gradual inclination of about 25 feet/mile to the northeast.

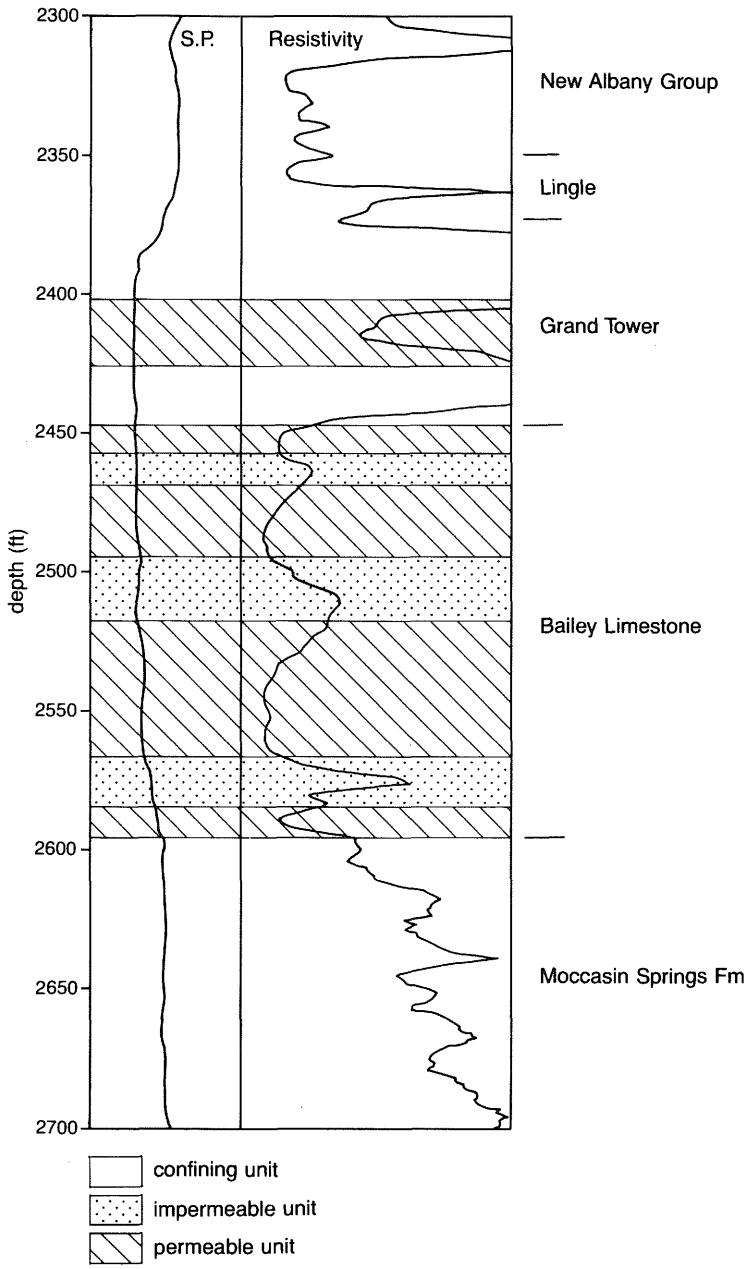

Figure 21 Injection system in WDW2 indicating permeable and impermeable zones delineated with available geophysical logging.

Determination of Horizontal Hydraulic Gradient

If the horizontal gradient is to be properly calculated, the hydraulic head within the injection system must be known for various locations. The initial reservoir pressure, obtainable from drill stem tests (DSTs), would be an excellent source of data. For initial reservoir pressure calculations, the pressure versus time chart from the DST is needed. This chart, however, was not available for wells in this area. Final flow and final closed-in pressures, as well as static water levels, were used to calculate the horizontal gradient. According to limited, high-quality data, the greatest horizontal gradient existed between wells 54 (WDW2) and 57. The hydraulic gradient (dh/dl) has a magnitude of 3.5×10^{-4} in a general direction of north to south.

Field Investigations

Two phases of geophysical logging were performed at the Velsicol site. During phase I, data on porosity and qualitative permeability, stratigraphic orientation, and the lithology of the rock units within the disposal zone were obtained from the Devonian Observation Well (DOW), Well 49. Data reduction indicated the units most favorable for fluid infiltration. Phase II was a detailed study based on information obtained from phase I. Results from phase II included quantitative data on permeability (air and water), bulk compressibility, hydraulic conductivity, specific discharge, and specific storage of the injection horizon. Those units with the greatest injection potential were further characterized for thickness, storativity, and transmissivity. In addition, hydraulic testing (flowmeter and injection testing) of the injection system was conducted.

Phase I Investigations

Records (well logs, drilling records, and other data) provided a general overview of the structure and regional continuity of stratigraphic units particularly important to waste injection and confinement. These data, however, were only one aspect of the overall integrated approach used to characterize the injection system. Additional data were needed to precisely define the character of possible confining and injection intervals. The methods and techniques used to characterize the disposal zone are discussed briefly and considered in detail in appendix A.

Existing geophysical logs. After a review of the historical records, a preliminary estimate was made of the stratigraphic location of the potential confining units (upper and lower) and the impermeable units associated with the operational waste disposal well (WDW2). These hydrogeologic units were delineated using four principal downhole geophysical logs, which were run during initial well (WDW2) construction in 1971. The logs were the Sidewall Neutron Log (SNL), Induction Electric Log (IEL), Gamma Ray Log (GRL), and Microlog (MIL). The hydrogeologic units determined from analysis of these logs are presented in figure 22. Consideration of all four logs was necessary to fully evaluate porosity, qualitative permeability, shale percentage, and lithology of the geologic materials. Interpretation methods used in the evaluation of these logs are discussed in appendix B.

Additional existing geophysical logs include the Temperature/Salinometer and GR/Neutron Logs run in the DOW in 1981 and 1973, respectively, and a Sonic Log (SL) run in WDW1 in 1965.

However, since logging instrument technology has progressed dramatically and subsequent equations and modeling of formation characteristics have advanced since these logs were run, a new suite of logs was run. Use of these geophysical logs enabled further delineation of the hydrogeologic characteristics of the injection system.

Phase I geophysical logging. A suite of logs was selected on the basis of the considerations discussed above and the physical dimensions of the casing and tubing in the three wells at Velsicol. The only well suitable for study during phase I was the DOW. Dresser Atlas performed the logging. The two types of porosity logs run were the Compensated Neutron Log (CNL) and the Borehole Compensated Sonic Log (BCS). The Minilog (MIL) was run to qualitatively determine permeability. Resistivity parameters were determined by the Dual Induction Spherically Focused

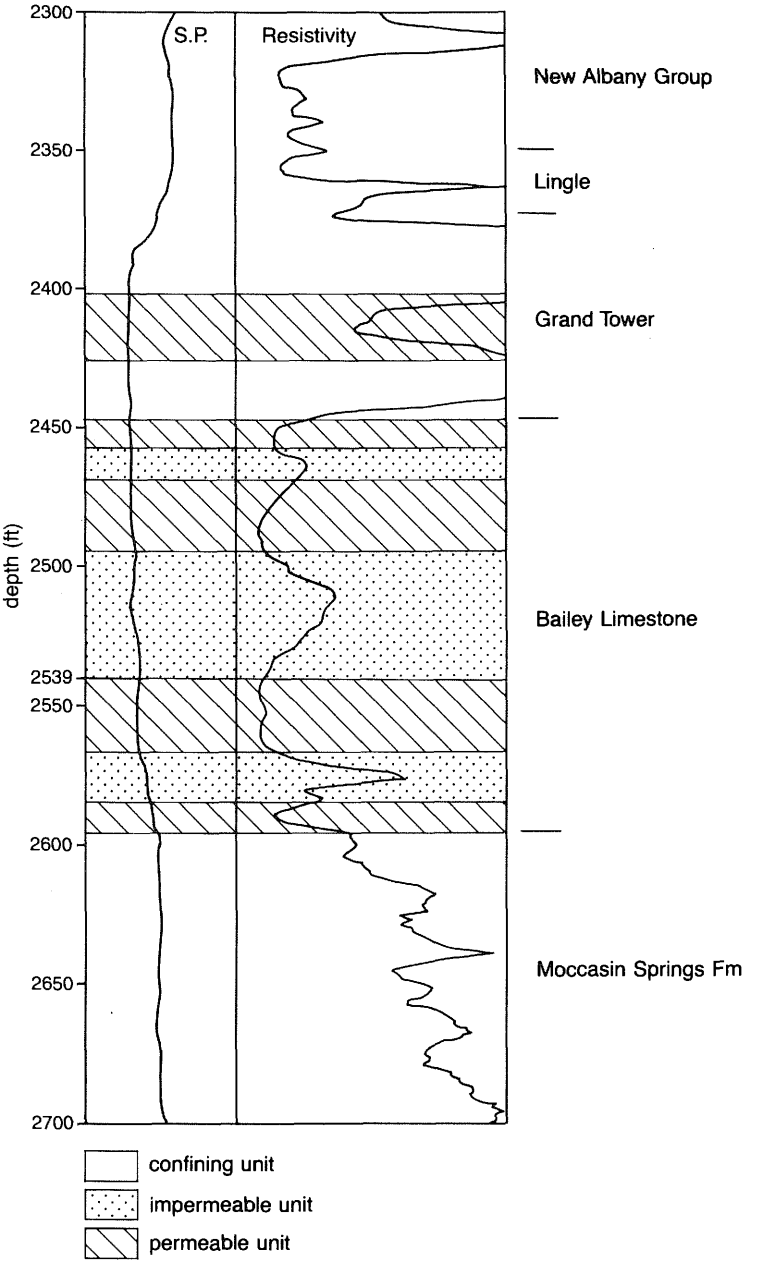

Figure 22 Injection system in WDW2 indicating permeable and impermeable zones delineated after phase I logging.

Log (DISFL). Finally, to provide the best stratigraphic correlation between the three wells at Velsicol, the Gamma Ray Log (GR) was run. (See appendix A for a discussion of the theory and general application of these logs.)

The techniques used to reduce the geophysical log data are discussed in appendix B. The data from these logs, analyzed and reported in 2-foot intervals, are presented in table 2. With the use of these modern logging tools and incorporation of improved analytical techniques, it was possible to obtain more accurate hydrogeologic data of the geologic materials constituting the injection interval. These data consisted of the formation's matrix-corrected CNL porosity ([POR]Ncor), matrix-corrected BCS porosity ([POR]BCScor), cross-plotted porosity ([POR]xp), secondary porosity ([POR]sec), true resistivity (Rt), matrix lithology (MA), water saturation (SW), shale volume (Vsh), and qualitative permeability (k). The same data were obtained from existing logs for WDW2 and are reported in table 3. Important parameters from these tables are summarized in table 4.

Table 2 Data from geophysical logs run in the DOW

DEPTH GL (ft)	GR (API)	(POR) Nls (%)	(POR) Ncor (%)	t (sec)	(POR) BCScor (%)	(POR) xp (%)	(POR) sec (%)	RT (ohm-m)	MA	SW (%)	Vsh (%)	k
2434	28	4.3	4.3	53	3.8	4.3	0.5	50.0	LS	100	6.2	N
36	40	5.0	5.0	53	3.8	5.0	1.2	65.0	LS	100	15.4	N
38	35	12.0	12.0	60	8.8	10.0	3.2	20.0	LS	100	11.5	N
40	25	18.0	18.0	69	15.1	16.4	2.9	11.0	LS	100	3.8	N
42	30	19.0	19.0	69	15.1	16.7	3.9	7.0	LS	100	7.7	Y
44	25	23.8	23.8	77	20.8	21.7	3.0	5.0	LS	100	3.8	Y
46	22	22.6	22.6	76	20.1	21.1	2.5	4.8	LS	100	1.5	Y
48	23	23.0	17.0	70	18.2	18.2	0.0	7.0	DOL	100	2.3	N
50	30	16.0	10.0	62	12.7	12.0	0.0	10.0	DOL	100	7.7	N
52	30	17.5	11.5	57	9.3	9.7	2.2	16.0	DOL	100	7.7	N
54	22	19.0	13.0	60	11.3	11.7	1.7	13.0	DOL	100	1.5	N
56	17	22.0	16.0	62	12.7	13.3	3.3	9.0	DOL	100	0.0	N
58	20	20.6	14.6	63	13.4	13.6	1.2	10.0	DOL	100	0.0	N
60	28	21.8	15.8	61	12.0	12.7	3.8	9.0	DOL	100	6.2	N
62	27	24.6	18.6	65	14.8	15.6	3.8	7.0	DOL	100	5.4	Y
64	32	24.0	18.0	66	15.5	16.0	2.5	5.5	DOL	100	9.2	Y
66	22	25.5	19.5	70	18.2	18.5	1.3	4.8	DOL	100	1.5	Y
68	23	28.5	22.5	78	23.7	23.5	0.0	4.0	DOL	100	2.3	Y
70	17	29.2	23.2	82	26.5	26.0	0.0	3.3	DOL	100	0.0	Y
72	18	28.0	28.0	82	24.3	25.7	3.7	3.0	LS	100	0.0	Y
74	17	30.0	30.0	87	27.9	28.8	2.1	3.2	LS	100	0.0	Y
76	17	28.0	28.0	83	25.0	26.3	3.0	3.5	LS	100	0.0	Y
78	19	26.8	20.8	78	23.7	23.2	0.0	3.9	DOL	100	0.0	Y
80	17	26.3	20.3	77	23.0	22.6	0.0	4.4	DOL	100	0.0	Y
82	20	29.0	23.0	74	21.0	21.4	2.0	4.0	DOL	100	0.0	Y
84	24	23.5	17.5	71	18.9	18.5	0.0	4.6	DOL	100	3.1	Y
86	26	21.3	15.3	63	13.4	13.7	1.9	7.1	DOL	100	4.6	N
88	23	22.3	16.3	64	14.1	14.5	2.2	10.0	DOL	100	2.3	N
90	23	16.5	10.5	60	11.3	11.1	0.0	11.0	DOL	100	2.3	N
92	30	16.4	10.4	56	8.6	8.9	1.8	16.0	DOL	100	7.7	N
94	29	19.8	13.8	57	9.3	10.2	4.5	21.0	DOL	100	6.9	N
96	60	19.0	13.0	60	11.3	11.6	1.7	20.0	DOL	100	30.8	N
98	84	18.5	12.5	60	11.3	11.5	1.2	15.0	DOL	100	49.2	N
2500	52	19.3	13.3	62	12.7	12.7	0.6	14.0	DOL	100	24.6	N
2	37	18.2	12.2	57	9.3	9.8	2.9	14.0	DOL	100	13.1	N
4	33	22.0	16.0	59	10.7	11.8	5.3	11.0	DOL	100	10.0	N
6	45	23.0	17.0	64	14.1	15.1	2.9	8.0	DOL	100	19.2	N
8	30	19.8	13.8	60	11.3	12.1	2.5	9.0	DOL	100	7.7	N
10	23	20.0	14.0	58	10.0	11.3	4.0	8.5	DOL	100	13.1	N
12	20	22.8	16.8	60	11.3	13.2	5.5	8.2	DOL	100	0.0	N
14	32	20.7	14.7	64	14.1	14.4	0.6	9.0	DOL	100	9.2	N
16	30	20.1	14.1	60	11.3	12.4	2.8	10.5	DOL	100	7.7	N
18	42	20.8	14.8	62	12.7	13.6	2.1	8.5	DOL	100	16.9	N
20	38	19.0	13.0	60	11.3	12.1	1.7	10.0	DOL	100	13.8	N
22	30	20.3	14.3	56	8.6	10.4	5.7	11.0	DOL	100	15.4	N
24	23	21.7	15.7	61	12.0	13.3	3.7	10.0	DOL	100	2.3	N
26	24	20.0	14.0	60	11.3	12.2	2.7	8.0	DOL	100	3.1	N
28	23	16.0	10.0	57	9.3	9.7	0.7	9.0	DOL	100	2.3	N
30	23	19.0	13.0	61	12.0	12.5	1.0	10.0	DOL	100	2.3	N
32	21	20.4	14.4	63	13.4	13.8	1.0	12.0	DOL	100	0.8	Y

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Table 2 Continued

DEPTH GL (ft)	GR (API)	(POR) Nls (%)	(POR) Ncor (%)	t (sec)	(POR) BCScor (%)	(POR) xp (%)	(POR) sec (%)	RT (ohm-m)	MA	SW (%)	Vsh (%)	k
2534	33	22.5	16.5	60	11.3	12.2	5.2	10.0	DOL	100	10.0	Y
36	27	22.0	16.0	63	13.4	13.9	2.6	7.5	DOL	100	5.4	Y
38	28	24.3	18.3	65	14.8	15.5	3.5	6.5	DOL	100	6.2	Y
40	29	24.0	18.0	63	13.4	14.2	4.6	5.8	DOL	100	6.9	Y
42	35	17.3	11.3	61	12.0	11.8	0.0	7.1	DOL	100	11.5	N
44	40	16.5	10.5	59	10.7	10.6	0.0	9.0	DOL	100	15.4	N
46	42	21.3	15.3	63	13.4	13.7	1.9	8.5	DOL	100	16.9	Y
48	40	22.5	16.5	70	18.2	17.7	0.0	6.7	DOL	100	15.4	Y
50	40	20.6	14.6	66	15.5	15.1	0.0	6.7	DOL	100	15.4	Y
52	38	15.6	15.6	65	12.3	13.3	3.3	10.0	LS	100	13.8	N
54	29	8.6	8.6	57	6.6	7.4	2.0	20.0	LS	100	6.9	N

Table 3 Data from existing geophysical logs run in WDW2[1]

DEPTH GL (ft)	GR (API)	(POR) Nls (%)	(POR) Ncor (%)	t (sec)	(POR) BCScor (%)	(POR) xp (%)	(POR) sec (%)	RT (ohm-m)	MA	SW (%)	Vsh (%)	k
2582	26	8.1	8.1	63	10.9	10.1	0.0	30.0	LS	90	4.6	N
84	30	10.0	10.0	66	13.0	12.2	0.0	28.0	LS	77	7.7	N
86	34	15.0	15.0	71	16.5	16.3	0.0	17.0	LS	74	10.8	N
88	38	14.7	14.7	73	18.0	17.1	0.0	13.0	LS	81	13.8	Y
90	37	13.5	13.5	73	18.0	16.9	0.0	13.0	LS	82	13.1	Y
92	26	7.8	11.1	68	8.8	10.0	2.3	20.0	SS	100	4.6	Y
94	29	6.1	9.3	65	7.1	8.2	2.2	38.0	SS	98	6.9	N

1 All logs used for study were from WDW2 (run during well installation), except the Sonic Log (SL), which was from WDW1 (run during well installation). The methods of analysis used were the same as above. All depths measured are from Kelly Bushing (KB), which is 12 feet above GL.

From the data (see appendix B) it appeared that the host formation, the Bailey Limestone, was composed mainly of a clean dolomite with less than 20 percent shale throughout most of the interval logged. Since the Bailey Limestone is predominantly a dolomite, secondary porosity is always a consideration. A comparison of CNL and BCSL data suggested that secondary porosity may account for up to 10 percent of the total porosity. The intervals with higher relative permeability have a slightly higher secondary porosity and, in turn, total porosity.

Also, the entire interval is primarily 100 percent water saturated with a fluid resistance of approximately 0.247 ohm-m. At a formation temperature of about 80°F and depth of 2,460 feet GL, the fluid composition was estimated to be approximately 24,000 ppm NaCl.

Phase I log analysis provided qualitative data of the disposal horizon. On the basis of this analysis, an additional section of the disposal horizon (2,518 to 2,539 ft KB [Kelly Bushing]) was eliminated as a possible injection zone (fig. 23).

Table 4 Summary of important formation characteristics

(POR)xp,ave = 16%	(POR)xp,max= 28.8	%(POR)xp, min = 8.9%
(POR)sec,ave = 1.98%	(POR)sec,max= 5.7%	
tave = $66.7x10^{-6}$ sec/ft		
tmax = $87x10^{-6}$ sec/ft		
tmin = $56x10^{-6}$ sec/ft		
Rt,ave = 8.6 ohm-m	Rt,max= 21 ohm-m	Rt,min= 3 ohm-m
Vsh,ave = 8.05%	Vsh,max= 49.2%	Vsh,min= 0.0%

Formation lithology (based on 98 feet of "higher permeability, higher porosity" unit), 61.0% dolomite, 35.0% limestone, and 4.0% sandstone.

Phase II Geophysical Logging

Phase II analysis consisted of a detailed site-specific evaluation of the injection/confining interval. Continuous Spinner Flowmeter logging (CSFL) and core analysis formed the basis of the study. Scanning Electron Microscope (SEM) analysis and formation brine/wastewater analysis were also conducted.

Continuous spinner flowmeter logging. The foregoing data were obtained exclusively from a static environment, i.e., no fluid injection into the well. For a quantitative evaluation of the response of the formation to "normal" or near-normal injection rates, a Continuous Spinner Flowmeter Log (CSFL) was run in WDW2. (An X-Y Caliper Log run prior to the CSFL provided borehole volumetric data to be used in conjunction with the CSFL data.) Again, as with the previous set of geophysical logs, borehole conditions in WDW2 restricted the interval available for logging. But work-over operations subsequent to the WDW2 logging permitted coverage of all anticipated injection zones as delineated by historical and phase I logging (fig. 23).

The CSFL data were used in two ways. First, the data enabled the delineation of specific injection zones and the calculation of the percentage of total flow into each zone. Second, the data were used to identify the lower boundary of fluid infiltration (i.e., the upper limit of the basal confining unit).

To evaluate the effect of varying injection rates, we recorded flow rates at three surficial injection rates: 75 gallons per minute (gpm), 100 gpm, and 150 gpm. The results are reported in table 5. Fluid loss is the percentage, on a volumetric basis, of fluid moving into a particular unit. For example, on average, 14 percent of the fluid flows into injection zone 1. The 150-gpm rate is the closest to the "average" waste injection rate (182 gpm) for WDW2 (see p. 58).

The repeatability of the flowmeter was verified by taking measurements as the flowmeter moved both up and down the borehole. With the flowmeter stationary, data were collected adjacent to suspected high permeability units and below the base of the anticipated injection horizon (2,594 ft KB from the other geophysical surveys). The validity of the results was checked by obtaining data with a stationary flowmeter in the 7-inch casing. At surficial injection rates of 75 gpm, 100 gpm,

Table 5 Fluid loss percentage calculated from CSFL

Injection zone no.	Depth (ft below KB)	Fluid Loss (%) injection rates (gpm)			
		75	100	150	Average
1	2448-2458	11	15	17	14
2	2552-2558	40	38	29	36
3	2584-2594	49	47	54	50

and 150 gpm, calculated flow rates in the 7-inch casing were 81 gpm, 107 gpm, and 163 gpm, respectively (margin of error less than 10%).

The effective interval of injection at the time of logging the CSFL (from the base of the 7-inch casing to the deepest depth of penetration of the logging tool) was from 2,437 to 2,614 feet KB. If conditions remain stable, fluid should infiltrate exclusively into the zones listed in table 5 and shown on figure 23. No flow was detected below 2,614 feet.

As shown on figure 23, data from the CSFL were not consistent with the interpretation of the geophysical logs. First, the interval from 2,468 to 2,496 feet was identified from both the historical and phase I logging as a potential injection zone, but the CSFL indicated an absence of flow into this interval. Second, data from the CSFL indicated that only a portion of the potential injection interval from 2,538 to 2,568 feet allowed substantial fluid infiltration. And third, on the basis solely of porosity and permeability data, zone 3 should have accepted less fluid than either zones 1 or 2;

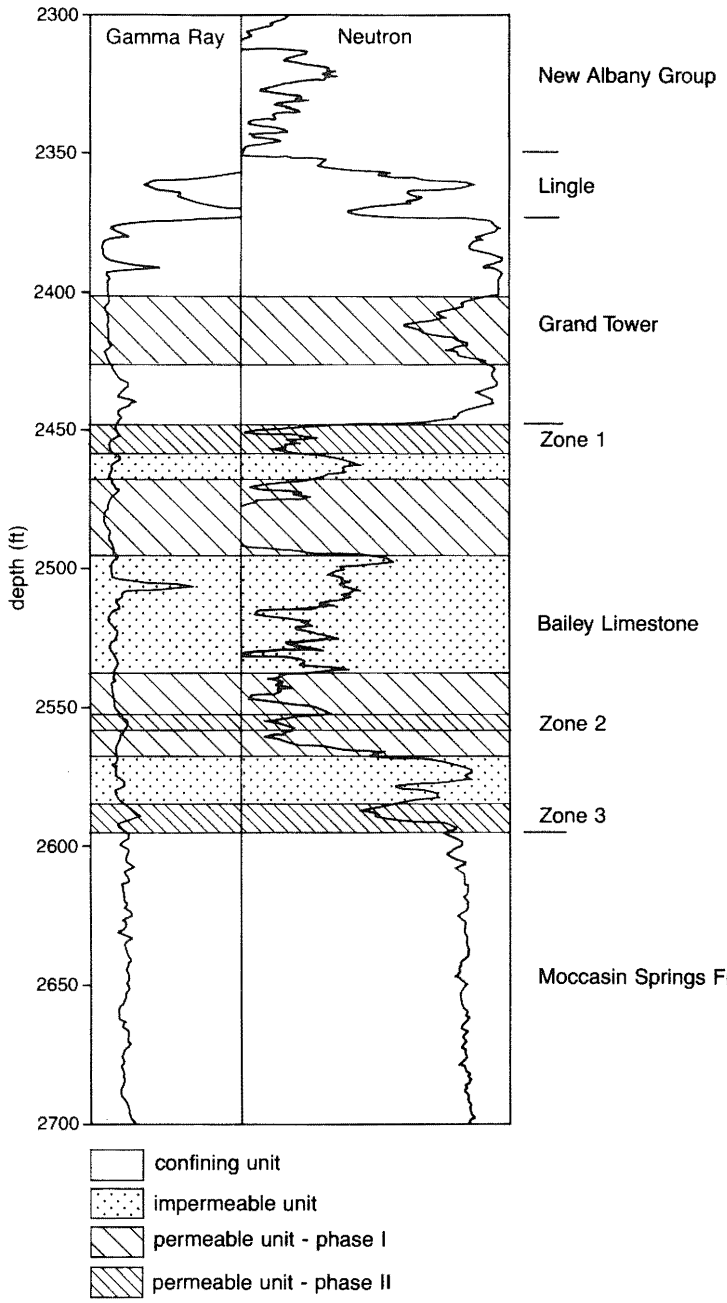

Figure 23 Injection system in WDW2 indicating permeable and impermeable units delinated after phase II logging.

however, this scenario was not supported by the CSFL data. In an effort to resolve these discrepancies and to obtain two additional parameters (quantitative permeability and bulk compressibility) essential to injection-interval evaluation, we conducted lab testing of sidewall cores.

Core retrieval and analysis. Several criteria were used to choose the coring zones. In order of decreasing priority, the selection criteria were to (1) cover all possible injection zones determined from the historical and phase I logging, (2) obtain cores from the anticipated lower confining unit indicated by logging data, and (3) cover a range of permeabilities and other physical properties present in the disposal horizon. Core depths are indicated in figure 24 and table 6.

Twenty-nine sidewall cores were retrieved with Gearhart's Hard Rock Coring tool. Gearhart Industry Inc. Corelab performed the core analysis. Additional core study was done at the ISGS. The core analysis provided data on quantitative permeability, bulk compressibility, and mineralogic composition, and provided a means to evaluate the accuracy of the downhole geophysical methods employed. The results of the core analysis are reported in table 7 and figures 25 and 26.

Table 6 Core location and analysis

Core no.	Core depth	kw[1] (Y,N)	Strength[2] test (Y,N)	Comments[3]
1	2663.0	N	N	No ka
2	2622.0	Y	Y	
3	2620.0	Y	N	
4	2617.5	N	N	No ka
5	2606.0	N	N	
6	2605.0	Y	Y	
7	2588.5	Y	N	
8	2573.5	Y	N	
9	2572.5	N	N	No ka
10	2560.5	N	N	
11	2556.5	N	N	No ka
12	2555.0	Y	Y	
13	2551.5	N	N	No ka
14	2539.5	N	N	
15	2509.5	Y	Y	
16	2508.5	N	N	
17	2491.5	N	N	
18	2490.5	N	N	
19	2484.5	Y	Y	
20	2482.5	N	N	No ka
21	2481.0	N	N	
22	2479.5	N	N	
23	2478.5	N	N	No ka
24	2463.5	N	N	
25	2462.5	N	N	
26	2457.5	N	N	No ka
27	2456.5	N	N	
28	2451.5	Y	Y	
29	2450.5	N	N	No ka

1 Water permeabilities (kw) derived from air permeabilities (ka) by applying a Klinkenburg correction.
2 Separate test which yields Poisson's ratio, Young's modulus, and bulk compressibility (corrected for in situ pore and confining pressures).
3 Basic analysis and x-ray diffraction performed on all cores. Basic analysis consists of ka, total porosity, water saturation (Sw), and fluorescence. X-ray diffraction identifies all minerals that have an abundance of 1% or more by weight and the total clay percentage.

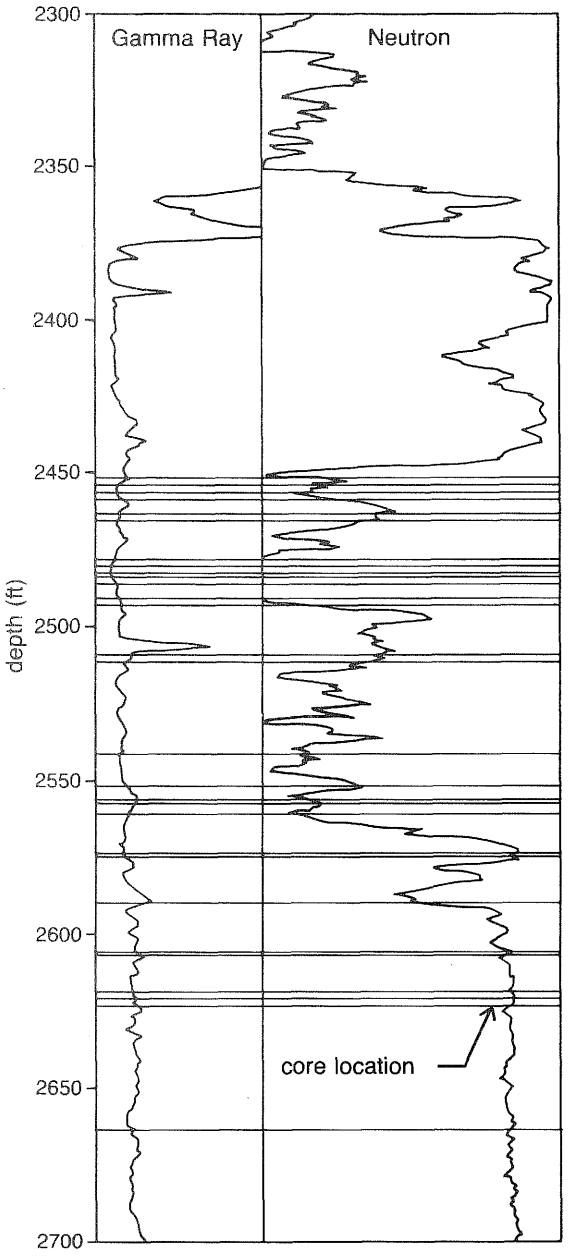

Figure 24 Core locations for WDW2.

Available data indicate that the discrepancies between the injection zones identified from phase I and phase II are due to the presence of brucite ($Mg[OH]_2$). The supporting data used to develop the brucite-formation hypothesis are summarized below and more fully described in appendix C.

Mineralogic analysis of sidewall cores identified brucite (up to 45% by weight) to be present in potential injection zones, as identified from phase I logging. Brucite, not present in the injection system prior to well operation, forms during waste injection. Brucite apparently formed in zones having the highest potential for fluid flow, as identified from phase I logging. Brucite formation does not reduce porosity (as identified from geophysical logs) but does reduce the permeability significantly. Flow rates in the different injection zones appear from CSFL results to be proportional to the brucite concentration within that zone, i.e., zones with higher brucite concentrations have lower flow rates.

Table 7 Results of core analysis

Depth (ft KB)	POR (%)	ka (md)	kw (md)	Compress x10^{-12} (cm sec^2/gm)
2450.5		24.2		
51.5	26.1	0.640	0.476	15.5
56.5	27.7	62.54		
62.5	13.2	0.0076		
63.5	11.5	0.0087		
79.5	26.4	0.178		
81.0	24.8	0.017		
82.5	56.1			
84.5	30.8	14.97	12.940	8.70
90.5	29.4	2.292		
91.5	24.2	0.457		
2508.5	9.9	0.0089		
09.5	11.4	0.017	0.001	3.36
39.5	17.7	0.203		
51.5	8.9			
55	18.0	0.060	0.017	8.41
60.5	17.1	0.095		
73.5	5.2	0.0050	0.00013	
88.5	16.6	0.021	0.004	11.9
2605	3.1	0.0055	0.00042	4.71
06	4.6	0.0029		
17.5	4.8			
20	4.6	0.0034		
22	3.8	0.0038		
63	6.7			

The source of ions for brucite formation is not clear. The source of OH^- is the injected waste (pH > 12), but the source of Mg^{2+} is unclear. Two possible sources are the waste fluid or the dolomite within the injection zones.

Hydrogeology of the site. Having developed a hypothesis to explain brucite formation, we quantified the hydrogeologic characteristics of the injection system, which allowed the data to be used as parameter input for the numerical model. The disposal interval was divided into 12 units based on hydrogeologic characteristics (fig. 27 and table 8), using data derived from figure 23. These 12 units were used for differentiating the stratigraphic cross sections (figs. 17, 18, and 19). Local and regional stratigraphic/structural studies, presented in Stratigraphic and Structural Definition of the Injection System, page 23, were also considered to ensure that the units chosen were not localized anomalies (i.e., noncontinuous).

Table 8 lists the units and their associated characteristics. Permeability, air (ka) and water (kw), and bulk compressibility data were obtained from core analysis. Hydraulic conductivity (K) and specific storage (Ss) measurements were derived from these results. The porosity measurements (POR) were taken from table 2 (geophysical logging results) and core analysis results. Storativity (S) and transmissivity (T) data were calculated only for the three injection zones delineated previously (table 9). Units 2, 9, and 11 in table 8 correspond to injection zones 1, 2, and 3, respectively. The thicknesses (b) for units 2, 9, and 11 were determined from figure 27.

The three gas-storage field wells mentioned in Stratigraphic and Structural Definition of the Injection System, page 24, provided additional permeability data for the intervals corresponding to unit 1 and the overlying strata (above 2,402 feet KB). Values for vertical water permeabilities of

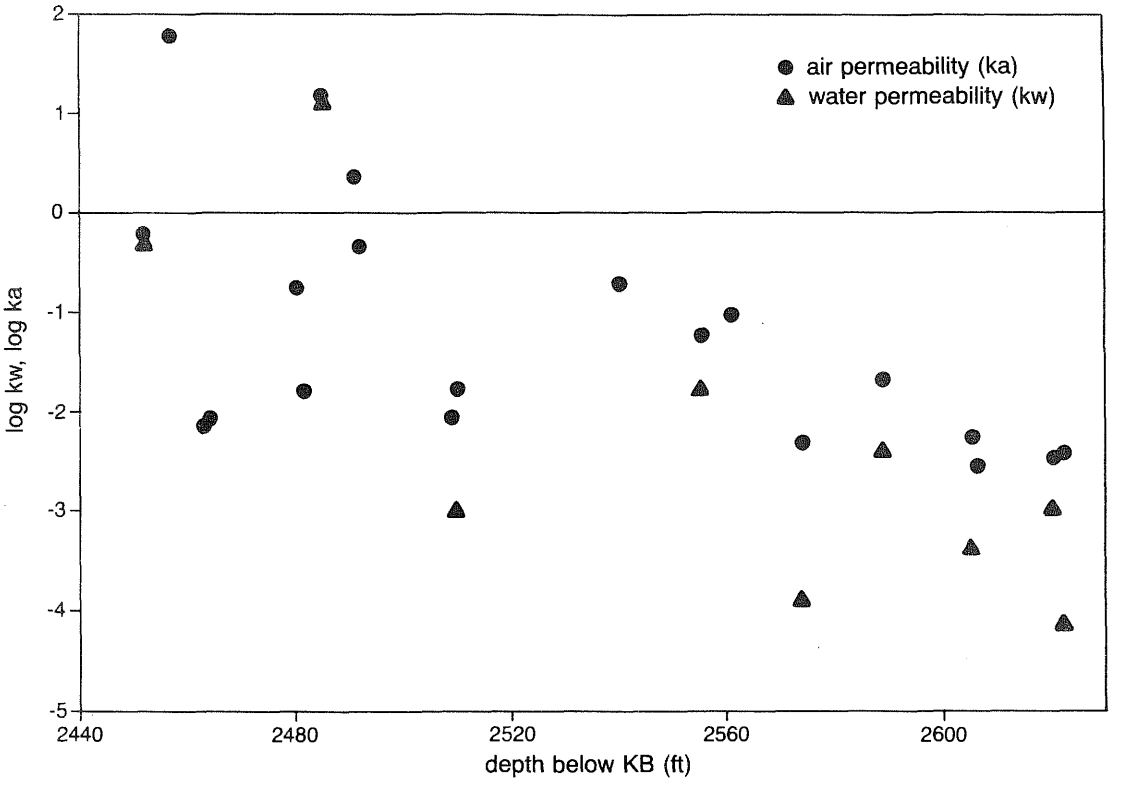

Figure 25 Core permeabilities (air and water) versus depth for WDW2.

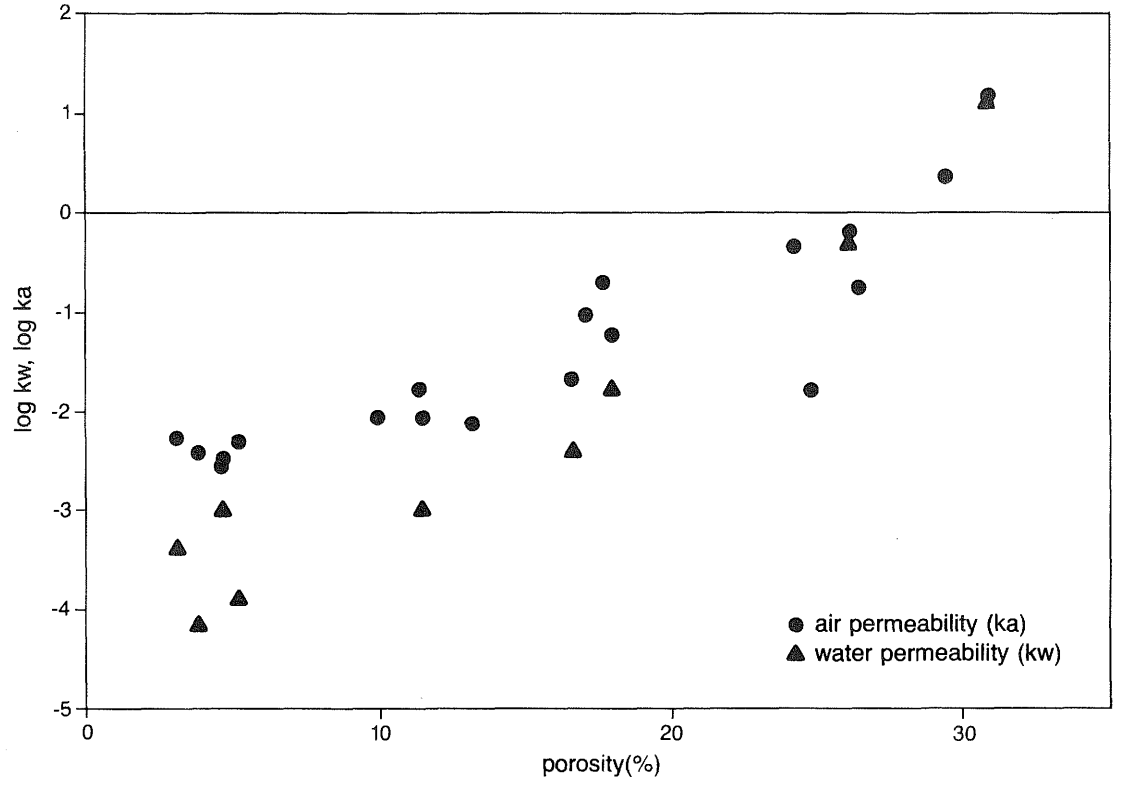

Figure 26 Core permeabilities versus core porosities for WDW2.

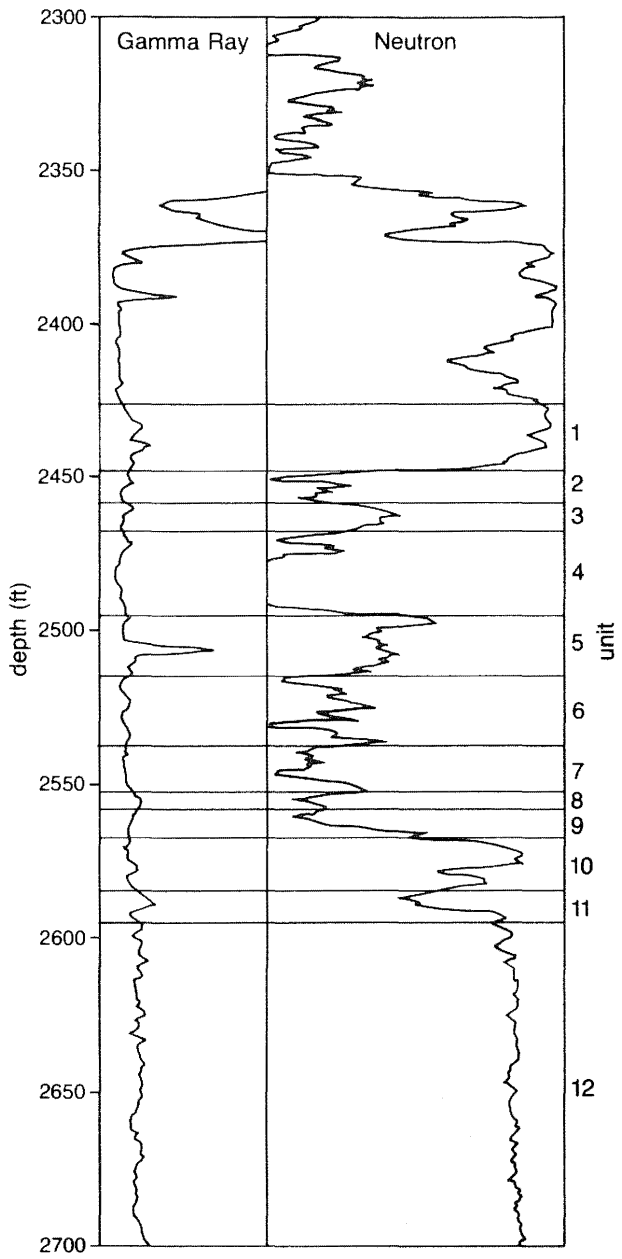

Figure 27 Unit locations for WDW2.

7.85x10^{-5} md (millidarcys) for the interval corresponding to unit 1 and 3.51x10^{-5} md for the overlying strata were obtained.

Long-Term Injection Test

A long-term injection test was conducted to obtain T and S values for the injection formation. An injection test is similar to a standard pump test except that water is injected into the well instead of being withdrawn from it.

The injection test started at 10 a.m., July 9, 1987, and was completed at 7 a.m., July 24, 1987. The test ended at this time because of a power outage scheduled by the power company. Velsicol

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Table 8 Summary of hydrogeological data for a portion of the disposal system

Depth (ft KB)	POR (%)	ka (md)	kw (md)	Compressx10^{-12} (cm sec^2/gm)	K[a]x10^{-8} cm/sec	Ss[b]x10^{-8} cm^{-1}	Unit
2432	2.0						1
34.5	2.0						1
36	4.0						1
38	2.0						1
40	7.8	7.85x10^{-5}**					1
42	4.0						1
44	4.3						1
46	5.0						1
48	10.0						1
50	21.7						1
50.5	24.2						1
51.5	26.1	.640	.476	15.5	52.73	2.67	2
52	21.1						2
54	18.2						2
56	18.2						2
56.5	27.7	62.54					2
57.5	18.2						2
58	15.0						2
60	12.0						3
62	9.7						3
62.5	13.2	.0076					3
63.5	11.5	.0087					3
64	11.7						3
66	13.3						3
68	13.3						3
70	15.6						4
72	16.0						4
74	18.5						4
76	18.5						4
78	23.5						4
79.5	26.4	.178					4
80	26.0						4
81	24.8	.017					4
82	25.7						4
82.5	56.1						4
84	28.8						4
84.5	30.8	14.97	12.940	8.70	1434	2.21	4
86	26.3						4
88	23.2						4
90	22.6						4
90.5	29.4	2.292					4
91.5	24.2	.457					4
92	21.4						4
94	18.5						4
96	13.7						5
98	14.5						5
2500	11.1						5
02	8.9						5
04	10.2						5
06	11.6						5
08	11.5						5
08.5	9.9	.0089					5
09.5	11.4	.017	.001	3.36	.111	.831	5
10	12.7						5
12	9.8						5
14	11.8						5
16	15.3						6
18	11.0						6
20	11.0						6

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Table 8 Continued

Depth (ft KB)	POR (%)	ka (md)	kw (md)	Compressx10^{-12} (cm sec^2/gm)	K^ax10^{-6} cm/sec	Ss^bx10^{-6} cm^{-1}	Unit
22	14.3						6
24	9.5						6
26	9.5						6
28	12.2						6
30	14.2						6
32	14.2						6
34	11.9						6
36	9.3						6
38	12.0						6
39.5	17.7	.203					7
40	14.1						7
42	12.2						7
44	13.9						7
46	15.5						7
48	14.2						7
50	11.8						7
51.5	8.9						7
52	10.6						8
54	13.7						8
55	18.0	.060	.017	8.41	1.88	1.62	8
56	17.7						8
56.5	17.0						8
58	15.1						8
60	13.3						9
60.5	17.1	.095					9
62	17.8						9
64	14.5						9
66	7.0						9
68	6.2						9
70	4.0						10
72	1.0						10
73.5	5.2	.0050	.00013		.0144		10
74	1.0						10
76	1.0						10
78	6.2						10
80	5.0						10
82	5.0						10
84	5.5						11
86	8.9						11
88	9.8						11
88.5	16.6	.021	.004	11.9	.443	1.90	11
90	7.0						11
92	4.0						11
94	4.0						11
96	4.0						12
98	4.0						12
2600	4.0						12
02	4.2						12
04	4.4						12
05	3.1	.0055	.00042	4.71	.0465	.597	12
06	4.6	.0029					12
17.5	4.8						12
20	4.6	.0034					12
22	3.8	.0038					12
63	6.7						12

** Average vertical water permeability (kaw) and POR from three gas injection wells in the study area.

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Table 9 Additional hydrogeological data for primary injection zones

Section	b (ft)	$S^c \times 10^{-6}$ (-)	$T^d \times 10^{-6}$ (cm^2 / sec)
2	10	8.14	161
8	6	2.96	3.44
10	10	5.79	1.35

Explanation for tables 8 and 9:

(a) $K = kw\rho g / \mu$

where

K = hydraulic conductivity
kw = water permeability (Klinkenburg corrected air permeability)
ρ = water density = 0.997 gm/cm^3*
g = acceleration due to gravity = 980 cm/sec^2
μ = water viscosity = 0.008705 gm/cm sec*

* temperature used to determine ρ and μ was taken to be 26°C. This came from Temperature Log run in WDW2 assuming the cooling effect due to past injection was extremely localized (see appendix A).

(b) $Ss = \rho g (\alpha + n\beta)$

where

Ss = specific storage
α = matrix bulk compressibility
β = fluid bulk compressibility* = 4.513×10^{-11} $cm\text{-}sec^2/g$
n= porosity

* temperature used to determine β was taken to be 26°C (see note above).

(c) $S = Ssb$

where

S = storativity
Ss = specific storage
b = zone thickness

(d) $T = Kb$

where

T = transmissivity
K = hydraulic conductivity
b = zone thickness

injected water from its stormwater retention ponds during the test. Table 10 shows the physical and chemical properties of the fluid injected during the in injection test (Velsicol, 1987). Table 11 shows the volume and rate of fluid injected. The average injection rate was 288.4 gpm.

Head data were collected at the DOW using a Stevens water level recorder (fig. 28). The water level recorder was set with a 1:1 gearing and an 8-day chart.

Data obtained from the DOW were analyzed by two techniques: Theis analysis and Cooper-Jacob analysis (see Todd 1980 or Freeze and Cherry 1979 for a detailed explanation of these techniques). Theis analysis is a curve-fitting technique; therefore, the T and S values obtained from this method depend on the analyst's judgment. The Cooper-Jacob technique is somewhat less subjective since the data plot is a straight line on semilog paper.

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Table 10 Selected chemical and physical properties of water injected during injection test (Velsicol 1987)

Suspended solids	29 mg/L
Dissolved solids	1205 mg/L
Sodium chloride	794 mg/L
Sodium hydroxide	235 mg/L
pH	8.0
Specific gravity	1.004
Sample temperature	58°F

Table 11 Volume injected into WDW2 during injection test

Reporting date	Hours operated	Volume injected (gallons)	Injection rate (gpm)
7/10/87	21	340,673	270.4
7/11	24	414,607	287.9
7/12	24	422,409	293.3
7/13	24	419,684	291.2
7/14	24	423,836	294.2
7/15	24	419,042	290.8
7/16	24	401,760	278.8
7/17	24	418,939	290.8
7/18	24	411,973	285.9
7/19	24	413,270	286.9
7/20	24	411,616	285.7
7/21	24	410,420	284.9
7/22	24	424,717	294.8
7/23	24	424,211	294.4
7/24	24	419,352	291.0
Average		411,767	288.4

Table 12 Analysis of injection test

Method	S (-)	Transmissivity (m^2/min)
Theis	2.75×10^{-4}	0.385
Cooper-Jacob (r = 0.960)	2.47×10^{-4}	0.386

r = correlation coefficient for the linear regression

For the Cooper-Jacob technique, head buildup was plotted versus log time (fig. 29). Linear regression was used to calculate the parameters (S and t_o) for this method. An iterative approach was taken since the data used in the analysis depend on the outcome of the analysis. For the Cooper-Jacob method, u ($u = r^2S / (4Tt)$) must be less than to 0.01. From the definition of u and the value of T and S, a minimum time can be determined (i.e., only field data where $t > t_{min}$ can be used). Thus, an iterative technique was necessary to calculate T and S. Table 12 shows the results of the analyses (only the values for the final iteration of the Cooper-Jacob analysis are presented). Note the good agreement between the Theis and Cooper-Jacob analyses. The values obtained by the Cooper-Jacob technique are considered to be the more accurate since this technique is less subjective.

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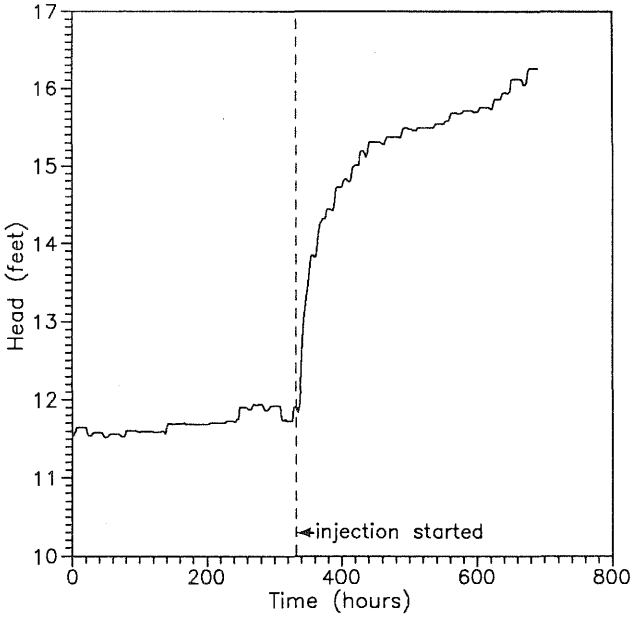


Figure 28 Water level record for DOW, including data from injection test.

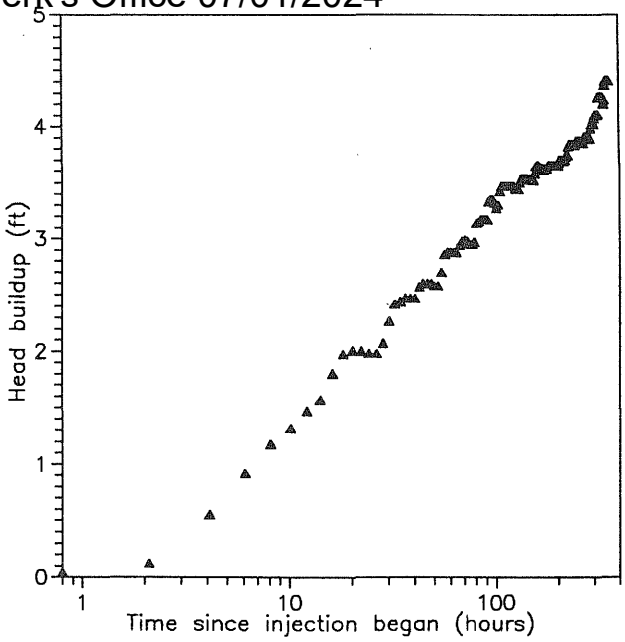


Figure 29 Plot of data used for Cooper-Jacob analysis.

4. NUMERICAL MODELING

Model Selection

Model selection is an important step in conducting a modeling investigation of a groundwater flow problem. The model should be able to handle all significant physical processes of the groundwater flow system. If the model does not incorporate these processes, it cannot be expected to simulate the field situation with any degree of accuracy.

The literature contains descriptions of many general and specialized numerical models. At the outset of this project, it was thought that a model capable of simulating three-dimensional (3D) flow and flow through complex hydrogeologic regimes would be required. Several 3D groundwater flow models have been developed, including the Sandia Waste Isolation Flow and Transport Model (SWIFT) (Reeves and Cranwell, 1981) and the Heat and Solute Transport Program (HST3D) (Kipp 1987). SWIFT and HST3D are finite difference groundwater flow and transport models that are independent modifications of SWIP (INTERCOMP, 1976). This original model, developed to model the effects of deep-well waste injection, includes sophisticated well functions rarely incorporated into other models. Although SWIFT and HST3D have a more general focus than does their predecessor, both models retain these well functions, and either model could be used for this project. Since a version of HST3D compatible with the Prime 9650 computer used in this project was available before a similar version of SWIFT (II), HST3D was selected.

Model Description

HST3D is a descendent of the Survey Waste Isolation Program (SWIP) written for the U.S. Geological Survey by INTERCOMP Resource Development and Engineering Consultants. HST3D represents a complete rewrite of SWIP with many major and minor modifications, improvements, and corrections.

Overview of Model

HST3D simulates saturated groundwater flow and associated heat and solute transport in three dimensions. The following equations are solved numerically: the saturated groundwater flow equation, formed from combining the conservation of total fluid mass and Darcy's Law for flow through porous media; the heat transport equation from the conservation of enthalpy for the fluid and porous medium; and the solute transport equation from the conservation of mass for a single solute, which may adsorb onto the porous medium and/or decay (Kipp 1987). These equations are coupled through the dependence of advective transport on the interstitial fluid velocity field, fluid viscosity on temperature and solute concentration, and fluid density on pressure, temperature, and solute concentration.

For the dependent variables of pressure, temperature, and mass fraction, numerical solutions are obtained successively using a set of modified equations that more directly link the original equations through the velocity, density, and viscosity coupling terms. Finite difference techniques are used for the spatial and temporal discretization of the equations. When supplied with appropriate boundary and initial conditions and system-parameter distributions, a wide variety of heat and solute transport simulations can be performed (Kipp 1987).

The basic source-sink term represents wells. A complex well-flow model may be used to simulate specified flow rate and pressure conditions at the land surface or within the aquifer, with or without pressure constraints. Types of boundary conditions include specified value, specified flux, leakage, heat conduction, an approximate free surface, and two types of aquifer influence functions. All boundary conditions may be functions of time (Kipp 1987).

Assumptions Incorporated into the Model

Since this project was concerned with simulation of fluid flow and not heat and/or contaminant transport, only the assumptions incorporated into the flow model will be discussed. Kipp (1987) incorporated the following assumptions into the partial differential equation describing groundwater flow:

- Groundwater fully saturates the porous medium within the region of groundwater flow.
- Groundwater flow is described by Darcy's Law.
- The porous medium and the fluid are compressible.
- The porosity and permeability are functions of space.
- The coordinate system is chosen to be aligned with the principal directions of permeability tensor so that this tensor is diagonal for anisotropic media.
- The coordinate system and the principal directions of the permeability tensor are orthogonal.
- The coordinate system is right-handed with the z-axis pointing vertically upward.
- The fluid viscosity is a function of space and time through dependence on temperature and solute concentration.
- Density-gradient diffusive fluxes of the bulk fluid are neglected relative to advective-mass fluxes.
- Dispersive-mass fluxes of the bulk fluid from spatial-velocity fluctuations are excluded.

Input Data

Input data required by HST3D for modeling fluid movement may be categorized as follows: hydrogeologic properties of the aquifer, physical dimensions of the aquifer, physical dimensions of the well(s), hydraulic properties of the well(s), and physical and chemical properties of the fluid. Additional input data are required for any attempts to model solute and/or heat transport.

Physical Configuration of the Injection System

As defined here, the injection system refers to the geologic deposits that constitute the injection zone and its associated confining units. The hydrogeology of the site is described in chapter 3. The physical dimensions and hydrogeologic properties of the injection system used as model input will be described where appropriate in each section.

Description of the Injection and Observation Wells

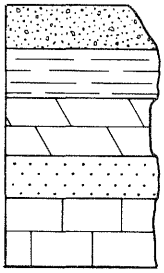
Waste Disposal Well 2 (WDW2) at the Velsicol Chemical Corporation's Marshall Plant was modeled. WDW2 is a packer-annulus-type well completed in Devonian limestone (fig. 30). Originally, the well was drilled to a total depth of 6,007 feet and was completed open-hole from 2,440 to 2,737 feet. Preceding the phase II field testing of the well, Velsicol completed extensive well workover procedures to remove debris, which had partially filled the well. These procedures included a high-pressure jet wash of the well bore. In addition to suspending and removing the debris in the well, the tool scoured the well bore. Thus it is assumed that the skin effect for this well would be negligible. Access for geophysical tools to total depth was blocked at 2,610 feet, presumably due to bridging of materials sloughed from the well face. However, the bridging probably did not plug the well from a hydraulic standpoint.

Located 506 meters due north of WDW2 is the Devonian Observation Well (DOW), which was completed open-hole starting near the top of the Devonian limestone (fig. 31). Total depth for this well is 2,580 feet. Water-level data were collected from this well during this project.

Physical and Chemical Properties of the Fluids

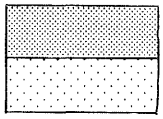
HST3D requires input of various physical properties of the fluids, including density, temperature, viscosity, and compressibility. These data are required for the fluid injected and the native fluid in the formation (brine). Fluid-compressibility data for injected wastes and/or brines were generally not available but were estimated on the basis of the chemical composition of these fluids. Much of these required input data were available from a database compiled by the ISGS.

Lithology



Unconsolidated
Shale
Dolomite
Sandstone
Limestone

Aquifers (USDW)



Primary freshwater aquifer (0-2,500 mg/l)
Secondary aquifer (2,500-10,000 mg/l)

Stratigraphic Units

Q	Quaternary
P	Pennsylvanian
M	Mississippian
Mc	Chesterian sandstone
Msg, sl	Ste. Genevieve Limestone
	St. Louis Limestone
Msa	Salem Limestone
Mb	Borden Siltstone
Mch	Chouteau Limestone
M/D	Mississippian/Devonian
M/Dna	New Albany Group
D	Devonian
Dlgb	Lingle Limestone
	Grand Tower Limestone
	Bailey Limestone
S	Silurian
Sm	Moccasin Springs Fm
Su	Undifferentiated dolomite
O	Ordovician
Om	Maquoketa Shale
Ogp	Galena-Platteville dolomite
Osp	St. Peter Sandstone
Opdc	Prairie du Chien dolomite
Є	Cambrian
Єep	Eminence-Potosi dolomite

Injection System Components

M/Dna	Upper confining unit
Dlgb	Injection unit
Sm	Lower confining unit

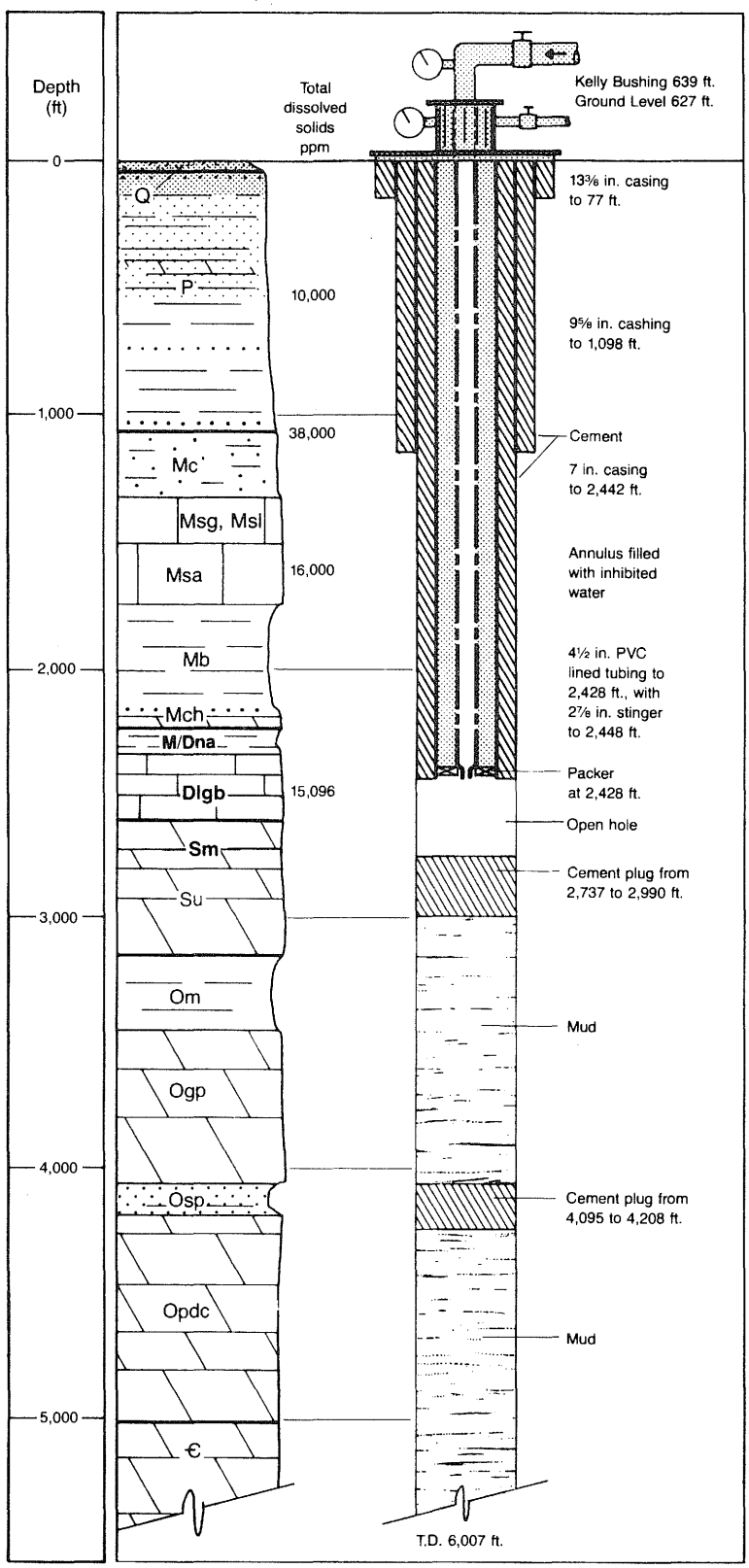


Figure 30 Schematic for WDW2 (modified from Brower et al. 1989).

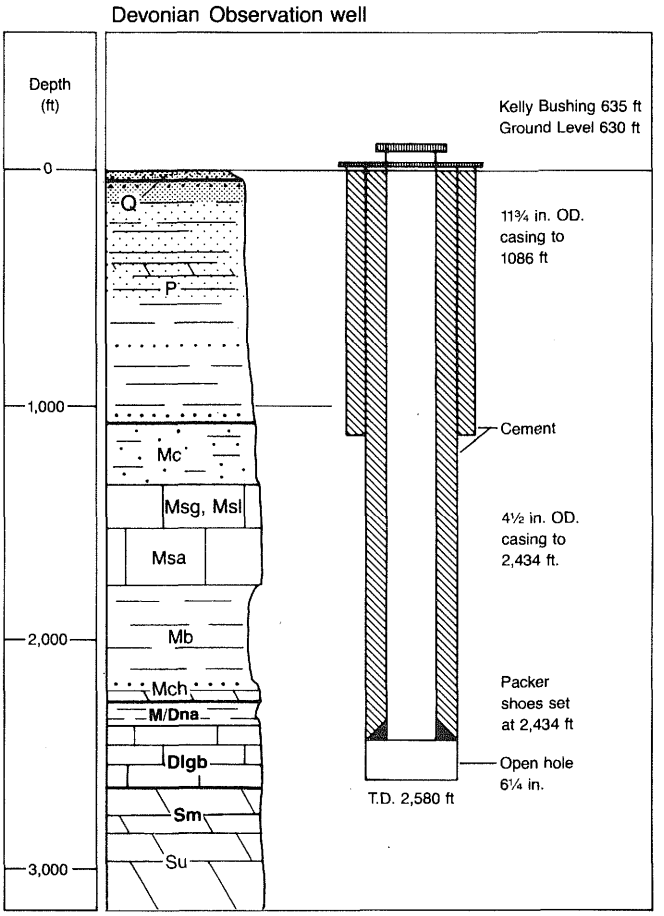


Figure 31 Schematic for DOW (Velsicol 1984).

General Parameters

Velsicol injected hazardous waste consisting of production wastewater and surface runoff water from on-site process areas. Chlorinated pesticides were produced at this site. The waste was highly alkaline (pH > 12) and contained pesticides and other chlorinated hydrocarbons. The relative concentrations of constituents in the waste were NaCl > NaOH > hexachlorocyclopentadiene (hex) > chlordane.

Velsicol has been required by permit to sample and analyze the waste injected into WDW2 and the brine from the DOW. Thus an extensive database of physical and chemical properties of the injected fluid and brine is available. This database was compiled by the ISGS and used extensively in this project. For WDW2, available data date back to early 1973, when operating reports were first required. Data for dissolved solids, specific gravity, and viscosity are presented in table 13.

Table 13 Selected parameters for fluids injected via WDW2

Parameter (unit)	Range	Average	Standard deviation	Number
Dissolved solids (mg/L)	200 - 254,000	38,346	35,388	671
Specific gravity (-)	0.9948 - 1.14	1.027	0.025	538
Viscosity (centipoise)	0.7161 - 0.9822	0.7857	0.0700	33

Data for dissolved solids in table 13 show the variability of the injected fluid, which is predominantly storm water runoff. Brower et al. (1989) attributed this variation in dissolved solids to variation of precipitation frequency and intensity.

A relationship between specific gravity and viscosity seems to exist (fig. 32). Linear regression of these variables produced a correlation coefficient of 0.873. If additional viscosity data had been available, this correlation might have improved.

The mean value for specific gravity of the waste was used as input for the numerical model. For comparison, Devonian brine sampled during construction of WDW2 had a specific gravity of 1.011. The linear relationship between viscosity and specific gravity was assumed to be valid; thus, viscosity was determined using the mean specific gravity of the waste (fig. 32).

All modeling was conducted under isothermal conditions. Although the temperature of the injected fluid varied throughout the year, it was assumed that the temperature of the formation would not change significantly from its mean temperature because of injection. The formation temperature was determined from a temperature log run down the DOW on December 18, 1986. The mean formation temperature was 34.4°C (94°F).

Compressibility of the Fluids

Lab-determined values for the compressibility of the waste and brine were not available; however, compressibility values for common saline solutions were available in the literature. Millero et al. (1974) published compressibility values for NaCl, $MgCl_2$, $NaSO_4$, and $MgSO_4$ as a function of temperature and molality. Figure 33 depicts the fluid compressibility in relation to temperature and molality for NaCl solutions.

Roy et al. (1989) characterized the brine and waste as predominantly NaCl solutions. Table 14 shows the chemical analysis of the Velsicol waste, Velsicol dilute waste, and Devonian brine. In this context, waste refers only to the fluids from the plant processes. Dilute waste, typically the fluid injected, comprises fluids from the plant processes and surface runoff. The sample of Devonian brine was obtained from the DOW in June 1987.

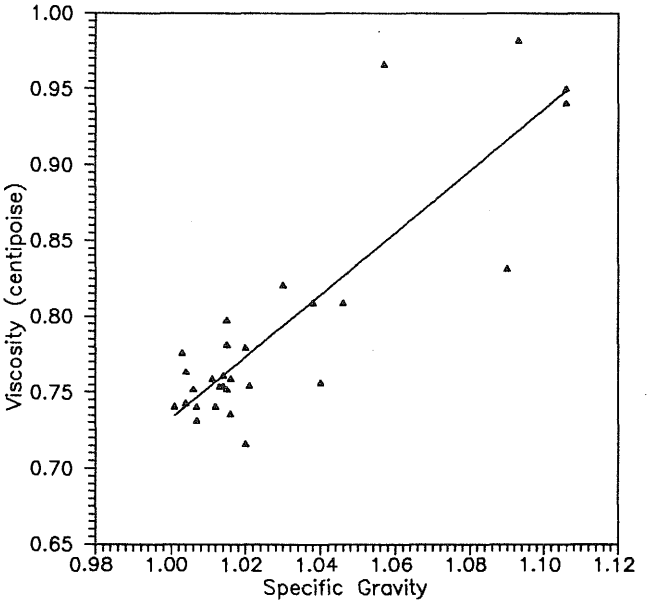


Figure 32 Relationship between waste viscosity and specific gravity.

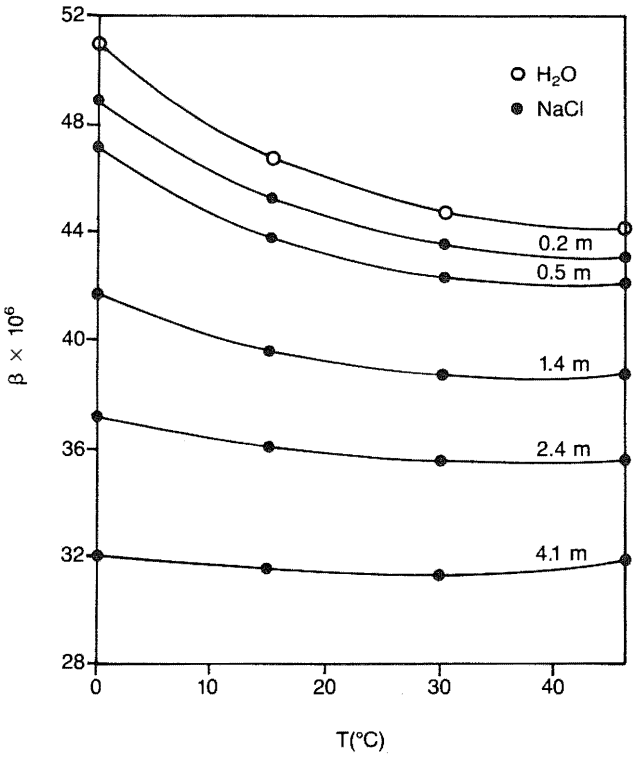


Figure 33 The compressibility of water and NaCl solutions versus temperature (Millero et al. 1974).

Table 14 Chemical analysis of waste and brine

Parameter (unit)	Waste	Dilute waste	Brine
pH	12.92	12.85	9.07
Eh (mV)[a]	+572	+572	-154
EC (mmhos @ 25°C)	403	56[b]	22
TDS (mg/L)	215,900[b]	37,300[b]	—
Cl (mg/L)	112,664	15,400	12,700
F (mg/L)	151	—	20.1
Na (mg/L)	86,350	—	8,370
SO_4 (mg/L)	61.5	—	182
NO_3 (mg/L)	274	—	25.1
Mg (mg/L)	<0.07	—	117.0

a: relative to a standard ZoBell solution
b: Mravik (1987)
from Roy (1987)

Concentrations of the major anion and cation were used to determine the molality of each fluid. Compressibility of each fluid was determined on the basis of the molality and two assumptions: (1) that the temperature was 34.4°C and (2) that the fluids could be considered NaCl solutions. Table 15 shows the molality and compressibility of the three fluids.

Review of the TDS data for the waste and dilute waste indicated that the "average" waste injected into WDW2 (TDS = 38,346 mg/L) had a slightly higher TDS concentration than the dilute waste. Thus the compressibility of the "average" waste should be close to, but slightly lower than, the compressibility of the dilute waste. (See table 18 for the value used.)

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Table 15 Compressibility of waste and brine

Fluid	Molality (moles/kg)	Compressibility (1/Pa)
Waste	3.76	3.185×10^{-10}
Dilute waste	0.799	4.105×10^{-10}
Brine	0.703	4.145×10^{-10}
Waste	—	4.46×10^{-10}

Volume of Injected Waste

Since waste injection began in March 1972, Velsicol (1987) reported that 1.4623×10^9 gallons of fluid have been injected via WDW2. Simple volumetric equations were used to determine the extent to which these fluids have moved within the injection zone.

Cross-plotted analysis of geophysical logs indicated that the thickness-averaged porosity of the injection zone is 12.5 percent. Assuming that waste has flowed through the entire thickness (174 ft) of the injection zone and radially from the well, the pore volume of the injection zone from WDW2 to the DOW (1,660 ft) is 1.406×10^9 gallons. Thus the cumulative volume of injected fluid is equivalent to 1.04 pore volumes. To account for this fact, model input of fluid data was based on the physical properties of the waste. In this project, only groundwater flow was simulated; thus, the properties of the fluid must be homogeneous throughout the injection system. To consider nonhomogeneous fluids, one would need to model solute transport.

Modeling Results

Most numerical modeling studies of groundwater flow include several modeling phases, which have also been followed in this study. First, verification of the model is conducted. In this stage, the model is used to simulate known analytical solutions. This phase is typically followed by history matching or model calibration. Here, the model was used to simulate field data, usually collected during a pump test. Sensitivity analysis generally follows model calibration. During this phase, the effect of pertinent parameters is quantified. The final stage is the prediction stage, which is an exercise in "what if." For example, what will the pressure buildup be at the well if a certain flow rate is continued for 30 years. The following discussion describes each of these phases for this project.

Model Verification

Model verification was necessary since HST3D was a new code. Verification allowed the modeler a chance to become familiar with this new model and to check the model accuracy versus analytical solutions. HST3D was verified using two analytical solutions: unsteady radial flow in a confined aquifer with constant pumping rate (Theis 1935), and unsteady radial flow in leaky systems with no storage in the semipervious layer at a constant pumping rate (Hantush 1964).

Theis Solution. Theis solution is an analytical solution for unsteady radial flow in confined aquifers. This solution is readily available in any groundwater text and is not repeated here. Input data for the analytical solution and HST3D are listed in table 16.

A radial coordinate system was used to discretize the groundwater flow domain: 50 nodes in the r-direction and 20 nodes in the z-direction. The radius of the aquifer simulated was 24,960 m. No-flow conditions were applied at all boundaries.

Figure 34 shows the drawdown at a point 100 m from the pumping well determined by numerical and analytical methods. The two solutions are identical.

Leaky Aquifer Solution . HST3D was also verified against an analytical solution for wells in leaky systems without storage in the semipervious layer (no storage in the semipervious is an as-

Table 16 Input data for the Theis solution

HST3D	Analytical solution
aquifer thickness, b = 3.05 m hydraulic conductivity, K = 3.29 x 10^{-4} m/sec porosity, n = 0.20 matrix compressibility, α = 3.34 x 10^{-8} Pa^{-1} fluid compressibility, β = 4.53 x 10^{-10} Pa^{-1} viscosity, μ = 0.001 kg/m-sec fluid density, ρ = 999.5 kg/m^3 pumping rate, q = 3.00 x 10^{-3} m^3/sec	transmissivity, T = 0.001 m^2/sec storativity, S = 0.001 pumping rate, q = 3.0 x 10^{-3} m^3/sec

sumption inherent to HST3D) (Hantush 1964). A radial coordinate system was used to discretize the aquifer: 50 nodes in the r-direction and 5 nodes in the z-direction. No-flow conditions were applied at the lower and radial boundaries. A leaky aquifer boundary condition is applied at the top boundary. The remaining input data for this simulation are listed in table 17.

The drawdown for a well 20 m from the pumping well was determined using the analytical and numerical solutions (fig. 35). The numerical solution tends to slightly underestimate the drawdown. These results are closer to the analytical solution than those reported by Ward et al. (1984) and are considered to be acceptable.

Model Calibration

Data used for model calibration (history matching) were obtained from the long-term injection test described in chapter 3 (p. 42). and plotted on figure 28. The conceptual model for the injection system was based on data presented in Long-Term Injection Test (p. 42) and is shown on figure 36. The hydraulic conductivity and physical dimensions in the vertical direction are also depicted on this figure. Other pertinent input data are listed in table 18. The injection system was discretized with radial coordinates: 60 nodes in the r-direction and 22 nodes in the z-direction.

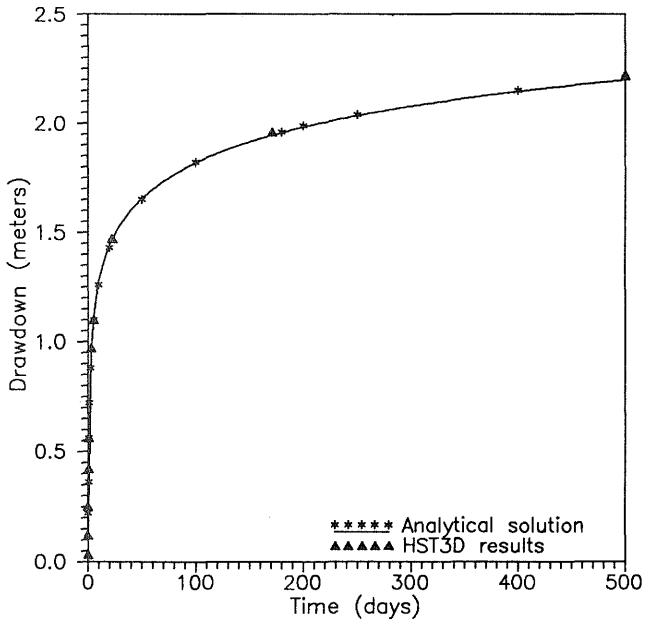

Figure 34 (left) Comparison of model-predicted drawdowns with results from Theis Analysis.

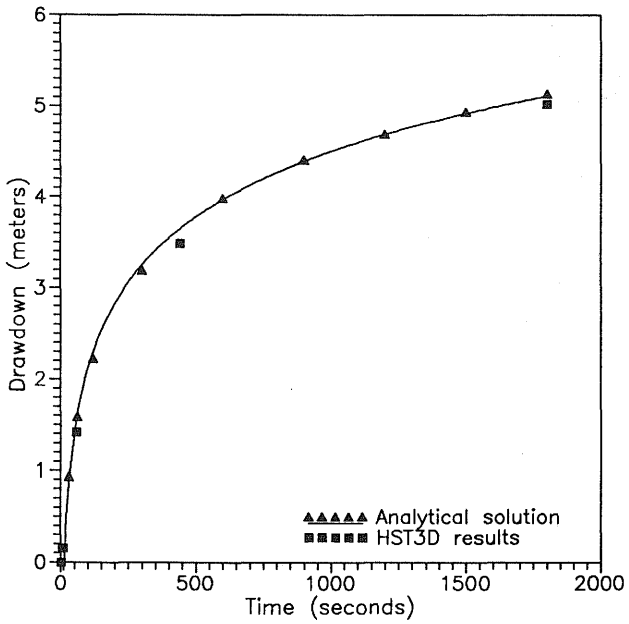

Figure 35 Comparison of model-predicted drawdowns in relation to time with Hantush Analysis.

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Table 17 Input data for leaky aquifer simulation

HST3D	Analytical solution
aquifer thickness, b = 3.05 m	transmissivity, $T = 10^{-3}$ m^2/sec
aquifer intrinsic hydraulic conductivity, $K = 3.35 \times 10^{-11}$ m^2	storativity, $S = 10^{-4}$
matrix compressibility, $\alpha = 3.34 \times 10^{-8}$ Pa^{-1}	aquitard hydraulic conductivity, $K' = 3 \times 10^{-10}$ m/sec
fluid compressibility, $\beta = 4.53 \times 10^{-10}$ Pa^{-1}	aquitard thickness, b' = 0.30 m
fluid density, $\rho = 999.5$ kg/m^3	pumping rate, q = 0.014 m^3/sec
viscosity, $m = 1.00 \times 10^{-3}$ kg/m-sec	
aquitard intrinsic hydraulic conductivity, $K = 3.06 \times 10^{-17}$ m^2	
aquitard thickness, b' = 0.30 m	
pumping rate, q = 0.014 m^3/sec	

Table 18 Selected input data for model calibration

radius, r = 15870.90 m
$\beta = 4.00 \times 10^{-10}$ Pa^{-1}
$\alpha = 4.50 \times 10^{-10}$ Pa^{-1}
$\rho = 1020$ kg/m^3
$\mu = 7.87 \times 10^{-4}$ kg/m-sec

No-flow conditions were applied at the top and bottom boundaries, while an aquifer influence was applied at the radial boundary.

Kipp (1986) describes the use of aquifer influence boundary conditions (AIF BC) as a simple, but approximate, method for embedding an inner region of groundwater simulation within a larger region where groundwater flow may be treated in an approximate fashion. The use of aquifer influence functions reduces the size of the computational grid with a corresponding reduction in computer storage and execution time.

The natural hydraulic gradient of the Devonian limestone is very low (see p. 32); thus, the hydraulics of the injection well will dominate the groundwater hydraulics in the area surrounding the well. The flow rate across an AIF boundary is a function of the potentiometric head and hydrogeologic characteristics of the aquifer. The use of the AIF BC was favored over a specified head or flow-type BC, since the AIF is a more accurate representation of the hydraulics of the injection system.

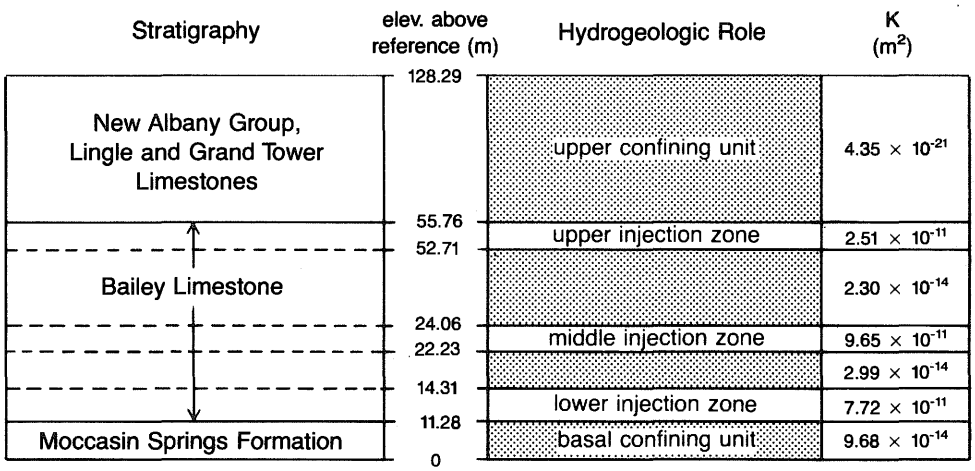

Figure 36 Conceptual model 1 of the injection system.

The T and S values calculated on the basis of input data, as well as the values determined from field testing, are presented in table 19. The input data and field data match reasonably well. Closer agreement of the field and model T and S values probably could have been obtained with minor adjustments to the input data (chiefly K, α, and β); however, the T and S values used were considered satisfactory.

The model values for T and S were even more satisfactory considering that two of the chief input parameters, α and β, are consistent with published values. Fluid compressibility (β) has been previously discussed (p. 52).

Table 19 Comparison of transmissivity (T) and storativity (S) values

	Field test	**HST3D**
T (m^2/min)	0.386	0.373
S (-)	2.47×10^{-4}	2.65×10^{-4}

Our rock compressibility (α) values also agreed with values in the literature. Birch (1966) reports that $\alpha = 1.22 \times 10^{-11}$ Pa^{-1} for dolomite. Domenico and Mifflin (1965) report α for sound rock ranges from 10^{-9} to 10^{-10} Pa^{-1}, while α for jointed rock ranges from 10^{-8} to 10^{-10} Pa^{-1}. Since secondary porosity was present in the cores retrieved, one would have expected that α for the dolomite at the study site would be slightly greater than $\alpha = 1.22 \times 10^{-11}$ Pa^{-1}. In fact, the values of the cores tested range from 1.55×10^{-10} to 3.26×10^{-11} Pa^{-1}. Thus the use of $\alpha = 4.50 \times 10^{-10}$ Pa^{-1} for model calibration seemed reasonable. As discussed in appendix C, the scanning electron microscopy (SEM) work indicated that secondary porosity was present, primarily in the form of vugginess and some localized microfractures. The microfractures were very small and tended to be interconnected. Because of the close spacing and size of the microfractures, modeling flow through this geologic material as flow through porous media was considered to be a valid assumption.

The intrinsic permeability values for the three injection zones ranged from 2.5×10^{-11} to 9.7×10^{-11} m^2 (25.4 to 97.8 darcys). Schmoker et al. (1985) summarized data for limestone and dolomite petroleum reservoirs throughout the United States. These authors report that only 11 percent of all dolomite reservoirs exceed 0.1 darcy. Freeze and Cherry (1979) list 0.2 darcy as an upper permeability limit for limestone and dolomite. Clearly, the permeability values for the injection zones seem to be quite high. The permeabilities used as model input were based on the results of the injection test and were higher than the laboratory-determined permeabilities. There appear to be two explanations for the apparent high permeability values. First, the permeability values were actually calculated from transmissivity values and thickness of "permeable" units of the aquifer. The thickness of these units could have been underestimated. Another possibility was that the cores may not be representative of the overall injection system. Greater emphasis was placed on the results of the injection test, since this is an in situ measurement of the system.

In addition to aquifer transmissivity, another control on specifying intrinsic permeability was the results of the flowmeter survey conducted during phase II of the field experiments. The intrinsic permeability of the three injection zones was adjusted so that the flow into each of these three zones matched the flow profile defined by the flowmeter. Thus in the model, 48.1 percent of the injected fluid flowed into the lower injection zone, 36.2 percent into the middle zone, and 15.7 percent into the upper zone.

Figure 37 depicts the head build-up at the DOW during the injection test and the buildup predicted by HST3D versus time. The model overpredicted the head buildup at times by less than 20 hours; however, the results at later times are very close. Oscillation of the head buildup (field data) is also evident in figure 37. This oscillation is believed to be a manifestation of earth tides and not a variation in the pumping rate.

Matching model results with the later field results was considered more important because the main use of the model was to predict long-term effects of injection. The input data were reasonable, and the predicted head buildup matched reasonably well the head buildup observed in the field; therefore, model calibration was deemed successful.

Sensitivity Analysis

A rigorous sensitivity analysis as described by Yeh (1986) was not conducted. The sensitivity analysis conducted here involved varying significant parameters and noting the effect of this variation on head buildup (Δh) at the DOW, the parameter of interest. The significance of various parameters (i.e., injection rate, hydraulic conductivity) was observed during the two previous stages of this project. Based on these observations, sensitivity analysis was conducted for the following parameters: boundary conditions, injection rate, rock compressibility, fluid compressibility, hydraulic conductivity, and anisotropy. The sensitivity analysis is summarized here and described in detail in appendix D.

Injection rate and hydraulic conductivity were the most sensitive input parameters. That is, a given change in injection rate or hydraulic conductivity would produce the largest change in Δh observed at the DOW. The type of boundary condition and the location of the boundary could also significantly affect the head buildup predicted by the model. In decreasing order, the most sensitive parameters were injection rate and hydraulic conductivity, rock compressibility, anisotropy, and fluid compressibility.

Model Projections for Long-Term Injection

Using the conceptual model developed during the model calibration phase, we investigated the effects of long-term, continuous injection at two rates: 1.150×10^{-2} and 2.208×10^{-2} m^3/sec. The first injection rate is the "average" rate at which the company injected waste during the life of the well. This was calculated by dividing the cumulative volume of waste injected by the length of operation for WDW2. The second injection rate is the maximum average injection rate permitted by the Illinois Environmental Protection Agency (IEPA 1987).

Embedded in this calculation of the "average" injection rate is the assumption that the well was operated on a continual basis; however, WDW2 was not in operation continually. A larger head buildup in the injection system would be produced by assuming continuous (24-hour) operation because pressure in the injection system would never bleed off.

HST3D was used to predict the head buildup in the injection system over a 30-year period. The decline in head was also modeled for an additional 30-year postinjection period. Thirty years was chosen since this is typically the length of service for an injection well. Because of problems experienced with HST3D, the injection rate during the postinjection period could not be set to zero. During the postinjection period, the injection rate was set as low as possible, $q = 1.82 \times 10^{-4}$ m^3/sec. Figure 38 shows the head buildup in relation to radial distance from the injection well after 10,927 days (30 years). At the DOW, Δh after this time is 0.03 m. Thus, use of $q = 1.82 \times 10^{-4}$ m^3/sec during the postinjection period did not significantly impact the pressure decline during the postinjection period.

Injection Scenario 1

Injection scenario 1 is injection for 30 years at a rate of 1.150×10^{-2} m^3/sec, followed by a postinjection period in which $q = 1.82 \times 10^{-4}$ m^3/sec. Figure 39 shows the response of the injection system during both 30-year periods (262,980 hours each). Head buildup at the DOW increases exponentially. After 30 years of injection, $\Delta h = 1.61$ m at the DOW. In terms of Δh, steady state was approached but not reached. The head buildup at the DOW also dropped exponentially. Approximately 900 hours after the change in the injection rate, the head buildup was approximately half of its maximum value. Nearly 7.5 years (66,000 hours) after the change in the injection rate,

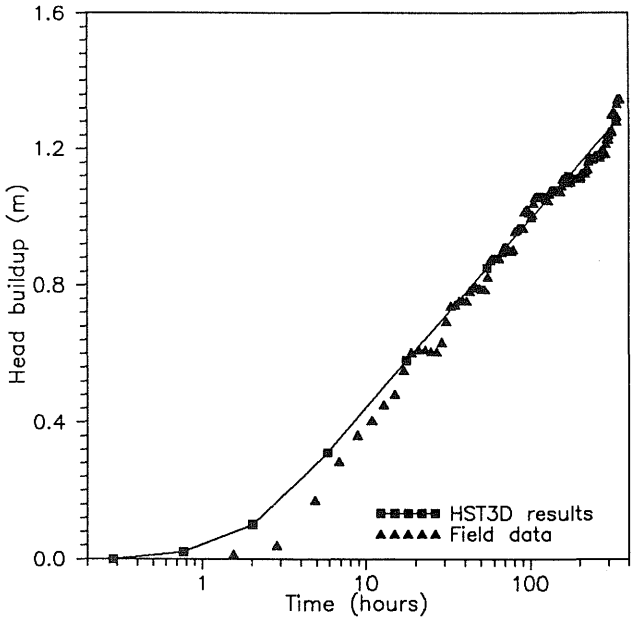

Figure 37 (left) Comparison of model-predicted Δh versus field data for DOW.

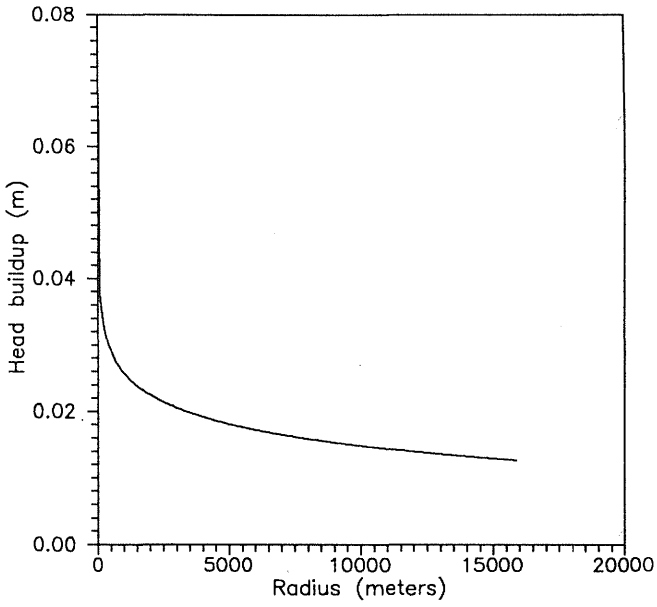

Figure 38 Head buildup versus radial distance from WDW2 $q = 1.82 \times 10^{-4}$ m^3/sec.

the head buildup was only 0.01 m, after correcting for Δh due to injection at $q = 1.82 \times 10^{-4}$ m^3/sec. During the 30-year postinjection period, the head buildup did not reduce to 0.00 m.

Injection Scenario 2

During the second injection scenario, the effects of injection for 30 years at $q = 2.208 \times 10^{-2}$ m^3/sec were investigated. A postinjection period followed during which $q = 1.82 \times 10^{-4}$ m^3/sec. Figure 40 shows the head buildup at the DOW. The results were similar to the results for injection scenario 1. The head buildup increased exponentially to a maximum Δh = 3.20 m after 30 years of injection. Also, after the injection rate was reduced, the head fell exponentially. The head buildup approached but did not go to 0.00 m during the postinjection period.

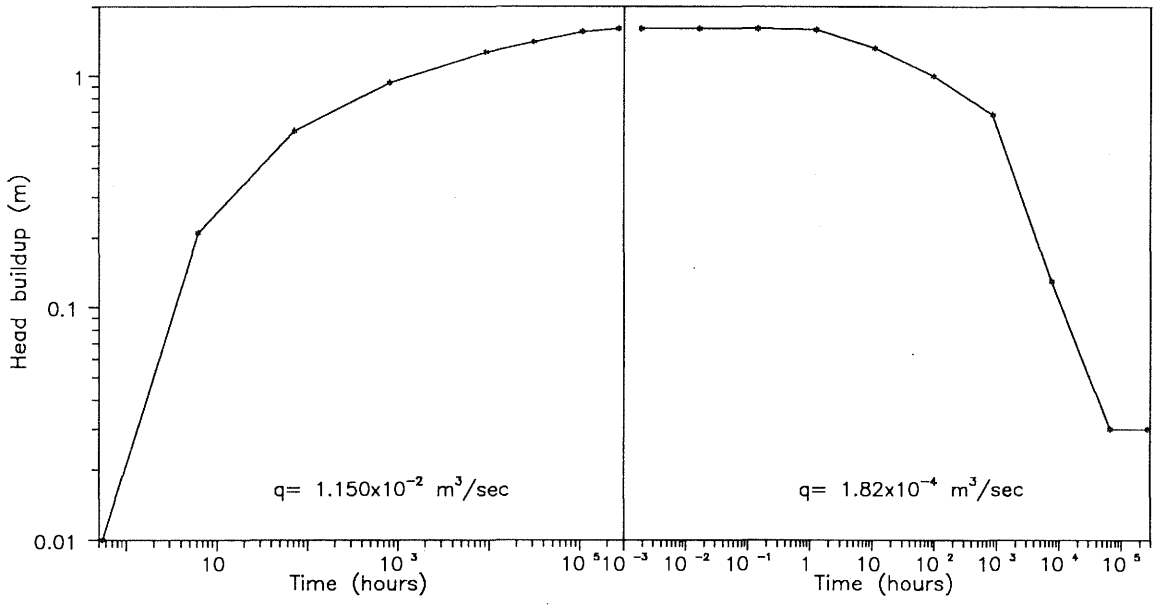

Figure 39 Injection scenario 1: head buildup and decline with time at the DOW.

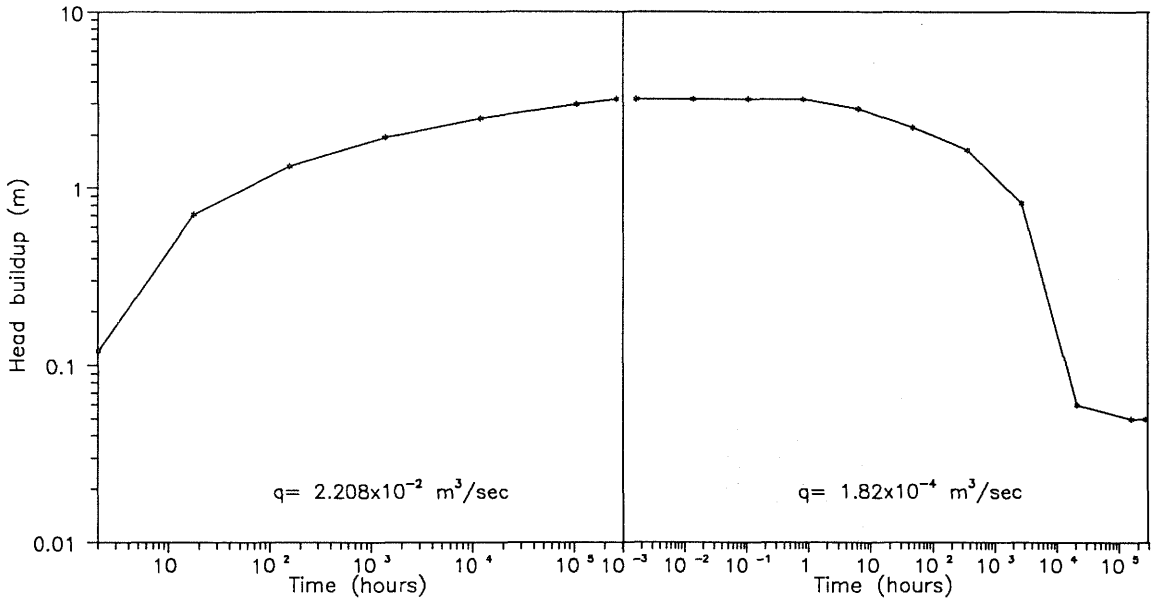

Figure 40 Injection scenario 2: head buildup and decline with time at the DOW.

Figure 41 shows the head buildup at the WDW2 during the injection and postinjection periods. The results were similar to the results shown in figure 40 except the magnitude of the head buildup was greater at the injection well. After 30 years of injection, Δh at WDW2 was 7.88 m. For comparison, Δh at WDW2 for injection scenario 1 was 4.22 m.

Maximum hydraulic pressure was 7.081×10^6 Pa (1,027 psi) and occurred at the bottom of the well after 30 years of injection under injection scenario 2. The pressure at the base of the confining layer equaled 6.687×10^6 Pa (970 psi). The pressure increase due to 30 years of injection was 7.73×10^4 and 6.69×10^4 Pa at the bottom of the well and the base of the confining unit, respectively. The pressures resulting from injection scenario 1 ($q = 1.150 \times 10^{-2}$ m^3/sec) were slightly lower than those listed here.

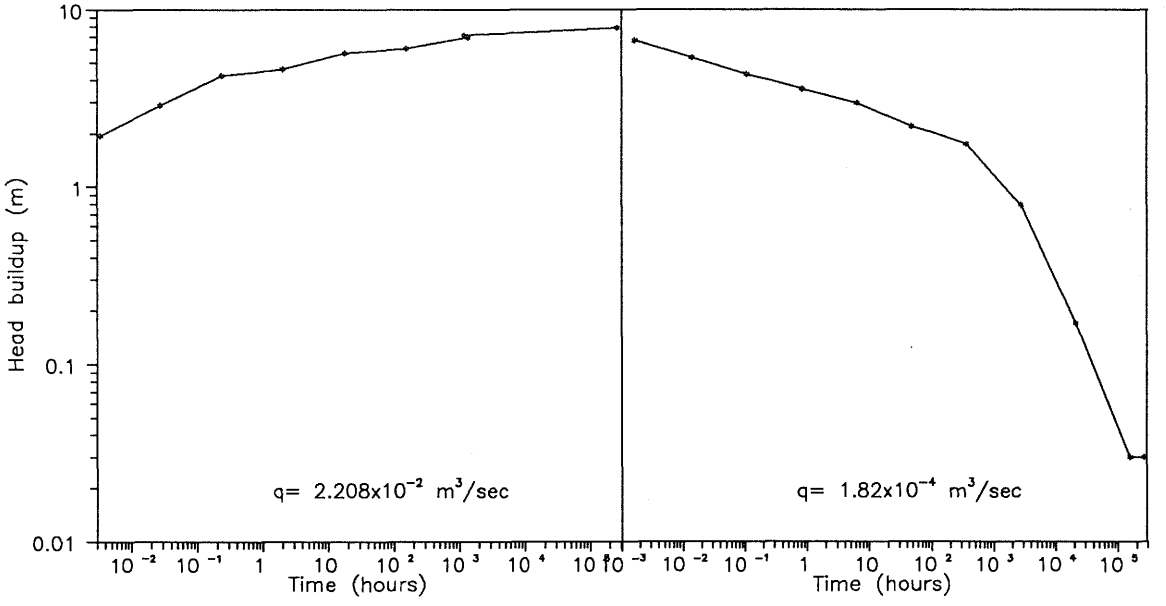

Figure 41 Injection scenario 2: head buildup and decline with time at WDW2.

In Illinois, the hydraulic fracture gradient is generally considered to be equal to $1.5x10^4$ Pa/m (0.65 psi/ft). Using this value, the hydraulic pressure necessary to initiate fractures was calculated as 1.19×10^7 Pa (1,694 psi) for the bottom of the well (depth = 794.3 m) and as $1.12x10^7$ Pa (1,591 psi) for the base of the confining unit (746.2 m). Thus pressures due to 30 years of continuous injection at the maximum permitted injection rate were much less than the pressure calculated to initiate hydraulic fracturing.

Hypothetical Conduits

During this final phase of modeling, the hydraulic response due to the presence of hypothetical conduits was investigated throughout the injection system. Jones and Haimson (1986) describe some hypothetical conduits pertinent to underground injection. These conduits, which allow fluid movement from the injection zone, include abandoned wells, microannuli at the injection well, and permeable fault zones. Time constraints restricted the investigation to the effect of a microannulus at the injection well. Accomplishing this task required numerical modeling to evaluate whether the pressure response in the injection system or in an overlying unit could be used to identify fluid movement from the injection zone. Three monitoring strategies were evaluated: monitoring at the injection well (WDW2), at the observation well (DOW), and in the overlying aquifer.

A new conceptual model of the site hydrogeology was developed for this task (fig. 42). A thicker sequence of geologic materials than that previously used included the Devonian limestones, the overlying New Albany Shale (a confining unit), the "Carper sand" (a permeable unit), and the Borden Siltstone (another confining unit). Since "Carper sand" lies near the base of Borden Siltstone, for purposes of modeling, it is considered the basal horizon of this formation. Hydrogeologic characteristics for these units appear on figure 42.

For this conceptual model, the head buildups at the injection and monitoring wells were slightly lower than the buildups used in the original model; however, the results were considered acceptable. The slight decrease (0.03 m at the DOW) was probably due to the greater thickness of compressible geologic materials for the conceptual model.

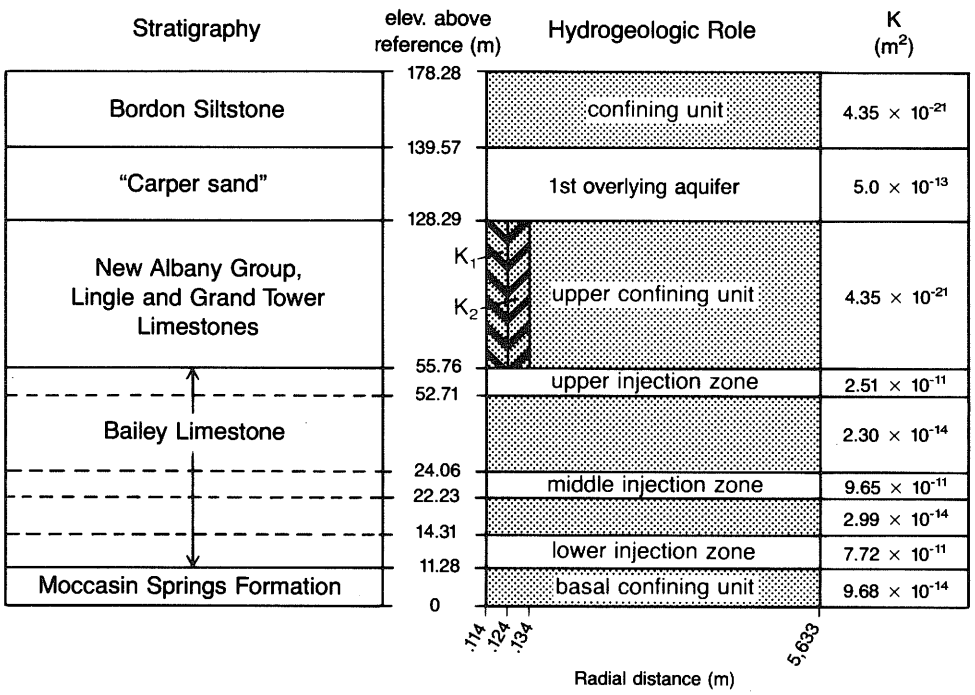

Figure 42 Conceptual model 2 of the injection system

Modeling Results: Hypothetical Conduit Scenario

In this scenario, a microannulus was assumed to have developed at the injection well. Extending from the top of the uppermost injection zone to the base of the Carper, the microannulus connected these two permeable units (fig. 42) and was input into the model as two zones. The first zone was considered the microannulus, and the second zone, a transition between the microannulus and the New Albany Shale. Both zones were 0.01 m thick and discretized using three nodes. Several runs were made, with different zone permeabilities (table 20). CT3DB1 was the baseline run used for comparison.

Table 20 Permeability (m^2) of the microannulus

Run	Microannulus (K1)	Transition zone (K2)
CT3DB1	4.35×10^{-21}	4.35×10^{-21}*
CT3DB2	1.00×10^{-12}	1.00×10^{-14}
CT3DB3	1.00×10^{-10}	1.00×10^{-12}
CT3DB5	1.00×10^{-9}	1.00×10^{-11}
CT3DB4	1.00×10^{-8}	1.00×10^{-10}

* same permeability as New Albany shale.

For this series of model runs, the maximum permitted injection rate ($q = 2.208 \times 10^{-2}$ m^3/sec) was used to maximize the pressure gradients in the injection system. Injection continued at this rate for 365 days. Because the "Carper sand" does not produce water or hydrocarbons, hydrogeologic data for this unit are rare. On the basis of interpretations of geophysical logs from wells near Marshall, which indicated that the Carper is a permeable sandstone, permeability was assumed to be 5.0×10^{-13} m^2.

For analysis of results, a head difference of 0.05 m, when compared with results of CT3DB1, was considered monitorable. Differences of less than 0.05 m were not considered sufficient to be monitored because of errors in measurement, head fluctuations due to earth and/or barometric tides, and related factors.

Head buildup in relation to time is shown for WDW2 (fig. 43), DOW (fig. 44), and the base of the Carper at WDW2 (fig. 45). As the permeability of the microannulus increased, the head buildup at WDW2 decreased slightly. For CT3DB4 ($K1 = 1.00 \times 10^{-8}$ m^2), difference in head buildup was -0.23 m after 1 year. Head buildup for the other cases were lower— for instance, Δh = -0.10 m when $K1 = 1.00 \times 10^{-10}$ m^2. A change in the head build-up of this magnitude at an operating injection well might not be monitorable because of head buildup associated with other factors, such as wellbore plugging and pipe friction increases.

For the five cases investigated, no monitorable difference in head buildup was observed at the DOW (fig. 44). For CT3DB4 ($K1 = 1.00 \times 10^{-8}$), head buildup was lower than the other cases by just 0.01 m after 365 days. Thus monitoring the DOW would not detect the leak at the microannulus. Monitorable differences in head buildup were predicted at the base of the Carper in three of the four cases. For CT3DB3, the difference after 365 days was 0.08 m. The differences after 365 days were greater for CT3DB5 (0.77 m) and CT3DB4 (3.98 m). The radial extent of head buildup at the base of the Carper varied for each of the cases. For CT3DB5, it was approximately 100 m, and for CT3DB4, more than 6,000 m (fig. 46).

In summary, monitoring the DOW would not reveal the presence of a leaky microannulus, in part because of the distance between the injection and observation wells. Monitoring the injection well might reveal a leaky microannulus, but the differences in head buildup for the cases investigated might be masked by well bore plugging, corrosion buildup in the tubing, and other related factors. Finally, monitoring in the overlying aquifer appears to be the best alternative, but it depends on the hydraulic conductivity of the microannulus. As the hydraulic conductivity of the hypothetical

conduit increases, the volume of fluid moving into the overlying aquifer and the head buildup also increases. The head buildup observed in the Carper is also a function of its hydraulic conductivity. Lower Δh would be observed if the Carper were more permeable. On the other hand, higher Δh would be observed over a smaller area if the Carper had a lower hydraulic conductivity.

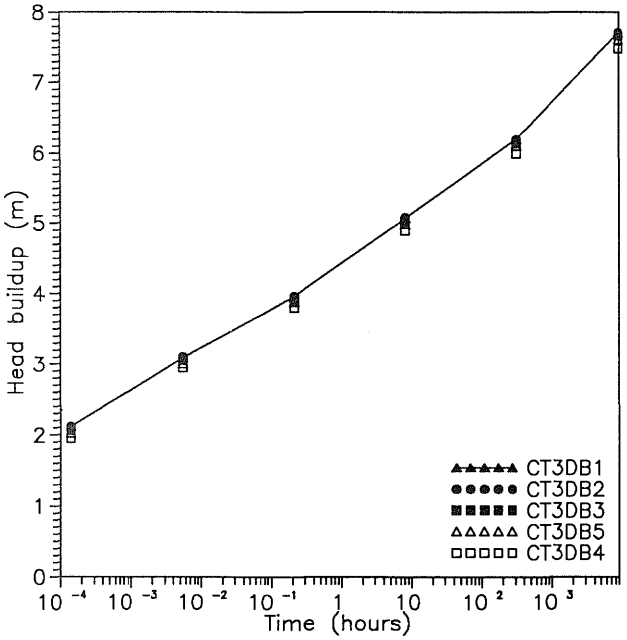

Figure 43 Effect of microannulus on the head buildup at the WDW2.

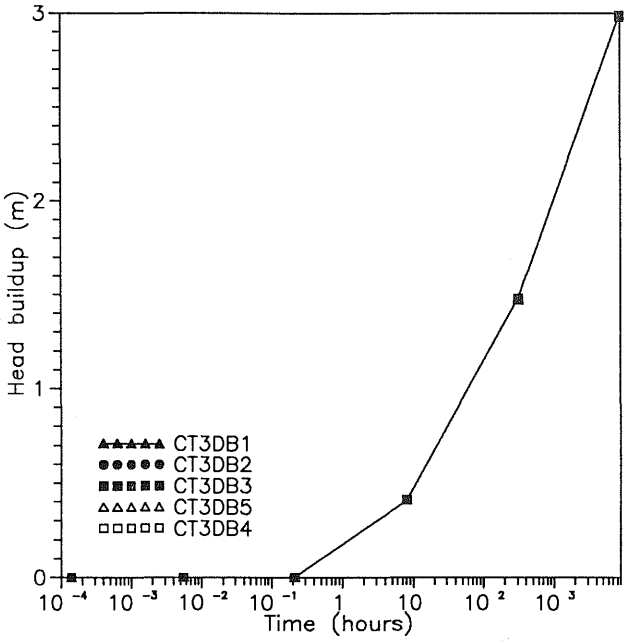

Figure 44 Effect of microannulus on the head buildup at the DOW.

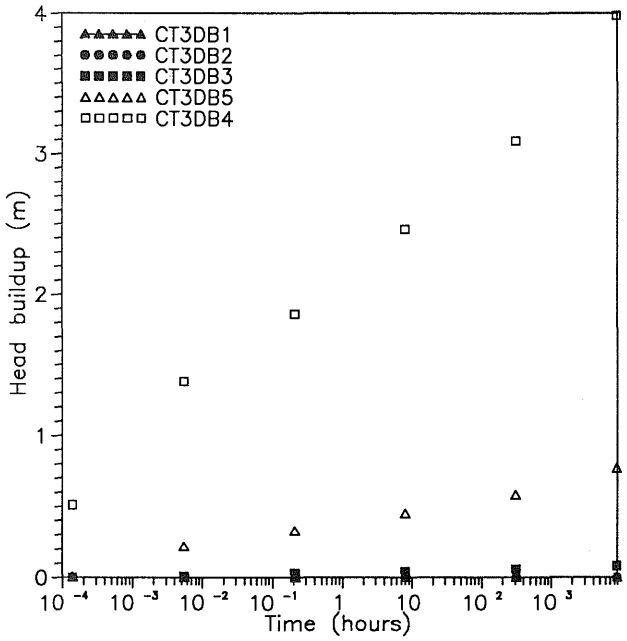

Figure 45 Effect of microannulus on the head buildup in the "Carper sand."

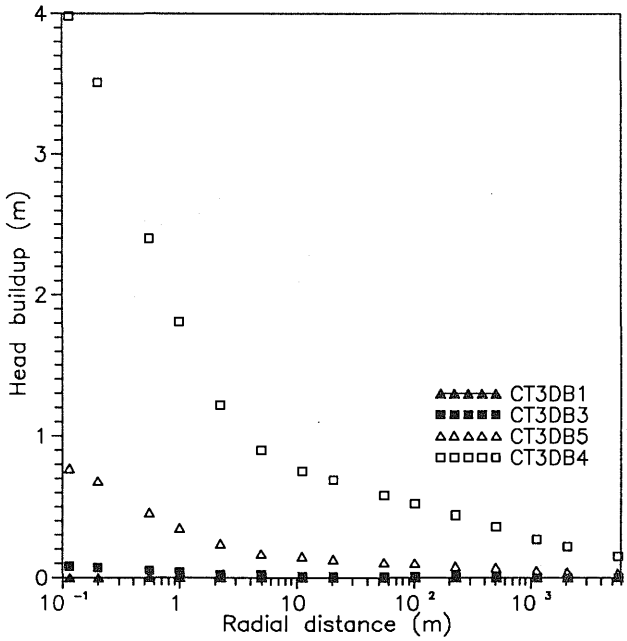

Figure 46 Head buildup in the "Carper sand" versus radial distance from WDW2.

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5. SUMMARY AND CONCLUSIONS

Evaluation of Injection Scenarios

Available records and logs pertinent to the injection system were studied, hydraulic tests were conducted, geophysical logs were run, and other tests were conducted on-site to determine the hydrogeologic characteristics of the injection system. Regional and site-specific descriptions of the system's stratigraphy, structural geology, and hydrogeology were generated from analyses of these logs and test results. These descriptions formed the basis of input for the numerical groundwater flow model (HST3D) used to investigate the hydraulic effects of injection upon the injection system. Other input included data on the physical and chemical characteristics of the injected wastewater and the native brine in the injection system.

Before the effects of various injection scenarios were investigated, HST3D was verified with respect to two analytical solutions (figs. 34 and 35) and calibrated with respect to data collected during an injection test (fig. 37). Both verification and calibration were considered satisfactory.

Once calibrated, the model was used to predict the effects of various injection scenarios. The effect of long-term injection was investigated at two constant injection rates: the average historical rate (1.150×10^{-2} m^3/sec) and the maximum average permitted rate (2.208×10^{-2} m^3/sec). Under both scenarios, significant head buildup was observed at the injection well and radially from it. During the simulated 30-year injection period, steady state was approached but not obtained during either injection scenario. During the subsequent 30-year postinjection period, decrease in head buildup was fairly rapid—dropping to half in less than 2,000 hours for both scenarios. The maximum hydraulic pressures at the bottom of the well and at the base of the upper confining unit were significantly lower than the pressures calculated to initiate hydraulic fracturing.

The continuity of the regional stratigraphy and its qualitative permeability were determined from the regional and site-specific study. Numerical modeling indicated that the pressures resulting from waste injection were lower than pressures calculated to initiate hydraulic fracturing; thus new fractures would not be initiated. From a hydraulic viewpoint, therefore, waste injected within this injection system would be contained and would be considered protective of human health and the environment for the two injection scenarios investigated.

These results are based on an assumption that hydraulic conductivity remains constant. However, from available data it appears that the high pH of the injected wastewater causes it to react with the dolomite present in the injection zones, forming brucite ($Mg[OH]_2$), which reduces the hydraulic conductivity of the injection zone. Apparently, greater amounts of brucite formed in the zones where there was a greater flow of fluids; thus the zones with higher permeability were affected first. This hypothesis must be verified by additional work, which is beyond the scope of this project. At the study site, the long-term effect of this decrease in permeability on injectivity needs to be investigated. Any further decrease in the hydraulic conductivity of the injection zones will invalidate the results of the numerical modeling conducted for this study. In addition, any reduction in hydraulic conductivity of the injection zones will most likely cause an increase in hydraulic pressure if the injection rate remains constant. In such a case, hydraulic fracturing may be of concern.

Evaluation of Monitoring Strategies

The model was also used to investigate the hydraulic response throughout the injection system when a hypothetical conduit was introduced. In this scenario, a microannulus at the injection well was introduced, hydraulically connecting the uppermost injection zone and an aquifer immediately overlying the upper confining unit.

Model results were reported in terms of difference in head build-up when the microannulus was and was not present. At the WDW2, Δh (-0.23 m) was greatest for the scenario with the greatest microannulus permeability ($1x10^{-8}$ m^2). A difference of this magnitude at an operating well would be considered unmonitorable because of interferences such as increased Δh resulting from well bore plugging or tubing corrosion. At the DOW, Δh was considered too low to be monitorable. The difference in the overlying aquifer (Carper sand) was considered monitorable for the microannulus permeability greater than or equal to $1x10^{-10}$ m^2. The head buildup in the Carper is a function of its hydraulic conductivity, the hydraulic conductivity of the microannulus, and the radial distance from the microannulus. Thus from a practical standpoint and for the scenario modeled, the overlying aquifer is the only viable location for hydraulically monitoring leakage via the microannulus.

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APPENDIX A. THEORY AND PRACTICAL APPLICATION OF GEOPHYSICAL LOGGING INSTRUMENTS

Geophysical logging was used in this study to investigate the site and regional hydrogeology, and this section briefly explains the basic operational theory and applications of the geophysical tools used. Comprehensive coverage of every aspect of tool theory or all possible applications is beyond the scope of this project. These tools and their many applications are discussed in greater detail in Bateman 1985a, Bateman 1985b, Helander 1983, Leach et al. 1974, Curtis 1966, Peebler, Hallenburg 1984, Dobrin 1976, Kovacs and Associates 1981, Pickett 1977, Hilchie 1977, Brock 1984a, Brock 1984b, Rider 1986, Gearhart, Gearhart 1983, Dresser Atlas 1981, Schlumberger 1984, Schlumberger 1985, Dresser Atlas 1985a, Dresser Atlas 1985b, Dresser Atlas 1985c, Prasada Rao 1985, Keys and MacCary 1971, and Martin 1982. The discussion below draws liberally from these references.

Caliper Log (CL)

The Caliper Log tool is a theoretically uncomplicated instrument. Most tools still rely on a single or a series of potentiometers (fig. A-1). The potentiometers respond to a number of arms (caliper arms), which transmit information about the borehole environment to the potentiometer actuator. This information is relayed as a series of pulses to the surface recording equipment, which then processes the data.

There are a number of different arm configurations with the CL tool. For the purposes of injection/confining interval evaluation, the one- and four-arm tools are appropriate.

For applications that utilize the numerical CL data, such as calculations involving the Flowmeter Log (FL), the more sensitive four-arm CL tool is employed. For other applications, such as mudcake and washout location and general borehole conditions, a one-arm CL tool (usually run in mechanical combination with another device, such as an Neutron Log, Density Log, or Permeability Log) is utilized almost invariably.

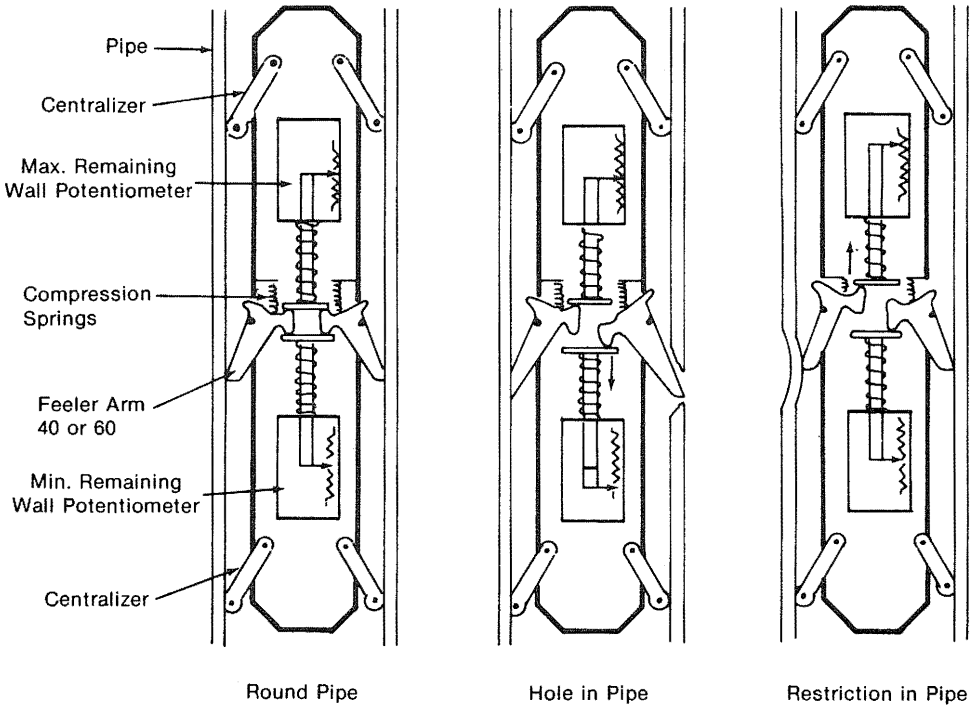

Figure A-1 Caliper Log tool that utilizes a dual potentiometer configuration (from Dresser Atlas 1985c)

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Flowmeter Log (FL)

Several types of Flowmeter Log tools are available, and they all operate in a similar fashion. The tool considered in this report is the continuous variety, which would be the most appropriate at the high flow rates often encountered in waste-disposal wells.

The Continuous Spinner Flowmeter Log (CSFL) tool, shown in figure A-2, incorporates an impeller into its design. The impeller rotates in response to fluid movement. This rotation generates a series of electrical pulses that are transmitted uphole to the surface equipment for computer processing. The number of pulses generated is proportional to the number of revolutions per second of the impeller, which can be related to flow velocity. The volumetric flow rate, the measurement of most interest, can be calculated from borehole diameter data obtained from the four-arm CL tool.

The CSFL tool measures fluid velocity very satisfactorily in turbulent fluid flow. Although this flow regime is encountered most often, it nonetheless requires verification. One method of defining whether a flow regime is turbulent is to use the Reynold's Number (Re). Re is defined as

$$Re = vD\rho/\mu \qquad [A\text{-}1]$$

where ρ = fluid density, g/cm^3
v = average fluid velocity, cm/sec
D = hole diameter, cm
μ = fluid viscosity, poise

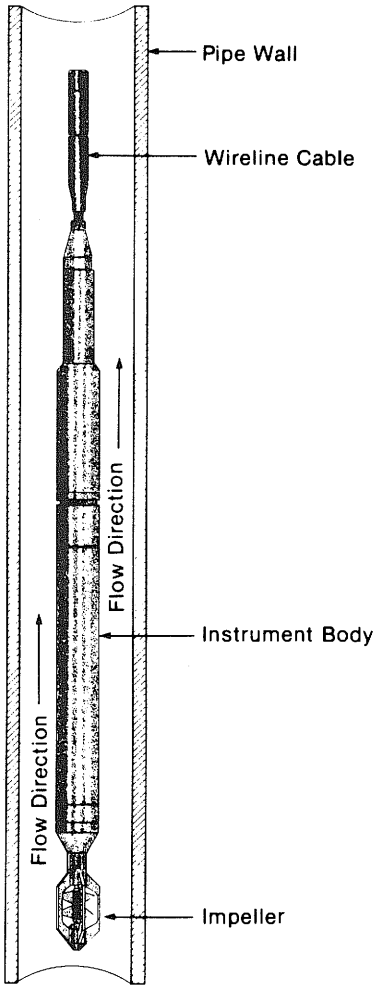

Figure A-2 Continuous Spinner Flowmeter Log tool (from Dresser Atlas 1981).

Re values of 3,000 or greater are used to represent turbulent flow in most literature dealing with fluid flow. For most applications of the CSFL tool in injection/confining interval evaluation, fluid will be injected at the surface to initiate impeller movement. A useful conversion in Re calculations is

$$v = (0.3637)Q/D^2 \quad [A-2]$$

where v = average fluid velocity, cm/sec
D = hole diameter, cm
Q = flowrate, barrels per day

This conversion is combined with the definition of the Reynold's Number to yield

$$Re = (0.3637)Q\rho/\mu D \quad [A-3]$$

Gamma Ray Log (GRL)

As its name suggests, the GRL detects gamma rays—random, high-energy electromagnetic waves emitted during the decay of unstable radioisotopes. The radioisotopes normally found in rocks are ^{40}K and the daughter products of the uranium and thorium decay series. The GRL discussed here is unable to differentiate the contribution of each individual radioisotope to the total intensity of gamma radiation.

The detector of the tool normally consists of a sodium iodide (NaI) crystal optically coupled to a photomultiplier tube. Atoms of the NaI crystal absorb gamma ray collision energy, which places the electrons of the atoms in a higher energy state. When the excited electrons lose this acquired energy and fall back into their original state, they give off light that is converted to a voltage pulse through the photomultiplier tube. These pulses are transmitted uphole and converted, on the appropriate scale, to a measure of the gamma ray intensity.

Because of the high natural concentration of ^{40}K in clay minerals, shales generally exhibit a high gamma ray intensity. On the other hand, sandstones and carbonates generally produce a lower gamma ray count because of their relatively low concentration of clays and other highly radioactive constituents. Because of this difference in gamma ray intensity, various lithologies can easily be identified (allowing correlation of lithologic units), and a rock unit's shale volume can be determined.

During phase I logging, a GRL that used a Geiger Mueller type of detector was run. The Geiger Mueller replaced the Scintillation type of detector employed in the previous GRL. This change results in a smoother, less fluctuating GR, which provides a better estimate of the formation's natural gamma ray activity (GR, measured in API units).

Sonic Log (SL)

The Sonic Log is an acoustic device that generates acoustic waves and measures reflected acoustic waves. The measurements taken from the SL tool are the direct result of the propagation of acoustic (elastic) waves through the borehole environment. The two important waves to the SL tool are the compressional (longitudinal) and the shear (transverse) waves.

The initial energy to produce the sound (acoustic) waves is generated by the transmitter (T) portion of the tool (fig. A-3). The velocity of a shear wave (Vs) is given by:

$$Vs = (\mu/\rho)^{0.5} \quad [A-4]$$

where μ = modulus of shear for the medium
ρ = density of the medium

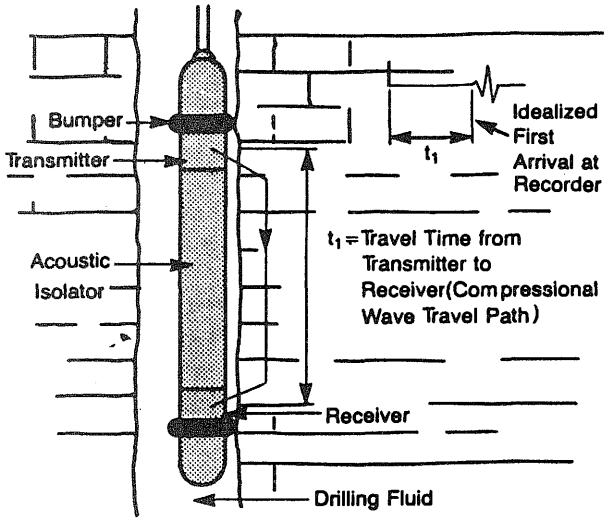

Figure A-3 (left) Generalized Sonic Log tool (from Helander 1983).

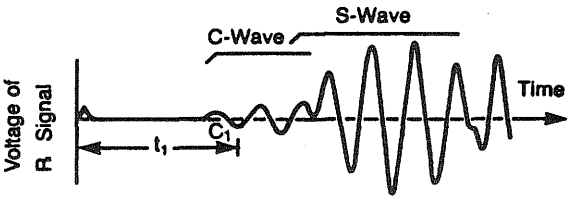

Figure A-4 Idealized schematic of receiver (R) signal (from Helander 1983).

Since the incident energy generated by the SL transmitter must first traverse a liquid medium in the borehole (where $\mu = 0$), it would appear that no shear wave would be generated, and subsequently received, by the SL tool. However, the occurrence of both shear and compressional waves in the response from the tool (fig. A-4) is a curious and useful anomaly. This apparent discrepancy can be resolved by noting that as the compressional wave strikes an interface or simply an adjacent medium with different elastic properties, a shear wave is produced. Therefore, as the compressional wave traverses from the transmitter (T) to the receiver (R) on the tool, the wave generates a shear wave that can, in this manner, be detected by the receiver circuitry. Shear waves generally are of a larger amplitude and about half as fast as compressional waves.

The transmitter-receiver array is chosen to account for abnormalities present in the borehole environment, i.e., washouts and tool tilting. The standard transmitter-receiver (T-R) arrangement is shown in figure A-5. Although other T-R configurations are available, this configuration is most nearly suited to the needs of injection/confining interval evaluation. The specific SL tool that incorporates this T-R array into its design is the Borehole Compensated Sonic Log (BCSL) tool. The main benefit of this type of T-R spacing is the compensation for washouts and tool tilting effects on travel time measurements.

Since the compressional wave has the fastest velocity of propagation, it is the one of most concern with the BCSL. If t_{fl} is the time taken to travel through the pore space (fluid travel time) and t_{ma} is the time taken to travel through the matrix, the total travel time will be t (the travel time recorded by the BCSL tool). The porosity (POR)BCS (Borehole Compensated Sonic) can be represented be the Wyllie time-average equation,

$$(POR)BCS = (t - t_{ma})/(t_{fl} - t_{ma}) \qquad [A\text{-}5]$$

The compressional wave (p-wave, also called C-wave) takes the path of least resistance. Areas of isolated (not interconnected) pockets of porosity, which would normally be found in the case of secondary porosity, will not have a pronounced effect on the travel time of the p-wave. By comparing the BCSL data with data from a tool that is influenced by the total porosity (primary and secondary), the amount of secondary porosity present can be estimated. The following equation applies to this situation,

$$(POR)tot = (POR)sec + (POR)prim \qquad [A\text{-}6]$$

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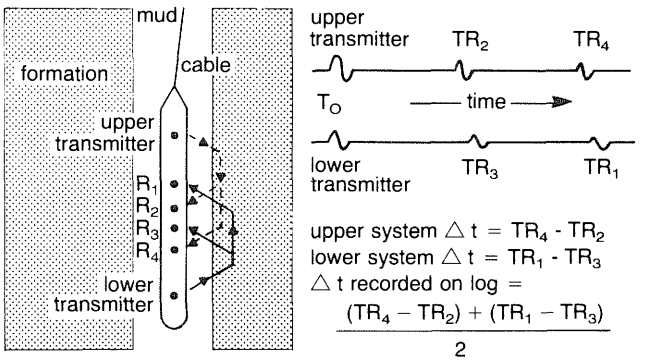

Figure A-5 Generalized Borehole Compensated Sonic Log tool (from Bateman 1985b).

During phase I logging, the BCSL was run in place of the SL. A more advanced detection system in the BCSL allows compensation for environmental factors that affect the signal transit time (t) used by the BCSL to make porosity determinations. A more accurate porosity profile results with the use of the BCSL.

One other SL tool that should be mentioned is the Long Spaced Sonic Log (LSSL) tool. It incorporates a longer T-R spacing than does the BCSL tool. In this manner, the LSSL tool is affected by a zone farther away and less disturbed by drilling operations than the zone at the borehole interface. This tool has been used for shear wave analysis, which when combined with compressional wave data results in an evaluation of some of the formation's strength characteristics, such as the pressure required to fracture the formation and the formation's elastic properties. If a hole has a large potential for washouts, this tool may be the best SL tool to use.

Neutron Log (NL)

The neutron is a fundamental particle found in the nucleus of all atoms except hydrogen, which contains only a proton. The neutron is a chargeless particle with about the same mass as the proton. The NL tool exploits these two properties of the neutron particle. The neutron source is usually a mixture of americium and beryllium, which react together to continuously emit neutrons.

Since the neutron is a small and electrically neutral particle, it passes with ease through most matter. During its passage, the neutron particle loses energy by colliding with other atoms. When the neutron's energy is reduced to a level equal to the surrounding matter (a function of absolute temperature), the neutron is called a thermal neutron. The energy of a thermal neutron is in the range of 0.025 eV.

Simple force relationships reveal that the maximum energy loss in the collision of two balls occurs when the two balls are of equal mass. Since the neutron and the hydrogen atom's proton have nearly equal masses, hydrogen dominates the behavior of neutrons and, in turn, the response of the NL tools. The thermal neutron flux is therefore controlled by the hydrogen content of the formation. Since hydrogen is found in the water molecules filling the pore space, the thermal neutron flux is a direct indication of the porosity of the formation.

Environmental factors such as hole size and mud weight influence the response of the NL tool. This influence can be corrected by taking two readings of thermal neutron flux at different spacings and using them to define the slope of the response line of the tool. This slope is relatively unaltered by environmental effects. The Compensated Neutron Log (CNL) tool utilizes this concept. The primary measurement of the CNL tool is therefore a ratio of the two count rates, far and near. Figure A-6 shows a CNL tool schematic.

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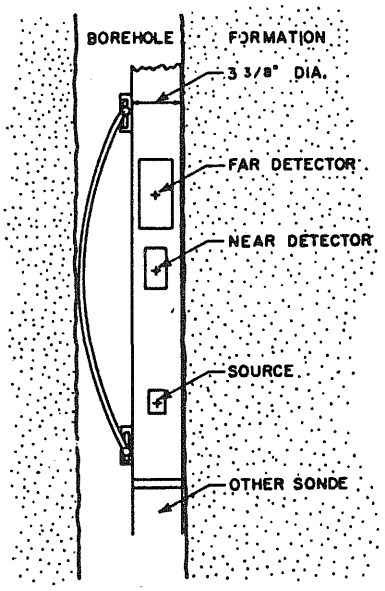

Figure A-6 Generalized Compensated Neutron Log tool (from Bateman 1985b).

The CNL displays a measurement of total porosity. Thus, it can be combined with the BCSL to provide an estimate of secondary porosity. Along with another porosity device, usually the BCSL or the Compensated Density Log (CDL), a lithologic determination may be made in addition to an accurate estimate of total porosity (cross-plotted porosity).

The CNL has replaced the Sidewall Neutron Log (SNL). The CNL utilizes a dual detector while the SNL has only one. The second detector enables the CNL to compensate effectively for environmental factors not taken into account with the SNL, such as salinity and temperature of the borehole fluid and diameter of the borehole. Accounting for these factors results in a more accurate determination of porosity with the CNL, ([POR]Nls).

Density Log (DL)

The DL utilizes a focused gamma ray source, normally cesium-137, which emits gamma rays into the formation from a pad assembly that is forced against the borehole wall via a back-up arm. The gamma rays interact with the electrons in the material opposite the focused source mainly through Compton scattering. This results in the gamma ray losing energy at each collision. The intensity of the back-scattered gamma ray is then measured by the gamma ray detectors (usually two) (fig. A-7). The measured gamma ray intensity is a function of the electron density of the formation. As the electron density of the formation increases, the probability of collision increases, resulting in reduced gamma ray intensity measured by the gamma ray detectors. The electron density, ρ_e, has been related to the bulk density, ρ_b, by the following equation,

$$\rho_e = \rho_b(2Z/A) \qquad [A\text{-}7]$$

where Z = atomic number or the number of electrons per atom
A = atomic weight

In most cases, the ratio, 2Z/A, is approximately equal to 1.0. Therefore $\rho_e = \rho_b$, and the apparent bulk density response of the tool is a response to the bulk density, ρ_b, of the formation material opposite the tool.

A two-detector DL or Compensated Density Log (CDL), which was used for phase I logging, allows for the compensation of the mudcake's effect on CDL tool response. In this way, an accurate

total porosity measurement is obtained. CDL response can be compared to BCSL porosity to estimate secondary porosity or cross-plotted with the BCSL or CNL to produce lithologic and total porosity determinations.

Resistivity Log (RL)

The property of a material that opposes the flow of an electrical current is called electrical resistance. Resistivity is a measure of the resistance of a volume of material. Several authors have noted that formation resistivity can be determined by,

$$R = KV/I \qquad [A\text{-}8]$$

where R = resistivity
K = geometric factor specific for a particular tool
V = potential across current path
I = current.

Since the RL tool measures the potential, and K and I are known, R can be calculated. The calculated resistivity is dependent on the amount of porosity and fluid contained in the pores.

RL tools have a number of applications. For this study, the resistivity device was needed for two purposes: to determine an accurate, true formation resistivity for fluid saturation calculations, cementation factor determinations, and stratigraphic correlations; and to estimate the invasion of borehole fluids into the formation, which may affect the RL tool's response.

Two appropriate resistivity logging systems are available: the Dual Laterolog Microspherically Focused Log tool and the Dual Induction Laterolog (Spherically Focused Log) tool. Although both systems will provide the necessary results, specific borehole conditions dictate which one is appropriate. The former is used when sea water or brine mud fills the borehole and the latter when fresh or oil-based mud is present. For this discussion, the Dual Induction Laterolog (DIL) tool will be considered. (The Dual Induction Spherically Focused Log [DISFL] tool is similar in principle to the DIL.)

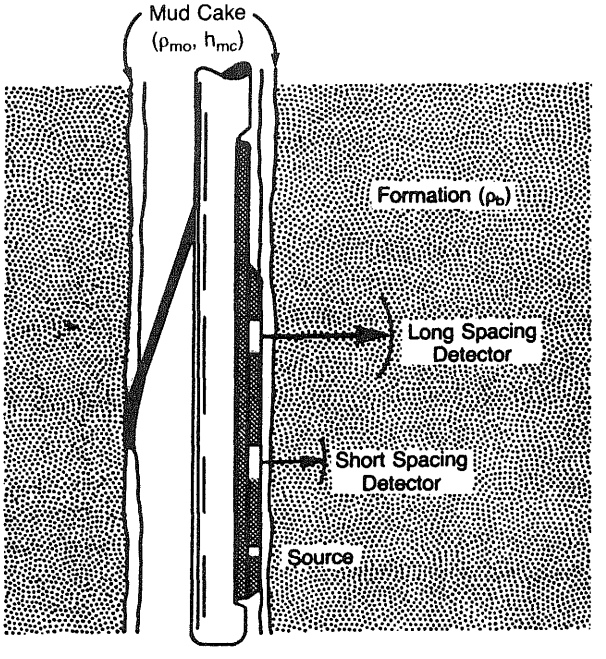

Figure A-7 Generalized two-detector Density Log tool (from Helander 1983).

The DIL tool comprises two sections: the induction and the lateral. The induction section produces two measurements, the "induction log deep" and the "induction log medium"; the lateral section yields one, the "laterolog."

The induction section, shown in schematic in figure A-8, is equipped with transmitter-receiver (T-R) coil pairs. An alternating current is applied to the transmitter, which generates a magnetic field around the tool, thereby inducing current flow in the surrounding formation. The current flow generates a magnetic field in the formation which, in turn, induces a voltage in the receiver coils. The measured voltage is proportional to the formation conductivity, which is inversely related to the formation resistivity.

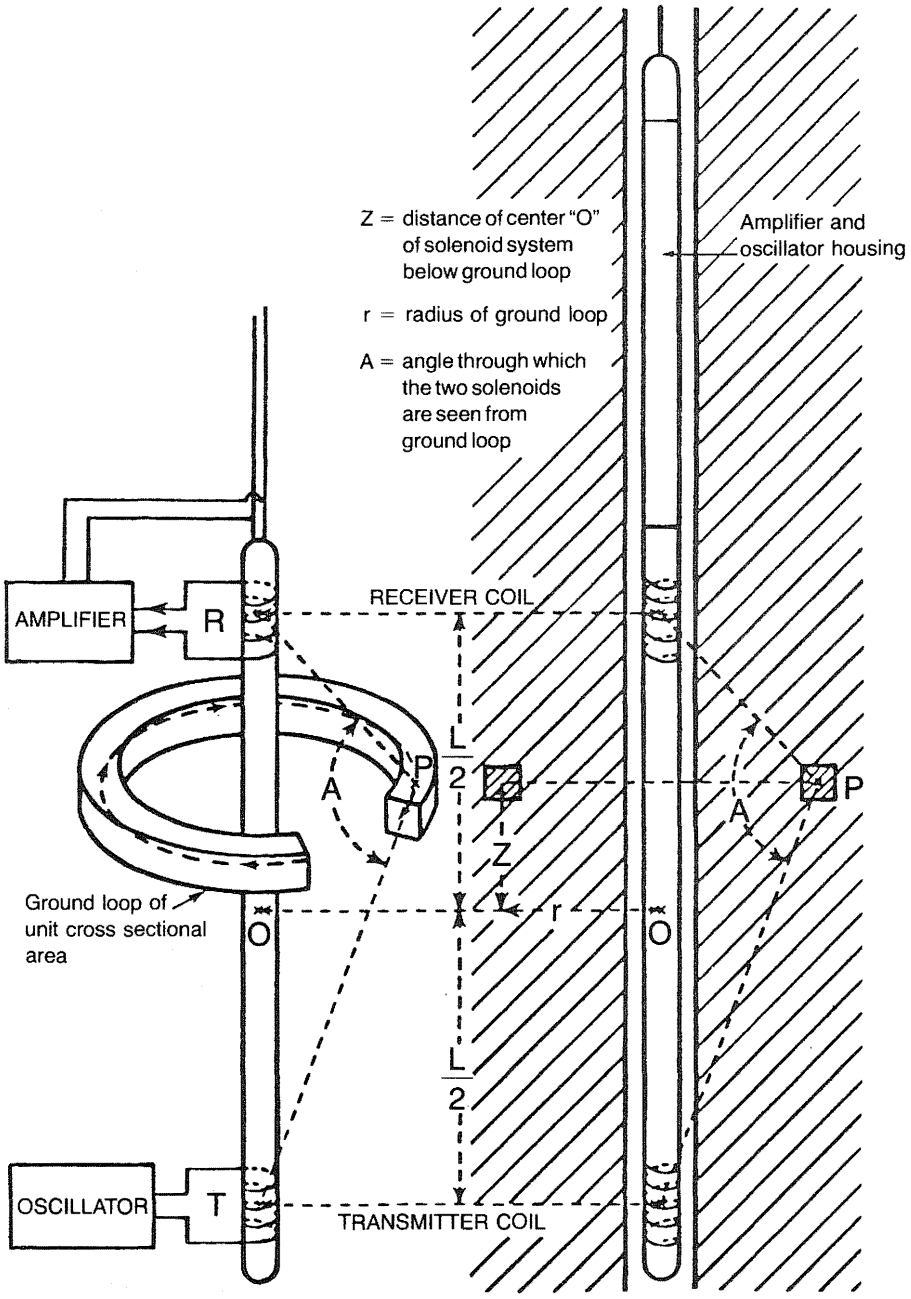

Figure A-8 Schematic diagram of induction log principles (from Hallenburg 1984).

Lateral devices pass a current of constant intensity from the tool into the formation (fig. A-9). This current flow creates equipotential spheres around the source electrode (A). Potential measuring electrodes (M, N) record the potential created by the current flow. The potential measured is then converted to formation resistivity.

The three curves generated have different depths of investigation into the formation, because of T-R spacing on the induction section and A-M,N spacing on the laterolog section. In this way, an evaluation of the amount of invasion is made, which is used to correct the deepest measurement (induction log deep) for invasion effects to produce an accurate, true formation resistivity. This resistivity can be used to obtain the cementation factor and fluid saturation of the formation.

The DISFL has replaced the Induction Electric Log (IEL). With the addition of one more resistivity curve to the output of the DISFL, the Induction Log Medium resistivity, and a deeper reading Induction Log Deep resistivity, factors that affected the resistivity response of the DISFL can be taken into account. These factors include the depth of invasion of the borehole fluids and the effect of this invasion on the determination of a true resistivity for the formation. The result is an Induction Log Deep resistivity corrected for invasion effects, which is considered more accurate than the formation's true resistivity determined by the IEL.

Permeability Log (PL)

The Permeability Log tool used most frequently today is the Minilog (MIL) tool. The MIL replaced the Microlog. Advanced electronics have increased the sensitivity of the Minilog as compared with the Microlog. Use of the Minilog results in more accurate information on permeability, mud (Rm), mud filtrate (Rmf), and mudcake (Rmc) resistivities.

The MIL, which utilizes the same resistivity theory discussed for the RL, is not discussed in detail here. The output of the MIL tool consists of two measurements: normal and lateral resistivities. The lateral configuration is described above. The normal measurement utilizes a slightly different system, shown in general schematic in figure A-10. The two arrays are housed in a nonconductive, fluid-filled rubber pad that is forced against the borehole wall by a back-up arm. This configuration is necessary to prevent the borehole fluid from short-circuiting the closely spaced current electrodes.

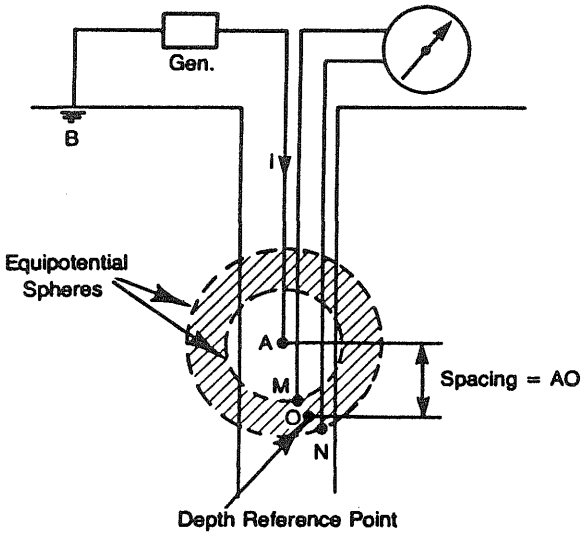

Figure A-9 (left) Schematic diagram of lateral logging system (from Helander 1983).

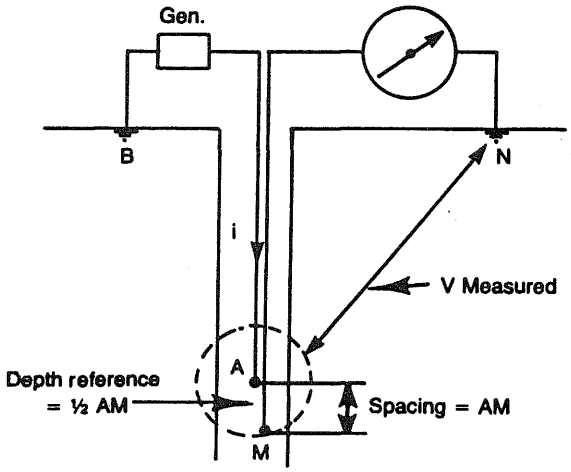

Figure A-10 Schematic diagram of normal logging system (from Helander 1983)

By utilizing two different configurations, MIL can produce varying depths of investigation. A comparison of the curves indicates the presence and magnitude of invasion of the borehole fluids into the formation. This enables a qualitative determination of the presence of permeability.

Spontaneous Potential Log (SPL)

Although the SPL system has one of the simplest physical configurations (fig. A-11), it is the result of many different factors. The SPL system records the change in naturally occurring potentials as a function of depth in the borehole. Two types of potential may contribute to the total Spontaneous Potential (E_{sp}): electrochemical (E_c) and electrokinetic (E_k). In well log analysis it is assumed that the measured SP response is due solely to the electrochemical component; therefore, $E_{sp} = E_c$.

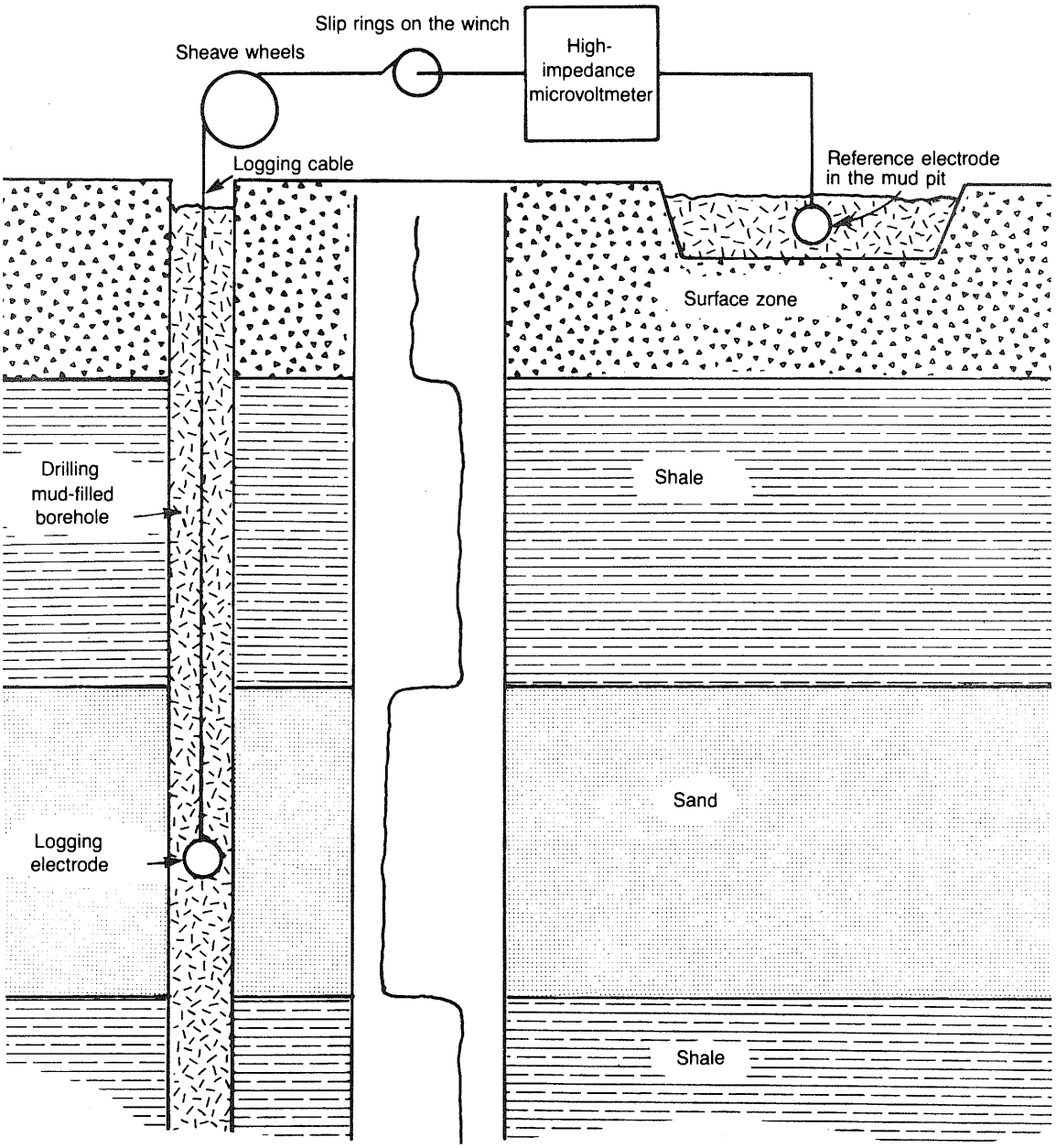

Figure A-11 Schematic diagram of spontaneous potential circuit.

The electrochemical potential is composed of the membrane potential (E_m) and the liquid junction potential (E_j). The membrane potential is caused by the separation of two fluids of different activity by a permeable, charged membrane. An analogy might be mud and formation water separated by shale. The liquid junction potential is the result of the contact of two solutions of differing activity, such as mud filtrate and formation water.

The E_{sp} is commonly written as

$$E_{sp} = -K_c \log(R_{mf}/R_w) \qquad \text{[A-9]}$$

where $K_c = 61 + 0.133T(°F)$
R_{mf} = mud filtrate resistivity
R_w = formation water resistivity.

This equation illustrates one application of the SPL system, namely R_w determination. The other applications relevant to this study are stratigraphic correlation and qualitative permeability estimation. The latter two are available through a consideration of the fluids and formation materials that give rise to the membrane and liquid junction potentials.

Temperature Log (TL)

The TL tool is simply a device that records the magnitude of the subsurface temperature. This is accomplished by incorporating into the tool's design a sensor element that provides ultrasensitive, stable readings over a suitable temperature range. A temperature probe in contact with the borehole environment transmits the thermal energy to the sensor, which converts the energy to a signal coverted by the surface equipment to absolute and differential temperature. These data can be useful to injection/confining interval evaluation in several ways. First, in many injection wells the temperature of the injection fluid is anomalously cooler than the native formation temperature. This anomaly can often be detected by the TL, providing another method, along with the CSFL, for delineating the location of fluid infiltration into a formation. Also, data from the TL provide temperature values to be used in the selection of appropriate temperature-corrected fluid and formation parameters (such as fluid density and water compressibility) necessary in many calculations.

Radioactive Tracer Log (RATL)

The Radioactive Tracer Log tool "traces" the movement of a radioactive source. This is accomplished by injecting a short-lived, radioactive isotope (usually ^{131}I) from one section of the tool and recording its movement with a detection gamma ray package housed in another section of the tool. As the radioactive isotope decays, it emits gamma rays that are detected by the gamma ray apparatus. It is in this way that the position of the radioactive "slug" can be monitored as it makes its way through the cased and uncased borehole. Thus it is another technique for delineating fluid flow within the injection zone.

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APPENDIX B. REDUCTION AND ANALYSIS OF GEOPHYSICAL LOG DATA

Improved modeling techniques (correction charts) were used to interpret the advanced suite of logs run during phase I and II. Use of these charts generally improved the accuracy of data obtained from the phase I and II logs, compared with logs run during WDW2 construction. Figures B-1, B-2, and B-3 are examples of the correction charts used. By using these modern logging tools and incorporating improved analytical techniques, we were able to determine more accurately the following hydrogeologic data on geologic materials constituting the injection interval: the forma-tion's matrix-corrected CNL porosity ([POR]Ncor), matrix corrected BCS porosity ([POR]BCScor), cross-plotted porosity ([POR]xp), secondary porosity ([POR]sec), true resistivity (Rt), matrix lithology (MA), water saturation (SW), shale volume (Vsh), and qualitative permeability (k). These values, computed at 2-foot intervals throughout the injection zone, are reported in table B-1. The same parameters for geophysical logs run down WDW2 are reported in table B-2.

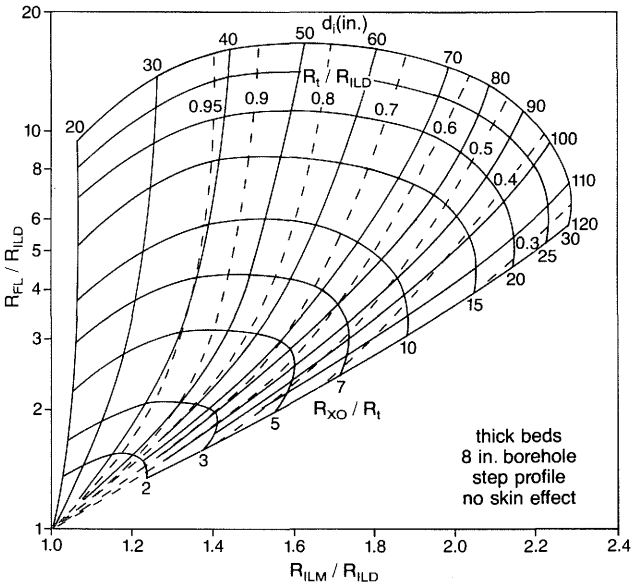

Figure B-1 (left) "Tornado" chart for Dual Induction-Focused Log analysis (Dresser Atlas 1981).

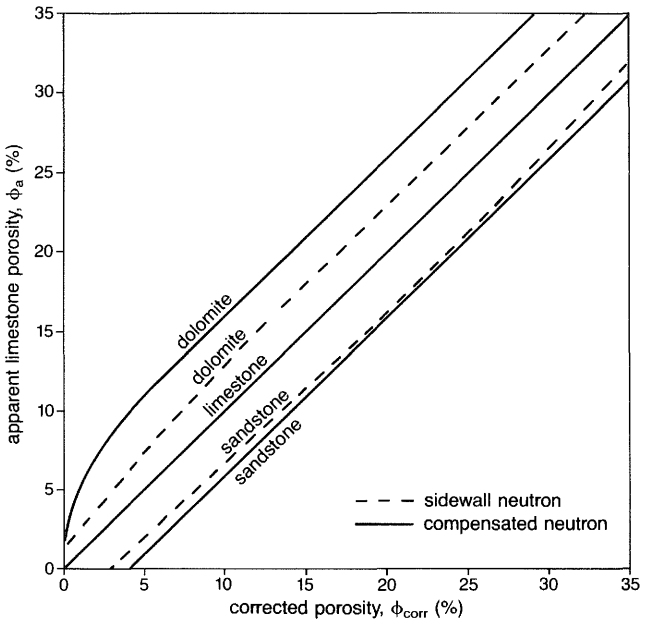

Figure B-2 Neutron porosity lithologic correction chart (Dresser Atlas 1981).

Table B-1 Data from geophysical logs run in the Devonian Observation Well

Depth GL (ft)	GR (API)	(POR) Nls (%)	(POR)[1] Ncor (%)	t (sec)	(POR)[2] BCScor (%)	(POR)[3] xp (%)	(POR)[4] sec (%)	RT[5] (ohm-m)	MA[6]	SW[7] (%)	Vsh[8] (%)	k[9]
2,434	28	4.3	4.3	53	3.8	4.3	0.5	50.0	LS	100	6.2	N
36	40	5.0	5.0	53	3.8	5.0	1.2	65.0	LS	100	15.4	N
38	35	12.0	12.0	60	8.8	10.0	3.2	20.0	LS	100	11.5	N
40	25	18.0	18.0	69	15.1	16.4	2.9	11.0	LS	100	3.8	N
42	30	19.0	19.0	69	15.1	16.7	3.9	7.0	LS	100	7.7	Y
44	25	23.8	23.8	77	20.8	21.7	3.0	5.0	LS	100	3.8	Y
46	22	22.6	22.6	76	20.1	21.1	2.5	4.8	LS	100	1.5	Y
48	23	23.0	17.0	70	18.2	18.2	0.0	7.0	DOL	100	2.3	N
50	30	16.0	10.0	62	12.7	12.0	0.0	10.0	DOL	100	7.7	N
52	30	17.5	11.5	57	9.3	9.7	2.2	16.0	DOL	100	7.7	N

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Table B-1 *continued*

Depth GL (ft)	GR (API)	(POR) Nls (%)	(POR)[1] Ncor (%)	t (sec)	(POR)[2] BCScor (%)	(POR)[3] xp (%)	(POR)[4] sec (%)	RT[5] (ohm-m)	MA[6]	SW[7] (%)	Vsh[8] (%)	k[9]
54	22	19.0	13.0	60	11.3	11.7	1.7	13.0	DOL	100	1.5	N
56	17	22.0	16.0	62	12.7	13.3	3.3	9.0	DOL	100	0.0	N
58	20	20.6	14.6	63	13.4	13.6	1.2	10.0	DOL	100	0.0	N
60	28	21.8	15.8	61	12.0	12.7	3.8	9.0	DOL	100	6.2	N
62	27	24.6	18.6	65	14.8	15.6	3.8	7.0	DOL	100	5.4	Y
64	32	24.0	18.0	66	15.5	16.0	2.5	5.5	DOL	100	9.2	Y
66	22	25.5	19.5	70	18.2	18.5	1.3	4.8	DOL	100	1.5	Y
68	23	28.5	22.5	78	23.7	23.5	0.0	4.0	DOL	100	2.3	Y
70	17	29.2	23.2	82	26.5	26.0	0.0	3.3	DOL	100	0.0	Y
72	18	28.0	28.0	82	24.3	25.7	3.7	3.0	LS	100	0.0	Y
74	17	30.0	30.0	87	27.9	28.8	2.1	3.2	LS	100	0.0	Y
76	17	28.0	28.0	83	25.0	26.3	3.0	3.5	LS	100	0.0	Y
78	19	26.8	20.8	78	23.7	23.2	0.0	3.9	DOL	100	0.0	Y
80	17	26.3	20.3	77	23.0	22.6	0.0	4.4	DOL	100	0.0	Y
82	20	29.0	23.0	74	21.0	21.4	2.0	4.0	DOL	100	0.0	Y
84	24	23.5	17.5	71	18.9	18.5	0.0	4.6	DOL	100	3.1	Y
86	26	21.3	15.3	63	13.4	13.7	1.9	7.1	DOL	100	4.6	N
88	23	22.3	16.3	64	14.1	14.5	2.2	10.0	DOL	100	2.3	N
90	23	16.5	10.5	60	11.3	11.1	0.0	11.0	DOL	100	2.3	N
92	30	16.4	10.4	56	8.6	8.9	1.8	16.0	DOL	100	7.7	N
94	29	19.8	13.8	57	9.3	10.2	4.5	21.0	DOL	100	6.9	N
96	60	19.0	13.0	60	11.3	11.6	1.7	20.0	DOL	100	30.8	N
98	84	18.5	12.5	60	11.3	11.5	1.2	15.0	DOL	100	49.2	N
50	52	19.3	13.3	62	12.7	12.7	0.6	14.0	DOL	100	24.6	N
2	37	18.2	12.2	57	9.3	9.8	2.9	14.0	DOL	100	13.1	N
4	33	22.0	16.0	59	10.7	11.8	5.3	11.0	DOL	100	10.0	N
6	45	23.0	17.0	64	14.1	15.1	2.9	8.0	DOL	100	19.2	N
8	30	19.8	13.8	60	11.3	12.1	2.5	9.0	DOL	100	7.7	N
10	23	20.0	14.0	58	10.0	11.3	4.0	8.5	DOL	100	13.1	N
12	20	22.8	16.8	60	11.3	13.2	5.5	8.2	DOL	100	0.0	N
14	32	20.7	14.7	64	14.1	14.4	0.6	9.0	DOL	100	9.2	N
16	30	20.1	14.1	60	11.3	12.4	2.8	10.5	DOL	100	7.7	N
18	42	20.8	14.8	62	12.7	13.6	2.1	8.5	DOL	100	16.9	N
20	38	19.0	13.0	60	11.3	12.1	1.7	10.0	DOL	100	13.8	N
22	30	20.3	14.3	56	8.6	10.4	5.7	11.0	DOL	100	15.4	N
24	23	21.7	15.7	61	12.0	13.3	3.7	10.0	DOL	100	2.3	N
26	24	20.0	14.0	60	11.3	12.2	2.7	8.0	DOL	100	3.1	N
28	23	16.0	10.0	57	9.3	9.7	0.7	9.0	DOL	100	2.3	N
30	23	19.0	13.0	61	12.0	12.5	1.0	10.0	DOL	100	2.3	N
32	21	20.4	14.4	63	13.4	13.8	1.0	12.0	DOL	100	0.8	Y
2,534	33	22.5	16.5	60	11.3	12.2	5.2	10.0	DOL	100	10.0	Y
36	27	22.0	16.0	63	13.4	13.9	2.6	7.5	DOL	100	5.4	Y
38	28	24.3	18.3	65	14.8	15.5	3.5	6.5	DOL	100	6.2	Y
40	29	24.0	18.0	63	13.4	14.2	4.6	5.8	DOL	100	6.9	Y
42	35	17.3	11.3	61	12.0	11.8	0.0	7.1	DOL	100	11.5	N
44	40	16.5	10.5	59	10.7	10.6	0.0	9.0	DOL	100	15.4	N
46	42	21.3	15.3	63	13.4	13.7	1.9	8.5	DOL	100	16.9	Y
48	40	22.5	16.5	70	18.2	17.7	0.0	6.7	DOL	100	15.4	Y
50	40	20.6	14.6	66	15.5	15.1	0.0	6.7	DOL	100	15.4	Y
52	38	15.6	15.6	65	12.3	13.3	3.3	10.0	LS	100	13.8	N
54	29	8.6	8.6	57	6.6	7.4	2.0	20.0	LS	100	6.9	N

Notes for table B-1

1. Matrix corrected using figure B-2.
2. Matrix corrected using (POR)BCScor = (tlog - tma)/(tf1 - tma) x 1/Cp,
   where tma = 47.6×10^{-6} sec/ft for limestone
   tma = 43.5×10^{-6} sec/ft for dolomite
   tf1 = 189×10^{-6} sec/ft
   tlog = transit time from log
   tma = transit time of the matrix
   Cp = constant for shale correction
   assume Cp = 1, since no shale correction is needed
3. See figure B-3
4. (POR)sec = (POR)Ncor - (POR)BCScor
5. Since Rilm and Rild are approximately equal, a correction for invasion was not necessary; see figure B-1
6. Taken from (POR)N versus t crossplot, figure B-3
7. Using SW^2 = Ro/Rt = FRw/Rt = Rw/$(por)^2$Rt = Rw/(por)xp^2Rt, from this, all zones were 100% water saturated.
8. Using Vsh = (GRlog - GRc1)/(GRsh - GRc1),
   where GRlog = GR reading taken off log.
   GRcl = GR reading from the zone with the lowest GR (10 @ 2,474 ft).
   GRsh = GR reading from nearest shale zone (140 @ 2,242 ft).
9. Based on interpretation of MIL, Y denotes zone interpreted as having "significant" permeability. N denotes zone interpreted as not having "significant" permeability. MIL response is adversely affected by unevenness of borehole. A 4-arm caliper run indicated a very even borehole: 6.3-inch diameter from 2,424 to 2,524 ft, 6.2-inch diameter from 2,525 to 2,556 ft, and 5.8-inch diameter from 2,557 to 2,560 ft.

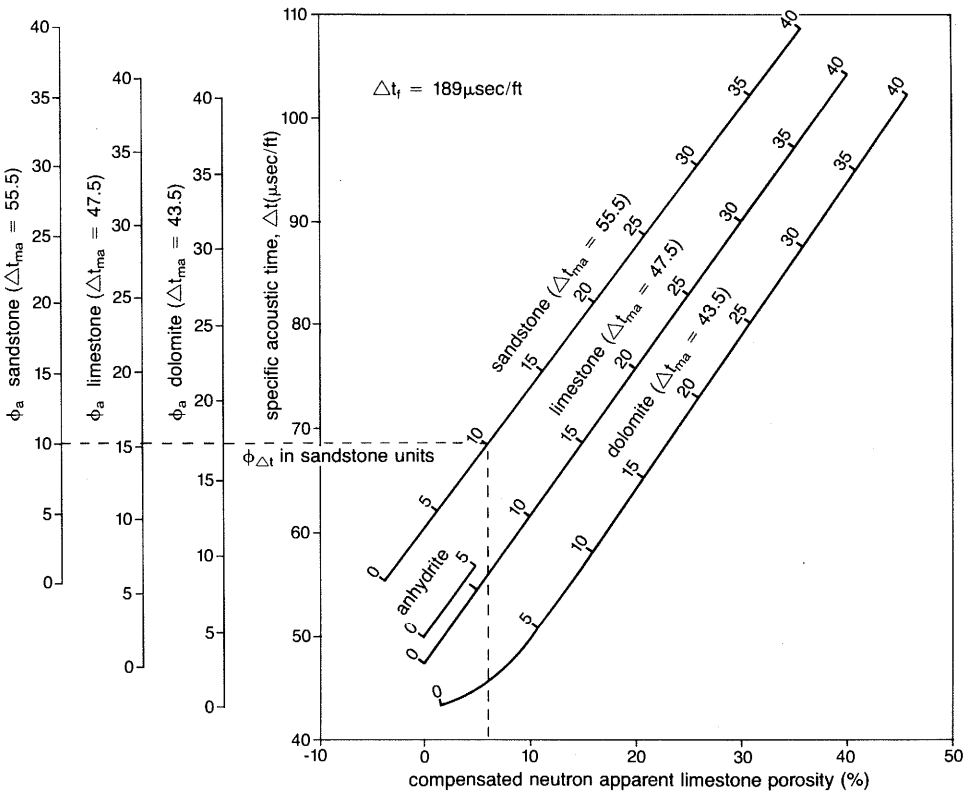

Figure B-3 Compensated Neutron Log and Borehole Compensated Acoustilog porosity crossplot (Dresser Atlas 1983).

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Table B-2* Data from existing geophysical logs run in WDW2**

DEPTH GL (ft)	GR (API)	(POR) Nls (%)	(POR) Ncor (%)	t (sec)	(POR) BCScor (%)	(POR) xp (%)	(POR) sec (%)	RT (ohm-m)	MA	SW (%)	Vsh (%)	k
2582	26	8.1	8.1	63	10.9	10.1	0.0	30.0	LS	90	4.6	N
84	30	10.0	10.0	66	13.0	12.2	0.0	28.0	LS	77	7.7	N
86	34	15.0	15.0	71	16.5	16.3	0.0	17.0	LS	74	10.8	N
88	38	14.7	14.7	73	18.0	17.1	0.0	13.0	LW	81	13.8	Y
90	37	13.5	13.5	73	18.0	16.9	0.0	13.0	LS	82	13.1	Y
92	26	7.8	11.1	68	8.8	10.0	2.3	20.0	SS	100	4.6	Y
94	29	6.1	9.3	65	7.1	8.2	2.2	38.0	SS	98	6.9	N

* For explanation of column headings, see table B-1.

** All logs used for study were run during well installation, and all were from WDW2 except the sonic log (SL), which was from WDW1. Analysis methods used were those described in table B-1. All depths measured are from Kelly Bushing (KB), which is 12 ft above ground level.

A brief discussion of the computation of the correction factors and assumptions used to analyze the logging data follows. The analysis focused on data from intervals with higher relative permeabilities (as displayed by the Minilog and higher porosities from the CNL). These zones were 2,440 to 2,506 ft GL, 2,532 to 2,552 ft GL, and 2,572 to 2,582 ft GL as logged in DOW.

From figure B-4:

m = 1.54 or 1.76; this value is in close agreement with an assumed value of m = 2 for limestone (Ls) and dolomite (Dol).

From Minilog:

Rm = 0.30 ohm-m

Therefore, from figure B-5,

Rmf = 0.23 ohm-m and

Rmc= 0.41 ohm-m

From temperature log on WDW2,

Temperature @ 2,460 ft = 75.6° F.

Determine Rw:

Using Archie's Equation:

$F = a/(por)^2 = Ro/Rw$ and

$SW^n = Ro/Rt$

where F = formation factor

Ro= true resistivity of the formation at 100% water saturation (when SW = 100%)

n = saturation exponent

a = constant

For limestone and dolomite,

Assume a = 1, m = n = 2

Therefore,

$F = 1/(por)^2$

$SW^2 = Ro/Rt$

@ 2473 ft assume SW = 100%

$SW^2 = Ro/Rt$

Ro = Rt

Assume Rt = Rildcorr

Correct Rild for invasion, figure B-1
Rildcorr = 3 ohm-m
Rt = 3 ohm-m
Ro = 3 ohm-m
Ro = F x Rw = Rw/(por)^2
Rw = Ro x (por)^2
Porosity is needed; assume por = porxp of Sonic vs CNS
porxp = 28.7%

Therefore,

Rw = 0.247 ohm-m

These factors were used to analyze the logging data reported in tables B-1 and B-2. Important hydrogeologic parameters of the injection zones are summarized in table B-3.

Table B-3 Summary of important formation characteristics

(POR)xp,ave = 16%	(POR)xp,max = 28.8%	(POR)xp,min = 8.9%
(POR)sec,ave = 1.98%	(POR)sec,max = 5.7%	
tave = 66.7x10^{-6} sec/ft		
tmax = 87x10^{-6} sec/ft		
tmin = 56x10^{-6} sec/ft		
Rt,ave = 8.6 ohm-m	Rt,max = 21 ohm-m	Rt,min = 3 ohm-m
Vsh,ave = 8.05%	Vsh,max = 49.2%	Vsh,min = 0.0%

Formation lithology (based on 98 ft of "higher permeability, higher porosity" zone), 61.0% dolomite, 35.0% limestone, and 4.0% sandstone.

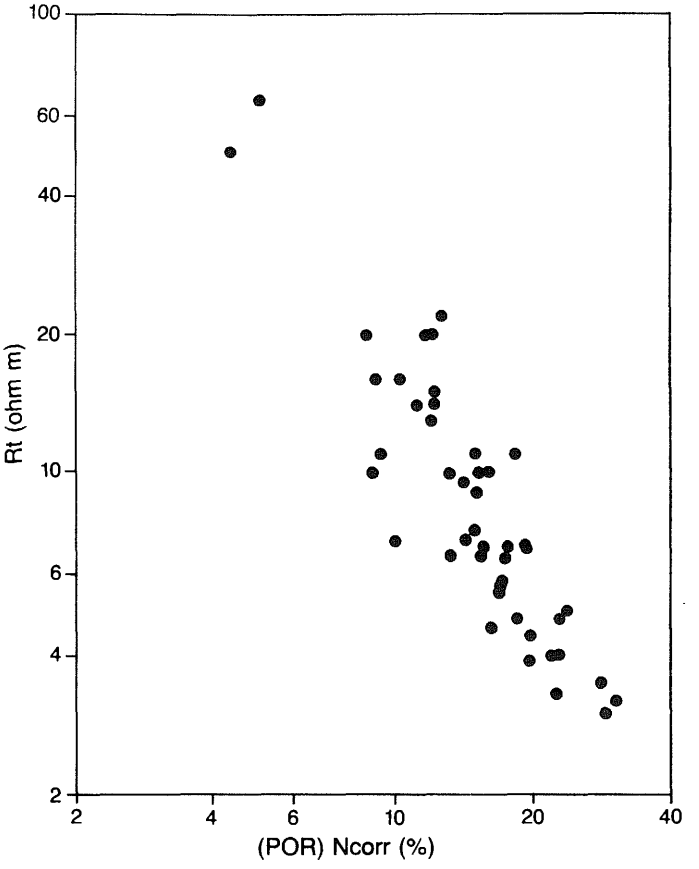

Figure B-4 Determination of the cementation factor.

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After reviewing the data, we concluded that the host formation, the Bailey Limestone, is composed mainly of a clean dolomite with less than 20 percent shale throughout most of the interval logged. Since the Bailey Limestone is predominantly a dolomite, secondary porosity is always a consideration. A comparison of CNL and BCSL data suggests that secondary porosity may account for up to 10 percent of the total porosity. The intervals with higher relative permeability have a slightly higher secondary porosity and therefore a higher total porosity.

The entire interval is primarily 100 percent water saturated and has a fluid resistance of approximately 0.247 ohm-m. At a formation temperature of about 80°F and depth of 2,460 feet GL, the fluid composition is estimated to be approximately 24,000 ppm NaCl (fig. B-6).

As stated in chapter 3, one use of the core data was to verify data obtained from the geophysical logs. Figure B-7 shows good agreement between the two methods for porosity data. Figure B-8 indicates a close correlation between the two methods for true formation resistivity values (Rt); this correlation becomes more apparent when the equation used to derive water saturation (Sw) is reviewed,

$$S_w^2 = \frac{Rw}{(por) \times \frac{2}{p}} \quad (1/R_t)$$

S_w is shown to be indirectly proportional to the square root of R_t.

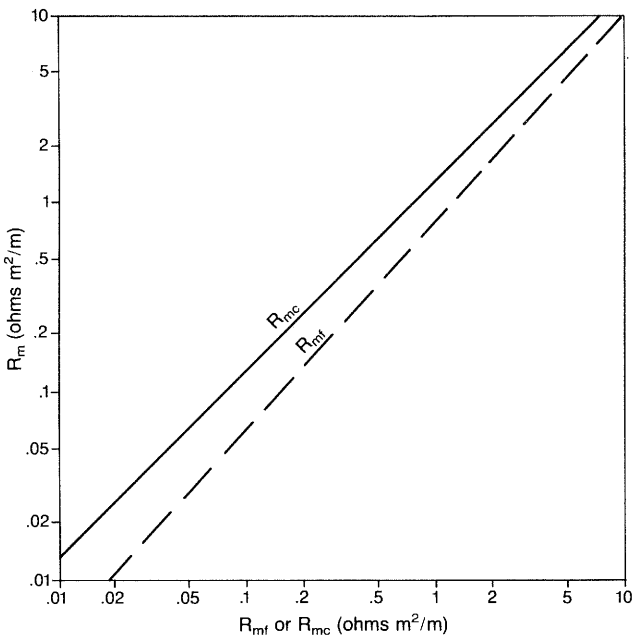

Figure B-5 Rm-Rmf-Rmc relationships (Gearhart).

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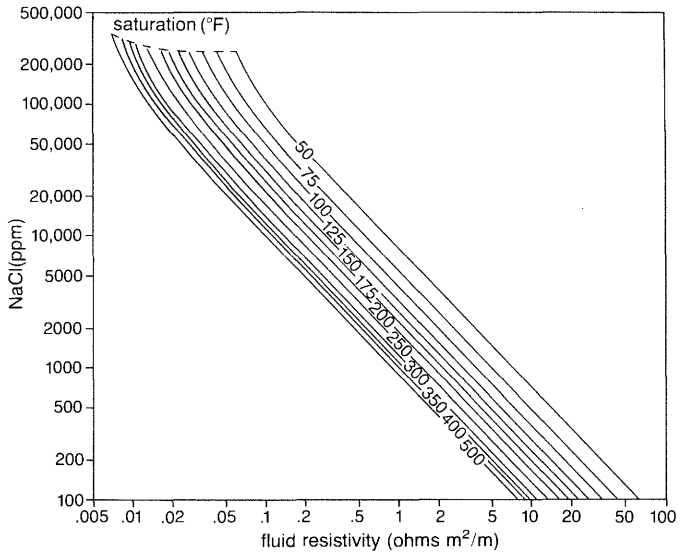

Figure B-6 NaCl concentration for different temperatures and fluid resistivities (Gearhart).

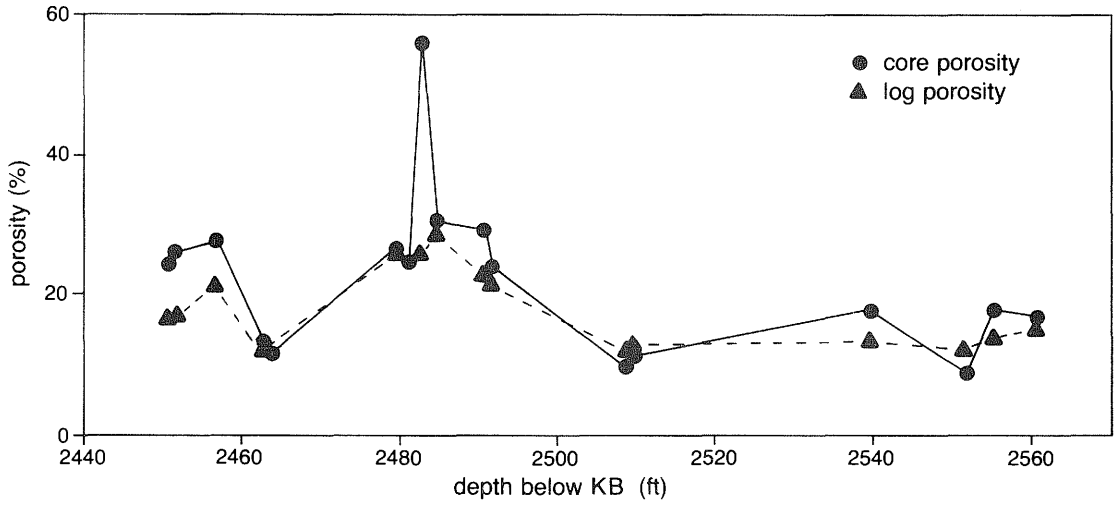

Figure B-7 Core porosity versus log porosity (phase I, cross-plotted porosity) for WDW2.

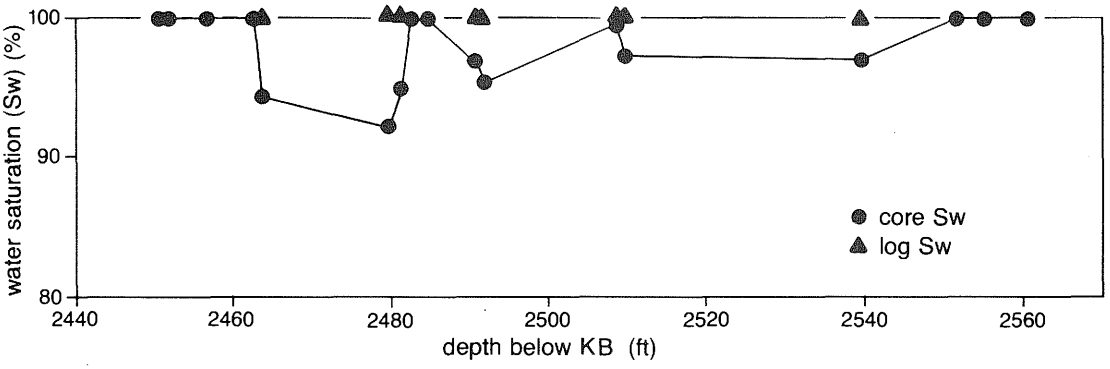

Figure B-8 Core water saturation versus log water saturation for WDW2 at designated depths. Log Sw obtained from phase I logging on the DOW.

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APPENDIX C. BRUCITE FORMATION: PROPOSED MECHANISM OF FORMATION

The hydrogeologic site descriptions developed from phase I and phase II data (see chapter 3) differed from each other significantly; however, the reason for these differences was not readily apparent. To develop a hypothesis to explain the results and increase our understanding of the site hydrogeology, we conducted additional analyses.

Core Analysis

Analysis of sidewall core obtained during phase II was critical to the development of a hypothesis to explain the discrepancies described in chapter 3. Our core analysis included hydraulic testing, mineralogic analysis, and scanning electron microscope (SEM) investigation.

Hydraulic Testing

Hydraulic testing provided no hard evidence to resolve the discrepancies between phase I and phase II data. Injection zones 1, 2, and 3 (fig. C-1) had abnormally high porosities and permeabilities, but core analysis data did not agree with the results from the CSFL. First, the zone from 2,468 to 2,496 feet KB showed some injection potential. Core analysis indicated that at least some portions of this zone (e.g., 2,481.0 ft KB) were not permeable enough to allow fluid flow; however, most of this zone appeared to have sufficient permeability. Second, the core from 2539.5 feet KB seemed to have sufficient porosity and permeability to allow fluid flow, but the CSFL did not show any flow at this location. On the basis of CSFL results, zone 3 should have had the highest porosity and permeability, zone 2 the next highest, and zone 1 the lowest; however, core analysis indicated just the opposite. Therefore, the same discrepancies were encountered with core analysis as with geophysical logging.

Mineralogic Analysis

Cores were also analyzed for their mineralogical content. Brucite was found in the anomalous zones, and its presence was confirmed by x-ray diffraction (XRD) analysis. Brucite was not expected to be present in the injection system environment of WDW2. Brucite is normally found in veins in serpentine and basic rocks and as flakes scattered through some marbles (Pough 1953). Roy et al. (1989) analyzed a sample of the native formation brine taken from the DOW. The sample was vastly undersaturated with respect to brucite, $Mg(OH)_2$. The ion activity product of Mg^{2+} and OH^- (brucite) in the sample was 3 percent of that predicted by the solubility of brucite determined by thermodynamic modeling (Roy 1987).

Mineralogical analysis conducted on a few representative samples of the original well cuttings collected during the drilling of WDW2 indicated that none of these samples contained brucite. Downhole geophysical data (table 2) also confirmed the absence of brucite and indicated that prior to injection, the disposal horizon was predominantly dolomitic.

Apparently the injected waste, which consisted of a number of organics in a very alkaline (pH>12), brinelike solution, created an environment in the injection system that promoted the formation of brucite. Although the waste had a component of Mg^{2+}, dolomite (from injection zone rock) was the most likely source of Mg^{2+} for two reasons. First, an increase in the brucite concentration accompanied a corresponding decrease in the dolomite concentration (fig. C-2). Second, the porosity throughout the injection zone subsequent to brucite precipitation should have been lower than the original (pre-injection) porosity if the brine was the source of the Mg^{2+}. Data from log analysis did not indicate a decrease in porosity. Therefore, on the basis of available data, the most plausible hypothesis is that dissolution of dolomite from injection zone rock released magnesium, which then combined with the OH^- in the waste stream to form brucite.

If this hypothesis is correct, the zones that originally had the highest porosities and permeabilities would accept the greatest volume of waste fluid and thus would show the highest brucite con-

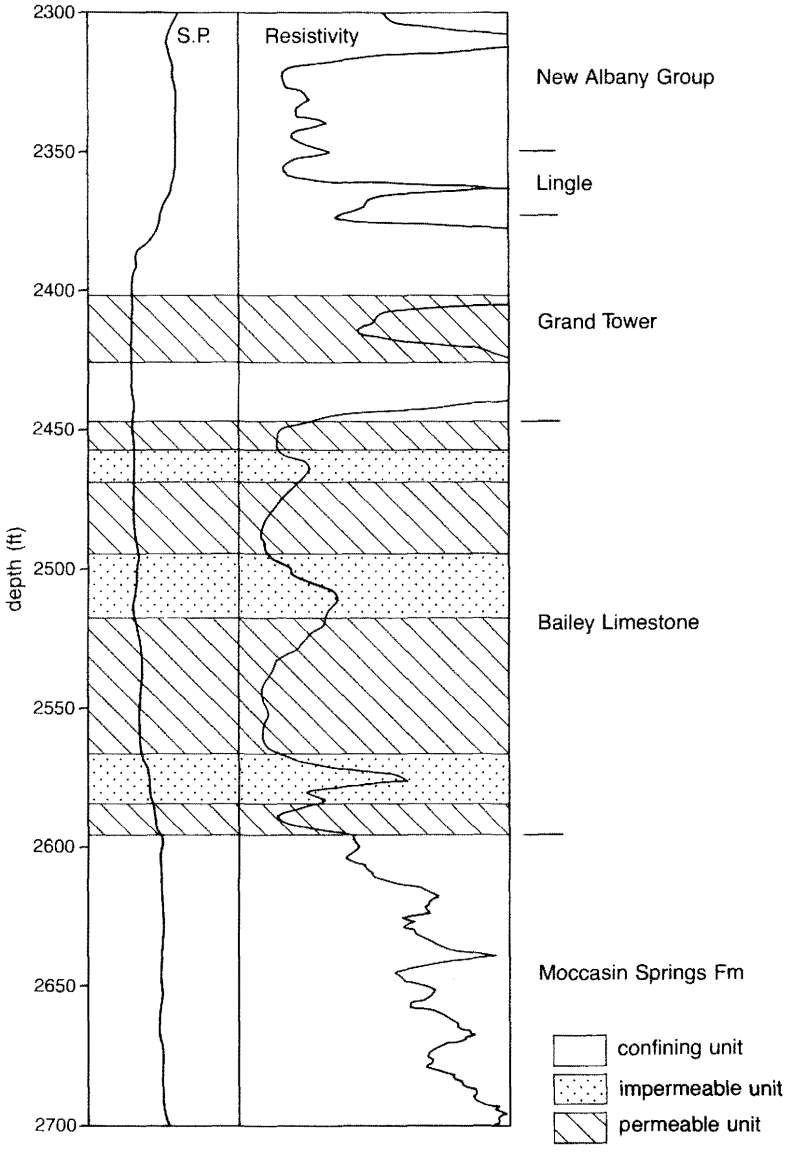

Figure C1 Injection system in WDW2 indicating permeable and nonpermeable zones delineated with the aid of geophysical logging.

centrations. Table C-1 gives porosity and brucite percentages for the cored intervals. For comparison, the Sidewall Neutron Log run during well construction was used to obtain original porosity data. Five intervals were identified and ranked on the basis of porosity characteristics. Zones with higher average porosity were given a higher porosity ranking.

Table C-2 shows the five highest ranked zones with their corresponding average brucite concentrations, air permeabilities (ka), and percentages of total flow (from the CSFL). These data indicate that the presence of brucite has a profound effect on fluid movement. However, laboratory permeability values for zones with higher brucite concentrations were greater than the values for zones with lower brucite concentrations, and laboratory porosity values for zones with higher brucite concentrations were similar to the pre-injection porosities.

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In an attempt to explain this finding, we reviewed the analytical procedure used to determine permeability. Laboratory permeabilities were performed on dried samples. If the cations (Na+) that may have been lodged between the brucite layers were lost during drying, a volume reduction in brucite would occur. Therefore, in samples with high brucite concentrations, abnormally high permeability measurements could be encountered, and the cores at 2,479.5, 2,481.0, 2,490.5, 2,491.5, 2,439.5, and 2,560.5 ft KB should have higher permeabilities than expected. These depths corresponded to the zones in which discrepancies were noted between core and CSFL analysis. The anomalously high core permeabilities appeared to be the result of a volume reduction of the brucite upon drying.

Table C-1 Core porosities and brucite concentrations

Depth (KB) (ft)	Original porosity (%)	Porosity ranking	Brucite (wt %)
2450.5	23	3	9
2451.5	25	3	21
2456.5	24	3	0
2462.5	17	-	18
2463.5	19	-	22
2479.5	30+	1	45
2481	30+	1	45
2484.5	30+	1	12
2490.5	30+	1	39
2491.5	30	1	31
2508.5	18	-	26
2509.5	19	-	35
2539.5	27	2	41
2551.5	20	2	38
2555	24	4	7
2556.5	28	2	45
2560.5	28	2	45
2572.5	4	-	2
2573.5	5	-	0
2588.5	15	5	0
2605	6	-	0
2606	6	-	0

Table C-2 Effect of brucite concentration on total flow

Porosity ranking	Brucite (wt %)	Ave ka (md)	Total Flow (vol %)
1	40	1	0
2	42.3	0.1	0
3	10	0.6	14
4	7	0.06	36
5	0	0.02	50

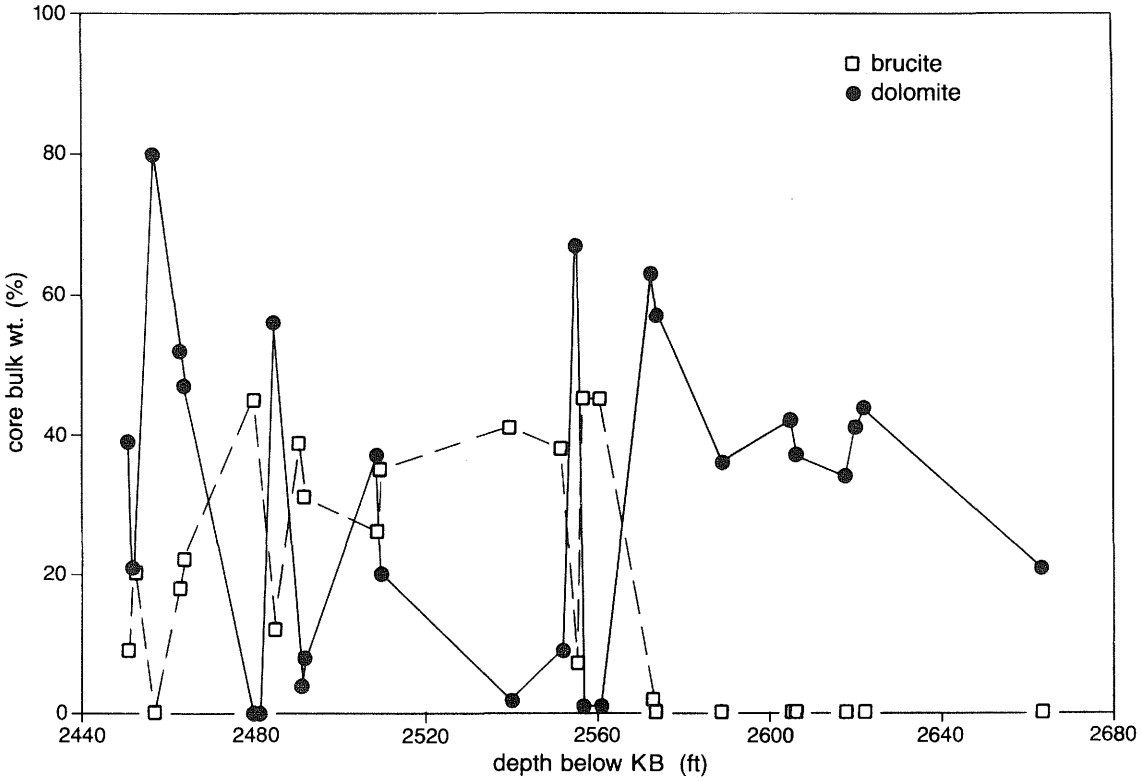

Figure C-2 Core composition: dolomite and brucite in WDW2.

On the basis of available data, this explanation appeared to be reasonable, but two problems with the results remained unresolved: (1) the cores at 2,462.5, 2,463.5, 2,508.5, and 2,509.5 ft KB showed slightly higher than expected brucite concentrations (approximately 25% brucite), and (2) the core at 2,484.5 ft KB had an extremely high core permeability (ka = 14.97 md) but a relatively low concentration of brucite (12%). Scanning Electron Microscope (SEM) analysis was performed on selected core samples in an attempt to resolve these discrepancies, gain additional information on the factors affecting fluid flow, and confirm some of the assumptions inherent in the previous discussion.

SEM Analysis

Eight cores chosen for analysis represented the three injection zones and the major areas where anomalous results were encountered by various analytical procedures (e.g., core analysis, CSFL, and standard geophysical logging). Generally, two magnifications were used per sample: approximately 100x to show the general porosity type and any large-scale features such as fracturing, and 1,000x to show the pore geometry and other small-scale features. Although a detailed discussion of SEM analysis results is beyond the scope of this project, a few generalizations can be made to help resolve the discrepancies noted.

SEM analysis was performed on dried samples; therefore, the effect of cation adsorption into the crystal lattice of brucite was assumed to be unrecognizable.

Data from historical and phase I logging indicated that the core at 2,484.5 ft KB should have had a high injection potential. When the CSFL indicated a lack of fluid flow into this zone, we reasoned—on the basis of core analysis—that the lack of flow into this zone could have been due to the presence of brucite in the sample. However, only 12 percent brucite was found in this core,

compared with an average of 40 percent in the other adjacent samples. Another explanation for the lack of flow was obviously needed. Figures C-3 and C-4 indicate that the predominant type of porosity in this sample is fracture porosity. Figure C-3 shows that the fracturing is discontinuous on a large scale. Figure C-4 is a close-up of the fracture depicted in figure C-3. The platy material on the fracture walls was interpreted to be brucite.

Another sample selected was the core at 2,479.5 feet KB, which is from the same zone as the previous sample. No fractures can be seen in figures C-5 and C-6, and the crystals and matrix of the sample are coated. Core analysis indicated that this sample was 45 percent brucite, so this coating was assumed to be brucite. With such a widespread occurrence of brucite, the decrease in permeability seems reasonable.

A sample from the uppermost injection zone (2,456.5 ft KB) (figs. C-7 and C-8) is free of the coating present in the previous samples. Core analysis indicated that this sample had no brucite, which agrees with SEM analysis and the supposition that brucite has not affected fluid flow in the uppermost injection zone.

The hypothesis used to resolve the brucite formation explains the available data and was confirmed to some extent by SEM analysis. But to evaluate this hypothesis more fully, additional work beyond the scope of this project is necessary.

Additional Research

To support the hypothesis developed regarding brucite formation, the following work should be done. A hydrogeochemical investigation of the Velsicol waste stream and the Devonian limestone, similar to that of Roy et al. (1989), should be conducted. Core from the DOW could be used in this type of investigation. This type of work would help define the conditions favorable for brucite formation.

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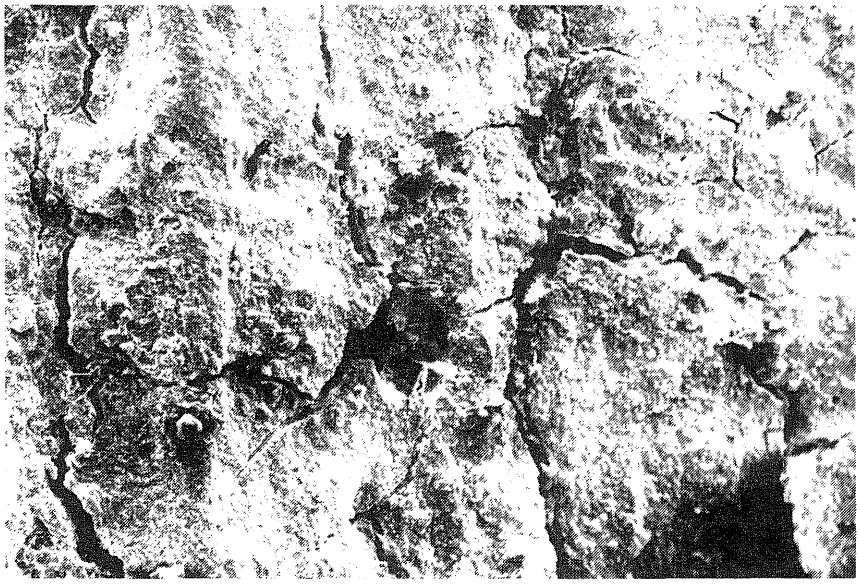

Figure C-3 SEM photograph of core at 2,484.5 feet KB (x58.5).

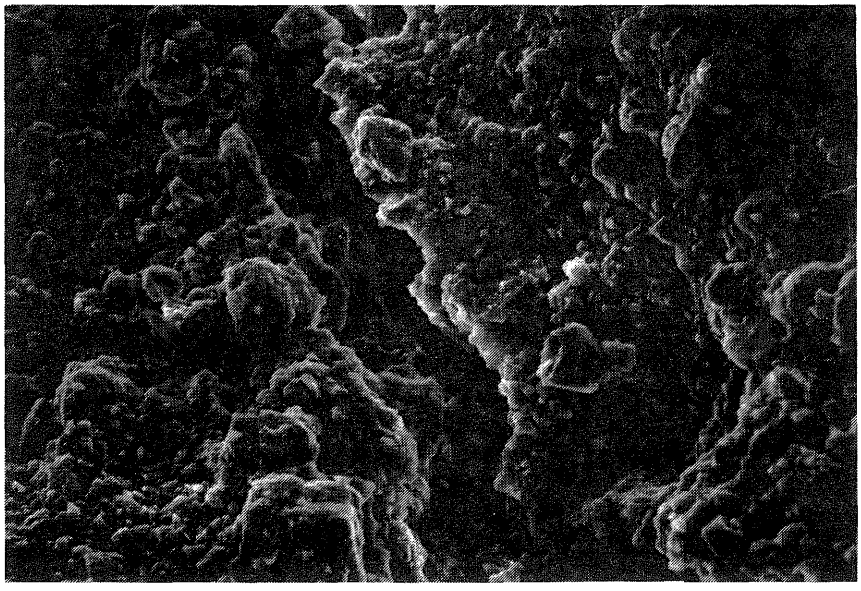

Figure C-4 SEM photograph of core at 2,484.5 ft KB (x 1,050).

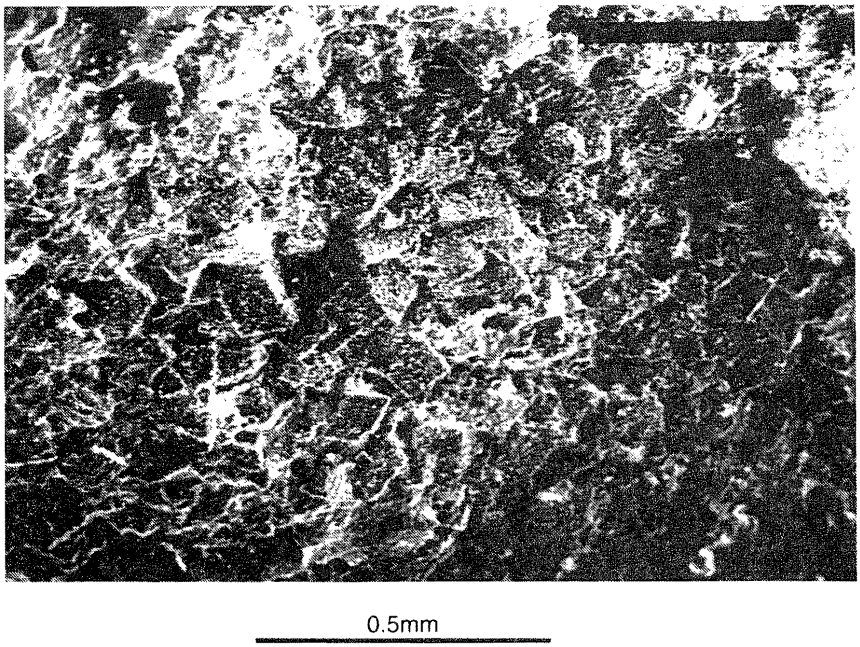

Figure C-5 SEM photograph of core at 2,479.5 KB (x80).

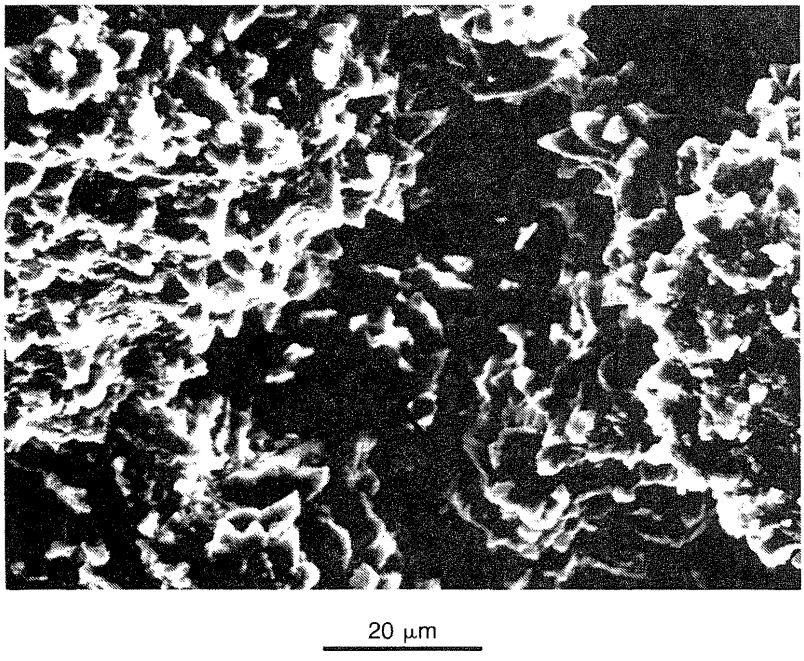

Figure C-6 SEM photograph of core at 2,479.5 KB (x1,080).

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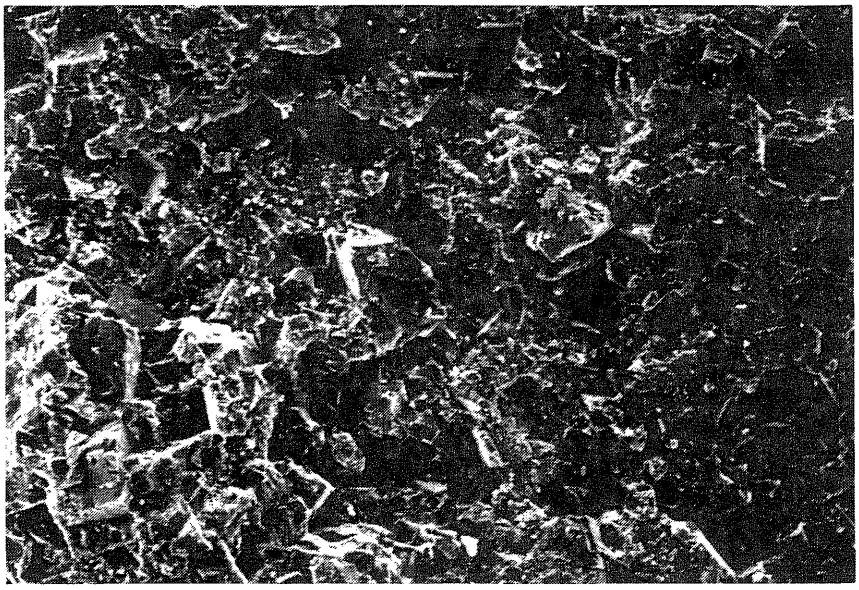

Figure C-7 SEM photograph of core at 2,456.5 KB (x113).



Figure C-8 SEM photograph of core at 2,456.5 feet KB (x1,160).

APPENDIX D. SENSITIVITY ANALYSIS

A rigorous sensitivity analysis as described by Yeh (1986) was not conducted. The sensitivity analysis conducted for this project involves the variation of significant parameters and the effect of this variation on head buildup (Δh) at the DOW, the parameter of interest. The significance of various parameters (injection rate, hydraulic conductivity, etc.) was observed during the validation and calibration stages of modeling. On the basis of these observations, sensitivity analysis was conducted for the following parameters: boundary conditions, injection rate, rock compressibility, fluid compressibility, hydraulic conductivity, and anisotropy.

Throughout this phase of the project, the same conceptual model as depicted in figure D-1 was used unless otherwise noted. The injection system was modeled using cylindrical coordinates with 60 nodes in the r-direction and 22 nodes in the z-direction. A no-flow boundary condition was applied at the upper and lower boundaries, while an aquifer influence function (AIF) condition was applied at the radial boundary.

Boundary Conditions

Boundary conditions (BC) are the most difficult and critical issue in the development of a conceptual model for a numerical modeling study and must be selected carefully (Franke and Reilly 1987). In all cases, the upper and lower boundaries were modeled as no-flow boundaries.

The type and distance of the radial boundary from the injection well were varied. For the purposes of comparison, VELS14I was considered the baseline run. Five other runs were made in order to note the effect of the boundary condition on head buildup at various locations within the injection system. Table D-1 summarizes the types of boundary conditions and results.

The results of VELS14G2 indicate that the no-flow boundary condition did not cause an increase in head buildup at the DOW during the 14-day period investigated, but a slight increase in Δh occurred at the radial boundary. For VELS14H, the radial boundary is located farther from the injection well than in VELS14G2; no Δh was observed at the radial boundary. These two runs and the other runs of the VELS14 series show that the radial boundary exerted no real influence on the head buildup at the DOW ($r = 505.95$ m) during the time period investigated.

VELS14I and VELS14I2 indicate the effect of the intrinsic permeability of the aquifer influence region (k_{AIF}). A reduction in k_{AIF} may increase the Δh observed at the radial boundary. Although

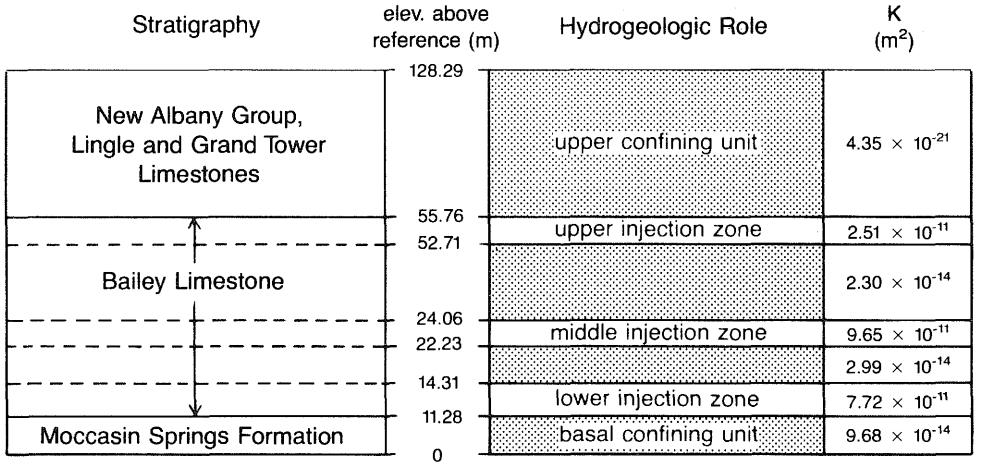

Figure D-1 Conceptual model 1 of the injection system.

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Table D-1 Effect of boundary conditions on head buildup

Run	No. of r-nodes	Radius (m)	Type[1] of BC	k_{AIF}[2] (m^2)	Δh @ DOW[3] (m)	Δh @ radial boundary (m)
VELS14I	60	15870.9	AIF	1.00×10^{-11}	1.28	0.01 t = 14.0 days
VELS14G2	60	15870.9	NF	—	1.28	0.02 t = 7.16 days
VELS14H	60	35703.0	NF	—	1.28	0.00 t < 14.0 days
VELS14I2	60	15870.9	AIF	1.00×10^{-12}	1.28	0.02 t = 14.0 days
VELS18H2	60	15870.9	AIF	1.00×10^{-11}	1.25	—
VELS18J	50	2090.8	AIF	1.00×10^{-11}	0.75	—

Notes: (1) AIF = aquifer influence boundary condition; NF = no-flow boundary condition; (2) k_{AIF} = intrinsic permeability of aquifer influence region; (3) all values given at t = 14.00 days.

not shown in Table D-1, if k_{AIF} were reduced, the cumulative fluid outflow via the AIF boundary also would be reduced. In this case, the cumulative fluid outflow across the radial boundary, in terms of the total volume of fluid injected, was reduced from 3.0 percent (VELS14I) to 0.69 percent (VELS14I2) when k_{AIF} was reduced one order of magnitude.

Over longer periods, the radial boundary would certainly influence the head buildup at the DOW. Thus the use of an AIF BC appeared to be a better choice for the radial boundary, especially when the model is used as a tool to predict long-term (30-year) effects of injection upon the system. In addition, the regional hydrogeologic investigation covered a 10-mile (16,000-m) radius from the well; thus use of a radius larger than 10 miles was considered speculative.

Two runs from the VELS18 series are included to show the effect of the position of the AIF BC. The conceptual model for the VELS18 series is more complex than the VELS14 series and includes a thicker sequence of geologic materials (fig. D-2). The results from VELS18H2 are in agreement with VELS14I, allowing for a slightly lower head buildup for VELS18H2 due to the greater thickness of compressible geologic materials. For VELS18J, distance to the radial

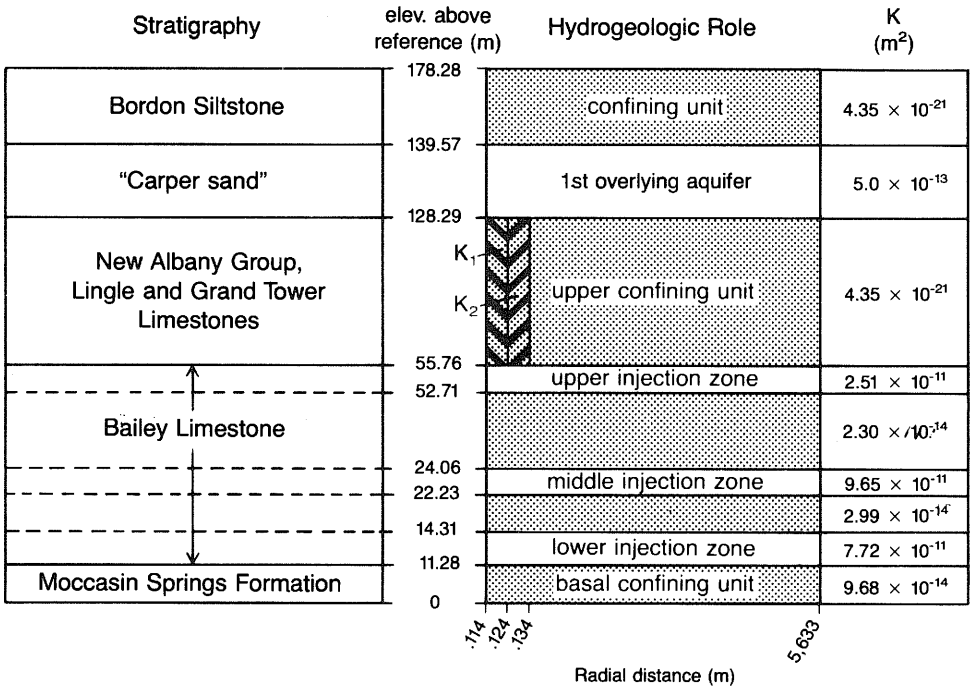

Figure D-2 Conceptual model 2 of the injection system.

boundary was much closer than for VELS18H2. In addition, the head buildup at the DOW was much lower, although k_{AIF} is the same for both runs. For both VELS18H2 and VELS18J, the AIF zone is more transmissive than the inner discretized zone; therefore, decreasing the radial distance of this zone from the injection well allows fluid to move more readily and with less head buildup. The results of VELS18H2 and VELS18J indicate the effect of the location of the boundary and the need to properly define the intrinsic permeability of the aquifer influence region.

Injection Rate

Three runs were made to investigate the effect of the injection rate upon head buildup at the DOW. VELS14I ($q = 1.820 \times 10^{-2}$ m^3/sec) is the baseline run. For VELS15A, the injection rate was increased 10 percent, $q_2 = 2.00\ 2 \times 10^{-2}$ m^3/sec. For VELS15B, the injection rate was decreased 10 percent to 1.638×10^{-2} m^3/sec. Figure D-3 shows the Δh at the DOW with time. Increasing the q by 10 percent resulted in a 10.2-percent increase in Δh. The increase in Δh was noticeable after several hours of injection. In a similar fashion, a 10-percent reduction in the injection rate resulted in a 9.4-percent decrease in Δh. This decrease was also noticeable after several hours of injection. Round-off error for the percentage increase/decrease of Δh was responsible for these values not being equal and the deviation of these values from 10 percent as predicted by Darcy's Law.

Rock Compressibility

Storativity may be defined according to the following equation (Lohman 1972).

$$S = n\gamma b(\beta + \alpha/n) \qquad [D\text{-}1]$$

where S = storativity (-)
n = porosity (-)
γ = unit weight of fluid (kg/m^3)
b = aquifer thickness (m)
β = fluid compressibility (Pa^{-1})
α = rock compressibility (Pa^{-1})

Rock compressibility (α) is one of two major components of storativity. For HST3D, Kipp (1987) indicated that it is more convenient to use rock and fluid compressibility than a storativity term, since fluid density (i.e., unit weight) may be variable.

Three runs were used to investigate the effects of rock compressibility. VELS14I was the baseline run with $\alpha = 4.50 \times 10^{-10}$ Pa^{-1}. For VELS15C, rock compressibility was reduced 10 percent to $\alpha = 4.05 \times 10^{-10}$. For VELS15D, α was increased 10 percent, $\alpha = 4.95 \times 10^{-10}$. Figure D-4 shows the results of the runs. Decreasing α by 10 percent resulted in a 1.6-percent increase in Δh at the DOW. Similarly, a 10-percent increase in α resulted in a 1.6-percent decrease in Δh. The increase and decrease in Δh were evident after several hours of injection.

Fluid Compressibility

Fluid compressibility (β) is the other major component of storativity. VELS14I, VELS15G, and VELS15H were used to investigate the effect of varying fluid compressibility on the head buildup at the DOW. For VELS14I, $\beta = 4.00 \times 10^{-10}$ Pa^{-1}. A 10-percent reduction in β was used for VELS15G, $\beta = 3.60 \times 10^{-10}$. For VELS15H, β was increased to $\beta = 4.40 \times 10^{-10}$.

Figure D-5 shows the results from these runs. Decreasing β did not cause any change in Δh. Increasing β produced a negligible change in Δh, which was probably due to round-off error. The lack of sensitivity of Δh to β can easily be explained. Referring back to equation D-1, one can see that S is proportional to the quantity $(\beta + \alpha/n)$. For the situation investigated here, α/n was approximately 8 times larger than β; thus minor changes in β did not affect S and did not affect Δh.

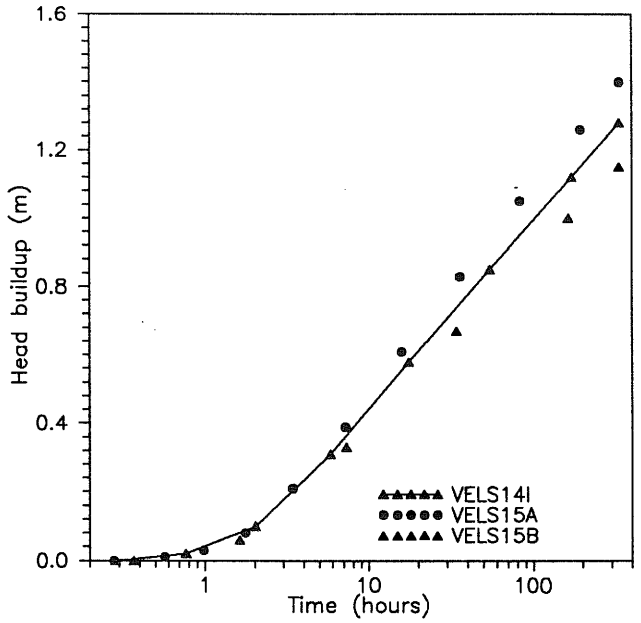

Figure D-3 (left) Sensitivity analysis: effect of injection rate.

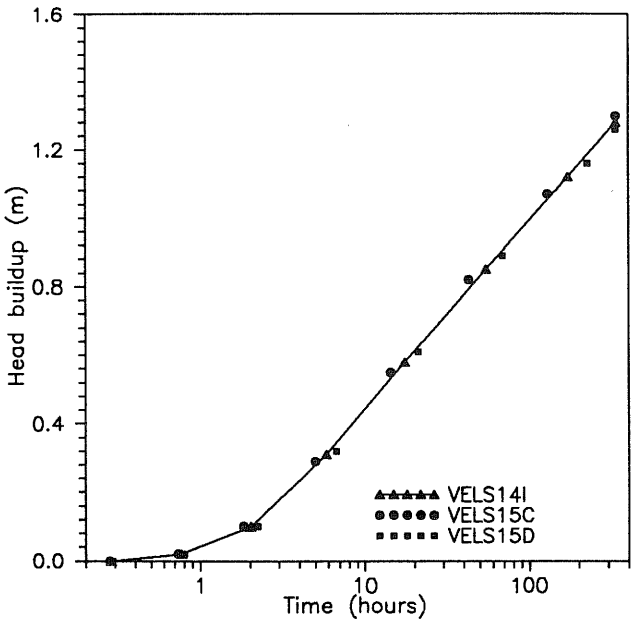

Figure D-4 Sensitivity analysis: effect of rock compressibility.

Hydraulic Conductivity

The results from VELS14I, VELS15I, and VELS15J were used to demonstrate the effect of hydraulic conductivity on Δh. For VELS15I, the hydraulic conductivity of each of the 7 layers was reduced by 10 percent, compared with the hydraulic conductivity values used for VELS14I. Similarly, the hydraulic conductivity values used in VELS15J were all increased by 10 percent.

Figure D-6 shows the results for all runs. As expected, decreasing the hydraulic conductivity resulted in an increase in Δh observed at the DOW. A 10-percent decrease in hydraulic conductivity resulted in a 9.4-percent increase (within round-off error of 10 percent) in Δh at the DOW. Increasing the hydraulic conductivity by 10 percent caused only a 7-percent decrease in Δh at the DOW. The deviation of this value from 10 percent, as predicted by Darcy's Law, is due to the K_{AIF}. The K_{AIF} for VELS15J was not increased from the value used for VELS14I, causing the head build-up within the inner aquifer region to be higher than anticipated.

Anisotropic Conditions

To this point, isotropic conditions have been assumed. On the basis of the hydrogeologic and geophysical tests conducted at the site during the project, it was not possible to establish the predominance of isotropic or anisotropic conditions. Thus, this series of runs was conducted to investigate the effect of this assumption.

Two runs were used to investigate this effect, VELS14I and VELS15K. Isotropic conditions (i.e., $k_r/k_z = 1$) were assumed for VELS14I. For VELS15K, k_z was decreased so that k was 10 times greater in the radial direction than in the vertical direction (i.e. $k_r/k_z = 10$). Figure D-7 indicates that under anisotropic conditions, Δh observed at the DOW was lower by approximately 2 percent than under isotropic conditions. Thus, if the assumption of isotropic conditions is not correct, the hydraulic conductivity of the geologic materials determined during model calibration may need to be reduced by nearly 2 percent.

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Summary of Sensitivity Analysis

On the basis of the preceding sensitivity analysis, injection rate and hydraulic conductivity were the most sensitive input parameters. That is, a given change in injection rate or hydraulic conductivity produced the largest change in Δh observed at the DOW. The type of boundary condition and the location of the boundary can also have a significant effect on the head buildup predicted by the model. In decreasing order, the most sensitive parameters were injection rate and hydraulic conductivity, rock compressibility, anisotropy, and fluid compressibility.

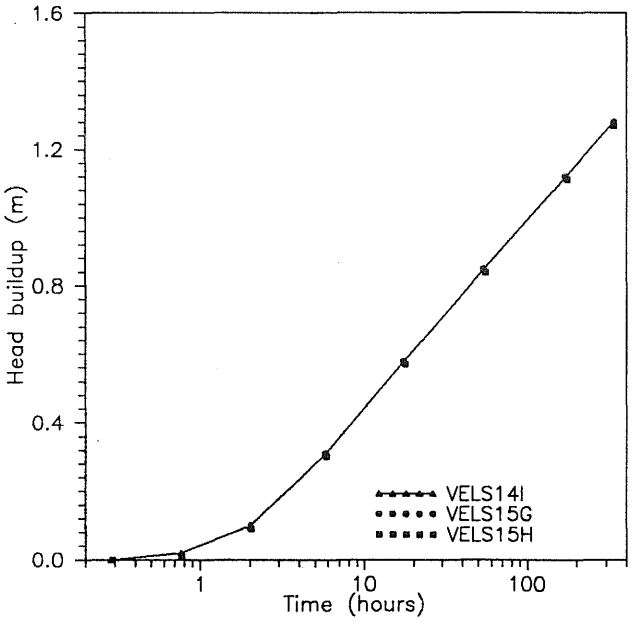

Figure D-5 (left) Sensitivity analysis: effect of fluid compressibility.

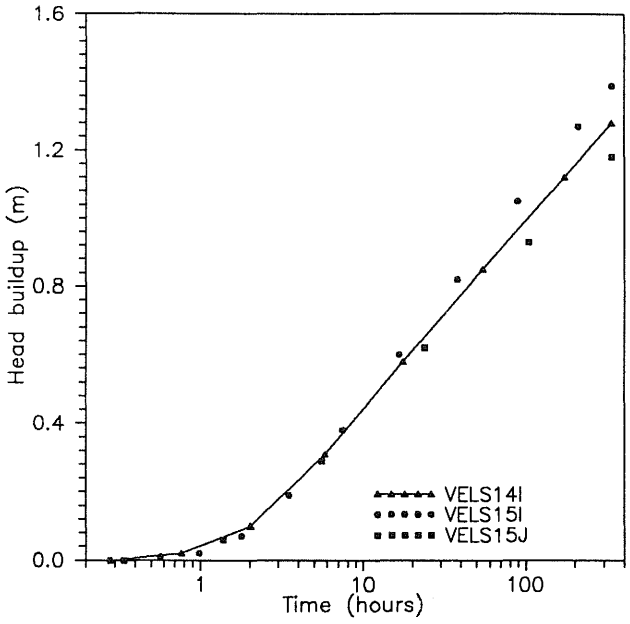

Figure D-6 Sensitivity analysis: effect of hydraulic conductivity.

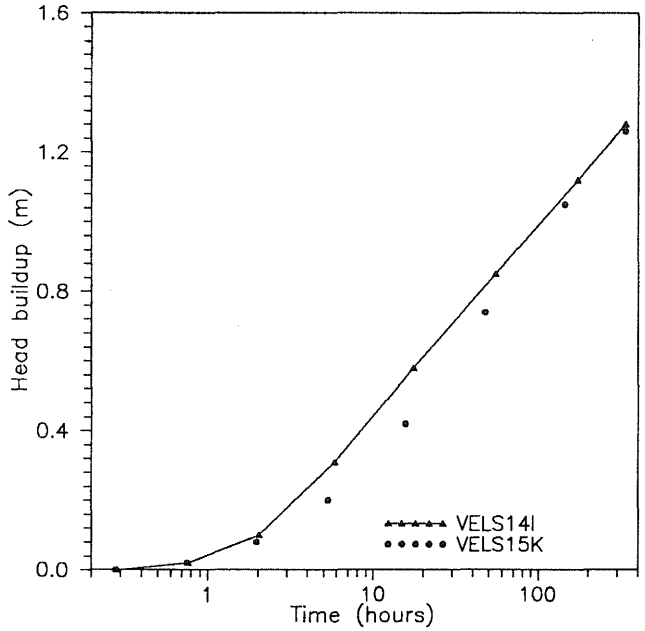

Figure D-7 Sensitivity analysis: effect of anisotropy.

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Appendix 9

Panno, S.V., and K.C. Hackley, 2010. Geologic influences on water quality. In Geology of Illinois, ed. D.R. Kolata and C.K. Nimz, 337-350. Champaign, Illinois: Illinois State Geological Survey.

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Geological Influences on Groundwater Quality

19

Samuel V. Panno and Keith C. Hackley

Introduction

The quality of groundwater is determined by the type and concentration of its chemical and biological constituents. These constituents, depending on their nature and concentrations, can produce water that is unsafe to drink or that has an objectionable taste or odor. Because naturally occurring substances are dissolved in or suspended as fine-grained solids in groundwater, in many cases, some water treatment is necessary before groundwater quality becomes acceptable for drinking purposes or industrial uses. This chapter discusses these naturally occurring substances, their common sources, and the general quality of the groundwater observed within the different aquifers in Illinois.

As municipal and industrial water supplies grew in importance during the early twentieth century, scientists began to study the chemical composition of groundwater and its relationship to the geological framework and associations with the host sediment or bedrock aquifers. The chemical interactions between aquifers and groundwater were identified during the first half of the century and rigorously examined during the latter half (Back and Freeze 1983). Water quality of municipal and private water supplies in Illinois has been routinely analyzed by the Illinois State Water Survey since its founding in 1895 as a means of tracing waterborne diseases (Illinois State Water Survey 2003). Today, studies of the chemical composition of groundwater are routinely performed on both public and private water supplies. The composition of groundwater is used to determine its potability and serves as a tool to determine the sources of naturally occurring and human-related contaminants.

Groundwater is derived from precipitation, such as rainfall or snow melt. Precipitation contains very low concentrations of dissolved minerals (approaching that of distilled water). The major ions—or electrically charged particles—present in rainwater and snow melt are calcium, magnesium, sodium, silica (as $Si(OH)_4$), sulfate, chloride, and nitrogen compounds (nitrate, ammonium, and organic nitrogen). The total concentration of all constituents typically is less than 5 to 10 mg/L (parts per million) (Table 19-1). The natural sources of these ions include airborne dust (calcium, magnesium, and silica) and aerosols from seawater (sodium and chloride), which are highest near the coastal areas (Drever 1997). The majority of the remaining ions are typically from airborne particulate matter and gases from industrial emissions, automobile exhaust, and the evaporation of volatile chemicals (e.g., anhydrous ammonia fertilizers). These latter constituents are discussed in Chapter 28, Karst Terrane.

Once rainfall and snowmelt seep into the ground, the water begins its journey to the water table through the connected pores and crevices in soil, unconsolidated sediment, and rocks. The water table is the elevation at which the geological sediments and rocks become saturated with water. Permeable sediments and bedrock below the water table constitute aquifers. Aquifers supply private citizens and municipalities with potable water and are also used as a source of water for irrigation and industrial purposes throughout much of the state.

Water is a solvent and, as such, is capable of dissolving and interacting with organic and inorganic components of soils, the minerals that make up unconsolidated deposits (e.g., sand and gravel), and with various types of bedrock. Dissolution of minerals within the soil, sediment, and bedrock is a slow process that can take days, years, or eons, depending on the solubility of the materials. These materials contribute to the amount of total dissolved solids (TDS) that are present in all groundwater. Major dissolved constituents of groundwater include the cations (positively charged ions) sodium, potassium, calcium, magnesium, and silica and the anions (negatively charged ions) bicarbonate, sulfate, chloride, and nitrate (Table 19-1). When trace-level ions, such as ammonium, iron, manganese, and arsenic, are present in relatively high concentrations, they create water-quality problems. These constituents come from the dissolution of rocks such as limestone and dolomite, the weathering of less-soluble rocks such as granite, the degradation of organic debris in the soil zone (e.g., trees and leaves), and man-made contaminants (discussed in Chapter 29, Pollution of Natural Waters).

In general, the chemistry of groundwater is controlled by the type of geological materials through which the water flows and the amount of time the water is in contact with these materials. For example, precipitation percolating into a limestone aquifer would dissolve the limestone (made of calcium carbonate), and the water (now groundwater) would contain predominantly calcium and bicarbonate ions. The dominant cations and anions are used to describe the gen-

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eral chemical composition, or "type," of groundwater. For example, limestone aquifers contain "calcium bicarbonate type" groundwater, and deep, granitic rock eventually produces "sodium chloride type" groundwater.

Aquifers and Aquitards: Effects on Groundwater Quality

Aquifers in Illinois are made up of two types of material: (1) sand and gravel deposits found in association with glacial till or along stream valleys, and (2) porous and permeable bedrock units. Sand and gravel aquifers are scattered throughout the state, but the largest deposits occur in northeastern and central Illinois. Bedrock aquifers containing usable groundwater are located throughout the state, but potable water is found only in the bedrock aquifers of the northern third and, to a lesser extent, the western and southern parts of the state. For example, fresh groundwater with less than 1,000 mg of TDS/L can be pumped from wells over 1,000 feet (305 m) deep in the northern part of the state, but saline (salty) groundwater is encountered several hundred feet or less below the surface in southern Illinois (Lloyd and Lyke 1995). Groundwater from bedrock found in the southern two-thirds of the state is usually too saline for human use (Figure 19-1). Salinity of groundwater generally increases with depth. Bedrock aquifers in the northern portion include shallow carbonate rocks (dolomite and limestone) as well as deep sandstones that are primarily made up of quartz and silicate minerals. The bedrock aquifers in the western and southern parts of the state are primarily shallow carbonate rocks.

Sand and gravel deposits typically contain abundant clasts (i.e., sand grains, pebbles, and cobbles) of limestone and dolomite that dissolve much faster than do clasts of other composition (e.g., quartz). Consequently, calcite and dolomite, once dissolved, dominate the chemical composition of the groundwater in these aquifers, forming a calcium-magnesium bicarbonate type of groundwater (Table 19-1). Similarly, bedrock aquifers are often made of fractured limestone and dolomite, resulting in groundwater with the same general chemical composition as that found in sand and gravel aquifers. Groundwater circulating through fractured sandstone aquifers, such as the Aux Vases Sandstone in southwestern Illinois, typically form a sodium bicarbon-

Table 19-1 Chemical composition[1] of averaged rainwater samples and single samples of different types of groundwater in Illinois. All parameters are reported in milligrams per liter except pH.

		Groundwater type								
	Rain[2]	Ca-Mg bicarbonate[3]	Na bicarbonate[4]	High NaCl[5]	High F[6]	High As[7]	High Mn, Fe[8]	High ammonium[9]	High sulfate[10]	Seawater[11]
pH	4.5	7.2	8.6	6.6	6.8	7.4	7.49	7.2	7.1	8.0
SC	21.1*	688	2,100	—	694	515	750	670	2,000	58,500*
Na	0.08	27.4	559	44,923	27.4	17.4	47.6	15.8	104	10,556
K	0.03	<1	<2	—	<2	1.74	1.82	3	4	380
Ca	0.24	90.1	6.0	5,740	109	67.9	82.3	82.3	279	400
Mg	0.04	33.9	3.1	2,173	20.5	32.9	41.8	36.6	96.7	1,272
SiO_2	—	19.1	8.6	15	14.8	18.1	21.8	22.7	20.1	6.43
HCO_3	—	443	1,108	61	385	479	560	480	301	140
SO_4	2.28	33.1	165	329	25.3	<0.09	16.3	0.34	981	2,649
Cl	0.15	7.4	37	85,569	25.1	1.1	41.8	0.55	8.5	18,908
F	—	0.37	—	—	1.46	0.2	0.1	—	0.28	1
NO_3	1.46	<1.9	0.26	0.0	0.09	<0.02	<0.2	0.35	<1.7	<0.5
NH_4	0.40	0.98	—	64	—	2.8	3.7	6.02	—	<0.5
Fe	—	1.89	<0.01	20	1.65	4.57	3.67	4.32	0.27	0.01
Mn	—	<0.03	<0.01	2.0	0.76	0.04	0.21	0.03	1.2	0.002
As	—	—	—	—	—	0.096	—	—	—	0.003
TDS	4.68*	661*	1,887*	142,194	611*	626*	821*	652*	1,796	34,477

[1]Abbreviations: SC, specific conductance; Na, sodium; K, potassium; Ca, calcium; Mg, magnesium; SiO_2, silicon dioxide, or silica; HCO_3, bicarbonate; SO_4, sulfate; Cl, chlorine; F, fluorine; NO_3, nitrate; NH_4, ammonia; Fe, iron; Mn, manganese; As, arsenic; TDS, total dissolved solids. Values followed by asterisk were calculated. —, data are unavailable.
[2]Average values from six active collection sites throughout Illinois from 1980 to 2003 (http://www.nadp.isws.illinois.edu).
[3]Hackley (2002); sample WRD-55, Mahomet aquifer, Champaign County.
[4]Panno (unpublished data 1995); Aux Vases Sandstone, Monroe County.
[5]Meents et al. (1952); sample 930, Ste. Genevieve Formation, Wayne County.
[6]Panno and Hackley (1997a); Valmeyeran Series limestones, Rosiclare, Hardin County.
[7]Holm (1995); sample 93-24A, Mackinaw Valley aquifer, Tazewell County.
[8]Holm (1995); sample 93-14, Mackinaw Valley aquifer, Tazewell County.
[9]Hackley (unpublished data); Mahomet aquifer, Mc Lean County.
[10]Hackley (2002); sample VER-94b, Mahomet aquifer, Vermilion County.
[11]Mason (1966).

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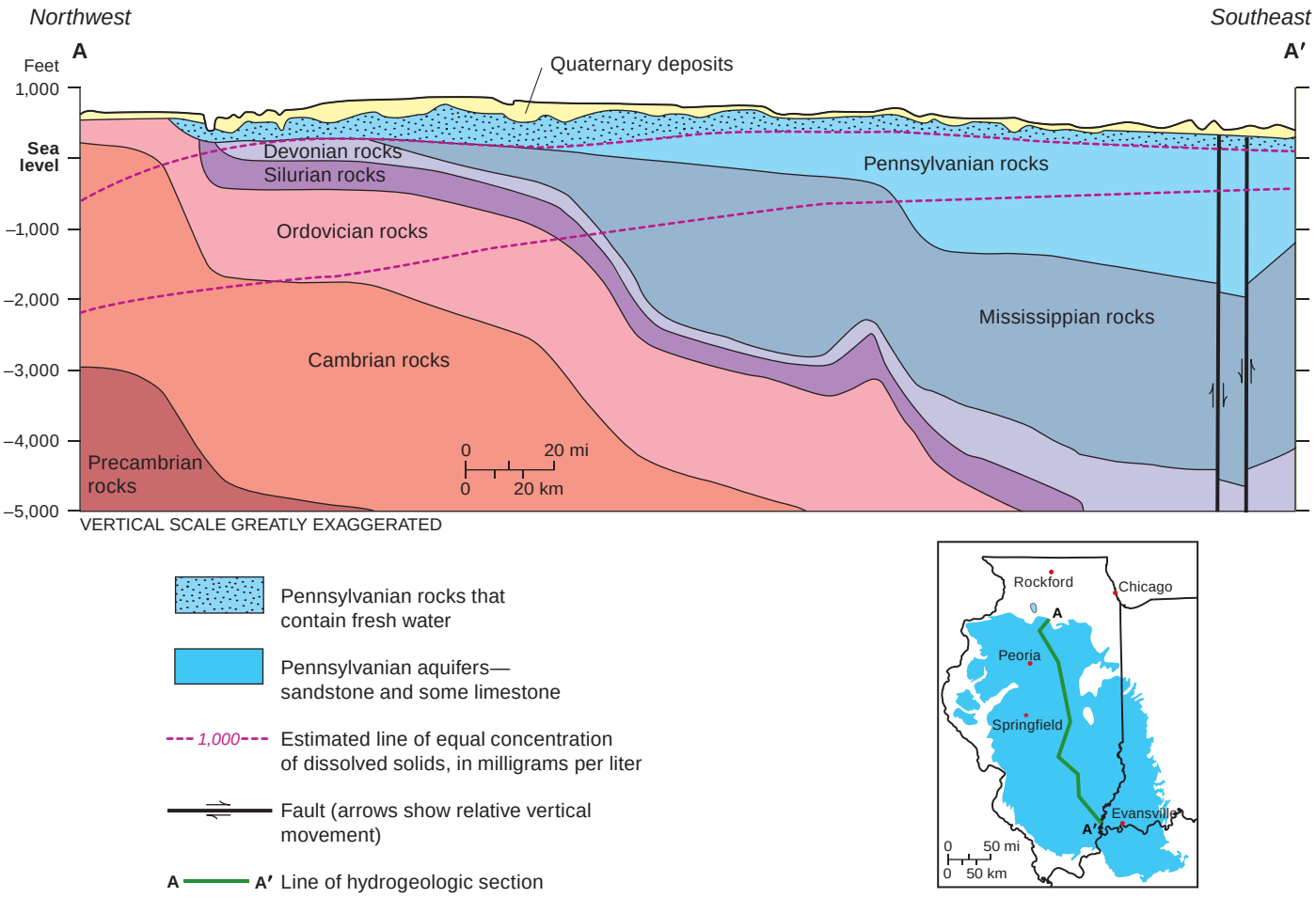

Figure 19-1 North-south cross section of Illinois showing estimated lines of equal concentration of total dissolved solids in groundwater (Lloyd and Lyke 1995).

ate type groundwater (Table 19-1). One way such groundwater is formed is for calcium bicarbonate groundwater to enter the sandstone, and, through ion exchange, calcium ions replace sodium ions on clay minerals (sodium is often present due to degradation of feldspars in the sandstone). This process is similar to that occurring when a water softener causes calcium and magnesium to exchange positions on a resin within the softener; the result in both cases is a "soft" sodium bicarbonate water.

Aquitards are those deposits or rocks that do not allow recharge water or groundwater to penetrate very easily (e.g., clay-rich glacial till and shale) (Chapter 18, Aquifers). These deposits or rock units protect groundwater from surface-borne contaminants, isolate groundwater from the atmosphere, and confine groundwater to a single aquifer or channel it to a series of connected aquifers. The isolation of groundwater for hundreds to thousands to tens of thousands of years can affect its chemistry by fostering reducing conditions, as is discussed later in this chapter. Additionally, the interaction of groundwater with the minerals of an aquitard can alter the chemical composition of the groundwater flowing through it and the chemical composition of adjacent aquifers. For example, recharge water interacting with the shale that bounds an aquifer often encounters the mineral pyrite (iron sulfide), which can be easily oxidized to form groundwater that has very high concentrations of sulfate (perhaps hundreds to thousands of milligrams per liter) (Table 19-1). Such sulfate-enriched groundwater, as it enters an underlying aquifer, can enrich the aquifer with sulfate even though there may have been no mineralogical source of sulfate in the aquifer.

Chemical Composition

There are a number of constituents that can be found in groundwater, and water quality depends on the type and concentration of these constituents. For example, groundwater in some locations is immediately potable; elsewhere it may have an objectionable taste and/or odor and may even be unsafe to drink. The U.S. Environmental Protection Agency (U.S. EPA) has developed a list of acceptable concentrations of natural and man-made contaminants for municipal drinking water. These standards, the National Pri-

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mary Drinking Water Regulations (NPDWR), are enforced by the U.S. EPA (1991, 2009). National Secondary Drinking Water Regulations (NSDWR) are U.S. EPA guidelines pertaining to constituents of drinking water based on cosmetic effects, taste, odor, and appearance. Both guidelines may be found on the U.S. EPA (2009) Web site.

The chemical components that are typically measured to help determine the general quality of groundwater include suspended solids, hardness, sodium, chloride, fluoride, sulfate, chemicals associated with reduction-oxidation (e.g., arsenic, iron, manganese, nitrate, and ammonium), assorted minor and trace constituents, dissolved gases (e.g., air, carbon dioxide, methane, and hydrogen sulfide), and stable and radioactive isotopes. Some of these constituents are occasionally referred to as "contaminants," but they can be naturally occurring.

Suspended Solids

Suspended solids in groundwater are occasionally observed in wells tapping aquifers that have relatively large porosity and permeability (e.g., sand and gravel, karst limestone/dolomite). Suspended solids include soil and other fine-grained material (e.g., clay, silt, and organic debris) small enough to pass through the tiny spaces between sand and gravel and through crevices in carbonate rock. Suspended solids can also include compounds that may precipitate in the water as it is withdrawn from the aquifer due to dramatic changes in temperature, pressure, pH, or oxygen content. Examples of dissolved constituents that can emerge from apparently clear water are calcium carbonate, which forms small white flakes when dissolved carbon dioxide is released from the water, and iron and manganese oxides, which form orange and black granules or coatings when water is exposed to oxygen. Such materials can make the water cloudy and can affect its taste unfavorably.

An extreme example of suspended solids in groundwater comes from the karst aquifers of southwestern Illinois. Karst aquifers have large crevices and conduits that can carry relatively large concentrations of suspended solids in the water. Several wells in one subdivision in southwestern Illinois intersected crevices that were in direct contact with at least one large sinkhole. During and following large rainstorms, soil washed into the sinkhole(s) and through the crevices that led to the wells. Pumps in the wells sent the sediment-laden water, now a muddy slurry, into the plumbing systems of several houses, and mud oozed from the fixtures (Figure 19-2) (Panno et al. 1996). In most cases, however, suspended solids in groundwater are not so extreme and can be removed by commercially available filters.



Figure 19-2 Examples of muddy tap water from a residential home in southwestern Illinois' karst region. Left and center: Water containing sediment from erosion of cropland adjacent to a sinkhole during and following relatively large rainfall events (1 inch [2.5 cm] or greater). Right: Fireplace ashes in water caused by dumping fireplace ashes into the sinkhole in the home's backyard. (Photograph by Joel M. Dexter.)

Rock-Water Interaction

The chemical characteristics of groundwater are determined by the interaction between groundwater and the minerals that make up the rock or sediment through which the water is moving (Figure 19-3). That is, the materials of the soil zone and the aquifer are dissolved and incorporated into the water moving through them. Some components may provide a characteristic taste to the water and some may make the water undrinkable based on taste, toxicity, or both.

Calcium, Magnesium, Bicarbonate, and Hardness

In areas where bedrock is dominated by limestone and/or dolomite or where sand and gravel aquifers contain abundant clasts of these carbonate minerals, the groundwater is typically a calcium bicarbonate type or calcium-magnesium bicarbonate type (Table 19-1; Figure 19-4). These rocks are dominated by calcite (calcium carbonate) and dolomite (calcium-magnesium carbonate), and both are soluble in slightly acidic rainwater (Table 19-1) and snowmelt and in carbon dioxide-enriched soil water (soil water made more acidic by the generation of carbon dioxide from root respiration and microbial degradation of organic debris). Carbonate minerals dissolve relatively fast when exposed to carbon dioxide-enriched waters.

Groundwater from aquifers made up of or containing carbonate rock is often referred to as "hard." Hard water contains calcium and magnesium that react with soap and produce soap scum or react with other anions to produce a solid scale or coating when the water is boiled and evapo-

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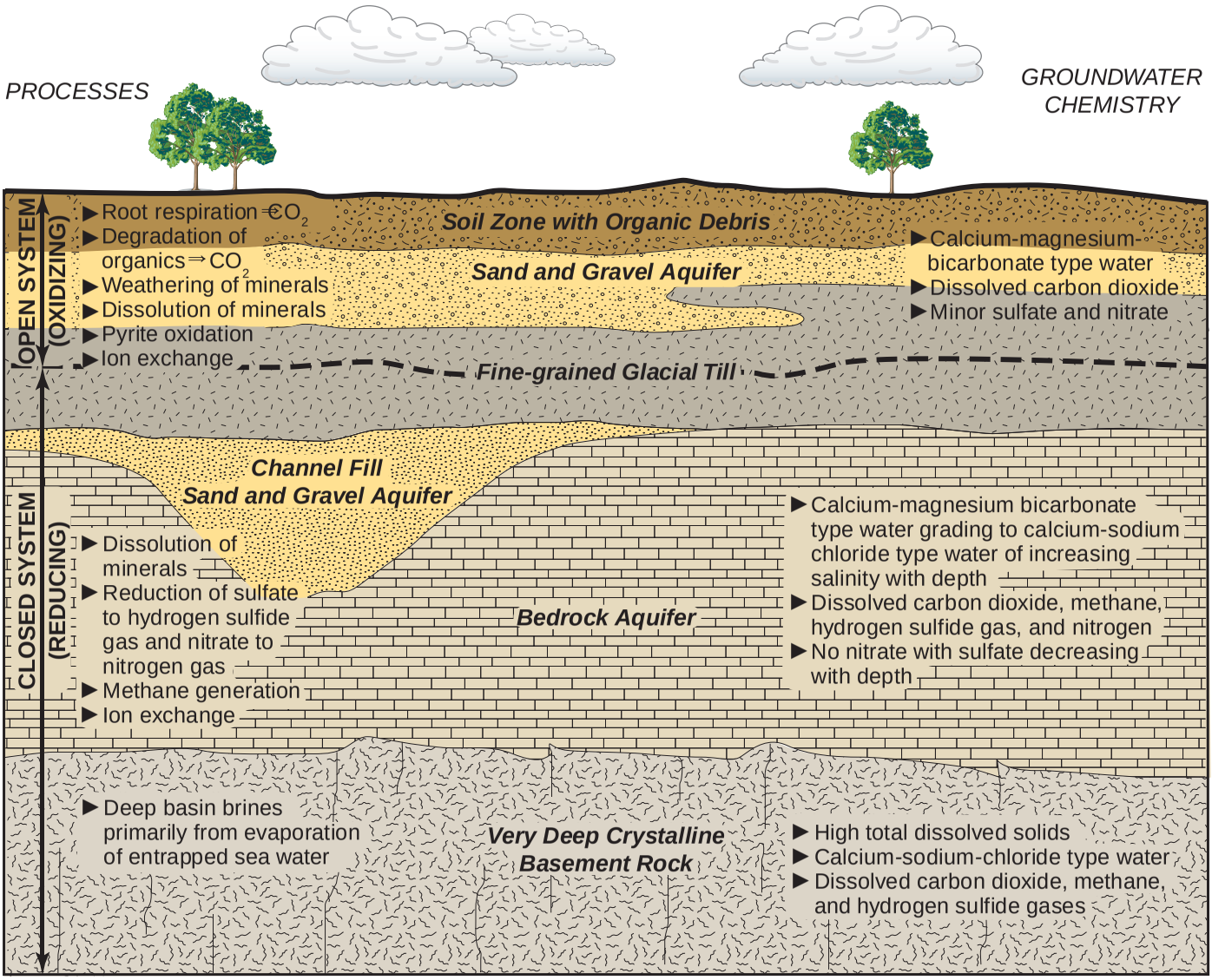

Figure 19-3 Conceptual model of the processes and chemical composition of groundwater in Illinois. Abbreviation: CO_2, carbon dioxide.

rated. Hardness and its components are not toxic, have no offensive taste or odor, and are under no U.S. EPA guidelines. Chemically, hardness is defined (Freeze and Cherry 1979) as (total calcium concentration × 2.5) + (magnesium × 4.1) and is expressed as milligrams per liter, or parts per million. For example, if water contains 5 mg of calcium/L and 5 mg of magnesium/L, then the hardness is 33 mg/L. Water with a hardness value greater than 120 mg/L is considered to be hard, and greater than 180 mg/L is considered to be very hard (Lehr et al. 1980). Because the presence of these minerals controls water chemistry, groundwater from carbonate mineral-rich aquifers is typically very hard. For example, the average hardness value for the groundwater of the karst limestone aquifers of Illinois is about 230 mg/L (Panno et al. 1996, 1997). Groundwater from sand and gravel aquifers in northern Illinois has hardness values of over 300 to 400 mg/L (Panno et al. 2005a).

The scale or coating from these dissolved minerals that can be found in pots used for boiling hard water and on the bottom of hot water heaters is a deposit of carbonate minerals. In some cases, hard water may be desirable because it tends to coat the interior of metal pipes containing copper or lead or joined by lead-bearing solder, thereby protecting the metals from leaching into the water supply (Lehr et al. 1980). However, continued coating of pipes with scale may eventually (after tens of years) constrict the interior of water pipes so that the water flow slows to a trickle. Hardness can be treated easily by commercially available water softening treatment systems. Water softeners typically consist of an ion-exchange system that exchanges sodium for calcium and magnesium. What enters the water softener as a hard, calcium-magnesium bicarbonate water discharges as a soft, sodium bicarbonate water.

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Figure 19-4 Groundwater discharging from a spring at Weldon Springs State Park near Clinton, Illinois. The dilute, calcium-bicarbonate groundwater that is recharged in the higher elevations to the north percolates into and flows through a sand and gravel layer in glacial till and discharges as springs in the low-lying area of the park. A pipe was inserted into this spring's discharge point and channeled to this facade; unlike its Wyoming namesake, Illinois' Old Faithful flows constantly (Panno and Hackley 2001b). (Photograph by Samuel V. Panno.)

Sodium and Chloride

Water may be classified according to its TDS content (Table 19-2). In Illinois, most groundwater from shallow aquifers is fresh, whereas relatively deep groundwater from within the Illinois Basin is saline to briney. Water containing chloride concentrations of approximately 250 mg/L or greater may have a salty taste. This concentration is the U.S. EPA recommended limit for drinking water (U.S. EPA 1991, 2009); chloride concentrations exceeding 1,000 mg/L may be unsafe for human consumption (Lin 1977, Lehr et al. 1980, U.S. EPA 1991). Sodium concentrations are not regulated by the U.S. EPA. However, high-sodium intake may be associated with hypertension in some individuals (U.S. EPA 1991), and the sodium concentration in drinking water should be considered by those for whom dietary sodium is a concern (Haman and Bottcher 1986).

Most shallow groundwater is relatively fresh and typically has little sodium and chloride dissolved in it. Usually, naturally occurring sodium and chloride concentrations in sand and gravel aquifers in Illinois are between about 1 and 15 mg/L (Panno et al. 2006a). However, sodium chloride is present in large concentrations in groundwater from deep aquifers of northern Illinois, in parts of central Illinois, and many parts of southern Illinois (Clayton et al. 1966).

Table 19-2 Classification of groundwater relative to total dissolved solids (TDS) contents (Hem 1986).

Water classification	TDS (mg/L)
Fresh	<1,000
Slightly saline	1,000 to 3,000
Moderately saline	3,000 to 10,000
Very saline	10,000 to 35,000
Brine	>35,000

Much of the bedrock in Illinois, however, is part of an underlying midcontinental sedimentary basin known as the Illinois Basin. Sedimentary basins such as this contain abundant saline groundwater that typically increases in salinity with depth (Figures 19-1 and 19-3); in the case of the Illinois Basin, salinity increases to a depth of about 1.2 miles (2 km) or so before it levels out (McIntosh et al. 2002). The source of the salinity of this groundwater has generated much interest. Walter et al. (1990) and Steuber et al. (1991, 1993) suggested that the salinity was due to the evaporation of seawater short of the precipitation of halite in Silurian and Devonian strata and a mixture of evaporated seawater and dissolution of evaporites in shallower Mississippian and Pennsylvanian strata. Recent work by Hanor and McIntosh (2006) suggests that saline groundwater of the Illinois Basin underwent extensive alteration as a result of rock-water interaction and were transformed from sodium chloride brines to calcium-sodium chloride brines with salinities up to 200,000 mg/L TDS.

Saline springs can be seen along structural features, such as along folds and faults in the Starved Rock area (the Old Salt Well) in La Salle County, in southwestern Illinois in the vicinity of oil fields near Columbia in Monroe County, and in southern Illinois near the Equality Fault Zone and the town of Equality in Saline County (Figure 19-5). Water from these springs is about as saline as seawater with about 35,000 mg/L TDS and is dominated by sodium and chloride; seawater is dominated by sodium and chloride and contains about 34,477 mg/L TDS (Table 19-1).

Saline groundwater and brines can be brought near or to the land surface by natural conditions, such as migrating up prominent fractures and/or faults in bedrock, or by anthropogenic activities, such as exploration for and exploitation of petroleum. The mixing of upward-migrating saline groundwater with fresh groundwater from shallow aquifers can make groundwater from private wells undrinkable and can present a very expensive problem for municipalities. An example of saline groundwater seeping into a freshwater aquifer can be found in east-central Illinois where the Mahomet aquifer crosses a major, roughly north-south–trending structural feature called the La Salle Anticlinorium (Figure 19-6). Saline water seeps up into the base of the aquifer from bedrock at a depth of about 300 feet (91 m) below the land surface near the Champaign-Piatt County line. Groundwater that normally has chloride concentra-

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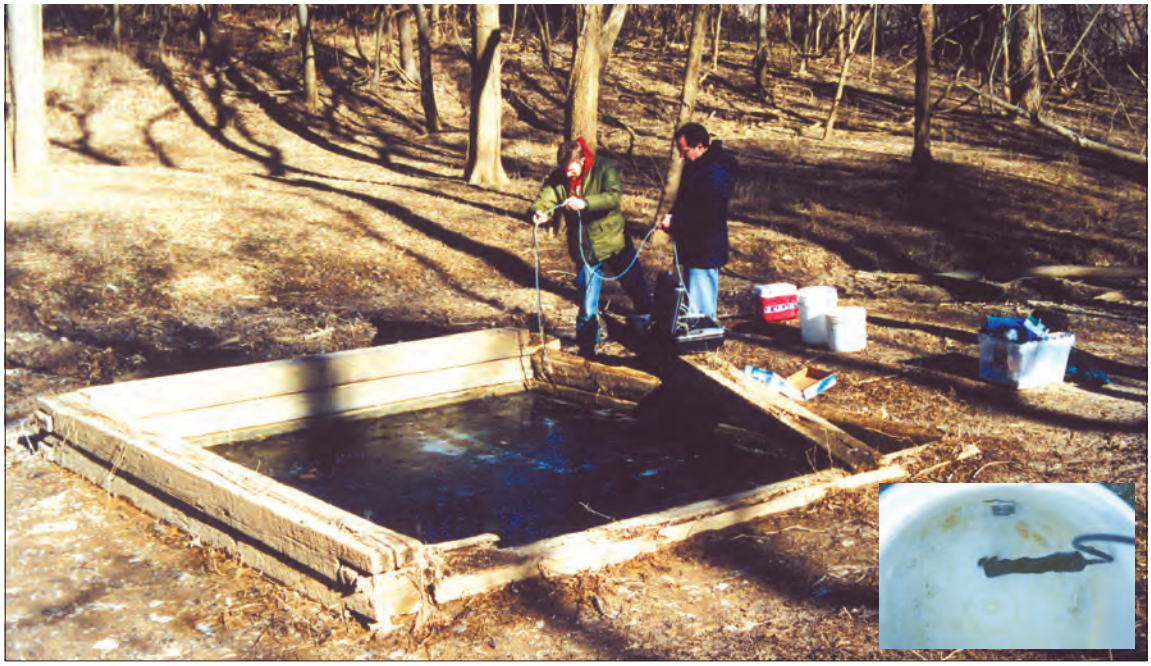

Figure 19-5 Equality Spring in Saline County in southern Illinois is a saline spring containing over 13,000 mg/L of sodium and chloride. The spring is over 6 feet deep (2 m), is encased by railroad ties, and was used as a commercial source of salt by early settlers of Illinois. (Photograph by Samuel V. Panno.)

tions less than or about 1 mg/L here exceeds 300 mg/L (Panno et al. 1994). Samples of groundwater from bedrock beneath the sand and gravel aquifer have chloride concentrations in the thousands of milligrams per liter (Panno et al. 2005a).

In addition, naturally saline springs in northern (e.g., Starved Rock State Park) and southern Illinois, usually located along fault zones or structural folds, discharge highly saline water into surface streams (Panno et al. 2005a, 2006a). Streams in areas where there are saline seeps have names such as the Saline River (Saline County) and the Salt Fork of the Vermilion River (Vermilion County). Because salt was an important commodity during early Illinois settlement by Europeans during the early 1800s, such seeps and their "salt works," initially used by Native Americans, became the nucleus of early settlements. Saline water was boiled in large iron kettles, and the residual salt was harvested and sold (Fliege 2002).

Fluoride

Fluoride typically is added to municipal water supplies because of its protective effects on teeth. However, fluoride in drinking water at concentrations greater than 3 mg/L can cause problems with tooth mottling, brown staining, and pitting in the teeth (dental fluorosis) in children with developing teeth (U.S. EPA 2009). The primary U.S. EPA drinking water standard is 4 mg/L. Fluoride concentrations greater than 4 mg/L can result in bone disease and bone and joint deformation (skeletal fluorosis) (Appelo and Postma 1994). The NSDWR for fluoride in drinking water is 2.0 mg/L (U.S. EPA 1991, 2009).

Groundwater from wells in most aquifers in Illinois has relatively low fluoride concentrations (usually about 0.5 mg/L) (Panno, unpublished data). Fluoride concentrations in groundwater are a function of the chemical composition of the groundwater and the presence or absence of fluorine-bearing minerals within an aquifer. Fluorine-bearing minerals include apatite (calcium phosphate), fluorite (calcium fluoride), and minerals that can exchange hydroxyl ions for fluoride ions (hornblende, mica, and clay minerals) (Hem 1986). Conrad et al. (1999) found that the greatest fluoride concentrations in Kentucky were associated with relatively deep, sodium bicarbonate-type groundwater with pH values between 7.6 and 8.0. The fluoride concentrations in Illinois aquifers are relatively low, in part, because calcium bicarbonate-type groundwater (found in limestone and sand and gravel aquifers of northern Illinois) limits the amount of the fluorite that can be dissolved (Hem 1986). Fluorite (calcium fluoride) deposits are found in southeastern Illinois within and near the town of Rosiclare, in Hardin County, site of the largest known fluorite deposits in the United States. Groundwater samples drawn from limestone for Rosiclare's municipal water supply contained 1.5 mg of fluoride/L (Panno and Hackley 2001a) (Table 19-1). Private wells that tapped into the groundwater of the Aux Vases Sandstone in southern Illinois have intersected groundwa-

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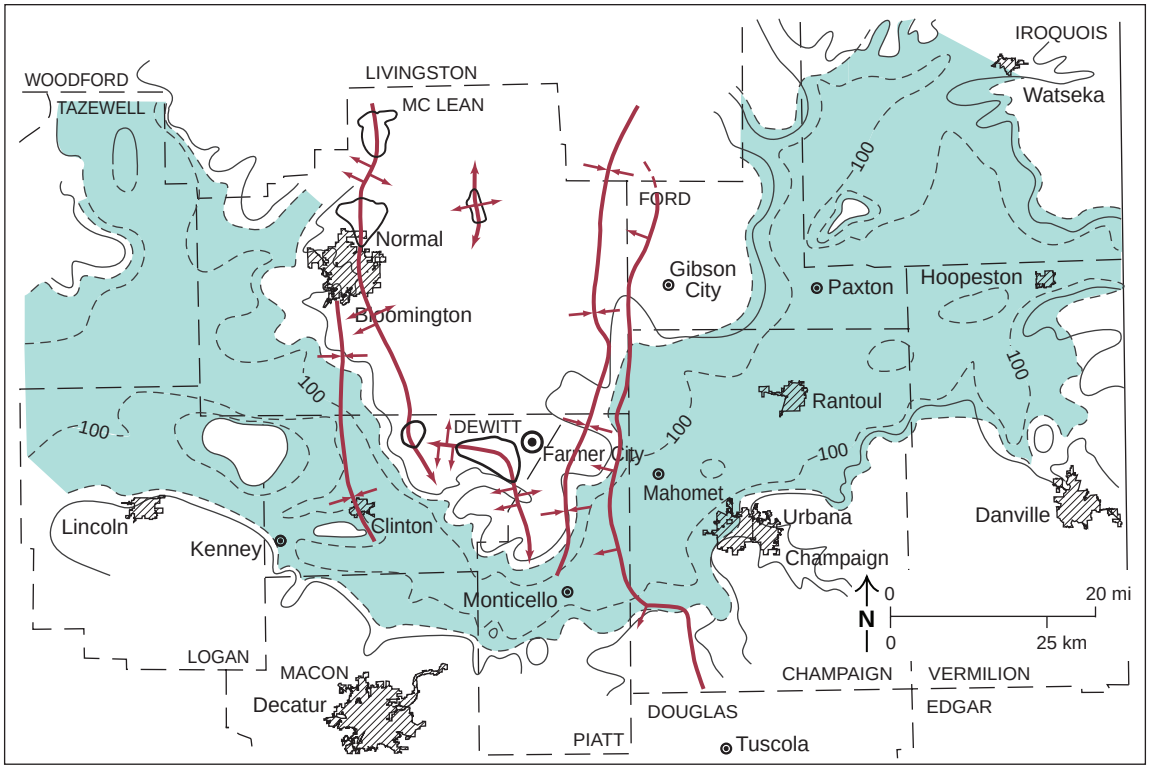

Figure 19-6 Saline groundwater can seep into a freshwater aquifer to contaminate it. Such a situation occurs in east-central Illinois where the Mahomet aquifer crosses the north-south cluster of folds known as the La Salle Anticlinorium. Dashed lines are thickness contours (in feet). (Modified from Panno et al. 1994.)

ter with fluoride concentrations as high as 9 mg/L (J. Bade, former sanitarian with the Monroe-Randolph Bi-County Health Department, personal communications 1997).

Sensitivity to Reduction-Oxidation

Oxygen

Oxygen, one of the most abundant elements on earth, very commonly combines with other elements. Depending on the nature of the bond, the bonded element is either reduced or oxidized. In simplest terms, reduction-oxidation (commonly shortened to redox) involves the gaining (reduction) or losing (oxidation) of electrons between elements, one of which is oxygen. The term "reduction" refers to the charge; an atom, molecule, or ion that gains an electron now has a reduced, or negative, charge. The loss of electrons through oxidation results in a positive charge. Redox reactions happen in pairs; there is no oxidation without a concurrent reduction. Redox-sensitive elements are those that either precipitate or dissolve in the presence or absence of dissolved oxygen and other electron-bearing, often oxygen-bearing, ions (e.g., nitrate and sulfate). The abundance of dissolved oxygen (and oxygen-bearing ions) usually decreases with depth and confinement of an aquifer. Groundwater in shallow, unconfined aquifers typically has dissolved oxygen contents similar to that of surface water (about 8 mg/L). Groundwater in deeper aquifers and shallow, confined aquifers has little or no dissolved oxygen because it is readily used up by bacterial activity and other oxygen- and electron-consuming chemical reactions that occur within the aquifers (e.g., decomposition of organic matter and oxidation of pyrite); such groundwater is referred to as being under reducing conditions. Consequently, redox-sensitive elements are more readily dissolved in deeper, oxygen-depleted groundwater.

Arsenic

Arsenic is an element that is soluble in water, is redox-sensitive, and occurs naturally in minute concentrations in groundwater. The routine ingestion of water containing very low concentrations of arsenic has been linked to skin disease and cancer (Smith et al. 1992). The arsenic standard for community supply wells has been lowered by the U.S. EPA from 50 to 10 µg/L (parts per billion) for finished drinking water (Vorman 2001). Health problems, such as arsenic-induced cancers, have resulted, in other parts of the world, from drinking water with relatively large concentrations of arsenic (e.g., Bagla and Kaiser 1996). Arsenic concentrations of shallow glacial and alluvial aquifers of Illinois range from less than 1 to as high as 107 µg/L; the greatest arsenic concentrations are in the southern part of the state and in the Mahomet aquifer (glacial drift aquifer) (Table 19-1) (Figure 19-7) (Warner et al. 2003).

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Iron and Manganese

The solubilities of iron and manganese, metals that are commonly present in groundwater, are sensitive to changes in redox conditions. The concentrations of these metals are low in groundwater from shallow aquifers because the presence of dissolved oxygen in the water causes these metals to precipitate from solution. However, in deeper aquifers where dissolved oxygen has long been consumed by biological and chemical reactions, groundwater often contains abundant concentrations of dissolved iron and manganese (Table 19-1).

Groundwater containing relatively high concentrations of these dissolved metals may appear to turn yellow rapidly (within minutes) in a container. Such water can form orange to black coatings on porcelain fixtures and laundry due to precipitation of manganese oxides and iron oxyhydroxides upon exposure to oxygen (Figure 19-8). The presence of these metals in water can thus be a nuisance. Iron and manganese also can precipitate on well screens and eventually plug them. Such plugging is very likely one of the causes for reduced efficiency of a municipal well in an east-central Illinois municipal well field (Panno et al. 2005b). Iron and manganese can impart a metallic taste to water. The U.S. EPA limits for iron and manganese are 0.30 and 0.05 mg/L, respectively. The U.S. EPA limit is an NSDWR, based on taste and the problems just mentioned rather than on health risk (U.S. EPA 1991). Commercially available water softeners with salt and filters can effectively remove these metals.

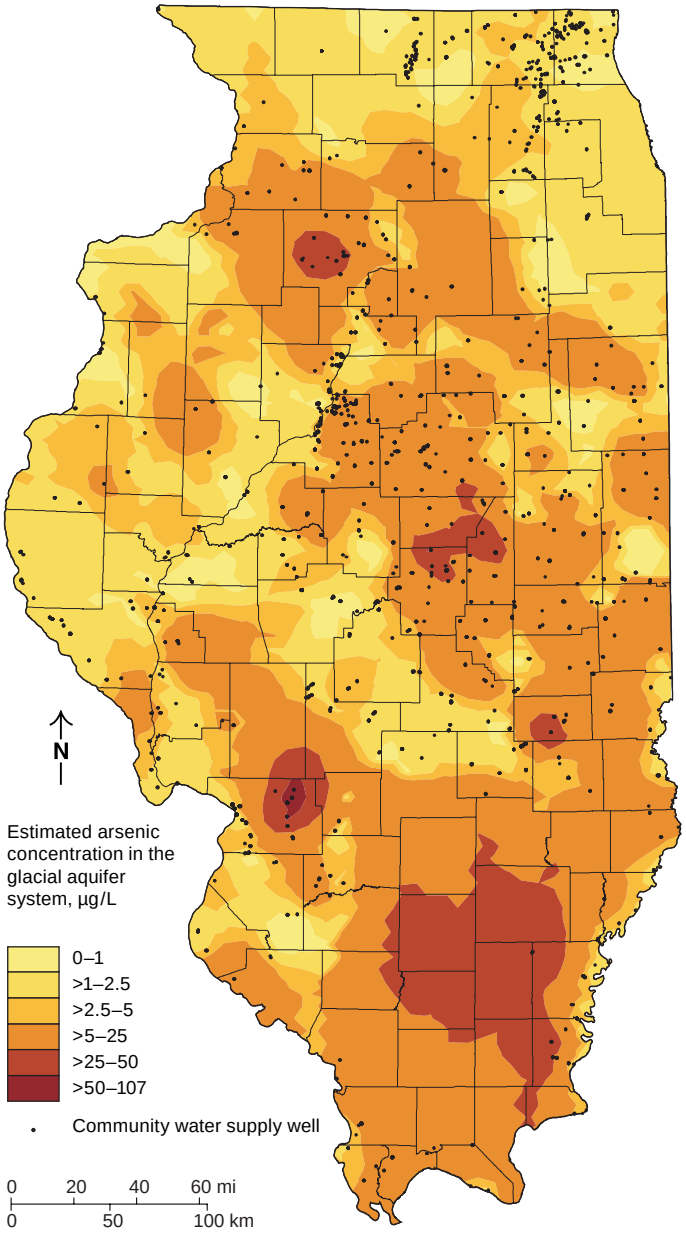

Figure 19-7 Contour map of estimated arsenic concentrations in Illinois groundwater (Warner et al. 2003).



Figure 19-8 Falling Springs, located near Dupo, in St. Clair County in southwestern Illinois, is an example of reduced groundwater. The spring discharges from a cave located 50 feet above the base of a cliff. As the groundwater is oxygenated, it precipitates manganese oxide and iron oxyhydroxide intermixed with calcite to form a black apron on the cliff. (Photograph by Joel M. Dexter.)

Nitrogen Compounds

Nitrogen compounds (nitrate, nitrite, ammonium, and

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organic nitrogen) are naturally occurring components of groundwater. Nitrate is the most common dissolved nitrogen compound in surface and shallow groundwater environments where the water is relatively oxidized. Usually the concentrations of these compounds are small. Naturally occurring nitrate concentrations (NO_3-N) are typically between 2.0 mg/L and 2.5 mg/L (Panno et al. 2006b). However, groundwater in some shallow aquifers in Illinois exceeds the U.S. EPA NPDWR of 10 mg of NO_3-N/L; water with concentrations at or exceeding 10 mg of NO_3-N/L may pose health problems. The potential sources of such high-nitrate concentrations are discussed in Chapter 29, Pollution of Natural Waters. Nitrate concentrations can be naturally reduced through denitrification, a process by which denitrifying bacteria convert nitrate to nitrogen gas. As a result, nitrate in groundwater is often stratified or layered; the greatest concentrations occur near the top of the water table and continually decrease with depth. Ammonium becomes more prevalent in the reducing conditions of deeper and confined aquifers. For example, the Mahomet aquifer of east-central Illinois has ammonium concentrations up to 6 mg/L (Table 19-1) (Hackley 2002). Roy et al. (2003) indicated that the source of ammonium in a deep sand and gravel of the Mahomet aquifer in east-central Illinois is the subsurface degradation of organic materials present in buried ancient soils (paleosols).

Sulfate

Sulfate is typically present in groundwater at concentrations in the tens of milligrams per liter, but it can be much higher. Sulfate concentrations of 250 mg/L or greater is a U.S. EPA NSDWR. Drinking water with such high sulfate concentrations may have objectionable taste and odor; however, there is no evidence of ill effects from drinking such water (Centers for Disease Control, U.S. EPA 1999). In Illinois, sulfate concentrations of several hundred to 2,000 mg/L were found from the deep bedrock Cambrian and Ordovician aquifers in northeastern Illinois (Gilkeson et al. 1981) and in east-central Illinois in the unconsolidated sands and gravels of the Onarga Valley portion of the Mahomet aquifer (Hamdan 1970). Gilkeson et al. (1981) determined that the large sulfate concentrations found in the Cambrian and Ordovician aquifers were from the dissolution of marine evaporites (the calcium sulfate mineral gypsum). Sulfate in the Onarga Valley is due to circulation of groundwater through the bedrock and the leaching of secondary sulfate minerals produced from pyrite oxidation (Table 19-1) (Panno et al. 1994, Hackley 2002).

Dissolved Gases

A variety of dissolved gases are commonly associated with groundwater (Figure 19-3): nitrogen, oxygen, carbon dioxide, methane, and hydrogen sulfide. Other gases that are often present but usually in low concentrations are the noble (inert) gases, hydrogen, chlorofluorocarbons, and radon. As water penetrates into the ground, gases typically found in the atmosphere are dissolved in the water. Thus, nitrogen is common in groundwater. Nitrogen also may be produced from microbial denitrification reactions. Due to biochemical reactions within the aquifers, oxygen is quickly consumed during oxidation of organic matter and other reduced compounds such as the sulfides found in the soils and deeper sediments. Carbon dioxide is added to the infiltrating water in the soil zone due to root respiration and oxidation of organic matter. The addition of carbon dioxide increases the carbonic acid, lowering the water's pH, which has important impacts on the solubility of the rocks and minerals through which the groundwater flows.

In reducing environments, hydrogen sulfide and methane become more prevalent. Hydrogen sulfide results in a rotten egg odor that is sometimes present in well water. The sources of hydrogen sulfide include the bacterial reduction of naturally occurring sulfate dissolved in groundwater and decomposing organic matter within confined aquifers or in aquitards. Although the odor is objectionable, the concentrations of hydrogen sulfide gas typically found in drinking water do not pose a health problem. Hydrogen sulfide can be tasted at concentrations at or exceeding 0.05 mg/L (Lehr et al. 1980). At concentrations of 0.2 mg/L, hydrogen sulfide can be corrosive to silverware, fixtures, and plumbing (Lin 1977). Most water treatment companies can install equipment capable of removing hydrogen sulfide from domestic water supplies using oxidation, chlorination, aeration, and filtration or ion exchange with chemically active compounds (Lemley et al. 1999, Ross et al. 1999).

Dissolved methane is quite common in Illinois groundwater (Figure 19-9). Methane occurs naturally from the microbial degradation of buried organic debris present in the glacial drift deposits throughout much of central and northeastern Illinois (Meents 1958, 1960; Coleman 1976). Many residents of Illinois have used this "drift gas" to run appliances or heat their homes (Meents 1960). Using isotope geochemistry, methane from glacial drift deposits can be distinguished from other sources, such as thermogenic methane associated with petroleum formation or generated in landfills (Coleman et al. 1977, 1988, 1995; Hackley et al. 1996). The ability to determine these differences is important when exploring possible environmental problems from methane-generating sources such as landfills.

Total Dissolved Solids

Total dissolved solids, or TDS, refers to the total mass

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of all dissolved constituents (as ions) present in groundwater. The U.S. EPA's NSDWR puts a suggested limit of 500 mg/L on this parameter. The TDS can easily be approximated by using a specific conductance or electrical conductance meter to measure the electrical conductivity of water (its ability to conduct electricity). Conductivity has the following relationship with TDS (Hem 1986):

TDS = specific conductance × 0.59.

Distilled water, having almost no dissolved minerals, would have a specific conductance of near zero. Rainwater is very dilute with a low specific conductance of about 20 microsiemens per centimeter (µS/cm), and water with a large TDS load (such as seawater) has a very high value (close to 60,000 µS/cm in the case of seawater) (Table 19-2). The specific conductance of the 500 mg/L standard would be about 850 µS/cm.

Environmental Isotopes

Isotopes are atoms of an element that have a different number of neutrons in the nucleus. Isotopes can be stable or radioactive. Because the number of protons and the electron configuration are the same as other atoms of that element, isotopes of a particular element behave similarly during chemical reactions. However, because the atomic weights are different, the isotopes of an element react at different rates, which results in different concentrations of isotopes in the coexisting phases of a compound or in the reaction products of chemical, physical, and biological processes. This natural partitioning process is very important in the field of stable isotope geochemistry and is quite useful for determining the source of water or certain dissolved constituents and for figuring out the geochemical processes that have occurred to give the present-day chemical composition of a certain groundwater. The use of environmental isotopes can help solve groundwater quality problems by establishing the source of contaminants (natural or human-induced). The isotopes can also be used to protect groundwater by helping to identify groundwater recharge areas and groundwater flow velocities. Elements with stable isotopes that are commonly used in groundwater studies include oxygen, hydrogen, carbon, sulfur, nitrogen, and, to a lesser degree, chlorine, strontium, helium, and beryllium.

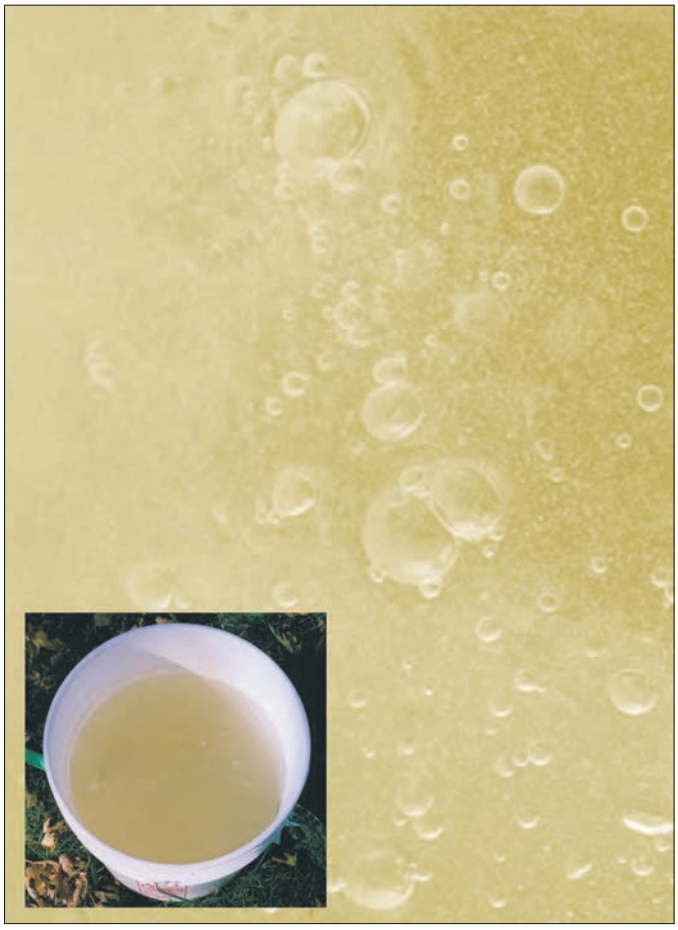

Figure 19-9 Gas (predominantly methane) bubbling out of groundwater pumped from the Mahomet aquifer in central Illinois. The largest bubbles were up to 1 inch (2.54 cm) in diameter. The presence of methane indicates reducing conditions within the aquifer. (Photographs by Samuel V. Panno.)

Radioactive isotopes have unstable nuclei and change into different atomic elements through spontaneous decay involving the emission of particles and energy. The rates of decay differ widely for the various radioactive isotopes, ranging from a fraction of a second to billions of years. The rate of decay is usually referred to as the half-life, the time needed for the concentration of the radioactive isotope to decrease by one-half. In hydrology, radioactive isotopes are typically used to determine the relative age of water and as tracers to help determine the source of water or of dissolved constituents in the water. Several radioactive isotopes are used in groundwater research; however, the most common are tritium (^{3}H), with a 12.3-year half-life, and carbon-14 (^{14}C), which has a 5,730-year half-life.

Two very good sources for information about isotope geochemistry applied to groundwater hydrology are Clark and Fritz (1997) and Kendall and McDonnell (1998). Examples of the use of isotope geochemistry applied to Illinois groundwater include the determination of origin of high-sulfate concentrations in deep aquifers of northern Illinois (Gilkeson et al. 1981), the processes controlling the enrichment of radium-226 and uranium-234 in the Cambrian and Ordovician aquifers of northern Illinois (Gilkeson et al. 1983), the origin of methane in glacial drift and Paleozoic bedrock (Coleman et al. 1988), detection of the impacts of landfill leachate and gases on local groundwater chemistry (Hackley et al. 1996, 1999), determination of sources of elevated nitrate concentrations (Panno et al. 2001, Hackley et

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al. 2007, Roadcap et al. 2002, Hwang et al. 2003), the origin of the Illinois Basin brines and Mississippi Valley-type ore deposits (Clayton et al. 1966, Richardson et al. 1988, Stueber and Walter 1991), and the age of groundwater in a buried bedrock valley of central Illinois (Hackley 2002).

Although the concentrations of most radioactive isotopes measured in Illinois groundwater are low and do not detrimentally affect groundwater quality, dissolved radium from the deep Cambrian and Ordovician aquifers of northern Illinois is often present in relatively high concentrations. More than 300 wells in this area exceeded the U.S. EPA NPDWR for radium (Gilkeson et al. 1983). Radium-226 and radium-228 concentrations in groundwater ranged from 2.3 to 50.2 picocuries per liter (pCi/L); the U.S. EPA regulatory limit for the two radionuclides is 5.0 pCi/L (U.S. EPA 1991, 2009). The source of the radium in the aquifers is thought to be fine-grained materials such as the shale layers that form the bounds of the sandstone aquifers.

Conclusion

The quality of groundwater in Illinois changes with depth and location of the aquifer. Shallow surficial aquifers, such as glacially deposited sand and gravel or bedrock units near the land surface in the northern third of the state, contain relatively dilute groundwater compared with groundwater from deeper bedrock aquifers in the central and southern two-thirds of the state. Most of the aquifers in Illinois are made up of carbonate rock or contain considerable amounts of carbonate rock fragments, resulting in an almost ubiquitous problem with hard water. Many of the unconsolidated sand and gravel aquifers are deposited within fine-grained glacial tills and are confined aquifers that are under reducing conditions. The reducing conditions result in considerable amounts of dissolved iron and manganese and, in some cases, methane (drift gas). Most private wells in rural areas of Illinois use water softeners to extract iron and decrease the hardness of the groundwater. Groundwater pumped from wells in the central and southern parts of the state quickly become more saline as depths of wells increase and penetrate into the Pennsylvanian and deeper Paleozoic aquifers. Sodium and chloride concentrations tend to increase as depth increases.

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Appendix 10

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Groundwater

Recharge and Groundwater Flow Within an Intracratonic Basin, Midwestern United States

by Samuel V. Panno[1], Zohreh Askari[2], Walton R. Kelly[3], Thomas M. Parris[4], and Keith C. Hackley[5]

Abstract

The conservative nature of chloride (Cl^-) in groundwater and the abundance of geochemical data from various sources (both published and unpublished) provided a means of developing, for the first time, a representation of the hydrogeology of the Illinois Basin on a basin-wide scale. The creation of Cl^- isocons superimposed on plan view maps of selected formations and on cross sections across the Illinois Basin yielded a conceptual model on a basin-wide scale of recharge into, groundwater flow within and through the Illinois Basin. The maps and cross sections reveal the infiltration and movement of freshwater into the basin and dilution of brines within various geologic strata occurring at basin margins and along geologic structures. Cross-formational movement of brines is also seen in the northern part of the basin. The maps and cross sections also show barriers to groundwater movement created by aquitards resulting in areas of apparent isolation/stagnation of concentrated brines within the basin. The distribution of Cl^- within the Illinois Basin suggests that the current chemical composition of groundwater and distribution of brines within the basin is dependent on five parameters: (1) presence of bedrock exposures along basin margins; (2) permeability of geologic strata and their distribution relative to one another; (3) presence or absence of major geologic structures; (4) intersection of major waterways with geologic structures, basin margins, and permeable bedrock exposures; and (5) isolation of brines within the basin due to aquitards, inhomogeneous permeability, and, in the case of the deepest part of the basin, brine density effects.

Introduction

The geochemical origin and the movement of brines within intracratonic sedimentary basins have been the subject of numerous studies for much of the latter half of the 20th century (e.g., Bethke et al. 1988; Hanor 1994). An understanding of these influences on the groundwater chemistry within the basin is important for water resource evaluation and natural resource exploitation. Moreover, reservoirs in intracratonic basins have been used for storage of natural gas, and the disposal of a variety of industrial, oil field, and other types of wastes (e.g., Bergstrom 1968). The magnitude of this disposal has increased considerably with injection of flow-back waters from unconventional oil and gas reservoirs and could increase with geologic carbon sequestration (Locke et al. 2013).

The Illinois Basin in the U.S. Midwest (Figure 1) is an anomaly among intracratonic basins because it contains no known halite-bearing evaporite sequences that could contribute to brine formation. The chemical composition and origin of brines in the Illinois Basin have been shown to be unique for Cambrian, Ordovician, Silurian–Devonian, and Mississippian–Pennsylvanian strata (Stueber et al. 1987; Walter et al. 1990; Stueber and Walter 1991, 1994; Panno et al. 2013). Groundwater movement within the Illinois Basin was studied by Cartwright (1970) using thermal anomalies in the southern half of Illinois and by Siegel (1989) using stable isotopes in northern Illinois. Both concluded that groundwater flows toward the center of the basin becoming more sluggish with depth, and discharges upward across confining units. Cartwright (1970) further suggested that upward movement of groundwater should occur along fractures associated with geologic structures.

Total dissolved solids (TDS) and chloride (Cl^-) concentrations of brines within intracratonic basins typically increase with depth (Domenico 1972). Within the Illinois Basin, Cl^- concentrations range from about 1 mg/L in shallow aquifers to over 200,000 mg/L for the deepest Paleozoic strata (Panno et al. 2013). Variable permeability and hydraulic gradients within Paleozoic

[1]Corresponding author: Illinois State Geological Survey, 615 E. Peabody Drive, Champaign, IL 61820; (217) 244-2456; E-mail: s-panno@illinois.edu

[2]Illinois State Geological Survey, 615 E. Peabody Drive, Champaign, IL 61820.

[3]Illinois Water Survey, 2204 Griffith Drive, Champaign, IL 61820.

[4]Kentucky Geological Survey, 504 Rose St., Lexington, KY 40508.

[5]Isotech Laboratories, Inc., 1308 Parkland Ct., 61821.

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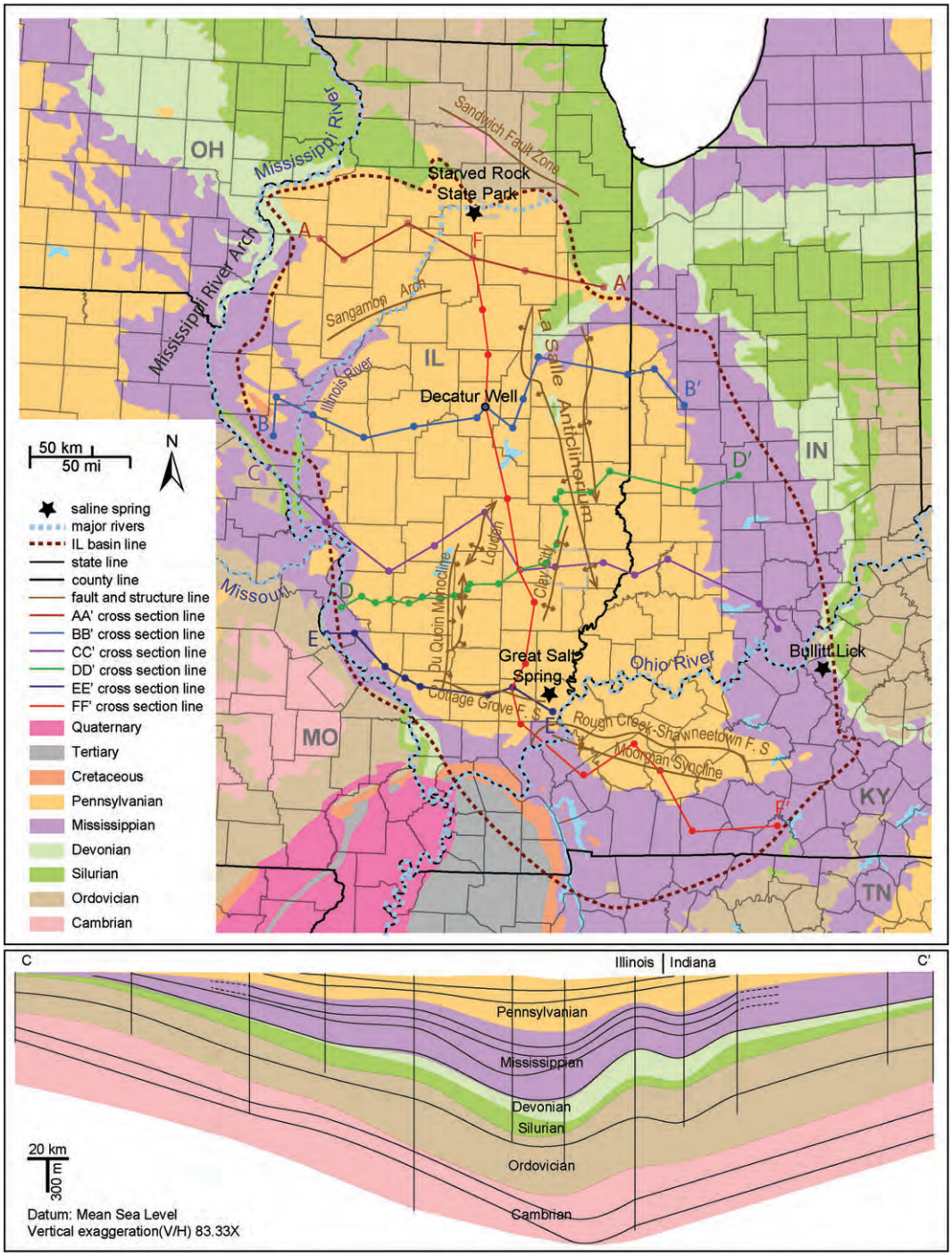

Figure 1. Cross section location map showing bedrock geology and structural features within the Illinois Basin. The bedrock geology was modified from Young (1992). East-west cross section C–C′ (at the bottom of the figure) shows the major strata, by age, of the basin.

strata, freshwater recharge at the margins of the basin and along zones of high permeability, and migration of brines through fractures associated with structural features all can cause departures from a monotonic increase in TDS and Cl^- concentrations with depth. Given the absence of halite-containing evaporites within the Illinois Basin, the conservative nature of Cl^- should allow it to act as a natural tracer revealing zones of recharge and preferential groundwater flow paths into, through, and out of the Illinois Basin (Figure 1). Chloride distribution should also indicate zones of low and high permeability, as well as zones of low flow, stagnation, or both. Mapping the distribution of Cl^- concentration in cross sections provides an efficient means of identifying dilution of basin brines within Paleozoic strata, mixing between aquifers, the isolating effects of aquitards, and potential flow paths along geologic structures (e.g., Panno et al. 1994).

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Whereas, there has been a great deal of research on the Illinois Basin, previous studies have focused on selected formations and only portions of the basin. No basin-wide scale study has been done that would provide a comprehensive understanding of the hydrogeology of the Illinois Basin. Consequently, there is limited information regarding groundwater movement within and only speculation regarding discharge from the basin. The purpose of this investigation was to develop a conceptual model of recharge to, groundwater movement within, and discharge from the Illinois Basin on a basin-wide scale. To do this, we created plan-view maps of selected formations and detailed cross sections extending across the Illinois Basin and added Cl^- concentration data from oil and gas wells, municipal and private water wells, gas-injection wells, and published data. The Cl^- concentrations are represented with symbols and isocons on maps and cross sections that yield information regarding the current hydrogeologic state of the basin. This is important because recharge, groundwater movement within, and discharge from the basin can have a direct bearing on the transport of hydrocarbons, the feasibility of the sequestration of CO_2, and maintaining groundwater quality in those areas affected by basin brines and could provide insight into the source or flow paths of brines for the formation of Mississippi Valley-type ore deposits.

Geology and Hydrogeology of the Illinois Basin

The geology of the Illinois Basin is summarized from Collinson et al. (1988) and Kolata and Nelson (2010). Briefly, the Illinois Basin developed on Precambrian crystalline basement and now underlies most of the state of Illinois, western and southwestern Indiana, western Kentucky, and a portion of northwestern Tennessee (Figure 1). The basin is filled with Paleozoic marine sedimentary rocks ranging from Cambrian through Pennsylvanian that gently dip toward the center of the basin and extend to a depth of up to 9144 m along the Rough Creek Graben in western Kentucky (Goetz et al. 1992; Figure 1). The geometry, distribution, and interrelationships of the carbonate rocks, sandstones, and shales of the basin play a key role in recharge to and groundwater flow within the basin. Paleozoic sandstones and carbonate rocks whose groundwater is brackish to saline elsewhere in the basin, constitute productive aquifers in the northern-most part and along the eastern and western margins of the Illinois Basin, and shales constitute effective aquitards within the basin.

Cambrian and Ordovician aquifers are used extensively as a source of potable water in the northern third of Illinois (Larson and Herzog 2004). The Cambrian Mount Simon Sandstone is rarely used because it is only potable in the northern one-fifth of the state and has a moderately low permeability due to its well-cemented nature. Shale, siltstone, and dolomite of the overlying Eau Claire Formation act as a confining unit. The overlying Ironton-Galesville Sandstone is made up of a well-sorted and fine-grained sandstone, confined by overlying dolomites, shales and some sandstones, and provides a reliable potable water source. The Ordovician Glenwood-St. Peter Sandstone and overlying fractured and creviced Galena-Platteville Dolomite constitute major aquifers for northern Illinois. Because of their close proximity, these aquifers and are often combined into a single hydrogeologic unit referred to as the Cambrian-Ordovician aquifer. The St. Peter Sandstone is a relatively thick, well-sorted, fine-to medium-grained and loosely cemented sandstone of marine origin and belongs to the Ancell Group, which includes the overlying Glenwood Formation made up of sandstone, dolomite, and shale (Willman et al. 1975). In addition to being a prolific aquifer, the St. Peter Sandstone has long been known as a source of high-quality pure quartz sand in northern Illinois where it is exposed at the surface near, within, and north of Starved Rock State Park (Lamar 1928). The St. Peter Sandstone ranges from 1 to up to 275 m thick, averages between 30 and 100 m thick throughout the Illinois Basin (Willman et al. 1975), and is either exposed or shallowly buried in northern Illinois and at the northern margin of the basin. In this article, we focused on the water quality data from the St. Peter Sandstone. The Upper Ordovician Maquoketa Shale constitutes a confining unit between the underlying Cambrian-Ordovician aquifer and overlying Silurian strata.

Silurian strata consist of mostly fractured and creviced dolomite in the northern part of the basin and limestone in the southern part of the basin. Because of its karst nature, water yields range from small to very large. Devonian strata are predominantly limestone with some dolomite and shale; these strata are not present in the northern part of the basin because of erosion. These strata yield only small to moderate volumes of groundwater and are confined from the overlying Mississippian strata by the New Albany Shale (Larson and Herzog 2004).

Similarly, Mississippian strata are missing from the northern part of the basin because of erosion and are made up of limestone, with lesser amounts of dolomite, shale, siltstone, and sandstone. These strata are exposed on the margins of the Illinois Basin in western and southwestern Illinois and on the eastern margin in central Indiana, and are well known for their karst nature. Overlying Pennsylvanian strata are made up of predominantly shale with beds of sandstone, siltstone and limestone, and coal measures. These strata are thin to missing in the extreme northern part of the Illinois Basin due to erosion. Pennsylvanian strata typically constitute an aquitard, although some of its sandstone and limestone layers can yield small amounts of potable groundwater in the vicinity of outcrop areas. In much of Illinois and Indiana, Paleozoic rocks are capped by a thick layer of Pleistocene glacial drift that includes thick sand and gravel layers that are typically sandwiched between clay-rich tills. The sand and gravel deposits are used extensively in these states as freshwater aquifers; the Mahomet aquifer is a classic example of a glacial drift aquifer (e.g., Kempton et al. 1991).

Groundwater of the Illinois Basin ranges from extremely fresh $Ca\text{-}HCO_3^-$ type water at the near surface to concentrated mixed-cation-Cl^- brines at the deepest

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part of the basin where Cl^- concentrations can be hundreds of grams per liter (Clayton et al. 1966). The salinity of the groundwater within the basin is typically stratified (Panno and Hackley 2010) with most shallow groundwater containing Na and Cl^- concentrations in sand and gravel aquifers between 1 and 15 mg/L for each ion (Panno et al. 2006). The sources of the Na-Ca-Cl-type brines of the Illinois Basin were studied by Stueber et al. (1987), Walter et al. (1990), Stueber and Walter (1991, 1994), Panno et al. (2013), and Labotka et al. (2015, 2016). These studies suggested, based on halide–halide and halide–cation ratios, and stable isotopes ($^{87}Sr/^{86}Sr$, δD and $\delta^{18}O$), that brines of the Illinois Basin originated as evaporated seawater and are composed of four geochemically distinct fluid regimes (Cambrian, Ordovician, Silurian–Devonian, and Mississippian–Pennsylvanian). Petroleum is found in Ordovician through Pennsylvanian rocks in the central and southern parts of the basin, and groundwater within these strata is highly saline. Because of the high salinity, few systematic hydrogeological studies have been conducted in these regions.

Methodology

Five east-west and one north-south cross section were constructed to illustrate the subsurface distribution of Cl^- in the Illinois Basin (Figure 1). The geologic data for the cross sections were compiled from geophysical logs from the Illinois State Geological Survey (ISGS) database and imported to GeoGraphix Discovery v5000 software (LMK Resources Inc., Houston, Texas) to create the cross sections and index maps. Boreholes that provided geologic data are represented as vertical lines in the cross sections; geologic structures were compiled from Nelson (1995).

The cross sections were populated with more than 600 Cl^- concentrations for groundwater samples from Cambrian through Pennsylvanian strata. Chloride concentration data are from Bartow et al. (1909), Meents (1952), Keller (1983), McIntosh et al. (2002), Panno et al. (2013), the Illinois State Water Survey (ISWS) Groundwater Quality Database (data available from ISWS on request), and the Kentucky Geological Survey (unpublished data). Well depths and screened intervals (or formation[s] from which groundwater was accessed) are available from these sources. Where brine data were acquired from oil fields, we used only samples collected before the onset of waterflood operations in oil fields to avoid possible contamination by mixing of brines or fresher waters from different stratigraphic units or dilution/contamination from drilling fluids. The Cl^- concentrations are represented with symbols, and by hand-contoured isocons, which represent locations of equal Cl^- concentrations. Adobe Illustrator CC 2015 (Adobe Systems, Incorporated, San Jose, California) was used for final editing and adding Cl^- concentration data for cross sections.

Chloride and TDS concentrations are highly correlated for these samples. The following equations developed by the authors of this article from data collected from fresh water aquifers, NaCl-enriched groundwater, and oil field brines in Illinois, were used to convert TDS concentrations to Cl^- concentrations (both in mg/L). Equations 1 and 2 were used for samples with TDS concentrations less than and greater than or equal to 5000 mg/L, respectively:

$$< 5000\,\text{mg/L} : Cl^- = 0.0022 \times TDS^{1.5328} \quad (R^2 = 0.895) \tag{1}$$

$$\geq 5000\,\text{mg/L} : \; Cl^- = 0.637 \times TDS \quad (R^2 = 0.989) \tag{2}$$

The relationship between TDS and Cl^- is supported by others working with a spectrum of water ranging from fresh to concentrated brines (Frape et al. 1984). For this article, the conversion was used for a direct comparison of Cl^- concentrations in cross sections and plan-view maps.

In addition to the cross sections, Cl^- isocon maps using simple interpolation were prepared for the Cambrian Mount Simon Sandstone (Figure 2) and the Ordovician St. Peter Sandstone (Figure 3). It is not clear, based on the sources of our data, whether the wells intersected both the Glenwood and St. Peter Sandstones or just the St. Peter Sandstone. Given their close proximity, and for our purposes we refer to the aquifer as the St. Peter Sandstone. The shaded counties contain one or more data points used in creating and contouring the St. Peter Sandstone map. A similar map, prepared for the Mount Simon Sandstone based on TDS data reported by Mehnert and Weberling, (2014; Figure 2), allowed comparison of Cl^- isocons with those of the St. Peter Sandstone (Figure 3). Not all cross sections and plan-view maps have the same density of data; consequently, some uncertainty/bias may be present in the interpretations. However, given the drilling activity in searching for fresh groundwater in the Illinois Basin, it is unlikely that formations containing potable groundwater would have gone undiscovered for more than a century.

Results and Discussion

Here we present, for the first time, plan view maps of selected formations and cross sections of the Illinois Basin containing Cl^- concentrations and isocons whose variability and patterns reflect the effects of freshwater recharge into and within a brine-dominated flow system. These patterns may be used as indicators of recharge, freshwater-brine mixing, cross-formational and flow-through movement of groundwater, and areas of brine stagnation within the basin.

Cambrian–Ordovician Aquifers

The aquifers of the Cambrian Mount Simon Sandstone, and the Ordovician Ironton-Galesville Sandstone, Glenwood-St. Peter Sandstone and Galena-Platteville Dolomite were referred to as the Cambrian-Ordovician Aquifer by Siegel and Mandel (1984) and Siegel (1989). However, they did not include the lowermost Mount

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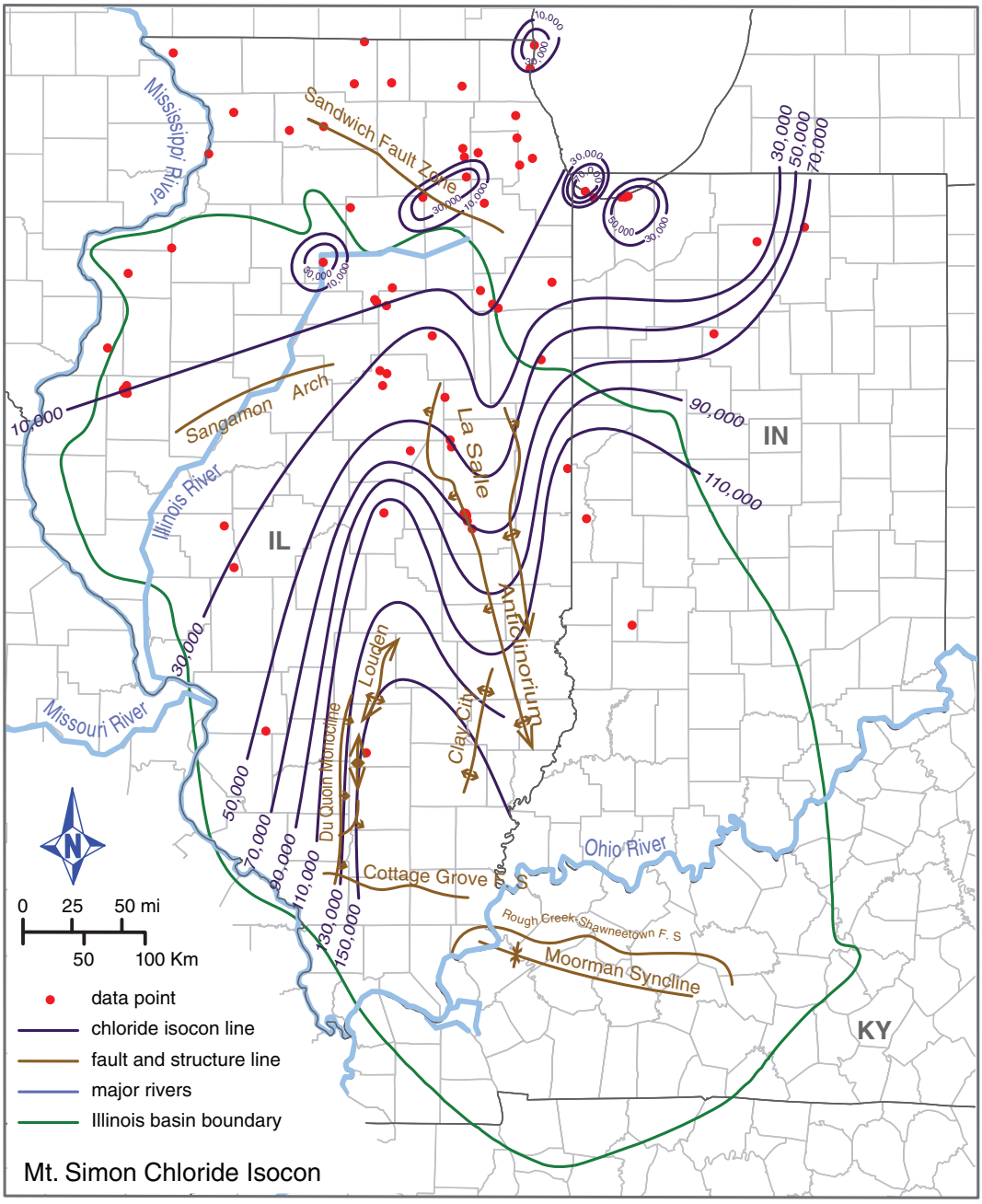

Figure 2. Chloride isocons in groundwater for the Mount Simon Sandstone. Water quality data (as TDS) are from Mehnert and Weberling (2014) and were converted to Cl^- concentrations using Equations 1 and 2.

Simon Formation because of the relatively high salinity of groundwater within this sandstone. These formations are used extensively in the northern third of Illinois for potable groundwater by municipalities and industries with wells that are often open to multiple aquifers (Larson and Herzog 2004).

Mount Simon Sandstone

The Mount Simon Sandstone represents the base of the Paleozoic sedimentary rock sequence that makes up the Illinois Basin. Unlike the St. Peter Sandstone, the Mount Simon Sandstone is rarely used as a freshwater resource because of its elevated TDS throughout the Illinois Basin. Mehnert and Weberling (2014) prepared a map of the distribution of TDS of brines within the Mount Simon Sandstone for much of the Illinois Basin. The data for this formation are from wells that are screened only within the Mount Simon Sandstone. We converted the TDS into Cl^- concentrations (for consistency within this investigation), contoured the data by hand, and added the Illinois River and pertinent geologic structures for interpretation purposes (Figure 2).

The Mount Simon isocon map shows preferential recharge from the northern, northwestern, and western boundaries of the Illinois Basin, and from north to south along the LaSalle Anticlinorium. The map also shows

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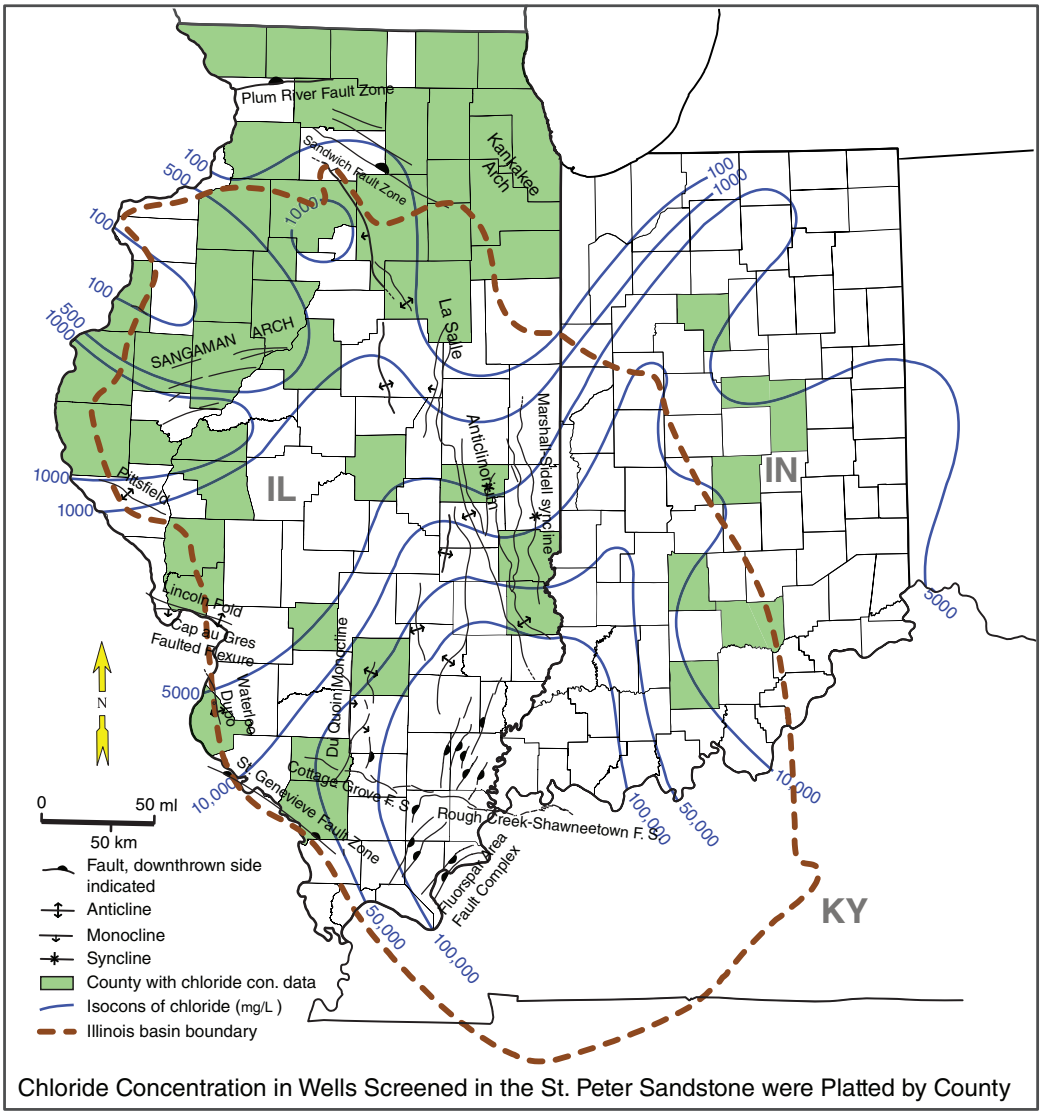

Figure 3. Chloride isocons in groundwater for the St. Peter Sandstone. Water quality data are from groundwater samples from wells screened in the St. Peter Sandstone. All concentrations are from published data and were plotted by county.

the presence of concentrated brines in the center of the basin in southern Illinois. Preferential recharge along the LaSalle Anticlinorium is of particular interest. The LaSalle Anticlinorium is a large geologic feature made up of numerous subparallel structures that collectively extend from southeastern Illinois to north-central Illinois and include anticlines, domes, monoclines, and synclines (Nelson 1995). Uplift of the LaSalle Anticlinorium occurred primarily during the late Paleozoic Era (Late Mississippian) but before the Pennsylvanian, and resumed after the Pennsylvanian. The anticlinorium was interpreted by Nelson (1995) to be the result of fault movement and displacement within the crystalline basement during the Late Paleozoic Era. Nelson (1995) suggests that the faults die out as they cut upward into the sedimentary rocks, and the structures of the LaSalle Anticlinorium become essentially drape folds. Recent seismic-reflection profiles by Kamp et al. (2016) suggest that the anticlinorium may be a fault system with strike-slip displacement.

The Mount Simon Cl^- isocon map (Figure 2) shows that salinity anomalies in the northern part of the basin and around the edge of Lake Michigan coincide with the Illinois River and the Sandwich Fault Zone. The saline anomaly farthest west and along the Illinois River (within and near Starved Rock State Park) contains nearly 40,000 mg/L of Cl^-. Just north and south of the anomaly, Cl^- concentrations are only 319 mg/L or less, and 7000 mg/L or less, respectively. This saline anomaly is coincident with the Illinois River and is probably associated with saline springs (Willman and Payne 1942) and relatively shallow saline wells (Panno, ISGS, unpublished data) of the Starved Rock State Park and surrounding area. The very low Cl/Br mass ratio of this groundwater (149 to 216; Panno, ISGS, unpublished data) suggests that the salinity originates from a mixture of brines from the underlying Cambrian and Ordovician strata, and perhaps crystalline basement brines (Table S1, Supporting Information). The upwelling of crystalline basement brines at

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least into lower Cambrian strata is likely, based on work by Panno et al. (2013) and Labotka et al. (2015, 2016).

St. Peter Sandstone

The distribution of Cl^- on the isocon map for the St. Peter Sandstone suggests that recharge takes place along the northwestern (from Iowa) and central and northeastern parts (from northern Illinois) of the margins of the Illinois Basin (Figure 3). Recharge in these areas and groundwater flow into the Illinois Basin within this formation is consistent with groundwater flow directions for the northern and northeastern portion of the Illinois Basin identified by Siegel (1989) and Young (1992) based on predevelopment potentiometric surface data. Stable isotope data were determined from saline water samples from the St. Peter Sandstone collected from a well near Decatur, IL located about 160 km south of Starved Rock State Park (Figure 1), about 50 km south of Siegel's (1989) study area. The Decatur, Illinois, sample showed isotopically light (δD and δ^{18}O of −61.7 and −9.13, respectively) indicating a component of Pleistocene glacial meltwater (Panno and Fanta, unpublished report, Electronic Supplement). These data are consistent with those of samples collected from wells within the St. Peter Sandstone located in the vicinity of the Decatur well (Kelly, ISWS, and Panno, ISGS, unpublished data; Figure 1).

The Cl^- isocons also show that enhanced recharge is occurring horizontally along the LaSalle Anticlinorium (Figure 3) similar to that of the Mount Simon Sandstone (Figure 2). Dilation of fractures along faults and folds associated with the anticlinorium could provide preferential groundwater flow paths for groundwater (e.g., Bethke 1986). The Cl^- isocons of the St. Peter Sandstone (Figure 3) reveal that enhanced recharge is occurring horizontally along the LaSalle Anticlinorium (Figure 3) very similar to that of the Mount Simon Sandstone (Figure 2). We suggest, based on these isocon maps, that the LaSalle Anticlinorium provides structural controls on recharge and groundwater movement within the Illinois Basin and serves as a preferential flow path from north to south probably along fractures and faults associated with the anticlinorium. Stueber and Walter (1994) noted that the δ^{18}O of brines from the Ordovician Galena Formation had a meteoric-water signature for only those samples collected along the LaSalle Anticlinorium. These data support the concept of its role as a zone of enhanced anisotropic permeability with greater and/or more rapid recharge and groundwater movement along this structure within at least Cambrian and Ordovician strata. This structure also has been identified as the location of thermal anomalies and saline springs (Cartwright 1970; Panno et al. 1994; Panno, ISGS, unpublished data) suggesting the anticlinorium is a zone of enhanced permeability throughout the entire Paleozoic sequence. In addition, the LaSalle Anticlinorium has been described by Bethke (1986) as a structure that may have "funneled" ore-forming solutions from the southern part of the Illinois Basin to the host rocks of the Upper Mississippi Valley ore district to the north (Figure 1) in post-Pennsylvanian time. Finally, whereas Devonian rocks are exposed in isolated locations along the LaSalle Anticlinorium, it is unlikely that recharge via these "windows" through the Pennsylvanian strata is responsible for the preferential flow patterns in the St. Peter Sandstone or the Mount Simon Sandstone.

Cross Sections of the Illinois Basin

Chloride isocons on the cross sections (Figures 4–8 and S1) reveal patterns of recharge, stratification, paths of preferential groundwater flow, zones of near stagnation, and flow directions within and through the basin. The isocons often reveal strong contrasts in groundwater Cl^- concentrations in adjacent stratigraphic units, which suggests areas with limited to negligible vertical mixing and near stagnant brines. Some of the cross sections also show the effects of the LaSalle Anticlinorium on enhanced recharge into the basin. In addition, the isocons show that the shales of the Pennsylvanian strata, where present, provide a low flow boundary for recharge into the underlying strata. The cross sections are discussed in detail further.

The northernmost part of the Illinois Basin is characterized by exposures of Cambrian and Ordovician strata. Consequently, these strata are more easily recharged and groundwater in this area contains the lowest concentrations of Cl^- in the Illinois Basin (Figure 4). As a result, some of the lowest Cl^- values (e.g., all values are below that of average seawater of 19,800 mg/L; Table S1) are found in this part of the basin. Here, the shallowest bedrock (Pennsylvanian strata) contains Cl^- concentrations that are typically less than 100 mg/L, and concentrations barely exceed 20,000 mg/L in the deeper, typically briny, Mount Simon Sandstone. The isocons of A–A′ (Figure 4) indicate recharge of low Cl^- water to all Paleozoic formations along the northernmost margins of the Illinois Basin where the Ordovician St. Peter Sandstone is exposed at and near Starved Rock State Park. The low Cl^- concentrations in this area are consistent with findings by Siegel (1989, 1991) and Panno et al. (2013), who showed, using groundwater chemistry and stable isotopes, that Pleistocene recharge extended into the Illinois Basin from the north and west. McIntosh et al. (2002) showed a similar recharge into Devonian and Mississippian strata from the east. As cross section A–A′ (Figure 4) shows evidence of several isolated/narrow plumes of groundwater with elevated Cl^- concentrations, it is likely that there is an upward hydraulic gradient where deeper, saline groundwater is welling up to the surface. The widespread saline anomaly within and in the vicinity of Starved Rock State Park (Willman and Payne 1942; Panno, ISGS, unpublished data) is coincident with these plumes. The sporadic occurrence of saline wells, springs, and plumes of saline groundwater in this area suggest the upward movement of saline groundwater along faults and fractures.

Farther south, freshwater recharge is evident along the western margin of the basin and along the LaSalle Anticlinorium where Pennsylvanian shale is thin to absent (Figure 5). The greatest recharge appears to have been to

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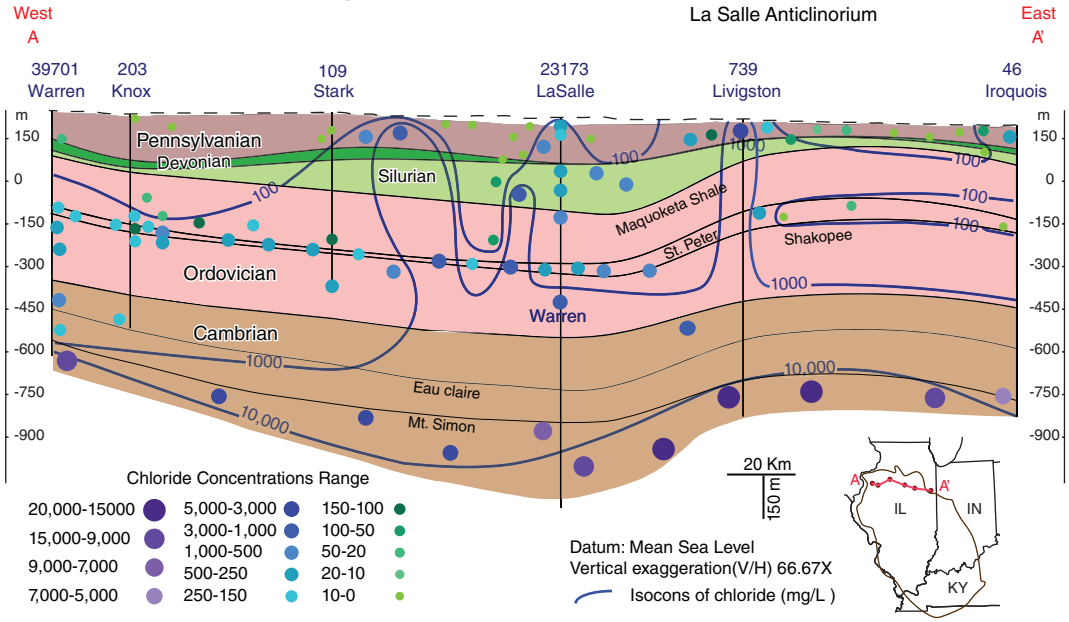

Figure 4. Cross section A–A′ extending east-west across northern Illinois. The most dilute groundwater in the Illinois Basin is found in the northern part of the basin because of the shallowness or exposure of the formations in this area, or both. Recharge is apparent from dilution effects from the west and east, and an upward movement of brines near the center of the cross section in the vicinity of the Illinois River.

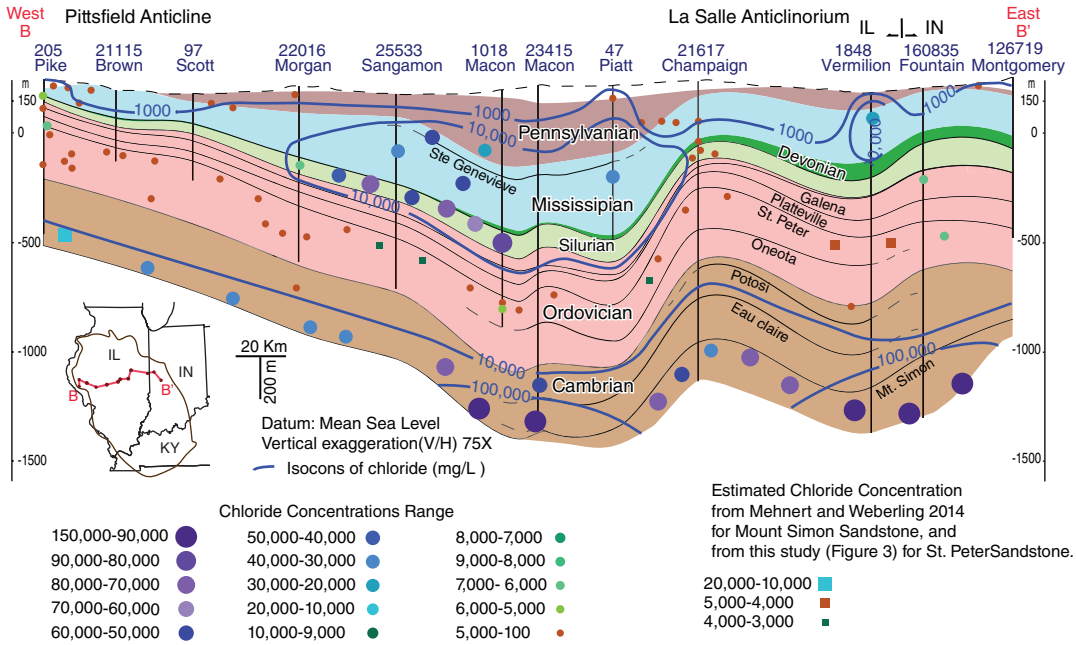

Figure 5. Cross section B–B′ extending east-west across central Illinois and central Indiana. The effects of freshwater recharge are apparent where Pennsylvanian strata are thin or absent and along the western and eastern margins of the basin and along the LaSalle Anticlinorium. Residual brines are present near the center of the cross section in Silurian–Devonian and Mississippian strata. The most concentrated brines are present near the center and far western part of the Cambrian strata.

Ordovician strata, primarily into the St. Peter Sandstone. Some of the lowest Cl^- concentrations are located along the LaSalle Anticlinorium. In the central region of cross section B–B′ (Figure 5), pools of dilute groundwater within the St. Peter Sandstone extend below pools of basin brines where Pennsylvanian strata are thickest. Greater concentrations of Cl^- lie within the Silurian, Mississippian, and Pennsylvanian strata above (many greater than 50,000 mg/L) and the Cambrian strata below (some greater than 100,000 mg/L). The greatest Cl^- concentrations are found within Cambrian strata on either side of the LaSalle Anticlinorium probably related to the effects of north to south fresh-water recharge within the Cambrian along the anticlinorium (Figure 2).

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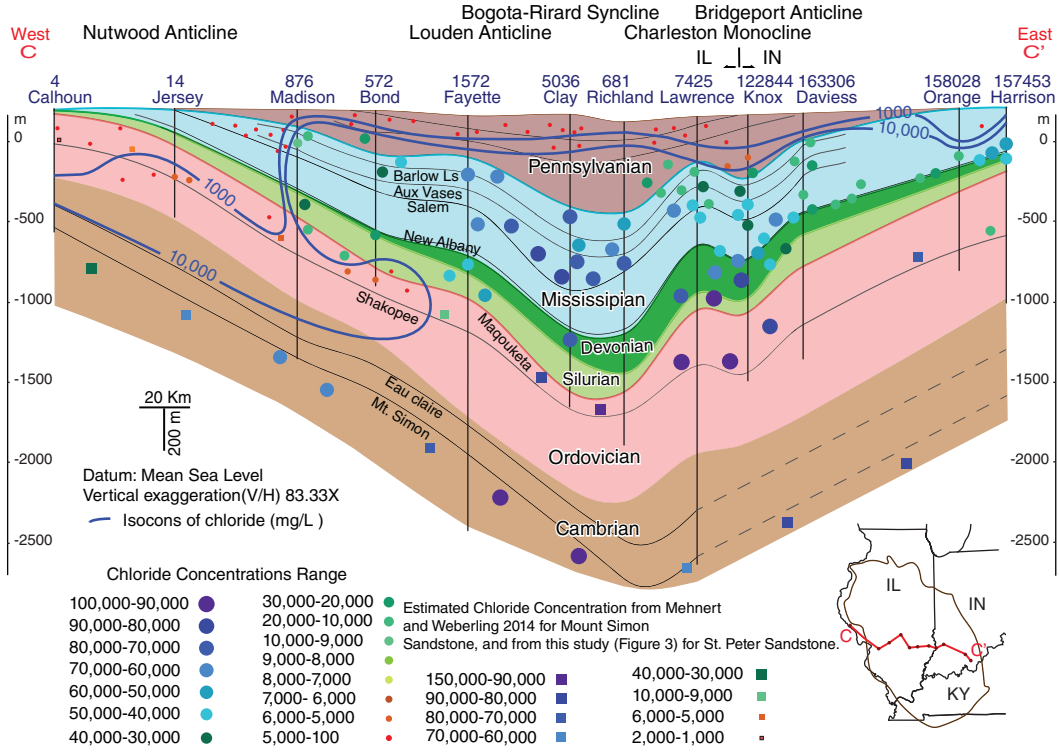

Figure 6. Cross section C–C′ extending east-west across southern Illinois and southern Indiana. The effects of freshwater recharge are most prominent at the western edge of the basin and in upper 200 m of Pennsylvanian strata. The most concentrated brines are present in the Cambrian Mount Simon Formation near the center of the basin.

Across the central portion of the Illinois Basin, cross section C–C′ reveals dilution of brines along zones of recharge at the western and, to a lesser extent, at the eastern edges of the basin where Pennsylvanian strata have been eroded (Figure 6). A relatively large plume of freshwater from the west has penetrated deep into the basin along Ordovician strata. The exposure of Ordovician, Silurian–Devonian, and Mississippian strata along the Mississippi River is a likely location for focused recharge, probably from glacial meltwaters during the Pleistocene Epoch. As the plume approaches the deepest part of the basin, it is bounded above by the Maquoketa Shale, below by the Eau Claire Formation, as well as above and below by brines with greater Cl^- concentrations. Dilution of brine within the Mount Simon Sandstone is also present from both the west and east, but to a lesser extent.

Freshwater recharge is indicated for much of the Pennsylvanian strata where Cl^- concentrations are less than 100 mg/L for the upper 50 to 100 m. Conversely, Cl^- concentrations in Mississippian through Silurian strata near the center of the basin exceed 50,000 mg/L where they are bounded above by thick Pennsylvanian strata and below by the New Albany Shale. Brines within these dominantly carbonate rock strata are diluted by freshwater recharge from both the west and east (Figure 6).

Just south of cross section C–C′, cross section D–D′ reveals similar conditions, but extends no deeper than Ordovician strata due to the paucity of geologic and geochemical data in this area (Figure 7). As with cross section C–C′, Cl^- concentrations suggest active recharge from the west and east where Pennsylvanian strata are thin or absent. Recharge from the east and west extends into Paleozoic strata from both sides of the basin. The eastern portion of the cross section within Indiana reveals greater recharge from the east within Silurian through Mississippian strata. This is supported by McIntosh et al. (2002) who found that the Silurian–Devonian strata provided a hydrologic pathway for recharging Pleistocene meltwater to depths up to 1 km across the eastern margin of the basin, and recharge from Mississippian strata, through underlying fractured New Albany Shale, and into Silurian–Devonian strata in the southeastern part of the Illinois Basin. Cross section D–D′ suggests recharge from the west is entering exposed Ordovician and Mississippian strata along the Mississippi River Arch (Figure 7).

Freshwater recharge is limited within the center of the basin where Pennsylvanian strata are thick (more than 600 m). Dilution of Cl^- concentrations of 1000 mg/L or less is consistent across Pennsylvanian strata to a depth of 60 to 120 m; however, limited data suggests that Cl^- concentrations rapidly increase, with depth, to greater than 10,000 mg/L within Pennsylvanian strata. Chloride concentrations within the center of cross section D–D′ (along the deepest part of the basin) reveal the presence of concentrated brines within all strata. Freshwater recharge from the north is apparent within the LaSalle Anticlinorium in the eastern half of the cross section and occurs within Upper Ordovician through Mississippian strata.

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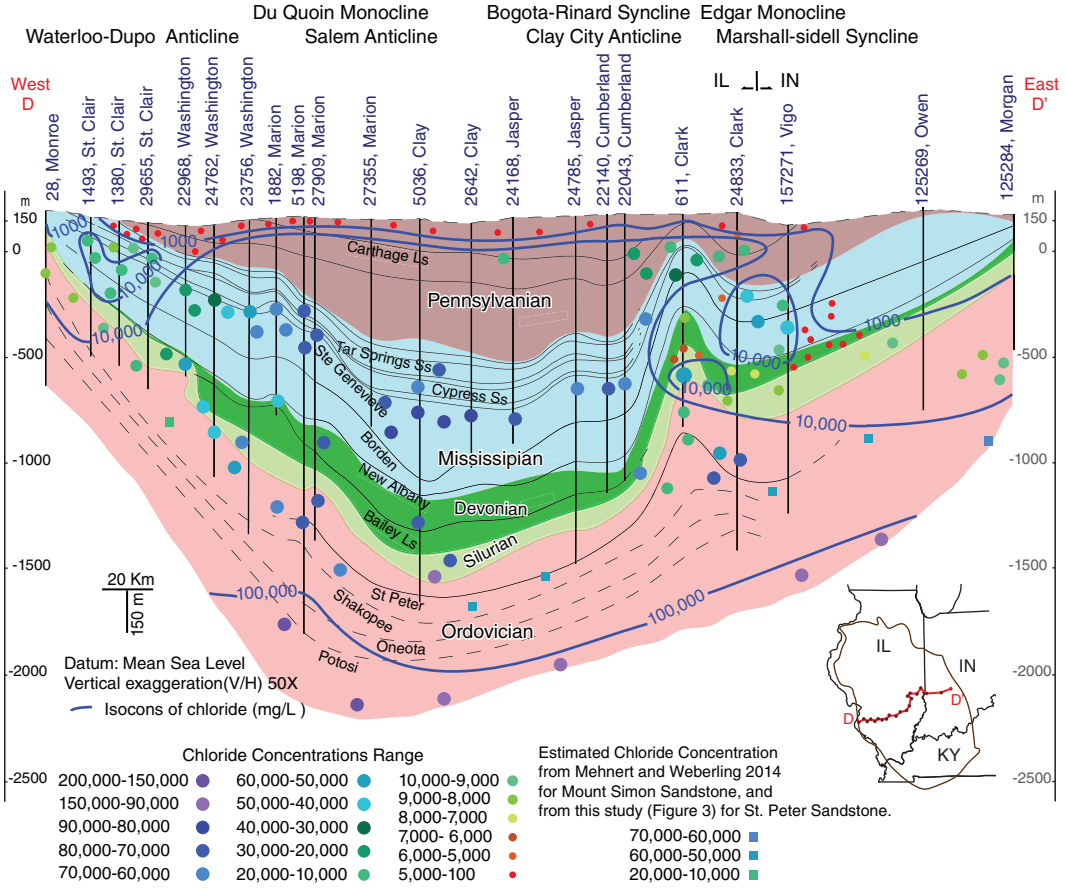

Figure 7. Cross section D–D′ extending east-west across southern Illinois and southern Indiana. Freshwater recharge affects the western and eastern margins of the basin, but not to the extent seen in cross sections farther north. Brines are also diluted along the LaSalle Anticlinorium (groundwater movement toward the reader). Again, the most concentrated brines are present in the Cambrian strata.

Farther south, cross section E–E′ does not extend beyond the Illinois-Indiana border and does not extend below Ordovician strata because of the paucity of geologic data (Figure S1). As with the cross sections C–C′ and D–D′, to the north, Cl^- concentrations show a plume of dilute water extending into the basin from the west. The absence of Pennsylvanian shale in the west has facilitated groundwater recharge where Ordovician through Mississippian strata are exposed along the Mississippi River Arch and in southwestern Illinois.

Constructed along the long axis of the Illinois Basin, cross section F–F′ reveals the effects of recharge, groundwater flow, and zones of stagnation within nearly the entire basin. It was used, in conjunction with the plan-view maps and east-west cross sections, as a conceptual model of recharge into, distribution of brines and brine-freshwater mixing within, and groundwater flow within and through the Illinois Basin. Based on the Cl^- concentrations and associated isocons, freshwater recharge is entering all Paleozoic formations including Cambrian strata in northern Illinois as seen in cross section A–A′ and B–B′ (Figures 4 and 5), and from the east and west (Figures 6, 7, and S1). Along the northern basin margin, Cl^- concentrations reveal a pool of dilute groundwater extending from Pennsylvanian strata at the surface downward into the Cambrian Mt. Simon Sandstone (Figure 8). The effects of freshwater recharge along the LaSalle Anticlinorium are seen in a short segment of the Mount Simon Formation about 200 km from the northern edge of the cross section. Here, Cl^- concentrations of Mount Simon brines are diluted below 100,000 mg/L. The overall distribution of isocons and Cl^- concentrations indicates groundwater flow from north to south through Ordovician strata with preferential recharge to and groundwater movement through the St. Peter Sandstone. The isocons also reveal a pattern of increasing Cl^- concentrations with distance from northern and western recharge areas about two thirds of the way to the southern end of the basin. Beyond the recharge zone to the north, thick Pennsylvanian strata protect brines within Silurian–Devonian and Mississippian strata from dilution by recharge; this is in contrast to the dilution of brines seen in these formations in the southern part of the basin where Pennsylvanian strata are thin to absent.

The separation of the 100,000 mg/L isocon within Cambrian strata in the northern third of cross section F–F′ is associated with dilution of brines along the LaSalle Anticlinorium. The deepest part of the basin contains the greatest concentration of Cl^- (and TDS) that extends from

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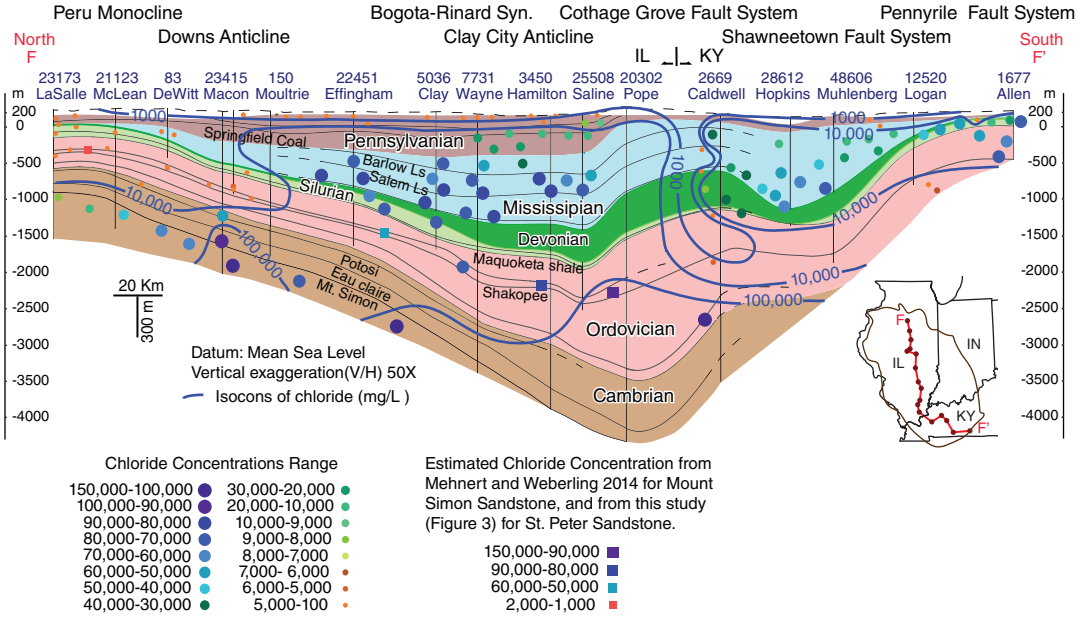

Figure 8. Cross section F–F′ extending north-south from northern Illinois to southwestern Kentucky. This cross section reveals the effects of freshwater recharge in the northern part of the basin, where much of the Paleozoic strata are exposed or near surface. The greatest dilution is apparent in the St. Peter Sandstone aquifer, and the most concentrated brines are present in Cambrian strata and up into Ordovician strata at the center of the basin. Focused recharge deep into Ordovician strata is apparent in the vicinity of the Ohio River near the Rough Creek-Shawneetown Fault System, where Pennsylvania strata is thin to absent.

Cambrian strata up into Ordovician strata. Cartwright (1970) and Siegel (1989) suggested that discharge of concentrated brines in southern Illinois may be by upward migration across leaky confining units. The area in this cross section where the greatest Cl^- concentrations extend into Ordovician strata is immediately beneath the Great Salt Spring located near Equality, Illinois with saline springs on either side of the Saline River indicating points of discharge. However, the saline water of the Great Salt Spring appears to be characteristic of Pennsylvanian strata based on Cl/Br mass ratios and not derived from Cambrian and Ordovician strata (Panno, ISGS, unpublished data). The saline springs in this area may suggest an upward hydraulic gradient, perhaps with mixing of the brines prior to reaching the surface. In addition, it is possible that concentrated crystalline basement brines are upwelling into the original brines of the Cambrian Mount Simon Formation near the center of the basin as was observed in the Decatur well to the north by Panno et al. (2013) and Labotka et al. (2015, 2016).

The inferred pattern of north-to-south brine migration is interrupted in the southern part of the basin at or near the Ohio River (Figure 1). Here, recharge occurs where the Ohio River intersects the Rough Creek-Shawneetown Fault System. In this area, Pennsylvanian strata are thin or missing and Cl^- contours indicate the presence of a fresh-water plume, presumably from the Ohio River (perhaps including Pleistocene glacial meltwaters) recharging carbonate bedrock aquifers. Surface waters are probably recharging underlying aquifers as they flow through Mississippian and Silurian–Devonian strata, and into Ordovician strata. The Cl^- isocons further suggest that the freshwater recharge within Ordovician strata flows to the south-southeast into Kentucky toward the southern end of the Illinois Basin. The freshwater recharge is probably mixing with basin brines as it flows through Ordovician strata. We speculate that the resulting saline groundwater from the southeastern margin of the Illinois Basin may be discharging to the numerous salt licks found in northern and central Kentucky (e.g., Bullitt's Lick; Figure 1). These salt licks were used by Native Americans and frontiersmen as a source of salt and as hunting spots where herds of bison, deer, and elk would frequent the area and where bison "licked out deep trenches in the salt-impregnated clay" (McDowell 1956). Based on the Cl/Br mass ratio of Bullitt's Lick (189), one of many salt licks located just southeast of Louisville, Kentucky, the saline water is Cambrian-Ordovician in origin (Panno, ISGS, unpublished data), which is consistent with the inferred flow patterns and groundwater mixing within the Illinois Basin.

Conclusions

We develop, for the first time, a conceptual model of the hydrogeology of the Illinois Basin on a basin-wide scale. This model, based on Cl^- isocons on plan-view maps of selected formations and cross sections across the basin, reveal the infiltration and movement of freshwater recharge into the basin and dilution of brines within all of the Paleozoic strata, inter-formational interactions, and groundwater flow within and through the Illinois Basin. Pathways of greater permeability (e.g., highly conductive

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lithologies and fractures associated with geologic structures) resulted in zones of dilute groundwater migrating through areas bounded on all sides by brines. Restrictions or barriers created by aquitards have created areas of near isolation/stagnation of concentrated brines within the basin. The Cl^- isocons suggest that the current chemical composition of groundwater and distribution of brines within the Illinois Basin is dependent on five parameters: (1) the presence of bedrock exposures along basin margins; (2) the permeability of geologic strata and their distribution relative to one another; (3) the presence or absence of major geologic structures; (4) the intersection of major rivers with geologic structures, basin margins, and permeable bedrock exposures; and (5) the isolation of brines within the basin resulting from aquitards, inhomogeneous permeability, and, in the case of the deepest part of the basin, brine density effects.

Cambrian Mount Simon Sandstone is bounded below by crystalline basement and above by the Eau Claire Formation and contains original brines (as determined by Labotka et al. 2016). Groundwater within the deepest part of the basin located in far southern Illinois may be under near stagnant conditions, or at least that part of the basin constitutes a zone of low flow within Cambrian and lower Ordovician strata. Based on previous work by McIntosh et al. (2002); Siegel (1989, 1991), and this study, groundwater flow through the basin appears to be from the northern, eastern, and western margins of the basin and dominantly through the Ordovician St. Peter Sandstone, and carbonate rocks of the Silurian–Devonian and Mississippian strata. Silurian–Devonian strata, consisting of mostly carbonate rocks, are bounded by the underlying Ordovician Maquoketa Shale and the overlying Devonian New Albany Shale. Similarly, the carbonate rocks of the Mississippian strata are bounded below and above by the New Albany Shale and the shale-dominated Pennsylvanian strata, respectively, where remnant brines remain. Our findings are consistent with Stueber and Walter (1994) who suggested that the remnant brines within the Silurian–Devonian and Mississippian strata are due to the bounding shale layers. We suggest that the inhomogeneous hydraulic characteristics of the Silurian–Devonian and Mississippian strata (i.e., dual porosity) probably help maintain brine compositions within these strata.

Pennsylvanian strata, where present, act as a confining unit to protect brines of the underlying Mississippian strata from freshwater recharge. Where Pennsylvanian strata are thin or absent, brines of the Mississippian strata have been diluted to various degrees, and, in some cases, to potable groundwater. Exposures of formations near basin margins allow recharge from meteoric water and, in the past, glacial meltwaters. Where the Mississippi River intersects bedrock exposures along the Mississippi River Arch (western margin of the Illinois Basin), enhanced recharge is likely responsible for freshwater plumes that extend deep into the basin from the west. The intersection of major rivers with major geologic structures is responsible for relatively rapid fresh-water recharge and movement of groundwater through the Illinois Basin. Evidence of Pleistocene meltwater recharge is observed along the LaSalle Anticlinorium where associated faults and fractures have created a zone of enhanced anisotropic permeability. Glacial meltwaters appear to have flushed out much of the brines within the St. Peter Sandstone within the northern part of the Illinois Basin during the Pleistocene based on data by Siegel (1989, 1991) and this study. Subsequently, deep-seated brines welled up along fault and fracture planes and created saline springs and the sporadic occurrence of saline wells near the Illinois River.

Chloride isocons within the Cambrian Mount Simon Sandstone and the St. Peter Sandstone reveal a marked dilution along the LaSalle Anticlinorium that extends into southern Illinois. This pattern of dilution also was observed in younger formations along the anticlinorium in the cross sections. In far southern Illinois, the intersection of the Rough Creek–Shawneetown Fault System (a major fault zone across the southern part of the basin) and the Ohio River has resulted in enhanced recharge deep into the Illinois Basin extending from surficial Mississippian strata, through Devonian and Silurian strata, and continuing to near the base of Ordovician strata. Within Ordovician strata, we speculate that the freshwater plume joins groundwater flowing through Ordovician strata via the St. Peter Sandstone and continues south into Kentucky where it discharges to numerous salt licks and saline springs near and south of Louisville and perhaps into northern Tennessee. These observations are consistent with an overall north to south flow of groundwater within the Illinois Basin and discharge along its southern boundaries.

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Supporting Information

Additional Supporting Information may be found in the online version of this article. Supporting Information is generally *not* peer reviewed.

Appendix S1. Chloride Content and Cl/Br Ratios of Brines of the Illinois Basin and References.

Table S1. Maximum Cl^- concentrations and median Cl/Br ratios (the ± refers to range) reported for geologic strata within the Illinois Basin. The Cl^- concentrations of

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seawater and Precambrian Shield brines are added for comparison.

Figure S1. Cross section E–E′ extending east-west across far southern Illinois. Because this cross section is truncated at the Illinois–Indiana state boundary, the effects of freshwater recharge are only seen along the western margin of the basin.

Appendix S2. Illinois State Geological Survey Unpublished Report.

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Appendix 11

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Geochemistry of the Cambrian–Ordovician Aquifer System in the Northern Midwest, United States

By D.I. SIEGEL

REGIONAL AQUIFER-SYSTEM ANALYSIS—
NORTHERN MIDWEST AQUIFER SYSTEM

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1405-D



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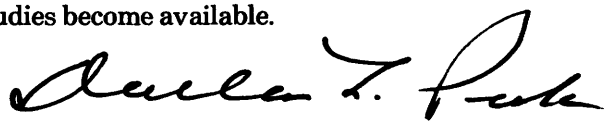
FOREWORD

THE REGIONAL AQUIFER-SYSTEM ANALYSIS PROGRAM

The Regional Aquifer-System Analysis (RASA) Program was started in 1978 following a congressional mandate to develop quantitative appraisals of the major ground-water systems of the United States. The RASA Program represents a systematic effort to study a number of the Nation's most important aquifer systems, which in aggregate underlie much of the country and which represent an important component of the Nation's total water supply. In general, the boundaries of these studies are identified by the hydrologic extent of each system and accordingly transcend the political subdivisions to which investigations have often arbitrarily been limited in the past. The broad objective for each study is to assemble geologic, hydrologic, and geochemical information, to analyze and develop an understanding of the system, and to develop predictive capabilities that will contribute to the effective management of the system. The use of computer simulation is an important element of the RASA studies, both to develop an understanding of the natural, undisturbed hydrologic system and the changes brought about in it by human activities, and to provide a means of predicting the regional effects of future pumping or other stresses.

The final interpretive results of the RASA Program are presented in a series of U.S. Geological Survey Professional Papers that describe the geology, hydrology, and geochemistry of each regional aquifer system. Each study within the RASA Program is assigned a single Professional Paper number, and where the volume of interpretive material warrants, separate topical chapters that consider the principal elements of the investigation may be published. The series of RASA interpretive reports begins with Professional Paper 1400 and thereafter will continue in numerical sequence as the interpretive products of subsequent studies become available.



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ENGLISH-TO-METRIC UNITS CONVERSION FACTORS AND ABBREVIATIONS

For readers who prefer to use metric (International System) units rather than the inch-pound units used in this report, conversion factors are listed below.

Multiply inch-pound unit	*By*	*To obtain metric unit*
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per square mile per year [$(ft^3/mi^2)/yr$]	0.01093	cubic meter per square kilometer per year [$(m^3/km^2)/yr$]
	Temperature	
degree Fahrenheit (°F)	0.5556 (°F−32)	degree Celsius (°C)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Sea Level Datum of 1929."

SYMBOLS AND DEFINITIONS

δ	Isotopic composition expressed as permil differences in the measured isotopic ratios of sample and standard.
$\delta^{13}C$	Standard expression of the ratio of the ^{13}C ion with respect to the ^{12}C ion.
δD	Standard expression of the ratio of the ^{2}H ion (deuterium) with respect to the ^{1}H ion.
$\delta^{18}O$	Standard expression of the ratio of the ^{18}O ion with respect to the ^{16}O ion.
$\delta^{34}S$	Standard expression of the ratio of the ^{34}S ion with respect to the ^{32}S ion.
$\mu g/L$	Micrograms per liter.
Eh	Oxidation potential, log activity of e^1.
e^1	Electron.
(g)	Gaseous.
meq/L	Milliequivalents per liter.
mg/L	Milligrams per liter.
P_{CO_2}	Partial pressure of carbon dioxide.
PDB	PeeDee belemnite ^{13}C isotopic standard.
pCi/L	Picocuries per liter.
pH	Negative log activity of H^+.
ppm	Parts per million.
SI	Saturation index.
SMOW	Standard Mean Ocean Water ^{18}O and ^{2}H isotopic standard.
(s)	Solid.

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GEOCHEMISTRY OF THE CAMBRIAN-ORDOVICIAN AQUIFER SYSTEM IN THE NORTHERN MIDWEST, UNITED STATES

By D.I. SIEGEL

ABSTRACT

Distributions of solutes in aquifers of Cambrian and Ordovician age were studied in Minnesota, Wisconsin, Iowa, Illinois, northwestern Indiana, and northern Missouri to determine the sources of solutes and the probable chemical mechanisms that control regional variations in water quality. This work is part of the Northern Midwest Regional Aquifer-System Analysis project, whose objective is to describe and model the regional hydrogeology of the Cambrian-Ordovician aquifer system in the study region. The data base used included more than 3,000 ground-water-quality analyses from all major aquifers, but especially from the St. Peter, Jordan, and Mount Simon Sandstones and their equivalents. Regional variations in the water chemistry of glacial drift and other sedimentary units that overlie the Cambrian-Ordovician aquifer system in recharge areas in Minnesota, Iowa, Wisconsin, and Illinois were also studied, but to a lesser degree.

The most important chemical variation in the aquifer is the change in water type from calcium-sodium-sulfate-bicarbonate water to sodium-calcium-sulfate-bicarbonate and sodium-chloride waters along the longest regional flow path from northwestern Iowa to the Illinois basin. Sodium predominance downgradient from the recharge area is probably related to mechanisms of ion exchange and shale-membrane filtration near the Illinois and Forest City basins.

The most striking aspect of the distribution of dissolved solids and carbon isotopic content of bicarbonate is the increase in concentration and isotopic enrichment from southwestern Wisconsin, southern Minnesota, and northwestern Illinois south toward Missouri. This trend is perpendicular to the present hydraulic gradient that trends from northwestern Iowa southeastward to the Illinois basin. The distribution of dissolved solids defines a "plume" of dilute water having a dissolved-solids concentration of about 500 milligrams per liter, compared with surrounding concentrations more than twice as large. Distribution of the isotopic content of oxygen ($\delta^{18}O$) and hydrogen (δD) in water closely parallels that of dissolved solids and shows covariance similar to modern meteoric water. The isotopic contents are more depleted (lighter) toward the south, perpendicular to the direction of current hydraulic gradients. The degree of depletion, compared with the isotopic content of modern recharge water, indicates that the plume and a significant fraction of the ground water in Iowa, northern Missouri, and possibly central Illinois may have originated as recharge during Pleistocene time.

Distributions of dissolved trace constituents in the aquifers probably are related to the proximity to mineralogic sources as well as chemical and hydraulic mechanisms. For example, concentrations of some constituents, such as cadmium and arsenic, are largest in the vicinity of the Dakota Formation in northwestern Iowa. Other constituents, such as beryllium and vanadium, have larger concentrations near the edge of the Forest City basin in southwestern Iowa and northwestern Missouri. Strontium and fluoride concentrations generally increase from north to south, which suggests the input of these trace constituents during the recharge events. However, concentrations of bromide, radium-226, and lithium show distribution patterns similar to the "plume" defined by dissolved solids and isotopes of water, suggesting dilution of concentrations of trace constituents by Pleistocene recharge. Concentrations of other constituents are partly controlled by aquifer temperature, such as silica in south-central Iowa, and solubility controls, such as barium in northeastern Illinois. Additional information on the chemical and mineralogical composition of the aquifer matrix and the isotopically lightest ground water is needed to evaluate the hypothesis of Pleistocene mixing before more quantitative studies can be done to evaluate the different proposed mechanisms that have controlled and modified the water chemistry over time. This study, however, indicates that the ground water in the region is thousands of years old. The study also indicates that the major chemical trends in the aquifers probably are related as much to paleohydrogeologic flow systems during Pleistocene time as to the present flow system, which may postdate the retreat of the last ice sheet about 12,000 years ago.

Manuscript approved for publication November 15, 1985.

INTRODUCTION

Sandstone and dolomite strata of Cambrian and Ordovician age make up much of the sedimentary rocks overlying the Precambrian basement in the northern Midwest and form the major aquifer system of that area. In October 1978, the U.S. Geological Survey began a regional assessment of the Cambrian-Ordovician aquifer system in that area (Steinhilber and Young, 1979) as part of its national Regional Aquifer-System Analysis (RASA) program (Bennett, 1979). The major goals of the RASA program are to (1) gain an understanding of the hydrogeologic system in each region, including the nature of the hydrogeologic units, ground-water flow system, and chemical quality of the water, and (2) describe the regional interaction of components of the system, especially as affected by large-scale withdrawal of ground water. The latter goal is accomplished by constructing digital-computer models that simulate the ground-water flow system.

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PURPOSE AND SCOPE

This report describes the hydrologic and geochemical mechanisms that cause regional differences in groundwater quality in the northern Midwest. Other regional reports on the aquifer system are being published as chapters of U.S. Geological Survey Professional Paper 1405. They include chapter A, a summary of the Northern Midwest RASA (H.L. Young, U.S. Geological Survey, written commun., 1988), chapter B, which describes the regional hydrogeology and water quality (Young, in press), chapter C, which describes a regional three-dimensional ground-water model of the study area (Mandle and Kontis, in press), and chapter E, which describes a detailed three-dimensional ground-water flow model of the Chicago-Milwaukee area (H.L. Young and A.J. MacKenzie, U.S. Geological Survey, written commun., 1988).

The study covers about 161,000 mi^2 in northern Illinois, northwestern Indiana, Iowa, southeastern Minnesota, northern Missouri, and Wisconsin (fig. 1). The border of the study area delimits either the natural physical or hydrologic boundaries of the aquifer system or places where the aquifers are not used because of poor water quality. The northern boundary, from northwestern Iowa to northeastern Wisconsin, delineates the erosional edge of Cambrian rocks overlying crystalline basement rocks of Precambrian age. The Missouri River is a discharge line and forms the western and southwestern boundary. Beyond the eastern and southeastern boundary in Michigan, Illinois, and Indiana, water in the aquifer is too highly mineralized to be used. As a first approximation, the brine-saltwater interface at about 30,000 mg/L is assumed to be a minimal-flow boundary.

The primary subject of the study is the Cambrian- and Ordovician-age rocks that form the dominant aquifer system in the study area. However, because some wells developed in the Cambrian-Ordovician aquifer system are also open to the overlying carbonate rocks of the Silurian-Devonian aquifer, the latter, although only a minor aquifer regionally, is included in the study.

ACKNOWLEDGMENTS

I express my appreciation to many U.S. Geological Survey colleagues for their assistance in this study. Special thanks go to E.C. Alexander, Jr., and H.E. Wright, Jr., University of Minnesota, and to E.G. Perry, Jr., Northern Illinois University, for discussions on Pleistocene geology and environmental isotope geochemistry in the study area, and to the many geologists in State agencies with whom I had helpful conversations.

HYDROGEOLOGIC SETTING

The regional hydrogeology of the Cambrian-Ordovician aquifer system in the northern Midwest is summarized in Professional Paper 1405-B. The following is a brief regional synopsis of the structural, lithologic, and hydrologic features of the geologic formations in the study area and a description of the vertical discretization of geologic units into layers used in the regional flow model. Detailed accounts of the geology and hydrology of each of the States in the study area can be found in publications of State agencies and the U.S. Geological Survey referenced in Professional Paper 1405-B. The nomenclature used in this report was established for the Northern Midwest RASA (see Professional Paper 1405-B) and does not necessarily coincide with that previously accepted by the U.S. Geological Survey. It follows usage prevalent in the majority of the study area, or usage of a particular State, where appropriate.

The consolidated sedimentary rocks in the northern Midwest consist of sandstone, carbonate, and shale sequences that range in age from Precambrian to Cretaceous (fig. 2). They overlie the eroded surface of the Precambrian basement complex, which consists of crystalline igneous and metamorphic rocks. This basement complex forms the North American craton, the more permanent nucleus of the continent. The widespread sedimentary rocks were deposited in the midcontinental interior by a series of transgressions and regressions of the epeiric Sauk and Tippicanoe seas (King, 1959) as the craton subsided. Irregular subsidence resulted in the formation of the Illinois, Michigan, and Forest City basins, beginning in Early Cambrian time. The major structurally high areas, the Kankakee, Transcontinental, and Wisconsin arches, also began developing during Cambrian time (fig. 2). Cambrian and Ordovician rocks presently crop out or subcrop beneath Pleistocene drift and Holocene sediments in southeastern Minnesota, northeastern Iowa, northern Illinois, and southern Wisconsin. A band of Silurian and Devonian rocks subcrop beneath glacial drift along the trend of the Kankakee arch between Michigan and Illinois, along the eastern part of Wisconsin, and in northeastern Iowa (fig. 2). Mississippian and younger rocks border the major sedimentary basins and are present southwest and east of the Silurian rocks.

The Cambrian and Ordovician rocks in the northern Midwest have long been divided into rock-stratigraphic units on the basis of lithology and lateral continuity. For this study, the units were grouped into five aquifer layers and four confining layers on the basis of their hydrologic properties. Figure 3 is a generalized geologic

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FIGURE 1.—Location and general features of the Northern Midwest Regional Aquifer-System Analysis area.

section from Missouri to Wisconsin, which shows this hydrogeologic grouping. The first and deepest hydrogeologic unit, the Mount Simon aquifer (aquifer layer 1), is composed mainly of the Mount Simon Sandstone and its equivalents. This basal sandstone rests on the Precambrian basement complex in much of the study area, but on older Precambrian red clastic rocks in Minnesota and western Wisconsin. The latter are included in aquifer layer 1. The Mount Simon Sandstone is a marine, fine- to coarse-grained conglomeratic sandstone and ranges in thickness from less than 100 ft in Minnesota and Wisconsin to more than 2,500 ft in the northern part of the Illinois basin. In the northern part of the area it is overlain by shale, dolomitic sandstone, siltstone, and dolomite of the Eau Claire Formation, which constitutes a regional confining unit. The Eau Claire is predominantly a fine-grained sandstone in Wisconsin but has varying amounts of shale. The Eau

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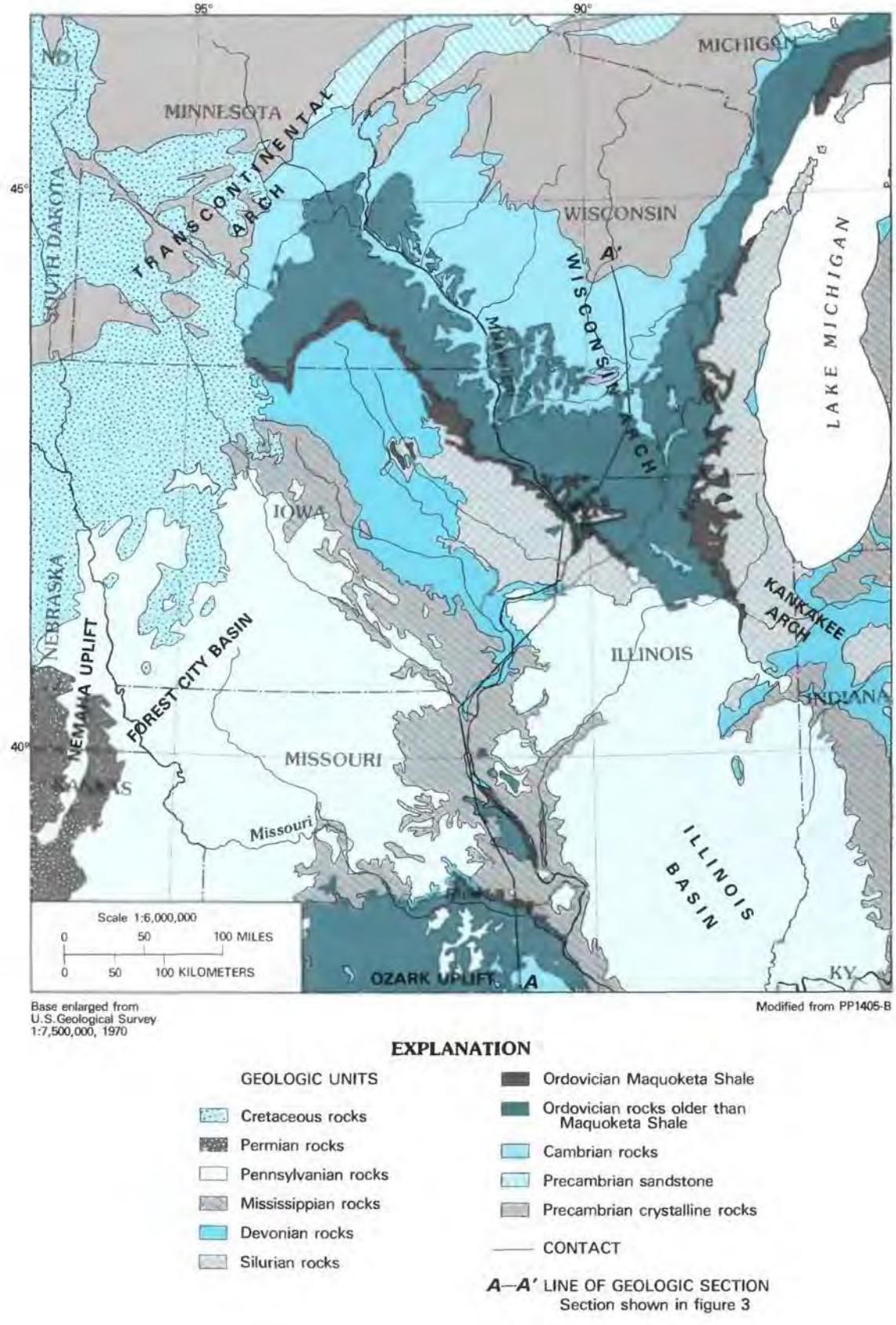

FIGURE 2.—General bedrock geology of the northern Midwest. (Modified from Young, in press.)

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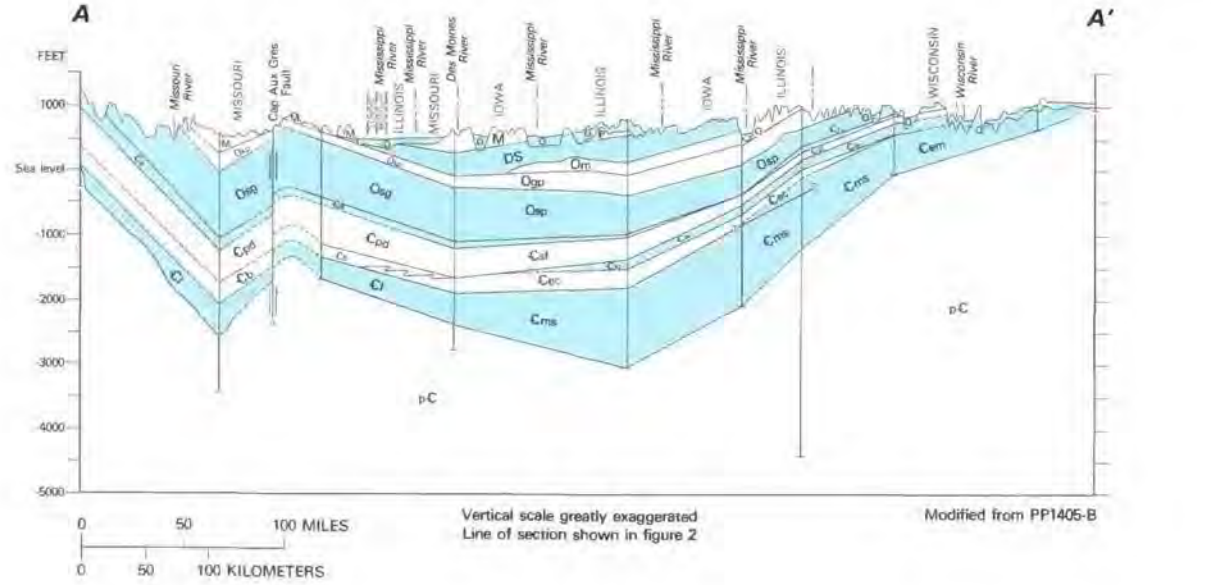

EXPLANATION

CORRELATION OF GEOLOGIC UNITS AND AQUIFER LAYERS (shown in blue)

Designated aquifer layers			
5	Q	Pleistocene	QUATERNARY
	P		PENNSYLVANIAN
	M		MISSISSIPPIAN
4	DS		DEVONIAN and SILURIAN
	Om	Upper Ordovician	ORDOVICIAN
	Okp, Ogp, Osg, Osp	Middle Ordovician; Middle and Lower Ordovician	
3	Ce, Cj, Cpd, Csf, Cst, Cig, Cw, Cb, Cec, Cem, Cl, Cms	Upper Cambrian	CAMBRIAN
2			
1			
	pC		PRECAMBRIAN

DESCRIPTION OF UNITS (aquifers shown in blue)

- Q — Pleistocene deposits
- P — Pennsylvanian rocks
- M — Mississippian rocks
- DS — Devonian and Silurian rocks
- Om — Maquoketa Shale
- Okp — Kimmswick, Decorah, and Plattin Formations
- Ogp — Galena Dolomite, Decorah and Platteville Formations
- Osg — St. Peter Sandstone; Smithville Formation; Powell, Cotter, and Jefferson City Dolomites; Roubidoux Formation; Gasconade Dolomite
- Osp — St. Peter Sandstone, Prairie du Chien Group
- Ce — Eminence Dolomite
- Cj — Jordan Sandstone
- Cst — St. Lawrence Formation, Potosi Dolomite, Franconia Formation
- Cst — St. Lawrence Formation, Tunnel City Group in Iowa and Wisconsin
- Cpd — Potosi and Derby-Doerun Dolomites, Davis Formation
- Cb — Bonneterre Formation
- Cl — Lamotte Sandstone
- Cem — Elk Mound Group, undifferentiated—Where differentiated, consists of Ironton and Galesville Sandstone Members of the Wonewoc Sandstone, Eau Claire Formation, Mount Simon Sandstone in Iowa and Wisconsin
- Cig — Ironton and Galesville Sandstones
- Cw — Wonewoc Sandstone in Iowa and Wisconsin
- Cec — Eau Claire Formation
- Cms — Mount Simon Sandstone
- pC — Precambrian crystalline rocks

CONTACT—Dashed where approximate

FAULT—Arrows indicate relative vertical movement

FIGURE 3.—Geologic section from Missouri to Wisconsin. (Modified from Young, in press.)

Claire is not strongly confining in much of Wisconsin and is hydrologically connected with the underlying Mount Simon Sandstone and the overlying Ironton and Galesville Sandstones, except toward the south where the upper part becomes more shaly. To the south in Missouri, the Eau Claire grades into dolomite of the Bonneterre Formation. In northern Illinois, the lower part of the Eau Claire, the Elmhurst Sandstone Member, is included in aquifer layer 1, which is locally termed the "basal sandstone aquifer." In south-central Minnesota, the Eau Claire Formation consists, in part, of glauconitic "greensands."

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Aquifer layer 2, the Ironton-Galesville aquifer, is the combined Ironton and Galesville Sandstones and, in Iowa and Wisconsin, the equivalent Wonewoc Formation. It is generally less than 100 ft thick but exceeds 200 ft in the Illinois basin. It consists of calcareous to dolomitic sandstone in Minnesota, Wisconsin, and northern Illinois. The aquifer layer is absent in southern Illinois and is thin or absent and grades into carbonate rocks of the lower part of the Davis Formation in southwestern Iowa and Missouri. Shaly sandstones of the Franconia Formation and limestone and dolomite of the St. Lawrence Formation overlie and confine the Ironton-Galesville aquifer in the north. The southern equivalent of the St. Lawrence-Franconia confining unit is the upper Davis Formation through Potosi Dolomite interval.

The composition of the third aquifer layer varies with its geographic location. In most of the study area it consists of, from oldest to youngest, the Jordan Sandstone, the overlying Prairie du Chien Group, and the St. Peter Sandstone. In Missouri, the Gasconade Dolomite-Smithville Formation sequence is a general equivalent and replaces the Prairie du Chien Group. Also, the Jordan Sandstone is replaced by the Eminence Dolomite in Missouri and all but the extreme northwestern part of Illinois. These formations are generally in hydrologic connection. They are treated as a single unit because fractures commonly penetrate through the Prairie du Chien Group.

The Jordan Sandstone is a coarse- to medium-grained orthoquartzite to dolomitic sandstone in Minnesota, Wisconsin, and Iowa, grading into sandy dolomite and dolomite in southern Iowa, northern Missouri, and all but the extreme northwestern part of Illinois. The Prairie du Chien Group consists of fossiliferous dolomite and limestone interbedded with thin, discontinuous beds of sandstone, siltstone, and shale. Aquifer layers 1 and 3 generally range from 200 to 600 ft in thickness in the northern half of the study area but thicken to more than 1,500 ft in the Illinois basin. The St. Peter Sandstone is a laterally persistent clean and friable orthoquartzite, generally 100 to 200 ft thick except locally in northern Illinois, where thickness exceeds 700 ft upon pre-St. Peter karstic topography.

The Maquoketa Shale forms a very effective confining unit above aquifer layer 3 over much of the study area. The Maquoketa consists of thick pyritic shales except in western Iowa and Minnesota, where the shales grade into interbedded dolomitic limestones and shaly dolomites that provide a hydraulic connection with overlying and underlying carbonates. The shaly dolomites, which make up the Galena Dolomite and Decorah and Platteville Formations or equivalents, are generally of low permeability where overlain by the Maquoketa and are included as part of the confining unit. The base of the confining unit is the Glenwood Formation, which consists generally of shale and silty, shaly sandstone. Extensive phosphatic beds are present within the Maquoketa in Iowa. The Cambrian-Ordovician aquifer system is further confined by thick sequences of younger Paleozoic rocks south of the outcrop of the Maquoketa Shale.

Aquifer layer 4 consists of the carbonate rocks of the Silurian through Middle Devonian and is termed the Silurian-Devonian aquifer for this study. The rocks are dominantly thick- to thinly bedded dolomites, limestones, and shales that are hydraulically connected by fractures. Where not eroded, they generally range in thickness from 200 to 500 ft, but they are more than 1,000 ft thick in the Illinois basin. The excellent confinement of the Maquoketa Shale, which separates aquifer layer 4 from aquifer layer 3, limits the potential of water in aquifer layer 4 to affect the chemistry of water in the Cambrian-Ordovician aquifer system. However, the opposite may be true where the Maquoketa is mainly a fractured carbonate. The very thick sequence of younger consolidated rocks from the Upper Devonian through the Pennsylvanian contains little aquifer material and, for the purposes of this study, is considered to be a confining unit between aquifer layers 4 and 5. In Iowa, the Mississippian is classified as a separate aquifer (Horick and Steinhilber, 1973).

Aquifer layer 5 consists of the combined Holocene surficial deposits, Pleistocene glacial drift, or Cretaceous rocks that form the land surface over most of the study area. This layer directly overlies the units of the Cambrian-Ordovician aquifer system in much of the Cambrian-Ordovician outcrop areas in Minnesota, Iowa, Wisconsin, and Illinois. Most drift is calcareous because of carbonate minerals derived from the glacial erosion of Paleozoic limestones and dolomites in Manitoba and Michigan and within the study area. Except for the Driftless Area of southwestern Wisconsin and adjacent small areas in Illinois and Iowa, the entire study area was glaciated during the Pleistocene. Cretaceous rocks that overlie the Cambrian and Ordovician rocks in western Minnesota and Iowa consist of varicolored marine shales, siltstones, and lignitic sandstones of the Dakota Formation, which commonly contains disseminated pyrite in its basal part.

The ground-water reservoir is recharged by infiltration of precipitation through the soil into the underlying rock. Because glacial deposits are the surficial rocks in most of the northern Midwest, they receive most of the initial recharge. Aquifer layers 1 through 4 also are recharged by infiltration of precipitation where they crop out at the land surface, such as in the Driftless

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Area. These aquifers also receive recharge by vertical seepage across confining beds, where they subcrop beneath aquifer layer 5 and where they are penetrated by buried bedrock valleys eroded by glacial meltwater streams during Pleistocene time. Both field observation and steady-state simulation of the ground-water flow system (Mandle and Kontis, in press) indicate that vertical head gradients in the Cambrian-Ordovician aquifers (aquifer layers 1 through 3) are generally upward where overlain by the Maquoketa Shale in Iowa, Illinois, and Wisconsin (fig. 4). Vertical head gradients are downward in the Cambrian-Ordovician outcrop areas in much of south-central Minnesota, south-central Wisconsin, and northern Iowa.

Ground water flows from topographically high recharge areas to low discharge areas. Most of the ground water in aquifer layer 5 moves within local flow systems of a few miles in length and discharges to small first- and second-order tributaries of the major rivers. Ground-water movement in the unconfined parts of the Cambrian-Ordovician aquifer system is similar, but the flow systems are larger and discharge is toward the major river valleys. Figure 5 is a representation of the original predevelopment potentiometric surface of aquifer layer 3, for which the most data are available, and is generally representative of the predevelopment potentiometric heads in the lower aquifer layers. The more localized flow systems in the unconfined areas are shown by the topographic control and steeper gradient of the contours there. In the confined areas, ground water moves toward the Illinois and Michigan basins but can discharge only as upward leakage across confining units. Thus the rate of lateral flow into the basins is greatly decreased. The longest flow paths in the aquifer system (more than 300 mi) extend from recharge areas in northwestern Iowa to the center of the Illinois basin (fig. 5). Shorter flow paths (less than 50 mi) in the northern part of the area extend from recharge areas: in central Minnesota to the Minnesota River; in central Wisconsin, central Minnesota, northeastern Iowa, and northwestern Illinois to the Mississippi River; and in eastern Wisconsin and northeastern Illinois toward Lake Michigan. Penetration of aquifer layers by the Mississippi River valley during the Pleistocene causes the flow system in the northern part of the study area to have shorter flow paths. This effect of the Mississippi River is most pronounced in aquifer layers 3 and 4 and is less pronounced in layers 1 and 2. For example, flow in layer 3 discharges to the Mississippi River as far south as about 50 mi south of the Wisconsin-Illinois State line, but the direct influence of the river on aquifer layer 1 extends only as far as the Minnesota-Iowa State line. Aquifer layer 4 discharges toward the Mississippi River downstream from northeastern Iowa.

GEOCHEMISTRY

METHODS OF INVESTIGATION

The interpretation of regional ground-water quality is based on a synthesis of more than 3,000 chemical analyses of ground water available from the U.S. Geological Survey WATSTORE (Water Data Storage and Retrieval System) data base, publications of State and Federal agencies, and scientific journals. Published descriptions of the water chemistry of parts of the Cambrian-Ordovician aquifer system were reviewed, particularly in the following references (grouped by State): Minnesota—Winter (1974), Norvitch and others (1973), and Maderak (1965); Wisconsin—Kammerer (1981), Holt and Skinner (1973), and Ryling (1961); Iowa—Horick and Steinhilber (1978); Missouri—Feder (1979) and Gann and others (1971, 1973); and Illinois—Larson (1963), Gibb and O'Hearn (1980), and Schicht and others (1976). Description and analyses of brines in Cambrian-Ordovician aquifer units were obtained from Meents and others (1952), Graf and others (1965, 1966), Bond (1972), and the files of the Indiana and Michigan Geological Surveys and the Illinois State Water Survey.

Mean concentrations are used where multiple analyses are available. In general, analyses that did not balance electrochemically within 5 percent were deleted from the data base. Some partial analyses of brines include data for only dissolved solids and chloride, but these analyses were used to complete the areal distribution of dissolved solids along the southeastern boundary of the study area. Thus, the lines of equal concentration there should be considered approximate.

One hundred and sixty-four ground-water samples were collected for the study during the period 1980–82 to determine the concentrations of trace constituents and radiochemical species as well as stable isotope ratios. Seventy-five samples were collected to determine the isotopic composition of oxygen and hydrogen in the ground water and of carbon in bicarbonate. The isotopic composition of sulfur in sulfate was determined for selected samples. Field pH, alkalinity, and temperature of the water were measured at critical sample locations along ground-water flow paths to enable calculation of chemical species at equilibrium. Analyses were made using methods described in American Public Health Association (1980) and Skougstad and others (1979). Isotopic composition of water, carbon in inorganic carbon, and sulfur in sulfate was determined by standard methods. By convention, the isotopic variations are expressed as $\pm \delta$ values in parts per thousand (permil) differences in the measured isotopic ratios in a sample and in appropriate standards: Standard Mean Ocean Water (SMOW) for oxygen ($\delta^{18}O$) and

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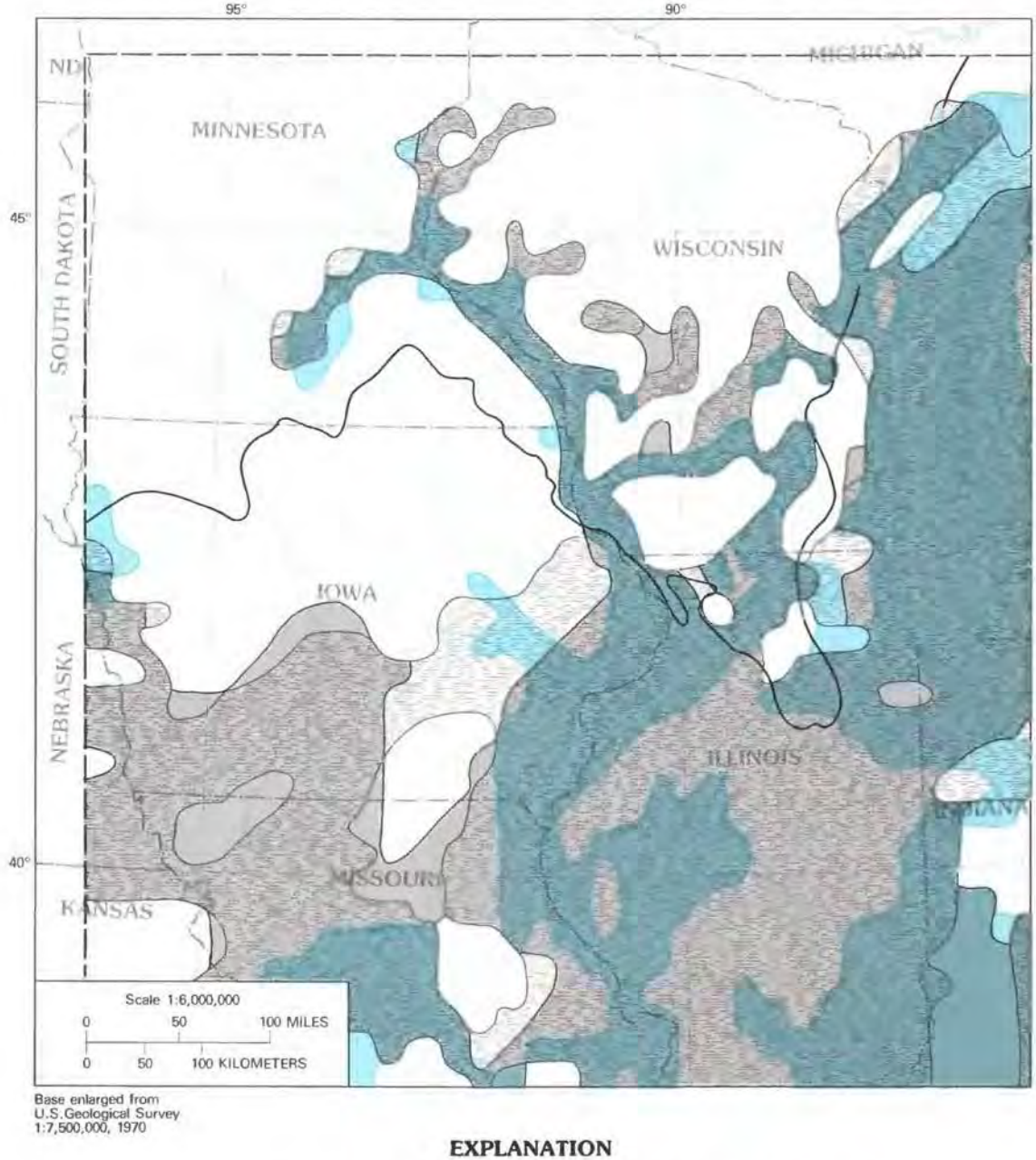

EXPLANATION

SIMULATED DISCHARGE AREA—Shows area where the ground-water flow model indicates upward flow from the aquifer layer for predevelopment conditions

- Aquifer layer 3
- Aquifer layer 2
- Aquifer layer 1
- NORTHERN BOUNDARY OF MAQUOKETA SHALE
- BOUNDARY OF GROUND-WATER FLOW MODEL

FIGURE 4.—Simulated predevelopment discharge areas for aquifer layers 1, 2, and 3. (Modified from Mandle and Kontis, in press.)

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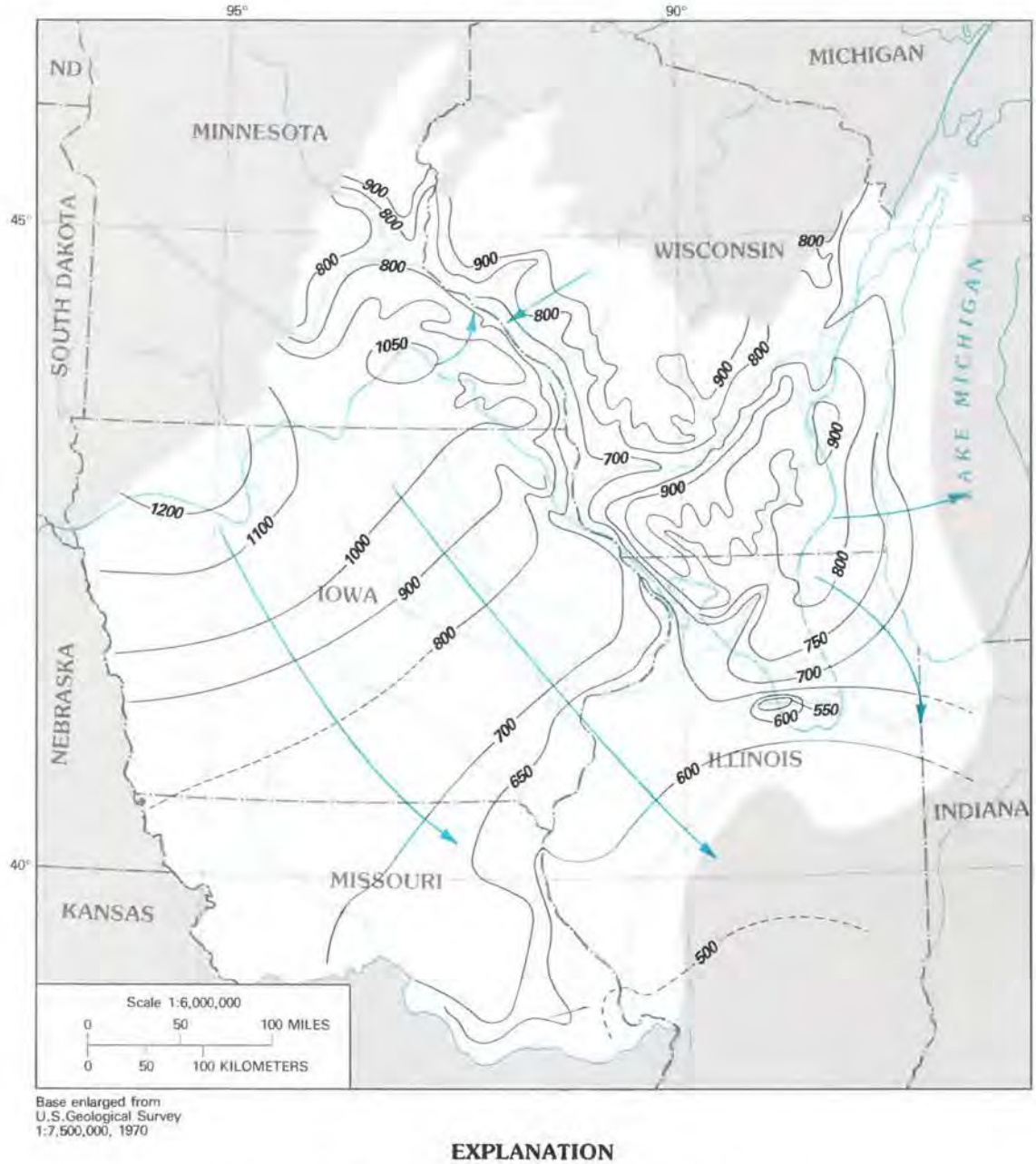

EXPLANATION

600 — POTENTIOMETRIC CONTOUR—Shows altitude of predevelopment potentiometric surface for aquifer layer 3. Dashed where approximate. Interval, in feet, is variable. Datum is sea level

DIRECTION OF GROUND-WATER MOVEMENT

NORTHERN BOUNDARY OF MAQUOKETA SHALE

FIGURE 5.—Approximate predevelopment potentiometric surface for aquifer layer 3. (Modified from Young, in press.)

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hydrogen (δD) in water, Canyon Diablo troilite for sulfur ($\delta^{34}S$), and PeeDee belemnite (PDB standard) for carbon ($\delta^{13}C$). Results of the analyses for the study are given in tables 1, 2, and 3 (at the end of the report). Figure 6 shows the locations of the wells in aquifer layers 1, 3, and 5 sampled for this study and the locations of selected wells in aquifer layers 1 and 3 with WATSTORE and published analyses. Data distribution for aquifer layer 5 was dense throughout the recharge areas of Wisconsin, Minnesota, Iowa, and Illinois; consequently, the locations of only new data for this aquifer layer are shown in figure 6. In subsequent figures that show areal distribution of solutes, only locations of data collected during this study are plotted.

Maps showing the areal distribution of solutes were derived from a composite of data from aquifer layers 1 and 3, for which there is significant regional coverage. It is recognized that because the lithologies of these layers are different, the chemistry may be different. However, the composited data are used as a first approximation in describing the regional chemical patterns for the following reasons:

1. The chemical quality of ground water in aquifer layers 1 and 3 is essentially the same in outcrop areas in Minnesota, Wisconsin, Illinois, and Iowa.
2. In the major confined areas in Iowa, Missouri, Illinois, and eastern Wisconsin, all but a few data points are from aquifer layer 3 (fig. 6).

The maps of areal solute distribution in this report, therefore, represent mainly aquifer layer 3 in the confined part of the aquifer and aquifer layers 1, 2, and 3 in outcrop areas. Where data distribution was dense, maps of concentrations of dissolved solids and particular ions were prepared, in part, by data-management techniques described by Kontis and Mandle (1980).

The detailed evaluation of the water quality of the Cambrian-Ordovician aquifer system was restricted to aquifer layers 3 and 5, for which the areal distribution of data was considered sufficient to evaluate regional trends and variations in concentrations of major dissolved constituents. In most of Wisconsin and north-central Illinois, aquifer layers 1, 2, and 3 are unconfined and are hydraulically connected; thus water quality in those aquifer layers is probably similar. All statistical calculations were made using computer methods of the Statistical Analysis System (SAS Institute, Inc., 1979).

DISSOLVED SOLIDS

The chemical quality of the water in the Cambrian-Ordovician aquifer system varies widely from recharge areas to discharge areas. Dissolved-solids concentrations range from less than 200 mg/L in the outcrop areas in Wisconsin and southeastern Minnesota to more than 200,000 mg/L in the Illinois basin. The 500-mg/L line of equal dissolved solids (isopleth) in figure 7 roughly outlines the extent of the predominantly unconfined flow systems in the northern half of the study area. The 500-mg/L line also is approximately parallel to the outcrop pattern of the Maquoketa Shale in Illinois and Wisconsin, the major confining unit between the Cambrian-Ordovician aquifer system and the overlying units. Dissolved solids generally increase in the direction of the hydraulic gradient.

In Iowa, the 500-mg/L line shows a plume-shaped zone of fresher water trending from the northeast to the south-southwest across the Maquoketa Shale outcrop (figs. 2, 7). In both Iowa and Missouri, the gradient toward increasing dissolved solids (fig. 7) varies but is generally perpendicular to the direction of the hydraulic gradient shown in figure 5. For example, along the flow path that is approximately coincident with geochemical section A–A' (fig. 6), dissolved solids decrease from 2,400 mg/L at well 59 (Hibbing, Iowa) to 440 mg/L at well 144 (Altoona, Iowa) in the south-central part of the State. Dissolved solids increase southeast of Altoona to more than 100,000 mg/L in the Illinois basin (fig. 7). Dissolved solids normally increase along the hydraulic gradient because as the residence time of water in the aquifer increases, the water has a longer period of interaction with the rock minerals (Chebotarev, 1955; Back and Hanshaw, 1965). The discordance of increasing dissolved-solids distribution with the hydraulic gradient in the central part of the study area is an abnormal occurrence and poses a major geochemical anomaly that is examined and discussed in a later section, "Hypothetical Geochemical Models."

CHEMICAL CLASSIFICATION

Water chemistry in the aquifer system was classified by calculating percentages of equivalents per liter for major cations and anions. Maps were prepared showing the areal distribution of water types according to the method described by Back (1966). These maps were used to relate water chemistry to lithologic changes in aquifers and to evaluate possible geochemical and hydrologic processes that control the evolution of water chemistry along and across the hydraulic gradients.

A wide range of water types is present in the Cambrian-Ordovician aquifer system. Water recharged to the system through aquifer layer 5 ranges from a Ca-Mg-HCO_3 type in the northern part of the area to a Ca-Na-SO_4-HCO_3 type in northwestern Iowa and southwestern Minnesota (fig. 8). Dissolved solids in aquifer layer 5 range from less than 300 to more than 2,000 mg/L in Minnesota, Wisconsin, and northwestern Iowa.

Water chemistry in the Cambrian-Ordovician aquifer system in recharge areas in Minnesota, Wisconsin, Illinois, and Iowa is very similar to that in the overlying

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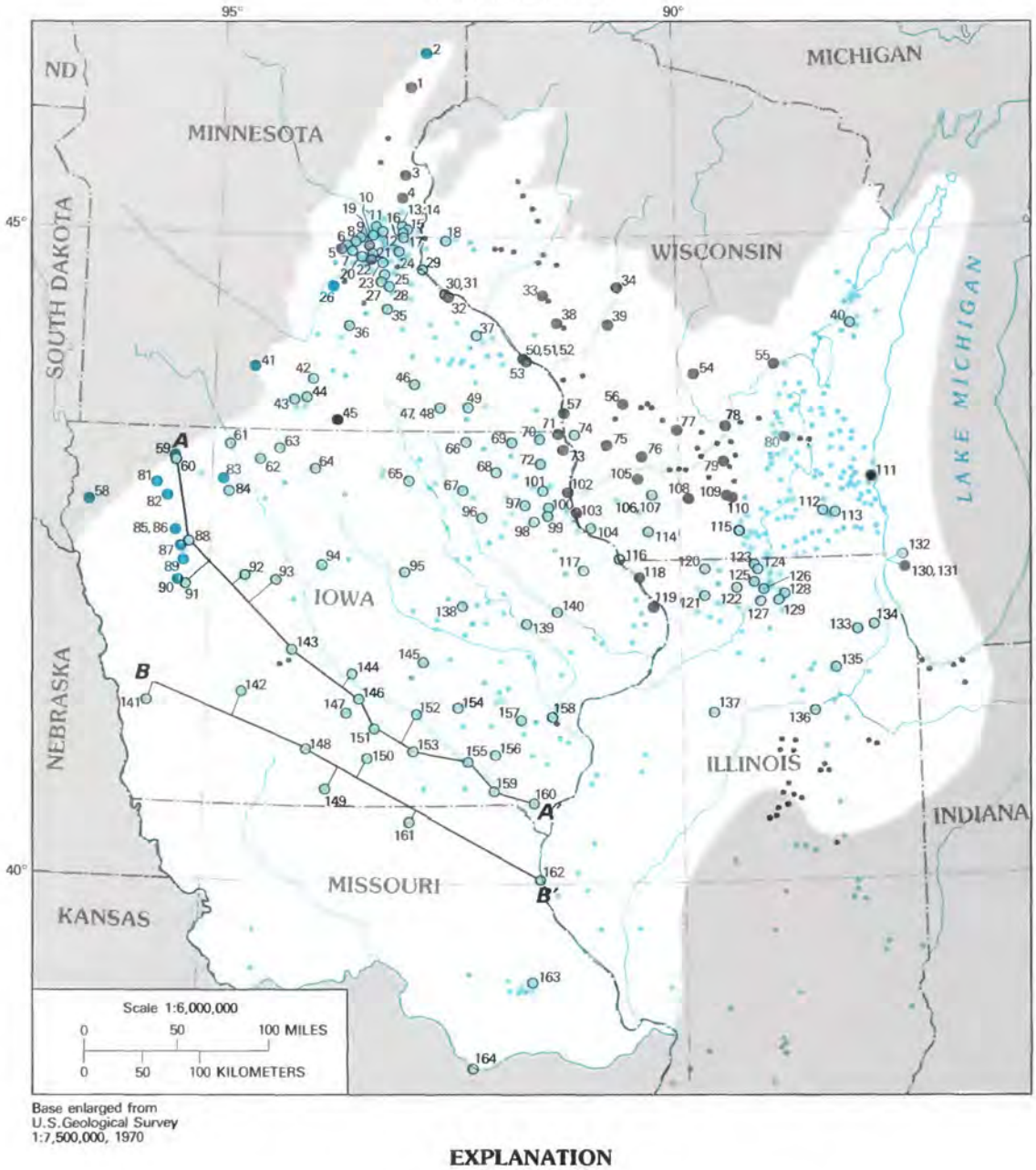

EXPLANATION

WELL WITH CHEMICAL ANALYSIS—Sample collected during this study. Numbers refer to tables 1, 2 and 3

- 39 Mount Simon aquifer
- 65 St. Peter-Prairie du Chien-Jordan aquifer
- 45 Silurian-Devonian aquifer
- 89 Drift or Cretaceous aquifer

WATSTORE and published data

- Mount Simon aquifer
- St. Peter-Prairie du Chien-Jordan aquifer

B——B′ LINE OF GEOCHEMICAL SECTION—Sections shown in figures 17 and 18

FIGURE 6.—Location of wells with water-quality analyses and location of geochemical sections *A-A′* and *B-B′*.

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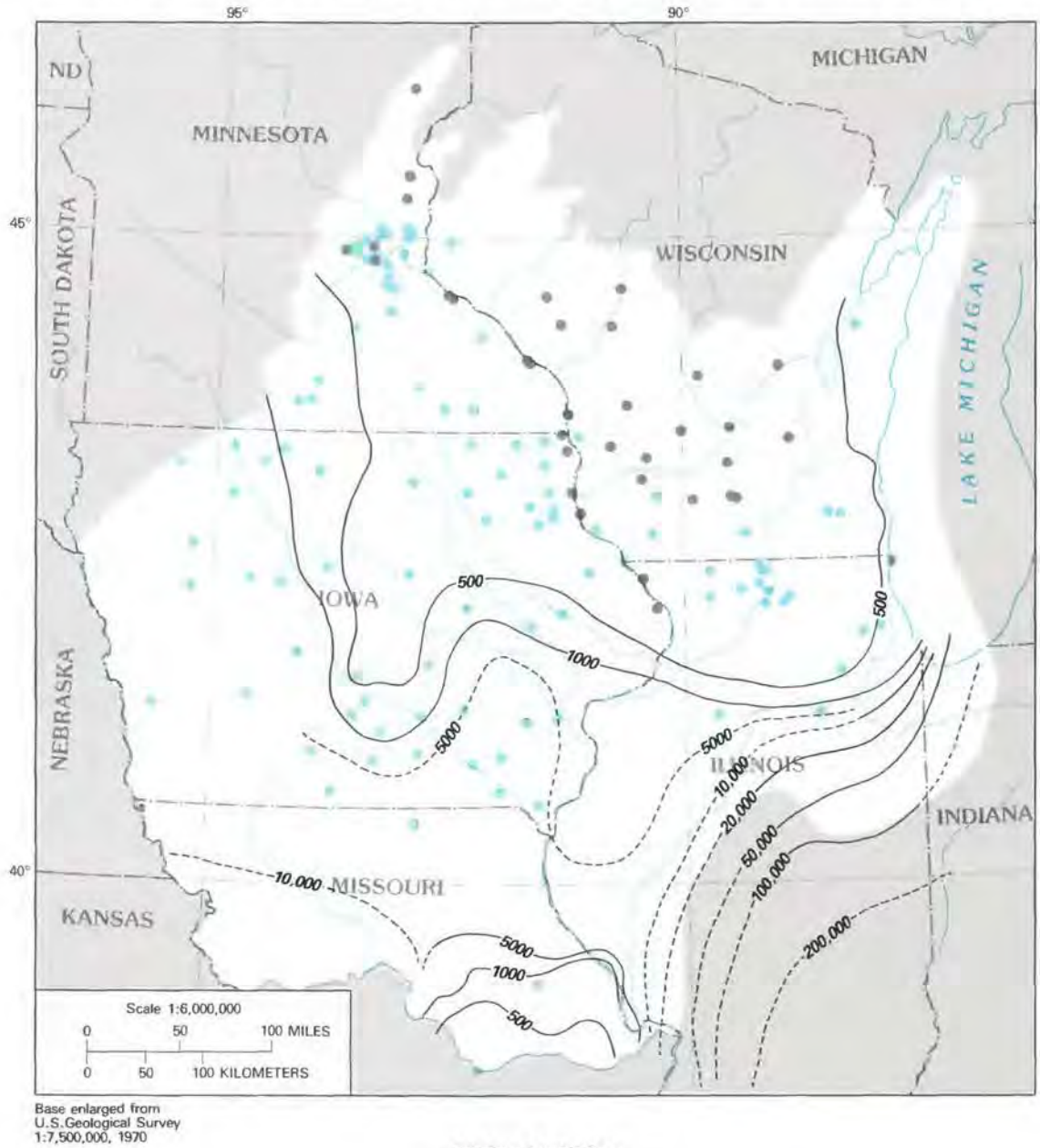

EXPLANATION

—500--- LINE OF EQUAL DISSOLVED-SOLIDS CONCENTRATION—Dashed where approximate. Interval, in milligrams per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 7.—Dissolved-solids distribution in aquifer layers 1 and 3. (Modified from Young, in press.)

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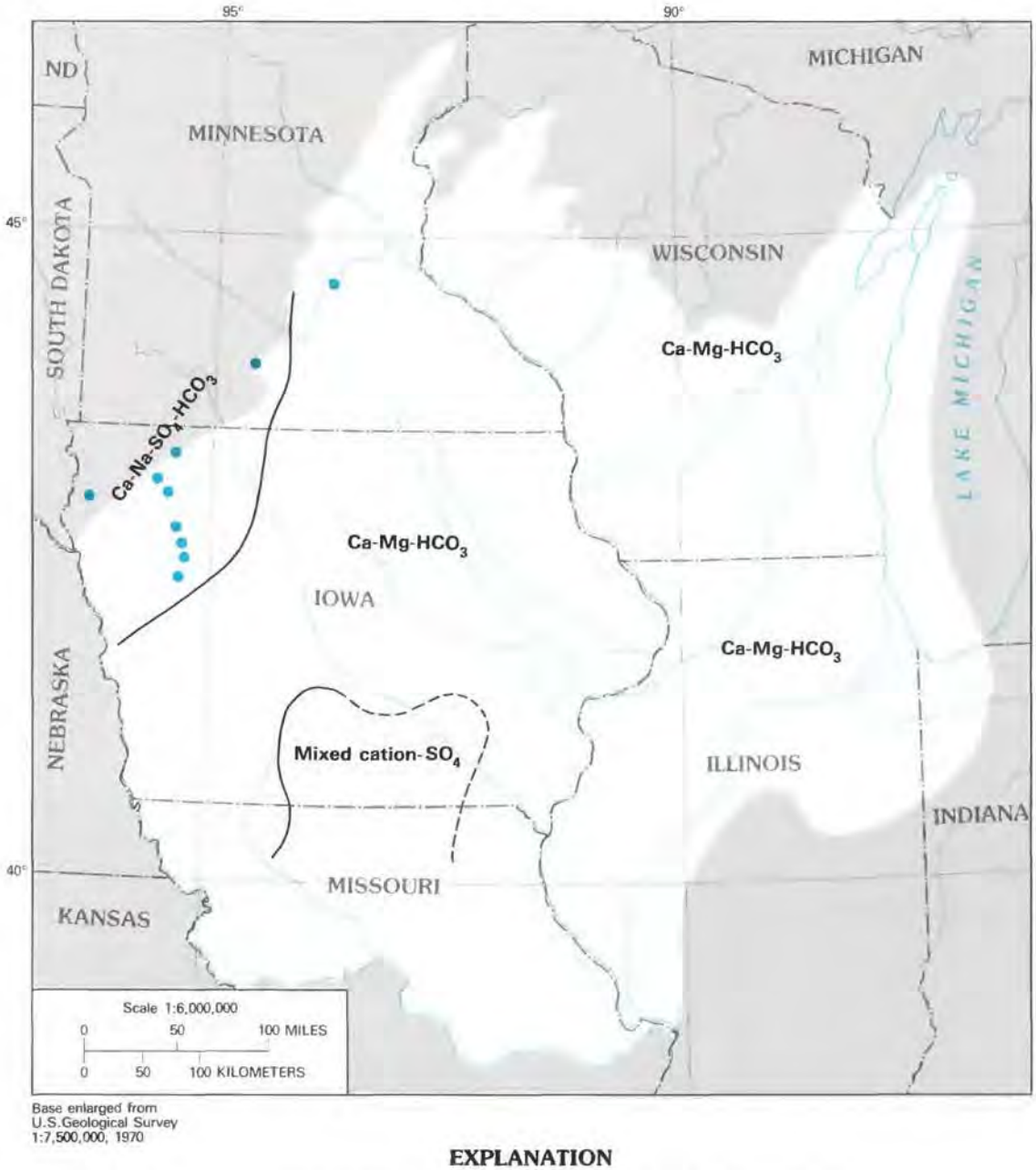

EXPLANATION

HYDROCHEMICAL FACIES ZONE BOUNDARY—Dashed where approximate

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY
Open to aquifer layer 5

FIGURE 8.—Hydrochemical facies of ground water in aquifer layer 5.

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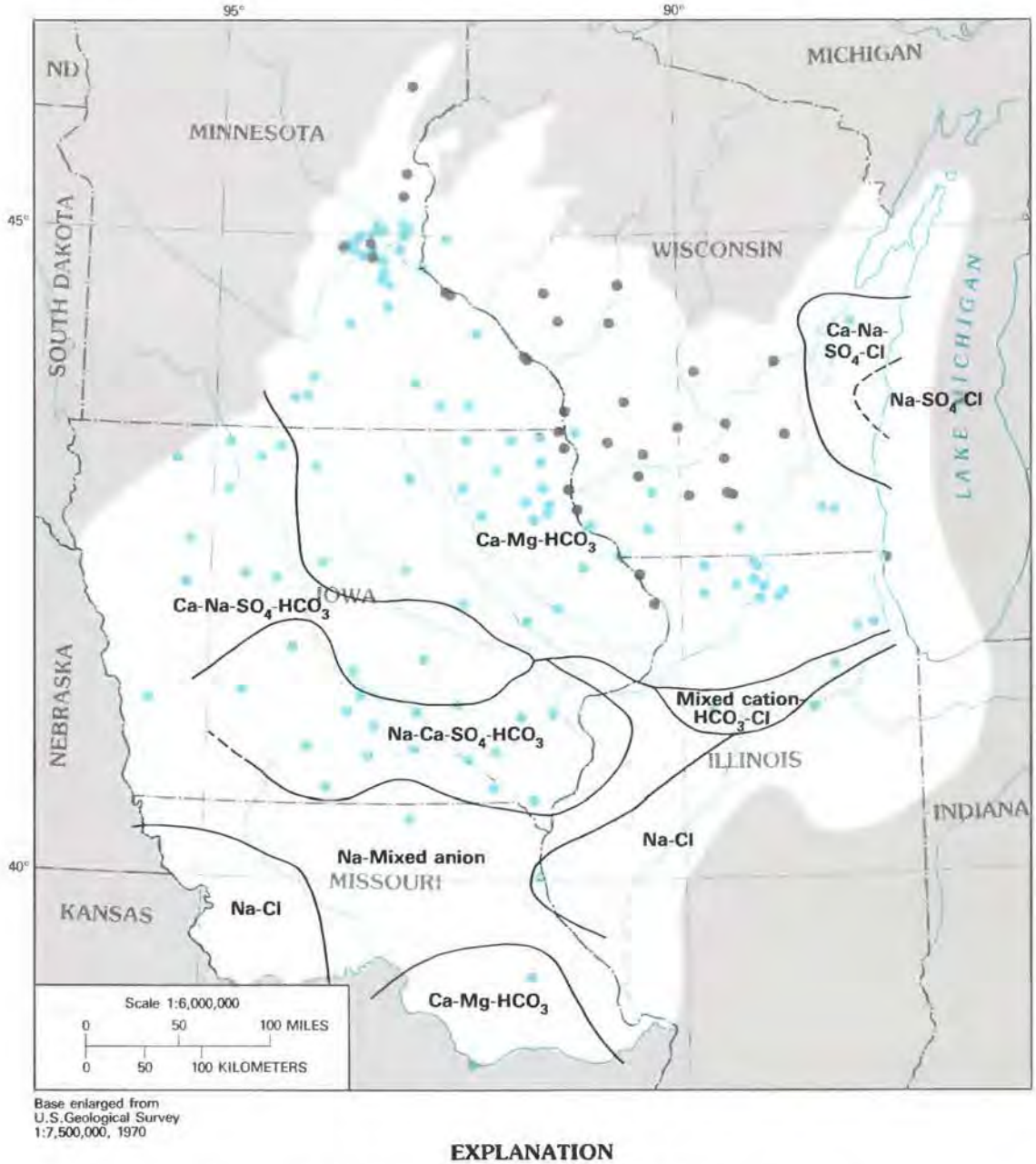

EXPLANATION

HYDROCHEMICAL FACIES ZONE BOUNDARY—Dashed where approximate

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

FIGURE 9.—Hydrochemical facies of ground water in aquifer layers 1 and 3.

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aquifer layer 5. Water in both aquifer layers 1 and 3 in the northern part of the study area is a Ca-Mg-HCO_3 type, but water in northwestern Iowa and southwestern Minnesota is a Ca-Na-SO_4-HCO_3 type (fig. 9).

The most pronounced geochemical changes occur in the confined parts of the aquifer system. Along flow paths confined by the Maquoketa Shale from eastern Wisconsin east toward the Michigan basin, water chemistry changes from Ca-Mg-HCO_3 to Ca-Na-SO_4 and Na-Cl-SO_4 waters, a transition to the Ca-SO_4 and Ca-Cl_2 types of brines in the Michigan basin (fig. 9). From northern Illinois to central Illinois also, the water changes from a Ca-Mg-HCO_3 type to a Na-Cl type similar to the brines in the Illinois basin.

The largest variability in water chemistry occurs along confined flow paths in the aquifer system from northwestern Iowa to central Illinois. Water type evolves along the hydraulic gradient to the Illinois basin from the Ca-Na-SO_4-HCO_3 water that typically is present in the Dakota Formation and overlying drift of aquifer layer 5 to Na-Ca-SO_4-HCO_3, Na-anion (no dominant anion), and Na-Cl water. This change occurs in aquifer layer 3 even though the dissolved-solids concentration decreases along the central part of the flow path. South of the Na-Ca-SO_4-HCO_3 facies in south-central Iowa, the water is of either the Na-Cl or the Na-anion type.

Few generalizations can be made about variations in water types in aquifer layers 1 and 2 or with depth in individual aquifer layers because of the scant data on the areal distribution of the major solutes in aquifer layers 1, 2, and 4. Saline water is present in aquifer layer 1 at several locations along the Mississippi River valley. Chemical data from municipal wells in aquifer layer 1 at Red Wing, Minn. (fig. 1), indicate that the water type changes from Ca-Mg-HCO_3 to Na-Cl at depth (table 4). This change in water quality with depth can occur with increases of dissolved solids from less than 500 to several thousand milligrams per liter (Hall and others, 1911; Thiel, 1944). A similar increase in dissolved solids and change in water type in aquifer layer 1 occurs near Lake Michigan, where high salinity makes aquifer layer 1 nonpotable in some places. Samples collected from aquifer layer 1 in a deep test well drilled for this study at Zion, Ill. (fig. 1), illustrate the increase in salinity with depth (table 4). This increase in salinity is also found in aquifer layer 1 within the Illinois basin in central Illinois and eastern Indiana (Meents and others, 1952; R.J. Shedlock, U.S. Geological Survey, written commun., 1983). These data plus scant data from wells in south-central Iowa (fig. 6) suggest that the Na-Cl water type in Iowa in aquifer layer 1 may be present much farther up the hydraulic gradient than in aquifer layer 3.

TABLE 4.—*Selected chemical data that show variation of water quality with depth in aquifer layer 1*

[Results in milligrams per liter, except as indicated. Map number is location in figure 6.]

	Well name			
	USGS test well Zion, Illinois		Red Wing no. 1 west, Minnesota	Red Wing no. 3, Minnesota
Map number	130	131	30	32
Date of collection	12-10-80	1-14-81	2-12-80	2-13-80
Field pH (standard units)	7.2	—	7.4	7.4
Dissolved solids, residue on evaporation	2,800	58,300	410	1,110
Calcium, Ca	311	1,000	64	80
Magnesium, Mg	39	930	27	44
Sodium, Na	440	15,000	53	250
Potassium, K	16	270	6.8	7.9
Sulfate, SO_4	1,300	1,400	34	36
Chloride, Cl	370	37,000	80	550
Interval sampled (feet below land surface)	1,775–1,935	3,120–3,475	350–630	385–770

GEOCHEMICAL PROCESSES

CALCIUM-MAGNESIUM-BICARBONATE WATER TYPE

The major geochemical and hydrologic processes that cause the changes in dissolved-solids concentrations and water types in the Cambrian-Ordovician aquifer system can be evaluated at different levels of complexity. Qualitatively, the Ca-Mg-HCO_3 water in all layers probably reflects the dissolution of calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$] in the aquifer matrix and overlying drift. The chemical reactions involved in the dissolution of carbonate minerals are a combination of hydrolysis and dissociation. The major source of acidity in the northern part of the study area is probably carbon dioxide in the atmosphere and soil. The pertinent reactions for the dissolution of calcite by carbonic acid may be expressed by

$$CO_{2(g)} + H_2O = H_2CO_3, \quad (1)$$

$$H_2CO_3 = H^+ + HCO_3^-, \quad (2)$$

$$HCO_3^{-1} = H^+ + CO_3^{2-}, \quad (3)$$

and

$$(Ca_{1-x}Mg_x)CO_{3(s)} + 2H^+ = (1-x)Ca^{2+} + xMg^{2+} + 2HCO_3^-. \quad (4)$$

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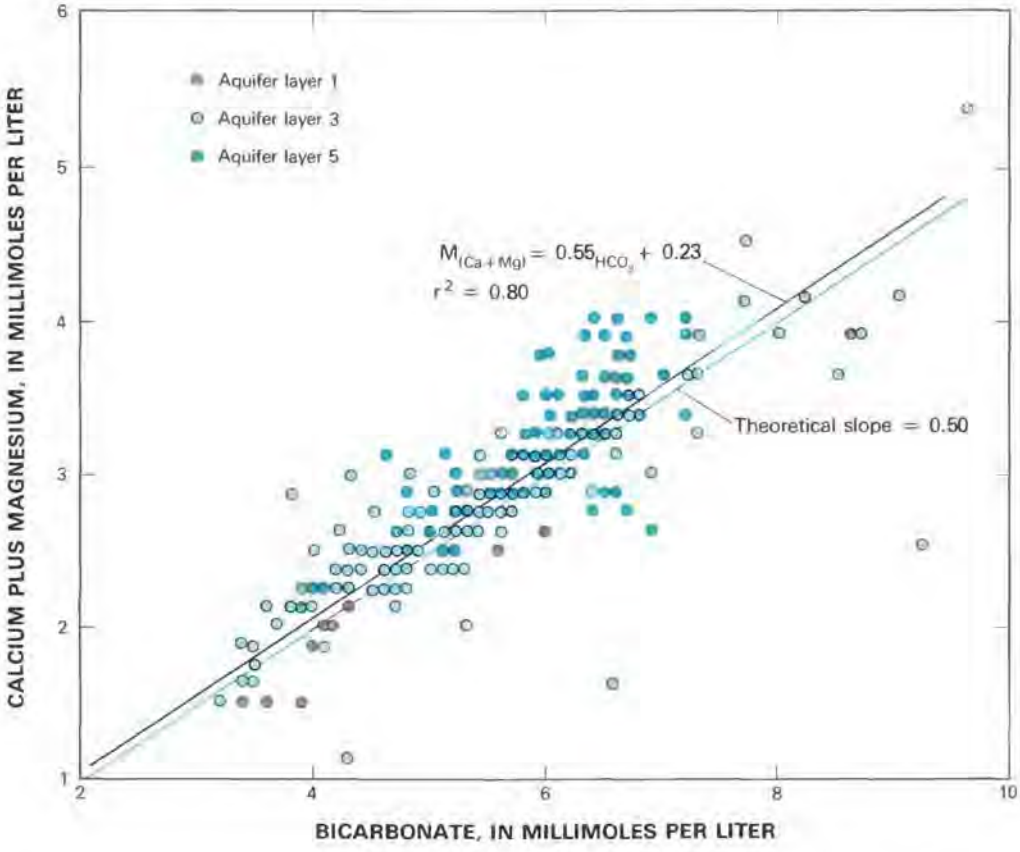

FIGURE 10.—Correlation of calcium plus magnesium and bicarbonate in ground water from the Ca-Mg-HCO_3 facies in aquifer layers 1, 3, and 5 in the northern outcrop area of the Cambrian-Ordovician aquifer system.

Combining equations 1 through 4 and neglecting CO_3^{2-} because of the near-neutral pH conditions in the aquifer,

$$(Ca_{1-x}Mg_x)CO_{3(s)} + H_2O + CO_{2(g)} = (1-x)Ca^{2+} + xMg^{2+} + 2HCO_3^- \quad (5)$$

Little information exists on the mole fractions of calcium and magnesium in the major carbonate minerals in either the Cambrian-Ordovician aquifer system or the overlying units in aquifer layer 5. A large number of rock analyses of carbonate units from Minnesota obtained from the Cambrian-Ordovician aquifer system are available—for example, Prokopovich and Schwartz (1956), Thiel and Stauffer (1947), and Stauffer (1950)—and show that there is both wide vertical and wide areal variability in the CaO and MgO content of the aquifer carbonate rocks and confining units. It is likely that there is a similar variability in calcium and magnesium content of the carbonate rocks elsewhere in the study area.

However, if dissolved calcium, magnesium, and bicarbonate in the ground water result mainly from the dissolution of carbonate minerals according to equation 5, then the molar proportions of $(Ca^{2+}+Mg^{2+})$ to HCO_3^- should be linear with a slope of 0.5. Calcium and magnesium are summed because of variability of the mole fractions within the carbonate minerals. The line of regression (fig. 10) of $(Ca^{2+}+Mg^{2+})$ versus HCO_3^- for ground-water samples in aquifer layers 1, 3, and 5 in the northern outcrop area of the Cambrian-Ordovician aquifer system in Minnesota, Wisconsin, and northeastern Iowa has a slope of 0.55. The coefficient of correlation (r^2) is 0.80, which indicates a good fit between the carbonate-dissolution model and field data.

The state of equilibrium between ground water and carbonate minerals can be tested by use of saturation indices (*SI*), expressed as

$$SI_{\text{mineral}} = \log \frac{IAP}{K_{sp}}, \quad (6)$$

where *IAP* is the ion-activity product calculated from analytical data and K_{sp} is the solubility product, an

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equilibrium constant for ions in a saturated solution in contact with excess solid phases.

A saturation index of 0.0 indicates that *IAP* and K_{sp} are equal and that thermodynamic equilibrium of the solution exists with the solid phase in question; a negative or positive index indicates undersaturation and oversaturation, respectively. Saturation indices for calcite and dolomite in selected water samples from aquifer layer 3 in Iowa and northeastern Missouri were determined by use of WATEQF, a U.S. Geological Survey water chemical-equilibrium calculation program (Truesdell and Jones, 1974; Plummer and others, 1976). Saturation indices calculated for calcite and dolomite range generally from about 0.0 to +0.6 and from −0.2 to +1.0, respectively (fig. 11), for wells in Iowa and northeastern Missouri.

The accuracy of the saturation index for determining equilibrium between solution and carbonate minerals depends largely on the accuracy of field measurements of pH and alkalinity. The most accurate method of measuring pH is by using a flow-through cell or bath until pH is constant for at least 15 minutes (Thorstenson and others, 1979). Precision by this method can be within 0.05 pH unit. Unfortunately, during this study the general accuracy of field pH measurements may have been within only ±0.1 pH unit. Accurate field measurements of alkalinity should be done by potentiometric titration to inflection points rather than to specified end points (Barnes, 1964), which was the method used during this study. The combined errors in pH measurements and alkalinity determinations could result in errors in saturation indices for carbonate dissolution reactions within a range of 20 percent. Within these error limits, ground water in the Cambrian-Ordovician aquifer system seems to be nearly saturated or oversaturated with respect to calcite and dolomite (fig. 11).

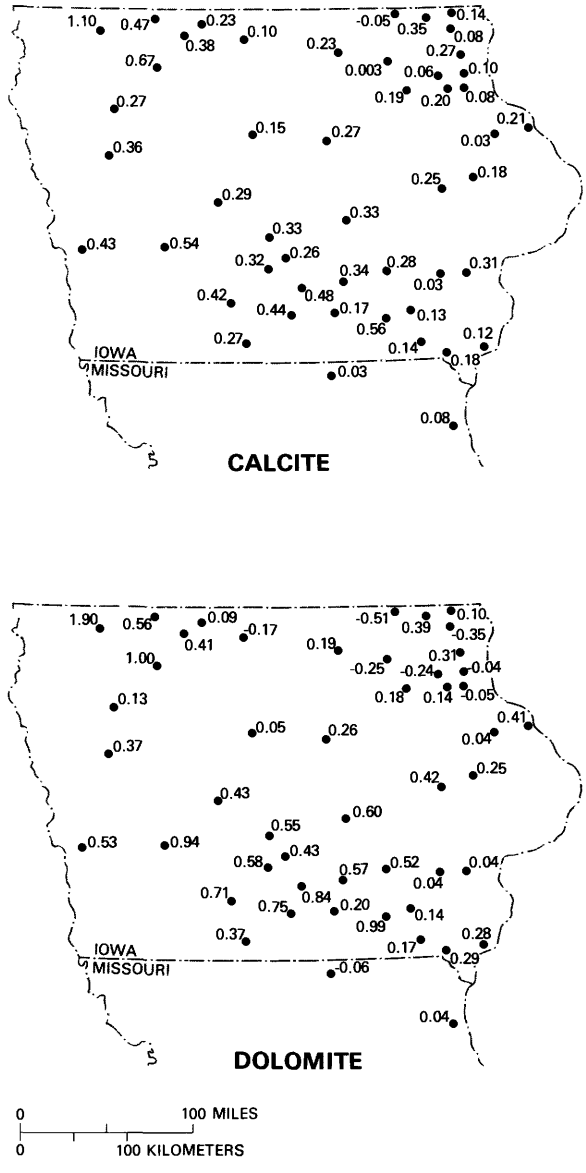

FIGURE 11.—Saturation indices for calcite and dolomite in water from selected wells in aquifer layer 3 in Iowa and northeastern Missouri.

CALCIUM-SODIUM-SULFATE-BICARBONATE WATER TYPE

Ca-Na-SO_4-HCO_3 water is common in the drift and the Dakota Formation (table 5) and is present in all aquifer layers that subcrop beneath the Dakota Formation. For instance, samples of water collected at "nests" of vertically spaced observation wells (piezometers) in aquifer layers 1, 2, and 3 in southwestern Minnesota are all of the Ca-Na-SO_4-HCO_3 type (table 6). The relative chemical uniformity of water in aquifer layers 1, 2, and 3 observed in the piezometers in southwestern Minnesota is an important factor in evaluating chemical and hydrologic mechanisms that affect changes in chemistry southeastward along the major direction of groundwater flow in Iowa. Water-quality data are scant for aquifer layers 1, 2, and 4. If the chemistry of water recharging these aquifer layers is similar to the chemistry of the ground water in aquifer layer 3, one can probably assume that the major geochemical mechanisms that control the water chemistry in all aquifer layers in the recharge areas are generally similar.

The origin of Ca-Na-SO_4-HCO_3 water in the Dakota Formation, the Quaternary drift, and the Cambrian-

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TABLE 5.—*Selected chemical analyses of water from the Dakota Formation in northwestern Iowa*

[Map number is location in figure 6]

	Well name				
	Sutherland no. 3	Primghar	Arthur no. 4	Schaller no. 3	Ruthven no. 5
Map number	82	81	90	89	83
Date of collection	2-23-82	2-23-82	2-22-82	2-22-82	2-23-82
Temperature (°C)	9.9	11.1	11.9	7.1	12.3
Field pH (standard units)	7.3	7.4	7.4	7.5	7.5
Calcium, Ca (mg/L)	320	—	260	310	220
Magnesium, Mg (mg/L)	80	—	63	100	58
Sodium, Na (mg/L)	96	—	140	190	100
Lab alkalinity, as HCO_3 (mg/L)	341	412	285	415	404
Sulfate, SO_4 (mg/L)	930	1,000	850	1,200	520
Chloride, Cl (mg/L)	6.7	20	8.5	16	5.0
Dissolved solids, residue on evaporation (mg/L)	1,790	—	1,560	2,340	1,160
Arsenic, As (μg/L)	<50	<50	<50	<50	<50
Barium, Ba (μg/L)	9	9	10	8	13
Cadmium, Cd (μg/L)	<2	<2	<2	<2	<2
Chromium, Cr (μg/L)	<5	<5	<5	<5	<5
Silica, SiO_2 (mg/L)	11	10	5	12	11
Sulfide, S (μg/L)	<3	<3	<3	<3	<3
Selenium, Se (μg/L)	<5	<5	<5	<5	<5
Copper, Cu (μg/L)	6	2	4	3	4
Iron, Fe (μg/L)	2,900	1,400	2,900	71	4,200
Manganese, Mn (μg/L)	640	—	460	2,600	270
Nickel, Ni (μg/L)	<10	—	<10	<10	<10
Lead, Pb (μg/L)	<50	—	<50	<50	<50

Ordovician aquifer system in northwestern Iowa and southwestern Minnesota is related to both the oxidation of pyrite and the dissolution of carbonate minerals. Oxidation of pyrite produces sulfuric acid that dissociates to sulfate and hydrogen ions as follows:

$$FeS_{2(s)} + 7/2 O_{2(g)} + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+. \quad (7)$$

Depending on the Eh (redox potential) and pH of the water, the resultant ferrous iron may then be oxidized to ferric iron,

$$Fe^{2+} + 1/4 O_2 + H^+ = Fe^{3+} + 1/2 H_2O, \quad (8)$$

which hydrolyzes to form insoluble iron oxides or hydroxide, for example,

$$Fe^{3+} + 3H_2O = Fe(OH)_{3(s)} + 3H^+. \quad (9)$$

TABLE 6.—*Water-quality data for water samples obtained from piezometers at Schroeder and Kingstrom sites, Goodhue County, Minn., January 1980*

[Results in milligrams per liter, except as indicated Analyses by Minnesota Department of Health]

	Well name					
	Schroeder no. 5	Schroeder no. 2	Schroeder no. 4	Kingstrom no. 1	Kingstrom no. 3	Kingstrom no. 4
Aquifer layer	1	2	3	1	2	3
Field pH (standard units)	7.1	7.3	7.2	7.2	7.3	7.1
Calcium, Ca	148	136	116	140	140	136
Magnesium, Mg	41	51	56	63	51	39
Sodium, Na	52	62	111	149	74	51
Potassium, K	10	19	24	20	26	9.7
Silica, SiO_2	6.6	6.3	6.7	6.4	5.7	6.6
Manganese, Mn (μg/L)	69	89	48	240	97	59
Iron, Fe (μg/L)	1,900	4,500	2,600	4,600	3,500	50
Alkalinity, as $CACO_3$	306	320	317	328	315	317
Sulfate, SO_4	300	370	317	490	400	290
Chloride, Cl	5.5	9.3	33	49	13	8.6
Dissolved solids, sum of constituents	860	960	1,000	1,300	1,000	800

Acidity produced in the oxidation process may be neutralized by carbonate minerals (eq. 5) that are found as part of the matrix in the Dakota Formation and the underlying aquifer units.

Sulfate in the Dakota Formation and other aquifers in northwestern Iowa and southwestern Minnesota has also been attributed to possible dissolution of either gypsum ($CaSO_4 \cdot 2H_2O$) or anhydrite ($CaSO_4$) (Winter, 1974; Munter and others, 1983). No petrographic evidence of primary evaporite minerals has been noted in the literature, however. Dissolution of gypsum proceeds rapidy compared with dissolution of carbonates and other common minerals in the aquifer matrix. The hydraulic conductivity of the Dakota Formation is generally low owing to bedded shale and siltstone. Therefore, the residence time of ground water in the Dakota probably is long. This is supported by the carbon-14 dates for water in the Dakota ranging from 22,000 to more than 35,000 years B.P. (before present) (D.L. Iles, South Dakota Geological Survey, written commun., 1982). Because of this long residence time, ground water in the Dakota Formation should be in equilibrium with gypsum, if gypsum is present, as should the ground water in aquifer layer 3, where the ground water is recharged from the Dakota. However, negative saturation indices for gypsum in ground water in aquifer layer 3 in northwestern Iowa (fig. 12) show the water to be undersaturated with respect to gypsum, and this indi-

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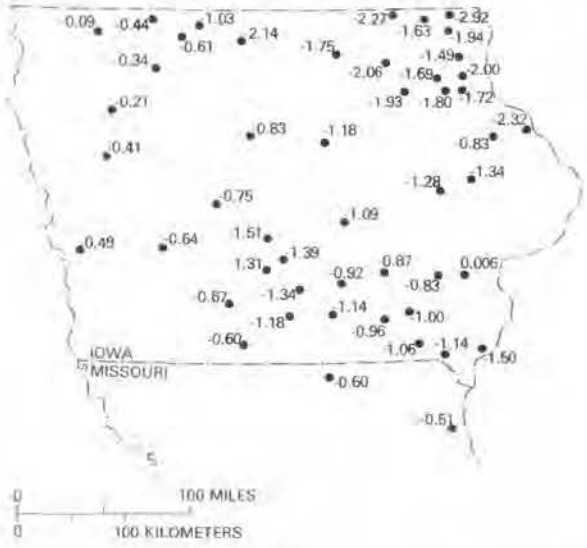

EXPLANATION

0.75 WELL LOCATION—Number is saturation index, *SI* (see text for discussion)

FIGURE 12.—Saturation indices for gypsum in water from selected wells in aquifer layer 3 in Iowa and northeastern Missouri.

rectly indicates that there is not enough gypsum in the Dakota Formation to be the source of sulfate, as suggested by other investigators.

Data on the isotopic composition of sulfur in sulfate is another way to test independently whether the sulfur is from the oxidation of pyrite (FeS_2) or the dissolution of gypsum or anhydrite. Negative $\delta^{34}S$ values typically indicate that the source of sulfur is weathered sulfide from shales, whereas positive values generally indicate an evaporitic mineral source (Holser and Kaplan, 1966; Hitchon and Krouse, 1972; Hoefs, 1980).

The $\delta^{34}S$ in sulfate from the Cambrian-Ordovician aquifer system and the Dakota Formation in northwestern Iowa (fig. 13) ranges from −10.8 to −1.0 permil (parts per thousand, written o/oo), considerably lighter than $\delta^{34}S$ associated with marine evaporites in the Cretaceous Period (Claypool and others, 1980). $\delta^{34}S$ of pyrite and other disseminated sulfide minerals in shales tends to be less than +10 o/oo, the lower limit for evaporitic sulfate (Holser and Kaplan, 1966). These values are similar to isotopic sulfur ratios in streams that drain basins underlain by marine Cretaceous rock, roughly similar to the Dakota Formation, in the MacKenzie River Basin of Canada (Hitchon and Krouse, 1972). The values of $\delta^{34}S$ indicate that the original source of sulfur was probably pyrite in the Dakota Formation.

The isotopic composition of the sulfur in sulfate reflects the isotopic composition of the sulfur in the original pyrite and depends on many factors. Sulfur isotopes approach equilibrium at earth temperatures and pressures very slowly (Pearson and Rightmire, 1980). Most differences in sulfur isotope content in aqueous sulfur compounds are caused by kinetic fractionation accompanying inorganic or bacterial reduction or by oxidation of sulfur compounds (Kaplan and Rittenburg, 1964; Goldhaber and Kaplan, 1974). Hydrogen sulfide degassing is a common problem in many wells in the Dakota Formation; this indicates that reducing conditions do exist locally in the formation (U.S. Geolgical Survey, unpub. data; Burkart, 1984). In southwestern Minnesota, methane is also common in both drift and the underlying Cambrian-Ordovician aquifer system (Coleman, 1978, 1979).

$\delta^{34}S$ in sulfate in aquifer layer 3 is enriched downgradient from the northwestern recharge area in central Iowa but is still less than +10 o/oo (fig. 13). The $\delta^{34}S$ enrichment may be related to the preferential bacterial reduction and consequent loss of sulfur-32 in H_2S or metal sulfide precipitates. Although sulfide in solution is present in the aquifer system in central Iowa (fig. 14), data are insufficient to document the presence of such possible bacteriological mediation of the reduction process. The low concentrations of sulfide may reflect precipitation of pyrite or other metal sulfides. Calculations from the WATEQF program show that sulfide-bearing solutions are supersaturated with respect to pyrite.

Some input of sulfur to the aquifer system could have been from the oxidation of pyrite in the Maquoketa Shale along the outcrop area in northeastern Iowa. However, the scant data on the isotopic content of sulfur in sulfate in central Iowa (fig. 13) show $\delta^{34}S$ greater than +5 o/oo, which is considerably heavier than that of the sulfur in sulfate derived from either the oxidation of pyrite in northwestern Iowa or from the Maquoketa Shale in northeastern Iowa.

Elsewhere in the aquifer system, $\delta^{34}S$ in sulfate may indicate a sulfur source from evaporite minerals. East of the Maquoketa confining unit in northern Illinois, $\delta^{34}S$ in sulfate in oxidized water is about +20 o/oo and is too enriched to be derived solely from the oxidation of sulfide minerals (Perry and others, 1982). Gilkeson and others (1981) proposed that some of the sulfate may have been placed in the aquifer system during Pleistocene glaciations and may be related to Michigan basin evaporites. Hydraulic gradients in Illinois, at least during the Wisconsin ice advances, could have been from east to west, reversed from current hydraulic gradients, because of the pressure head from the weight of the ice sheets that periodically covered the Lake Michigan

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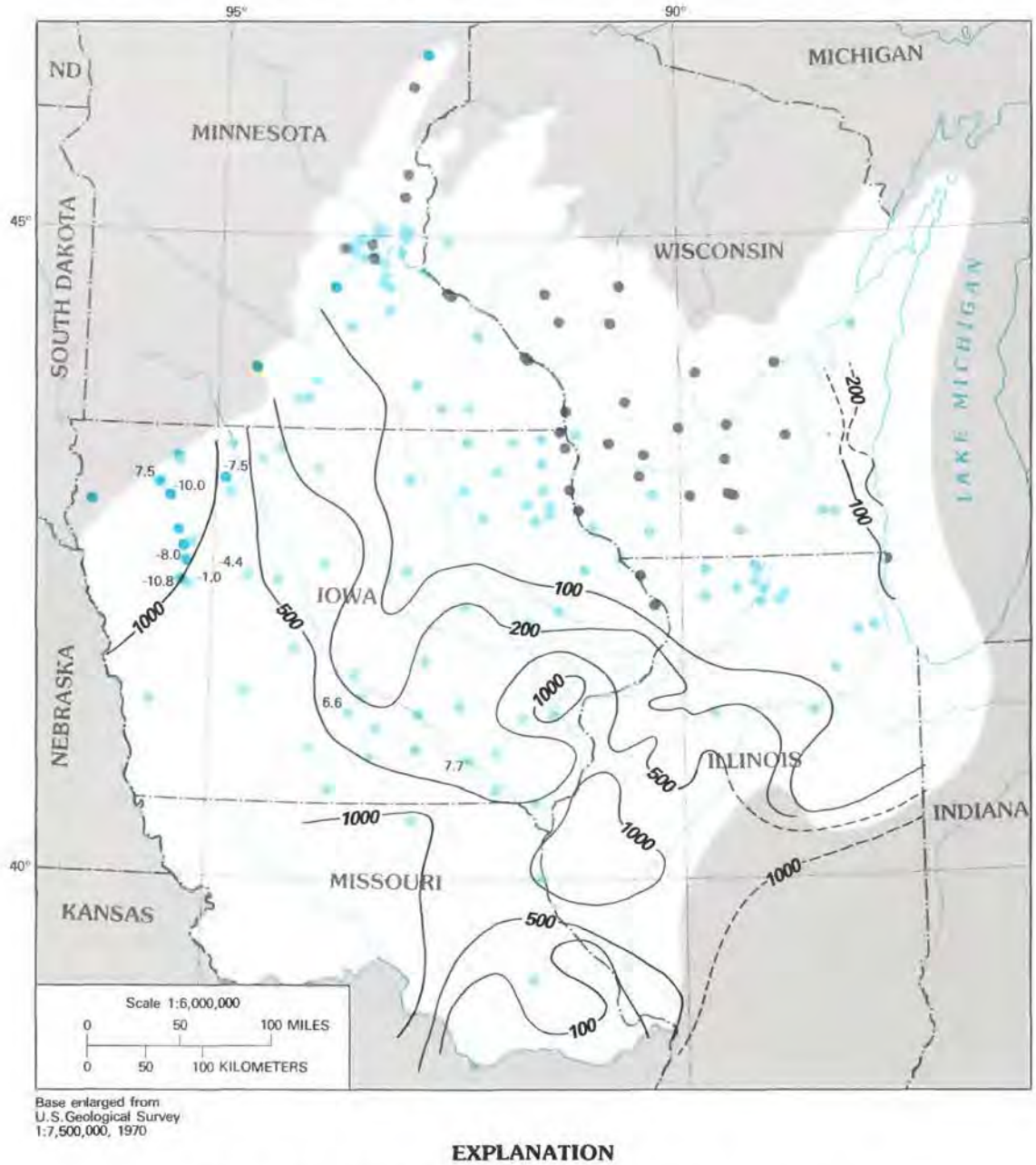

EXPLANATION

—500— LINE OF EQUAL CONCENTRATION OF SULFATE—Dashed where approximate. Interval, in milligrams per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY
Number is isotopic composition of sulfur in sulfate, $\delta^{34}S$, permil

- Open to aquifer layer 1
- -4.4 Open to aquifer layer 3
- -7.5 Open to aquifer layer 5

FIGURE 13.—Sulfate distribution in aquifer layers 1 and 3 and sulfur isotopic composition in sulfate in water from selected wells in aquifer layer 3 and aquifer layer 5 (Dakota Formation).

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EXPLANATION

1.0 WELL LOCATION—Number is sulfide concentration in milligrams per liter

FIGURE 14.—Sulfide distribution in water from selected wells in aquifer layer 3 in Iowa.

basin (Gilkeson and others, 1981; Filley and Parizek, 1983; Siegel and Mandle, 1983). The influence of Pleistocene glaciations on the water chemistry of the Cambrian-Ordovician aquifer system was profound and is discussed in a later section, "Isotopic Composition of Water and Pleistocene Recharge Model."

SODIUM-MIXED ANION WATER TYPE

The evolution of Ca-Na-SO_4-HCO_3 water to Na-Ca-SO_4-HCO_3 and Na-Cl water is well illustrated in figure 15, a plot of analyses in terms of equivalent weights on the trilinear diagram of Piper (1944). Data from wells along geochemical sections A–A' and B–B' indicate a trend toward sodium predominance on the cation plot, and toward chloride predominance on the anion plot. The increase in sodium and the decrease in calcium and magnesium along the flow path could be the result of several processes.

Sodium could be contributed by dissolution of sodium-bearing silicate or evaporite minerals in the aquifer system. However, no petrographic evidence exists to indicate the presence of halite (NaCl) in the aquifer system, and the dissolution rate of sodic plagioclase ($NaAlSi_3O_8$) is much too slow to account for the concentrations of sodium found in central Iowa.

The inverse relationship between concentrations of sodium and alkaline-earth metals could also be explained by ion exchange, which has been identified in many aquifer systems elsewhere (for example, Foster, 1950; Krothe and Parizek, 1979; Thorstenson and others, 1979; Krothe and Bergeron, 1981; Chapelle and Knobel, 1983). Exchange would follow the generalized reaction

$$M^{2+} + Na_2\text{-Clay} = 2Na^{+} + \text{M-Clay}, \qquad (10)$$

where M^{2+} is $Ca^{2+} + Mg^{2+}$ or other alkaline-earth metals.

Micaceous clays such as illite and glauconite are more common in the Cambrian-Ordovician aquifer system than are mixed-layered clays such as montmorillonite and smectite, which are usually associated with cation exchange. Major clay minerals in the Ordovician Decorah Formation and Glenwood Formation, which are part of the Maquoketa confining unit that separates aquifer layer 3 from aquifer layer 4, are kaolinite and illite (Parham and Austin, 1967, 1969). However, distinctive beds of potassium montmorillonite have been identified in the Decorah Formation and other Ordovician formations throughout the study area (Mossler and Hayes, 1966). Although the presence of montmorillonite in Ordovician and Cambrian rocks suggests that significant cation-exchange capacity may be present in the aquifers, such exchange probably cannot completely account for the linear plot of the cations (fig. 15). If cation exchange were the dominant mechanism, the plot would trend more parallel to the calcium-sodium axis rather than toward the sodium apex (Piper, 1944), unless exchange of calcium and magnesium for sodium occurred at rates that would maintain similar Ca:Mg molar ratios along the flow path. Covariance of the molality of sodium to molality of (Ca + Mg) has a low coefficient of correlation (r^2) of 0.3 and a slope of +2.1. If ion exchange were a major process, r^2 would be closer to unity and the slope would be close to −2 (Chapelle, 1983). Given the areal variability and probable scarcity of clays having high cation-exchange capacity for calcium and magnesium in the aquifer system, it is unlikely that much ion exchange occurs except in recharge areas underlain by clayey till and the Dakota Formation.

Mixtures of two waters will also plot on straight lines if all solutes remain in solution and do not increase or decrease as a result of chemical reactions. The linearity of the cation plot (fig. 15) may indicate simple mixing of Na-mixed anion water with Ca-Na-mixed anion water, but the curvilinear fit of the anion data indicates sources and sinks along the flow path with respect to bicarbonate and sulfate.

Although cation trends on the trilinear diagrams could indicate mixing of two types of water, sodium and chloride concentrations along the major southeastward direction of ground-water flow across Iowa probably

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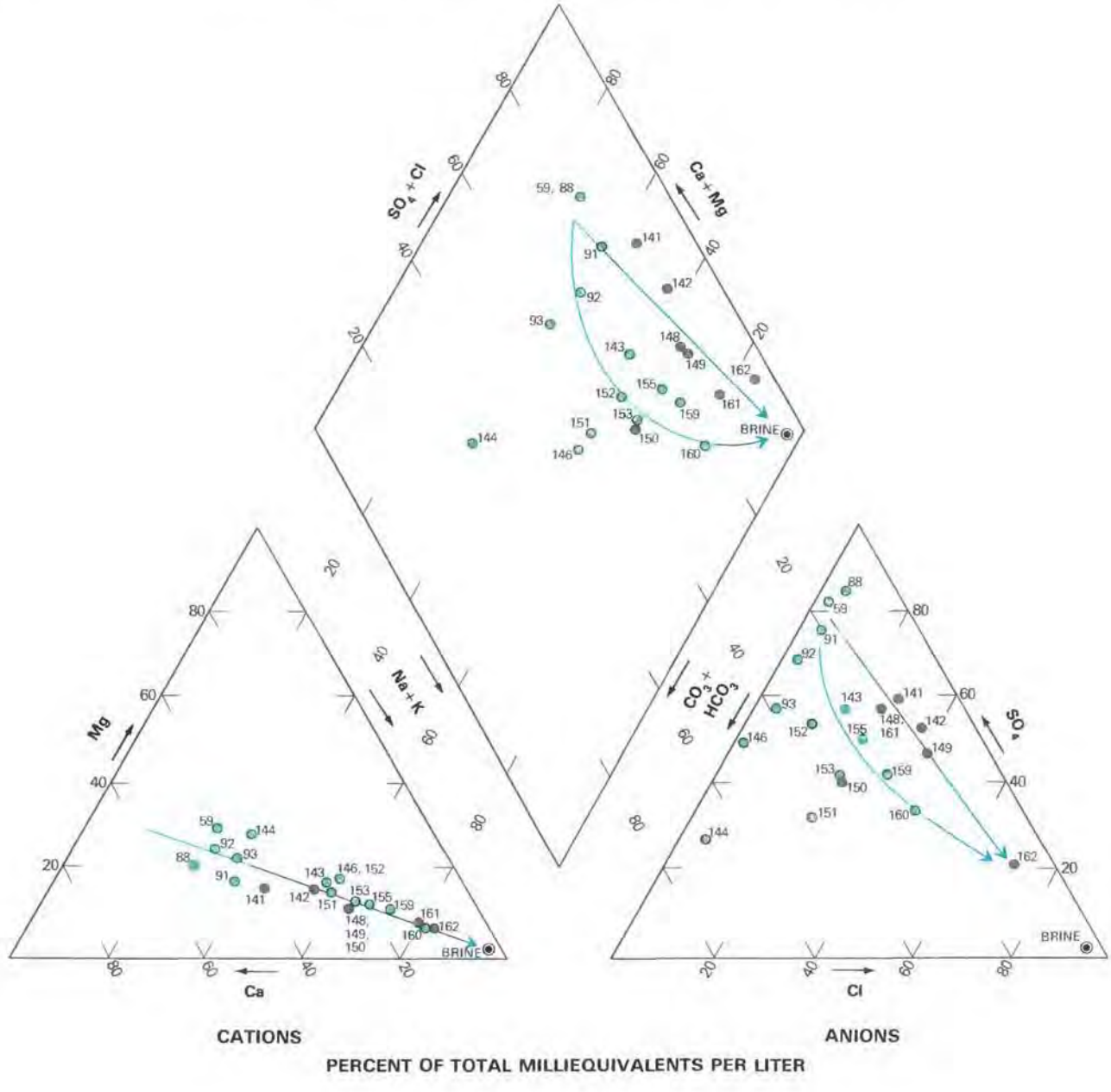

FIGURE 15.—Trilinear diagram of water chemistry along geochemical sections *A-A'* and *B-B'*.

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reflect a gradual mineralization of the waters as they approach the Na-Cl brines of the Illinois basin. The origin of the brines is related to reverse chemical osmosis and membrane filtration (Graf and others, 1965; Clayton and others, 1966; Hanshaw and Coplen, 1973; Graf, 1982). The combined effects of these processes that concentrate sodium and chloride probably extend upgradient in the Cambrian-Ordovician aquifer system outside the Illinois basin proper. For example, chloride concentrations increase to more than 100 mg/L in southern Iowa, halfway down the regional flow paths from northwestern and western Iowa to southeastern Iowa (fig. 16). The overall trend toward more chloride-rich waters occurs even in central Iowa within the plume of low-dissolved-solids water, where concentrations of chloride are several times greater than to the northeast (figs. 7, 16). Figures 17 and 18 show concentrations of major constituents along geochemical sections A–A' and B–B'. Concentrations of chloride and sodium begin to increase from south-central Iowa down the major flow paths to the southeast toward the Illinois basin.

The trilinear plot of anions (fig. 15) shows that, although chloride is less than 10 percent, sulfate decreases from about 80 percent at the recharge area in western Iowa to about 55 percent near the Mississippi River. Bicarbonate plus carbonate increases from less than 20 percent to more than 40 percent. The apparent inverse relationship between equivalents of these constituents suggests that sulfate is possibly being reduced to sulfide along the hydraulic gradient, probably with an associated loss of oxygen, in the presence of a reducing agent such as organic material.

If the reducing agent is organic material, the following reactions are possible:

$$15CH_2O + 2Fe_2O_3 + 8SO_4^{2-} + H_2CO_3 = 4FeS_2 + 16HCO_3^- + 8H_2O \quad (11)$$

or

$$SO_4^{2-} + 2CH_2O + 2H^+ = H_2S + 2CO_2 + 2H_2O. \quad (12)$$

Hematite (Fe_2O_3) and ferric oxyhydroxide [FeO(OH)] are common in the Cambrian-Ordovician aquifer system. Organic material is less common, but bacteriogenic decomposition of organic material occurs within the overlying Dakota Formation. Thus, recharge from the Dakota Formation and possible reduction of organic material in shales associated with aquifer layer 3 could produce bacteriogenic methane in water. Methane concentrations of as much as 15 ppm in aquifer layer 3 and 7 ppm in aquifer layers 2 and 1 were identified in southwestern Minnesota (Coleman, 1978; Minnesota Department of Natural Resources, written commun., 1981).

The equivalent weight of sulfate lost should approximately equal that of bicarbonate gained if the reactions are a reasonable explanation for the observed chemical changes (eqs. 11, 12). A plot of equivalents of sulfate against bicarbonate for sections A–A' and B–B' shows the contrary (fig. 19); as sulfate decreases, bicarbonate remains the same, at about 5 meq/L. Furthermore, saturation indices indicate that the ground water is oversaturated or is nearly in equilibrium with calcite and dolomite (fig. 11). Bicarbonate concentrations remain constant even in the vicinity of the dilute plume in central Iowa. If the dilute plume is caused by dilution of ground water with recharge water of low dissolved-solids content, the uniform bicarbonate concentrations and saturation indices would suggest that ground water has reequilibrated with carbonate minerals in the aquifer since the dilution episode or episodes. The mechanism, timing, and amount of such recharge can be explained hypothetically by glacial advances during the Pleistocene and are discussed later in the section "Isotopic Composition of Water and Pleistocene Recharge Model."

TRACE AND MINOR CONSTITUENTS

The areal distribution of many trace constituents in the aquifer system is related approximately to the availability of the constituents in the source rocks. Although specific data on the trace-element content of the aquifer matrix is lacking, compilation of the average distribution of elements in major rock types (Turekian and Wedepohl, 1961; Drever, 1982) indicates that higher concentrations of many transition metals are found in shales rather than in carbonate rocks or sandstones. Concentrations of the alkaline earth strontium and of halogens, such as bromine and fluorine, are more variable with respect to rock type.

The areal distribution of the transitional metals cadmium and arsenic in the aquifer system may be related to the proximity of the argillaceous Dakota Formation. Concentrations of these metals are generally less than 5 μg/L, except where the aquifer subcrops beneath the Dakota Formation in northwestern Iowa and southwestern Minnesota (fig. 20). Scant data suggest that selenium concentrations are less than 5 μg/L except at one location beneath the Dakota Formation. Cadmium concentrations may also increase to more than 5 μg/L in southeastern Iowa and northeastern Missouri on the edge of the Illinois basin. Concentrations of iron and manganese increase where the aquifer is overlain by the Dakota Formation and by drift derived from the Dakota (fig. 21). For example, concentrations of iron

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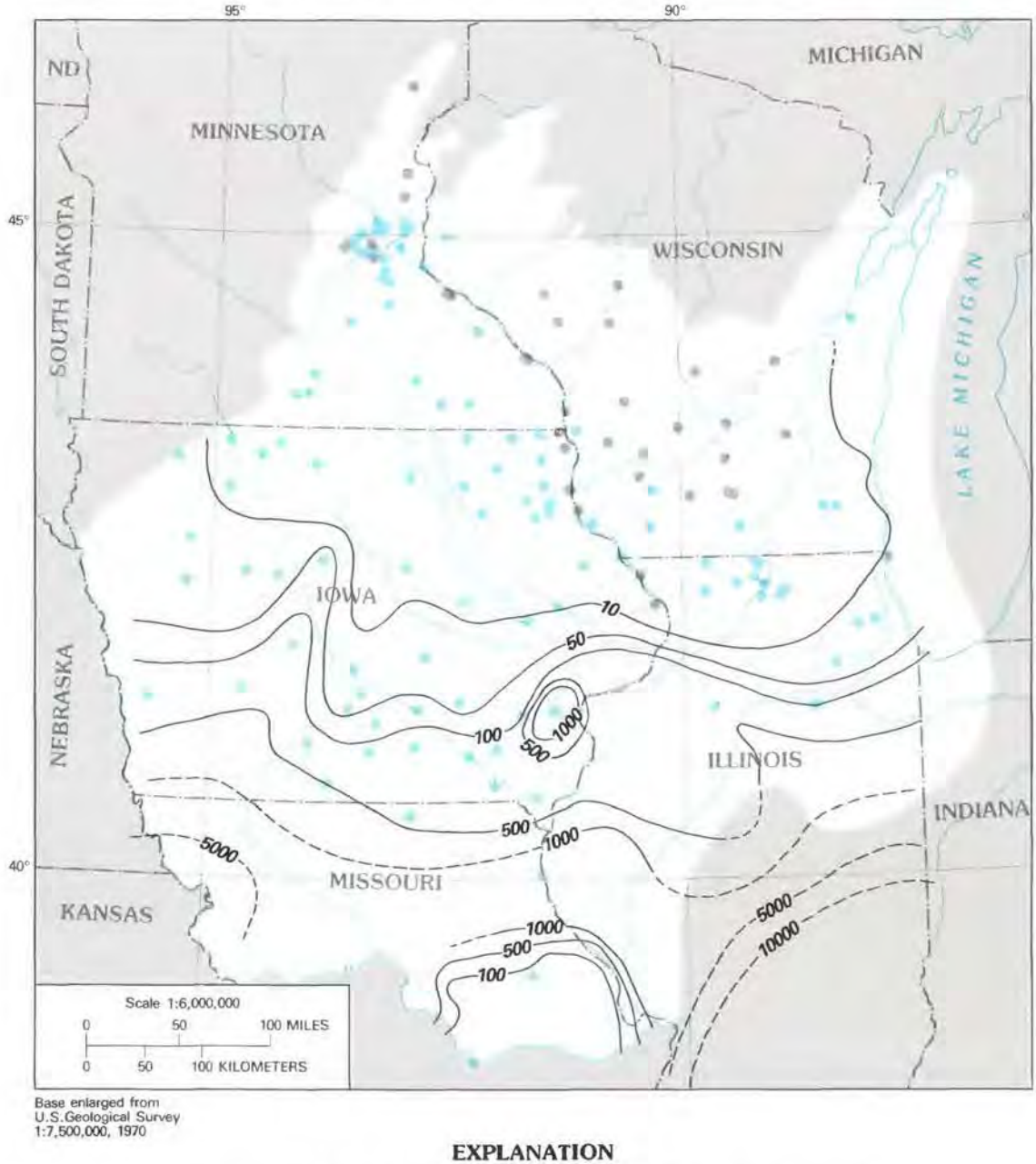

EXPLANATION

50 — LINE OF EQUAL CHLORIDE CONCENTRATION— Dashed where approximate. Interval, in milligrams per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 16.—Chloride distribution in aquifer layers 1 and 3.

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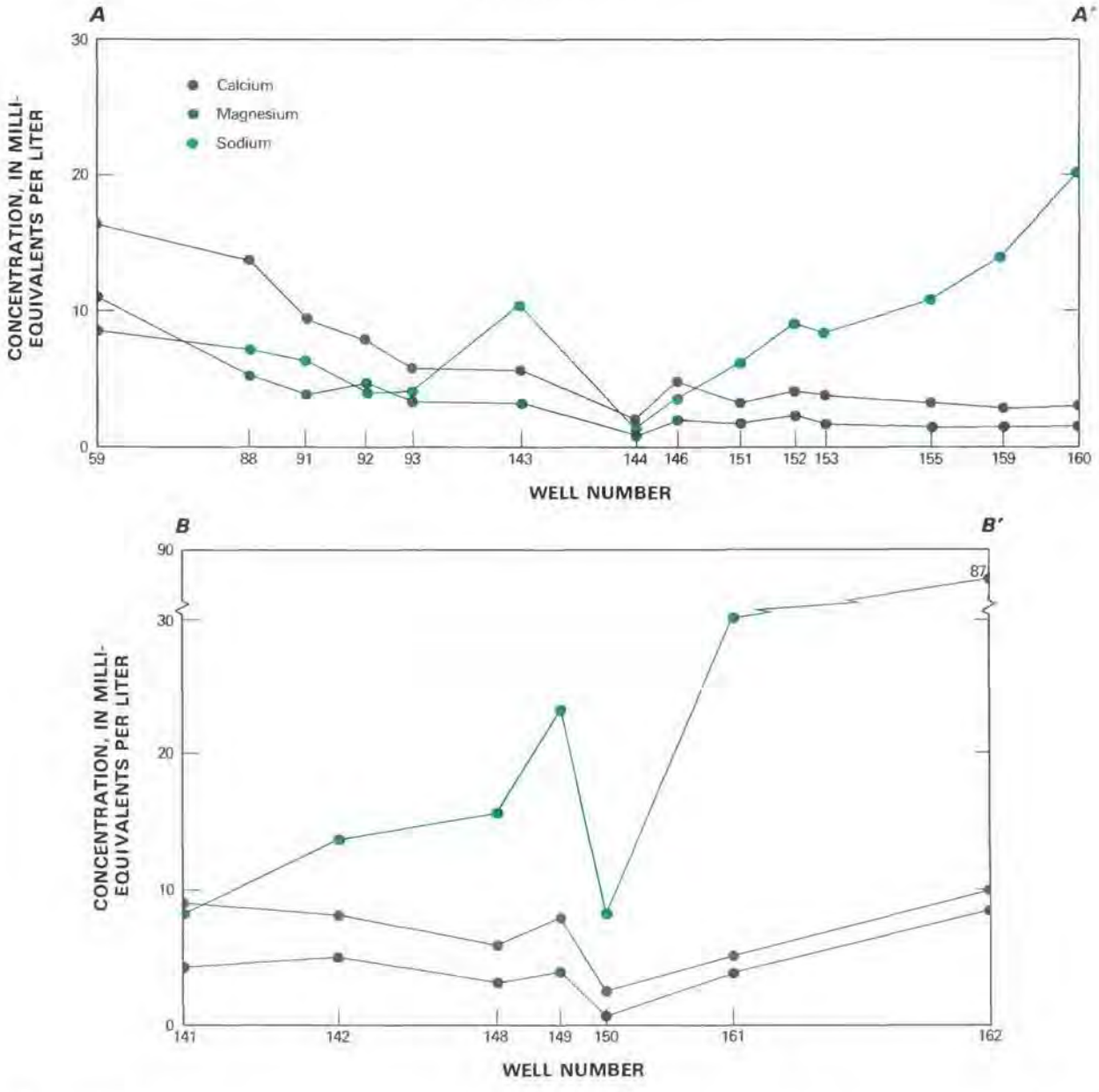

FIGURE 17.—Concentrations of major cations in water from wells in aquifer layers 1 and 3 along geochemical sections A-A' and B-B'. (Location of wells shown in fig. 6.)

and manganese exceed 1,000 μg/L and 100 μg/L, respectively, in northwestern Iowa. Concentrations of iron, manganese, copper, lead, and cobalt increase in southwestern Iowa near the margin of the Forest City basin (figs. 21, 22). Concentrations of cadmium and copper are more than 5 and 20 μg/L, respectively, in southeastern Iowa near the western flank of the Illinois basin (figs. 20, 22).

The controls on the concentrations of these and other trace metals are complicated and are related as much to complexation of metals by organic and inorganic ligands, sorption of metals onto solids, and oxidation-reduction potential of the water as to the metal content of the source rock (Garrels and Christ, 1965; Stumm and Morgan, 1981; Eichenberger and Chen, 1982; Hem, 1985). The influence of these processes on the trace-metal content of the water cannot be evaluated at the present time because the detection limits of the analyses for the metals were at reconnaissance levels and because information on the composition of dissolved organic carbon in the water and regional mineralogical and trace-metal composition of the aquifer matrix are

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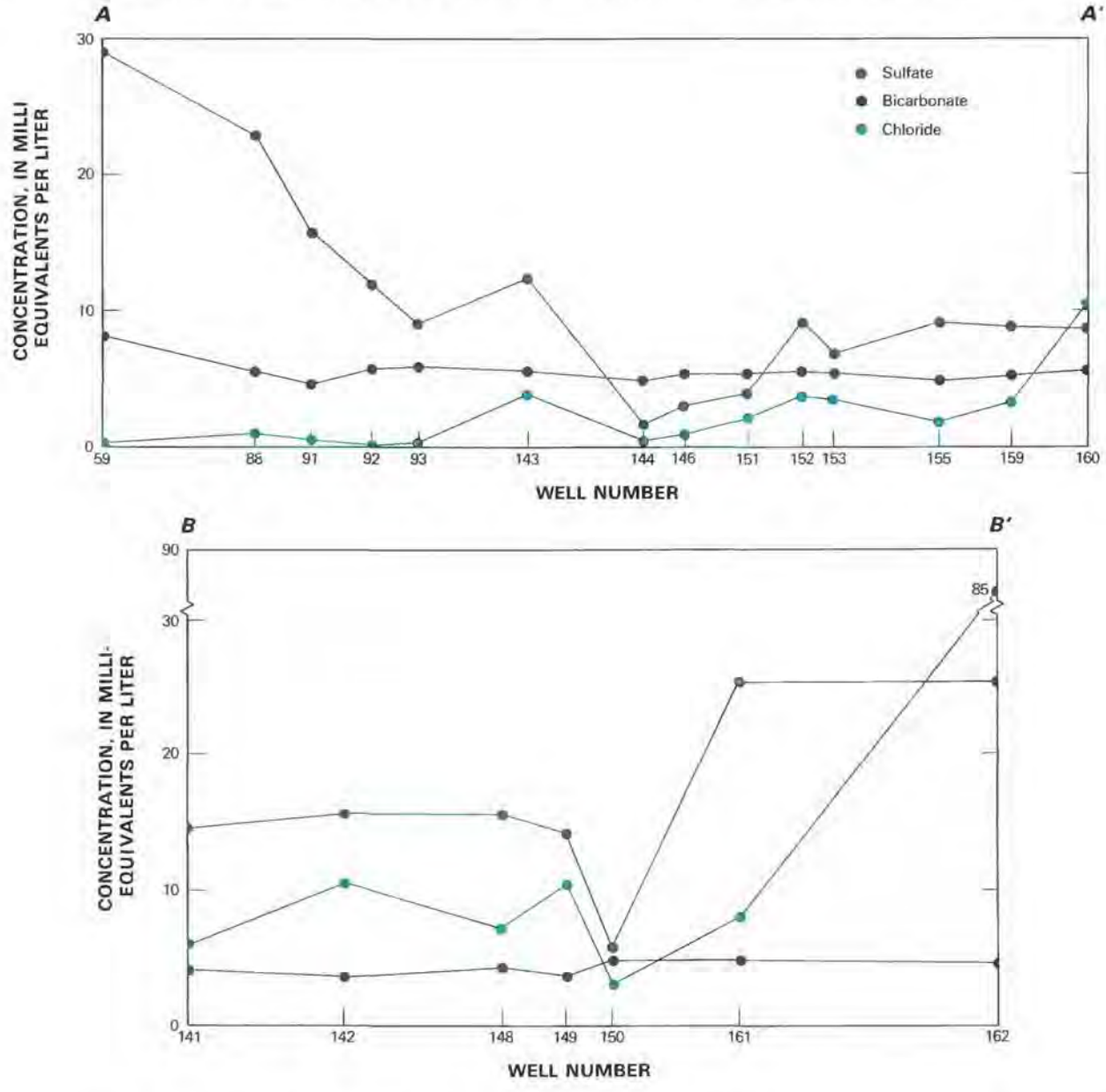

FIGURE 18.—Concentrations of major anions in water from wells in aquifer layers 1 and 3 along geochemical sections *A-A'* and *B-B'*. (Location of wells shown in fig. 6.)

lacking. Some trace metals, such as iron, can be reduced by bacteria at the pH values prevalent in the aquifer. Reducing conditions, identified by measurable dissolved sulfide, are present throughout the aquifer where it is confined by the Maquoketa Shale (fig. 14) and locally in the Dakota Formation (Burkart, 1984), and they probably are a major control on trace-metal concentrations in western Iowa.

The relationship between some trace-metal concentrations in ground water and proximity to the Forest City basin may be indicated by concentrations of beryllium and molybdenum of more than 1 and 10 μg/L, respectively, in southwestern Iowa (fig. 23). Concentrations of these and other metals may increase near the Illinois basin. However, no trace-metal data for water from the Cambrian-Ordovician aquifer system are available for that area. Several wells in northeastern and north-central Iowa inexplicably have molybdenum concentrations of more than 10 μg/L.

Some trace constituents that have relatively similar average concentrations in different sedimentary rock types show increases in concentration in ground water

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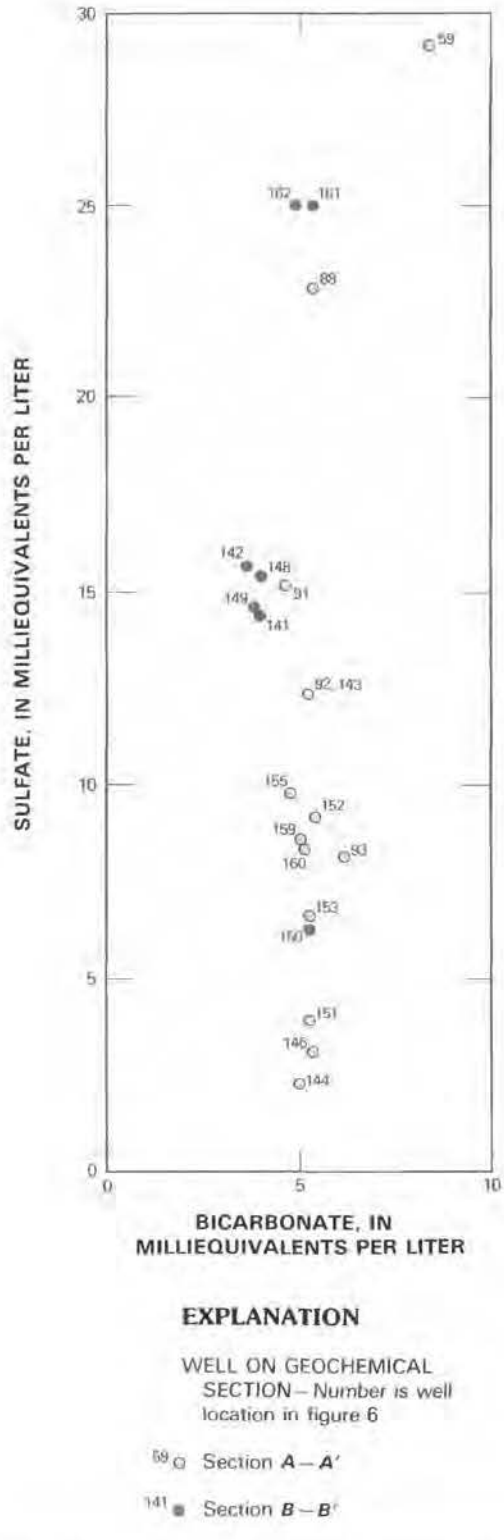

FIGURE 19.—Sulfate-bicarbonate relationship along geochemical sections *A-A'* and *B-B'*.

southwestward across Iowa and eastward across Wisconsin. For example, fluoride concentrations increase from less than 1 to more than 2 mg/L, lithium from less than 10 to more than 400 μg/L, boron from less than 200 to more than 2,000 μg/L, and strontium from less than 1,000 to more than 6,000 μg/L across Iowa (figs. 24–27). Strontium concentrations exceed 1,000 μg/L in eastern Wisconsin where dissolved solids generally exceed 500 mg/L (Nichols and McNall, 1957; Kammerer, 1981). Boron concentrations exceed 5,000 μg/L near the western edge of the Illinois basin (fig. 26).

There is no identifiable plume of dilute concentration of trace constituents in Iowa (as there is for dissolved solids), with the exception of bromide (fig. 28) and possibly lithium (fig. 25). Bromide concentrations in the aquifer are generally less than 0.5 mg/L except near the western edge of the Illinois basin, where concentrations approach 10 mg/L. In central and southern Iowa, a broad zone of bromide concentration of less than 0.5 mg/L is surrounded by areas of bromide concentrations of greater than 1.0 mg/L (fig. 28). This distribution roughly matches the dilution shown by the dissolved-solids distribution (fig. 7). Bromide is a conservative, relatively nonreactive constituent and therefore is a good indicator of hydrological processes that involve mixing of different water types. The lack of similar dilution plumes in the distribution of strontium, fluoride, and boron suggests that chemical processes other than mixing have controlled the distribution of these trace constituents, thus masking the reacharge plume(s).

Concentrations of barium in the ground water are related both to source and to geochemical processes. Gilkeson and others (1981) showed that barium concentrations or more than 1 mg/L in northeastern Illinois are due to a zone of reducing conditions in the confined Cambrian-Ordovician aquifer system. Sulfate ion is reduced to sulfide, thereby allowing concentrations of barium to increase until the solubility limit of barite ($BaSO_4$) is reached. Concentrations exceeding 100 μg/L in the northwestern part of the study area are probably due to barium contained in shales of the Dakota Formation (fig. 29). Concentrations also exceed 100 μg/L in the northeastern corner of Iowa near the Mississippi River. The cause of the higher barium concentrations in Iowa is unknown. Higher barium concentrations also are present in the aquifer in southeastern Wisconsin along the strike of the Maquoketa Shale, apparently an extension of the conditions in northeastern Illinois. Additional work is needed to determine whether the solubility of barite controls the high barium concentrations in these waters.

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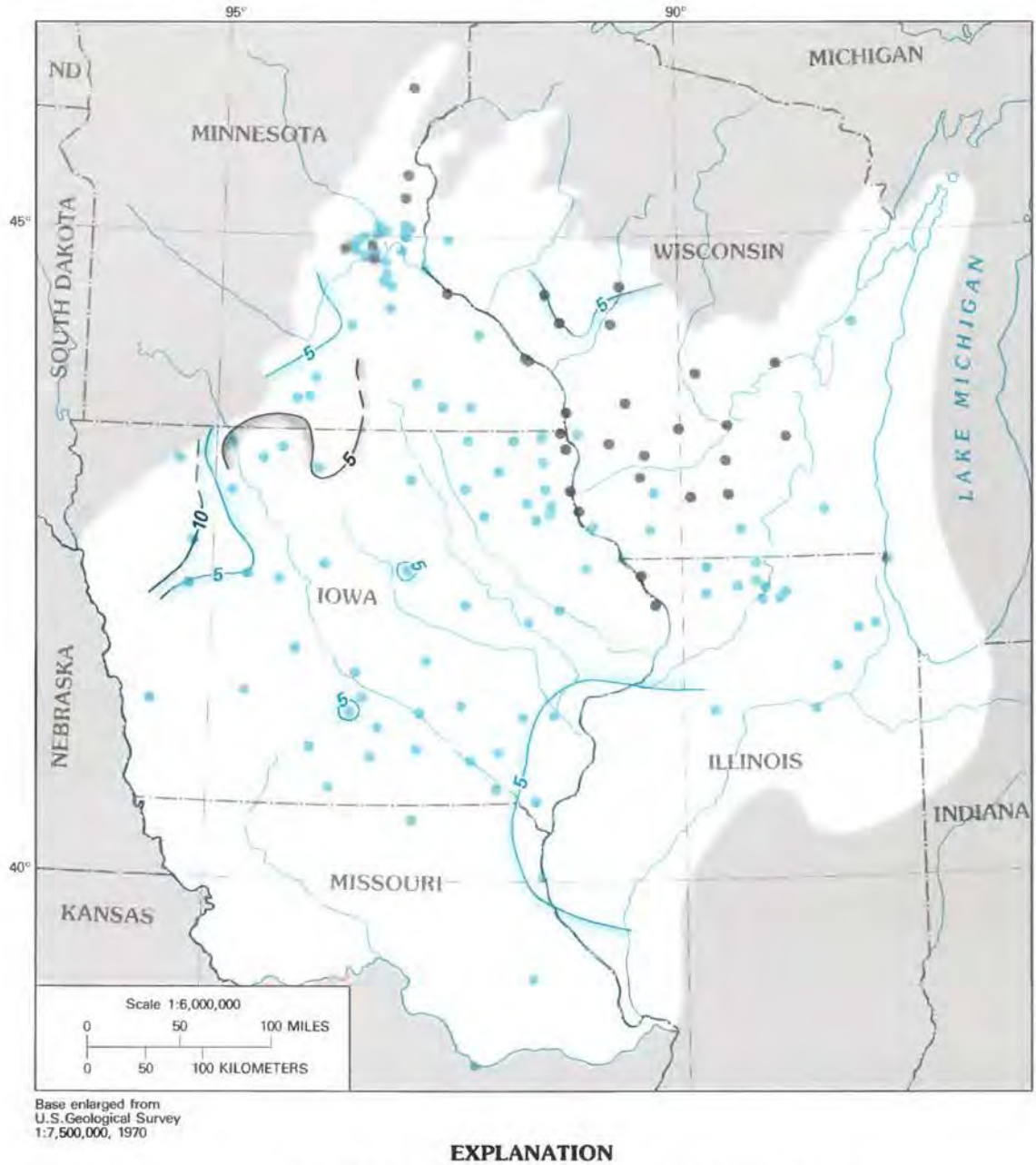

EXPLANATION

LINES OF EQUAL CONCENTRATION—Stippled in direction of lower concentration. Dashed where approximate. Interval, in micrograms per liter, is variable

5 Cadmium

5 Arsenic

10 Selenium

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 20.—Distribution of dissolved cadmium, arsenic, and selenium in aquifer layers 1 and 3.

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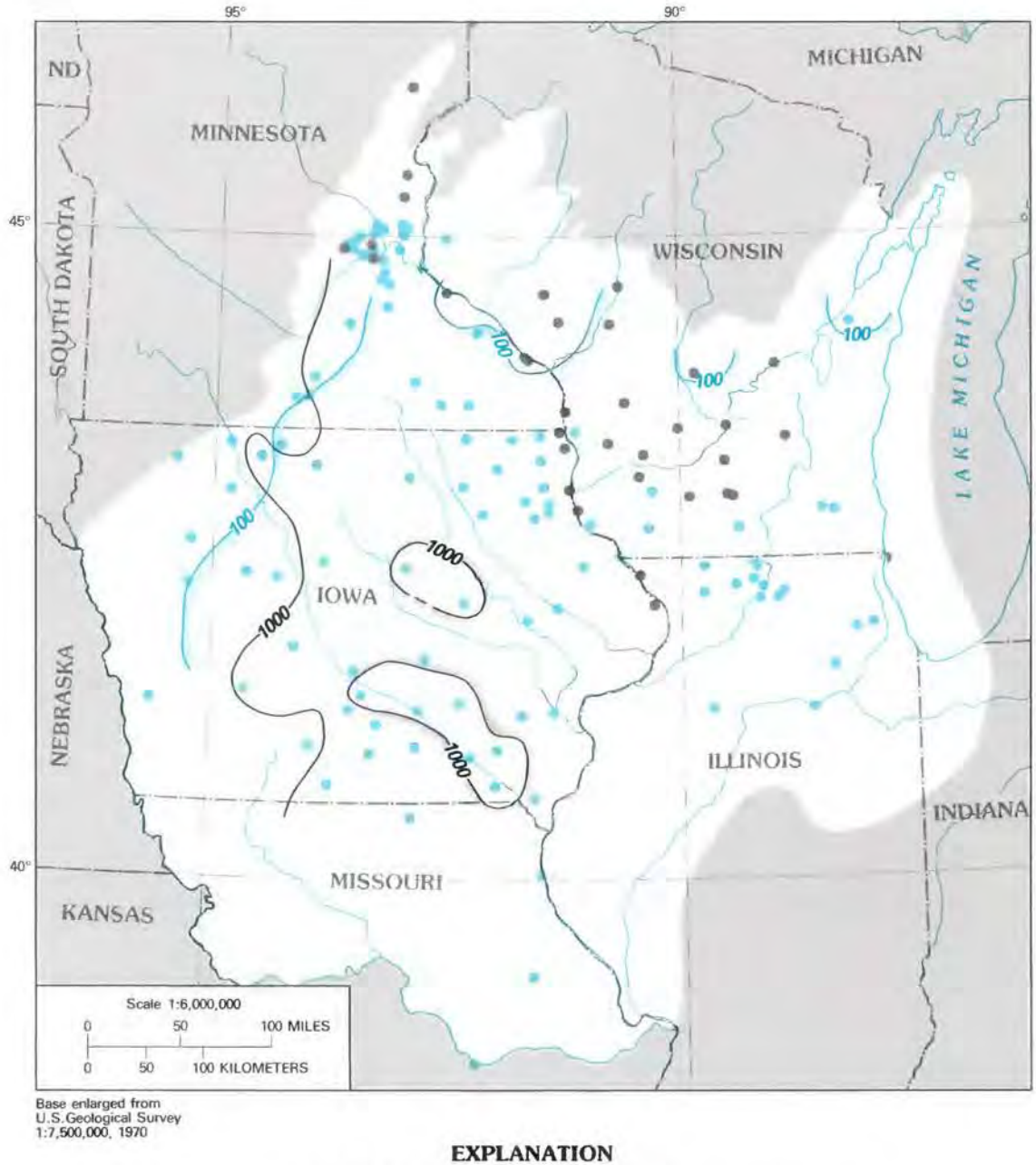

EXPLANATION

LINES OF EQUAL CONCENTRATION—Stippled in direction of lower concentration. Dashed where approximate. Interval, in micrograms per liter, is variable

--1000— Iron

—100— Manganese

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 21.—Distribution of dissolved iron and manganese in aquifer layers 1 and 3.

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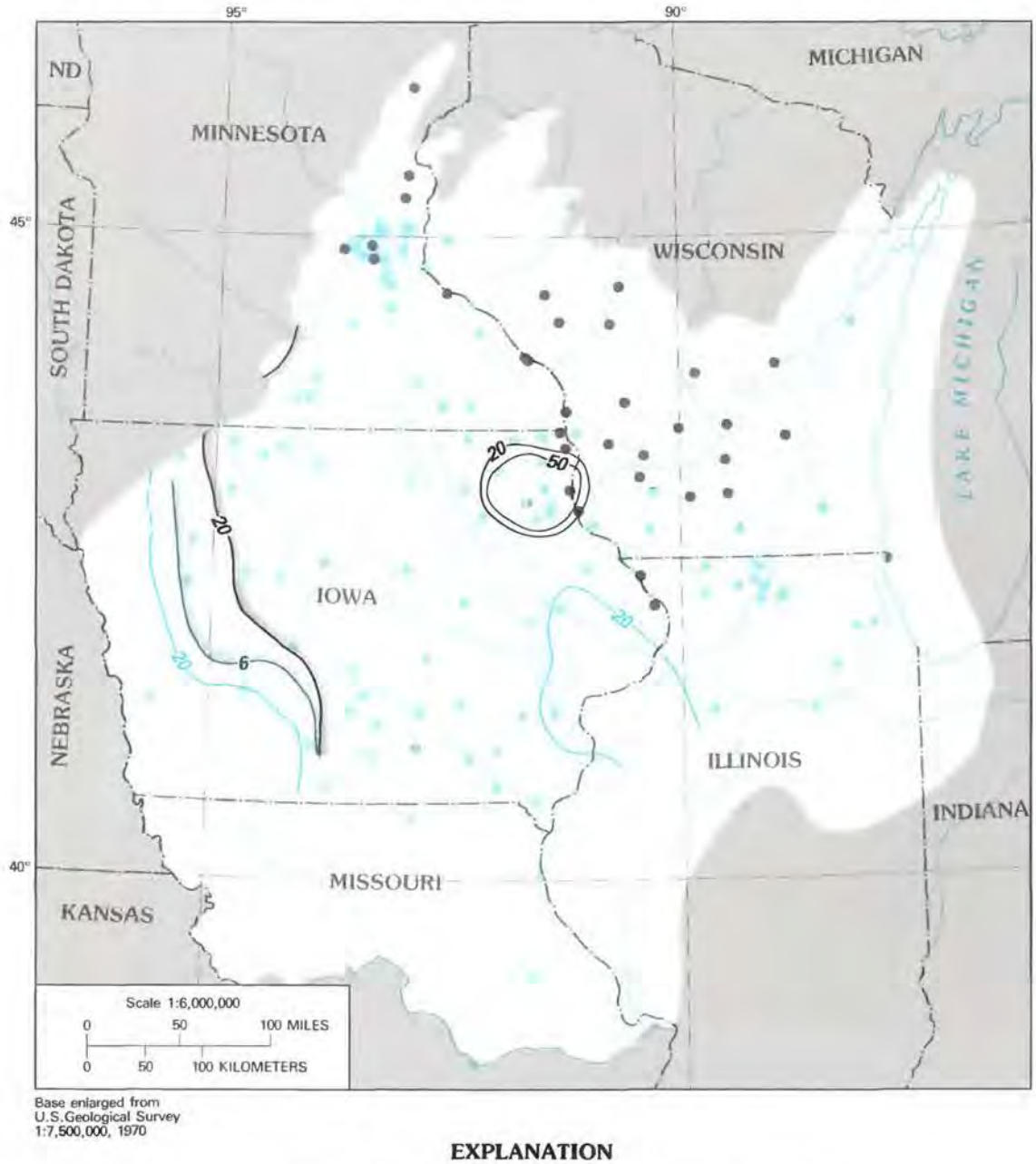

EXPLANATION

LINES OF EQUAL CONCENTRATION—Stippled in direction of lower concentration. Dashed where approximate. Interval, in micrograms per liter, is variable

20 Copper

20 Lead

6 Cobalt

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 22.—Distribution of dissolved copper, lead, and cobalt in aquifer layers 1 and 3.

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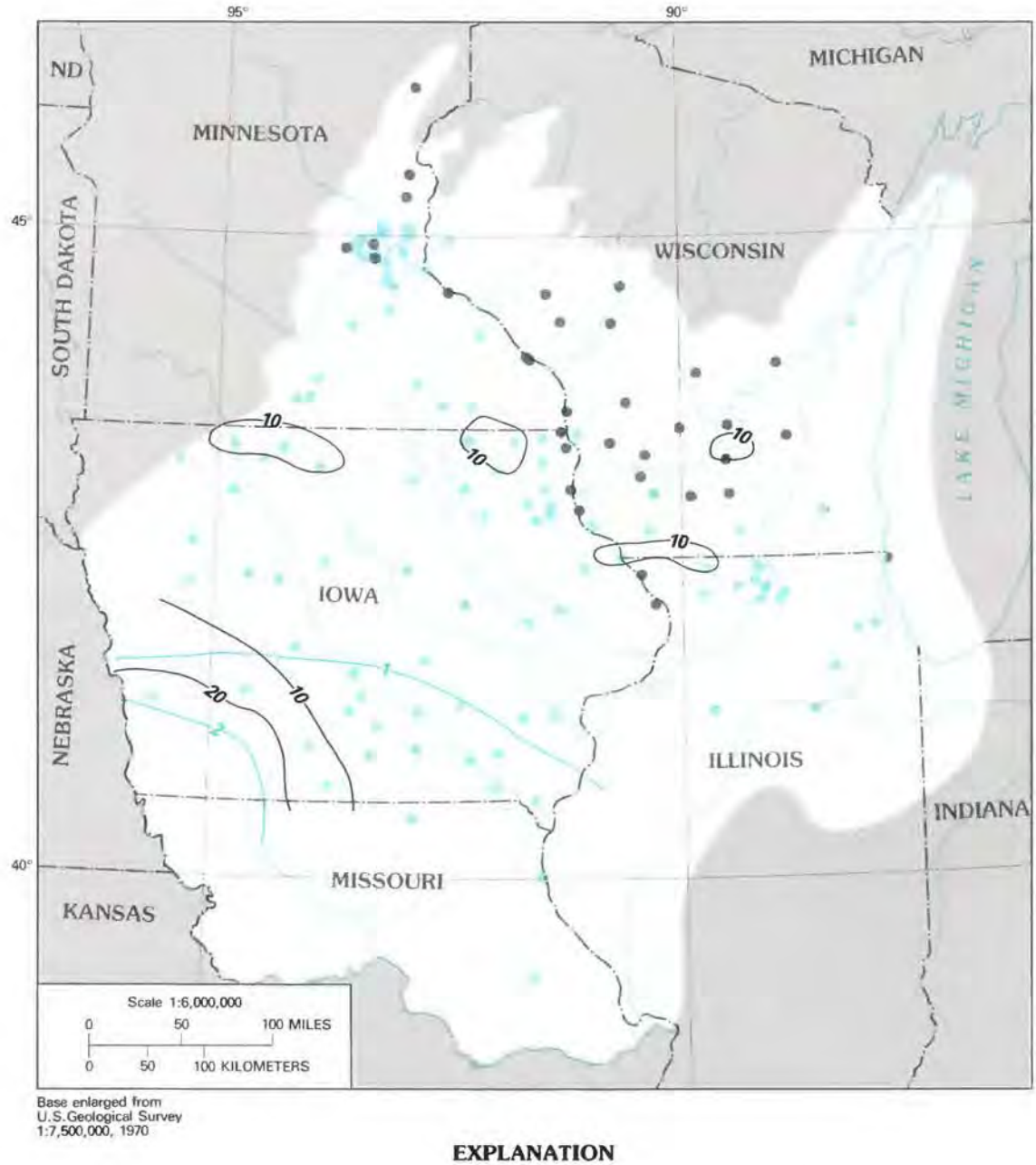

EXPLANATION

LINES OF EQUAL CONCENTRATION—Interval, in micrograms per liter, is variable

—10— Molybdenum

—2— Beryllium

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 23.—Distribution of dissolved molybdenum and beryllium in aquifer layers 1 and 3.

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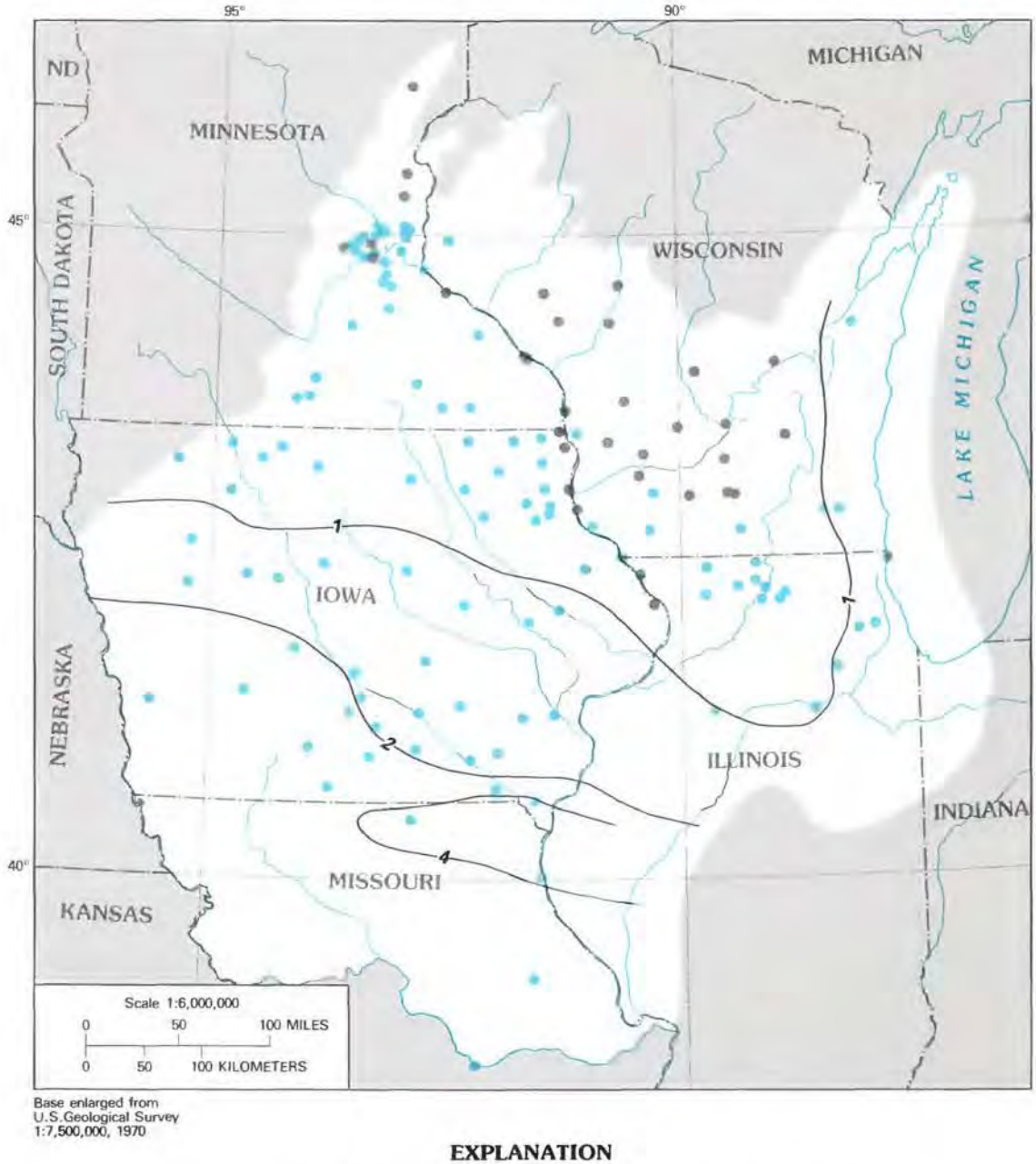

EXPLANATION

—4— LINE OF EQUAL FLUORIDE CONCENTRATION—Interval, in milligrams per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

FIGURE 24.—Distribution of dissolved fluoride in aquifer layers 1 and 3.

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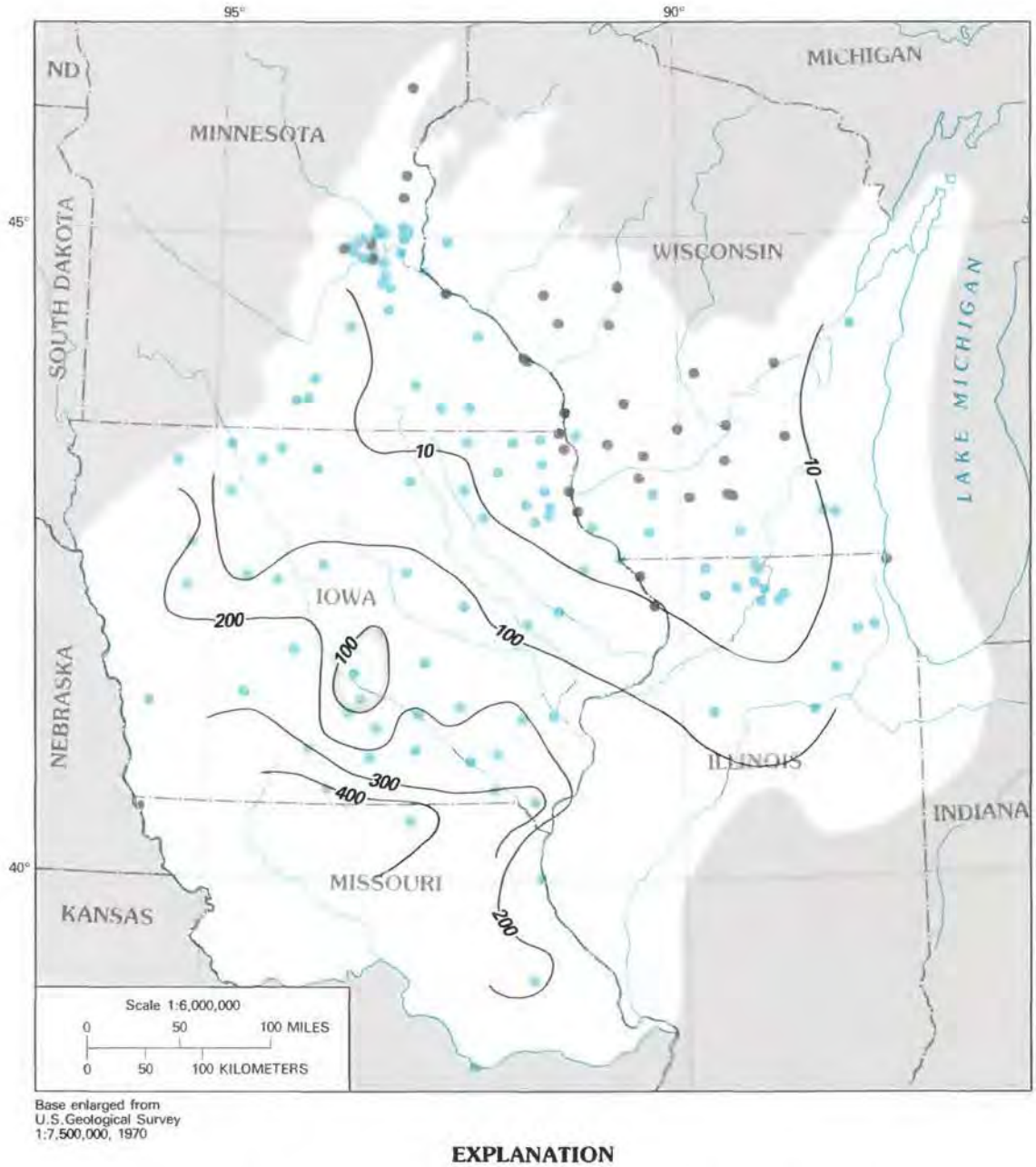

EXPLANATION

—100— LINE OF EQUAL DISSOLVED LITHIUM CONCENTRATION—Stippled in direction of lower concentration. Interval, in micrograms per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

FIGURE 25.—Distribution of dissolved lithium in aquifer layers 1 and 3.

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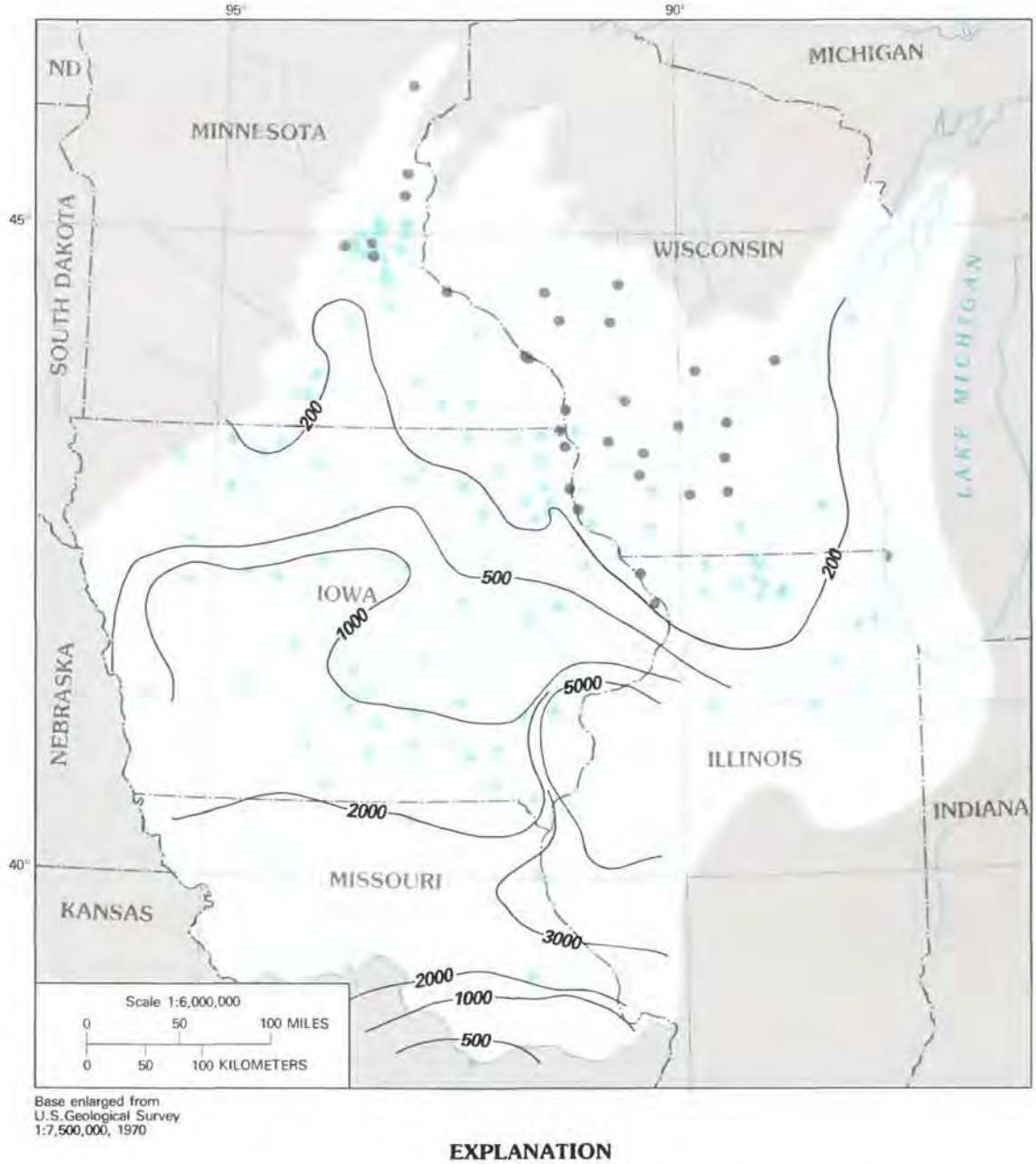

EXPLANATION

—200— LINE OF EQUAL BORON CONCENTRATION—Interval, in micrograms per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 26.—Distribution of dissolved boron in aquifer layers 1 and 3.

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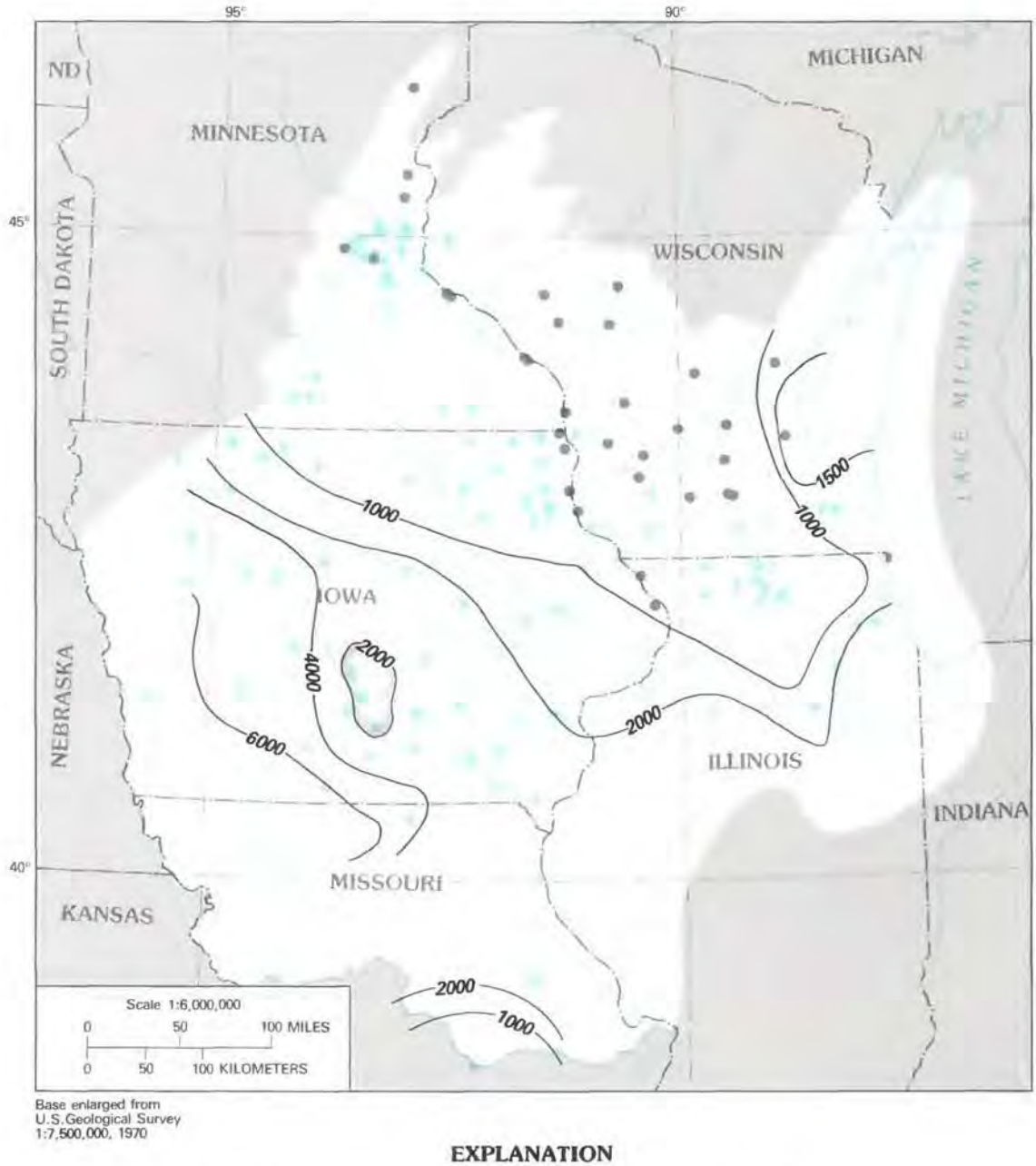

EXPLANATION

—1000— LINE OF EQUAL DISSOLVED STRONTIUM CONCENTRATION—Stippled in direction of lower concentration. Interval, in micrograms per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

■ Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 27.—Distribution of dissolved strontium in aquifer layers 1 and 3.

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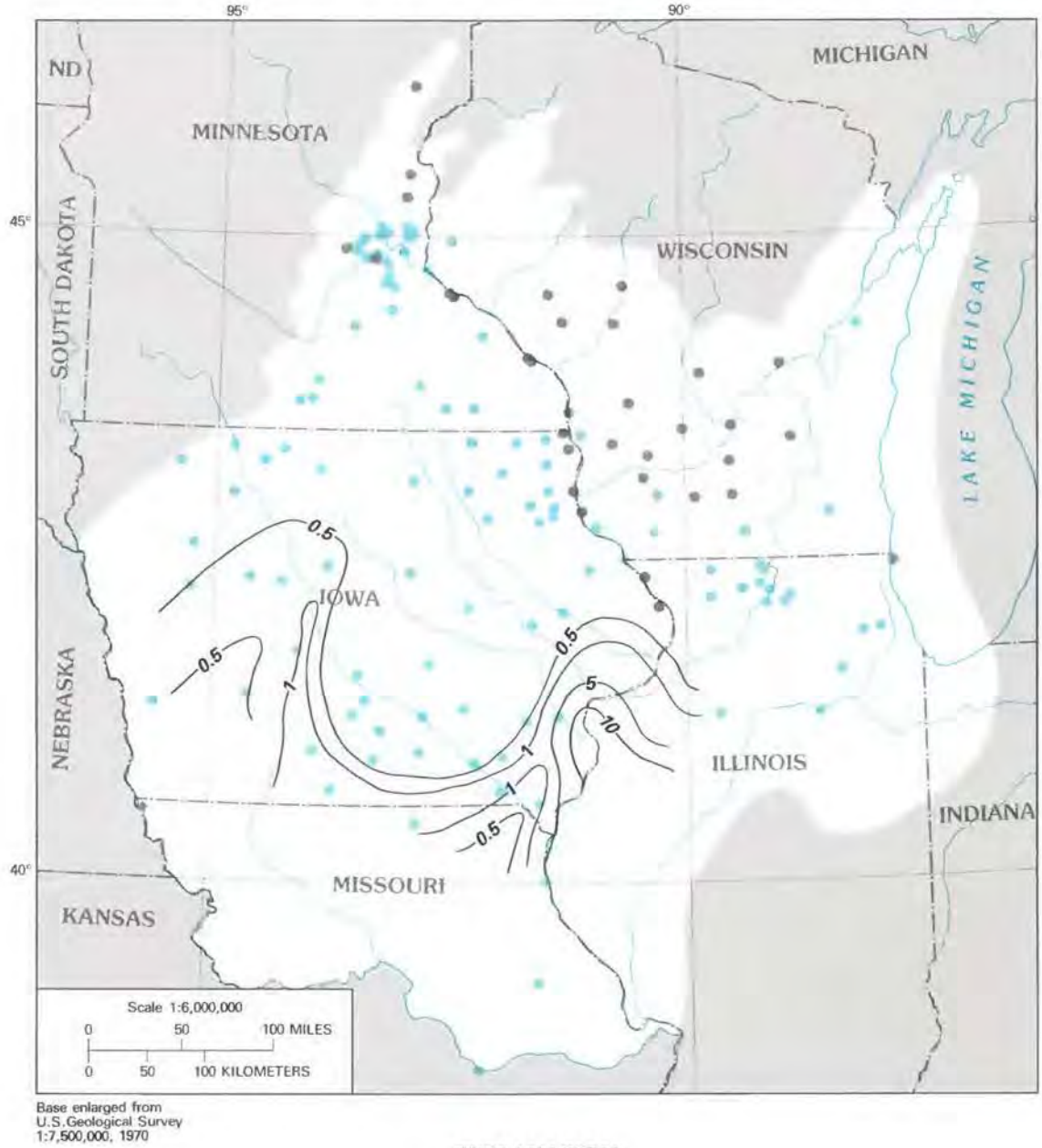

EXPLANATION

—5— LINE OF EQUAL BROMIDE CONCENTRATION—Interval, in milligrams per liter, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

FIGURE 28.—Distribution of dissolved bromide in aquifer layers 1 and 3.

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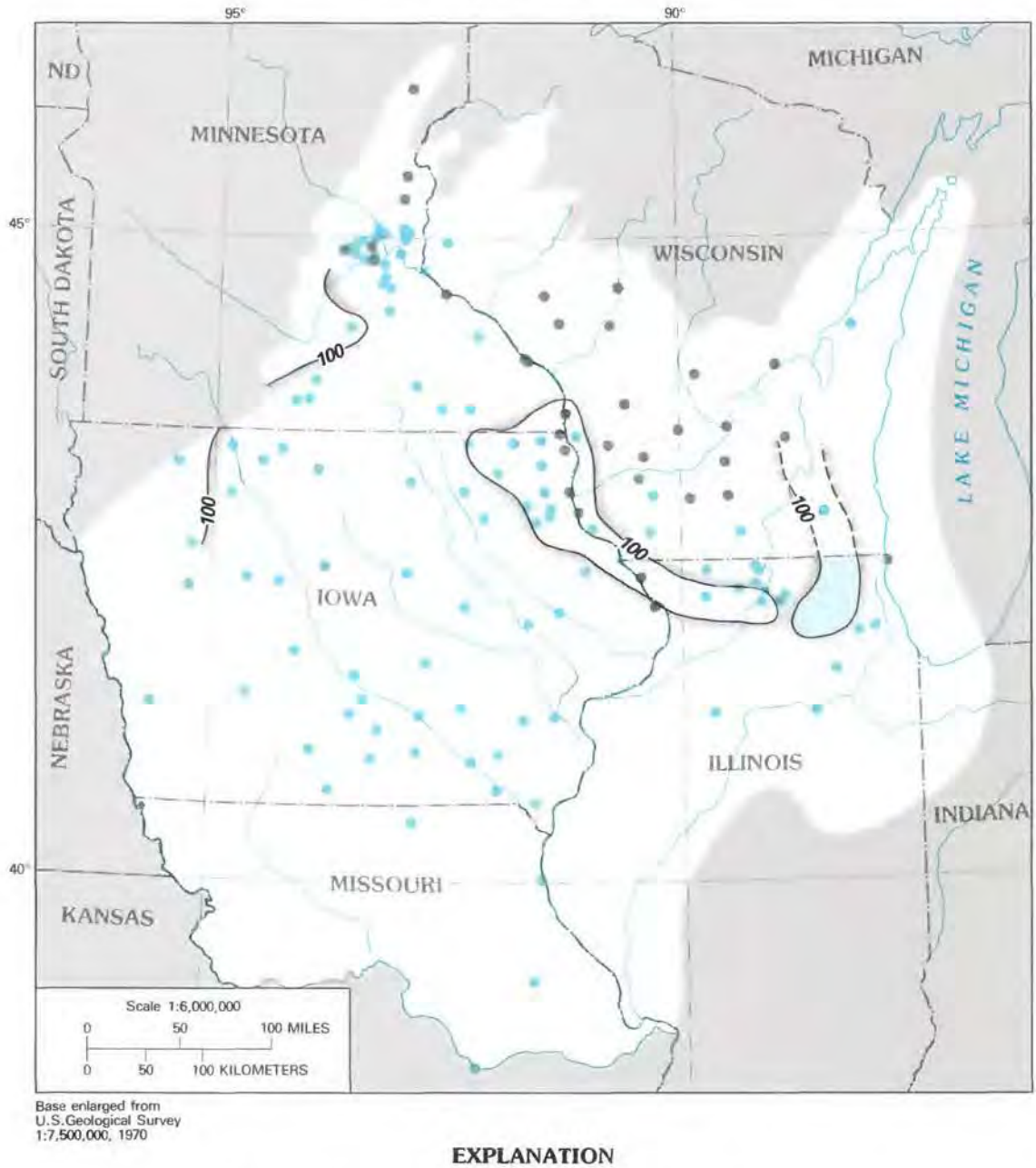

EXPLANATION

—100— LINE OF EQUAL DISSOLVED BARIUM CONCENTRATION—Stippled in direction of lower concentration. Dashed where approximate. Interval 100 micrograms per liter

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

DATA FROM GILKESON AND OTHERS (1981)

FIGURE 29.—Distribution of dissolved barium in aquifer layers 1 and 3.

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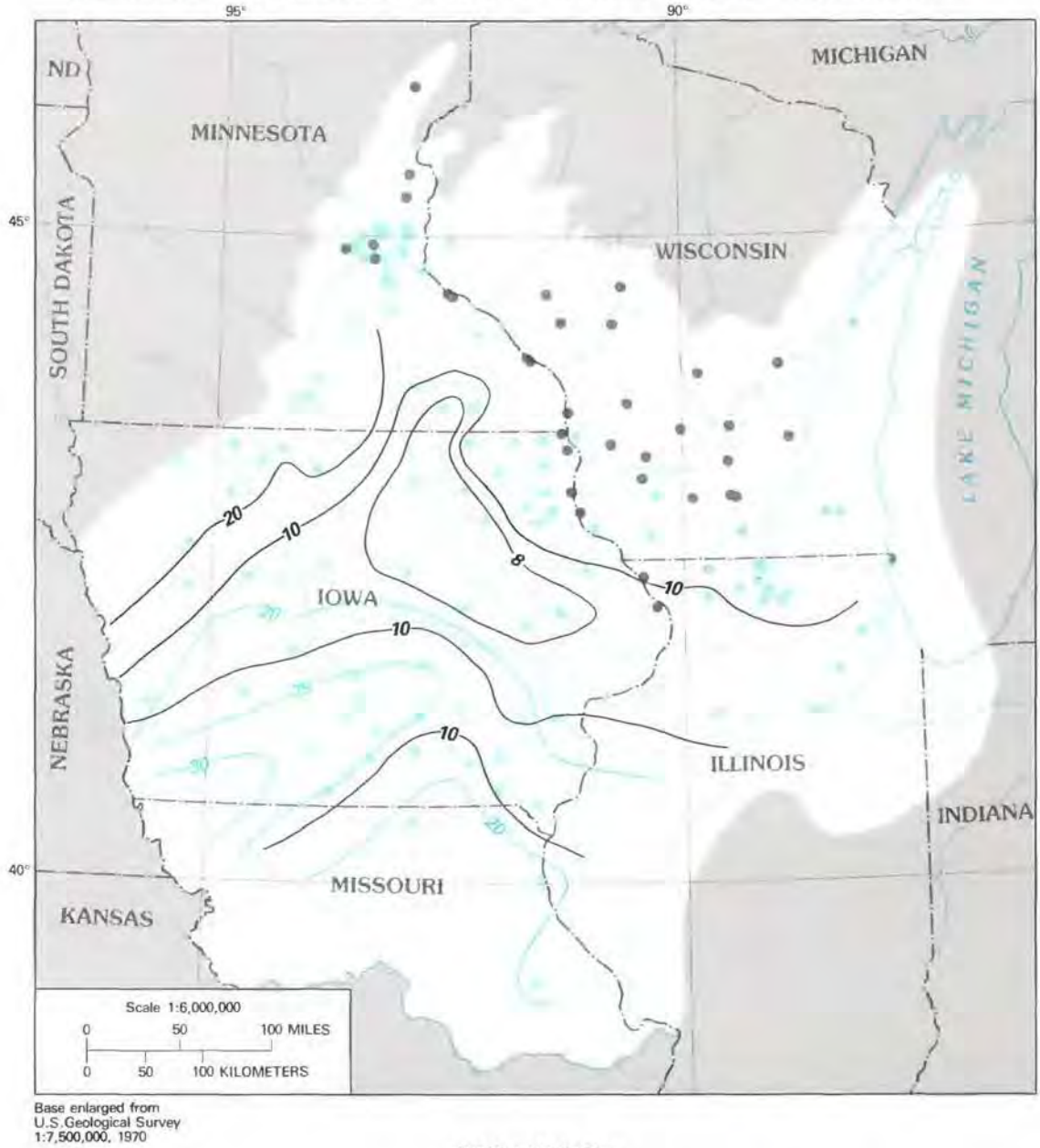

EXPLANATION

—20— LINE OF EQUAL DISSOLVED SILICA CONCENTRATION—Interval, in milligrams per liter, is variable

LINE OF EQUAL GROUND-WATER TEMPERATURE—Interval 5 degrees Celsius

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 30.—Distribution of dissolved silica and ground-water temperature in aquifer layers 1 and 3.

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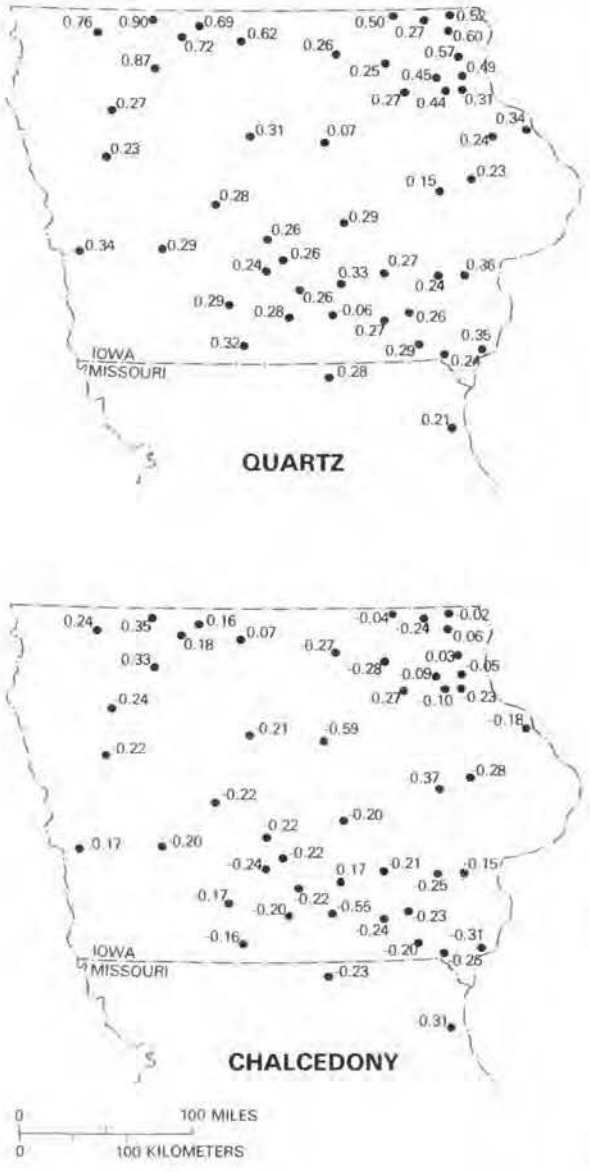

FIGURE 31.—Saturation indices for quartz and chalcedony in water from selected wells in aquifer layer 3 in Iowa and northeastern Missouri.

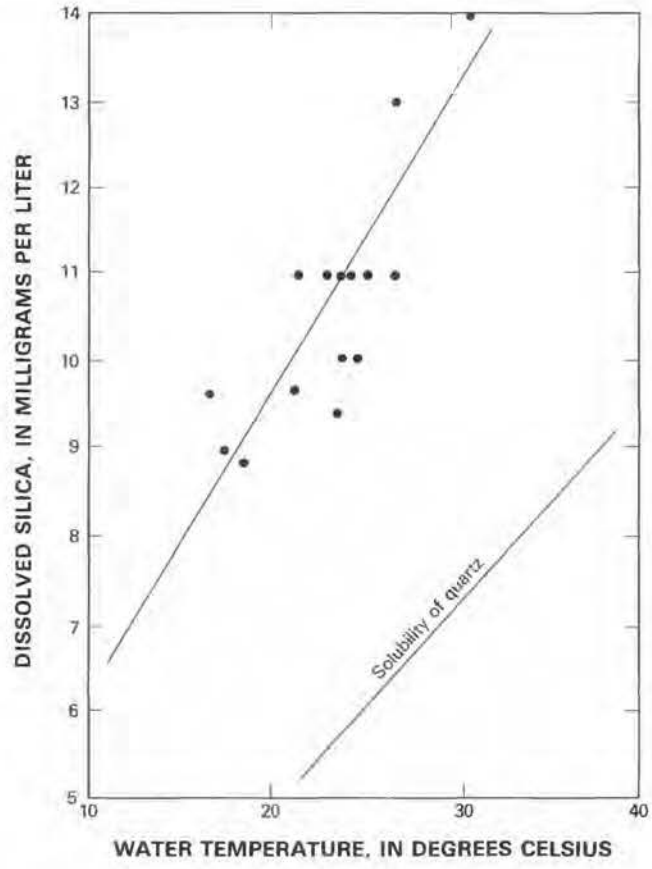

FIGURE 32.—Comparison of dissolved silica concentration and the solubility of quartz with water temperature in southwestern and southern Iowa and northeastern Missouri.

Concentrations of silica in the aquifer system range from less than 8 to more than 20 mg/L (fig. 30). The differences in silica content are related to the solubility of silicate phases in the aquifer matrix. Saturation indices show oversaturation of quartz and undersaturation of chalcedony (fig. 31); this is a typical occurrence in many waters. The solubility of silica in surface and ground water is related to solid-phase products of aluminosilicate mineral dissolution, but no aluminum data are available to test the thermodynamic models of such dissolution in a formal sense.

Concentrations of silica greater than 20 mg/L are present in the recharge area in northwestern Iowa, where the Dakota Formation and the overlying drift contain siliceous shales. Concentrations decrease downgradient to less than 10 mg/L in central Iowa, increase to more than 10 mg/L in south-central Iowa, and then decrease to less than 10 mg/L in southeastern Iowa. The distribution patterns of silica and temperature are very similar, showing the direct relationship of silica solubility to water temperature. However, the data in figure 32 indicate that the relationship of quartz solubility with temperature is not the control on dissolved silica (Helgeson, 1969). This suggests that silica phases other than quartz are contributing silica to the ground water.

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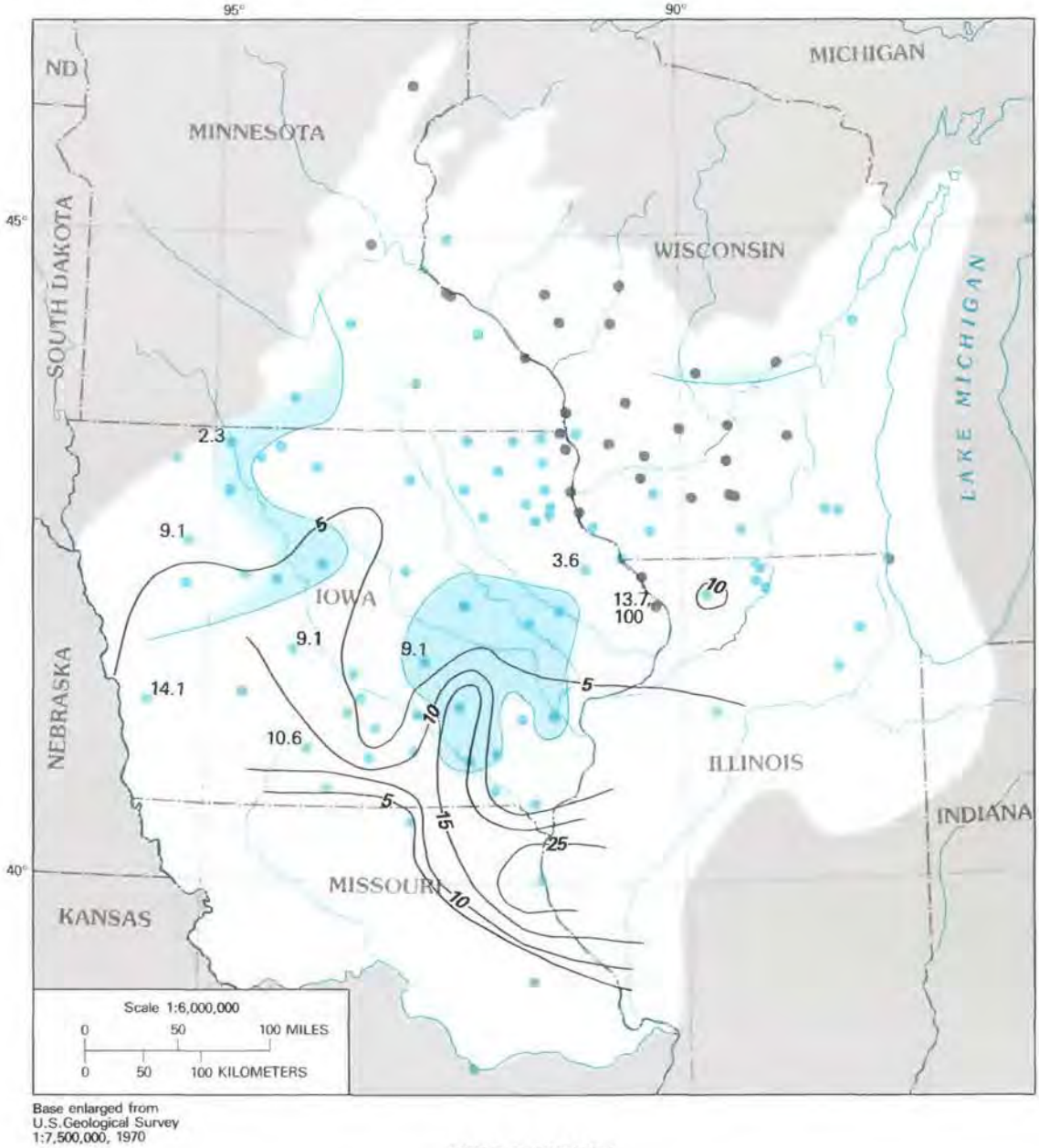

EXPLANATION

—10— LINE OF EQUAL RADIUM-226 CONCENTRATION—Interval, in picocuries per liter, is variable

AREA WHERE DISSOLVED URANIUM CONCENTRATION EXCEEDS 1 MICROGRAM PER LITER

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY
Number is activity ratio of $^{234}U/^{238}U$

13.7 Open to aquifer layer 1

9.1 Open to aquifer layer 3

FIGURE 33.—Distribution of dissolved uranium and radium-226 in aquifer layers 1 and 3.

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The distribution of uranium and radium-226 in the aquifer system shows the effects of the dilution plume in Iowa (fig. 33) on the concentration of these constituents. Uranium exceeds 1 μg/L in northwestern and southeastern Iowa but is less than 1 μg/L in central and southern Iowa and in northern Missouri in the vicinity of the plume of low dissolved solids. The 5-pCi/L line of radium-226 activity clearly defines the shape of the plume. Activity increases to more than 15 pCi/L southward near the Iowa-Missouri border, but the scant available data show a decrease to 5 pCi/L in northern Missouri.

High radium activities have been identified in Iowa (Brown and Morris, 1959; Lucas, 1960, 1985; Morris and Klinsky, 1962; Horick and Steinhilber, 1978; Cochran and Hahne, 1979), eastern Wisconsin (Lucas, 1960, 1985; Hahn, 1984), and northeastern Illinois (Lucas and Ilcewicz, 1958; Krause, 1959, 1960; Larson and Weatherford, 1960; Lucas, 1960, 1985; Emrich and Lucas, 1963; Kristoff and others, 1975; Gilkeson and Cowart, 1982; Gilkeson and others, 1983).

The sources of the high radium concentrations in the ground water are probably related to uranium-238 and thorium-232 in the aquifer matrix. These radioisotopes decay to radium-226 and 228, respectively. In Illinois, Gilkeson and others (1978) used radium-226 and radium-228 concentrations in 33 samples of Cambrian and Ordovician rocks to estimate the equivalent amounts of uranium-238 and thorium-232, assuming equilibrium between the parent-daughter nuclides. Calculated average uranium-238 concentrations ranged from about 1 ppm in sandstone to about 3 ppm in shale. Direct determinations of uranium-238 indicated that uranium-238 and radium-226 are in equilibrium or near equilibrium in the Cambrian-Ordovician rocks.

The activity of radium-226 and concentrations of uranium in solution may not be directly correlated, however, because of restraints on the solubility of uranium in different redox (reduction-oxidation) environments. Uranium is mobile in oxidizing environments and immobile in reducing environments (Hostetler and Garrels, 1962; Langmuir, 1978). Gilkeson and Cowart (1982) observed a decrease in total uranium concentrations from a few tenths μg/L to less than 0.01 μg/L across a reduction front along a flow path in the Cambrian-Ordovician aquifer system in northeastern Illinois. Downgradient from the reduction front, however, uranium increased to more than 0.3 μg/L under oxidizing conditions. The decrease in uranium in the central part of Iowa also could be due partly to more reducing conditions along the major flow paths. The increase in uranium in southeastern Iowa, however, probably is not caused by increased uranium solubility in oxidizing conditions, because other chemical constituents, such as dissolved sulfide, indicate probable reducing conditions.

Radium-226 activity can be increased in the ground water along a reducing front because of decay of uranium in the water and uranium previously precipitated in the aquifer matrix. The decrease in uranium in Iowa is not accompanied by an increase in radium-226 from northeast to southwest. Therefore, concentrations of uranium and radium-226 in central Iowa seem to be related more to the dilution events than to geochemical processes in the aquifer system.

The activity ratio of $^{234}U/^{238}U$ generally increases across a reducing front because of alpha-recoil transfer (Kronfeld and others, 1975; Cowart and Osmond, 1977). No such increase in the activity ratio is apparent from the data in central Iowa. However, to relate redox relationships to uranium and radium in ground water, more detailed sampling is necessary at a closer spacing than for the reconnaissance purposes of this study. Defining sources and sinks for radium and uranium in the study area would require more detailed information on the concentrations and isotopic variability of these constituents and thorium in aquifer matrices and ground water. For example, in a more detailed study, Gilkeson and Cowart (1982) determined $^{234}U/^{238}U$ alpha-activity ratios in ground water from the aquifer system along a flow path from the unconfined to confined system in northeastern Illinois. Where the aquifer is confined by the Maquoketa Shale, ratios exceed 20, but in the unconfined area, ratios are generally less than 5. The disequilibrium in the confined area is pronounced, and Gilkeson and Cowart (1982) suggest that dissolved uranium was emplaced in the aquifer during Pleistocene glaciation when flow directions may have been different from those of today. Uranium-234 could then have been leached from glacial till and the Maquoketa Shale. However, the observed disequilibrium still is problematical, because the role of geochemical and radiogenic mechanisms in enriching the isotopic ratio is not fully understood (Gilkeson and others, 1978).

Similar disequilibria are found in selected samples of water from aquifer layer 3 in Iowa. $^{234}U/^{238}U$ activity ratios determined from a few selected water samples showed disequilibrium and range from 2.3 to 14.1 with no discernible pattern (fig. 33). For example, the ratio is 9.1 for water in the northwest recharge area associated with the Dakota Formation as well as for water in the central dilute plume area. The scant data suggest that the ratio in Iowa increases generally toward the south, but additional data are needed to verify the trend.

A water sample from a 2,673-ft-deep test well drilled during this study at Green Island in extreme eastern Iowa is of particular interest. The sample from the interval 1,741 to 2,673 ft in the Mount Simon Sand-

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stone had the extraordinarily high ratio of 100 (fig. 33). This may be the largest known uranium disequilibrium in an aquifer system. Gilkeson and Cowart (1982) indicate that the highest reported ratio prior to their work was 12.3. They measured activity ratios as high as 28.6 in the Cambrian-Ordovician aquifer system in northeastern Illinois and activity ratios "greater than 40" in the aquifer system in other parts of Illinois.

Gilkson and Cowart (1982) hypothesize that such extreme disequilibrium may be related to influx of uranium-234-enriched uranium derived from fine-grained materials during the emplacement of glacial meltwater during the Pleistocene. The uranium-234-enriched ground water could be further enriched by isotopic fractionation caused by precipitation of the uranium in the reducing zone downgradient from the meltwater recharge front. Unfortunately, the scant areal distribution of the uranium isotope data for this study is not sufficient to evaluate this hypothesis further, and the causes of the isotopic enrichment are still unknown.

ISOTOPIC COMPOSITION OF WATER AND PLEISTOCENE RECHARGE MODEL

The direction of the dilute plume, from northeastern Iowa to south-southwestern Iowa, suggests a flow system having recharge areas in southeastern Minnesota and northeastern Iowa and discharge areas in Missouri or farther south. The study region was glaciated numerous times during the Pleistocene Epoch. Work by Boellstorff (1976, 1980) indicates that at least Nebraska and Iowa were glaciated as long ago as 2.5 m.y. (million years) and that the classic Nebraskan-Kansan sequence of glaciation—now referred to as Pre-Illinoian (Richmond and Fullerton, 1986)—occurred 1.0 to 0.4 m.y. ago. At least five ice advances occurred in Iowa and Nebraska during this time. No similar sequence of glaciation has been identified in Wisconsin and Illinois to date, but evidence of such glaciation could be obscured by glaciation during Illinoian and Wisconsin time, from about 100,000 to 12,000 yr B.P. (years before present).

The extent of major glaciations (fig. 34) has been estimated from the stratigraphic relationships among glacial deposits (Flint, 1972). Pre-Illinoian advances extended almost to the Missouri River and covered much of the study area. Later advances during Illinoian time covered most of Illinois and parts of Wisconsin. During Wisconsin time, numerous ice lobes advanced into Wisconsin, Minnesota, Iowa, and Illinois.

Theoretical reconstructions of the temperature distribution in continental Pleistocene glaciers have indicated that a pressure-melting zone probably was extensive in the basal part of the ablation zone. The zone may have extended upgradient for a few hundred miles from frozen ice margins (Hooke, 1977; Sugden, 1977; Moran and others, 1980). Glacial movement in these unfrozen areas involved basal sliding (Weertman, 1957, 1961, 1964; Clayton and Moran, 1974). Landforms such as drumlins, tunnel valleys, and streamlined ridges are field evidence for basal melting (Wright, 1973; Clayton and Moran, 1974; Moran and others, 1980) where meltwater under high hydrostatic head could have recharged the Cambrian-Ordovician aquifer system in outcrop areas.

The isotopic composition of oxygen and hydrogen in the ground water in the aquifer system is important geochemical evidence for such recharge. The distribution of $\delta^{18}O$ and δD in modern precipitation shows excellent covariation with both mean annual air temperature and latitude because of isotope fractionation by the Raleigh distillation effect (Dansgaard, 1964). Covariation between $\delta^{18}O$ and δD of modern precipitation defines an average meteoric water line (Craig, 1961), expressed as

$$\delta D = 8\,\delta^{18}O + 10, \qquad (13)$$

to which the isotopic content of ground water can be compared. If past ground-water recharge occurred under climatic conditions similar to those of today, then the isotopic composition of the ground water should be similar to that of modern recharge. However, if the ground water originally precipitated at temperatures colder than today, its isotopic composition should be lighter than modern recharge but should still plot near the meteoric water line (eq. 13). Deviations of the data from the trend of the line indicate that geochemical processes, such as water-rock interaction, evaporation, or ultrafiltration, have modified the isotopic composition of the water.

The relationship of $\delta^{18}O$ to δD in ground water in the Cambrian-Ordovician aquifer system exclusive of the Illinois basin is similar to the isotopic composition of modern precipitation (fig. 35). This indicates that the water in the Cambrian-Ordovician aquifer system outside the Illinois basin retains its meteoric nature and has been relatively unaltered by significant reactions with the aquifer matrix. Water in the Illinois basin is enriched in oxygen-18 because of probable exchanges between carbonate rock and water at temperatures more than twice the temperature in the fresher and shallower parts of the aquifer system (Clayton and others, 1966). The average $\delta^{18}O$ and δD of modern precipitation in the study area ranges from about −8 to −6 ‰ and from −70 to −50 ‰, respectively, from

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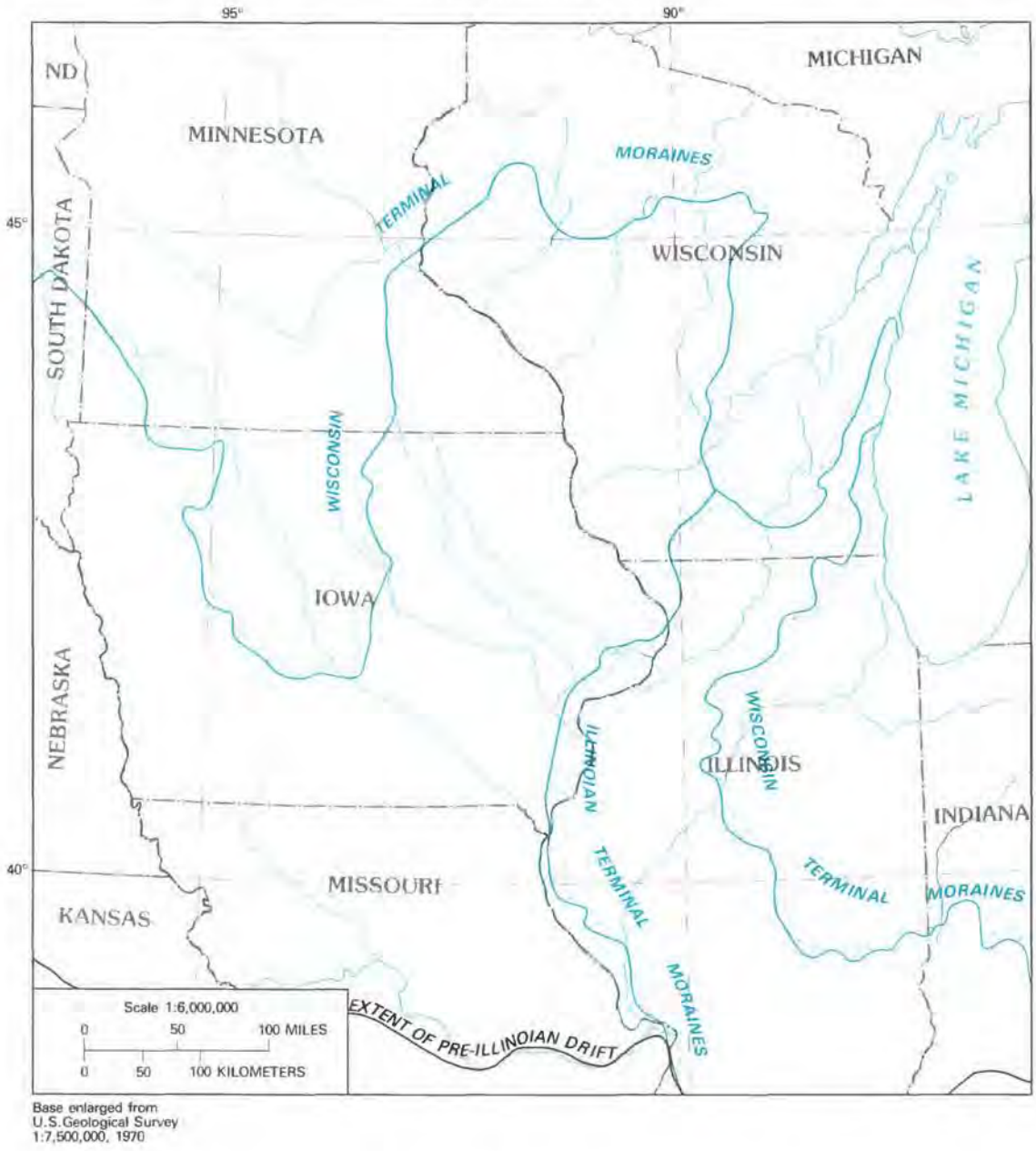

FIGURE 34.—Extent of major glaciations in the northern Midwest during the Pleistocene Epoch.

north to south (Yurtsever, 1975). The difference in $\delta^{18}O$ and δD between water in the aquifer and in modern precipitation, as much as −9 and −70 o/oo, respectively, indicates past recharge to the aquifer system that is isotopically similar to water now precipitated at colder latitudes hundreds of miles north of the study area. No shift occurs in the isotopic content of water across the Holocene-Pleistocene boundary in regional aquifers unaffected by glaciation (Hanshaw and others, 1978). This suggests that the light isotopic composition of the ground water is not a result of continental differences in the isotopic composition of interstadial precipitation.

Isotopically light ground water in the aquifer system in northern Illinois has been described previously and explained as Pleistocene recharge (Clayton and others, 1966; Gilkeson and others, 1981; Perry and others, 1982). Regional distribution of the isotopic composition of water in the aquifer system (figs. 36, 37) closely approximates the distribution of dissolved solids (fig.

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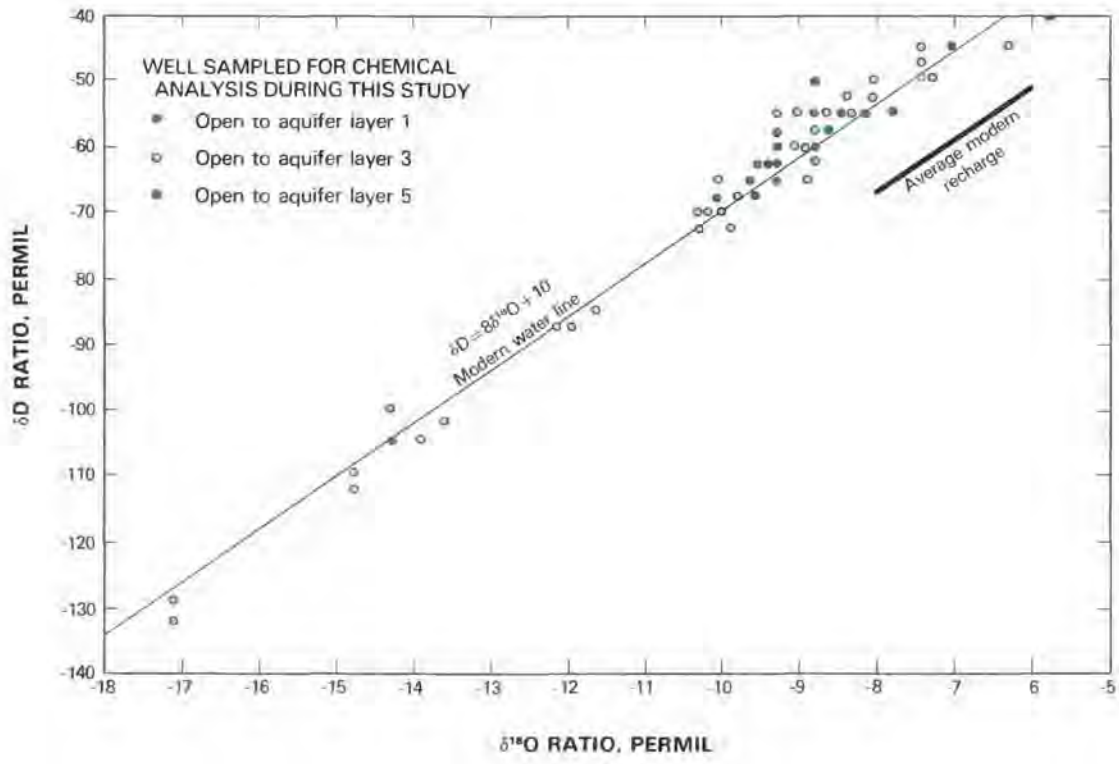

FIGURE 35.—$\delta^{18}O$-δD relationship for ground water in the northern Midwest.

7). In Iowa and Missouri, ground water is isotopically lighter toward the south, approximately perpendicular to the direction of the modern hydraulic gradient. The boundary of the dilute plume in central Iowa is coincident with the −10 o/oo $\delta^{18}O$ isoline. The plume, although isotopically about 2 to 4 o/oo lighter with respect to $\delta^{18}O$ than modern recharge at the same latitude, is isotopically heavier than surrounding ground water. The extension of the −10 o/oo line into south-central Iowa and the distribution of dissolved solids suggest a ground-water flow direction approximately perpendicular to that of today.

The $\delta^{18}O$ content of North American ice sheets could have ranged from about −40 o/oo (Dansgaard and Tauber, 1969) to −9 o/oo (Emiliani, 1971). Yapp and Epstein (1977), using calculations from δD of cellulose in plant material entrained in drift, suggest an intermediate $\delta^{18}O$ of −15 o/oo for the ice of the latest Wisconsin advance. If the isotopically lightest water in the aquifer system in southern Iowa were emplaced during this time, virtually all the ground water in the southwestern part of the study area would be recharged from glacial meltwater. This is unlikely because the dissolution of carbonate and silicate minerals at aquifer temperatures (less than 40 °C) would not produce concentrations of dissolved solids exceeding 2,500 mg/L or the large equivalent percentages of chloride and sodium found in the southwestern part of the aquifer. Therefore, the isotopic content of the ground water probably represents a mixture of meltwater with $\delta^{18}O$ depleted to less than −17 o/oo and pre-Pleistocene ground water with $\delta^{18}O$ enriched to more than −17 o/oo, and perhaps similar to the isotopic content of modern recharge.

The shape of the dilute plume looks similar to the shape of the Des Moines lobe which covered part of north-central Iowa during the last advance of Wisconsin ice. This suggests that the plume may be related to this ice advance. The isotopic content of water in the dilute plume would be lighter than −10 o/oo if the plume were caused by meltwater recharge under the lobe through the outcrop area in southern Minnesota. However, the possible displacement of ground water having low dissolved solids from overlying Paleozoic aquifers to aquifer layer 3 by vertical leakage of subglacial meltwater cannot be ruled out unequivocally at this time.

Scant data indicate that dissolved-solids concentrations in aquifer layer 4 are generally more than 1,000 mg/L where the aquifer is overlain by Mississippian rocks in central Iowa but are generally less than 500 mg/L in outcrop areas north of the Mississippian erosional edge (U.S. Geological Survey, unpub. data).

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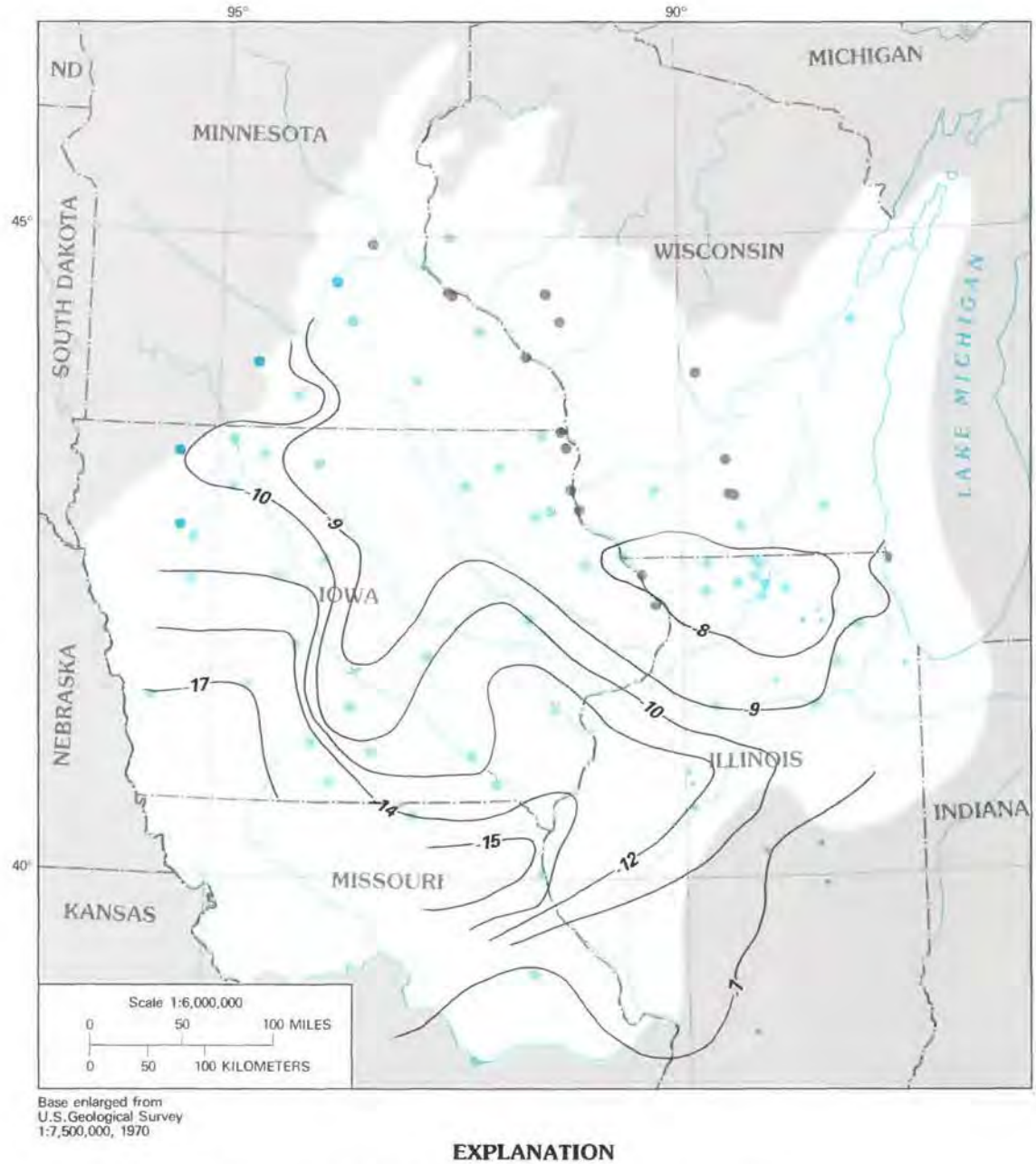

EXPLANATION

—8— LINE OF EQUAL $\delta^{18}O$ RATIO— Interval, permil, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3
- Open to aquifer layer 5

WELL WITH ANALYSIS FROM OTHER SOURCE

- Open to aquifer layer 3

FIGURE 36.—Distribution of $\delta^{18}O$ ratio in aquifer layers 1, 3, and 5.

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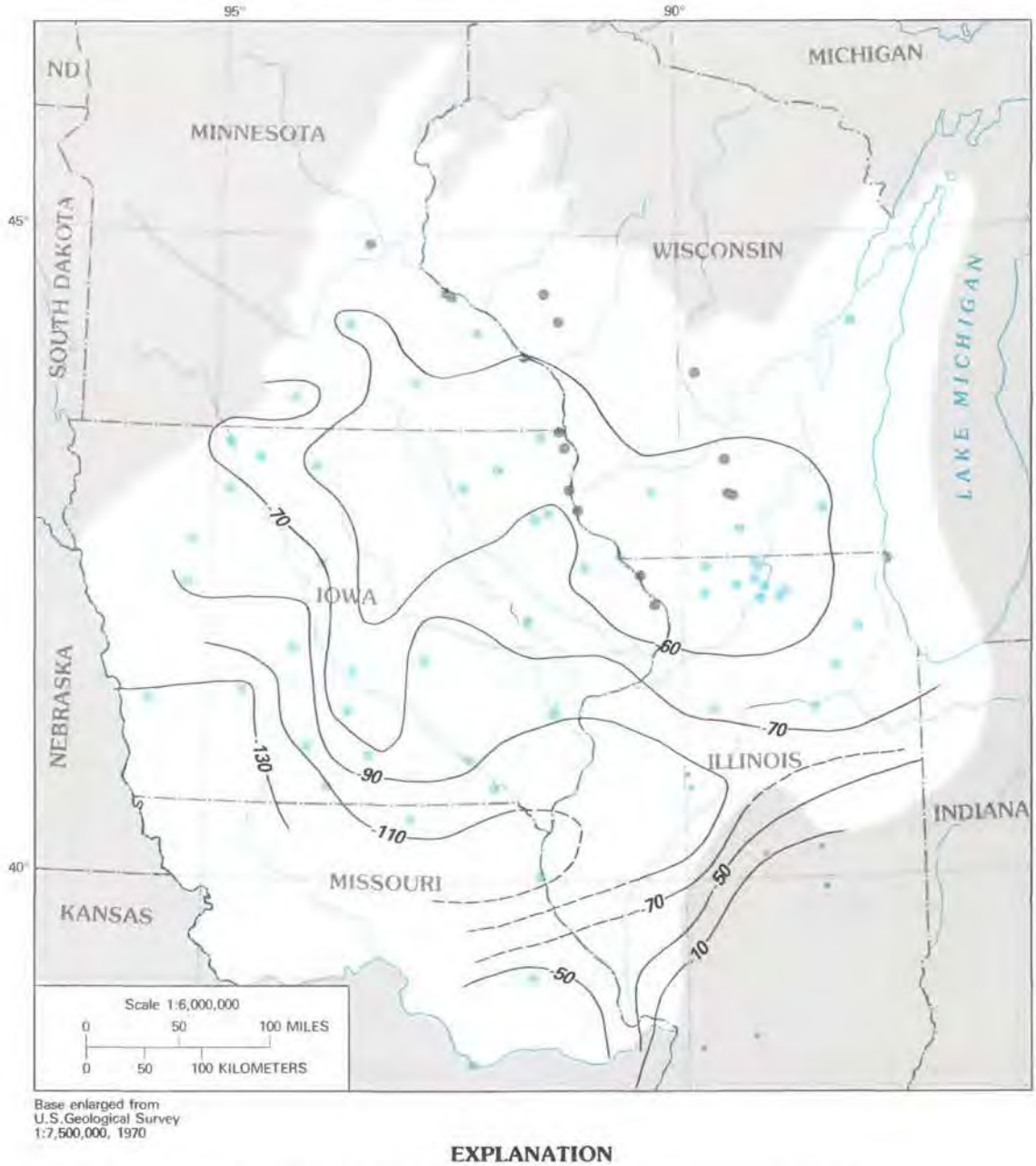

EXPLANATION

---70--- LINE OF EQUAL δD RATIO—Dashed where approximate. Interval, permil, is variable

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

- Open to aquifer layer 1
- Open to aquifer layer 3

WELL WITH ANALYSIS FROM OTHER SOURCE

- Open to aquifer layer 3

FIGURE 37.—Distribution of δD ratio in aquifer layers 1 and 3.

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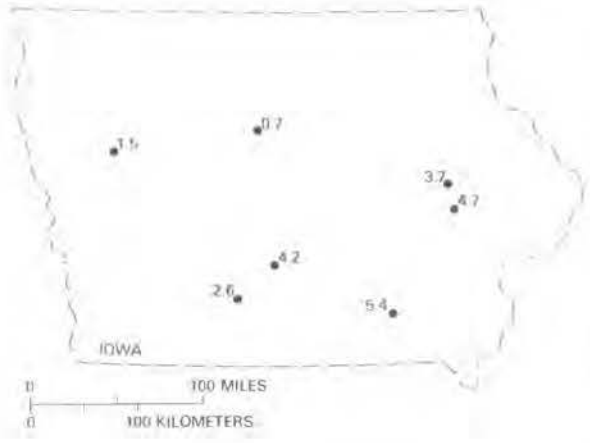

FIGURE 38.—Carbon-14 data for water from selected wells in aquifer layer 3 in Iowa.

Dissolved-solids concentration in ground water from Mississippian rocks in north-central Iowa is more than 500 mg/L. The 1,000-mg/L isoline of dissolved solids in the Mississippian rocks roughly outlines a dilute plume trending from north-central to southwestern Iowa (Horick and Steinhilber, 1973), similar to the plume in aquifer layer 3.

Downward movement of meltwater from the base of the Des Moines lobe into the Mississippian rocks could have started a series of downward displacements of water from layer to layer: recharge of water with low dissolved solids into the Mississippian; higher disolved-solids water (more than 1,000 mg/L) from the Mississippian into aquifer layer 4; and water with low dissolved solids from aquifer layer 4 into aquifer layer 3, forming the dilute plume. Water in aquifer layer 4 could have had a $\delta^{18}O$ content ranging from −8 to −6 o/oo if it were not mixed with meltwater recharge from previous glaciations. Downward flow of water from aquifer layer 4 to aquifer layer 3 could have resulted in both dilution and isotopic enrichment. However, additional isotopic data for ground water from aquifer layer 4 and the Mississippian in central Iowa are needed to evaluate better the influence of the Des Moines lobe on the Cambrian-Ordovician aquifer system.

The time, or times, of meltwater emplacement is unknown. Seven carbon-14 analyses of ground water from aquifer layer 3 in Iowa have a range of 0.7 to 5.4 percent modern carbon (fig. 38). These values correspond to apparent ages ranging from more than 30,000 to about 15,000 yr B.P., respectively, corrected for isotopic dilution by dissolution of carbonate aquifer minerals. The smallest amount of modern carbon occurs in central Iowa within the dilute plume. This could reflect either the age of water in aquifer layer 3 or a composite age of water from aquifer layers 3 and 4, if vertical recharge occurred beneath the ice of the Des Moines lobe. A small amount of modern carbon may have been introduced in the sampling procedure at other sites as contamination from atmospheric carbon dioxide (E.C. Alexander, University of Minnesota, written commun., 1982; L.N. Plummer, U.S. Geological Survey, oral commun., 1982). Water in aquifer layer 1 at St. Paul, Minn., has an apparent age of more than 35,000 yr B.P. (Alexander and others, 1983), and very likely water in the Cambrian-Ordovician aquifer system in southern Iowa and northern Missouri also contains little or no measurable carbon-14 because flow paths are many times longer than in Minnesota.

The possible emplacement of meltwater during the late Pleistocene was independently tested using the steady-state three-dimensional ground-water flow model of Mandle and Kontis (in press) to simulate the Cambrian-Ordovician aquifer system under the pressure head caused by the weight of the glacial ice about 18,000 yr B.P. The head values for the water-table aquifer (aquifer layer 5) in the ice-covered areas (fig. 39) were estimated as the sum of the elevation head at the land surface and the pressure head from the ice. The water-table aquifer is represented by constant-head nodes in the model and provides the hydraulic driving force to simulate ground-water flow. An average Wisconsin glacial ice-sheet configuration was assumed similar to that described by Denton and Hughes (1981). The static steady-state topography of the ice sheets at maximum advance calculated by Denton and Hughes (1981) was based on the modern analog of the Greenland and Antarctic ice sheets. This may be incorrect because geologic evidence suggests that the Laurentide ice sheet did not attain a steady-state profile everywhere but may have been highly dynamic (Clark, 1980; Andrews, 1982). Nevertheless, the Denton and Hughes (1981) model is probably a first approximation for the general morphometry of the major ice lobes that entered the northern Midwest during Wisconsin time. Hydraulic parameters, boundaries, and nodal distribution for all aquifer layers were those used in a steady-state flow model of the modern Cambrian-Ordovician aquifer system described by Mandle and Kontis (in press). The position of the ancestral Mississippi River was assumed to be similar to its present position. Although the ancestral Mississippi River was displaced in some areas during the late Pleistocene, the displacement did not significantly alter the general drainage pattern from

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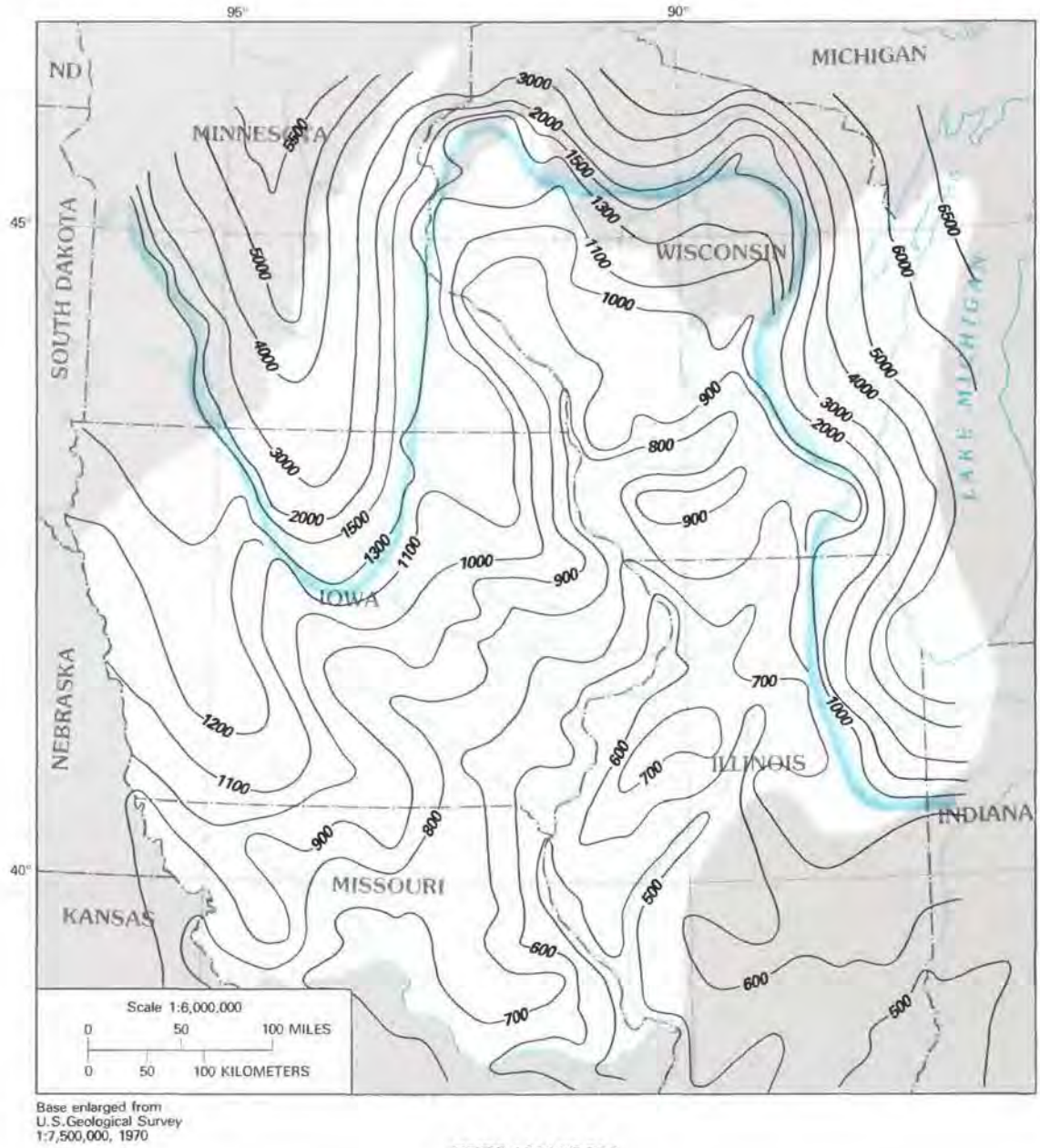

EXPLANATION

—800— POTENTIOMETRIC CONTOUR—Shows altitude of assumed potentiometric surface for aquifer layer 5, 18,000 years B.P. Contour interval, in feet, is variable. Datum is sea level

APPROXIMATE ICE MARGIN

FIGURE 39.—Assumed hydraulic head for aquifer layer 5 incorporating effects of ice thickness at the average advance of ice, about 18,000 yr B.P., during late Wisconsin time.

north to south near the border of Iowa and Illinois (Flint, 1972).

Results of the steady-state flow model show that the distribution of ice at the average Wisconsin advance probably did not significantly change the direction of ground-water flow in most of Iowa and Missouri (fig. 40). Ground-water flow paths, in general, were from northwestern Iowa southeastward to the Illinois basin.

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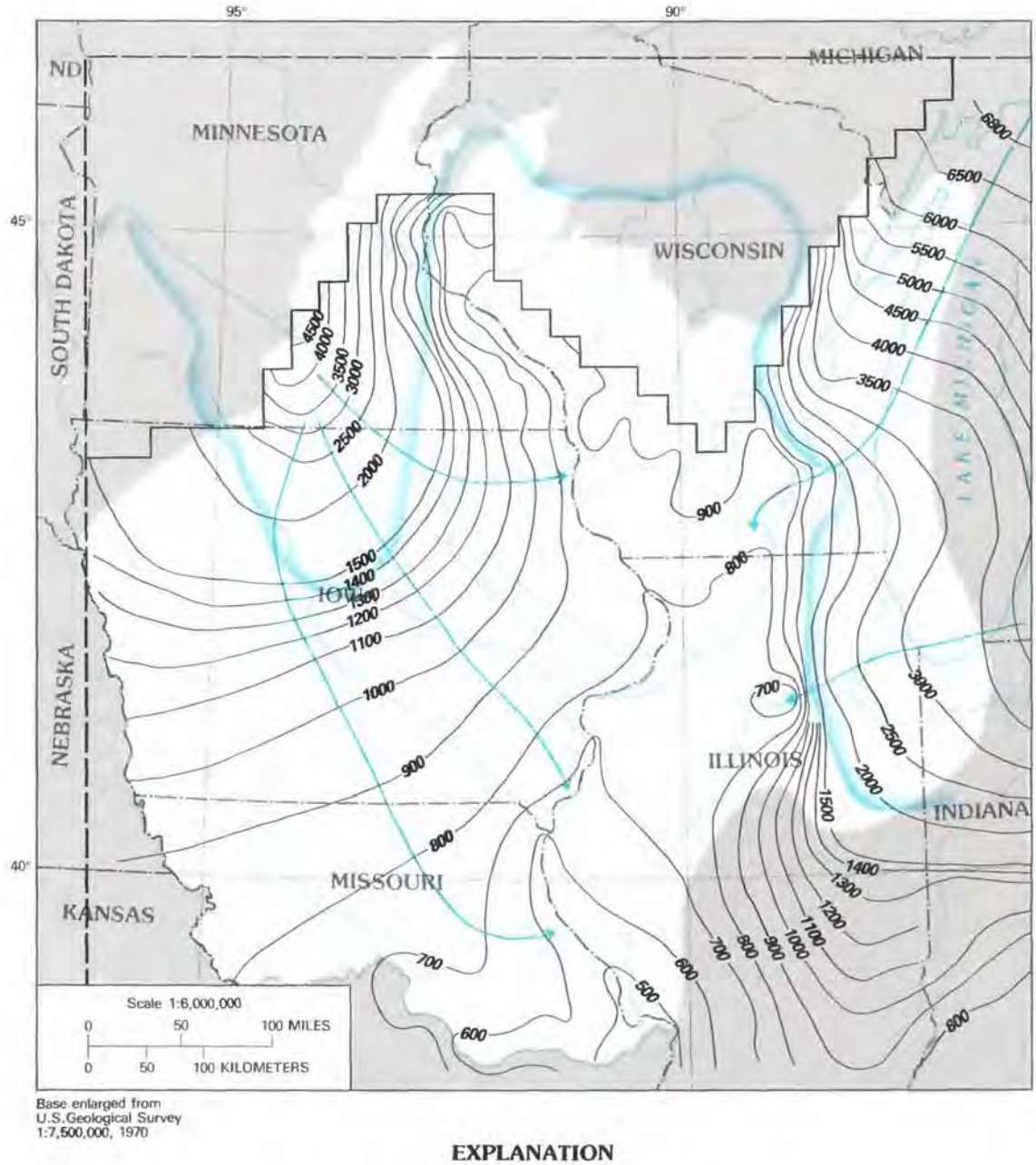

EXPLANATION

—900— POTENTIOMETRIC CONTOUR—Shows altitude of simulated potentiometric surface for aquifer layer 3, 18,000 years B.P. Contour interval, in feet, is variable. Datum is sea level

APPROXIMATE ICE MARGIN

GENERALIZED GROUND-WATER FLOW PATH

MODELED LAYER 3 BOUNDARY

BOUNDARY OF GROUND-WATER FLOW MODEL

FIGURE 40.—Simulated hydraulic head in aquifer layer 3 at the average advance of ice, about 18,000 yr B.P., during late Wisconsin time.

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Some ground-water flow was diverted from central to northeastern Iowa from a local ground-water divide that is symmetrical with the axis of the Des Moines lobe in Iowa. In eastern Wisconsin and Illinois, simulated ground-water flow was opposite from that of today: ground-water recharge zones were in the vicinity of Lake Michigan, and discharge zones were the outcrop areas in Wisconsin, northeastern Iowa, southeastern Minnesota, and northern Illinois. Results of the flow model show that, during late Wisconsin time, the net movement of ground water was not in the direction of the dilute plume, from northeastern to southwestern Iowa. Much of the outcrop area of the aquifer in Wisconsin, Iowa, and Illinois was probably a discharge zone, as suggested by the results of the flow model, and not a recharge zone, as suggested by the geochemical data.

Model-calculated horizontal flow rates of the present flow system in Iowa are extremely slow, ranging from a few feet per year in the recharge area in northwestern Iowa to less than 1 ft/yr in deeper parts of the aquifer (Mandle and Kontis, in press). These flow rates indicate that residence time for most of the water in the aquifer system could be tens of thousands to hundreds of thousands of years. The slow flow rates compare favorably with the carbon-14 date of more than 35,000 yr B.P. for water in aquifer layer 1 from a well in St. Paul, Minn. (Alexander and others, 1983).

Model-calculated horizontal flow rates under the Des Moines lobe are about 10 times larger than present flow rates. Model-calculated vertical leakage from aquifer layer 4 to aquifer layer 3 in the confined part of Iowa is less than 5,000 (ft^3/mi^2)/yr, even under simulated glacial head from the Des Moines lobe. This amount of vertical leakage is insignificant with respect to the total amount of water in aquifer layer 5. The volume of water per square mile in aquifer layer 3 is approximately 2×10^9 ft^3, assuming an average thickness of 300 ft and a porosity of 0.25. Only about 2.5 percent of the water in the aquifer would be replaced in 10,000 yr at the maximum calculated flow rates owing to glacial-ice loading.

This computed result suggests that downward leakage from younger Paleozoic rocks to aquifer layer 3 probably did not cause the dilute (low dissolved solids) plume in Iowa. However, fracture permeability in younger confining units and in the carbonate rocks of the aquifer system was not specifically addressed in the model because of the paucity of field data needed to define fracture locations and patterns. Consequently, the possibility of larger amounts of vertical leakage during glaciation still exists and needs to be tested by additional isotopic data, as discussed previously.

An alternative hypothesis to explain the isotopically defined plume in Iowa is a southerly displacement of ground water having an isotopic content similar to that of modern recharge from the outcrop area in southern Minnesota. Model-calculated flow rates in aquifer layer 3 for the average ice advance in south-central Minnesota range from 10^{-6} to 10^{-5} ft/s. At the fastest rate, meltwater would move downgradient about 60 mi in 1,000 yr. The Des Moines lobe probably was on the outcrop area in southern Minnesota for 2,000 yr, from about 16,000 to 14,000 yr B.P. (Wright, 1972), so the model results indicate that it is possible to have had significant meltwater displacement of ground water ($\delta^{18}O$ content of about −8 o/oo) toward Iowa. The meltwater that replaced the ambient ground water would be isotopically very light. This characteristic should be identifiable today in southern Minnesota, where the aquifer is confined and flow rates are low. On the contrary, $\delta^{18}O$ content of water in aquifer layer 3 in south-central Minnesota is about −9 o/oo; this $\delta^{18}O$ content is only slightly depleted relative to modern recharge and is not characteristic of isotopically depleted water, such as is found in southern Iowa and central Illinois.

The hypothetical steady-state model of the ground-water flow system at the maximum glacial advance during Wisconsin time shows that flow rates are increased significantly only under, and immediately next to, the ice sheets. The simulated effect of the additional pressure head on the potentiometric gradient contributed by the ice sheets is dampened considerably within 30 to 50 mi from the edge of the ice (fig. 40). The steady-state model simulations of predevelopment conditions and with glacial-ice loading during Wisconsin time suggest that the time necessary for a unit volume of recharge in northeastern Iowa and in southern Minnesota to reach north-central Missouri would have been at least tens of thousands of years. Confinement by the ice could accelerate flow rates in Iowa south of the Maquoketa Shale outcrop.

HYPOTHETICAL GEOCHEMICAL MODELS

Previous studies of the chemistry of regional aquifer systems have used mass-balance and reaction models to evalute, at least semiquantitatively, the extent of chemical mass transfer from solid to aqueous phases and the evolution of different water types—for example, Thorstenson and others (1979), Plummer (1977), Chapelle (1983), Plummer and Back (1980), and Plummer and others (1983). These models have been particularly useful for evaluating chemical changes associ-

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ated with mixing of different water types—for example, Plummer (1975) and Wigley and Plummer (1976).

The extent to which these approaches can be successfully used in the present study of the geochemistry of the Cambrian-Ordovician aquifer system is limited, because critical data are still unavailable on the solid phases in the aquifer, the isotopic composition of Pleistocene glacial meltwater and precipitation, the pre-Pleistocene topography and water table, and local values for hydraulic characteristics.

The chemical composition of major solid phases, such as calcite, in the aquifer matrices in central Iowa is unknown. Information on bulk chemistry of the rocks and petrographic information on the type and nature of cementation in the rocks are necessary to check the accuracy of mass-balance calculations of net dissolution or precipitation of carbonate minerals (Chapelle, 1983). Identification of clay minerals in the aquifer matrix also is needed to determine appropriate ion-exchange selectivity coefficients for use in thermodynamic models of reaction progress. Estimates of ion-exchange selectivity coefficients from water chemistry (Thorstenson and others, 1979) are not applicable because of possible multiple sources and mechanisms for observed increases in sodium concentrations in southern Iowa and northern Missouri. No direct information is available on the isotopic composition of carbon in the aquifer matrix. Such data are critical to the use of $\delta^{13}C$ information to check the mass-balance models. Furthermore, detailed mass-transfer models that have been used to evaluate carbon isotopes in other aquifer systems (Wigley and others, 1978) cannot be applied to the Cambrian-Ordovician aquifer system because location and magnitude of past recharge were pulselike, depending on the configuration, timing, and duration of the ice sheets during the Pleistocene. Present-day concentrations of solutes may not represent steady-state conditions, and effects of hydrodynamic dispersion on the isotopic composition of ground water during recharge events cannot be excluded.

The $\delta^{18}O$ and δD composition of ground water in the Cambrian-Ordovician aquifer system is probably a composite derived from numerous episodes of Pleistocene recharge to the aquifer system. Assuming that the isotopic composition of the water is conservative, based on the clustering of data around the modern meteoric water line discussed previously (fig. 35), a mixing model can be prepared. However, to prepare such a model, the isotopic composition of both the pre-Pleistocene ground water and the Pleistocene recharge must be known. Within the aquifer system, the isotopic gradient toward lighter water from central to southwestern Iowa shows *no reversal* in trend (figs. 36, 37). The isotopically lightest water may, consequently, be even more depleted in $\delta^{18}O$ than −17 o/oo. Estimation of the $\delta^{18}O$ of Pleistocene recharge is also difficult because the $\delta^{18}O$ of meltwater from glacial ice could have ranged at least from −40 to −15 o/oo. The isotopic composition of precipitation in the region during the Pleistocene may have been different from what it is today.

A mixing model of a chemically conservative constituent is made using the generalized equation

$$C_1(1-Q_2)+C_2Q_2=C_{mixture}, \quad (14)$$

where

C_1=concentration in water 1,
C_2=concentration in water 2, and
Q_2=fraction of water 2 in the mixture.

As an example of a mixing model, the following conditions were assumed:

1. Pre-Pleistocene ground water had an istotopic composition similar to the present-day recharge water of about −7 o/oo of $\delta^{18}O$.
2. Glacial meltwater entered the aquifer, resulting in a $\delta^{18}O$ of −17 o/oo, the most isotopically depleted water identified.
3. Subsequent recharge southwestward caused the plume outlined by the −10 o/oo line of $\delta^{18}O$. This recharge water is assumed to have a $\delta^{18}O$ value of −8 o/oo, which is about 1 o/oo lighter than modern recharge.

It follows from these assumptions and for equation 14 that a 1:2.3 mixture of meltwater ($\delta^{18}O$ of −40 o/oo) and pre-Pleistocene ground water ($\delta^{18}O$ of −7 o/oo) would produce an observed $\delta^{18}O$ of −17 o/oo. This first-phase mixture subsequently would have had to be mixed with Pleistocene recharge ($\delta^{18}O$ of −8 o/oo) at ratios of up to 1:9 to produce the present isotopically heavier plume in central Iowa. If the $\delta^{18}O$ of the first mixture were lighter than −17 o/oo, the second-phase dilution would be larger. If recharge in the second mixing phase was isotopically heavier, that is, derived from precipitation during warm interstadial periods (Emiliani, 1955; Ruddiman and McIntyre, 1976), a smaller volume of recharge would have been required. For example, if in the hypothesized second mixing phase $\delta^{18}O$ of Pleistocene recharge in the plume area was about 1 o/oo heavier than in modern precipitation (−6 rather than −7 o/oo), the mixing ratio of ground water with $\delta^{18}O$ of −17 o/oo and recharge with −6 o/oo would have been about 1:2 to produce the heavier plume. These exercises indicate that the amount of Pleistocene meltwater currently in the plume area of aquifer layer 3 could be as much as 90 percent, depending on which isotopic values were chosen in the calculations. If the

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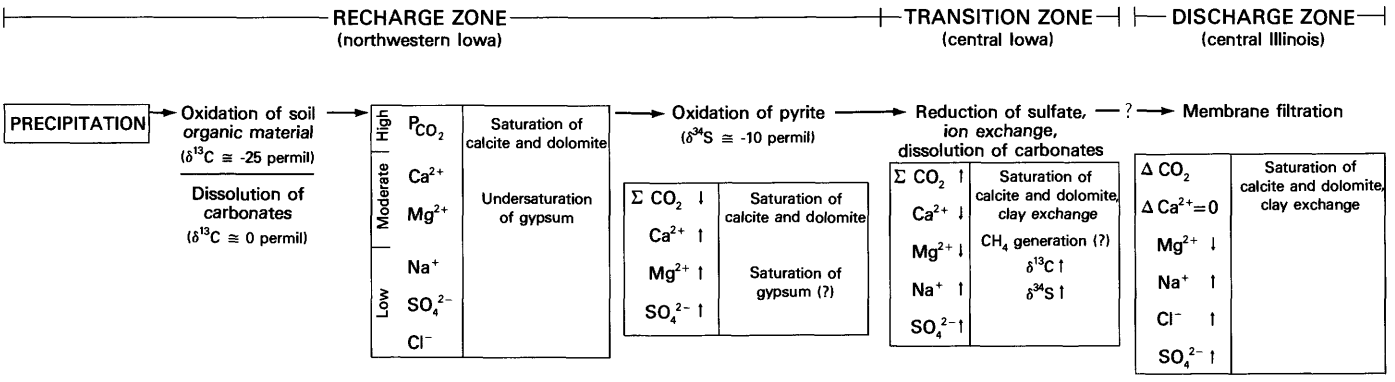
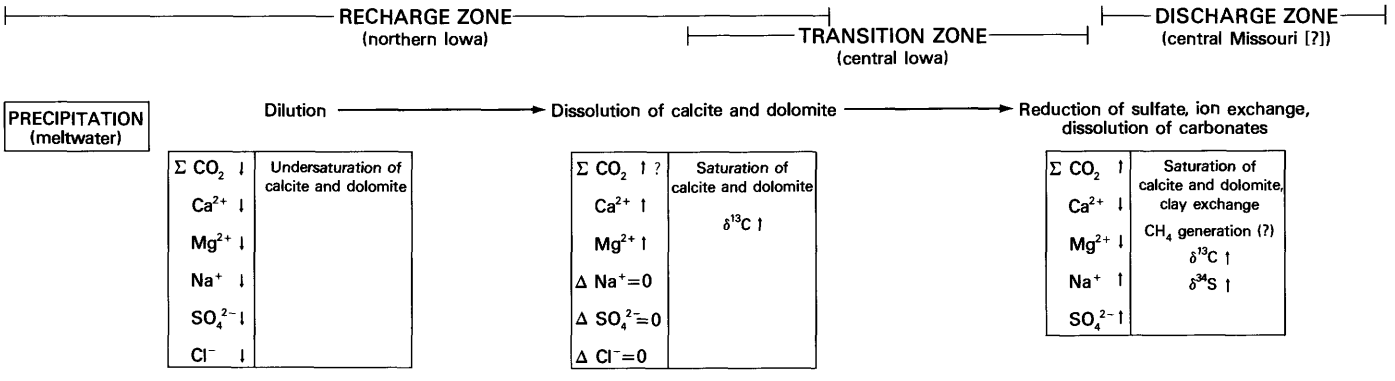


EVOLUTION OF WATER CHEMISTRY FROM NORMAL RECHARGE



EVOLUTION OF WATER CHEMISTRY FROM MELTWATER RECHARGE

FIGURE 41.—Hypothetical geochemical models for the evolution of water chemistry in the Cambrian-Ordovician aquifer system.

$\delta^{18}O$ of the pre-Pleistocene ground water was heavier than that of modern precipitation, the total percentage of Pleistocene glacial meltwater in the aquifer system would be less.

The hypothetical hydrologic and geochemical processes that may have affected the water quality of the Cambrian-Ordovician aquifer system are illustrated in figure 41. Preglacial water quality in the major recharge areas in Wisconsin, Minnesota, and northeastern Iowa may be controlled by dissolution of carbonate minerals in the aquifer matrix. Dissolution of carbonate minerals, ion exchange, and oxidation of pyrite may modify the water quality in northwestern Iowa and southwestern Minnesota. Oxidation of pyrite in the Dakota Formation and in glacial till derived from the Dakota Formation produces sulfuric acid (eq. 7) that would increase both the dissolution of carbonate minerals and the concentration of sulfate. Activities of sulfate and calcium may locally approach the solubility of gypsum, although, generally, ground water in the aquifer system and the overlying Dakota Formation and glacial drift is undersaturated with respect to gypsum and other evaporite minerals. Sulfate reduction, oxidation of organic material, and methane generation decrease concentrations of sulfate and increase inorganic carbon content. Downgradient into the transition zones of Ca-Na-SO_4-HCO_3 and Na-Ca-SO_4-HCO_3 facies in Iowa, additional sulfate reduction, unaccompanied by ion exchange, could cause carbonate precipitation. Membrane filtration near and in the Illinois basin may have caused precipitation of calcite, possible dolomitization of the aquifer matrix in the Illinois basin (Graf and

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others, 1966; Nesbitt, 1980; R. Shedlock, U.S. Geological Survey, written commun., 1982), and increases in sodium and chloride concentrations.

Glaciation and emplacement of Pleistocene meltwater in the aquifer system in Iowa and Missouri could cause dilution of all ground-water solutes. Although concentrations of conservative solutes, such as bromide and chloride, remained low, redissolution of carbonate minerals in the aquifer matrix increased the bicarbonate, calcium, and magnesium until equilibrium with the carbonate minerals was reestablished. This dilution and reequilibration process could have occurred many times. Glaciation also could temporarily enhance the extent of pyrite oxidation in Iowa because additional pyrite was exposed to the atmosphere by glacial erosion of the Dakota Formation.

The hypothetical model can be tested by evaluating the variations in $\delta^{13}C$ in dissolved inorganic carbon. $\delta^{13}C$ inorganic carbon in ground water from wells in aquifer layer 1 in southeastern Minnesota, southern Wisconsin, and northeastern Iowa ranges from about −14 to −8 o/oo (fig. 42). $\delta^{13}C$ is more than −9 o/oo in aquifer layer 3 in northern Illinois and less than −17 o/oo in northwestern Iowa. Of major interest is the enrichment of $\delta^{13}C$ from about −11 to more than −8 o/oo from northeast to southwest in Iowa, approximately perpendicular to the direction of the present hydraulic gradient.

The average of $\delta^{13}C$ in the major recharge areas in Minnesota and Wisconsin is close to −12 o/oo in aquifer layer 1, a value that is typically obtained by the simple closed-system dissolution of carbonate minerals with $\delta^{13}C$ of 0 o/oo (Wigley and others, 1978) by soil carbon dioxide with $\delta^{13}C$ of about −25 o/oo. Recharge to the aquifer system through the Dakota Formation in northwestern Iowa would obtain dissolved carbon from the oxidation of isotopically depleted organic material from both soils and lignite. The $\delta^{13}C$ of the lignite is also probably about −25 o/oo, and consequently the observed −17 to −18 o/oo $\delta^{13}C$ of inorganic carbon in the ground water in aquifer layer 3 is probably caused by fractionation processes. One likely process is bacterially mediated oxidation of methane, which would produce isotopically depleted carbon dioxide with $\delta^{13}C$ of less than −25 o/oo (Fenchel and Blackburn, 1979), and ultimately result in $\delta^{13}C$ of dissolved inorganic carbon in the ground water of less than −12 o/oo. However, sulfate reduction followed by methane production can also enrich the $\delta^{13}C$ of inorganic carbon (Nissenbaum and others, 1972; Claypool and Kaplan, 1974).

The enrichment in $\delta^{13}C$ in aquifer layer 3 from about −11 o/oo in northeastern Iowa to more than −8 o/oo in southwestern Iowa can be explained by successive episodes of glacial-meltwater dilution, dissolution of carbonate minerals in the aquifer matrix, and reequilibration of ground water with respect to the carbonate system. However, it is necessary to assume that the inorganic carbon in the meltwater that recharged the aquifer system had a $\delta^{13}C$ of more than −10 o/oo. The involvement of organic carbon in the dissolution of carbonate rock beneath modern glaciers is minimal, although the presence of atmospheric carbon dioxide in meltwater cannot be overlooked (Hanshaw and Hallet, 1978). The $\delta^{13}C$ of modern atmospheric carbon dioxide is about −7 o/oo (Hoefs, 1980). If most of the meltwater recharge occurred subglacially and if the carbon isotopic composition of Pleistocene atmospheric carbon dioxide was similar to that of today, then the observed enrichment of $\delta^{13}C$ from −11 to −8 o/oo of the dissolved inorganic carbon in the ground water would be conceptually consistent with the meltwater recharge model. During glacial-meltwater emplacement, $\delta^{13}C$ of inorganic carbon also could be enriched by sulfate reduction followed by methane production, as discussed earlier.

Infiltration of meltwater through soils could result in soil carbon dioxide of varying isotopic composition depending on the type of vegetation (Fontes, 1980; Hoefs, 1980). Studies of plant succession after the latest Wisconsin glacial retreat in the Midwest indicate that many stages in plant succession can occur after glaciation and could range from black spruce forests to open woodlands (Wright, 1976). These vegetation types can develop even on the mantle of rock debris that covers stagnant ice. The simplest interpretation of the succession in central Minnesota, for example, is probably that the earlier colonization of herb tundra vegetation was followed by shrub and forest tundra, spruce forest, and, ultimately, pine (Birks, 1975; Gordon and Birks, 1982). These types of vegetation, as well as prairie grasses, have $\delta^{13}C$ values between about −37 and −24 o/oo (Hoefs, 1980). The isotopic composition of carbon dioxide derived from the oxidation of this vegetation would not be too different from that of modern soils. Repeated dissolution of carbonate minerals by meltwater with such dissolved soil carbon dioxide would result in $\delta^{13}C$ of dissolved inorganic carbon of about −12 o/oo, rather than the observed enriched values of carbon-13.

SUMMARY AND CONCLUSIONS

The evolution of the water quality in the Cambrian-Ordovician aquifer system in the northern Midwest United States is complicated because of many possible geochemical processes and the probable effects of Pleistocene glaciation on the aquifer system. Modern

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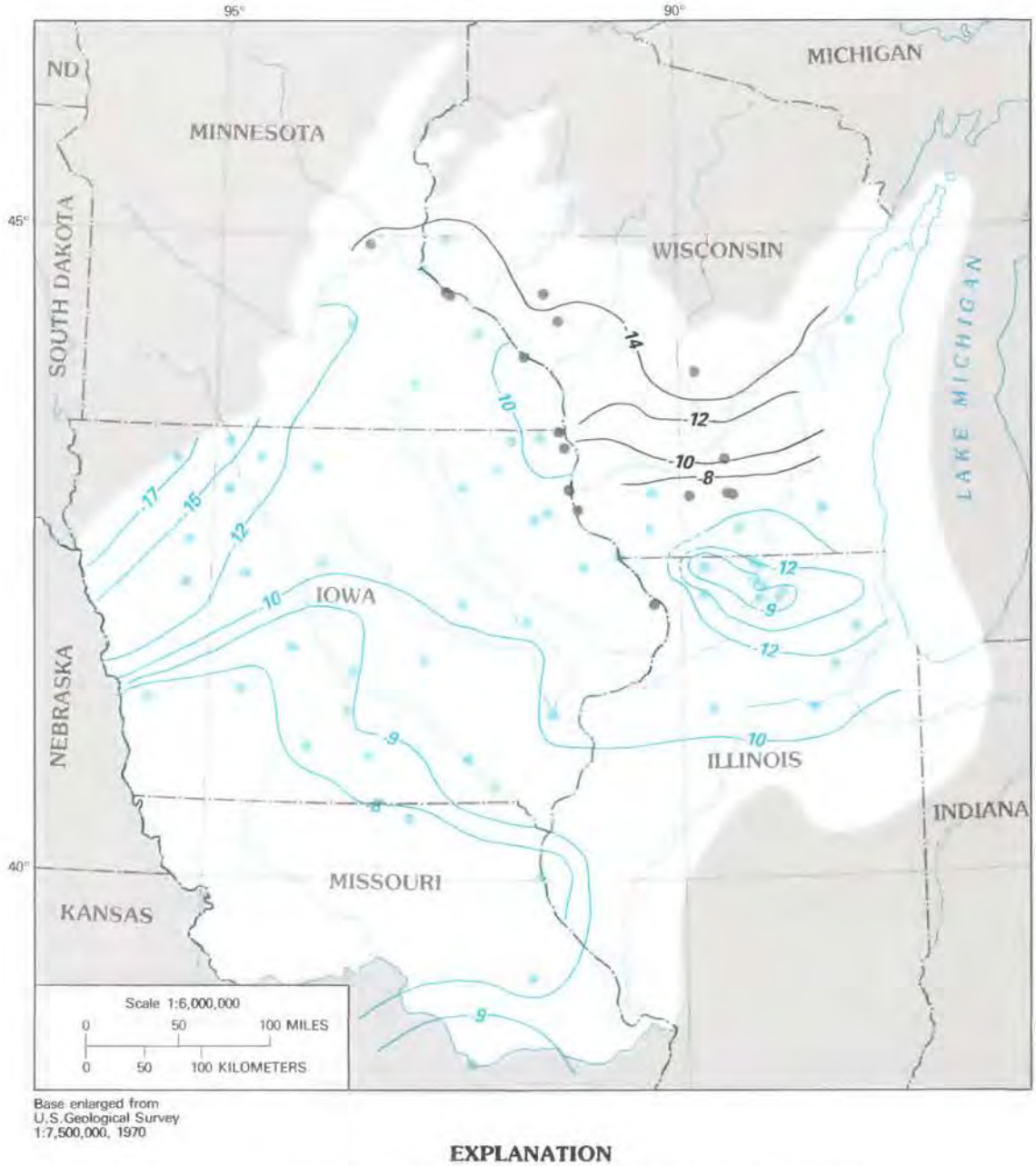

EXPLANATION

LINES OF EQUAL $\delta^{13}C$ RATIO—Dashed where uncertain. Interval, permil, is variable

—10— Aquifer layer 1

—12— Aquifer layer 3

WELL SAMPLED FOR CHEMICAL ANALYSIS DURING THIS STUDY

Open to aquifer layer 1

Open to aquifer layer 3

FIGURE 42.—Distribution of $\delta^{13}C$ ratio in aquifer layers 1 and 3.

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ground-water types may be, in part, a result of ground-water types prior to Pleistocene ice advances.

Ground water in recharge areas in Wisconsin, southern Minnesota, northeastern Iowa, and north-central Illinois is the Ca-Mg-HCO_3 type and is identical in both the glacial drift and the underlying Cambrian-Ordovician aquifer system. Dissolved-solids concentrations are less than 500 mg/L, and the major geochemical process probably is dissolution of carbonate minerals by soil carbon dioxide. In northwestern Iowa and southwestern Minnesota, however, the ground-water type in both the drift and the Cambrian-Ordovician aquifer system is Ca-Na-SO_4-HCO_3 because of the oxidation of pyrite in the Dakota Formation that overlies the aquifer system. Ground water is generally undersaturated with gypsum, and the negative $\delta^{34}S$ values in sulfate indicate that pyrite is a primary sulfur source. Dissolved-solids concentrations in places exceed 1,000 mg/L.

Ground-water type changes from Na-Ca-SO_4-HCO_3 to Na-Cl along the major flow path from northwestern Iowa to the Illinois basin. This is probably due to membrane filtration that would result in calcite precipitation coincident with increases in sodium and chloride.

A plume of dilute water containing less than 500 mg/L of dissolved solids trends north to south in central Iowa under the confining Maquoketa Shale. The plume suggests that paleo-ground-water flow probably was perpendicular to the present hydraulic gradient. This interpretation also is suggested by the general trend of increasing dissolved solids perpendicular to the present hydraulic gradient in Iowa and Missouri.

Ground water in southern Iowa and northern Missouri is considerably more depleted in the heavier stable isotopes, oxygen-18 and hydrogen-2, than is modern recharge water. This evidence may suggest a Pleistocene, and probably a glacial-meltwater, origin of recharge. A plume of ground water isotopically heavier than ground water in southern Iowa, but isotopically lighter than modern recharge, is coincident with the plume of low-dissolved-solids water in central Iowa. It is hypothesized that the isotopic content and dilution of ground water in Iowa and Missouri probably was caused by glacial meltwater emplaced in the aquifer system when glacial ice covered the present recharge areas in northeastern Iowa and southern Minnesota. The emplaced water extends hundreds of miles from the recharge areas. This may suggest that some of the recharge occurred subglacially, under considerably steeper hydraulic gradients than those of the present.

Dilution by the emplaced water decreased the concentrations of solutes such as chloride and sulfate in central Iowa, but bicarbonate concentrations remained about the same. Reequilibration of ground water with carbonate minerals in aquifer matrices, suggested by marked enrichment of $\delta^{13}C$ in dissolved inorganic carbon, could have maintained the level of bicarbonate concentrations. Dilution and re-reaction of the water with the aquifer matrix did not significantly change the ground-water types that are present down the modern hydraulic gradient. The overall chemical character of the ground water in the aquifer system in Iowa was probably established prior to glaciation and the recharge of meltwater.

Reconnaissance data on the distribution of trace solutes show that concentrations of cadmium, arsenic, and selenium seem to be related to the proximity of the Dakota Formation, which onlaps the western edge of the aquifer system in northwestern Iowa and southwestern Minnesota. Iron, manganese, cobalt, cadmium, copper, and lead concentrations are higher in proximity to the Dakota Formation in northwestern Iowa and on the edge of the Forest City basin in southwestern Iowa. Concentrations of beryllium and molybdenum are generally higher near the Forest City basin than elsewhere in the aquifer system. Silica concentrations correlate roughly with ground-water temperature in south-central Iowa and northern Missouri; however, the solid phases controlling the solubility of silica are unknown.

Concentrations of lithium, strontium, boron, and fluoride increase from north to south in Iowa and northern Missouri in a direction perpendicular to the present hydraulic gradient. Distributions of lithium, radium-226, and bromide show a plume of lower concentration similar to the plumes of low dissolved solids and the distribution of stable isotopes of water. Uranium isotopes are at disequilibrium and show activity ratios of uranium-234 to uranium-238 as large as 100. High barium concentrations in northern Illinois and eastern Wisconsin are probably due to a zone of reducing conditions that markedly lower the sulfate concentration. Thus, barium concentrations increase until the solubility limit of barite is reached. Increased concentrations of sulfate and positive $\delta^{34}S$ values of sulfur in sulfate east of the reducing zone in eastern Wisconsin and northeastern Illinois probably indicate emplacement of sulfate derived from evaporitic gypsum. This may have occurred during Pleistocene glaciation, when the load of glacial ice could have reversed ground-water flow from east to west. Ground water from the Michigan basin could have discharged through the present recharge area in central Wisconsin and northern Illinois, where the aquifer either crops out at the land surface or subcrops beneath glacial drift.

It is possible to derive scenarios for the net dilution and dissolution process from calculations using data on the stable isotopes of the water. Such calculations are

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nonunique and are used only for the hypothetical interpretation of geochemical data because (1) the number of glacial advances in Wisconsin and Minnesota prior to Wisconsin time is uncertain, (2) the pre-Pleistocene regional ground-water flow system and topography are unknown, (3) information on the chemical and clay-mineral composition of the aquifer matrix in central Iowa is scant, (4) estimates of the isotopic composition of Pleistocene ice sheets have a large range, (5) different interpretations are made of the shape of the continental ice lobes, (6) no direct information is available on the leakance of younger rocks that overlie the aquifer south of the Maquoketa Shale outcrop, and (7) the extent of isotopic depletion in ground water south of the study area is unknown.

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CHEMICAL AND ISOTOPIC ANALYSES OF GROUND WATER SAMPLED DURING THE STUDY (TABLES 1-3)

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TABLE 1.—*Chemical analyses of major constituents in water from wells sampled for this study*

[Results in milligrams per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Field pH (standard units)	Calcium, Ca	Magnesium, Mg	Sodium, Na	Potassium, K	Field alkalinity, as HCO_3	Sulfate, SO_4	Chloride, Cl	Silica, SiO_2	Dissolved solids, sum of constituents
						Aquifer layer 1, Illinois						
118	422418090255501	10-23-80	7.4	50	26	1.3	2.8	--	5.9	1.3	7.7	230
130	422803087475303	12-10-80	7.2	310	39	440	16	--	1300	370	7.5	2600
131	422803087475304	01-14-81	--	1000	930	15000	270	--	1400	37000	4.4	56000
						Aquifer layer 1, Iowa						
71	432953091172001	06-24-80	7.5	37	45	2.7	1.9	317	19	2.9	8.2	270
73	432206091130301	06-10-80	7.9	31	18	99	4.7	245	52	45	8.0	410
102	430240091110001	06-09-80	7.7	62	27	55	4.0	323	52	59	8.6	430
119	420842090165702	05-15-81	7.6	57	37	9.3	5.9	366	20	8.7	10	330
						Aquifer layer 1, Minnesota						
1	461209093550701	02-21-80	6.5	13	4.4	3.8	1.3	50	5.2	--	19	--
3	453038092584301	05-13-80	7.0	64	22	9.6	2.4	340	<5.0	2.7	20	--
4	452008092595001	05-13-80	7.3	52	14	5.0	1.6	241	<5.0	1.0	13	--
5	445648093395101	05-19-80	7.4	68	24	23	5.4	368	30	6.5	11	350
19	445704093215611	09-04-80	7.8	58	19	33	7.6	244	47	33	7.2	330
21	445153093202101	05-20-80	--	39	13	29	6.7	239	<5.0	20	7.6	--
30	443354092323201	02-12-80	6.7	64	27	53	6.8	276	34	80	8.3	410
31	443407092315501	02-12-80	6.8	40	19	79	4.4	250	27	98	9.2	400
32	443300092302901	02-12-80	7.0	80	44	250	7.9	262	36	550	8.6	1100
50	440324091404001	02-13-80	7.4	56	20	130	8.1	364	85	99	7.0	590
51	440324091401501	02-13-80	7.0	60	21	180	9.0	362	180	140	7.4	760
52	440318091388180	02-13-80	6.9	52	20	80	6.3	351	57	56	8.4	450
53	440312091381201	02-13-80	7.2	56	21	49	6.2	312	37	28	8.3	360
						Aquifer layer 1, Wisconsin						
33	443436091281401	08-06-80	6.8	13	5.9	2.0	1.7	65	11	1.2	16	84
34	443841090393001	08-20-80	6.7	34	8.9	7.7	1.0	99	14	17	20	180
38	442141091185601	08-13-80	7.2	16	6.7	3.8	3.6	68	19	4.2	17	110
39	442045090453601	08-20-80	6.4	2.8	1.2	1.2	1.4	16	6.1	1.3	11	36
54	435743089485701	08-21-80	7.8	21	9.0	1.6	.4	110	4.2	.7	8.9	100
55	440219088555701	08-19-80	8.0	27	34	15	1.8	256	27	2.3	21	260
56	434312090353901	08-22-80	7.8	51	27	1.2	1.0	268	19	1.0	9.8	240
57	433921091132101	10-08-81	7.6	45	29	1.9	1.3	294	11	2.6	9.9	250
75	432336090460601	08-28-80	7.6	50	28	1.7	1.0	268	17	.9	11	240
76	432042090231701	08-28-80	7.7	55	26	2.7	1.0	232	18	3.2	12	230
77	433144089595901	09-05-80	7.2	22	11	3.9	2.5	--	13	7.1	11	--
78	433220089282601	09-05-80	7.4	65	42	1.8	.6	378	32	5.0	7.1	340
79	431849089311002	07-24-80	7.7	51	29	2.5	.9	329	3.0	.8	13	260
80	432717088501701	09-05-80	7.3	60	31	3.7	1.7	--	21	3.7	9.4	--
103	425246091042101	08-19-81	7.3	180	40	140	12	280	370	180	8.7	1100
105	431108090263101	08-29-80	7.4	57	32	5.2	1.5	305	6.0	5.3	12	270
108	430055089534001	07-18-80	7.3	67	37	6.0	1.0	354	28	13	6.7	360
110	430058089251401	07-22-80	7.6	54	31	2.9	1.8	329	6.4	1.8	9.0	270
						Aquifer layer 3, Illinois						
120	422606089434501	08-29-80	7.6	66	34	3.2	.6	341	5.2	.6	13	290
121	421331089442201	08-29-80	7.4	74	42	9.8	3.0	329	3.2	1.1	9.5	330
122	421658089235101	08-20-80	7.4	110	50	25	1.5	256	86	39	21	530
123	422738089114601	08-23-80	7.1	81	41	3.5	1.8	402	29	7.2	11	390
124	422545089103301	08-23-80	7.4	91	49	5.7	.6	451	32	20	8.7	440
125	421855089121601	08-23-80	7.3	62	29	2.9	.7	329	11	.8	12	280
126	421614089062301	09-03-80	6.7	120	57	59	4.9	232	140	120	16	650
127	420953089080501	09-05-80	7.4	65	32	5.0	.5	232	16	2.3	15	250
128	421025088564401	09-04-80	7.0	67	34	3.7	1.0	244	14	1.9	14	260
129	421329088531701	09-05-80	7.1	95	47	14	1.8	207	74	38	13	440
132	422803087475306	09-01-81	7.2	94	23	41	11	--	150	13	8.0	510
133	415632088071201	06-21-80	8.3	74	23	52	18	597	170	18	7.0	660
134	415818087565201	05-02-80	--	24	7.2	85	4.3	268	44	22	7.1	330
135	413847088214801	08-27-80	7.3	54	27	64	1.9	280	69	20	7.5	390
136	411858088363401	08-28-80	7.4	71	35	97	12	195	110	90	7.8	520
137	411933089403701	08-28-80	7.0	38	19	370	12	317	200	350	9.3	1200

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TABLE 1.—*Chemical analyses of major constituents in water from wells sampled for this study*—Continued

[Results in milligrams per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Field pH (standard units)	Calcium, Ca	Magnesium, Mg	Sodium, Na	Potassium, K	Field alkalinity, as HCO_3	Sulfate, SO_4	Chloride, Cl	Silica, SiO_2	Dissolved solids, sum of constituents
						Aquifer layer 3, Iowa						
59	431620095250201	09-03-80	8.0	340	130	190	10	505	1400	26	22	2400
61	432412094503301	09-09-81	7.3	240	74	50	6.0	841	570	2.6	27	1400
62	431750094303001	09-08-81	7.4	180	61	63	5.0	744	440	2.3	18	1100
63	432256094183301	06-25-80	7.3	110	35	58	3.1	441	200	1.9	18	650
64	431350093544201	06-25-80	7.3	78	27	19	4.0	421	17	1.1	14	370
65	430800092540301	06-26-80	7.8	66	26	16	6.8	317	48	2.0	7.0	330
66	432650092170201	06-24-80	7.4	60	18	4.2	1.7	274	14	1.3	11	250
67	430337092190701	06-25-80	7.5	52	21	6.9	4.3	263	27	.9	6.8	250
68	431216091572001	06-23-80	7.5	69	29	3.5	1.1	297	37	9.4	11	320
69	432606091470301	06-23-80	7.2	93	24	5.0	1.6	386	10	9.4	18	370
70	432800091295301	06-24-80	7.5	56	28	3.5	.8	366	3.6	2.1	12	300
72	431638091284102	06-24-80	7.3	86	21	3.2	.9	341	24	6.5	14	330
84	430210094500001	09-08-81	7.6	240	78	100	7.3	744	800	6.6	26	1600
88	423840095135001	09-04-80	7.2	280	64	170	43	329	1100	30	8.3	1900
91	421831095152101	09-04-80	7.5	190	48	150	32	282	730	32	9.3	1300
92	422339094375101	09-02-80	7.2	170	59	98	26	317	590	14	9.0	1100
93	422136094173401	09-05-80	7.5	120	44	92	25	372	390	20	9.0	890
94	422855093481501	09-02-80	7.3	120	43	140	20	363	370	71	8.4	960
95	422611092552501	09-02-80	7.4	78	32	74	21	329	180	11	8.0	570
96	425049092063801	06-11-80	7.7	50	24	15	6.6	293	39	1.3	6.6	290
97	425708091383001	06-10-80	7.3	82	27	6.0	2.6	347	47	13	10	370
98	424820091324001	06-09-80	7.6	65	27	4.5	1.6	293	43	8.9	10	310
99	425138091234901	06-09-80	7.5	62	29	6.7	5.0	293	54	1.7	7.4	310
100	425550091233001	06-09-80	7.5	60	27	4.6	2.8	317	28	1.9	11	290
101	430330091264301	06-24-80	7.5	87	39	7.4	1.2	366	75	14	13	420
116	423141090385801	08-26-81	7.6	52	33	2.2	2.2	329	16	2.5	9.5	280
117	422640091002701	08-26-81	7.8	50	24	62	11	329	90	21	8.3	430
138	421010092180301	06-23-80	7.5	83	40	73	14	400	200	6.8	7.2	630
139	420200091363001	07-21-80	7.4	59	31	74	13	341	170	10	7.8	540
140	420718091165401	07-23-80	7.5	62	30	68	13	341	160	14	7.9	530
141	412407095391201	09-02-81	7.7	190	55	210	36	244	690	240	9.7	1600
142	413015094391302	09-02-81	7.8	170	63	330	35	219	750	380	11	1900
143	415021094072801	09-02-81	7.5	110	44	240	28	317	590	140	9.7	1300
144	413931093292001	09-01-81	7.6	58	24	53	12	305	110	14	11	440
145	414430092433001	09-01-81	7.5	79	37	100	16	354	270	21	11	710
146	412736093241201	07-30-81	7.5	61	26	83	13	329	150	28	11	540
147	412025093322201	06-10-81	7.7	55	22	140	17	305	240	30	12	670
148	410235093564901	06-10-81	7.6	130	44	360	28	244	740	250	14	1700
149	404422093445602	07-28-81	7.4	170	56	520	26	232	700	410	13	2000
150	405858093175701	06-10-81	7.8	60	23	200	19	317	300	110	11	890
151	411332093142101	06-10-81	7.8	57	22	140	17	317	190	75	11	680
152	412020092471001	08-12-81	7.6	86	37	200	22	329	440	62	11	1000
153	410305092490701	07-28-81	7.5	65	26	190	17	317	320	130	4.8	910
154	412356092211001	07-30-81	7.4	100	46	150	15	341	430	34	11	960
155	405750092142001	06-09-81	8.0	74	32	250	20	293	470	140	8.7	1100
156	410115091571801	06-09-81	7.5	75	31	240	20	280	470	130	10	1100
157	411812091412601	08-05-80	7.3	93	46	240	20	286	550	63	10	1200
158	411907091220001	10-29-80	7.2	530	78	2500	70	295	2200	3600	10	9200
159	404421091575801	06-09-81	7.5	69	28	330	20	305	410	250	11	1300
160	403839091333801	08-05-80	7.6	62	28	490	17	312	400	370	9.5	1500
						Aquifer layer 3, Minnesota						
6	445607093364701	05-19-80	7.6	84	44	25	3.8	535	26	.9	20	470
7	445409093342801	05-19-80	7.7	52	29	4.1	4.0	312	<5.0	2.9	17	--
8	445831093305701	05-19-80	7.5	80	34	6.4	2.2	406	8.0	6.2	23	360
9	450015093280001	05-14-80	7.6	76	34	3.7	2.2	358	28	5.5	23	350
10	450127093204201	05-14-80	7.3	88	41	5.3	2.6	447	12	.50	20	390
11	450510093172501	05-14-80	--	64	24	5.6	1.8	302	9.5	3.1	21	280
12	450337093130901	05-14-80	6.8	68	29	5.4	1.5	269	61	8.2	19	330
13	450532093000301	05-12-80	7.3	48	17	4.1	1.8	213	8.0	3.2	15	200
14	450532093000302	05-12-80	7.2	56	18	7.9	3.7	233	<5.0	1.7	8.9	--
15	450417092570401	05-12-80	--	40	16	3.2	1.2	212	<5.0	<.5	15	--
16	450238093000401	05-12-80	7.0	56	18	5.4	1.8	219	8.3	4.7	16	220
17	450039092594501	05-14-80	6.8	56	19	7.9	1.7	232	35	6.2	19	260

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TABLE 1.—*Chemical analyses of major constituents in water from wells sampled for this study*—Continued

[Results in milligrams per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Field pH (standard units)	Calcium, Ca	Magnesium, Mg	Sodium, Na	Potassium, K	Field alkalinity, as HCO_3	Sulfate, SO_4	Chloride, Cl	Silica, SiO_2	Dissolved solids, sum of constituents
20	445124093270801	05-20-80	7.6	68	27	5.5	1.7	347	12	2.9	22	310
22	445153093202102	05-20-80	7.6	76	32	5.2	1.4	371	11	3.3	17	330
23	444825093125001	05-22-80	--	68	27	3.7	1.7	--	11	<.5	23	--
24	445348093022901	05-21-80	--	100	36	14	1.9	--	71	45	22	470
25	444227093125201	05-21-80	--	65	20	4.8	1.1	305	10	.5	14	260
27	443849093143601	01-30-80	6.6	140	36	45	11	394	300	7.8	21	760
28	443806093085901	05-21-80	7.6	68	24	2.8	1.1	322	10	<.5	15	--
35	442648093091301	05-21-80	--	76	29	3.0	1.3	--	35	.6	15	930
36	441851093341801	09-03-80	--	90	35	22	4.2	378	33	1.6	22	400
37	441454092101001	02-12-80	--	72	27	9.1	.8	--	18	24	17	310
42	435542093570501	02-29-80	7.0	140	41	65	4.3	452	340	1.3	15	830
43	434547094095802	01-29-80	7.5	160	44	68	4.9	428	450	1.5	15	960
44	434601094010001	02-29-80	7.4	110	32	30	4.6	472	69	.6	23	510
46	435333092503901	09-02-80	--	72	20	4.3	3.1	317	21	1.1	7.6	290
47	434221092341701	05-07-80	--	60	22	3.1	2.8	260	34	.9	7.6	260
48	434235092340201	05-07-80	--	64	22	3.0	2.5	269	34	.8	8.3	270
49	434242092160503	05-06-80	--	56	21	2.3	1.1	262	12	2.6	9.3	230
					Aquifer layer 3, Missouri							
161	402842092511801	04-07-81	7.4	110	49	710	25	319	1200	450	8.6	2700
162	400217091295201	04-07-81	7.3	210	100	2000	46	300	1200	3000	6.7	6700
163	391622091343301	04-06-81	7.5	72	36	280	19	450	280	190	8.5	1100
164	383543092103001	04-06-81	7.4	51	23	43	5.6	360	36	27	8.0	370
					Aquifer layer 3, Wisconsin							
18	445910092331301	08-04-80	7.8	36	20	2.9	.8	195	6.5	3.5	19	200
29	444504092473601	08-14-80	7.5	13	5.8	2.5	.8	46	13	2.3	19	94
40	441849088051801	08-08-80	7.3	300	48	110	15	195	870	170	9.8	1600
74	432800091062501	11-10-81	7.7	61	35	4.2	.6	304	8.0	8.6	18	290
104	424423090552801	08-26-80	7.1	120	57	17	.7	439	47	41	26	640
106	430117090173201	08-27-80	7.6	63	33	2.3	.8	329	16	4.5	13	310
107	430132090172601	08-27-80	6.8	12	6.1	3.2	.7	51	13	2.8	22	89
109	430136089274301	05-12-80	7.5	94	49	21	1.1	390	34	91	20	520
112	425245088274701	05-29-80	7.5	56	28	4.4	1.8	305	2.2	1.3	9.9	260
113	425153088195501	10-21-82	7.6	53	22	7.0	1.6	266	19	1.7	10	250
114	424407090200001	08-26-80	7.6	66	37	3.8	.5	341	19	3.1	11	310
115	424404089204701	09-04-80	7.5	57	30	20	3.9	280	31	41	15	340
					Aquifer layer 4, Minnesota							
45	433615093403001	09-02-80	--	58	20	100	2.6	512	66	2.1	22	520
					Aquifer layer 4, Wisconsin							
111	430618087571001	11-21-80	7.7	68	28	35	2.6	--	240	15	9.8	510
					Aquifer layer 5, Iowa							
58	425526096210711	09-03-80	8.0	250	97	170	16	305	1100	21	14	1800
60	431620095250511	09-03-80	8.0	300	110	150	8.8	442	1200	30	23	2000
81	430512095371801	02-23-82	7.4	--	--	--	--	--	--	--	10	--
82	425824095300901	02-23-82	7.3	320	80	96	--	--	930	6.7	11	--
83	430745094541101	02-23-82	7.5	220	58	100	--	--	520	5.0	11	--
85	424348095231601	04-15-80	8.0	120	38	74	9.9	355	260	18	9.0	710
86	424348095231602	09-04-80	8.1	97	35	25	3.0	396	170	1.6	27	560
87	423618095194511	09-04-80	8.0	180	42	28	3.7	397	370	1.1	24	850
89	422950095174301	02-22-82	7.5	310	100	190	--	1200	16	12	--	--
90	422009095210101	02-22-82	7.4	260	63	140	--	850	8.5	5.0	--	--
					Aquifer layer 5, Minnesota							
2	462710092454001	02-21-80	--	60	15	13	1.7	--	15	39	19	270
26	443710093453501	09-03-80	--	82	35	80	3.6	378	100	36	24	550
41	440026094355401	09-03-80	--	87	24	18	2.2	268	130	5.0	29	430

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of sample	Arsenic, As	Boron, B	Barium, Ba	Bromide, Br (mg/L)	Cadmium, Cd	Cobalt, Co	Chromium, Cr	Copper, Cu
			Aquifer layer 1, Illinois							
118	422418090255501	10-23-80	<1	20	160	.20	<1	4	--	<10
130	422803087475303	12-10-80	<1	1000	10	1.4	5	6	--	<10
131	422803087475304	01-14-81	2	11000	50	.20	10	<3	--	36
			Aquifer layer 1, Iowa							
71	432953091172001	06-24-80	1	30	130	<.10	2	<3	--	<10
73	432206091130301	06-10-80	2	220	60	<.10	<1	<3	--	13
102	430240091110001	06-09-80	1	160	80	<.10	2	<3	--	<10
119	420842090165702	05-15-81	1	10	160	<.10	<1	<3	--	<10
			Aquifer layer 1, Minnesota							
1	461209093550701	02-21-80	<1	<50	18	--	<1	<3	<1	<10
3	453038092584301	05-13-80	<1	60	48	--	<1	<3	<1	<10
4	452008092595001	05-13-80	<1	<50	37	--	<1	<3	<1	<10
5	445648093395101	05-19-80	1	250	150	--	<1	<3	<1	11
19	445704093215611	09-04-80	1	210	150	.30	8	<3	--	<10
21	445153093202101	05-20-80	<1	20	280	--	<1	<1	<1	<10
30	443354092323201	02-12-80	<1	210	520	--	<1	<3	<1	<10
31	443407092315501	02-12-80	<1	--	33	--	2	<3	2	<10
50	440324091404001	02-13-80	<1	620	32	--	<1	<3	<1	20
51	440324091401501	02-13-80	<1	80	37	--	<1	<3	<1	<10
52	440318091388180	02-13-80	<1	43	33	--	<1	<3	<1	<10
53	440312091381201	02-13-80	<1	32	40	--	<1	<3	<1	1
			Aquifer layer 1, Wisconsin							
33	443436091281401	08-06-80	1	<20	20	.40	5	<3	--	10
34	443841090393001	08-20-80	1	10	60	.10	6	<3	--	10
38	442141091185601	08-13-80	<1	40	20	.70	5	<3	--	<10
39	442045090453601	08-20-80	2	10	20	<.10	2	<3	--	<10
54	435743089485701	08-21-80	1	<20	40	<.10	2	<3	--	<10
55	440219088555701	08-19-80	6	50	80	.20	3	<3	--	<10
56	434312090353901	08-22-80	1	<20	20	.30	<1	<3	--	<10
57	433921091132101	10-08-81	1	10	40	.10	1	10	--	10
75	432336090460601	08-28-80	1	20	50	.30	3	<3	--	<10
76	432042090231701	08-28-80	2	30	30	.20	4	<3	--	<10
77	433144089595901	09-05-80	1	20	40	.40	2	<3	--	<10
78	433220089282601	09-05-80	1	<20	40	.40	3	<3	--	11
79	431849089311002	07-24-80	4	<20	30	.20	3	<3	--	<10
80	432717088501701	09-05-80	1	30	250	.30	2	<3	--	<10
103	425246091042101	08-19-81	1	190	20	.90	2	10	--	10
105	431108090263101	08-29-80	1	50	50	.20	3	<3	--	<10
108	430055089534001	07-18-80	1	<20	60	.90	3	<3	--	<10
110	430058089251401	07-22-80	2	30	20	.30	<1	<3	--	<10
			Aquifer layer 3, Illinois							
120	422606089434501	08-29-80	1	20	20	.20	4	<3	--	<10
121	421331089442201	08-29-80	2	80	21000	.20	3	<3	--	<10
122	421658089235101	08-20-80	1	40	110	.60	3	<3	--	<10
123	422738089114601	08-23-80	<1	<20	40	.10	<2	<3	--	<20
124	422545089103301	08-23-80	<1	--	40	.10	<2	<3	--	<20
125	421855089121601	08-23-80	1	<20	130	.20	<2	<3	--	<20
126	421614089062301	09-03-80	1	270	80	.60	4	<3	10	<10
127	420953089080501	09-05-80	2	20	100	.70	3	<3	--	<10
128	421025088564401	09-04-80	1	50	110	.30	4	<3	--	<10

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Fluoride, F (mg/L)	Iron, Fe	Lithium, Li	Manganese, Mn	Molybdenum, Mo	Lead, Pb	Selenium, Se	Strontium, Sr	Vanadium, Va	Beryllium, Be	Sulfide, S (mg/L)
					Aquifer layer 1, Illinois						
118	.30	670	<4	10	<10	<10	<1	46	<6	<.7	--
130	1.0	2700	180	190	<10	17	<1	13000	<6	<.7	<.1
131	.30	8500	2100	9800	<10	170	<1	100000	<6	<1.0	<.1
					Aquifer layer 1, Iowa						
71	.20	220	7	9	<10	<10	<1	100	<6	<.7	--
73	.20	170	15	15	<10	<10	<1	230	<6	.7	--
102	.30	250	18	14	<10	62	<1	360	<6	<.7	--
119	.10	11	13	14	<10	<10	<1	960	<6	<1.0	--
					Aquifer layer 1, Minnesota						
1	.10	4800	2	450	<1	<10	<1	--	--	--	--
3	.26	1100	5	70	2	<10	<1	--	--	--	--
4	.20	550	4	90	2	<10	<1	--	--	--	--
5	.72	2200	11	30	<1	<10	1	--	--	--	--
19	.40	610	20	14	<10	34	<10	690	<6	<.7	--
21	.30	380	18	20	<1	<1	2	--	--	--	--
30	.18	<50	29	59	2	<1	3	--	--	--	--
31	.28	300	20	38	<1	<10	--	--	--	--	--
50	.56	200	56	25	<1	<1	<1	--	--	--	--
51	.04	580	63	<20	<1	<1	<1	--	--	--	--
52	1.3	340	31	21	<1	<1	1	--	--	--	--
53	.39	340	22	24	<1	30	4	--	--	--	--
					Aquifer layer 1, Wisconsin						
33	.50	6	0	210	0	10	<1	24	<6	<.7	<.1
34	.20	<3	5	5	<10	13	<1	58	<6	<.7	<.1
38	.60	6500	<4	190	<10	<10	<1	20	<6	2.0	<.1
39	.10	<3	<4	2	<10	<10	<1	12	<6	3.0	<.1
54	.20	<3	<4	260	<10	<10	<1	39	<6	3.0	<.1
55	.40	50	7	11	<10	<10	<1	1100	<6	2.0	<.1
56	.20	40	<4	29	<10	16	<1	36	<6	4.0	--
57	<.10	440	4	17	10	10	<1	59	6	1.0	--
75	.10	310	<4	14	<10	17	<1	40	<6	<.7	<.1
76	.10	150	<4	16	<10	<10	<1	45	<6	1.0	<.1
77	.10	10	<4	45	<10	<10	<1	41	<6	<.7	.2
78	.10	9	<4	5	<10	<10	<1	44	<6	<.7	<.1
79	.10	<3	<4	<1	<10	<10	<1	46	<6	<.7	<.1
80	.30	840	<4	49	<10	<10	<1	1700	<6	<.7	<.1
103	.20	1700	50	16	11	10	<1	4400	6	1.0	<.1
105	.20	750	5	26	<10	<10	<1	58	<6	<.7	.2
108	.10	8	<4	<1	10	13	<1	38	<6	<.7	<.1
110	.10	140	<4	16	<10	<10	<1	76	<6	.8	.1
					Aquifer layer 3, Illinois						
120	.20	1500	<4	28	13	18	<1	61	<6	<.7	--
121	.30	270	5	13	<10	12	<1	540	<6	<.7	--
122	.20	100	5	<1	<10	14	1	110	<6	1.0	--
123	.10	3	5	<1	<10	21	<1	48	<6	<.7	--
124	.10	16	6	<1	<10	<10	<1	43	<6	<.7	--
125	.10	21	4	5	<10	<10	<1	48	<6	<.7	--
126	.20	330	6	58	<10	11	<1	160	<6	<.7	--
127	.20	1700	<4	44	<10	<10	<1	120	<6	<.7	--
128	.20	<3	<4	<1	<10	<10	<1	72	<6	<.7	--

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of sample	Arsenic, As	Boron, B	Barium, Ba	Bromide, Br (mg/L)	Cadmium, Cd	Cobalt, Co	Chromium, Cr	Copper, Cu
129	421329088531701	09-05-80	1	30	50	.50	3	<3	--	<10
132	422803087475306	09-01-81	1	290	2	.10	1	3	--	10
133	415632088071201	06-21-80	1	560	80	.20	1	<3	--	<10
134	415818087565201	05-02-80	1	910	20	.20	<1	<3	--	11
135	413847088214801	08-27-80	1	470	30	.40	<1	<3	--	<10
136	411858088363401	08-28-80	1	270	30	.70	2	<3	--	<10
137	411933089403701	08-28-80	<1	850	20	1.0	5	<3	--	<10
				Aquifer layer 3, Iowa						
59	431620095250201	09-03-80	3	300	20	.20	7	<3	--	<10
61	432412094503301	09-09-81	2	300	23	.10	1	<3	--	<10
62	431750094303001	09-08-81	2	210	21	<.10	1	4	--	<10
63	432256094183301	06-25-80	1	140	60	<.10	<1	<3	--	<10
64	431350093544201	06-25-80	1	70	140	<.10	<1	<3	--	<10
65	430800092540301	06-26-80	1	250	60	<.10	3	<3	--	<10
66	432650092170201	06-24-80	1	70	140	.10	<1	<3	--	<10
67	430337092190701	06-25-80	<10	310	70	<.10	<1	<3	--	<10
68	431216091572001	06-23-80	1	60	140	.10	<1	<3	--	<10
69	432606091470301	06-23-80	1	20	120	.10	<1	<3	--	<10
70	432800091295301	06-24-80	<10	<20	60	.10	2	<3	--	<10
72	431638091284102	06-24-80	<10	30	80	<.10	<1	<3	--	<10
84	430210094500001	09-08-81	1	360	31	<.10	1	<3	--	<10
88	423840095135001	09-04-80	1	2200	20	.90	6	<3	--	<10
91	421831095152101	09-04-80	1	1100	30	.50	4	<3	--	<10
92	422339094375101	09-02-80	1	990	20	.80	5	<3	--	<10
93	422136094173401	09-05-80	1	1200	20	.80	3	<3	--	<10
94	422855093481501	09-02-80	2	1100	20	.90	4	<3	--	<10
95	422611092552501	09-02-80	1	1100	30	.40	4	<3	--	<10
96	425049092063801	06-11-80	<10	220	70	<.10	<1	<3	--	<10
97	425708091383001	06-10-80	4	50	110	.10	<1	<3	--	<10
98	424820091324001	06-09-80	1	140	140	<.10	1	<3	--	<10
99	425138091234901	06-09-80	2	180	60	<.10	<1	<3	--	<10
100	425550091233001	06-09-80	<10	130	100	<.10	<1	<3	--	<10
101	430330091264301	06-24-80	<10	80	100	.10	2	<3	--	<10
116	423141090385801	08-26-81	2	<20	150	<.10	<1	<3	--	<10
117	422640091002701	08-26-81	1	460	40	.10	<1	<3	--	<10
138	421010092180301	06-23-80	<10	590	30	.10	3	<3	--	<10
139	420200091363001	07-21-80	1	610	30	.30	<1	<3	--	<10
140	420718091165401	07-23-80	1	570	40	.30	2	<3	--	<10
141	412407095391201	09-02-81	<10	820	17	.90	<2	<6	--	<20
142	413015094391302	09-02-81	1	1300	23	.20	<2	<6	--	<20
143	415021094072801	09-02-81	1	1700	21	.60	<1	<3	--	<10
144	413931093292001	09-01-81	<10	600	48	.10	<1	<3	--	<10
145	414430092433001	09-01-81	<10	1100	27	.10	<1	<3	--	<10
146	412736093241201	07-30-81	2	760	40	.20	<1	<3	--	<10
147	412025093322201	06-10-81	<10	1200	170	.20	<1	<3	--	<10
148	410235093564901	06-10-81	1	1600	310	.90	<2	<6	--	<20
149	404422093445602	07-28-81	1	1900	20	1.5	<1	<3	--	<10
150	405858093175701	06-10-81	1	1500	130	.40	<1	<3	--	<10
151	411332093142101	06-10-81	1	1100	120	.30	<1	<3	--	<10
152	412020092471001	08-12-81	1	1400	30	.30	<1	<3	--	<10
153	410305092490701	07-28-81	1	1400	30	.40	<1	<3	--	<10
154	412356092211001	07-30-81	2	870	30	.20	<1	<3	--	<10
155	405750092142001	06-09-81	1	1400	130	.50	<1	<3	--	<10
156	410115091571801	06-09-81	1	1300	100	.50	<1	<3	--	<10
157	411812091412601	08-05-80	2	670	30	.40	4	<3	--	<10
158	411907091220001	10-29-80	1	5700	30	9.8	6	10	--	24
159	404421091575801	06-09-81	1	1700	140	.80	<1	<3	--	<10
160	403839091333801	08-05-80	3	1600	30	.50	5	<3	--	<10

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Fluoride, F (mg/L)	Iron, Fe	Lithium, Li	Manganese, Mn	Molybdenum, Mo	Lead, Pb	Selenium, Se	Strontium, Sr	Vanadium, Va	Beryllium, Be	Sulfide, S (mg/L)
129	.20	<3	<4	<1	<10	<10	<1	83	<6	<.7	--
132	1.4	650	24	14	10	10	<1	8300	6	1.0	<.1
133	1.1	22	49	13	<10	54	<1	3900	<6	2.0	--
134	3.5	200	73	11	12	<10	<1	710	<6	4.0	--
135	1.1	4	59	48	<10	21	<1	1800	<6	<.7	--
136	.70	9	67	10	<10	18	<1	1300	<6	<.7	--
137	1.5	580	220	9	<10	<10	<1	2700	<6	<.7	--
					Aquifer layer 3, Iowa						
59	.30	82	140	550	<10	26	<1	3000	<6	<.7	--
61	.30	1500	70	330	20	<10	<1	1100	<6	<1.0	.8
62	.40	99	51	130	<10	10	<1	1100	<6	<1.0	1.0
63	.30	2600	30	36	25	<10	<1	350	<6	<.7	--
64	.40	260	23	25	17	<10	<1	320	<6	<.7	--
65	.70	380	31	8	21	<10	<1	510	<6	<.7	--
66	.60	630	10	10	<10	<10	<1	150	<6	<.7	--
67	.60	91	14	5	<10	17	<1	280	<6	<.7	--
68	.30	<3	7	2	17	<10	1	220	<6	<.7	--
69	.20	7	7	25	16	<10	<1	100	<6	<.7	--
70	.10	<3	<4	2	<10	<10	<1	52	<6	<.7	--
72	.20	15	5	3	15	<10	<1	97	<6	<.7	--
84	.30	2500	72	170	<10	10	<1	1900	<6	<1.0	.7
88	1.7	1300	210	59	<10	24	<1	9100	<6	<.7	--
91	2.0	3700	170	57	<10	22	<1	6000	<6	<.7	--
92	1.5	2100	95	39	<10	18	<1	4400	<6	<.7	--
93	1.6	2600	150	33	<10	14	<1	5200	<6	<.7	--
94	1.3	210	130	14	<10	13	<1	4000	<6	<.7	--
95	1.2	1200	120	18	<10	10	<1	2200	<6	<.7	--
96	.80	150	24	8	<10	<10	<1	530	<6	<.7	--
97	.40	6	5	4	<10	66	1	250	<6	<.7	--
98	.50	7	<4	37	<10	<10	2	150	<6	<.7	--
99	.40	22	14	8	11	78	<1	370	<6	<.7	--
100	.50	260	9	9	<10	87	<1	270	<6	2.0	--
101	.30	210	9	9	16	<10	<1	120	<6	<.7	--
116	.20	170	7	10	<10	<10	<1	92	<6	<1.0	<.1
117	.90	280	77	8	<10	<10	<1	1100	<6	<1.0	.1
138	1.1	1400	110	19	<10	<10	<1	1900	<6	<.7	--
139	1.3	170	90	3	<10	<10	<1	1500	<6	<.7	--
140	1.2	120	79	4	<10	<10	<1	1600	<6	<.7	--
141	2.9	2500	240	120	<20	<20	<1	6300	<12	<2.0	1.0
142	2.7	370	280	17	<20	<20	<1	5800	<12	<2.0	.5
143	2.3	440	270	8	<10	<10	<1	4700	<6	<1.0	.5
144	1.7	120	63	4	<10	<10	<1	1300	<6	<1.0	.5
145	1.4	320	140	5	<10	<10	<1	2300	<6	<1.0	.8
146	1.7	2000	86	18	<10	<10	<1	1700	<6	<1.0	--
147	2.7	210	150	3	<10	<10	<1	2100	<6	<1.0	.1
148	2.7	1300	350	18	<20	<20	<1	5700	<6	<2.0	.1
149	2.8	720	420	10	<10	<10	<1	6000	<6	<1.0	<.1
150	2.7	840	200	8	<10	<10	<1	2400	<6	<1.0	.9
151	2.2	800	130	12	<10	<10	<1	1800	<6	<1.0	<.1
152	1.2	2300	210	32	<10	<10	<1	2500	<6	<1.0	.2
153	1.6	51	4	<1	<10	<10	<1	44	<6	<1.0	<.1
154	1.3	2200	170	18	<10	<10	<1	2300	<6	<1.0	--
155	1.7	2100	260	91	<10	<10	<1	2700	<6	<1.0	<.1
156	1.6	530	240	8	<10	<10	<1	2500	<6	<1.0	<.1
157	1.3	290	220	4	<10	16	<1	2500	<6	<.7	--
158	1.5	10000	620	130	<10	17	<1	19000	5	<1.0	--
159	2.3	1200	290	12	<10	<10	<1	2500	<6	<1.0	<.1
160	4.1	770	360	8	<10	<10	<1	2600	<6	1.0	--

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of sample	Arsenic, As	Boron, B	Barium, Ba	Bromide, Br (mg/L)	Cadmium, Cd	Cobalt, Co	Chromium, Cr	Copper, Cu
			Aquifer layer 3, Minnesota							
6	445607093364701	05-19-80	<1	210	110	--	<1	<3	<1	<10
7	445409093342801	05-19-80	<1	10	160	--	<1	<3	<1	21
8	445831093305701	05-19-80	11	10	270	--	<1	<3	<1	15
9	450015093280001	05-14-80	<1	80	75	--	<1	<3	<1	11
10	450127093204201	05-14-80	<1	110	11	--	<1	<3	<1	<10
11	450510093172501	05-14-80	<1	100	90	--	<1	<3	<1	<10
12	450337093130901	05-14-80	<1	80	63	--	<1	<3	<1	12
13	450532093000301	05-12-80	--	--	--	--	--	--	--	--
14	450532093000302	05-12-80	<1	<50	59	--	<1	<3	<1	<10
15	450417092570401	05-12-80	<1	<50	13	--	<1	<3	<1	<10
16	450238093000401	05-12-80	<1	<50	25	--	<1	<3	<1	<10
17	450039092594501	05-14-80	<1	90	110	--	<1	<3	<1	<10
20	445124093270801	05-20-80	1	70	190	--	<1	<3	8	<10
22	445153093202102	05-20-80	1	240	150	--	<1	<3	7.9	<10
23	444825093125001	05-22-80	2	80	190	--	<1	<3	<1	--
24	445348093022901	05-21-80	<1	80	53	--	<1	<3	<1	<10
25	444227093125201	05-21-80	<1	110	120	--	--	--	--	--
27	443849093143601	01-30-80	2	400	17	--	<1	<3	<1	<10
28	443806093085901	05-21-80	<1	70	91	--	<1	<3	<1	<10
35	442648093091301	05-21-80	<1	90	50	--	<1	<3	<1	<10
36	441851093341801	09-03-80	1	30	110	--	10	<3	--	<10
37	441454092101001	02-12-80	<1	<50	57	--	<1	<3	1	<10
42	435542093570501	02-29-80	5	20	46	--	<1	<3	1	<10
43	434547094095802	01-29-80	6	270	47	--	<1	<3	<1	<10
44	434601094010001	02-29-80	6	20	44	--	<1	<3	<1	<10
46	435333092503901	09-02-80	1	90	80	--	10	<3	<1	30
47	434221092341701	05-07-80	<1	120	48	--	<1	<3	<1	<10
48	434235092340201	05-07-80	1	80	44	--	<1	<3	--	<10
49	434242092160503	05-06-80	<1	<50	35	--	<1	<3	<1	16
			Aquifer layer 3, Missouri							
161	402842092511801	04-07-81	0	2100	30	3.0	2	<3	--	0
162	400217091295201	04-07-81	0	3100	30	5.6	13	<3	--	0
163	391622091343301	04-06-81	0	2200	40	1.0	1	<3	--	0
164	383543092103001	04-06-81	0	320	100	.10	3	<3	--	0
			Aquifer layer 3, Wisconsin							
18	445910092331301	08-04-80	0	<20	20	.60	2	<3	--	<10
29	444504092473601	08-14-80	1	<20	20	.90	4	<3	--	<10
40	441849088051801	08-08-80	7	400	20	.90	4	<3	--	<10
74	432800091062501	11-10-81	0	<20	30	<.10	1	3	--	10
104	424423090552801	08-26-80	1	30	160	.40	4	<3	--	<10
106	430117090173201	08-27-80	1	30	30	.30	6	4	--	<10
107	430132090172601	08-27-80	1	30	30	.30	3	<3	--	<10
109	430136089274301	05-12-80	2	30	90	<.10	6	<3	--	<10
112	425245088274701	05-29-80	0	80	950	<.10	<1	<3	--	<10
113	425153088195501	10-21-82	--	--	150	--	--	--	--	--
114	424407090200001	08-26-80	1	30	40	.10	5	4	--	<10
115	424404089204701	09-04-80	1	80	40	.30	3	<3	--	<10
			Aquifer layer 4, Minnesota							
45	433615093403001	09-02-80	5	250	60	.10	11	<3	--	<10
			Aquifer layer 4, Wisconsin							
111	430618087571001	11-21-80	3	180	30	.30	2	<3	--	<10

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Fluoride, F (mg/L)	Iron, Fe	Lithium, Li	Manganese, Mn	Molybdenum, Mo	Lead, Pb	Selenium, Se	Strontium, Sr	Vanadium, Va	Beryllium, Be	Sulfide, S (mg/L)
					Aquifer layer 3, Minnesota						
6	.30	330	14	190	<10	<10	1	--	--	--	--
7	.20	1200	11	230	<10	<10	<1	--	--	--	--
8	.20	1200	6	<20	<10	<10	<1	--	--	--	--
9	.24	<50	6	320	<10	<10	1	--	--	--	--
10	.26	430	8	470	<10	--	<1	--	--	--	--
11	.18	<50	4	280	<10	<10	<1	--	--	--	--
12	.20	<50	3	320	<10	<10	<1	--	--	--	--
13	--	--	3	--	<10	<10	<1	--	--	--	--
14	.27	640	7	30	<10	<10	<1	--	--	--	--
15	.18	<50	2	70	<10	<10	<1	--	--	--	--
16	.19	50	4	<20	<10	<10	<1	--	--	--	--
17	.18	<50	2	<50	<1	--	<1	--	--	--	--
20	.18	590	5	70	3	<10	<1	--	--	--	--
22	.24	430	5	30	3	<10	<1	--	--	--	--
23	.12	<50	5	140	2	<10	<1	--	--	--	--
24	.12	<50	12	20	1	<10	2	--	--	--	--
25	.14	130	7	1000	<1	<10	<1	--	--	--	--
27	.15	1120	7	22	<1	<10	1	--	--	--	--
28	.12	200	5	40	2	<10	<1	--	--	--	--
35	.14	160	7	90	<10	<10	<1	--	--	--	--
36	.40	39	29	330	<10	44	<1	450	<6	<.7	--
37	.17	<50	5	<20	<1	<10	<1	--	--	--	--
42	.43	660	29	190	15	<10	3	--	--	--	--
43	.18	2200	29	200	2	<10	2	--	--	--	--
44	.28	2400	17	300	4	<10	2	--	--	--	--
46	.40	200	8	22	<10	51	1	320	<6	<.7	--
47	.37	320	8	20	<1	<10	<1	--	--	--	--
48	.40	150	8	20	1	<10	1	--	--	--	--
49	.24	240	3	20	<1	1	<1	--	--	--	--
					Aquifer layer 3, Missouri						
161	5.1	110	390	21	0	<10	<1	4500	0	<.7	--
162	4.7	12	680	19	0	25	<1	9300	0	<.7	--
163	2.7	140	230	9	0	<10	<1	2400	0	<.7	--
164	1.2	130	37	18	0	<10	<1	570	0	<.7	--
					Aquifer layer 3, Wisconsin						
18	.20	<3	<4	<1	<10	<10	<1	34	<6	<.7	<.1
29	.10	<3	<4	1	<10	14	<1	21	<6	2.0	<.1
40	1.3	2500	90	65	<10	18	<1	15000	<6	<.7	<.1
74	.10	6	4	1	10	10	<1	62	6	1.0	<.1
104	.20	<3	5	2	<10	13	<1	120	<6	<.7	<.1
106	.20	7	<4	1	<10	17	<1	50	<6	<.7	<.1
107	.10	45	<4	7	<10	<10	<1	15	<6	<.7	<.1
109	.10	14	<4	2	21	<10	<1	78	<6	<.7	--
112	.30	440	8	6	<10	<10	<1	1200	<6	<.7	.6
113	.30	120	4	21	--	--	--	1200	--	--	--
114	.20	3	<4	2	<10	<10	<1	58	<6	<.7	<.1
115	.10	59	<4	190	<10	<10	<1	58	<6	<.7	<.1
					Aquifer layer 4, Minnesota						
45	.30	210	22	100	<10	55	<1	190	<6	<.7	--
					Aquifer layer 4, Wisconsin						
111	.90	150	12	12	12	16	1	13000	<6	<1.0	.2

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of sample	Arsenic, As	Boron, B	Barium, Ba	Bromide, Br (mg/L)	Cadmium, Cd	Cobalt, Co	Chromium, Cr	Copper, Cu
					Aquifer layer 5, Iowa					
58	425526096210711	09-03-80	2	480	20	.60	6	<3	--	<10
60	431620095250511	09-03-80	3	280	20	.10	6	<3	--	13
81	430512095371801	02-23-82	<50	--	9	--	<2	--	<5	<10
82	425824095300901	02-23-82	<50	--	9	--	<2	--	<5	<10
83	430745094541101	02-23-82	<50	--	13	--	<2	--	<5	<10
85	424348095231601	04-15-80	<10	--	<100	--	1	--	<1	<10
86	424348095231602	09-04-80	2	150	30	<.10	4	<3	--	<10
87	423618095194511	09-04-80	10	340	30	.20	6	6	--	<10
89	422950095174301	02-22-82	<50	--	8	--	<2	--	<5	<10
90	422009095210101	02-22-82	<50	--	10	--	<2	--	<5	<10
					Aquifer layer 5, Minnesota					
2	462710092454001	02-21-80	<1	120	49	--	<1	<3	<1	<10
26	443710093453501	09-03-80	5	220	70	.40	9	<3	--	<10
41	440026094355401	09-03-80	9	110	160	<.10	11	<3	--	<10

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TABLE 2.—*Chemical analyses of selected trace constituents in water from wells sampled for this study*—Continued

[Results in micrograms per liter, except as indicated. Analyses by U.S. Geological Survey, except Minnesota analyses by Minnesota Department of Health. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Fluoride, F (mg/L)	Iron, Fe	Lithium, Li	Manganese, Mn	Molybdenum, Mo	Lead, Pb	Selenium, Se	Strontium, Sr	Vanadium, Va	Beryllium, Be	Sulfide, S (mg/L)
					Aquifer layer 5, Iowa						
58	.80	140	170	230	<10	22	<1	4300	<6	<.7	--
60	.30	78	110	720	<10	28	<1	2600	<6	<.7	--
81	--	1400	--	--	--	--	<5	--	--	--	<.1
82	.57	2500	--	640	--	<50	<5	--	--	--	<.1
83	.36	4200	--	270	--	<50	<5	--	--	--	<.1
85	2.0	30	--	130	--	<10	<10	--	--	--	--
86	.40	34	33	210	<10	20	<1	770	<6	<.7	--
87	.50	27	45	220	<10	20	<1	1100	<6	<.7	--
89	.43	71	--	2600	--	<50	<5	--	--	--	<.1
90	.82	2900	--	460	--	<50	<5	--	--	--	<.1
					Aquifer layer 5, Minnesota						
2	.15	<0	6	<0	<1	<10	3	--	--	--	--
26	.30	1500	20	710	<10	34	0	370	<6	<.7	--
41	.20	1800	17	320	<10	34	1	240	<6	<.7	--

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TABLE 3.—*Analyses of stable isotopes, uranium, and radium-226 in water from selected wells sampled for this study*

[Analyses by U.S. Geological Survey. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Stable isotope ratios (permil) $\delta^{18}O$	δD	$\delta^{13}C$	$\delta^{34}S$	Uranium, U (µg/L)	Radium-226, Ra (pCi/L)	Carbon-14 (percent modern)
			Aquifer layer 1, Illinois						
118	422418090255501	10-23-80	-8.4	-54.0	--	--	<.6	1.1	--
130	422803087475303	12-10-80	-9.3	-63.0	--	8.7	<.6	6.9	--
131	422803087475304	01-14-81	-9.0	-57.5	--	--	28.9	99	--
			Aquifer layer 1, Iowa						
71	432953091172001	06-24-80	-8.4	-55.0	-11.7	--	<.3	1.4	--
73	432206091130301	06-10-80	-8.8	-54.5	-11.3	--	.5	2.0	--
102	430240091110001	06-09-80	-9.2	-56.5	-10.0	--	<.5	2.0	--
119	420842090165702	05-15-81	-8.4	-58.0	-11.1	--	<.6	2.2	--
			Aquifer layer 1, Minnesota						
1	461209093550701	02-21-80	--	--	--	--	<.6	1.7	--
19	445704093215611	09-04-80	-9.6	-64.5	-13.2	--	<.5	2.8	--
30	443354092323201	02-12-80	-10.0	-67.0	-9.9	--	<.6	5.5	--
32	443300092302901	02-12-80	-10.2	-68.0	-10.2	--	<.6	11	--
51	440324091401501	02-13-80	-9.2	-60.5	-12.4	--	<.5	4.6	--
52	440318091388180	02-13-80	-9.5	-61.5	-12.5	--	<.6	2.8	--
			Aquifer layer 1, Wisconsin						
33	443436091281401	08-06-80	-9.2	-65.5	-14.4	--	<.6	.2	--
34	443841090393001	08-20-80	--	--	--	--	<.6	.4	--
38	442141091185601	08-13-80	-9.2	-63.0	-12.3	--	<.7	.5	--
39	442045090453601	08-20-80	--	--	--	--	<.6	.3	--
54	435743089485701	08-21-80	-9.4	-62.5	-14.2	--	2.0	.5	--
55	440219088555701	08-19-80	--	--	--	--	3.7	.5	--
56	434312090353901	08-22-80	--	--	--	--	<.5	.2	--
57	433921091132101	10-08-81	--	--	--	--	<.6	2.2	--
75	432336090460601	08-28-80	--	--	--	--	<.6	.9	--
76	432042090231701	08-28-80	--	--	--	--	<.6	.7	--
77	433144089595901	09-05-80	--	--	--	--	<.6	.5	--
78	433220089282601	09-05-80	--	--	--	--	<.6	.2	--
79	431849089311002	07-24-80	-8.8	-60.0	-8.2	--	.9	<.1	--
80	432717088501701	09-05-80	--	--	--	--	<.6	5.9	--
103	425246091042101	08-19-81	-8.6	-56.5	-11.0	--	.7	2.8	--
105	431108090263101	08-29-80	--	--	--	--	<.5	1.7	--
108	430055089534001	07-18-80	--	--	--	--	.7	.8	--
109	430136089274301	05-12-80	-9.4	-60.0	-13.1	--	22	<.1	--
110	430058089251401	07-22-80	-8.8	-51.0	-8.6	--	.8	1.2	--
			Aquifer layer 3, Illinois						
120	422606089434501	08-29-80	-7.4	-47.5	-8.4	--	--	--	--
121	421331089442201	08-29-80	-8.0	-50.5	-12.6	--	<.6	13	--
122	421658089235101	08-20-80	-8.4	-52.5	--	--	--	--	--
123	422738089114601	08-23-80	-8.8	-58.0	-14.0	--	<.6	.1	--
124	422545089103301	08-23-80	-8.6	-56.0	-12.3	--	<.6	.1	--
125	421855089121601	08-23-80	-7.4	-49.5	-7.3	--	<.6	.8	--
126	421614089062301	09-03-80	-8.4	-54.5	-14.0	--	.9	.5	--
127	420953089080501	09-05-80	-7.4	-46.0	-8.2	--	--	--	--
128	421025088564401	09-04-80	--	--	-7.9	--	--	--	--
129	421329088531701	09-05-80	-8.4	-51.5	-9.4	--	--	--	--
132	422803087475306	09-01-81	-9.6	-68.5	--	15.5	.7	6.0	--
133	415632088071201	06-21-80	-8.9	-64.0	-14.6	--	<1.6	2.7	--
135	413847088214801	08-27-80	-9.5	-61.5	-11.8	--	<.6	2.2	--
136	411858088363401	08-28-80	-9.0	-60.5	-10.6	--	--	--	--
137	411933089403701	08-28-80	-9.4	-61.5	-11.3	--	<.6	5.8	--

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TABLE 3—*Analyses of stable isotopes, uranium, and radium-226 in water from selected wells sampled for this study*—Continued

[Analyses by U.S. Geological Survey. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Stable isotope ratios (permil) $\delta^{18}O$	δD	$\delta^{13}C$	$\delta^{34}S$	Uranium, U (µg/L)	Radium-226, Ra (pCi/L)	Carbon-14 (percent modern)
			Aquifer layer 3, Iowa						
59	431620095250201	09-03-80	-10.2	-71.5	-17.2	--	3.7	2.7	--
61	432412094503301	09-09-81	-9.4	-68.5	-13.8	-10.0	2.6	5.8	--
62	431750094303001	09-08-81	-9.0	-64.5	-16.0	-9.9	<.6	1.9	--
63	432256094183301	06-25-80	--	--	--	--	.6	1.6	--
64	431350093544201	06-25-80	-6.3	-45.5	-11.2	--	<.6	1.2	--
65	430800092540301	06-26-80	--	--	--	--	<.5	2.0	--
66	432650092170201	06-24-80	--	--	--	--	<.5	.4	--
67	430337092190701	06-25-80	-8.3	-54.5	-10.2	--	.4	1.1	--
68	431216091572001	06-23-80	-9.2	-54.0	-10.6	--	.8	.3	--
69	432606091470301	06-23-80	--	--	--	--	.9	<.1	--
70	432800091295301	06-24-80	-8.9	-59.5	-10.0	--	.7	<.1	--
72	431638091284102	06-24-80	--	--	--	--	.5	.2	--
84	430210094500001	09-08-81	-9.9	-70.0	-18.8	-8.5	<.7	.4	--
88	423840095135001	09-04-80	--	--	--	--	.7	8.0	--
		09-08-81	-10.8	-78.5	-14.7	-9.2	--	--	--
91	421831095152101	09-04-80	-12.0	-87.0	-12.5	-1.1	.6	7.3	1.5
92	422339094375101	09-02-80	--	--	-10.1	-4.4	1.2	5.0	--
93	422136094173401	09-05-80	-12.3	--	--	-1.0	1.1	9.1	--
94	422855093481501	09-02-80	-10.0	-70.0	-11.4	--	1.2	6.5	<0.7
95	422611092552501	09-02-80	--	--	--	--	.7	3.6	--
96	425049092063801	06-11-80	--	--	--	--	.5	2.4	--
97	425708091383001	06-10-80	--	--	--	--	2.4	.6	--
98	424820091324001	06-09-80	-8.6	-54.0	-10.0	--	4.9	.8	--
99	425138091234901	06-09-80	-9.0	-54.5	-11.2	--	<.5	1.8	--
100	425550091233001	06-09-80	--	--	--	--	.4	1.7	--
101	430330091264301	06-24-80	--	--	--	--	1.4	1.4	--
116	423141090385801	08-26-81	-8.2	-54.5	-11.2	3.9	.8	2.0	--
117	422640091002701	08-26-81	-8.8	-61.5	-10.2	-8.4	<.6	1.8	--
138	421010092180301	06-23-80	--	--	-10.1	--	1.1	2.7	--
139	420200091363001	07-21-80	-10.0	-66.0	-10.1	--	<7.0	2.8	3.7
140	420718091165401	07-23-80	--	--	--	--	1.6	1.8	--
141	412407095391201	09-02-81	-17.1	-131.0	-7.3	11.8	<.6	6.2	--
142	413015094391302	09-02-81	-17.1	-132.0	-6.9	13.6	<.5	12	--
143	415021094072801	09-02-81	-13.6	-103.0	-8.6	6.5	.7	9.4	--
144	413931093292001	09-01-81	--	--	-8.9	--	<.6	6.5	--
		09-08-81	-8.6	-61.0	-9.2	2.5	--	--	--
145	414430092433001	09-01-81	-9.9	-72.5	-9.3	1.8	<1.1	3.2	--
146	412736093241201	07-30-81	--	--	--	--	<.6	3.3	--
147	412025093322201	06-10-81	-9.6	-64.5	-9.0	6.6	<.5	4.7	4.2
148	410235093564901	06-10-81	-14.7	-109.0	-8.1	-2.0	<.5	13	2.6
149	404422093445602	07-28-81	-16.5	-124.0	-7.7	16.2	<.6	7.1	--
150	405858093175701	06-10-81	-10.3	-72.0	-8.9	-4.6	<.5	5.8	--
151	411332093142101	06-10-81	--	--	--	--	<.6	3.9	--
152	412020092471001	08-12-81	--	--	--	--	<.6	9.0	--
153	410305092490701	07-28-81	--	--	--	--	<.5	11	--
154	412356092211001	07-30-81	--	--	--	--	.9	17	--
155	405750092142001	06-09-81	-12.1	-88.5	-9.3	7.7	1.2	16	5.4
156	410115091571801	06-09-81	--	--	--	--	1.3	9.6	--
157	411812091412601	08-05-80	--	--	--	--	<.5	7.1	--
158	411907091220001	10-29-80	-19.4	-86.5	-10.6	--	<1.6	8.2	--
160	403839091333801	08-05-80	--	--	--	--	.9	9.9	--
			Aquifer layer 3, Minnesota						
36	441851093341801	09-03-80	-7.6	-54.5	-12.4	--	3.1	.4	--
37	441454092101001	02-12-80	-9.5	-62.5	-9.0	--	1.2	.3	--
43	434547094095802	01-29-80	-10.2	-70.0	--	--	1.0	3.7	--
46	435333092503901	09-02-80	-9.0	-59.0	-11.4	--	<.5	.8	--

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TABLE 3—*Analyses of stable isotopes, uranium, and radium-226 in water from selected wells sampled for this study*—Continued

[Analyses by U.S. Geological Survey. Map number is location in figure 6. Site identification number is the well label in the U.S. Geological Survey WATSTORE data base]

Map no.	Site identification number	Date of collection	Stable isotope ratios (permil) $\delta^{18}O$	δD	$\delta^{13}C$	$\delta^{34}S$	Uranium, U (µg/L)	Radium-226, Ra (pCi/L)	Carbon-14 (percent modern)
			Aquifer layer 3, Missouri						
161	402842092511801	04-07-81	-13.9	-104.0	-6.2	--	<.6	3.3	--
162	400217091295201	04-07-81	-14.8	-112.0	-6.1	--	<.6	31	--
163	391622091343301	04-06-81	-7.2	-49.0	-7.6	--	1.9	3.4	--
164	383543092103001	04-06-81	-7.0	-46.0	-9.0	--	.8	2.1	--
			Aquifer layer 3, Wisconsin						
18	445910092331301	08-04-80	-10.5	--	-13.4	--	<.6	<.1	--
29	444504092473601	08-14-80	-9.4	--	-6.2	--	1.5	.5	--
40	441849088051801	08-08-80	-14.0	-98.0	-12.6	--	1.4	8.9	--
74	432800091062501	11-10-81	--	--	--	--	<.6	<.1	--
104	424423090552801	08-26-80	--	--	--	--	.9	<.1	--
106	430117090173201	08-27-80	-9.0	-59.0	-10.7	--	<.5	<.1	--
107	430132090172601	08-27-80	--	--	-6.2	--	<.6	.2	--
112	425245088274701	05-29-80	-8.6	-56.5	-9.0	--	<.5	3.3	--
113	425153088195501	10-21-82	--	--	--	--	--	3.0	--
114	424407090200001	08-26-80	--	--	-6.1	--	1.0	.5	--
115	424404089204701	09-04-80	-9.2	-62.0	-13.0	--	<.6	.1	--
			Aquifer layer 4, Minnesota						
45	433615093403001	09-02-80	-9.6	-63.0	-14.4	--	1.2	.3	--
			Aquifer layer 4, Wisconsin						
111	430618087571001	11-21-80	--	--	--	--	.8	.3	--
			Aquifer layer 5, Iowa						
58	425526096210711	09-03-80	--	--	--	--	<.5	.8	--
60	431620095250511	09-03-80	--	--	--	--	1.6	.8	--
81	430512095371801	02-23-82	--	--	--	-7.5	--	--	--
82	425824095300901	02-23-82	--	--	--	-10.0	--	--	--
83	430745094541101	02-23-82	--	--	--	-7.5	--	--	--
85	424348095231601	09-04-80	-8.1	-55.5	-14.2	--	<.5	.1	--
86	424348095231602	09-04-80	-8.6	-57.5	-7.6	--	6.1	.1	--
87	423618095194511	09-04-80	--	--	--	--	1.3	.3	--
89	422950095174301	02-22-82	--	--	--	-8.0	--	--	--
90	422009095210101	02-22-82	--	--	--	-10.8	--	--	--
			Aquifer layer 5, Minnesota						
2	462710092454001	02-20-80	--	--	--	--	1.1	.1	--
26	443710093453501	09-03-80	-7.8	-55.5	-13.8	--	3.2	.2	--
41	440026094355401	09-03-80	-9.5	-67.0	-10.2	--	<.6	.2	--

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JOHN C. FRYE, Chief
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GEOLOGIC MAP OF ILLINOIS

COMPILED BY
H. B. WILLMAN AND OTHERS

1967

SOUTHERN

NORTHERN

STRUCTURE ON TOP OF GALENA GROUP AND INDEX TO CROSS-SECTIONS

EXPLANATION

GLACIAL MAP

THICKNESS OF SUPERFICIAL DEPOSITS

SUB-ST. PETER GEOLOGIC MAP

SUB-MIDDLE AND UPPER DEVONIAN GEOLOGIC MAP

SUB-PENNSYLVANIAN GEOLOGIC MAP

C-C' EAST-WEST CROSS-SECTION BELLEVILLE TO CARMI

A-A' NORTH-SOUTH CROSS-SECTION CAIRO TO ROCKFORD

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J. E. LAMAR, B.S., *Geologist*
L. D. MCVICKER, B.S., *Chemist*
ENID TOWNLEY, M.S., *Geologist*
LESTER L. WHITING, M.S., *Geologist*
H. B. WILLMAN, PH.D., *Geologist*
JUANITA WITTERS, M.S., *Physicist*
G. ROBERT YOHE, PH.D., *Senior Chemist*
KENNETH E. CLEGG, M.S., *Associate Geologist*
WILLIS L. BUSCH, A.B., *Economic Analyst*

RESEARCH AFFILIATES AND CONSULTANTS

RICHARD C. ANDERSON, PH.D., *Augustana College*
DAVID A. CASTILLON, PH.D., *Southwest Missouri State Univ.*
JOHN P. FORD, PH.D., *Eastern Illinois University*
DONALD L. GRAF, PH.D., *University of Illinois*
S. E. HARRIS, JR., PH.D., *Southern Illinois University*
W. HILTON JOHNSON, PH.D., *University of Illinois*
HARRY V. LELAND, PH.D., *University of Illinois*
A. BYRON LEONARD, PH.D., *University of Kansas*
LYLE D. MCGINNIS, PH.D., *Northern Illinois University*
L. EDGAR ODOM, PH.D., *Northern Illinois University*
T. K. SEARIGHT, PH.D., *Illinois State University*
GEORGE W. WHITE, PH.D., *University of Illinois*

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HANDBOOK OF ILLINOIS STRATIGRAPHY

H. B. Willman, Elwood Atherton, T. C. Buschbach,

Charles Collinson, John C. Frye, M. E. Hopkins,

Jerry A. Lineback, and Jack A. Simon

ABSTRACT

This handbook describes briefly the 730 stratigraphic units that are named in Illinois. It contains references to original and more recent descriptions, charts showing the development of the stratigraphic classifications, and maps indicating the distribution, thickness, and structure of many units.

Precambrian rocks are not exposed in Illinois and have been encountered in only a few deep borings. However, Paleozoic rocks as much as 14,000 feet thick occur in Illinois, and all Paleozoic systems except the Permian are represented and well exposed. The type region of the Mississippian System is along the Mississippi Valley in Illinois, Iowa, and Missouri. The Mesozoic Era is represented in Illinois only by the Cretaceous System, which is present in the Mississippi Embayment area in extreme southern Illinois and locally in western Illinois. Both the Tertiary and Quaternary Systems of the Cenozoic Era are represented. Tertiary rocks occur in southern Illinois and in small, widely separated patches elsewhere; Quaternary rocks, which include the Pleistocene glacial deposits, are found almost everywhere in the state.

INTRODUCTION

Although it is regarded as a flat prairie state, the boundaries of three-fourths of Illinois are the deep valleys of the Mississippi, Ohio, and Wabash Rivers. These rivers and their tributaries have deeply entrenched themselves into the prairie, in many places exposing a variety of rock formations in the steep valley slopes. With the exception of intrusive igneous rocks in extreme southern Illinois, the exposed rocks are all sedimentary.

The branch of geology that describes the sequence of the layered rocks is called stratigraphy. It enables geologists and others to determine the position of a rock exposure (or of a sample from a boring) in the sequence, thus in effect establishing the age of the rock. The order, distribution, and composition of the rocks in Illinois have been studied since the days of the early settlers. After nearly 150 years of investigations, some 730 stratigraphic

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ERA, ERATHEM	PERIOD, SYSTEM	EPOCH, SERIES	ORIGIN AND CHARACTER	GREATEST THICKNESS (ft)[1]	AGE (millions of years)[2]
CENOZOIC	QUATERNARY	PLEISTOCENE	Continental — glacial, river and stream, wind, lake, swamp, and colluvial deposits and soils	600	
			Major unconformity		1.5
	TERTIARY	PLIOCENE	Continental — river deposits, mostly gravel, some sand	50	
			Major unconformity		7
		EOCENE	Deltaic — mostly sand, some silt	300	
		PALEOCENE	Marine — mostly clay, same sand	150	
			Unconformity		64-65
MESOZOIC	CRETACEOUS	GULFIAN	Deltaic and nearshore marine — sand, some silt and clay, locally lignitic	500	
			Major unconformity		125[3] / 136[4] / 225[5] / 280[6]
PALEOZOIC	PENNSYLVANIAN	VIRGILIAN, MISSOURIAN, DESMOINESIAN, ATOKAN, MORROWAN	Marine, deltaic, continental — cyclical deposits, mostly shale, sandstone, and siltstone with some limestone, coal, clay, black sheety shale; sandstone dominant in lower part, shale above; coal most prominent in middle part, limestone in upper part	3000	
			Major unconformity		315[7]
	MISSISSIPPIAN	CHESTERIAN	Marine, deltaic — cyclical deposits of limestone, sandstone, shale	1400	
		VALMEYERAN	Marine, deltaic — limestone, siltstone, shale, chert, sandstone	2000	
		KINDERHOOKIAN	Marine — shale, limestone, siltstone	150	345
	DEVONIAN	UPPER	Marine — shale, limestone	300	
			Unconformity		
		MIDDLE	Marine — largely limestone, some shale	450	
			Major unconformity		
		LOWER	Marine — cherty limestone, chert	1300	395
	SILURIAN	CAYUGAN	Marine — shale, siltstone, limestone	100	
		NIAGARAN	Marine — dolomite, limestone, shale, local reefs	1000	
		ALEXANDRIAN	Marine — dolomite, limestone, shale	150	
			Unconformity		430-440
	ORDOVICIAN	CINCINNATIAN	Marine — shale, limestone, siltstone, dolomite	300	
			Unconformity		
		CHAMPLAINIAN	Marine — limestone, dolomite, sandstone	1400	
			Major unconformity		
		CANADIAN	Marine — dolomite, sandstone	1000	500
	CAMBRIAN	CROIXAN	Marine — sandstone, dolomite, shale	4000	
			Major unconformity		525[8] / 570[9]
PRECAMBRIAN			Intrusive igneous rocks — mostly granite		

[1] Greatest thickness in one locality.

[2] Radiometric age of beginning of interval. (After Harland [1964] and others. Estimates from chart by Van Eysinga [1972].)

[3] Beginning of Gulfian (est.).

[4] Beginning of Cretaceous.

[5] Beginning of Mesozoic.

[6] End of Pennsylvanian.

[7] Beginning of Pennsylvanian (est.).

[8] Beginning of Croixan (est.).

[9] Beginning of Cambrian.

Fig. 1—Summary of the age, origin, and thickness of Illinois rocks.

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names are currently used in Illinois. Most of these units have been named in the past 50 years, and more will be named in future studies. However, no new stratigraphic names are introduced in this handbook.

The handbook is designed as a guide to the stratigraphic classification of the rocks of Illinois. It includes brief descriptions of all units now recognized by the Illinois State Geological Survey, as well as references to more extensive descriptions in other publications. More complete lists of references to these units and to the many abandoned stratigraphic names encountered in the literature can be found in Illinois State Geological Survey Bulletin 92, *Bibliography and Index of Illinois Geology Through 1965.*

Knowledge of the stratigraphic sequence of the rocks of Illinois (fig. 1) has been of great value in the search for and the development of the mineral resources of the state. Many of the rock formations have been the source of the limestone, dolomite, gravel, sand, and clay used in highway and building construction and for industrial and agricultural purposes. Illinois formations have produced, and still contain, large resources of coal and oil, as well as important but more limited resources of fluorspar, zinc, lead, and other minerals. They are also a major source of water.

In recent years, the requirements of a rapidly expanding population have brought about the general realization that mineral resources are exhaustible. The wise use and care of the air, sea, and land, and the rocks that underlie them have become necessary to assure a favorable environment and to prolong the availability of the raw materials needed for modern life.

The Stratigraphers

The foundations of stratigraphic geology in Illinois go back to the 1830s when the state contained only about 200,000 people, most of them settled along the major valleys in the southern half of the state. Modern geological literature seldom acknowledges the geologists of that time, who on foot, by boat, and later by horse and buggy, explored unknown and often dangerous areas. Their contributions are briefly summarized here, along with those of noted geologists active before the 1930s (fig. 2).

The observations of the early travelers largely concerned minerals, soils, and topography, but H. R. Schoolcraft (1825) and C. U. Shepard (1838) described some stratigraphic features (White and Slanker, 1962; White, 1969). One of the first to make significant observations about the nature, sequence, and ages of the rocks of Illinois was David Dale Owen, a geologist from New Harmony, Indiana, who in the late 1830s was commissioned by the Federal Government to explore the geology of parts of Iowa, Wisconsin, and Illinois. He correctly identified the ages of many formations exposed along the Ohio and Mississippi Rivers.

In the 1840s, James Hall of the New York State Geological Survey correlated, largely on the basis of fossils, many of the rock units in the Mississippi Valley with the New York section, which had become the American standard reference section. Hall prepared a geologic map (fig. 3), which, in spite of scanty information, brought out some of the prominent features of the bedrock geology of Illinois, including the basin-like configuration of the rock formations.

In 1851 the Illinois State Legislature authorized a geological survey of the state, and J. G. Norwood was appointed the first State Geologist of Illinois. No official reports were published during Norwood's tenure (1851 to 1858), although he published several papers on Carboniferous fossils. The geology of the state was still largely unknown in 1858 when A. H. Worthen was appointed Director of the Geological Survey of Illinois. Worthen and his associates—H. M. Bannister, F. H. Bradley, G. C. Broadhead, E. T. Cox, Henry Engelmann, H. C. Freeman, H. A. Green, and James Shaw—surveyed the entire state and, between 1866 and 1875, published reports on every county except De Witt in five large volumes (fig. 4). They discovered and traced throughout the state, with remarkably few errors, nearly all the major units now recognized. These five volumes and an additional three volumes contain descriptions of numerous fossils, many of them new species, by Worthen and leading paleontologists of the day—Leo Lesquereux on plants, F. B. Meek and S. A. Miller on invertebrates, J. S. Newberry on vertebrates, Orestes St. John on fishes, S. H. Scudder on insects, E. O. Ulrich on bryozoans, and Charles Wachsmuth and Frank Springer on crinoids and blastoids.

Worthen's 1875 geologic map of Illinois (fig. 5) showed how enormously knowledge of the stratigraphy of Illinois had expanded in the 32 years since Hall's map. Later geologic maps (Stuart Weller, 1906a, 1907; DeWolf et al., 1917; J. Marvin Weller et al., 1945; and Willman et al., 1967) have added many details (figs. 6, 10) but have not greatly altered

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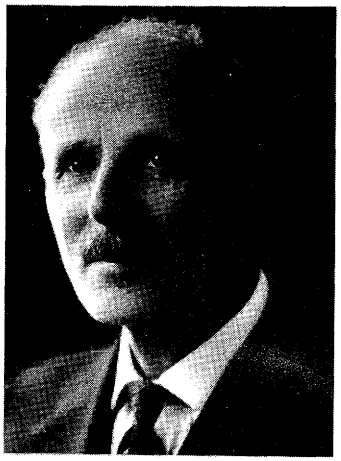
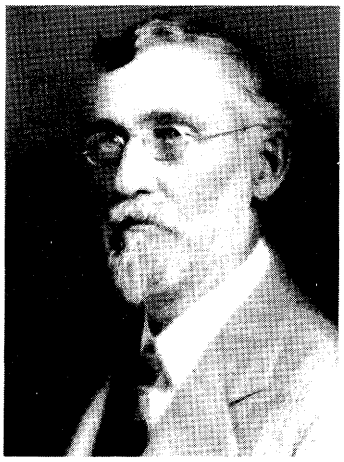
Amos H. Worthen
1813-1888



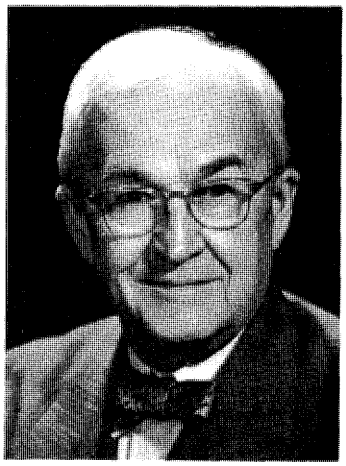
Stuart Weller
1871-1927



Thomas E. Savage
1866-1947



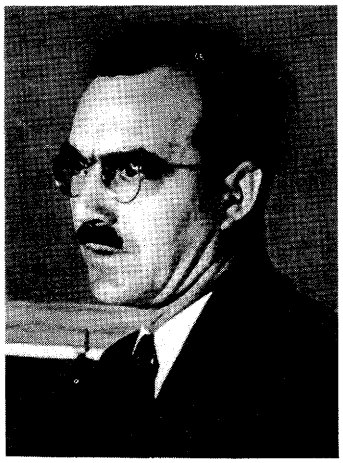
Frank Leverett
1859-1943



Gilbert H. Cady
1882-1970



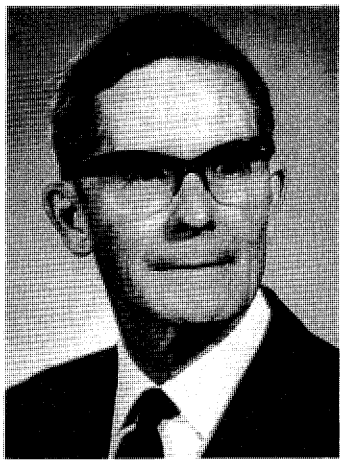
Morris M. Leighton
1887-1971



J. Marvin Weller
1899-



Harold R. Wanless
1898-1970



Lewis E. Workman
1899-

Fig. 2—Major contributors to the stratigraphy of Illinois.

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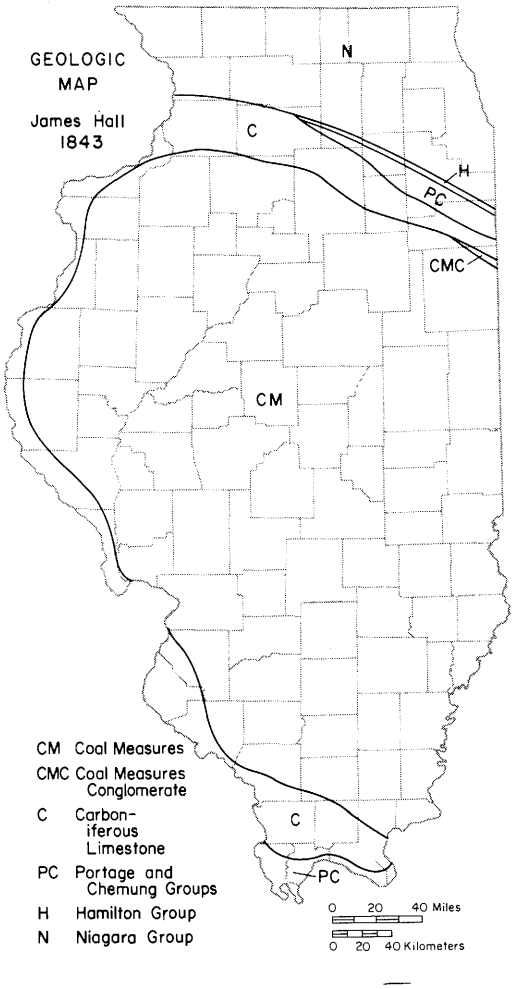

Fig. 3—Geologic map of Illinois by James Hall (1843).

the distribution of the major stratigraphic units shown by Worthen. One of Worthen's major contributions was the tracing, with only a few errors, of the major coal seams, to which he assigned numbers that are still used. On the other hand, he maintained that the drift—the bouldery surface clays—had been deposited in a sea into which the boulders had been carried by icebergs. He persisted in this belief after some American geologists, including some of Worthen's own staff, interpreted the drift as deposits left by glaciers that had advanced from the northern regions and covered much of the Midwest north of the Ohio and Missouri Rivers. In common with most other geologists of his time, Worthen thought the loess, too, was a water deposit. The Worthen Survey reports are still a source of much basic stratigraphic data, however, and contain information about localities that are no longer accessible.

In the latter part of the 19th century, the glacial origin of the drift and the wind deposition of the loess were increasingly accepted in Illinois, as is demonstrated by the studies of T. C. Chamberlin, Johan Udden, and Frank Leverett. Leverett's work in the 1890s, including his 1899 monograph on the Illinois Glacial Lobe, established the classification of the Pleistocene Series, based on glacial and interglacial stages, that is still used in Illinois.

The end of the 19th century and the early years of the 20th saw the beginning of stratigraphic studies by several geologists who made many important contributions to Illinois stratigraphy. Their work was stimulated by the formation of the new Illinois State Geological Survey in 1905—the original Survey had ceased to exist some years earlier. H. Foster Bain was appointed as director and was subsequently succeeded by F. W. DeWolf,

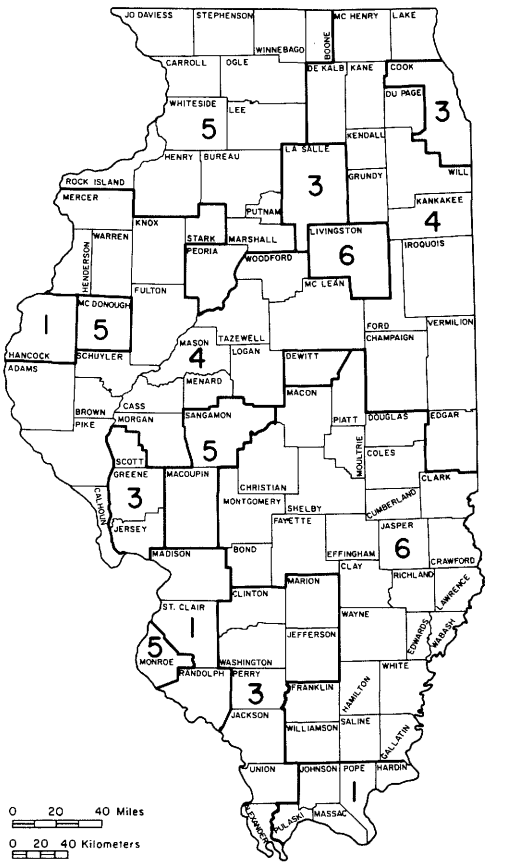

Fig. 4—Index to volumes issued by the Geological Survey of Illinois (Worthen Survey) in which individual counties are described.

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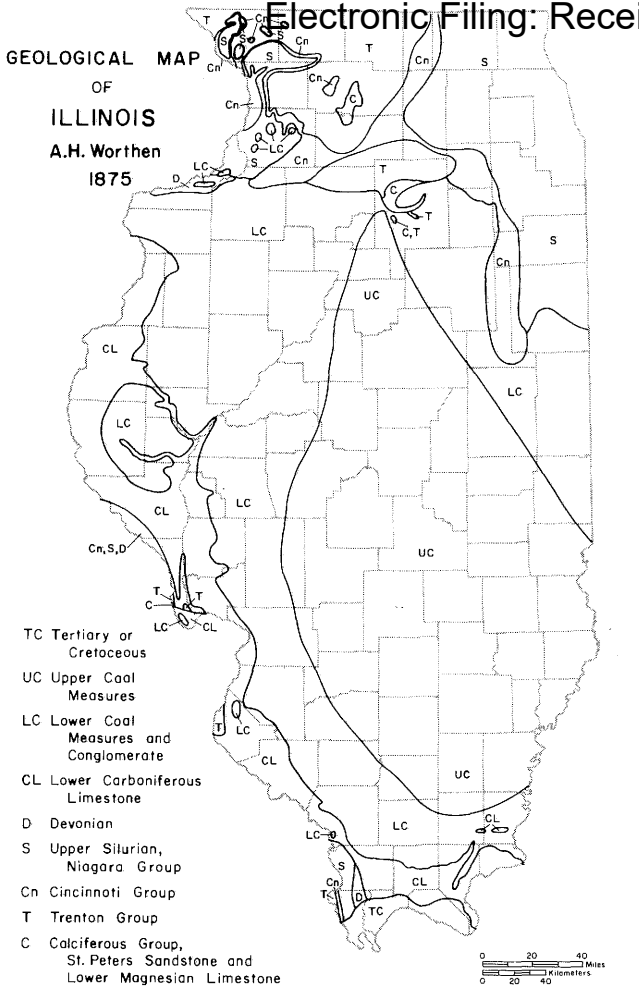

Fig. 5—Geologic map of Illinois by A. H. Worthen (1875).

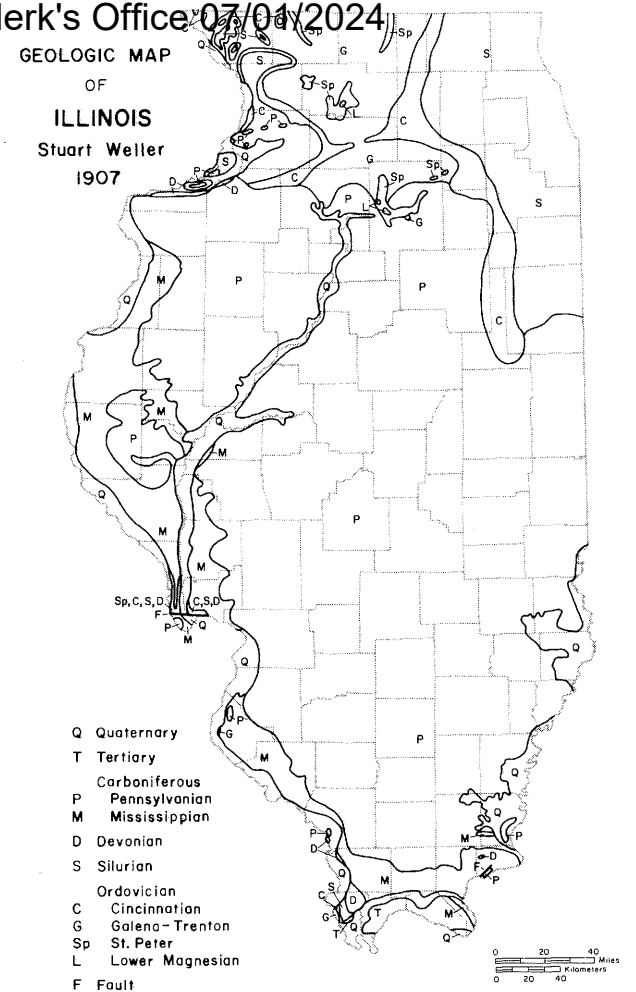

Fig. 6—Geologic map of Illinois by Stuart Weller (1907).

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who was later named chief. Among the outstanding geologists who worked for the Survey were G. H. Cady, whose studies for nearly 50 years were mainly of Pennsylvanian stratigraphy; T. E. Savage, an authority on Silurian stratigraphy who also contributed to Ordovician, Pennsylvanian, and Pleistocene stratigraphy; and Stuart Weller, who is best known for his studies of the Mississippian System but who also contributed to the Silurian and Devonian stratigraphy. Weller's geologic maps of Illinois in 1906 and 1907 (fig. 6) refined and added many details to the previous maps.

Before 1920, many geologists whose major interests were elsewhere made contributions to Illinois stratigraphy, including W. C. Alden, H. F. Bain, H. H. Barrows, R. S. Blatchley, Charles Butts, J. E. Carman, G. H. Cox, N. M. Fenneman, J. W. Goldthwait, O. H. Hershey, Henry Hinds, F. H. Kay, C. R. Keyes, R. D. Salisbury, E. W. Shaw, A. C. Trowbridge, Jon A. Udden, and E. O. Ulrich.

In the 1920s, studies of the Pleistocene were expanded under the direction of M. M. Leighton, who became Chief of the Illinois State Geological Survey in 1923. Leighton made many contributions to the classification of the glacial deposits and to knowledge of the buried soils. Associated with him during this time were F. C. Baker, J H. Bretz, George E. Ekblaw, Paul MacClintock, and others.

J. Marvin Weller and H. R. Wanless widely traced many thin units of the Pennsylvanian rocks in the state, and they emphasized the cyclical nature of the sediments. G. H. Cady continued studies of Pennsylvanian stratigraphy in an expanded program in coal geology and paleontology. Studies by A. C. Noé added greatly to the knowledge of Pennsylvanian plants. Weller and A. H. Sutton continued the Mississippian studies initiated by Weller's father, Stuart Weller. J. E. Lamar and A. H. Sutton described the Cretaceous and Tertiary strata in southern Illinois, and Lamar made a detailed study of the St. Peter Sandstone. L. E. Workman directed an expanded program in subsurface studies that added much to the knowledge of the entire stratigraphic column.

Many details of the distribution and character of the formations were added by studies of areal and economic geology, particularly by L. F. Athy, J. R. Ball, C. F. Bassett, A. H. Bell, A. C. Bevan, J H. Bretz, H. E. Culver, N. M. Fenneman, D. J. Fisher, R. S. Knappen, Frank Krey, J. E. Lamar, L. A. Mylius, J. N. Payne, W. W. Rubey, F. T. Thwaites, H. R. Wanless, and J. M. Weller.

Many of the above geologists continued stratigraphic studies after 1930, and they were joined by others who contributed significantly to Illinois stratigraphy. In addition to those still active in Illinois, the later stratigraphers included G. H. Emrich, G. O. Raasch, and J. S. Templeton (Cambrian); C. A. Bays, E. P. DuBois, A. M. Gutstadt, Paul Herbert, Jr., T. G. Perry, and Templeton (Ordovician); J. J. C. Ingels, H. A. Lowenstam, and C. A. Ross (Silurian); H. R. Schwalb and D. H. Swann (Devonian); G. V. Cohee, C. L. Cooper, C. G. Croneis, W. H. Easton, Tracey Gillette, C. B. Rexroad, A. J. Scott, Swann, and F. E. Tippie (Mississippian); K. E. Clegg, G. A. Desborough, C. O. Dunbar, L. G. Henbest, R. M. Kosanke, P. E. Potter, E. S. Richardson, Jr., J. M. Schopf, E. F. Taylor, and Raymond Siever (Pennsylvanian); Potter, W. A. Pryor, and Ross (Cretaceous-Tertiary); and J. A. Brophy, F. L. Doyle, H. E. Eveland, R. F. Flint, C. L. Horberg, W. E. Powers, P. R. Shaffer, F. L. Staplin, John Voss, and H. L. Wascher (Pleistocene).

The study of subsurface stratigraphy in Illinois received major impetus from the discovery of oil in the deeper parts of the Illinois Basin, from improved methods of geophysical logging, from extensive exploration for coal reserves, and from the search for geologic structures suitable for underground storage of natural gas. During these developments, many company geologists made contributions to Illinois stratigraphy.

Uses of Stratigraphy

An understanding of the nature and stratigraphic relations of the rocks on which we live is fundamental to progress in the various fields of applied geology—in the search for and the development of mineral resources needed to support life (economic geology), in the solution of many construction and excavation problems (engineering geology), and in effective management of the environment (environmental geology).

Stratigraphy is used to direct exploration for most minerals, to evaluate recovery methods, and to expedite production. In engineering geology, knowledge of the sequence of rocks, their character, and their variations is needed for selecting suitable sites for foundations, dams, highways, tunnels, underground storage of gas and liquid petroleum products, waste disposal, and many other projects. In environmental geology, which in effect includes all the applications of geology related

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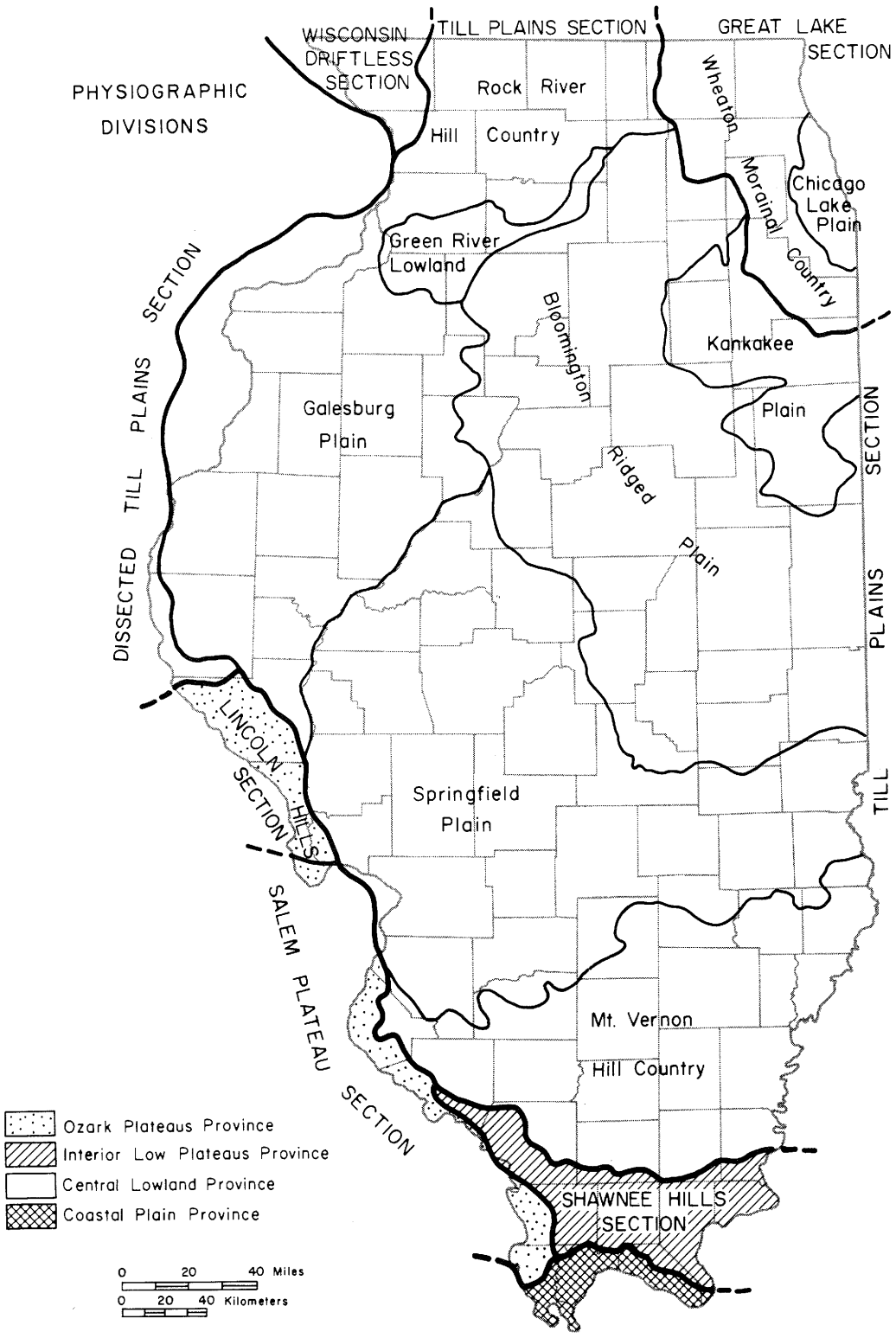

Fig. 7—Physiographic divisions of Illinois (after Leighton et al., 1948).

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TABLE 1—SOURCE ROCKS OF ILLINOIS MINERAL RESOURCES*

Pleistocene	Gravel, common sand, peat, molding sand, clay products
Tertiary	Fuller's earth, gravel
Cretaceous	Gravel
Pennsylvanian	Coal, crude oil, gas, clay and shale products, stone, building stone, portland cement
Mississippian	Crude oil, gas, stone, clay and shale products, building stone, fluorspar, zinc, lead, lime, whiting, rock wool†
Devonian	Crude oil, gas, stone, tripoli, ganister†, novaculite gravel†
Silurian	Crude oil, gas, stone, building stone, lime, deadburned dolomite, rock wool†
Ordovician	Crude oil, gas, stone, silica sand, portland cement, building stone, zinc, lead, natural cement†
Cambrian	Stone

*Ground water is produced from all systems.
†Not produced at present.

to man, stratigraphy is indispensible in regional planning, in effective use and preservation of mineral resources, in protection of water supplies, in selection of sites for waste disposal, and in many aspects of pollution control.

Illinois has abundant resources of the common rocks and minerals needed for building purposes, fuel for energy, water for domestic and industrial purposes, and soils for food production. Mineral resources that have been produced from the various systems of rocks are listed in table 1. Mineral production in Illinois in 1972, not including water, agricultural products, mineral products manufactured in Illinois, or mineral materials processed in Illinois, was valued at $701,242,000, and nine different mineral products had values exceeding $1,000,000 (table 2). According to the U.S. Bureau of Mines, Illinois ranked eleventh in the nation in mineral production in 1972.

TABLE 2—ILLINOIS MINERAL PRODUCTION IN 1972 (Malhotra, 1974)

Commodity	Quantity	Value (in thousands)
Coal	65,521,000 tons	$402,301
Crude oil	34,874,000 bbl	121,013
Natural gas	1,194,000 MMcf	334
Natural gas liquids	168,000 bbl	566
Common clays	1,610,000 tons	2,652
Refractory clays	106,000 tons	662
Fluorspar	132,405 tons	9,961
Gravel	17,734,000 tons	23,367
Sand - construction	17,023,000 tons	19,109
Sand - industrial	5,173,000 tons	19,218
Crushed and broken stone	56,260,000 tons	94,225
Lead	1.335 tons	401
Zinc	11,378 tons	4,039
Others*		3,393
Total $701,242,000		

* Including absorbent clays, dimension stone, tripoli, silver, peat, gem stones, and germanium, the values for which are withheld to avoid disclosing data from individual companies.

Geographic Setting

Illinois overlooks the confluences of several great rivers—the Mississippi, Ohio, Missouri, Illinois, Tennessee, Cumberland, and Wabash. The state is about 380 miles long and 210 miles in maximum width, and it extends from the Great Lakes to the Gulf Coastal Plain.

More than three-fourths of Illinois is in the Till Plains Section of the Central Lowland Province (fig. 7). The Till Plains Section in Illinois is subdivided into seven areas. Four are largely in Illinoian drift (Rock River Hill Country, Galesburg Plain, Springfield Plain, Mt. Vernon Hill Country), but only locally do they have prominent glacial topography; they differ principally in the nature of their preglaciation surface. Two others (Green River Lowland, Kankakee Plain) are lowland areas, large parts of which are covered by sand dunes. The seventh area (Bloomington Ridged Plain) has prominent glacial topography characteristic of Wisconsinan glaciation. The deeply dissected Wisconsin Driftless Section, the glaciated Great Lakes Section, and a small area of the Dissected Till Plains Section also belong to the Central Lowland Province. The Great Lakes Section includes the strongly morainal area of Wisconsinan drift bordering Lake Michigan (Wheaton Morainal Country) and the plain that was covered by Lake Chicago (Chicago Lake Plain).

Small parts of the Lincoln Hills and the Salem Plateau Sections of the Ozark Plateaus Province, which are prominent in Missouri, extend into Illinois along the Mississippi River. These areas are both deeply dissected, but

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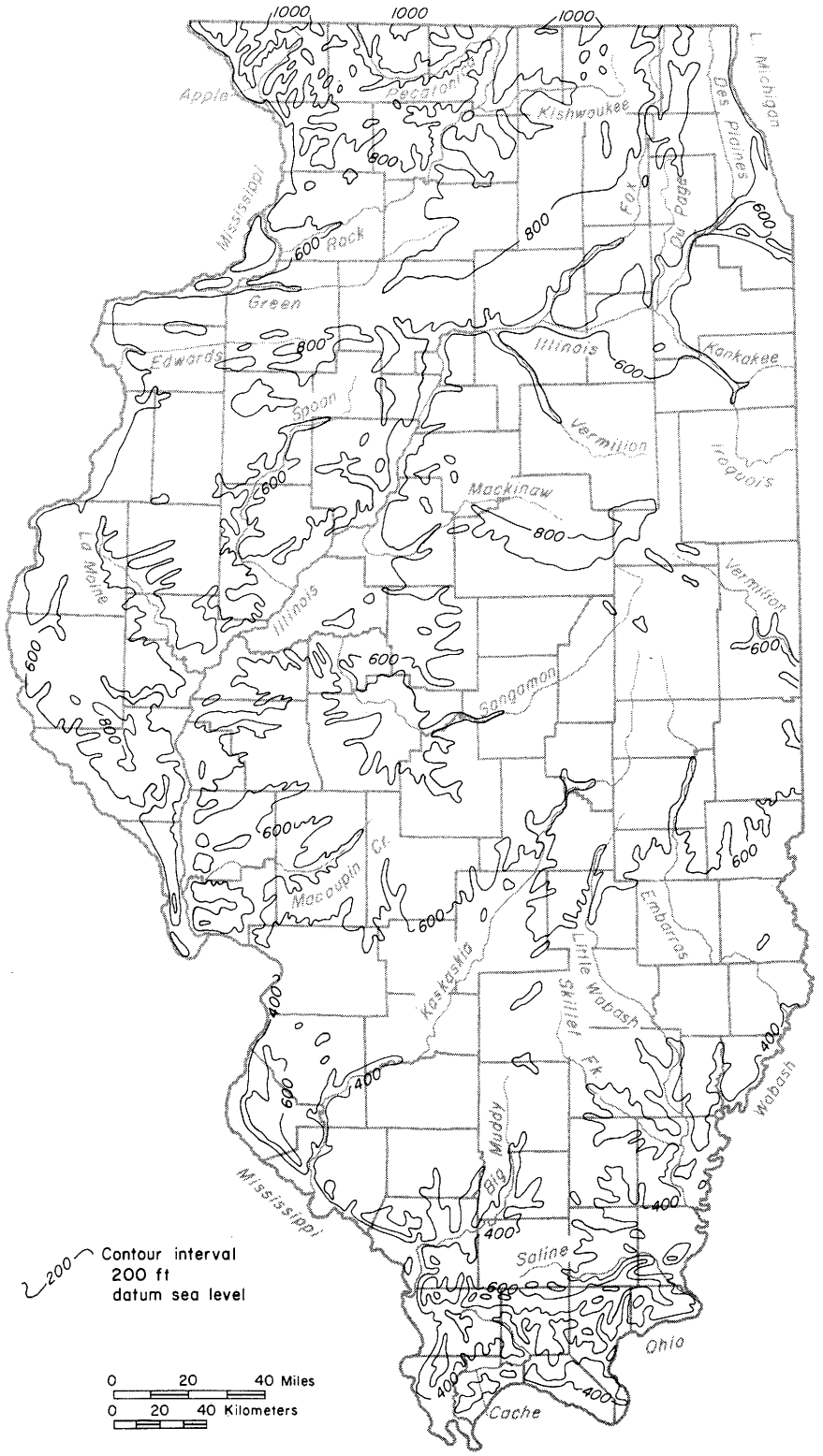

Fig. 8—Topography and rivers of Illinois.

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the topography differs because the Lincoln Hills Section has flat-lying rocks and the Salem Plateau Section has faulted and warped strata.

The Shawnee Hills Section of the Interior Low Plateaus Province includes a rough-surfaced area with relatively high relief that is commonly referred to as the Illinois Ozarks. It is an unglaciated area in which much of the topography is controlled by the bedrock and local structures, including several faults and Hicks Dome.

Cache Valley, which was the Ancient Ohio Valley, sharply separates the Shawnee Hills from the Coastal Plain Province, the northern tip of which is in extreme southern Illinois. The Coastal Plain Province is characterized by rounded hills developed on relatively soft Cretaceous, Tertiary, and Pleistocene sediments.

Illinois has a total relief of about 950 feet, ranging from 285 feet above sea level at the junction of the Ohio and Mississippi Rivers in the southern tip of the state to 1235 feet above sea level at the top of Charles Mound in Jo Daviess County near the Wisconsin state line. However, more than half of Illinois is at an elevation between 600 and 800 feet above sea level (fig. 8).

The maximum local relief in Illinois is about 600 feet at Bald Knob, Cave Hill, and a few other localities in the Shawnee Hills of southern Illinois. Relief reaches 400 feet locally in the Driftless Area of northwestern Illinois, in Calhoun and Jersey Counties near the meeting of the Illinois and Mississippi Rivers, and at Peoria. About 200 feet of relief is common along the Mississippi River, along the Illinois River below La Salle, and at the front of the Bloomington Morainic System in northern Illinois. Outcrops of bedrock formations are abundant in all these areas, except along the Bloomington Morainic System.

The local relief is generally much less pronounced. Large areas of the Illinoian till plain are extremely flat—almost table-like—and many a square mile has less than 20 feet of relief. Most of the Wisconsinan till plain is distinguished by numerous rough-surfaced morainic ridges that are generally 50 to 100 feet high, a mile or two wide, and continuous for 50 to 100 miles. They are separated by intermorainic areas with more subdued, undulating topography, commonly described as "rolling" topography.

In some counties no exposures of the bedrock formations occur, and other counties have outcrops only in the larger valleys. In many areas exposures exist only as roadcuts, quarries, and other man-made excavations. Consequently, the stratigraphic sequence in much of the state is determined almost entirely from subsurface data—principally from borings for water, oil, coal, and other minerals, and for waste disposal wells, underground storage of gas and liquid petroleum products, and sanitary systems. Logs of approximately 200,000 borings are on file at the Illinois State Geological Survey in Urbana. Many of these are geophysical logs. Sample cuttings from more than 58,000 borings and cores from more than 9000 borings also are filed at the Survey.

Illinois is divided into 102 counties. The counties and the township grid are shown in figure 9. The topography of the entire state has been mapped in 15-minute quadrangle units (scale: 1 inch = approximately 1 mile). About 50 percent of the state has been mapped topographically in 7.5-minute quadrangle units (scale: 2.5 inches = approximately 1 mile).

Geologic Setting

The rocks of Illinois above the basement complex (the Precambrian rocks) are dominantly marine sediments deposited during the Paleozoic Era (fig. 1). They are the consolidated bedrock formations. The Cretaceous rocks of the Mesozoic Era, which are largely marine deltaic or nearshore sediments, are found only in relatively small areas in southern and western Illinois (fig. 10) and, except for a few thin units, are unconsolidated. Rocks of the Cenozoic Era include those forming at present and are the unconsolidated surficial rocks that directly underlie the surface of almost the entire state (fig. 11).

The Paleozoic rocks have a present maximum thickness of about 14,000 feet in the deep part of the Illinois Basin (fig. 12). Because the Paleozoic systems generally thicken southward into the deep part of the basin, the sum of the maximum thicknesses of the systems is not much greater, being only about 16,000 feet. However, because of unconformities and irregular deposition, the sum of the maximum thicknesses of the formational units in the state is much greater, about 25,000 feet. The Mesozoic rocks at their maximum are only about 500 feet thick. The Cenozoic rocks are as much as 600 feet thick but in most of the state are much thinner.

All the Paleozoic systems except the Permian are represented in Illinois. Rocks near Danville and La Salle once identified as Permian are now recognized as Pennsylvanian.

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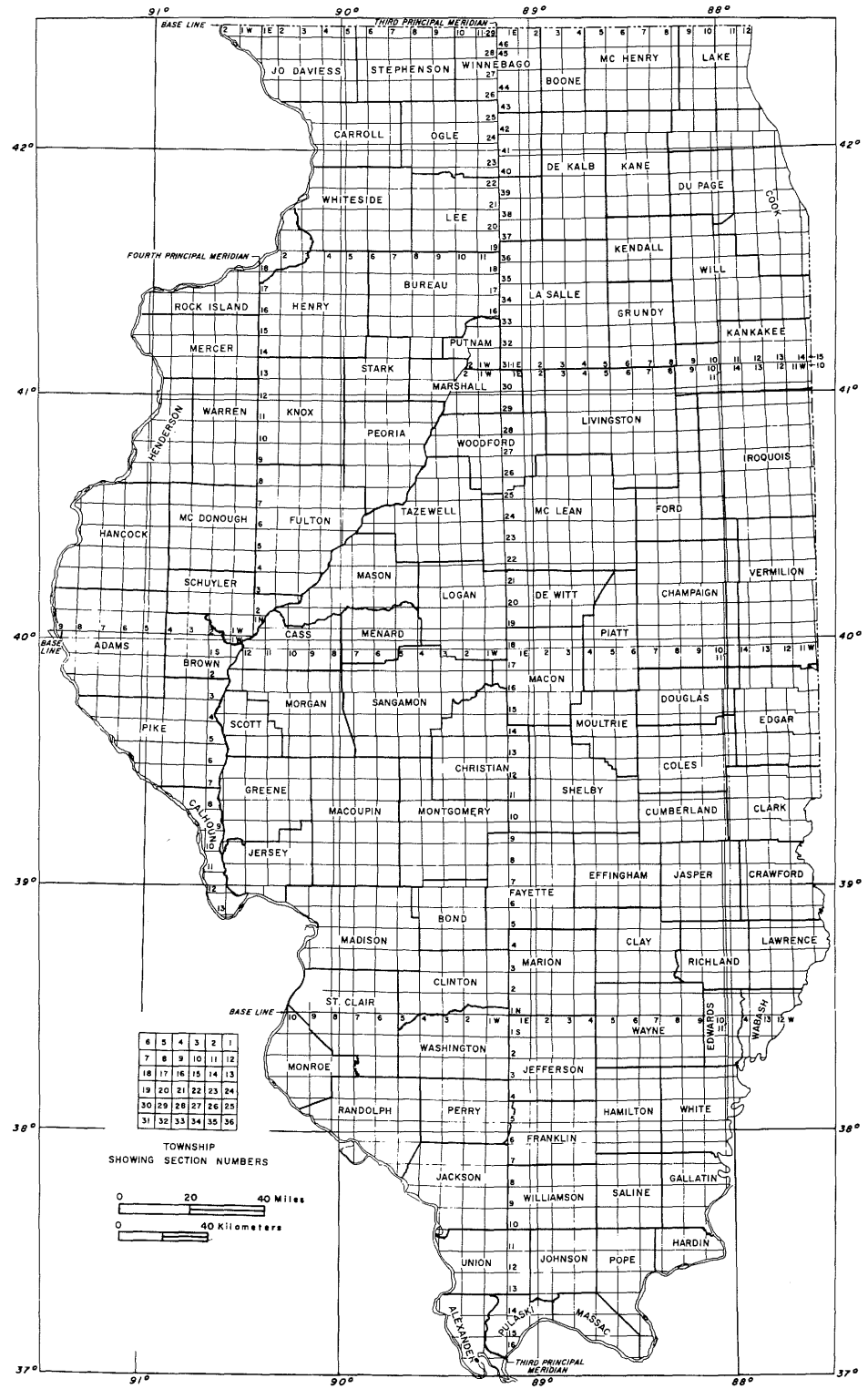

Fig. 9—Index map showing counties and townships.

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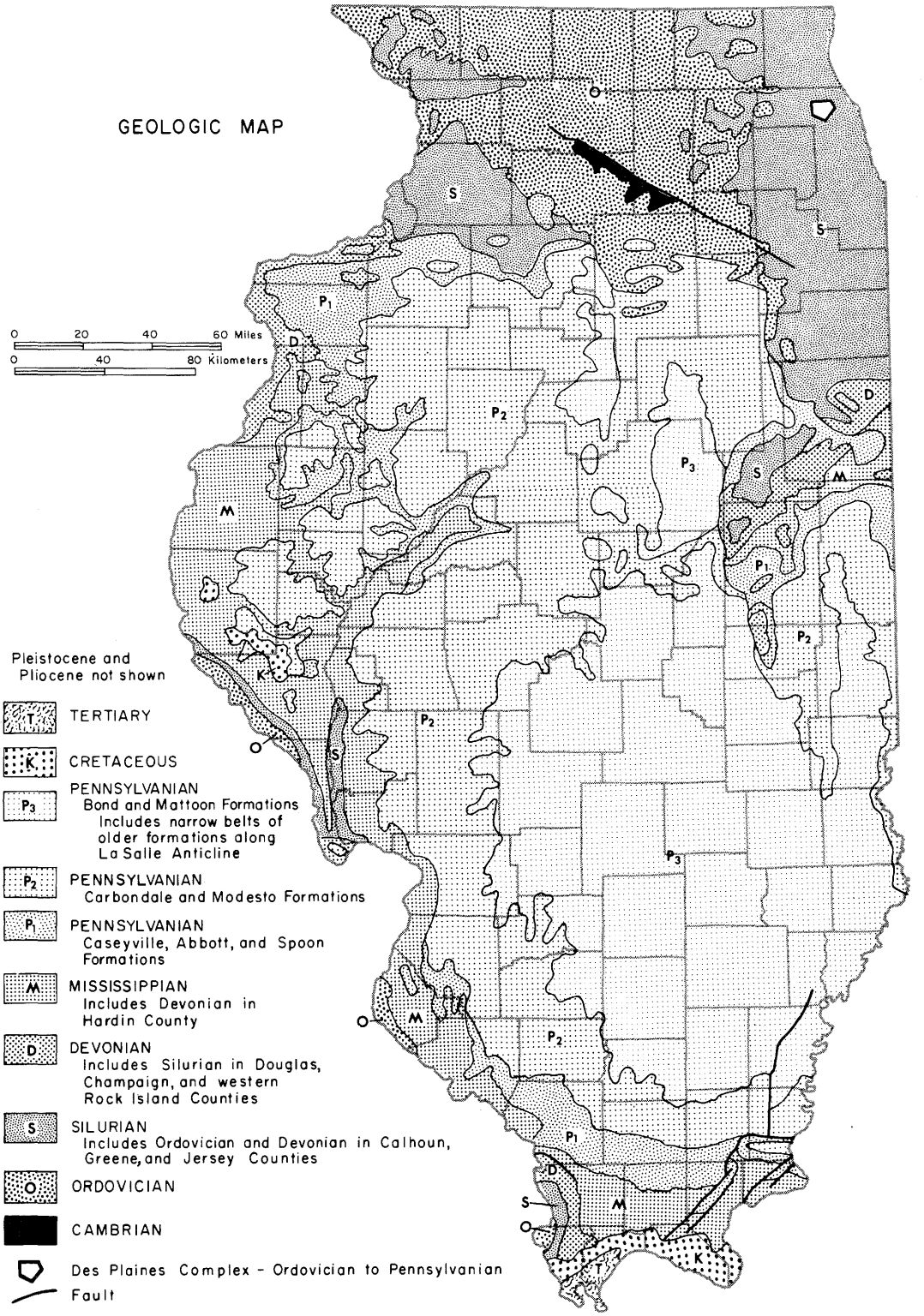

Fig. 10—Generalized areal geology of the bedrock surface (Willman and Frye, 1970).

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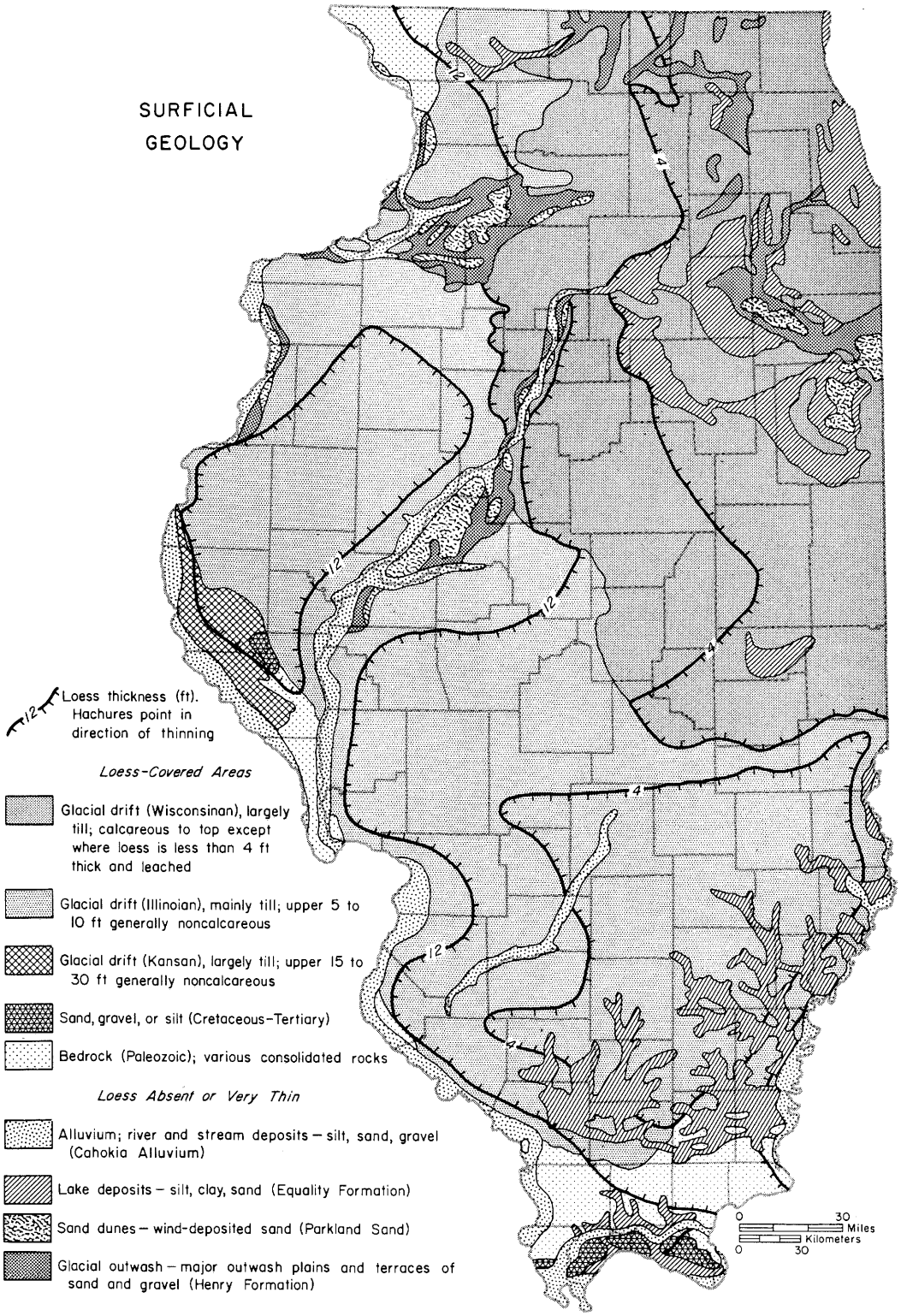

Fig. 11—Generalized surficial geology of Illinois. In uneroded areas the loess thins from 25-100 feet thick in the bluffs of the major valleys to 1-2 feet in areas farthest from the valleys.

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All the commonly recognized major subdivisions (series) of the Paleozoic systems except the lower and middle series of the Cambrian System are present in Illinois. The Mesozoic Era is poorly represented, as the Triassic and Jurassic Systems and the lower Cretaceous (Comanchean) Series are absent and the upper Cretaceous (Gulfian) rocks occur in only relatively small areas. The Cenozoic record is more complete, although the Tertiary System is confined largely to the southern margin of the state and the Oligocene and Miocene Series are not present. The areal distribution of the Paleozoic systems at the surface of the bedrock (fig. 10) is related to structure, unconformities, and the relief of the bedrock surface.

Geologic Structure—The structure of Illinois has been described as a spoon-shaped basin, called the Illinois Basin (fig. 12). It is oriented NNW to SSE, with the tip of the spoon in Kentucky and Tennessee and its eastern edge largely in Indiana. The deepest part of the basin is near or a little south of the mouth of the Wabash River, where Indiana, Kentucky, and Illinois meet. In the broadest definition, the Illinois Basin extends to the tops of the bordering positive areas, the major arches and uplifts, where the direction of the regional slopes is reversed. In this sense, essentially all of Illinois is within the basin, and the basin has a maximum depth of about 15,000 feet. However, the basin is defined by some as the much smaller area bounded by the −500-foot or −1000-foot contour on top of the Ottawa Megagroup (Trenton top), and by others as the area underlain by the Pennsylvanian rocks (the Eastern Interior Coal Basin).

The structure of the basin is not simple (figs. 12, 13). It is the product of a long history of repeated tectonic movements (Swann, 1968; Atherton, 1971). The major structure within the basin is the La Salle Anticlinal Belt, the western edge of which is a relatively steep monoclinal slope that faces west. Along it the strata in places decline as much as 2000-3000 feet on a slope as steep as 20 degrees. Faulting accounts for only a minor part of the relief in the La Salle Anticlinal Belt, although deep-seated faulting in Precambrian rocks may account for the deformation of the overlying sedimentary rocks. The deep part of the basin, from the southern end of the La Salle Anticlinal Belt to the similar but shorter, east-facing Du Quoin Monocline, is called the Fairfield Basin (fig. 12). Many smaller structures occur throughout the state.

The strata in the southern part of the basin are broken by a complex of faults (Weller et al., 1920; Stonehouse and Wilson, 1955; Baxter et al., 1963; Baxter and Desborough, 1965; Baxter et al., 1967). Some of them are thrust faults, such as the Shawneetown Fault, but most are normal faults, many of which bound grabens. A few faults have displacements of over 1000 feet, but most displacements are much smaller. Folds and faults also occur throughout the basin but, with a few exceptions, have gentle slopes and less than 200 feet of relief.

Perhaps the most intense deformation is in the Des Plaines and Glasford Disturbances (fig. 12), which are roughly circular cryptoexplosion structures. Such structures were once interpreted as being volcanic in origin, but they are now believed to be astroblemes—structures produced by meteorite impact. Neither disturbance is exposed at the surface. The Des Plaines Disturbance (Emrich and Bergstrom, 1962; Buschbach and Heim, 1972) is buried by glacial drift. The Glasford Disturbance (Buschbach and Ryan, 1963) was formed in the Ordovician Period and buried by the youngest Ordovician and later Paleozoic rocks.

Hicks Dome (fig. 12), an even larger structure, lacks the intense deformation of the disturbances and is likely the result of a deep igneous intrusion. Igneous rocks (intrusive breccias, dikes, and sills) are present in the dome and in the surrounding areas (Baxter and Desborough, 1965). A few other domes in southern Illinois also may be related to igneous intrusion (English and Grogan, 1948). Numerous dikes and sills are encountered in coal mines and oil wells (Clegg and Bradbury, 1956). Other domal structures are related to the burial of Silurian reefs, many of which grew several hundred feet above the sea floor. Compaction and solution of rocks deposited around the rigid reefs resulted in the development of domal structures that continue hundreds of feet above the tops of the reefs.

The sinking of the Illinois Basin, relative to the surrounding positive areas, appears to have begun in Cambrian time, and it continued intermittently until the end of the Paleozoic Era, at least until after the end of the Pennsylvanian. During much of this time the basin appears to have been open to seas advancing from the south and at times from the west. During maximum invasions the seas spread over the entire basin and the surrounding positive areas. The differences between the structures of the several horizons mapped (figs. Pc-1, O-3, P-8), illustrate the progres-

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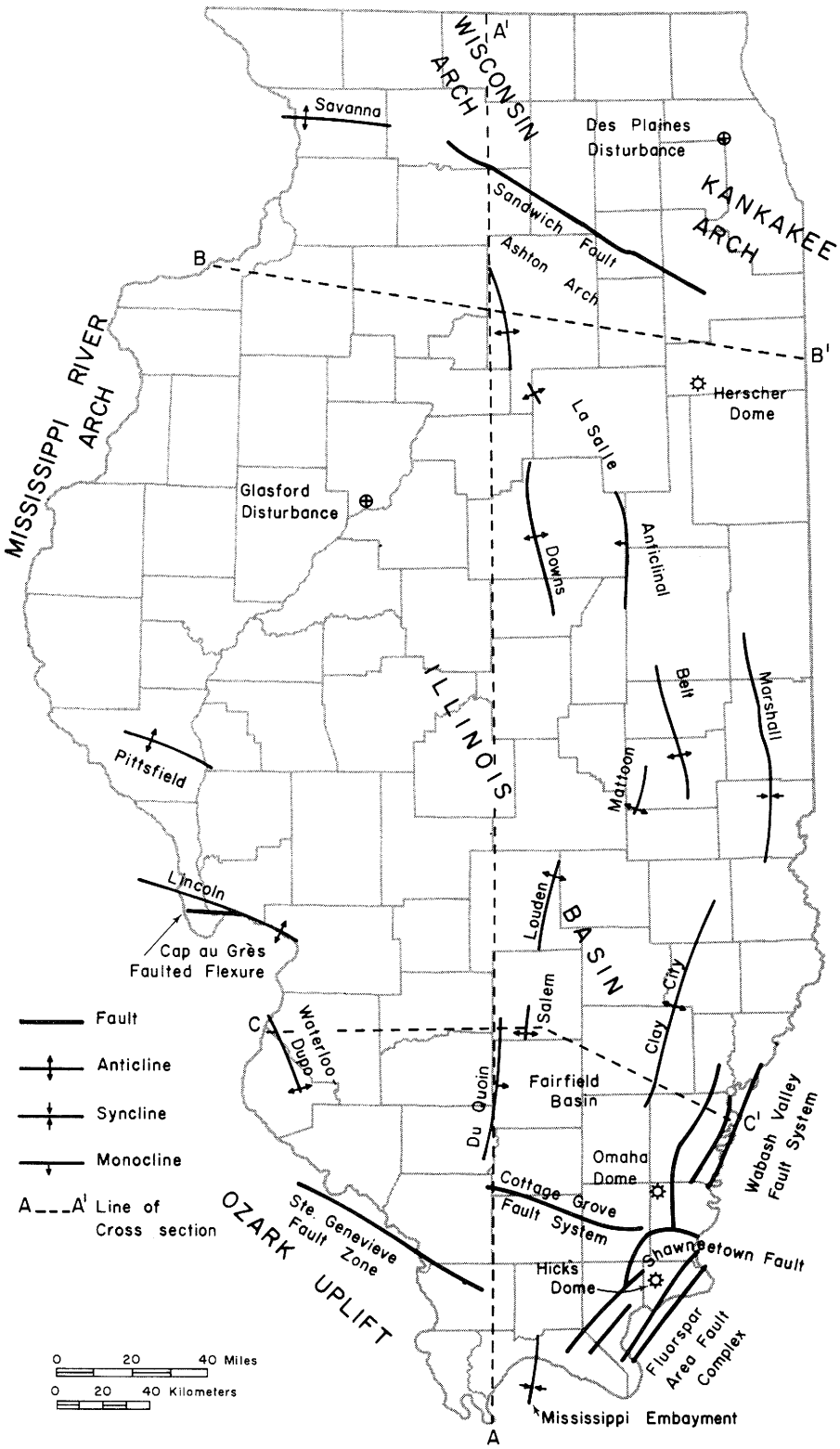

Fig. 12—Principal geologic structures of Illinois.

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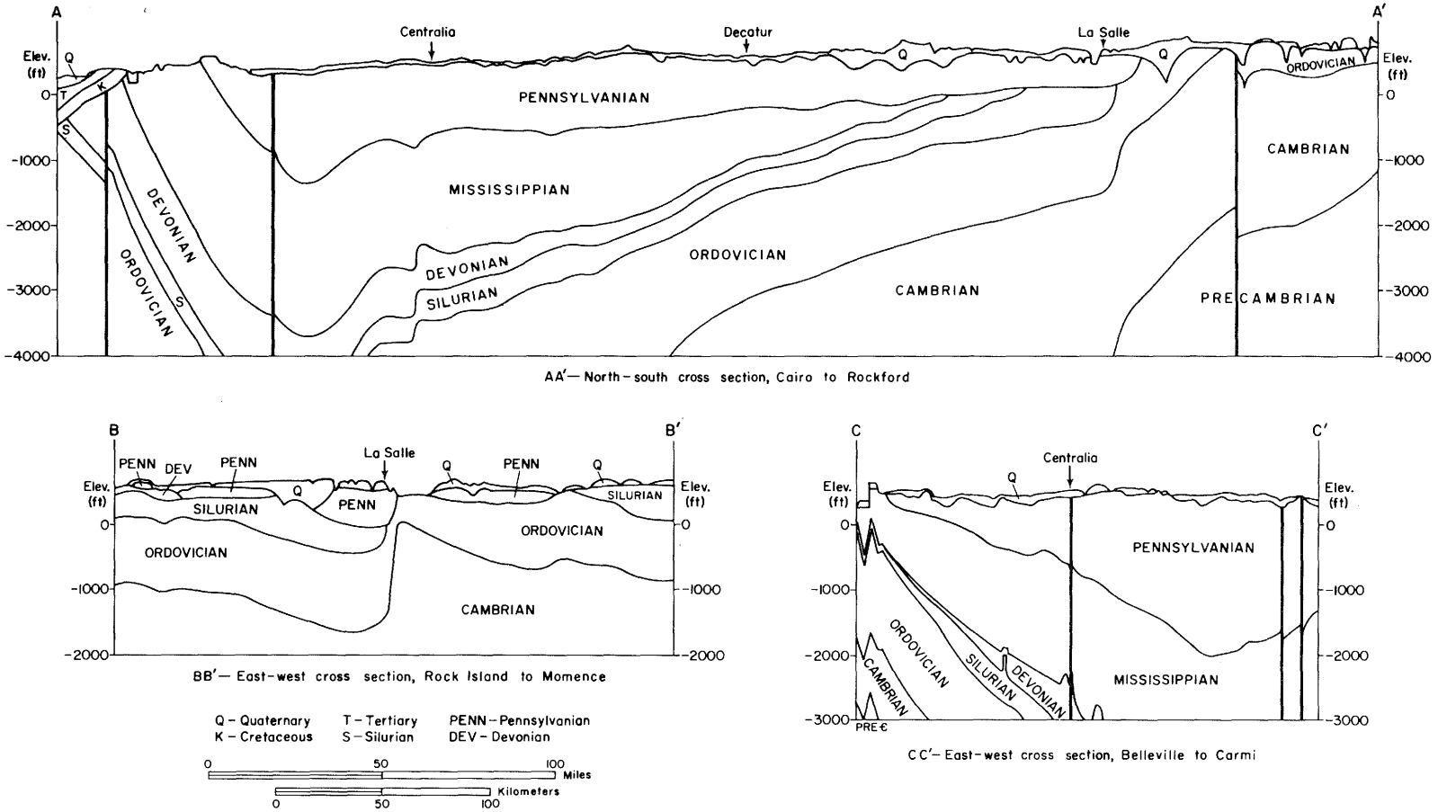

Fig. 13—Geologic cross sections along the lines shown in figure 12 (after Willman et al., 1967).

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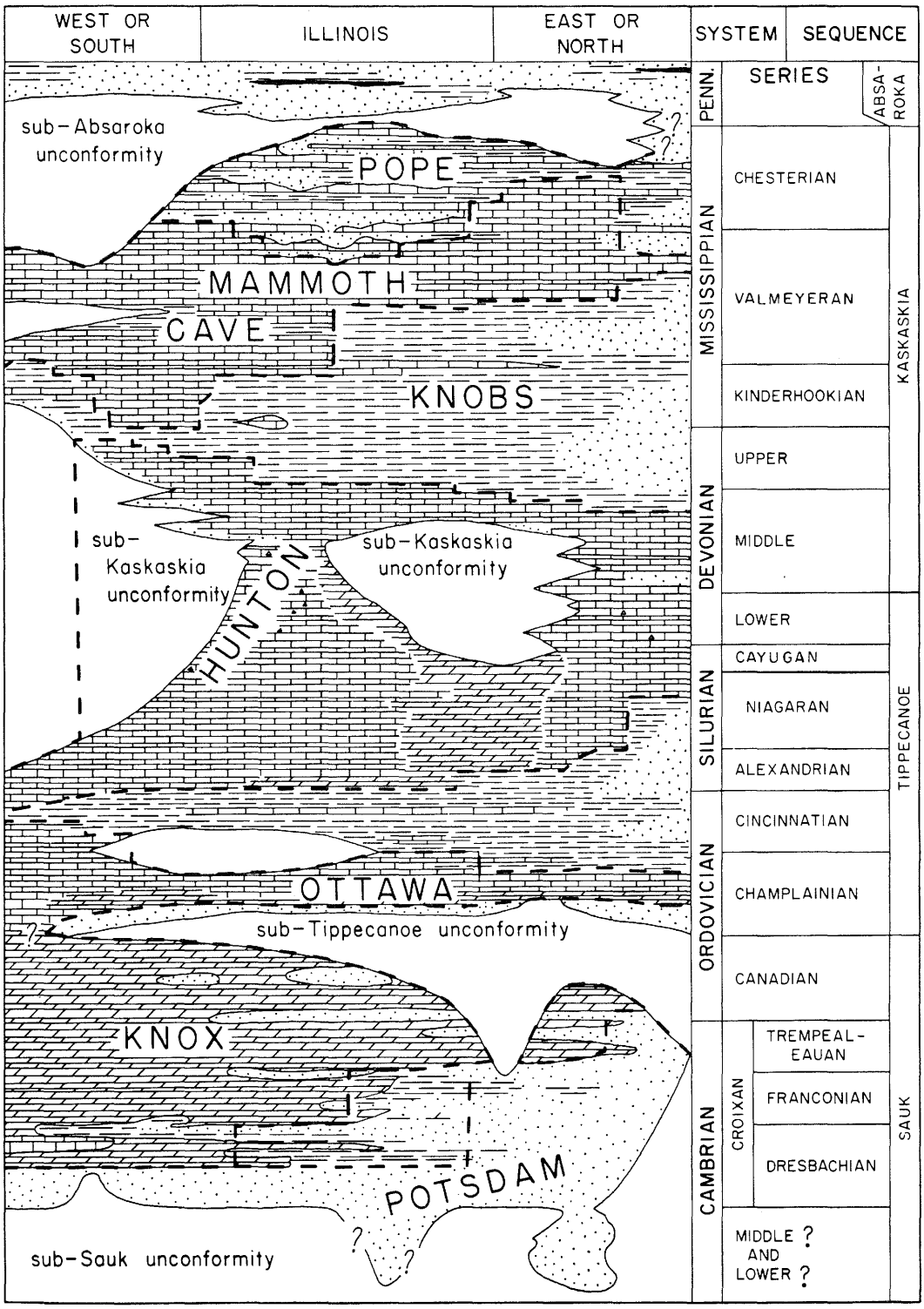

Fig. 14—Pre-Pennsylvanian megagroups and sequences of Illinois (Swann and Willman, 1961).

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sive development of the basin. Tectonic movements resulted in the development of major unconformities during the intervals between each of the units mapped.

The absence of Permian, Triassic, Jurassic, and lower Cretaceous rocks prevents a close determination of the time when major tectonic movements ended in the Illinois Basin and when uplift of the east-west Pascola Arch south of Illinois in Kentucky and Missouri closed the Illinois Basin and gave it its present spoon-shaped configuration. However, the upper Cretaceous rocks of the Gulf Embayment area clearly overlap the intensely faulted area in southern Illinois, and only a few minor faults, possibly the result of slumping or solution-collapse, have been found cutting the Cretaceous, Tertiary, or the almost universally present Pleistocene rocks. Some local thickening of Cretaceous rocks along projections of major grabens has been interpreted as indicating renewed movement along the faults during or following deposition of the Cretaceous rocks (Ross, 1963). The last major movements, which deformed the Pennsylvanian rocks, probably occurred at the time of the last major tectonic disturbances in the eastern part of the continent—the Appalachian Revolution at the end of the Paleozoic Era. Since that time, the development of the Mississippi Embayment Syncline and renewed uplift of the Ozark Dome have gently warped the Cretaceous and Tertiary strata.

Unconformities—Unconformities are a major factor in the structure and distribution of the bedrock formations in Illinois. Seven major unconformities produced by widespread withdrawal of the sea, erosion, and readvance of the sea, accompanied by significant tectonic disturbances, are recognized in Illinois (fig. 1). Four other unconformities show no significant deformation. The erosion that produced the unconformities is generally considered to be subaerial—by rivers and streams—but at least parts of some unconformities may well be produced by marine planation. Local unconformities that occur on the flanks of the Illinois Basin are due to fluctuations in the margins of the seas.

Diastems (intervals of nondeposition) are abundant in some formations and locally account for the absence of units where no unconformity is present. During these intervals corrosion surfaces were produced in some places by the solution of the sea floor. In local areas, particularly near faults, solution has removed buried carbonate units many feet thick, simulating an unconformity. Solution thinning is most apparent in stylolitic bedding surfaces, which in some carbonate formations are abundant enough to suggest that many feet of rock may have been dissolved.

The major unconformities have regional continuity throughout much of the continent, and, as they represent significant events in the geologic history of any region, they are used in stratigraphic classification as boundaries delineating units called sequences (Sloss, 1963). The sequences recognized in Illinois (fig. 14) have strongly overlapping relations. They indicate the major intervals of relative tectonic stability, although progressive sinking of the Illinois Basin continued.

The sub-Cretaceous unconformity at the base of the Embayment Sequence developed during the long interval between Pennsylvanian and late Cretaceous time, during which several thousand feet of Paleozoic strata, and also any early Mesozoic strata that may have been present, were eroded. The truncation of several thousand feet of Pennsylvanian strata across anticlinal structures requires the same amount of general lowering of the surface by erosion. It has also been estimated that to reach their present degree of coalification Pennsylvanian coals must have been buried by sediments about a mile thicker than those now present (Damberger, 1971). The eroded rocks may have included some of Permian age, because marine Permian rocks found in eastern states probably were deposited in a sea that advanced eastward across Illinois, Indiana, and Ohio. In most of the area where the Cretaceous and Tertiary strata are absent, erosion may have continued into Pleistocene time and perhaps even to the present in the driftless areas, but projections of the sub-Cretaceous unconformity in southern Illinois to the area of Cretaceous rocks in western Illinois and to central Iowa suggest that most of the truncation of the Paleozoic rocks occurred before late Cretaceous time.

Bedrock Surface—The top of the bedrock is marked by deep valleys that were incised mainly during the early part of the Pleistocene Epoch (fig. 15). As a result, the deposits of the Pleistocene overlie, and in many areas completely conceal, a surface dissected by major valleys as much as 400 feet deep, many with tributaries entrenched 100-200 feet. The variety of unconsolidated surficial rocks that unconformably overlie the bedrock surface reflects (1) the climatic changes from rigorous glacial climates to interglacial climates somewhat warmer than those of the present, (2) the various agents of transportation (glacial, fluvi-

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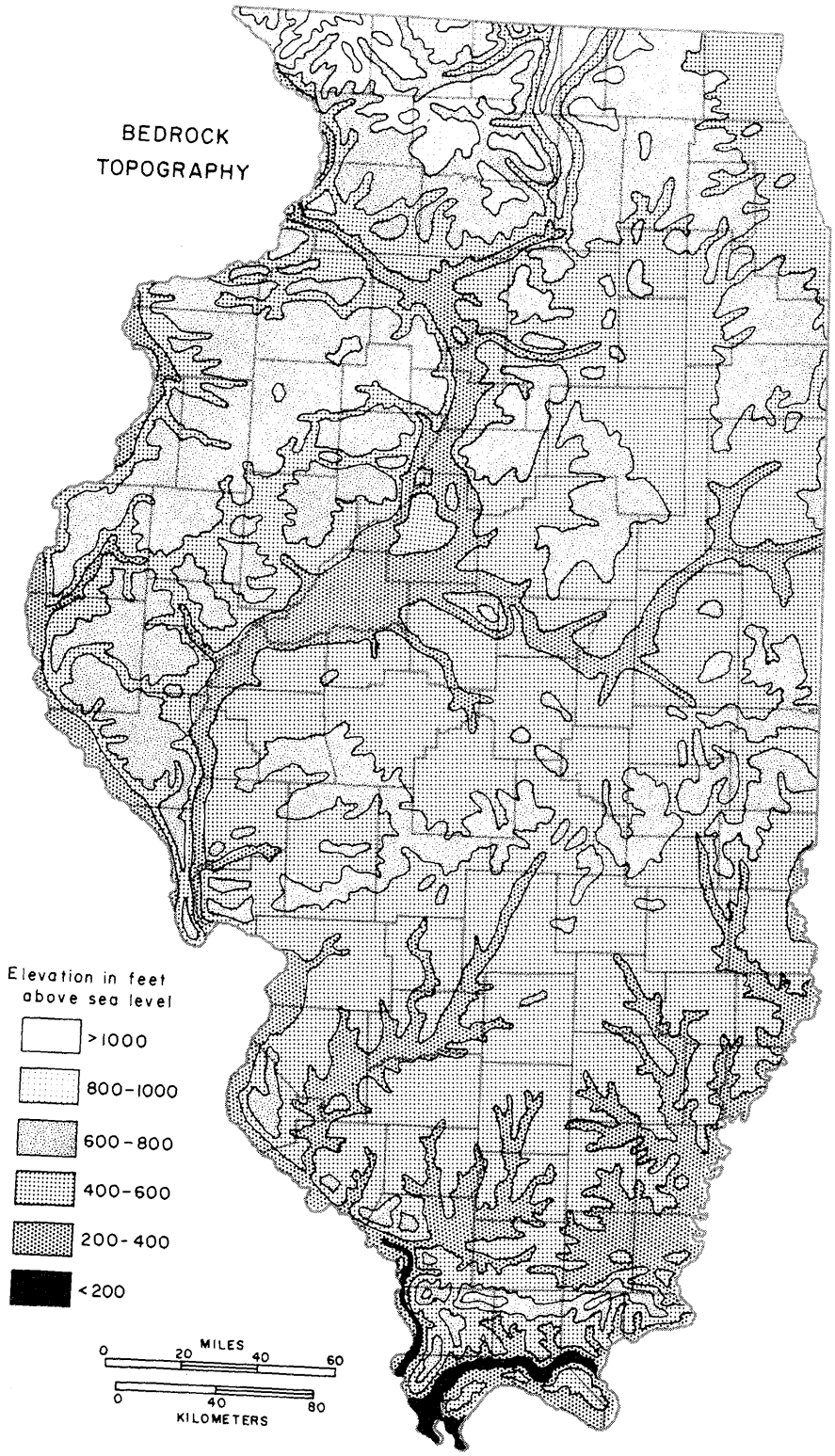

Fig. 15—Topography of the bedrock surface of Illinois (after Horberg, 1950a, and Willman and Frye, 1970).

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al, and eolian), and (3) the environments in which the sediments were deposited—hills and flat uplands, valleys and lowlands, and lakes and swamps. The surficial sediments are of special interest because they are the rocks on which we live, the soil that provides our food, the mineral resources with which we build, and the source of much of the water we drink.

Stratigraphic Classification

In the early reports on the geology of Illinois only a few terms were used in stratigraphic classification (fig. 16), and those were used somewhat inconsistently. Most of the named units were called formations and assigned to a system, a unit designating age. By the late 1800s, the rapidly increasing number of named units made apparent the need for a more systematic classification. Largely following recommendations by the International Geological Congress of 1901, a classification was developed that had one set of terms for rock units and another for equivalent units of time. That classification was used in Illinois from about 1910 to 1958.

The same classification was accepted, with minor changes, in the stratigraphic code of 1933, which was drawn up by a committee representing several national organizations (Ashley et al., 1933). The classification was later modified to meet the particular conditions in the Pennsylvanian and Pleistocene rocks. These modifications, however, did not change the fundamental parallelism of the rock and time terms, and in effect retained the single classification scheme.

In the 1940s and 1950s, concern increased regarding the inadequacies of the single classification scheme for precise communication. Use of the same name for a rock unit and its time of deposition often resulted in confusion. In many reports it was not clear whether a reference to time of deposition of a unit referred to the interval from its oldest to its youngest part regionally, to the time represented by deposition of the type section, or to the time of deposition in the local area described. To avoid this confusion, completely independent classifications were devised for rock units based on lithology and rock units based on time of deposition, the latter serving as the basis for geologic time classification.

This multiple classification scheme brought about the development of other independent stratigraphic classifications, each based on the need for recognition of units differentiated by some particular characteristic of the rocks. The multiple classification scheme was adopted by the Illinois State Geological Survey in 1958 (Willman, Swann, and Frye), at which time six classifications were recognized—classifications based on lithology, time of deposition, paleontology, cycles of sedimentation, facies, and soils. Since then, classifications based on unconformities (Sloss, 1963; Sloss et al., 1949; Swann and Willman, 1961), morphology, or surface expression (Frye and Willman, 1962; Willman and Frye, 1970), and hydrogeology (Maxey, 1964) have been recognized in Illinois (fig. 16).

Of the nine classifications recognized, only rock- and time-stratigraphic classifications apply to all rocks. All rocks belong to some formation in the rock-stratigraphic classification, and all formations are assigned to some system or systems in the time-stratigraphic classification. The other rock and time units and the other classifications are used only when needed. The other classifications have more limited application and are described briefly in the sections pertaining to the systems for which they are most useful.

The rock-stratigraphic classification, which differentiates units of rock distinguished by lithologic characteristics recognizable in the field, is designed as the basic framework for stratigraphic description, for areal geology, for geologic structure mapping, and for various economic purposes. The formation, which is the fundamental unit, has a distinctive lithology or a characteristic variation in lithology, and adequate thickness and lateral extent to meet the practical requirements of the classification. In general, it is traced laterally through changes in lithology as far as the boundaries in its type locality can be traced with confidence, but beyond that area another formation is differentiated. The boundaries of rock-stratigraphic units commonly transect time surfaces; in fact, they are marked in many cases by vertical cut-offs, which are steps used to maintain lithologic unity (figs. 14, Q-8). Rock-stratigraphic units do not intertongue and therefore do not recur in a vertical section. In contrast, facies units, which commonly have intricate intertonguing and gradational boundaries and are more restricted lithologic types, generally are independent of rock-stratigraphic classification. Similarities between adjacent formations are shown by their grouping into subgroups, groups, and megagroups (fig. 16). Subdivisions of formations are based on minor characteristics or on units too thin to be classified as formations and are recognized as members and beds.

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The time-stratigraphic classification serves as a basis for the geologic time classification, for regional correlations, and for historical interpretations. Time-stratigraphic units are units of rock bounded by time planes based on a designated horizon in a type section. Most are defined by fossil content—the limiting range of a fossil or an assemblage of fossils that has been established in the biostratigraphic classification. In nonfossiliferous rocks and in those lacking useful fossils, isotopic dating, unconformities, bentonites, and other distinctive and persistent lithologic characteristics are used for time-stratigraphic classification, particularly in small regions. The system, the fundamental unit of the classification, is the smallest unit generally applicable on a world-wide basis. Units progressively lower in rank—series, stage, substage—are differentiated by relative significance and commonly have only regional usefulness.

BEFORE 1910
(Worthen, 1866; Weller, 1906)

System
Group
Formation

1910-1932
(Carman, 1910; Cady, 1919; Wanless, 1929)

Rock	*Time*
Group	Era
Subgroup	
System	Period
Subsystem	
Series	Epoch
Formation	Stage

1932-1958
(Wanless & Weller, 1932; Ashley et al., 1933; Willman & Payne, 1942; Wanless, 1957)

Rock	*Time*
General	
	Era
System	Period
Series	Epoch
Group	Epoch
Formation	Stage
Member	Substage
Pennsylvanian	
System	Period
Group	
Cyclothem	Cycle
Member	
Pleistocene	
Series	Epoch
Stage	Age
Substage	Sub-age

1958 — PRESENT
(Willman, Swann, & Frye, 1958; Kosanke et al., 1960; American Commission on Stratigraphic Nomenclature, 1961; Swann & Willman, 1961; Swann, 1963; Maxey, 1964; Willman & Frye, 1970; Frye & Willman, 1970)

I. ROCK-STRATIGRAPHIC CLASSIFICATION
(Units of rock differentiated on lithology)
- Megagroup
- Group
- Subgroup
- Formation
- Member
- Bed

II. TIME-STRATIGRAPHIC CLASSIFICATION (Units of rock differentiated on time of deposition) — GEOLOGIC-TIME CLASSIFICATION (Derived units of time)

Erathem	Era
System	Period
Series	Epoch
Stage	Age
Substage	

III. BIOSTRATIGRAPHIC CLASSIFICATION
(Units of rock differentiated on the basis of paleontology)

Range of single taxon	*Abundance of single taxon*	*Fauna or flora*
Range-zone	Peak-zone	Assemblage-zone

IV. CYCLICAL CLASSIFICATION

(Units of rock differentiated on sedimentary cycles)	(Corresponding unit of geologic time)
Cyclothem	Cycle

V. FACIES CLASSIFICATION
(Units of rock differentiated on lateral changes in composition)
- Facies (informal lithologic name)

VI. SOIL-STRATIGRAPHIC CLASSIFICATION
(Units of rock differentiated on weathering profiles)
- Soil

VII. UNCONFORMITY-BASED CLASSIFICATION
(Units of rock bounded by unconformities)
- Sequence

VIII. MORPHOSTRATIGRAPHIC CLASSIFICATION
(Units of rock differentiated on physiographic expression)
- Drift
- Terrace (informal name)

IX. HYDROSTRATIGRAPHIC CLASSIFICATION
(Units of rock differentiated on hydrologic properties)
- Aquifer

Fig. 16—Development of the stratigraphic classifications used in Illinois. The references include reports that introduced changes in the classification and others that show typical usage.

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The terms "lower," "middle," and "upper" for rock- and time-stratigraphic units and "early," "middle," and "late" for time units are used only informally to indicate relative position, and they are not capitalized. The only exception is for the Devonian System, in which geographic terms have not been accepted for the names of series and Lower, Middle, and Upper Devonian Series continue to be used.

The various classifications used in Illinois conform in principle and in most details to the stratigraphic code adopted by the American Commission on Stratigraphic Nomenclature (1961), which at present formally recognizes only classifications based on lithology, time, paleontology, soils, and geologic climate.

Nomenclature

The terms used in descriptions of lithology follow common field usage, but they differ somewhat because of individual preferences of the authors, particularly in descriptions of carbonate rocks. In general, the Wentworth classification is used in descriptions of grain size of clastic rocks. The patterns and symbols used in the figures are identified in figure 17.

Thickness Maps

Explanations not fully given in the legends of the thickness maps are as follows:

1) Isopachs are drawn only in the area where the named unit is overlain by the next younger unit.

2) The "outcrop areas" are those where the unit is exposed or directly underlies unconsolidated surficial materials—glacial drift, alluvial materials, loess, or Cretaceous and Tertiary sediments. As the top of the unit is eroded, no isopachs are drawn in these areas.

3) The term "Eroded" refers to areas of the bedrock surface where the unit has been entirely eroded. On some maps, areas in subsurface where the unit was eroded at a major unconformity are differentiated.

4) The term "Absent" is applied to areas where the unit was never deposited and the boundary is at (or close to) a shoreline; it also applies to areas where the absence of the unit results from a change in facies and the boundary is a vertical cut-off.

5) Closed areas of thinning are indicated by hachures.

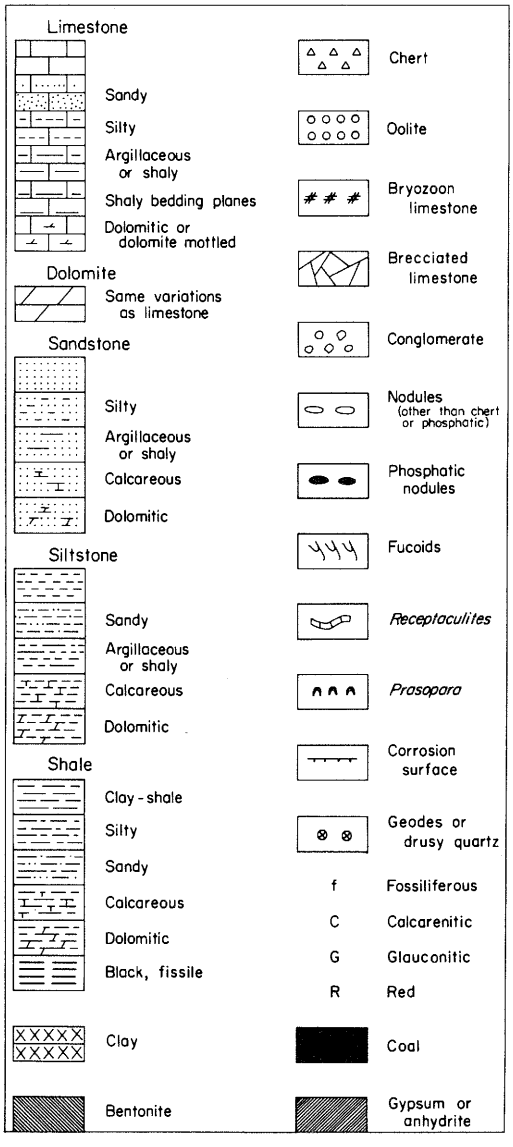

Fig. 17—Patterns and symbols used in figures.

6) Many of the thickness maps are generalizations from detailed maps in the Illinois State Geological Survey files.

Styling

In the following descriptions of the stratigraphic units, the formal name of the unit is followed by the reference to the person or persons who introduced the name, after which appear the names of those who made significant redefinitions, not including changes in rank.

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Units are described from oldest to youngest in the order in which they first appear in the section, and once introduced they are not repeated.

The illustrations for each system of rocks are numbered separately. Figure numbers for all except the Introduction are preceded by a code letter indicating the relevant system. Specifically, the prefix "Pc" indicates Precambrian, "€" Cambrian, "O" Ordovician, "S" Silurian, "D" Devonian, "M" Mississippian, "P" Pennsylvanian, "K" Cretaceous, "T" Tertiary, and "Q" Quaternary.

PRECAMBRIAN ROCKS

Elwood Atherton

The Precambrian rocks, which are commonly referred to as the basement, lie at depths ranging from about 2000 feet below the surface in the northernmost part of Illinois to about 14,000 feet below the surface in the deepest part of the Illinois Basin in southern Illinois (fig. Pc-1). Only 20 borings have penetrated and sampled the Precambrian basement in Illinois.

Illinois is part of a Precambrian granite-rhyolite terrane, relatively uniform in rock type and age, that extends from the Mississippi River eastward into Ohio (Rudman et al., 1965). Aeromagnetic maps of Illinois show a strong, anomalous magnetic gradient band parallel to and along the Rough Creek Fault Lineament in southern Illinois, indicating that this may be a zone of significant intrusive activity. The anomaly pattern shows an over-all homogeneity north of the lineament, suggesting a rough uniformity in composition of the deep rocks in that area. The gravity map of Illinois shows regionally denser crust south of this lineament (Heigold, in preparation).

Age determinations for the uppermost Precambrian rocks in Illinois range, with one exception, from about 1100 to 1400 million years (m.y.) (Lidiak et al., 1966) and fall within the Precambrian Y time unit designated by the United States Geological Survey (James, 1972). The exception was the determination made on granite samples from one well in La Salle County, which gave the anomalously low age of only 640 m.y. If correct, that date suggests that younger Precambrian rocks may be present in local areas. Because Cambrian deposition in Illinois probably began about 525 million years ago in Croixan

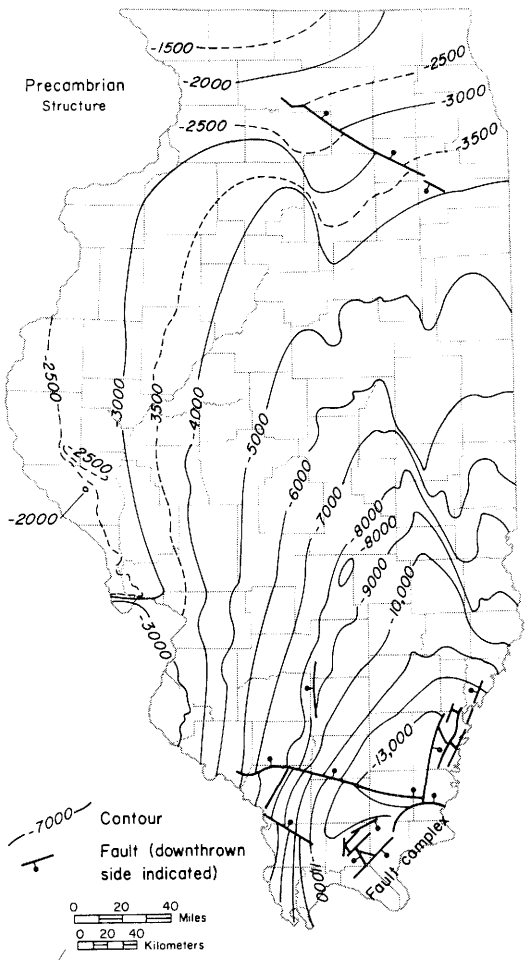

Fig. Pc-1—Structure on top of the Precambrian basement.

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(late Cambrian) time (fig. 1), the unconformity on the Precambrian rocks represents an interval of 600 to 900 m.y.

The buried surface of the Precambrian, where it can be adequately studied, is hilly (Atherton, 1971). In Pike County in western Illinois, two deep tests 8 miles apart reveal a relief of about 800 feet on the Precambrian surface. Several tests found the basal Cambrian Mt. Simon Sandstone unexpectedly thin or absent over the Precambrian. Presumably, these wells encountered Precambrian hills too high to have been covered by the regional blanket of Mt. Simon Sandstone. Too few Precambrian tests have been drilled in the deep part of the Illinois Basin to indicate the local relief, but, if information from adjacent states is a reliable indication, the relief may be several hundred feet. Wells that pass through the Mt. Simon normally enter fresh-looking igneous rock. The feldspar grains in the arkose forming the base of the Mt. Simon and in the underlying granitic rock also have a fresh appearance. Any weathered material that may once have accumulated was evidently eroded before deposition of the Paleozoic sediments.

The Precambrian rocks from the 20 borings in Illinois have included 10 red granites, 4 pink granites, one gray granite, 4 granodiorites (two of which occur in the same wells as granites), one felsite (in the same well as granite), one rhyolite, one red granophyre, and one red-brown granite porphyry (Grogan, 1949; Bradbury and Atherton, 1965). All but one of the granites contain potash feldspar and quartz as the chief constituents, various amounts of plagioclase, and biotite as the chief dark mineral. The other granite, from Will County, is alkalic and contains riebeckite rather than biotite. Apatite and zircon are present in all the granites, and sphene, fluorite, epidote, and allanite occur in many. The granites are medium to coarse grained, and most appear to be somewhat porphyritic.

The granodiorites are similar to the granites but contain greater amounts of ferromagnesian minerals. The rhyolite is porphyritic, with phenocrysts of quartz and red feldspar in an aphanitic groundmass. The granophyre in composition falls between the compositions of the granite and the rhyolite; it contains an abundance of micropegmatite. No mafic igneous rocks or metasediments have been encountered in the basement of Illinois, but reports of these rock types in the Precambrian of adjacent states suggest that they may be present.

PALEOZOIC ERATHEM

H. B. Willman

The Paleozoic Erathem—the rocks deposited during the Paleozoic Era (Sedgwick, 1838)—originally included only the rocks now referred to the Cambrian, Ordovician, Silurian, and Devonian Systems, but the definition of the name was expanded in 1840 to include the Carboniferous (Mississippian and Pennsylvanian) and Permian Systems (Phillips, 1840), and present usage follows that definition.

The Paleozoic rocks of Illinois (fig. 1) are separated from the older Precambrian and younger Mesozoic rocks by great unconformities. The basal unconformity is marked by the absence of rocks of late Precambrian and early and middle Cambrian age, an interval approximately as long as all the time that has passed since then—more than half a billion years. The unconformity at the top of the Paleozoic represents more than 125 million years and is marked by the absence of the youngest Pennsylvanian, the Permian, and all the Mesozoic rocks older than late Cretaceous. Between these unconformities the Paleozoic Erathem in Illinois contains sediments representing the oldest six of the seven systems.

The Paleozoic rocks are dominantly marine sediments, representing repeated invasions of the sea into the interior of the continent. The

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seas generally advanced from the south, and the land-derived sediments deposited in them came mainly from the north, northeast, and east, with smaller amounts from sources in the southeast and northwest. Very small contributions came from the Ozarks to the west. Above the thick sandstones of the Cambrian System, carbonate sediments are dominant through the middle Mississippian, whereas shale and sandstone dominate the younger deposits. Sandstones in the Cambrian and up through the Devonian rocks consist mainly of well rounded quartz grains and a minor amount of stable heavy minerals of a limited suite. Many are almost entirely quartz sand, but others contain some clay, silt, and more varied heavy minerals. The sand of the early Paleozoic sandstones was reworked largely from late Precambrian sandstones and has passed through several cycles of erosion and transportation. The Mississippian and early Pennsylvanian sandstones are largely quartz sandstones but are not as well rounded or sorted or as pure as the older sandstones, which suggests that the sources of the older sandstones were being covered by the Paleozoic sediments. The later Pennsylvanian sandstones are noticeably angular, poorly sorted, silty, feldspathic, and micaceous, and have a larger suite of only moderately stable heavy minerals. They appear to be first-cycle sediments derived from more recently exposed or accessible granitic and metamorphic rocks.

The term "Paleozoic" means ancient life, and fossils of the Paleozoic rocks represent the oldest abundant life. Algal-like fossils and burrows and trails of worm-like organisms are found in the Precambrian rocks of other regions, but only rarely. A great variety of marine invertebrate animals characterized the Paleozoic Era. Marine vertebrates (fishes) developed during Ordovician time, but it was not until Devonian time that plants became abundant enough on land to furnish the food that permitted fresh-water and land-dwelling animals to develop. Although fossils are scarce in Illinois Cambrian rocks, they are abundant in many other Paleozoic strata. By late Mississippian time plants were abundant, and during the Pennsylvanian Period they flourished profusely. In swampy areas they accumulated and eventually formed coal beds. Amphibious vertebrates became more common late in the Paleozoic, but invertebrates continued to be the dominant form of animal life throughout the era.

CAMBRIAN SYSTEM

T. C. Buschbach

The Cambrian System (Sedgwick, 1835, p. 390) is named for Cambria, the Roman name for northern Wales, where the type section is well exposed. All Cambrian sediments in Illinois are considered late Cambrian in age and are assigned to the Croixan Series. However, as the Mt. Simon Sandstone (at the base), which forms more than half the system in the northern two-thirds of the state, contains no fossils, middle and early Cambrian strata could be present even though not identifiable (Bell et al., 1964). The possibility that Precambrian sandstones also may be represented in the Mt. Simon (Workman and Bell, 1948) seems less likely (Templeton, 1950).

The Cambrian System is differentiated from the overlying Ordovician in northern Illinois by both fossils and lithology, but in much of southern Illinois, where the contact is deeply buried and has been penetrated in only a few borings, Cambrian and Ordovician rocks consist of similar types of dolomite. Consequently, the boundary may occur within an interval of several hundred feet.

Cambrian strata underlie all of Illinois, but they are exposed only in relatively small areas in Ogle and Lee Counties (Bevan, 1935, 1939; Willman and Templeton, 1951) (fig. €-1). However, they directly underlie thick glacial drift in a larger area in Lee and De Kalb Counties (Weller et al., 1945; Willman et al., 1967), where they occur on the south, or upthrown, side of the Sandwich Fault (fig. 10). Cambrian rocks range from about 1000

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feet thick in southwestern Illinois to more than 3500 feet in the eastern part of the state (fig. €-2).

Cambrian strata in Illinois are dominantly sandstone, which is generally white but locally is stained or mottled red or yellow. The sand is subangular to well rounded, poorly to well sorted, and predominantly medium grained, although it varies from fine to coarse grained and some beds contain small quartz pebbles. Much of the sandstone is friable, dominantly quartz, and noncalcareous. The basal zone, as much as 350 feet thick, is strongly arkosic. In extreme northern Illinois

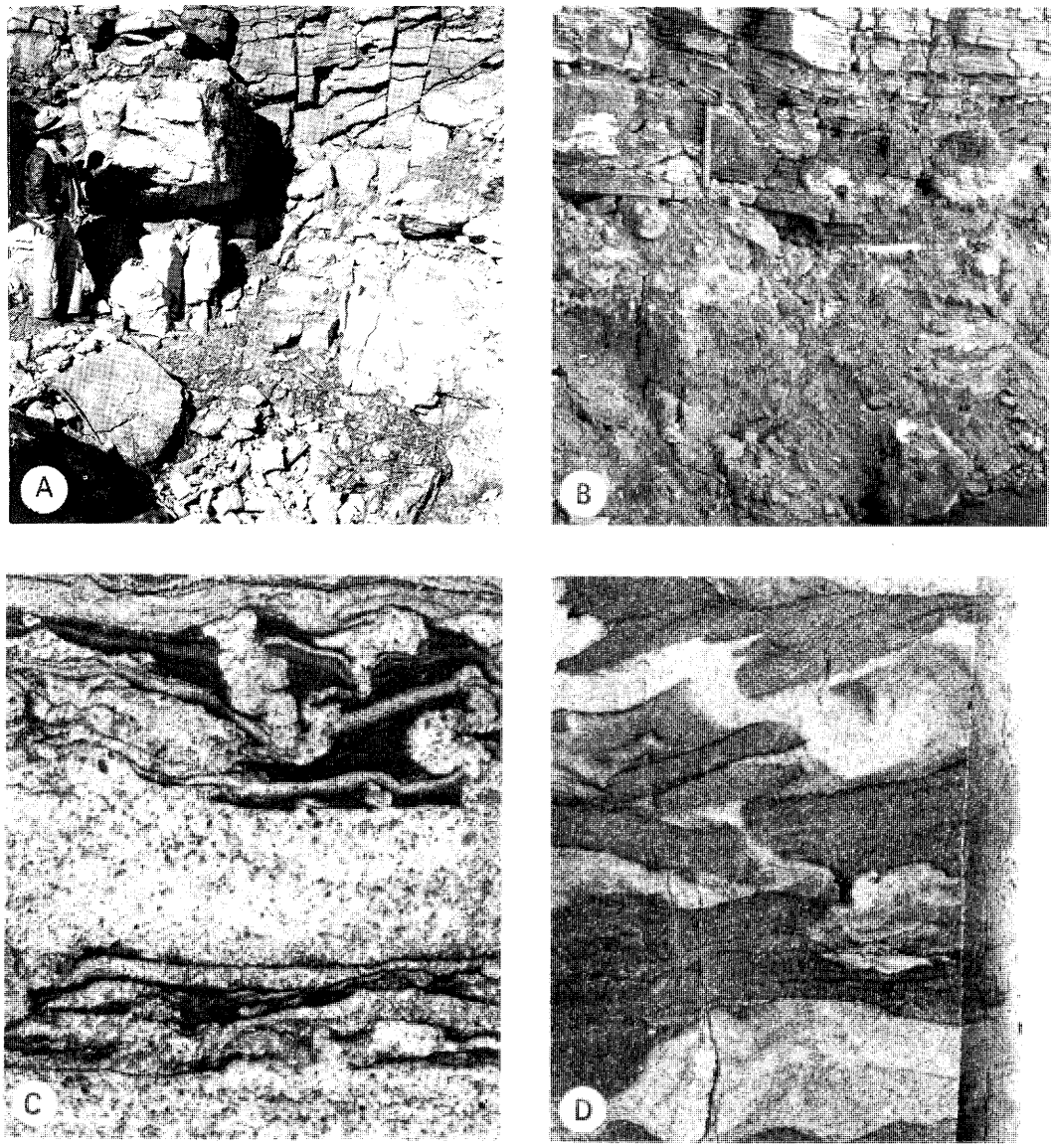

Fig. €-1—Exposures and cores of Cambrian rocks.
A—Massive Potosi Dolomite in a quarry 4 miles northwest of Ashton, Ogle County.
B—Cambrian-Ordovician unconformity showing well bedded Oneota Dolomite overlying massive Potosi Dolomite in a quarry in Lee County, 6 miles south of Rochelle, Ogle County (Willman and Templeton, 1951, p. 113).
C—Core of Eau Claire Formation showing penecontemporaneous deformation of shale beds in shaly sandstone; from a boring in Champaign County (×2).
D—Core of Ironton Sandstone showing flat-pebble conglomerate; from a boring in Champaign County (×2).

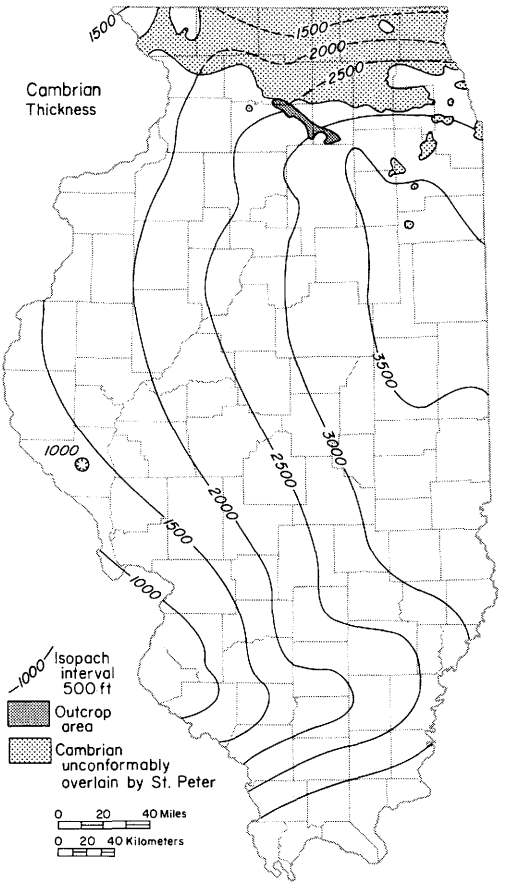

Fig. Є-2—Thickness of the Cambrian System. The dashed lines show reconstructed thicknesses.

the Cambrian System, although 90 percent sandstone, contains a persistent dolomite, the Potosi Formation (fig. Є-3). The Franconia Formation, the upper part of the Ironton Sandstone, and the Eau Claire Formation contain dolomitic sandstone. As these three units thicken southward and grade into dolomite, the proportion of sandstone diminishes to probably no more than 25 percent in extreme southern Illinois (fig. Є-4).

Classification of the Cambrian rocks in Illinois is based largely on classifications that developed in the late 1800s in the outcrop areas to the north in Wisconsin and Minnesota and to the southwest in Missouri, long before the few Cambrian outcrops in Illinois had been recognized. Deep drilling, primarily for ground water, in the Chicago area and later in scattered localities throughout the state, penetrated the Cambrian formations and permitted correlations with the outcrop areas (fig. Є-5). More recently, some units not present or not recognized in the outcrop areas have been differentiated in the very thick subsurface Cambrian sections in Illinois by studies of samples from borings (Templeton, 1950; Buschbach, 1964).

The dominantly sandstone units in the lower part of the Cambrian System are collectively called the Potsdam Sandstone Megagroup (figs, 14, Є-3), and the upper dolomite units are referred to the Knox Dolomite Megagroup, which extends upward to include Ordovician dolomite formations. An interval of interbedded sandstone, siltstone, shale, and dolomite units separates the Potsdam and Knox Megagroups, except in southwestern Illinois (fig. Є-4).

The Cambrian System rests with major unconformity (the sub-Sauk unconformity) (fig. 14) on Precambrian igneous rocks (Pc-1), most of which are granite. The Precambrian surface is commonly referred to as a peneplain, but knobs of Precambrian rocks as much as 500-1000 feet high rise sharply into the Cambrian rocks (Workman and Bell, 1948; Atherton, 1971). Only a few such knobs are known in the Illinois Basin, most of them marginal to the Ozark region, but many others may exist.

The Cambrian System is generally separated from the overlying Ordovician System by a sharp change in lithology, but no erosional or structural evidence of an unconformity is apparent. Similar relations exist between rock-stratigraphic units within the Cambrian, but many have transitional contacts. The next higher major unconformity is the sub-Tippecanoe unconformity at the base of the St. Peter Sandstone or Everton Formation. Cambrian and Ordovician strata in the interval of relatively parallel units (fig. 14) between the sub-Tippecanoe unconformity and the basal Cambrian unconformity are referred to the Sauk Sequence.

The sand that composes most of the Cambrian rocks in Illinois was derived almost entirely from the region to the north and was deposited in a marine embayment. The roundness of the grains and the presence of a suite of stable heavy minerals, limited both in variety and quantity, suggest that most of the sands were derived from Precambrian, or possibly early Cambrian, sandstones, which at that time probably covered a large area of the Canadian Shield. In some beds the more varied suite of heavy minerals typical of granitic terranes indicates occasional erosion by the rivers through the sandstones into the Precambrian granites, but the characteristics of most

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of the sands suggest they had passed through at least one and possibly several cycles of erosion, transportation, and deposition. The highly arkosic basal sandstone may have been derived from closer sources. In southwestern Illinois the sand probably came from the Ozark region, which was strongly dissected before late Cambrian time. In eastern and southern Illinois, beds of shale in the Cambrian strata appear to be continuous, have thicker units to the south and southeast, and were probably derived from Appalachian sources.

All the sandstones above the Mt. Simon, and possibly even the uppermost Mt. Simon, grade southward through dolomitic sandstone and sandy dolomite facies into dolomite that is relatively pure, except for some beds that contain chert, drusy quartz, and glauconite. The southward thickening of the dolomite and the lack of recognizable unconformities suggest the progressive sinking of the Illinois Basin during Croixan time. The bordering positive areas, and in fact much of the interior of the continent, were submerged by the seas during that time, and perhaps only the higher areas of the Canadian Shield remained as land.

Fossils are scarce in Cambrian sediments, but the seas were not without life; trilobite debris forms black streaks in some beds. The fauna has not been intensively studied, but Raasch (Willman and Templeton, 1951) reported *Dikelocephalus, Illaenurus,* and *Saukiella*, as well as unnamed species of trilobites from the Franconia exposures at Oregon, Ogle County, and *Cryptozoon, Hypseloconus,* and *Saukiella* from outcrops of the Potosi Formation. Oboloid brachiopods, gastropods, algal domes, and worm borings also are present but poorly preserved. The fauna is much better known in Wisconsin (Twenhofel et al., 1935; Raasch, 1951), Minnesota (Bell et al., 1956), and Missouri (Lochman-Balk, 1956).

CROIXAN SERIES

The Croixan Series (Winchell, 1873, p. 70; 1900), named for the St. Croix River in eastern Minnesota, has also been called the Upper Cambrian, the St. Croix, and the St. Croixian Series. The type section consists of all strata of Cambrian age (about 600 feet) exposed in the St. Croix Valley. There Cambrian strata overlie Precambrian rocks, and the uppermost Cambrian formation, the Jordan Sandstone, is overlain by the Oneota Dolomite, the oldest Ordovician formation in that area. The Croixan Series is defined on the basis of its trilobite faunas; it extends from the *Cedaria* Zone at the base to the *Plethopeltis* Zone (Howell

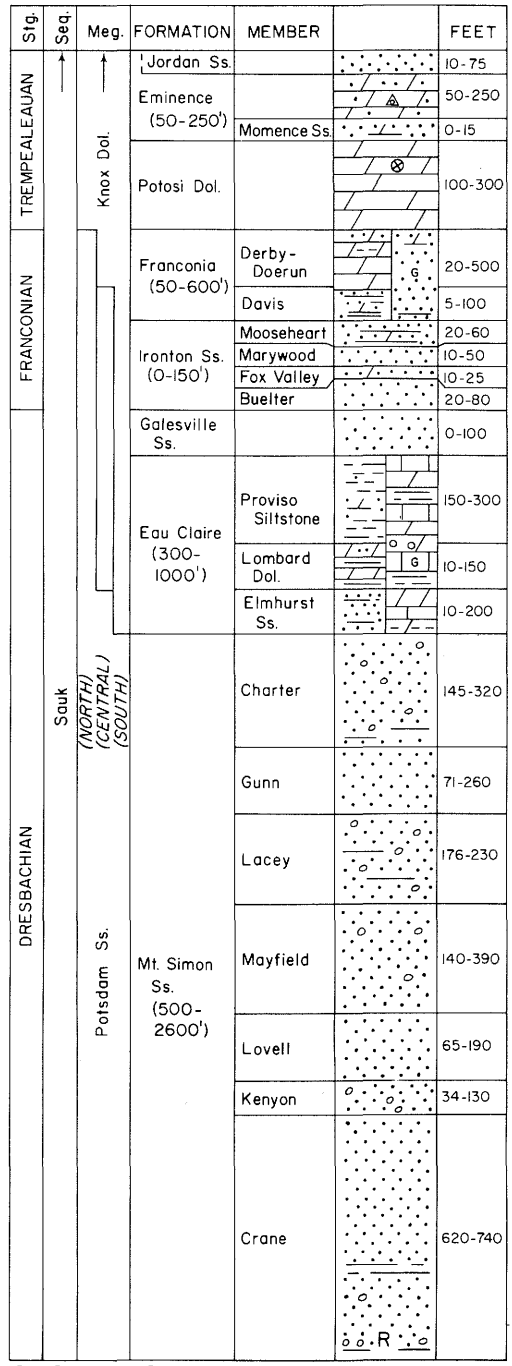

Fig. C-3—Columnar section of the Cambrian System.

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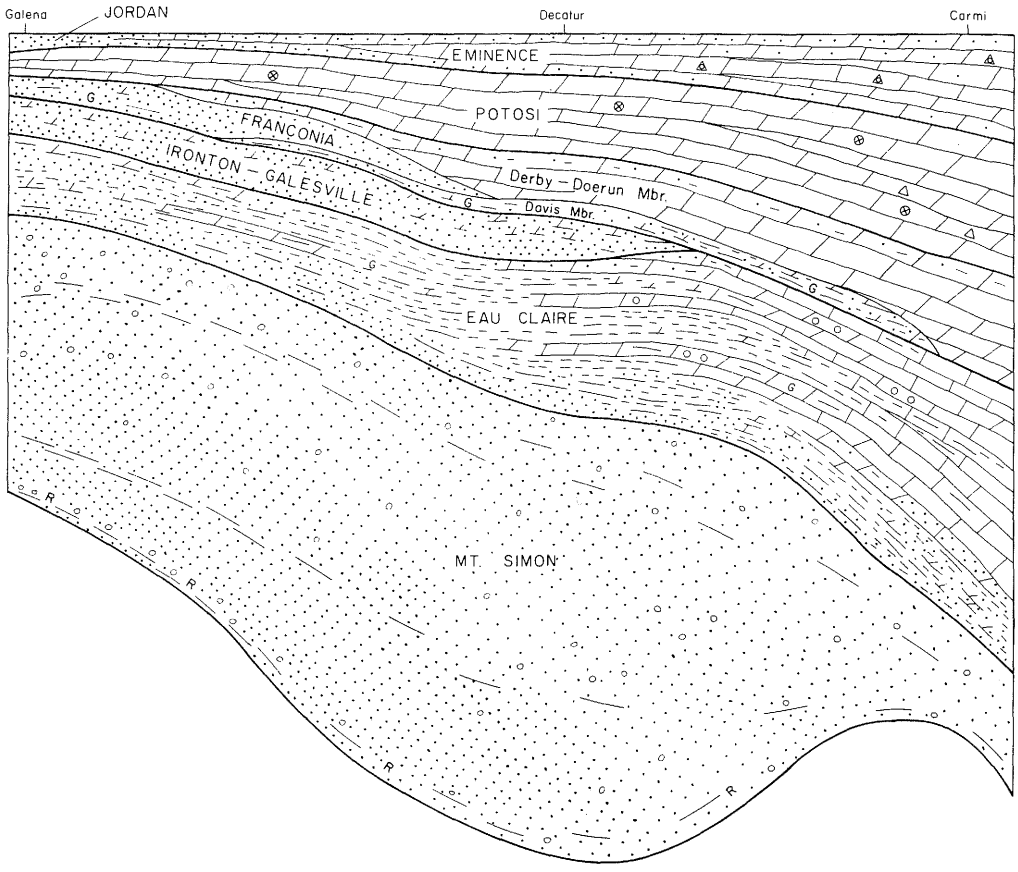

Fig. C-4—Diagrammatic cross section of the Cambrian System from northwestern to southeastern Illinois.

et al., 1944) or the *Saukia* Zone (Raasch, 1951) at the top. The Croixan Series is subdivided into the Dresbachian (oldest), Franconian, and Trempealeauan Stages (fig. C-3). All Cambrian strata in Illinois are assigned to the Croixan Series. The thickness of the Croixan, therefore, is the same as that for the Cambrian System (fig. C-2). Information about Cambrian rocks in extreme southern Illinois is scarce and middle, or even lower, Cambrian strata may be present in that part of the Illinois Basin.

Dresbachian Stage

The Dresbachian Stage (Winchell, 1886, p. 334-337), named for Dresbach, Winona County, Minnesota, consists of all strata of Croixan age below the *Elvinia* Zone. It includes the *Cedaria* (oldest), *Crepicephalus*, and *Aphelaspis* Zones (Howell et al., 1944). In Illinois the stage is represented by 1500-3500 feet of sandstone and dolomite that is differentiated into the Mt. Simon Sandstone (below), the Eau Claire Formation, and the Galesville Sandstone. As the Mt. Simon and Galesville Sandstones lack fossils, the precise boundaries of the stage are uncertain (Buschbach, 1964). These strata were originally called the Dresbach Sandstone (or Formation) and in some areas are now referred to as the Dresbach Group.

SAUK SEQUENCE

The Sauk Sequence (Sloss et al., 1949, p. 111), named for Sauk County, Wisconsin, consists of all strata between the unconformity on the top of the Precambrian rocks and the sub-Tippecanoe unconformity at the base of the St. Peter Sandstone or Everton Formation. In Illinois it therefore includes all strata of Cambrian and Canadian (lower Ordovician) age (fig. 14). Local channeling at the base of some of the sandstones may have been mainly submarine and no unconformities are recog-

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nized within the sequence. The sequence was uplifted by gentle warping and minor faulting and was deeply eroded before deposition of the overlying Tippecanoe Sequence (Atherton, 1971).

POTSDAM SANDSTONE MEGAGROUP

The Potsdam Sandstone Megagroup (Emmons, 1838, p. 214-217, 230), named for Potsdam, St. Lawrence County, New York, consists of the dominantly sandstone formations that compose the lower part of the Cambrian strata in the Illinois Basin. The megagroup underlies all of Illinois but is not exposed. It has a maximum thickness of more than 2600 feet in northeastern Illinois. The name "Potsdam" was widely used in early reports for the basal Cambrian sandstone, but later its use was restricted to the type region. It was reinstated for the megagroup by Swann and Willman (1961) (figs. 14 and €-3). Traced southward from southern Wisconsin, where the entire Cambrian section is included in the Potsdam, the clastics become finer grained and grade to dolomite that is included in the Knox Megagroup. Throughout most of Illinois, however, the megagroups are separated by a zone of mixed dolomite, siltstone, and sandstone that is not included in either group. In the northern tier of counties in Illinois, the top of the Potsdam is commonly the top of the Franconia Formation. In the rest of the northern and in the central part of the state, the top is placed at the top of the lowest member (Elmhurst) of the Eau Claire Formation. In southern Illinois, the top of the Potsdam is the top of the Mt. Simon Sandstone.

Mt. Simon Sandstone

The Mt. Simon Sandstone (Ulrich, *in* Walcott, 1914, p. 354) is named for Mount Simon, an escarpment near Eau Claire, Wisconsin, where the type section consists of 234 feet of coarse-grained, partly conglomeratic sandstone overlying Precambrian granite and overlain by fine-grained sandstone of the Eau Claire Formation. The Mt. Simon Sandstone, although not exposed, underlies all of Illinois except in local areas where it failed to cover hills on the Precambrian surface. It ranges from less than 500 to 2600 feet thick, with the greatest thickness in northeastern Illinois (fig. €-6). The Mt. Simon consists of

<table>
<tr><th>Anderson 1919</th><th>Thwaites 1923, 1927</th><th>Workman 1935</th><th colspan="2">Willman and Payne 1942</th><th colspan="2">Workman and Bell 1948
SOUTH / NORTH</th><th colspan="2">Present Buschbach 1964, 1971</th></tr>
<tr><td rowspan="5"></td><td>Mendota</td><td rowspan="2">Jordan-Gunter</td><td colspan="2" rowspan="2">Jordan</td><td rowspan="2">Eminence</td><td rowspan="2">Gunter-Jordan</td><td rowspan="2">Jordan</td><td>Eminence</td></tr>
<tr><td>Jordan</td><td>Members</td></tr>
<tr><td>Trempealeau</td><td>Trempealeau</td><td colspan="2">Trempealeau</td><td>Potosi</td><td>Trempealeau</td><td colspan="2">Potosi</td></tr>
<tr><td>Mazomanie</td><td>Franconia</td><td colspan="2">Franconia</td><td>Derby-Doerun</td><td>Franconia</td><td>Franconia</td><td>Derby-Doerun</td></tr>
<tr><td rowspan="2">Jordan</td><td rowspan="2">Dresbach</td><td>Ironton M.</td><td colspan="2">Ironton M.</td><td>Davis</td><td>Ironton M.</td><td>Ironton</td><td>Davis
Mooseheart</td></tr>
<tr><td>Galesville</td><td rowspan="4">Dresbach Group</td><td>Galesville</td><td></td><td>Galesville</td><td rowspan="4">Ironton
Galesville</td><td>Marywood
Fox Valley
Buelter</td></tr>
<tr><td>St. Lawrence</td><td>Eau Claire</td><td>Eau Claire</td><td>Eau Claire</td><td>Bonne Terre</td><td>Eau Claire</td><td>Eau Claire</td><td>Proviso
Lombard
Elmhurst</td></tr>
<tr><td>Dresbach</td><td>Mt. Simon</td><td>Mt. Simon</td><td>Mt. Simon</td><td>Lamotte</td><td>Mt. Simon
Fond du Lac?</td><td>Mt. Simon</td><td>Charter
Gunn
Lacey
Mayfield
Lovell
Kenyon
Crane</td></tr>
</table>

Fig. €-5—Development of the classification of the Cambrian System.

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fine- to coarse-grained, partly pebbly, friable sandstone, most of which is coarser grained, more poorly sorted, and more angular than younger Cambrian and Ordovician sandstones. The pebbles, mostly quartz, are as much as 8 mm in diameter in central northern Illinois and only 3.5 mm in northeastern Illinois. Most of the sandstone is white, but in some areas much of it is red, particularly the lower part, and in other localities some of it is yellow to light greenish gray. A basal zone, as much as 350 feet thick, is strongly arkosic. Beds of red and green micaceous shale, in some places 15 feet thick, occur, especially in the upper 300 feet and the lower 600 feet of the formation. Relatively fine-grained units alternate with coarse-grained, pebble-bearing units to divide the Mt. Simon into seven members: Crane Member, at the base (fine to medium grained), Kenyon Member (pebbly), Lovell Member (medium grained), Mayfield Member (interbedded pebbly and medium grained), Lacey Member (pebbly), Gunn Member (medium grained), and Charter Member (pebbly). These units are recognized in borings in north-central Illinois (Templeton, 1950), but have not been traced throughout the state. Only the upper three have been recognized in northeastern Illinois (Buschbach, 1964). The base of the Mt. Simon is the sub-Sauk unconformity. The contact with the overlying Eau Claire Formation is conformable. The Mt. Simon is probably entirely marine, but its characteristics are unknown in a large part of the state. The lower part of the formation has been correlated with Cambrian and Precambrian sandstones in the Lake Superior region, in particular with the Bayfield Sandstone of northern Wisconsin, the Fond du Lac Sandstone in Minnesota, and the Jacobsville Sandstone of northern Michigan, and also with lower and middle Cambrian sediments in Kentucky and Tennessee. However, because there is no evidence of formational breaks within the Mt. Simon, it is retained as a unit in the Croixan Series. The Mt. Simon Sandstone is an important aquifer in northern Illinois, and on several major structures it is used for the storage of natural gas.

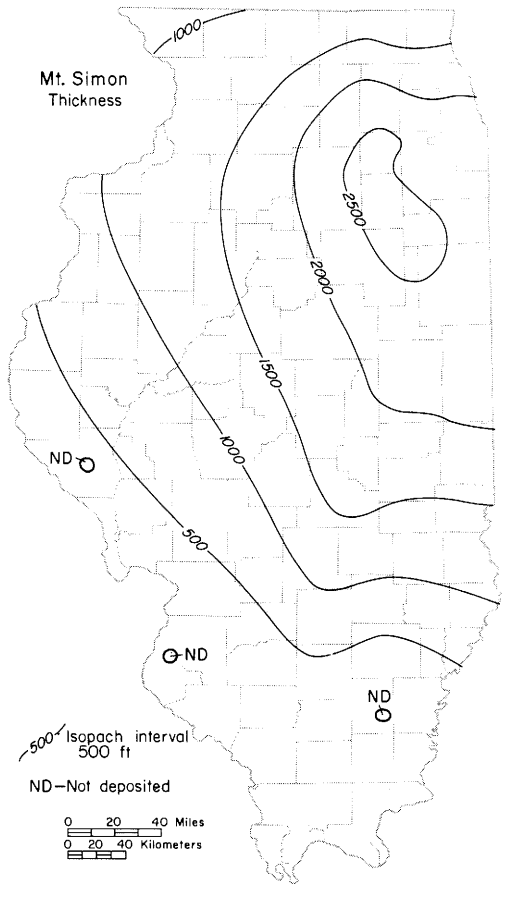

Fig. C-6—Thickness of the Mt. Simon Sandstone.

Crane Member—The Crane Member of the Mt. Simon Sandstone (Templeton, 1950, p. 154), the basal member, is named for Crane School, De Kalb County, 4 miles south of the type section, which is the interval from 3105-3845 feet deep in Wyman No. 1 boring (NE NE SE 35, 41N-5E) (sample set [SS] 1301). It is relatively fine grained, but some of it is medium grained and a few small pebbles are present in places. The lower part is generally shaly, silty, and arkosic. It is 620-740 feet thick, and it has been differentiated in only a few wells in central northern Illinois.

Kenyon Member—The Kenyon Member of the Mt. Simon Sandstone (Templeton, 1950, p. 154), which overlies the Crane Member, is named for Kenyon School, De Kalb County, 3.25 miles southeast of the type section, which is the interval from 2975-3105 feet deep (SS 1301) in the same boring as the Crane Member. The Kenyon Member is 34-130 feet thick. Where less than 80 feet thick it consists of coarse-grained sandstone containing small quartz pebbles, but elsewhere it is conglomeratic sandstone interbedded with nonconglomeratic layers.

Lovell Member—The Lovell Member of the Mt. Simon Sandstone (Templeton, 1950, p. 155), which overlies the Kenyon Member, is named for Lovell School, De Kalb County, three-fourths of a mile south of the type section, which is the interval from 2850-2975 feet deep (SS 1301) in the same boring as the Crane Member. The Lovell Member is 65-190 feet thick. It is largely fine- to medium-grained sandstone, although it ranges from very fine to very coarse. It is finer grained than the adjacent members.

Mayfield Member—The Mayfield Member of the Mt. Simon Sandstone (Templeton, 1950, p. 155), which overlies the Lovell Member, is named for Mayfield Township, De Kalb County, 5 miles west of the type section, which is the interval from 2495-2850 feet deep (SS 1301) in the same boring as the Crane Member. The Mayfield Member is 145-390 feet thick. It is composed of interbedded very coarse-grained conglomeratic sandstone and finer grained nonconglomeratic sandstone.

Lacey Member—The Lacey Member of the Mt. Simon Sandstone (Templeton, 1950, p. 155) overlies the Mayfield Member. It is named for Lacey School, De Kalb County, 2.5 miles east of the type section. The member is 1880-2070 feet deep in McQueen No. 1 boring (SW NE NE 27, 42N-3E) (SS 1466). The Lacey Member is 176-230 feet thick and is principally conglomeratic sandstone, although beds of fine-grained sandstone occur in the middle part and locally in the lower part. Beds of red shale are more common in the Lacey and higher members than in the lower members. Only the Lacey and higher members of the Mt. Simon are differentiated in northeastern Illinois (Buschbach, 1964).

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Gunn Member—The Gunn Member of the Mt. Simon Sandstone (Templeton, 1950, p. 155), which overlies the Lacey Member, is named for Gunn School, De Kalb County, 2.75 miles northwest of the type section. The member is 1648-1880 feet deep (SS 1466) in the same boring as the Lacey Member. The Gunn Member is 130-150 feet thick in the Chicago area, but elsewhere it is 71-260 feet thick. It is a relatively fine-grained member, but the sand ranges from fine to medium grained. A few thin conglomeratic beds are present in some areas.

Charter Member—The Charter Member of the Mt. Simon Sandstone (Templeton, 1950, p. 156), the uppermost member, is named for Charter Oak School, De Kalb County, 3.5 miles north of the type section, which is the interval from 1381-1648 feet deep (SS 1466) in the same boring as the Lacey Member. The Charter Member is 145-320 feet thick. It is medium- to fine-grained, partly conglomeratic sandstone with some red micaceous shale at or near the base.

KNOX DOLOMITE MEGAGROUP

The Knox Dolomite Megagroup (Safford, 1869, p. 151, 158-159; Swann and Willman, 1961, p. 477), named for Knox County, Tennessee, is relatively pure dolomite. The unit underlies the St. Peter Sandstone and overlies either the Potsdam Sandstone Megagroup or, as in much of Illinois, the interbedded sandstone and dolomite that is not included in either the Potsdam or the Knox Megagroups. The Knox Megagroup includes strata of Cambrian (Croixan) and Ordovician (Canadian and Chazyan) age (figs. 14, €-3). It underlies all of Illinois except small areas in northern Illinois where the sub-Tippecanoe unconformity cuts entirely through the dolomite formations and the St. Peter Sandstone rests on the Franconia Formation or, locally, on the Ironton Sandstone (fig. O-13). Although dominantly dolomite, in the northern part of the state the megagroup contains relatively thin sandstones—the New Richmond and Gunter Sandstones, the Momence Sandstone Member of the Eminence Formation, the Jordan Sandstone, and numerous thin beds in the Shakopee Dolomite (figs. €-3, O-8). The sandstones generally thin southward and disappear near the middle of the state. The megagroup, on the other hand, thickens southward from 300-500 feet in much of northern Illinois to more than 6000 feet in extreme southern Illinois (fig. €-7). The southward thickening of the Knox is related to northward truncation of the upper part of the Shakopee Dolomite and also to inclusion of the Everton Dolomite at the top of the megagroup in the extreme southern part of the state. In addition, the Franconia Formation and the Ironton and Galesville Sandstones grade southward into dolomite, resulting in repeated lowering of the base of the Knox until it reaches the top of

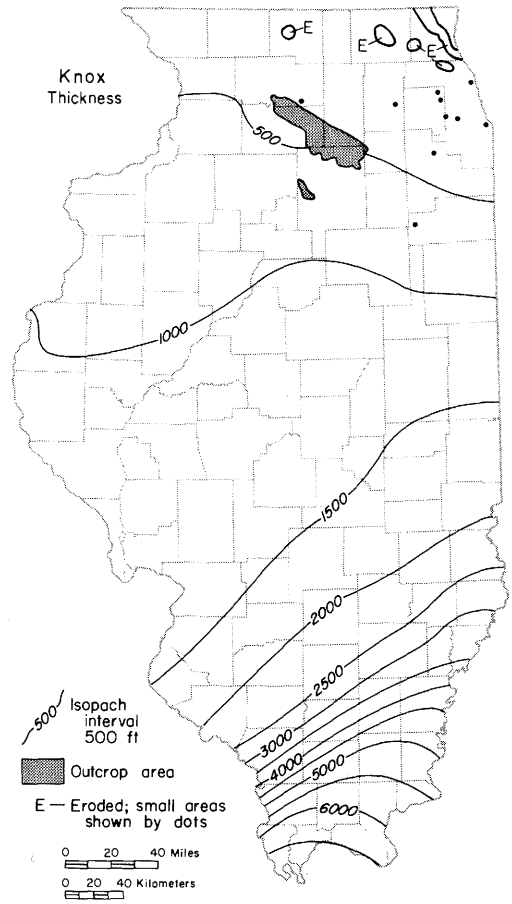

Fig. €-7—Thickness of the Knox Dolomite Megagroup.

the Mt. Simon Sandstone. In the northern part of the state, where the Knox is partly exposed and many wells penetrate the formations, the Knox is differentiated into several formations, which lessens the need to recognize the megagroup. In southern Illinois where the distinguishing characteristics of many formations disappear and the formations cannot be differentiated, the megagroup is more essential. The Knox Dolomite Megagroup is equivalent to the Knox Formation or Knox Group, as it is called in states south and east of Illinois, and to the Arbuckle and Ellenberger Formations or Groups in states to the southwest.

Eau Claire Formation

The Eau Claire Formation (Ulrich, *in* Walcott, 1914, p. 354) consists of dolomite and dolomitic sandstone, siltstone, and shale overlying the relatively clean sandstone of the Mt. Simon Sandstone and underlying the clean sandstone of the Galesville Sandstone. It is named for

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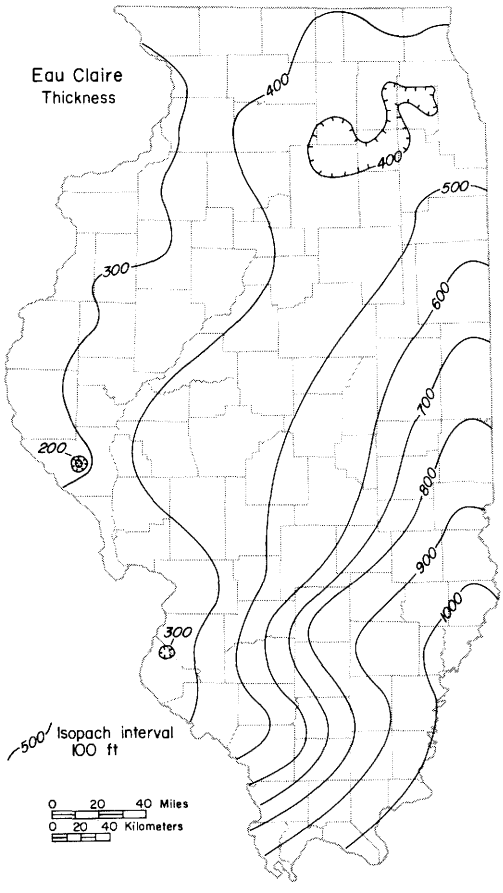

Fig. €-8—Thickness of the Eau Claire Formation.

Eau Claire, Eau Claire County, Wisconsin, where the type section consists of 100 feet of thin-bedded, partly shaly, fossiliferous sandstone (fig. €-1C). The Eau Claire Formation underlies all of Illinois, but it is not exposed. It ranges from less than 300 feet thick in the western part of the state to more than 1000 feet in the southeast (fig. €-8). In northern and western Illinois the Eau Claire Formation is dominantly dolomitic, fine- to medium-grained, gray sandstone, but it includes shaly siltstone and silty, sandy, glauconitic, brownish gray dolomite (fig. €-9). In central and eastern Illinois it is dominantly dolomitic, orange to pinkish gray siltstone and green, gray, or red shale, but it includes light gray, glauconitic, partly oolitic limestone and dolomite. In southern Illinois it is dominantly fine-grained, gray dolomite or limestone but it includes some beds of siltstone, shale, and sandstone. Some beds of the Eau Claire are oolitic, others are brecciated. The base of the Eau Claire is characterized by a "sooty" sandstone in which the sand grains are coated with a fine black powder consisting of pyrite (Workman and Bell, 1948). In northeastern Illinois the Eau Claire Formation is differentiated into three members that have been widely traced throughout the northern half of the state—the Elmhurst Sandstone Member (at the base), the Lombard Dolomite Member, and the Proviso Siltstone Member (Buschbach, 1964). Some beds in the Eau Claire contain abundant fragments of inarticulate brachiopods and trilobites, which can easily be observed in samples from borings, but the fauna has not been studied in Illinois. The Eau Claire is recognized from Minnesota to Kentucky and Ohio. West of Illinois it is equivalent to the Bonneterre Formation.

Elmhurst Sandstone Member—The Elmhurst Sandstone Member of the Eau Claire Formation (Buschbach, 1964, p. 32), the basal member, is named for Elmhurst, Du Page County, half a mile east of the type section, which is at a depth of 1640-1759 feet in a boring (Wander Co. No. 11, SE NW NE 10, 39N-11E) (SS 15,336). The Elmhurst Member is widely distributed in the northern half of Illinois and is 10-200 feet thick. Most of it is fine- to medium-grained, fossiliferous, gray sandstone that contains various amounts of interbedded gray shale. The basal part contains the sooty zone.

Lombard Dolomite Member—The Lombard Dolomite Member of the Eau Claire Formation (Buschbach, 1964, p. 32) overlies the Elmhurst Member and is named for Lombard, Du Page County, 2 miles west of the type section, which is at a depth of 1535-1640 feet (SS 15,336) in the same boring as the Elmhurst Member. The Lombard Member is recognized in northeastern Illinois, where it ranges from a few to 150 feet thick. It consists chiefly of grayish brown, glauconitic, partly sandy dolomite containing beds of greenish gray shale. It contains beds of limestone in Kane and Du Page Counties. Northward and westward it grades to sandstone, and southward it becomes more shaly.

Proviso Siltstone Member—The Proviso Siltstone Member of the Eau Claire Formation (Buschbach, 1964, p. 32), the uppermost member, is named for Proviso Township, Cook County, 2 miles east of the type section, which is at a depth of 1385-1535 feet (SS 15,336) in the same boring as the Elmhurst Member. It is widely present in the northern part of Illinois. It is 150-300 feet thick, except near the northern boundary of the state where it grades to sandstone and is not differentiated. It is dominantly dolomitic, sandy, firm, orange to pinkish gray, feldspathic, slightly glauconitic siltstone that commonly contains beds of greenish gray, pink, or red shale. Along its northern limit it is sandstone and shale, but southward it becomes more dolomitic. The upper few to 40 feet consists of fine-grained dolomitic sandstone or sandy dolomite that is transitional to the overlying Galesville Sandstone.

Galesville Sandstone

The Galesville Sandstone (Trowbridge and Atwater, 1934, p. 45), a clean, unfossiliferous sandstone, is named for Galesville, Trempealeau County, Wisconsin, where the type section is in an exposure on Beaver Creek. The section exposes poorly sorted, fossiliferous sandstone of the Ironton Formation overlying 88 feet of the Galesville Sandstone, which in turn lies on fossiliferous sandstone and shale of the Eau Claire Formation. In earlier reports Galesville and Ironton Sandstones were called the Dresbach Sandstone. In many borings in Illinois the Galesville is not easily distinguished from the overlying Ironton Sandstone, and their combined thickness is shown in figure €-10. The Galesville occurs throughout the northern half of Illinois but is not exposed. It is commonly 40-100 feet thick. At its southern margin, the Galesville grades laterally through a zone of dolomitic sandstone about 50 miles wide to nonsandy dolomite of the Knox Megagroup. The name "Galesville" is applied as far south as the sandy zone can be identified, at which place the for-

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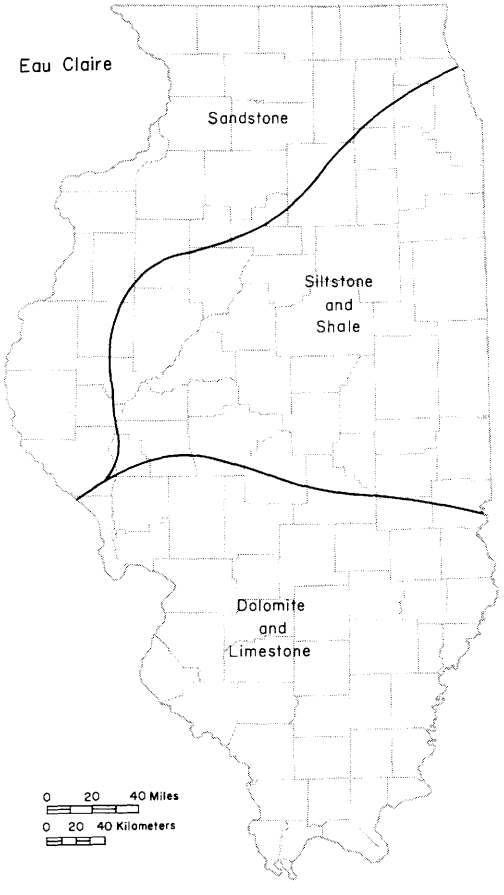

Fig. €-9—Dominant rock types in the Eau Claire Formation.

mation is terminated by vertical cut-off. The Galesville Sandstone consists of white to light buff, clean to locally silty, fine-grained, moderately well sorted, friable, and generally nondolomitic sandstone (Buschbach, 1964). Locally, light buff to pink dolomite is a cementing material. From a petrographic study and analysis of sedimentary structures, Emrich (1966) concluded that the Galesville and Ironton Sandstones were derived from pre-existing sedimentary rocks north of Illinois and were deposited on a broad, shallow shelf. The Galesville appears to be conformable with both the overlying and underlying formations. It is also recognized in Iowa, Minnesota, Michigan, and Indiana. It is not traced directly to the Missouri outcrop region, but it probably is equivalent to the upper carbonate beds of the Bonneterre Formation. The Galesville and the overlying Ironton Sandstone form an important aquifer in northern Illinois.

Franconian Stage

The Franconian Stage (Howell et al., 1944, chart 1) includes the strata from the *Elvinia* Zone (at the base) to the top of the *Dikelocephalus postrectus* Zone and is based on the type section of the Franconia Formation at Franconia, Chisago County, Minnesota. Some stratigraphers prefer to place the top of the stage lower in the Franconia, at the top of the *Ptychaspis-Prosaukia* Zone of Bell et al. (1956)—the *Prosaukia* Zone of Lochman-Balk and Wilson (1958). These faunal zones have not been differentiated in Illinois, but the Ironton and Franconia Formations are at least approximately equivalent to the type Franconia Formation and are included in the Franconian Stage.

Ironton Sandstone

The Ironton Sandstone (Thwaites, 1923, p. 93-94), a relatively coarse-grained sandstone overlying the finer grained Galesville Sandstone and underlying the glauconitic, argillaceous sandstone of the Franconia Formation, is named for Ironton, Sauk County, Wisconsin, where it consists of a few feet of hard, calcareous, coarse-grained sandstone classified as the basal member of the Franconia Formation. In Illinois, a much thicker coarse-grained sandstone at this position, previously included in the Dresbach Sandstone, was correlated with the Ironton Member of the Franconia, but it later was made a separate formation (fig. €-5). The Ironton Sandstone, like the Galesville (fig. €-10), occurs throughout the northern half of Illinois and is not exposed. The Ironton is commonly 50-100 feet thick, but it is somewhat thinner in northwestern Illinois. Near the northern boundary of Illinois, the Ironton is medium-grained, poorly sorted, white sandstone with coarse-grained beds near the top. It

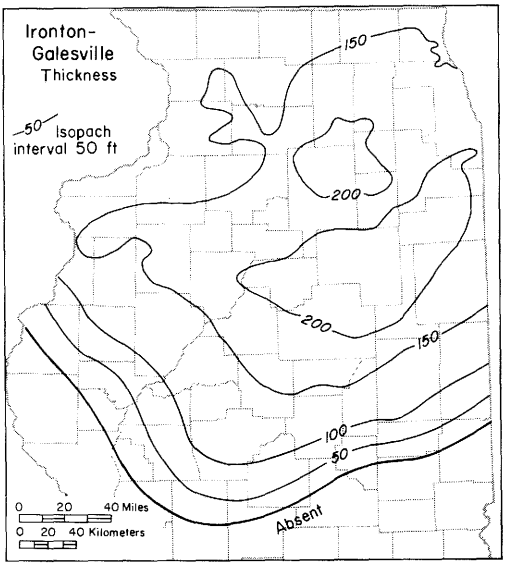

Fig. €-10—Thickness of the Ironton and Galesville Sandstones.

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generally contains light pinkish buff dolomite as a cementing material and as pebbles in conglomeratic layers (fig. €-1D). Farther south it is more dolomitic. At its southern margin it grades into sandy dolomite, and, like the Galesville Sandstone, is terminated by vertical cutoff. The Ironton Sandstone is coarser grained than sandstones in the formations above and below, and it lacks the clay and glauconite commonly associated with the overlying Franconia (Buschbach, 1964). Variations in grain size and dolomite content serve to divide the Ironton into four members: the Buelter Member (at the base) is medium-grained sandstone; the Fox Valley Member is medium- to coarse-grained dolomitic sandstone; the Marywood Member is finer grained and less dolomitic sandstone; and the Mooseheart Member (at the top) is medium- to coarse-grained dolomitic sandstone. The petrographic characteristics of the Ironton Sandstone have been described by Emrich (1966). In the outcrop region in Wisconsin, the Ironton is fossiliferous and contains the *Elvinia* Zone, which marks the base of the Franconian Stage. Worm borings are common in some of the dolomitic beds, which are called wormstone beds. The Ironton Sandstone is conformable with the formations above and below. It is also present in Minnesota, Michigan, and Indiana but is an undifferentiated part of the Galesville Sandstone in those areas. It is correlated with the lower part of the Davis Formation in Missouri.

Buelter Member—The Buelter Member of the Ironton Sandstone (Buschbach, 1964, p. 36), the basal member, is named for Buelter School, Kane County, 2 miles east of the type section, which is at a depth of 1180-1230 feet in Batavia city well No. 3 (SE SW NE 22, 39N-8E) (SS 6901). It is widely present in northern Illinois, where it is 20-80 feet thick. It is dominantly medium-grained, moderately well sorted, rarely dolomitic sandstone. The contact with the underlying fine-grained, well sorted sandstone of the Galesville is generally sharp.

Fox Valley Member—The Fox Valley Member of the Ironton Sandstone (Buschbach, 1964, p. 37), which overlies the Buelter Member, is named for the Fox River Valley, where the type section occurs at a depth of 1168-1180 feet in the same well as the Buelter type section. The Fox Valley Member is commonly 10-25 feet thick. It consists of poorly sorted medium- to coarse-grained sandstone that is consistently dolomitic. Dolomite occurs as cementing material and as stringers of light pink to buff sandy dolomite interbedded with the sandstone. Brown spheroids and oolites are present in the dolomite.

Marywood Member—The Marywood Member of the Ironton Sandstone (Buschbach, 1964, p. 37), which overlies the Fox Valley Member, is named for Marywood, Kane County, 4 miles south of the type section, which is at a depth of 1120-1168 feet in the same well as the Buelter type section. The Marywood Member appears to be as widespread as the other members, but in some areas it is not readily separated from the units above and below. It is 10-50 feet thick and consists of sandstone that is finer grained and less dolomitic than the units above and below.

Mooseheart Member—The Mooseheart Member of the Ironton Sandstone (Buschbach, 1964, p. 37), the uppermost member, is named for a Kane County lake, Mooseheart Lake, 2 miles southwest of the type section, which is at a depth of 1092-1120 feet in the same well as the Buelter type section. The Mooseheart Member is 20-60 feet thick. It consists of poorly sorted, medium- to coarse-grained dolomitic sandstone. Coarse grains of glauconite occur in the upper beds.

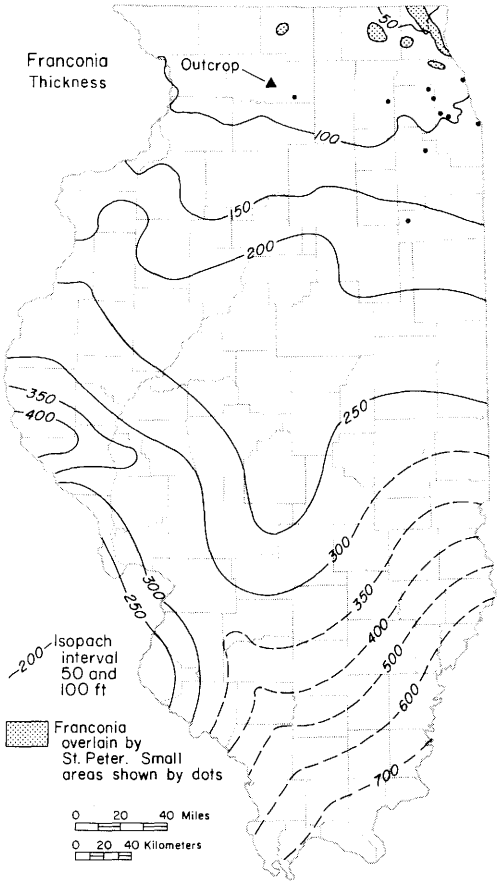

Fig. €-11—Thickness of the Franconia Formation.

Franconia Formation

The Franconia Formation (Berkey, 1897, p. 373) consists of glauconitic, argillaceous sandstone and dolomite underlying the relatively pure Potosi Dolomite. It is named for Franconia, Chisago County, Minnesota, where the type section consists of 100 feet of sandstone and shale. In Illinois, these strata were originally differentiated as Mazomanie by Thwaites (1927) and first assigned to the Franconia by Workman (1935). The Franconia Formation underlies all of Illinois but is exposed in only one locality, half a mile east of Oregon, Ogle County, where the upper 30 feet, overlain by the Potosi Dolomite, is poorly exposed. This is the oldest formation exposed in Illinois, although it and older Cambrian strata may underlie the glacial drift along the south side of the Sandwich Fault Zone in Ogle, Lee, or De Kalb Counties. The Franconia Formation thickens southward from about 50 feet near the northern boundary of Illinois to probably 500-700 feet in the southern part of the state (fig. €-11). In extreme northern Illinois, the Franconia consists largely of gray to pink, glauconitic, silty, argillaceous, fine-grained, dolomitic sandstone that contains various amounts of red and green shale. Raasch reported several

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species of trilobites, oboloid brachiopods, and worm casts in the exposure at Oregon (Willman and Templeton, 1951). Southward from that area the lowermost part of the Franconia becomes increasingly shaly (Davis Member), and the uppermost part grades to silty and sandy dolomite (Derby-Doerun Member). In north-central Illinois these two units are separated by a wedge of fine-grained, glauconitic, dolomitic sandstone similar to the strata that compose the entire Franconia of extreme northern Illinois. In the central and southern parts of the state, the glauconitic sandstone is absent, and the silty, shaly sandstone of the Davis is directly overlain by the relatively pure dolomite of the Derby-Doerun. Because of its diminishing amounts of sand, shale, and glauconite, the upper part of the Franconia is difficult to differentiate from the overlying Potosi Dolomite, and the base of the Knox Dolomite Megagroup steps down to include the Derby-Doerun Member. In Illinois the Franconia is conformable with the overlying and underlying formations. It is also recognized in Wisconsin, Iowa, Michigan, Indiana, and Kentucky, and it is equivalent to the Elvins Group in Missouri.

Davis Member—The Davis Member of the Franconia Formation (Buckley, 1907; 1909, p. 33), the basal member, is named for outcrops on Davis Creek, St. Francois County, southeast Missouri. It is recognized as a shaly sandstone unit at the base of the Franconia throughout all of Illinois except the extreme north, where the entire Franconia is represented by shaly and glauconitic sandstone, and in the southeast (Lawrence and Hamilton Counties), where the unit appears to have graded to dolomite and is included in the Knox Megagroup. It ranges from a few feet thick in the north to about 100 feet in the south. It grades from shaly sandstone in the north to silty, sandy, argillaceous dolomite in the south. The member is characterized by green, gray, or red shale partings and by flat-pebble conglomerate.

Derby-Doerun Member—The Derby-Doerun Member of the Franconia Formation (Buckley, 1907; 1909, p. 44) overlies the Davis Member in central and southern Illinois. In north-central Illinois it is the upper part of the Franconia where the lower part of the Franconia is fine-grained glauconitic sandstone. The Derby and the overlying Doerun were named separately for exposures in the vicinity of mines operated by the Derby Lead Company and the Doerun Lead Company near Elvins, St. Francois County, Missouri. Their similar lithology and a conformable relationship resulted in their being combined as a formation with a hyphened name (Hayes and Knight, 1961). In north-central Illinois the Derby-Doerun is silty argillaceous dolomite. Farther south it becomes quite pure, except for a thin zone at the top that is slightly sandy, argillaceous, and glauconitic. The member is about 20 feet thick in the north and it thickens to probably more than 500 feet in the southeast. It is included in the Knox Dolomite Megagroup.

Trempealeauan Stage

The Trempealeauan Stage (Howell et al., 1944, chart 1) consists of the strata from the base of the *Platycolpus-Scoevogyra* Zone to the top of the *Plethopeltis* Zone as they are represented in the type section of the Trempealeau Formation (now called the St. Lawrence Formation) at Trempealeau, Trempealeau County, Wisconsin. However, more recent work (Raasch, 1951; Lochman-Balk and Wilson, 1958) favors placing the base of the Trempealeauan somewhat lower—at the base of the *Saukia* Zone in the Franconia Formation. As the fossil zones have not been recognized in Illinois, the exact position of the base of the Trempealeauan Stage is uncertain and is placed at the top of the Franconia Formation. The Potosi, Eminence, and Jordan Formations are included in the Trempealeauan Stage.

Potosi Dolomite

The Potosi Dolomite (Winslow, 1894, p. 331, 351, 355), named for Potosi, Washington County, Missouri, is a relatively pure dolomite overlying the sandstone and sandy dolomite of the Franconia Formation and underlying the sandy Eminence Formation. In northern Illinois it was called Trempealeau (Workman and Bell, 1948) until the type Trempealeau was renamed "St. Lawrence" and "Trempealeauan" was used for the stage name. Potosi was then extended to northern Illinois (Buschbach, 1964). The Potosi Dolomite underlies essentially all of Illinois, except in parts of northern Illinois where it was truncated by the sub-Tippecanoe unconformity. It is exposed in the

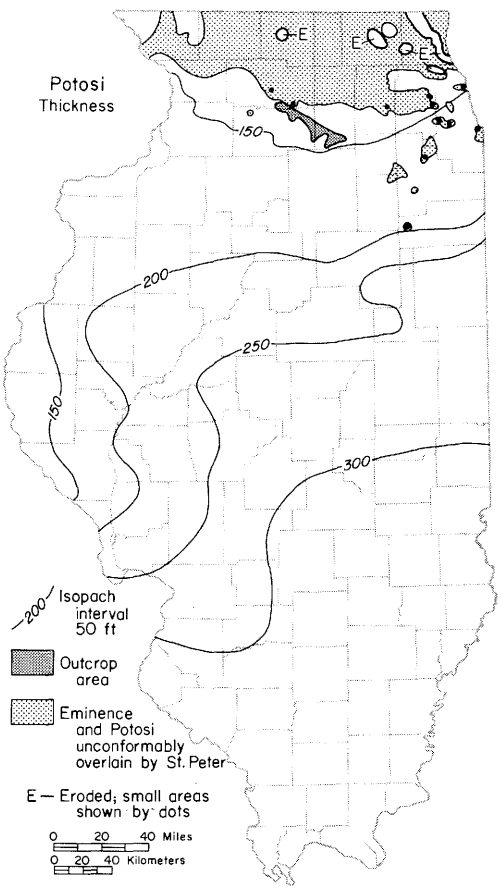

Fig. C-12—Thickness of the Potosi Dolomite.

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Oregon and Ashton areas in Ogle and Lee Counties (Willman and Templeton, 1951) (fig. €-1A), where it is generally overlain by the St. Peter Sandstone. The exception is one exposure in Lee County, 4 miles south of Rochelle, Ogle County, where it is overlain by the Oneota Dolomite (fig. €-1B). The Potosi ranges from 100 feet thick in northern Illinois to more than 300 feet in southern Illinois (fig. €-12). It consists of finely crystalline, pure to slightly argillaceous, brown to pinkish gray dolomite that is very slightly glauconitic at the top and glauconitic and sandy at the base. Drusy quartz covers the surfaces of small cavities in most areas and characterizes the formation in both outcrops and well samples. The Potosi contains algal domes and rare trilobite and gastropod remains. In the southern two-thirds of the state the Potosi is conformable with the Franconia below and the Eminence above, but in wide areas in northern Illinois it is unconformably overlain by the St. Peter Sandstone. Locally over the Ashton Arch the Eminence is absent and the Oneota overlies the Potosi. The Potosi is equivalent to the St. Lawrence Dolomite in Wisconsin (Ostrom, 1967), Michigan (Catacosinos, 1973), and Minnesota (Stauffer and Thiel, 1941) and to the Trempealeau Dolomite in Indiana (Gutstadt, 1958a).

Eminence Formation

The Eminence Formation (Buckley, 1908, p. 286), a sandy dolomite overlying the Potosi Formation, is named for Eminence, Shannon County, Missouri. It was traced into central Illinois by Workman and Bell (1948) and extended by Buschbach (1964) to northeastern Illinois, where it previously had been included in the Trempealeau or the Oneota. The formation underlies most of Illinois, except the northern part, where it was truncated by the sub-Tippecanoe unconformity at the base of the St. Peter Sandstone. Over the Ashton Arch it appears to thin to a feather edge. It is not exposed in Illinois. The Eminence is 50-250 feet thick in the areas where it is overlain by the Gunter Sandstone or the Oneota Dolomite (fig. €-13). It consists of light gray to brown or pink, sandy, fine- to medium-grained dolomite that contains oolitic chert and thin beds of sandstone. The formation contains less drusy quartz than the Potosi and is sandier and finer grained than the Oneota. In the southern third of Illinois the Eminence loses much of its sand and becomes an undifferentiated part of the Knox Megagroup. Sandstone at the base of the formation is differentiated as the Momence Sandstone Member. The irregular distribution of the Momence and the overlying Gunter Sandstone suggests that the formation may be bounded by minor unconformities, but otherwise the relations appear to be conformable. Except around the margins, sedimentation in the Illinois Basin was probably essentially continuous from Cambrian into Ordovician time. In the extreme northwestern part of Illinois, the Eminence Formation grades laterally into the Jordan Sandstone.

Momence Sandstone Member—The Momence Sandstone Member of the Eminence Formation (Buschbach, 1964, p. 41) is named for Momence, Kankakee County, just east of the type section, which is at a depth of 1650-1660 feet in the Hughes Oil Company No. 1 Parish boring (NW NW SW 24, 31N-13E) (SS 997). It is the only member differentiated in the Eminence Formation and occurs at the base. The Momence Member varies from 0-15 feet thick but is somewhat discontinuous. It consists of light gray, dolomitic, poorly sorted sandstone, and in places contains interbedded green and gray sandy shale.

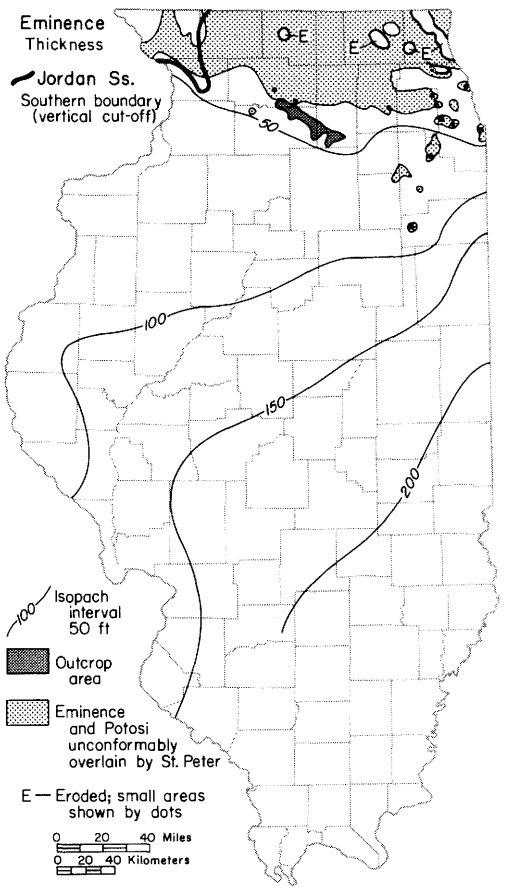

Fig. €-13—Thickness of the Eminence Formation.

Jordan Sandstone

The Jordan Sandstone (A. Winchell, 1872), the uppermost Cambrian formation in the extreme northwestern part of Illinois, is named for Jordan, Scott County, Minnesota, where it is exposed in quarries and outcrops along Sand Creek (N.H. Winchell, 1874, p. 149). It is not exposed in Illinois but is a few to 75 feet thick in wells in Jo Daviess and Carroll Counties. In exposures along the Mississippi River a short distance northwest of Illinois in Iowa, Minnesota, and Wisconsin, the formation is a white to yellowish gray, partly iron-stained sandstone that is medium to fine grained at its base. In some places the upper part is coarse to very coarse grained (Stauffer and Thiel, 1941). It varies from thin to thick bedded. Cross bedding is common. Fossils are abundant in some beds in the outcrop area. East and south of Jo Daviess and Carroll Counties the Jordan Sandstone grades laterally to the Eminence Formation.

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ORDOVICIAN SYSTEM

H. B. Willman and T. C. Buschbach

The Ordovician System (Lapworth, 1879, p. 12-14) underlies all of Illinois except a few areas in the northern part of the state where it has been eroded and Cambrian rocks are at the surface (fig. O-1). The name "Ordovician" is derived from *Ordovices*, the Roman name for a people who inhabited Wales, where these rocks are well exposed. Before "Ordovician" was introduced, these strata were included in the Silurian System, and they were called Lower Silurian in the early reports on Illinois stratigraphy.

Ordovician rocks are widely exposed in northern Illinois, particularly along the upper Illinois Valley, the Rock Valley, the Pecatonica Valley, and the Upper Mississippi Valley and its tributaries north of Savanna. Elsewhere in Illinois they are exposed only along truncated anticlines—in Calhoun and Jersey Counties, Monroe County, and Alexander County. Typical exposures are shown in figure O-2.

The Ordovician System, where overlain by the Silurian System, ranges from 700 feet thick in extreme northeastern Illinois to more than 5000 feet in southern Illinois (fig. O-1). The variations in thickness are related to major unconformities that occur at the top and within the Ordovician System and to original southward thickening of many of the formations. The structure of the system is shown by the map of the structure of the top of the Galena Group (fig. O-3).

The Ordovician System is subdivided into three series based on faunal correlations and on lithologic tracing from Illinois to their type regions. The Canadian Series and the Champlainian Series have been traced to New York State, and the Cincinnatian Series to Cincinnati, Ohio.

The Ordovician System in Illinois is dominantly dolomite and limestone. It is differentiated into 26 formations and 66 members (fig. O-4). Four of the formations are dominantly sandstone, four are shale, and 18 are limestone or dolomite. Most of the formations extend throughout the state and many throughout the Mississippi Valley. Some even have lithologic continuity eastward to New York and Virginia, southward to Tennessee, westward to Colorado, and northward to northern Michigan and Ontario (Templeton and Willman, 1963).

The Ordovician System is separated from the systems above and below it by unconformities, but both unconformities are difficult to recognize in parts of the state, particularly in the subsurface. In the southern part of Illinois, the lowermost Ordovician dolomites are not readily separable from the Cambrian dolomites that underlie them, especially in areas where the basal Ordovician Gunter Sandstone is missing. The upper Ordovician (Cincinnatian) shales in some areas contain dolomitic siltstones that are not readily separable from similar early Silurian sediments that fill erosional channels cut into the Cincinnatian strata.

Within the Ordovician System other unconformities occur, particularly at the base of the Champlainian (the sub-Tippecanoe unconformity) and the base of the Cincinnatian Series. Within the Champlainian Series, a lesser but widespread unconformity occurs at the base of the Trentonian Stage. The Champlainian rocks contain numerous minor diastems that reflect interruptions in sedimentation but do not indicate withdrawal of the sea. Corrosion surfaces, which truncate only a few inches of strata, represent temporary cessation of carbonate deposition and solution of the sea floor. Current-produced features include wavy scour surfaces, which generally have a relief of less than 6 inches, and giant ripple marks.

During most of Ordovician time, Illinois was in a broad sea, far from the shores and from the sources of clastic sediments. Most of the sediments were moderately deep-water, fine-grained carbonate. During mid-Champlainian Blackriveran time, shallow-water argillaceous carbonates and evaporites (Joachim, Glenwood) were deposited; later, during Trentonian time, coarse calcarenites (Kimmswick) accumulated in the southern part of Illinois. The sand in the Canadian and early Champlainian sandstones came from the north. Only during Cincinnatian time, when large deltas were being built in the Appalachian region, did clay and silt from the east dominate the clastic sediments in Illinois.

During Canadian time the sea covered the entire state, and sedimentation was essentially

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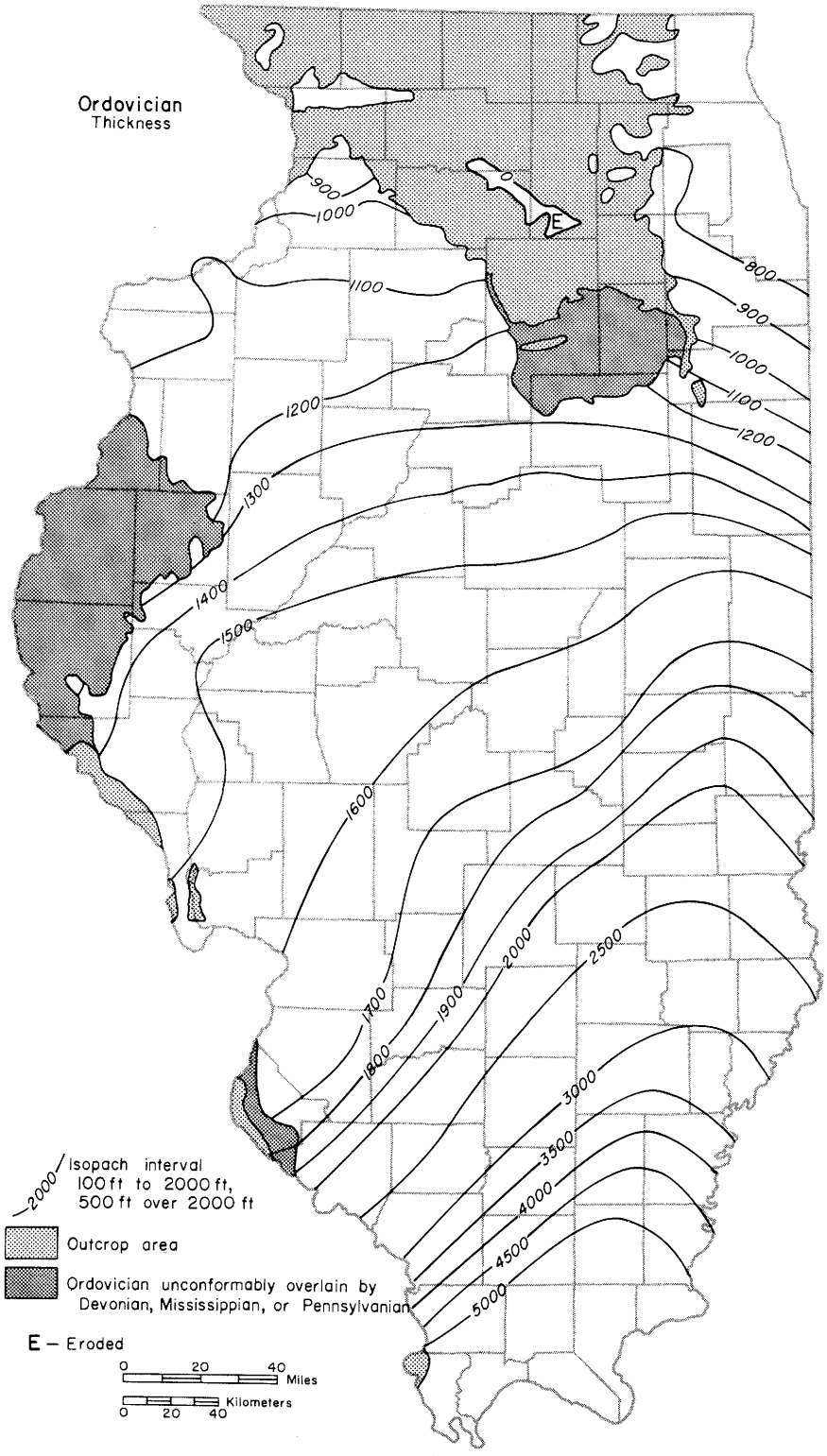


Fig. O-1—Thickness of the Ordovician System.

similar to that of the Cambrian. The Canadian sediments were deeply eroded before the early Champlainian (Chazyan) sediments—largely dolomite, sandy dolomite, and sandstone—were deposited in Illinois. These sediments have much the same character as the Canadian rocks, but in Illinois they were eroded from all except the extreme southwestern part of the state before St. Peter deposition. Their composition suggests they could originally have been as extensive as the Canadian sediments.

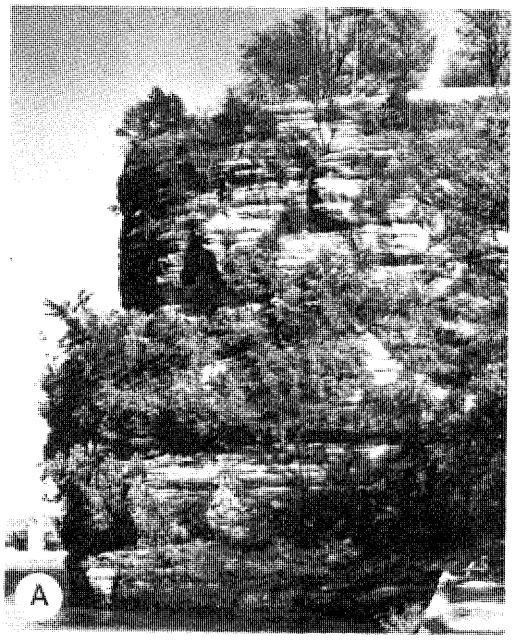
The St. Peter Sandstone, at the base of the Champlainian Series in most of Illinois, is an unusually extensive, very pure, uniformly fine-grained, and well sorted quartz sandstone, which appears to have been deposited by a sea advancing northward across the Illinois Basin (Dapples, 1955). South of Illinois it grades into sandy carbonates. Across north-central Illinois the final episode of St. Peter deposition was a broad, east-west, offshore bar of medium-grained sandstone (fig. O-16). North of the bar, and partly contemporaneous with it, the poorly sorted sandstone, impure dolomite, and shale of the Glenwood accumulated, and south of the bar the shaly limestone of the Dutchtown and the sandy and argillaceous dolomite of the Joachim were deposited. These impure sediments join the St. Peter to form the Ancell Group.

In the Champlainian Series overlying the Ancell, dominantly carbonate rocks are characterized by the persistence of thin units that are identified by relative purity, texture, bentonite beds, and fossils. The argillaceous materials in the Champlainian carbonate rocks in northern Illinois came largely from a northerly source, as is shown by the gradual change in Trentonian rocks from nearly pure carbonate in Illinois to calcareous shale at the northern margin in Minnesota (fig. O-23). The thin shale, sandstone, and siltstone beds in the Blackriveran and lower Trentonian rocks in southwestern Illinois thicken onto the Ozarks, which the overlapping relations of the basal Trentonian strata show were at least intermittently above sea level. The red-brown shales in the Guttenberg Formation thicken to the south in Illinois and the red color may be from the residuum on Cambrian and early Ordovician carbonate rocks in the Ozarks. Although the amount of shale also increases northward from northern Illinois, the red color does not extend far north of the state boundary.

Seven thin beds of bentonite are widely present in the Ordovician section in Illinois, most of them in the Champlainian Series. Bentonites have been found locally at several other horizons, and others may occur at distinctive, smooth-surfaced bedding planes like those commonly associated with bentonites. Although the bentonites in Illinois are generally less than an inch thick, a few, possibly thickened locally by squeezing, are 3 or 4 inches thick. Most of them are correlated with much thicker beds in Kentucky, Tennessee, and Virginia (Templeton and Willman, 1963).

The rocks of the Canadian Series contain few fossils, but the Champlainian and Cincinnatian rocks have large faunas, and fossils are abundant in many beds (fig. O-5). An occasional high-spired gastropod is the most prevalent invertebrate fossil found in the Canadian rocks, but algal domes are common, particularly in the Shakopee Dolomite. In the Champlainian Series the Chazyan strata and the Ancell Group strata have few fossils other than worm borings, except in the Dutchtown, which is not exposed in Illinois. The Platteville and Galena Groups contain a variety of fossils, among which brachiopods, bryozoans, gastropods, and corals are most abundant. Crinoidal debris is abundant in some beds, particularly in southern Illinois. Pelecypods and trilobites are common in a few beds, and conodonts are numerous in the limestones. Fucoids of several types, possibly impressions of marine plants, are abundant and widely distributed in many beds. Several faunal zones based on abundance of one or more species of invertebrates are recognized (fig. O-24) and are widely useful for identification of the formations. The base of the Trentonian rocks is well defined by an abundance of several species that appear for the first time.

In the Cincinnatian strata, brachiopods and many species of bryozoans are abundant in most limestones and calcareous shales. Fossils are not common, however, in the very argillaceous limestone, the brown shales and siltstones, or the light greenish gray shales. One to three beds at or near the base of the Scales Shale and another bed 60-70 feet above the base contain a distinctive fauna of small fossils, mostly gastropods and pelecypods less than a quarter of an inch in greatest dimension. These beds are called depauperate beds, and the intervals in which they occur depauperate zones. The beds are mainly phosphatic and pyritic and are generally only an inch or two thick, although locally they are as much as a foot thick. The lower zone is very persistent, but the upper has been found only in northeastern and central Illinois.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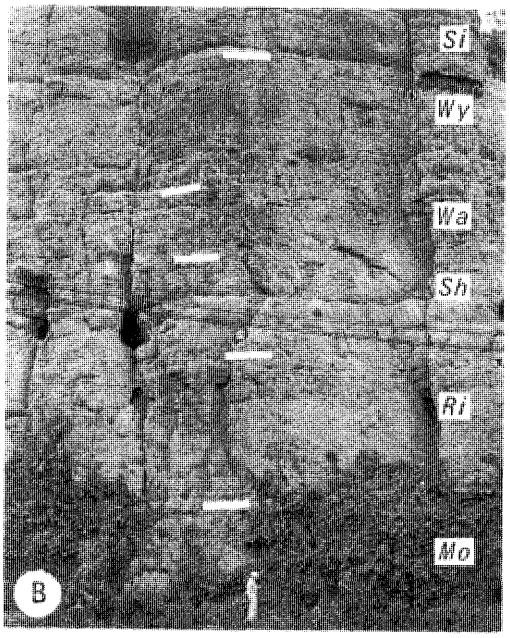
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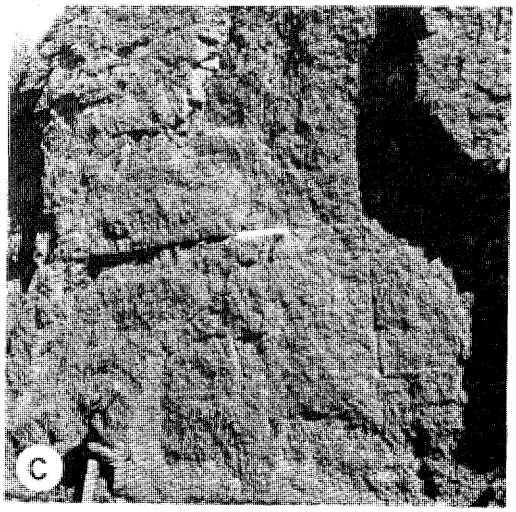
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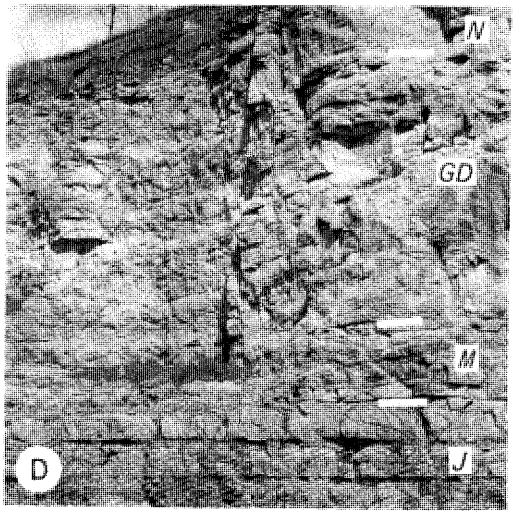
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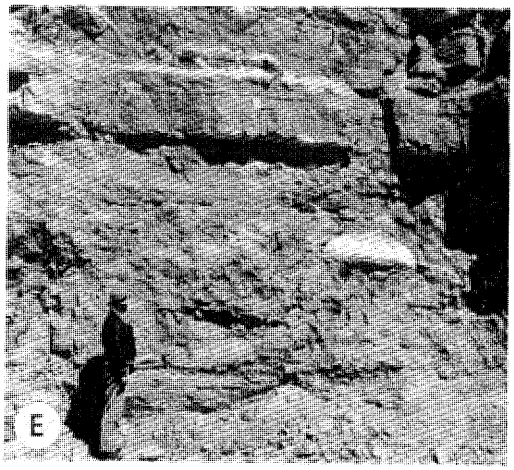
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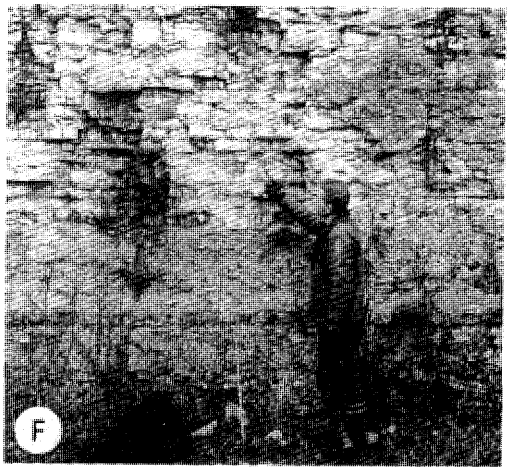
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CANADIAN SERIES

The Canadian Series (Dana, 1874, p. 214), named for exposures in eastern Canada, unconformably overlies Cambrian dolomite (Eminence) throughout most of Illinois, but in northwestern Illinois it overlies Cambrian sandstone (Jordan). The series, in turn, is overlain unconformably by Champlainian sandstone (St. Peter), except in the southernmost part of the state where it is overlain by sandy dolomite (Everton) (fig. O-4). The lower Ordovician strata in Illinois have been included in the Canadian Series since 1963 (Templeton and Willman). They were called the Lower Magnesian (Owen, 1840) until the early 1900s, at which time they were named the Prairie du Chien or Lower Ordovician Series (fig. O-6). The Canadian Series is represented in Illinois by the Prairie du Chien Group, which chiefly consists of as much as 2500 feet of cherty dolomite that contains some beds of sandstone. Canadian strata contain few megafossils, and preservation of the fossils is generally poor. Gastropods, cephalopods, and algal mounds are the most common evidences of the life from the Canadian seas.

Prairie du Chien Group

The Prairie du Chien Group (Bain, 1906, p. 18) includes all strata of Canadian age in Illinois. The group is named for exposures near Prairie du Chien, Crawford County, Wisconsin, where it consists of 200-300 feet of dolomite and sandstone. The group is present throughout much of Illinois (fig. O-7). It is almost entirely absent in the northern two tiers of counties and is missing locally in the rest of the northern third of the state, having been removed by solution and erosion before the St. Peter Sandstone was deposited. It is also absent in areas where Cambrian rocks crop out near the Sandwich Fault Zone, on the Ashton Arch, and on the Oregon Anticline. Prairie du Chien strata crop out along the Fox and Rock Valleys, mainly just south of the Sandwich Fault Zone. The group thickens southward, chiefly by the addition of younger beds at the top, to about 800 feet along a line between Edgar and Monroe Counties. South of there, the base of the Prairie du Chien cannot be picked with confidence, but the group appears to thicken to at least 2500 feet. In the southern part of the state, Prairie du Chien strata combine with the underlying Cambrian carbonates to form the Knox Dolomite Megagroup. The Prairie du Chien Group consists of cherty dolomite with some interbedded sandstone. It is subdivided into the Gunter Sandstone (at the base), the Oneota Dolomite, the New Richmond Sandstone, and the Shakopee Dolomite (fig. O-8). The Prairie du Chien Group is equivalent to Beekmantown strata in Ohio, upper Knox in Tennessee, and upper Arbuckle in Oklahoma.

Gunter Sandstone

The Gunter Sandstone (Ball and Smith, 1903, p. 26) is named for the now abandoned Gunter post office in Miller County, central Missouri, where it is 2.5-18 feet thick in exposures along the Osage River. It is absent in outcrops of lower Prairie du Chien strata in Lee and Ogle Counties, Illinois. In subsurface, the Gunter is commonly a few to 20 feet thick and has a widespread but patchy distribution (fig. O-9). It is continuous and 10-25 feet thick between the centers of La Salle and McLean Counties in north-central Illinois. The Gunter consists of medium- to fine-grained, moderately sorted, subrounded quartz grains. It contains thin beds of light gray, fine-grained dolomite and small amounts of green shale. Sharp contacts and irregular distribution of the sandstone suggest unconformities at its top and bottom. The Gunter is tentatively correlated with the Rose Run Sandstone at the base of the upper Knox in eastern Ohio and eastern Kentucky.

Oneota Dolomite

The Oneota Dolomite (McGee, 1891, p. 331-333) is named for exposures along the Oneota River (now Upper Iowa River), Allamakee County, northeastern Iowa. In Illinois it is exposed in quarries and ravines along the Ashton Arch near the Fox and Rock Rivers (Willman and Templeton, 1951). The Oneota underlies all of Illinois

Fig. O-2—Exposures of Ordovician rocks.

A—St. Peter Sandstone in Starved Rock along the Illinois River in Starved Rock State Park, 4 miles southeast of La Salle, La Salle County.

B—Type section of the Dunleith Formation showing the Mortimer (Mo), Rivoli (Ri), Sherwood (Sh), Wall (Wa), and Wyota (Wy) Members overlain by the Sinsinawa Member (Si) of the Wise Lake Formation at East Dubuque, Jo Daviess County (Templeton and Willman, 1963, geol. sec. 28, p. 238).

C—Massive Wise Lake Formation overlying the thinner bedded Dunleith Formation, which contains lenses and beds of white chert, in a quarry on the south side of Freeport, Stephenson County.

D—Relatively thin-bedded Platteville Limestone Group showing the Nachusa (N), Grand Detour (GD), and Mifflin (M) Formations overlying the thick-bedded Joachim Dolomite (J) in a quarry at West Point Landing, Calhoun County (Templeton and Willman, 1963, geol. sec. 11, p. 228).

E—Massive Oneota Dolomite containing a large algal growth; in a quarry in Lee County, 6 miles south of Rochelle, Ogle County.

F—Thin-bedded dolomite of the Quimbys Mill Formation overlying massive dolomite of the Nachusa Formation in a quarry on River Street in Dixon, Lee County.

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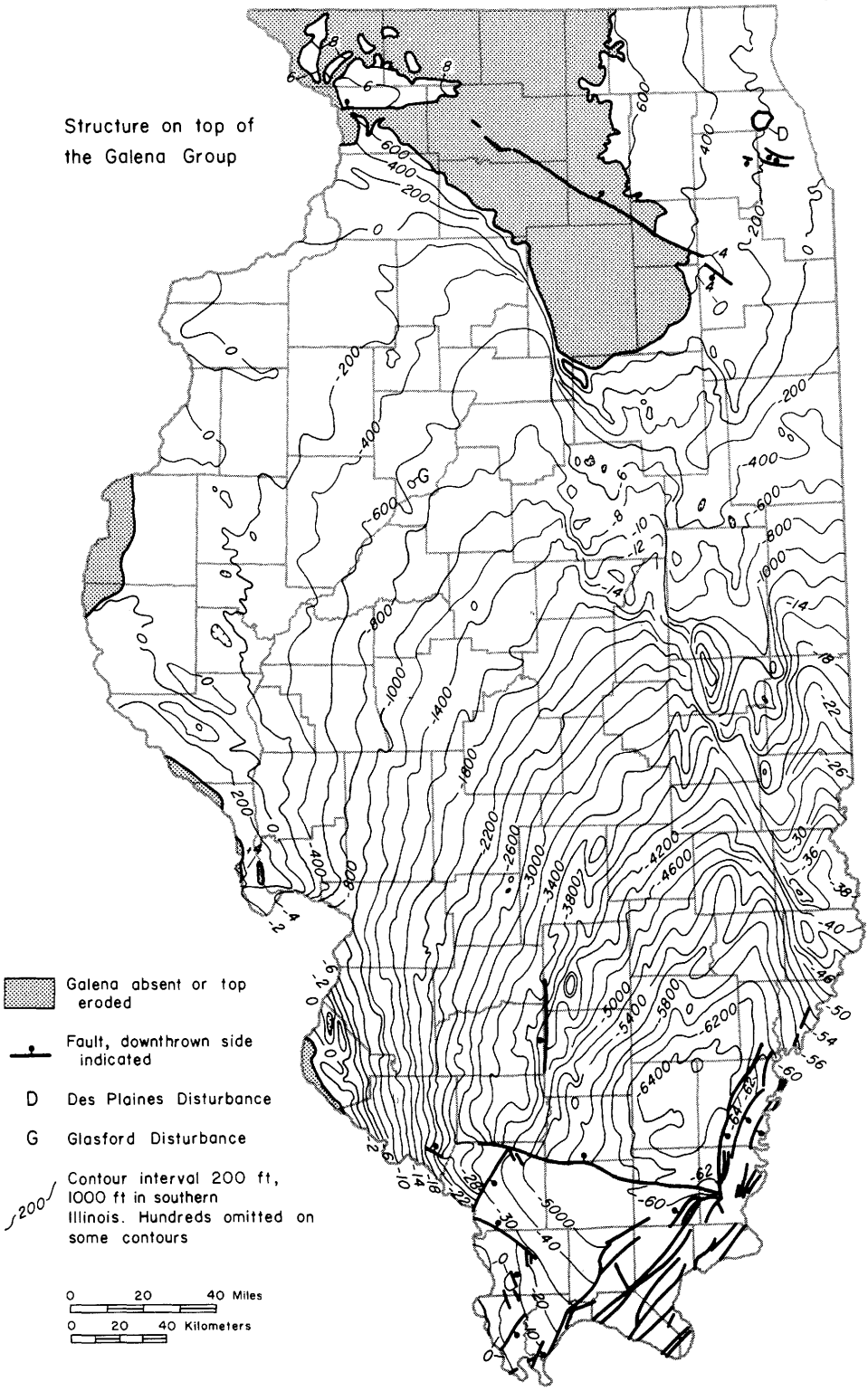

Fig. O-3—Structure of the top of the Galena Group (after Bristol and Buschbach, 1973).

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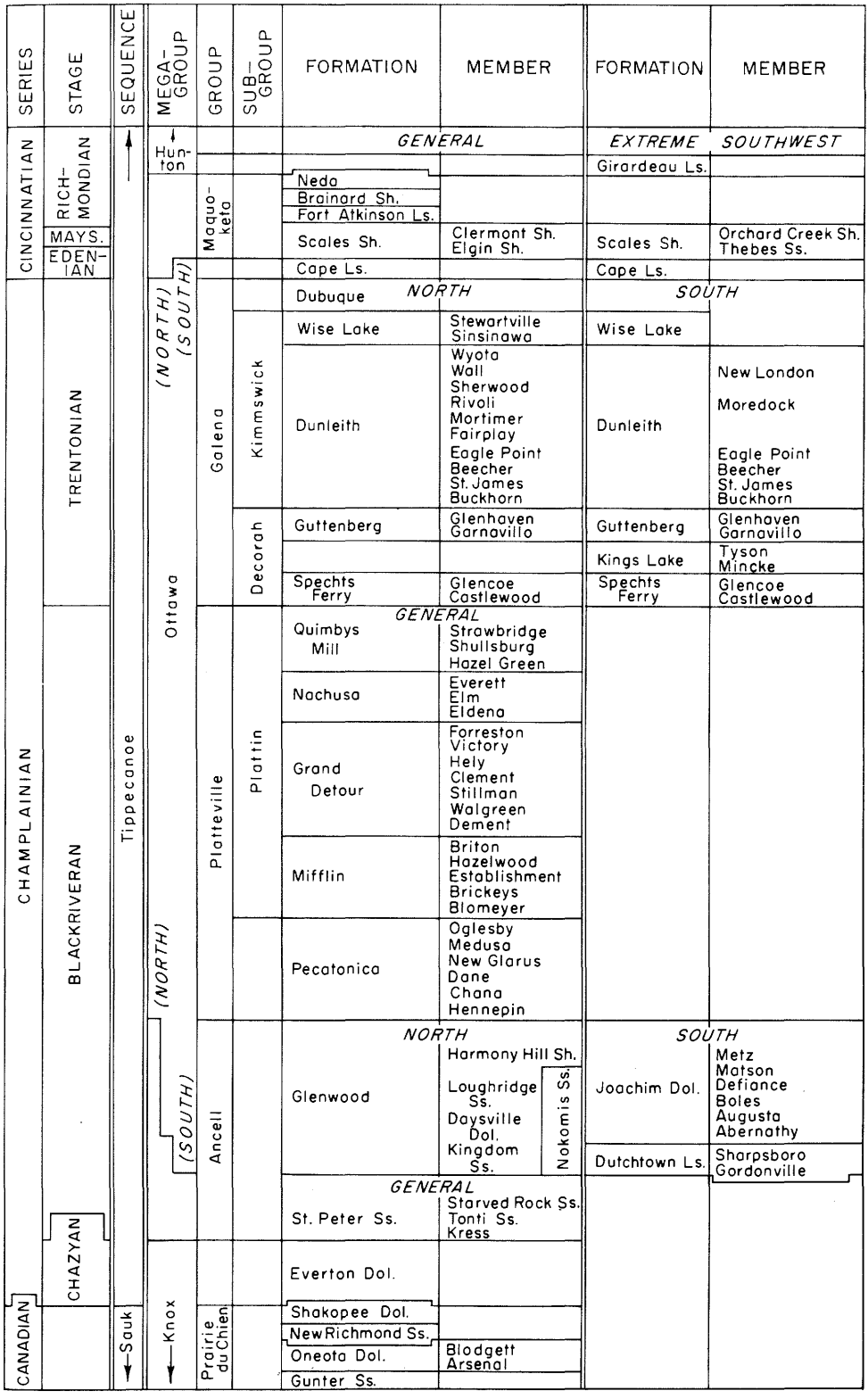

Fig. O-4—Classification of the Ordovician System.

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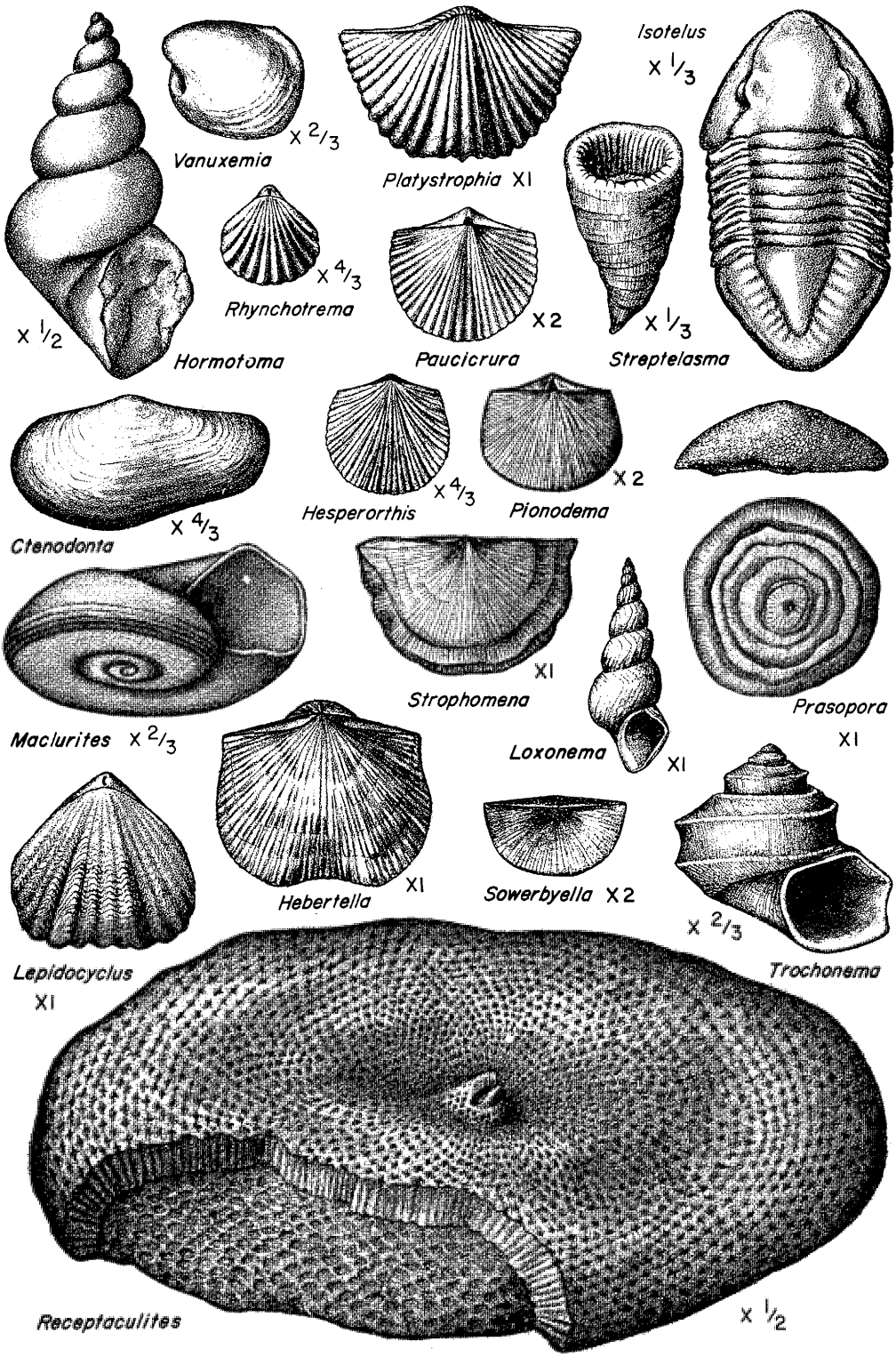

Fig. O-5—Typical Ordovician fossils.

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Worthen 1866	Winchell 1874 (Minn.)	Wooster 1882 (Wis.)	Bain 1906		Workman and Bell 1948	Present, Buschbach 1964		
Lower Magnesian Ls.	Shakopee Ls.	Willow River Beds	Prairie du Chien Group	Shakopee Dol.	Shakopee Dol.	Knox Megagroup / Prairie du Chien Group	Shakopee Dol.	
		New Richmond Beds		New Richmond Ss.	New Richmond Ss.		New Richmond Ss.	
		Lower Magnesian Proper		Oneota Dol.	Oneota Dol.		Oneota Dol.	Blodgett Mbr.
								Arsenal Mbr.
					Gunter Fm.		Gunter Ss.	

Fig. O-6—Development of the classification of the Canadian Series.

except the northernmost part of the state (fig. O-9). Where overlain by New Richmond or Shakopee, the Oneota ranges in thickness from about 100 feet in the north to slightly over 300 feet in central Illinois. It is 200-500 feet thick to the southwest and probably considerably thicker to the southeast, where its boundaries are not distinct in the subsurface. The Oneota consists of fine- to coarse-grained, light gray to brownish gray, cherty dolomite that contains minor amounts of sand and, at its base, thin shaly beds. The chert is generally white, light or pinkish gray, or banded, and is in part sandy and oolitic. The chert occurs in layers, lenses, isolated nodules, and irregularly shaped bodies that have a distinctive branching habit. The coarse grain size characterizes the Oneota. In northern Illinois the formation is subdivided into the Arsenal Member, a very cherty lower unit, and the Blodgett Member, a slightly cherty and slightly sandy upper unit (Buschbach, 1964). The Oneota overlies the Gunter Sandstone, or, where the sandstone is absent, rests unconformably on the Cambrian Eminence Dolomite. The contact between the Oneota and the overlying New Richmond is sharp. Macrofossils are rare in the Oneota and are mostly gastropods and algal masses (fig. O-2E). The Oneota is equivalent to the Gasconade Formation of Missouri and to the upper nonsandy part of the Chepultepec Formation in the Kentucky subsurface.

Arsenal Member—The Arsenal Member of the Oneota Dolomite (Buschbach, 1964, p. 45) is the lower, very cherty member. It is named for the Joliet Arsenal, Will County, where the type section is represented in a boring (NE NE SW 25, 34N-9E) by samples (SS 6199) from 980-1085 feet deep. The Arsenal Member is recognized in the northeastern quarter of the state, where it varies from 90 to almost 200 feet thick. It is a cherty to very cherty dolomite that is light gray with some brown or pink tinting. The dolomite is medium grained but has some coarsely crystalline zones. The chert is white or light gray, partly banded, and only rarely oolitic. Sand grains are rare, but thin shale partings are common near the base.

Blodgett Member—The Blodgett Member of the Oneota Dolomite (Buschbach, 1964, p. 45) is the upper, noncherty, or only slightly cherty, member. It is named for the town of

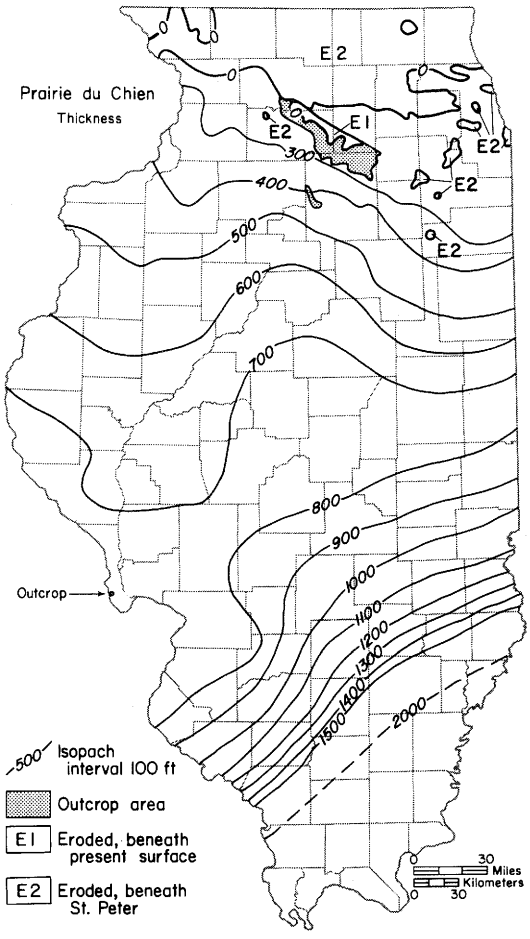

Fig. O-7—Thickness of the Prairie du Chien Group.

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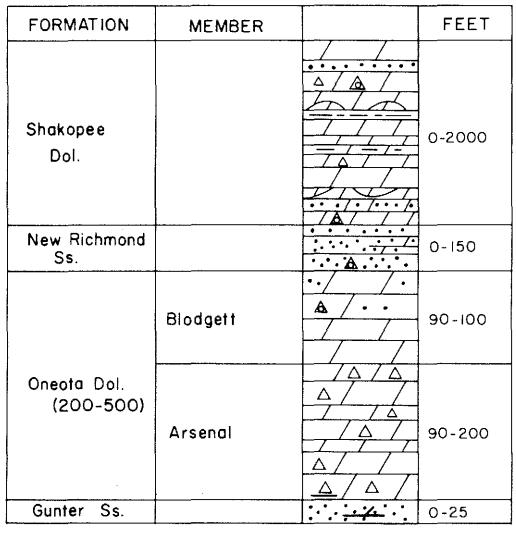

Fig. O-8—Columnar section of the Prairie du Chien Group.

Blodgett, western Will County, 3 miles southwest of the type section, which is in a boring (NE NE SW 25, 34N-9E) and is represented by samples (SS 6199) from 885-980 feet deep. The Blodgett is recognized in the northeastern quarter of the state, where it ranges from 90 to over 100 feet thick. It is dolomite, sandy in part, very slightly glauconitic, light or pinkish gray, and medium to fine grained. Oolitic chert is present but not abundant. Thin green shale partings are widely spaced throughout the member.

New Richmond Sandstone

The New Richmond Sandstone (Wooster, 1882, p. 106), named for New Richmond, St. Croix County, Wisconsin, overlies the Oneota Dolomite and is overlain by the Shakopee Dolomite. It is well exposed along Franklin Creek, Lee County, and along the Fox River, west of Sheridan, La Salle County (Willman and Templeton, 1951). The New Richmond is present in the north-central and west-central parts of the state (fig. O-10). It is more than 100 feet thick in an area extending south-southwest from La Salle County to Jersey County, and it exceeds 150 feet in southern La Salle County. It is eroded from northernmost Illinois, and it wedges out southward and eastward. The New Richmond is sandstone with some interbedded sandy dolomite. The sandstone is white to light gray, fine to medium grained, subrounded to rounded, friable, moderately sorted, cross bedded, and ripple marked. The dolomite is sandy, light colored, fine grained, and contains oolitic chert. The characteristics of the dolomite are similar to those of the overlying Shakopee Dolomite. The heavy mineral suite in the New Richmond is characterized by abundant tourmaline and the presence of garnet (Willman and Payne, 1943). The contact at the base of the New Richmond is locally unconformable. The upper contact is transitional, and the New Richmond appears to grade upward and laterally into the Shakopee. The New Richmond Sandstone is equivalent to the lower part of the Roubidoux Formation in Missouri.

Shakopee Dolomite

The Shakopee Dolomite (Winchell, 1874, p. 138-139), named for outcrops at Shakopee, Scott County, Minnesota, overlies the New Richmond Sandstone or, where the New Richmond is absent, the Oneota Dolomite. It underlies the St. Peter Sandstone or, in southern Illinois, the Everton Dolomite. The Shakopee is exposed in Illinois along the Illinois River and its tributaries, from La Salle east to Utica, La Salle County; along the Fox River near Sheridan and Millington in La Salle and Kendall Counties; and along the Rock River and its tributaries between Franklin Grove, Lee County, and a point 2.5 miles west of Oregon, Ogle County (Willman and Templeton, 1951). It also occurs along the Mississippi River bluffs in Calhoun County in a small exposure on the crest of the Lincoln Anticline. In that locality it has been correlated with the Cotter (?) Dolomite (Rubey, 1952), but the Everton Dolomite has recently been traced to the adjacent area in Missouri, making it possible that the small Illinois outcrop may belong to the Everton. The Shakopee is present throughout much of Illinois (fig. O-11), but in the north-

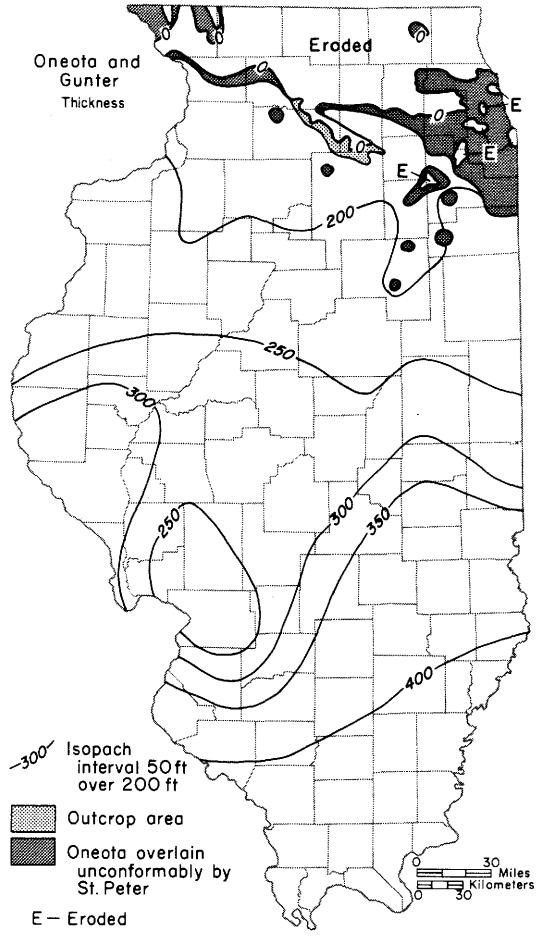

Fig. O-9—Thickness of the Oneota Dolomite and the Gunter Sandstone.

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ern two tiers of counties it has been extensively removed by pre-St. Peter solution and erosion, and in north-central Illinois it is eroded from parts of the Ashton Arch and the Oregon Anticline near the Sandwich Fault Zone. Closely spaced wells in the northern half of the state show irregularities of 50-100 feet in the thickness of the Shakopee. It thickens regularly southward and reaches almost 600 feet at a line drawn between Edgar and Monroe Counties. South of that line the Shakopee is not separated from the underlying carbonates with confidence, but it appears that the Shakopee, chiefly by the addition of younger beds at its top, reaches a thickness exceeding 2000 feet near the southern tip of Illinois. The Shakopee consists of argillaceous to pure, very fine-grained dolomite with some thin beds of medium-grained, cross-bedded sandstone, medium-grained dolomite, green to light gray shale, and buff siltstone. The dolomite is light gray to light brown, with the brown increasing toward the deep part of the Illinois Basin. It contains oolitic, partly sandy chert in discontinuous bands and isolated nodules. Some beds of the Shakopee are brecciated or conglomeratic. Bedding surfaces show ripple marks and mud cracks. Several layers of bentonite are present in a quarry 2.5 miles west of Oregon (Willman and Templeton, 1951). Fossils are not abundant; those reported are chiefly gastropods and cephalopods. However, algal stromatolites are common in mats and domes that range from a few inches to more than 10 feet thick. The Shakopee is equivalent to the Jefferson City and Cotter Dolomites of Missouri, and to the south it may include strata equivalent to the younger Powell and Smithville–Black Rock Formations.

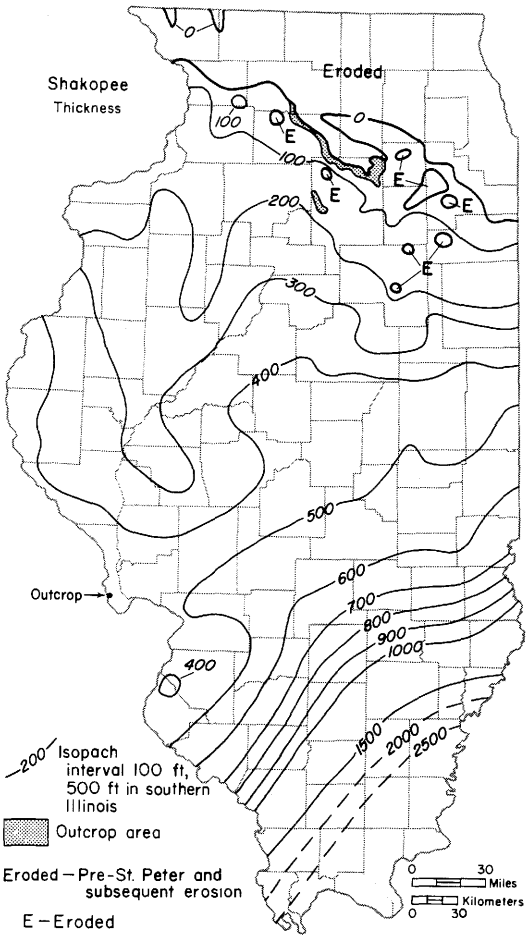

Fig. O-11—Thickness of the Shakopee Dolomite.

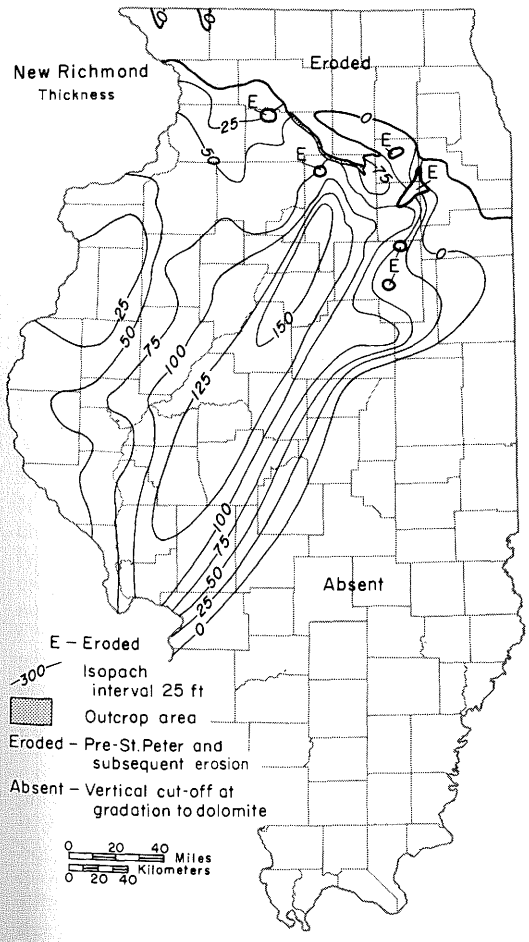

Fig. O-10—Thickness of the New Richmond Sandstone.

TIPPECANOE SEQUENCE

The Tippecanoe Sequence (Sloss et al., 1949, p. 115), named for Tippecanoe County, Indiana, consists of the strata overlying the Sauk Sequence and underlying the Kaskaskia Sequence (fig. 14). In Illinois the base of the sequence is at the sub-St. Peter–Everton (sub-Champlainian) unconformity (fig. O-13), and the top is bounded by the sub-Dutch Creek–Wapsipinicon (sub-Middle Devonian) unconformity (fig. D-7). It, therefore, includes strata of middle to late Ordovician, Silurian, and early Devonian age. Although

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minor or local unconformities occur within the sequence, its formations have a similar tectonic environment and are generally parallel throughout the state. They overlap the more deformed Sauk Sequence, and, in turn, were deformed and partly truncated before they were overlapped by the Kaskaskia Sequence.

CHAMPLAINIAN SERIES

The Champlainian Series (Emmons, 1842, p. 99-126; Schuchert and Barrell, 1914, p. 16, 25), named for Lake Champlain, New York, unconformably overlies Canadian dolomite throughout Illinois and is unconformably overlain by Cincinnatian shales and limestone. The name "Champlainian" has been used in Illinois since 1963 (Templeton and Willman). Before then, these strata were called Middle Ordovician or subdivided into the Chazyan and Mohawkian Series.

The Champlainian rocks are dominantly carbonates, mostly limestone in the south and dolomite in the north, but they include the St.

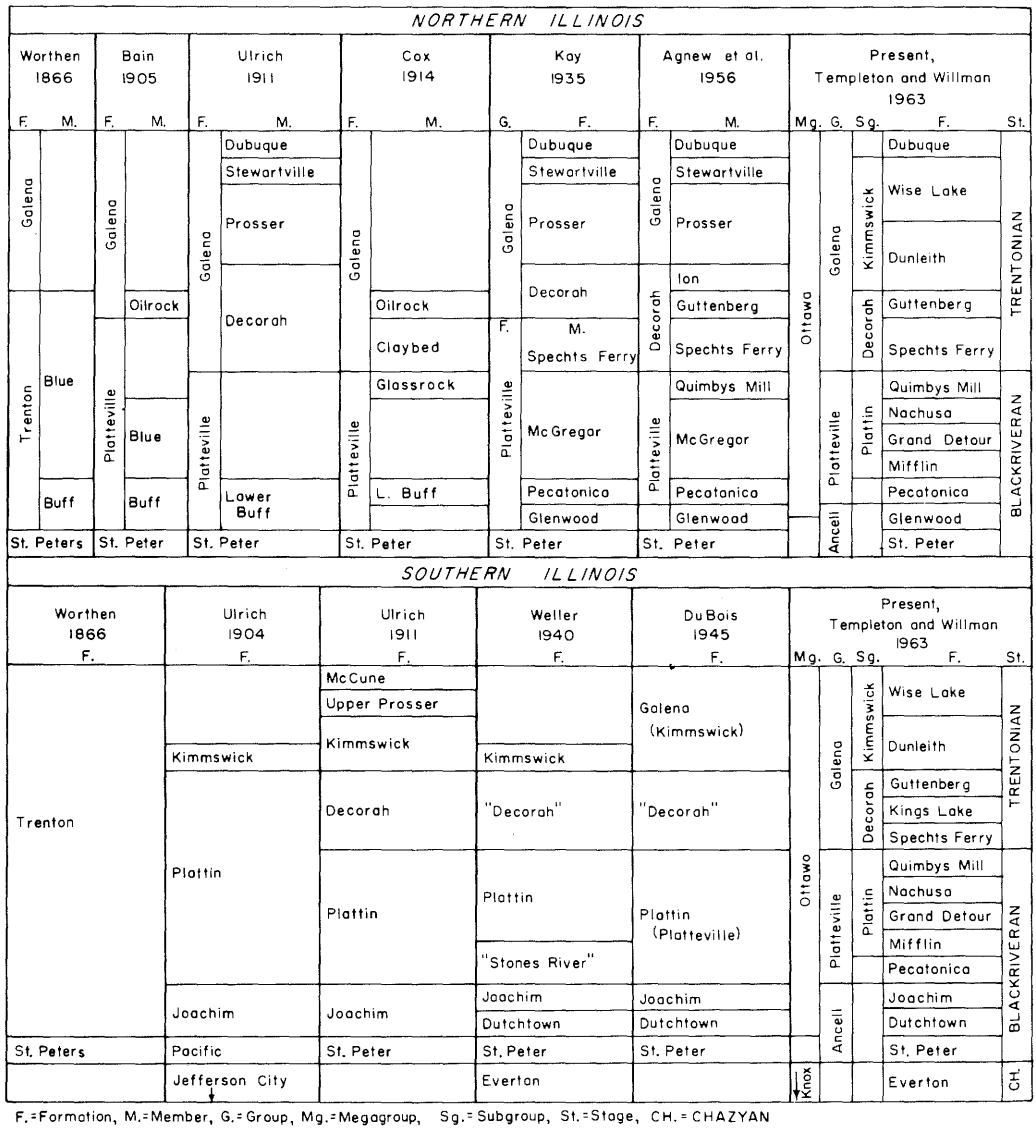

Fig. O-12—Development of the classification of the Champlainian Series.

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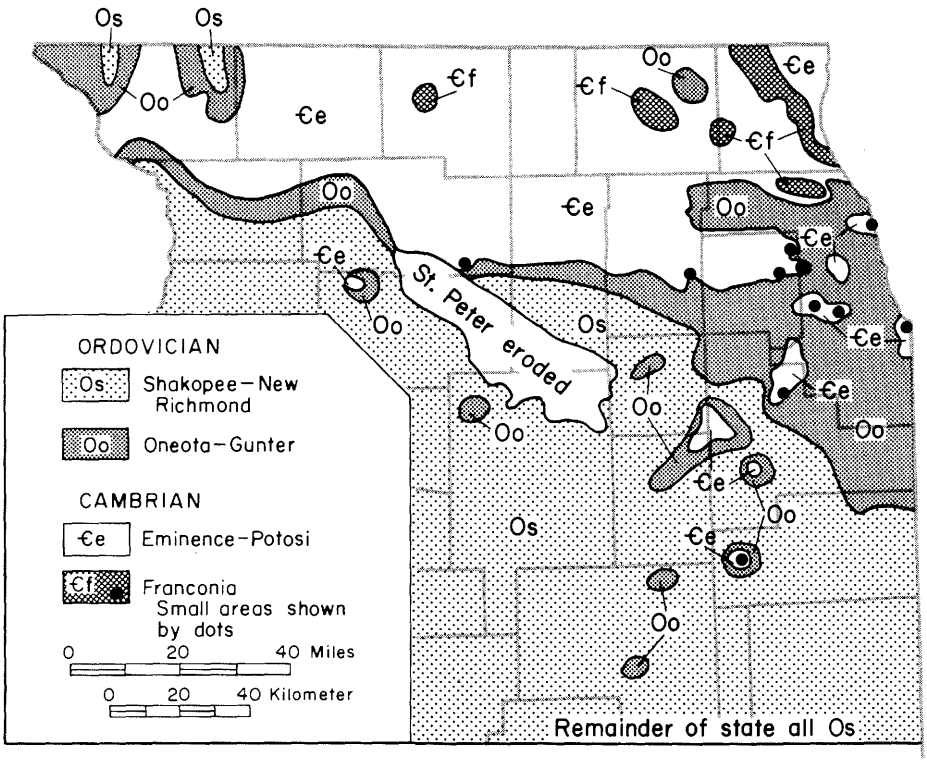

Fig. O-13—Geologic map of the sub-St. Peter surface in northern Illinois.

Peter Sandstone at the base, except in the southwestern part of the state where dolomite and sandstone of the Chazyan Everton Formation underlies the St. Peter. The series ranges in thickness from 1700 feet in the south to 500 feet in the north.

The Champlainian Series is subdivided into the Chazyan, Blackriveran, and Trentonian Stages (fig. O-4), which are based on the New York section (Kay, 1960). Although the classification in New York has been repeatedly modified, these stages have wide regional extent and their boundaries correspond to the major faunal and physical changes in the Champlainian of Illinois (Templeton and Willman, 1963). Different classifications developed in the outcrop areas in northern and southern Illinois, but many of the differences have been eliminated (fig. O-12).

The unconformity at the base of the Champlainian rocks is one of the major unconformities in Illinois. It separates the Sauk Sequence (below) from the Tippecanoe Sequence (above) (fig. 14). Throughout most of Illinois the sub-Tippecanoe unconformity cuts deeply into Canadian rocks and locally through both the Canadian and the Cambrian Trempealeauan into Franconian rocks (fig. O-13). The Sauk Sequence dips southward in the Illinois Basin at a low angle, slightly greater than that of the overlying Tippecanoe Sequence (fig. 13). In the northern Illinois outcrop area, the Sauk rocks show more local deformation than the overlying Tippecanoe strata. Throughout most of Illinois the sub-Tippecanoe unconformity represents the combined effects of unconformities that occur both above and below the Chazyan strata, and the relative significance of the two unconformities has not been evaluated. The St. Peter Sandstone, which overlies the sub-Tippecanoe unconformity in most of the state, rests on a very irregular erosional surface, in part the result of a karst topography developed on the underlying carbonate rocks. A thick accumulation of residual materials (Kress Member) occurs at the base of the St. Peter in some localities (Buschbach, 1964).

An unconformity at the base of the Trentonian rocks is widespread and is accompanied by major changes in lithology and fauna, but it does not deeply truncate the underlying strata. The uppermost Blackriveran Quimbys Mill Formation is missing in some areas north

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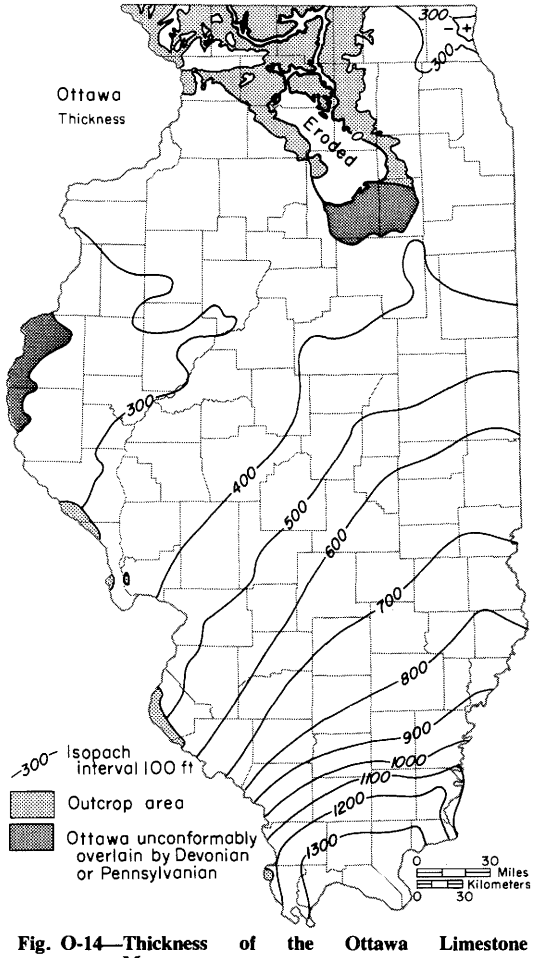

Fig. O-14—Thickness of the Ottawa Limestone Megagroup.

of Illinois, but in Illinois only the upper part is eroded, and that only locally. The Blackriveran-Trentonian contact generally is a strongly pitted, iron-stained corrosion surface. The basal Trentonian Spechts Ferry Formation thins eastward and is absent in the eastern half of Illinois, where it probably never was deposited.

Minor unconformities also occur in Champlainian strata at the base of the Pecatonica Formation and the base of the Guttenberg Formation, both accompanied by concentrations of phosphate nodules and the local absence of several feet of the underlying formation.

Chazyan Stage

The Chazyan Stage (Emmons, 1842, p. 107; Grabau, 1909, p. 223), named for Chazy, New York, includes in Illinois only the Everton Dolomite, which is not exposed but is encountered in drilling in the southwestern part of the state. The Everton is correlated with the type Chazyan on the basis of the fauna in the Everton type area in Arkansas and by subsurface tracing (Templeton and Willman, 1963).

Everton Dolomite

The Everton Dolomite (Ulrich, 1907, p. 251-252), named for Everton, Arkansas, occurs in subsurface in southwestern Illinois. It is exposed only a few miles west of Illinois near Rockview and Dutchtown, south and west, respectively, of Cape Girardeau, Missouri. A major unconformity separates the Everton from Canadian rocks below, and a strong unconformity separates it from the St. Peter Sandstone above. The Everton Dolomite has been penetrated in only a few wells in Illinois, but at least locally it consists of a sandstone overlain by a dolomite. As these units were formerly considered unnamed formations, the Everton was classified as a group (Templeton and Willman, 1963), but more recently differentiation of the Everton in Illinois has seemed less feasible and the Everton is here classified as a formation. Although over 500 feet thick in southeastern Missouri and probably also in extreme southern Illinois, the Everton strata thin rapidly northeastward. They are 100-125 feet thick in Monroe County, Illinois, and are probably not present in Illinois north of St. Clair County, although a small exposure in Calhoun County, assigned to the Shakopee, may be Everton.

Blackriveran Stage

The Blackriveran Stage (Vanuxem, 1842, p. 38-45; Moore, 1949), named for the Black River in New York State, consists of the strata included in the Ancell and Platteville Groups, which are present throughout most of Illinois (fig. O-19). Although the Ancell strata contain few fossils, the Platteville strata contain many that are characteristic of Blackriveran strata in New York (fig. O-5). Many of the distinctive lithologic units of the Platteville in Illinois have been traced to the Black River region in New York (Templeton and Willman, 1963).

OTTAWA LIMESTONE MEGAGROUP

The Ottawa Limestone Megagroup (Wilson, 1938, 1946, p. 21; Swann and Willman, 1961, p. 478), named for Ottawa, Ontario, Canada, consists of the dominantly carbonate rocks overlying the St. Peter Sandstone and underlying the clastic rocks of the Cincinnatian Series. It consists largely of the Galena and Platteville Groups, but in southwestern Illinois it includes at the top the Cape Limestone, which underlies the Maquoketa Shale Group, and at the base it includes the domi-

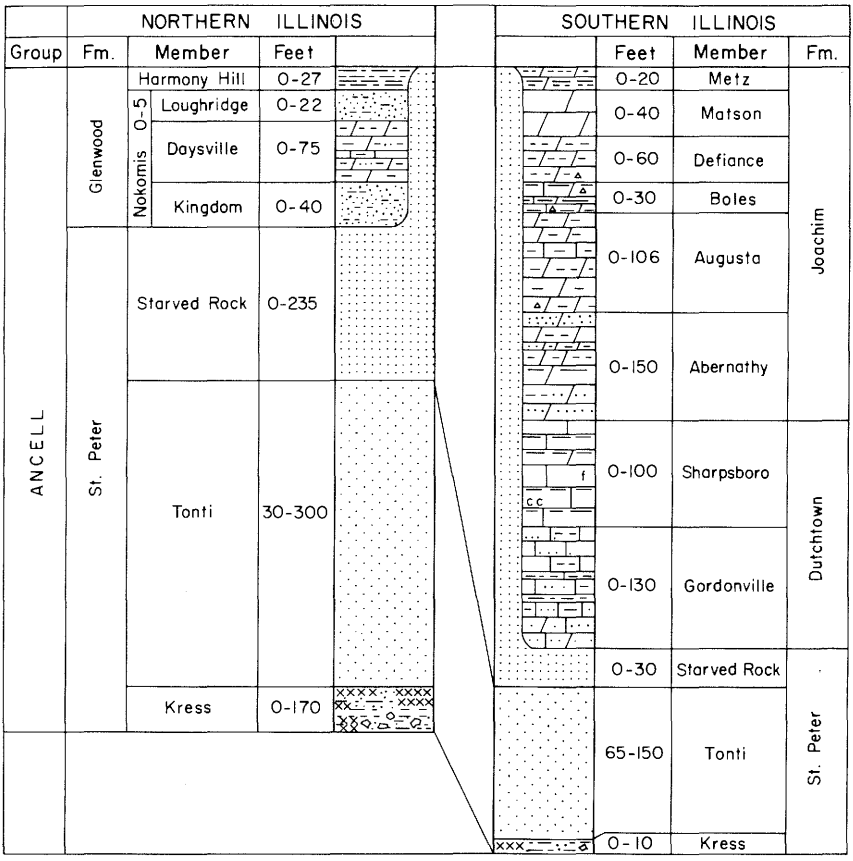

Fig. O-15—Columnar section of the Ancell Group (after Templeton and Willman, 1963).

nantly dolomite Dutchtown and Joachim Formations in the upper part of the Ancell Group. At the base in northern Illinois it locally includes the Daysville Dolomite Member of the Glenwood Formation. The Ottawa Megagroup underlies most of the state and thickens from about 300 feet in northern Illinois to 1300 feet in southern Illinois (fig. O-14). In local areas where the St. Peter Sandstone is absent, the Ottawa Megagroup rests on the Knox Dolomite Megagroup but generally is readily distinguished from it.

Ancell Group

The Ancell Group (Templeton and Willman, 1963, p. 29), named for Ancell in southeastern Missouri, consists of the sandstone and the argillaceous and sandy limestone and dolomite formations that overlie the Everton Dolomite and underlie the Platteville Group, which is relatively pure limestone. The type section is a composite of several sections in the bluffs north of Ancell, between Dutchtown and Rock Levee, Missouri. As the Everton is present only in southern Illinois, the Ancell Group overlies Canadian strata in most of the state or Cambrian strata locally. Ancell strata underlie most of Illinois, and they vary in thickness from a few feet to as much as 900 feet. The St. Peter Sandstone is the basal formation in the group. North of a line roughly extending from Chicago to Quincy, the Ancell strata above the St. Peter Sandstone consist of the members of the Glenwood Formation, but south of that line they consist of the Joachim and Dutchtown Formations (fig. O-15). The Glenwood, Dutchtown, and Joachim Formations all appear to have a facies relation to the upper part (Starved Rock Member) of the St. Peter Sandstone (fig. O-16).

St. Peter Sandstone

The St. Peter Sandstone (Owen, 1847, p. 169-170; Calvin, 1906, p. 73; Bevan, 1926, p. 6) is named for the St. Peter River in Minnesota, now called the Minnesota

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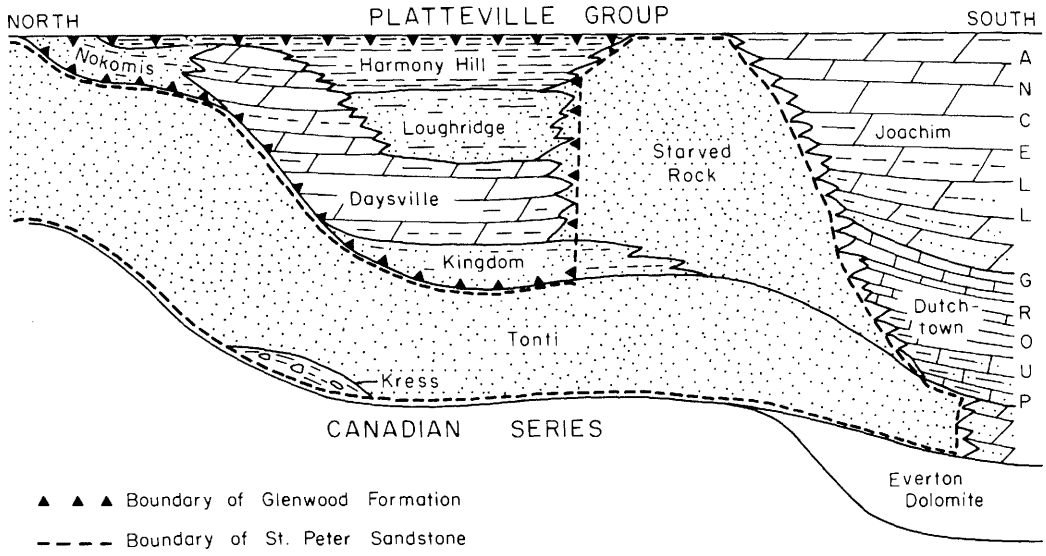

Fig. O-16—Diagrammatic cross section of the Ancell Group (after Templeton and Willman, 1963).

River. The type section is in the river bluffs at Fort Snelling on the southeast edge of Minneapolis. The St. Peter Sandstone is present in most of Illinois (fig. O-17). Because of a major unconformity at its base, the St. Peter truncates formations as old as the Cambrian Franconia Formation (fig. O-13). It is generally overlain by the Glenwood Formation in northern Illinois, the Joachim Dolomite in the central part of the state, and the Dutchtown Limestone in the extreme south, and it has a facies relation to these formations (fig. O-16). The St. Peter is well exposed along the Illinois and Fox Rivers near Ottawa (fig. O-2A), the Rock River near Oregon, and the Mississippi River near West Point Landing in Calhoun County. The St. Peter Sandstone varies from only a few feet to more than 700 feet thick, but commonly it is 100-200 feet thick. The greater thicknesses occur in northern Illinois, where the pre-St. Peter surface had sharp relief on a strongly developed karst topography and a north-facing escarpment of early Ordovician and late Cambrian dolomite formations (Buschbach, 1961). The St. Peter consists largely of fine to medium, well sorted, well rounded, frosted grains of quartz sand that is friable or weakly cemented. Except in a few local areas, the St. Peter is exceptionally pure quartz sand, essentially free from clay, carbonates, and heavy minerals. Some beds have low-angle cross bedding, but the bedding is largely horizontal (Lamar, 1928a; Willman and Payne, 1942; Buschbach, 1964). The St. Peter includes three members, the Kress Member at the base (chert, sand, clay, and shale), the Tonti Sandstone Member, and the Starved Rock Sandstone Member (fig. O-15). The St. Peter is nonfossiliferous, except for local worm borings (*Scolithus*) and a few scolecodonts in the upper part of the formation. The St. Peter is generally considered to be a marine sand deposited near the shore of a sea advancing from the south (Dapples, 1955). It is equivalent to a sandy zone at the base of the Pamelia Formation in New York and to a light-colored dolomite at the base of the Murfreesboro Limestone in Tennessee. The St. Peter

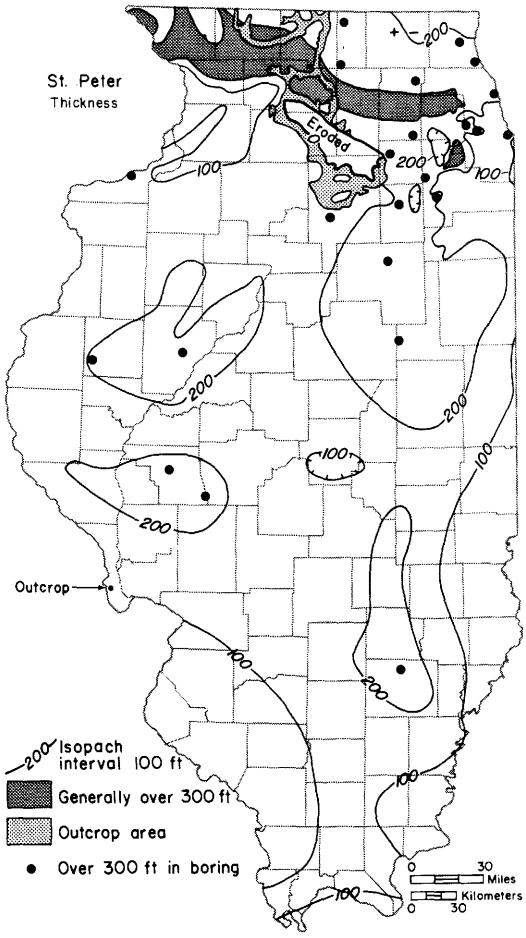

Fig. O-17—Thickness of the St. Peter Sandstone.

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Sandstone is extensively quarried for silica sand and is one of the major aquifers in Illinois.

Kress Member—The Kress Member of the St. Peter Sandstone (Buschbach, 1964, p. 51), the basal member, is named for Kress Creek, a stream northwest of West Chicago, Du Page County, near which a well (NW NE SE 32, 40N-9E) encountered 64 feet of conglomerate at the base of the St. Peter, the top at a depth of 940 feet. The type section is represented by samples from the well (SS 1169). The Kress Member is very irregular in occurrence but has been encountered in many wells. Its maximum thickness is 170 feet in a well in Ogle County, where a thin layer of bentonite occurs near its base. The Kress in some places is a coarse rubble or conglomerate of chert in a matrix of clay or sand, a residue from the solution of the underlying cherty dolomites and sandstones. At other places the Kress is largely red sandy clay, red and green shale, and argillaceous sandstone that represent reworking of the residual materials by the advancing St. Peter sea. The conglomerate is locally exposed in the Oregon region, Ogle County, and the shale is exposed at Utica, La Salle County.

Tonti Sandstone Member—The Tonti Sandstone Member of the St. Peter Sandstone (Templeton and Willman, 1963, p. 45), the middle member, is named for Tonti Canyon in Starved Rock State Park. The top of the sandstone is exposed in the canyon, but the type section is at Starved Rock, La Salle County (SW NW NW 22, 33N-2E), where the contact with the overlying Starved Rock Sandstone Member and the upper 40 feet of the Tonti Member are exposed. The Tonti is entirely exposed in the bluffs at Split Rock, 4 miles northwest of Starved Rock. The Tonti Member generally forms the greater part of the St. Peter Sandstone, and in many areas all the St. Peter is Tonti. Although commonly from 100-200 feet thick, it is locally over 500 feet thick. The Tonti Member is chiefly fine-grained, well sorted, friable, highly porous sandstone, but locally in western Illinois it is even finer grained, silty, less porous, and partly cemented by secondary silica. It is noncalcareous, except in southern Illinois where it contains some dolomitic beds.

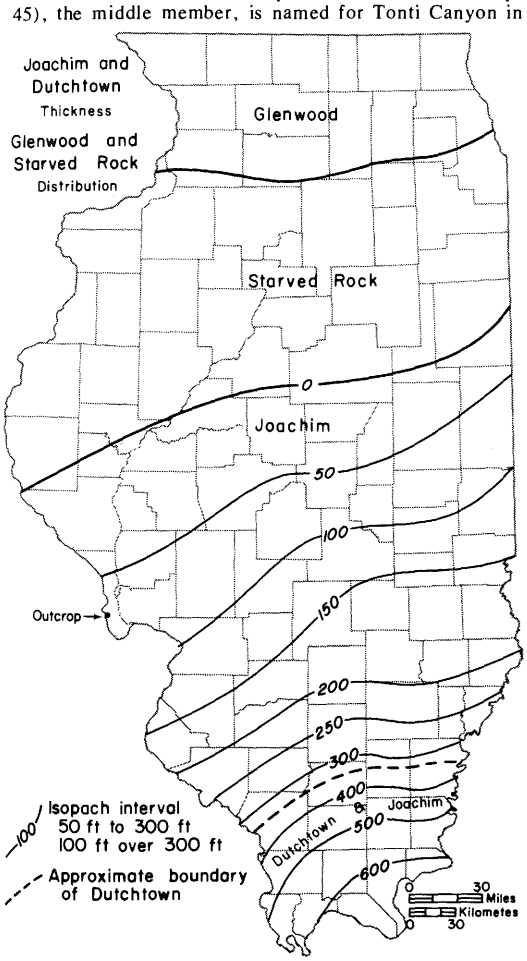

Fig. O-18—Thickness of the Dutchtown Limestone and Joachim Dolomite and the distribution of the Starved Rock Sandstone Member of the St. Peter Sandstone and the Glenwood Formation.

Starved Rock Sandstone Member—The Starved Rock Sandstone Member of the St. Peter Sandstone (Templeton and Willman, 1963, p. 46), the uppermost member, is named for Starved Rock in Starved Rock State Park, La Salle County. The type section is in Starved Rock and French Canyon (W1/2 NW 22, 33N-2E), where the member is 90 feet thick. All except the upper few feet of the member is exposed in Starved Rock. The Starved Rock Sandstone differs from the Tonti Member in being largely medium grained rather than fine grained and somewhat more cross bedded. It has a sharp contact with the Tonti Sandstone in most exposures (Willman and Payne, 1942). It is commonly 60-100 feet thick and occurs in a broad band, extending southwestward from the Chicago area to the Mississippi River in the Quincy area (fig. O-18). It is locally present in extreme southern Illinois. The Starved Rock Member is believed to represent an offshore bar that separated Glenwood sedimentation on the north from Joachim sedimentation on the south, and it has a facies relation to both. At Starved Rock the lower part of the member contains thin beds with the poor sorting characteristic of the sandstones in the Glenwood Formation.

Glenwood Formation

The Glenwood Formation (Calvin, 1906, p. 60-61; Bevan, 1926, p. 6), a highly varied unit of sandstone, dolomite, and shale overlying the St. Peter Sandstone, is named for Glenwood Township, Winneshiek County, northeastern Iowa. The type section is in a ravine 3 miles northeast of Decorah (SE SW 6, 98N-7W). The Glenwood Formation is widely present in northern Illinois (fig. O-18). It underlies the Platteville Group, from which it is separated by an unconformity that is widespread and sharp but has only minor relief. It is exposed in Illinois only in the Rock River region above Dixon. Although absent in some localities, especially near the Wisconsin state line, thicknesses of 25-50 feet are common and the formation is as much as 75 feet thick in places. The Glenwood Formation is characteristically poorly sorted sandstone, impure dolomite, and green shale. The sandstones have a distinctive bimodal, or "pudding stone," texture, with medium grains of well rounded quartz sand, like those of the St. Peter Sandstone, in a matrix of very fine sand and coarse silt. This is frequently referred to as Glenwood texture, in contrast to the well sorted St. Peter texture. The Glenwood sandstones also contain a variety of heavy minerals, including abundant garnet, whereas the St. Peter has a very low content of a limited suite of heavy minerals, consisting largely of tourmaline and zircon. The Glenwood Formation is subdivided into five members—the Kingdom Sandstone Member at the base is overlain by the Daysville Dolomite Member, the Loughridge Sandstone Member, and the Harmony Hill Shale Member. The lower three have gradational contacts and

generally thicken and thin at the expense of each other. Locally in northwestern Illinois the Daysville Dolomite Member is absent, and the name "Nokomis Sandstone Member" is applied to all the sandstone of Glenwood type underlying the Harmony Hill Shale. In extreme western Illinois the St. Peter Sandstone is overlain by a green shale, above which a well sorted St. Peter-like sandstone is informally called the "Re-Peter" sandstone. In Illinois the green shale has been correlated with the Kingdom Sandstone and the "Re-Peter" with the Starved Rock Sandstone (Templeton and Willman, 1963). In Iowa the green shale has been correlated (Agnew, 1955) with type Glenwood Shale, which is the Harmony Hill Shale. If the latter is correct, the "Re-Peter" may correlate with the Hennepin Sandstone Member, which in places is a St. Peter-like sandstone at the base of the overlying Pecatonica Formation. The Glenwood Formation contains a few worm borings, a few scolecodonts, and, in places, dark red algae or spores.

Kingdom Sandstone Member—The Kingdom Sandstone Member of the Glenwood Formation (Templeton and Willman, 1963, p. 49), the basal member, is named for Kingdom, Lee County, which is 3 miles south of the type section (ravine in NE SE NW 36, 23N-9E, Ogle County), where it is 7.9 feet thick. It commonly is 5-20 feet thick but has a maximum thickness of 40 feet. It has the poor sorting typical of the Glenwood texture. In most of the outcrops it has a sharp contact with the underlying Tonti Sandstone Member of the St. Peter. It thins northward and westward as it grades into the overlying Daysville Member, and farther north it is equivalent to the lower part of the Nokomis Member.

Daysville Dolomite Member—The Daysville Dolomite Member of the Glenwood Formation (Templeton and Willman, 1963, p. 50), which commonly overlies the Kingdom Sandstone Member, is named for Daysville, Ogle County, which is 3 miles southwest of the type section (ravine in NW NW SW 6, 23N-11E), where it is 23.8 feet thick. It is commonly 15-25 feet thick in the outcrop area but is about 45 feet thick, and locally 75 feet thick, in subsurface in an area extending from De Kalb County eastward to Lake Michigan. It thins rapidly northward, and southward it grades into the Starved Rock Member of the St. Peter Sandstone. The Daysville is the only calcareous member of the Glenwood. It is largely argillaceous, silty, sandy, greenish gray to white, chalky to dense dolomite and occurs in irregular beds. Locally it is conglomeratic with intraformational dolomite pebbles, and, where it directly overlies the Tonti Sandstone Member of the St. Peter, the basal part contains interbedded layers of sandstone of the St. Peter type. Worm borings are the only fossils known.

Loughridge Sandstone Member—The Loughridge Sandstone Member of the Glenwood Formation (Templeton and Willman, 1963, p. 51), the upper sandstone member, is named for Loughridge School, which is 5 miles northwest of the type section, a ravine 4 miles north of Grand Detour, Ogle County (N1/2 NW NE NE 25, 23N-9E), where it is 9.8 feet thick. It is differentiated only in the area where the Daysville Dolomite is present. The Loughridge is commonly less than 10 feet thick in the outcrop area but is 22 feet thick in a well at Dixon. It has the typical Glenwood texture. It merges westward and northward with the upper part of the Nokomis Sandstone Member and southward in subsurface with the Starved Rock Sandstone Member of the St. Peter Sandstone.

Nokomis Sandstone Member—The Nokomis Sandstone Member of the Glenwood Formation (Templeton and Willman, 1963, p. 51), which commonly includes all the sandstone of the formation in extreme northern Illinois and farther north, is named for Lake Nokomis, 1.5 miles west of the type section in the bluff on the west side of the Mississippi River at Lock and Dam No. 1 in Minneapolis, Minnesota, where the member is 10.8 feet thick. It rests on the St. Peter Sandstone and is overlain by the Harmony Hill Shale Member. The Nokomis Member results from the merger northward of the Kingdom and Loughridge Sandstone Members beyond the margin of the intervening Daysville Dolomite Member. It has the typical Glenwood texture and generally rests sharply on the underlying St. Peter Sandstone. It has a maximum thickness of 11 feet in Illinois but is generally less than 5 feet and is absent in places.

Harmony Hill Shale Member—The Harmony Hill Shale Member of the Glenwood Formation (Templeton and Willman, 1963, p. 52), the uppermost member, is named for Harmony Hill School, which is 1 mile northwest of the type section, a ravine 5 miles north of Grand Detour, Ogle County (W1/2 SE SE NE 24, 23N-9E), where the member is 5.9 feet thick. It is the most widely distributed member of the Glenwood Formation but is locally absent in the outcrop area and is generally absent in subsurface in northeastern Illinois. It is commonly 1-5 feet thick but has a maximum thickness of 27 feet in southwestern Ogle County. The Harmony Hill Member is a green, pyritic, finely laminated shale containing thin laminae of silt and very fine sand, but in places it becomes very sandy, and locally it is black. Phosphatic pellets are common near the top. It contains a few fragments of scolecodonts, *Lingula*, and minute, dark red algae or spores. It is conformable, usually gradational, with the underlying members, but it locally rests unconformably on the St. Peter Sandstone. It is unconformably overlain by the Pecatonica Formation. In some areas in the Upper Mississippi Valley it is the only unit included in the Glenwood and is called the Glenwood Shale.

Dutchtown Limestone

The Dutchtown Limestone (McQueen, 1937, p. 12), which overlies the St. Peter Sandstone and underlies the Joachim Dolomite in extreme southern Illinois (fig. O-18), is named for Dutchtown, Cape Girardeau County, Missouri. The type section is in a bluff 1 mile east of Dutchtown. The Dutchtown Limestone is not exposed in Illinois, but it has been penetrated in wells as far north as southern Jackson County, thinning in that direction from a known thickness of about 150 feet in the Cape Girardeau area (fig. O-18). However, drilling near by in Kentucky suggests it is as much as 200 feet thick in southeastern Illinois (DuBois, 1945; Templeton and Willman, 1963). The Dutchtown is largely dark gray (nearly black), argillaceous, lithographic limestone and dolomite. When freshly broken it has a strongly fetid odor. It contains beds of gray and brown shaly limestone and dolomite, calcareous siltstone, and dolomitic sandstone. Its dark color and prevalence of limestone differentiates it from the overlying Joachim Dolomite. It is differentiated into two members, the Gordonville below (largely dolomite) and the Sharpsboro above (largely limestone). The Dutchtown is fossiliferous, and mollusks, ostracodes, and conodonts are the most abundant fossils. It appears to grade laterally into the St. Peter Sandstone. The Dutchtown Limestone is correlated with similar dark limestone in the Murfreesboro Limestone in Tennessee and the Pamelia Limestone in New York.

Gordonville Member—The Gordonville Member of the Dutchtown Limestone (Templeton and Willman, 1963, p. 54), the lower member, is named for Gordonville, Cape Girardeau County, Missouri, 4.5 miles northwest of the type sec-

tion, which is in the Geiser Quarry, 1.25 miles east of Dutchtown (SW NW NW 20, projected, 30N-13E), where the upper 5 feet is exposed. In wells in Illinois the Gordonville Member ranges from 130 feet thick in southern Pulaski County to 45 feet in southwestern Jackson County, north of which it thins out rapidly. It does not extend as far north as the overlying Sharpsboro Member. The Gordonville Member normally consists of dolomite with subordinate amounts of limestone, but in southern Jackson County, close to the transition into the St. Peter Sandstone, it is composed mainly of dolomite-cemented, medium-grained sandstone. The dolomite and limestone are mostly sandy, silty, greenish gray to dark gray, and a few layers are dark brown to black.

Sharpsboro Member—The Sharpsboro Member of the Dutchtown Limestone (Templeton and Willman, 1963, p. 55), the upper member, is named for Sharpsboro, Cape Girardeau County, Missouri, a railroad station 5.5 miles southeast of the type section, the same as that for the Gordonville Member, where the lower 10.5 feet of the Sharpsboro is exposed. The Sharpsboro Member is 65 feet thick in a well in Pulaski County, but it is 100 feet in the type locality, as shown by a well at Cape Girardeau, Missouri. It apparently thins out rapidly in Jackson County, Illinois, extending only a short distance north of the limit of the Gordonville Member. The Sharpsboro Member is largely a dark gray, dark brown, or black lithographic limestone. It contains beds of dark gray dolomite, sandy limestone, and dark brown shale. A few beds of light gray dolomite, like that found in the Joachim above, occur near the top. The contact with the Joachim is conformable. The fauna of the Dutchtown Limestone comes largely from the Sharpsboro Member.

Joachim Dolomite

The Joachim Dolomite (Winslow, 1894, p. 331, 352; McQueen, 1937, p. 12), the uppermost formation in the Ancell Group in southern Illinois, is named for Joachim Creek in Jefferson County, Missouri, along which the lower part is partially exposed. A more complete section in the bluffs between Cape Girardeau and Dutchtown, Missouri, has been suggested as a supplementary reference section (Templeton and Willman, 1963, p. 55). The Joachim Dolomite is exposed in Illinois only in Calhoun County (fig. O-2D), where the Mississippi River cuts through the Lincoln Anticline. However, it underlies all of Illinois south of a line extending from near Quincy to Kankakee (fig. O-18). North of there it has a gradational contact with the Starved Rock Member of the St. Peter Sandstone. The Joachim thins northward by progressive termination of the basal Joachim strata. It is as much as 385 feet thick in extreme southern Illinois. The Joachim Dolomite has a highly varied lithology, but individual units are widely persistent. Although largely light gray, argillaceous, silty or sandy dolomite, it contains beds of brownish gray, relatively pure dolomite, beds of sandstone and limestone, some thin shale beds, and numerous algal domes of pure dolomite. In the outcrop area, chert occurs only near the middle, but it is more common in the subsurface in Illinois. Layers of anhydrite in the subsurface appear to have been dissolved in the outcrop area, producing the brecciated layers that are common in the dolomite. Mud cracks and ripple marks are common in some beds. The general absence of marine fossils suggests that the Joachim was deposited in a shallow, closed basin. The Joachim contains much more clastic material than the Platteville strata above, which are dominantly limestone in the area where the Joachim is present. It is lighter colored than the Dutchtown below. The Joachim Dolomite is best exposed on the flanks of the Ozark Dome in Missouri, and it is differentiated into six members on the basis of exposures in that area. The Abernathy Member (at the base) is sandy, the Augusta is thick bedded and silty, the Boles is thin bedded and shaly, the Defiance is thick bedded and silty, the Matson is brown, pure, and massive, and the Metz (at the top) is thin bedded and silty. Only the Metz, Matson, and the top of the Defiance are exposed in Illinois, but all the members can generally be recognized in samples from wells. All are successively overlapped northward. In Missouri the name "Joachim" is restricted to the units below the Boles, and the overlying beds are included in the Rock Levee Formation. The Joachim Dolomite is correlated with the upper part of the Pamelia Formation in New York.

Abernathy Member—The Abernathy Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 58), the basal member, is named for Abernathy School, 2 miles north of the type section, which is 1.5 miles east of Dutchtown, Missouri (SE NW NE 20, projected, 30N-13E). The upper 25.6 feet is exposed at the type section. In southern Illinois the Abernathy is present in the subsurface, extending northward as far as Jackson County. It is as much as 150 feet thick in a well in Pulaski County but more commonly is 50-100 feet thick. The Abernathy Member is largely silty, sandy, thick-bedded dolomite containing layers of dolomitic, medium-grained sandstone. It contains some dark brown layers of limestone and dolomite. A persistent layer of sandstone of St. Peter type 1.5-14 feet thick occurs at the top. Chert is common just below the sandstone.

Augusta Member—The Augusta Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 59), which overlies the Abernathy Member, is named for Augusta, Franklin County, Missouri, 5 miles west of the type section, which is a railroad cut on the south side of the Missouri Valley a mile southwest of St. Albans (SW NE SW 10, 44N-2E), where the member is 29 feet thick. It extends northward in subsurface as far as southern Calhoun County, Illinois, where it is 16 feet thick. It thickens southward, is generally 50-75 feet thick in the outcrops in Missouri, and is 106 feet thick in a well in Pulaski County, Illinois. The Augusta Member consists of relatively pure to very silty, light gray, white-weathering dolomite, generally in thick beds. The member contains layers of pure, brown, algal dolomite or limestone. Many individual beds are distinctive and can be widely traced. Locally the basal part is a siltstone or contains layers of green shale, indicative of its facies relation to the upper part of the St. Peter Sandstone. The Augusta is less sandy and the sand is finer grained than that in the Abernathy Member below; it is thicker bedded and less shaly than the Boles above.

Boles Member—The Boles Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 60), which overlies the Augusta Member, is named for Boles, Franklin County, Missouri, 6 miles southwest of the type section, a quarry on the north side of the Missouri Valley 1 mile southwest of Matson, St. Charles County (NE cor. SE NE SW 4, 44N-2E), where the member is 19.1 feet thick. The Boles Member is commonly about 20 feet thick, ranging from 15-30 feet. It consists largely of thin to medium beds of dense silty dolomite and vuggy pure dolomite, separated by layers of dark red-brown to gray-green shale as much as 5 inches thick. Many bedding surfaces are ripple marked, and mud cracks are common. It contains several bands of white to black chert nodules and is the only persistent chert zone in the outcropping Joachim. However, chert is absent in places, and in subsurface in Illinois it occurs in other members of the Joachim. The Boles is distinguished from both the Augusta below and the Defiance above by its thin bedding, abundance of shale, and the chert bands.

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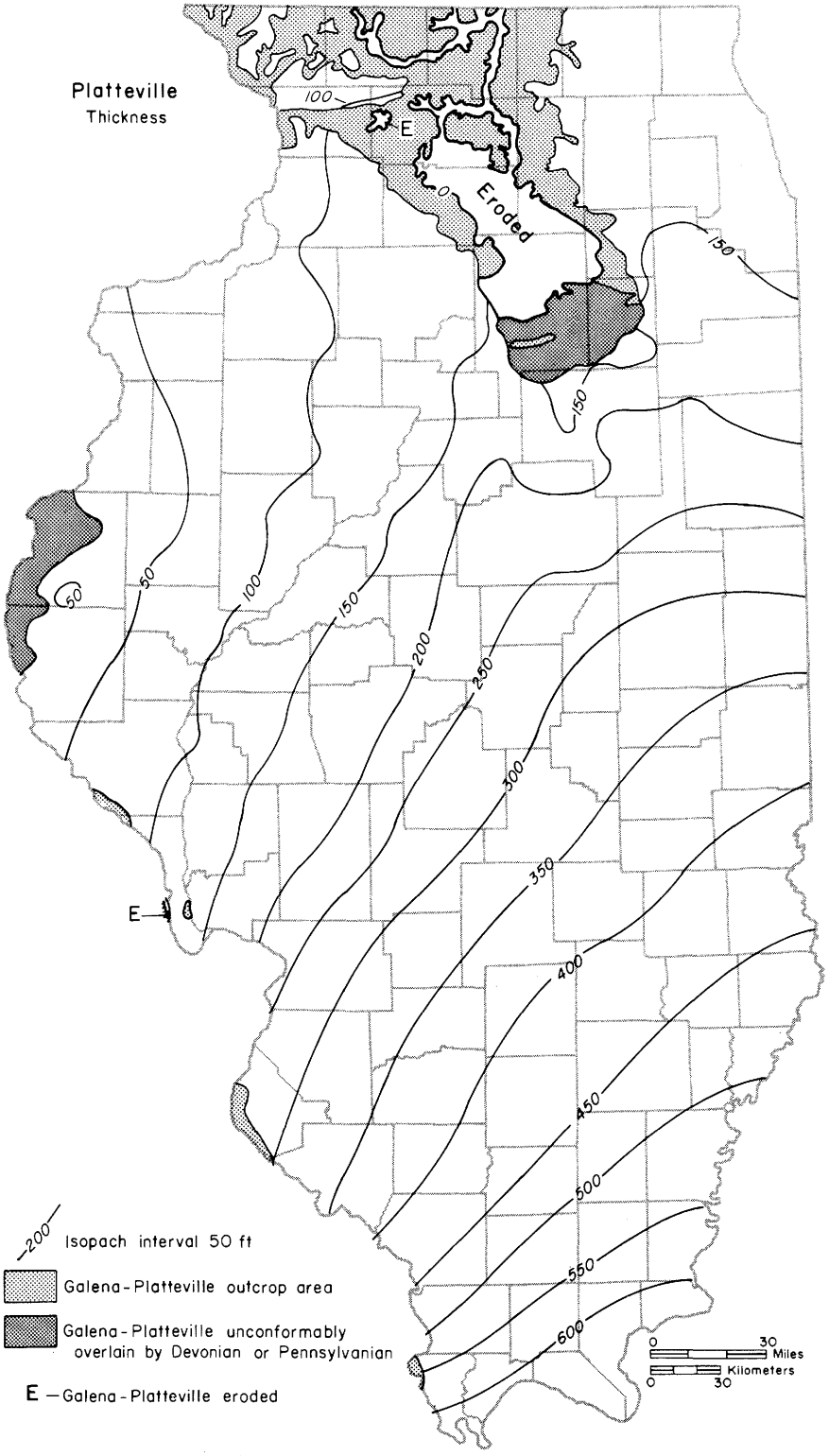

Fig. O-19—Thickness of the Platteville Group.

Defiance Member—The Defiance Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 60), which overlies the Boles Member, is named for Defiance, St. Charles County, Missouri, 3 miles northeast of the type section, the same exposure as the Boles Member type section, where the Defiance is 20.5 feet thick. The Defiance Member is exposed in Illinois only in the Mississippi bluffs at West Point Landing, Calhoun County. The Defiance Member is usually 20-40 feet thick and dominantly silty dolomite. It contains numerous algal domes, and beds of limestone are common in the southern part of the outcrop area. The Defiance Member is similar in lithology to the Augusta Member.

Matson Member—The Matson Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 61), which overlies the Defiance Member, is named for Matson, St. Charles County, Missouri, just east of the type section in the north bluff of the Missouri Valley (NE NE NE 4, projected, 44N-2E), where the member is 29.8 feet thick. The Matson Member persists throughout the area of the Joachim. In Illinois it is exposed only at West Point Landing in Calhoun County, where it is 21 feet thick. It is about 30 feet thick in the outcrop area, but in subsurface in Illinois it commonly is 15-40 feet thick. The Matson Member differs from the other Joachim Members in being relatively pure, brown, finely porous dolomite that generally appears to be massive but is finely laminated, the laminae separated by thin films of dark brown clay. Locally it contains a few thin beds of the lithologic types common in the Defiance and Augusta Members. The Matson appears to be largely algal in origin. Ostracodes occur locally in the basal beds, and a marine fauna with corals, brachiopods, and trilobites has been observed in the basal beds at one locality near Zell, Missouri.

Metz Member—The Metz Member of the Joachim Dolomite (Templeton and Willman, 1963, p. 62), which overlies the Matson Member, is named for Metz Lake, 5 miles north of the type section, a quarry in the east bluffs of the Mississippi River, just north of West Point Landing, Calhoun County (SE NE SE 19, 7N-2W), where the member is 9.5 feet thick. The Metz Member is present throughout the area of the Joachim Dolomite and commonly is about 15 feet thick, ranging from 7-20 feet. The Metz consists of light gray, silty, thin- to medium-bedded dolomite but has a few beds of pure, darker dolomite. It contains algal domes, mud-cracked surfaces, and scour surfaces. It differs from the underlying relatively pure Matson Member, but many of the beds have a lithology similar to that of the Defiance and Augusta Members. The dominance of dolomite differentiates it from the relatively pure, lithographic limestone of the Platteville Group, which overlies it unconformably.

Platteville Group

The Platteville Group (Bain, 1905, p. 18-21; Calvin, 1906, p. 60-61; Templeton and Willman, 1963, p. 63) is named for Platteville, Wisconsin, which is 4 miles east of the type exposures along the Little Platte River. For a specific type section, Kay (1931, p. 369, 371) designated a ravine exposure (SW NW NW 20, 3N-1W, Grant County, Wis.), but Templeton and Willman (1963) suggested as an alternate a more accessible roadcut 5 miles southwest of Platteville (SE SW SE 1, 2N-2W), where the group is 53.6 feet thick. In the type region, the Platteville Group includes the dominantly limestone formations that overlie the Glenwood Formation of the Ancell Group and underlie the Spechts Ferry or Guttenberg Formations of the Galena Group. In an east-west area through central Illinois it overlies the St. Peter Sandstone, and south of there it overlies the Joachim Dolomite. The Platteville Group is widely exposed in northern Illinois—in the Rock and Pecatonica Valleys above Dixon, in a small area near Galena in Jo Daviess County, and near Ottawa and La Salle in La Salle County (fig. O-19). The southern outcrop area, largely in Missouri on the east flank of the Ozark Dome, extends from Cape Girardeau north to St. Louis and, beyond a short covered interval, to exposures on the Lincoln Anticline. In Illinois the Platteville crops out at West Point Landing in Calhoun County (fig. O-2D). The group is only about 30 feet thick in extreme western Illinois, but it thickens to 135 feet in the Dixon outcrop area and southward to over 600 feet in subsurface in the extreme southern part of the state. In northern Illinois the Platteville Group is largely blue-gray, lithographic, partly dolomite-mottled limestone, but in some areas, such as that near Dixon, it is gray, very fine-grained, cherty dolomite. In southern Illinois it is largely brown, lithographic, partly dolomite-mottled, slightly shaly limestone. It is subdivided (fig. O-20) into the Plattin Subgroup (above) which is dominated by the typical limestone facies, and the Pecatonica Formation, a persistent dolomite except where it grades to limestone in southern Illinois. The units are separated by a widespread corrosion surface, probably a diastem. The Plattin Subgroup is subdivided into the Mifflin (at the base), Grand Detour, Nachusa, and Quimbys Mill Formations on the basis of differences in purity, bedding, and texture. The Platteville formations and members have great lateral continuity and many of them are recognized in samples from borings (Buschbach, 1964). The Platteville Group is generally fossiliferous, containing a large and varied fauna. The Platteville Group was incorrectly correlated in early reports with the Trenton Limestone of New York. It is equivalent to the Lowville and Chaumont Formations of the Black River Group in New York, the upper part of the Stones River Group in Tennessee, the upper part of the High Bridge Group in Kentucky, and the Black River Limestone in Indiana and Michigan.

Pecatonica Formation

The Pecatonica Formation (Hershey, 1894, p. 175; 1897), the basal formation of the Platteville Group, is named for exposures along the Pecatonica River north of

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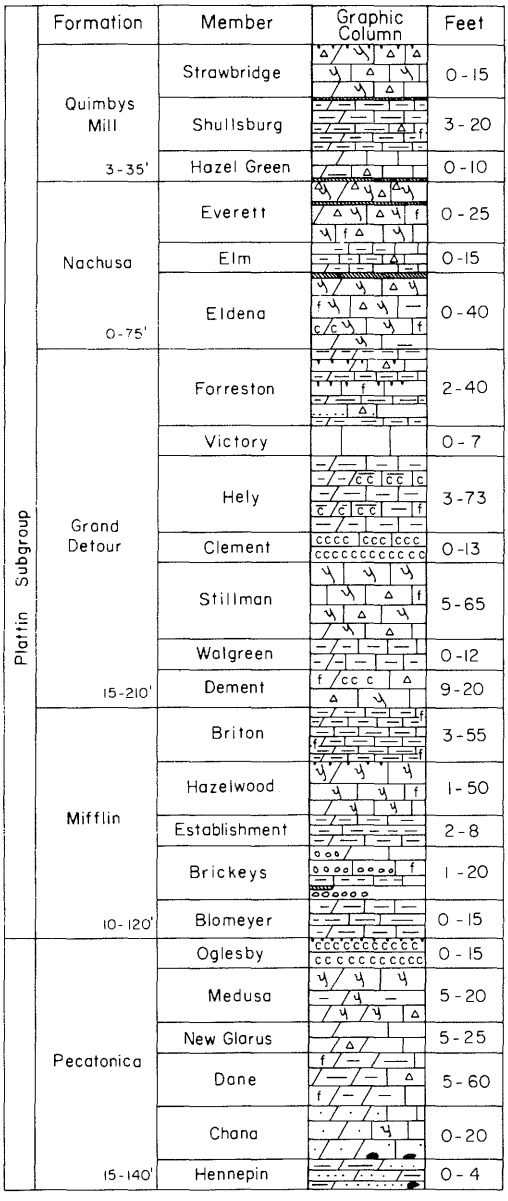

Fig. O-20—Columnar section of the Platteville Group (after Templeton and Willman, 1963).

the Illinois-Wisconsin state line. A section in the quarries and a roadcut on the East Branch of the Pecatonica River just north of Woodford, Lafayette County, Wisconsin (W 1/2 NW NE 14, 2N-5E), where it is 22.2 feet thick, has been designated the type section (Templeton and Willman, 1963, p. 73). The Pecatonica Formation overlies the Glenwood Formation or the St. Peter Sandstone in northern Illinois and the Joachim Dolomite in southern Illinois. It is overlain by the Mifflin Formation and is separated from both overlying and underlying units by sharp contacts that are at least regional diastems, perhaps unconformities. In Illinois the Pecatonica Formation is exposed only in the northern area, but it is a distinctive unit widely recognized in subsurface (Buschbach, 1964). It is locally absent in northern Illinois over anticlines, in extreme western Illinois, and in the southern outcrop area north of Perry County, Missouri. It is commonly about 20 feet thick in northern Illinois, but it thickens to 150 feet in extreme southern Illinois. North of a line from southeastern Missouri, through north-central Illinois, and into northwestern Indiana, the Pecatonica Formation is mainly brown, finely vuggy dolomite in medium to thick beds and has large chert nodules at a few horizons. South of there it is largely brownish gray lithographic limestone mottled with dolomite. The Pecatonica is subdivided into six members: the Hennepin (at the base) varies but is generally dolomitic siltstone, the Chana is sandy, the Dane is argillaceous, the New Glarus is pure, the Medusa is weakly argillaceous and strongly fucoidal, and the Oglesby at the top is coarse calcarenite. The Pecatonica has a dominantly brachiopod-molluscan fauna but generally is less fossiliferous than the overlying Platteville formations. The Pecatonica is a widely distributed unit in the Mississippi Valley, and it is equivalent to the Ridley Formation in Tennessee and to the lower beds in the Lowville of New York.

Hennepin Member—The Hennepin Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 75) is named for Hennepin County, eastern Minnesota. The type section is in a bluff on the west side of the Mississippi River at Lock and Dam No. 1 in Minneapolis (NE SW NW 17, 28N-23W), where the member is 2.3 feet thick. It varies from a dolomitic sandstone to a siltstone and to very sandy silty dolomite, which differentiates it from the relatively pure, although sandy, Chana Member above. It is locally present in extreme northern Illinois, where it is a dolomitic sandstone containing phosphate pebbles and is commonly 2-4 feet thick. It differs from the sandstone in the Glenwood Formation below in that it contains carbonates and its sands have a texture like that of the St. Peter. It appears in places to be a reworking of Glenwood sediments at the beginning of Platteville carbonate deposition.

Chana Member—The Chana Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 76) is named for Chana, Ogle County, 9 miles east of the type section (ravine in W1/2 SE SE NE 24, 23N-9E), where it is 6.2 feet thick. In the northern outcrop area it is commonly less than 5 feet thick, but it reaches 20 feet in southern Illinois. In the northern area it is largely brown, thick-bedded, vuggy, pure dolomite that contains disseminated sand grains and, in places, thin beds of sandstone of the St. Peter texture. The basal part commonly has slightly argillaceous or shaly beds and phosphatic pebbles. In southern Illinois it is largely pure, thick-bedded limestone.

Dane Member—The Dane Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 76) is named for Dane County, Wisconsin. The type section is a quarry and roadcut in Dane County, 4 miles north of New Glarus, Green County (SW NW NE 34, 5N-7E), where the member is 8.2 feet thick. The Dane Member commonly is 5-10 feet thick in the outcrop area, but it is as much as 60 feet in extreme southern Illinois. It consists of slightly argillaceous, partly cherty, brown dolomite or limestone in thin to medium beds separated by thin shale partings. The Dane is the most fossiliferous of the Pecatonica members, and it is characterized regionally by the abundance of *Öpikina minnesotensis*.

New Glarus Member—The New Glarus Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 77)

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is named for New Glarus, Green County, Wisconsin, and the type section is in the same section as the Dane Member. The New Glarus is 5.7 feet thick at the type section, is generally about 5 feet thick in the northern outcrop area, and thickens to 25 feet in extreme southern Illinois. It is dolomite in northern Illinois and limestone in southern Illinois and is relatively pure, thick bedded, and locally cherty.

Medusa Member—The Medusa Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 77) is named for the Medusa Cement Company plant, 2 miles northeast of Dixon, Lee County, which is 1.5 miles south of the type section, a quarry on the east side of the Rock River Valley (SW SW NW 22, 22N-9E), where the member is 5.2 feet thick. In the northern outcrop area it is commonly 5-7 feet thick, but it thickens to 20 feet in extreme southern Illinois. In the outcrop area it consists of dolomite or of limestone heavily mottled with dolomite. It is slightly argillaceous, very fucoidal, and thick bedded to massive. South of Ogle County it contains chert nodules.

Oglesby Member—The Oglesby Member of the Pecatonica Formation (Templeton and Willman, 1963, p. 77) is named for Oglesby, La Salle County, and the type section is in Matthiessen State Park east of Oglesby (NE NE NE 31, 33N-3E), where the member is 12 feet thick. It is absent in Illinois north of the type locality, but it is as much as 15 feet thick in southern Illinois. It is pure, light gray, white, or buff calcarenite that is laminated, rarely conglomeratic, and locally cross bedded. It is medium to coarse grained in the type locality but fine grained elsewhere. A strong iron-stained corrosion surface occurs on the top and is equivalent to a similar surface on the top of the Medusa Member in northern Illinois, where the Oglesby is absent.

Plattin Subgroup

The Plattin Subgroup (Ulrich, 1904, p. 111; Weller and St. Clair, 1928, p. 109-110) is named for Plattin Creek, Jefferson County, Missouri, near the mouth of which it is partially exposed. As originally defined, it included strata equivalent to the Decorah at the top but not the Pecatonica below. Weller and St. Clair removed the Decorah, and, as thus defined, the Plattin was long considered equivalent to the Platteville in northern Illinois. Because the Plattin did not include the Pecatonica Formation of the Platteville Group (the Pecatonica is not present in the Plattin Creek area), the Plattin was reclassified as a subgroup (Templeton and Willman, 1963, p. 78). The Plattin is a distinctive unit, particularly in the northern outcrop area and in other regions where it is dominantly fine-grained and lithographic limestone, separated by a minor unconformity from the dolomitic Pecatonica Formation below. The Plattin Subgroup includes the Mifflin (at the base), Grand Detour, Nachusa, and Quimbys Mill Formations. The Plattin Formation, as defined in Missouri, consists of the strata from the oolite in the Brickeys Member of the Mifflin Formation to the base of the Decorah Formation. The Plattin Subgroup is equivalent to the McGregor Formation in the Upper Mississippi Valley above Dubuque, Iowa, except in the lead-zinc district where the McGregor has been redefined to exclude the Quimbys Mill Formation (Agnew and Heyl, 1946).

Mifflin Formation

The Mifflin Formation (Bays, 1938, p. 269) is named for Mifflin, Iowa County, Wisconsin, just west of the type section, a roadcut and bluff on the east side of the Pecatonica River (NE NE NE 34, 5N-1E), where it is 17.8 feet thick. The Mifflin is a widespread, thin-bedded, relatively shaly limestone overlying the thick-bedded, generally more dolomitic Pecatonica Formation and underlying the medium-bedded, less shaly Grand Detour Formation. It is exposed widely in north-central Illinois and in a small area at West Point Landing in Calhoun County (fig. O-2D). It is commonly 15-25 feet thick in the northern area, but it thickens to 120 feet in subsurface in southern Illinois. The Mifflin Formation is dominantly gray, lithographic limestone, most of it thin bedded and shaly. Locally it grades to shaly fine-grained dolomite in the northern outcrop area and to sandy shale and sandstone in extreme western Illinois. The shale partings in the Mifflin are gray to green, in contrast to the generally brownish gray to red-brown partings in the Grand Detour. In the northern outcrop area the Mifflin is characterized by a persistent, massive, middle unit, and in Calhoun County and farther south it has a distinctive oolite in the lower part that is widely recognized in subsurface. The oolite forms the top of the Rock Levee Formation in Missouri. The Mifflin is differentiated into five members: the Blomeyer (at the base), is argillaceous; the Brickeys is pure; the Establishment is argillaceous; the Hazelwood is pure; and the Briton (at the top) is argillaceous. In the northern outcrop area the Blomeyer, Brickeys, and Establishment Members are thin and differ only slightly in clay content. Where these units are not differentiated, they are combined as the lower shaly unit and assigned to the Establishment Member. The Mifflin then consists of a threefold (shaly, massive, shaly) sequence. The Mifflin is the most fossiliferous formation in the Platteville Group, containing an abundant and varied brachiopod, molluscan, and bryozoan fauna. It is the lower, shaly part of the McGregor Limestone north of Illinois, and is correlated with strata in the upper part of the Camp Nelson Formation in Kentucky, the lower part of the Lebanon Limestone in Tennessee, and with the upper part of the lower division of the Lowville Limestone in New York.

Blomeyer Member—The Blomeyer Member of the Mifflin Formation (Templeton and Willman, 1963, p. 80) is named for Blomeyer, Cape Girardeau County, Missouri, about 6 miles southwest of the type section, which is a small quarry a quarter of a mile east of the highway junction at Rock Levee (NW cor. NE NW 24, 30N-13E), where the member is 12.1 feet thick. The Blomeyer is irregularly present, but it is as much as 15 feet thick in subsurface in southern Illinois. It is less than a foot to 3 feet thick in the northern outcrop area. The Blomeyer consists of argillaceous, fine-grained limestone, or locally dolomite, that weathers thin-bedded to shaly.

Brickeys Member—The Brickeys Member of the Mifflin Formation (Templeton and Willman, 1963, p. 81) is named for Brickeys, Ste. Genevieve County, Missouri, which is 3 miles east of the type section, a quarry on the east side of

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Missouri Highway 25 (SE SW SE 28, 39N-7E), where the member is 15.5 feet thick. The Brickeys Member is commonly 13-20 feet thick in the outcrop area in Missouri but is as much as 40 feet thick in subsurface in southern Illinois. Where locally differentiated in the northern outcrop area, it is 1-2 feet thick. In the southern area much of the Brickeys Member is relatively pure, brown, lithographic limestone, but it contains a few beds of gray to buff, argillaceous limestone and dolomite. Several beds are strongly oolitic; others are a fine conglomerate or breccia. The member also contains a few beds of green shale as much as 5 inches thick, domes of *Stromatocerium*, several scour surfaces with a relief of 2-8 inches, and, in one locality, a thin bentonite near the base. The shale beds are persistent from Calhoun County, Illinois, to Ste. Genevieve County, Missouri, but elsewhere the unit is dominantly a relatively pure limestone containing oolite beds. In the northern outcrop area the Brickeys is relatively pure but not oolitic.

Establishment Member—The Establishment Member of the Mifflin Formation (Templeton and Willman, 1963, p. 82) is named for Establishment Creek in Ste. Genevieve County, Missouri. The type section is an exposure in a tributary ravine just north of the village of Zell (W1/4 34, 38N-8E), where the member is 5.5 feet thick. The Establishment Member is 2-8 feet thick in southern Illinois, where it is a green shale with thin interbeds of argillaceous, chalky limestone. The shale facies appears to be limited to a region bordering the Ozarks and is a persistent marker bed; elsewhere the member is thin-bedded, shaly, brown lithographic limestone. In the northern area it is limestone, commonly about 5 feet thick, and is gray, dolomite mottled, argillaceous, thin bedded, and shaly. It contains a few thin beds of calcarenite.

Hazelwood Member—The Hazelwood Member of the Mifflin Formation (Templeton and Willman, 1963, p. 82) is named for Hazelwood School, Lee County, 2 miles west of the type section, a quarry on the east side of the Rock River Valley 3.5 miles north of Dixon (SW SW NW 22, 22N-9E), where it is 5.7 feet thick. The Hazelwood Member is widespread, but it is missing in Calhoun County. It is commonly 4-6 feet thick in the northern outcrop area, but it thickens southward and, judging from exposures near Cape Girardeau, Missouri, is probably as much as 50 feet thick in subsurface in southern Illinois. In the northern outcrop area, the Hazelwood is relatively pure, gray, thick-bedded to massive, lithographic limestone generally dolomite mottled, fucoidal, and with few fossils. A ferruginous corrosion surface occurs on the top. In the southern area, the Hazelwood is relatively pure, brown, fucoidal, fine-grained limestone, thicker bedded than the members above and below.

Briton Member—The Briton Member of the Mifflin Formation (Templeton and Willman, 1963, p. 83) is named for Briton School, 2 miles northeast of Dixon and 1.5 miles southwest of the type section, which is in the same quarry as the Hazelwood type section. The Briton is 10 feet thick in the type section. It is the uppermost shaly member of the Mifflin and is widely present. It is 3-12 feet thick in the northern outcrop area, but it thickens southward to as much as 55 feet in the southern outcrop area in Missouri and probably has a comparable thickness in subsurface in southern Illinois. In the northern outcrop area it is largely light gray, white-weathering, fossiliferous, lithographic, argillaceous limestone in thin wavy beds that have strong green shale partings. It grades to dolomite in a few places. In the southern area it is less argillaceous and only slightly shaly but is distinctly more impure than adjoining members.

Grand Detour Formation

The Grand Detour Formation (Templeton and Willman, 1963, p. 83) is named for Grand Detour, Ogle County, which is 3 miles east of the type section, a quarry in the west bluff of the Rock River, on the Walgreen estate 2 miles north of Dixon (NE 20, 22N-9E), where it is 52.3 feet thick. The Grand Detour Formation extends throughout most of Illinois, overlying the Mifflin Formation, underlying the Nachusa Formation, and conformable with both. It is generally about 50 feet thick in the northern outcrop area and in exposures in Calhoun County (fig. O-2D), but it thickens southward in subsurface to about 210 feet in southern Illinois. That it thickens rapidly south of Randolph County is suggested by the near-by exposures in Missouri. The Grand Detour consists largely of dolomite-mottled, lithographic, slightly argillaceous to pure limestone that contains thin beds of calcarenite; in places it is fine- to medium-grained dolomite. Most of it is medium bedded, with thin, brown-red, dark gray, or black shale partings, but it contains persistent units that are thick bedded to massive, fucoidal, and pure. The Dement Member (at the base) is pure; the Walgreen is argillaceous or shaly; the Stillman is pure, fucoidal, and massive; the Clement is calcarenite; the Hely is argillaceous; the Victory is pure and white or very light gray; and the Forreston (at the top) has alternating pure and argillaceous beds with red-brown shaly partings. Scour and corrosion surfaces occur between and within some of the members. The Grand Detour is generally fossiliferous, having a varied brachiopod-molluscan fauna and several species of corals, among which *Lambeophyllum* and *Tetradium* are particularly common. The medium bedding and the dark, generally red-brown, shale partings distinguish the Grand Detour from the Mifflin below with its thin beds and green shale partings, and from the Nachusa above, which is purer, more uniform, and thick bedded to massive. The Grand Detour is the upper part of the McGregor Limestone north of Illinois and is equivalent to strata in the upper part of the Camp Nelson Formation, the Oregon Formation, and the lower part of the lower member of the Tyrone Formation in Kentucky, the upper part of the Lebanon Formation in Tennessee, and the upper part of the Lowville Limestone in New York.

Dement Member—The Dement Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 84) is named for Dement Avenue in Dixon, Lee County, 2 miles south of the type section (part of the Grand Detour type section), where the Dement is 8 feet thick. The Dement Member is generally 3-8 feet thick in the northern outcrop area and in the Calhoun County exposures, but it thickens southward to 20 feet in the Cape Girardeau area. In northern Illinois it is relatively pure, dolomite-mottled, gray, lithographic, thick-bedded limestone, but locally it is fine-grained dolomite. It contains a few thin calcarenitic layers and a few scattered chert nodules. In the southern area it is brown, fucoidal, and only locally cherty, but near St. Louis it is a conglomeratic, vuggy, very fine-grained calcarenite.

Walgreen Member—The Walgreen Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 85) is named for the Walgreen estate, on which the type section (part of the Grand Detour type section) occurs. The Walgreen Member is 8.3 feet thick in the type section and is generally 5-10 feet thick in the outcrop areas in northern Illinois and eastern Missouri. Most of it is gray, thin- to medium-bedded, argillaceous, shaly limestone that contains disseminated fossil debris and thin beds of purplish gray calcarenite. In the southern outcrop area it is brown, thicker bedded, and less argillaceous than in northern Illinois.

Stillman Member—The Stillman Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 85) is

named for Stillman's Run, a stream 1.5 miles east of the type section, which is a quarry just north of Byron, Ogle County (NE NE SE 30, 25N-11E), where it is 5.3 feet thick. The member is 5-8 feet thick in the northern outcrop area, but in the southern outcrop area it thickens from 5 feet in Calhoun County to 64 feet at Cape Girardeau, Missouri. The Stillman Member consists of dolomite-mottled, lithographic limestone, or, in places, vuggy, fine- to medium-grained dolomite. It is generally pure, cherty, fucoidal, and thick bedded or massive. In the southern area it is divisible into an upper fucoidal unit, a middle argillaceous to shaly, partly cherty unit, and a basal calcarenitic fucoidal unit.

Clement Member—The Clement Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 86) is named for Clement Station, Ste. Genevieve County, Missouri, which is 7 miles north of the type section in a ravine 0.5 mile north of the village of Zell (W1/4 34, 38N-8E), where it is 13 feet thick. The Clement Member is only 1-4 inches thick where locally present in the northern outcrop area. It is 6 feet thick in outcrops near Cape Girardeau. The Clement consists of purplish gray, medium- to coarse-grained calcarenite. Where thick it occurs in 2-15 inch beds that are locally cross bedded. It grades to calcarenitic limestone in some areas.

Hely Member—The Hely Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 86) is named for Hely's upper quarry on the south side of Cape Girardeau, Missouri, which, with the adjoining Federal and Marquette quarries is the type section (NW NE and SE NW 18, 30N-14E). It is 3-5 feet thick in the northern Illinois outcrop area and 5-8 feet in the northern part of the southern outcrop area, but south of Ste. Genevieve it thickens rapidly, and in the type section it is 73 feet thick. The Hely Member consists of argillaceous, lithographic limestone in thin to medium beds with thin shale partings. Much of the member is calcarenitic or contains thin calcarenite layers. It is locally cherty and generally not fucoidal.

Victory Member—The Victory Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 86) is named for Mt. Victory School, Calhoun County, 4.5 miles north of the type section, a quarry north of West Point Landing (SE NE SE 19, 7N-2W), where it is 5.5 feet thick. The Victory Member is commonly only a foot or less thick in the northern outcrop area but is 3 feet thick in La Salle County, and in the southern outcrop area it ranges from 3.5 feet near St. Louis to 7 feet at Cape Girardeau. The Victory Member is a distinctive, white to light gray lithographic limestone containing calcite flecks that give it the "bird's-eye" appearance typical of limestones equivalent to Platteville limestones in other regions. Many of the calcite flecks are fillings of coralites of *Tetradium*. The Victory Member is massive to thick bedded and locally contains a little chert. In northern Illinois it locally grades to light gray, white-weathering dolomite, and it is not as distinctive as it is in the southern area, where it is the most easily identified member of the Platteville Group. Although generally absent north of Illinois, beds similar to the Victory occur in Kentucky, Tennessee, and New York.

Forreston Member—The Forreston Member of the Grand Detour Formation (Templeton and Willman, 1963, p. 87) is named for Forreston, Ogle County, which is 7 miles northeast of the type section, a quarry in Carroll County on the north side of a ravine 1 mile northwest of Brookville (NE SE NW 21, 24N-7E), where it is 17.9 feet thick. The Forreston Member is commonly 5-25 feet thick in the northern outcrop area and in the northern part of the southern outcrop area, but it thickens southward to 40 feet at Cape Girardeau. It consists largely of dolomite-mottled lithographic limestone or fine-grained dolomite. It is commonly fossiliferous. In many exposures it can be differentiated into three cyclical units, each consisting of a thin-bedded, shaly unit at the base and a thicker bedded, purer unit at the top. The shaly units generally contain the thickest red-brown shale partings in the Grand Detour. The member contains some chert, and thin beds of calcarenite are common. In subsurface in west-central Illinois, a sandy zone about 5 feet thick is present at or near the base.

Nachusa Formation

The Nachusa Formation (Templeton and Willman, 1963, p. 87), which overlies the Grand Detour Formation, is named for the village of Nachusa, Lee County. The type section is a quarry on the east edge of Dixon (SE SE SW 33, 22N-9E), where the Nachusa is 17.8 feet thick. It is 15-20 feet thick in the northern part of the southern outcrop area, but south of Ste. Genevieve in the Cape Girardeau area it thickens rapidly to 75 feet. It thins to less than 5 feet in subsurface in central western and extreme northwestern Illinois. The Nachusa consists largely of fine- to medium-grained, vuggy dolomite in northern Illinois (fig. O-2F) and dolomite-mottled lithographic limestone in the southern area (fig. O-2D). It is pure to slightly argillaceous, cherty, fucoidal, and thick bedded to massive. The weathered surface is deeply etched. In parts of northern Illinois the Nachusa resembles the dolomite of the Galena Group, and in some areas it has been miscorrelated with the Galena. In the southern outcrop area it contains layers of bentonite, calcarenite, and conglomeratic limestone. A persistent argillaceous and thin-bedded zone in the Nachusa is used to subdivide the formation into three members; the Eldena (at the base) is thick bedded and slightly argillaceous; the Elm is thin bedded and argillaceous; and the Everett (at the top) is massive and pure. The Nachusa is moderately fossiliferous; corals, brachiopods, and gastropods are the most common fossils. In the northern area, the Nachusa is characterized by the abundance of *Foerstephyllum halli*, but a few specimens also are found in upper Grand Detour strata. *Foerstephyllum* is present but not common in the southern outcrop area. The Nachusa has a sharp contact with the overlying Quimbys Mill Formation but a gradational contact with the Grand Detour below. The Nachusa is absent in the Mississippi Valley northwest of Illinois, but it occurs in northern Michigan. It is correlated with the Chaumont Formation of New York and Ontario because of striking similarities in fauna and lithology, with the upper part of the lower member of the Tyrone Formation in Kentucky, and with the lower member of the Carters Limestone in Tennessee.

Eldena Member—The Eldena Member of the Nachusa Formation (Templeton and Willman, 1963, p. 89) is named for Eldena, Lee County, 6 miles southeast of the type section (part of the Nachusa type section), where it is 7.5 feet thick. It is commonly 5-10 feet thick in the northern outcrop area and in Calhoun County, but south of there it thickens to 14 feet in Ste. Genevieve County, Missouri, and to 40 feet at Cape Girardeau, Missouri. It has the typical Nachusa lithology, except that the lower part has thin partings of blue-gray to gray-green or brown shale, and it is slightly more argillaceous than the Everett Member. In the southern area it contains finely conglomeratic and pseudo-oolitic beds, and a bentonite as much as 6 inches thick occurs at or near the top. It is equivalent to the Leray Member of the Chaumont Formation in New York.

Elm Member—The Elm Member of the Nachusa Formation (Templeton and Willman, 1963, p. 89) is named for Elm

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Street in Dixon, Lee County, just southwest of the type section (part of the Nachusa type section), where the member is 2.8 feet thick. It is widely present, but it is absent in subsurface in western Illinois. It is 1-4.5 feet thick in the northern outcrop area, is 7 feet thick in Calhoun County and near Ste. Genevieve, Missouri, and it thickens southward to 15 feet at Cape Girardeau. It consists of argillaceous, gray, cherty dolomite or limestone and is mainly nonfucoidal. It is thin bedded and has thin shale partings. It commonly weathers to a smooth surface, which distinguishes it from the members above and below that have pitted surfaces. It is equivalent to the Glenburnie Member, a similar shaly unit, in the Chaumont Formation in New York.

Everett Member—The Everett Member of the Nachusa Formation (Templeton and Willman, 1963, p. 90) is named for Everett Street in Dixon, Lee County, near the type section (part of the Nachusa type section), where the member is 7.5 feet thick. It averages about 7 feet thick in the northern outcrop area, and is commonly about 20 feet thick in the southern area. The Everett has the typical Nachusa lithology, differing from the Eldena Member in being more massive, very abundantly fucoidal, and generally purer. At the top of the member there is a distinctive bed of fine-grained, dense dolomite or limestone 3-8 inches thick that has a smooth, white-weathering surface and overlies a band of very large chert nodules. A thin bed of bentonite occurs 8-9 feet below the top in the southern outcrop area. The Everett is equivalent to the Watertown Member of the Chaumont Formation in New York.

Quimbys Mill Formation

The Quimbys Mill Formation (Agnew and Heyl, 1946, p. 1585), which overlies the Nachusa Formation, is named for Quimby's Mill near Etna, Lafayette County, Wisconsin (SE SE 11, 1N-1E) (Templeton and Willman, 1963, p. 235). The type section is a small quarry near the mill where the formation is 12 feet thick. The Quimbys Mill is close to 12 feet thick throughout the northern outcrop area in Illinois and 30-35 feet thick in the southern outcrop area in Illinois and Missouri, but it locally thins in subsurface and in Sangamon County is only 3 feet thick. In the type area and in a small exposure in extreme northwestern Illinois, the Quimbys Mill is brown lithographic limestone with brown shale partings. Because of its pronounced conchoidal fracture it is known as the "Glassrock." In the outcrop area in central northern Illinois, it is light brown, dense, very fine-grained, slightly argillaceous dolomite that weathers yellow-buff (fig. O-2F). It is thin to medium bedded and has thin brown shale partings. In the southern outcrop area the formation is fine-grained to lithographic limestone, the shale partings are greenish gray, the bedding and weathered surfaces are relatively smooth, and it contains some thin layers of conglomerate, fossil debris, and bentonite. The Quimbys Mill Formation is differentiated into three members; the Hazel Green (at the base) is thick bedded, slightly shaly, and weathers white; the Shullsburg is thin bedded and shaly; and the Strawbridge (at the top) is thick bedded, slightly shaly, and finely fucoidal. The Quimbys Mill is generally fossiliferous, containing brachiopods (especially *Strophomena*), bryozoans, horn corals, trilobites, and the ostracode *Eoleperditia*. The Quimbys Mill has a sharp contact, probably a diastem, with the underlying Nachusa, and its top is a ferruginous, pitted surface that is a regional unconformity with low relief. The Quimbys Mill is overlain by the Spechts Ferry Formation, the basal formation of the Galena Group, in extreme northwestern Illinois and in Calhoun County, but the Spechts Ferry thins out eastward and is not present in the northern outcrop area or in subsurface in eastern Illinois, where the Guttenberg Formation overlies the Quimbys Mill Formation. The Quimbys Mill extends eastward into Ontario, but it appears to be absent in the New York section. It is equivalent to the upper member of the Tyrone Formation in Kentucky and the upper member of the Carters Limestone in Tennessee.

Hazel Green Member—The Hazel Green Member of the Quimbys Mill Formation (Templeton and Willman, 1963, p. 91), the basal member, is named for Hazel Green, Grant County, Wisconsin, 6 miles southwest of the type section (part of the Quimbys Mill type section), where the Hazel Green is 1.7 feet thick. It is as much as 2.5 feet thick in the northern outcrop area in Illinois and 10 feet in the southern outcrop area at Cape Girardeau, Missouri. The Hazel Green Member consists of lithographic limestone or fine-grained dolomite, mainly pure and thick bedded. It has a smooth, light buff to white, weathered surface. A bentonite at the base near Cape Girardeau extends as far north as Lincoln County, Missouri.

Shullsburg Member—The Shullsburg Member of the Quimbys Mill Formation (Templeton and Willman, 1963, p. 92), which overlies the Hazel Green Member, is named for Shullsburg, Lafayette County, Wisconsin, 5 miles east of the type section (part of the Quimbys Mill type section), where the Shullsburg is 2.5 feet thick. It is as much as 5 feet thick in the northern outcrop area in Illinois and 7 feet in Calhoun County, but it thickens to about 20 feet near St. Louis and commonly is about 15 feet thick in outcrops south of there. The Shullsburg consists of brown to buff, slightly argillaceous, lithographic limestone or fine-grained dolomite. It is thin to medium bedded, strongly shaly in the north, but only slightly shaly in the southern outcrop area. In Missouri it contains some white, "glassy" beds. In northern Illinois the bedding surfaces at some places are mud-cracked or ripple-marked.

Strawbridge Member—The Strawbridge Member at the top of the Quimbys Mill Formation (Templeton and Willman, 1963, p. 92) is named for Strawbridge, Lafayette County, Wisconsin, 3 miles southwest of the type section (part of the Quimbys Mill type section), where the Strawbridge is 7.8 feet thick. It is about 7 feet thick in the northern outcrop area in Illinois and 10-15 feet thick in the southern outcrop area. It is similar in lithology to the Shullsburg Member but is less argillaceous, generally thicker bedded, and has fewer and thinner shale partings. It is partly cherty, especially at the top, in northern Illinois. It contains numerous fucoids, which are scarce in the older members of the formation and much smaller than those in the underlying Nachusa Formation.

Trentonian Stage

The Trentonian Stage (Vanuxem, 1838, p. 257, 276, 283; Kay, 1948, p. 1411), named for Trenton Falls in New York State, is represented in Illinois by the strata of the Galena Group. These rocks are present throughout most of Illinois (fig. O-21). They are correlated with the type Trentonian of New York on the bases of both faunal and lithologic similarity (Templeton and Willman, 1963). Trentonian strata are generally fossiliferous and the fauna contains many forms not found in

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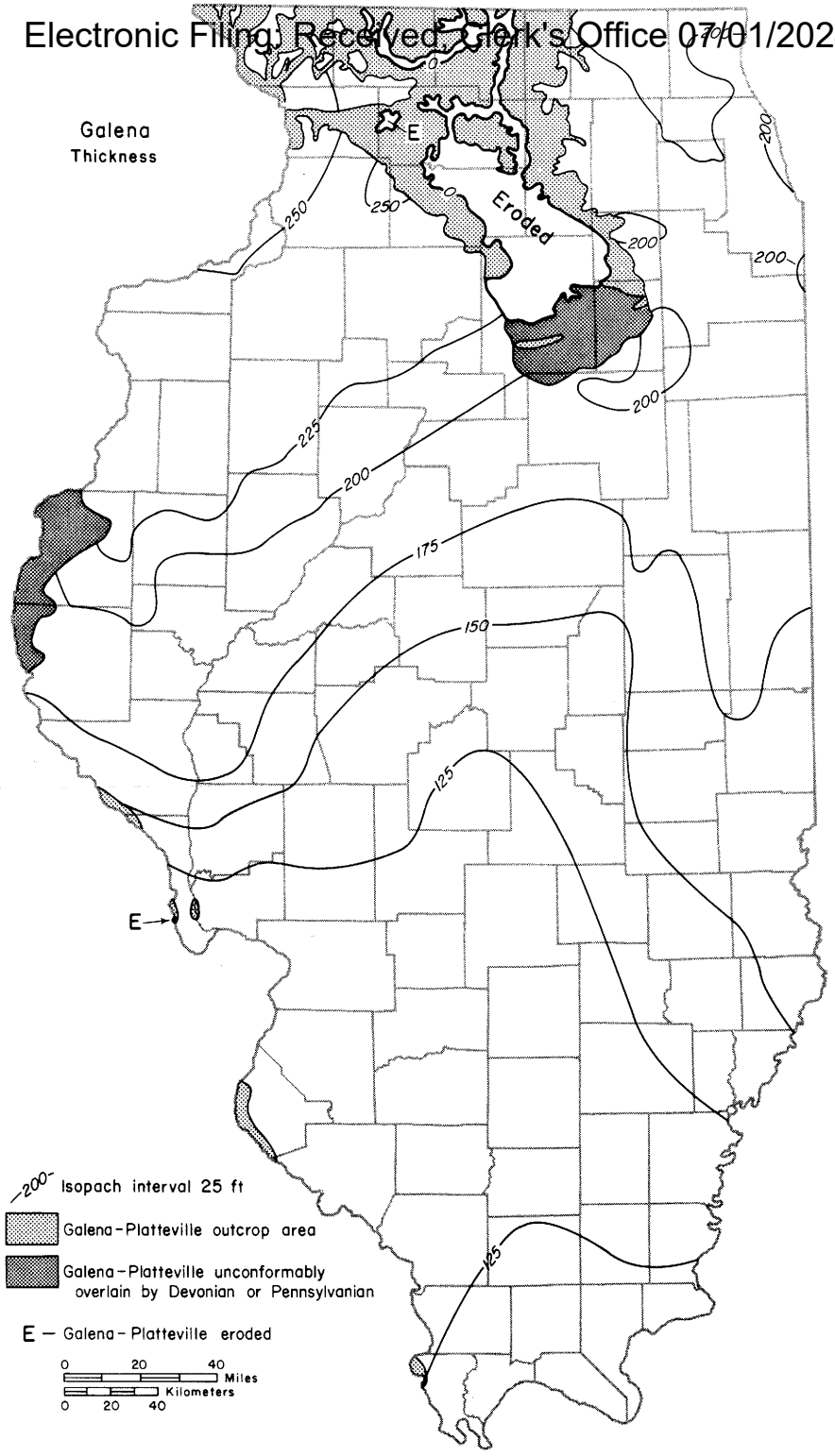

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the Blackriveran below or the Cincinnatian above.

Galena Group

The Galena Group (Hall, 1851, p. 146-148; Kay, 1935b, p. 289; Templeton and Willman, 1963, p. 93) consists of limestone and dolomite formations overlying the Platteville Group and underlying the Maquoketa Group of the Cincinnatian Series. The Galena Group is named for Galena in Jo Daviess County, and several sections in the vicinity of Galena have been designated the type section. Hall put the base of the Galena in the Decorah Subgroup, either at the top or the base of the Guttenberg Formation; Kay raised it to the top of the Decorah; and Templeton and Willman lowered it to the base of the Decorah, which is the present usage in Illinois. The Galena Group is present in all of Illinois (fig. O-21) except (1) the areas where the older rocks are exposed in central northern Illinois and in Calhoun County and (2) an area along the crest of the La Salle Anticline, largely in La Salle County, where Galena strata were eroded before deposition of the Pennsylvanian rocks. The Galena is extensively exposed in northern Illinois (fig. O-2B, C), but elsewhere it crops out only in small areas on anticlinal structures in Calhoun, Monroe, and Alexander Counties. The Galena Group is 250-275 feet thick in the northern outcrop area, but the upper part is truncated by the Cincinnatian Series in central Illinois, and south of there the group is only 100-125 feet thick. The group is divided into two subgroups (fig. O-22)—the Decorah at the base is a shaly unit and the Kimmswick above it is relatively pure limestone and dolomite. The shaly Dubuque Formation, although included as the top of the Galena Group in northwestern Illinois, is not included in the Kimmswick Subgroup. The Galena Group has three major facies (fig. O-23). A fine-grained limestone facies is present only in extreme northwestern Illinois, where as much as 50 feet of limestone at the base of the group changes rapidly to dolomite southward and eastward. In most of northern Illinois, the group is entirely dolomite. Southward, the lower part becomes limestone, and a short distance south of La Salle only the uppermost part is dolomite. The lower part is largely coarse calcarenite, overlain by fine-grained limestone. Still farther south, the fine-grained limestone is truncated so that the group is entirely calcarenite and calcarenitic limestone. Galena Group strata are generally fossiliferous (fig. O-5), but fossils are poorly

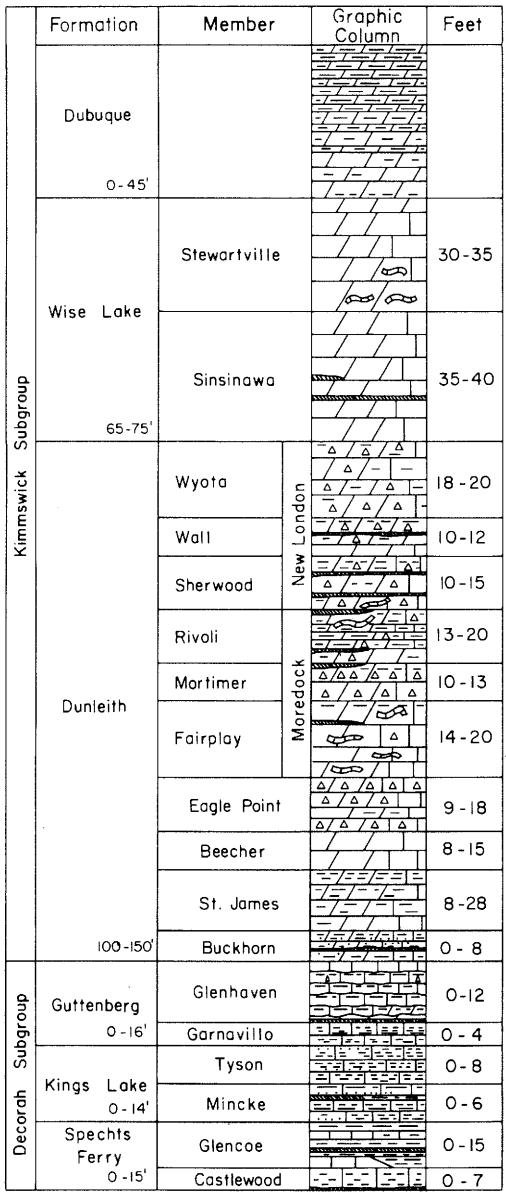

Fig. O-22—Columnar section of the Galena Group (after Templeton and Willman, 1963).

preserved in the dolomite facies. *Receptaculites oweni*, an alga (fig. O-5), is perhaps the most characteristic fossil, but several zones characterized by abundance of certain species of brachiopods and bryozoans are persistent (fig. O-24). The Galena Group is equivalent to the Trenton Group of New York, the Lexington Limestone of Kentucky, and the Nashville Group of Tennessee.

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Decorah Subgroup

The Decorah Subgroup (Calvin, 1906, p. 84; Kay, 1935b, p. 289; Herbert, 1949) consists of the shaly limestone and dolomite formations at the base of the Galena Group. It is named for exposures at Decorah, Winneshiek County, Iowa. At Decorah it is called the Decorah Formation and includes the Spechts Ferry, Guttenberg, and Ion Members. Kay took the Spechts Ferry out of the Decorah and put it in the Platteville, but Herbert showed that the Spechts Ferry belonged in the Decorah. Templeton and Willman (1963) removed the strata equivalent to the Ion from the Decorah in Illinois because they are not shaly. The Decorah is extensive in Illinois and is exposed in central northern and extreme northwestern Illinois in a small area near West Point Landing in Calhoun County, and at Valmeyer in Monroe County. It is 15-30 feet thick in western Illinois, but it thins eastward and is generally only 1-5 feet thick in the central and eastern parts of the state. The Decorah consists of three formations—the Spechts Ferry (at the base) is green shale and limestone; the overlying Kings Lake is largely limestone, partly silty and sandy; and the Guttenberg (at the top) is limestone with beds of brown-red shale. The Kings Lake thins out northward and is not present in northern Illinois. Both the Kings Lake and the Spechts Ferry thin out eastward, and in central and eastern Illinois the Decorah consists only of the Guttenberg Formation. The Decorah strata in Illinois are very fossiliferous, containing abundant bryozoans and brachiopods. *Refinesquina*, *Sowerbyella*, and *Pionodema* (fig. O-5) are especially abundant. Decorah strata in Illinois correlate with the Rockland Formation in New York, the Curdsville and Logana Members of the Lexington Limestone in Kentucky, and the lower part of the Hermitage Limestone in Tennessee.

Spechts Ferry Formation

The Spechts Ferry Formation (Kay, 1928, p. 16; 1935b, p. 287) consists of as much as 15 feet of interbedded shale and limestone. It is the basal formation of the Galena Group, underlying the Kings Lake or Guttenberg Formations and unconformably overlying various Platteville formations. The type section is in a ravine at Spechts Ferry, Dubuque County, Iowa (SW NW 4, 90N-2E), where it is 7.8 feet thick (Agnew et al., 1956, p. 307; Templeton and Willman, 1963, p. 106). The Spechts Ferry Formation is exposed in northwestern Illinois along the Galena River in Jo Daviess County (cen. 34, 29N-1E) and in small areas near West Point Landing in Calhoun County, and Valmeyer, Monroe County. It is commonly 5-10 feet thick in wells in western Illinois but is absent in the central and eastern parts of the state. Limestone is dominant in the south and shale in the north. Much of the shale is bright green, but it is locally greenish gray and the basal few inches is dark brown. The formation is characterized by two bentonites and by the persistence of distinctive thin beds of dense, fine-grained to earthy limestone, coquinite, and dark purplish gray, coarse-grained calcarenite. It is subdivided into the Castlewood Member (at the base), which is dominantly limestone, and the Glencoe Member (at the top), which is limestone and shale—in places dominantly shale. In the mining district in northwestern Illinois, it is called the "Clay bed." *Pionodema subaequata* (fig. O-5) is abundant in the Spechts Ferry. Other Trentonian fossils are common, particularly bryozoans (Perry, 1962). The Spechts Ferry Formation is the *Stictoporella* bed of early reports. It rests on a distinctive, pitted, ferruginous, and phosphatic surface on the top of the Quimbys Mill Formation, and the basal beds locally contain fragments of that formation. In northwestern Illinois, where the Kings Lake is absent, the Spechts Ferry is overlain by the Guttenberg Formation, the basal beds of which contain phosphate nodules. The Spechts Ferry Formation is correlated with the Selby Member of the Rockland Formation in New York and the Curdsville Limestone in Kentucky and Tennessee.

Castlewood Member—The Castlewood Member of the Spechts Ferry Formation (Templeton and Willman, 1963, p. 107), the basal member, is largely limestone in its type section near Castlewood, St. Louis County, Missouri (NE SE SE 21, 44N-4E), where it is 6.9 feet thick. It is a massive bed 3-7 feet thick in the type region, but it is only a few inches to 1.5 feet thick in northwestern Illinois. The limestone commonly overlies a thin bentonite, generally less than an inch thick, which rests on dark brown shale up to 3 inches thick. The limestone is fine grained, slightly argillaceous, and more like limestone beds in the Glencoe Member above than the pure lithographic limestone of the Plattin below, from which it is separated by a widespread unconformity. Fossils are not abundant, but *Pionodema subaequata* and other Trentonian fossils are present. It has been called the *Lingula elderi* bed in Minnesota, where it is equivalent to the lower part of the Carimona Limestone (Weiss, 1955).

Glencoe Member—The Glencoe Member of the Spechts Ferry Formation (Templeton and Willman, 1963, p. 110), which overlies the Castlewood Member, is named for Glencoe, St. Louis County, Missouri, which is 3 miles west of the type section, the same as that for the Castlewood Member, where the Glencoe is 5.3 feet thick. It is commonly 5-8 feet thick in the area near the Mississippi River, but it thins to the east. The most persistent and thickest Ordovician bentonite, commonly 1-3 inches thick and locally as much as 8 inches thick, occurs in the lower part of the Glencoe Member, interbedded with green, gray, or brown shale. Locally the bentonite is altered to a distinctive, hard, pink bed, which is almost entirely potash feldspar. The Glencoe is largely green shale, but it contains beds of calcarenite, greenish gray argillaceous limestone, and dark purplish gray coarse-grained limestone. Some beds are a coquina of *Pionodema subaequata*. In the Upper Mississippi Valley, the trilobite *Isotelus gigas* (fig. O-5) is common in an argillaceous limestone bed near the base.

Kings Lake Formation

The Kings Lake Formation (Herbert, 1949; Templeton and Willman, 1963, p. 110) overlies the Spechts Ferry

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Formation, underlies the Guttenberg Formation, and is conformable with both. It is named for Kings Lake, a village in Lincoln County, Missouri, a mile east of the type section in the Mississippi River bluffs (SE SE NE 26, 50N-2E), where it is 9.2 feet thick. The Kings Lake Formation is exposed in Illinois only near West Point Landing in Calhoun County, but it is widely exposed in eastern Missouri. It is locally missing on the flanks of the Ozarks, where it is overlapped by the Dunleith Formation. It is commonly 5-10 feet thick but is locally as much as 15 feet thick. It thins out northward and does not extend to the northern outcrop area of the Decorah. The Kings Lake Formation consists largely of argillaceous, very silty, dolomitic limestone with a few thin beds of shale, calcarenite, and bentonite. It locally contains fine sand. It is subdivided into two members. The Mincke Member, at the base, contains more shale and calcarenite than the overlying Tyson Member. Many of the characteristics of the Kings Lake are transitional from those of the Spechts Ferry to those of the Guttenberg, but the Kings Lake is more silty and sandy than either of them. It contains a mixture of Spechts Ferry and Guttenberg fossils—the most abundant being *Pionodema subaequata*, *Zygospira recurvirostris*, and locally *Sowerbyella curdsvillensis* (fig O-5). Strata lithologically similar to the Kings Lake appear to be missing in the New York section but are widely present in Kentucky in the lower part of the Logana Formation and in Tennessee in the Hermitage Formation.

Mincke Member—The Mincke Member of the Kings Lake Formation (Templeton and Willman, 1963, p. 111), the lower member, is named for Mincke Hollow, a small tributary of the Meramec Valley in St. Louis County, Missouri. The mouth of the hollow is a quarter of a mile southwest of the type section, which is in a railroad cut in the Meramec Valley bluff (near cen. E1/2 SE SE 21, 44N-4E), where the member is 6.3 feet thick. In Illinois it is exposed only near West Point Landing, Calhoun County. The Mincke Member thins northward from the type section to 4.9 feet in the Kings Lake type section and 3.6 feet at New London, Missouri. The Mincke Member consists of interbedded 1-5 inch beds of (1) silty argillaceous limestone that locally contains a small amount of fine sand, (2) very fossiliferous calcarenite, and (3) green to brown shale. A bed of yellow bentonite 0.5-2 inches thick is persistent in a bed of brown shale 1-1.5 feet below the top.

Tyson Member—The Tyson Member of the Kings Lake Formation (Templeton and Willman, 1963, p. 111), the upper member, is named for Tyson Hollow, St. Louis County, Missouri, the mouth of which is 0.5 mile northeast of the type section, the same section as the Mincke type section, where the Tyson is 7.5 feet thick. It thins northward to 4.3 feet in the Kings Lake type section and to 3.9 feet at New London, Missouri. The Tyson Member is largely dolomitic, silty, argillaceous limestone that weathers buff and chalky. It occurs in medium to thick beds and contains a few thin beds of buff to reddish brown shale, coarse calcarenite, and coquinite.

Guttenberg Formation

The Guttenberg Formation (Kay, 1928, p. 16; 1935b, p. 289) at the top of the Decorah Subgroup in Illinois, overlies the Spechts Ferry Formation in northwestern Illinois and the Kings Lake Formation in the southwestern part of the state. It is named for Guttenberg, Clayton County, Iowa, and the type section is in a ravine 0.5 mile north of the town. It is better exposed in a roadcut on U.S. Highway 52 on the northwest side of Guttenberg,

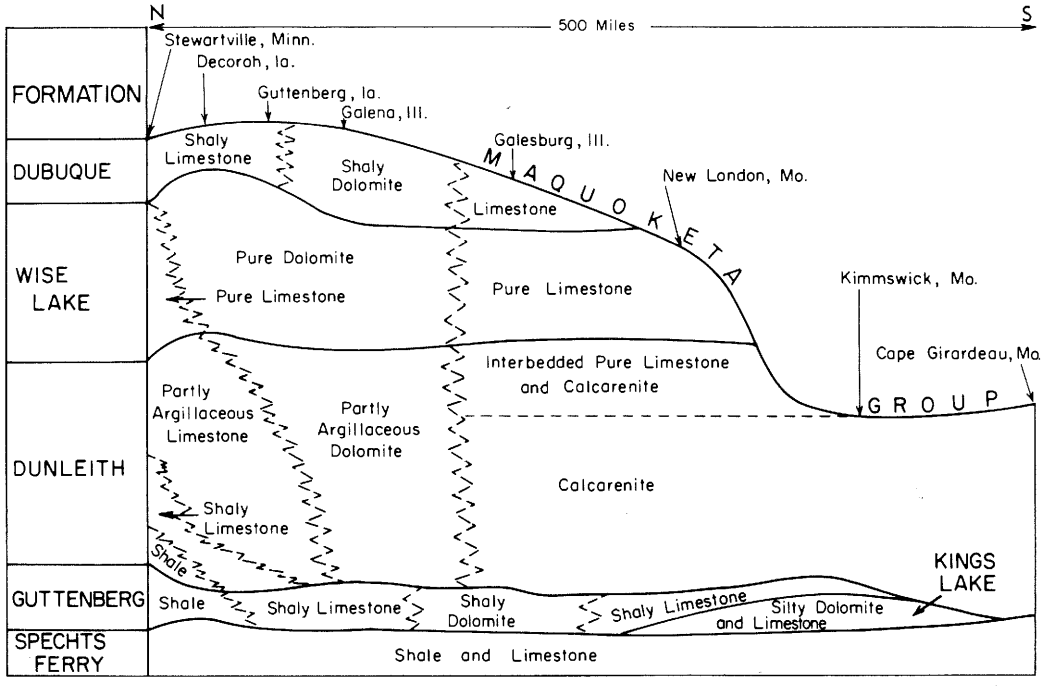

Fig. O-23—Diagrammatic cross section showing the facies in the Galena Group (after Templeton and Willman, 1963).

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where the formation is 16.5 feet thick (Templeton and Willman, 1963, p. 236). The Guttenberg Formation is widely present in Illinois, and it is exposed in the localities described in the Decorah discussion. It is about 15 feet thick in the northwestern Illinois outcrop area and is 10-15 feet thick in southwestern Illinois. It thins eastward and is 3-5 feet thick in the outcrop area in central northern Illinois. In subsurface elsewhere it is only 1-3 feet thick and locally is missing. On the flanks of the Ozarks it is thinned and cut out in some localities by overlap of the Dunleith Formation. In the western part of Illinois, the Guttenberg consists of thin-bedded, tan, white-weathering, very fine-grained limestone interbedded with brown-red shale. Eastward it grades to brown, white-weathering, medium-grained, vuggy dolomite containing thin beds of brown-red shale. The dolomite facies is well exposed in the central northern outcrop area. The lower part, which is grayer, more argillaceous, and less shaly than the upper part, is differentiated as the Garnavillo Member, and the upper part is the Glenhaven Member. A thin but widely present bentonite occurs in a shale at the base of the Glenhaven. In the northwestern Illinois mining district the Guttenberg is locally thinned by solution of the limestone beds, largely in and close to the ore bodies, leaving a residue of brown-red shale called the "oilrock," which is only 2-4 feet thick. The reddish color of the Guttenberg is in part due to the abundance of minute resinous particles, probably the spores of algae. The Guttenberg has an abundant and varied fauna of brachiopods, bryozoans, mollusks, and, in places, a few trilobites. *Sowerbyella* (fig. O-5) is most abundant in the Guttenberg, which includes the *Rhinidictya* and *Ctenodonta* beds of early reports. The Guttenberg Formation is equivalent to the Napanee Member of the Rockland Formation in New York, the upper part of the Logana Formation in Kentucky, and the middle part of the Hermitage Formation in Tennessee.

Garnavillo Member—The Garnavillo Member of the Guttenberg Formation (Templeton and Willman, 1963, p. 113), the lower member, is named for Garnavillo, Clayton County, Iowa, 7.5 miles northwest of the type section in the roadcut of U.S. Highway 52 on the northwest side of Guttenberg (SW SW 5, 92N-2W), where the member is 1.7 feet thick. The Garnavillo is present throughout most of the area where Guttenberg strata occur, but it does not extend as far east as the overlying Glenhaven Member. It is 2-3 feet thick in southwestern Illinois. It consists of gray to gray-tan, white-weathering, argillaceous limestone in medium beds with thin gray-brown shale partings. Phosphatic nodules are widely present in the lower foot in the northwestern outcrop area, where the Kings Lake Formation is missing.

Glenhaven Member—The Glenhaven Member of the Guttenberg Formation (Templeton and Willman, 1963, p. 113), the upper member, is named for Glenhaven, Grant County, Wisconsin, 2.5 miles northeast of the type section, in the same exposure as the type section for the Garnavillo Member, where the Glenhaven is 14.8 feet thick. The Glenhaven Member thins southward from the type area to 10-12 feet in north-

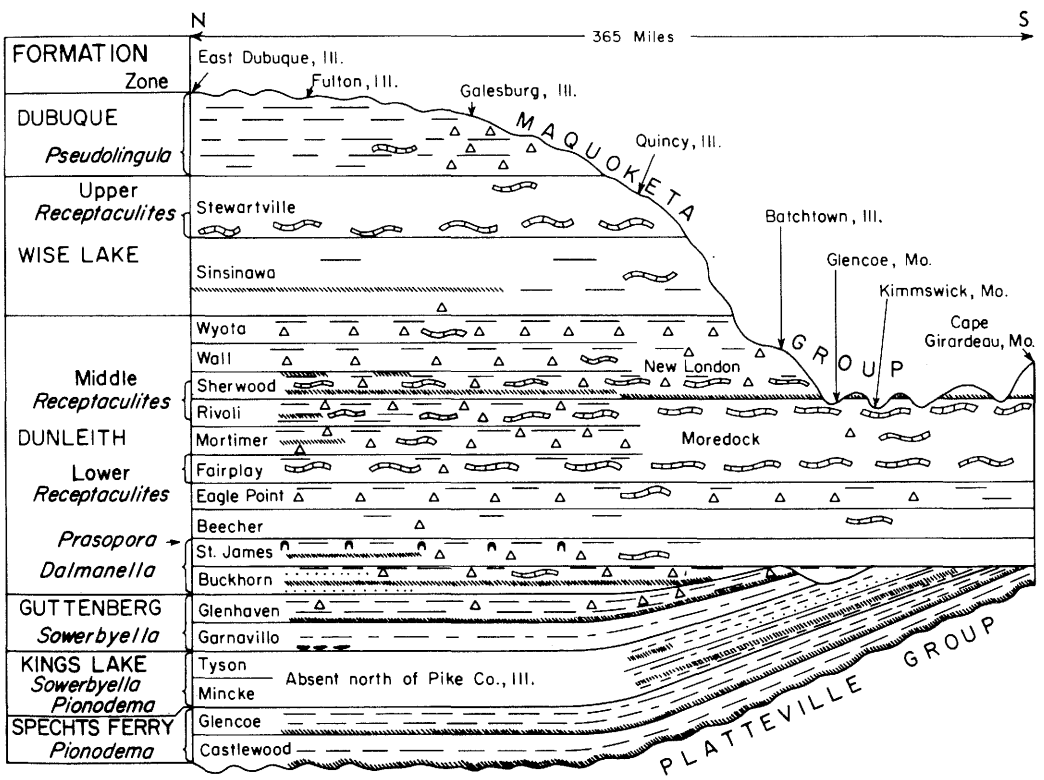

Fig. O-24—Diagrammatic cross section of the Galena Group showing the principal faunal zones and bentonite beds (after Templeton and Willman, 1963).

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western Illinois and 7-9 feet in southwestern Illinois. In northwestern Illinois the Glenhaven is commonly separated from the overlying Dunleith Formation by a transition zone as much as a foot thick. The Glenhaven consists of tan, white-weathering, lithographic to very fine-grained limestone in beds 1-4 inches thick that are separated by layers of dark brown-red shale, generally thin but locally as much as 2 inches thick. The lower part is consistently more shaly, thinner bedded, and has wavier bedding planes than the upper part. The upper is purer and has more fossil debris and calcarenite layers. Lenses of chert are widely present in a single layer 1-2 feet above the base of the upper part and are scattered through the lower foot in the southwestern outcrops. In places in subsurface the entire formation is cherty. A bentonite bed up to 1 inch thick is widely present at the base of the Glenhaven in both northern and southern outcrop areas.

Kimmswick Subgroup

The Kimmswick Subgroup (Ulrich, 1904, p. 111; Templeton and Willman, 1963, p. 114) consists of the dominantly pure limestone and dolomite formations that compose the middle part of the Galena Group. It excludes the shaly strata of the Dubuque Formation at the top and the shaly formations of the Decorah Subgroup at the base. It is named for Kimmswick, Jefferson County, Missouri, and the type section is in a quarry about a mile west of Kimmswick on the north side of Rock Creek just west of the mouth of Black Creek (approximately SE NE 18, 42N-6E). The Kimmswick Subgroup occurs throughout the area of the Galena Group. It is about 250 feet thick in northern Illinois, thins rapidly in an east-west belt through the central part of the state, and it is only 90-125 feet thick in most of the southern half of the state. It is dominantly limestone in the southern two-thirds of the state and dolomite north of there. It is subdivided into the basal Dunleith Formation, which contains some argillaceous beds and is medium bedded and generally cherty, and the Wise Lake Formation, which is pure, massive, and not cherty. Only the Dunleith Formation is present in the Kimmswick type locality because the Wise Lake is truncated by the Cincinnatian Series south of the belt through the central part of the state where the Galena Group thins.

Dunleith Formation

The Dunleith Formation (Templeton and Willman, 1963, p. 114), which overlies the Guttenberg Formation and underlies the Wise Lake Formation in the Galena Group, is named for Dunleith Township, Jo Daviess County. The type section is an exposure in the Mississippi River bluffs on the north side of East Dubuque (SE 19, 29N-2W), where the formation is 132 feet thick, including the unexposed lower 20 feet (fig. O-2B). The type section for the lowest strata (the St. James and Buckhorn Members) is at Buena Vista, Stephenson County. The Dunleith Formation is exposed (fig. O-2C) in most of the area described in the discussion of the Galena Group. It is commonly 120-125 feet thick in the northern outcrop area and is 135 feet thick near New London, Missouri, where it is overlain by the Wise Lake Formation. South of New London, where the Wise Lake and upper Dunleith beds are missing, the formation is only about 100 feet thick. At East Dubuque the lower 27 feet is dolomite-mottled lithographic limestone and the upper 85 feet is dolomite. South and east of there, the limestone is progressively replaced by dolomite from the top down, and at Galena and farther east the formation is all dolomite, except for local areas such as north of Morris, Grundy County, in which it is dolomite-mottled limestone. In northwestern Illinois the Dunleith consists of alternating pure and argillaceous units. The pure units are medium to thick bedded and vuggy and the argillaceous units thin to medium bedded and dense. Chert nodules are common, particularly in the argillaceous units. The formation is subdivided into 10 conformable members, most of them consisting of a pure unit overlain by a thinner argillaceous unit. The Buckhorn (at the base) is overlain by the St. James, Beecher, Eagle Point, Fairplay, Mortimer, Rivoli, Sherwood, Wall, and Wyota Members. In Illinois the upper six members are recognized only in the northern dolomite and limestone facies. The argillaceous content decreases eastward and southward, and the member differentiation is less useful in the central northern outcrop area, although most of the members can be identified by such minor characteristics as abundance and types of chert, persistent thin bentonite beds, corrosion zones, fucoidal zones, and common fossils. In subsurface in northeastern Illinois the formation is even purer, contains little or no chert, and its members have not been differentiated (Buschbach, 1964). The southern limestone facies occurs throughout central and southern Illinois but is exposed only at Lowell, La Salle County, at Valmeyer, Monroe County, and near West Point Landing, Calhoun County. The lower four members are recognizable in the outcrops but rarely in subsurface. The overlying part of the Dunleith is divided into only two members, a lower massive calcarenite (Moredock Member) and an upper cherty, thin- to medium-bedded, calcarenitic limestone (New London Member). The Dunleith is sparsely fossiliferous in the dolomite facies, although *Paucicrura* [*Dalmanella*], *Prasopora*, and *Receptaculites* (fig. O-5) characterize certain zones. Bryozoans and crinoidal debris are particularly abundant in the southern limestone facies. The Dunleith Formation is called the "Drab" in the lead-zinc district, and it is equivalent to the upper part of the Decorah Shale and the lower part of the Prosser Limestone in the Mississippi Valley north of Illinois, to the Jessamine, Benson, and Brannon Members of the Lexington Limestone in Kentucky, to the upper part of the Hermitage and most of the Bigby-Cannon Formations in Tennessee, and to the Kirkfield Formation, the Sherman Fall Formation, and the Rust Member of the Coburg Formation in New York.

Buckhorn Member—The Buckhorn Member of the Dunleith Formation (Templeton and Willman, 1963, p. 119), the basal member, is named for Buckhorn Corners, Stephenson County, 2 miles east of the type section in a quarry at Buena Vista (NW SW NE 15, 28N-7E), where the member is 8.3 feet thick. It is commonly 5-8 feet thick but is generally absent in southwestern Illinois, where it is overlapped by the St. James Member. The Buckhorn consists of argillaceous, medi-

um to coarse, blue-gray dolomite heavily speckled with black, particularly at the top. It contains green shale partings and in the northwestern area is slightly sandy. It locally contains several very thin layers of bentonite. *Paucicrura [Dalmanella] rogata* is especially common. The Buckhorn is called the "Blue" in the lead-zinc district. With the overlying St. James Member, it is equivalent to the Ion Member at the top of the Decorah in the region northwest of Illinois.

St. James Member—The St. James Member of the Dunleith Formation (Templeton and Willman, 1963, p. 119), which overlies the Buckhorn Member, is named for St. James Cemetery in Stephenson County, 3 miles northwest of the type section, in the same exposure as the Buckhorn type section, where the St. James is 13.3 feet thick. It is called the "Gray" in the lead-zinc district. The St. James Member commonly is about 14 feet thick in the dolomite facies in northern Illinois and 8-12 feet thick in the southern limestone facies. In northern Illinois it is light tan, pure, medium-bedded, vuggy dolomite, but thin green shale partings are common in the upper 2-4 feet. It has black speckles but not as many as the Buckhorn. *Prasopora simulatrix* (fig. O-5) is common in the upper few inches in the extreme northwestern part of the state but has been found eastward only as far as Rockford, where it is rare. In the southern area the St. James is a coarse-grained, gray to brown, faintly gray-speckled calcarenite that locally has a few inches of conglomerate at the base.

Beecher Member—The Beecher Member of the Dunleith Formation (Templeton and Willman, 1963, p. 120) overlies the St. James Member and is named for Beecher Street in East Dubuque, Jo Daviess County, which is near the type section (part of the Dunleith type section), where the member is 6.3 feet thick. It commonly is about 8 feet thick in the northern outcrop area and 12 feet in the southern area. In the type section the Beecher is lithographic to fine-grained, dolomite-mottled limestone, typical of the northern limestone facies, but in most of northern Illinois it is relatively pure, noncherty, mainly massive, vuggy dolomite. High purity and massiveness differentiate it from the cherty Eagle Point Member above and the more argillaceous St. James below. In the southern limestone facies it is coarse-grained, gray to pink, almost wholly massive, pure calcarenite.

Eagle Point Member—The Eagle Point Member of the Dunleith Formation (Templeton and Willman, 1963, p. 120) overlies the Beecher Member and is named for Eagle Point, a prominent bluff on the west side of the Mississippi Valley in Dubuque County, Iowa, 2 miles north of the type section (part of the Dunleith type section), where the member is 11.8 feet thick. It is commonly 12-18 feet thick in the northern outcrop area and 9-10 feet in the southern area. It is characterized by well defined bands of chert nodules. It consists of slightly argillaceous dolomite-mottled limestone in the type section, but it is dolomite in most of northern Illinois. In the southern outcrop area it is calcarenite containing bands of chert, is finer grained, denser, and more argillaceous than the members above and below.

Fairplay Member—The Fairplay Member of the Dunleith Formation (Templeton and Willman, 1963, p. 121) overlies the Eagle Point Member, and is named for the town of Fairplay, Grant County, Wisconsin, 6 miles northeast of the type section (part of the Dunleith type section), where the member is 19.8 feet thick. It is commonly 14-20 feet thick. In the type section it consists of relatively pure, lithographic limestone and is the top of the northern limestone facies. It is largely free of chert, but scattered nodules appear locally. The upper 1-3 feet is persistently argillaceous or shaly. *Receptaculites oweni* is common in many beds, and the Fairplay is the Lower *Receptaculites* Zone. These characteristics extend into the northern dolomite facies, but the member is not differentiated in the southern limestone facies.

Mortimer Member—The Mortimer Member of the Dunleith Formation (Templeton and Willman, 1963, p. 121) overlies the Fairplay Member and is named for Mortimer Street in East Dubuque, Jo Daviess County, near the type section (part of the Dunleith type section) (fig. O-2B), where the member is 11.3 feet thick. It is commonly 10-13 feet thick. It consists of thick-bedded vuggy dolomite that contains bands of large white chert nodules. Its purity is between that of the pure Fairplay Member below and the argillaceous Rivoli above. It has a 2.2-foot argillaceous zone at the top in the type section, which thins to 5-6 inches in the Dixon and Rockford areas. It contains a few dense argillaceous beds. Thin lenses of bentonite occur along a prominent bedding plane at the top.

Rivoli Member—The Rivoli Member of the Dunleith Formation (Templeton and Willman, 1963, p. 122) overlies the Mortimer Member and is named for Rivoli Street in East Dubuque, Jo Daviess County, near the type section (part of the Dunleith type section) (fig. O-2B), where the member is 19 feet thick. The Rivoli Member thins eastward from the type section and is 13 feet thick in central northern Illinois. It is the most argillaceous of the Dunleith members. The upper 5 feet is a persistent argillaceous zone that is very cherty in the type section. The lower 5-6 feet contains bands of large chert nodules. Corrosion surfaces are strongly developed in the Rivoli. Thin lenses of bentonite are locally present at or near the top and probably occur at other horizons, especially along sharp reentrants. *Receptaculites oweni* is abundant in upper Rivoli strata and the overlying Sherwood Member—the Middle *Receptaculites* Zone.

Sherwood Member—The Sherwood Member of the Dunleith Formation (Templeton and Willman, 1963, p. 123) overlies the Rivoli Member and is named for Sherwood Street in East Dubuque, Jo Daviess County, near the type section (part of the Dunleith type section) (fig. O-2B), where the Sherwood is 13.6 feet thick. The Sherwood Member is 10 feet thick in central northern Illinois. It consists of relatively pure, vuggy dolomite with a strong argillaceous zone in the top 3.6 feet in the type section. Chert is erratic in occurrence, except for an almost continuous bed of chert just above the base in some areas. One of the most persistent bentonites, as much as 3 inches thick, occurs about 3 feet above the base, and another occurs locally at the base of the upper argillaceous zone.

Wall Member—The Wall Member of the Dunleith Formation (Templeton and Willman, 1963, p. 123) overlies the Sherwood Member and is named for Wall Street in East Dubuque, Jo Daviess County, near the type section (part of the Dunleith type section) (fig. O-2B), where the Wall is 9.7 feet thick. The Wall Member is commonly 10-12 feet thick. It is less argillaceous than the Sherwood below and more argillaceous than the Wyota above. The argillaceous zone at the top is not prominent, but the upper 1-3 feet commonly has more argillaceous mottling and thin, wavy shale partings than the beds below. A widespread bentonite bed as much as 4 inches thick occurs near the middle of the member. Chert nodules are common, and the beds above the bentonite are more cherty than those below.

Wyota Member—The Wyota Member of the Dunleith Formation (Templeton and Willman, 1963, p. 124), the uppermost member in northern Illinois, overlies the Wall Member, and is named for Wyota Street in East Dubuque, Jo Daviess County, near the type section (part of the Dunleith type section) (fig. O-2B), where the Wyota is 19.9 feet thick. The Wyota Member is commonly 18-20 feet thick. Most of it is purer than the Wall but less pure than the overlying Sinsinawa Member of the Wise Lake Formation. It is characterized by the persistence of thin beds with argillaceous flecks, particularly in the upper 10 feet, and by abundant chert nodules in well defined bands. The upper 2-4 feet is slightly ar-

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gillaceous, locally shaly, and in many exposures makes a strong reentrant that marks the top of the Dunleith Formation.

Moredock Member—The Moredock Member of the Dunleith Formation (Templeton and Willman, 1963, p. 124) occurs in the southern limestone facies, overlying the Eagle Point Member. It is named for Moredock Lake, at Valmeyer, Monroe County, near the type section in the Mississippi River bluff (cen. N line SW 3, 3S-11W), where the member is 58.4 feet thick. The Moredock is commonly 60-70 feet thick where overlain by the New London Member, but in many exposures in the southern outcrop area the Moredock is overlain unconformably by Maquoketa Group strata, as it is at the type section, or by the Cape Limestone, and the upper few feet of the member are missing. The Moredock is exceptionally pure, coarse-grained calcarenite that is massive, cross-bedded, crinoidal, nearly white, and banded with pink, buff, and gray beds. Although the member is generally noncherty, large chert nodules or lenses of chert occur locally. It is distinguishable from the Eagle Point Member, which is finer grained, has bands of chert nodules, and is less pure.

New London Member—The New London Member of the Dunleith Formation (Templeton and Willman, 1963, p. 125) occurs in the southern limestone facies, overlying the Moredock Member and underlying the Wise Lake Formation. It is named for New London, Ralls County, Missouri, 2 miles south of the type section in a roadcut and in the bluff east of U.S. 61 on the north side of Salt River (NE SW 25, 56N-5W), where it is 32.8 feet thick. The top of the member is not exposed in the type section, but it occurs in a roadcut and bluff half a mile south of Frankford, Ralls County, on the north side of Peno Creek (SE NE and NE SE 2, 54N-4W). The New London consists of fine-grained to lithographic, calcarenitic, cherty limestone that contains beds of fine- to medium-grained calcarenite and some thin argillaceous and slightly shaly beds. Red-brown shale partings occur locally. It is finer grained than the Moredock below, coarser than the Wise Lake above, and less pure and thinner bedded than either. A persistent bentonite, as much as 2 inches thick, commonly marks the base of the member. It is believed to be equivalent to the bentonite near the base of the Sherwood Member in the northern area. The entire member is exposed only in the extreme northern part of the southern outcrop area, where it is 35-45 feet thick. South of there it is generally overlapped by Cincinnatian strata, but the lower 3-5 feet, identified by the bentonite at its base, is present locally.

Wise Lake Formation

The Wise Lake Formation (Templeton and Willman, 1963, p. 125) consists of relatively pure dolomite and limestone overlying the cherty Dunleith Formation and underlying the shaly Dubuque Formation. It is named for Wise Lake, a lake on the Mississippi River floodplain near the type section at the north end of a prominent bluff, 6 miles south of Galena, Jo Daviess County (cen. NE 21, 27N-1E), where the formation is 70.9 feet thick. The Wise Lake Formation, persistently 67-75 feet thick, occurs throughout the northern outcrop area (fig. O-2B, C) and southward in subsurface to the central part of the state, where it is sharply truncated by Cincinnatian strata. The Wise Lake consists of noncherty, medium- to thick-bedded, vuggy, pure dolomite in the northern outcrop area. The southern limestone facies is not exposed in Illinois, but in outcrops near New London, in Ralls County, Missouri, it is thick-bedded, fine-grained, to lithographic, pure limestone. The Wise Lake is subdivided into two members; the basal Sinsinawa Member is thinner bedded and slightly less pure than the Stewartville above it. *Receptaculites oweni* (fig. O-5) is abundant and persistently present in the lower 10-15 feet of the Stewartville, called the Upper *Receptaculites* Zone, and is associated with a gastropod-cephalopod fauna. *Maclurites cuneata* and *Hormatoma major* (fig. O-5) are common in some localities. The Sinsinawa Member is less fossiliferous but contains gastropods and, in places, a few *Receptaculites*. The Wise Lake Formation is the purest of the carbonate formations in the Galena Group and is equivalent and lithologically similar to relatively pure formations throughout much of the continent. The Wise Lake is thought to represent the greatest submergence of the continent during Paleozoic time. The Wise Lake Formation consists of strata formerly included in the Stewartville Formation and in the upper part of the Prosser Formation in the Upper Mississippi Valley. It is equivalent to the Steuben Member of the Cobourg Limestone in New York and Ontario, the upper part of the Lexington Limestone in Kentucky, and the upper part of the Bigby-Cannon Formation in Tennessee.

Sinsinawa Member—The Sinsinawa Member of the Wise Lake Formation (Templeton and Willman, 1963, p. 126), the lower member, is named for the Sinsinawa River in Jo Daviess County, along which it is well exposed. The type section is a roadcut along U.S. Highway 20 on the east side of the Galena River at Galena (SW SE NE 20, 28N-1E), where ber is 33 feet thick, although a few feet at the top (exposed in the Wise Lake type section) is missing. The Sinsinawa Member is 35-40 feet thick. Where exposed in the northern outcrop area (fig. O-2B), most of it is medium- to thick-bedded, pure, vuggy dolomite, but it contains a few dense, slightly argillaceous beds. A 1-2 inch bed of bentonite is widely present about 17 feet above the base, and a thin bentonite occurs locally about 7 feet higher. The Sinsinawa Member is equivalent to the upper, noncherty part of the Prosser Limestone of Minnesota.

Stewartville Member—The Stewartville Member of the Wise Lake Formation (Ulrich, 1911, pl. 27), the upper member (originally the Stewartville Formation), is named for Stewartville, Olmstead County, Minnesota, which is half a mile east of the type section, a quarry on the north side of the Root River, where 28 feet of dolomite in the lower part of the member is exposed (Kay, 1935a, p. 567). The Stewartville Member is about 60 feet thick in the type locality, but only 30-35 feet thick in northern Illinois. It is largely thick-bedded, pure dolomite, and many samples from the lower 10-15 feet (the Upper *Receptaculites* Zone) contain almost no insoluble residue. The bedding becomes thinner upward as a gradual transition to the shaly Dubuque Formation above takes place. The top of the Stewartville is placed at the lowest definitely argillaceous or shaly bedding plane. Above this position is the first occurrence of *Pseudolingula iowensis*, which is common in the higher, more shaly part of the Dubuque Formation. The Stewartville Member is the *Maclurea* bed of early reports.

Dubuque Formation

The Dubuque Formation (Sardeson, 1907, p. 193) is the shaly dolomite at the top of the Galena Group. It is named for Dubuque, Dubuque County, Iowa, and the type section is a quarry in Dubuque, east of Columbia College at the top of the West 14th Street hill, where 33 feet of Dubuque, its top eroded, is exposed. In Illinois the Dubuque Formation occurs only in the northwestern part of the state, where it is 40-45 feet thick (Templeton and Willman, 1963, p. 128). It is truncated by Maquoke-

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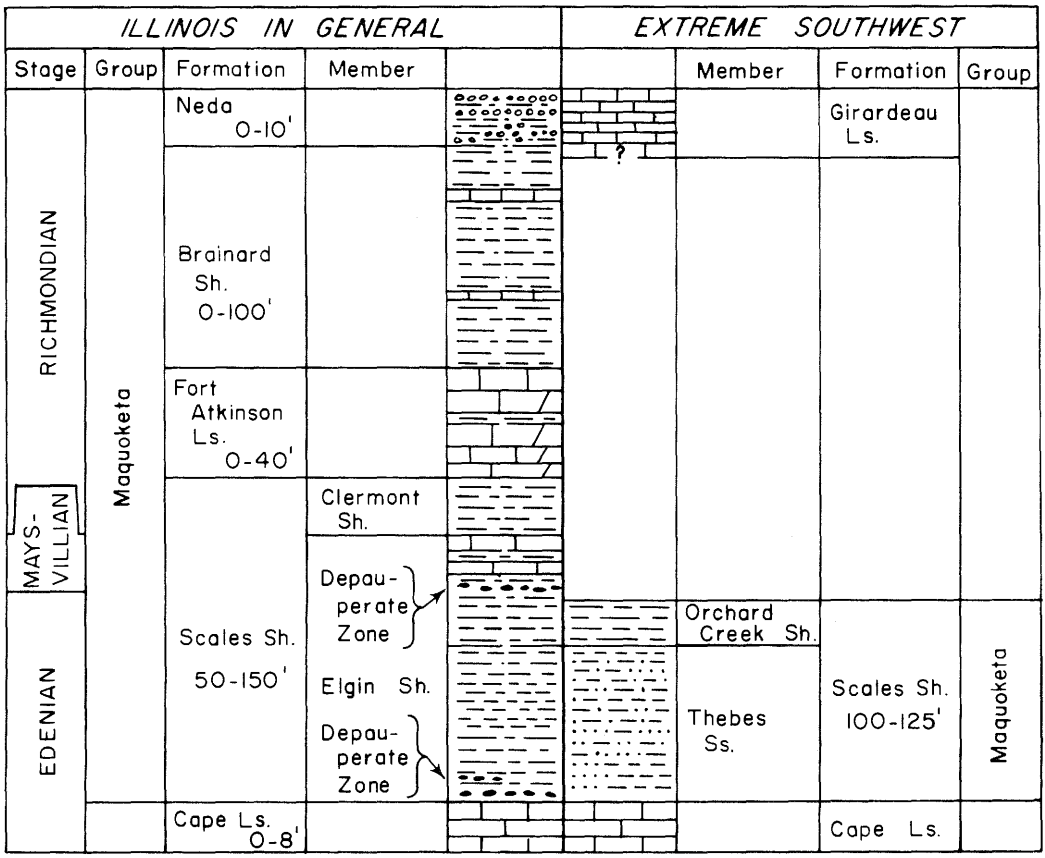

Fig. O-25—Columnar section of the Cincinnatian Series (after Templeton and Willman, 1963).

ta Group strata south of Galesburg in Knox County. It is also absent in subsurface in northeastern Illinois, but equivalent beds may be included in the Wise Lake Formation. The lower 20 feet of the Dubuque Formation grades uniformly from the pure, thick-bedded dolomite of the underlying Wise Lake Formation to shaly dolomite. A 4-inch bed of dolomite set off by relatively strong shale partings occurs 8 feet above the base of the formation and is a widely traceable marker bed. In the upper part of the formation, beds of dolomite 1-6 inches thick that are dense, fine-grained, and argillaceous are interlayered with beds of dolomitic shale 1-8 inches thick. A thin bed of red-brown shale occurs 20 feet below the top. Calcite-filled vugs are common in the upper 2 feet. *Paucicrura [Dalmanella]*, *Sowerbyella, Pseudolingula iowensis,* and crinoid debris are common in the shaly beds in the upper 15 feet. Some beds contain numerous, minute, brown-red, spore-like forms that are probably algae. The Dubuque is overlain unconformably by the Maquoketa Group. Although the contact is sharp, there is slight, if any, truncation of the Dubuque in the outcrop area in Illinois. The Dubuque is equivalent to the *Oxoplecia* Zone of early reports. It is correlated with the Hillier Member at the top of the Cobourg Formation in New York, the Cynthiana Limestone in Kentucky, and the Catheys Formation in Tennessee.

CINCINNATIAN SERIES

The Cincinnatian Series (Meek and Worthen, 1865, p. 155), named for Cincinnati, Ohio, is the uppermost series of the Ordovician System (fig. O-4). It is separated by unconformities from the Champlainian Series below and the Silurian Alexandrian Series above. In Illinois the Cincinnatian Series includes the Cape Limestone, the Maquoketa Group, and the Girardeau Limestone (fig. O-25). Where not affected by sub-Silurian erosion (fig. O-26), the series is 180-350 feet thick.

The Cincinnatian strata in Illinois were long believed to be equivalent to only the uppermost (Richmond) strata in the type region at Cincinnati (fig. O-27) but now are correlated

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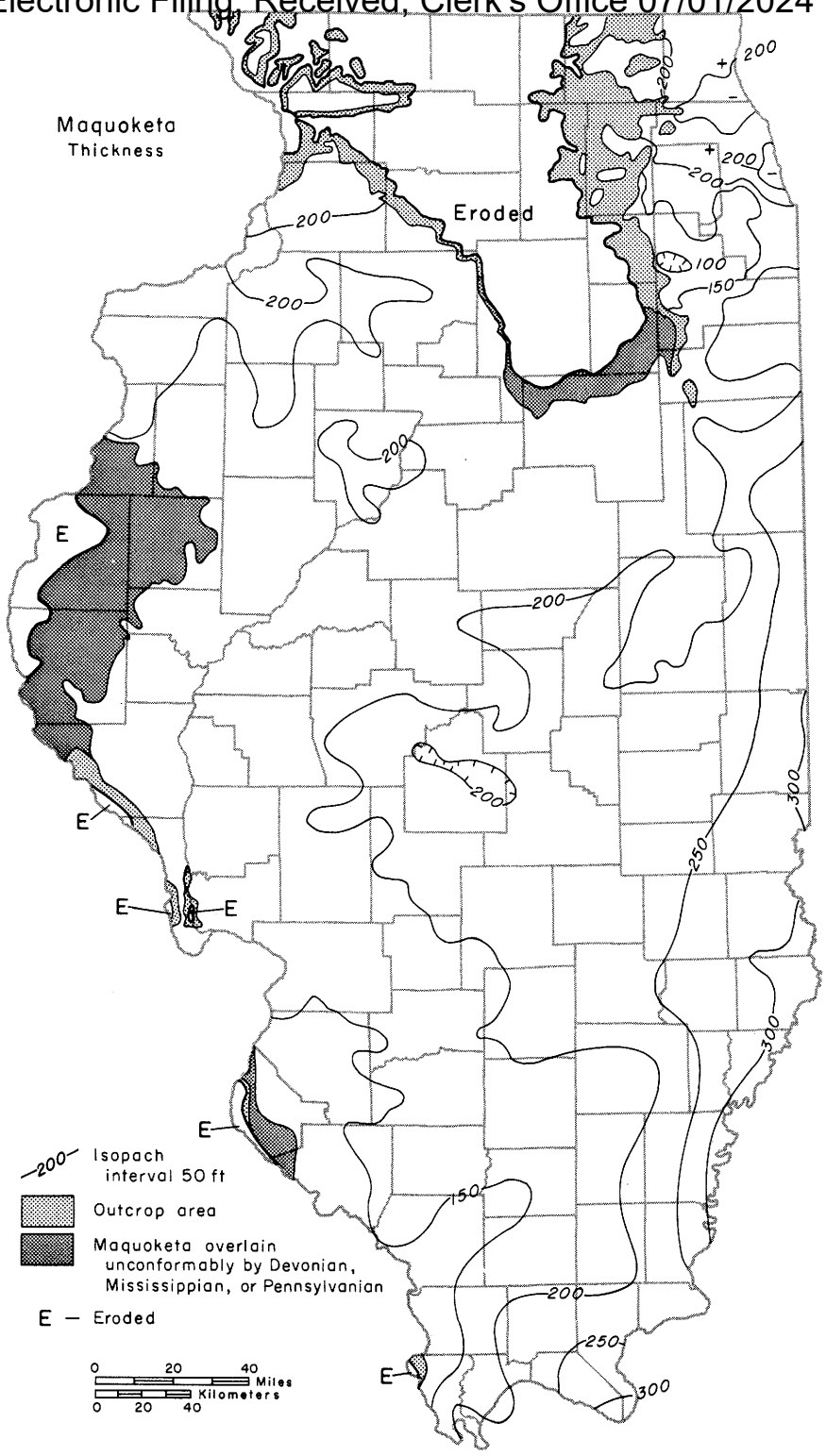

Fig. O-26—Thickness of the Maquoketa Group.

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with the entire series and are subdivided into the Edenian (earliest), Maysvillian, and Richmondian Stages (Templeton and Willman, 1963). The fauna of the Cincinnatian strata in Illinois has not been studied in sufficient detail to determine the precise position of the stage boundaries.

Despite unconformities at the top and bottom, it appears that almost the entire Cincinnatian Series is represented in Illinois. The Cape Limestone at the base of the Cincinnatian in southern Illinois is as old or older than the oldest Cincinnatian strata at Cincinnati. The Fort Atkinson Limestone, in the middle of the Maquoketa Shale Group, has a fauna that closely matches that of the Richmondian Waynesville Limestone of the type region (Savage, 1925a). The *Cornulites* Zone, which occurs near the top of the Richmondian, is present in the upper part of the Brainard Shale

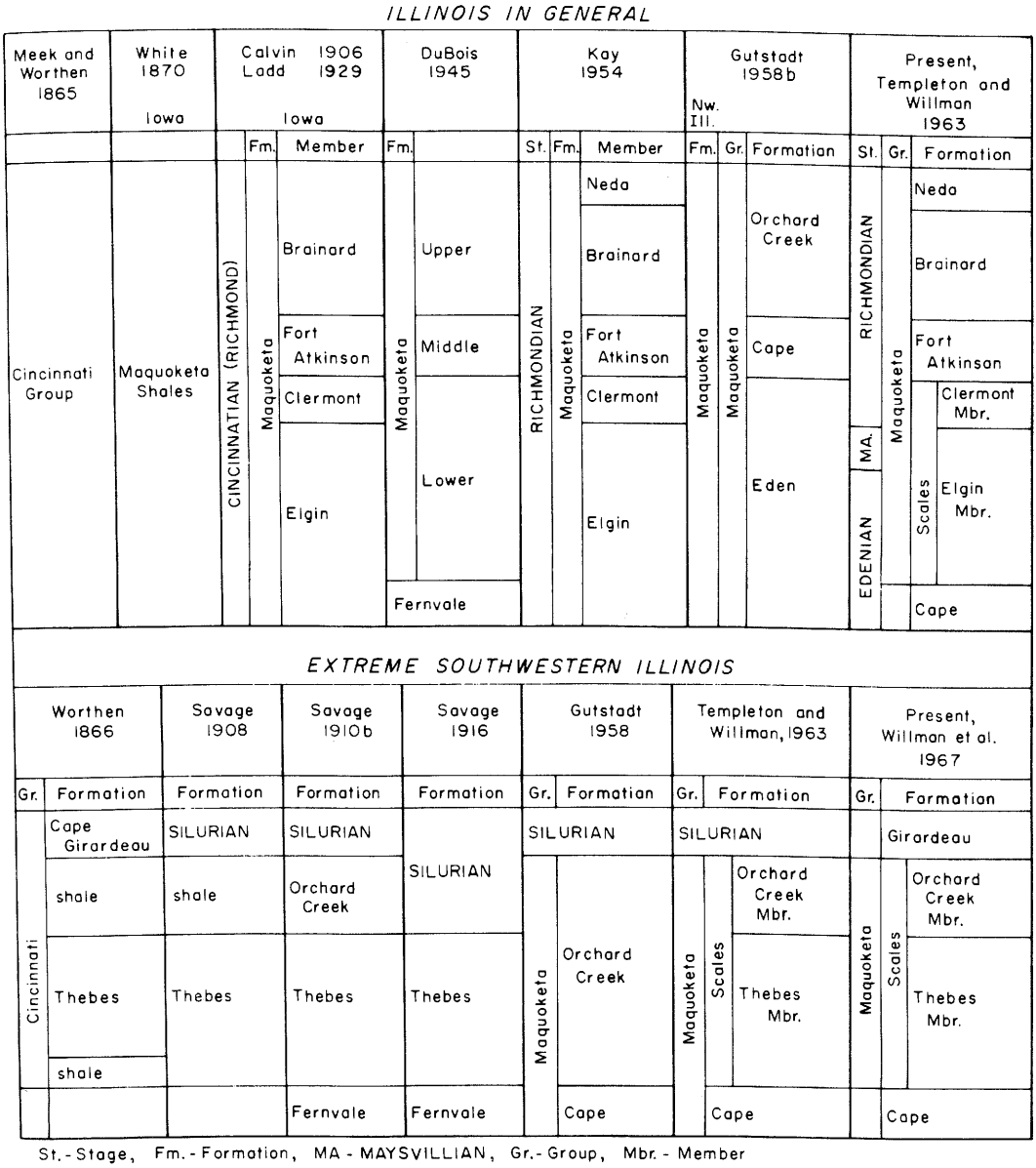

Fig. O-27—Development of the classification of the Cincinnatian Series.

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in Illinois. The Neda Formation and the Girardeau Limestone at the top may be younger than the youngest strata in the type Cincinnatian.

The unconformity at the base of Cincinnatian strata is marked by the sharp truncation of the upper half of the Trentonian Galena Group limestone and dolomite by the Cincinnatian strata in an east-west belt across central Illinois. The Dubuque and Wise Lake Formations and the upper part of the Dunleith Formation were eroded in this belt and are not known south of there, although they may be present in subsurface in the southeastern part of the state where the Galena Group thickens. The Lower Depauperate Zone at the base of the Maquoketa Group is continuous across the truncated formations. Impact of a large meteorite near Glasford in western Illinois probably accounts for the intensive deformation of the Champlainian and older strata before deposition of the Maquoketa Group in that area (Buschbach and Ryan, 1963).

Edenian Stage

The Edenian Stage of the Cincinnatian Series (Newberry, 1873, table opp. p. 89; Twenhofel et al., 1954, chart), the basal stage, is based on the Eden Group, named for Eden Park in Cincinnati, Ohio. In Illinois it includes the Cape Limestone and the lower part of the Scales Shale (essentially the part underlying the Upper Depauperate Zone), which consists of the Thebes Sandstone Member and probably the Orchard Creek Shale Member in extreme southern Illinois and the middle and lower parts of the Elgin Shale Member elsewhere. The presence of dark brown to nearly black shale is characteristic of the Elgin Shale Member and lower Edenian strata in the type region of the Cincinnatian.

Maysvillian Stage

The Maysvillian Stage of the Cincinnatian Series (Foerste, 1905, p. 150; Twenhofel et al., 1954, chart), which overlies the Edenian Stage, is named for Maysville, Kentucky. In Illinois it consists of strata in the upper part of the Scales Formation, including the Upper Depauperate Zone and the overlying argillaceous limestone beds that contain *Isotelus* in abundance. The Girardeau Limestone in the extreme southwestern part of Illinois is approximately at this position, but its relation to the Upper Depauperate Zone is not known. Its fauna has long been considered to be more closely related to Silurian than to Ordovician faunas (Savage, 1917), and it therefore probably is late Richmondian in age.

Richmondian Stage

The Richmondian Stage of the Cincinnatian Series (Winchell and Ulrich, 1897, p. ciii; Twenhofel et al., 1954, chart), the uppermost stage, is named for Richmond, Indiana. In Illinois it includes the uppermost part of the Scales Shale, the Fort Atkinson Limestone, the Brainard Shale, the Neda Formation, and the Girardeau Limestone. The red shales of the Neda suggest correlation with red shales and sandstones in the Queenston and Juniata Formations at the top of the Cincinnatian Series in the Appalachian region.

Cape Limestone

The Cape Limestone (Templeton and Willman, *in* Gutstadt, 1958b, p. 524), the oldest Cincinnatian formation, is named for Cape Girardeau, Missouri, and the type section is an exposure on Main Street just north of Broadway in Cape Girardeau, where the formation is 8.5 feet thick, the maximum thickness observed (Templeton and Willman, 1963, p. 134). The Cape Limestone has a patchy distribution in the outcrop area in Missouri from St. Louis to Cape Girardeau. It occurs in the southwestern part of Illinois, where Cincinnatian strata deeply truncate the Trentonian Series, but it is exposed only at Valmeyer, Monroe County (SW 3, 3S-11W), where it is 1.5 feet thick. A few small outcrops formerly occurred near Thebes in Alexander County but are now covered. The Cape Limestone occurs mainly in shallow channels eroded in the top of the Dunleith Formation. In the northern part of the area, it is overlain by the Elgin Shale Member of the Scales Shale, as shown by the presence of the Lower Depauperate Zone above it at Valmeyer. In the southern part of the outcrop area, it is overlain by the Thebes Sandstone Member of the Scales. The Cape Limestone is a light gray to reddish gray, coarse-grained, fossiliferous calcarenite. It occurs in medium to thick beds with weak shaly partings. It has a large fauna characterized by brachiopods, particularly *Lepidocyclus capax*, and crinoids. The Cape Limestone was for many years called the Fernvale Limestone. It is correlated with the Fernvale Limestone in Arkansas and Oklahoma but not with the type Fernvale in Tennessee, which, being Richmondian in age, is much younger.

Maquoketa Shale Group

The Maquoketa Shale Group (White, 1870, p. 180-182) is named for exposures on the Little Maquoketa River in Dubuque County, Iowa. It underlies most of Illinois (fig. O-26), unconformably overlying the Galena Group and truncating the upper half of the Galena in the southern part of the state, except for the southwestern area where it rests conformably

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on the Cape Limestone. It is unconformably overlain by Silurian strata, which locally truncate the upper half of the Maquoketa, except in the southwestern area where it is overlain conformably by the Girardeau Limestone. In western Illinois the sub-Kaskaskia unconformity at the base of the Middle Devonian rocks cuts through the Silurian strata and into the Maquoketa, and farther west near the Mississippi River it completely truncates the Maquoketa (fig. O-26). The sub-Absaroka unconformity at the base of the Pennsylvanian rocks locally cuts through the Maquoketa along the La Salle Anticline (fig. P-4). Except where thinned by the unconformities, the Maquoketa is 180 to nearly 350 feet thick.

Throughout most of Illinois the Maquoketa Shale Group (fig. O-25) consists of a lower unit, dominantly shale (the Scales Shale), overlain by a middle limestone (the Fort Atkinson Limestone), and an upper shale (the Brainard Shale) (DuBois, 1945; Gutstadt, 1958b; Templeton and Willman, 1963; Buschbach, 1964). In northern Illinois, the Neda Formation (red shale and hematitic oolite) is locally present at the top of the group. In extreme southwestern Illinois, the Maquoketa Group includes only the Scales Shale. Some of the complex facies variations within the Maquoketa Group in Illinois have been shown by DuBois (1945, fig. 3), but his middle zone is not equivalent in all areas to the Fort Atkinson Limestone, which is now restricted to the section in which limestone or dolomite is dominant.

The Maquoketa Shale contains two zones with distinctive pyritic and phosphatic beds, called depauperate zones because they contain only small fossils, largely a coquina of mollusks. The Lower Depauperate Zone, at the base of the Scales Shale, is widely present throughout the state, but the Upper Depauperate Zone, near the top of the Scales, has been found only locally in central and northeastern Illinois. The limestone beds and the calcareous shale beds in the Maquoketa Group generally contain a large and varied fauna (fig. O-5). Large brachiopods are common, and branching bryozoans are especially abundant. In a zone near the top in northwestern Illinois, specimens of *Phragmopora* that reach 4 inches in diameter are locally abundant. Some beds of calcarenite consist largely of bryozoan and crinoidal debris.

Various group and formation names have been used in differentiating the type Cincinnatian (Weiss and Norman, 1960). In southeastern Indiana, part of the type region, the Cincinnatian strata are assigned to the Maquoketa Group (Gray, 1972). The Maquoketa Group is equivalent to Collingwood and Queenston strata in Ontario and New York, to the Sylvan Shale to the southwest, and to the Reedsville Shale and the Sequatchie Formation to the south and southeast of Illinois.

Scales Shale

The Scales Shale (Templeton and Willman, 1963, p. 135, in which it was called the Scales Formation), the "lower shale" formation in the Maquoketa Group in most of Illinois, is named for Scales Mound, Jo Daviess County, and the type section is a railroad cut on the west side of the town (SW NE SW 26, 29N-2E). Only the lower 30 feet, overlying the Dubuque Formation, is exposed in the type section, but the upper 18 feet is exposed 5 miles east in another railroad cut (SW SW SW 15, 29N-3E). The Scales Shale is extensive but is exposed only in northwestern Illinois and in small areas near West Point Landing in Calhoun County, Valmeyer in Monroe County, and Thebes in Alexander County. The formation is generally 75-100 feet thick, but it ranges from 50-150 feet thick. The lower part is generally dark gray to dark brown shale, which is differentiated as the Elgin Shale Member. At the top of the Scales is a gray shale—the Clermont Shale Member—that contains beds of argillaceous limestone. In the southwestern part of Illinois, brown sandstone and siltstone at the base of the Scales is differentiated as the Thebes Sandstone Member, and the shale overlying it is the Orchard Creek Shale Member. The Scales Shale has been called "the lower brown shale member" (Willman and Payne, 1942), "the lower shale zone" (DuBois, 1945), or the Scales Formation (Templeton and Willman, 1963).

Elgin Shale Member—The Elgin Shale Member of the Scales Shale (Calvin, 1906, p. 60, 98) is named for Elgin, Fayette County, Iowa. It forms the major part of the formation and is partly exposed in many localities in northwestern Illinois and locally in the other outcrop areas of the Maquoketa Group. Although dominantly shale, and in some areas almost entirely shale, the member contains beds of dolomite, limestone, siltstone, and sandstone. The lower two-thirds of the shale is commonly dark gray or dark brown, and locally in eastern Illinois it is nearly black. The shale generally becomes lighter in color to the northwest, and in the Scales type section only a few beds are dark. The Lower Depauperate Zone consists of one or several thin depauperate beds at the base or in the lower few feet of the Elgin Shale. At Valmeyer, Monroe County, depauperate beds occur at the base of the shale and as much as 9 feet above the base. A similar depauperate bed, the Upper Depauperate Zone, occurs in the upper part of the Elgin Shale Member. It was formerly exposed in the Goose Lake clay pit in Grundy County but is now covered. At Goose Lake it is 60 feet above the base of the Scales Shale, is 20 feet below the top, and is overlain by shale and argillaceous limestone containing *Isotelus*, which forms the top of the member. The Upper Depauperate Zone has been encountered in borings only in central and northeastern Illinois.

Clermont Shale Member—The Clermont Shale Member of the Scales Shale (Calvin, 1906, p. 60, 98), the upper member, is named for Clermont, Fayette County, Iowa. It is dominantly gray shale overlying the zone of interbedded shale and limestone in the upper part of the Elgin Shale Member. Where that zone cannot be distinguished, which is commonly the case in subsurface, it is not differentiated. It is generally

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15-20 feet thick but thickens in central and southeastern Illinois.

Thebes Sandstone Member—The Thebes Sandstone Member of the Scales Shale (Worthen, 1866, p. 139; Savage, 1909, p. 515) is named for Thebes, Alexander County, and the type section consists of exposures in the Mississippi River bluffs in Thebes (SW SE 8, 15S-3W). The Thebes Sandstone Member is exposed in Illinois only in the vicinity of Gale and Thebes, and it occurs in subsurface only in the extreme southwestern part of the state. It overlies the Cape Limestone and grades or intertongues eastward and northward into the lower part of the Elgin Shale Member. It is overlain by the Orchard Creek Shale Member, which probably is also laterally equivalent to part of the Elgin Shale Member. About 65 feet of the Thebes Sandstone Member is exposed in the bluff north of Thebes (SE 5, 15S-3W), but it has a maximum thickness of about 160 feet. The Thebes consists of dark brown, silty, fine-grained sandstone, largely medium to thick bedded and locally cross bedded. In places it is largely brown siltstone, but it locally contains beds of gray to brown shale several feet thick. Several types of fucoid marks are common in the upper 35 feet.

Orchard Creek Shale Member—The Orchard Creek Shale Member of the Scales Shale (Savage, 1909, p. 515) is named for a small exposure along Orchard Creek, 2 miles south of Thebes, Alexander County. This section is now covered, but the Orchard Creek is exposed in the Mississippi River bluffs a mile north of Thebes (SE 5, 15S-3W), where it is 27 feet thick, overlies the Thebes Sandstone Member, and is overlain by the Girardeau Limestone. The Orchard Creek Shale Member is exposed locally in and near the Mississippi bluffs in Alexander County from Gale southward almost to Fayville. It is 10-30 feet thick in the outcrop area. It is largely blue-gray shale, but in the thickest exposures the upper part is interbedded with fine-grained limestone. The Orchard Creek is probably a lateral equivalent of part of the Elgin Shale Member, but its precise position is uncertain, and it could be equivalent even to the Brainard Shale. It is differentiated only where it overlies the Thebes Sandstone Member. The Orchard Creek contains a large fauna (Savage, 1917). It was long assigned to the Silurian System, but the presence of *Climacograptus putillus* indicates Cincinnatian age (Pryor and Ross, 1962).

Fort Atkinson Limestone

The Fort Atkinson Limestone (Calvin, 1906, p. 60, 98), the "middle limestone" formation in the Maquoketa Group, is named for exposures at Fort Atkinson, Winneshiek County, Iowa. It is exposed in northeastern Illinois, particularly at Wilmington, Will County (SE SW NW 25, 33N-9E) and near the Dresden Island Dam, Grundy County (SE NE NW 34, 34N-8E). The Fort Atkinson Limestone has been called the Divine Limestone (Lamar and Willman, 1931) and the "middle limestone" (DuBois, 1945). It is widely distributed in subsurface in Illinois and is commonly 15-40 feet thick. However, in some areas, for instance in much of the Maquoketa outcrop area in northwestern Illinois, it becomes very shaly and is inseparable from the shales above and below. In other areas it includes limestone laterally equivalent to the shale formations above and/or below. The Fort Atkinson changes within short distances from white or pink, coarse-grained, crinoidal limestone to brown fine-grained dolomite or gray argillaceous limestone. In some localities the upper part is limestone, the lower part dolomite. The amount of interbedded shale varies greatly. The Fort Atkinson is generally fossiliferous with a large fauna of brachiopods and bryozoans (Savage, 1925a). It correlates with the Waynesville Limestone in Ohio and Kentucky.

Brainard Shale

The Brainard Shale (Calvin, 1906, p. 60, 97), the "upper shale" formation in the Maquoketa Group, is named for an exposure near Brainard, Fayette County, Iowa. It occurs throughout the area of the Maquoketa Group, except in local areas where it is truncated by the sub-Silurian unconformity. Although widely present near the surface in the mounds and ridges in northwestern Illinois, it is generally covered by slumped material from the overlying Silurian dolomite formations, and actual outcrops are small and scarce. It is exposed locally in northeastern Illinois, particularly near Channahon and Ritchey in Will County, near Elgin in Kane County, and in small areas in Calhoun and Jersey Counties. The Brainard Shale is 75-100 feet thick where it is not deeply truncated by the sub-Silurian unconformity. In the outcrops it consists of greenish gray to green shale, partly dolomitic, and locally silty. In subsurface it contains beds of siltstone, and locally limestone or dolomite. It is generally much lighter colored and softer than the Scales Shale. Two thin bentonite beds locally occur near the top in southeastern Illinois. The Brainard is commonly fossiliferous, and the presence of *Cornulites* in the upper part suggests equivalence to the Elkhorn Formation at the top of the Richmondian strata in Indiana and Ohio.

Neda Formation

The Neda Formation (Savage and Ross, 1916, p. 193, in which it was called Neda iron ore), the youngest formation in the Maquoketa Group in northern Illinois, is named for exposures near Neda, Dodge County, Wisconsin. The Neda Formation occurs in local areas in northern Illinois and is exposed along the Kankakee River southeast of Ritchey, Will County (26, 27, 35, 36, 32N-10E, particularly in NE NW SW 36). In that area it is 4-8 feet thick, overlies the green Brainard Shale, and is overlain by the Kankakee Formation or, locally, by 1-2 feet of the Wilhelmi Formation of Silurian age. The Neda is generally less than 10 feet thick in Illinois. It is largely red shale interbedded with red-brown or black oolite consisting of flattened spheroids of geothite or hematite that average about 0.5 mm across. In places it contains a few beds of gray or green shale. Athough it rests sharply on the underlying Brainard Shale, there is no evidence of an unconformity. The upper contact, however, is sharp and erosional. The basal Silurian rocks in places contain streaks of reddish shale and black oolites that were probably reworked from the Neda. The Neda occurs only in areas where the Brainard Shale is relatively thick and where the basal Silurian formations, the Wilhelmi and Elwood Formations, which generally occur in channels eroded in the top of the Brainard, are absent or very thin. The major unconformity, therefore, is on top of the Neda Formation, which favors its assignment to the Maquoketa Group (Workman, 1950; Buschbach, 1964) rather than to the basal Silurian Noix Oolite Member (Athy, 1928). The Neda is not fossiliferous in Illinois, but Savage and Ross (1916) reported a Cincinnatian fauna in the Neda in its type region. The Neda is believed to be a thin western tongue of the Queenston delta of the Appalachian region.

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Girardeau Limestone

The Girardeau Limestone was originally named the Cape Girardeau Limestone (Swallow, 1855, p. 109) for outcrops at Cape Point, 1.5 miles northeast of Cape Girardeau, Missouri (SW NE SE 28, 31N-14E), but the shorter form "Girardeau" has been used since the late 1800s (Savage, 1909). In Illinois it occurs only in the extreme southwestern part, and it is exposed only near Thebes, Alexander County. About 30 feet is exposed along Orchard Creek south of Thebes (SW SE NW 21, 15S-3W), which is about its maximum thickness, although the base is not exposed. The base appears to be conformable on the Orchard Creek Shale, the upper part of which contains a few limestone beds like the Girardeau. The top is a prominent unconformity that northward from Thebes completely truncates the Girardeau before reaching Gale. The Girardeau Limestone consists of unevenly bedded, fine-grained to lithographic, dark brown limestone. It has shaly partings and silicified silty interbeds that commonly contain black chert nodules. The Girardeau contains a large fauna, most of it preserved on the bedding planes (Savage, 1917). Although Savage considered the fauna had affinities closer to the Silurian than the Ordovician, the strong unconformity at the top and the transitional, local character of the fauna have caused many to favor its classification as Ordovician, a practice followed in Illinois since 1967 but still considered tentative. The relation of the Girardeau to the Maquoketa elsewhere in Illinois is not known. Judged on the basis of thickness of the underlying Maquoketa strata, it could be approximately equivalent to the Fort Atkinson Limestone, but it does not resemble it. It could be as young or younger than the Neda Formation, the interpretation at present favored.

SILURIAN SYSTEM

H. B. Willman and Elwood Atherton

The Silurian System (Murchison, 1835, p. 48-49; Lapworth, 1879, p. 12-14), named for the Silures, a tribe of people who lived in the type area in Wales during Roman times, underlies most of Illinois and is the surface of the bedrock in four areas (fig. S-1). Silurian strata are well exposed in all four areas (fig. S-2). In northeastern Illinois, Silurian rocks are exposed in large, deep quarries in the Chicago region and in the bluffs of the Des Plaines, Kankakee, Du Page, and Fox Valleys, but in the northern half of that area they are deeply buried by glacial drift. In northwestern Illinois, the Silurian strata are the resistant rocks that cap nearly all the mounds, and they are well exposed in the Mississippi River bluffs from the Galena area southward to the Rock Island vicinity and also along tributary valleys for several miles east of the bluffs. In western Illinois, the Silurian System has been uplifted along the Lincoln Anticline and the Cap au Grès Faulted Flexure and is well exposed in the Mississippi and Illinois River bluffs in Jersey and Calhoun Counties. In southern Illinois, the exposures are limited to the Mississippi bluffs and tributary valleys in Alexander County and southern Union County. The Silurian rocks in all these areas were long called Niagara Limestone (Worthen, 1866; Bannister, 1868; Shaw, 1873).

The Silurian System has a maximum thickness of nearly 1000 feet in and below some pinnacle reefs in the area east of East St. Louis. However, the system is more commonly 400-600 feet thick in that area and farther north (fig. S-1). South of the pinnacle reefs the Silurian rocks are generally only 300-400 feet thick.

The Silurian System is subdivided into three series—the Alexandrian Series (below), which is based on exposures in Alexander County, Illinois, and the Niagaran and Cayugan Series, both based on exposures in the Niagara Falls area in New York and Ontario. Because of pronounced changes in lithology, different rock-stratigraphic classifications have developed in the widely separated outcrop areas in Illinois, and 15 formations and 10 members are now recognized (figs. S-3 to S-10). The subsurface correlations between the outcrop areas have not been firmly established for some units.

The Silurian rocks are dominantly carbonates—almost entirely dolomite in the northern part of the state (Willman, 1943, 1973) but

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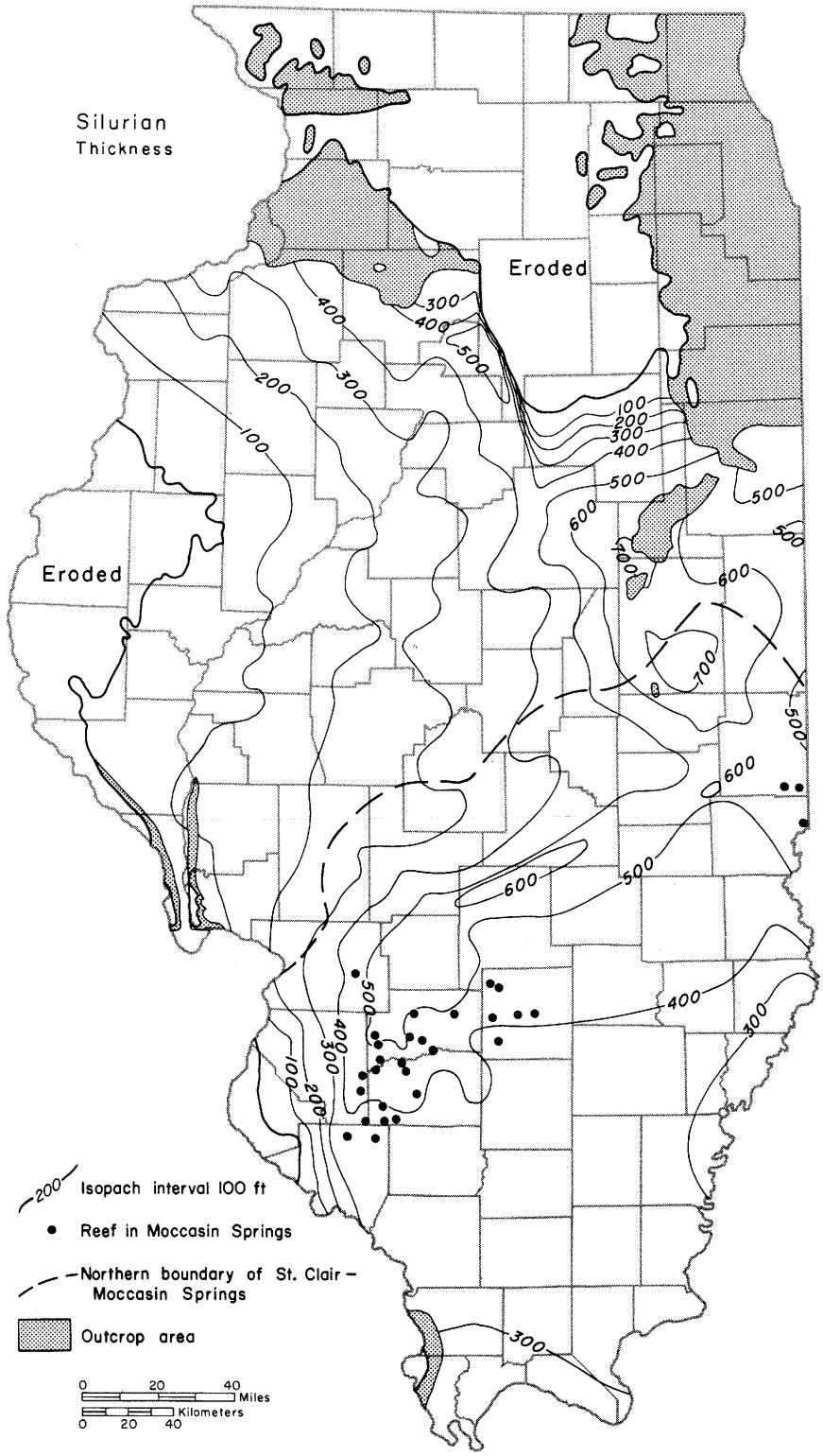

Fig. S-1—Silurian System thickness, outcrop areas, nomenclature boundary, and reefs in the Moccasin Springs Formation.

largely limestone, siltstone, and shale in the southern part (Lowenstam and DuBois, 1946; Lowenstam, 1949). With the overlying Devonian carbonate rocks, they form the Hunton Limestone Megagroup.

The Alexandrian formations, the lower Niagaran rocks, and all of the Silurian rocks south of the reefs maintain distinctive characteristics and lateral continuity for long distances (fig. S-11), but where reefs are present the sediments have abrupt lateral variations in lithology, and few units can be widely traced. The reefs are very pure carbonate. The northern reefs, in the Racine Formation, are mainly dolomite, but the southern reefs, in the Moccasin Springs Formation, are largely limestone. The interreef rocks are less pure, varying from cherty silty dolomite to argillaceous dolomite around the Racine reefs and from argillaceous limestone to calcareous shale and siltstone around the Moccasin Springs reefs. However, in northwestern Illinois the interreef rocks, except in local areas, are nearly pure dolomite and are similar in lithology to the reef rock.

Illinois was almost continuously beneath the sea during Silurian time. The most striking features in the Silurian sea were the reefs that formed in Niagaran time in a broad area reaching from the Ozark region northeastward across Illinois, Indiana, and Ohio to Ontario (Lowenstam, 1949, 1957). Another group of reefs in northwestern Illinois, Iowa, northeastern Illinois, and eastern Wisconsin may have been part of an archipelago bordering the Wisconsin Arch. The two belts of reefs essentially meet in the Kankakee Arch area and form part of a barrier around the Michigan Basin.

In the relatively deep water south of the reef front and around the southernmost reefs, the sediments that were deposited during the growth of the reefs are largely red, green, gray, impure, noncherty limestone, siltstone, and shale; farther north, the reefs are surrounded by gray, cherty, silty dolomite. The red sediments are more dominant to the southwest and probably were derived from that direction.

In the southern reef area, the oldest reefs probably began to grow during deposition of the upper part of the St. Clair Formation, as indicated by the presence of local lenses of pure sediments, probably wash from reefs. However, the major reefs began to grow a little later, at or just above the base of the Moccasin Springs Formation. In the northern areas, major reef growth began at approximately the same time as in the south, the beginning of Racine deposition. The great thickness of the southern reefs appears to be related to the progressive sinking of the deep part of the Illinois Basin, the Fairfield Basin (fig. 12).

The reefs continued as prominent features through Silurian time, although the presence of Niagaran fossils in the upper parts of some reefs suggests that reef growth did not extend into Cayugan time. However, as all of the reefs are overlain unconformably by Middle Devonian or younger sediments, the Cayugan, and perhaps even the early Devonian, parts of the reefs could have been present and eroded. In either case, the sea continued to occupy the Illinois Basin around and south of the reefs into Devonian time, and several hundred feet of Lower Devonian sediments were deposited in the basin and largely filled it.

In the classification based on major unconformities, the Silurian rocks belong to the Tippecanoe Sequence (fig. 14). They are separated from the underlying Ordovician rocks by an unconformity, as previously described. In the part of the Illinois Basin south of the reefs, deposition appears to have been essentially continuous from Silurian to Devonian time, but the sub-Kaskaskia unconformity at the base of the Middle Devonian rocks truncates the reefs and the Niagaran, Lower Devonian, and Cayugan rocks on the flanks of the reefs. Cayugan and Lower Devonian sediments may not have been deposited north of the area of the Moccasin Springs Formation (fig. S-1), but if they were present they must have been eroded, because the unconformity cuts deeply into Niagaran strata in that area. Well rounded, medium-grained quartz sand found locally in upper Silurian rocks in subsurface is largely Middle Devonian sand introduced along joints (Summerson and Swann, 1970). In extreme western Illinois, the Silurian strata were entirely eroded before the Middle Devonian limestone was deposited. No major unconformities are recognized within the Silurian System, although sharp contacts and channeling between the Kankakee and Edgewood Formations in western Illinois and the Sexton Creek and Edgewood Formations in southern Illinois may indicate movements on local structures on the flank of the Ozarks. The Alexandrian and Niagaran rocks are separated by a widespread, smooth surface that probably indicates a diastem.

Fossils are generally abundant in the relatively pure carbonate rocks of the Silurian System (fig. S-12) but are scarce in the more

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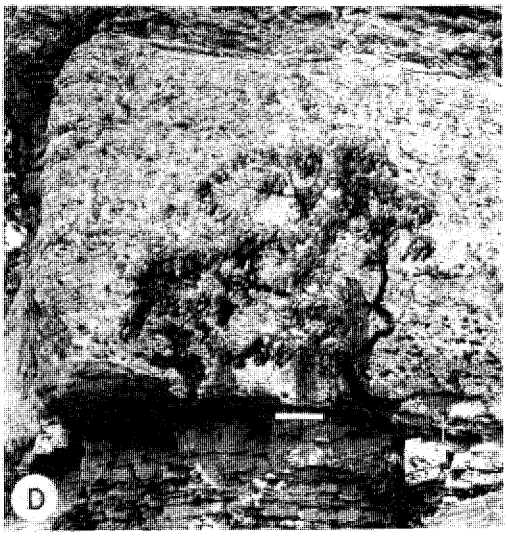

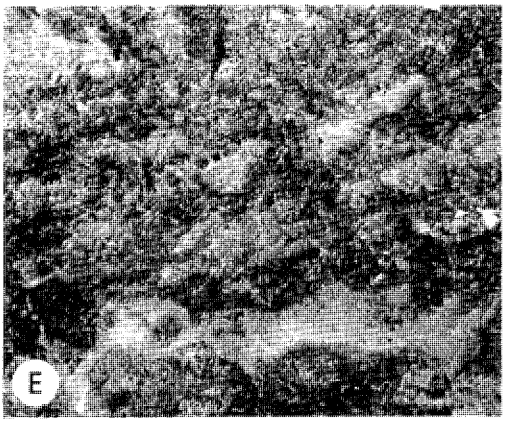

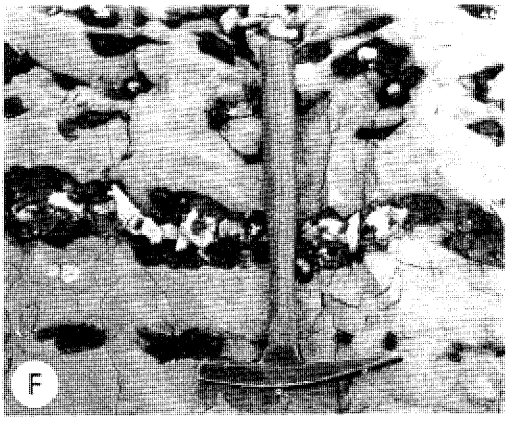

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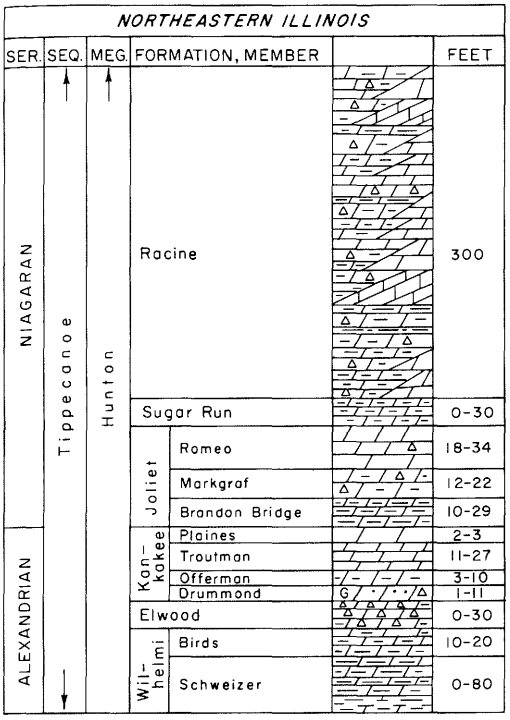

Fig. S-3—Columnar section of the Silurian System in northeastern Illinois.

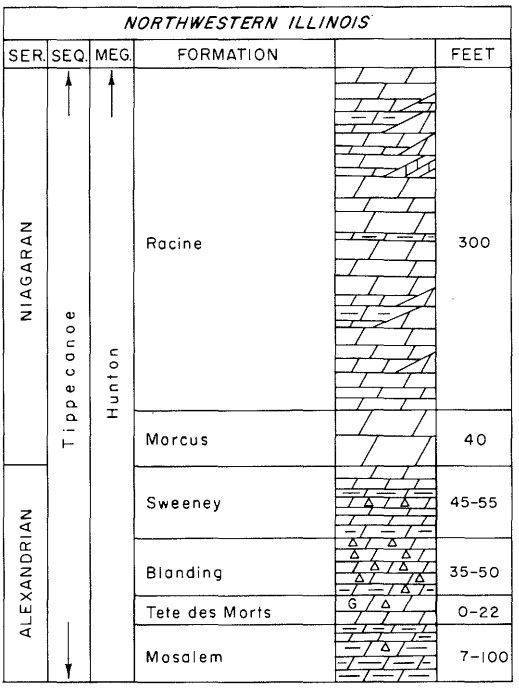

Fig. S-4—Columnar section of the Silurian System in northwestern Illinois.

argillaceous and silty strata. Five faunal zones are extensive. (1) The *Platymerella* Zone at the base of the Kankakee Formation is essentially equivalent to the *Virgiana* Zone found to the north in Wisconsin, Michigan, and Ontario. The two fossils are closely related pentamerids. (2) The *Microcardinalia* Zone at the top of the Kankakee Formation and in the upper part of the Sweeney Formation is widely present at the top of Alexandrian rocks. (3) A zone of abundant arenaceous Foraminifera, characterized by Ammodiscidae, occurs at the base of Niagaran strata, although it has not been found in northwestern Illinois. (4) The *Pentamerus* Zone, which in Illinois occurs only in the northwestern part of the state, is regionally present at or near the base of the Niagaran Series. (5) The uppermost Niagaran reefs in northeastern Illinois contain distinctive fossils characteristic of the Guelph Formation of New York and Ontario, referred to as the Guelph fauna, or the *Megalomus* Zone. *Megalomus* is present but not common in the youngest Niagaran strata in both northeastern and northwestern Illinois. Fossils characteristic of the Guelph are also found in the top of the reef at Marine, Madison County (Lowenstam, 1949).

The Niagaran reefs are very fossiliferous and contain a great variety of invertebrates, especially stromatactis-like forms, corals, stromatoporoids, bryozoans, brachiopods, and crinoids (Lowenstam, 1949, 1950, 1957; Ingels, 1963; and others), whereas the interreef rocks are sparsely fossiliferous and the fauna, principally sponges, crinoids, and brachiopods, differs in many aspects from that of the reefs (Lowenstam, 1948a).

Fig. S-2—Exposures and textures of Silurian rocks.

A—Massive dolomite in the core of a Racine (Niagaran) reef, at the top of the Material Service Corporation (Stearns) quarry on Archer Avenue at 28th Street, Chicago.

B—Steeply dipping, well bedded dolomite forming the flank of a Racine (Niagaran) reef, in the Material Service Corporation quarry at Thornton, Cook County.

C—Massive Marcus Dolomite in a quarry 3 miles east of Fulton, Whiteside County.

D—Massive Tete des Morts Formation overlying the Mosalem Formation at the top of Silurian escarpment, 4 miles southeast of Galena, Jo Daviess County.

E—Mottled, porous, pure dolomite characteristic of Racine reef facies in the Chicago area (×1).

F—Dense, argillaceous dolomite containing chert nodules characteristic of Racine interreef facies in the Chicago area. The outer, porous parts of the nodules are blackened by air pollutants.

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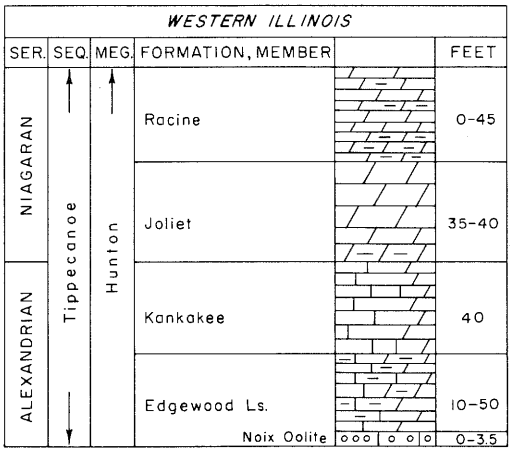

Fig. S-5—Columnar section of the Silurian System in western Illinois.

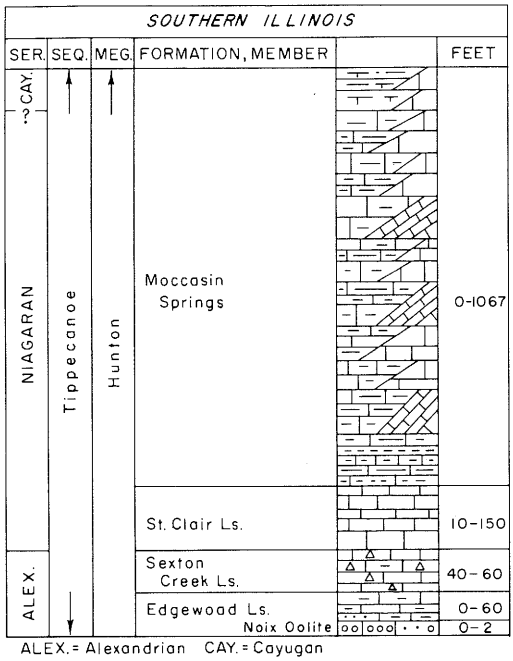

Fig. S-6—Columnar section of the Silurian System in southern Illinois.

HUNTON LIMESTONE MEGAGROUP

The Hunton Limestone Megagroup (Taff, 1902, p. 3; Swann and Willman, 1961, p. 478), named for the former hamlet of Hunton, Coal County, Oklahoma, comprises dominantly carbonate rocks of Silurian and Devonian age that in Illinois lie between the late Ordovician clastic rocks (Maquoketa Shale Group) and the late Devonian clastic rocks (New Albany Shale Group) at the base of the overlying Knobs Megagroup (fig. 14). In local areas, siltstone and shale in the base of the Silurian System are not included in the megagroup, whereas limestone in the uppermost Ordovician strata is included. At the top of the Hunton, shale of Middle Devonian age, locally present, is excluded, but basal Upper Devonian limestone is included.

Hunton strata occur throughout most of Illinois, but are absent in the central northern region and in small areas in western and southern Illinois where Ordovician and older

Worthen 1866	Savage 1912		Savage 1916		Savage 1926		Savage 1942		Willman 1943, 1962		Berry and Boucot 1970		Willman 1973, Present	
Niagara	NIAGARAN		NIAGARAN		NIAGARAN	Port Byron / Racine	NIAGARAN	Guelph / Racine	NIAGARAN	Racine	P. / L.	Racine	NIAGARAN	Racine
						Waukesha		Bellwood		Waukesha	WEN.	Waukesha		Sugar Run
						Joliet		Joliet		Joliet		Joliet	Joliet	Romeo, Markgraf, Brandon Bridge
								Rockdale						
	ALEXANDRIAN	Essex	ALEXANDRIAN	Kankakee	ALEXANDRIAN	Kankakee	ALEXANDRIAN	Brassfield	ALEXANDRIAN	Kankakee	LLANDOVERY	Kankakee	ALEXANDRIAN	Kankakee: Plaines, Troutman, Offerman, Drummond
		Channahon		Edgewood		Edgewood		Edgewood		Edgewood		Edgewood		Elwood
													Wil.	Birds, Schweizer

Wil.= Wilhelmi, L.= Ludlow, P.= Pridoli, WEN.= Wenlock

Fig. S-7—Development of the classification of the Silurian System in northeastern Illinois.

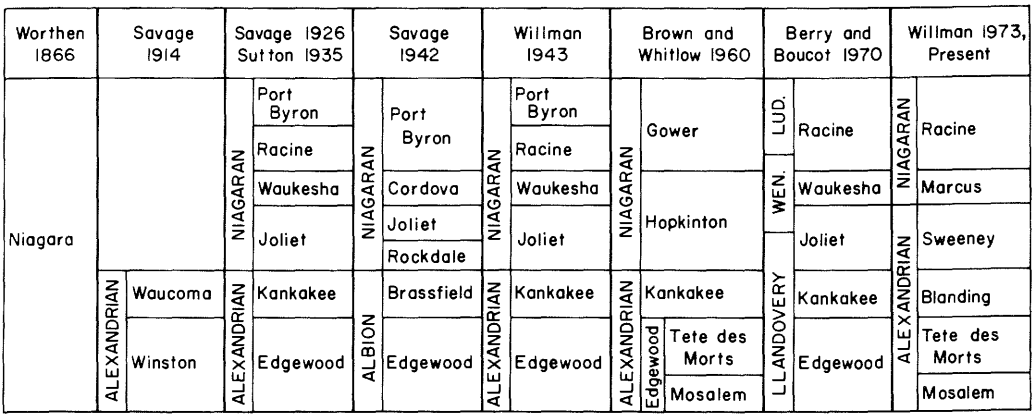

Fig. S-8—Development of the classification of the Silurian System in northwestern Illinois.

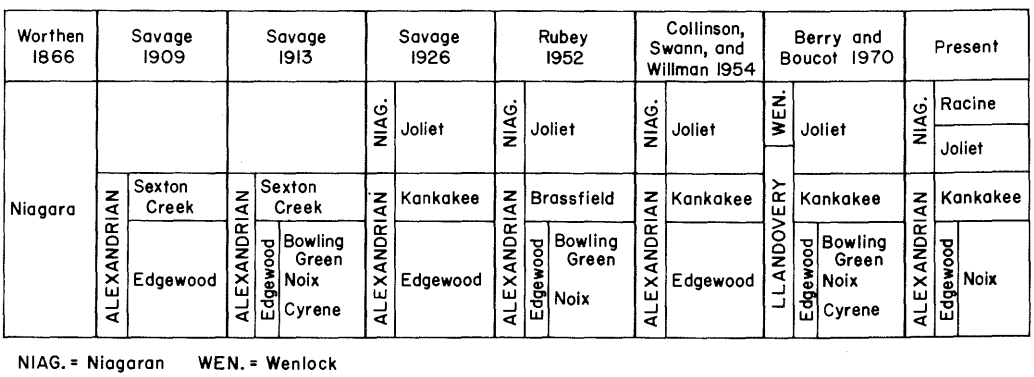

Fig. S-9—Development of the classification of the Silurian System in western Illinois.

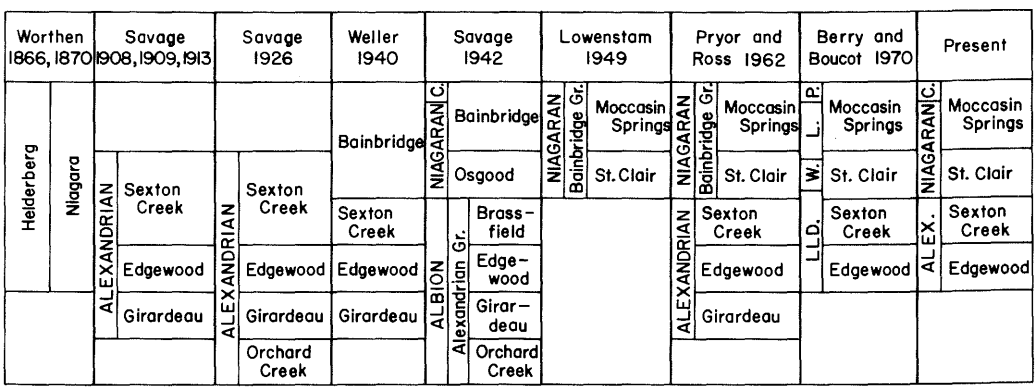

Fig. S-10—Development of the classification of the Silurian System in southern Illinois.

rocks are exposed. The megagroup thickens from those areas to over 1800 feet in the southeastern part of the state (fig. S-13). It varies from being almost entirely dolomite in northern Illinois to limestone in southern Illinois. It contains some thin or local noncarbonate units—particularly the Devonian chert units in the extreme southwestern part of Illinois, some shaly strata in the Silurian Moccasin Springs Formation, and the patchy Dutch Creek Sandstone at the base of the Middle Devonian Series.

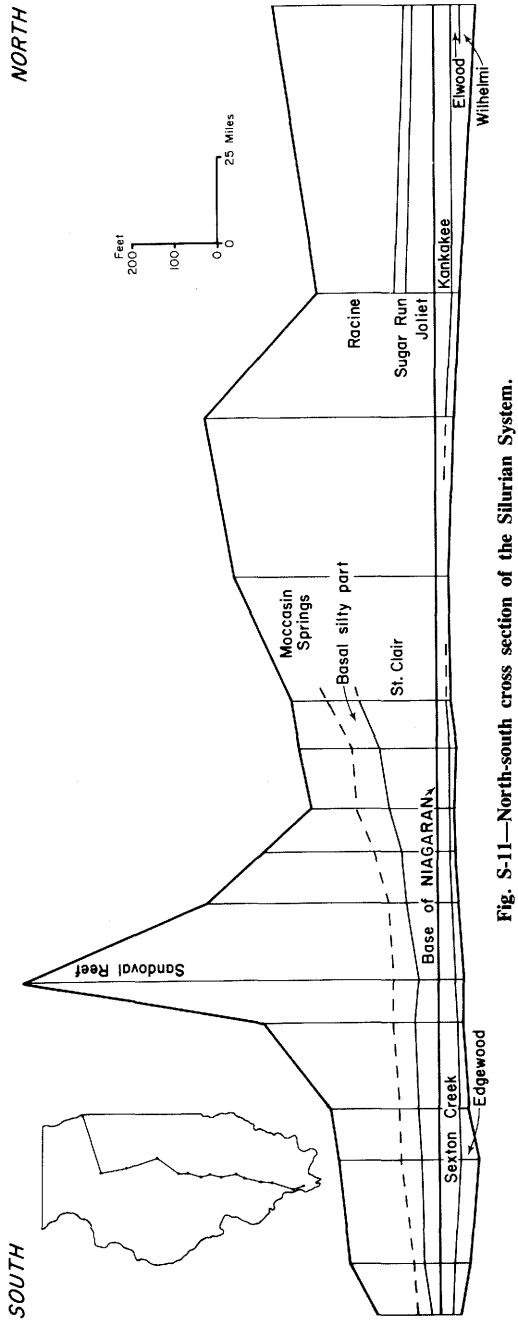

Fig. S-11—North-south cross section of the Silurian System.

The Hunton Megagroup includes within it the sub-Kaskaskia unconformity, along which in some areas Middle Devonian strata completely truncate Lower Devonian and Silurian strata, leaving only Middle Devonian strata in the Hunton Megagroup. In other areas, the sub-Absaroka unconformity, at the base of the Pennsylvanian System, truncates all the Devonian strata, so that the megagroup consists entirely of Silurian carbonates. In a few places the sub-Absaroka unconformity cuts out the Hunton entirely. In a small area in northwestern Schuyler County, the Upper Devonian New Albany Shale Group truncates the Hunton Megagroup and rests on the Ordovician Maquokota Shale Group.

ALEXANDRIAN SERIES

The Alexandrian Series (Savage, 1908, p. 110; 1916, p. 312; Weller, 1940, p. 19; Willman et al., 1967), named for exposures in Alexander County, consists of early Silurian strata including and underlying the *Microcardinalia* Zone and overlying Ordovician rocks. Alexandrian strata occur throughout most of the area of Silurian rocks (fig. S-14) and, where they fill erosional channels in the Maquoketa Shale Group, are locally as much as 150 feet thick. The Alexandrian strata were included in the Niagaran until Savage (1908) recognized that they contain a fauna older than that in the lower part of the Niagaran type section in New York (fig. S-10). At first the Alexandrian Series included only the Girardeau and Edgewood Formations, but later Savage expanded the series to include the Orchard Creek Shale below and the Sexton Creek Limestone above. Weller (1940) returned the Orchard Creek to the Ordovician, and later Willman et al. (1967) followed suggestions by several authors and placed the Girardeau, also, in the Ordovician. Alexandrian strata throughout Illinois are generally argillaceous limestone or dolomite at the base, overlain by purer glauconitic limestone or dolomite that is very cherty in some areas. The series is divisible into two parts by a zone of *Platymerella manniensis* that is present at the base of the Kankakee Formation in northeastern and western Illinois but has not been found elsewhere.

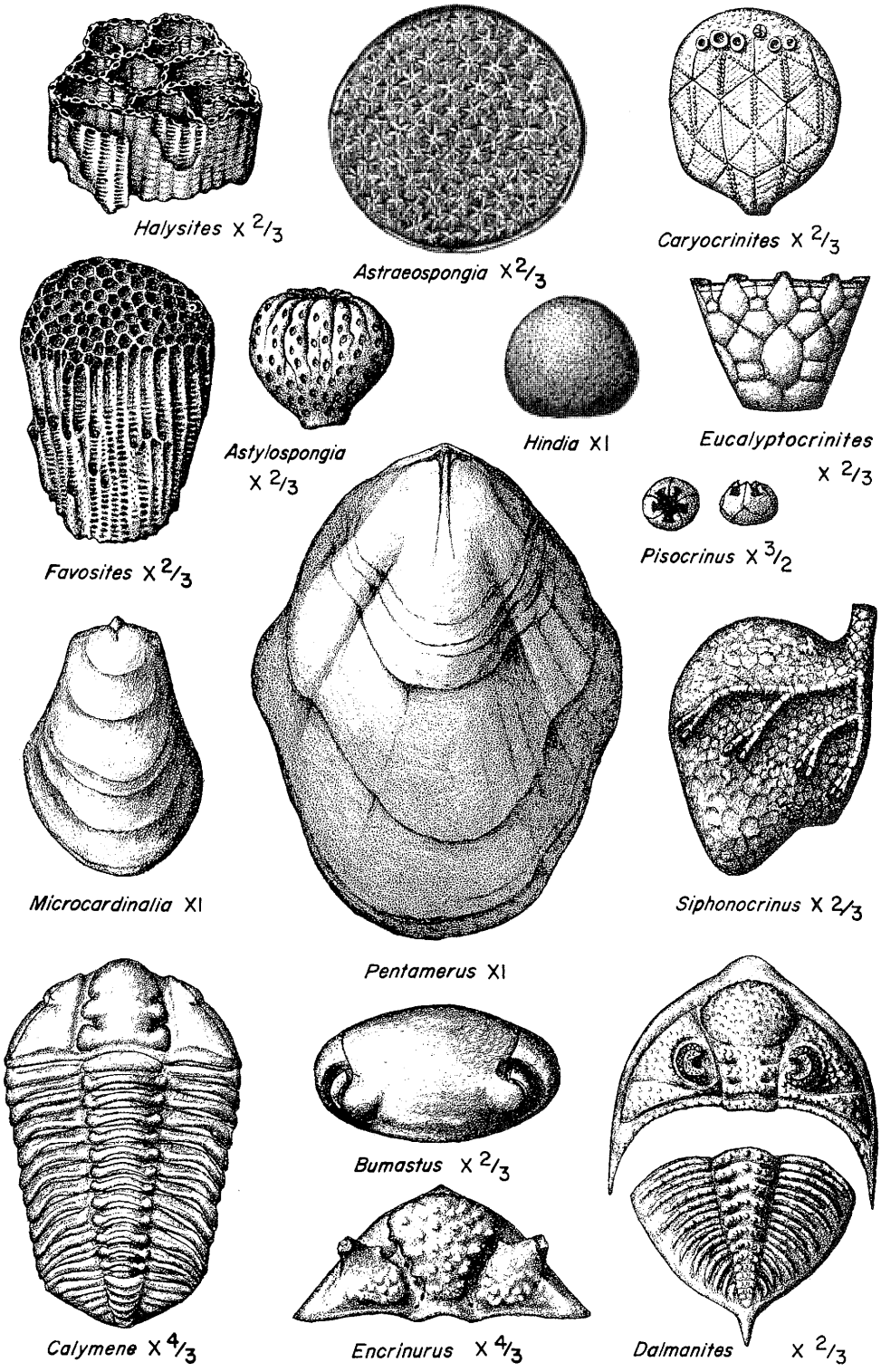

Fig. S-12—Typical Silurian fossils.

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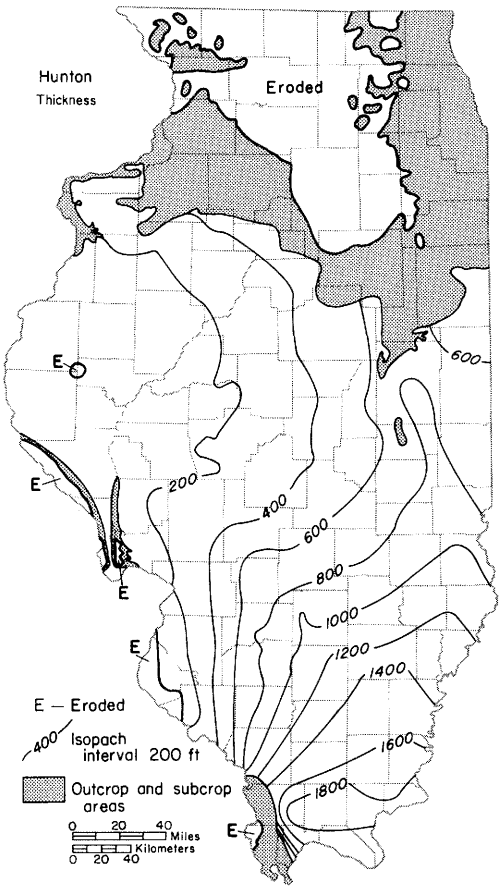

Fig. S-13—Thickness of the Hunton Limestone Megagroup (modified from Bond et al., 1971).

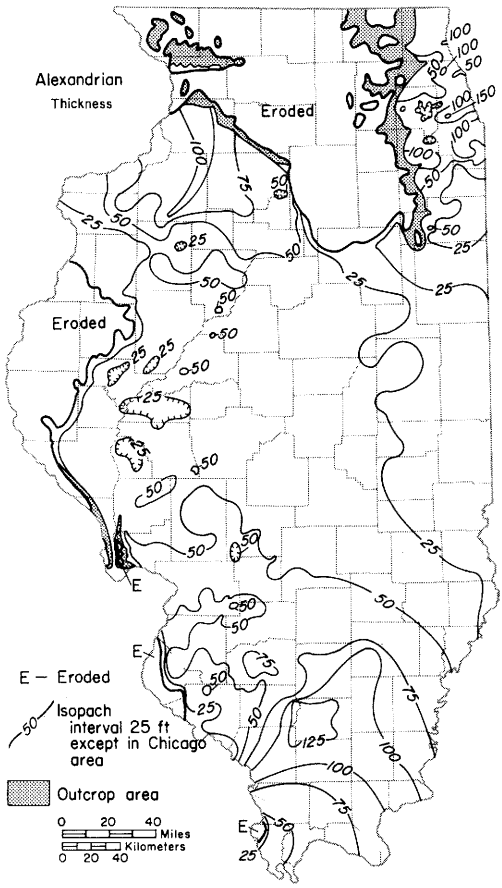

Fig. S-14—Thickness of the Alexandrian Series.

Wilhelmi Formation

The Wilhelmi Formation (Willman, 1973, p. 12) is the basal formation in the Alexandrian Series in northeastern Illinois (fig. S-3) and is named for Wilhelmi Airport on the south side of Joliet, Will County, which is about 5 miles northeast of the type section (railroad cut in SE SW SE 35, 35N-9E). Earlier it had been referred to as the lower shaly part of the Edgewood Formation. It is as much as 100 feet thick where it fills deep channels in the Maquoketa Shale Group, but it is thin or absent in other areas. The lower part of the Wilhelmi Formation is medium to dark gray, very argillaceous dolomite and dolomitic shale. This unit is differentiated as the Schweizer Member and is present only where the formation is thick. The overlying moderately argillaceous dolomite, differentiated as the Birds Member, is characteristic of the relatively thin part of the formation. In some areas the basal dolomitic shale is difficult to differentiate from shale of the underlying Maquoketa Group, but the latter generally is greenish gray. The Wilhelmi is lithologically similar to the Mosalem Formation in northwestern Illinois. It probably correlates with the lower part of the Edgewood Formation in western Illinois but is more argillaceous than the latter. It is absent in southern Illinois. Strata of similar lithology occur in the basal Edgewood in Iowa and are locally present in the base of the Mayville in Wisconsin and the Brassfield in Indiana and Kentucky. The Wilhelmi contains early Llandoverian graptolites (Ross, 1962a).

Schweizer Member—The Schweizer Member of the Wilhelmi Formation (Willman, 1973, p. 13), the basal member, is named for Schweizer School a mile east of the type section, which is part of the type section of the Wilhelmi Formation. Although widely present in subsurface in northeastern Illinois and as much as 80 feet thick, the Schweizer Member is well exposed only in and near the type section, where it is 25 feet thick. It consists of medium to dark gray dolomitic shale at the base that grades to very argillaceous, silty dolomite at the top. A thin bed of limestone conglomerate marks the base in the type section.

Birds Member—The Birds Member of the Wilhelmi Formation (Willman, 1973, p. 13), which overlies the Schweizer Member, is named for the railroad siding at Birds, 2 miles northwest of the type section, which is part of the Wilhelmi Formation type section. The uppermost part of the member and its contact with the overlying Elwood Formation are ex-

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posed in a ravine half a mile northeast (NW NW SE 36, 35N-9E). The Birds Member consists of 10-20 feet of slightly to moderately argillaceous, slightly cherty, thin-bedded, medium-gray dolomite. It is distinguished by several thin beds of relatively pure, finely laminated, fossiliferous dolomite.

Elwood Formation

The Elwood Formation (Willman, 1973, p. 14), which overlies the Wilhelmi Formation in northeastern and north-central Illinois (fig. S-3), is named for the town of Elwood, Will County. The type section, which is 5 miles north of the town, lies in a ravine 3 miles southwest of Joliet, on the southeast side of the Des Plaines River Valley (NW NW SE 36, 35N-9E), where the formation is 27 feet thick. The Elwood, which previously was referred to as the upper cherty zone of the Edgewood Formation, is a slightly argillaceous, light brownish gray, thin- to medium-bedded, fine-grained dolomite that contains layers of dense white chert as much as 4 inches thick. Chert forms 40-50 percent of the upper part of the formation but is less abundant downward. Although widely present in the Joliet area, it is erratic in occurrence elsewhere. It is exposed locally along the Fox River Valley north of Aurora (SE SW 3, 38N-8E) and has been traced westward in subsurface as far as Peru, La Salle County. The abundance of chert decreases laterally, and in places equivalent beds may not be separable from the Wilhelmi Formation. In some areas, particularly in subsurface, very cherty strata previously correlated with the Kankakee Dolomite probably belong to the Elwood Formation. The Elwood Formation appears to be conformable to the Wilhelmi below and the Kankakee above. It is lithologically similar to the Blanding Formation in northwestern Illinois and to strata included in the Mayville Formation in Wisconsin.

Kankakee Formation

The Kankakee Formation (Savage, 1916, p. 316), the uppermost formation in the Alexandrian Series in northeastern, central, and western Illinois (figs. S-3, S-5), is named for the Kankakee River in Will County, and the type section is in Cowan's Quarry and adjacent bluffs of the river 3.5 miles southeast of Ritchey (SE SW NW 26, 32N-10E), where the formation is 18 feet thick. The Kankakee Formation is commonly about 40 feet thick where exposed along the Des Plaines River Valley southwest of Joliet (Willman, 1973) and in subsurface elsewhere in northeastern Illinois. It has a similar thickness in exposures in Calhoun and Jersey Counties in western Illinois (Rubey, 1952), but in part of western Illinois it is completely truncated by Middle Devonian strata. In the type area the Kankakee Formation consists largely of greenish to pinkish gray, fine- to medium-grained, slightly cherty, glauconitic dolomite, generally in wavy beds 2-4 inches thick that are separated by thin green clay partings. It is differentiated into four members. The Drummond Member (at the base) is the most massive, and commonly contains a few rounded quartz sand grains and the most glauconite. The overlying Offerman Member is very thin bedded, slightly argillaceous, and weathers lighter in color than the other members. The overlying Troutman Member makes up the greater part of the formation and has the typical character of the formation. It is overlain by the nearly white Plaines Member, which is massive except for a few thin clay partings near the base. The top of the Plaines is a distinctive, flat surface that is smooth except for small sharp-sided pits about half an inch deep that form a roughly evenly spaced pattern at 3-6 inch intervals. The pits are filled with bright green clay. This surface has been interpreted as an unconformity at the base of the Niagaran Series, but there is slight if any truncation of the Plaines Member, which is only 2-3 feet thick, and the surface is more likely a corrosion surface on which strata may be absent because of nondeposition rather than subaerial erosion. The Kankakee Formation is generally fossiliferous, and corals, particularly *Halysites* and *Favosites* (fig. S-12), are common to abundant throughout the formation (Savage, 1926). Although the basal Drummond Member contains the *Platymerella* Zone, these fossils are also locally common in the upper few feet of the underlying Elwood Formation. The Plaines Member at the top of the formation contains the *Microcardinalia* Zone where that fossil, along with *Pentamerus oblongus* (fig. S-12), occurs in dense clusters, most commonly in the lower part of the member and occasionally as scattered individuals in the Troutman Member below. The Kankakee Formation is traced in subsurface from the type region to exposures in Calhoun and Jersey Counties in western Illinois, where the formation is somewhat purer and the wavy bedding and green clay partings are less conspicuous. The formation varies from fine-grained, gray limestone in the north part of the western Illinois outcrop area to porous brown dolomite in the south part. The Kankakee is not differentiated into members in western Illinois, but the *Platymerella* Zone is present at the base and the *Microcardinalia* Zone at the top. The Kankakee is lithologically similar to the Sweeney Formation in northwestern Illinois. Although fossils indicate the equivalence of the Kankakee to the Sexton Creek Limestone in southern Illinois, the type Sexton Creek does not closely resemble the Kankakee. It lacks both the upper and lower faunal zones, and may be equivalent to only part of the Kankakee. The Kankakee Formation is essentially equivalent to the Brassfield of Indiana, Kentucky, and Ohio, but the Brassfield locally includes strata equivalent to the Wilhelmi and Edgewood in Illinois. The Kankakee is equivalent to the Mayville, Byron, and Hendricks Formations in eastern Wisconsin. However, the Mayville and Byron locally include strata equivalent to the Wilhelmi and Elwood Formations.

Drummond Member—The Drummond Member of the Kankakee Formation (Willman, 1973, p. 17), the basal member, is named for Drummond, Will County, 5.5 miles southwest of the type section in a railroad cut on the southeast side of the Des Plaines River Valley, 2 miles southwest of Joliet, Will County (NW SE SW 30, 35N-10E), where the member is 8.5 feet thick. It is as much as 11 feet thick in the Joliet area but thins to only 1 foot thick along the Kankakee River. The Drummond Member is pure, vesicular to coarsely vuggy, gray dolomite that generally contains abundant grains of glauconite, scattered grains of well rounded quartz sand, relatively large chert nodules, and large colonies of corals. The *Platymerella* Zone occurs in the lower part, with the fossils most common in lenses of chert.

Offerman Member—The Offerman Member of the Kankakee Formation (Willman, 1973, p. 17), which overlies the Drummond Member, is named for Offerman School, three-fourths of a mile southeast of the type section, which is in the same exposure as the Drummond Member. In the type section the member is only 2.5 feet thick, a minimum thickness, but

it more commonly is about 3 feet thick along the Kankakee River and 6-11 feet thick in quarries at Joliet, Elmhurst, and Hillside. The Offerman Member differs from the underlying and overlying members in being more argillaceous, less vesicular, and thinner bedded, and in having smoother bedding surfaces and a lighter colored weathered surface.

Troutman Member—The Troutman Member of the Kankakee Formation (Willman, 1973, p. 18), which overlies the Offerman Member, is named for Troutman Grove Cemetery, Will County, 2 miles south of the type section, the lower part of which is in the same exposure as the Drummond Member, whereas the upper part is in a small quarry one-fourth of a mile east (SW NW SE 30, 35N-10E). The two sections are correlated by a thin bed of white clay that occurs near or slightly above the middle of the member in both sections and also in nearly all exposures of the member in northeastern Illinois. The Troutman is 27 feet thick in the type locality but thins to 11 feet along the Kankakee River. The Troutman Member has the typical lithology of the Kankakee Formation. It contains a few widely scattered nodules of chert.

Plaines Member—The Plaines Member of the Kankakee Formation (Willman, 1973, p. 18), the uppermost member, is named for Plaines Station, a railroad switching point on the southeast side of the Des Plaines River 1.75 miles southwest of Joliet, Will County. The type section is at the top of a small quarry, where it overlies the type section of the upper part of the Troutman Member. The Plaines Member is 2.2 feet thick in the type section but elsewhere is 1.5-3.4 feet thick. It is widely exposed along the Kankakee and Des Plaines Rivers. The dolomite is pure, massive, medium grained, and nearly white, and the top is the smooth surface that marks the top of the formation. The *Microcardinalia* Zone is largely in the Plaines Member.

Mosalem Formation

The Mosalem Formation (Brown and Whitlow, 1960, p. 36) is the basal formation in the Alexandrian Series in northwestern Illinois (fig. S-4) and is named for Mosalem Township in Dubuque County, Iowa. The type section, a roadcut south of the village of King (E1/2 SE 27, 88N-3E) exposes the upper 60 feet, nearly the entire thickness. Brown and Whitlow named the Mosalem and the overlying Tete des Morts as members of the Edgewood Formation, but, because they are distinctly different in lithology, Willman (1973, p. 31) made them separate formations and discontinued the use of Edgewood in northwestern Illinois. The Mosalem strata were originally named "Winston" (Savage, 1914) for exposures at the east end of the railroad tunnel at Winston, Jo Daviess County, but later were included in the Edgewood Formation (fig. S-8). The Mosalem is well exposed in many places in northwestern Illinois north of the Savanna Anticline and is as much as 100 feet thick where it fills channels eroded into the Maquoketa Shale Group. Typical thick exposures can be seen in the Mississippi River bluffs 6 miles south of Galena (SE SW SE 21, 27N-1E) and south of Pearl City, Stephenson County (NE cor. 17, 26N-6E). The formation is generally much thinner and is only 7 feet thick in Mississippi Palisades State Park north of Savanna, Carroll County (SW NE SE 28, 25N-3E). The Mosalem grades from very argillaceous, medium to dark gray dolomite and dolomitic shale at the base in the thick sections, to moderately argillaceous, fine-grained, dense, gray, yellow-brown-weathering dolomite at the top. It differs from the overlying Tete des Morts Formation in being more argillaceous and thinner bedded and in containing a few bands of white chert nodules and several thin, pure, vesicular, fossiliferous, laminated beds. Where thin, the Mosalem is slightly to moderately argillaceous and thick bedded. The formation is largely nonfossiliferous, but Savage (1914) listed a small fauna. The Mosalem is similar in character to the Wilhelmi Formation in northeastern Illinois and probably is equivalent to part of the Edgewood Formation in western and southern Illinois.

Tete des Morts Formation

The Tete des Morts Formation (Brown and Whitlow, 1960, p. 39) (fig. S-4), named for Tete des Morts Creek, Dubuque County, Iowa, overlies the Mosalem Formation in northwestern Illinois north of an east-west line through Hanover, Jo Daviess County. The type section is in the same exposure as the type section of the Mosalem Formation. The formation was originally designated a member of the Edgewood Formation but was later classified as a formation in Illinois (Willman, 1973, p. 33). It is the prominent cliff-forming unit at or near the top of many mounds and ridges in the Driftless Area in northwestern Illinois (fig. S-2D). The underlying Mosalem Formation and the Maquoketa Shale Group below are generally covered in the slopes below the Tete des Morts. The Tete des Morts is about 24 feet thick in the type locality, but in Illinois it is commonly about 20 feet thick, with a range of 18-22 feet, except where it thins to absence within a short distance at its southern limit. The Tete des Morts Formation is mainly pure, fine- to medium-grained, vesicular, massive, gray dolomite in which corals, particularly *Favosites*, are common. It generally contains little chert, but a persistent band of chert nodules and chert lenses occurs in a thin, slightly argillaceous, well bedded zone 1-2 feet thick 7-8 feet below the top. Scattered chert nodules occur locally in the lower part of the formation, and thin vein-like lenses of white chert are common, particularly in the upper part. Glauconite is common to abundant in the upper part and common to rare in the lower part. Weathered surfaces are deeply etched and exceptionally rough. Except for corals, fossils are scarce. The Tete des Morts most closely resembles the glauconitic Drummond Member at the base of the Kankakee Formation in northeastern Illinois, but if the nearly identical Elwood and Blanding Formations, which have conspicuous layers of chert, are equivalent, the Tete des Morts must be older than the Drummond, and it may be laterally equivalent to upper beds of the Wilhelmi Formation.

Blanding Formation

The Blanding Formation (Willman, 1973, p. 35) (fig. S-4), which overlies the Tete des Morts Formation in northwestern Illinois, is named for the village of Blanding, Jo Daviess County, 3 miles south of the type section in the upper part of the Mississippi River bluffs (SE SW SE 21, 27N-1E), where the formation is 51.5 feet thick. The formation was originally named "Waucoma" (Savage, 1914) but later was assigned to the Kankakee Dolomite (Savage, 1926). The Blanding Formation is commonly 35-50 feet thick, and is widely exposed both north and south of the Savanna Anticline, along which it is eroded. It consists of brownish to pinkish gray, fine-

grained, slightly argillaceous to pure dolomite in 2-6 inch beds. It contains layers of white chert, most of them 1-3 inches thick and commonly separated by 4-6 inches of dolomite. In some localities chert forms 50 percent of the upper part of the formation. The cherty residuum above the Tete des Morts Formation on many of the mounds in the Driftless Area is derived from the Blanding Formation. The basal 3-8 feet of the formation at some places contains only a little chert, largely in scattered nodules. The dolomite in this basal zone is slightly more argillaceous than that above, and it may be equivalent to a thicker well bedded zone quarried for building stone, the "quarry beds," farther west in Iowa. Silicified corals are common in the Blanding, and Savage (1926) listed other fossils. The Blanding Formation is similar in lithology to the Elwood Formation in northeastern Illinois, but the latter has been traced in subsurface westward only to Peru, La Salle County, and the equivalence of the two units is not considered established.

Sweeney Formation

The Sweeney Formation (Willman, 1973, p. 36) (fig. S-4), which overlies the Blanding Formation in northwestern Illinois, is named for the Sweeney Islands in the Mississippi River, a short distance west of the type section, an exposure in the bluffs in Mississippi Palisades State Park, north of Savanna, Carroll County (SW SE NE 33, 25N-3E), where the formation is 55 feet thick. It is also well exposed in the Mississippi River bluffs south of the Savanna Anticline and in quarries at Fulton in Whiteside County (cen. NE SW 21, 22N-3E). Savage (1926) correlated this unit with the Niagaran Joliet Formation in northeastern Illinois, but it has slight lithologic resemblance to the Joliet, is similar to the Kankakee Formation, and contains the *Microcardinalia* Zone characteristic of the upper Kankakee. The Sweeney Formation is commonly 45-55 feet thick and occurs throughout the Silurian outcrop area in northwestern Illinois, although it is eroded from most of the mounds north of Hanover. The Sweeney Formation is light pinkish to brownish gray, vesicular, pure dolomite in tight beds 1-4 inches thick with thin, green clay partings. Near the base and in a zone near the middle of the formation, the partings become thicker and are shaly. In places the formation contains no chert, but scattered nodules are not rare, and in a zone 3-5 feet thick 15-20 feet above the base the chert occurs in layers, lenses, and nodules. *Microcardinalia* and *Pentamerus oblongus* are common in this zone, generally in the chert. Silicified corals are common throughout the formation. It is equivalent to the upper part of the Hopkinton in Iowa and it is tentatively correlated with the Kankakee and the Sexton Creek Formations elsewhere in Illinois.

Edgewood Formation

The Edgewood Formation (Savage, 1909, p. 517-518) (figs. S-5, S-6), the basal Alexandrian formation in western and southern Illinois, is named for exposures near Edgewood, Pike County, Missouri. The Edgewood is as much as 50 feet thick where exposed along the Lincoln Anticline in Calhoun and Jersey Counties, but in places it is reduced to 10 feet or less where it is truncated by the Kankakee Formation (Rubey, 1952). The upper 33 feet is well exposed in a quarry at Monterey School, Calhoun County (NE SW 11, 12S-2W), and at Twin Springs in Pere Marquette State Park in Jersey County (NW SE 9, 6N-13W) (Collinson et al., 1954). The formation varies from a soft, fine-grained, thin- to medium-bedded, argillaceous, brown, dolomitic limestone containing disseminated fine sand in the northern part of the outcrop area, to a hard, massive, porous, brown dolomite or very dolomitic limestone in the southern part. In the northern part the lower few feet is a massive gray oolite or oolitic limestone—the Noix Oolite Member. The oolite is fossiliferous in places, but the remainder of the formation contains few fossils (Savage, 1913). The Edgewood Formation is also exposed along and near the Mississippi River in Alexander County in southern Illinois, where its maximum thickness is about 4 feet and it is locally absent. It thickens eastward in subsurface to as much as 60 feet. Good exposures occur in roadcuts near Gale (NE NE NW 4, 15S-3W) (Pryor and Ross, 1962). In that area the Edgewood is a massive, gray, crystalline limestone. The lower 2 feet is a conglomerate of pebbles from the Girardeau Limestone, mixed with oolites and fine quartz sand in a clear calcite matrix. The oolitic bed is assigned to the Noix Oolite Member. The oolite is also locally present in subsurface throughout southern Illinois.

Noix Oolite Member—The Noix Oolite Member of the Edgewood Formation (Keyes, 1898, p. 59, 62) is named for exposures along Noix Creek near Louisiana, Pike County, Missouri. It is generally at or close to the base of the Edgewood Formation but is lenticular and absent in some areas. It commonly is 1.5-3.5 feet thick in western Illinois (Rubey, 1952), and it is as much as 2 feet thick in southern Illinois (Pryor and Ross, 1962).

Sexton Creek Limestone

The Sexton Creek Limestone (Savage, 1909, p. 518; Ulrich, 1911), which overlies the Edgewood Formation in southern Illinois (fig. S-6), is named for exposures in the Mississippi River bluff at the mouth of Sexton Creek in Alexander County (SW 27, 14S-3W), where it is about 40 feet thick, but it is best exposed 4 miles northeast, just north of the mouth of Dongola Hollow (SW SE NW 12, 14S-3W). It was originally defined to include higher strata, now differentiated as the St. Clair Limestone, but was restricted to its present boundaries by Ulrich (1911). The Sexton Creek locally truncates the Edgewood Limestone to rest directly on the Girardeau Limestone. The Sexton Creek and its contact with the Edgewood Limestone are exposed in a roadcut a quarter of a mile southeast of Gale (NE NE NW 4, 15S-3W) (Pryor and Ross, 1962). The formation is a thin-bedded, fine-grained, cherty, gray limestone. The upper part is thicker bedded and is mottled red. In the areas where it is relatively thick, the Sexton Creek commonly contains persistent bands of black chert nodules. The formation is correlated with the Kankakee Formation in northern Illinois on the basis of its fossils, although the faunal zones that mark the top and bottom of the Kankakee Formation have not been found in the Sexton Creek. The Sexton Creek is approximately equivalent to the Brassfield Limestone in Indiana and Kentucky.

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NIAGARAN SERIES

The Niagaran Series (Hall, 1842, p. 57; Swartz et al., 1942, chart 3) is based on the Niagara Falls section in New York, as restricted by differentiation of the pre-Clinton strata as the Alexandrian Series (Savage, 1908, p. 434). It consists of the strata above the *Microcardinalia* Zone (*Stricklandinia* or *Stricklandia* Zone of early reports) up to and including the faunal zone characteristic of the Guelph Formation in New York and Ontario, which is commonly identified as the *Megalomus* Zone. According to Berry and Boucot (1970, pl. 2), the Niagaran in Illinois is equivalent to most of the Upper Llandovery, the Wenlock, the Ludlow, and part of the Pridoli Series in Europe (figs. S-7 to S-10). Niagaran strata crop out in all four outcrop areas of Silurian rocks in Illinois (fig. S-1) and are present in subsurface throughout most of the Illinois Basin (S-15). They are overlain by the Cayugan Series only in southern Illinois, where the position of the top of the Niagaran is not definite but at present is placed in the upper part of the Moccasin Springs Formation. Elsewhere in Illinois the top of the Niagaran Series is truncated by Middle Devonian or younger strata. Niagaran strata have a maximum thickness of a little more than 1000 feet in Marion County, where the Sandoval Reef stood high above the surrounding interreef Niagaran (fig. S-11). Three facies were recognized in the Niagaran strata by Lowenstam (1949). A dominantly shaly facies (Bainbridge Group) occurs in the southern part of the state and also surrounds numerous reefs in the northern part of that area. A facies of intermediate purity (Thorn Group) extends from western Illinois to the Chicago region, and in it the reefs are surrounded by cherty, generally silty dolomite. A relatively pure facies (Coe Group) occurs in northwestern Illinois where the reefs are surrounded by dolomite that is generally purer than it is in the other facies. These units are at present recognized as facies, not groups, and different rock-stratigraphic classifications are used within the three facies (figs. S-3 to S-6). The boundary between the southern and northern facies is transitional through a broad zone entirely in subsurface, but, for practical purposes of changing nomenclature, it is placed at the northern boundary of the area in which a distinctive electric log marker, the "two-kick, three-kick zone," can be recognized (figs. S-1, S-16). The position of the boundary of the northwestern facies is not as well known and

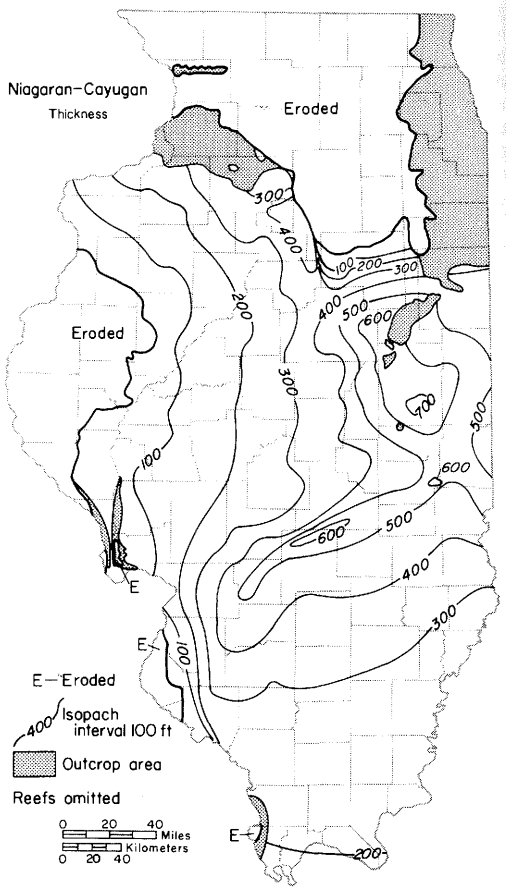
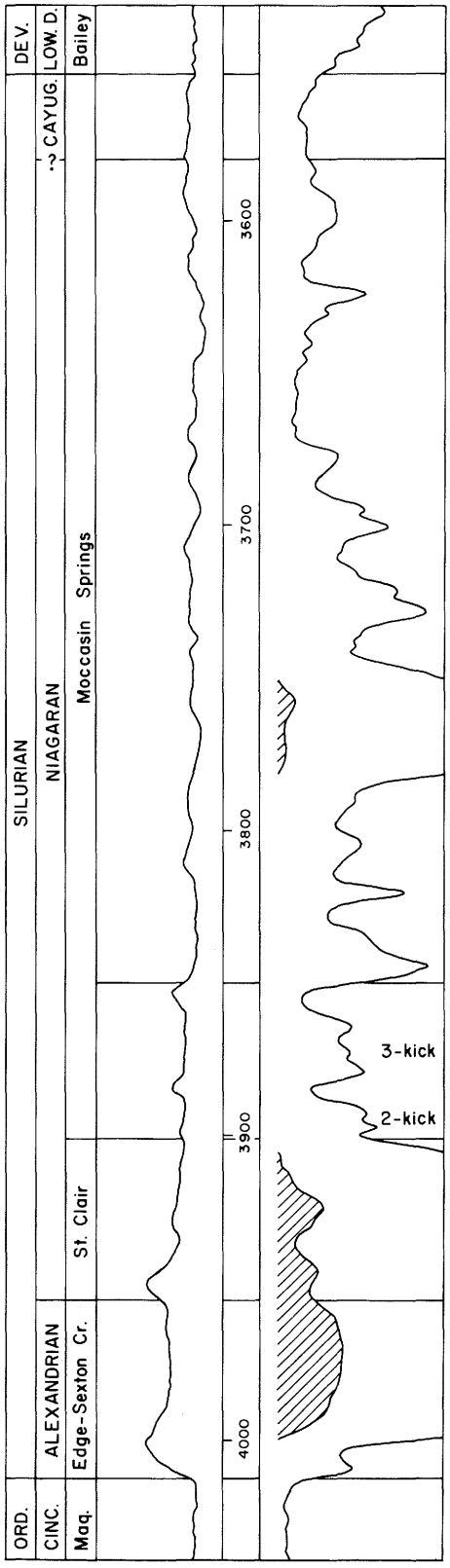


Fig. S-15—Thickness of the Niagaran Series; includes the Cayugan Series in southern Illinois.

the rock-stratigraphic units have not as yet been traced far from the outcrop area.

Joliet Formation

The Joliet Formation (Savage, 1926, p. 522) (figs. S-3, S-5) is named for Joliet, Will County, and the type section is in the National Stone Company quarry on the south side of Joliet (NE SE 21, 35N-10E), where the formation is 68 feet thick. The Joliet Formation is differentiated as the basal formation of the Niagaran Series in an area extending from Chicago to Calhoun County in western Illinois (fig. S-1). It is 70-80 feet thick in exposures along the Des Plaines River Valley, but only about 40 feet along the Kankakee River. It is 35-40 feet thick along the Mississippi River at Grafton in Jersey County, but farther west the top is truncated by Middle Devonian strata, and in southern Calhoun County the formation is entirely eroded. In exposures in northeastern Illinois along the Des Plaines, Kankakee, Du Page, and Rock Rivers, the Joliet Formation is differentiated into a basal shaly, red, green, and gray member (the Brandon Bridge



Member), overlain by nearly white, generally cherty dolomite that is silty at the base, grades to slightly silty at the top (the Markgraf Member), and is, in turn, overlain by nearly white, locally red-mottled, pure dolomite (the Romeo Member). In western Illinois, much of the Joliet is similar to the Romeo Member, although there is a weakly shaly zone at the base. The Romeo Member is prominent on electric logs and has been traced widely in subsurface. The basal shaly zone of the Joliet Formation is characterized by an abundance of arenaceous Foraminifera, among which Ammodiscidae are prominent (Dunn, 1942). This zone is also present at the base of the Joliet in Jersey County (Collinson et al., 1954) and at the base of the St. Clair Limestone in southern Illinois. It has not been found in northwestern Illinois or in Wisconsin north of Milwaukee, but eastward it is well represented in the Osgood Formation of Indiana. Outside the area where the Joliet is differentiated, the position of its top is not well established, but in northwestern Illinois the Marcus Formation may in part be equivalent to the Joliet, and in southern Illinois the top of the Joliet correlates to a horizon within the St. Clair Limestone.

Brandon Bridge Member—The Brandon Bridge Member of the Joliet Formation (Willman, 1973, p. 20), the basal member, is named for Brandon Bridge over the Des Plaines River on the southwest side of Joliet, Will County, and the type section is in the Lincoln Stone Company quarry southwest of the bridge (S1/2 SE 20 and N1/2 NE 29, 35N-10E), where the member is 29 feet thick. The Brandon Bridge thins southward and is only 10.5 feet thick where exposed along the Kankakee River east of the Warner Bridge in Kankakee County (NW SE SW 31, 32N-11E). In the Joliet area the Brandon Bridge Member is differentiated into two parts by a bed of green to black shale as much as a foot thick, but generally only an inch or two thick. The lower part is the more shaly and contains beds of red crinoidal dolomite interbedded with very argillaceous gray and red dolomite. The upper part is less shaly and most of it is gray, mottled with red and green. The top is placed at the highest strong shaly parting. The abundance of arenaceous Foraminifera in the member has been noted, and *Bumastus* (fig. S-12) is locally present, particularly in the middle shale.

Markgraf Member—The Markgraf Member of the Joliet Formation (Willman, 1973, p. 21), which overlies the Brandon Bridge Member, is named for the abandoned Markgraf quarry on the north side of the Des Plaines River, on the southwest side of Joliet, Will County (SW SW 16, 35N-10E), where the member is 22.1 feet thick. It thins southward and is only 12.3 feet thick where exposed along the Kankakee River at the mouth of Rock Creek Canyon (SW SE SW 32, 32N-11E). The Markgraf Member is light gray, nearly white, medium-bedded dolomite. Along the Des Plaines River the member consists of three approximately equal units—a basal very silty dolomite, a middle moderately silty and argillaceous dolomite with bands of chert nodules, and an upper slightly argillaceous dolomite that also contains bands of chert nodules. Along the Kankakee River, where the member is relatively thin, the dolomite all resembles the upper unit along the Des Plaines Valley.

Romeo Member—The Romeo Member of the Joliet Formation (Willman, 1973, p. 22), the top member, is named for Romeo, Will County, where part of the member is exposed at the top of quarries now largely filled with water. The type section is in the National Stone Company quarry, 6 miles south of Romeo, on the southwest side of Joliet, where it is part of the type section for the Joliet Formation, and is 20.2 feet thick. It ranges from 18 feet in Rock Creek Canyon

Fig. S-16—Electric log of the Silurian System.

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along the Kankakee River to 34 feet thick in a quarry at Elmhurst in Du Page County. The member consists of light gray to white, gray-weathering, pure, vesicular, thin- to medium-bedded dolomite, commonly with tight stylolitic bedding surfaces. It locally has pink mottling. It contains silicified fossils and several bands of chert nodules in the type locality, but in many exposures it exhibits little or no chert. Corals are common and locally abundant.

Marcus Formation

The Marcus Formation (Willman, 1973, p. 37) is the basal Niagaran unit in northwestern Illinois (fig. S-4). It is named for Marcus, Carroll County, 4 miles northwest of the type section, which is in an abandoned quarry in the southern part of Mississippi Palisades State Park (SW SE SE 33, 25N-3E), where it is 40.3 feet thick. It was differentiated as the "*Pentamerus* beds" in early studies and later was named "Waukesha" (Savage, 1926). The Marcus Formation occurs in northwestern Illinois both north and south of the Savanna Anticline, along which it is eroded. North of the anticline it occurs only in the deepest part of the syncline, but it extends eastward to Shannon, Carroll County, and is well exposed north of Mt. Carroll, Carroll County (SE NW NW 25, 25N-4E). South of the anticline it is well exposed in quarries east of Fulton (SW NE NW 19, 22N-4E). The Marcus is uniformly close to 40 feet thick. It consists of pure, vesicular, brown, massive dolomite (fig. S-2C). The lower 10-20 feet is generally crowded with the shells of *Pentamerus oblongus* (fig. S-12), which is also common in the upper part along with other fossils, especially corals. The Marcus Formation occurs at the position occupied by the Joliet Formation farther east and south, but it does not resemble it lithologically, and strata equivalent to the Marcus may be missing at the corrosion surface that marks the base of the Joliet. The abundance of *Pentamerus* suggests correlation of the Marcus with the Schoolcraft in Wisconsin and the Reynales in New York.

Sugar Run Formation

The Sugar Run Formation (Willman, 1973, p. 22), which overlies the Joliet Formation in northeastern Illinois (fig. S-3), is named for Sugar Run, a stream on the south side of Joliet, Will County, along which it is well exposed. The type section, just south of the stream, is in the National Stone Company quarry, which is also the location of the type section for the Joliet Formation. The lower 26 feet of the Sugar Run is exposed at the top of the east face of the quarry. The Sugar Run strata, informally called the "building stone beds," were originally included with overlying interreef Racine strata in the Waukesha Formation (Savage, 1926), but later the Waukesha was restricted to the lower beds (Willman, 1943) (fig. S-7); recently Waukesha was replaced with Sugar Run (Willman, 1973). The Sugar Run Formation is about 30 feet thick in the Joliet area and its contact with the overlying Racine Formation is exposed on the north side of Joliet, particularly where State Highway 4A ascends the east bluff of the Des Plaines Valley (NW NW SE 34, 36N-10E). The Sugar Run Formation is exposed along the Des Plaines River from Joliet to Sag Bridge, in quarries at Elmhurst and Hillside, along the Du Page River at Naperville, along the Fox River Valley at Aurora and Batavia, and along the Kankakee River from Rock Creek Canyon to Wiley Creek. It is absent in subsurface in some areas, in which it may be laterally equivalent to interreef strata included in the Racine Formation. The Sugar Run is slightly to moderately argillaceous and silty, very fine-grained, dense to slightly vesicular, light greenish gray, buff-weathering dolomite that occurs in medium to thick smooth-surfaced beds. It has been extensively quarried for building stone. Rock from quarries near Lemont was called "Athens Marble" and that from Joliet was called "Joliet Marble." The basal 7 feet of the Sugar Run grades uniformly into the pure Romeo Member of the Joliet Formation below. The Sugar Run generally has few macrofossils, but trilobites, particularly *Calymene*, are found in the Lemont area and elsewhere, and a varied fauna has been described (Lowenstam, 1948a).

Racine Formation

The Racine Formation (Hall, 1861), the uppermost Niagaran Formation in northern and western Illinois (figs. S-3, S-4, S-5), is named for exposures in quarries at Racine, Wisconsin. The quarries at Racine are in reefs, and the term "Racine" was introduced in northeastern Illinois for similar rocks (Savage, 1926, p. 524). Savage gave the name "Waukesha" to the impure cherty dolomite thought to underlie the reefs but in fact equivalent to them. He also included in the Waukesha the strata under the reefs that were used for building stone. Later, Waukesha was restricted in northeastern Illinois to the latter strata, and the overlying reef and interreef strata were combined in the Racine (Willman, 1943). At the same time the Racine was redefined to include the uppermost Niagaran strata that had been differentiated by Savage on the basis of their fossils as being equivalent to the Port Byron Formation of northwestern Illinois, although similar in lithology to the Racine. For the same reason, the term "Port Byron" was discontinued in northwestern Illinois, and Racine was extended to include the entire sequence of reef-bearing rocks. The Racine is well exposed in the Chicago area (fig. S-2A, B), especially in the large quarries at Thornton, McCook, La Grange, Hillside, and Elmhurst (Bretz, 1939; Willman, 1943, 1962, 1973; Willman et al., 1950; Lowenstam et al., 1956). In northwestern Illinois it is well exposed at the top of the Mississippi bluffs in Palisades State Park north of Savanna, in the bluffs south of Fulton to Port Byron, and at Morrison, Whiteside County (Sutton, 1935; Willman, 1943, 1973). In western Illinois it is exposed only in a small area at Grafton, Jersey County. The Racine is as much as 300 feet thick. In some areas it is almost entirely pure reef rock (fig. S-2E); in others it is largely silty or argillaceous, cherty interreef rock (fig. S-2F). In places the two types of rocks intertongue. Dark gray to black shaly beds are present locally. At Blue Island, a thickness of several feet of such beds was encountered during the digging of the Calumet Sag Channel and they have been informally called the "Blue Island beds" or "*Lecthaylus* shale" (Lowenstam, 1948a). Reefs start at various levels in the Racine. Many are well defined reefs with flank beds dipping steeply away from a central massive core. In other areas the reef bodies overlap. The Racine reef rock is exceptionally pure dolomite, largely vesicular to coarsely vuggy, medium grained and light gray to white. It commonly is mottled with various shades of gray. In some reefs, many of the vugs are filled with asphaltum. The

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steeply dipping flank beds are generally pure dolomite, but some beds grade into argillaceous dolomite as the slopes diminish. The Racine reefs are highly fossiliferous. In northwestern Illinois much of the Racine consists of flat-lying, pure, reef type of dolomite, and reef structures do not appear to be as common as they are in northeastern and central Illinois. No reefs are present in the small area where the Racine is exposed at Grafton in Jersey County, western Illinois. About 45 feet of Racine is exposed at Grafton, but immediately west of there the formation is truncated by Middle Devonian strata. The interreef rocks in northeastern Illinois are largely impure, varying from moderately silty to very silty or very argillaceous, and lenticular bodies of shale are locally present on the flanks of some reefs. The interreef rocks are commonly very cherty, the chert generally in irregularly scattered nodules. The interreef rocks in many places contain beds of relatively pure dolomite, probably wash from the reefs. Near the reefs some beds have a strongly nodular character, suggesting deposition in water that was subject to frequent agitation. The Racine is equivalent to the upper part of the St. Clair and to all except the youngest part of the Moccasin Springs in southern Illinois. It is correlated with and is similar in lithology to the Gower in Iowa, the Engadine in northern Wisconsin, and the Wabash in Indiana.

St. Clair Limestone

The St. Clair Limestone (Penrose, 1891a, p. 102-103) (fig. S-6), named for St. Clair Springs, 8 miles northeast of Batesville, Independence County, Arkansas, is the basal formation of the Niagaran Series in southern Illinois. It is well exposed in the Mississippi River bluffs north of the mouth of Dongola Hollow, in Alexander County (SW SE NW 12, 14S-3W). Although only 10-20 feet thick where exposed in Alexander County, it thickens northward to 80-100 feet in the deeper part of the Illinois Basin, and it is as much as 150 feet thick at its northern margin, where it grades into the Joliet and Racine Formations. The strata now included in the St. Clair were originally in the upper part of the Sexton Creek (Savage, 1909), but Weller later (1940) included them in the lower part of the Bainbridge Formation (fig. S-10). Lowenstam (1949), noting that the pink crinoidal limestone of the lower Bainbridge is almost identical to that of the St. Clair in Arkansas, extended the St. Clair to Illinois and introduced Moccasin Springs for the upper, red, shaly part of the Bainbridge and elevated Bainbridge to a group. The St. Clair consists of coarsely crystalline calcite grains and abundant pink crinoidal remains in a fine-grained limestone matrix. The amount of crinoidal debris decreases upward. The matrix contains a small amount of silt, clay, and some very fine sand. The limestone occurs in medium to thick beds and is generally free of chert. It contains an abundance of arenaceous Foraminifera. The St. Clair Limestone is thought to be equivalent to the Joliet Formation and the lower part of the Racine Formation in northern Illinois. The Brandon Bridge Member of the Joliet, like the St. Clair, contains a few thin beds of pink crinoidal dolomite and abundant Foraminifera. Pink mottling also occurs in the Romeo Member of the Joliet and locally also in the Racine. The St. Clair is correlated with the Osgood, Laurel, Waldron, and Louisville Formations in Indiana.

Moccasin Springs Formation

The Moccasin Springs Formation (Lowenstam, 1949, p. 16) (fig. S-6) overlies the St. Clair Limestone in southern Illinois and is named for the village of Moccasin Springs, which is 9 miles north of Cape Girardeau, Cape Girardeau County, Missouri, and 3 miles north of the type section, a ravine in the Mississippi River bluffs (SE SE NW 24, 32N-14E). The formation is 100-130 feet thick in the outcrop area, and a thick section is exposed along Sammons Creek (Salamans on some maps), Alexander County (cen. S line 2, 15S-3W) (Pryor and Ross, 1962). The formation thickens northeastward and is commonly 160-200 feet thick, but it is as much as 400 feet thick bordering the reefs. The Moccasin Springs is dominantly red, or red- and gray-mottled, very silty, argillaceous limestone and calcareous siltstone, with shale common near the top. Beds that lack the red mottling become more abundant upward and northward. The Moccasin Springs contains numerous reefs (fig. S-1), some as much as 1000 feet thick (Lowenstam, 1949) (fig. S-11). The Moccasin Springs reefs are dominantly limestone, have well defined flank structures, and many have been large producers of oil. The interreef Moccasin Springs is differentiated into three members that have not been formally named. The lower is red- and gray-mottled shale and silty limestone that grades eastward from the outcrop area into alternating beds of mottled argillaceous limestone and red calcareous siltstone that have a characteristic and widely traceable electric log curve described as the "2-kick, 3-kick zone" (fig. S-16) throughout much of the basin and bordering the reefs. The overlying member is more uniformly red to greenish gray limestone, but it has some argillaceous and silty beds. The uppermost member is dominantly green shale, but it contains beds of red-brown siltstone and limestone. The position of the St Clair–Moccasin Springs contact in the northern Illinois Niagaran is uncertain, and the Moccasin Springs may be equivalent to only the upper part of the Racine Formation, including and above the "*Lecthaylus* shale" that is approximately 200 feet above the base of the Racine. Ross (1962b) reported a lower Ludlovian *Monograptus* from about 50 feet below the top of the Moccasin Springs, which makes it possible that much of the formation above that position may be Cayugan in age. The interreef facies of the Moccasin Springs Formation is similar to the Mississinewa Shale Member of the Wabash Formation in Indiana and the Henryhouse Formation in Arkansas and Oklahoma.

CAYUGAN SERIES

The Cayugan Series (Clarke and Schuchert, 1899; Swartz et al., 1942, chart 3) is based on the Cayugan Group of New York and includes all the strata of Silurian age above the contact of the Guelph and Salina Formations in the New York type section. As the uppermost Racine strata in northern Illinois have been correlated with the Guelph Formation, no Cayugan age strata are recognized in that area. However, the generally accepted interpretation that the reefs isolated the basin in which the Salina evaporites accumulated in-

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troduces the possibility that some of the highest reefs may have continued to grow in Cayugan time. Reefs of Cayugan age could have been eroded from Illinois before they were overlapped by Middle Devonian strata. In the deeper part of the Illinois Basin, the Moccasin Springs Formation appears in places to grade upward into the Bailey Formation, which is largely of Lower Devonian age (Collinson and Schwalb, 1955), but in the outcrop area in Illinois the contact is sharp (Pryor and Ross, 1962). As the conodonts suggest that the lowermost beds of the Bailey are upper Silurian (Collinson, 1967), the Cayugan Series probably includes the upper part of the Moccasin Springs and the lower part of the Bailey Formation. Late Silurian graptolites have been reported from strata equivalent to the upper part of the Moccasin Springs in Missouri (Berry and Satterfield, 1972).

DEVONIAN SYSTEM

Charles Collinson and Elwood Atherton

The Devonian System (Sedgwick and Murchison, 1839), named for Devonshire, England, may originally have covered all of Illinois, but if so it was eroded from the northern part of the state, largely before Pennsylvanian time (fig. D-1). The upper and lower boundaries of the system in Illinois have been controversial, but in recent years they have become more precise, mainly because of zonation of the conodonts (Collinson, 1961, 1967; Collinson et al., 1971). The lower boundary is now placed in the lower part of the Bailey Formation rather than at its base (fig. D-2). The upper boundary is placed as high as the lower few feet of the otherwise Mississippian Hannibal Formation or, where those beds are missing, on the top of the Louisiana Limestone or the Saverton Shale. In many earlier reports, the upper boundary was placed as low as the top of the Cedar Valley Limestone or the Lingle Limestone, thus putting nearly all the New Albany Shale Group into the Mississippian System.

The Devonian is less than 100 feet thick in a large part of central and western Illinois, but it thickens into the deep part of the Illinois Basin to more than 1800 feet thick (fig. D-1). It is exposed only in limited areas along and near the Mississippi and Ohio Valleys, principally where the valleys truncate anticlinal areas (fig. D-3).

The Devonian System is subdivided into three series, Lower, Middle, and Upper. It is the only system in Illinois for which these terms have not been replaced by geographic names. Major stages in the development of the classification are shown in figures D-4 and D-5. The development of separate classifications for the northern and southern parts of the state results from the rise of the Sangamon Arch (fig. D-10) across north-central Illinois during, or at least by the end of, Lower Devonian time. Because the Sangamon Arch, rather than the Mississippi River Arch (fig. 12), formed a barrier in the Middle Devonian seas, the formations deposited in central and southern Illinois differ from those in northwestern Illinois. During late Devonian time, the Sangamon Arch subsided, and the seas spread entirely across the area.

The Lower Devonian rocks are dominantly siliceous limestone, dolomite, and chert; the Middle Devonian strata are largely pure limestone and dolomite; and the Upper Devonian sediments are dominantly black, gray, and green shale, although smaller amounts of limestone and siltstone are present. The Lower and Middle Series, with the underlying Silurian carbonates, compose the Hunton Limestone Megagroup, whereas the overlying clastic rocks form the basal part of the Knobs Megagroup (fig. D-2).

The large amount of silica in the Lower Devonian formations appears to have originated partly as finely divided quartz silt that was physically transported to the seas, and partly as a product of intensive weathering of the bordering upland areas, of transportation to the seas in solution, and of deposition as primary or diagenetic chert.

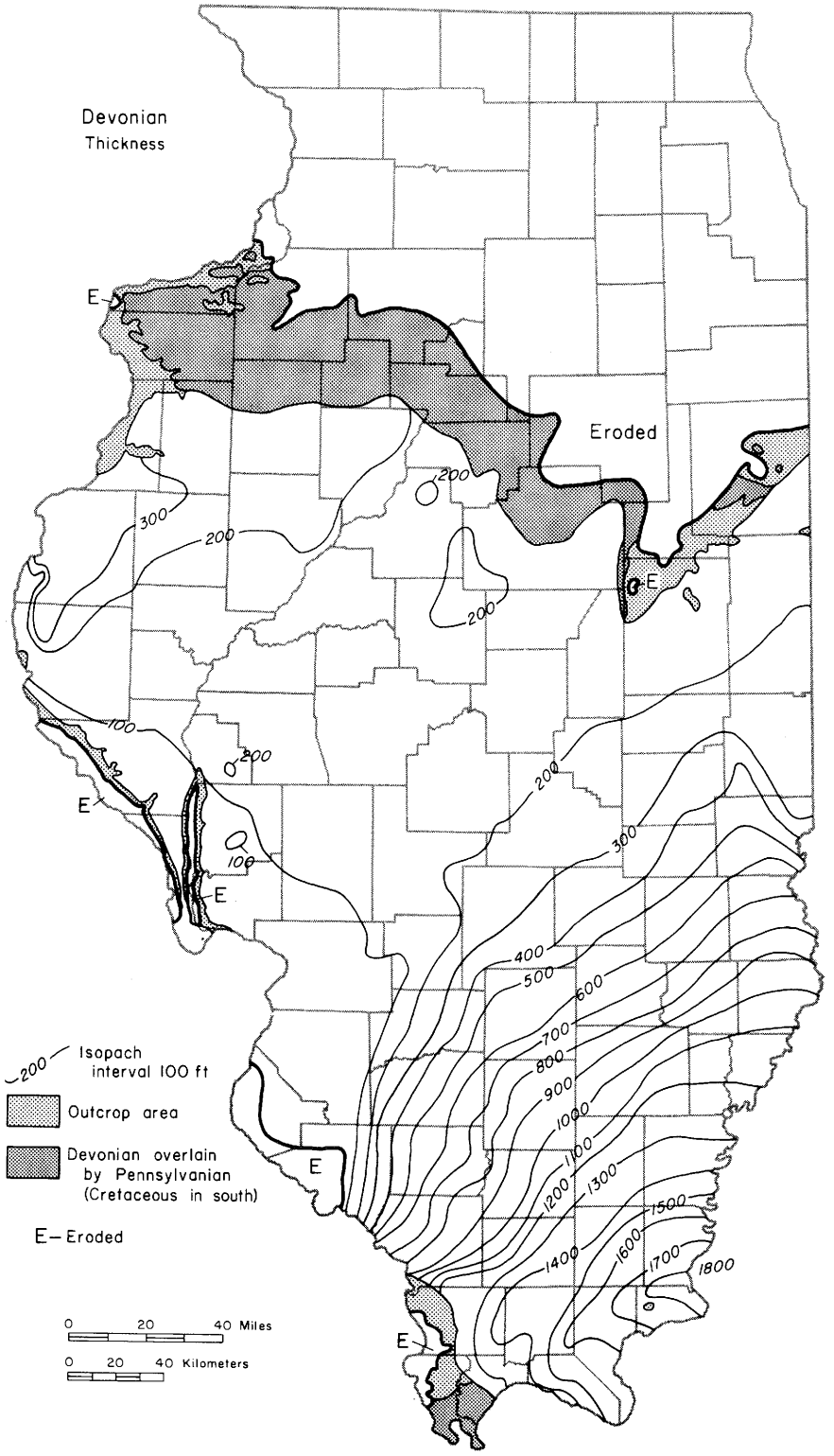

Fig. D-1—Thickness of the Devonian System.

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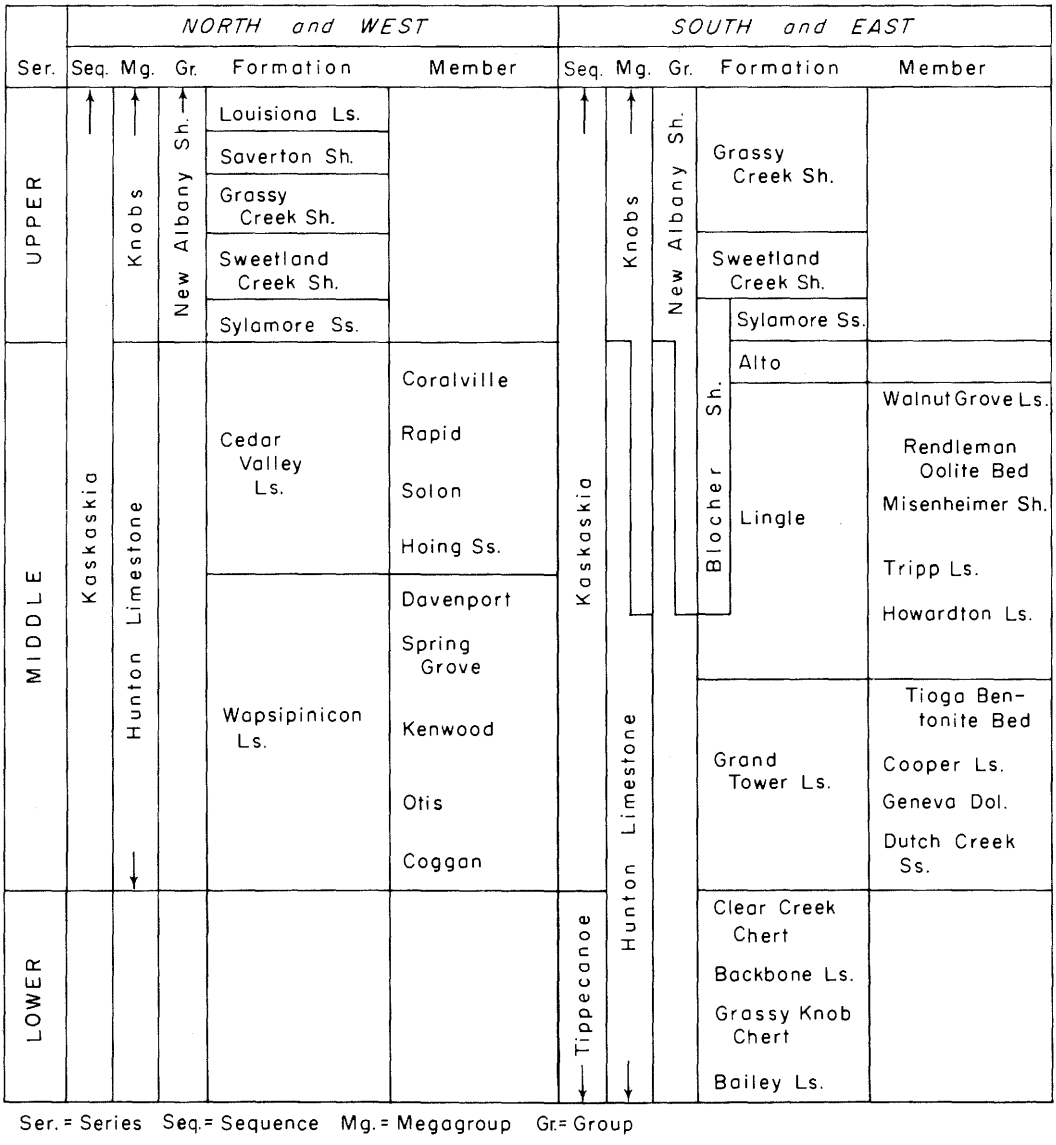

Fig. D-2—Classification of the Devonian System.

Most Middle Devonian rocks in Illinois are normal marine limestone, but north of the Sangamon Arch the normal sediments are interbedded with evaporites. By late Middle Devonian time, argillaceous sediments rich in spores and in finely disseminated organic debris were being deposited in the relatively deep seas in the southern part of the Illinois Basin, forming black, laminated, fissile shale. The conditions favoring this type of sedimentation were widespread during late Devonian time and black sediments covered the entire basin, although at times the supply of organic material was reduced and gray and green shales were deposited. On the flanks of the positive areas, calcareous sediments accumulated and, in places, are interbedded with black shale.

Middle Devonian rocks, particularly on and near the flanks of the basin, contain beds, lenses, and "floating grains" of quartz sand (Summerson and Swann, 1970). Most of the

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sand is well rounded and was derived by erosion from earlier Paleozoic formations (such as the St. Peter Sandstone) that were exposed on the Ozark Uplift and the Wisconsin Arch. These sands are thin and discontinuous but they are present throughout the basin. A thin bed of bentonite, the Tioga Bentonite, that originated from volcanoes in the eastern United States is widely traceable in late Middle Devonian rocks.

Fossils are common in only a few local beds of the siliceous Lower Devonian rocks, but they are common to abundant in the normal marine Middle Devonian limestones. Brachiopods and corals are the most common and best preserved of the macrofossils (figs. D-6, D-3E). Virtually no fossils are found in the widespread hypersaline limestones. In the Upper Devonian Series, macrofossils are abundant in the limestones but sparse in the shales. However, *Tasmanites* are abundant and conodonts are common to abundant in the series. The ranges of many Devonian fossils are given by Collinson et al. (1967a).

In the Illinois Basin, sedimentation was continuous from Silurian into Devonian time and from Devonian into Mississippian time. The major unconformity in the Devonian System is at the base of the Middle Devonian, where an extensive unconformity resulted from regional uplift, withdrawal of the seas, and minor warping. As a result, the Middle Devonian Series successively overlies Lower Devonian, Silurian, and Ordovician strata (fig. D-7) along what is termed the sub-Kaskaskia unconformity—the base of the Kaskaskia Sequence.

The regional correlations of the Devonian formations of Illinois have been discussed by Weller (1944b), Cooper (1944), and Collinson et al. (1967a, b).

LOWER DEVONIAN SERIES

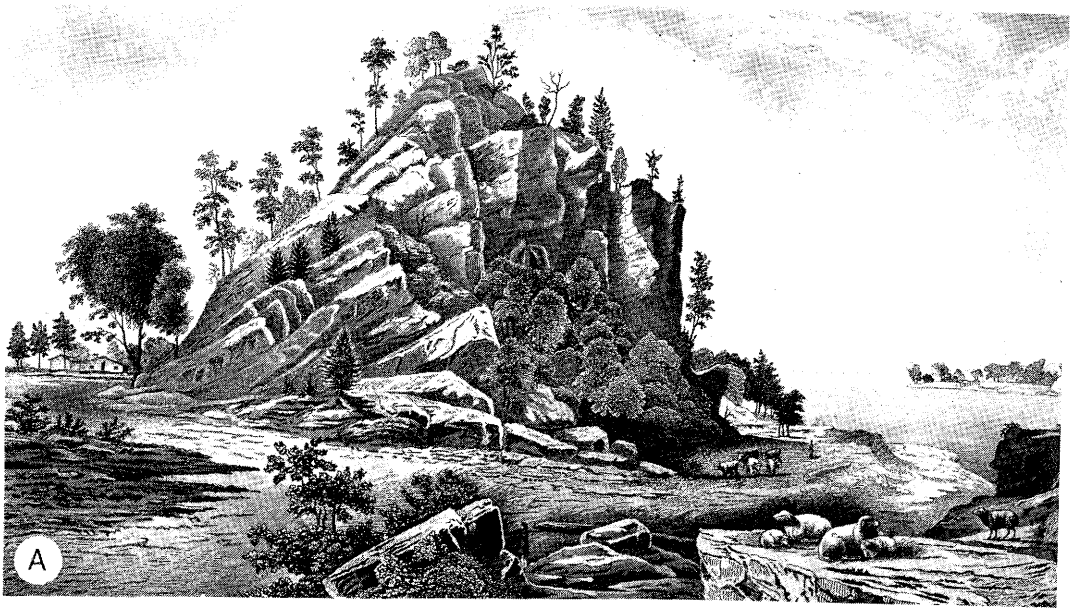
As in most of the Mississippi Valley region, Lower Devonian rocks in Illinois are largely siliceous—cherty, silty limestone and dolomite, and chert formations. They have long been called the Lower Devonian Series (Bassett, 1925), although the New York terms "Helderbergian," "Helderbergian and Oriskanian," and "Ulsterian" have been used at times in Illinois and are still used in other regions (fig. D-5). The name "Lower Devonian" is generally applied to Devonian strata older than the Onondaga Group of the New York section. They are correlated with Emsian and older strata of Europe (Collinson et al., 1967a).

In Illinois the Lower Devonian underlies the southern third of the state, thickening southward from its northern boundary to 1200 feet in the extreme south (fig. D-8). Near the northern boundary the Lower Devonian rocks surround and partially overlap middle Silurian reefs, north of which they are truncated by the sub-Kaskaskia unconformity. They may have originally extended over all of Illinois, unless the Sangamon Arch and the positive areas bordering Illinois were above sea level during this epoch. South of the Silurian reefs, Lower Devonian strata are successively truncated by the unconformity. Along the western edge of the state, the Lower Devonian strata are truncated by the present surface on the flanks of the Ozark Uplift, and they are well exposed in Jackson, Union, and Alexander Counties (Weller, 1944a; Weller and Ekblaw, 1940; Pryor and Ross, 1962).

The Lower Devonian Series includes the Bailey Limestone (siliceous and cherty) at the base, the Grassy Knob Chert, the Backbone Limestone (pure), and the Clear Creek Chert (fig. D-9). The Bailey grades downward into the shale at the top of the Silurian Moccasin Springs Formation. Fossils are scarce in the Bailey, but the few conodonts found there suggest that the base of the Lower Devonian Series is within the lower part of the Bailey (Collinson et al., 1967a).

Bailey Limestone

The Bailey Limestone (Ulrich, *in* Buckley and Buehler, 1904, p. 110) is named for Bailey's Landing on the Mississippi River, Perry County, Missouri, a settlement long abandoned but thought to have been at or near the village of Grand Eddy. As the original type section is not exposed, Croneis (1944) designated as a neotype the outcrops in the river bluffs at and north of Red Rock Landing, half a mile east of Grand Eddy (11, 35N-12E). The Bailey Limestone underlies much of the deep part of the Illinois Basin and it has a maximum thickness of as much as 500 feet. It is 200-300 feet thick in the Illinois outcrop area, which extends from the south line of Jackson County to Olive Branch, Alexander County. It is exposed in high cliffs in the Mississippi River bluffs, especially in the Pine Hills area in Union County about 5 miles southeast of Grand Tower, where about 400 feet of Bailey, Grassy Knob, and Backbone is exposed (fig. D-3B). The Bailey is dominantly gray to greenish gray, silty, cherty, thin-bedded, very hard limestone. Some beds are argillaceous. The chert is black to dark gray and occurs in bands of nodules and in beds, some of which are 1-2 feet thick. Beds of calcareous and silicified siltstone occur in places. In the northern area, bordering the Silurian reefs, the Bailey is less cherty and is greenish gray, argillaceous dolomite. An upper zone, 0-100 feet thick, is pure, white, coarsely crystalline, only slightly cherty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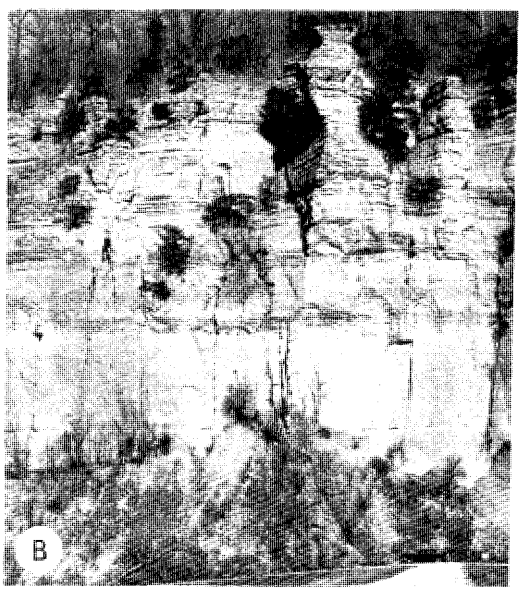
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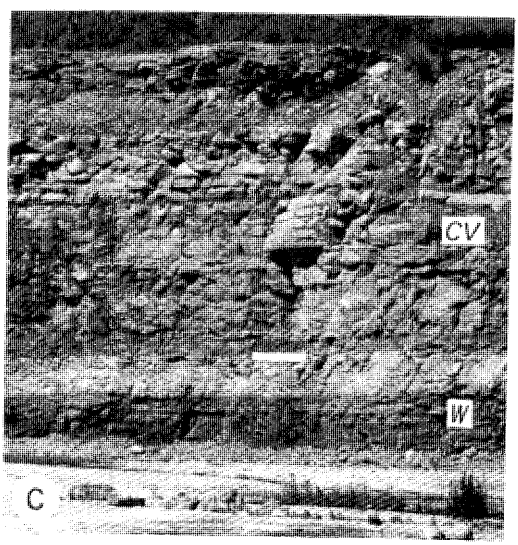
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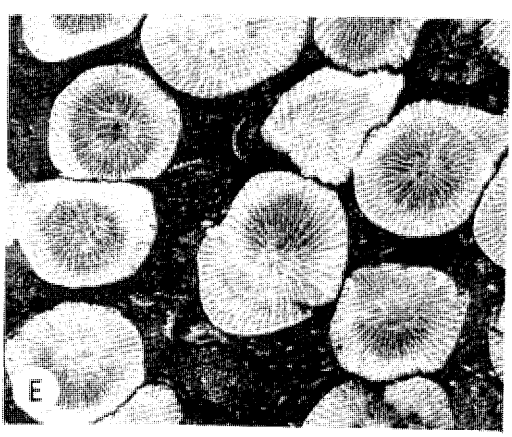
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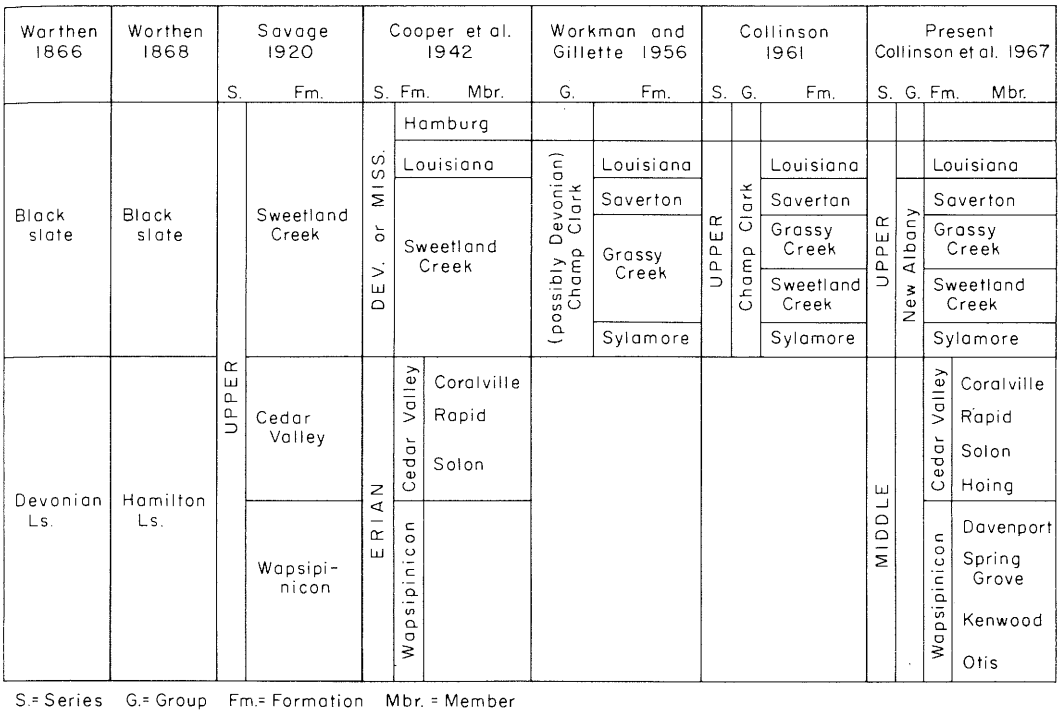

Fig. D-4—Development of the classification of the Devonian System in northern Illinois.

limestone similar to the Backbone Limestone, from which it is separated by the Grassy Knob Chert. It has been traced widely in subsurface and referred to as the "unnamed limestone" (Collinson et al., 1967a). The sparse fauna of the Bailey includes *Leptaena rhomboidalis, Dalmanites* sp. (pygidia), several species of rhynchonellid brachiopods, crinoids, and conodonts. Most of the fauna occurs in the upper part. The presence of *Scyphocrinus elegans* low in the formation has been interpreted as indicating that the lower part is uppermost Silurian in age and that no break in sedimentation occurred between the Silurian and Devonian Systems in this region. The Bailey is overlain conformably by the Grassy Knob Chert and in many localities is not readily differentiated from it (Weller et al., 1952; Pryor and Ross, 1962).

Grassy Knob Chert

The Grassy Knob Chert (Savage, 1925b, p. 139-144), which overlies the Bailey Limestone, is named for Grassy Knob, a prominent high area on the Mississippi River bluffs 4 miles east of Grand Tower, Jackson County. The type section is in the west face of the knob (SW SW 27, 10S-3W). The formation is exposed in and near the Mississippi River bluffs in Jackson, Union, and Alexander Counties and occurs in subsurface through the deep part of the Illinois Basin (Collinson et al., 1967a). It is about 200 feet thick in the outcrop area but thickens to about 300 feet in the basin to the east. The Grassy Knob differs from the Bailey Formation below in being lighter colored and in containing more thick beds of solid chert, especially in the middle part of the formation (Weller, 1940), which is well exposed 2 miles southeast of Reynoldsville, Union County (NW cor. 32, 13S-2W). The Grassy Knob is gradational to the Bailey Limestone below. It is more sharply differentiated from the Backbone Limestone above, although no unconformity is evident. In the southern part of the Devonian outcrop area, where the Backbone is absent, the Grassy Knob is not readily separated from the Clear Creek Chert. Fossils are rare in the Grassy Knob Chert.

Backbone Limestone

The Backbone Limestone (Savage, 1920, p. 169-178), which overlies the Grassy Knob Chert, is named for an

Fig. D-3—Exposures and textures of Devonian rocks.

A—Middle Devonian Limestone (Lingle and Grand Tower) in ridge ("the Backbone") along the Mississippi River north of Grand Tower, Jackson County (from Worthen, 1868, opp. p. 61).

B—Bailey Limestone in the Pine Hills (Mississippi River bluffs), 5 miles north of Wolf Lake, Union County.

C—Cedar Valley (CV) and Wapsipinicon (W) Limestone in Collinson Stone Company Quarry, 1 mile southeast of Milan, Rock Island County. The rock face is about 70 feet high.

D—Fine-grained, fossiliferous limestone characteristic of the Cedar Valley Limestone in the Rock Island area, Rock Island County (×1).

E—Dark gray, fine-grained Middle Devonian limestone containing white corals; polished section of core from depth of 3270 feet in Marion County (×1).

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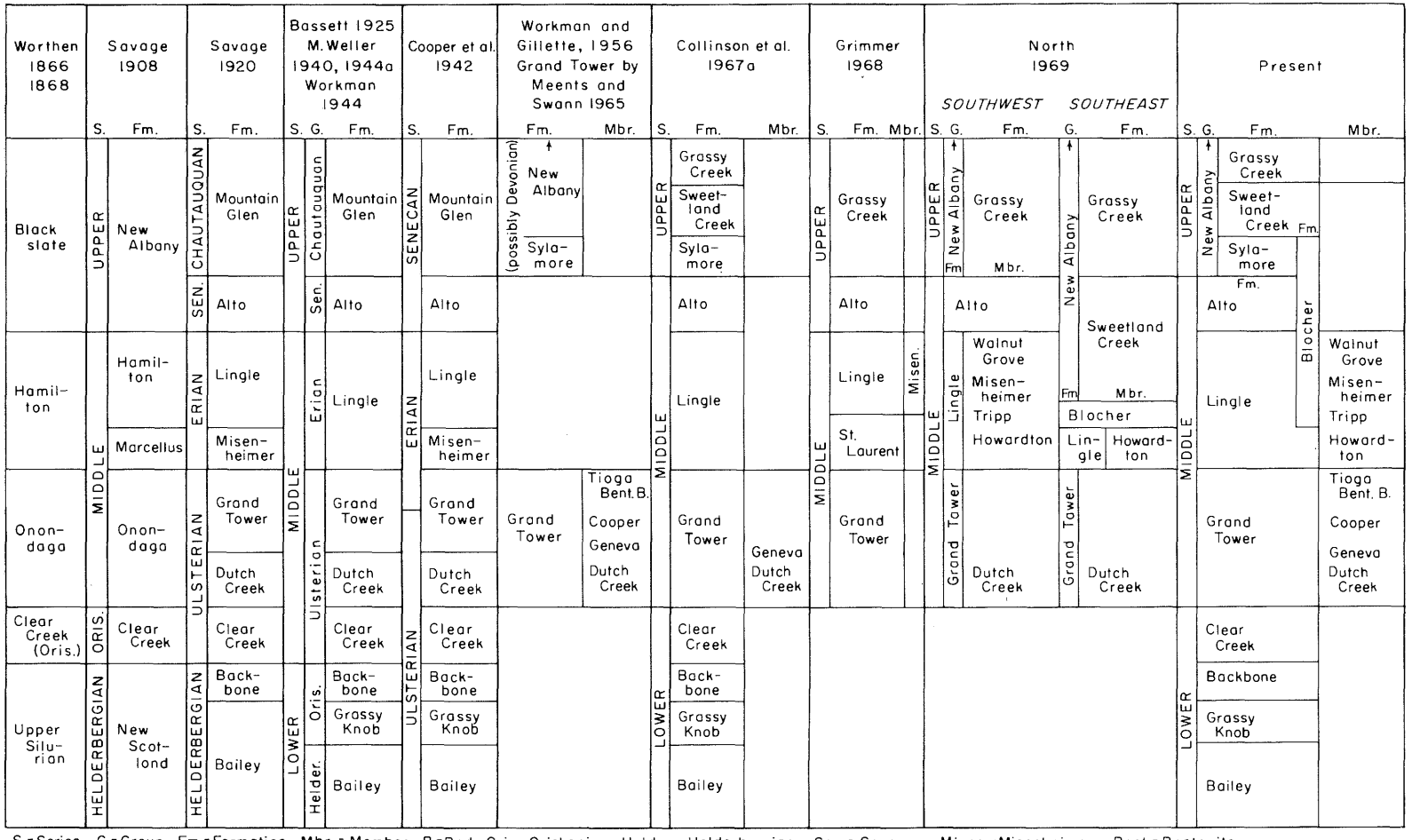

S.=Series G.=Group Fm.=Formation Mbr.=Member B.=Bed Oris.=Oriskanian Helder.=Helderbergian Sen.=Senecan Misen.=Misenheimer Bent.=Bentonite

Fig. D-5—Development of the classification of the Devonian System in southern Illinois.

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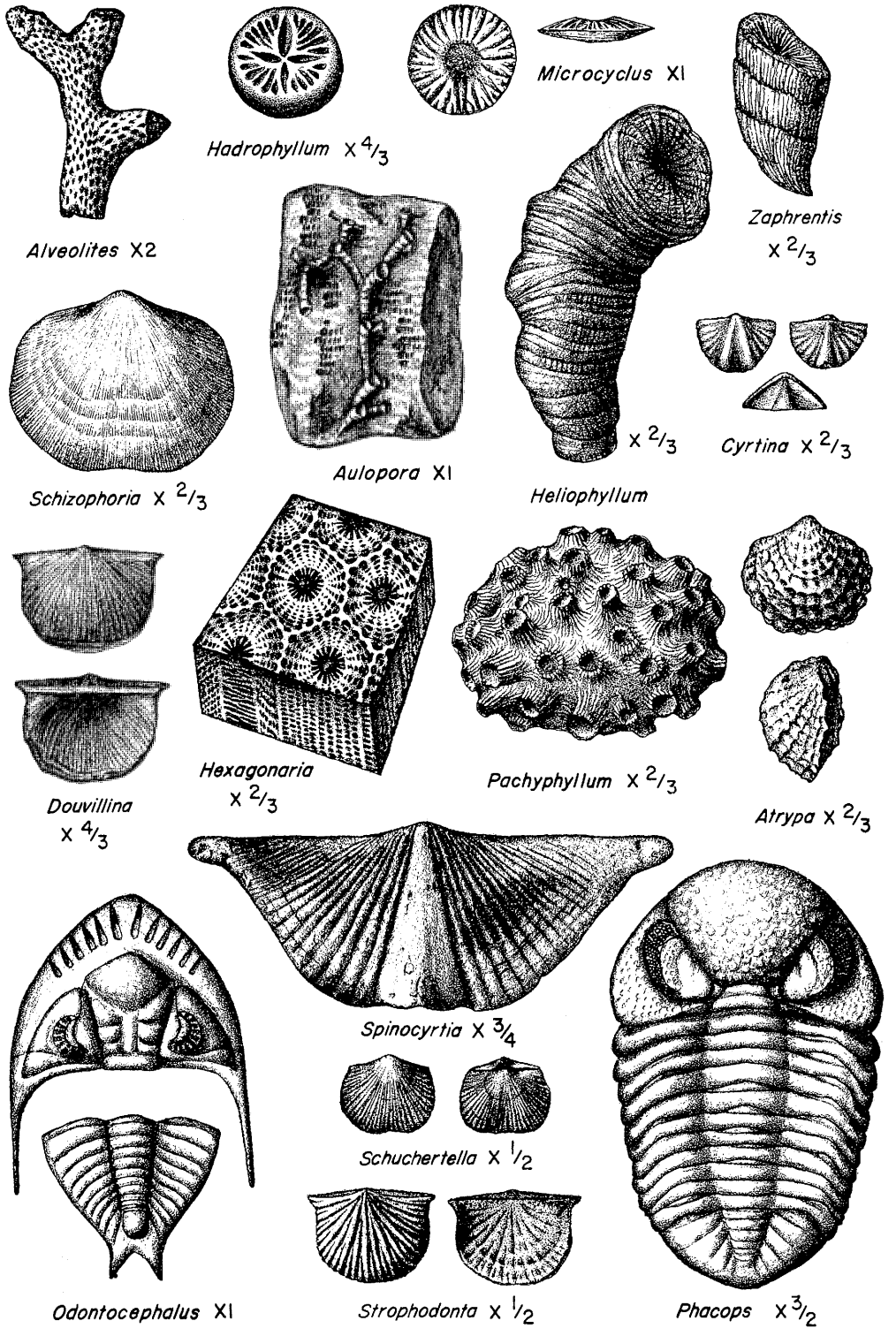

Fig. D-6—Typical Devonian fossils.

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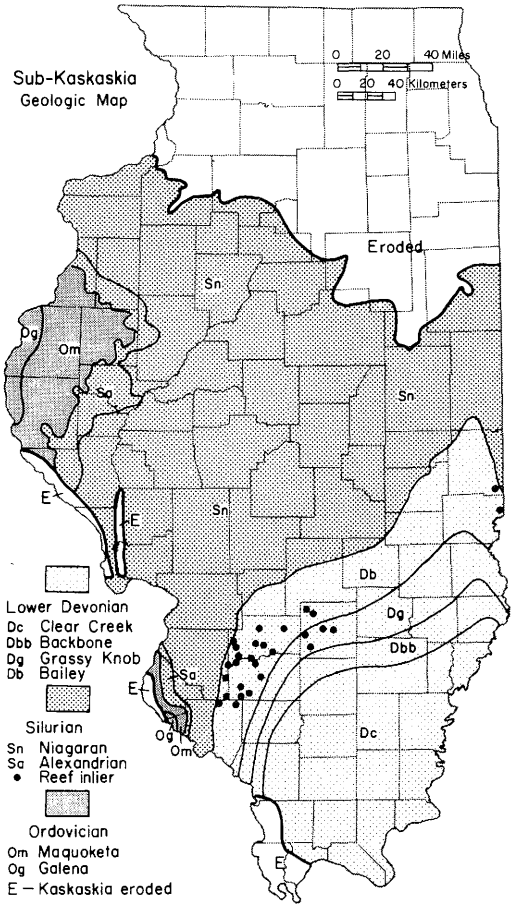

Fig. D-7—Geologic map of the sub-Kaskaskia surface.

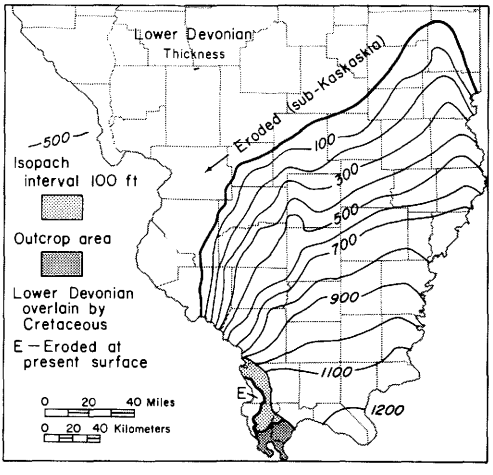

Fig. D-8—Thickness of the Lower Devonian Series.

isolated ridge called the Backbone along the Mississippi River north of Grand Tower, Jackson County. The type section is in a quarry at the south end of the ridge (SE SW SW 24, 10S-4W), where only the upper 38 feet of the formation, overlain by the Clear Creek Chert, is exposed. The Backbone Limestone appears to be as much as 200 feet thick where it rims the deep part of the Illinois Basin, but it becomes thinner within the deeper part and in places is absent (Collinson et al., 1967a). In the outcrop area in Jackson and Union Counties, the Backbone Limestone is about 100 feet thick, but it thins southward and is absent (or becomes cherty and is not recognized) in the Devonian outcrop area in Alexander County. The Backbone Limestone consists of light gray, massive, crystalline, pure limestone that commonly contains many large crinoid stems and a few scattered chert nodules. It has a large fauna that is dominated by brachiopods, notably *Acrospirifer murchisoni* and *Costispirifer arenosus*, but gastropods, bryozoans, conodonts, and trilobites are common. The fossils indicate a correlation with the Oriskany in New York. The Backbone is continuous with the Little Saline Limestone in Missouri.

Clear Creek Chert

The Clear Creek Chert (Worthen, 1866, p. 126-129; Savage, 1920, p. 174-175), the uppermost Lower Devonian formation, is named for Clear Creek in Union County, along which the formation is exposed for about 5 miles (T11-12S, R2W), although no specific type section has been designated. As originally defined by Worthen (1866), the Clear Creek may have included the Backbone Limestone and possibly the Grassy Knob Chert, but Savage (1920) restricted the name to the chert formation above the Backbone. The Clear Creek Chert is exposed along the Mississippi Valley from the south end of the Backbone in Jackson County, south to the vicinity of Tamms, Alexander County. It is well exposed in a quarry on the west bluff of Cache Valley northwest of Tamms

FORMATION		FEET
Clear Creek Chert		300-600
Backbone Ls.		0-200
Grassy Knob Chert		200-300
Bailey Ls.		200-500

Fig. D-9—Columnar section of the Lower Devonian Series.

(NE NW 36, 14S-2W). The thickness of the Clear Creek is difficult to determine, but it is at least 300 feet thick in the outcrop area. Bald Knob, the highest point in southern Illinois, rises 600 feet above Clear Creek and appears to be all Clear Creek Chert, but the thickness is complicated by structure. The formation thickens eastward from the outcrop area to about 600 feet in the southern part of the basin. The Clear Creek is dominantly chert; much of it is white, or generally lighter in color than the chert in the lower formations (Weller, 1940). It contains some beds of gray, very fine-grained, siliceous limestone, which in places are separated from the chert beds by stylolitic partings. Such partings are also common in the chert. The proportion of limestone is generally small in most outcrops, but it is larger near the top of the formation and increases in subsurface north and east from the outcrop area. Solution of the limestone beds and fracturing of the chert beds has produced modifications of the original deposit that are variously described as novaculite, ganister, and tripoli (Lamar, 1953). The novaculite and ganister have been used for gravel and for making silica brick. The tripoli, which consists of finely divided particles of silica in vein-like bodies, is used in abrasives. The Clear Creek is much more fossiliferous than the Grassy Knob, and some chert beds are largely casts of fossils, particularly of the brachiopod *Eodevonaria melonicus*.

MIDDLE DEVONIAN SERIES

The term "Middle Devonian Series" has been commonly used in Illinois since 1925 (Bassett), but previously the New York terms "Ulsterian," "Erian," and "Senecan" were used for these rocks. As now defined, the Middle Devonian Series is based on the boundaries established in Europe and is equivalent to the Eifelian and Givetian Stages (Collinson, 1967).

The Middle Devonian Series underlies much of the southern two-thirds of Illinois and, although commonly less than 100 feet thick in the central and western parts, it thickens to more than 400 feet in the southeastern part (fig. D-10). It is exposed in small areas in southern, western, and northwestern Illinois (fig. D-3).

In Illinois the Middle Devonian Series includes strata from the base of the Grand Tower or the Wapsipinicon to the top of the Alto or Cedar Valley Formations (fig. D-11), although evidence from the conodont fauna indicates that in some places the upper boundary may lie within the upper part of the Cedar Valley and the Blocher. Lowermost Middle Devonian rocks may be absent in Illinois because of the major unconformity at the base.

A broad, gentle arch, the Sangamon Arch (Whiting and Stevenson, 1965), extended

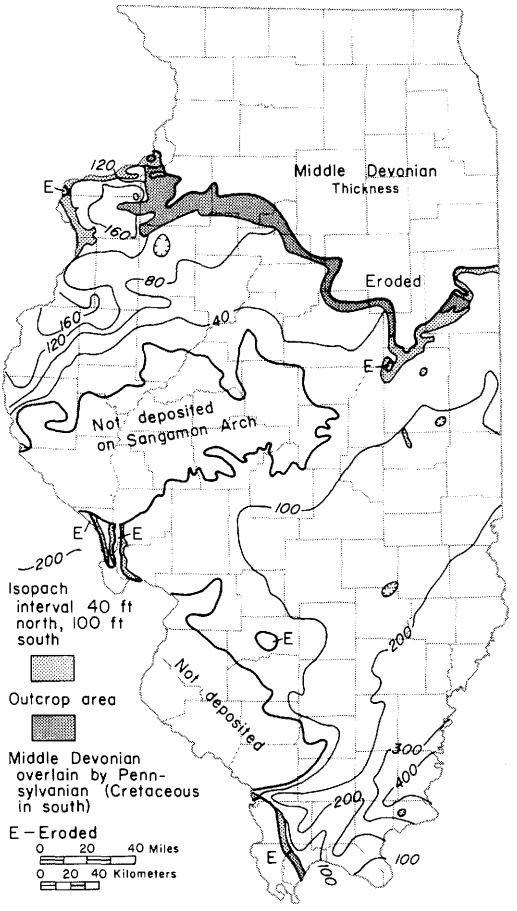

Fig. D-10—Thickness of the Middle Devonian Series.

northeast-southwest across north-central Illinois (fig. D-10) and served as a barrier in the Middle Devonian seas. The formations north of the arch were long considered to be uppermost Middle Devonian or Upper Devonian and younger than the formations south of the arch (Cooper et al., 1942), but more recent studies have indicated the general equivalence of the sediments on both sides (Collinson, 1967).

The Middle Devonian Series is dominantly limestone, although it is dolomitic in some areas. The upper part grades laterally to black shale in the deep part of the Illinois Basin, and a thin sandstone or sandy limestone occurs at the base in many areas. The top of the limestone or dolomite is the top of the Hunton Megagroup.

The Middle Devonian strata are generally very fossiliferous, and the large fauna is domi-

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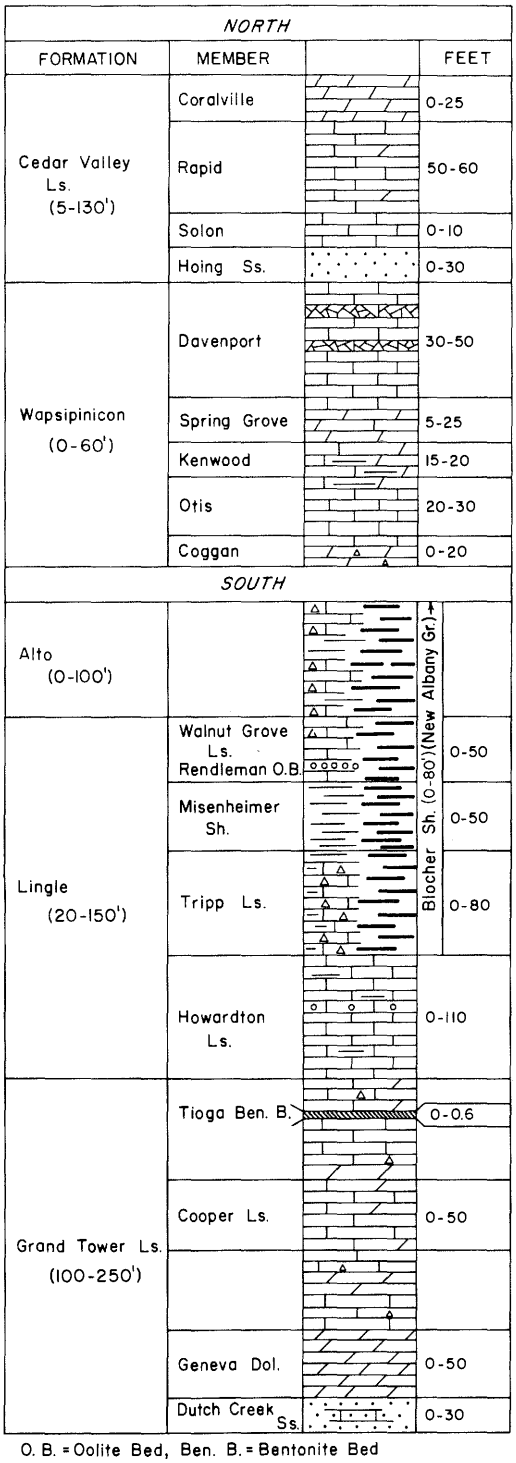

Fig. D-11—Columnar section of the Middle Devonian Series.

nated by brachiopods, corals, and conodonts, although other forms are common. Because of the sub-Kaskaskia unconformity, the Middle Devonian strata truncate Lower Devonian, Silurian, and uppermost Ordovician strata (fig. D-7).

KASKASKIA SEQUENCE

The major unconformity at the base of the Middle Devonian Series, or in some areas the base of the Upper Devonian Series, is widely present throughout the eastern part of the United States, and the strata between the unconformity and the next higher major unconformity (which in Illinois is at the base of the Pennsylvanian System) are called the Kaskaskia Sequence (Sloss et al., 1949) (fig. 14). The Kaskaskia Sequence is named for the Kaskaskia River in south-central Illinois. The original definition of the sequence placed its top at the base of the Mississippian Aux Vases Sandstone, excluding the Chesterian Series. However, because the sub-Aux Vases unconformity is confined to the margin of the basin and the Chesterian strata generally have the same structural attitude as the underlying Valmeyeran Series, the Kaskaskia was extended upward to the base of the Pennsylvanian System (Swann and Willman, 1961).

Wapsipinicon Limestone

The Wapsipinicon Limestone (Norton, 1895, p. 127, 155-166) is named for the Wapsipinicon River in Iowa, along which the type section consists of exposures between Troy Mills and Central City, Linn County, Iowa. It occurs in the basin northwest of the Sangamon Arch (fig. D-12), where it unconformably overlies Silurian and Ordovician strata (fig. D-7) and is overlain by the Cedar Valley Limestone. It has a maximum thickness of about 60 feet near the Mississippi River and thins southeastward. It lenses out on the flanks of the Sangamon Arch, where it is overlapped by the Cedar Valley Limestone. The Wapsipinicon is exposed in Illinois only in the vicinity of Rock Island, and the principal exposures are in quarries and outcrops at Milan (fig. D-3C), Rock Island, and Andalusia in Rock Island County, and at Cleveland in Henry County (Savage, 1921b; Savage and Udden, 1921; Collinson et al., 1967b; Edmund and Anderson, 1967). The Wapsipinicon is dominantly fine-grained to lithographic, pure limestone, but some beds are argillaceous and dolomitic. Beds of anhydrite and gypsum occur locally in the subsurface in the westernmost part of the area, particularly in Hancock County. They are probably equivalent to the prominent brecciated beds that occur in the outcrop sections. Pods and lenses of sandstone occur in places, especially at and near the base. In the type region six members are differentiated, but in Illinois only the upper five are recognized (fig. D-11)—the Coggan Member (cherty dolomite) at the base, the Otis Member

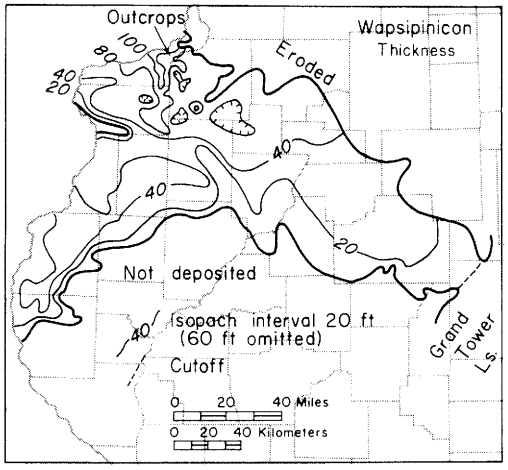

Fig. D-12—Thickness of the Wapsipinicon Limestone (after James, 1968).

(lithographic limestone), the Kenwood Member (argillaceous dolomitic limestone), the Spring Grove Member (dolomite and dolomitic limestone), and the Davenport Member (lithographic limestone) at the top. The Wapsipinicon apparently was deposited in hypersaline waters and fossils are very rare.

Coggan Member—The Coggan Member of the Wapsipinicon Limestone (Norton, 1894, p. 23-24), at the base of the Wapsipinicon in Illinois, is named for Coggan, Linn County, Iowa, where the type section is at the Illinois Central Railroad crossing of the Buffalo River. The Coggan Member is not exposed in Illinois, but it occurs locally in subsurface and is as much as 20 feet thick in the area between Galesburg, Knox County, and Muscatine, Iowa. It consists of massive, buff, cherty dolomite. It also contains a thin bentonite that has been correlated with the Tioga Bentonite Bed, which occurs near the top of the Grand Tower Formation southeast of the Sangamon Arch.

Otis Member—The Otis Member of the Wapsipinicon Limestone (Norton, 1894, p. 22-24), which overlies the Coggan Member (or Silurian dolomite where the Coggan is absent), is named for the railway junction called Otis, east of Cedar Rapids, Linn County, Iowa. The Otis Member is 26 feet thick where exposed in a quarry at Cleveland, Henry County (S1/2 31, 18N-2E). It is fine-grained to lithographic, light gray to brown limestone with a few lenses of chert. In the region where it thins out on the flanks of the Sangamon Arch, lenses of quartz sandstone as much as 5 feet thick occur at the base.

Kenwood Member—The Kenwood Member of the Wapsipinicon Limestone (Norton, 1894, p. 23; Stainbrook, 1935, p. 251), which overlies the Otis Member, is named for Kenwood Park in the northern part of Cedar Rapids, Linn County, Iowa, where the type section is an exposure along Indian Creek. As originally defined, the Kenwood included strata later differentiated as the Spring Grove Member (Stainbrook, 1935). The Kenwood is 15-20 feet thick in the outcrop area. It is 10 feet thick where exposed at the base of a quarry half a mile southeast of Milan, Rock Island County (NW 25, 17N-2W), and 16 feet in the quarry on the south side of Rock Island, Rock Island County (SE 14, 17N-2W), but the base is not exposed in either quarry. The Kenwood consists of laminated or thin-bedded, argillaceous, dolomitic limestone with strongly brecciated beds and pockets of clay.

Spring Grove Member—The Spring Grove Member of the Wapsipinicon Limestone (Stainbrook, 1935, p. 251-252) formerly was the upper part of the Kenwood. It is named for Spring Grove Township, Linn County, Iowa, where the type section is on the right bank of the Wapsipinicon River (cen. 24, 86N-7W). It is probably as much as 25 feet thick in subsurface, but it is only 5-10 feet thick in the outcrop area, where it is exposed in the quarries at Milan and Rock Island. The Spring Grove Member is brown laminated dolomite and dolomitic limestone that weathers into thin plates. It is nonfossiliferous.

Davenport Member—The Davenport Member of the Wapsipinicon Limestone (Norton, 1894, p. 24; Stainbrook, 1935, p. 252), the uppermost member, overlies the Spring Grove Member and is overlain by the Cedar Valley Limestone. It is named for Davenport, Scott County, Iowa, near which it is exposed, but no type section has been designated. As originally used, the name "Davenport" was applied to a Lower Davenport Member and an Upper Davenport Member. However, the upper, fossiliferous member was later assigned to the Cedar Valley, and the lower member was renamed the Davenport Member (Stainbrook, 1935). The Davenport is 40-50 feet thick in subsurface, but is 30 feet thick where exposed in the quarries at Milan and Rock Island and only 18 feet thick across the river near Linwood, Iowa. It consists of pure, hard, light gray to brownish gray, fine-grained to lithographic limestone. It contains many beds of limestone breccia and, in subsurface, anhydrite and gypsum. No fossils have been found in it.

Cedar Valley Limestone

The Cedar Valley Limestone (McGee, 1891, p. 314), named for the valley of Cedar River, Iowa, overlies the Wapsipinicon Limestone and underlies the New Albany Shale Group of the Upper Devonian Series. No type section has been designated. The Cedar Valley underlies a large area in north-central and northwestern Illinois (fig. D-13). It is exposed in the Rock Island area where the Mississippi River and its tributaries have cut into the Mis-

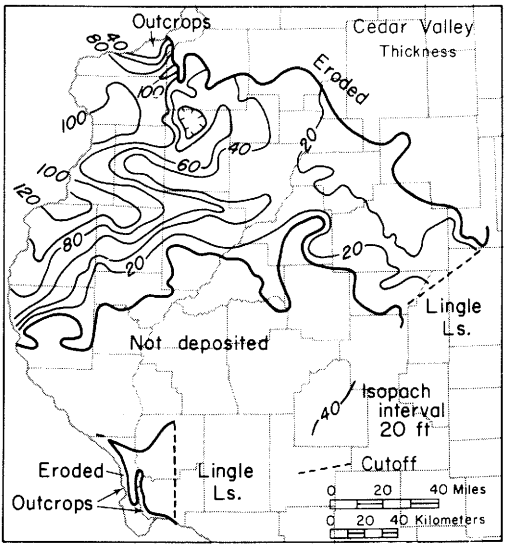

Fig. D-13—Thickness of the Cedar Valley Limestone (after James, 1968).

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sissippi River Arch (fig. D-3C). Southward, the Cedar Valley overlaps the Wapsipinicon Limestone and thins out on the flank of the Sangamon Arch, except at the northeastern and southwestern ends of the arch where the Middle Devonian seas temporarily covered the arch, and the Cedar Valley sediments are continuous with strata included in the Lingle Limestone. The strata deposited immediately south of the southwestern part of the Sangamon Arch are exposed in Calhoun and Jersey Counties, and, because they are more like the Cedar Valley than the Lingle, the name Cedar Valley has long been used in that area (Rubey, 1952). The Cedar Valley has a maximum thickness of about 130 feet in the subsurface in Hancock County, but it generally thins to the east and south (fig. D-13). It is about 60 feet thick in exposures near Rock Island. In the Calhoun and Jersey County outcrops it is 4-40 feet thick, but in most of the area it is less than 15 feet thick. The Cedar Valley is largely a highly fossiliferous, crystalline, light gray limestone (fig. D-3D), but it contains some fine-grained, argillaceous beds, thin shaly partings, and sandstone. In the northern outcrop area it is subdivided into four members—the Hoing Sandstone Member at the base, the Solon Member (pure, very fossiliferous), the Rapid Member (argillaceous, partly fossiliferous), and the Coralville Member (pure, very fossiliferous) at the top. In the area south and southwest of Rock Island, the Cedar Valley is medium-grained, detrital limestone that in Hancock and Adams Counties locally contains fine-grained, rounded quartz sand. The Solon and Rapid Members are not differentiated in that area. In the southern outcrop area the Cedar Valley grades from brown, thin-bedded, fine-grained, cherty, argillaceous, sandy limestone at the base to thick-bedded, pure, crystalline, highly fossiliferous limestone in the upper part. The Cedar Valley apparently has conformable relations to the Wapsipinicon below. Its sharp erosional contact with the New Albany above indicates a minor unconformity, although the faunal evidence indicates only a brief interruption in sedimentation. In places the Cedar Valley is overlain unconformably by Pennsylvanian strata. The fauna of the Cedar Valley is very large (Savage, 1920, 1921b; Cooper and Cloud, 1938; Rubey, 1952; Collinson and Scott, 1958b; and others) and is characterized by abundant brachiopods and corals (fig. D-6). The Cedar Valley has a large conodont fauna that indicates the Upper Devonian age of the uppermost beds in some areas. In general, the fauna correlates the Cedar Valley with Hamilton strata in New York and the upper part of the North Vernon Limestone in Indiana (Collinson et al., 1967b).

Hoing Sandstone Member—The Hoing Sandstone Member of the Cedar Valley Limestone (Hinds, 1914, p. 12), the basal member, was originally called the "Hoing oil sand" for its occurrence in a well on the Hoing Farm, near Colmar, McDonough County, the discovery well of the Colmar-Plymouth oil field (Blatchley, 1914). It was called the Hoing sand, or the "Hoing" sandstone, until formally designated the Hoing Sandstone (Howard, 1961). The Hoing is patchy in western Illinois. Although it is commonly only a few inches thick, it reaches 30 feet thick in the Colmar-Plymouth oil field. Where well developed it is a clean, friable sandstone composed of well rounded, fine to medium quartz grains. However, where it directly overlies the Silurian dolomite it commonly contains residual debris from erosion of the dolomite. At the exposure at the Monterey School, Calhoun County (NE SW 11, 12S-2W), the Hoing Member is 0-2 feet thick and consists of sandstone, shale, and chert conglomerate overlying the deeply eroded Silurian dolomite (Collinson et al., 1954). Thin lenses of sand also occur locally higher in the Cedar Valley Limestone.

Solon Member—The Solon Member of the Cedar Valley Limestone (Norton, 1897, p. 148; Keyes, 1913, p. 205-206), the basal member where the Hoing is not present, is named for Solon, Johnson County, Iowa, but no type section has been designated. In Illinois the Solon Member has a maximum thickness of about 10 feet but is absent locally. It is 6-8 feet thick where exposed in quarries southeast of Milan and on the south side of Rock Island. It is a fine- to medium-grained, grayish brown, very fossiliferous limestone with brecciated beds. It is characterized by an abundance of brachiopods, mainly *Atrypa independensis*, and corals, notably biostromes of *Hexagonaria profunda* (fig. D-6). Conodonts also are abundant and indicate correlation with the upper Hamilton in New York (Collinson et al., 1967b).

Rapid Member—The Rapid Member of the Cedar Valley Limestone (Keyes, 1912, p. 149; 1913, p. 205-206), which overlies the Solon, is named for a locality in Johnson County, Iowa, not specified by Keyes. The Rapid is the most widespread and thickest member. It is as much as 60 feet thick in the Rock Island area, but it thins to the east and south. It forms the upper 53 feet of the quarry southeast of Milan. The member consists of gray to buff, fine-grained, argillaceous, locally dolomitic limestone. Most of it is thick bedded, but the upper and lower parts are thin bedded and have shaly partings. Some beds, especially near the top and bottom, are very fossiliferous. Brachiopods and corals are most common, particularly *Atrypa, Stropheodonta, Chonetes, Spirifer, Schizophoria, Pentamerella, Hexagonaria, Favosites,* and *Heliophyllum* (Edmund and Anderson, 1967) (fig. D-6). Conodonts indicate a late Middle Devonian age (Collinson et al., 1967b).

Coralville Member—The Coralville Member of the Cedar Valley Limestone (Keyes, 1912, p. 149; 1913, p. 205-206), the uppermost member, is named for Coralville, Johnson County, Iowa, and the type section is in quarries 1 mile northeast of Coralville. The Coralville is present in Illinois only in the western part of the area of the Cedar Valley. It is as much as 25 feet thick and is unconformably overlain by the Sweetland Creek Shale of the New Albany Group. It consists of brown, medium-grained dolomite that in places is a stromatoporoid reef. The Coralville is abundantly fossiliferous; brachiopods, corals, bryozoans, and stromatoporoids are the most common fossils. The conodonts indicate that in places the boundary of the Middle and Upper Devonian Series lies within the Coralville (Collinson et al., 1967b), but most, if not all, of the Coralville in Illinois is Middle Devonian in age.

Grand Tower Limestone

The Grand Tower Limestone (Keyes, 1894, p. 30, 42), which forms the lower part of the Middle Devonian Series in Illinois south of the Sangamon Arch, is named for Grand Tower, Jackson County (fig. D-3A). The type section, not designated by Keyes, was probably intended to be, and currently is accepted as, the exposure in the Devil's Bake Oven, an isolated hill half a mile north of Grand Tower (SW SE NE 23, 10S-4W), where the formation is 157 feet thick. The Grand Tower thins out northward against the Sangamon Arch, westward against the Ozark Uplift, and southward at the southern margin of Illinois (fig. D-14). It apparently was not deposited on the Sparta Shelf, an eastward projection of the Ozarks, but it does occur in the Wittenberg Trough, along the south side of the Sparta Shelf, and it is as much as 160 feet thick there (Meents and Swann, 1965). From the

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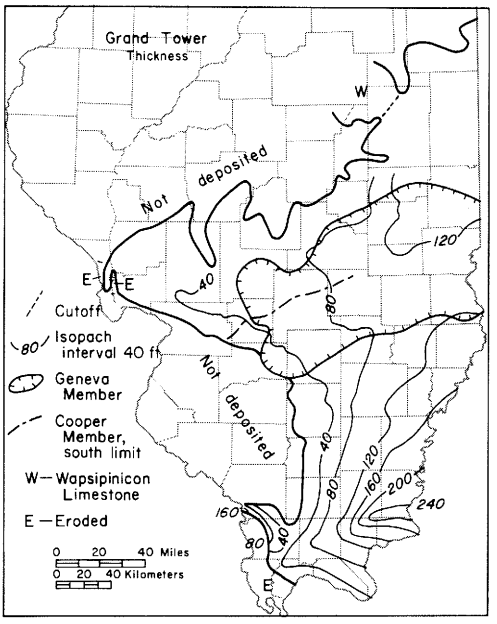

Fig. D-14—Thickness of the Grand Tower Limestone (after North, 1969).

Sparta Shelf it thickens eastward to reach a maximum of 250 feet. The Grand Tower is mostly coarse-grained, light gray, medium- to thick-bedded, cross-bedded, pure, fossiliferous limestone, but it also contains lithographic limestone, which becomes more abundant upward (North, 1969). At the base a calcareous sandstone or sandy limestone with sandstone beds is differentiated as the Dutch Creek Sandstone Member. In the central and eastern parts of the state the Grand Tower is largely dolomite, the lower part of which is brown dolomite differentiated as the Geneva Dolomite Member, and the upper part is a laminated, gray to tan, fine-grained dolomite that has not been named. In the northern part of its area, the Grand Tower is represented primarily by a light gray, lithographic limestone differentiated as the Cooper Limestone Member. A thin bentonite widely present near the top of the formation is the Tioga Bentonite Bed. The Grand Tower Limestone is abundantly fossiliferous, and a large macrofauna (S. Weller, 1897; Savage, 1920; Grimmer, 1968) and conodont fauna (Orr, 1964; Collinson et al., 1962) have been described. The base of the Grand Tower is a major unconformity—the base of the Kaskaskia Sequence—and in the northern part of its area the Grand Tower sharply overlaps the entire Lower Devonian Series and rests on the Silurian System. The Grand Tower correlates with all but the upper part of the Wapsipinicon Limestone in northern Illinois and Iowa, with the Geneva Dolomite and Jeffersonville Limestone in Indiana, and with the Onondaga in New York (Collinson et al., 1967a).

Dutch Creek Sandstone Member—The Dutch Creek Sandstone Member of the Grand Tower Limestone (Savage, 1920, p. 170-171, 175; Meents and Swann, 1965, p. 6) is named for Dutch Creek, a tributary of Clear Creek in central Union County, but no type section has been designated. An exposure along a secondary road 1.1 miles northwest of its junction with Illinois Highway 127 (W1/2 NW 27, 11S-2W), about 2 miles north of Dutch Creek, has been used as a reference section (Meents and Swann, 1965). There the gradation of the member to the overlying part of the Grand Tower and the unconformable contact on the underlying Clear Creek can be seen. The Dutch Creek was originally called the Oriskany Sandstone by Worthen (1866). Because of the discontinuous nature of the sandstone and its lateral and vertical gradation to sandy dolomite or limestone, Meents and Swann (1965) restricted the Dutch Creek to localities where beds of sandstone are present and classified it as a member of the Grand Tower Limestone. The Dutch Creek is exposed at many localities in Union, Alexander, and Jackson Counties (Weller and Ekblaw, 1940), and it is present in subsurface at many places throughout the area of the Grand Tower Limestone. However, the principal occurrences are in the outcrop area and in Wayne and adjacent counties of eastern Illinois (Collinson et al., 1967a). The Dutch Creek is as much as 30 feet thick in the outcrop area but is more commonly less than 15 feet, in many areas only a foot or two thick. It is a fossiliferous, calcareous sandstone composed of well rounded, well sorted, medium to fine quartz grains. In many areas the sandstone is interbedded with sandy limestone. The abundant fauna is principally brachiopods and corals. The fossil mold of the coral *Pleurodictyum problematicum* is an especially distinctive indicator of the member. Prominent brachiopods include *Amphigenia curta, Rhipidomella* cf. *R. penelope,* and *Protoleptostrophia perplana.*

Geneva Dolomite Member—The Geneva Dolomite Member of the Grand Tower Limestone (Collett, 1882, p. 63, 81-82), named for Geneva, Shelby County, Indiana, is continuous from its type locality westward into eastern and central Illinois, where it is as much as 50 feet thick but is not exposed. In Illinois it is the basal member of the Grand Tower Limestone, wherever the patchy Dutch Creek Sandstone Member is not present, but in Indiana it is classified as a formation (Shaver et al., 1970). The Geneva is dark brown, crystalline, porous, pure dolomite. It contains finely disseminated organic material and produces oil in several fields (Schwalb, 1955). In some localities floating grains of rounded, coarse to fine quartz sand occur in the Geneva, particularly in its lower part. The Geneva is essentially nonfossiliferous but contains a few chitinozoans and scolecodonts (Collinson et al., 1967a). The member grades laterally into the lower part of the Grand Tower (Meents and Swann, 1965; North, 1969).

Cooper Limestone Member—The Cooper Limestone Member of the Grand Tower Limestone (Swallow, 1855, p. 108, 196) is named for Cooper County, Missouri, where it is classified as a facies of the Calloway Limestone (Koenig, 1961). In Illinois it is as much as 50 feet thick in a belt 60-90 miles wide that extends eastward across the state south of the Sangamon Arch (fig. D-14). It is exposed only in Calhoun County (Meents and Swann, 1965), where it previously was considered part of the Cedar Valley Limestone. It is sparsely fossiliferous, gray, dense, lithographic, pure limestone, but it contains scattered grains of quartz sand in some localities. On its northern margin it is overlapped by the Lingle Limestone, and on the south it grades laterally to the light-colored dolomite that overlies the Geneva Dolomite Member. It is similar to the Wapsipinicon Limestone north of the Sangamon Arch and probably is continuous with it west of Illinois.

Tioga Bentonite Bed—The Tioga Bentonite Bed of the Grand Tower Limestone (Ebright et al., 1949, p. 10), named for Tioga County, Pennsylvania, where it was first discovered in drill cuttings from the Tioga gas field, is widely present in Illinois 10-30 feet below the top of the formation, but no outcrops have been found (Meents and Swann, 1965), except re-

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cently in a quarry at Tuscola in Douglas County. Although possibly as much as 6-8 inches thick in southeastern Illinois, it most commonly is only 1-2 inches thick. Its occurrence is patchy, but it has been observed in more than 100 wells and can be recognized on sonic logs even in areas where it is only a quarter of an inch thick. It is greenish to brownish gray shale that contains biotite flakes and an abundance of mixed-layer clay minerals that distinguish it from the normal shales.

Lingle Formation

The Lingle Formation (Savage, 1920, p. 171, 176; Weller, 1944a, p. 95-96; North, 1969, p. 14-22) is named for Lingle Creek in southern Union County. The type section is a poorly exposed outcrop on a branch of Lingle Creek (SE SW SW 26, 13S-2W). A more complete exposure occurs 3.25 miles west of Cobden, Union County (NW NE 34, 11S-2W). Because the sequence is complex and the exposures poor and widely scattered (Weller, 1940), the Lingle has been variously interpreted (fig. D-5). Savage (1920) differentiated a shale at the base—the Misenheimer Shale—as a separate formation, but Weller (1944a) included the shale in the Lingle and abandoned the name "Misenheimer." Grimmer (1968) and North (1969) related the type Misenheimer to a shale well above the base of the Lingle and reinstated Misenheimer but made it a member of the Lingle. The Lingle occurs throughout a large area south of the Sangamon Arch, generally overlapping the Grand Tower (fig. D-15), and it has a maximum thickness of about 110 feet. The Lingle Formation is an interval of mixed limestone and shale. It is more argillaceous, more shaly, darker colored, and finer grained than the Grand Tower below, and less silty and dolomitic than the Alto Formation above. North (1969) subdivided the Lingle into the Howardton Limestone Member (argillaceous, shaly) at the base, the Tripp Limestone Member (argillaceous, silty, cherty), the Misenheimer Shale Member, and the Walnut Grove Limestone Member (cherty, very silty, glauconitic) at the top. The Walnut Grove is characterized by the Rendleman Oolite Bed near its base. Of the four members, the Misenheimer and Walnut Grove occur only near the outcrop area in southwestern Illinois (fig. D-15). North interpreted these two members and the more extensive Tripp Member below as grading laterally eastward into the New Albany Shale Group, with the Tripp Member essentially equivalent to the Blocher Shale. However, the relations are not clearly demonstrable, and faunal evidence suggests that all three members plus the overlying Alto and Sylamore Formations may be equivalent to the Blocher. Some of the Lingle strata are very fossiliferous, and both macrofossils (Savage, 1920; Grimmer, 1968) and conodont faunas (Orr, 1964) have been described. Characteristic fossils include *Microcyclus discus* (fig. D-6), *Devonochonetes coronatus*, and *Mucrospirifer mucronatus*. They relate the Lingle to the upper half of the Hamilton in New York (Collinson et al., 1967a).

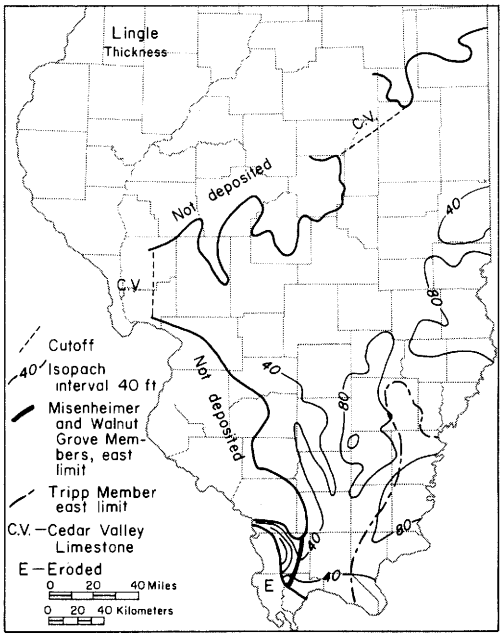

Fig. D-15—Thickness of the Lingle Formation (compiled from North, 1969).

Howardton Limestone Member—The Howardton Limestone Member of the Lingle Formation (North, 1969, p. 22-25), the basal member, is named for Howardton, Jackson County, 2 miles east of the type section, which is in a quarry in the Backbone ridge north of Grand Tower (NE NE SE 23, 10S-4W), where it is 33 feet thick. The Howardton extends throughout much of the area of the Lingle, but it is overlapped by the Tripp Member in the northern part. It is as much as 110 feet thick in southeastern Illinois and generally thins northward and westward. It is gray, fine-grained, slightly silty, argillaceous limestone, most of which has thin, shaly partings. The basal few feet is characterized by a small, button-shaped coral, *Microcyclus*, and the top by a thin intraformational microbreccia with light-colored limestone fragments in a dark matrix. The base of the Howardton is the original Grand Tower–Lingle contact of Savage (1920).

Tripp Limestone Member—The Tripp Limestone Member of the Lingle Formation (North, 1969, p. 25-28) overlies the Howardton Limestone Member and is named for Tripp School, 200 yards northwest of the type section, an outcrop on the south side of Kratzinger Hollow, 1 mile northwest of Jonesboro, Union County (N1/2 NE NW 23, 12S-2W). The upper 17 feet of the member is exposed at the type section and 22-foot thicknesses are found in near-by wells. The Tripp is widespread and reaches 80 feet thick in south-central Illinois, although it is absent in southeastern Illinois (fig. D-15). The member contains limestone, dolomite, chert, siltstone, and shale. It is largely cherty, argillaceous, silty limestone, but beds of shale are abundant near its base and top. About half of the member is dolomite on the margin of the Sparta Shelf. Glauconite, quartz sand, oolite, and beds of phosphate pellets are locally abundant in the northern and western parts of the member. Crinoids, brachiopods, and corals are abundant in some beds.

Misenheimer Shale Member—The Misenheimer Shale Member of the Lingle Formation (Savage, 1920, p. 169-178; Grimmer, 1968, p. 407-415) overlies the Tripp Member and is named for Misenheimer Creek in Union County. Grimmer (1968) described the type section as an exposure 3 miles west of Mill Creek (SW NW 35, 13S-2W) in the south branch of a tributary of Cooper Creek. He designated an exposure on the south bank of Green Creek, 33 feet southwest of Illinois Highway 146, 1.75 miles northwest of Jonesboro (NE NW 23, 12S-2W), where the shale is about 25 feet thick, as a

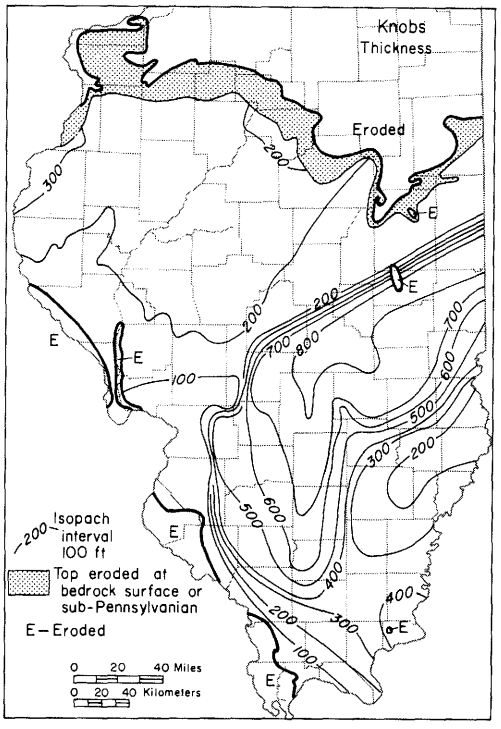

Fig. D-16—Thickness of the Knobs Megagroup.

principal reference section. Both Grimmer (1968) and North (1969) placed the type Misenheimer well above the base of the Lingle (where Savage had placed it), but Grimmer assigned the strata below the Misenheimer to the St. Laurent Formation of Missouri, whereas North subdivided them into the Howardton and Tripp Members of the Lingle. The Misenheimer occurs only in and near the outcrop region in Jackson, Union, and Alexander Counties (fig. D-15). It consists of as much as 50 feet of dark gray to gray-brown, calcareous, spore-bearing shale that contains a few macrofossils.

Walnut Grove Limestone Member—The Walnut Grove Limestone Member of the Lingle Formation (North, 1969, p. 29-30), the uppermost member, is named for Walnut Grove Church, Union County, 1 mile southeast of the type section, an outcrop near the head of a small tributary of Clear Creek (SE SE SW 22, 11S-2W), where the member is 29 feet thick. The Walnut Grove occurs only in and near the outcrop area in Jackson, Union, and Alexander Counties (fig. D-15), and its maximum thickness is about 50 feet. It is cherty, very silty, glauconitic, spore-bearing, fine-grained, fossiliferous limestone locally interbedded with very dark brown, calcareous shale. The Rendleman Oolite Bed near the base is a distinctive key bed. Fossils include crinoids, corals, brachiopods, and sporangites.

Rendleman Oolite Bed—The Rendleman Oolite Bed (North, 1969, p. 30-31) is named for Rendleman School, 1 mile east of the type section (part of the Walnut Grove type section), where it is 1.5 feet thick and occurs 4 feet above the base of the Walnut Grove Member. It is a persistent, distinctive bed. The ooliths, which are poorly sorted and have a maximum diameter of 1 mm, occur in a fine-grained limestone matrix.

Alto Formation

The Alto Formation (Savage, 1920, p. 168-178), which overlies the Lingle Formation in southwestern Illinois, is named for Alto Township, Union County, where the type section is along a creek (cen. N½ NE NE 34, 11S-2W). The Alto Formation is in essentially the same area as the Misenheimer and Walnut Grove Members of the Lingle Formation (fig. D-15). It is as much as 100 feet thick. The lower part consists of dolomitic and calcareous shale and siltstone; the shale resembles the Misenheimer. The upper part is silty, cherty, gray to dark gray dolomite that grades from coarsely crystalline at the top to finely crystalline at the base. White, gray, and black chert nodules are abundant. On the basis of its few macrofossils (*Devonochonetes* sp., *"Reticularia" laevis* and *Mucrospirifer mucronatus)*, Savage assigned the Alto to the Upper Devonian, but the conodont fauna (Orr, 1964), which includes *Polygnathus cristata*, relates the Alto to the uppermost Middle Devonian (Collinson et al., 1967a). Although Savage (1920) and Workman and Gillette (1956) believed the Alto extended under the oldest part of the New Albany Shale, Weller (1940) and North (1969) interpreted both the Lingle and Alto as grading laterally into the New Albany. North correlated the Alto with the upper part of the Sweetland Creek Shale in the deep part of the Illinois Basin, but Collinson et al. (1967a) interpreted the uppermost conodont faunas of the Blocher Shale, below the Sweetland Creek, as Upper Devonian in age, in which case both the Alto and the part of the Lingle Formation above the Howardton Member are probably equivalent to the Blocher.

KNOBS MEGAGROUP

The Knobs Megagroup (Swann and Willman, 1961, p. 480-481) consists of the Devonian and Mississippian clastic rocks that overlie the Hunton Limestone Megagroup and underlie the Mammoth Cave Limestone Megagroup throughout the Illinois Basin (fig. 14). It is named for the Knobs, an area of highly dissected Devonian and Mississippian shales that partially surrounds the Bluegrass Region and lies in front of the Highland Rim Escarpment of Kentucky and Indiana. In much of the Illinois Basin, the Knobs Megagroup includes shale, siltstone, and sandstone from the base of the Blocher Shale of the New Albany Group to the top of the Borden Siltstone; but on the flanks of the basin, where shallow-water carbonates were deposited, the stratigraphic interval is restricted at both top and bottom. The Knobs has a maximum thickness of about 1000 feet, but it is much thinner in western Illinois and it thins out in places (fig. D-16). The Knobs is mainly black shale in most of the basin, but in central Illinois it is dominated by the great volume of gray siltstone and silty shale in the Borden delta.

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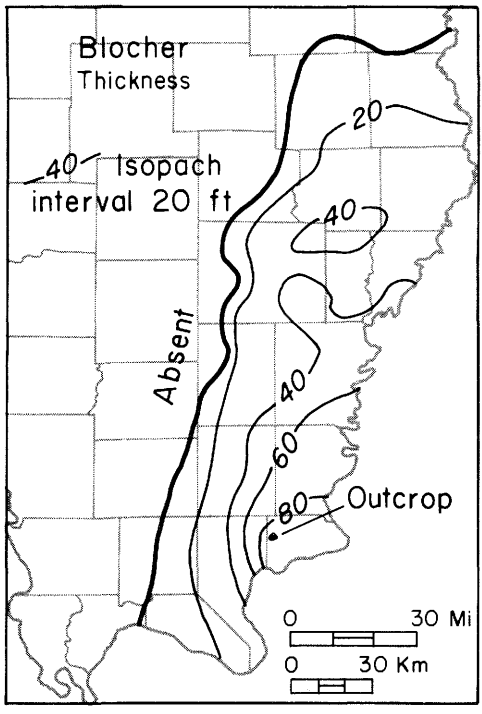

Fig. D-17—Thickness of the Blocher Shale (after North, 1969).

New Albany Shale Group

The New Albany Shale Group (Borden, 1874, p. 158) is named for New Albany, Floyd County, Indiana, where it is largely black shale that overlies the Sellersburg Limestone (Lingle Formation in Illinois) and is overlain by the Rockford Limestone (Chouteau Limestone in Illinois). The unit, originally called the New Albany black slate, is classified as a formation in the type region (Shaver et al., 1970). It consists of the essentially continuous body of Middle and Upper Devonian and Kinderhookian (lower Mississippian) black, gray, and green shale. It includes the Blocher, Sweetland Creek, Grassy Creek, Saverton, and Hannibal Shales (figs. D-2, M-3). It has a maximum thickness of about 400 feet and is exposed in western and southern Illinois. Lineback (1968a) differentiated the New Albany in Indiana into the Blocher Member (calcareous to dolomitic, pyritic shale rich in organic matter) at the base, the Selmier Member (greenish gray mudstone), the Morgan Trail Member (black, fissile, siliceous, pyritic shale), the Camp Run Member (alternating greenish gray mudstone and black shale), and the Clegg Creek Member (black, silty or dolomitic, pyritic shale) at the top. These units have been recognized in subsurface in eastern Illinois, but, except for the Blocher, they have not been traced widely. Black shale containing Devonian sharks' teeth has been found in crevices in the Silurian dolomite in the Chicago area (Bretz, 1939), indicating that the New Albany formerly extended across the Kankakee Arch. The name "Mountain Glen Shale," formerly used for the New Albany in southwestern Illinois (Savage, 1920; Weller, 1940), was replaced by "New Albany" (Workman and Gillette, 1956). The New Albany has now been extended to include comparable shales in western Illinois, and the term "Champ Clark Group" used by Workman and Gillette (1956) is no longer needed for the Upper Devonian formations. The New Albany, particularly the dark shale, contains an abundance of brown resinous spores, *Tasmanites*, which are called *Sporangites* in many reports. Conodonts are common, but normal marine macrofossils are scarce, except in a few limestone beds near the base and top. The New Albany is correlated with the Antrim and Ellsworth Shales of Michigan and the Chattanooga of Tennessee (Collinson et al., 1967a).

Blocher Shale

The Blocher Shale (Campbell, 1946, p. 840; Lineback, 1968a, p. 1295-1298), the basal formation in the New Albany Group, is named for Blocher, Scott County, Indiana, and the type section is 1.5 miles southeast of Blocher on Highway 50, 1 mile east of the Baltimore and Ohio Railroad. It originally included only the lower 8-10 feet of black shale in the type area, but Lineback (1968a) extended it upward about 6 feet to the base of the *Spathiocaris* Zone, which is a gray shale more easily traced, and that position is now accepted. The Blocher Shale extends from the type locality into eastern Illinois (Workman and Gillette, 1956), where it is as much as 80 feet thick, but it thins out in the central part of the state (fig. D-17). North (1969) correlated it with the Tripp Member of the Lingle Formation, but the conodont fauna suggests that it is equivalent also to higher parts of the Lingle, the Alto Formation, and the earliest Upper Devonian strata (Collinson et al., 1967a).

UPPER DEVONIAN SERIES

The term "Upper Devonian Series" has been in general use in Illinois since 1925 (Bassett), prior to which the New York terms "Senecan" and "Chautauquan" had been used in addition to Upper Devonian (figs. D-4, D-5). Upper Devonian sediments underlie

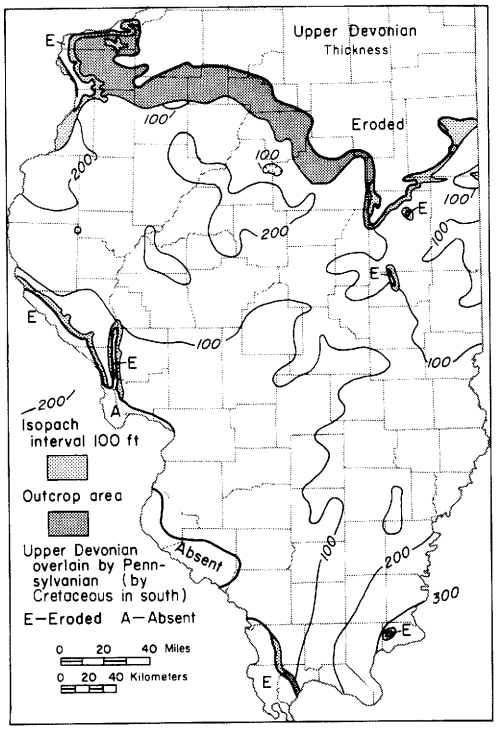

Fig. D-18—Thickness of the Upper Devonian Series.

most of southern and western Illinois. They completely overlap the then subsiding Sangamon Arch, on which Middle Devonian sediments had not been deposited (fig. D-18). They are more than 300 feet thick in Hardin County and as much as 275 feet thick in Mercer County, but elsewhere they are generally less than 200 feet.

In the Devonian type region in England, Upper Devonian applies to the Frasnian (lower) and Famenian (upper) Stages. Conodont studies by Collinson (1967) placed the base of the Frasnian at the base of the Sylamore Sandstone in central and western Illinois, at the top of the Alto Formation in southwestern Illinois, and a few feet below the top of the Blocher Shale in southeastern Illinois. Savage (1920) included the Alto and younger Devonian rocks in the Upper Devonian, as did Weller (1940), Cooper et al. (1942), Cooper (1944), and Orr (1964). However, Weller (1944b), on sedimentational evidence, and Collinson et al. (1967a), on the basis of conodont faunas, tentatively placed the Alto in the Middle Devonian, which is the current practice. The position of the top of the Upper Devonian Series was long debated, as described under the discussion of the Devonian System, but the top of the Louisiana Limestone (or a few feet above it in the Hannibal Shale) in western Illinois, the top of the Grassy Creek Shale in southwestern Illinois, and a position near the top of the New Albany Group in eastern Illinois are now generally accepted as the top of the Upper Devonian.

In the major part of the Illinois Basin the Upper Devonian Series consists largely of the black and gray shale of the New Albany Group, but on the flanks of the Ozark Uplift and on the Mississippi River Arch it also includes limestone, sandstone, and siltstone (fig. D-19). The Louisiana Limestone contains a large variety of macrofossils (Williams, 1943), but the shales generally contain few. Zonation in the series, therefore, is based largely on the conodonts, which, along with abundant *Tasmanites*, are common in the shale formations.

The Upper Devonian rocks are generally conformable on the Middle Devonian strata, but in western and southwestern Illinois a minor unconformity occurs at the base of the Sylamore Sandstone, of the Sweetland Creek Shale, or of the Grassy Creek Shale.

Sylamore Sandstone

The Sylamore Sandstone (Penrose, 1891b, p. 113, 114), the basal Upper Devonian formation in central and western Illinois (Workman and Gillette, 1956), is named for Sylamore Creek, Stone County, central northern Arkansas. It is widely but sporadically present in Illinois, is rarely more than 5 feet thick, and generally varies from a few inches to a mere thin layer of sand embedded in the base of the Sweetland Creek Shale or the Grassy Creek

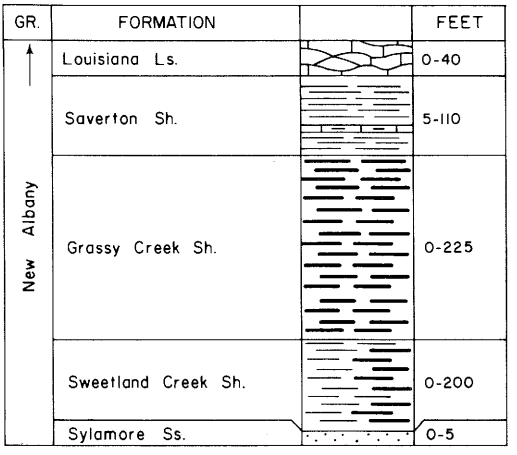

Fig. D-19—Columnar section of the Upper Devonian Series.

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Shale. It consists of well rounded, fine to medium, quartz sand grains, like those in the older Paleozoic sandstones. It varies from friable sandstone to grains cemented with pyrite, calcite, or dolomite. In the western part of Illinois, it rests unconformably on the Middle Devonian Cedar Valley Formation or Wapsipinicon Limestone, on Silurian dolomite, or locally on Ordovician limestone. In eastern Illinois it probably is equivalent to thin sandy beds in the upper part of the Blocher Shale and the lower part of the Sweetland Creek Shale. It is more or less continuous through Missouri, north and west of the Ozark Uplift, to the type locality, and it is correlated with the Hardin Sandstone east of the Ozarks in Kentucky and Tennessee.

Sweetland Creek Shale

The Sweetland Creek Shale (Udden, 1899, p. 65-78; Collinson et al., 1967a, p. 960-961) is named for Sweetland Creek, Muscatine County, Iowa, and the type section is an exposure along that creek, 4 miles northeast of Muscatine (cen. N1/2 27, 77N-1W), where it is 14 feet thick and is overlain by 6 feet of Grassy Creek Shale. As originally defined, the Sweetland Creek included all the Devonian shale at the type locality. It therefore was essentially equivalent to Grassy Creek Shale (Workman and Gillette, 1956). As now defined (Collinson et al., 1967a), the Sweetland Creek Shale is restricted to the dominantly gray and green shale that underlies the black Grassy Creek and extends throughout much of the Illinois Basin (Collinson, 1961; North, 1969). The Sweetland Creek Shale is only a few inches thick in southwestern Illinois, but reaches 50 feet thick in northwestern Illinois and 200 feet in southeastern Illinois, where it appears to be essentially continuous with the Selmier Member of the New Albany Shale in Indiana. Although dominantly gray in the western part of Illinois, the Sweetland Creek contains some dark gray to black beds. In the central and eastern parts of Illinois, it is generally dark and not readily separated in well samples from the Blocher Shale below and the Grassy Creek Shale above. However, in that area it is easily identified on geophysical logs, which show persistent variations that permit key beds to be widely traced within the formation (North, 1969). Macrofossils are scarce, but the conodonts have been studied in considerable detail and indicate ages ranging from early to middle Upper Devonian (Klapper and Furnish, 1962; Collinson et al., 1962).

Grassy Creek Shale

The Grassy Creek Shale (Keyes, 1898, p. 59-63; 1912, p. 149; Collinson et al., 1967a, p. 961) is named for Grassy Creek, a stream in Pike County, Missouri. It originally included all the black, gray, and green shale below the Louisiana Limestone and above the Cedar Valley or older formations, but in 1912 Keyes differentiated the upper gray shale as the Saverton Shale, and Collinson et al. (1967a) restricted the Grassy Creek further by assigning the lower gray and green shale to the Sweetland Creek Shale. No type section was designated and some of the sections referred to by Keyes include Maquoketa Shale (Weller, 1936). Mehl (1960) named a section in the Mississippi bluffs several hundred feet north of the Champ Clark Bridge at Louisiana, Pike County, Missouri, as the type locality (SW NW NE 18, 54N-1W). In Illinois the Grassy Creek was at first restricted to the western part of the state, but in 1956 Workman and Gillette extended it to central and southwestern Illinois in place of the Mountain Glen Shale, a name long used in that area (Savage, 1920; Weller, 1940). Still later it was extended to eastern Illinois (Collinson et al., 1967a; North, 1969). The Grassy Creek occurs in nearly all the area in which Upper Devonian strata appear. It is well exposed in Pike, Calhoun, and Jersey Counties in western Illinois and in Union County and locally in Hardin County in southern Illinois (fig. D-18). In subsurface its high resistivity on electric logs serves to differentiate it from the Saverton Shale above and from the Sweetland Creek Shale below.

Saverton Shale

The Saverton Shale (Keyes, 1912, p. 149), a gray shale overlying the black Grassy Creek Shale and underlying the Louisiana Limestone, is named for Saverton, Ralls County, Missouri. No type section was designated by Keyes, but Mehl (1960) named an exposure in the Mississippi River bluff at Louisiana, Pike County, Missouri, as the type section, the same exposure named as the type for the Grassy Creek Shale. Because the Louisiana Limestone is limited to a small area in Illinois (fig. D-20), the Saverton is more commonly overlain by the Mississippian "Glen Park" or Hannibal Formations. The Saverton is well exposed in western Illinois in and near the Mississippi and Illinois River bluffs in Pike, Calhoun, and Jersey Counties. It is 5-110 feet thick in western Illinois, but is generally less than 10 feet thick where overlain by the Louisiana Limestone. In eastern and southern Illinois, it is commonly not differentiated and is included in the Hannibal Formation. The Saverton is a bluish to greenish gray, silty shale that contains both thin sandy beds and calcareous beds and grades to calcareous siltstone in the upper part. It grades into the overlying Louisiana Limestone, the lower part of which in places grades laterally into the uppermost Saverton. The few macrofossils present in the Saverton include *Spirifer marionensis* and *Orbinaria puxidata*. Conodonts are abundant, especially in the siltstone at the top, and *Palmatolepis minuta, P. gracilis, P. glabra,* and *P. quadratinodosa marginifera* indicate an Upper Devonian age (Scott and Collinson, 1961; Collinson et al., 1967a).

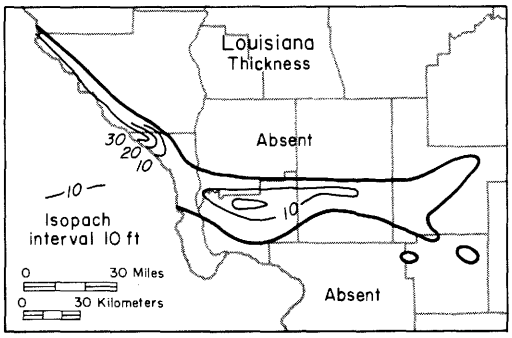

Fig. D-20—Thickness of the Louisiana Limestone.

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Louisiana Limestone

The Louisiana Limestone (Keyes, 1892, p. 289) is named for Louisiana, Pike County, Missouri, where it is well exposed in the Mississippi River bluffs. No type section was designated, but a prominent exposure on the south side of Louisiana, where it is underlain by the Saverton Shale and overlain by the Hannibal Shale, is commonly accepted as the type section. The Louisiana occurs in an area 10-25 miles wide extending eastward from the Mississippi River into west-central Illinois (fig. D-20). It is a lenticular body as much as 40 feet, but more commonly 10-20 feet thick. It is exposed along the Mississippi and Illinois Valleys in Pike, Calhoun, and Jersey Counties. The formation is light gray to buff, lithographic limestone with thin shale partings and dolomite interbeds. The limestone is very pure and is probably a chemical precipitate. It contains a large variety of macrofossils dominated by small brachiopods, particularly *Schuchertella, Chonetes, Cyrtina,* and *Ambocoelia*, but microcrinoids, bryozoans, and ostracodes also are common (Williams, 1943). The Devonian or Mississippian age of the Louisiana Limestone and its relation to the similar McCraney Limestone, which is exposed in Illinois essentially within sight of the type Louisiana in Missouri, were major controversies for many years (Collinson, 1961; Scott and Collinson, 1961). Studies of the conodont faunas demonstrated that the Louisiana was of Upper Devonian age and the McCraney was of Mississippian age, resolving both problems and substantiating field tracing of the units in the Mississippi River bluffs in Illinois. The Louisiana is unconformably overlain by the "Glen Park" Formation, but, as the faunas indicate only a short interruption in sedimentation, the unconformity appears to be related to minor uplift on the flank of the Lincoln Anticline.

MISSISSIPPIAN SYSTEM

Elwood Atherton, Charles Collinson, and Jerry A. Lineback

The Mississippian System (Winchell, 1869; Williams, 1891), which overlies the Devonian System and underlies the Pennsylvanian System, is named from exposures in the bluffs of the Mississippi River in Iowa, Illinois, and Missouri (fig. M-1). In earlier reports these strata were called "Carboniferous limestone," or "Lower Carboniferous" (Worthen, 1866) to differentiate them from the upper Carboniferous or "Coal Measures," that are now called the Pennsylvanian System. "Carboniferous" continues to be used in other countries, and the U.S. Geological Survey recognizes the Mississippian and Pennsylvanian Systems as the Carboniferous Systems (Keroher, 1970).

The Mississippian System is well developed in the Illinois Basin east of the type exposures, and it covers most of Illinois south of a line running roughly from Monmouth, Warren County, to Hoopeston, Vermilion County (fig. M-2). It crops out in a belt around the western and southern rim of the Illinois Basin from Henderson County on the west through Hardin County on the southeast, but on the north side of the basin it is overlapped by Pennsylvanian strata and does not crop out. In northeastern Illinois it is at the top of the bedrock but is covered by glacial drift. The system is over 3200 feet thick in southern Illinois but thins northward because of truncation and because of depositional thinning of many of its component formations (fig. M-3).

Although limestone is the dominant rock type in the Mississippian System, a large siltstone delta is present in central and eastern Illinois, and shale and sandstone formations are prominent in parts of the system. The lowest part of the system consists mainly of shale and siltstone and is included in the upper part of the Knobs Megagroup (fig. 14). Limestone, which makes up most of the middle part of the system, is referred to the Mammoth Cave Limestone Megagroup. The alternating limestone-shale and sandstone-shale formations of the upper part compose the Pope Megagroup. Three major varieties of limestone occur in the system—(1) very fine-grained or lithographic, dense, medium-gray, mostly cherty limestone; (2) medium- to coarse-grained, light gray, crinoidal or bryozoan limestone, part of it very cherty; and (3) medium- to coarse-grained, light gray to white, oolitic limestone. The shales are mainly dark greenish gray, but thin beds of red and green shale are extensive. The sandstones are very fine to fine grained and light gray or light greenish gray. The siltstones are light greenish gray.

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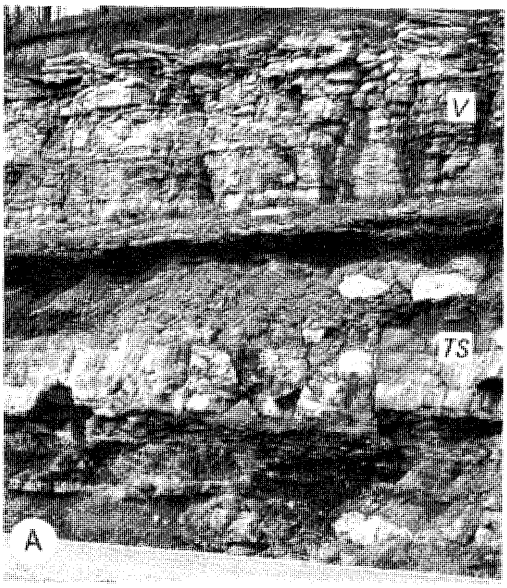

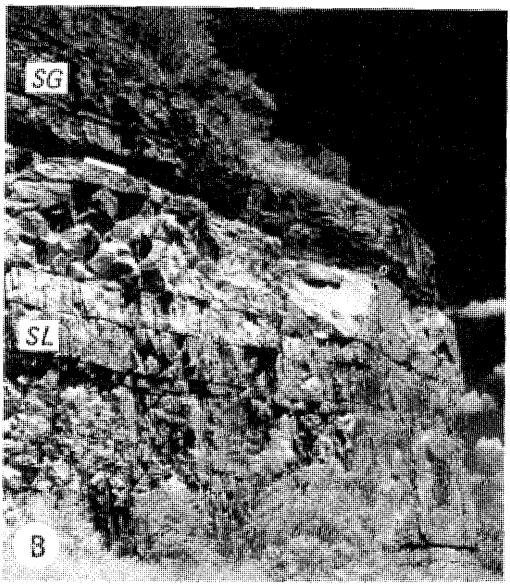

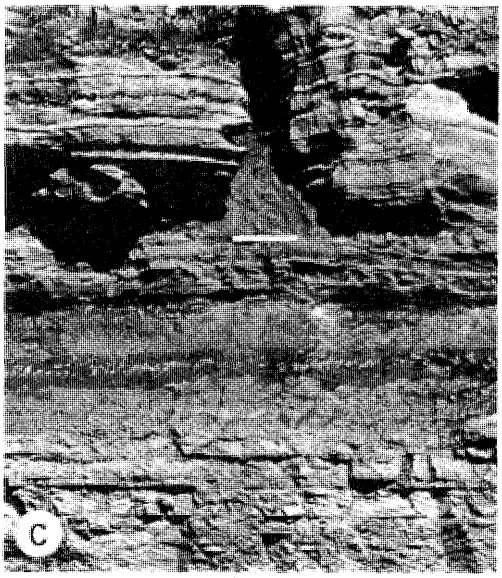

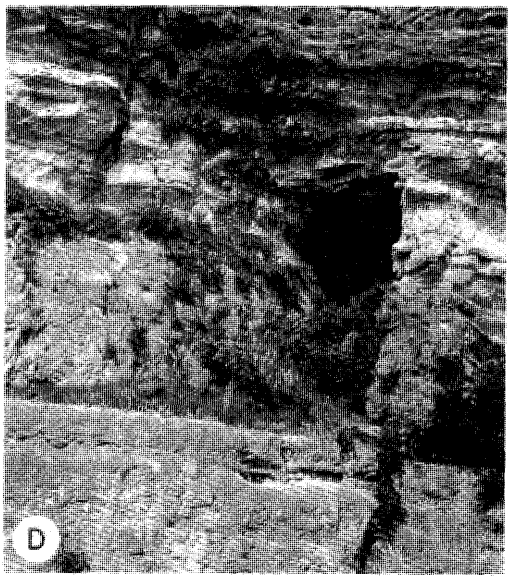

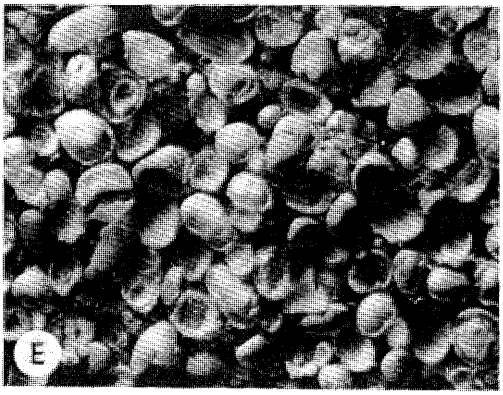

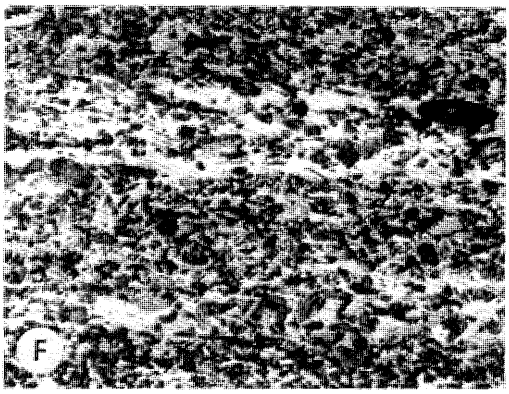

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Much of the limestone and shale is exceedingly fossiliferous (fig. M-4). Brachiopods are particularly numerous, with spiriferids and productids most abundant. The Burlington Limestone, and, to a lesser extent, the Keokuk Limestone consist mainly of crinoidal debris and are zoned on the basis of crinoid genera and species. Fenestrate bryozoan debris, mostly of *Archimedes*, is abundant in some beds in the Warsaw, Salem, and Ullin Formations. Blastoids, particularly pentremitids, are characteristic of some limestone units in the Chesterian Series, as are *Schizoblastus* and *Metablastus* in the Valmeyeran and *Orophocrinus* and *Globocrinus* in the Kinderhookian. Shark teeth are common in some beds of the Burlington and Keokuk Limestones, and Foraminifera, particularly endothyrids, are abundant in the Salem Limestone. Conodonts are common to abundant throughout the Mississippian and provide a basis for biostratigraphic zonation (Collinson et al., 1962). Thin beds of coal occur in the Chesterian (late Mississippian) sandstones, and the megaspores in the coals indicate dominance of a lepidocarp-lepidodendrid flora (Winslow, 1959).

Three series, all with type localities in Illinois, are differentiated at time planes established by differences in faunas. The Kinderhookian Series, at the base, is dominantly shale and is relatively thin. The Valmeyeran, in the middle, is relatively thick and is dominantly limestone and siltstone. The Chesterian, at the top, is also thick and consists of alternations of limestone-shale and sandstone-shale formations.

The main sources of the siliceous clastic sediments in the Mississippian System appear to have been northeast of Illinois, although some sediment came from the northwest and minor quantities from the Ozark region. The delta represented by the Borden Siltstone grew southeastward into the Illinois Basin. The Chesterian sands were carried into the basin by the Michigan River, which also came from the northeast (fig. M-31). The sands are moderately angular and lack the high degree of rounding characteristic of older sandstones, which were probably beneath the seas or buried by younger formations during Mississippian time.

The boundary between the Devonian and Mississippian Systems occurs in the New Albany Shale Group. Its exact position has long been controversial, but it is now widely accepted, on the basis of conodont evolution, as probably occurring near the base of the Hannibal Shale, above the Louisiana Limestone, and probably in or below the highly variable "Glen Park" Formation (Collinson et al., 1971). The Louisiana Limestone is present in only a small area, and the Devonian-Mississippian boundary commonly occurs within the shale sequence. The contact is generally conformable, but in western Illinois a minor unconformity marks the contact of the "Glen Park" Formation on the Louisiana Limestone.

The contact between the Mississippian and Pennsylvanian Systems is one of the major unconformities in Illinois and is the boundary between the Absaroka Sequence and the Kaskaskia Sequence (fig. 14). Strata in the Illinois Basin were warped, faulted, and truncated by erosion at the close of the Mississippian Period. Valleys as much as 450 feet deep were cut into Chesterian strata and subsequently were filled with Pennsylvanian sediments (Bristol and Howard, 1971). The Pennsylvanian rocks progressively overlap older Mississippian formations northward and westward from the southern part of the Illinois Basin. Around the margin of the basin the Pennsylvanian rocks overlap older systems.

KINDERHOOKIAN SERIES

The Kinderhookian Series (Meek and Worthen, 1861b, p. 288; Collinson, 1961, p. 102) is named for the village of Kinderhook, northwestern Pike County, where the type section consists of exposures in the Mississippi River bluffs. There Kinderhookian strata overlie the Devonian Saverton Shale, and the McCraney Limestone is at the top of the section. The younger Kinderhookian strata, which lie be-

Fig. M-1—Exposures and textures of Mississippian rocks.

A—Vienna Limestone overlying the sheet facies of the Tar Springs Sandstone in roadcut (about 40 feet high) of Illinois Highway 3 on southeast side of Chester, Randolph County.

B—Massive Ste. Genevieve Limestone overlying well bedded St. Louis Limestone in Mississippi River bluff (about 60 feet high) on northwest side of Alton, Madison County.

C—Kinkaid Limestone showing clay-filled solution cavity in the Goreville Member at the top overlying a layer of shale with a red bed (black) at the top of the Cave Hill Member; in Southern Illinois Limestone Company quarry north of Buncombe, Johnson County.

D—Well bedded St. Louis Limestone with a cave in its base overlying massive Salem Limestone in Mississippi River bluff a mile northwest of Prairie du Rocher, Randolph County.

E—Oolitic texture of the Ste. Genevieve Limestone at Anna, Union County (×10).

F—Granular texture of the Ullin Limestone along Mill Creek, south of Anna, Union County (×1).

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tween the Burlington Limestone (above) and the McCraney (below), are exposed near by (Collinson, 1961). The Kinderhookian extends throughout most of western, central, and southern Illinois (fig. M-5) but is well exposed only along the Mississippi and Illinois Valleys in western Illinois. Small exposures occur around Hicks Dome in Hardin County

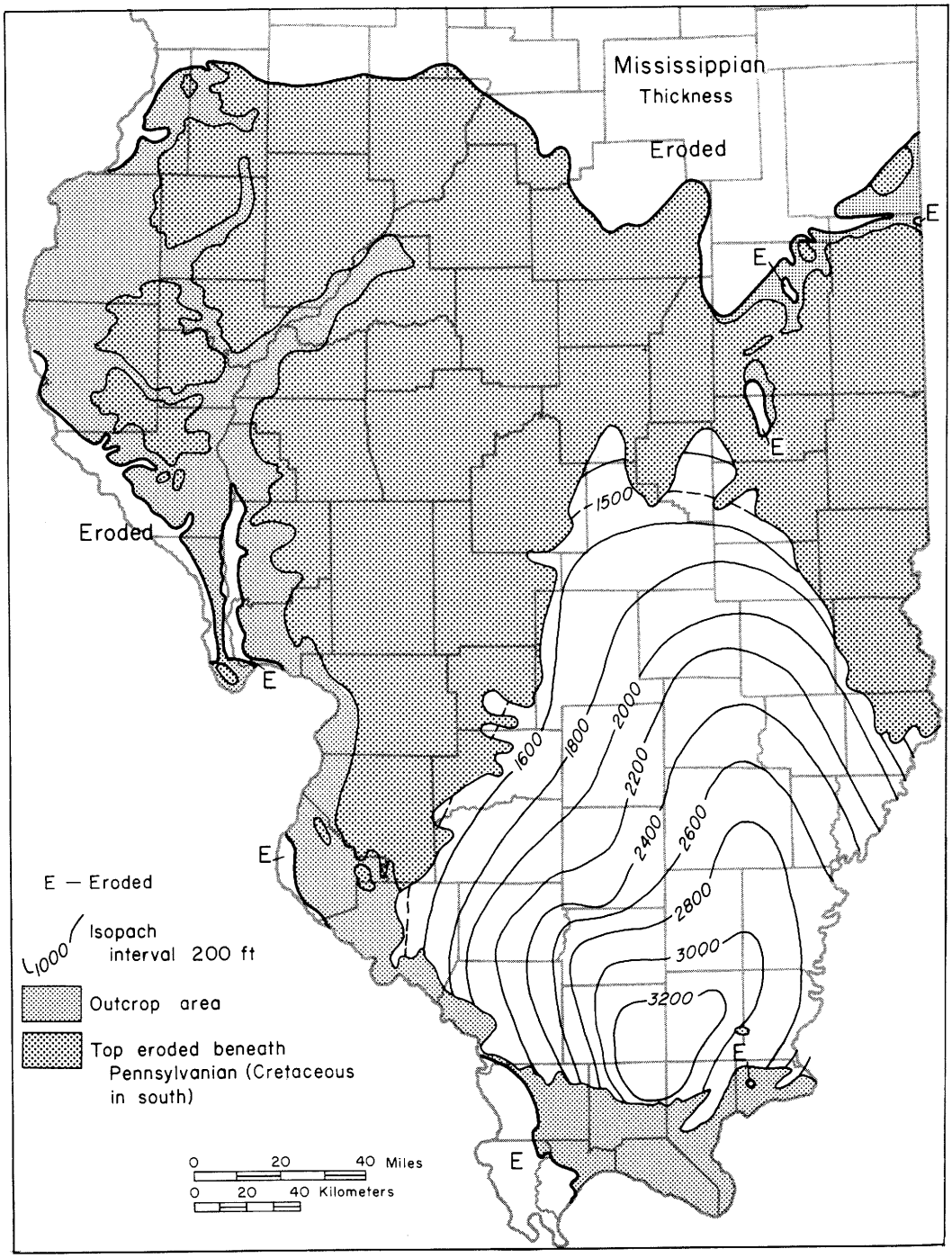

Fig. M-2—Areal extent of the Mississippian System in Illinois. Thickness is shown where upper Chesterian strata are present.

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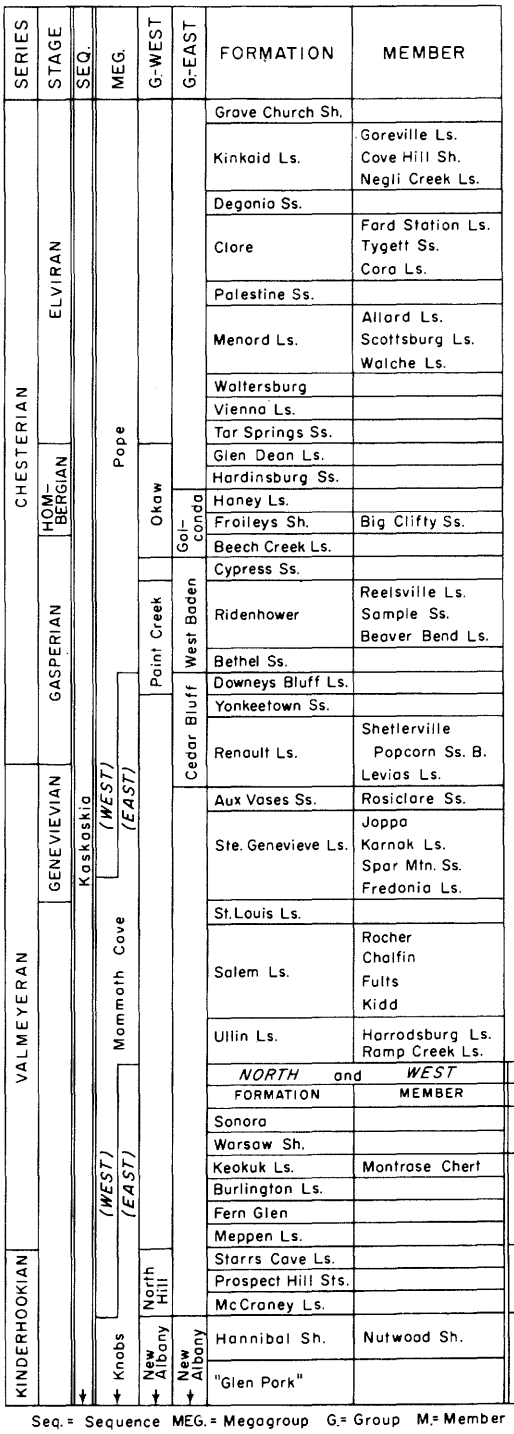
and at Horseshoe in Saline County (N1/2 36, 9S-7E). Elsewhere along its boundary, it is overlapped by younger Mississippian or Pennsylvanian strata.



NORTH and WEST		SOUTH and EAST	
FORMATION	MEMBER	FORMATION	FORMATION
Sonora		Fort Payne	
Warsaw Sh.			
Keokuk Ls.	Montrose Chert	Borden Sts. Bilyeu M.	Springville Sh. Stote Pond M.
Burlington Ls.			
Fern Glen			
Meppen Ls.			
Starrs Cove Ls.		Chouteau Ls.	
Prospect Hill Sts.			
McCraney Ls.			
Hannibal Sh.	Nutwood Sh.	Hannibal Sh.	
"Glen Pork"			

Seq.= Sequence MEG.= Megagroup G.= Group M.= Member B.= Bed

Fig. M-3—Classification of the Mississippian System.

The Kinderhookian is as much as 167 feet thick in western Illinois, where the North Hill Group (fig. M-6) is well developed, and 100 to 120 feet thick in a belt running east from Calhoun County where the "Glen Park" is well developed. It is thin in the eastern and southern parts of the Illinois Basin. The Kinderhookian Series is dominantly shale but has a thin, extensive limestone at the top and a limestone-siltstone-shale formation locally developed at the base.

As originally defined (fig. M-7), the Kinderhook Group included all the strata between the black shale (Grassy Creek) and the Burlington Limestone, strata previously correlated with the Devonian Chemung Group of New York. Later, the black shale was also included in the Kinderhook Group, which was assigned to the Mississippian System. After the Kinderhookian was made a series, the position of the Mississippian-Devonian boundary became controversial (Stainbrook, 1935; Weller, 1939). Studies of the conodont faunas resulted in a redefinition of the Kinderhookian Series to include only those strata overlying the Louisiana Limestone and underlying the Meppen Limestone, or the Burlington where the Meppen is absent (Collinson, 1961). As thus defined, the Kinderhookian Series includes the upper part of the New Albany Group, the widespread Chouteau Limestone, and, in a small area in western Illinois, the North Hill Group.

The Kinderhookian Series is generally conformable with the Upper Devonian Series (below) and the Valmeyeran Series (above), but in western Illinois both contacts are marked by local unconformities that resulted from minor uplifts on the flanks of the Ozarks.

"Glen Park" Formation

The "Glen Park" Formation (Ulrich, 1904, p. 110; Moore, 1928, p. 138-140) is named for Glen Park Sta-

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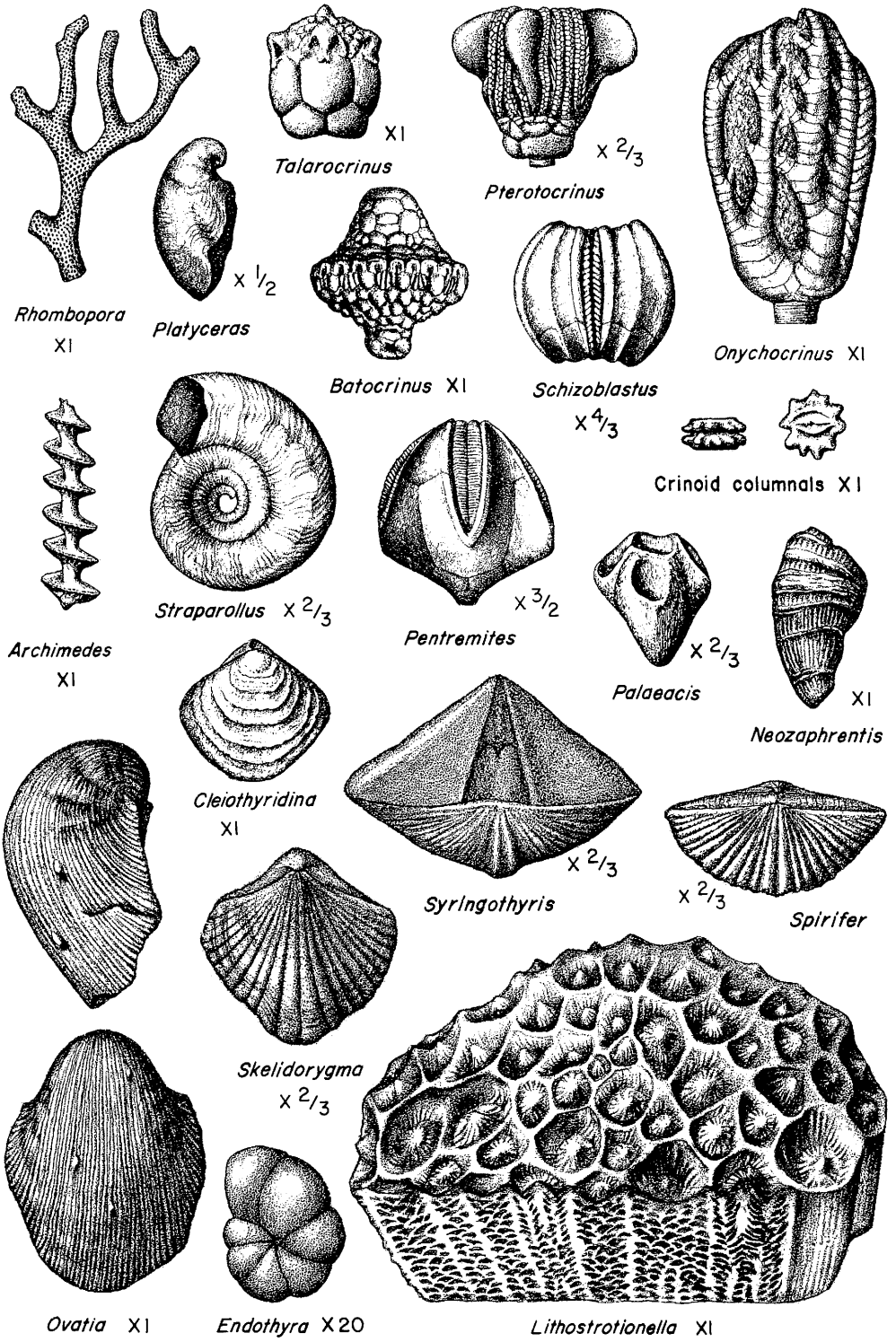

Fig. M-4—Typical Mississippian fossils.

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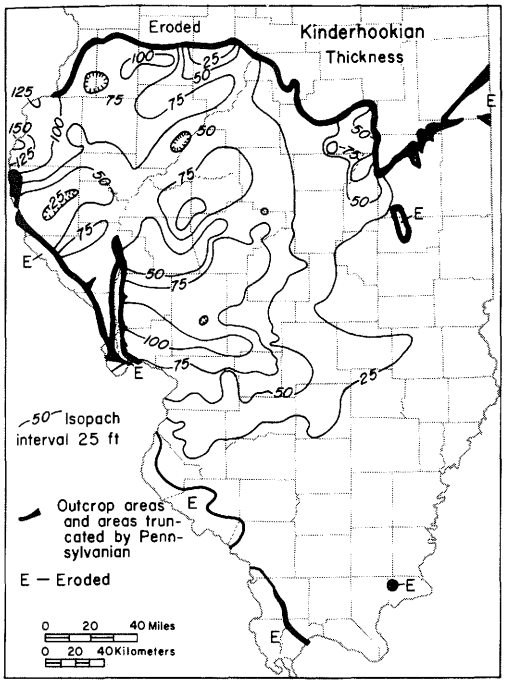

Fig. M-5—Thickness of the Kinderhookian Series.

tion, about 25 miles south of St. Louis, Jefferson County, Missouri, where 1.4 feet of fossiliferous oolitic limestone was named Glen Park. Stuart Weller (1914, p. 464-467) gave the name "Hamburg Oolite" to exposures of the oolitic limestone at Hamburg that he considered to be younger than the type Glen Park, but the name was preempted and Moore (1928) redefined the name "Glen Park" to include the strata at Hamburg. However, studies of the conodonts indicate that the two units are not of the same age—the type Glen Park being Devonian and the Hamburg strata Mississippian—but the name "Glen Park" has been retained pending introduction of a new name.

The "Glen Park" is exposed in and near the Mississippi River bluffs in Calhoun, Pike, and Jersey Counties, and in the lower Illinois Valley in Calhoun and Jersey Counties. It is restricted to western Illinois where its thickness varies greatly but does not exceed 25 feet in the outcrop area. Much of the thick brown shale included in the "Glen Park" by Workman and Gillette (1956) is now included in the Hannibal Shale. The lithology of the "Glen Park" varies considerably and may be almost any combination of sandy, silty, brown or buff limestone, buff siltstone, silty shale, oolitic limestone, limestone conglomerate, or thin sandstone beds. In Gresham Hollow, about a mile southeast of Hamburg, Calhoun County (NW 1, 10S-3W), it consists of calcareous, blue-gray siltstone overlying light gray to buff, silty, dense, fine-grained limestone. The limestone contains beds of dolomitic siltstone bearing *Tasmanites* and also lenses of highly fossiliferous, white to buff, conglomeratic, oolitic, cross-bedded limestone. Stuart Weller (1906b) described the fauna. The "Glen Park" rests with apparent erosional contact on the Louisiana Limestone, or on the Saverton Shale where the Louisiana is not present. However, no unconformity is generally recognizable where the "Glen Park" is absent.

Hannibal Shale

The Hannibal Shale (Keyes, 1892, p. 289) is named for Hannibal, Missouri, where about 75 feet of sandy shale between the Louisiana Limestone (below) and the Burlington Limestone (above) was included in the forma-

NORTHWESTERN REGION

GROUP	FORMATION	FEET
North Hill	Starrs Cave Ls.	0-10
	Prospect Hill Sts.	20-25
	McCraney Ls.	20-40
New Albany	Hannibal Sh.	20-100

WESTERN and CENTRAL REGION

New Albany	Chouteau Ls.	0-70
	Hannibal Sh. Nutwood Sh. Mem.	0-70
	"Glen Park"	0-40

EASTERN and SOUTHERN REGION

New Albany	Chouteau Ls.	0-20
	Hannibal Sh.	0-30

Fig. M-6—Columnar section of the Kinderhookian Series.

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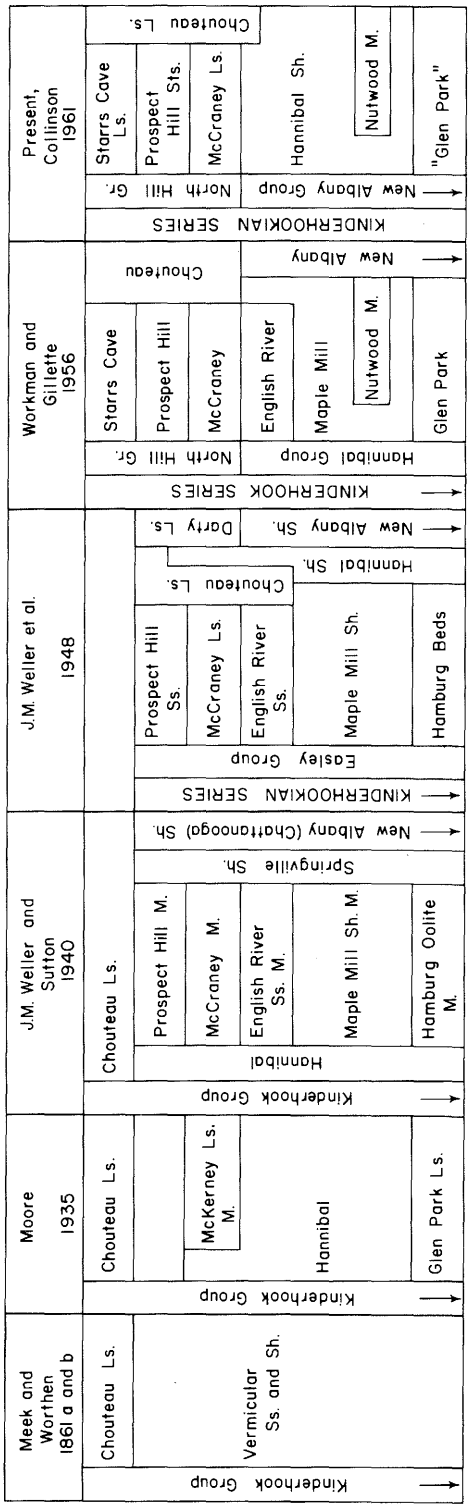

Fig. M-7—Development of the classification of the Kinderhookian Series.

tion. The formation is now defined as the shale overlying the "Glen Park" Formation and underlying the Chouteau Limestone, both of which are absent in the Hannibal type section. It is included in the New Albany Group. The Hannibal Shale was called Maple Mill by Workman and Gillette (1956), but Collinson (1961) found that the Maple Mill Shale in Iowa correlates with the Saverton Shale of the Upper Devonian, and the original name was reinstated. The Hannibal Shale is widely exposed in the Mississippi and Illinois Valleys in western Illinois, and it extends eastward in subsurface across the state. It has a maximum thickness of about 100 feet in Calhoun County, but it thins eastward and is difficult to differentiate from the underlying Devonian shale in the deeper part of the basin. The Hannibal, as exposed in the McCraney North Section, Pike County (NE NE 15, 4S-7W), is almost entirely a green to gray, argillaceous siltstone in the northern part of the outcrop area (Collinson, 1964). The lower part becomes increasingly argillaceous southward and consists of silty shale in Calhoun and Jersey Counties—for example, at Teneriffe School, Jersey County (NW cor. 9, 7N-13W). In the southern part of the outcrop area, the Hannibal contains a lens of black shale as much as 40 feet thick that is differentiated as the Nutwood Member. A siltstone facies formerly called the English River Formation (Workman and Gillette, 1956) is well developed in the upper part of the Hannibal in Adams and Hancock Counties. The Hannibal Shale contains abundant conodonts, which show that the upper part of the formation is equivalent to the Chouteau Limestone in the area where the Chouteau and the North Hill Group are absent. Megafossils are scarce, but the brachiopod *Chonopectus* is abundant in some beds of the siltstone facies. "Roostertail" markings (*Taonurus caudagalli*) and irregular tubular markings (*Scalarituba missouriensis*) are common features, and they are the reason the Hannibal Shale was originally known as the "Vermicular Sandstone and Shales."

Nutwood Shale Member—The Nutwood Shale Member of the Hannibal Shale (Workman and Gillette, 1956, p. 27) is named for Nutwood, Jersey County, where the type section is exposed along a creek through "The Narrows," just northeast of the village (SE NW 34, 8N-13W), where the Nutwood is 13 feet thick. The Nutwood occurs in a limited area from Calhoun County east to Christian County and south to Bond and northern St. Clair Counties. It is as much as 40 feet thick but is less than 20 feet thick within most of its extent. It is a silty, slightly calcareous or noncalcareous, dark brown to black, spore-bearing (*Tasmanites*) shale that grades laterally and vertically into gray Hannibal Shale. It commonly is in the lower part of the Hannibal, but in places it is at the base and rests on the "Glen Park" Formation or on Devonian strata.

MAMMOTH CAVE LIMESTONE MEGAGROUP

The Mammoth Cave Limestone Megagroup (Miller, 1917, p. 3; Swann and Willman, 1961, p. 481) consists of the dominantly limestone groups and formations that overlie the siliceous clastic rocks of the Knobs Megagroup and occur below the lowest well developed sandstone formations of late Valmeyeran

or early Chesterian age at the base of the Pope Megagroup. It is named for Mammoth Cave, Kentucky. The name was introduced, first as a formation name and later as a series name, for the relatively pure limestone in the interval from the base of the St. Louis Limestone to the base of the Big Clifty Sandstone. The Mammoth Cave is entirely Mississippian in age, but both upper and lower contacts are time-transgressive and are marked by a series of step-like, vertical cut-offs (figs. 14, M-3). It occurs throughout the area of Mississippian rocks in Illinois, but it thins from nearly 2000 feet in extreme southern Illinois to little more than 100 feet in east-central Illinois (fig. M-8). It crops out extensively along the Mississippi and Illinois Valleys in western Illinois and along the Mississippi and Ohio Valleys in southern Illinois.

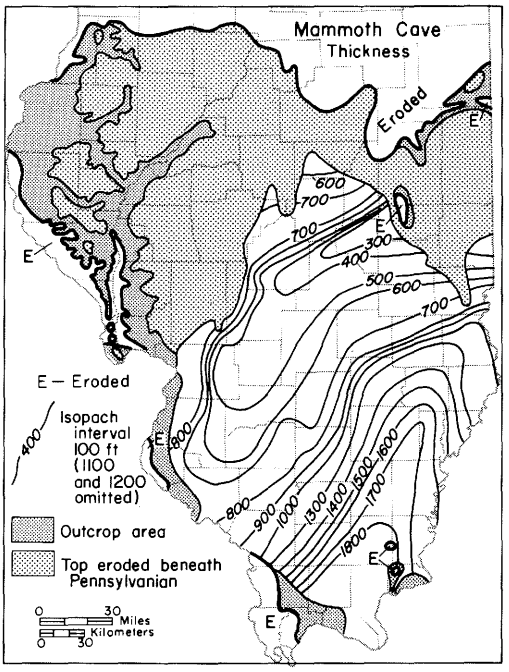

Fig. M-8—Thickness of the Mammoth Cave Limestone Megagroup. Thickness is shown where Chesterian strata are present.

Chouteau Limestone

The Chouteau Limestone (Swallow, 1855, p. 101), the uppermost formation in the Kinderhookian Series, is named for Chouteau Springs, Cooper County, Missouri, where the name was applied to 70 feet of limestone between the "Encrinital Limestone" (Burlington) and the "Vermicular Sandstone" (Hannibal). The name "Rockford," which was applied to the formation in Indiana, was used in southeastern Illinois until the older name, Chouteau, was accepted for all of Illinois (Buschbach, 1952). The Chouteau extends over almost all of Illinois south of a line from Calhoun County to northern Vermilion County (fig. M-9), but it is exposed only in Calhoun and Jersey Counties (Buschbach, 1952; Rubey, 1952; Collinson et al., 1954) and in a small area around Hicks Dome in Hardin County (Weller et al., 1952). It is well exposed in Pere Marquette State Park, southwestern Jersey County, and in the Meppen North Section, Calhoun County (SW NE 23, 12S-2W), where it is about 60 feet thick (Collinson, 1957, 1969). The Chouteau is generally less than 20 feet thick, but it thickens to nearly 80 feet in southern Calhoun County. The Chouteau consists of irregular beds of light brownish or greenish gray, lithographic to very fine-grained limestone with wavy bedding planes. The beds vary from a few inches to nearly 1 foot thick. Locally it is fine-grained dolomite. In a narrow belt extending northeastward from the Ozark region it is red or pink. Gray and buff chert nodules are present and locally abundant where the formation is more than 30 feet thick, but where it is less than 20 feet thick chert is absent. Geodes 1-8 inches in diameter and filled with calcite are common. Macrofossils also are common and conodonts are present in nearly all beds (Collinson, 1961). The Chouteau Limestone normally overlies the Hannibal Formation with apparent conformity, and in places the lower part grades laterally into the upper part of the Hannibal Shale, but in southwestern Illinois the Chouteau locally overlaps the Hannibal and lies unconformably on Devonian to Ordovician formations. In central and eastern Illinois the Chouteau is overlain by the Borden Siltstone, in western Illinois by the Burlington

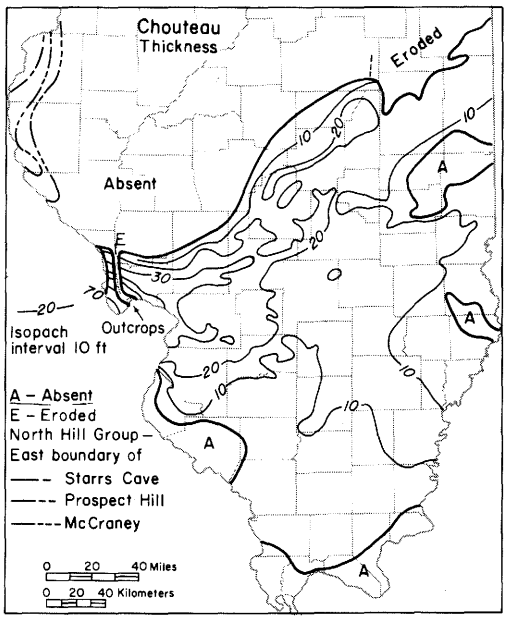

Fig. M-9—Thickness of the Chouteau Limestone and areal extent of the formations of the North Hill Group (after Buschbach, 1952; Workman and Gillette, 1956).

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Limestone, in southwestern Illinois by the Meppen or Fern Glen Formations, and in Union County and vicinity by the Springville Shale (Buschbach, 1952).

North Hill Group

The North Hill Group (Laudon, 1931, p. 344) is named for the North Hill area of Burlington, Iowa. The name was introduced for the oldest member of the Hampton Formation, but Laudon later (1935) made the unit a formation. Workman and Gillette (1956) made it a group to include the McCraney Limestone at the base, the Prospect Hill Siltstone, and the Starrs Cave Limestone. These formations, extensive in Iowa, are confined in Illinois to a narrow belt east of the Mississippi River in extreme western Illinois (fig. M-9), where they have a maximum thickness of about 110 feet. The group is conformable on the Hannibal Shale but is overlain unconformably by the Burlington Limestone. Conodonts and other fossils indicate that the North Hill Group correlates with the Chouteau Limestone (Collinson, 1961).

McCraney Limestone

The McCraney Limestone (Moore, 1928, p. 20) is named for McCraney Creek (misspelled McKerney in the original publication), near which the limestone crops out in the Mississippi River bluffs north of Kinderhook, northwestern Pike County. It was originally designated a member of the Hannibal Formation, but Workman and Gillette (1956) made it the basal formation in the North Hill Group. The McCraney occurs only in extreme western Illinois (fig. M-9). It has a maximum thickness of 58 feet near the Mississippi River but thins eastward, and within 15-20 miles it is entirely absent. It is well exposed along Fall Creek, southern Adams County (SE 23, 3S-8W). The McCraney Limestone consists of alternating thin layers of light gray to buff lithographic limestone with buff to brown, very fine-grained dolomite. A bed of coarsely oolitic limestone forms the top of the McCraney where the formation is thick. The McCraney is conformable with the underlying Hannibal and the overlying Prospect Hill, but where the latter is absent the McCraney is unconformably overlain, and in places completely truncated, by the Burlington Limestone. The conodont fauna shows that the McCraney correlates with the lower part of the Chouteau and the upper part of the Hannibal (Collinson, 1961; Scott and Collinson, 1961).

Prospect Hill Siltstone

The Prospect Hill Siltstone (Moore, 1928, p. 20; Workman and Gillette, 1956, p. 30), named for Prospect Hill, near Burlington, Iowa, was originally designated a member of the Hannibal Formation, but Workman and Gillette (1956) differentiated the uppermost beds as the Starrs Cave Formation and made the Prospect Hill a formation in the North Hill Group. It occurs in extreme western Illinois within the area underlain by the McCraney Limestone (fig. M-9). It has a maximum thickness of 29 feet but thins eastward to its boundary. It is exposed above the McCraney along Fall Creek in southern Adams County (SE 23, 3S-8W). The siltstone is light gray to buff, calcareous, pyritic, massive, and friable. It is con-

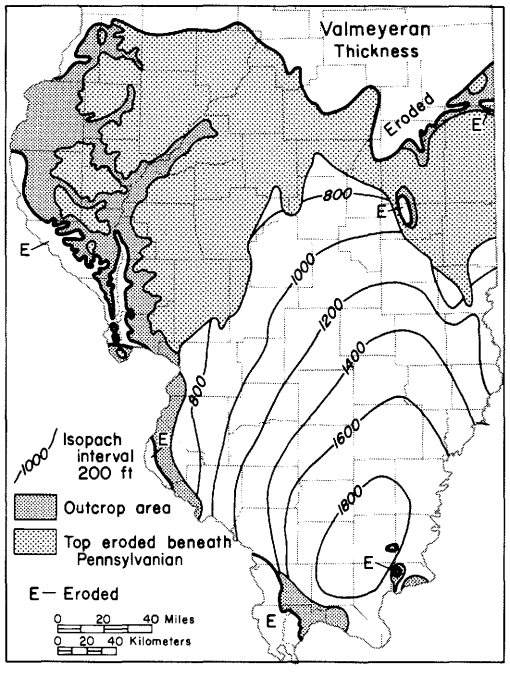

Fig. M-10—Thickness of the Valmeyeran Series. Thickness is shown where Chesterian strata are present.

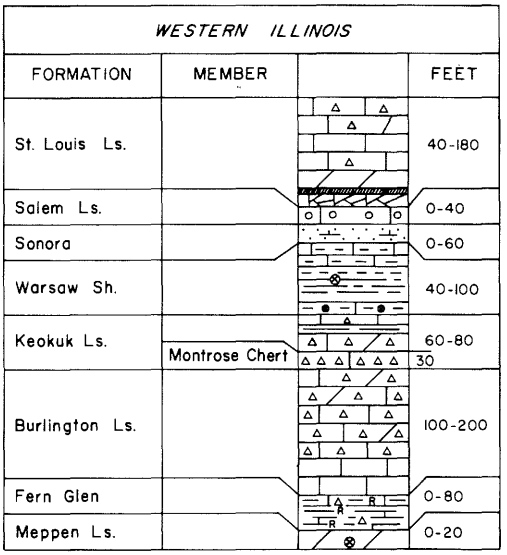

Fig. M-11—Columnar section of the Valmeyeran Series in western Illinois.

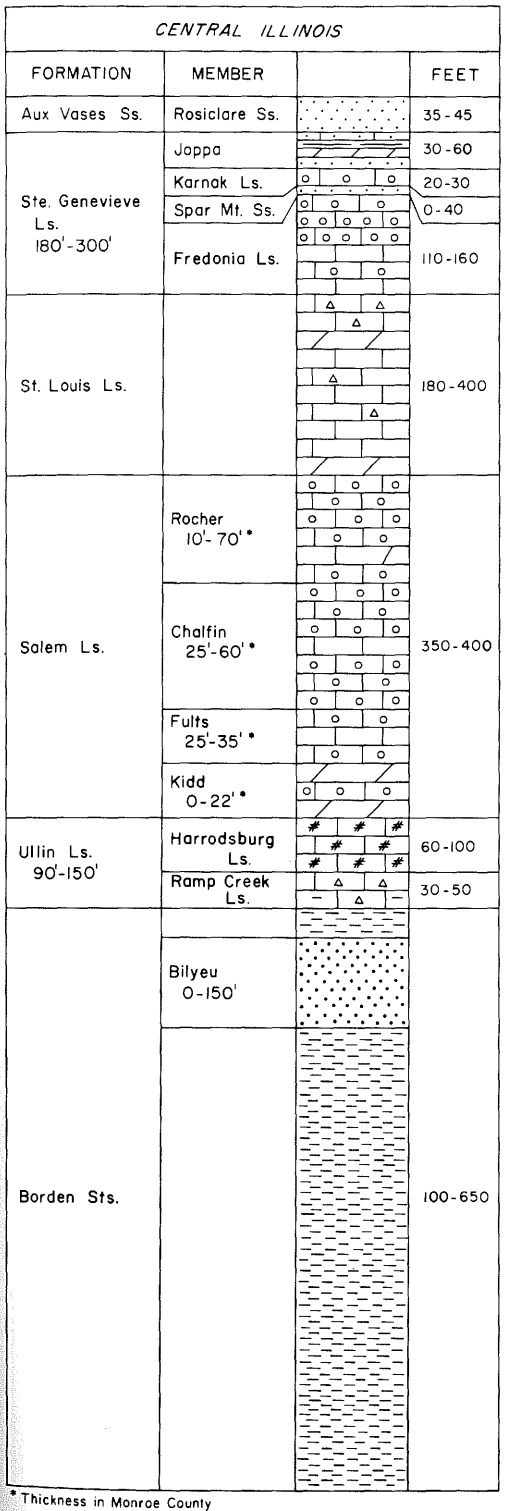

Fig. M-12—Columnar section of the Valmeyeran Series in central Illinois.

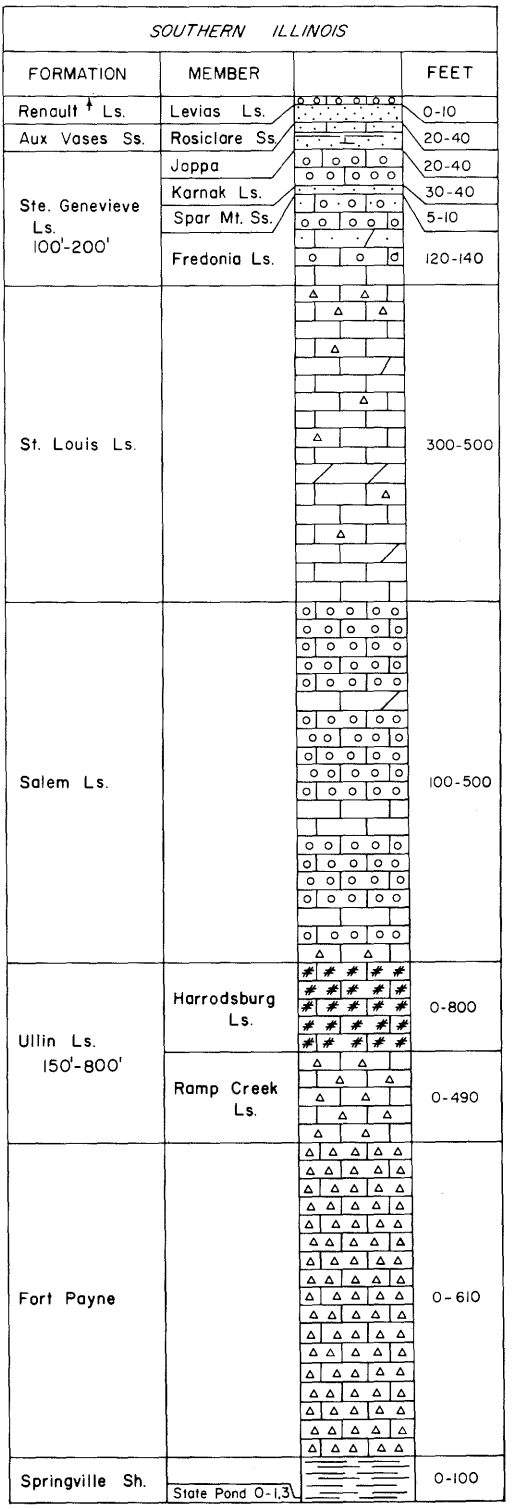

Fig. M-13—Columnar section of the Valmeyeran Series in southern Illinois.

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formable with the underlying McCraney and the overlying Starrs Cave, but where the latter is absent it is overlain unconformably by the Burlington Limestone. It contains few macrofossils, but the abundant conodonts show a close correlation with the upper part of the Chouteau Limestone (Collinson, 1961, 1964).

Starrs Cave Limestone

The Starrs Cave Limestone (Collinson, *in* Workman and Gillette, 1956, p. 31), the uppermost formation in the North Hill Group, is named for Starrs Cave on the Flint River near Burlington, Iowa, where the type section consists of 2.7-3.5 feet of oolitic, very light gray limestone containing many brachiopods and corals (NW NW 19, 70N-2W). Laudon (1931) referred to this unit as the *Schellwienella* Zone. In Illinois the Starrs Cave occurs only in western Hancock County (fig. M-9), where it is 2-12 feet thick but is not exposed. It is a buff to light brownish gray, coarsely oolitic, locally dolomitic limestone. It conformably overlies the Prospect Hill Siltstone and is unconformably overlain by the Burlington Limestone. It has an abundant macrofauna dominated by brachiopods and is correlated with the Chouteau Limestone (Collinson, 1961).

VALMEYERAN SERIES

The Valmeyeran Series (Weller and Sutton, *in* Moore, 1933, p. 261-262) is named for Valmeyer, Monroe County, near which much of the series is exposed. It is the middle series of the Mississippian System and includes formations assigned to two series (Osagian and Meramecan) in other areas. The Valmeyeran Series underlies most of central and southern Illinois (fig. M-10) and includes strata from the top of the Chouteau Limestone upward to the base of the Shetlerville Member of the Renault Limestone (Swann, 1963) (figs. M-3, M-11, M-12, M-13). The series is thickest, over 1800 feet, in southeastern Illinois, and it thins to 600 feet or less before being truncated by erosion in northern Illinois (fig. M-10). It probably originally covered all of northern Illinois, as 200 feet of Valmeyeran strata are preserved in fault blocks in the Des Plaines Disturbance (Emrich and Bergstrom, 1962).

The Valmeyeran is characterized by lateral changes due to depositional pinchouts and lateral gradation. In the type area along the Mississippi River near St. Louis, the Valmeyeran is predominantly carbonate formations. In central Illinois the Burlington and Keokuk Limestones pinch out eastward and the lower part of the Valmeyeran consists of the thick Borden Siltstone (fig. M-14). Eastward, in southeastern Illinois, the Borden is replaced as the dominant unit by the very thick Ullin Limestone and then by thick siliceous limestone of the Fort Payne Formation. The sediment of the Borden Siltstone was transported from the northeast by a major river and deposited in the inland sea as a delta that spread to and overlapped the Keokuk and Burlington carbonates. The deep-water, sediment-starved basin adjacent to the delta was later filled with Fort Payne and Ullin sediments (Swann et al., 1965; Lineback, 1966, 1968a, 1968b).

The overlying Salem and St. Louis Limestones are more persistent across the basin than the underlying units, but they, too, show facies that reflect water depth. Massive biocalcarenitic Salem grades laterally northward into fine-grained evaporite-bearing carbonates of the St. Louis (Lineback, 1972). Near the top of the Valmeyeran Series, the members of the Ste. Genevieve Limestone show rapid facies changes and the contact with the underlying St. Louis Limestone is stepped up and down in response to local lithologic changes.

Because of the complex facies variations in the Valmeyeran Series, knowledge of the relations between the many units has grown slowly, and the classification has been repeatedly changed (fig. M-15).

Borden Siltstone

The Borden Siltstone (Cumings, 1922, p. 487) is named for Borden, Clark County, Indiana, where it is well exposed. It forms an elongate, tongue-shaped delta immediately east of the pinchout of the Burlington and Keokuk Limestones. It is continuous with the Borden Group of Indiana. The formation reaches more than 650 feet thick (fig. M-16), but it does not crop out in Illinois. The Borden in Illinois is dominantly gray to brownish gray, argillaceous, slightly calcareous, glauconitic, fine-grained siltstone, with lesser amounts of silty shale, some greenish gray coarse siltstone or fine sandstone, and light-colored, fossiliferous, cherty limestone. A persistent bed of coarse siltstone and fine sandstone is differentiated as the Bilyeu Member. Beds of fine sandstone and coarse siltstone near the base of the Borden are informally called the "Carper sand" (Moulton, 1926), and the name has been extended to similar beds in the Springville Shale (Lineback, 1968a). Some of the sandstones contain oil (Stevenson, 1964). The Borden Siltstone delta was deposited as a series of southward-developing imbricate topset, foreset, and bottomset beds (Swann et al., 1965; Lineback, 1966). Depositional dips of foreset bedding planes range from 25-120 feet per mile toward the delta margin. The delta was built into a deep-water basin. The "Carper sand" is now believed to have been deposited by multiple turbidity flows off the mouths of distributaries. At least six major turbidite systems as much as 300 feet thick have been recognized, some of which extend for many miles and lens out or grade into the Springville Shale. The Borden is laterally equivalent to the Warsaw Shale and is separated from it by a vertical cut-off at the

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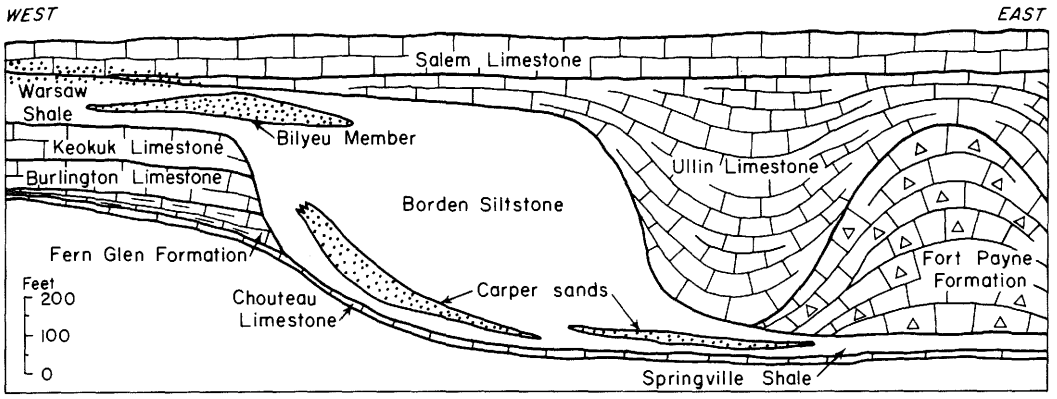

Fig. M-14—Diagrammatic east-west cross section across central Illinois showing the Borden Siltstone delta (after Lineback, 1968b).

position of the eastern pinchout of the Burlington and Keokuk Limestones (fig. M-14). In southern and southeastern Illinois, the Borden is separated from the equivalent Springville Shale by a vertical cut-off where the siltstone thins to less than 100 feet thick. The Borden overlies the Chouteau Limestone and is overlain by the Fort Payne Formation, or the Ullin, Salem, or St. Louis Limestones.

Bilyeu Member—The Bilyeu Member of the Borden Siltstone (Lineback, 1968a, p. 5) is named for Bilyeu Cemetery, Christian County, about 2 miles north of the type section, which is in the National Petroleum Company No. 1-A Bilyeu, Haldon et al., south well (NW NW SW 10, 13N-1E), where the member is 102 feet thick, extending from 1616 to 1718 feet deep. The Bilyeu consists of siltstone that is coarser than most of the Borden and also of fine sandstone. It is 0-150 feet thick and extends in the subsurface through Piatt, De Witt, Macon, Christian, Montgomery, Sangamon, and parts of adjacent counties in central Illinois. The Bilyeu Member extends westward beyond the eastern pinchout of the Burlington and Keokuk Limestones and, therefore, in that area is a member of the Warsaw Shale.

Springville Shale

The Springville Shale (Savage, 1920, p. 169-178; Collinson and Scott, 1958a, p. 11), the basal formation of the Valmeyeran Series in southern Illinois, is named for the now abandoned village of Springville, Union County, which was located a short distance southeast of the type exposures in the bed and banks of a creek 4 miles southeast of Anna (SE 3, 13S-1W). Savage included in the Springville the thin Chouteau Limestone and the shale in the upper part of the New Albany Group, but these were removed by Collinson and Scott (1958a). The Springville Shale crops out discontinuously northward from the type exposures to Jonesboro, in a fault slice along the Shawneetown Fault in Saline County, and on the flanks of Hicks Dome in Hardin County. The Springville is as much as 100 feet thick, but in most of southern Illinois it is less than 50, and in some places it is absent. The formation consists of greenish gray to dark brownish gray, clayey shale. A bed of soft glauconitic shale at the base is differentiated as the State Pond Member. In places, the Springville is mottled red and green and has been informally called the "calico shale." Lenses of the "Carper sand" are present in the areas of thicker shale. The shale is the deep-water equivalent of the Borden delta, and it is separated from the Borden Siltstone by vertical cut-off where the Borden thins to 100 feet (Lineback, 1966) (fig. M-14). The Springville overlies the Chouteau Limestone or, where the Chouteau is absent, the New Albany Group. It is overlain by the Fort Payne Formation or the Ullin Limestone.

State Pond Member—The State Pond Member of the Springville Shale (Collinson and Scott, 1958a, p. 5), at the base of the formation, is named for State Pond, an artificial lake a mile northwest of Jonesboro, Union County. The type section is in the south bank of the stream, below the spillway of the dam (NW SE 14, 12S-2W), where the member is 14-15 inches thick. It is a greenish gray, soft, glauconitic shale containing phosphate nodules. It has yielded conodonts and ostracodes typical of the Fern Glen, Burlington, and Keokuk Limestones and probably is a deep-water equivalent of all three formations.

Meppen Limestone

The Meppen Limestone (Collinson, 1969, p. 12) is named for the village of Meppen, Calhoun County, and the type section is in a quarry 0.6 mile north of Meppen (SW NE 23, 12S-2W), where the formation is 7 feet thick, consists of buff, massive dolomite containing numerous small calcite geodes, and stands out as a distinct buff band in the quarry face. The formation occurs along the western edge of Illinois in an area extending from Calhoun County to Monroe County. It is well exposed in Calhoun and Jersey Counties and has a maximum thickness of 22 feet at Chautauqua, Jersey County (SE SE NE 13, 6N-12W). The Meppen is a tan or buff, very fine-grained, slightly crinoidal, dolomitic limestone or calcareous dolomite that commonly contains many calcite geodes 0.5-2 inches in diameter. The Meppen rests unconformably on the Chouteau Limestone, and at Chautauqua the relation is clearly angular. The Meppen is overlain conformably by the Fern Glen Formation, but north of the Lincoln Anticline the Fern Glen grades into the Burlington, and the Burlington overlaps the Meppen. The Meppen Limestone was called Sedalia in Illinois for many years (Rubey, 1952; Collinson et al., 1954) be-

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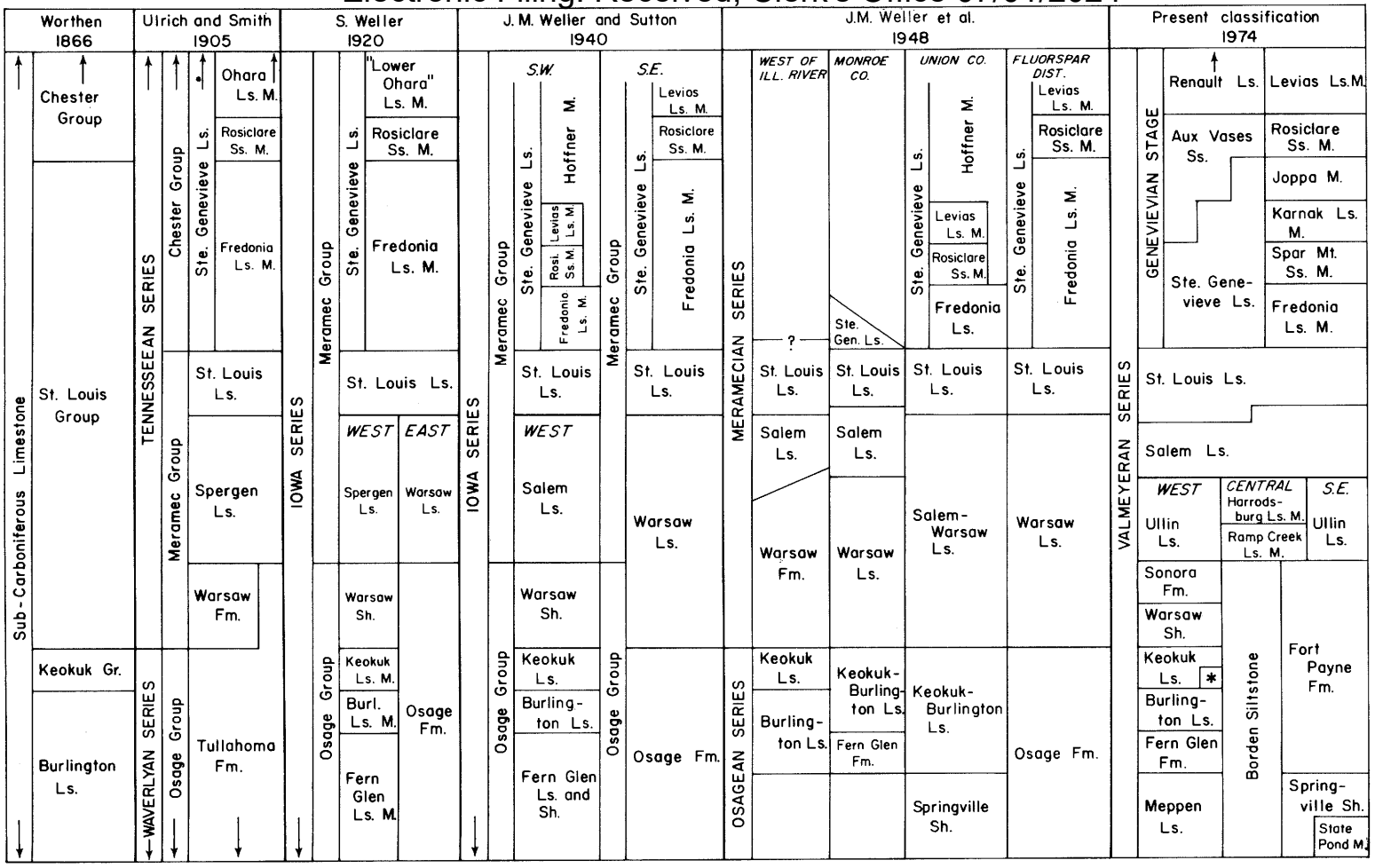

Burl. = Burlington, Rosi. = Rosiclare, * = Montrose Chert M.

Fig. M-15—Development of the classification of the Valmeyeran Series.

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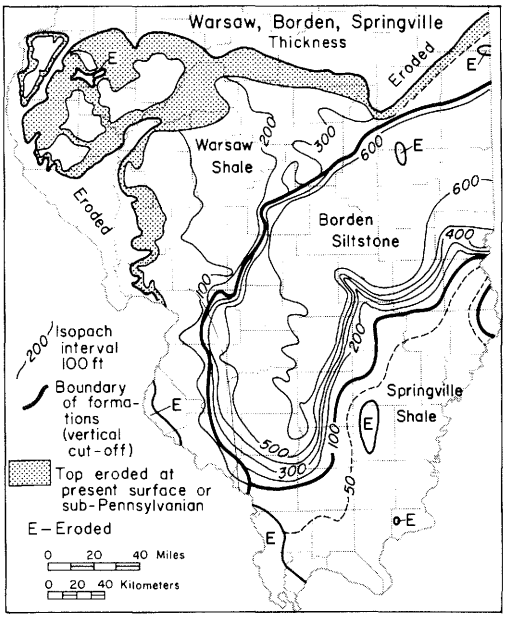

Fig. M-16—Thickness of the Warsaw Shale, Borden Siltstone, and Springville Shale.

cause of its lithologic similarity to the upper dolomitic portion of the Chouteau Limestone in Missouri, which had been named Sedalia by Moore (1928). However, the conodont faunas have shown that the Missouri Sedalia is Kinderhookian, whereas the Illinois "Sedalia" is Valmeyeran. The Meppen contains lower Valmeyeran conodonts, such as *Pseudopolygnathus multistriatus, Polygnathus communis carinus,* and *Bactrognathus hamatus,* but no diagnostic Kinderhookian species. The conodont *Gnathodus semiglaber–Pseudopolygnathus multistriatus* Zone occurs in the Meppen Formation (Collinson et al., 1962). Lithologically and faunally, the Meppen correlates better with the Pierson Limestone of central Missouri than with the Sedalia.

Fern Glen Formation

The Fern Glen Formation (S. Weller, 1906b, p. 438) is named for Fern Glen Station on the Missouri Pacific Railroad, 20 miles west of St. Louis, where the type section, in the Missouri River bluffs, consists of 30-40 feet of red and green calcareous shale, shaly limestone, and a basal bed of massive, yellowish gray, magnesian limestone. The Fern Glen occurs in western Illinois from Randolph County north to Jersey County and in a belt extending northeast to southwestern Champaign County. It is typically exposed in the Chautauqua West Section, southern Jersey County (SW NE 13, 6N-12W), where it includes about 20 feet of calcareous shale, crinoidal limestone, and greenish gray chert (Collinson, 1969). It is also well exposed near Valmeyer, Monroe County (SE SE 3, 3S-11W). Throughout most of its extent, the Fern Glen is less than 50 feet thick, but in a few small areas in St. Clair, Sangamon, and Christian Counties, it approaches 100 feet. The formation consists of green and red calcareous shale and of gray, green, and red limestone and dolomite that is partly argillaceous. The lower part is generally shaly and noncherty, while the upper part is mainly limestone containing small nodules of greenish gray chert. The Fern Glen overlaps the underlying Meppen Limestone to rest on truncated older rocks, as old as the Maquoketa Shale Group. It grades vertically and laterally into the overlying Burlington Limestone, and the boundary is ordinarily drawn at the top of the youngest red or green bed. Fossils are abundant, notably brachiopods, corals, and crinoids. The more common fossils include the brachiopods *Spirifer vernonensis, S. rowleyi, Athyris lamellosa,* and *Leptaena rhomboidalis*, the bryozoan *Evactinopora sexradiata*, and the coral *Cyathaxonia arcuata.* The conodont *Bactrognathus–Polygnathus communis* Zone occurs in the Fern Glen Formation and the lower part of the Burlington Limestone.

Burlington Limestone

The Burlington Limestone (Owen, 1852, p. 90-140; Hall, 1857, p. 190; Van Tuyl, 1925, p. 120) is named for the city of Burlington, Des Moines County, Iowa, where the formation is well exposed and about 70 feet thick. Owen used the term "Encrinital group of Burlington," Hall called it the Burlington Limestone, and Van Tuyl gave it its present definition by transferring the "beds of passage" (Montrose Chert Member) from the Burlington to the Keokuk. The Burlington extends from Henderson County in the northwest across a roughly triangular area southward to Jackson County and eastward to Iroquois County (fig. M-17). Good outcrops are found in the Mississippi River bluffs from Quincy, Adams County, to near Alton, Madison County (Collinson, 1964). In the vicinity of Quincy the lower 25 feet is relatively pure and is quarried as the "Quincy Lime." The

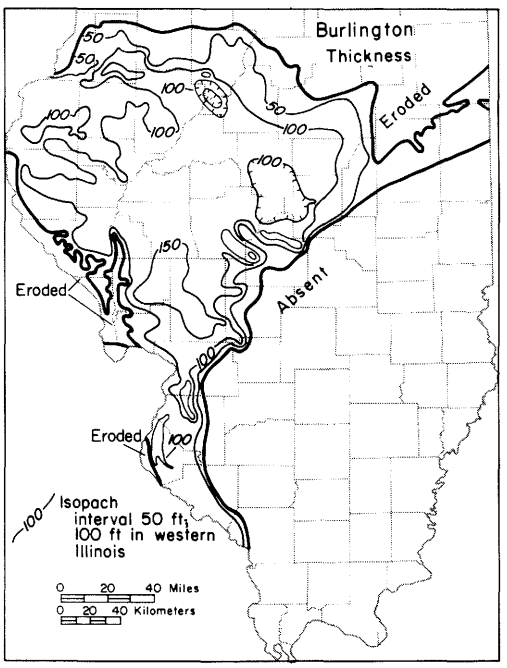

Fig. M-17—Thickness of the Burlington Limestone.

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formation is commonly 100-150 feet thick, but it is as much as 200 feet thick in western Christian County. It terminates sharply to the east where overlapped by the Borden Siltstone (fig. M-14). In the northwestern part of its extent the Burlington consists largely of very pure, coarsely crystalline, light gray limestone in medium to thick beds. It contains a few beds of fine-grained, brownish gray, dolomitic limestone. Beds and nodular masses of light gray or white chert are common, especially in the middle and upper parts of the formation. Some beds are glauconitic. Large crinoid stems are abundant, and many beds are almost entirely crinoidal debris. The top of the Burlington is marked throughout a wide area by a bed 2-10 inches thick that contains many fish teeth and spines. Farther south the Burlington becomes more cherty, the crystalline limestone beds are few and fine-grained beds more common, and fossils are much less abundant. Chert in some places forms as much as 50 percent of the formation, but the chert is exceedingly lenticular and the amounts vary greatly (Rubey, 1952). In the southern area the Burlington and the overlying Keokuk can be distinguished only by their fossils and are generally referred to as the Burlington-Keokuk Limestone. The Burlington lies conformably on the Fern Glen and Meppen Formations, and unconformably on older beds where the Fern Glen and Meppen are absent. Among the common fossils restricted to the Burlington are *Cryptoblastus melo, Globoblastus norwoodi, Dictyoclostus burlingtonensis, Rhipidomella burlingtonensis, Stenocisma bisinuata, Spirifer grimesi, S. forbesi,* and *Spiriferella plena* (Weller and Sutton, 1940). Many crinoids have been described. The lower part of the Burlington Formation is in the conodont *Bactrognathus-Polygnathus communis* Zone, and the upper half is in the conodont *Bactrognathus-Taphrognathus* Zone (Collinson et al., 1971). The Burlington and the overlying Keokuk represent a shallow-water, largely clastic, carbonate sediment that was deposited on the western flank of the Illinois Basin while the Borden delta was expanding into the basin from the northeast.

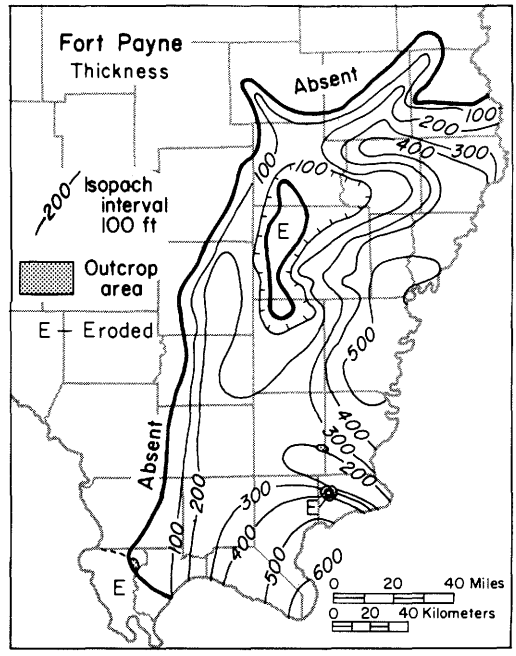

Fig. M-18—Thickness of the Fort Payne Formation.

Keokuk Limestone

The Keokuk Limestone (Owen, 1852, p. 91, 92; Hall, 1857, p. 190; Van Tuyl, 1925, p. 142) is named for Keokuk, Lee County, Iowa. At the type locality about 70 feet of Keokuk Limestone overlying the Burlington Limestone is well exposed along Soap Creek and in the Mississippi River bluff near the mouth of the creek. The Keokuk occurs throughout much the same area as the underlying Burlington (fig. M-17), and it is well exposed along the Mississippi and Illinois Rivers in western Illinois. The Keokuk is 60-80 feet thick for much of its extent. Like the Burlington, the Keokuk is primarily a biocalcarenite. In the type region the lower 30 feet is very cherty and is differentiated as the Montrose Chert Member (Collinson, 1964). The part of the Keokuk above the Montrose is composed of beds of fossiliferous, crinoidal limestone interbedded with fine-grained limestone, argillaceous dolomite, and calcareous gray shale. The shale beds increase upward in number and thickness. The limestone is light gray, speckled with darker gray, brown, or black, and contains beds and nodules of chert. It is generally thinner bedded and darker than limestone of the Burlington, and the shale partings are more numerous. The contact with the overlying Warsaw Shale is gradational. In contrast to the crinoidal limestone of the Burlington, the Keokuk shows a great heterogeneity of skeletal remains, with abundant bryozoans, corals, and brachiopods. The Keokuk contains bryozoans in much greater abundance and diversity than does the Burlington, with *Archimedes* and *Worthenopora* especially common. Distinctive brachiopods include *Spirifer logani, Dictyoclostus crawfordsvillensis, Orthotetes keokuk,* and *Rotaia subtrigonia* (Weller and Sutton, 1940). The conodont *Gnathodus texanus—Taphrognathus* Zone essentially coincides with the Keokuk Formation (Collinson et al., 1971).

Montrose Chert Member—The Montrose Chert Member of the Keokuk Formation (Keyes, 1895, p. 320) is named for Montrose, Lee County, Iowa, and the type section consists of 30 feet of very cherty limestone at the base of the Keokuk Limestone where it is exposed along the Mississippi River between Montrose and Keokuk. Earlier, these beds had been termed the "Keokuk cherty limestones" (Owen, 1852) or the "cherty beds of passage" separating the Keokuk and Burlington (Hall, 1857). The Montrose Chert Member is generally about 30 feet thick and consists of gray, medium- to coarse-grained, fossiliferous limestone and light gray dolomite in beds 2-10 inches thick. It contains nodules and beds of blue-gray chert. The chert is dominant in many places and commonly is strongly brecciated (Collinson, 1964).

Warsaw Shale

The Warsaw Shale (Hall, 1857, p. 54-56) is named for Warsaw, Hancock County, and the exposure in Geode Glen at Warsaw has become the type section (NW NW 10, 4N-9W) (Collinson, 1964). The Warsaw is widely

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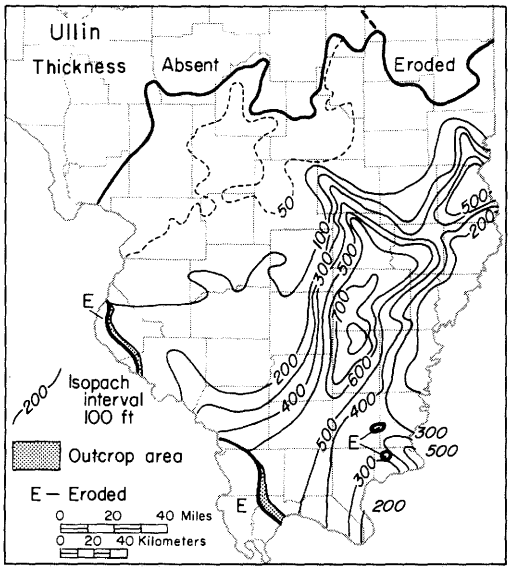

Fig. M-19—Thickness of the Ullin Limestone.

present in the bluffs of the Mississippi and Illinois Valleys in western and southwestern Illinois. It consists of as much as 300 feet of siltstone in west-central Illinois (fig. M-16), but it thins to less than 100 feet in the outcrop area, where it consists of gray shale containing beds of argillaceous limestone. Quartz geodes are common and locally abundant; some are replacements of fossils. Some contain petroleum. The Warsaw is fossiliferous, with brachiopods, bryozoans, and crinoids especially common. The corkscrew bryozoan, *Archimedes* (fig. M-4), is so abundant that the formation was called the *Archimedes* limestone in early reports. Coarse silt and fine sandstone differentiated as the Bilyeu Member of the Borden Siltstone in central Illinois continues westward into the Warsaw Shale, where it becomes a member of the Warsaw. The Warsaw is overlain by the Sonora Formation or by the Ullin, Salem, or St. Louis Limestones. The Warsaw Shale overlies the Keokuk Limestone, and where the Keokuk and Burlington Limestones pinch out eastward the Warsaw is separated from the Borden Siltstone by a vertical cut-off (Lineback, 1966) (fig. M-14).

Sonora Formation

The Sonora Formation (Keyes, 1895, p. 320) is named for the now extinct village of Sonora, Hancock County, about a mile north of the type section of the formation in the Sonora quarries (SE NW 31, 6N-8W), where about 20 feet of sandy, cross-bedded dolomite grades to porous, dolomitic sandstone. The Sonora crops out most widely in the Mississippi River bluffs and along tributary valleys in Adams and Hancock Counties. It is typically exposed at Jackson Cemetery, Hancock County (SE NW 14, 7N-8W), where it is more than 20 feet thick and consists of beds of argillaceous and dolomitic, cross-bedded sandstone alternating with sandy shale. The Sonora is generally about 20 feet thick between Niota and Hamilton, but elsewhere it is thinner, becoming only 2-3 feet thick in the Warsaw area (Collinson, 1964). Although characteristically a sandy formation, the lithology varies laterally and vertically. The dolomite is arenaceous to argillaceous and sparsely fossiliferous, but fragments of fenestellid bryozoans occur throughout. The sandstone is generally light buff, dolomitic, argillaceous, and fine grained. The shale is generally greenish gray and sandy. Both Salem and St. Louis overlie the Sonora in places. The contact with the overlying St. Louis varies from conformable to erosional. In most localities where the contact is exposed, the lower part of the St. Louis is brecciated, possibly by the solution of a layer of gypsum or anhydrite. The Sonora grades laterally into the Salem Limestone and the upper part of the Warsaw Shale (Collinson, 1964). The Sonora lies within the conodont *Taphrognathus varians—Apatognathus* Zone (Collinson et al., 1971).

Fort Payne Formation

The Fort Payne Formation (Smith, 1890, p. 155-156) is named for Fort Payne, De Kalb County, Alabama. It consists of dark, very fine-grained, siliceous, cherty limestone. The Fort Payne is confined to southern Illinois. It is over 610 feet thick in Pope County, and thins northward and westward (fig. M-18). The best exposure of the Fort Payne in Illinois is in a fault slice along the Shawneetown Fault near the former community of Horseshoe, Saline County, where at least 150 feet of steeply dipping beds are exposed. The Fort Payne is also exposed on the flanks of Hicks Dome in Hardin County, where it is largely weathered to chert. Eleven feet of chert exposed in the bluff in Alexander County west of Ullin, Pulaski County, is also assigned to the Fort Payne. In the subsurface the Fort Payne consists of quartz and carbonates in silt- and clay-sized particles. In the lower part it contains nodular chert and fossils, especially crinoids, and some clay minerals. The dark color is caused by pyrite and organic matter. The Fort Payne overlies the Springville Shale, the Chouteau Limestone, or the lower portion of the foreset slope of the Borden Siltstone delta in southern Illinois. It is overlain by the Ullin Limestone. The Fort Payne occurs as an irregular tongue-shaped body that partially filled a deep-water basin bordered by the foreset slopes of the Borden delta in southern Illinois and southeastern Indiana (Lineback, 1966). It is the northernmost extension of a large body of siliceous and cherty rocks that extends through western Kentucky to Mississippi and Alabama and eastward to the Appalachian Mountains.

Ullin Limestone

The Ullin Limestone (Lineback, 1966, p. 29-34) is named for Ullin, Pulaski County, near which the type section was compiled from three exposures (secs. 14, 21, and 22, 14S-1W), which have a total thickness of about 630 feet. Its maximum thickness is more than 800 feet in Hamilton County and it thins generally northward (fig. M-19). It is exposed in the Mississippi River bluffs in Monroe, St. Clair, and Madison Counties and in southern Illinois in Union, Pulaski, and Hardin Counties. The Ullin Limestone is largely light-colored, fine- to coarse-grained limestone (fig. M-1F) that is rich in bryozoans and crinoids. It overlies the Fort Payne Formation, or the Borden, Springville, Warsaw, or Chouteau Formations

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where the Fort Payne is absent. It underlies the Salem Limestone and pinches out beneath it in western Illinois. The Ullin can generally be subdivided into two members, the Harrodsburg Limestone Member, above, and the Ramp Creek Limestone Member, below. The Harrodsburg is generally lighter colored, coarser grained, less cherty and less argillaceous than the Ramp Creek, whereas the Ramp Creek contains more crinoidal debris and is glauconitic in places. However, the Harrodsburg and Ramp Creek Members are similar in many places, and in about one-third of the area of the Ullin they cannot be differentiated. Where the Ullin is thickest, in Hamilton County, both members are light-colored calcarenite rich in bryozoans. Where the Ullin is thin, as it is on the crest of the Borden delta and on the highest parts of the Fort Payne tongue, both members become more crinoidal and are indistinguishable. The Ullin Limestone filled deep-water trenches bordered by depositional slopes of the Borden delta and the Fort Payne Formation.

Ramp Creek Limestone Member—The Ramp Creek Limestone Member of the Ullin Limestone (Stockdale, 1929, p. 233-242) is named for the village of Ramp Creek, Monroe County, Indiana, and the type section is a near-by exposure of 21 feet of siliceous and argillaceous limestone (NW NW 35, 8N-1W). The name "Ramp Creek" was originally applied to the lower part of the Harrodsburg Limestone, but Harrodsburg was later restricted to the upper, purer limestone (Smith, 1965). The Ramp Creek in Illinois is the lower, cherty, argillaceous limestone of the Ullin (Lineback, 1966). The Ramp Creek is 0-490 feet thick. It includes the brachiopod *Marginirugus magnus* Zone.

Harrodsburg Limestone Member—The Harrodsburg Limestone Member of the Ullin Limestone (Hopkins and Siebenthal, 1897, p. 296-297; Stockdale, 1939, p. 72-73; Smith, 1965, p. 11; Lineback, 1966, p. 33) is named for Harrodsburg, Monroe County, Indiana. The original type section was destroyed by highway construction, but an exposure 1 mile north of Harrodsburg is used as a standard reference section (Shaver et al., 1970). The Harrodsburg Member is exposed along the Mississippi Valley in western and southwestern Illinois and in Hardin County in southeastern Illinois. It is over 800 feet thick in Hamilton County, but it thins northward and pinches out at the margin of the formation. It consists of light-colored bryozoan and crinoid debris. In Monroe County the Harrodsburg strata were included in the Kidd Member of the Salem by Baxter (1960a), but they were excluded from the Kidd by Lineback (1972).

Salem Limestone

The Salem Limestone (Cumings, 1901, p. 233) is named for Salem, Washington County, Indiana, where it is extensively quarried for Indiana building stone. It was called "Spergen Hill" or "Spergen" limestone in early reports. No type section was designated, but a quarry 0.8 mile east of Salem is considered the principal reference section (Shaver et al., 1970). The Salem Limestone forms prominent outcrops in Illinois in parts of Hardin County, along the Mississippi River in Randolph (fig. M-1D), Monroe, and Madison Counties, and in places in western Illinois. It is over 500 feet thick in southeastern Illinois and thins northward (fig. M-20). Small patches occur northwest of the area mapped. The Salem generally overlies the Ullin, but where the Ullin pinches out northward the Salem rests on the Warsaw Shale or the Sonora Formation. The Salem is overlain by the St. Louis Limestone. The Salem is a biocalcarenite consisting of rounded, broken, fossil fragments and whole small fossils, commonly with banded, oolitic-like overgrowths, that are imbedded in a matrix that ranges from micrite to sparite. Endothyrid foraminifers are commonly abundant (fig. M-4). Minor lithologies in the Salem include biocalcilutite, biocalcirudite, sucrosic dolomite, dolomitic limestone, fine-grained limestone, fossiliferous crystalline limestone, sandstone, chert, and the evaporites anhydrite and gypsum. Some fine-grained, silty, dolomitic beds weather yellow and form reentrants on the weathered faces. The Salem differs from the underlying Ullin by having a greater variety of fossils and fossils with banded overgrowths. In the outcrop area in Monroe County and extending from Prairie du Rocher, Randolph County, to Dupo, St. Clair County, the Salem is divided into the Kidd (at the base), Fults, Chalfin, and Rocher Members, largely on the basis of differences in textures (Baxter, 1960a). The Kidd and Fults Members are lithologically and faunally similar to the type Salem in Indiana. The upper part of the Salem grades laterally into the St. Louis Limestone in Madison County and northward (Lineback, 1972). The lower part can be identified into Christian County and northward, but the biocalcarenite grades laterally into dolomitic limestone and fossiliferous limestone that contain evaporites and sandstone in places. The lateral gradation is the result of the southward deepening of the water from shallow water near the shore in north-central Illinois to deeper water near the center of the Illinois Basin.

Kidd Member—The Kidd Member of the Salem Limestone (Baxter, 1960a, p. 19-22; Lineback, 1972, p. 5), the basal member, is named for Kidd, Monroe County, and the type section is in the Mississippi River bluffs east of the village (NE NE 1, 5S-10W). As originally defined, it included the Harrodsburg Member of the Ullin Limestone, but it was

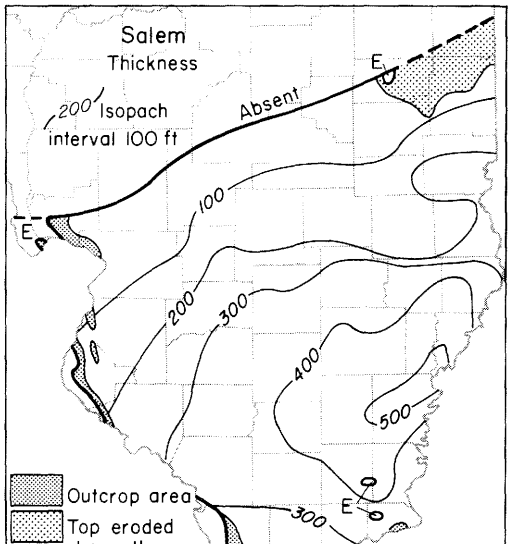

Fig. M-20—Thickness of the Salem Limestone.

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restricted by Lineback to the biocalcarenite below the Fults Member and above the Ullin. In the type section the Kidd consists of about 22 feet of chert-free, high-calcium biocalcarenite, largely made up of medium and coarse grains of fragmented fossils, mostly crinoid columnals and bryozoan detritus, in beds 2-3 feet thick. The foraminifers *Endothyra* sp., *Tournayella* sp., and *Globoendothyra* sp. are present. *Globoendothyra baileyi* is common and becomes more common in the upper half of the member.

Fults Member—The Fults Member of the Salem Limestone (Baxter, 1960a, p. 22-24) is named for Fults, Monroe County, and the type section is in the bluffs three-fourths of a mile northwest of the town (SE NE 20, 4S-10W), where the member is 29.4 feet thick. It is 25-34 feet thick in the outcrop area in Monroe and St. Clair Counties. The Fults Member consists largely of thin- to medium-bedded, fine-grained, silty, cherty, more or less dolomitic limestone, but it contains beds of medium-grained limestone composed of fragmented fossils. *Globoendothyra baileyi* and *Eoendothyranopsis spiroides* are common.

Chalfin Member—The Chalfin Member of the Salem Limestone (Baxter, 1960a, p. 24-27) is named for the village of Chalfin Bridge, Monroe County, and the type section is in the Mississippi River bluffs 1 mile southwest of the village (NE SW 7, 4S-10W), where the member is 39.5 feet thick. It is 26-57 feet thick in the outcrop area. The Chalfin consists of varying thicknesses of fine-grained limestone; fine- to medium-grained, fossiliferous, locally oolitic limestone; and semilithographic limestone, some of it brecciated. The lower 10 feet is predominantly a calcarenite composed of bryozoan detritus, crinoid columnals, microcrystalline pellets, and a few oolites. *Eoendothyranopsis* group *pressus-rarus, Koninckopora sahariensis, K. inflata, Septabrunsiina,* and profuse *Calcisphaera* characterize the Chalfin.

Rocher Member—The Rocher Member of the Salem Limestone (Baxter, 1960a, p. 27-29), the uppermost member, is named for Prairie du Rocher, Randolph County, and the type section is in the Mississippi River bluffs above a large spring 1 mile northwest of the town, where the member is 69.3 feet thick. It thins northward to 10-15 feet at Valmeyer, Monroe County. The Rocher is mined for high-calcium limestone just north of the type section. It is composed largely of marine fossils, predominantly Foraminifera, but it also includes crinoid and bryozoan fragments, brachiopods, corals, and echinoids. Endothyrids and calcareous spheres with calcite centers, questionable fossils classified as *Calcisphaera*, are abundant (Baxter, 1960b). The microfauna is similar to that of the Chalfin and the lower part of the St. Louis. The limestone varies from slightly oolitic to oolite. It occurs in thick, cliff-forming beds, broken by an occasional thin bed.

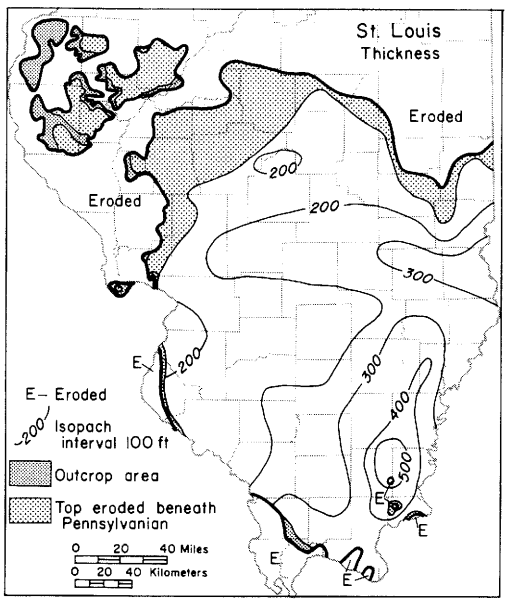

Fig. M-21—Thickness of the St. Louis Limestone.

St. Louis Limestone

The St. Louis Limestone (Engelmann, 1847, p. 119-120; Ulrich, 1904, p. 103) is named for St. Louis, Missouri, where it is extensively exposed. No type section was designated. The St. Louis is typically exposed in Illinois in the Mississippi River bluffs at Alton, Madison County (Collinson et al., 1954) (fig. M-1B). It is also well exposed in the Mississippi and Illinois Valleys in western and southern Illinois (fig. M-1D) and along the Ohio River in Hardin County (fig. M-21). The St. Louis is 500 feet thick in southeastern Illinois and thins northwestward to less than 200 feet before being truncated by pre-Pennsylvanian erosion. The St. Louis Limestone in Illinois is characterized by fine-grained, micritic to lithographic, cherty limestone, but it contains beds of dolomite, crystalline limestone, fossiliferous limestone, and evaporites. The evaporites are represented in the outcrop areas by limestone breccias. The outcrop areas of the St. Louis are characterized by abundant sink holes. The St. Louis overlies the Salem Limestone except in the parts of western Illinois where it lies on the Warsaw Shale or the Sonora Formation. It is overlain by the Ste. Genevieve Limestone. The lower part of that formation grades laterally into the St. Louis Limestone, and in those places the formations are separated by a vertical cut-off. The rugose coral *Lithostrotionella* is common and characteristic (fig. M-4). In the St. Louis–Alton area the lower part of the St. Louis is included in the conodont *Taphrognathus varians–Apatognathus* Zone and the upper part in the *A. scalenus—Cavusgnathus* Zone. The upper St. Louis has common *Eoendothyranopsis, Koninckopora pruvosti,* and large archaediscids.

Genevievian Stage

The Genevievian Stage (Swann, 1963, p. 20-21) is named for the Ste. Genevieve Limestone, the type section for which is at Ste. Genevieve, Missouri. It is the only stage at present differentiated in the Valmeyeran Series and covers only the latest part of Valmeyeran time (fig. M-3). It consists of all the strata contemporaneous with the Ste. Genevieve Limestone where its top corresponds with the last occurrence of *Platycrinites penicillus*. The *Platycrinites–Talarocrinus* boundary is the basis for the time plane separating the Valmeyeran and Chesterian Series. It falls within the Renault Limestone at the top of the Levias Member. The base of the Genevievian Stage is less well defined, but in the Illinois Basin it is placed at the top of the St. Louis

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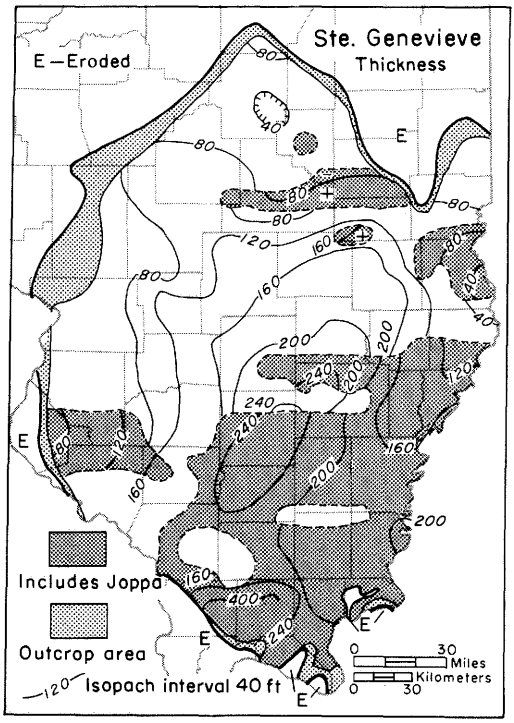

Fig. M-22—Thickness of the Ste. Genevieve Limestone.

Limestone, which is the base of the *Gnathodus bilineatus—Cavusgnathus charactus* Zone, somewhat higher than the disappearance of *Lithostrotion* and *Lithostrotionella* with large corallites, where it was originally placed.

Ste. Genevieve Limestone

The Ste. Genevieve Limestone (Shumard, 1860, p. 406) is named for Ste. Genevieve, Missouri, where it is about 100 feet thick, and the type section consists of outcrops in the bluffs along the Mississippi River 1-4 miles southeast of Ste. Genevieve. The Ste. Genevieve overlies the St. Louis Limestone and underlies the Aux Vases Sandstone throughout much of the southern half of the Illinois Basin. It crops out from the vicinity of Alton, Madison County (fig. M-1B), south along the Mississippi Valley to Randolph County and from Union County, where it is about 300 feet thick, eastward across southern Illinois to Hardin County, where it averages about 250 feet thick (fig. M-22). The Ste. Genevieve is generally light gray, but some beds of oolite (fig. M-1E) are nearly white. Chert is common and is generally gray, but in some places it is black. Thin beds of sandstone and sandy limestone, some traceable for many miles, occur mainly in the upper half of the formation. The sandstone is generally calcareous, light greenish gray, and very fine grained. A little shale, mainly dark greenish gray but locally red, purple, or green, occurs in the upper part of the formation. The Ste. Genevieve is subdivided into four members: the Fredonia Limestone Member at the base, the Spar Mountain Sandstone Member, the Karnak Limestone Member, and the Joppa Member (sandstone, limestone, dolomite, and shale). Near its western border the Ste. Genevieve has a conglomeratic bed at its base and rests unconformably on the eroded top of the St. Louis Limestone. Elsewhere the two formations appear to be conformable and, in the transition zone, beds with Ste. Genevieve lithology intertongue with beds with St. Louis lithology. The contact is placed below the lowest prominent oolitic bed. The contact between the Ste. Genevieve and the overlying Aux Vases Sandstone is conformable, but it is marked by a series of downward steps to the west as the upper limestone beds grade westward into sandstone. Weathered surfaces of the Ste. Genevieve generally show abundant fossils, mainly crinoid fragments. *Platycrinites ("Platycrinus") penicillus* and *Pugnoides ottumwa* are characteristic, although they occur rarely in older or younger strata. The Ste. Genevieve is in the lower part of the *Gnathodus bilineatus—Cavusgnathus charactus* Zone (Collinson et al., 1971). The Ste. Genevieve Formation extends into eastern Missouri, southwestern Indiana, and western Kentucky. The Pella beds of Iowa are correlated with the Ste. Genevieve.

Fredonia Limestone Member—The Fredonia Limestone Member of the Ste. Genevieve Limestone (Ulrich and Smith, 1905, p. 24, 40; Swann, 1963, p. 27, 66), the lowest and thickest member, is named for Fredonia, Caldwell County, Kentucky (14-I-18). The Fredonia originally included the dominantly limestone section from the base of the Rosiclare Sandstone to the top of the underlying St. Louis Limestone, but it was restricted by Swann (1963) to the limestone between the base of the Spar Mountain Member and the St. Louis Limestone. The Fredonia is generally 80-100 feet thick, but from Effingham County north to Coles County it thins rapidly to 20 feet or less. The limestone is light gray, mainly oolitic, cross-bedded, and crinoidal, but it includes some darker lithographic limestone beds like those in the St. Louis below.

Spar Mountain Sandstone Member—The Spar Mountain Sandstone Member of the Ste. Genevieve Limestone (Tippie, 1945, p. 1657), which overlies the Fredonia Limestone Member, is named for Spar Mountain, Hardin County, where the type section, on the south-facing slope (NE 4, 12S-9E), consists of 8-15 feet of light gray to greenish gray, calcareous, glauconitic sandstone or siltstone grading to very sandy limestone. The Spar Mountain extends throughout most of the area of the Ste. Genevieve (fig. M-22). Lenses of similar sandstone and sandy calcarenite occur sporadically at other levels in the Ste. Genevieve, and the Spar Mountain is difficult to differentiate from them in some areas. It is erratic in thickness and has a varied lithology, including beds of dolomite, limestone, sandy limestone, sandstone, and thin shale. In the northern part of its extent, it is as much as 40 feet thick. In the western part of the basin—for example, in western Washington County—the Spar Mountain grades laterally into the Aux Vases Sandstone and is separated from it by vertical cut-off.

Karnak Limestone Member—The Karnak Limestone Member of the Ste. Genevieve Limestone (Swann, 1963, p. 28-29, 71) is named for Karnak, Pulaski County, about 4 miles southeast of the type section in Johnson County (SW SW 32, 13S-2E, and NW NW 5, 14S-2E), where the top 16 feet of an estimated 20-25 feet of limestone is exposed in cuts on Illinois Highway 37. The Karnak is a persistent unit and is generally traceable throughout the area of the Ste. Genevieve (fig. M-22), but in western Washington County it thins and grades laterally into the Aux Vases Sandstone. The Karnak is generally 10-35 feet thick. The limestone is relatively pure, oolitic, crinoidal, mostly light gray, and cross-bedded.

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Joppa Member—The Joppa Member of the Ste. Genevieve Limestone (Swann, 1963, p. 29, 71), the uppermost member, is named for Joppa Junction, Johnson County, about half a mile west of the type section (SW SW 32, 13S-2E), where the member comprises 32 feet of shale and limestone overlying the Karnak Limestone Member. In southeastern Illinois the Joppa generally includes prominent limestones that allow it to be readily separated from the Aux Vases Sandstone. However, in most of the western and northern parts of the basin it is impractical to separate the Joppa from the Aux Vases, and there the Joppa is terminated by a vertical cut-off. The Joppa is 20-50 feet thick. Most of the limestone is sandy and oolitic, and part of it is red and hematitic. The sandstone is generally very fine grained and calcareous, resembling that of the Aux Vases. The shale is largely dark greenish gray, but red and green shales are common.

POPE MEGAGROUP

The Pope Megagroup (Swann and Willman, 1961, p. 481-482), named for Pope County in southern Illinois, comprises sandstone-shale units alternating with limestone-shale units of late Valmeyeran and Chesterian age that overlie the Mammoth Cave Limestone Megagroup and underlie the Pennsylvanian System and younger rocks (fig. 14). The lateral extent of the Pope Megagroup in Illinois is the same as that of the base of the Ste. Genevieve Limestone to the north (fig. M-22) and that of the Aux Vases Sandstone to the south (fig. M-23). The outcrop area runs along and near the Mississippi and Ohio Rivers from Alton, Madison County, south to Grand Tower, Jackson County, and then eastward through Hardin County. The Pope thickens from its truncated edge on the north to about 1300 feet near its southern border, only slightly thicker than the Chesterian Series (fig. M-26). The Pope Megagroup is roughly equivalent to the Chesterian Series, but it includes the Spar Mountain Member of the Ste. Genevieve (Valmeyeran) to the north and the Aux Vases (Valmeyeran) in most of its extent. Near its southeastern border the base of the Pope is locally a little higher than that of the Chesterian. The Pope is generally conformable on the Mammoth Cave Megagroup, except for minor erosional channels at the base of the Aux Vases Sandstone. It is separated from the overlying Pennsylvanian System by a major unconformity that has a relief of as much as 450 feet.

Aux Vases Sandstone

The Aux Vases Sandstone (Keyes, 1892, p. 295) is named for the Aux Vases River in Ste. Genevieve County, Missouri, and the type section consists of outcrops in the Mississippi River bluffs at the mouth of the Aux Vases River (N1/2 NW1/4 13, 37N-9E). The Aux Vases consists of sandstone, siltstone, and minor amounts of shale and, locally, dolomite and limestone. It occurs in much

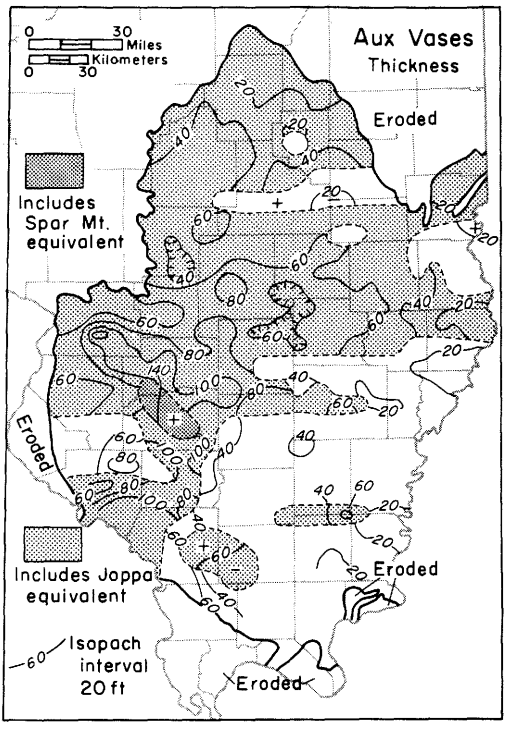

Fig. M-23—Thickness of the Aux Vases Sandstone.

of the area of the Chesterian Series (fig. M-23). It crops out along the Mississippi River Valley in St. Clair, Monroe, and Randolph Counties, being particularly well exposed in the bluffs 2-3 miles southeast of Prairie du Rocher, Randolph County. In southern Illinois it crops out principally in Union, Johnson, and Hardin Counties. The thickness map of the Aux Vases (fig. M-23) shows discontinuities because in some areas the base is dropped to include the equivalents of the underlying Joppa Member of the Ste. Genevieve Limestone where the Joppa grades to sandstone and shale. In a much smaller area, the base is dropped to include equivalents of the Spar Mountain Sandstone Member where the Karnak Member lenses out or grades to sandstone (Swann and Atherton, 1948; Swann, 1963). In the area where the Joppa Member is present, all of the Aux Vases is assigned to the Rosiclare Sandstone Member. In southeastern Illinois the Aux Vases is commonly 20-40 feet thick, but north and west of there, where it includes Joppa equivalents, it is 60-80 feet thick. It thickens to the west and reaches a maximum of 130-160 feet in the small area where it includes Joppa and Spar Mountain equivalents. The sandstone is light gray to greenish gray, locally pink or red, hematitic, calcareous, very fine to fine grained. In many places it grades to coarse siltstone. Lenses of brown dolomite occur in the lower part. The shale in the Aux Vases is dark gray and sandy, and the siltstone is green or gray. Where it includes Joppa equivalents, the Aux Vases commonly contains beds or lenses of gray, yellow, brown, pink, or red oolitic limestone.

Rosiclare Sandstone Member—The Rosiclare Sandstone Member of the Aux Vases Sandstone (Ulrich and Smith,

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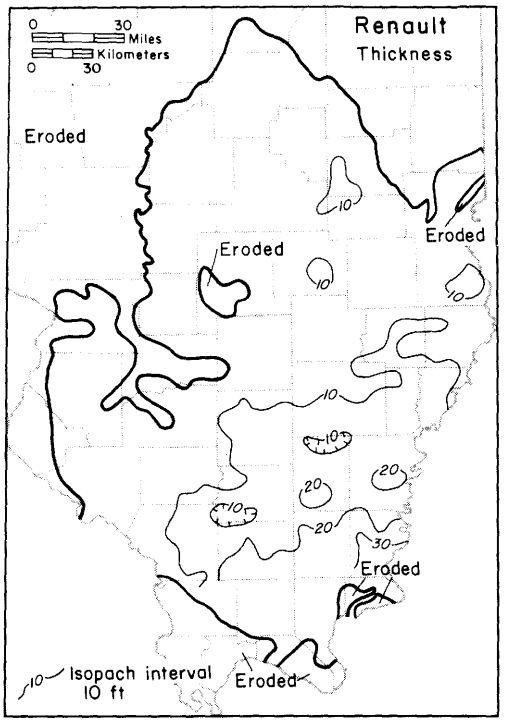

Fig. M-24—Thickness of the Renault Limestone.

1905, p. 24, 40; Swann, 1963, p. 80) is named for Rosiclare, Hardin County; its type section is in the Ohio River bluffs just below the town (NW SE and SW SE 5, 13S-8E). As originally defined, the Rosiclare Sandstone was a member of the Ste. Genevieve Limestone, and the name was widely misapplied to the sandstone now called the Spar Mountain Sandstone Member of the Ste. Genevieve. However, the type Rosiclare was found to be equivalent to the Aux Vases Sandstone (Swann and Atherton, 1948; Swann, 1963). The Rosiclare Sandstone has long been correctly correlated throughout the eastern part of the Illinois Basin, where it is an important oil producer. Consequently, the name "Rosiclare" is retained for a member of the Aux Vases. The Rosiclare is the main body of the Aux Vases in the area where it overlies the Joppa Member of the Ste. Genevieve and, therefore, does not include lateral equivalents of the Ste. Genevieve Limestone. It is commonly 20-40 feet thick.

Cedar Bluff Limestone Group

The Cedar Bluff Limestone Group (Swann, 1963, p. 63) is named for the quarry of the Cedar Bluff Limestone Company, formerly the Ohara quarry, southeast of Princeton, Caldwell County, Kentucky (S1/2 21-H-20). It consists of the Downeys Bluff, Yankeetown, and Renault Formations in areas where these formations are dominantly limestone (fig. M-25). It occurs in southeastern Illinois and is exposed in Hardin County. It was originally called the Ohara Limestone, but the name Ohara is widely used for the Karnak Member of the Ste. Genevieve in the subsurface. The Valmeyeran-Chesterian contact falls within the Cedar Bluff Group at the top of the Levias Limestone Member of the Renault Formation.

Renault Limestone

The Renault Limestone (S. Weller, 1913, p. 120, 122; Swann, 1963, p. 79), the lower part of which is Valmeyeran in age and the upper part Chesterian, is named for Renault Township, Monroe County, and the type section consists of exposures in the valley of Horse Creek. A typical exposure 4 miles northeast of the village of Renault on the south side of Dry Fork (SE SW 23, 4S-9W) is accepted as the type section (Swann, 1963). The interbedded sandstone and shale unit overlying the limestone portion in the type area was originally regarded as the upper part of the Renault but now is assigned to the Yankeetown. The Renault is a widespread, relatively thin formation, averaging only about 8 feet thick (fig. M-24), but it ordinarily stands out as a high-resistive unit on electric logs. The Renault thickens to more than 40 feet in part of Johnson County. It consists of a lower relatively pure limestone, the Levias Member (Valmeyeran), and an upper sandy limestone, the Shetlerville Limestone Member (Chesterian), which in turn includes a persistent sandstone bed (Popcorn Sandstone Bed) at its base. In some earlier reports the Levias Member was miscorrelated with strata below the Aux Vases Sandstone and it was therefore classified as a member of the Ste. Genevieve Formation.

Levias Limestone Member—The Levias Limestone Member of the Renault Formation (Sutton and J. M. Weller, 1932, p. 430, 439) is named for Levias, Crittenden County, Kentucky, and the type locality is just east of the town (10-J-16). It was originally the uppermost member of the Ste. Genevieve Limestone and was introduced as a replacement of the earlier name "Lower Ohara," but it was assigned to the Renault Limestone when it was found to overlie the Aux Vases Sandstone. The Levias is well developed in and near Hardin County, but north and west of there it is not easily distinguished and it is recognized only sporadically north of Lawrence County and west of Franklin County. In Hardin County the Levias commonly is 10-25 feet thick, but it has a maximum thickness of 35 feet. The limestone is relatively pure, cross-bedded, medium- to coarse-grained, white oolite containing some pink and light green ooliths. It contains some fine-grained limestone, and a few feet at the base is sandy. The Levias Limestone contains *Platycrinites penicillus* and is the top of the Valmeyeran Series.

Shetlerville Limestone Member—The Shetlerville Limestone Member of the Renault Formation (S. Weller, *in* S. Weller et al., 1920, p. 123; Swann, 1963, p. 82) is named for Shetlerville, Hardin County. Weller designated it a formation, citing exposures of about 30 feet of limestone just east of Shetlerville as the type section. Swann (1963) put the upper shaly part in the Yankeetown, restricted the Shetlerville to 15 feet of limestone exposed in a quarry one-fourth of a mile south of Shetlerville (SE NE SW 35, 12S-7E), and classified it as a member of the Renault. Most of the limestone is dark greenish or brownish gray, sandy, and oolitic. The basal portion grades to sandstone and is named the Popcorn Sandstone Bed. Some beds are light colored and resemble the underlying Levias Member. The basal contact is sharp and may be unconformable. The Shetlerville contains the crinoid *Talarocrinus* (fig. M-4) and is the basal part of the Chesterian Series.

Popcorn Sandstone Bed—The Popcorn Sandstone Bed in the base of the Shetlerville Member of the Renault Limestone (Swann, 1963, p. 32) is named for Popcorn Spring, 700 feet

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north of Popcorn Church in Lawrence County, Indiana (SE SE SW 5, 6N-2W), where it forms the base of the Paoli Formation. It is a bed of sandstone, shale, or impure limestone a few inches or a few feet thick. It occurs in Hardin County, but it is not widely recognized in Illinois.

CHESTERIAN SERIES

The Chesterian Series (Worthen, 1860, p. 312-313; Swann, 1963, p. 20), the uppermost series of the Mississippian System, is named for Chester, Randolph County, where it is well exposed in the bluffs of the Mississippi River. It was originally called the Kaskaskia Limestone (Hall, 1857) and the *Archimedes* Limestone (Swallow, 1858) before it was named the Chester Limestone. Later it was made the Chester Group, and since 1948 has been the Chesterian Series (J. M. Weller et al., 1948). The Aux Vases Sandstone, long considered to be the base of the Chesterian, is excluded from the series because it is in the *Platycrinites penicillus* Zone near the top of the Valmeyeran Series (Swann, 1963).

The Chesterian Series consists of limestone-shale formations alternating with sandstone-shale formations (fig. M-25). It extends from the major unconformity at the base of the Pennsylvanian System (sub-Absaroka unconformity) down to the base of the Shetlerville Member of the Renault Formation, which is the top of the Valmeyeran Series.

The Chesterian Series occupies much of the southern half of Illinois (fig. M-26). It is a little more than 1400 feet thick in Johnson County in the southern part of the Illinois Basin and thins outward to its truncated edge. The thickness pattern reflects sub-Pennsylvanian valleys that generally run from northeast to southwest and cut into the Chesterian rocks. Chesterian strata crop out in western and southern Illinois from near Valmeyer south to Grand Tower and then eastward through Hardin County to the Ohio River.

The Chesterian Series is subdivided into three stages, the Gasperian (below), Hombergian, and Elviran (Swann, 1963). These units were derived from the New Design, Homberg, and Elvira Groups, which had been used like provincial time-stratigraphic units (figs. M-27 and M-28). The series includes five groups, 20 formations, and 14 members, and it forms the major part of the Pope Megagroup (fig. 14).

Many of the Chesterian limestones and shales are abundantly fossiliferous. The sandstones are much less fossiliferous, but contain some plant fossils. Coals, a few inches thick at most, occur in some of the Chesterian sandstones. Many of the limestones contain abundant crinoidal fragments, and the series is characterized by the presence of *Talarocrinus*, which distinguishes it from the underlying Valmeyeran containing *Platycrinites penicillus*. Blastoids and the corkscrew bryozoan, *Archimedes*, are common and characteristic (fig. M-4). Several conodont assemblage zones, shown in figure M-25, are useful in differentiating Chesterian rocks (Collinson et al., 1971).

Many of the Chesterian formations have distinctive characters on electric logs (fig. M-29), but the sandstone bodies, although widely traceable, have great lenticularity (fig. M-30).

The clastic sediments in the Chesterian Series were transported by the ancient Michigan River from the northeast and were deposited in deltaic bodies in the marine embayment in the Illinois Basin (Potter, 1962a; Swann, 1963, 1964). The alternation of limestone and sandstone formations resulted from lateral shifts in the mouth of the river and in the position of the shoreline (fig. M-31) during the progressive sinking of the basin (fig. M-32).

On the thickness maps of the Chesterian Series, the eroded margins of the formations from Alton, Madison County, south and east to the Ohio River in Hardin County are largely at the present surface, but the margins trending northeast across the state from the Mississippi Valley are beneath Pennsylvanian strata.

Gasperian Stage

The Gasperian Stage (Swann, 1963, p. 21-22, 67), the oldest stage of the Chesterian Series, is derived from the Gasper Limestone of Kentucky (Butts, 1917), which is named for the Gasper River, northwest of Bowling Green, Kentucky. It includes rocks from the base of the Shetlerville Member of the Renault Limestone to the top of the Beech Creek Limestone (fig. M-25). The upper part of the Cedar Bluff Group is included in the Gasperian, but the lower part is Valmeyeran and the group was described under Valmeyeran. Sandstone predominates in the Gasperian Stage. In the Anna district of southwestern Illinois, sandstone of the Cypress alone constitutes about half of the Gasperian Stage. In the fluorspar district, where the Gasperian Stage is about 300 feet thick, about 200 feet is sandstone. Marine fossils occur in limestones

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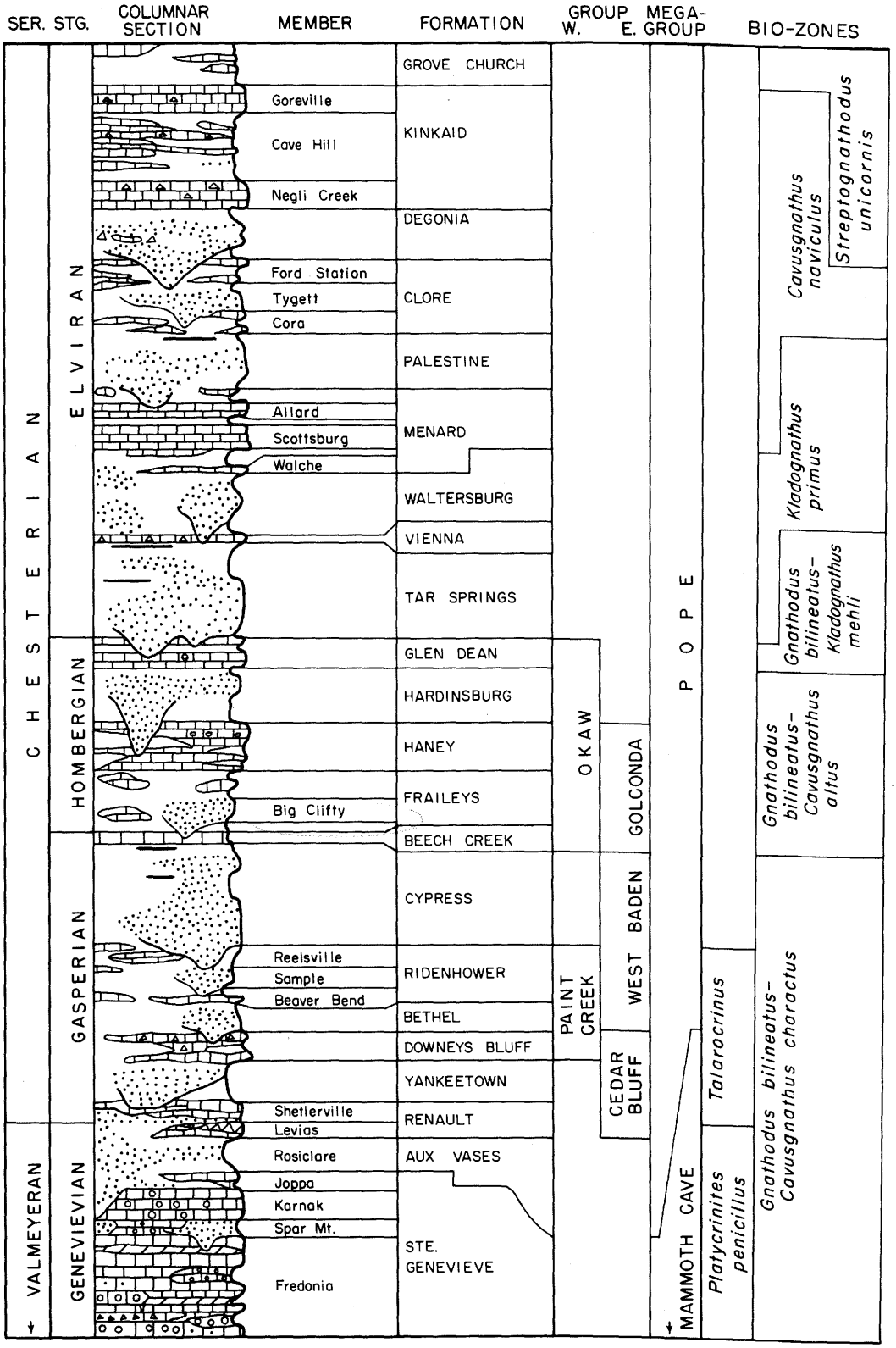

Fig. M-25—Columnar section of the Chesterian Series (after Swann, 1963), showing biozones (after Collinson et al., 1971). In the columnar section, the blank areas are shale.

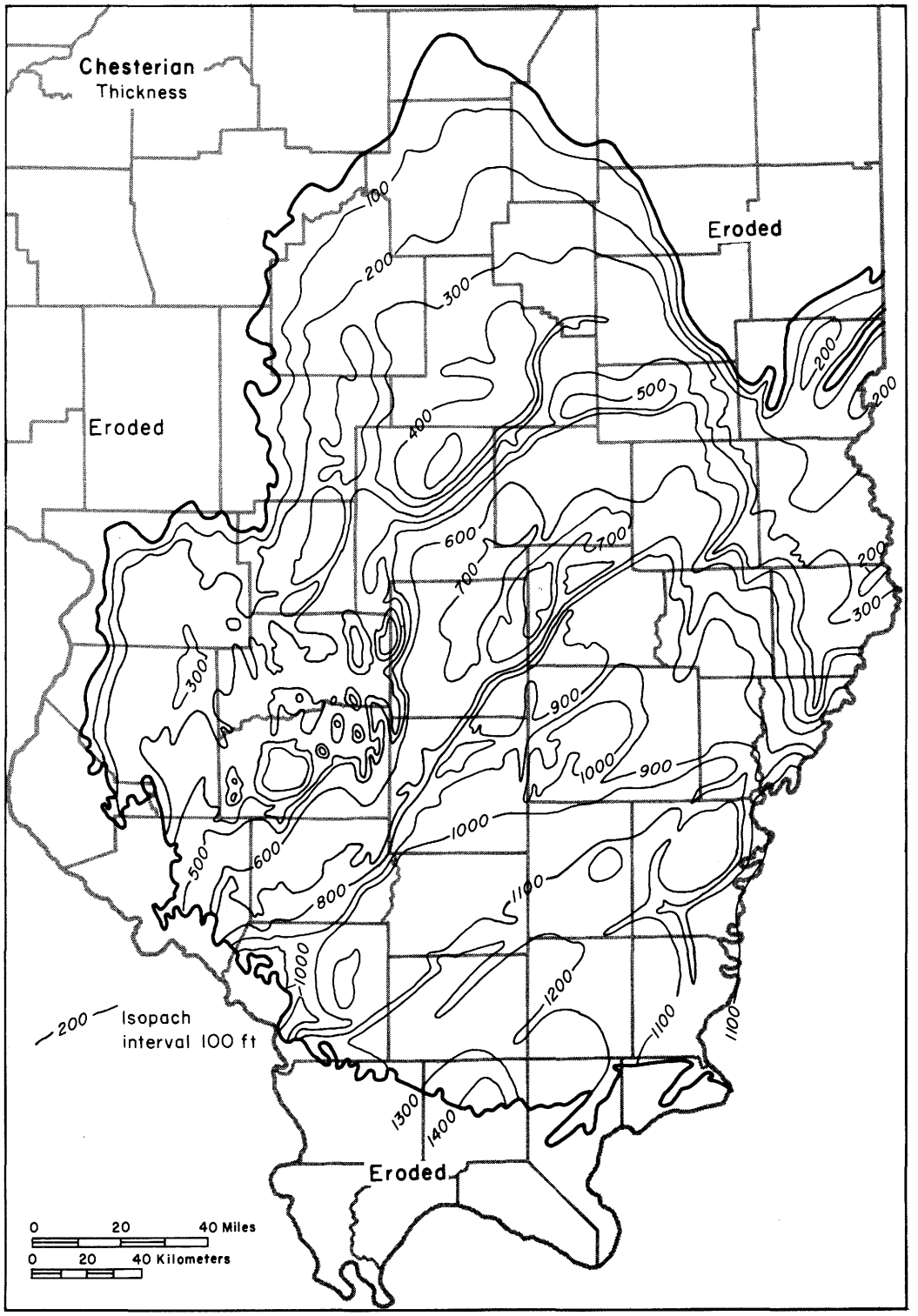

Fig. M-26—Thickness of the Chesterian Series.

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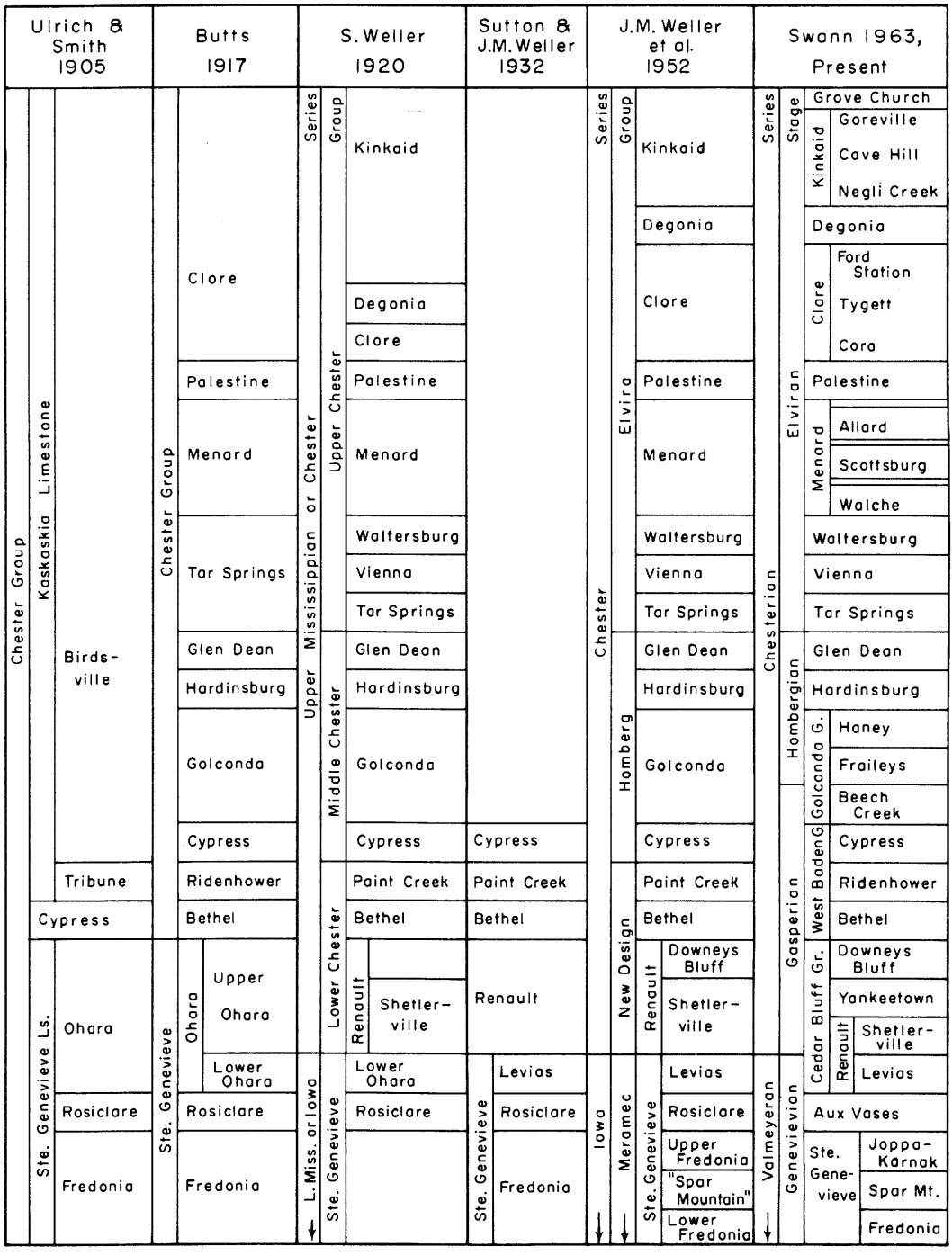
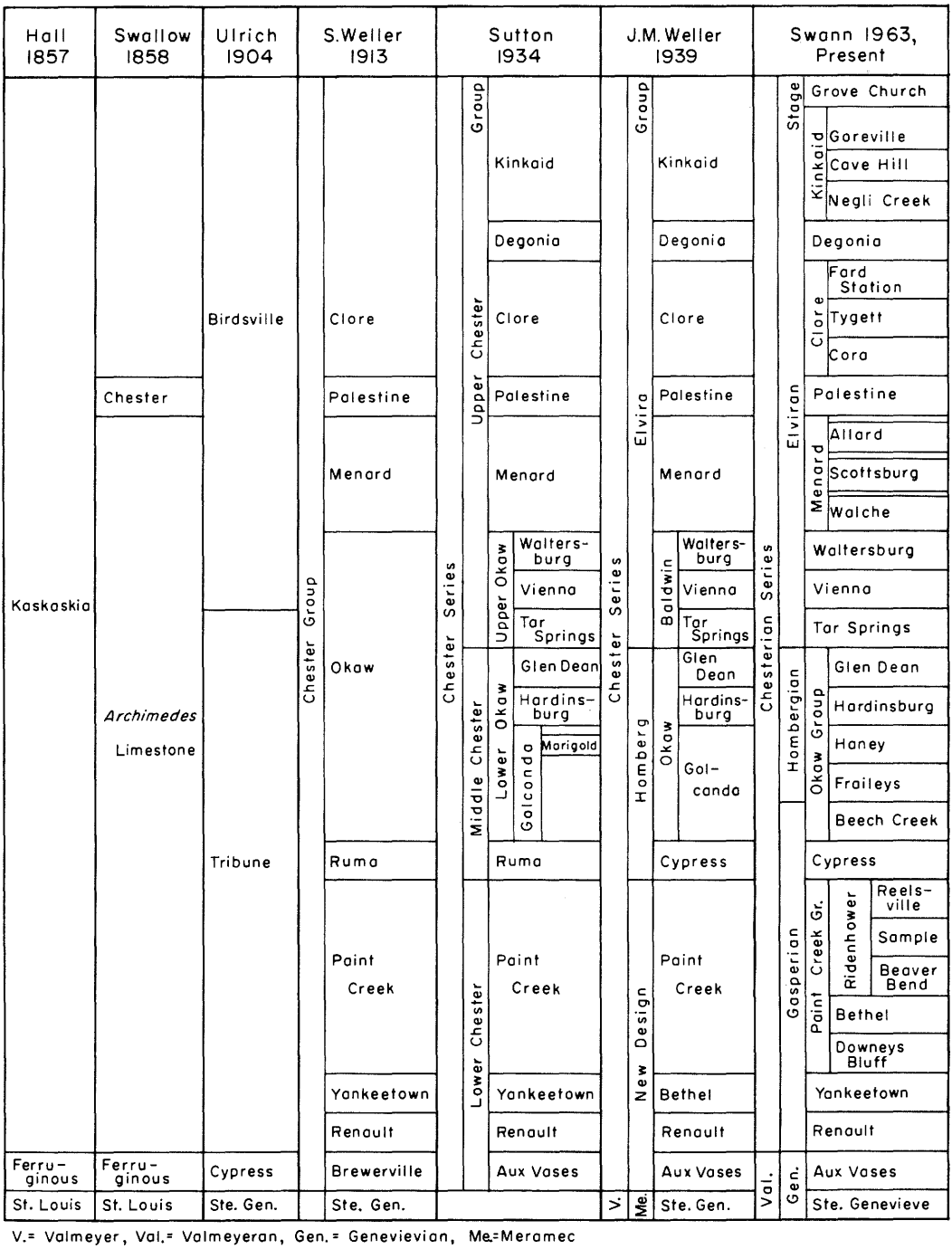


Fig. M-27—Development of the classification of the Chesterian Series in southeastern Illinois—the Fluorspar District (after Swann, 1963).



V.= Valmeyer, Val.= Valmeyeran, Gen.= Genevievian, Me.=Meramec

Fig. M-28—Development of the classification of the Chesterian Series in southwestern Illinois—the Chester District (after Swann, 1963).

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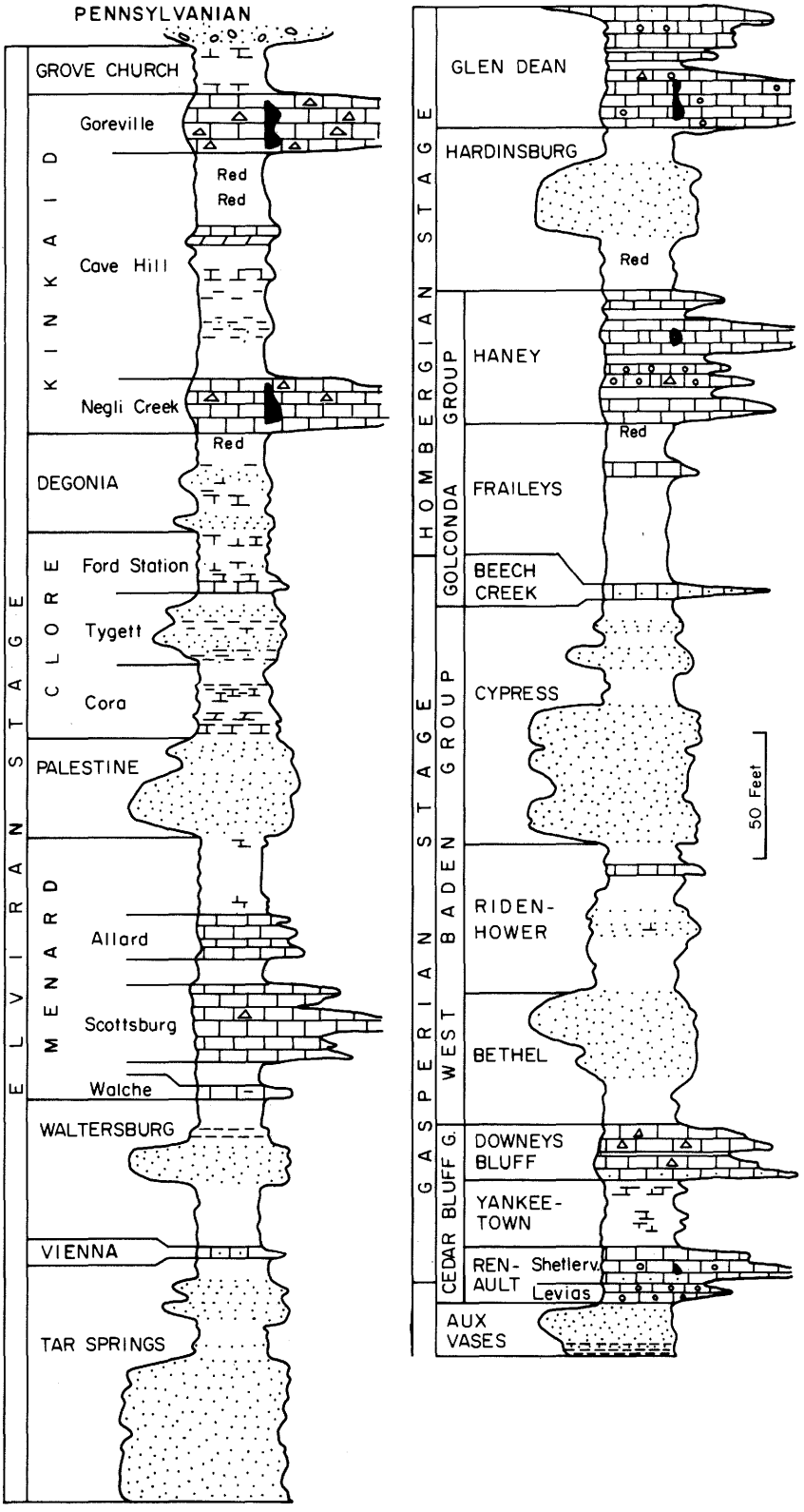

Fig. M-29—Typical electric log of the Chesterian Series.

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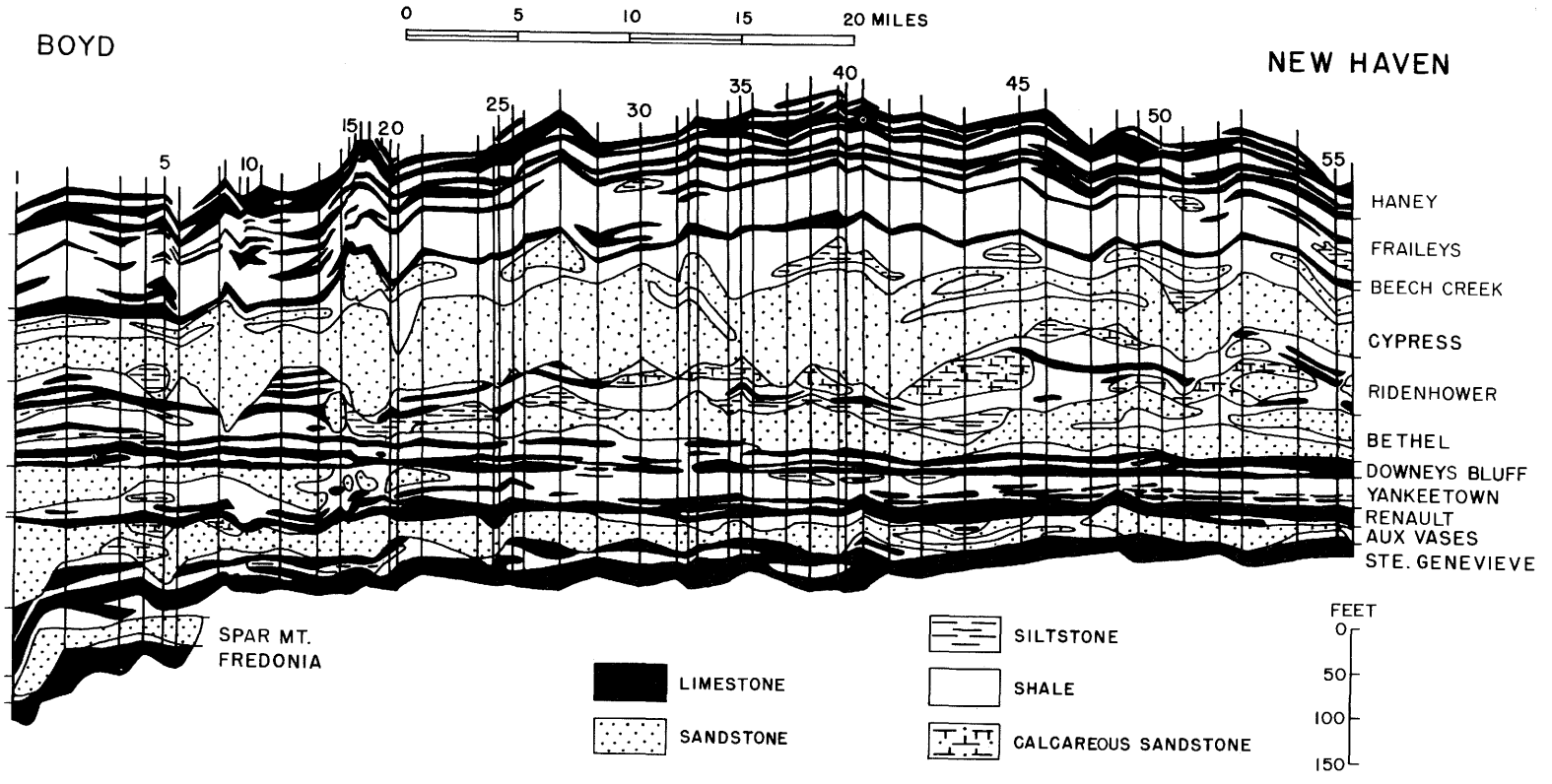

Fig. M-30—Cross section of the lower Chesterian strata between Boyd, Jefferson County, and New Haven, Gallatin County (after Swann and Atherton, 1948).

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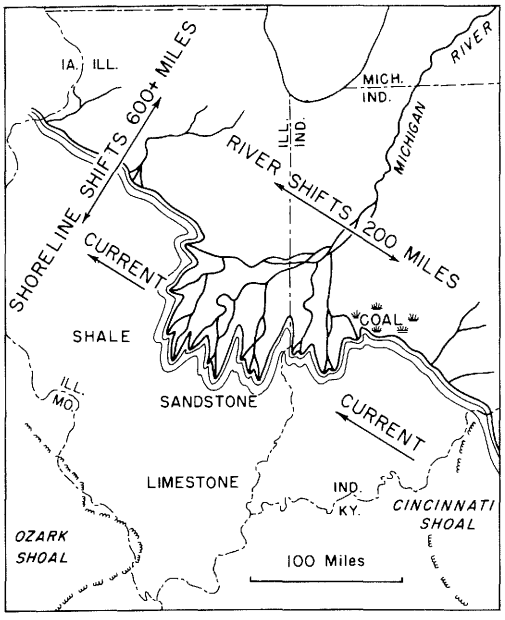

Fig. M-31—Paleogeography at an intermediate stage during Chesterian sedimentation (after Swann, 1963).

and shales of the Paint Creek Group and the Renault Limestone. The bryozoan *Cystodictya labiosa* Zone and the crinoid *Talarocrinus* Range Zone are the most definitive faunal zones of the Gasperian Stage, although the *Talarocrinus* Zone does not include the Beech Creek Limestone.

Yankeetown Sandstone

The Yankeetown Sandstone (S. Weller, 1913, p. 120) is named for Yankeetown School, Monroe County, near which the type section (NE cor. SE 26, 4S-9W) consists of cherty sandstone grading to chert. The Yankeetown is a sandstone-shale unit in western Illinois that grades into a limestone-shale unit in eastern Illinois. Although only about 20 feet thick in the outcrop area, it can be traced northeastward into the upper part of a thick sandstone in Washington County, where it is separated by a thin limestone (Renault) from the Aux Vases Sandstone below. As thus differentiated, the Yankeetown Sandstone includes sandstone and shale formerly regarded as being in the upper part of the Renault. The Yankeetown is about 60 feet thick in much of the central part of its extent (fig. M-33). To the north it thins to less than 20 feet, and to the south and southwest it thickens in places to a little over 100 feet. Red shale is extensively developed near the top of the Yankeetown, but other shales present are dark greenish gray, green, and variegated. The sandstone is much like that in the Bethel, mainly white or light gray to light greenish gray, very fine, angular, and incoherent. Chert occurs only in, and close to, the western outcrop belt. Southeastward the sandstone facies changes to a limestone-shale facies, the change occurring near the northwestern corner of Hamilton County (Swann and Atherton, 1948). At about the same place, the Bethel Sandstone, which is predominantly shale to the northwest, becomes predominantly sandstone to the southeast, which misled many into thinking that the Bethel and Yankeetown were equivalent (fig. M-7). The sandstone of the Yankeetown was commonly called "Benoist," and the names "Benoist" and "Bethel" were mistakenly regarded as being interchangeable. In the limestone-shale facies, most of the shales are dark greenish gray and green, with some red in the upper part. The limestones are light gray, buff, brown, or gray. Some are oolitic, some crinoidal, some silty, and some lithographic.

Paint Creek Group

The Paint Creek Group (S. Weller, 1913, p. 120; Swann, 1963, p. 76) is named for Paint Creek, a stream in Randolph County,

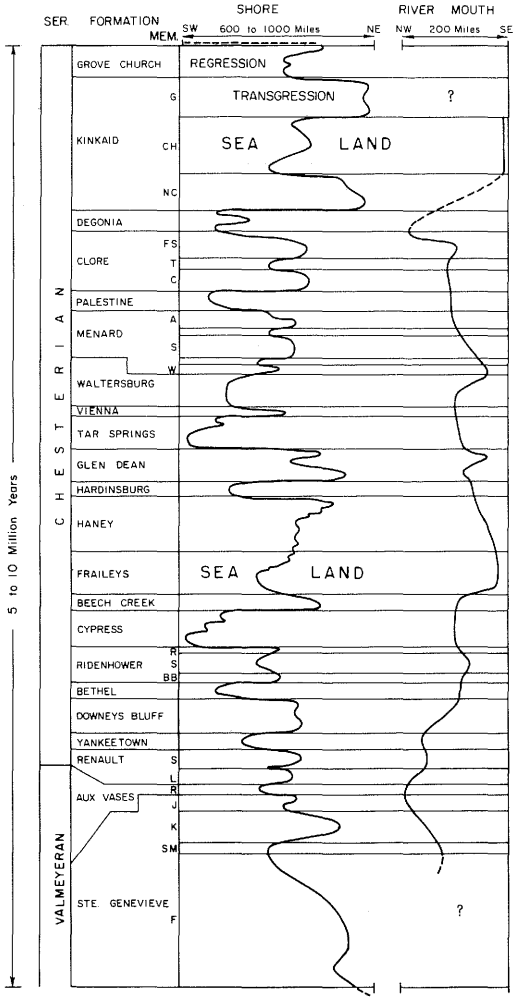

Fig. M-32—Changes in position of the shoreline and the position of the Michigan River during late Valmeyeran and Chesterian times (after Swann, 1963).

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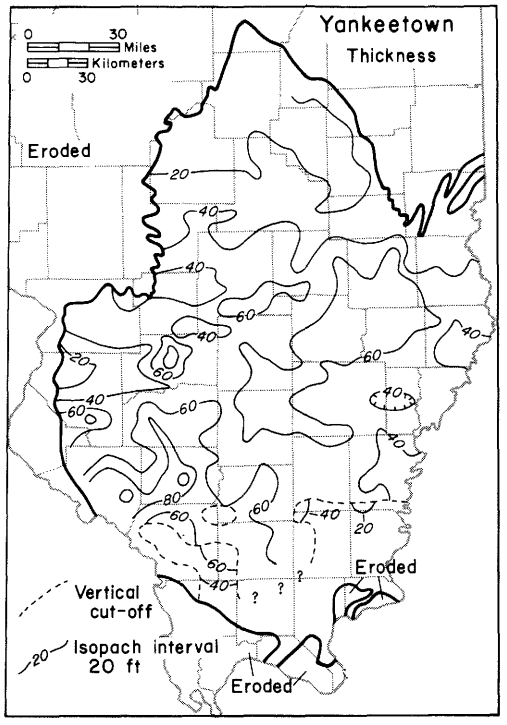

Fig. M-33—Thickness of the Yankeetown Sandstone.

and the type section is along a tributary west of McCuen School (E1/2 2, 5S-9W). It is recognized only in western Illinois, where it is dominantly shale and limestone and consists of the Downeys Bluff, Bethel, and Ridenhower Formations (fig. M-25). Although the Bethel is normally a sandstone, it is shale in that area and includes a bed of bright red shale. The name was formerly used in southeastern Illinois for the strata now included in the Ridenhower Formation.

Downeys Bluff Limestone

The Downeys Bluff Limestone (Atherton, 1947, p. 129) is named for Downeys Bluff, Hardin County, and the type section is in a bluff along the Ohio River (NW SE 5, 13S-8E). It was originally regarded as a member of the Paint Creek Formation in southwestern Illinois and of the Renault Formation in southeastern Illinois, but it was later traced across the Illinois Basin (Dana and Scobey, 1941). It is now a formation at the base of the Paint Creek Group in southwestern Illinois and at the top of the Cedar Bluff Group in southeastern Illinois (fig. M-25). The Downeys Bluff generally is 20-30 feet thick in Gallatin, Saline, and parts of Jackson and adjacent counties (fig. M-34), where it consists of two limestone benches separated by a thin shale. Elsewhere the Downeys Bluff consists of only the upper of the two benches, generally 5-10 feet thick but locally 10-20 feet thick. Where two benches of the Downeys Bluff are present, the upper is typically cherty and the lower is slightly silty or very finely sandy. Limestone of the Downeys Bluff is white or light brownish gray and crinoidal. Many crinoid segments are replaced by pink chert. The pink crinoids are an excellent diagnostic characteristic that is better developed in the western than in the eastern part of Illinois.

West Baden Group

The West Baden Group (Cumings, 1922, p. 514; Gray et al., 1960, p. 44) is named for West Baden, Orange County, Indiana, and consists of the Bethel, Ridenhower, and Cypress Formations. It occurs in southeastern Illinois and is most useful in an area where the Ridenhower is dominantly sandstone and separation of the formations is difficult—in places impractical (Swann, 1963).

Bethel Sandstone

The Bethel Sandstone (Butts, 1917, p. 63-64) is named for Bethel School, 3.5 miles west of Marion, Crittenden County, Kentucky. It is dominantly sandstone in much of Illinois, but it grades to shale to the west. The Bethel is 20-40 feet thick in much of its northwestern area (fig. M-35), but locally it is thinned by pre-Cypress erosion. The formation thickens to the southeast, reaching just over 100 feet in eastern Gallatin County. The sandstone of the Bethel is, in general, the coarsest grained of the Chesterian sandstones. Locally, it includes a few small quartz pebbles and a basal conglomerate of limestone and shale pebbles. Most of the sandstone is light gray to light

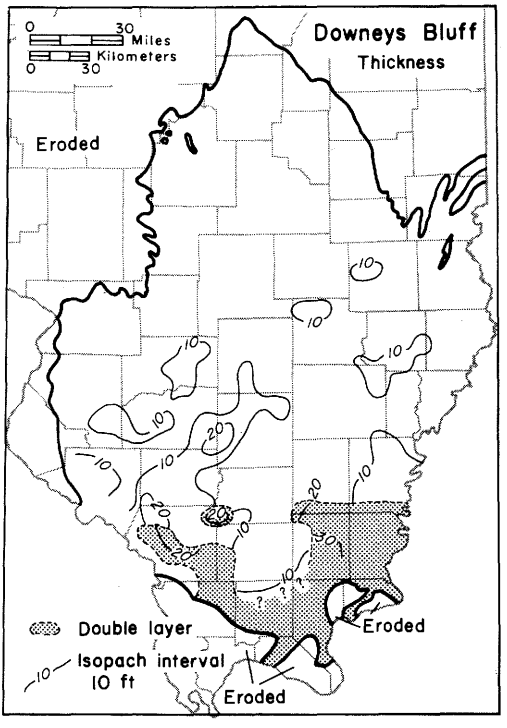

Fig. M-34—Thickness of the Downeys Bluff Limestone.

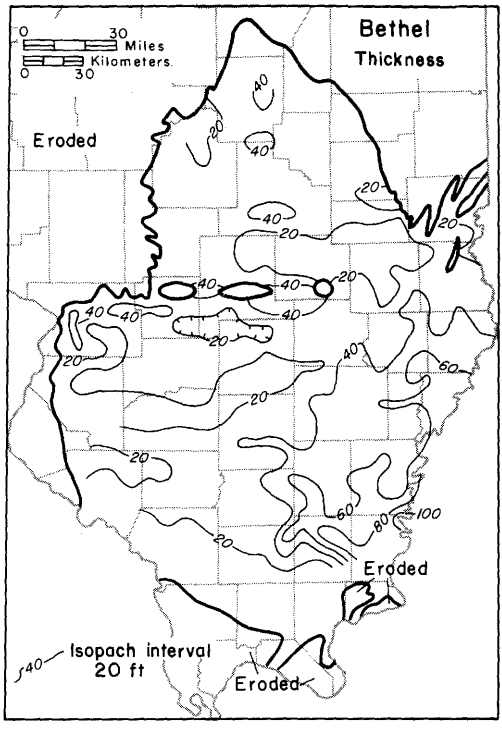

Fig. M-35—Thickness of the Bethel Sandstone.

greenish gray, but a few thin lenses are green or medium gray. Dark greenish gray shale partings are common, and some contain carbon and mica flakes. As the sandstone grades westward to shale, red and green shales become more noticeable. Along the outcrop belt in southwestern Illinois, a persistent bed of deep red, structureless clay about 15 feet thick is prominent. In places, numerous fragmentary plant fossils, including *Lepidodendron*, are present.

Ridenhower Formation

The Ridenhower Formation (Butts, 1917, p. 73) is named for Ridenhower School, Johnson County, and the type section is at Indian Point, 5 miles south of Vienna (SE SW 32, 13S-3E), where the formation is 60 feet thick and consists of shale with beds of fossiliferous limestone. The formation is a markedly varied unit that is mainly shale but contains beds of limestone and sandstone. It occurs between two clastic formations, dominantly sandstone. Locally, in parts of central and eastern Illinois, the formation is subdivided into the Beaver Bend Limestone Member (below), the Sample Sandstone Member, and the Reelsville Limestone Member, but in most of Illinois these units cannot be differentiated. They are well developed in Indiana and Kentucky, where they were named. The average thickness of the Ridenhower Formation in southern Illinois is about 33 feet, but at several places it is more than 80 feet thick (fig. M-36). The contact of the Ridenhower with the overlying Cypress Sandstone is generally sharp. In some places the Ridenhower is absent and the Cypress rests on the Bethel Sandstone. The shale of the Ridenhower is mainly dark greenish gray, but red, green, and brown shales are common. Much of the shale is calcareous and fossiliferous. The limestone includes sandy, oolitic, crinoidal, and lithographic beds, most of which are light to dark gray and brown, but buff, green, pink, and yellow beds are present. Some distinctive beds can be traced for several tens of miles. The proportion of limestone in the formation increases westward, so that near its western limit the formation is almost all limestone. In contrast, the proportion of sandstone is greatest in southeastern Illinois from Hardin County north-northeast along the Wabash River. The fauna of the Ridenhower resembles that of the Renault. The bryozoans *Cystodictya* and *Archimedes* and the blastoid *Pentremites* are common.

Beaver Bend Limestone Member—The Beaver Bend Limestone Member of the Ridenhower Formation (Malott, 1919, p. 9-10), the lowermost member, is named for a prominent bend in Beaver Creek, Lawrence County, Indiana, and the type section is a railroad cut half a mile east of Huron. The Beaver Bend is classified as a formation in Indiana. It consists of limestone and shale, and in southeastern Illinois it can be differentiated from the Reelsville Member only locally, where the intervening Sample Sandstone is present.

Sample Sandstone Member—The Sample Sandstone Member of the Ridenhower Formation (Butts, 1917, p. 70-73), the middle member, is named for the town of Sample, Breckenridge County, Kentucky, and the type section is in a railroad cut on the north bank of Sinking Creek, 1 mile east of Sample. The Sample Sandstone Member is dominantly sandstone and shale. It occurs locally in southeastern Illinois.

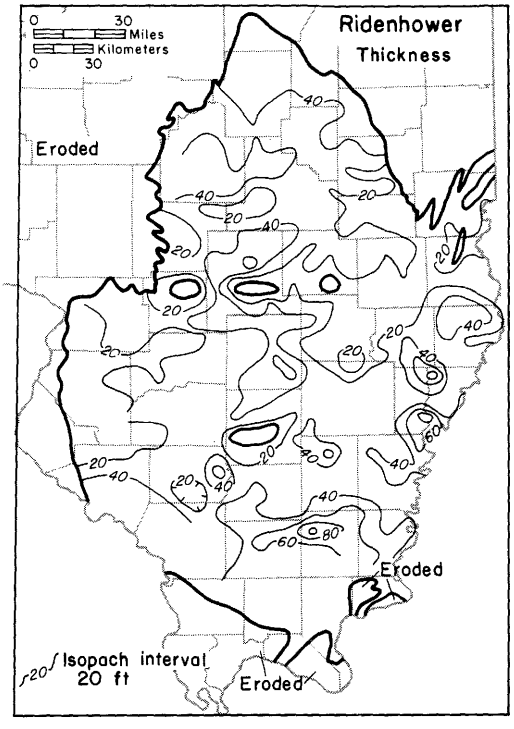

Fig. M-36—Thickness of the Ridenhower Formation.

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Reelsville Limestone Member—The Reelsville Limestone Member of the Ridenhower Formation (Malott, 1919, p. 10-11), the uppermost member, is named for Reelsville, Putnam County, Indiana, and the type section is on the Eel River, just south of Reelsville, where the member is 2.5 feet thick. It is classified as a formation in Indiana. It is dominantly limestone but contains beds of shale. It is not differentiated in the type section of the Ridenhower Formation, and it has limited distribution in southeastern Illinois, mostly in subsurface. The *Agassizocrinus* cf. *leavis* Peak Zone is equivalent to the Reelsville Member.

Cypress Sandstone

The Cypress Sandstone (Engelmann, 1863, p. 189-190) is named for Cypress Creek, Union County, and the type section is in bluffs along the creek about 6 miles southeast of Anna (T12 and 13S-1E). The name Ruma, now abandoned, was given to equivalent strata in Randolph County (S. Weller, 1913). The Cypress and the Tar Springs Sandstone are the thickest and most persistent sandstone formations of the Chesterian Series. In the central part of southern Illinois, the Cypress is generally well over 100 feet thick, and it reaches 200 feet thick (fig. M-37). It thins outward from that area, and it is only 20-30 feet thick near the outcrops in southern Randolph County. It varies from thick bodies of sandstone to shale and sandy shale interbedded with some thin beds of sandstone. The massive sandstone in the Cypress is white to light gray, fine to medium grained, angular, and generally friable. It makes up about half of the formation and typically is in a single body at the base of the formation. Some wells encounter two sandstone bodies, usually in the lower part of the formation, and others, mostly in the north and southwest but sporadically elsewhere, encounter only shale. Typically the upper part of the Cypress is more shaly than the lower, and commonly 5-30 feet of shale or sandy shale occurs at the top. Locally a few thin beds of sandstone lie immediately below the overlying Beech Creek Limestone. Sandstone beds near the top are generally cemented with calcite or dolomite. The shale in the Cypress is largely dark greenish gray, but some of the top beds are green, and a moderately persistent bed of red shale occurs about 10 feet below the top of the formation. In Randolph County in western Illinois, where the Cypress is almost entirely shale, the formation includes a considerable proportion of red and green shale. Beds of gray or green siltstone are present in the upper part of the Cypress, and a thin, dark green, quartzitic siltstone occurs near the top. Coal beds a few inches thick are sporadically present near the top of the Cypress, especially near its southern limit. The base of the Cypress and, to a lesser extent, surfaces in the middle part of the formation tend to parallel underlying structure more closely than they do the overlying Beech Creek Limestone, which suggests slight warping during Cypress time. Plant fossils, including *Lepidodendron* trunks, are present in the Cypress.

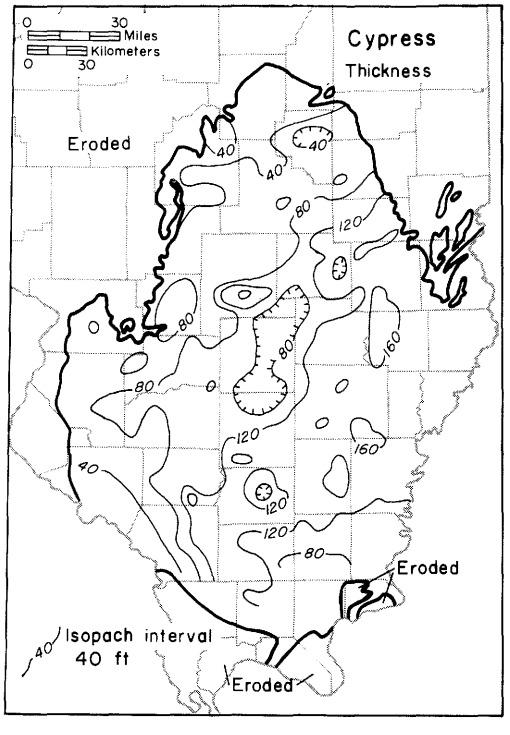

Fig. M-37—Thickness of the Cypress Sandstone.

Golconda Group

The Golconda Group (Brokaw, 1916, pl. 3; Ulrich, *in* Butts, 1917, p. 91-95; Swann, 1963, p. 68) is named for Golconda, Pope County, and the type section is in the bluffs of the Ohio River above Golconda (secs. 5, 8, 18, 13S-7E). It is a limestone-shale unit, but it has a sandstone member locally present in its lower part in the northeastern part of its area. It consists of the Beech Creek Limestone at the base, the Fraileys Shale, and the Haney Limestone (fig. M-25). The Golconda Group ranges from about 60 feet thick near its northern limit to over 180 feet near its southern limit.

Okaw Group

The Okaw Group (S. Weller, 1913, p. 120; S. Weller and J. M. Weller, 1939, p. 12; Swann, 1963, p. 76) is named for the Okaw River, now the Kaskaskia River, and the type section consists of exposures along the river in Randolph County (T4, 5, and 6S, R7 and 8W). The name is used only in western Illinois for formations from the Beech Creek through the Glen Dean (fig. M-25) in an area where the clastic units of the Hardinsburg are poorly developed and it is difficult to assign many small limestone outcrops to the proper formation.

Beech Creek Limestone

The Beech Creek Limestone (Malott, 1919, p. 11-15) is named for Beech Creek, Greene County, Indiana, and

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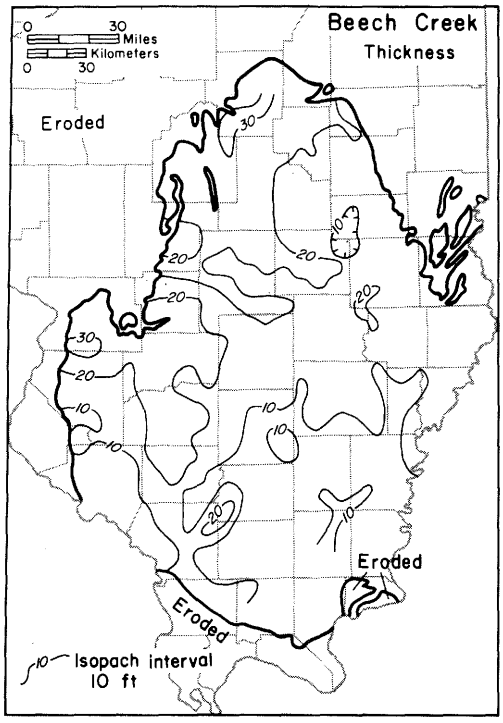

Fig. M-38—Thickness of the Beech Creek Limestone.

the type section is at the mouth of Ray's Cave, one-fourth of a mile south of Beech Creek. It is a relatively thin limestone unit, commonly called the "Barlow lime." It is very persistent and is widely used as a horizon for structure contour maps of the Illinois Basin (Bristol, 1968). The Beech Creek is unusual in that it thickens from south to north, counter to the trend of other Chesterian formations (fig. M-38). It is as much as 35-40 feet thick in the north but in areas in Hardin County it is thin, shaly, and difficult to identify. In some places the changes in thickness are abrupt and probably result from fusion of the formation with limestone beds that elsewhere are in the lower part of the Fraileys Shale. The lower part of the Beech Creek is argillaceous, dark brownish gray, dense to lithographic limestone, usually with scattered, black, rounded grains and a few fossils. The upper part is light brownish gray, fine to coarse grained, fossiliferous, and similar to much of the limestone higher in the Golconda Group. Some thin beds of oolitic limestone are present. The Beech Creek becomes somewhat sandy eastward, and in the vicnity of Saline and southern Hamilton Counties it seems to be represented locally by a bed of calcareous sandstone. *Euphemia randolphensis*, a pelecypod, and *Martinia contracta*, a brachiopod, are characteristic of some beds in the Beech Creek.

Hombergian Stage

The Hombergian Stage (Swann, 1963, p. 22, 70), the middle stage of the Chesterian Series, derived from the Homberg Group (J. M. Weller, 1939), is named for Homberg, Pope County. The Hombergian Stage includes strata from the top of the Beech Creek up to the top of the Glen Dean (fig. M-25). The limestones in this stage are typically light brownish gray, light gray, or buff to gray and many of them and their associated shales are abundantly fossiliferous. Red shales in the upper part of the Fraileys and the lower part of the Hardinsburg are extensive marker beds. The bryozoan *Prismopora serrulata* and the crinoid *Pterotocrinus* (fig. M-4) are typical Hombergian fossils.

Fraileys Shale

The Fraileys Shale (McFarlan et al., 1955, p. 18) is named for Fraileys Landing (abandoned), Hardin County, about a mile northeast of the type section in a bluff along Haney Creek (NE NE SE 9, 12S-10E), where the formation is 94 feet thick. It is dominantly shale, with minor amounts of limestone and, locally, sandstone. The Fraileys Shale is 80-100 feet thick in most of Williamson County, and it thins irregularly northward to 30-40 feet in the northern and northeastern areas (fig. M-39). Great variations in thickness within short distances have a reciprocal relation with units above and below. The Fraileys is dominantly dark gray shale. A bed of red shale a few feet below the top and a bed of siltstone just below the shale are persistent in the southern area. Limestone beds occur sporadically at numerous levels. A bed about 15 feet below the top is fairly persistent, but the others, mostly lenticular accumulations of fossil debris, thin rapidly and disappear within a short distance. Some of these beds

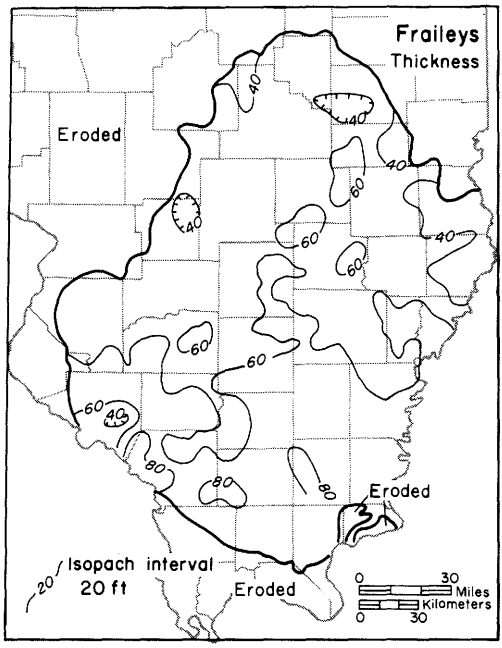

Fig. M-39—Thickness of the Fraileys Shale.

contain abundant fragments of bright red, orange, and green fossils, mainly bryozoans but also a few oolites and other detrital grains. In the north, limestone is fairly abundant locally in the Fraileys, particularly in the lower part, and in places it is difficult to distinguish limestone at the base of the Fraileys from the underlying Beech Creek Limestone. Sandstone in the Fraileys, where present in significant amount, is assigned to the Big Clifty Sandstone Member. The corkscrew-like axes of the bryozoan *Archimedes* reach a peak in number of species and abundance of specimens in the Fraileys and Haney Formations. A brachiopod faunal zone, the *"Camarophoria"—Stenoscisma explanata* Range Zone, extends from the Fraileys upward to the top of the Chesterian strata. The *Pterotocrinus capitalis* Range Zone is equivalent to the lower half of the Fraileys Shale.

Big Clifty Sandstone Member—The Big Clifty Sandstone Member of the Fraileys Shale (Norwood, 1876, p. 405) is named for Big Clifty Creek, Grayson County, Kentucky, and the type section is along the creek, 2 miles southwest of the village of Big Clifty. The Big Clifty enters Illinois from the east and wedges out within a few tens of miles. Many wells in Lawrence, northern and eastern Jasper, and southern Cumberland Counties encounter 15-20 feet of Big Clifty. It is near the middle of the Fraileys or, less commonly, near the base. A few sporadic occurrences have been found in Marion County and east of there. In Indiana the Big Clifty occupies nearly the whole of the interval represented by the Fraileys Shale in Illinois.

Haney Limestone

The Haney Limestone (McFarlan et al., 1955, p. 18) is named for Haney Creek, Hardin County. It is 35.5 feet thick in the type section, which overlies the type section of the Fraileys Shale (NE NE SE 9, 12S-10E). It is dominantly limestone, with a little interbedded shale. The formation thickens from north to south (fig. M-40). It is

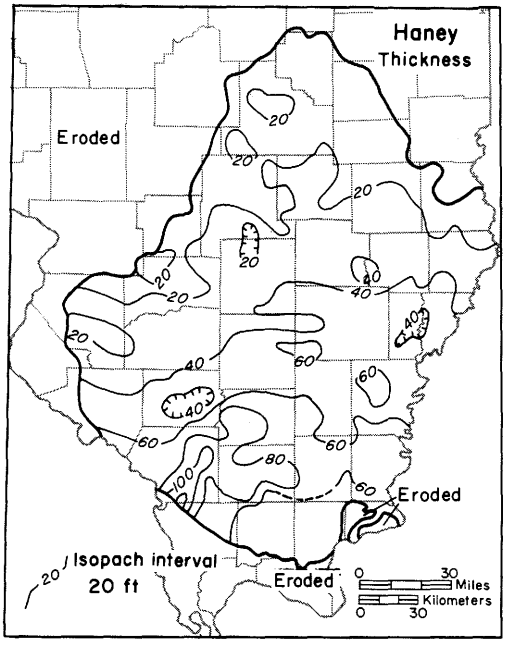

Fig. M-40—Thickness of the Haney Limestone.

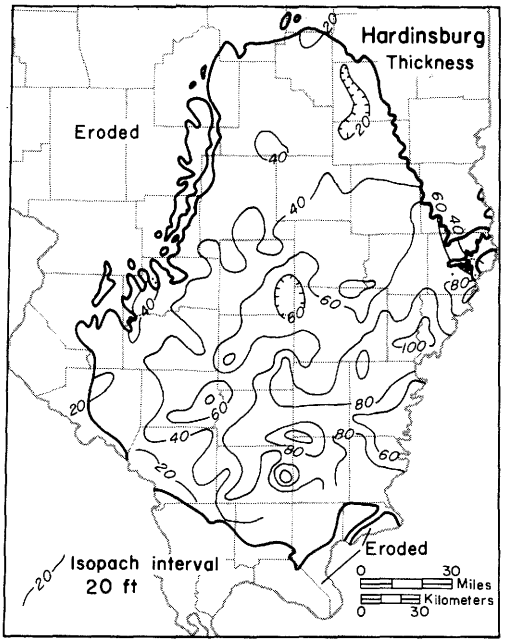

Fig. M-41—Thickness of the Hardinsburg Sandstone.

80-100 feet thick in much of Williamson County and even thicker in southern Jackson County, but it generally thins to less than 15 feet thick in Moultrie, Coles, and Cumberland Counties. In Washington County, the lower part of the Haney grades northwestward to shale, and the base of the Haney shifts to a higher horizon—the formation thinning from 60 feet or more to 35-40 feet. The limestone of the Haney is typically light gray to brownish gray or dark gray, coarse grained, and fossiliferous. Much of it is oolitic. In Randolph County a zone of white oolite about 20 feet thick in the Haney is informally called the "Marigold Oolite" (Sutton, 1934) for the village of Marigold, near which it is well exposed (SE 20, 5S-8W). In many places the oolitic beds alternate with non-oolitic beds or with shale. A little chert is commonly present in the Haney, and much of the limestone is shaly. The shale is dark gray and generally calcareous and fossiliferous. The individual limestone beds generally are markedly lenticular and are much less persistent laterally than are beds in the younger Chesterian limestones. In the southern part of the area, the Haney is characterized by an upper limestone unit about 25 feet thick, a middle shale up to 10 feet thick, and a lower limestone about 50 feet thick, the upper part of which is more shaly than the lower. To the northwest the Haney grades to a shale that cannot be readily distinguished from the overlying shale of the Hardinsburg or the underlying Fraileys.

Hardinsburg Sandstone

The Hardinsburg Sandstone (Brokaw, 1916, pl. 3; Butts, 1917, p. 23) is named for Hardinsburg, Breckenridge County, Kentucky, and it is 30 feet thick in the type section, which is near the town. It is a clastic unit commonly 50-100 feet thick but thinner to the north and west (fig. M-41). In Lawrence County, the Hardinsburg

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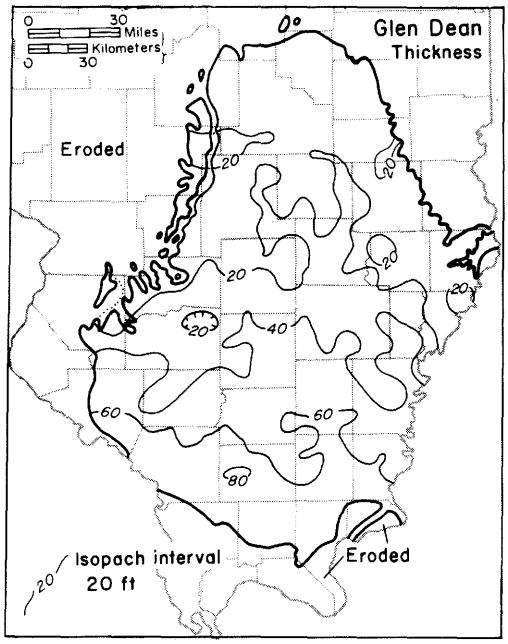

Fig. M-42—Thickness of the Glen Dean Limestone.

locally cuts entirely through the underlying Golconda Group and into the uppermost part of the Cypress Sandstone to attain a thickness of more than 240 feet. The formation has a thick-bedded sandstone facies and a thin-bedded, flaggy, shaly sandstone and shale facies, both exposed in the southern outcrop belt. Well developed sandstone bodies lens in and out of the section within fairly short distances at various horizons and locally make up almost the entire formation. The sandstone in the Hardinsburg is largely light gray, very fine grained, friable, and in part calcareous. The thick sandstone bodies are white and fine grained, whereas the thin bodies are generally gray or green and compact, some of them grading to siltstone. The sandstone bodies show a complex deltaic pattern with braids, tributaries, and distributaries (Potter, 1963). Much of the system is to the east in Indiana and Kentucky, but bifurcating arms extend into Illinois. Thin beds of coal occur locally in the upper part of the sandstone. The shale in the Hardinsburg is mainly dark gray or dark greenish gray. At the base of the Hardinsburg, red, green, and dark gray shale as much as 30 feet thick contains beds and nodules of lithographic, red and brown limestone and dolomite. In most places an erosional surface separates the shale from the upper part of the Hardinsburg, and in some places the surface cuts entirely through the shale, so that sandstone rests directly on the underlying Golconda Group.

Glen Dean Limestone

The Glen Dean Limestone (Butts, 1917, p. 97-102) is named for the town of Glen Dean, Breckenridge County, Kentucky, and the type section is in exposures along a railroad (abandoned) on both sides of the town. The Glen Dean is a limestone-shale unit that thickens from 5-15 feet in the north to 65-80 feet in the south (fig. M-42). In subsurface the top and base of the Glen Dean are put at the limits of well defined limestone strata. In the south, the Glen Dean typically has a threefold division into upper and lower limestone units separated by shale. In a few places a shale lens occurs in the lower limestone. Farther north only the lower limestone unit is generally present, and the formation is correspondingly thinner. In general, where the Glen Dean is relatively thick it contains a higher proportion of shale. The Glen Dean has fairly rapid lateral variations in thickness and in limestone-shale ratio, particularly in the upper two units, and boundaries between the subdivisions are not consistent throughout large areas. The Glen Dean is composed of limestone and various amounts of dolomite and shale. The limestone is light to medium brownish gray, coarse grained, and fossiliferous. Parts of it are oolitic and some beds are cherty. Well developed oolitic limestone is rare in younger Chesterian limestones. The shales are dark greenish gray and are generally fossiliferous. The bryozoan *Prismopora serrulata* is abundant and the blastoid *Pentremites spicatus* is also characteristic of the Glen Dean. The *Pterotocrinus acutus—P. bifurcatus* Assemblage Zone is equivalent to the Glen Dean.

Elviran Stage

The Elviran Stage (Swann, 1963, p. 23, 65), the youngest stage of the Chesterian Series, originally called the Elvira Group (J. M. Weller, 1939), is named for Elvira Township, Johnson County (12S-2E). It includes the nine formations younger than the Glen Dean Limestone (fig. M-25). The limestones of the Elviran Stage are generally darker and finer grained and contain more silt and argillaceous material and less abundant fossils than the older Chesterian limestones. Representative fossils include *Pentremites fohsi, Pterotocrinus menardensis, Composita subquadrata, Eumetria costata,* and *Sulcatopinna missouriensis.*

Tar Springs Sandstone

The Tar Springs Sandstone (Owen, 1856, p. 174; Butts, 1917, p. 103-105) is named for Tar Springs, Breckenridge County, Kentucky, and the type section is an exposure in a cliff at the town, where the sandstone is about 50 feet thick. It is one of the thickest and most persistent sandstone formations of the Chesterian Series. The Tar Springs is 75-130 feet thick for most of its extent in Illinois, thinning to about 50 feet near its northwestern limits (fig. M-43). It is locally more than 150 feet thick, and in the thicker portions the ratio of sandstone to shale is relatively high. Locally the formation is almost entirely sandstone or almost entirely shale (fig. M-1A). The sandstone is white to light gray, very fine grained to fine grained, locally medium grained, angular, and friable to well cemented. Conglomerate with coarse sand grains and limestone pebbles occurs at the base but is rare. In general, one to three well developed sandstone bodies make up a little more than half the formation. Commonly, a sandstone body occurs at the base of the formation, but sand-

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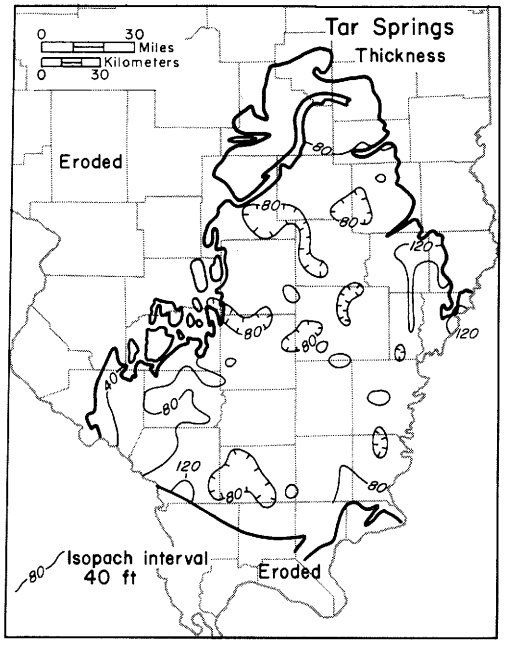

Fig. M-43—Thickness of the Tar Springs Sandstone.

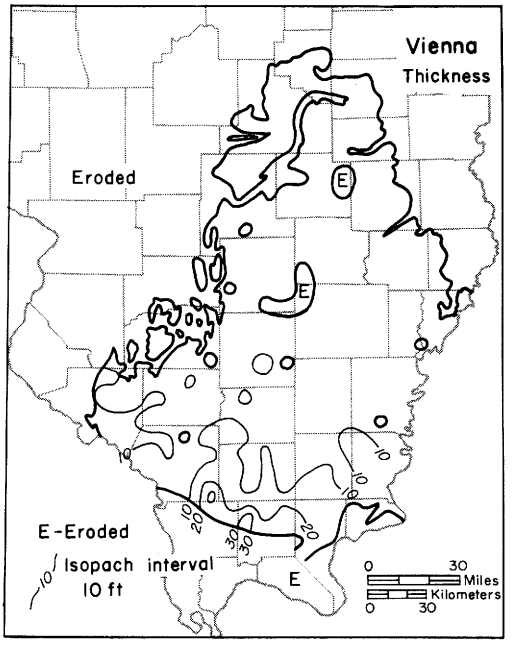

Fig. M-44—Thickness of the Vienna Limestone.

stones also occur at the middle and at the top. The sandstone bodies in the Tar Springs thicken or thin rapidly, and they have a deltaic distributary pattern similar to that of other Chesterian sandstones (Swann, 1963). The remainder of the formation is shale, siltstone, and shaly sandstone. The shale is dark gray and slightly carbonaceous. The siltstones and some of the thin-bedded sandstones are medium to dark olive gray. Commonly there is 3-15 feet of shale at the base and a little more than that at the top. Thin beds of coal occur locally near the top and middle of the formation, especially near the southern limit.

Vienna Limestone

The Vienna Limestone (S. Weller, 1920, p. 396-398) is named for Vienna, Johnson County, and the type section is in an old quarry west of the town (NE SW NW 5, 13S-3E), where the formation is 14 feet thick. It is a thin limestone, rarely more than about 8 feet thick and commonly only 3 or 4 feet (fig. M-44). However, in extreme southern Illinois the limestone thickens rapidly to 30 feet (fig. M-1A). Until recently, the calcareous shale locally present above and below the limestone bed was assigned to the Vienna (Swann, 1963). The limestone is mainly dark brownish gray, but some is brown or dark gray. It is generally very fossiliferous, with crinoid fragments predominating. It contains dark chocolate-brown chert nodules in the outcrop, but chert is rare in subsurface. Locally some beds are sandy. In places thin beds and partings of shale are interbedded with the limestone. The fauna includes the bryozoan *Prismopora serrulata*, which is also abundant in the Glen Dean, and the pelecypod *Sulcatopinna missouriensis*, which is abundant in the Menard.

Waltersburg Formation

The Waltersburg Formation (S. Weller, 1920, p. 398) is named for Waltersburg, Pope County, which is near the type section (SE cor. 17, 13S-6E). It is a clastic unit consisting mainly of shale, but it has beds of siltstone and

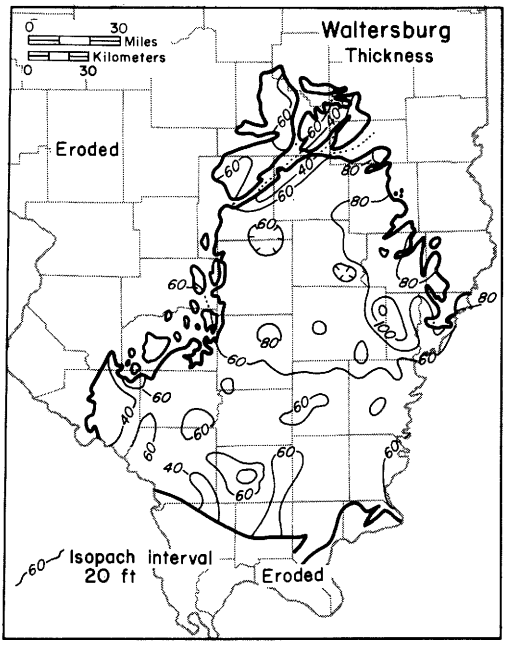

Fig. M-45—Thickness of the Waltersburg Sandstone.

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sandstone. The Waltersburg is 50-75 feet thick throughout most of Illinois (fig. M-45), but it thins to about 30 feet to the west in Randolph County and thickens to 80-100 feet to the northeast in Jasper and Richland Counties. The thickness increases at the edge of the Walche Member at the base of the Menard, where the top of the Waltersburg steps up from the base of the Walche to the base of the Scottsburg Limestone Member. The Waltersburg Formation is mainly dark gray, slightly carbonaceous shale, in part silty and sandy. Green shale occurs in the upper part of the Waltersburg, and a thin coal is present near the top of the formation close to its southern edge. In the south, some of the shale at the top and bottom of the formation is calcareous and fossiliferous, and until recently it was assigned to the Menard above or the Vienna below (Swann, 1963). The Waltersburg includes beds and laminae of dark gray and dark olive siltstone and beds of gray to white sandstone that is very fine to fine grained, locally quartzitic, and characteristically well jointed. Most of the thick sandstone bodies in the Waltersburg are within 30 miles of the Wabash River (Swann, 1951; Potter, 1963), are strongly linear, and trend northeast-southwest. They are well exposed on Bay Creek between Simpson and Grantsburg, near the Pope-Johnson county line.

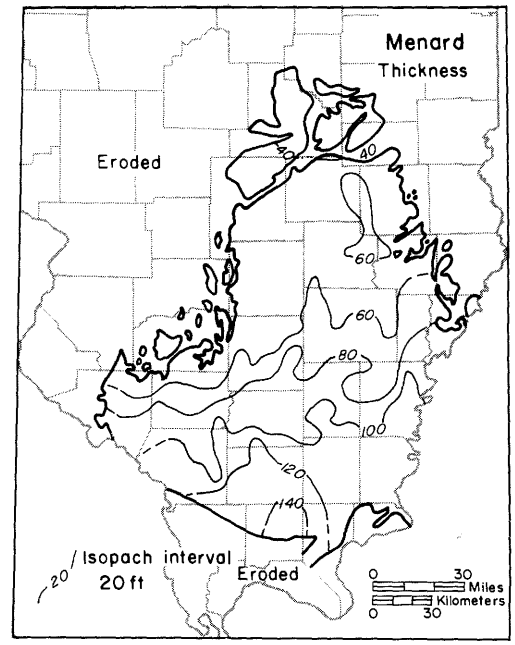

Fig. M-46—Thickness of the Menard Limestone.

Menard Limestone

The Menard Limestone (S. Weller, 1913, p. 120, 128) is named for Menard, Randolph County, where the type section is in the quarry at the Menard State Hospital (NE 23, 7S-7W). The formation is also well exposed in the Mississippi River bluffs at Menard and from Chester to Rockwood, Randolph County. It is a limestone-shale formation, generally 100-150 feet thick in the southern area, 80-100 feet in the central part, and 45-60 feet in the northern and northwestern area, beyond which it is truncated by pre-Pennsylvanian erosion (fig. M-46). The Menard is readily divisible into three limestone members—the Walche (below), the Scottsburg, and the Allard—which are separated by unnamed shale members; a third shale occurs at the top. The limestone of the Menard is argillaceous, dark brownish gray to brown and buff, dense, and fine grained to lithographic. Some beds are oolitic, and many beds contain fine to coarse, dark, rounded grains that give the rock a characteristic speckled aspect. The limestone members are more or less shaly, and they include beds of shale as thick as 5 feet. Chert is present in some places. The shale of the Menard Formation is calcareous, dark gray, and fossiliferous, and it contains thin beds and nodules of limestone. The shale between the Walche and Scottsburg Limestone Members is 3-10 feet thick in most of the area underlain by the Walche Member, beyond which it is not recognized. It thickens in the northeast to about 20 feet or more in Wabash County. The shale between the Scottsburg and Allard Limestone Members is 30-40 feet thick in the far south and thins to about 5 feet in the north. Beds of green shale and green dolomite occur in this unit, and in the south a limestone about 10 feet thick is present in the lower half. The shale at the top of the Menard is generally 20-30 feet thick in the southern part of its extent and 10-20 feet in the northern part. It includes, at the top, a bed of limestone about 5 feet thick. This bed is persistent south of about T6S, but it is generally very thin or absent farther north. Locally, especially in the north, the erosional surface at the base of the Palestine cuts into the shale and in places entirely through it. The initial appearance of *Spirifer increbescens* and *Composita subquadrata* is in the Menard (S. Weller, 1920). The pelecypod *Sulcatopinna missouriensis* is very abundant in places. The *Pentremites fohsi* Range Zone occurs in the lower part of the Menard (S. Weller, 1926).

Walche Limestone Member—The Walche Limestone Member of the Menard Formation (Swann, 1963, p. 38-39) is named for Walche's cut on the Illinois Central Railroad in Caldwell County, Kentucky, where the type section is exposed. Previously it was called the "Little Menard." It is 3-9 feet thick, generally gray to dark gray limestone, typically silty or sandy, and pyritic in part. The Walche is overlapped by the Scottsburg Member, and it is not recognized north of a curve running approximately from northern Wabash County through Wayne County to southwestern Franklin County, beyond which it appears to grade laterally into siltstone that is included in the Waltersburg Formation.

Scottsburg Limestone Member—The Scottsburg Limestone Member of the Menard Formation (Swann, 1963, p. 38-39) is named for Scottsburg, Caldwell County, Kentucky, which is 3 miles southwest of the type section in Walche's cut on the Illinois Central Railroad. It has commonly been referred to as the "Massive Menard." The member is 30-40 feet thick in the far south, but it thins northward to about 5 feet. Much of the limestone is dense and fine grained to lithographic. Some beds are dolomitic.

Allard Limestone Member—The Allard Limestone Member of the Menard Formation (Swann, 1963, p. 38-40) is named for Allard College School, Johnson County, 2.2 miles northeast of the type section, which is in a cut at the south end of the Illinois Central Railroad tunnel (SW NW NE 1, 13S-4E). The Allard Member is dominantly limestone, and it ranges from a little more than 30 feet in the far south to 10-12 feet in much of the northern area of the Menard.

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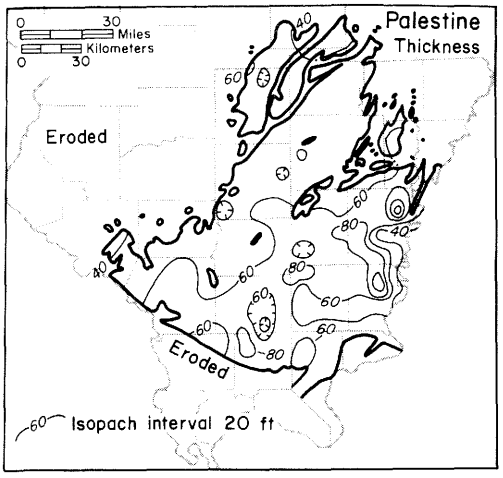

Fig. M-47—Thickness of the Palestine Sandstone.

Palestine Sandstone

The Palestine Sandstone (S. Weller, 1913, p. 120) is named for Palestine Township, Randolph County, where the type section occurs along tributaries of Tyndall Creek (29, 30, 6S-6W). It is a clastic unit that includes sandstone, shale, and siltstone. The Palestine tends to thicken southward (fig. M-47) but not as markedly as other Chesterian formations. It is commonly 50-60 feet thick, but it ranges from 25 to over 100 feet. It is thickest where massive (channel-phase) sandstone bodies are present. Much of the sandstone is gray, very fine grained, and more or less shaly. The thicker sandstone bodies are lighter colored and coarser grained, and grade to white, medium-grained sandstone. The shale is dark gray and generally silty or sandy. The siltstone is mainly dark gray with a little dark green. Much of the Palestine Sandstone is slightly carbonaceous. An underclay and coal bed mark the top of the Palestine at several localities in western Illinois (Swann, 1963). The Palestine does not have persistent traceable beds, such as characterize the younger Chesterian formations. The sandstone bodies lens rapidly in and out, but in most places the sandstone is in the upper and/or lower parts of the formation, rarely in the middle. Well developed channel sands in the lower part of the formation generally cut into the Menard Limestone. The sandstone bodies in the Palestine have the pattern of a deltaic distributary system (Potter, 1963). Fossil tree trunks of *Lepidodendron* are perhaps more common in the Palestine than in any of the other Chesterian sandstones.

Clore Formation

The Clore Formation (S. Weller, 1913, p. 120) is named for Clore School, Randolph County, and the type section is in gullies near the school (SE cor. 20, 7S-6W). The formation includes three members, a lower limestone and shale member (Cora), a middle sandstone and shale member (Tygett), and an upper limestone and shale member (Ford Station). Early geologists in places confused the Tygett Sandstone Member with either the Degonia Sandstone or the Palestine Sandstone and confined the Clore Formation to either the Cora or the Ford Station Member (Swann, 1963). The Clore is 40-60 feet thick near its northern and northwestern limits, and it thickens southward to a little more than 120 feet in parts of Pope and Johnson Counties (fig. M-48). The Clore is thinned by sub-Degonia channels in many more places than are shown in figure M-48. In several areas, sub-Pennsylvanian channels also cut into the Clore. The formation is dominantly shale throughout most of its extent, but the proportion of limestone increases southward. Near the southern outcrop belt the top is stepped up a few feet to include limestone equivalent farther north to the basal portion of the Degonia. At about the same place, the base is stepped down to include limestone equivalent to the uppermost portion of the Palestine. Fossils are generally abundant in the Clore. The fauna is made up mainly of bryozoans and brachiopods. The genera *Archimedes*, *Batostomella*, and *Rhombopora* (fig. M-4) are conspicuous among the bryozoans, and *B. nitidula* is an index fossil. The brachiopods *Spirifer increbescens* and *Composita subquadrata* are especially abundant.

Cora Limestone Member—The Cora Limestone Member of the Clore Formation (Swann, 1963, p. 40-41), the lowest member, is named for Cora, Jackson County, and the type section is near by at the mouth of Degonia Creek Hollow (SW SE 16, 8S-5W). The Cora is 15-45 feet thick. It varies from dominantly limestone to dominantly shale. In both facies it is interbedded limestone and shale and locally contains sandstone lenses. A zone in the Cora Member in which the limestone surfaces are covered with delicate branching bryozoans is the *Batostomella nitidula* Peak Zone (S. Weller, 1926).

Tygett Sandstone Member—The Tygett Sandstone Member of the Clore Formation (Swann, 1963, p. 40, 42), the middle member, is named for Tygett School, Union County, and the type section is on Bradshaw Creek, 1.5 miles north of the school (NE NW 24, 11S-1W), where it is 26 feet thick. It consists of sandstone and minor amounts of shale. *Sigillaria* trunks and fragments are common in some beds.

Ford Station Limestone Member—The Ford Station Limestone Member of the Clore Formation (Swann, 1963, p. 40, 42), the upper member, is named for the Ford Station siding of the Missouri Pacific Railroad, Randolph County, where the type section is in an abandoned quarry (NW SE

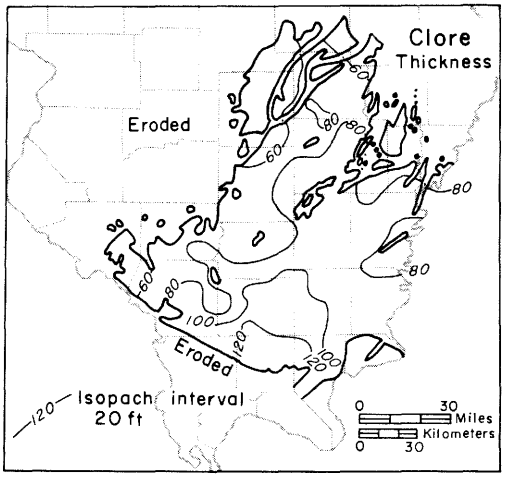

Fig. M-48—Thickness of the Clore Formation.

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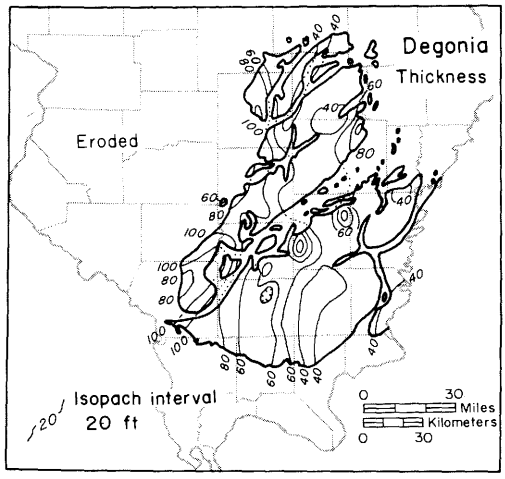

Fig. M-49—Thickness of the Degonia Sandstone.

33, 7S-6W). It is 38 feet thick in the type section but ranges from 20-50 feet thick. It consists of interbedded limestone and shale that include rare lenses of sandstone. Most of the shale in the Ford Station Member is dark gray to dark greenish gray and is generally calcareous and fossiliferous. The limestone is gray, buff, drab, or dark brownish gray, argillaceous, and shaly. Dolomite occurs irregularly.

Degonia Sandstone

The Degonia Sandstone (S. Weller, 1920, p. 281-290) is named for Degonia Township, Jackson County, where the type section is in the bluffs of the Mississippi River and small tributaries (12-16, 21-25, 8S-5W). It is a clastic unit, dominantly sandstone, that ranges from 150 feet of massive sandstone in western Illinois to as little as 20 feet of shale in the southeast (fig. M-49). Typically, it includes two well developed, lenticular beds of massive sandstone. The upper overlaps the lower and both are absent locally. Most of the shale is gray to dark gray, but an extensive bed of red shale occurs at the top of the formation. Thick elongate and thin sheet sand bodies occur in a dendritic pattern (Potter, 1963). A north-south sandstone body, locally more than 15 miles wide, is joined from the east by southwest-trending bodies that fill channel distributaries. In the thick bodies, the sandstone typically is white and fine grained (Atherton, 1947). In southwestern Illinois thin coal beds occur locally near the top and middle of the formation. The Degonia contains plant remains, with *Lepidodendron* the most common.

Kinkaid Limestone

The Kinkaid Formation (S. Weller, 1920, p. 281-290; Swann, 1963, p. 42) is named for Kinkaid Creek, Jackson County, where the type section is in exposures along the creek (SE NW NW 6, 8S-4W). It is a limestone-shale unit (fig. M-1C) and is one of the thicker Chesterian formations, commonly 120-160 feet thick. However, pre-Pennsylvanian erosion of valleys trending northeast-southwest has cut the formation, and particularly its upper member, into isolated areas (Bristol and Howard, 1971, 1974). The formation appears to have been highly resistant to erosion, because it caps the Chesterian Series in large areas, and slump blocks of Kinkaid occur on the slopes of steep-walled pre-Pennsylvanian valleys. The formation ranges from about 100 feet thick in the north to a little more than 170 feet near its southern margin (fig. M-50). It is divided into three members—the Negli Creek Limestone Member (below), the Cave Hill Shale Member, and the Goreville Limestone Member. The fauna of the Kinkaid is dominantly brachiopods, bryozoans, and blastoids and resembles that of several older Chesterian limestone formations, although it is less prolific. A species of *Martinia* is very common.

Negli Creek Limestone Member—The Negli Creek Limestone Member of the Kinkaid Formation (Logan, 1924, p. 11, 125; Malott, 1925, p. 112-114; Swann, 1963, p. 75), the lowermost member, is named for Negli Creek, Perry County, Indiana, along which the type section is an exposure of 12 feet of limestone (NW 36, 6S-3W). In Illinois it is a massive limestone very similar in thickness and lithology to the Goreville Limestone Member but more extensive. It thickens southward from 16 feet in Effingham County to 37 feet in Franklin County. Most of the limestone is brownish gray, but it has some light gray and brown beds. It is very fine grained but includes coarse grains of fossils. In places the lower part is lithographic. It is cherty, particularly in the upper part, but generally less cherty than the Goreville Member. Algal growths (*Girvanella*) are common in the lower part of the Negli Creek, and large gastropods and small biserial Foraminifera occur near the middle.

Cave Hill Shale Member—The Cave Hill Shale Member of the Kinkaid Formation (Swann, 1963, p. 42-43), the middle member, is named for Cave Hill, Saline County, where the type section is on the west slope of the hill (SE SW NW 5, 10S-7E). It is 108 feet thick in the type section, but is over-thickened 25-30 feet by tectonic squeezing. It is a limestone-shale unit about 65 feet thick in the northern area, thickening southward to a little more than 90 feet in the south. The proportion of limestone increases southward, and in the southern area the shale is largely limited to the top and bottom few feet (fig. M-1C). The upper shale, about 15 feet thick, consists of calcareous, dark gray and greenish gray shale at the top and red and green shale below. The red shale makes a fairly extensive marker bed. The middle limestone part contains a variety of carbonate rocks, mainly light brownish gray lithographic limestone, dark shaly limestone,

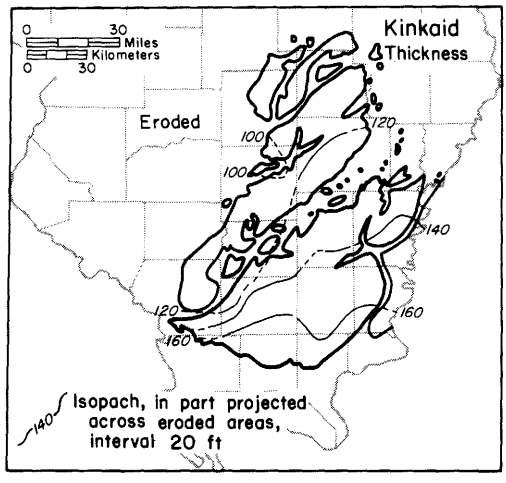

Fig. M-50—Thickness of the Kinkaid Limestone.

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and buff dolomite. The interbedded shale is mainly dark gray, but locally some is very dark gray or black. The basal shale, about 15 feet thick, consists of dark gray shale and locally some black shale. The lower third of the Cave Hill commonly includes some silty shale, a little gray to dark gray and green siltstone, and, in places, more or less shaly sandstone.

Goreville Limestone Member—The Goreville Limestone Member of the Kinkaid Formation (Swann, 1963, p. 43-44), the uppermost member, is named for Goreville, Johnson County, and the type section is in a quarry at Buncombe, 4 miles south of Goreville (SW SW SE 10, and NW NW NE 15, 12S-2E) (fig. M-1C), where the member is 40.5 feet thick. It is a resistant and relatively uniform, massive limestone about 30 feet thick, but it ranges from about 25 feet in the north to nearly 50 feet in the south. Most of the limestone is brownish gray but some of it is light gray or gray. It is very fine grained but includes coarse fossil grains, mostly crinoidal fragments. It is cherty to slightly cherty nearly everywhere.

Grove Church Shale

The Grove Church Shale (Swann, 1963, p. 44-45), the uppermost formation in the Chesterian Series in Illinois, is named for Cedar Grove Church, Johnson County, and the type section is in a roadcut and near-by gullies, 1.25 miles east of Lick Creek (W line NE NW 31, 11S-2E), where the formation is 16 feet thick. The formation has been largely eroded from Illinois by pre-Pennsylvanian erosion, and it occurs only in patches in Johnson, Pope, and Saline Counties, and probably in parts of adjacent counties. The maximum known thickness is 67 feet in the northern half of Johnson County. The Grove Church is a gray, fossiliferous shale and includes interbedded fossiliferous limestone. It was originally part of the Kinkaid Formation, but it was split off because it is dominantly shale. As a result, the Kinkaid is a dominantly limestone formation. It also has a distinctive fauna; some species have affinities to Pennsylvanian fossils, particularly the fusuline *Millerella* and some ostracodes (Cooper, 1947). The conodont fauna differs strikingly from that of the Kinkaid (Rexroad and Burton, 1961). The genus *Streptognathodus* comprises over one-third of the fauna of the Grove Church and there is a marked decrease in *Cavusgnathus*. Transitional forms show that the change is evolutional, rather than being a migratory influx.

PENNSYLVANIAN SYSTEM

M. E. Hopkins and J. A. Simon

Strata of the Pennsylvanian System constitute the bedrock in about two-thirds of the area of Illinois (36,806 out of 56,400 square miles) and underlie all or parts of 86 of the 102 counties of the state (fig. P-1). The name "Pennsylvanian Series" was introduced by H. S. Williams in a report on Washington County, Arkansas (Simonds, 1891, p. xiii), to designate strata generally called "Coal Measures." Later, the coal fields of Pennsylvania were named as the type area (Williams, 1891, p. 83). The name "Pennsylvanian" has been used in Illinois since the first report of the present Geological Survey (Weller, 1906a), but the terms "Coal Measures" and/or "Upper Carboniferous" were still used in many early reports of the Survey. The Pennsylvanian was classified as a series in Illinois until about 50 years ago and since then has been regarded as a system (fig. P-2).

Throughout most of the area they cover in Illinois, Pennsylvanian strata are concealed by unconsolidated Pleistocene deposits, but in many areas they have been exposed by stream erosion (fig. P-3). The lowermost Pennsylvanian strata are prominently exposed in escarpments that generally face south along the southernmost boundary of the Pennsylvanian, beyond the maximum advance of Pleistocene glaciers. The upper two-thirds of the Pennsylvanian section occurs in relatively flat areas, where the best exposures are generally in artificial cuts made in mining or in highway or railroad construction.

Although the maximum thickness of the Pennsylvanian in Illinois is about 2500 feet, the maximum composite thickness of the individual formations is more than 3300 feet. The formations generally thicken from northern and western Illinois toward the south and southeast. Thickness is also affected by progressive overlap to the north and northwest as lower units pinch out. In much of the Pennsylvanian area of western and northern Illinois, most of the members of the three lowest formations are relatively thin or missing. In places on the La Salle Anticline, these formations are absent and the Colchester (No. 2) Coal at the base of the Carbondale Formation rests directly on the St. Peter Sandstone of Ordovician age. In the extreme northwestern area of Pennsylvanian rocks, however, the

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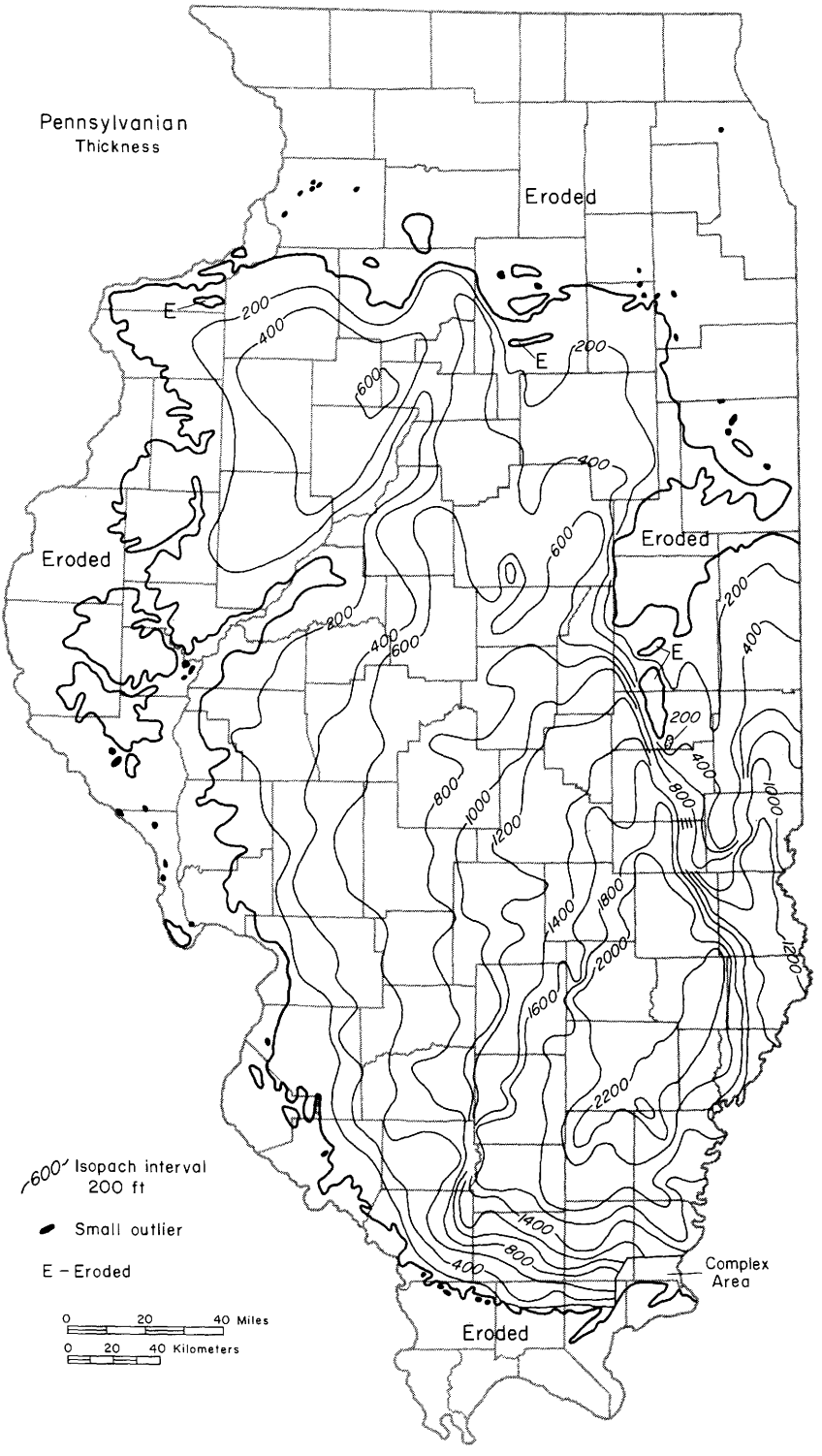
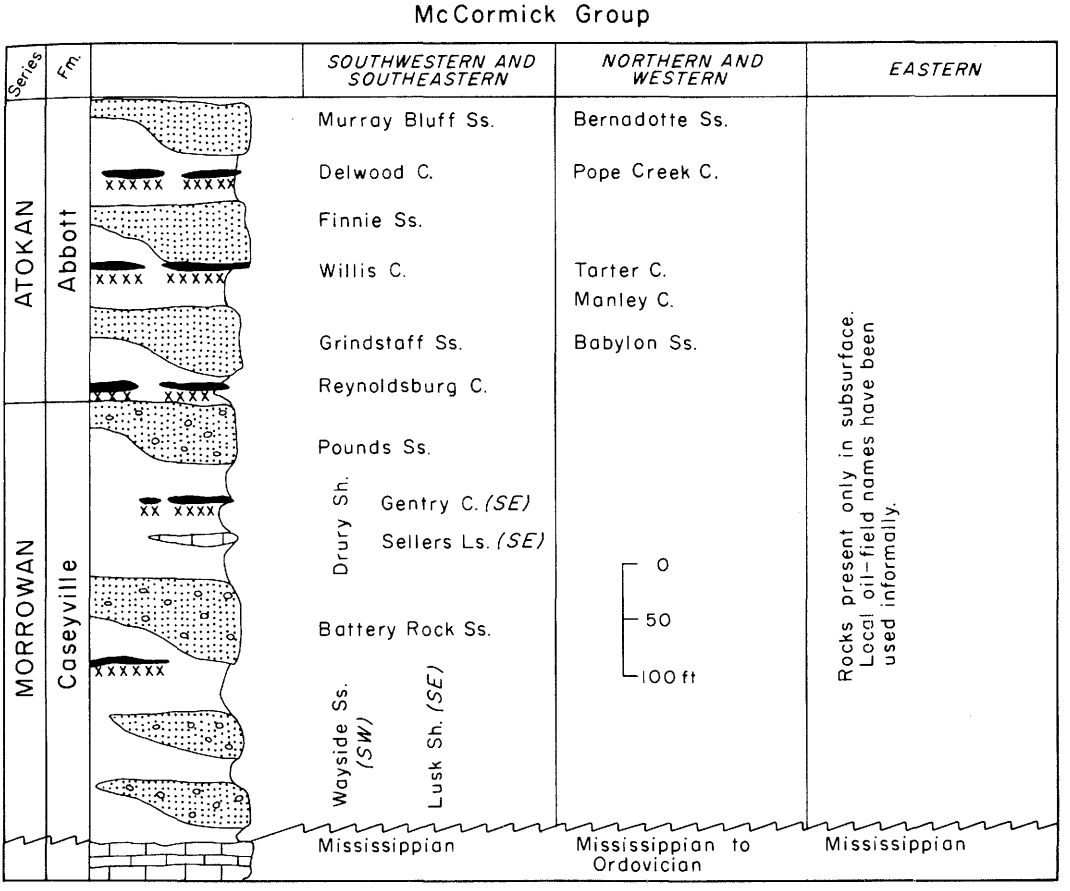


Fig. P-1—Thickness of the Pennsylvanian System.



P-2—Classification of the Pennsylvanian System. In the graphic column, blank space indicates gray shale. Named members are listed to the right of the graphic column. Figure is continued on next two pages.

three lowest formations are all well developed, particularly in Rock Island and Mercer Counties.

A major unconformity underlies the Pennsylvanian System (fig. P-4) and separates the Absaroka Sequence, which includes all the Pennsylvanian strata, from the Kaskaskia Sequence below. Pennsylvanian rocks overlie the youngest strata of the Mississippian System in extreme southern Illinois and progressively overlap older strata northward. In the extreme northern part of the coal basin, Pennsylvanian rocks directly overlie rocks of Ordovician and Silurian age.

The upper surface of the Pennsylvanian rocks is an eroded post-Pennsylvanian, pre-Pleistocene surface modified in part by further erosion during the Pleistocene (fig. 10). In a relatively small area in Adams, Pike, and Brown Counties in western Illinois, the Pennsylvanian is overlain by Gulfian (upper Cretaceous) rocks (Frye et al., 1964).

The Pennsylvanian System is characterized by many vertical changes in lithology, commonly abrupt, that produce 500 or more distinguishable units of sandstone, siltstone, shale, limestone, coal, and clay (Kosanke et al., 1960). Many of these units are laterally extensive, and even though others vary lithologically they can be correlated widely because of their positions in relation to continuous marker units, usually limestones, black fissile shales, or coals.

Typically, 90-95 percent of the system consists of clastic rocks. Sandstones commonly constitute 60 percent of the lower part of the section (McCormick Group). Most of the remainder is siltstone and shale, and less than 1 percent is coal and limestone. Sandstones constitute about 25 percent of the middle and

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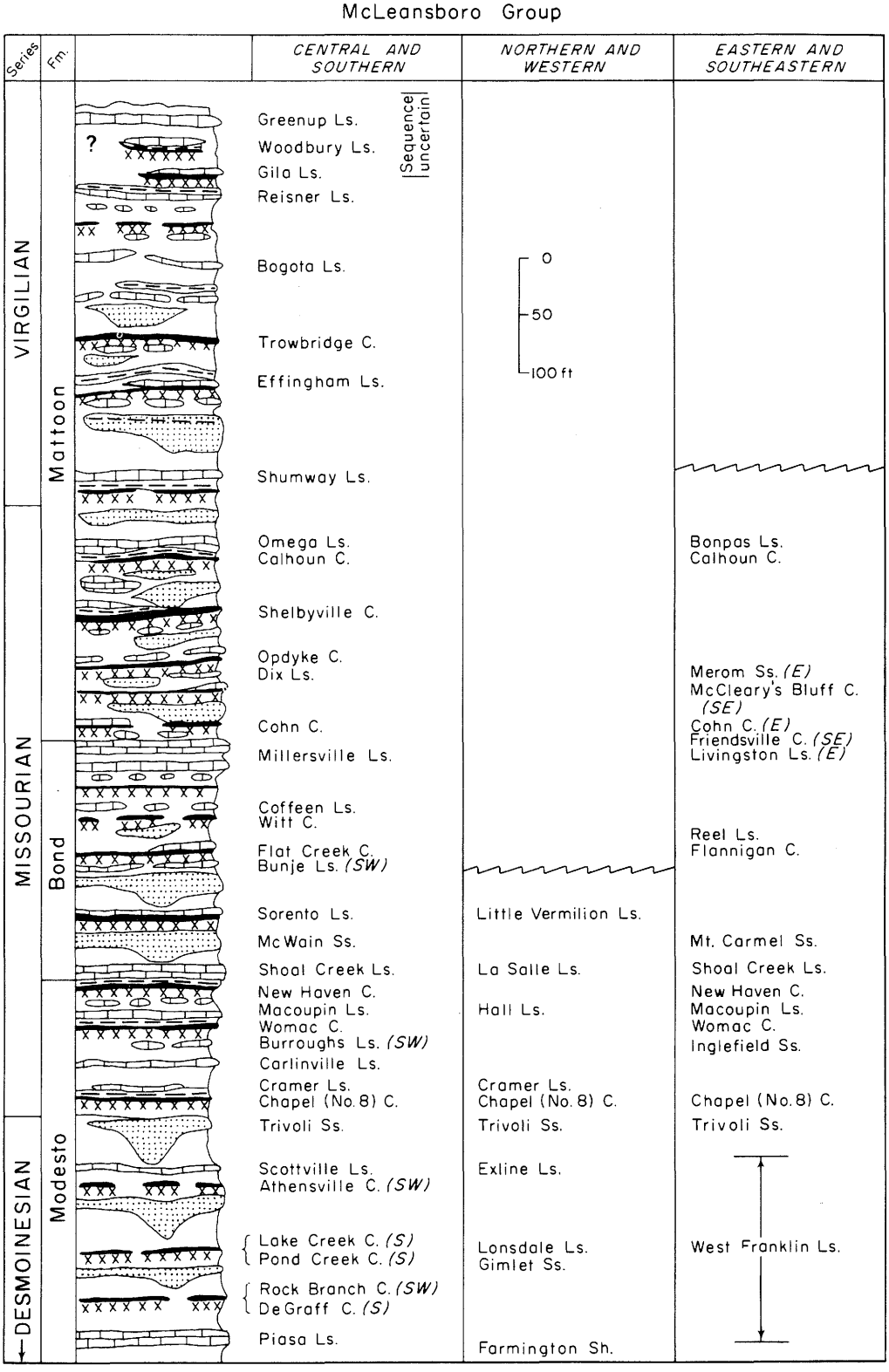
Kewanee Group

Series	Fm.	SOUTHWESTERN AND SOUTHEASTERN	NORTHERN AND WESTERN	EASTERN
DESMOINESIAN	Carbondale	Danville (No.7) C.	Danville (No.7) C.	Danville (No.7) C.
		Galum Ls.		
		Allenby C.		
		Bankston Fork Ls.		Bankston Fork Ls.
		Anvil Rock Ss.	Copperas Creek Ss.	
			Lawson Sh.	
		Conant Ls.		Conant Ls.
		Jamestown C.		Jamestown C.
		Brereton Ls.	Brereton Ls.	Brereton Ls.
		Anna Sh.	Anna Sh.	Anna Sh.
		Herrin (No.6) C.	Herrin (No.6) C.	Herrin (No.6) C.
			Spring Lake C.	
			Big Creek Sh.	
			Vermilionville Ss.	
		Briar Hill (No.5A) C.		Briar Hill (No.5A) C.
		Canton Sh.	Canton Sh.	Canton Sh.
		St. David Ls.	St. David Ls.	St. David Ls.
		Dykersburg Sh.		
		Harrisburg (No.5) C.	Springfield (No.5) C.	Harrisburg (No.5) C.
			Covel Cgl.	
		Hanover Ls.	Hanover Ls.	
		Excello Sh.	Excello Sh.	Excello Sh.
		Summum (No.4) C.	Summum (No.4) C.	Summum (No.4) C.
			Breezy Hill Ls.	
		Roodhouse C.	Kerton Creek C.	
		Pleasantview Ss.	Pleasantview Ss.	Pleasantview Ss.
			Purington Sh.	
		Shawneetown C.	Lowell C.	Shawneetown C.
		Oak Grove Ls.	Oak Grove Ls.	
		Mecca Quarry Sh.	Mecca Quarry Sh.	Mecca Quarry Sh.
			Jake Creek Ss.	
			Francis Creek Sh.	
			Cardiff C.	
		Colchester (No.2) C.	Colchester (No.2) C.	Colchester (No.2) C.
	Spoon		Browning Ss.	
			Abingdon C.	
		Palzo Ss.	Isabel Ss.	
		Seelyville C.		Seelyville C.
			Cheltenham Clay	
		De Koven C.	Greenbush C.	
		Davis C.	Wiley C.	
		Seahorne Ls.	Seahorne Ls.	
		Vergennes Ss.		
		Stonefort Ls.		
		Wise Ridge C.		
		Mt. Rorah C.	De Long C.	
		Creal Springs		
		Murphysboro C.		
		Granger Ss.		
		New Burnside C.	Brush C.	
		Bidwell, O'Nan C.		
			Hermon C.	
		Curlew Ls.	Seville Ls.	
		Litchfield, Assumption C.	Rock Island (No.1) C.	

0
50
100 ft.

Rocks present only in subsurface.
Local oil-field names have been used informally.

(Continued on next page)


McLeansboro Group
Series
Fm.
CENTRAL AND SOUTHERN
NORTHERN AND WESTERN
EASTERN AND SOUTHEASTERN
VIRGILIAN
MISSOURIAN
DESMOINESIAN
Mattoon
Bond
Modesto
Sequence uncertain
Greenup Ls.
Woodbury Ls.
Gila Ls.
Reisner Ls.
Bogota Ls.
Trowbridge C.
Effingham Ls.
Shumway Ls.
Omega Ls.
Calhoun C.
Shelbyville C.
Opdyke C.
Dix Ls.
Cohn C.
Millersville Ls.
Coffeen Ls.
Witt C.
Flat Creek C.
Bunje Ls. (SW)
Sorento Ls.
McWain Ss.
Shoal Creek Ls.
New Haven C.
Macoupin Ls.
Womac C.
Burroughs Ls. (SW)
Carlinville Ls.
Cramer Ls.
Chapel (No. 8) C.
Trivoli Ss.
Scottville Ls.
Athensville C. (SW)
Lake Creek C. (S)
Pond Creek C. (S)
Rock Branch C. (SW)
DeGraff C. (S)
Piasa Ls.
0
50
100 ft
Little Vermilion Ls.
La Salle Ls.
Hall Ls.
Cramer Ls.
Chapel (No. 8) C.
Trivoli Ss.
Exline Ls.
Lonsdale Ls.
Gimlet Ss.
Farmington Sh.
Bonpas Ls.
Calhoun C.
Merom Ss. (E)
McCleary's Bluff C. (SE)
Cohn C. (E)
Friendsville C. (SE)
Livingston Ls. (E)
Reel Ls.
Flannigan C.
Mt. Carmel Ss.
Shoal Creek Ls.
New Haven C.
Macoupin Ls.
Womac C.
Inglefield Ss.
Chapel (No. 8) C.
Trivoli Ss.
West Franklin Ls.

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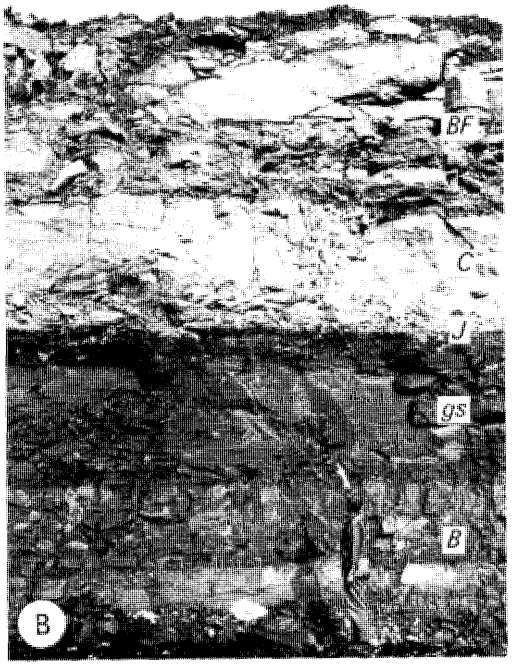

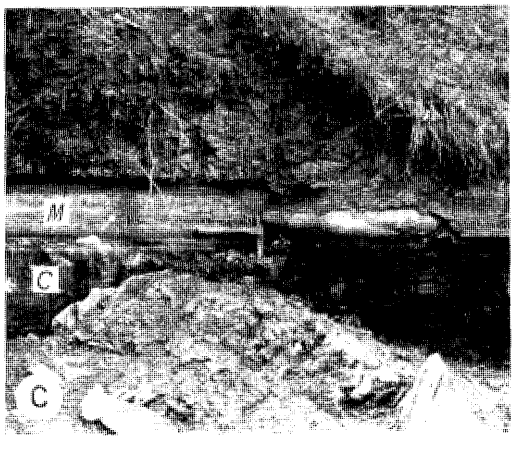

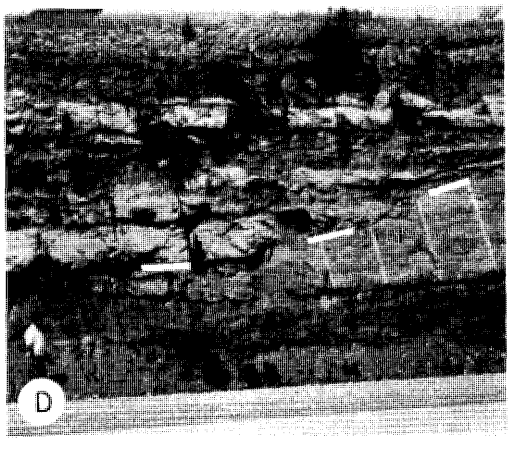

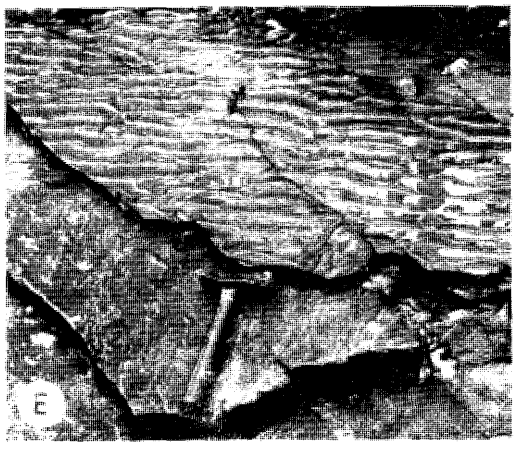

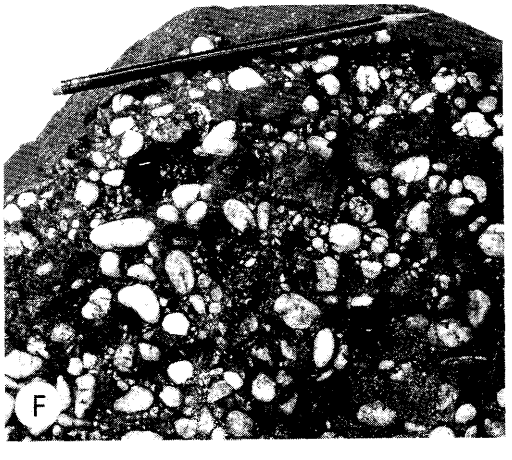

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upper parts of the system, although the percentage may be somewhat higher in the upper strata. In the upper part of the section, shale (dominantly of various shades of gray with smaller amounts of red, green, and black) and underclay commonly form 65-70 percent of the sequence. In general, 5-10 percent of the upper two-thirds of the sequence is limestone, the largest percentage in the Bond Formation.

Because of the abrupt and distinct vertical variations in lithology and the widespread lateral continuity of many of the Pennsylvanian units, their classification has undergone many changes (fig. P-5). The present Pennsylvanian classification was adopted (Kosanke et al., 1960) to make it conform to the Illinois State Geological Survey policy on stratigraphic nomenclature (Willman et al., 1958) (fig. 16). The multiple classification adopted by the Survey permitted recognition of cycles as a separate and distinct classification, thus removing cyclothems from the rock-stratigraphic classification, where they had been used in place of formations. After several alternatives for formations had been considered, the entire system was subdivided into seven formations, each a bundle of Pennsylvanian strata characterized by certain gross lithologic characteristics and separated from the overlying and underlying strata by the top or bottom of generally widely traceable members. The formations are differentiated by the relative abundance, character, and distribution of four basic lithologies—sandstone, shale, coal, and limestone. Adjacent formations that have closely related lithologic characteristics are combined into a group and three groups are recognized.

The present time-stratigraphic classification of the Pennsylvanian System in Illinois (fig. P-2) is based on that developed in the Midcontinent Region and was first published by the Illinois State Geological Survey on the Geologic Map of Illinois (Willman et al., 1967). Correlations with Midcontinent strata are based on both biostratigraphy and rock stratigraphy, and many biozones and rock units of the Midcontinent Region can be identified in the Illinois Basin. The sediments were continuous before the two regions were separated by post-Pennsylvanian erosion. A time-stratigraphic classification of the Pennsylvanian System in Illinois based on ostracodes (Cooper, 1946) used Midcontinent terms, but the correlations were not definitive and the classification was not followed.

The most common invertebrate macrofossils are brachiopods, crinoids, gastropods, and pelecypods, but corals, cephalopods, trilobites, foraminifers, bryozoans, and worms occur in some beds (fig. P-6) (Wanless, 1958). Biostratigraphic zones in the Pennsylvanian in Illinois are based on fusulinids (Dunbar and Henbest, 1942; Thompson et al., 1959; Thompson and Shaver, 1964), ostracodes (Cooper, 1946), and spores (Kosanke, 1950; Peppers, 1964, 1970; Winslow, 1959). Moore et al. (1944) discussed ranges of all fossil types in the Pennsylvanian of the United States. Floral zones for the nation as a whole were described by Read and Mamay (1964).

Coal-bearing Pennsylvanian strata have been fairly precisely correlated from spores and pollen in the coals. Palynological studies of other lithologic units, however, have not been extensive. Major time-stratigraphic intervals are delineated by their most abundant spore taxa and by the occurrence of certain genera and species that have relatively short stratigraphic ranges. Some of these fossils are limited to two or three coals, whereas others extend through one or more series. A coal can generally be precisely correlated with a named coal member, or at least placed within an interval containing two or three named coal members.

The Pennsylvanian of Illinois includes strata belonging to the recognized series of the Midcontinent, from oldest to youngest: Morrowan, Atokan, Desmoinesian, Missourian,

Fig. P-3—Exposures of Pennsylvanian rocks.

A—Battery Rock Sandstone Member of the Caseyville Formation capping an escarpment 8 miles north of Cave in Rock, Hardin County.

B—Strata overlying the Herrin (No. 6) Coal Member of the Carbondale Formation (at the man's feet), including the Bankston Fork Limestone Member (BF), Conant Limestone Member (C), Jamestown Coal Member (J, 1 inch thick), gray calcareous shale (gs), Brereton Limestone Member (B); in a strip mine southwest of Belleville, St. Clair County.

C—Mecca Quarry Shale Member (M) of the Carbondale Formation in which a large limestone concretion is present (at the hammer), overlying the Colchester (No. 2) Coal Member (C) just south of Viola, Mercer County.

D—The sub-Absaroka unconformity showing Pennsylvanian strata (Caseyville Formation) truncating Mississippian strata (Kinkaid Limestone) in a roadcut of U.S. Highway 51, north of Anna, Union County.

E—Asymmetrical current ripple marks and weak current laminations (parallel to hammer) in thin-bedded sandstone in the Caseyville Formation, near Pomona. Jackson County.

F—Quartz-pebble conglomerate in the Caseyville Formation near Shiloh Hill, Randolph County.

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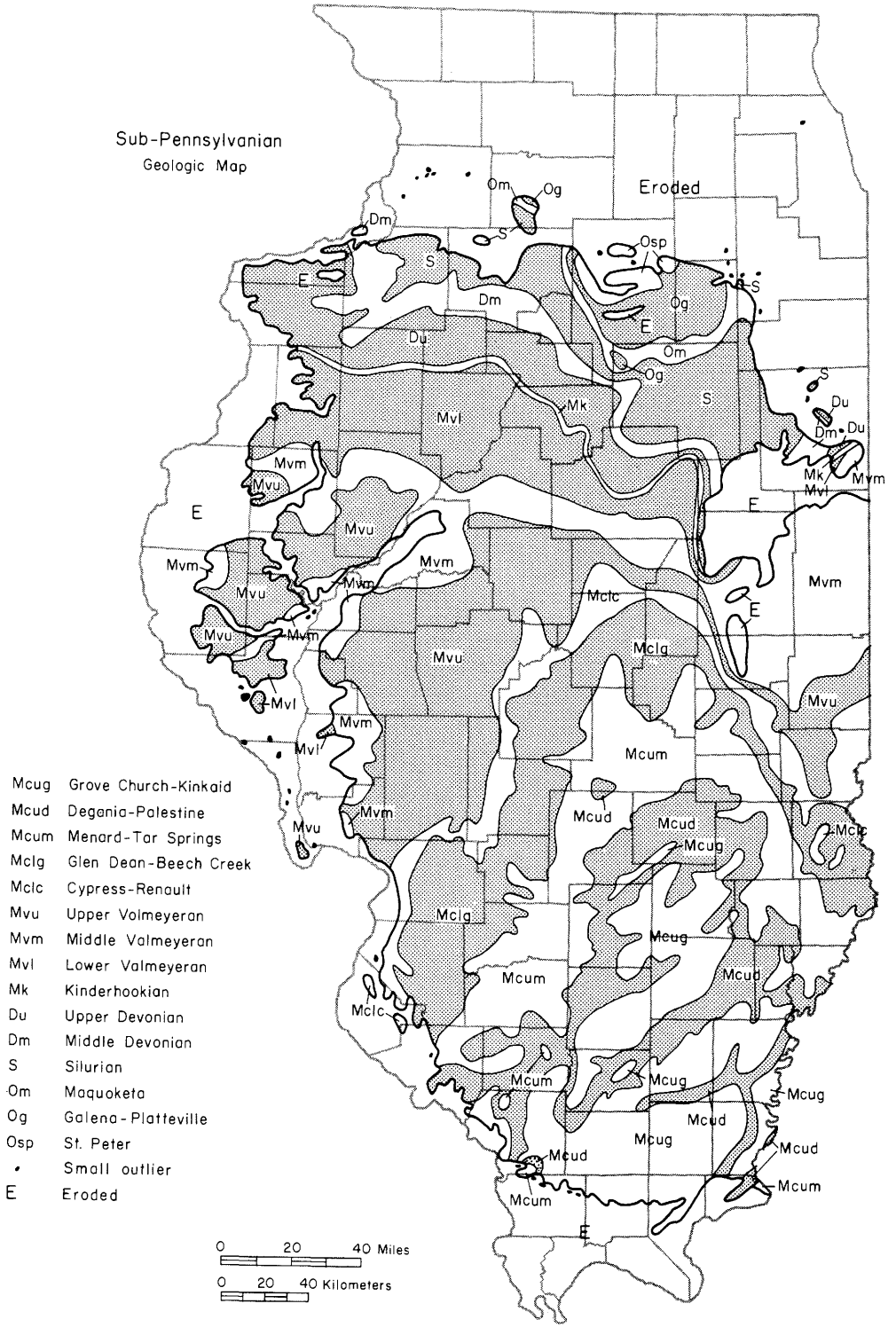

Fig. P-4—Geologic map of the sub-Pennsylvanian (sub-Absaroka) surface (after Willman et al., 1967).

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Worthen 1875		S. Weller 1906		DeWolf 1910	Shaw and Savage 1912	Wanless 1929, 1931a	Wanless and J.M. Weller 1932	Wanless, 1939 J.M. Weller, 1940	Kosanke et al. 1960 and this report	
COAL MEASURES	Upper	PENNSYLVANIAN	Upper	McLeansboro Fm.	McLeansboro Fm.	Formations subdivided into cyclical units called "Suites"; later called "Cyclical Formations" McLeansboro Fm.	Cyclical units called "Cyclothems" McLeansboro Fm.	McLeansboro Group	Mattoon Fm.	McLeansboro Group
									Millersville Ls. M. Bond Fm. *Shoal Creek Ls. M.*	
	Shoal Creek Ls.		*Shoal Creek Ls.*						Modesto Fm.	
								Anvil Rock Ss.	*Danville (No.7) Coal M.*	Kewanee Group
				No. 6 Coal Petersburg Fm.	Carbondale Fm.	Carbondale Fm.	Carbondale Fm.	Carbondale Group	Carbondale Fm.	
				No. 5 Coal La Salle Fm.						
	Lower		Lower	*No. 2 Coal*					*Colchester (No.2) Coal M.*	
								Palzo Ss.	Spoon Fm.	
				Pottsville Fm.	Pottsville Fm.	Pottsville Fm.	Pottsville Fm.	Tradewater Group	*Bernadotte Ss. M.* Abbott Fm.	McCormick Group
								Grindstaff Ss.	*Pounds Ss. M.* Caseyville Fm.	
								Caseyville Group		

Fig. P-5—Development of the classification of the Pennsylvanian System (after Kosanke et al., 1960). In Wanless (1939) and Weller (1940), the McLeansboro and Carbondale Groups were subdivided into cyclothems, and the Caseyville and Tradewater Groups in southern Illinois were subdivided into seven formations. In several reports from 1940 to 1950 the base of the McLeansboro was put at the top of the No. 6 Coal. Cyclothems are retained in a separate cyclical classification. Units bounding the groups and formations are in italics.

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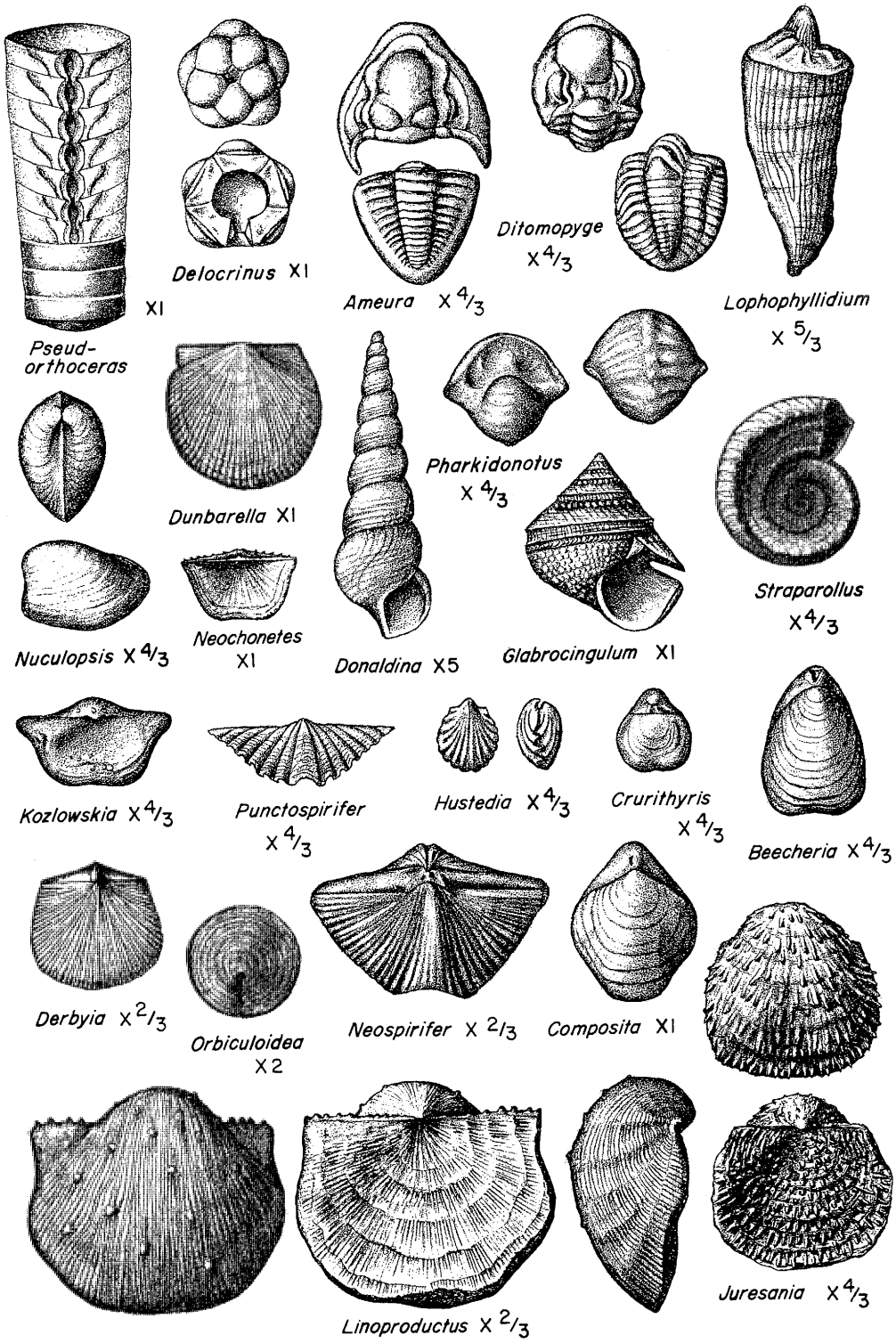

Fig. P-6—Typical Pennsylvanian fossils.

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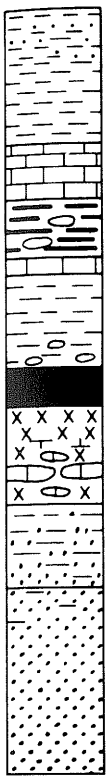

Fig. P-7—Arrangement of lithologic units in a cyclothem (after Willman and Payne, 1942).

and Virgilian (fig. P-2). Older strata of problematical age, sometimes referred to as the Springeran Series (Pennsylvanian and/or Mississippian), have not been recognized in Illinois. However, certain sink-hole or cave deposits lying on or in older carbonates in western and northeastern Illinois contain very early Pennsylvanian strata that have not been correlated with strata in other areas, although they are at present considered Morrowan. Because of the overlapping relations on the unconformity at the base of the Pennsylvanian, the basal Pennsylvanian strata vary in age, generally from Morrowan in southern Illinois to Atokan and Desmoinesian in western, northern, and eastern Illinois. The youngest Pennsylvanian strata in Illinois, found only at the top of the deepest part of the Fairfield Basin, belong in the lower part of the Virgilian Series. The spores of several coals preserved in down-faulted blocks in western Kentucky and adjacent southeastern Illinois suggest that most of the Virgilian may be represented in this part of the basin. Within the Pennsylvanian System in Illinois, no major, widespread unconformities with either large-scale overlaps or structural discordances are evident. Numerous erosional episodes, however, occurred during the development of fluvial and deltaic sandstones.

The many individual units of the Pennsylvanian generally occur in an orderly sequence, and the sequences are repeated many times throughout most of the succession. Although the idealized sequence shown in figure P-7 is rarely complete, the units that are present have the same relative position in the sequence. These sequences were early recognized as cycles of sedimentation (Udden, 1912; Weller, 1930, 1931) and were subsequently termed "cyclothems" (Wanless and Weller, 1932).

Cyclothems have been used extensively in geologic reports in the past 40 years (Wanless, 1929 [called suites], 1931a [called cyclical formations], 1957; Willman and Payne, 1942), but they are not entirely adequate for rock-stratigraphic classification. They are much smaller units than the formations and are most useful in detailed differentiation and field mapping of the Pennsylvanian sediments. The named cyclothems are listed in table 3.

Pennsylvanian sediments of the Illinois Basin were deposited in a gently subsiding trough that was open toward the south until post-Pennsylvanian time, when it was closed by uplift of the Pascola Arch south of Illinois. The greatest subsidence took place in the southeastern part of the state where the system is thickest.

Because of subsidence during and after the Pennsylvanian, the base of the Pennsylvanian is as much as 2500 feet lower in the deeper part of the basin than at the surface around the margin, and the Herrin (No. 6) Coal is as much as 1400 feet lower (fig. P-8). The major structural features within the Illinois Basin that influence the present distribution of Pennsylvanian strata are the La Salle Anticlinal Belt, the Fairfield Basin, the Du Quoin Monocline, and the Eagle Valley Syncline, which is in southeastern Illinois south of the Shawneetown Fault (fig. 12). Faulting is most prominent in southeastern Illinois, where the faults of the fluorspar district have caused Pennsylvanian strata to be preserved in grabens south of the principal margins of the Pennsylvanian. The distribution of Pennsylvanian formations is also influenced by the Shawneetown Fault, the Cottage Grove Fault System, and the Wabash Valley Fault System. Pennsylvanian outliers in southern Calhoun County are related to the Cap au Grès Faulted

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TABLE 3—ALPHABETIC LIST OF NAMED CYCLOTHEMS IN ILLINOIS, SHOWING FORMATION, DISTRIBUTION, AND PRINCIPAL REFERENCES
(after Kosanke et al., 1960)

Named cyclothem	Formation	Area of state	References
Abingdon	Spoon	Western	Weller et al., 1942b, p. 1586
Babylon	Abbott	Western	Wanless, 1931a, p. 189-190, 192-193; 1957, geol. sec. 41, p. 189
Bankston	Carbondale	Southwestern and southeastern	Weller, *in* Dunbar and Henbest, 1942, p. 16-18; Wanless, 1956, p. 11
Battery Rock	Caseyville	Southwestern and southeastern	Weller, 1940, p. 37; Wanless, 1938
Bogota	Mattoon	Central	Newton and Weller, 1937, p. 9, 19-24; Wanless, 1956, p. 12
Brereton	Carbondale	All	Wanless, 1931a, p. 180, 182-183, 190, 192
Briar Hill	Carbondale	Southwestern and southeastern	Kosanke et al., 1960; previous name, Crab Orchard Cyclothem, Wanless, 1938; Weller et al., 1942a, p. 16
Brush	Spoon	Western	Kosanke et al., 1960; previous name, Middle De Long Cyclothem, Wanless, 1931a, p. 188, 192; 1956, p. 9
Bunje	Bond	Southwestern	Kosanke et al., 1960; Wanless, 1955, p. 1764 (from Simon ms., 1946)
Carlinville	Macoupin	Southwestern	Ball, 1952, p. 34-37
Cohn	Mattoon	Eastern	Newton and Weller, 1937, p. 9, 18-19
Colbert	Spoon	Southeastern	Wanless, 1956, p. 5, 9
Cutler	Carbondale-Modesto	Southwestern, southeastern, and eastern	Kosanke et al., 1960; Siever, *in* Wanless, 1956
De Koven	Spoon	Southeastern	Weller, *in* Dunbar and Henbest, 1942, p. 16; Wanless, 1956, p. 10
De Long	Spoon	Western	Kosanke et al., 1960; previous name, Upper De Long Cyclothem, Wanless, 1931a, p. 188, 192; 1956, p. 9
Delwood	Abbott	Southeastern	Weller, 1940, p. 39; Wanless, 1956, p. 9
Fithian	Bond	Eastern	White et al., 1958, p. 1-3
Flannigan	Bond	Southeastern	Newton and Weller, 1937, p. 9-10
Flat Creek	Bond	Southwestern	Kosanke et al., 1960; Wanless, 1955, p. 1764 (from Simon ms., 1946)
Gila	Mattoon	Central	Newton and Weller, 1937, p. 9, 27-28
Gimlet	Modesto	Western, northern, southeastern, and eastern	Wanless, 1931a, p. 182, 192
Greenbush	Spoon	Western	Wanless, 1931a, p. 188, 192; 1956, p. 10
Greenup	Mattoon	Central	Newton and Weller, 1937, p. 9, 26-27
Grindstaff	Abbott	Southwestern and southeastern	Butts, 1925, p. 44; Weller, 1940, p. 39
Hall	Modesto	Northern	Weller, *in* Cooper, 1946, p. 12 (from Willman ms., 1931)
Hermon	Spoon	Western	Kosanke et al., 1960; previous name, Lower De Long Cyclothem, Wanless, 1931a, p. 188, 192; 1957, p. 73
Hicks	Modesto	Northern	Weller, *in* Cooper, 1946, p. 12 (from Willman ms., 1931)
Jamestown	Carbondale	Southeastern and eastern	Bell et al., 1931, p. 3; Wanless and Weller, 1932, p. 1007; Wanless, 1956, p. 10
La Salle	Modesto-Bond	Northern	Weller and Bell, 1936, p. 26 (from Willman ms., 1931)
Little Vermilion	Bond	Northern	Weller, *in* Cooper, 1946, p. 14; Cooper, 1946, p. 16 (from Willman ms., 1931)
Liverpool	Spoon-Carbondale	Western	Wanless, 1931a, p. 188, 192; 1956, p. 10; 1957, p. 85 and geol. secs. 24, 25, p. 198
Lowell	Carbondale	Northern	Willman and Payne, 1942, p. 87, 102-103, and geol. sec. 33, p. 300

(Continued on next page)

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TABLE 3—Concluded

Named cyclothem	Formation	Area of state	References
Lusk	Caseyville	Southeastern	Weller, 1940, p. 36-37
Macedonia	Abbott-Spoon	Southeastern	Weller, 1940, p. 39, 40; Wanless, 1956, p. 9
Macoupin	Modesto	Southwestern	Wanless, 1931b, p. 804, 811-812; Ball, 1952, geol. sec. 19, p. 85-86
Newton	Mattoon	Central	Newton and Weller, 1937, p. 9, 24-25
Omega	Mattoon	Central	Weller and Bell, 1936, p. 29-32; Wanless, 1956, p. 12
Pope Creek	Abbott	Western	Wanless, 1931a, p. 189-190, 192; 1957, p. 67-70
Pounds	Caseyville-Abbott	Southwestern and southeastern	Wanless, 1929, geol. sec. 4, p. 52, "Suite I"; Weller, 1940, p. 38-39
St. David	Carbondale	All	Wanless, 1931a, p. 182, 192; 1957, p. 102 and geol. sec. 21, p. 197
Seahorne	Spoon	Western and southwestern	Wanless, 1931a, p. 188, 192; 1957, p. 76 and geol. sec. 30, p. 200
Seville	Abbott-Spoon	Western	Wanless, 1931a, p. 189, 192; 1957, p. 70 and geol. sec. 33, p. 201
Shoal Creek	Modesto-Bond	Southwestern, southeastern, and eastern	Wanless, 1931b, p. 804, 812
Shumway	Mattoon	Central	Weller, *in* Dunbar and Henbest, 1942, p. 28; Wanless, 1956, p. 12
Sorento	Bond	Southwestern	Kosanke et al., 1960; Wanless, 1955, p. 1764 (from Simon ms., 1946)
Sparland	Carbondale-Modesto	Western and northern	Wanless, 1931a, p. 182, 192
Stonefort	Spoon	Southeastern	Kosanke et al., 1960; Weller, 1940, p. 39; Wanless, 1956, p. 9 (location in error)
Summum	Carbondale	All	Wanless, 1931a, p. 182, 192; 1957, p. 94 and geol. sec. 39, p. 204
Tarter	Abbott	Western	Wanless, 1956, p. 9; 1957, p. 66 and geol. sec. 34, p. 202
Tonica	Spoon-Carbondale	Northern	Kosanke et al., 1960; previously called Liverpool Cyclothem in northern Illinois (Willman and Payne, 1942, p. 95)
Trivoli	Modesto	All	Wanless, 1931a, p. 182, 192; 1956, p. 11; 1957, p. 121 and geol. sec. 8, p. 193
Wiley	Spoon	Western	Wanless, 1931a, p. 188, 192; 1956, p. 9; 1957, p. 79 and geol. sec. 42, p. 206
Witt	Bond	Southwestern	Kosanke et al., 1960 (from Gluskoter ms., 1958)
Woodbury	Mattoon	Central	Newton and Weller, 1937, p. 9, 28-30

Flexure. Numerous other flexures in the Pennsylvanian rocks in the basin are commonly related to structures that have greater relief in pre-Pennsylvanian strata. Domal structures in Pennsylvanian strata overlie many Silurian reefs.

The Pennsylvanian section is generally thinner in the area of the Sparta Shelf west of the Du Quoin Monocline in southwestern Illinois and in the shelf area north and west of the Illinois River. In both areas much of the section is present, but the lowermost or oldest strata were not deposited there and the youngest strata probably have been eroded from the area.

During Pennsylvanian time clastic sediments were generally carried into the seas occupying the Illinois Basin area by rivers flowing from the north, northeast, and east, and to a lesser extent from the northwest. When the seas withdrew, most of the major rivers flowed southwestward across Illinois. Much of the sedimentation occurred in large deltas on the gently subsiding basin (Wanless et al., 1963). The marine, brackish water, and delta-plain sediments have complex relations, and there is little agreement on interpretations of the environment of deposition of some strata.

Sandstones occur in two broad general types—channel facies and sheet facies (Andresen, 1961; Hopkins, 1958; Potter, 1962b,

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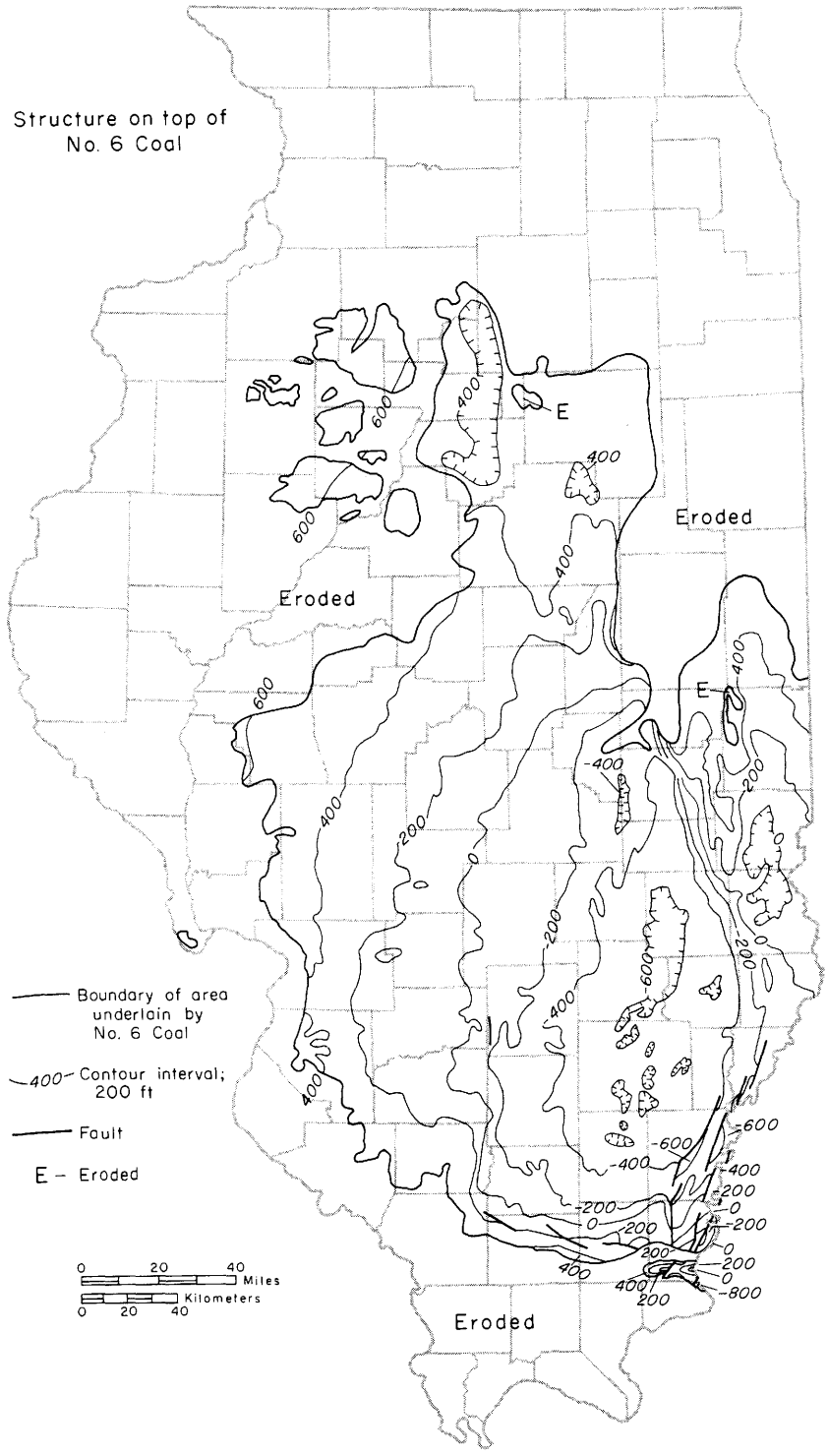

Fig. P-8—Structure of the top of the Herrin (No. 6) Coal Member (based on map by K. E. Clegg).

1963; Siever, 1957). Sandstones in channels are generally less than 100 feet thick, but where channels cross and two or more sandstones are in vertical juxtaposition, thicknesses of more than 100 feet are found. Some channel sandstones abruptly truncate lower strata in long, winding courses, suggesting that the sand filled valleys that had been subaerially eroded. The lower surface of the channel sandstone generally truncates sharply the strata below, but the upper surface commonly grades into the overlying rocks, which are generally siltstone. Most sandstones appear to be nonmarine, although some are clearly marine. The sheet sandstones are thinner than the channel sandstones and occur in widely traceable layers that commonly are conformable with strata above and below. Siltstones are common but generally are not as thick as the channel sandstones or some shales.

The shales that overlie limestones in the normal cyclical sequence are generally marine. The black fissile shales, which commonly occupy a position between a marine limestone and the top of the underlying coal, were marine muds deposited in restricted deoxygenated bottom waters. The gray shales that occur in several areas as large wedges or lenses between the black fissile shale and the coal were deposited in transitional environments, which probably ranged from prodelta to delta front to valley flat. The underclays below most coals or coal positions probably were deposited in relatively fresh water. Claystones other than underclays, commonly associated with the lighter colored marine limestones, generally are also marine.

Nearly 50 coals have been named in the Pennsylvanian of Illinois, but other coals, which are known to be present although as yet unnamed, bring the total to at least 75. Many of the coals are very widespread. The coals accumulated on broad delta plains in fresh-water environments, probably only slightly above sea level (Wanless et al., 1969). Some interstratified partings of mineral matter, mostly clay, also are extensive. The most notable example is the so-called "blueband" in the lower part of the Herrin (No. 6) Coal Member, a 1- to 3-inch clay parting that has been traced almost continuously throughout thousands of square miles.

Most limestones in the cyclical sequence above the coals were deposited in a marine environment and contain a large variety of fossils. Some limestones are relatively pure, particularly in younger Pennsylvanian strata, but most are characteristically argillaceous. Most of the nodular limestones that occur in a clay matrix in or below underclays are generally nonfossiliferous but some of them contain algal remains, ostracodes, and the worm *Spirorbis*. They are generally regarded as freshwater deposits, but some grade into marine limestone in a few areas.

Conglomerates composed of granules and pebbles of locally derived rocks are present at places in the channel sandstone deposits. Lenses and beds of conglomerate consisting of quartz pebbles derived from outside the Illinois Basin occur in sandstones in the Caseyville Formation. The Covel Conglomerate Member is a thin, unique, widespread limestone conglomerate that occurs a short distance below the Springfield (No. 5) Coal Member in northern Illinois. Claystone conglomerates or breccias altered to almost pure kaolinite commonly occupy the stratigraphic position of coals in channel fill in a few local areas (Smith and O'Brien, 1965).

MORROWAN SERIES

The Morrowan Series of the Pennsylvanian System (Adams, 1904, p. 28) is named for Morrow, Washington County, Arkansas, which lies a short distance from the type exposure on Hale Mountain. The series consists of marine and nonmarine rocks. The Caseyville Formation of the McCormick Group (fig. P-2) constitutes the entire Morrowan Series in Illinois (Willman et al., 1967). The top of the series may not correlate precisely with the top in the Midcontinent section.

Marine fossils are rare in the Caseyville, but the Sellers Limestone Member in southeastern Illinois contains a Morrowan fauna. The type region of the Morrowan in many places contains *Millerella*, a nonfusiform fusulinid that is also found in the Chesterian Series and in younger Pennsylvanian sediments and is the most advanced fusulinid found in Morrowan rocks. However, no fusulinids have been found in the Illinois Morrowan. The upper limit of the Morrowan in fusulinid-bearing rocks is placed at the base of the first strata containing *Profusulinella*.

The compression plant fossils of the Morrowan Series are in Zone 6 (*Neuropteris tennesseeana* and *Mariopteris pygmaea*) of Read and Mamay (1964). The roof shale of the Baldwin coal, which occurs in the Morrowan type section, contains a plant-impression flora similar to that above the Gentry Coal Member in southeastern Illinois. The relative ages of strata within the Morrowan Series in Illinois can best be determined from the spores,

which are abundant in Caseyville sediments, especially the coals. The Morrowan Series in Illinois is dominated by the genus *Lycospora*, which in some coals makes up as much as 80 percent of the spore population. Spores of herbaceous lycopods—*Densosporites*, *Cristatisporites*, and *Radiizonates*—are also abundant. *D. sinosus*, *R. striatus*, and *R. irregularis* are useful guide fossils for the lower part of the Morrowan, whereas *C. indignibundus* is typically found in the upper part. *Schulzospora* ranges up to the top of the Morrowan. *Triquitrites*, *Laevigatosporites*, and *Endosporites* are found in the lower part of the Morrowan but are very rare.

ABSAROKA SEQUENCE

The major unconformity at the base of the Pennsylvanian System marks the base of the Absaroka Sequence (Sloss et al., 1949, p. 121) (fig. 14), which is named for the Absaroka Mountains in northwestern Wyoming and southern Montana. In Illinois the sequence includes only the strata of the Pennsylvanian System, and its top is the major unconformity at the base of the Cretaceous System (Swann and Willman, 1961). Clastic sediments—shale, sandstone, and siltstone—dominate the sequence. Minor unconformities consisting of deeply entrenched valley systems occur within the Absaroka, but many of the erosional channels in the sequence were produced by entrenchment of river distributaries in deltaic sediments. Except for minor sedimentational dips on local structures, the strata in the sequence are essentially parallel. In the Appalachian Basin and the Midcontinent areas, this sequence continues upward into the Permian System, but no Permian rocks have been found in Illinois. The basal unconformity separating the Absaroka from the underlying Kaskaskia Sequence (fig. P-3D) has been characterized (Siever, 1951; Wanless, 1955; Bristol and Howard, 1971) as an erosion surface formed by streams draining to the south and southeast in western Illinois and to the southwest in central and southern Illinois. The surface has local relief of as much as 450 feet and relatively steep-sided valleys. It truncates all the older Paleozoic systems except the Cambrian (fig. P-4).

McCormick Group

The McCormick Group (Kosanke et al., 1960, p. 28) is named for McCormick in northwestern Pope County, where the various units of this group are prominently exposed. In Illinois the McCormick Group comprises strata of the Caseyville and Abbott Formations, from the base of the Pennsylvanian to the top of the Bernadotte Sandstone Member (fig. P-2). The McCormick Group comprises strata formerly included in the Tradewater and Caseyville Groups (Wanless, 1939; Weller, 1940). The McCormick Group in Illinois thickens from about 200 feet at the northwestern extent of the Pennsylvanian to at least 600 feet in southern Illinois, but it is absent in substantial areas in both western and northern Illinois. Lithologically, this group is almost entirely detrital. It is made up of 50-60 percent massive, predominantly cross-bedded, relatively pure quartz sandstone and 40 percent or more sandy shale and siltstone. The sandstones are seldom more than 100 feet thick. A few thin, nonpersistent coals and rare fossiliferous limestones occur locally. Several of the fine-grained sandstones and a few shales are calcareous in places and contain marine invertebrate fossils, but the bulk of the units of the McCormick Group are barren of animal fossils.

Caseyville Formation

The Caseyville Formation of the McCormick Group (Owen, 1856, p. 48) is named for Caseyville, on the Ohio River in southwestern Union County, Kentucky, near the type locality, "measured from outcrops on the Illinois shore of the Ohio River between the mouth of the Saline River and Gentry's Landing below Battery Rock," in Hardin County (Lee, 1916, p. 15-16). A well exposed reference section has been described along the Illinois Central Gulf Railroad in Pope County (NW SW SE 31, 11S-5E to NE SE NE 18, 12S-5E) (Kosanke et al., 1960, p. 28, 61-62). The Caseyville includes strata from the base of the Pennsylvanian to the top of the Pounds Sandstone Member. The top of the Pounds is generally difficult to recognize in the subsurface north of its outcrop.

The Caseyville Formation is widespread in southern Illinois, and rocks of similar age have been reported in northwestern Illinois in parts of Mercer and Rock Island Counties (fig. P-9). In southern Illinois the Caseyville Formation is as much as 500 feet thick, but 350 feet is a common maximum elsewhere. The Caseyville varies abruptly in thickness because the unconformable surface on which it was deposited has a relief of a few hundred feet—from the bottom of large valleys to the flat upland divides (Siever, 1951; Wanless, 1955; Bristol and Howard, 1971). To the north the Caseyville thins to zero and is overlapped by the Abbott Formation (fig. P-9). In Mercer and Rock Island Counties, the formation varies in thickness; it locally exceeds 100 feet.

The Caseyville Formation is primarily sandstone (fig. P-3A), siltstone, and shale. The sandstones are composed of quartz and very little clay or mica. Most contain quartz granules and pebbles, commonly less than half an inch (12 mm) in diameter, which occur either scattered throughout the sandstone or concentrated in beds of con-

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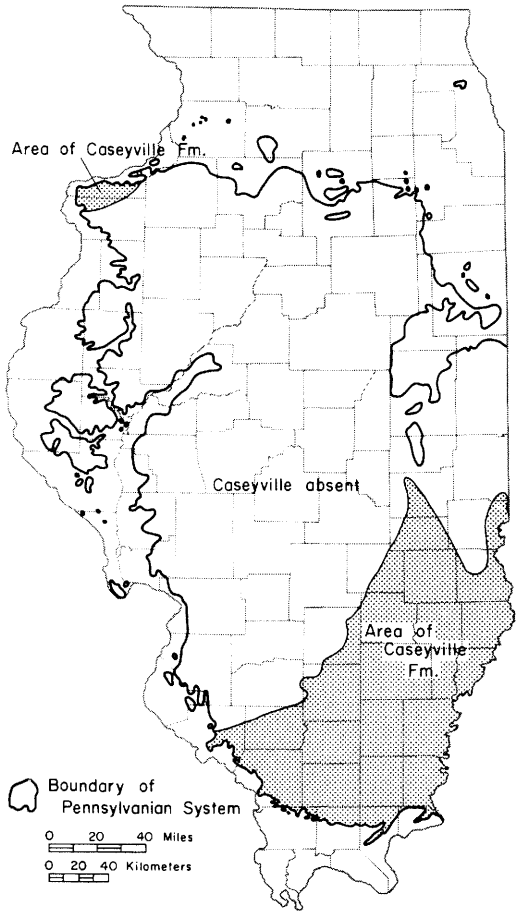

Fig. P-9—Extent of the Caseyville Formation (after Wanless, 1955).

glomerate (fig. P-3F). The coarser sandstones reach about 100 feet thick and show relatively uniform cross-bedding with dip directions to the west, south, or southwest (Potter and Olsen, 1954; Potter, 1962b, 1963) parallel to the direction of elongation of the sandstone bodies. In the finer grained sandstone units, which are usually less than 25 feet thick, the most prevalent sedimentary structure is ripple bedding (fig. P-3E). Shale or siltstone interbeds are common. Considerable oil has been produced for many years in the La Salle Anticlinal Belt in eastern Illinois from sandstones in the Caseyville.

The shales and siltstones are not as widely exposed. The thicker shale units in the Lusk and Drury Members are sandy and contain several beds of sandstone, some relatively coarse grained. A few shales associated with coals are dark, relatively fine and uniform, and their clay mineral content is high. Most of the Caseyville in northwestern Illinois is composed of medium gray to dark gray brittle shales interbedded with silty shales and a few clean quartz sandstones.

Several coal seams, most of them somewhat lenticular, are found in the Caseyville Formation, although only one—the Gentry Coal Member in southeastern Illinois—is named. In Rock Island and Mercer Counties, as many as seven impure coals up to 2 feet thick occur in the Caseyville (Searight and Smith, 1969).

Limestones are rare in the Caseyville Formation, the only one named being the Sellers Limestone Member, which is exposed in only one small area along the Ohio River Valley. Marine invertebrate fossils are found in this limestone, as well as in a few calcareous sandstone units, some of which contain reworked Mississippian fossils. The formation is otherwise barren of animal fossils.

The upper limit of the Caseyville, which is the top of the Pounds Sandstone Member, is commonly difficult to recognize in the subsurface north of its outcrop belt. Consequently, no separate map of the Caseyville thickness was prepared, but figure P-10 shows the combined thickness of the Caseyville, Abbott, and Spoon Formations. Included are strata from the base of the Pennsylvanian up to the base of the Colchester (No. 2) Coal, a widely recognizable key member that has been traced throughout the state. The Caseyville of Illinois correlates with all but the upper few feet of the Caseyville Formation of western Kentucky and with the lower part of the Mansfield Formation of Indiana.

Lusk Shale Member—The Lusk Shale Member of the Caseyville Formation (Weller, 1940, p. 36), the basal unit of the Pennsylvanian System in southeastern Illinois, is named for Lusk Creek in Pope County. The type section consists of exposures along the creek north of Waltersburg (12, 13S-6E). The thickness of the Lusk varies from zero to over 200 feet. The member is composed of various amounts of silty shale, siltstone, and sandstone. Quartz pebbles are common to abundant in some sandstone units as much as 25 feet or more thick, and these units are similar to the Battery Rock and Pounds Sandstone Members. Other sandstone units as much as 50 feet thick are fine grained. The Lusk contains a few thin, unnamed, nonpersistent coal seams and a few zones with marine fossils, most of them fragmentary. In general, all the Pennsylvanian rocks in southern Illinois below the Battery Rock Sandstone are assigned to either the Lusk Shale or the Wayside Sandstone.

Wayside Sandstone Member—The Wayside Sandstone Member of the Caseyville Formation (Lamar, 1925, p. 84-85) is named for Wayside, Johnson County, and the type section consists of outcrops near the village (N1/2 30, 11S-2E) (Wanless, 1956, p. 9). The Wayside is the lowermost unit of the Pennsylvanian System on the western side of the southern Illinois outcrop belt and is equivalent, at least in part, to the Lusk Shale to the east. Like the Lusk, it is a complex unit of interbedded lenticular sandstones as much as 50 feet thick that are separated by silty or sandy shales and siltstones, all part of a fluvial-deltaic complex. In the area south of Carbondale the thickness of the Wayside varies but averages about 70 feet.

Battery Rock Sandstone Member—The Battery Rock Sandstone Member of the Caseyville Formation (Cox, 1875, p. 204) is named for Battery Rock, a bluff of massive sandstone on the west bank of the Ohio River in Hardin County, the type section (26, 11S-10E). The Battery Rock Sandstone, a prominent bluff-forming unit (fig. P-3A), is very well developed in Gallatin, Hardin, and Pope Counties, where it is 50-100 feet thick in a large area. It is also as much as 100 feet thick in the western part of the southern Illinois outcrop belt, but there it is more lenticular. Along the southwestern side of the Illinois Basin, the sandstone extends only as far north as Randolph County. In the subsurface to the north and northeast of the outcrop belt, the Battery Rock is difficult to trace because several other thick sandstone units occur in the

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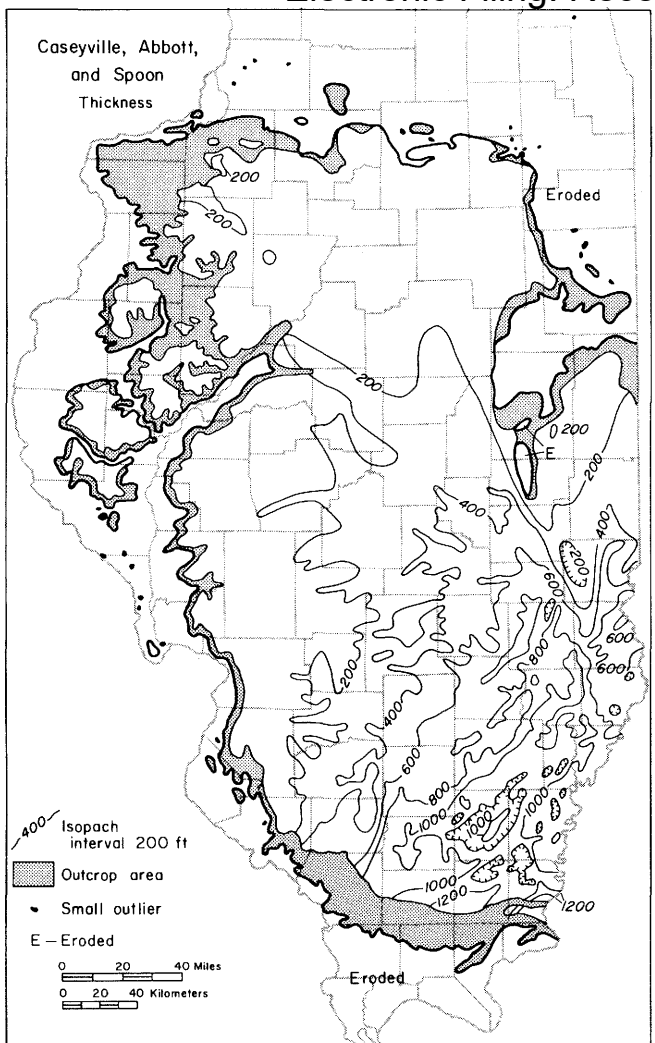

Fig. P-10—Combined thickness of the Caseyville, Abbott, and Spoon Formations (after Wanless, 1955).

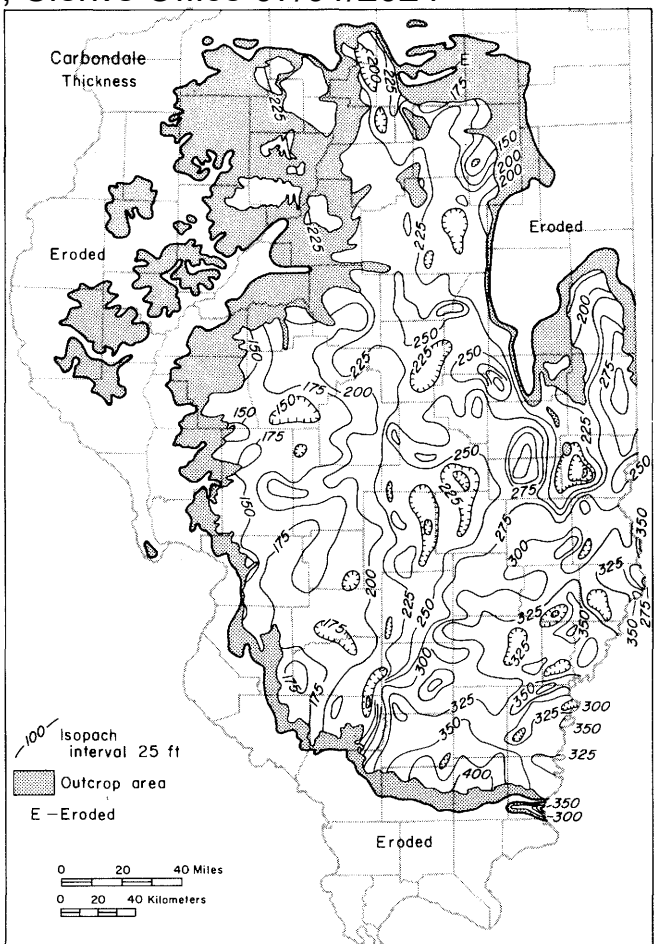

Fig. P-11—Thickness of the Carbondale Formation (based on map by K. E. Clegg).

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lower part of the McCormick Group. The Battery Rock is generally medium-grained sandstone, but at places it becomes coarse; almost everywhere it contains scattered quartz granules and pebbles, which in places form conglomerate beds. Although the Caseyville sandstones have been called conglomerates, the term "conglomeratic" is more appropriate. The Battery Rock is correlated with the lower Caseyville conglomerate, or Kyrock Sandstone Member, of western Kentucky and with the lower part of the Mansfield Sandstone of Indiana.

Drury Shale Member—The Drury Shale Member of the Caseyville Formation (Lamar, 1925, p. 91-95) is named for Drury Creek in Jackson County, and the type section consists of exposures along the creek south of Makanda (33, 34, 10S-1W). The Drury is a complex unit of sandy or silty shale, siltstone, and lenticular massive sandstone units, and is much like the Lusk Shale. It contains at least two thin, nonpersistent coals. The Drury is as much as 100-150 feet thick in places near the type area, but the thickness varies somewhat, partly because of differential erosion prior to deposition of the overlying Pounds Sandstone. All strata lying between the Battery Rock and Pounds Sandstones are considered equivalent to the Drury, but, for the sake of clarity in classification, the name "Drury" is not used in parts of southeastern Illinois where two other members of the Caseyville Formation—the Sellers Limestone and the Gentry Coal—occur within the Drury interval. Although rocks of Drury age are present in the subsurface of the southern part of the Illinois Basin, the Battery Rock and Pounds Sandstones cannot generally be differentiated in well logs, which makes it impractical to differentiate the Drury. The Drury is equivalent to part of the Mansfield Sandstone of Indiana.

Sellers Limestone Member—The Sellers Limestone Member of the Caseyville Formation (Wanless, 1939, p. 36, 101) is named for Sellers Landing, Hardin County, on the west bank of the Ohio River, near the type section (21, 11S-10E) (Wanless, 1956, p. 9). The Sellers Limestone is known only at the type locality, where about 10 feet is exposed. It is a major marine deposit in a complex fluvial-deltaic sequence. Part of the limestone is sandy and coarse grained and contains a varied marine fauna, but most of the Sellers is composed of beds of very fine-grained, argillaceous limestone interbedded with gray shale. No fusulinids, ostracodes, or conodonts have been found in the Sellers. It is equivalent to part of the Drury Shale, but no limestone correlatives are known.

Gentry Coal Member—The Gentry Coal Member of the Caseyville Formation (Kosanke et al., 1960, p. 29) is named for Gentry Landing, Hardin County, and the type locality consists of exposures near the landing (SW 26, 11S-10E). It previously was called the Battery Rock Coal (Owen, 1856, No. 1 vertical section). The Gentry Coal has been identified as a thin coal in several scattered localities in southeastern Illinois but is apparently not persistent. It was mined more than 100 years ago in small mines near the settlement of Lamb in Hardin County. It is underlain by a thin underclay, which overlies a thick, gray, silty shale that is equivalent to part of the Drury Shale. It is overlain by a shale that also is equivalent to part of the Drury Shale. Its exact relation to the Sellers Limestone has not been established, although field relations suggest that the Gentry is slightly above the Sellers.

Pounds Sandstone Member—The Pounds Sandstone Member of the Caseyville Formation (Weller, 1940, p. 38), the uppermost member, is named for Pounds Hollow in Gallatin County, and the type section consists of exposures along the hollow (35, 36, 10S-8E). The Pounds Sandstone is lithologically similar to the Battery Rock Sandstone and reaches 100 feet thick, forming long, abrupt bluffs in southern Illinois, usually north of the Battery Rock bluff. The Pounds is also known as far north as Rock Castle Creek in Randolph County (33, 6S-5W). Like other members of the Caseyville Formation, the Pounds Sandstone has not been widely traced in the subsurface north of the outcrop belt, although strata of this age and lithologic character are known to be present (fig. P-9). The Pounds is correlated with part of the Mansfield Sandstone of Indiana and the upper Caseyville conglomerate, or Bee Springs Sandstone Member, of western Kentucky.

ATOKAN SERIES

The Atokan Series of the Pennsylvanian System (Taff and Adams, 1900, p. 273) is named for Atoka, Atoka County, Oklahoma. No type section was designated, but the area near Atoka contains a sequence of a few thousand feet of sandstones and shales generally devoid of invertebrate fossils and truncated at the top by a major fault. In Illinois the Atokan Series consists of the strata composing the Abbott Formation of the McCormick Group (Willman et al., 1967) (fig. P-2). The base and top have not been defined by fossils, although fossiliferous zones are present within the series.

Where marine rocks are abundant, the Atokan is generally characterized as the two subzones of the earliest fusiform fusulinids, *Profusulinella* and *Fusulinella*, and the top is defined as the strata below the first appearance of *Fusulina* and *Wedekindellina*, although some confusion has arisen because *Fusulina* has been reported in the Atokan of the type area.

Plant fossil zones for the Atokan Series are Zones 7 (*Megatopteris* spp.) and 8 (*Neuropteris tenufolia*) of Read and Mamay (1964). Spore assemblages are the best means for correlating the Atokan strata in the Illinois Basin with Atokan strata of other areas. They are of greater diversity and their genera are more abundant and more evenly distributed than is true in the Morrowan Series. *Laevigatosporites*, *Calamites*, *Florinites*, and *Punctatisporites* increase in the upper part at the expense of *Lycospora*, which, with *Densosporites*, especially *D. annulatus*, and *Cristatisporites indignibundus*, is common in the lower part of the Atokan. Certain species of *Radiizonates* and *Torispora* are useful in defining the upper part.

Abbott Formation

The Abbott Formation of the McCormick Group (Kosanke et al., 1960, p. 30, 44) is named for Abbott Station on the Illinois Central Gulf Railroad, Pope County, along which the type section is exposed (5, 6, 7, 18, 19, 11S-5E). The Abbott Formation overlies the Caseyville and extends from the top of the Pounds Sandstone Member to the top of the Bernadotte Sandstone Member of western Illinois, which has been correlated with the Murray Bluff Sandstone Member of southern Illinois (fig. P-2). In subsurface, both the top and base of the Abbott are commonly difficult to determine. Only the sandstones and some

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of the coals have been named. In southern Illinois the Abbott overlaps the Caseyville Formation northward and is the basal formation of the Pennsylvanian System throughout most of the state outside the area of Caseyville strata. The Abbott is overlain by the Spoon Formation, which overlaps it in northern and northeastern Illinois and on some prominent anticlinal structures. The Abbott Formation has a maximum thickness of 300-350 feet in southern Illinois, but in western Illinois even where it is well developed it is generally less than 100 feet thick. It is similar to the Caseyville Formation in being composed primarily of detrital rocks, but it differs from the Caseyville in containing thicker, more widespread coals and in the character of the sandstones. The sandstones in the Abbott are generally finer grained, thinner in maximum development, contain more interstitial clay and mica flakes, and have no more than a few quartz granules and pebbles. These characteristics are transitional; the lower sandstones in the Abbott more closely resemble those in the Caseyville and the upper are similar to the impurer sandstones of the overlying Spoon Formation. Abbott shales are similar to those of the Caseyville but are in general less sandy. About half of the formation is shale; no named limestone units occur in the Abbott Formation. Calcareous sandstones, sandy limestones, and a few shale units contain marine fossils locally. Two marine limestones in southwestern Indiana (the Fulda and Ferdinand Members) and the Lead Creek Limestone Member in western Kentucky occur in strata equivalent to the lower part of the Abbott Formation in Illinois, as the associated coal floras show. The Abbott Formation is equivalent to the uppermost part of the Caseyville Formation and the lower part of the Tradewater Formation in western Kentucky and to the upper part of the Mansfield and essentially all of the Brazil Formation in Indiana.

Reynoldsburg Coal Member—The Reynoldsburg Coal Member of the Abbott Formation (Weller, 1940, p. 39), the lowermost named member in southern Illinois, is named for Reynoldsburg, Johnson County, and the type locality is north of Cedar Creek (W1/2 32, 11S-4E). The Reynoldsburg is well known only in a relatively small area in the central part of the southern Illinois outcrop belt, where the thickness of the coal is very irregular but is as much as 3 feet. It varies in character, apparently grading to a canneloid black shale near the type locality. The Reynoldsburg Coal has been mined locally in the type area. It is well exposed along Interstate 24 in the northernmost of a series of large highway cuts, which exposes all the Caseyville Formation and the lowermost part of the Abbott Formation. No coal at this position has been identified in western Illinois, but the No. 2 coal in western Kentucky is thought to be equivalent to the Reynoldsburg.

Grindstaff Sandstone Member—The Grindstaff Sandstone Member of the Abbott Formation (Butts, 1925, p. 44) is named for Grindstaff Hollow in Gallatin County, and outcrops along the hollow (NE cor. 28, 10S-8E) are the type section. The Grindstaff is similar in appearance and characteristics to the other two sandstones of the Abbott Formation in southern Illinois. It is best developed east of the Du Quoin Monocline. The Grindstaff is generally fine or medium grained, most of it is slightly micaceous, and it varies considerably in thickness up to 60 feet. It sometimes contains quartz granules and pebbles in the western part of the southern Illinois outcrop belt but generally fewer than occur in the underlying Caseyville sandstones. The sandstone is thickest and coarsest where it was deposited in local distributary or fluvial channels. It grades laterally into and overlies gray, silty or sandy shale. In a few places a very impure, sandy, clastic limestone or calcareous sandstone, formerly called the Boskydell Marine Zone or Boskydell Sandstone, is found at or near the position of the Grindstaff Sandstone in southwestern Illinois. The Grindstaff Sandstone is correlated with the Babylon Sandstone of western Illinois.

Babylon Sandstone Member—The Babylon Sandstone Member of the Abbott Formation (Wanless, 1931a, p. 189-190, 192-193), the lowest named member in western Illinois, is named for Babylon, Fulton County. The type locality is half a mile north of Babylon in the west bank of the Spoon River (NE NE 14, 7N-1E) (Wanless, 1957, p. 65, 205). The Babylon Sandstone is widely present in western Illinois and at its maximum is about 25 feet thick. In many places it is the lowest unit of the Pennsylvanian System and unconformably overlies Mississippian limestones. The sandstone is made up of relatively pure, subangular, medium to coarse quartz grains, most of which have been secondarily enlarged by quartz overgrowths that sparkle in sunlight (Wanless, 1957). The Babylon in western Illinois becomes thinner and sporadic in occurrence to the south. It is correlated with the Grindstaff Sandstone of southern Illinois.

Manley Coal Member—The Manley Coal Member of the Abbott Formation (Kosanke et al., 1960, p. 31) is named for Manley, Fulton County. It previously was called the Babylon Coal (Wanless, 1931a, p. 189-190, 192-193). It shares the type locality of the Babylon Sandstone Member (Wanless, 1957, p. 66, 205). The Manley Coal is widely distributed in western Illinois but occurs sporadically. It ranges up to 4 feet thick and has been mined in a few places. It varies from banded coal to cannel coal, and at one mine in Fulton County cannel coal 2.5-3 feet thick was once mined (Wanless, 1957). The Manley has not been identified in southern Illinois. It is correlated with the Shady Lane Coal Member of Indiana.

Willis Coal Member—The Willis Coal Member of the Abbott Formation (Butts, 1925, p. 62-63) is named for the Willis Mine in Gallatin County (SE SW 30, 10S-9E). The coal is present at widely scattered localities in the outcrop area in southern Illinois. It has been mined locally in southeastern Illinois, where it is 3-3.5 feet thick. In the type area the Willis is closely underlain by the Grindstaff Sandstone Member and is immediately overlain by about 40 feet of Finnie Sandstone. It is correlated with the Tarter Coal of western Illinois and the Lower Block Coal Member of Indiana.

Tarter Coal Member—The Tarter Coal Member of the Abbott Formation (Wanless, 1939, p. 15, 103) is named for Tarter Bridge over the Spoon River, Fulton County, and the type section consists of exposures near the bridge (SE 2, 5N-1E) (Wanless, 1956, p. 9; 1957, p. 67, 202). The Tarter Coal is thin and discontinuous throughout its outcrop area in western Illinois (Wanless, 1957), attaining a maximum thickness of slightly over 1 foot in many scattered outcrops. The interval from the Tarter Coal up to the Pope Creek Coal is usually only a few feet, and both coals are present in several outcrops. The Tarter is correlated with the Willis Coal of southern Illinois and the Lower Block Coal Member of Indiana.

Finnie Sandstone Member—The Finnie Sandstone Member of the Abbott Formation (Owen, 1856, No. 1 vertical section) is named for Finnie Bluff at the type locality, which is "along road for less than 2 miles north of Mulfordtown, Union County, Kentucky" (Glenn, 1912, p. 14). "Finnie" was adopted in Illinois to replace "Delwood Sandstone" (Kosanke et al., 1960, p. 31). The Finnie is widespread throughout much of southern Illinois east of the Du Quoin Monocline. Its bedding varies widely, as does its thickness (up to 60-70 feet). It is similar in appearance to other sandstones in the Abbott Formation and in a few localities contains scattered marine fossils. The distribution of the Finnie in the deeper part of the Illinois Basin has not been determined.

Delwood Coal Member—The Delwood Coal Member of the Abbott Formation (Weller, 1940, p. 40) is named for Delwood, Pope County, and the type locality consists of exposures near the village (NW NW 3, 11S-6E) (Wanless, 1956, p. 9). The Delwood Coal has been identified in several wide-

ly scattered outcrops in southern Illinois and in places is more than 3 feet thick. It is probably not continuous and locally may have been removed by channeling during development of a younger sandstone. Very little is known of the distribution of the Delwood in subsurface north of the outcrop belt. The name may have been applied to more than one coal and, in fact, recent palynological studies indicate the type Delwood may be equivalent to the Bidwell Coal Member of the lower part of the Spoon Formation. The Delwood has been correlated with the Pope Creek Coal of western Illinois, the Upper Block Coal Member of Indiana, and the No. 3 (Ice House) coal of western Kentucky.

Pope Creek Coal Member—The Pope Creek Coal Member of the Abbott Formation (Wanless, 1931a, p. 189-190, 192) is named for Pope Creek in Mercer County, and the type locality is along the creek (cen. 33, 14N-2W) (Wanless, 1929, p. 52; 1956, p. 9). The Pope Creek Coal is widespread in the western Illinois outcrop belt, where it is as much as 3 feet thick and averages about 1 foot (Wanless, 1957). The upper part of the coal is truncated in places by the Bernadotte Sandstone, but more commonly the coal is overlain by a gray shale several feet thick. The Pope Creek has been correlated with the Delwood Coal of southern Illinois, the Upper Block Coal Member of Indiana, and the No. 3 (Ice House) coal of western Kentucky.

Bernadotte Sandstone Member—The Bernadotte Sandstone Member (Savage, 1927, p. 307-316), which forms the top of the Abbott Formation in western Illinois, is named for the former town of Bernadotte, Fulton County, near the type locality (SW 19, 5N-2E) (Wanless, 1956, p. 9; 1957, p. 70-72, 103). The Bernadotte Sandstone is fairly extensive in western Illinois and attains thicknesses of 18 feet, though it commonly averages about 5 feet. It is very fine grained, only slightly micaceous, and the upper part is commonly cemented with silica. The Bernadotte differs from most Pennsylvanian sandstones in generally having a flat base and an uneven top, on the thicker parts of which overlying stratigraphic units tend to wedge out (Wanless, 1957). The Bernadotte is correlated with the Murray Bluff Sandstone of southern Illinois.

Murray Bluff Sandstone Member—The Murray Bluff Sandstone Member of the Abbott Formation (Weller, 1940, p. 40), the top member of the formation in southern Illinois, is named for the hill called Murray Bluff in Saline County, where the type section occurs (NE 35, 10S-5E). In the type section the sandstone is at least 60 feet thick and contains many liesegang rings (secondary iron-oxide diffusion banding). It is relatively thick in channel facies and thinner in nonchannel facies. The Murray Bluff has been identified at numerous localities throughout the outcrop area in southern Illinois, but its northward extent in the subsurface is generally not recognized. A sandstone occurs at this position in the areas where the Litchfield and Assumption Coals of the Spoon Formation are present. The Murray Bluff has been correlated with the Bernadotte Sandstone of western Illinois and the Aberdeen Sandstone Member of western Kentucky.

DESMOINESIAN SERIES

The Desmoinesian Series of the Pennsylvanian System (Keyes, 1893, p. 86-114) is named for the Des Moines River in Iowa, along which the strata of the series are exposed. No specific type section was designated. In Illinois the Desmoinesian includes all of the Spoon and Carbondale Formations of the Kewanee Group and the lower part of the Modesto Formation of the McLeansboro Group—up to the top of the Trivoli Sandstone Member (Willman et al., 1967) (fig. P-2). The Desmoinesian is the most widely developed series of the Pennsylvanian in the United States.

Fusulinids are abundant in many of the limestones in Illinois (Dunbar and Henbest, 1942), and the Desmoinesian is the *Fusulina* Zone. That genus is confined to the Desmoinesian Series, except for the one reported occurrence in Atokan rocks. Several other invertebrates, such as *Mesolobus*, *Chaetetes*, and *Prismopora*, are seldom found above the top of the Desmoinesian, and certain of their species are confined to this series. The exact upper boundary is difficult to determine in much of the Illinois Basin because an interval at the top of the Desmoinesian and the base of the Missourian is barren of fusulinids.

Floral Zones 9 (*Neuropteris rarinervis*) and 10 (*Neuropteris flexuosa* and *Pecopteris* spp.) of Read and Mamay (1964) are included in the Desmoinesian Series. In Illinois the series contains the thickest, most widespread coals, the spores of which are dominated by *Lycospora*. That genus suddenly disappears at the top of the Desmoinesian. *Thymospora pseudothiessenii*, which appears in the bottom third, also disappears at the top of the Desmoinesian. *Densosporites* occurs only in the lower half of the Desmoinesian, and *Schopfites* is diagnostic of approximately the middle third. There is a marked change in the spore flora at the Desmoinesian-Missourian boundary.

Kewanee Group

The Kewanee Group (Kosanke et al., 1960, p. 31) is named for Kewanee, Henry County, in western Illinois in the outcrop belt of its two formations—Spoon and Carbondale (fig. P-2). It includes strata previously classified as the Carbondale Formation or Group plus older and younger strata (P-5). The Kewanee Group is continuously recognized in all of the Illinois Basin within the confines of its outcrop limits. It normally lies above the Abbott Formation, but in northern and northeastern Illinois where the Abbott is missing it lies on rocks ranging in age from Valmeyeran (middle Mississippian) to Champlainian (middle Ordovician). It is overlain by the McLeansboro Group. The Kewanee Group contains the best developed cyclothems and more than 99 percent of the mapped coal reserves of the state (Cady et al., 1952). Lateral continuity of many of the lithologic units, especially the marine limestones, black fissile shales, coals, and underclays is remarkably extensive. The

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limestones, generally less than 5 feet thick, were deposited during marine transgressions from the west and southwest. Along with marine shales they alternate with fluvial and deltaic sediments that include siltstones, silty shales, elongate "channel" sandstones, and coals. The limestones are usually gray and argillaceous, and they contain a diverse marine fauna dominated by brachiopods, gastropods, crinoids, pelecypods, and Foraminifera (including fusulinids). The sandstones are texturally and mineralogically less mature than those of the McCormick Group in that they contain much more clay matrix, mica flakes, and feldspar grains, and their sand grains are less rounded and not as well sorted.

Spoon Formation

The Spoon Formation of the Kewanee Group (Kosanke et al., 1960, p. 32, 45) is named for the Spoon River, Fulton County, about a quarter of a mile east of the type section, which is in a roadcut and a railroad cut (NE SE 22, 6N-1E). The formation consists of strata from the top of the Bernadotte Sandstone of western Illinois or the Murray Bluff Sandstone of southern Illinois to the base of the Colchester (No. 2) Coal (fig. P-2), rocks formerly included in the upper part of the Tradewater Group. The Spoon Formation is present throughout most of the area in which Pennsylvanian strata occur. It is as much as 350 feet thick in southern Illinois but ranges from a few feet to less than 100 feet in northern and western Illinois. The formation is characterized by less sandstone and more coal and limestone than the Abbott Formation below and by less limestone and coal than the Carbondale Formation above. Sandstones are well developed in both elongate and sheet facies but do not constitute as much of the total section as they do in the lower formations. The sandstones show the general upward increase in the amount of argillaceous matrix and mica flakes that began in the sandstones in the Abbott Formation, from which they differ only slightly. The formation contains the first widespread limestones and coals, but they are thinner than those in the younger Pennsylvanian of Illinois. The coals of the Spoon are thicker and more extensive than those of the lower formations. The Spoon Formation correlates with the upper part of the Tradewater Formation and the lower part of the Carbondale Formation in western Kentucky and the very uppermost part of the Brazil Formation, all the Staunton Formation, and the lower part of the Linton Formation in Indiana.

Rock Island (No. 1) Coal Member—The Rock Island (No. 1) Coal Member of the Spoon Formation is the basal named member of the formation in western Illinois. It was first called Coal Number 1 (Worthen, 1868, p. 6, 10, 11) because it was believed to be the oldest (the first deposited) minable coal in Fulton, Morgan, Scott, and Schuyler Counties. It is typically exposed in the Spoon River Bluff near Seville, Fulton County (Worthen, 1870, p. 194). This exposure was designated the type section (SW SW 23, 6N-1E) by Wanless (1957, p. 72, 201). As that coal was correlated with the coal mined at Rock Island (Worthen and Shaw, 1873, p. 221, 229-232), the name Rock Island (No. 1) Coal came into general use. In western Illinois the Rock Island (No. 1) Coal occurs only in widely scattered areas. It attains a maximum thickness of about 8 feet in belts trending east-west or northeast-southwest (Wanless, 1965, p. 27, 29-30; Searight and Smith, 1969, p. 13), in other places only a few inches to a foot or two of coal is present, and it is absent throughout broad areas. The Rock Island Coal is tentatively correlated with the Assumption and the Litchfield Coals of west-central Illinois. It has been correlated with the Murphysboro Coal (Wanless, 1957), but the floras indicate it is lower than the Murphysboro (Kosanke, 1950). It is correlated with the Minshall Coal Member of Indiana.

Litchfield Coal Member—The Litchfield Coal Member of the Spoon Formation (Kay, 1915, table 9 and footnote, p. 139) is named for Litchfield, Montgomery County, where the coal was mined at a depth of 684 feet in the Litchfield Collieries Company Mine No. 7, which is the type section (SE NE NE 32, 9N-5W). In the mine, the Litchfield Coal occurs about 150 feet below the Lowell Coal and is 2-7 feet thick. It is not widely recognized throughout southern Illinois but has been found in a few drill holes. The Litchfield Coal is probably equivalent to the lower bench of the Assumption Coal and to the Rock Island (No. 1) Coal.

Assumption Coal Member—The Assumption Coal Member of the Spoon Formation (Cady, 1935, p. 53) is named for Assumption, Christian County, where the coal was mined at a depth of 1002 feet in the long-abandoned Assumption Coal and Mining Company Mine, which is the type section (NE NW SE 2, 12N-1E). In the mine the coal was 3-4 feet thick and was commonly split into 2 benches. In part of the mine the coal was overlain by limestone correlated with the Seville Limestone, which overlies the Rock Island Coal. The two benches were within 2 feet of each other in some parts of the mine. Where the coal seam was more widely split, the limestone formed the roof of the lower bench, and the interval to the upper bench, as much as 25 feet, consisted of sandstone and carbonaceous shale. The lower bench is the Assumption Coal Member. The extent of the Assumption Coal has not been ascertained, but a coal at approximately this position has been encountered in a few borings scattered throughout the Illinois Basin. The lower of the two benches is tentatively correlated with the Litchfield Coal of southwestern Illinois and the Rock Island (No. 1) Coal of western Illinois.

Seville Limestone Member—The Seville Limestone Member of the Spoon Formation (Wanless, 1931a, p. 189, 192) is named for Seville, Fulton County, where the type locality is in the southwest bank of the Spoon River (SW SW 23, 6N-1E) (Wanless, 1956, p. 9; 1957, p. 72-73, 201). The Seville Limestone is dark gray and argillaceous, and it contains a well preserved and diverse marine fauna. It is sporadic in occurrence and varies in thickness. It is seldom more than 4 feet thick, but more than 30 feet has been reported near Cuba, Fulton County. In several quarries in Rock Island and Mercer Counties, thicknesses up to 16 feet occur. The thicker occurrences are in narrow belts believed to have been estuaries, and in those areas the underlying Rock Island (No. 1) Coal is also thicker than elsewhere. The Seville Limestone is correlated with the Curlew Limestone Member of western Kentucky, the Lower Mercer Limestone of Ohio and Pennsylvania, and the Verne Shaly Limestone Member of Michigan (Wanless, 1957, p. 73). The name "Seville" has also been applied to this limestone in Missouri and Oklahoma.

Curlew Limestone Member—The Curlew Limestone Member of the Spoon Formation (Owen, 1856, No. 1 vertical section) is named for Curlew, Union County, Kentucky, where the type locality is an exposure on Indian Hill (Glenn, 1912, p. 24). The Curlew is gray, fine-grained, locally cherty limestone that seldom is more than 4 feet thick. It contains an abundant open-marine fauna. It is widespread, though sporadic, in southern Illinois and western Kentucky. The Curlew is correlated with the Seville Limestone.

Hermon Coal Member—The Hermon Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 33) is named for Hermon, Knox County. The unit formerly was called the Lower De Long Coal (Wanless, 1931a, p. 188-192). The type locality is along Brush Creek in Knox County, where the Hermon is the lowest of three thin coals (6, 8, 9N-2E) (Wanless, 1956, p. 9; 1957, p. 73-74). The Hermon Coal is found in many parts of western Illinois but is discontinuous. At most places it is represented by 2 inches or less of carbonaceous shale or bony coal. Near Canton in Fulton County, where it occurs locally over thick Rock Island Coal and thick Seville Limestone, the coal is as much as 4 feet thick. It is generally underlain by as much as 4 feet of gray underclay. No coal equivalent to the Hermon Coal has been recognized in southern Illinois.

Bidwell Coal Member—The Bidwell Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 32, 65) is named for Bidwell School in Johnson County, which is near the type locality (NE SE SW 5, 11S-4E). The Bidwell Coal, although discontinuous, is more widespread than most of the coals in the lower part of the Spoon Formation in southern Illinois and is 4 feet thick in places, although generally thinner. It has been identified in only a few drill holes north of the outcrop belt. The Bidwell has not been recognized in western Illinois.

O'Nan Coal Member—The O'Nan Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 32) is named for Dennis O'Nan Ditch, which flows across the tip of Indian Hill, Union County, Kentucky, the type locality (Glenn, 1912, p. 25). It previously was called the Curlew Coal (Owen, 1856, p. 47). The O'Nan Coal is generally thin, seldom over 1 foot thick in its scattered occurrences in southern Illinois. It is now believed to be equivalent to the Bidwell Coal.

New Burnside Coal Member—The New Burnside Coal Member of the Spoon Formation (Weller, 1940, p. 42) is named for New Burnside, Johnson County, which is near the type locality (SE SE SW 5, 11S-4E) (Kosanke et al., 1960, p. 32). The New Burnside Coal is well developed in scattered localities in southern Illinois and is as much as 5 feet thick where mined; however, in most of the area it is generally thinner. It occurs 15-25 feet above the Bidwell Coal. The New Burnside is correlated with the Brush Coal of western Illinois.

Brush Coal Member—The Brush Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 33) is named for Brush Creek, Knox County, where it is the middle of three thin coals. It previously was called the Middle De Long Coal (Wanless, 1931a, p. 188-192). The type locality is along the creek (6, 8, 9N-2E) (Wanless, 1956, p. 9; 1957, p. 74-75). The Brush Coal, widely recognized in western Illinois, consists primarily of carbonaceous shale or bony coal only a few inches thick, which is generally overlain by the underclay of the De Long Coal and underlain by a very persistent, purplish gray underclay that is commonly 3-5 feet thick. The Brush Coal is correlated with the New Burnside Coal of southern Illinois.

Cheltenham Clay Member—The Cheltenham Clay Member of the Spoon Formation (Wheeler, 1896, p. 247; White, 1909, p. 293) is named for the Cheltenham district in the southern part of St. Louis, Missouri. In Illinois, the name is applied locally to a complex claystone member that results from the thinning out of many units and the merging of several underclay units. The stratigraphic interval occupied by this member varies. The youngest deposits are at or immediately below the underclay of the Colchester (No. 2) Coal and the oldest are near the base of the underclay below the Brush (New Burnside) Coal. The Cheltenham is developed primarily in northern, western, and southwestern Illinois, areas where the Pennsylvanian section below the Colchester Coal is relatively thin. The Cheltenham Clay Member in Illinois is considered to be part of the Desmoinesian Series, but in Missouri similar deposits (Cheltenham Formation) are considered part of the Atokan Series (Howe and Koenig, 1961).

Granger Sandstone Member—The Granger Sandstone Member of the Spoon Formation (Kosanke et al., 1960, p. 32) is named for Grangertown, near Indian Hill, Union County, Kentucky, the type locality (Glenn, 1912, p. 24-26). It was originally called the Curlew Sandstone (Owen, 1856, No. 1 vertical section). The Granger Sandstone is widespread in southern Illinois, occurring in channel and nonchannel facies and varying considerably in thickness and bedding characteristics. About 40 feet of Granger Sandstone is well exposed in the Creal Springs Quarry in Williamson County (25, 10S-3E). The sandstone is probably present in much of the deeper part of the Illinois Basin.

Murphysboro Coal Member—The Murphysboro Coal Member of the Spoon Formation (Worthen, 1868, p. 11-12) is named for Murphysboro, Jackson County, where the type locality is in mines (SE 9, 9S-2W) (Wanless, 1956, p. 9). The Murphysboro Coal is well developed only in Jackson County and western Williamson County, where it has been reported to be locally more than 7 feet thick. In places it occurs in several benches separated by shale (Shaw and Savage, 1912). Mining started in this area around 1810, and the coal was sent to New Orleans in flatboats via the Big Muddy and Mississippi Rivers. Where the Murphysboro Coal is thick it is overlain by 40 or more feet of gray silty shale. In these areas the coal contains much less sulfur than elsewhere and resembles the Herrin (No. 6) and Harrisburg (No. 5) Coals, which also have low-sulfur contents where they have thick roof shales. Where relatively thin, the Murphysboro Coal contains much more sulfur, chiefly in the mineral pyrite. In early reports the Murphysboro Coal was correlated with the Colchester (No. 2) Coal, but its position was later found to be lower (Wanless and Weller, 1932), and it is now known to be between the No. 1 and No. 2 Coals.

Creal Springs Limestone Member—The Creal Springs Limestone Member of the Spoon Formation (Kosanke et al., 1960, p. 32, 64, 65) is named for Creal Springs, Williamson County. The type section consists of exposures in the sandstone quarry east of Creal Springs (NE SE SE 25, 10S-3E). The Creal Springs Limestone is gray, argillaceous, and in places cherty. It is seldom over 2 feet thick and contains an open-marine fauna. In the type area the Creal Springs lies on the Granger Sandstone, but throughout much of its extent it is separated from the underlying Murphysboro Coal by several feet of gray shale. The Creal Springs is lenticular and occurs sporadically in a large part of southern Illinois. In some places it was once correlated with the Curlew Limestone, but the fusulinids it contains indicate it is younger than the Curlew (Thompson et al., 1959).

Mt. Rorah Coal Member—The Mt. Rorah Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 33) is named for Mt. Rorah Church, which is about 2 miles north of the type locality (SE 25, 10S-4E; erroneously listed as section 35 in Wanless, 1956, p. 9, and Kosanke et al., 1960, p. 45). It previously was called the Bald Hill Coal (Cady, 1926, p. 259-260). The Mt. Rorah Coal occurs sporadically in a large part of southern Illinois, but it is seldom over 2 feet thick, generally no more than a few inches. It is correlated with the De Long Coal of western Illinois

De Long Coal Member—The De Long Coal Member of the Spoon Formation (Wanless, 1931a, p. 188-192), named for De Long, Knox County, is the uppermost of three thin coals that crop out about 1 1/2 miles southwest of De Long along Brush Creek, the type locality (6, 8, 9N-2E) (Wanless, 1956, p. 9; 1957, p. 188-192). It was called the Upper De Long Coal until "De Long," which had been applied to three coals, was restricted to the uppermost coal (Kosanke et al., 1960, p. 33). The De Long Coal is widespread in western Illinois but is not known to be more than a few inches thick. It

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is commonly made up of two thin coal seams separated by as much as 2 feet of claystone. The coal is separated from the overlying Seahorne Limestone by soft, poorly laminated shale 1-15 feet thick, and from the underlying Brush Coal by 1-3.5 feet of claystone and, commonly, a few inches of soft, light gray shale immediately over the Brush Coal. The De Long Coal is correlated with the Mt. Rorah Coal of southern Illinois.

Wise Ridge Coal Member—The Wise Ridge Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 33) is named for Wise Ridge, a hill about 3 miles west of the type section—a roadcut in Stonefort, Williamson County (NE SE 25, 10S-4E). It previously was called the Stonefort Coal (Wanless, 1939, p. 30, 103). The coal is lenticular but is widely present in southern Illinois. It is generally less than 3 feet thick and is very thin at some places. It is commonly separated from the Stonefort Limestone (above) by 1-2 feet of black fissile shale.

Stonefort Limestone Member—The Stonefort Limestone Member of the Spoon Formation (Henbest, 1928, p. 70-71) is named for Stonefort, Williamson County. The type locality consists of a roadcut and near-by ravines (NE SE 25, 10S-4E), a correction of the location given by Wanless (1956, p. 9) (Kosanke et al., 1960, p. 33). The Stonefort is a gray, fine-grained, marine limestone, seldom over 3 feet thick, that extends throughout the greater part of southern Illinois. It has been identified on geophysical logs of oil tests in much of the southern part of the Illinois Basin.

Vergennes Sandstone Member—The Vergennes Sandstone Member of the Spoon Formation (Shaw and Savage, 1912, p. 7) is named for Vergennes, Jackson County, and the type locality is near the town (N½ 11, 7S-3W). The outcrops indicate that the Vergennes is a channel sandstone at least 30 feet thick, but units above and below it are poorly exposed and its stratigraphic position is in question. The name Vergennes has not been extended beyond the type area, and recent studies by T. K. Searight suggest that the Vergennes may be equivalent to the Palzo Sandstone.

Seahorne Limestone Member—The Seahorne Limestone Member of the Spoon Formation (Wanless, 1931a, p. 191) is named for Seahorne Branch in Fulton County, and the type section consists of exposures along that stream (S½ SE 5, 3N-3E) (Wanless, 1956, p. 9; 1957, p. 76, 200). The Seahorne is best known in western Illinois, where it varies from limestone nodules in claystone to a solid ledge of limestone more than 6 feet thick. It is usually light gray. In some places it is conglomeratic or brecciated and consists of dark gray fragments that contain abundant brachiopods embedded in a light gray matrix that is dominated by a diverse gastropod fauna. Another fauna, *Spirorbis* and ostracodes, is found at places and is generally considered nonmarine. The Seahorne is not persistent but occurs at many places in Illinois and adjacent states. It is the caprock of the Tebo coal in Missouri (Wanless, 1957).

Davis Coal Member—The Davis Coal Member of the Spoon Formation (Owen, 1856, p. 41) is named for the Davis Mine, located half a mile east of Dekoven Station, Union County, Kentucky (Lee, 1916, p. 19, 30). It has also been called the No. 6 coal in western Kentucky. In Illinois the Davis Coal has about the same distribution as the De Koven Coal, which it underlies by as much as 30-40 feet. The Davis averages about 4 feet thick across much of southern Illinois, where it has been mined by surface methods (Butts, 1925). To the north and west the coal, as a rule, is thinner. It is correlated with the Wiley Coal of western Illinois.

Wiley Coal Member—The Wiley Coal Member of the Spoon Formation (Wanless, 1931a, p. 191) is named for Wiley School, Fulton County, near the type section (SW NW 16, 7N-2E) (Wanless, 1956, p. 9; 1957, p. 79, 206). The Wiley is a widespread coal in western Illinois. It is seldom more than 2 feet thick, although local occurrences of up to 3 feet are known. It is correlative with the Davis Coal of southern Illinois and western Kentucky. It may be equivalent to the Mineral coal of Missouri and Kansas (Wanless, 1957).

De Koven Coal Member—The De Koven Coal Member of the Spoon Formation (Lee, 1916, p. 30, 31) is named for Dekoven Station, Union County, Kentucky, near which it is well exposed. The De Koven Coal, also called the No. 7 coal in western Kentucky, occurs from a few to about 40 feet above the Davis Coal and is widespread throughout Williamson, Saline, and Gallatin Counties, averaging about 3 feet thick (Butts, 1925). It is also present to the north in the deeper part of the Illinois Basin, but there it is generally thinner. In Williamson County the De Koven Coal is split by a few feet of dark shale. The De Koven is correlated with the Greenbush Coal of western Illinois.

Greenbush Coal Member—The Greenbush Coal Member of the Spoon Formation (Wanless, 1931a, p. 191) is named for Greenbush Township, Warren County, the type locality (E½ 24, 8N-1W) (Wanless, 1956, p. 10; 1957, p. 81, 205). The Greenbush Coal is seldom more than a few inches thick, and it grades into a thin carbonaceous shale in some localities. It is correlated with the De Koven Coal of southern Illinois and western Kentucky.

Seelyville Coal Member—The Seelyville Coal Member of the Spoon Formation (Kosanke et al., 1960, p. 33; incorrectly spelled "Seeleyville") is named for Seelyville, Vigo County, Indiana, where the type locality is in mines (12N-7 and 8W). It was originally named Indiana Coal III (Ashley, 1899, p. 106-107) but informally called Seelyville in Indiana. In Illinois the Seelyville is known primarily in Edgar, Clark, and Crawford Counties, where it as much as 6 feet thick. It occurs locally in southern Illinois between the De Koven and Colchester Coals. In Indiana it is now called Seelyville Coal Member (III).

Palzo Sandstone Member—The Palzo Sandstone Member of the Spoon Formation (Cady, 1942, p. 9; Weller et al., 1942a, p. 10, footnote) is named for Palzo, Williamson County, and the type locality consists of exposures near the village (SE 16, 10S-4E) (Wanless, 1956, p. 10). The Palzo Sandstone is well developed throughout the state in both channel and nonchannel facies and is locally more than 50 feet thick. It is similar in appearance to other sandstones in the Spoon Formation in southern Illinois and is correlated with the Isabel Sandstone of western Illinois and the Sebree Sandstone Member of western Kentucky.

Isabel Sandstone Member—The Isabel Sandstone Member of the Spoon Formation (Wanless, 1931a, p. 192) is named for Isabel Township, Fulton County, which includes the type section (NW NE 16, 4N-3E) (Wanless, 1956, p. 10; 1957, p. 83, 199). The name is used in western Illinois for a sandstone that generally is relatively thin, fine-grained, micaceous, feldspathic, and cemented with various amounts of calcium carbonate. The Isabel and younger sandstones differ from the stratigraphically lower sandstones in western Illinois in that they are less quartzose, contain much more mica and feldspar, are not as well sorted, and do not show the abundant quartz overgrowths that produce the "sparkling sandstones." A sandstone is present at this position essentially throughout Illinois. In southern Illinois it is called the Palzo Sandstone.

Abingdon Coal Member—The Abingdon Coal Member of the Spoon Formation (Culver, 1925, p. 75) is named for Abingdon, Knox County, near the type locality (cen. 6, 9N-2E) (Weller et al., 1942b, p. 1589). The Abingdon is recognized only in western Illinois, where it varies in thickness but only locally exceeds 2 feet. It is absent from extensive areas. Although the Abingdon is not definitely recognized in other parts of the state, coals locally present near this position in northern and southern Illinois may be equivalent to the Abingdon Coal.

Browning Sandstone Member—The Browning Sandstone Member of the Spoon Formation, the youngest named member (Wanless, 1939, p. 14, 78), is named for Browning

Township, Schuyler County, which includes the type locality (18, 2N-1E) (Wanless, 1956, p. 10; 1957, p. 86). The Browning Sandstone has been recognized only in western Illinois (Wanless, 1957), where it occurs in both channel and sheet facies and ranges from less than 3 to as much as 80 feet thick. In some places the channel facies is almost entirely sandstone that grades upward into shale, but in other places most of it is silty shale and siltstone.

Carbondale Formation

The Carbondale Formation of the Kewanee Group (Shaw and Savage, 1912, p. 6; Wanless, 1939, p. 79; Willman and Payne, 1942, p. 86-87; Kosanke et al., 1960, p. 34) is named for Carbondale, Jackson County, which lies near the outcrop belt of these rocks. A type section consisting of three outcrops was established in Fulton County, western Illinois (SE NE 1, 7N-4E; NW NE NW 20, 8N-3E; and SW cor. 21, 8N-3E) by Kosanke et al. (1960, p. 34, 46). The Carbondale includes strata from the base of the Colchester (No. 2) Coal Member to the top of the Danville (No. 7) Coal Member (fig. P-2). Shaw and Savage included in the Carbondale the strata from the base of the Murphysboro Coal to the top of the Herrin (No. 6) Coal. The Murphysboro was thought to be equivalent to the Colchester (No. 2) Coal of western Illinois, and the intent was to make the Colchester Coal the base of the formation. Wanless (1939) redefined the Carbondale as a group (fig. P-5), and Willman and Payne (1942) included strata from the base of the Palzo Sandstone to the base of the Anvil Rock Sandstone in the Carbondale Group. The Carbondale Formation consists of a large number of named members, many of which possess remarkable lateral persistence in thickness and lithologic character. In the sandstones and gray silty shales, however, rapid lateral changes are common and are primarily responsible for local and regional changes in thickness. The formation varies from less than 150 feet in western and northeastern Illinois to more than 400 feet near its outcrop belt in southern Illinois (fig. P-11). The Carbondale sandstones occur in elongate, channel facies up to about 100 feet thick and also in thinner sheets. Most of the sandstones are subgraywackes and are more argillaceous than older Pennsylvanian sandstones, although only slightly more so than sandstones of the Spoon Formation. Gray shales are the most abundant type of sediment in Carbondale rocks. Some contain only marine fossils and others only plant fossils. Most of the thicker gray shales probably are either delta front or prodelta deposits. Sideritic nodules and bands are common, especially in the lower parts of the shales. The widespread limestones (fig. P-3B) are gray to dark gray, argillaceous, and normally fossiliferous. Associated with the marine limestones are extensive black fissile shales (fig. P-3C) that are generally less than 2 feet thick and contain marine fossils. Light gray nodular limestones, commonly without fossils, occur in the bottom part of the widespread underclays. The Carbondale Formation contains the principal economic coals of Illinois, the Herrin (No. 6) (fig. P-13), the Springfield-Harrisburg (No. 5) (fig. P-12), the Colchester (No. 2), and the Danville (No. 7) Coal Members, in order of importance as reserves. The Carbondale Formation correlates with the upper portion of the Carbondale Formation and approximately the lower 50 feet of the Sturgis Formation in western Kentucky, where the boundaries are the base of the Kentucky No. 6 coal and the top of the Kentucky No. 11 coal. Essentially the same interval is called the Carbondale Group in Indiana.

Colchester (No. 2) Coal Member—The Colchester (No. 2) Coal Member of the Carbondale Formation, the lowest member, was designated No. 2 by Worthen (1866, p. 59) for the coal in a mine shaft at Highland, Madison County. Worthen also used the name Colchester for the same coal at Colchester, McDonough County (1868, p. 11), and also (1870, p. 96-97) for an exposure 1.5 miles west of Vermont, Fulton County. Wanless (1956, p. 10) designated exposures near Colchester as the type section (12, 13, 5N-4W). The coal has also been called the La Salle (No. 2) Coal or the "Third Vein" coal in northern Illinois. The Colchester Coal is a normal, bright-banded coal (fig. P-3C). It is very extensive in Illinois and is thought to be one of the most widespread coals in the United States. It is generally thin, varying from a fraction of an inch to 18 inches in southern, central, and eastern Illinois, and is rather uniformly 2-3.5 feet thick throughout much of northern and western Illinois, where it has been extensively mined. It is overlain directly by either the black Mecca Quarry Shale Member, or, in parts of western and most of northern Illinois, by the gray Francis Creek Shale Member. It is underlain by a well developed underclay. It is correlated with the Croweburg coal of Missouri and Kansas, the Schultztown of western Kentucky, the Broken Arrow or Croweburg of Oklahoma, the Whitebreast of Iowa, the Colchester Coal Member (IIIa) of Indiana, and tentatively with the Lower Kittanning Coal of the Appalachian field (Wanless, 1957).

Cardiff Coal Member—The Cardiff Coal Member of the Carbondale Formation (Cady, 1915) is named for Cardiff, Livingston County, and the type locality is in mines at Cardiff (22, 23, 30N-8E). The name was not in general use until re-introduced by Peppers (1970). The Cardiff Coal is known only in northeastern Livingston, southeastern Grundy, and western Kankakee Counties, where it occurs in channels trending northeast-southwest eroded in gray shale. It generally is not more than 10 feet above the Colchester (No. 2) Coal. At a few localities the Cardiff directly overlies the Colchester Coal. The Cardiff Coal is highly lenticular and was reported in one mine to be 12 feet thick. It commonly is in more than one major bench, the benches separated by gray shale. Peppers (1970) described the flora and concluded that the Cardiff Coal is a little older than the Lowell Coal.

Francis Creek Shale Member—The Francis Creek Shale Member of the Carbondale Formation (Savage, 1927, p. 309) is named for Francis Creek in Fulton County and the type locality is along the creek (NE SW 22, 5N-1E) (Wanless, 1929, p. 89; 1956, p. 10; 1957, p. 88, 203). The shale is medium gray, silty, and more than 80 feet thick in northeastern Illinois. It forms a large clastic wedge that extends across the northern part of the area of Pennsylvanian rocks and thins out to the west and south (Smith, 1970). It has not been recognized in southern Illinois. The shale is best known for the famous Mazon Creek sideritic concretions that are found in the Kankakee-Will-Grundy Counties area and have yielded what is probably the best known Pennsylvanian flora in the United States (Noé, 1925). In Will County and at one place in Fulton County, concretions in the shale have a diverse fauna (Johnson and Richardson, 1970). The upper part of the Francis Creek commonly contains a few sandstone beds, probably equivalent to the Jake Creek Sandstone.

Jake Creek Sandstone Member—The Jake Creek Sandstone Member of the Carbondale Formation (Wanless, 1957, p. 85, 89, 204) is named for Jake Creek in Fulton County, and the type section is along the upper part of the creek (NE 13, 4N-1E). The Jake Creek is recognized only in western Illinois, where it attains a maximum thickness of 18 feet along a north-south belt about 1 mile wide and appears to be on top

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of the Francis Creek Shale. It may correlate with thin sandstones in the upper part of the Francis Creek Shale in other parts of the state.

Mecca Quarry Shale Member—The Mecca Quarry Shale Member of the Carbondale Formation (Zangerl and Richardson, 1963, p. 25) is named for Mecca, Parke County, Indiana, where the type section is in a small quarry that was excavated for study of the shale (SW NE 29, 15N-8W). The Mecca Quarry Shale is a hard, black fissile shale that locally is as much as 4 feet thick but more normally is 1-2 feet thick. It contains a varied marine fauna dominated by nektonic and planktonic forms. Large limestone concretions and small phosphatic lenses and nodules are common locally (fig. P-3C). The unit is very extensive in Illinois and adjacent states. It lies immediately above the Colchester (No. 2) Coal in much of southern and eastern Illinois and above the Francis Creek Shale in much of western and northern Illinois. Where the Francis Creek is more than about 30 feet thick, the Mecca Quarry is absent. The Mecca Quarry is generally overlain by the Oak Grove Limestone.

Oak Grove Limestone Member—The Oak Grove Limestone Member of the Carbondale Formation, originally called the Oak Grove beds (Wanless, 1931a, p. 184, 187, 192), is named for Oak Grove School in Fulton County, and the type section is in a ravine just north of the school (SW SE 6, 5N-3E) (Wanless, 1956, p. 10; 1957, p. 91, 197). In western and northern Illinois the Oak Grove consists of a remarkably persistent sequence of thin, lithologically and paleontologically distinctive limestone beds. Most of them are only a few inches thick, but some are a few feet thick. They are interbedded with dark gray and black shale beds that also have characteristic properties (Wanless, 1957, p. 91-94). The total thickness of the Oak Grove seldom exceeds 15 feet. Limestone units are less abundant in the Oak Grove in southern Illinois. The Lowell and Shawneetown Coals appear to occur within strata equivalent to the Oak Grove. Limestones equivalent to the Oak Grove are present in western Indiana, southern Iowa, and western Missouri.

Lowell Coal Member—The Lowell Coal Member of the Carbondale Formation (Willman and Payne, 1942, p. 102-105) is named for Lowell, La Salle County, where the coal is 10 inches thick in the type section, an exposure on the Vermilion River (SE SW 8, 32N-2E). It is a bright-banded, rather shaly coal underlain by a silty to sandy underclay and overlain by several feet of gray shale that contains two limestone beds, which are equivalent to upper units of the Oak Grove Limestone. The underclay overlies a siltstone containing plant root impressions, which in turn is underlain by gray shale containing additional limestone units equivalent to the Oak Grove Limestone. The Lowell Coal is present in northern Illinois and in the southern part of western Illinois. It is equivalent to the Shawneetown Coal in southwestern, southern, and eastern Illinois.

Shawneetown Coal Member—The Shawneetown Coal Member of the Carbondale Formation (Kosanke et al., 1960, p. 34-35) is named for Shawneetown, Gallatin County, where the type section is at a depth of 482.6 feet (erroneously given originally as 543.8 feet) in Union Colliery Company drill hole 28 (NW SW NW 23, 9S-9E) (Peppers, 1970, p. 43). It is the upper of two coals in southeastern Illinois lying between the Colchester (No. 2) and Summum (No. 4) Coals that had previously been called Coal 2A. The Shawneetown Coal is persistent in southern and eastern Illinois, but is known to crop out only in a strip mine near Mitchellsville, Saline County. It normally is thin, but in a few scattered drill holes it has been reported to be as much as 8 feet thick. It is overlain by dark shale and underlain by underclay. It is correlated with the Lowell Coal of northern and western Illinois and with the Survant Coal Member (IV) in eastern Indiana.

Purington Shale Member—The Purington Shale Member of the Carbondale Formation (Wanless, 1931a, p. 184, 188, 192) is named for the Purington Brick Company pit at East Galesburg, Knox County, which exposes the type section (SW 17, 11N-2E) (Wanless, 1956, p. 10). The Purington is a widespread gray shale that overlies the Oak Grove Limestone and attains a maximum thickness of about 50 feet in western and northern Illinois. It commonly contains marine fossils and sideritic concretions in the bottom part and becomes silty and sandy toward the top.

Pleasantview Sandstone Member—The Pleasantview Sandstone Member of the Carbondale Formation (Wanless, 1929, p. 90) is named for Pleasantview (now Pleasant View), Schuyler County, and the type locality is along Mill Creek (31, 2N-1E) (Wanless, 1956, p. 10; 1957, p. 190). The sandstone occurs as sheet facies 20 feet or less thick and as channel facies as much as 80 feet thick. In the channel facies the sandstone cuts through underlying strata down to, and locally through, the Colchester (No. 2) Coal (Ekblaw, 1931; Rusnak, 1957). The sandstone is best developed in western Illinois, but a sandstone commonly present a short distance below the Summum (No. 4) Coal throughout the Illinois Basin is probably equivalent to the Pleasantview. It is generally overlain by several feet of shale, which separates it from the underclay of the Summum Coal.

Kerton Creek Coal Member—The Kerton Creek Coal Member of the Carbondale Formation (Ekblaw, 1931, p. 391) is named for Kerton Creek in Fulton County, along which the type section is exposed (NE NE 15, 3N-2E) (Wanless, 1956, p. 10; 1957, p. 98, 189). This coal is recognized only in Fulton County, where it occurs in channels that had been only partially filled with the underlying Pleasantview Sandstone. The coal is up to 5 feet thick and is either canneloid or quite high in ash. The Summum (No. 4) Coal, which also thickens in the same unfilled channels, overlies the Kerton Creek by only a few feet. The Kerton Creek does not have an underclay but rests directly on the Pleasantview Sandstone. It is believed to correlate with the Roodhouse Coal of Greene County.

Roodhouse Coal Member—The Roodhouse Coal Member of the Carbondale Formation (Siever, *in* Wanless, 1956, correlation chart, pl. 1) is named for Roodhouse, Greene County, near the type section (NW 21, 12N-11W) (Kosanke et al., 1960, p. 35, 47). The coal is canneloid and, like the Kerton Creek Coal of southern Fulton County, occurs immediately above a channel facies of the Pleasantview Sandstone, apparently in channels that were not completely filled by the sandstone (Wanless, 1957, p. 98). The coal is as much as 5 feet thick near the center of the channels but is not present outside them. It directly overlies the Pleasantview Sandstone, without an underclay. It probably correlates with the Kerton Creek Coal in Fulton County.

Breezy Hill Limestone Member—The Breezy Hill Limestone Member of the Carbondale Formation (Pierce and Courtier, 1937, p. 17) is named for Breezy Hill, Crawford County, Kansas, where the type section is exposed. The Breezy Hill Limestone occurs in the lower part of the underclay of the Summum (No. 4) Coal in western and northern Illinois (Inden, 1968; Nance, 1970). The member is widespread, though sporadic. It occurs either as an irregular, silty limestone, rarely over 1 foot thick, or as nodular masses in claystone. The only fossils found in it in western Illinois are micritic patches and filaments, probably algal. This limestone is interpreted as fresh-water in Illinois and open-marine to the west in Kansas and Oklahoma, where it is several feet thick and contains a varied marine fauna. In Missouri it occurs at the base of the underclay of the Mulky coal (Inden, 1968; Nance, 1970).

Summum (No. 4) Coal Member—The Summum (No. 4) Coal Member of the Carbondale Formation (Wanless, 1931a, p. 182, 192) is named for Summum, Fulton County, near the type locality (NE 3, 3N-2E) (Wanless, 1956, p. 10; 1957, p. 204). The term "No. 4" was first used by Lesquereaux (1866, p. 213) for this coal near Shawneetown, Gallatin County. It was also applied incorrectly by Worthen (1870) to the Springfield (No. 5) Coal in parts of Fulton County. The coal, or the recognized position of the coal, is one of the

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most widespread stratigraphic markers in the state, but it is generally thin and has been mined only locally in Grundy, Kankakee, Fulton, and Saline Counties. It normally is overlain by the black Excello Shale and overlies an underclay. It is correlated with the Mulky coal of Missouri and Kansas, the Houchin Creek Coal Member (IVa) in Indiana, and the No. 8b coal in western Kentucky.

Excello Shale Member—The Excello Shale Member of the Carbondale Formation (Searight et al., 1953) is named for Excello, Macon County, Missouri. In Illinois, the Excello is composed of black fissile shale that is generally 1-3 feet thick and similar in character to the member in Missouri (Nance, 1970, p. 77). Large black limestone concretions commonly occur in the lower part. It generally directly underlies the Hanover Limestone, but in some places in western Illinois a lighter colored shale a few feet thick intervenes. The Excello immediately overlies the Summum (No. 4) Coal, except locally in northern Illinois where a few feet of gray shale separates them.

Hanover Limestone Member—The Hanover Limestone Member of the Carbondale Formation (Wanless, *in* Lamar et al., 1934, p. 84; 1957, p. 101) is named for Hanover School, Greene County, near the type locality (NE SW 27, 10N-11W) (Wanless, 1956, p. 10; 1957, p. 101). The Hanover is a thin marine limestone that is seldom more than 4 feet thick and in places is represented only by nodules of limestone or a thin concentration of marine fossils in which brachiopods are dominant. It is a persistent bed of gray, argillaceous, brecciated or nodular limestone in most of western and northern Illinois, where it overlies the black Excello Shale. It is poorly developed in southern Illinois. The Hanover is one of the most widespread Pennsylvanian limestones in the central United States and is equivalent to the Blackjack Creek Limestone of Kansas, Oklahoma, and Missouri (Wanless, 1957, p. 101).

Covel Conglomerate Member—The Covel Conglomerate Member of the Carbondale Formation (Willman, 1939, p. 174-176) is named for Covel Creek in La Salle County, and the type section is along the creek near its mouth (SE SW 26, 33N-3E) (Willman and Payne, 1942, p. 116; Wanless, 1956, p. 10). This unit is remarkably persistent in northern Illinois and is locally present in western and eastern Illinois. It is composed of rounded, dark gray to black, phosphatic limestone pebbles and water-worn marine fossils in a matrix of lighter gray limestone or of pyrite. In many places the member is covered with laminated algal growths. The Covel is generally 1-3 inches thick and is an easily recognized stratigraphic marker. It is also present in southern Iowa and western Indiana (Wanless, 1957).

Springfield and Harrisburg (No. 5) Coal Members—The Springfield (No. 5) Coal Member and the Harrisburg (No. 5) Coal Member of the Carbondale Formation are the same unit, but separate names are retained because of long-established usage—"Springfield" in central, northern, and western Illinois and "Harrisburg" in southern and eastern Illinois. The term "No. 5" was first applied to this coal by Worthen (1870, p. 93) in his description of the geology of Fulton County. It was later applied to the coal mined in the Springfield, Sangamon County, district (Shaw and Savage, 1913, p. 3), and underground exposures in coal mines were made the type section (16, 16N-4W) (Wanless, 1956, p. 10). The Harrisburg (No. 5) Coal Member (Shaw and Savage, 1912, p. 7) is named for Harrisburg, Saline County, where it is mined. The No. 5 Coal is second only to the Herrin (No. 6) Coal in commercial importance in Illinois. It is commonly 4-8 feet thick (fig. P-12). In southwestern Illinois it has been strip mined in a few pits where the Herrin is the principal coal. The coal is absent along the northern margin of the Pennsylvanian rocks. It is normally overlain by a black fissile shale, but in southeastern Illinois, in a belt several miles wide that trends southwestward, the coal is thick and it is overlain by the gray silty Dykersburg Shale. In that belt the coal is more commonly split by shale partings, and contains less pyrite than where it is overlain by the black fissile shale (Hopkins, 1968). The No. 5 Coal is the most important coal in Indiana, where it is now called the Springfield Coal Member (V), and in western Kentucky, where it is called the No. 9 (Mulford) coal. It is correlated with the Summit coal in Missouri.

Dykersburg Shale Member—The Dykersburg Shale Member of the Carbondale Formation (Hopkins, 1968, p. 4) is named for Dykersburg (called Absher on some maps), Williamson County, near which the type section is in the highwall of an abandoned coal strip pit (SE SE NE 34, 9S-4E). The Dykersburg is confined to a belt 3-15 miles wide that extends southwestward from Wabash County to the outcrop in Saline County. Most of it is gray silty shale containing some sandstone, particularly one major channel sandstone that replaces the Harrisburg Coal along a narrow band. The Dykersburg is as much as 100 feet thick in places. Where overlain by the Dykersburg Shale, the Harrisburg Coal is thicker, is commonly characterized by several shale splits, and contains much less sulfur (less pyrite) than in areas where it is overlain by black fissile shale or the St. David Limestone. The Dykersburg is also well developed in an adjacent area in western Indiana.

St. David Limestone Member—The St. David Limestone Member of the Carbondale Formation (Savage, 1927, p. 309) is named for St. David, Fulton County, and the type section consists of outcrops near the village (SE SE 17, 6N-4E) (Wanless, 1956, p. 10; 1957, p. 105, 197). The St. David is a thin, dark gray, argillaceous limestone containing an abundant open-marine fauna dominated by brachiopods; it also contains a few fusulinids. It is almost invariably present where the Springfield-Harrisburg (No. 5) Coal occurs, although the limestone and coal are generally separated by 1-3 feet of black fissile shale. The St. David is widespread in western Illinois, where its thickness is generally less than 1 foot but locally reaches 2 feet. In eastern and southwestern Illinois also it is persistent and locally is 3-4 feet thick. In southeastern Illinois and western Kentucky, it is continuous but is commonly no more than a few inches of very fossiliferous calcareous shale or impure limestone. The underlying black fissile shale is widely characterized by an abundance of *Dunbarella rectilaterarius* (fig. P-6) in its lower few inches. The St. David is usually absent where the gray Dykersburg Shale, which underlies it in places, is more than 25 or 30 feet thick.

Canton Shale Member—The Canton Shale Member of the Carbondale Formation (Savage, 1921a, p. 240-241) is named for Canton, Fulton County, and the type section consists of outcrops along Big Creek (cen. 9, 6N-4E). The Canton is a gray, rather uniform shale that tends to be decidedly silty in its upper part. In western and northern Illinois, where it is primarily recognized and is as much as 50 feet thick, the lower few feet is dark gray and contains a varied marine fauna and several layers of fossiliferous, calcareous concretions. In northern Illinois a 4-6 inch bed of canneloid coal occurs locally about 10 feet above the base of the Canton. In central and western Illinois, from south of Springfield to the vicinity of Du Quoin in Perry County, the interval between the Herrin (No. 6) and Springfield-Harrisburg (No. 5) Coals thins, and the Canton Shale is only a foot or so thick or is absent. In southern Illinois the shale above the St. David Limestone and the shale either immediately or a few feet above the Briar Hill Coal may be in part equivalent to the Canton.

Briar Hill (No. 5A) Coal Member—The Briar Hill (No. 5A) Coal Member of the Carbondale Formation (Glenn, 1912, p. 38) is named for Briar Hill, a hill near Dekoven Station, Union County, Kentucky. The name was adopted in Illinois (Cady, 1919a, p. 20; 1926, p. 255), and a locality in Saline County (9S-7E) was designated as representative for Illinois (Wanless, 1956, p. 10). In Kentucky, this coal is now referred to as the No. 10 coal. In Illinois, the Briar Hill is fairly continuous in southeastern Illinois and has been recognized as far as Clark County on the northeast and Mt. Vernon on the northwest. It is generally thin and has been mined only on a small scale in the state. The coal is overlain by a dark

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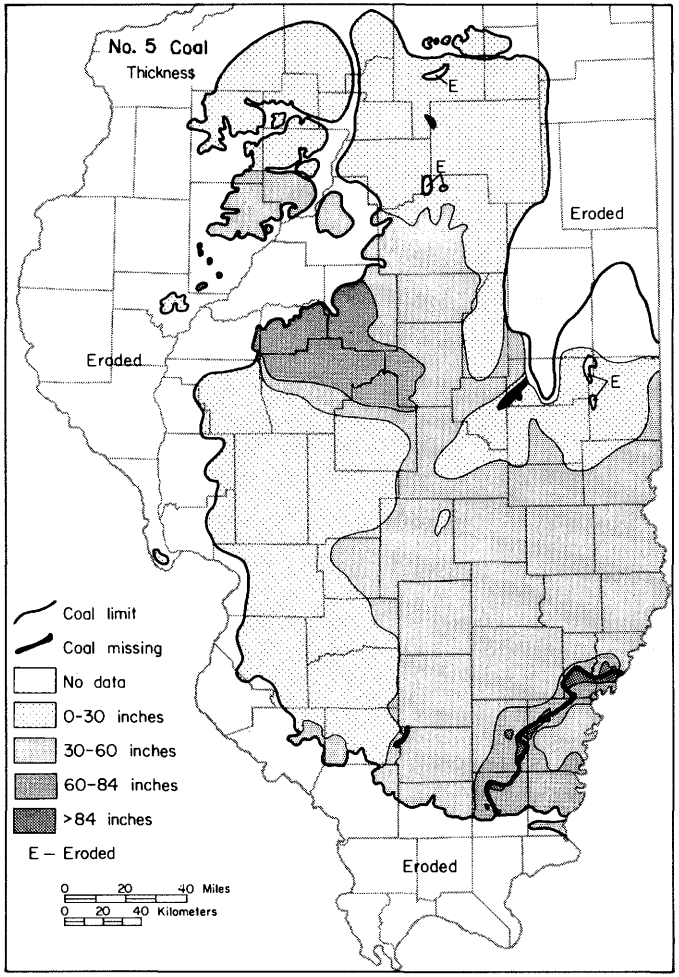

Fig. P-12—Thickness of the Harrisburg (No. 5) and Springfield (No. 5) Coal Members (based on map by K. E. Clegg).

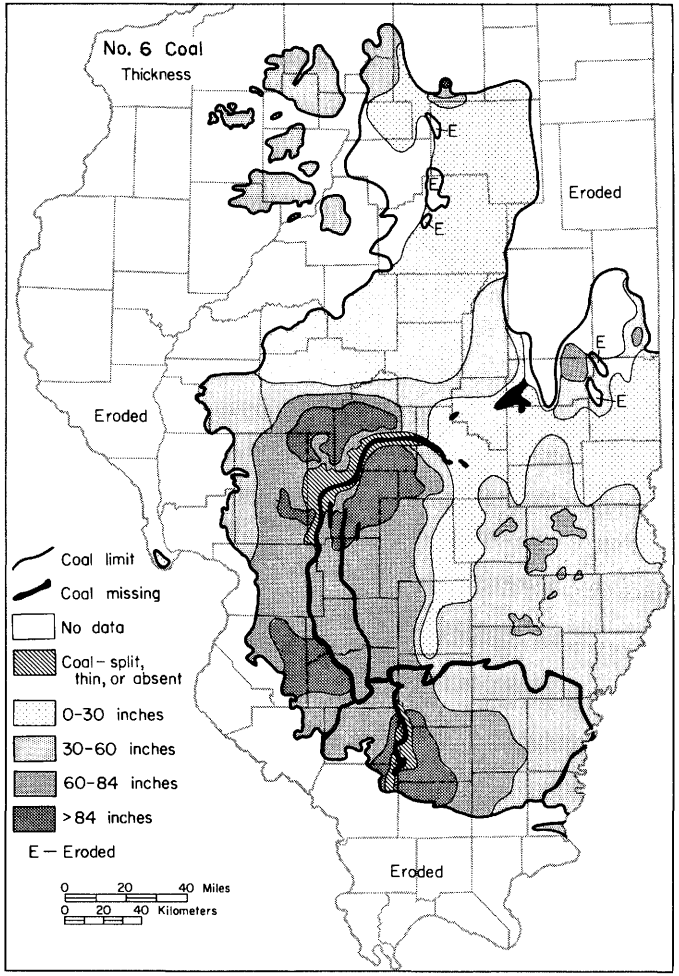

Fig. P-13—Thickness of the Herrin (No. 6) Coal Member (based on map by K. E. Clegg).

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gray to black shale that is fissile in places and is seldom over 2 feet thick. It is underlain by a hard silty underclay. It extends into southwestern Indiana.

Vermilionville Sandstone Member—The Vermilionville Sandstone Member of the Carbondale Formation (Cady, 1915, p. 29) is named for Vermilionville, La Salle County, and the type locality is west of the village, along the Vermilion River (SE 9, 32N-2E) (Wanless, 1956, p. 10). The Vermilionville is an argillaceous to silty, fine-grained sandstone that in places occupies channels cut into the underlying strata. In such channels it is as much as 80 feet thick. It is well developed in northern and western Illinois, where it occurs in the interval between the Herrin (No. 6) and the Springfield (No. 5) Coals. It is probably present in southern Illinois, where three sandstone units, all of which locally occur in channels, are present in this interval. One sandstone is below the Herrin Coal, another is below the Briar Hill (No. 5A) Coal, and a third is associated with the Dykersburg Shale. The Vermilionville is generally overlain by a few feet of the Big Creek Shale and is underlain by the Canton Shale. The Vermilionville was formerly called Cuba Sandstone in western Illinois (Savage, 1927) and Waupecan Sandstone in northeastern Illinois (Culver, 1922a).

Big Creek Shale Member—The Big Creek Shale Member of the Carbondale Formation (Savage, 1927, p. 309, 313, 315) is named for Big Creek in Fulton County, along which the type section occurs (7N-4E) (Wanless, 1957, p. 108). The shale is gray, soft, and sandy, is 10-30 feet thick, and grades into the underlying Vermilionville Sandstone. A shale is present at this position throughout much of the state, but the name has been used only in western Illinois.

Spring Lake Coal Member—The Spring Lake Coal Member of the Carbondale Formation (Cady, 1948, p. 5; Peppers, 1970, p. 59) is named for Spring Lake, La Salle County. The type section consists of exposures on the east bank of the Vermilion River on the northwest side of Streator, about three-fourths of a mile northeast of the lake (SE SW SW 23, 31N-3E) (Willman and Payne, 1942, p. 130, 295; Peppers, 1970, p. 59). The coal was described from several outcrops and mines in a small area near Streator, where it has a maximum thickness of 2.5 feet (Willman and Payne, 1942, Unit 43). It is separated from the overlying Herrin (No. 6) Coal by 11-17 feet of strata, the lower part of which consists of black fissile shale and gray shale. *Estheria* and *Leaia* are found in the gray shale. Spore analyses by Peppers (1970) suggest that its position is slightly above the Briar Hill Coal.

Herrin (No. 6) Coal Member—The Herrin (No. 6) Coal Member of the Carbondale Formation was originally named No. 6 Coal (Worthen, 1870, p. 93) and later called Herrin (No. 6) Coal (Shaw and Savage, 1912, p. 6) for Herrin, Williamson County, where the coal is extensively mined. It formerly was called the Brereton (No. 6) coal in western Illinois, the "Second Vein" (No. 5) coal in the La Salle area, and the Streator (No. 7) coal in the Streator area. The coal is a normal bright-banded coal. Its lower portion contains a prominent claystone parting (the "blue band") that normally is 1-3 inches thick. The Herrin Coal is present throughout much of the area of Pennsylvanian rocks (fig. P-13). It averages more than 6 feet thick in extensive areas and locally reaches 15 feet. It is thin in much of central Illinois but has been extensively mined in western, west-central, southern, and northern Illinois, as well as in the southern part of the Danville region of eastern Illinois. In some places the coal is cut out by channels filled with the Anvil Rock Sandstone Member. In parts of Illinois, silty gray shale as much as 100 feet thick overlies the Herrin Coal. Associated with this shale is a channel sandstone commonly as much as a mile wide and 60-80 feet thick that was mapped as Anvil Rock Sandstone (Hopkins, 1958; Potter and Simon, 1961), but later unpublished studies suggest that it may be in part contemporaneous with the coal. In areas where the coal is overlain by relatively thick bodies of the gray shale, the coal generally varies in thickness, locally contains gray shale lenses up to a few tens of feet thick, and has a much lower sulfur content than it does elsewhere (Gluskoter and Simon, 1968; Gluskoter and Hopkins, 1970). The gray shale overlies the coal in four areas, principally in parts of the following counties: (1) Williamson, Franklin, and Jefferson, (2) Madison and St. Clair, (3) eastern Macoupin, and (4) southern Vermilion. Except in these areas the Herrin Coal is generally overlain by either the Anna Shale Member (black fissile shale) or the Brereton Limestone Member. The Herrin Coal rests on a well developed underclay. The coal extends into western Indiana, where it is now called the Herrin Coal Member. It is extensively mined in western Kentucky, where it is known as the No. 11 coal, and it is correlated with the Lexington coal in Missouri and the Mystic Coal Member in Iowa.

Anna Shale Member—The Anna Shale Member of the Carbondale Formation (Jewett, 1941, p. 316-317) is named for Anna, Bourbon County, Kansas. It is a fissile, black, hard, carbonaceous shale that seldom is as much as 4 feet thick. Locally it contains dark gray, impure limestone concretions up to a foot thick. The Anna has a nektonic and planktonic marine fauna and many of the shells are fragmentary and pyritized. The Anna is persistent and generally accompanies the overlying Brereton Limestone, but in parts of southern Illinois the Anna lenses out and the Brereton Limestone lies directly on the Herrin (No. 6) Coal. The Anna otherwise generally lies in abrupt contact with the Herrin Coal, except where the thick wedges of silty gray shale intervene. The Anna Shale and the Brereton Limestone, and locally even higher units, thin to zero over the gray shale wedges.

Brereton Limestone Member—The Brereton Limestone Member of the Carbondale Formation (Savage, 1927, p. 309, 313-315) is named for Brereton, Fulton County, and the type section is along the east bank of Middle Copperas Creek (SE NE 1, 7N-4E) (Wanless, 1956, p. 10; 1957, p. 107, 111, 112, 195). It was formerly called the Herrin Limestone in southern Illinois. The Brereton Limestone is a distinctive marker unit widely developed throughout much of the Illinois Basin (fig. P-3B). It is usually dark gray, argillaceous, fine grained, and commonly less than 5 feet thick, but in places it is as thick as 18 feet. In northern Illinois it contains black phosphatic nodules. It has an open-marine fauna dominated by brachiopods, crinoids, and fusulinids. It is absent in areas where cut by channels in which the Anvil Rock Sandstone was deposited. It thins and disappears over thick deposits of the silty gray shale that locally overlies the Herrin (No. 6) Coal. In parts of southwestern, western, and eastern Illinois, the Brereton Limestone or the Anna Shale are lenticular and pinch out in places. Where both are absent, the overlying Lawson Shale or strata associated with the Jamestown Coal locally form the roof of the Herrin Coal. In southern and parts of west-central Illinois the Brereton is commonly overlain by a few inches to a few feet of the dark gray calcareous shale that underlies the Jamestown Coal. In the rest of the state the limestone is overlain by the Lawson Shale. The Brereton Limestone is present in southwestern Indiana and is quite persistent in western Kentucky, where it is called the Providence Limestone Member. It is correlated with the Myrick Station Member of Missouri.

Jamestown Coal Member—The Jamestown Coal Member of the Carbondale Formation (Bell et al., 1931, p. 3) is a widespread but thin coal in southern Illinois named for Jamestown, Perry County, which is near the type locality (NW NE 34, 5S-4W) (Wanless, 1939, p. 17, 19, 88; 1956, p. 10). The coal is seldom more than a few inches thick in southern Illinois (fig. P-3B), but in southern Clark County and adjacent Crawford County in eastern Illinois it is reported in drill records to be as much as 6 feet thick. The Jamestown Coal is equivalent to the Hymera Coal Member (VI), which is an im-

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portant commercial coal in Indiana, and to the No. 12 coal in western Kentucky.

Conant Limestone Member—The Conant Limestone Member of the Carbondale Formation (Kosanke et al., 1960, p. 35) is named for Conant, Perry County, near the type locality (NW NE 34, 5S-4W) (Wanless, 1939, p. 17, 88; 1956, p. 10). It previously was called the Jamestown Limestone (Bell et al., 1931, p. 3). The Conant is widespread from St. Clair to Gallatin Counties in southern Illinois (fig. P-3B) but is not recognized a short distance north of that area. It is also present locally in eastern Illinois. For most of its extent the limestone is less than 1 foot thick and lies immediately above the thin Jamestown Coal, but in Perry County it is as much as 4 feet thick in places and is separated from the Jamestown Coal by an equal thickness of dark gray shale. It is overlain by gray silty shale. The limestone is quite argillaceous and locally resembles the Brereton Limestone. It is characterized by an open-marine fauna dominated by the large productid brachiopod *Dictyoclostus*.

Pokeberry Limestone Member—The Pokeberry Limestone Member of the Carbondale Formation (Wanless, 1939, p. 17, 98) is named for Pokeberry School, Schuyler County, which is near the type locality (NW 26, 2N-1W) (Wanless, 1956, p. 11; 1957, p. 113, 188). The limestone is known only in the type area, where it is 15 feet above the Herrin Coal and 9 feet below the Danville (No. 7) Coal. It is a gray, dense, locally conglomeratic or brecciated limestone containing large fossils, most of them brachiopods. It has a very knobby upper surface. It was correlated by Wanless (1957, p. 113) with the Conant Limestone, but its position and correlation are uncertain. It may correlate with the Bankston Fork Limestone. The Pokeberry Limestone is not shown on the geologic column (fig. P-2).

Lawson Shale Member—The Lawson Shale Member of the Carbondale Formation (Kosanke et al., 1960, p. 35) is named for Lawson Creek in Bureau County, about a mile west of the type section (cen. 24, 16N-6E) (Wanless, 1956, p. 10; 1957, p. 112). It previously was called Sheffield Shale (Wanless, 1939, p. 102; 1956, p. 10; 1957, p. 112). The Lawson is typically a gray silty shale as much as 25 feet thick in western Illinois. It probably correlates with a similar shale that underlies the Anvil Rock Sandstone in southern Illinois. The upper part of the Lawson is in some places interbedded with sandstone that grades laterally into the Copperas Creek Sandstone. At other places the Copperas Creek lies unconformably on the shale. In much of west-central and southwestern Illinois the Lawson is a weak, gray and green mottled shale. It is underlain throughout most of western Illinois by the Brereton Limestone or, locally, by either the Anna Shale or Herrin (No. 6) Coal.

Copperas Creek Sandstone Member—The Copperas Creek Sandstone Member of the Carbondale Formation (Savage, 1927, p. 309) is named for Copperas Creek in Fulton County, along which the sandstone is well exposed (Wanless, 1957, p. 114), but no type section was designated. The Copperas Creek occurs in western Illinois as a widespread, thin-bedded sheet sandstone and as a channel sandstone. It is correlated with the Anvil Rock Sandstone of southern Illinois. The Copperas Creek channels appear to be part of a south-to-southeast drainage system that connects with the Anvil Rock Sandstone channels of the deeper part of the Illinois Basin.

Anvil Rock Sandstone Member—The Anvil Rock Sandstone Member of the Carbondale Formation (Owen, 1856, p. 45) is named for an anvil-shaped float block along a bluff 1.5 miles north of Dekoven Station, Union County, Kentucky. The sandstone underlies the Bankston Fork Limestone and overlies the gray shale above the Conant Limestone throughout southern Illinois, where it occurs as a channel sandstone as much as 80 feet thick. The name "Anvil Rock" was applied by Hopkins (1958) and Potter and Simon (1961) to a major channel sandstone, which replaces the Herrin Coal along a sinuous band extending through Montgomery, Bond, Clinton, Washington, Jefferson, and Franklin Counties (fig. P-13), which is now considered to be in part contemporaneous with the Herrin Coal and the immediately overlying gray silty shale. East of the Du Quoin Monocline the Anvil Rock occurs as a channel sandstone or, more commonly, as a sheet sandstone up to 20 feet thick (Hopkins, 1958; Potter and Simon, 1961). In the sheet facies it is normally a fine-grained, relatively impure, quartz sandstone incorporating considerable argillaceous material, but in the channel facies it is medium grained and less argillaceous. In the deeper channels the sandstone cuts through several underlying stratigraphic units, including the Herrin (No. 6) Coal. Some channels are only a few hundred feet across, but the major ones are up to 2 miles wide. In the sheet facies the dominant sedimentary structure is ripple bedding. In the channel facies, planar and trough cross-bedding are common.

Bankston Fork Limestone Member—The Bankston Fork Limestone Member of the Carbondale Formation (Cady, 1926, p. 261-262) is named for Bankston Creek in Saline County, where the type section consists of outcrops along the south side of the creek (NE NW 19, 9S-5E). The Bankston Fork is a fine-grained, argillaceous, thick-bedded limestone that is dolomitic in places (fig. P-3B). It is commonly nodular in the upper and lower portions and is generally divided into two benches by a greenish gray shale several inches thick. It is sparsely fossiliferous, its open-marine fauna dominated by brachiopods, fusulinids, and a few crinoids. It occurs in southwestern, central, eastern, and southeastern Illinois, where it is commonly several feet thick but seldom over 6 feet. It does not occur west of the Illinois River or in northern Illinois. It commonly is not present over the thick portions of the Anvil Rock Sandstone. The Bankston Fork correlates with the Universal Limestone Member of Indiana and is present in parts of western Kentucky, where it locally is as much as 8 feet thick.

Allenby Coal Member—The Allenby Coal Member of the Carbondale Formation (Kosanke et al., 1960, p. 35, 48) is named for Allenby, Saline County, and the type locality is in Williamson County, half a mile northeast of the village along the roadside east of a railroad crossing (NE NW 24, 9S-4E) (Kosanke, 1950, p. 79), where it occurs 1-2 feet above the Bankston Fork Limestone. It was formerly called the Bankston Coal (Wanless, 1939, p. 14, 76). It is a thin coaly zone occurring in much of Williamson, Saline, and Gallatin Counties. It is generally overlain by a greenish gray or gray shale and is underlain by underclay. It is minable locally in western Kentucky, where it is called the Baker coal.

Galum Limestone Member—The Galum Limestone Member of the Carbondale Formation (Bell et al., 1931, p. 3) is named for Galum Creek, Perry County, along which the type section occurs (near cen. N line 13, 6S-4W) (Wanless, 1956, p. 11). It is recognized only in and near Perry County. It is generally an impure, argillaceous, nodular, nonfossiliferous limestone that is seldom more than 3 feet thick. It is overlain by the underclay of the Danville (No. 7) Coal and underlain by a few feet of greenish gray shale that separates the Galum from the Bankston Fork Limestone.

Danville (No. 7) Coal Member—The Danville (No. 7) Coal Member of the Carbondale Formation (Bradley, 1870, p. 250-252), the uppermost member of the formation, is named for Danville, Vermilion County, near the type section (E½ 7, 19N-11W) (Wanless, 1956, p. 11), where it is an important commercial coal that has been mined since the latter part of the 1800s. In the type locality it is 6 feet thick and occurs 20 feet above the Herrin (No. 6) Coal. It previously was called the Sparland (No. 7) coal in western Illinois and the "First Vein" (No. 7) coal in northern Illinois. The Danville Coal is extensive and has been mined in Livingston, McLean, La Salle, and Marshall Counties in addition to Vermilion County. In most of the remainder of the state it is a thin coal, generally from a few inches to less than 3 feet thick. The position of the coal is easily recognized in the subsurface in both lithologic and geophysical logs. The No. 7 Coal is generally overlain by the Farmington Shale Member

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of the Modesto Formation, but in places the immediate roof is 1-2 feet of black fissile shale. It is underlain by a relatively thick underclay, which has been mined in La Salle and Marshall Counties as ceramic clay. The Danville Coal correlates with the Danville Coal Member (VII) of Indiana and is present as a thin coal in western Kentucky.

McLeansboro Group

The McLeansboro Group (DeWolf, 1910, p. 181; Weller, 1940, p. 36) is named for McLeansboro, Hamilton County, and the type section consists of strata in a diamond drill core from a boring near McLeansboro (SE SW SW NE 25, 4S-5E), where 811 feet of Pennsylvanian strata was encountered above the top of the Danville (No. 7) Coal, which defines the base of the group. The McLeansboro includes all Pennsylvanian rocks in Illinois above the No. 7 Coal and is made up of three formations—the Modesto, Bond, and Mattoon (fig. P-2). DeWolf originally applied formation status to the McLeansboro, but Weller (1940) elevated it to a group and Willman and Payne (1942) defined it as including all the Pennsylvanian strata in Illinois above the base of the Copperas Creek (Anvil Rock) Sandstone Member. About 400 feet of additional Pennsylvanian strata younger than those encountered in the type section drill hole are present in the deeper part of the Illinois Basin in Jasper County, and even younger Pennsylvanian rocks are present in western Kentucky. Lithologically the McLeansboro is similar to the Kewanee Group, but it contains more marine members, including thicker, less argillaceous limestones. Coals are not as thick and probably not as extensive in the McLeansboro. Most are less than 1 foot thick, although some coals are up to 4 feet thick. Variegated claystones, many of them dominantly red, occur several feet above and below some of the limestones. They are much less common in other Pennsylvanian groups. Light olive or tan argillaceous limestone units up to 3-4 feet thick and bearing only ostracodes, *Spirorbis*, and very few pelecypods are present in the McLeansboro, particularly in the upper part. They are similar to thicker limestones in the upper part of the Pennsylvanian in the Appalachian Basin. The Dix Limestone is the only one of these units that has been named. The McLeansboro Group extends into Indiana, and is equivalent to all but the lowest part of the Sturgis Formation of Kentucky.

Modesto Formation

The Modesto Formation of the McLeansboro Group (Kosanke et al., 1960, p. 36, 48, 67-70) is named for Modesto, Macoupin County, near which four outcrops described by Payne (1942) and Ball (1952) constitute the type locality and expose nearly all the formation (SW SE 35, 10N-7W and NE NW 2, 9N-7W; W1/2 NE NW 35, 10N-7W; SW SW SE 7, 12N-8W to NE SE SW 1, 12N-9W; and NE SW SW 16 to NE 17, 12N-9W). The Modesto Formation includes strata from the top of the Danville (No. 7) Coal to the base of the Shoal Creek Limestone Member or the La Salle Limestone Member (fig. P-2). It is overlain by the Bond Formation and underlain by the Carbondale Formation. The Modesto Formation thickens from less than 125 feet along the La Salle Anticlinal Belt in east-central Illinois to over 200 feet in northern Illinois and over 450 feet in southern Illinois, averaging about 350 feet (fig. P-14). It consists of sediments somewhat similar to those of the underlying Carbondale Formation, but the coals are thinner, the limestones are generally thicker and less argillaceous, and several red claystones and shales are associated with the open-marine limestones. With the exception of the Lonsdale, Piasa, and West Franklin Limestones, most of the limestones of this formation, however, are thin and argillaceous. Even though the coals are thin, many are widespread. The sandstones in places are thick channel deposits up to 80 feet thick. Gray shales in this formation are particularly thick and constitute by far the greater part of the formation. The Modesto Formation correlates with the Shelburn Formation and the overlying Patoka Formation of Indiana and a portion of the Sturgis Formation of western Kentucky.

Farmington Shale Member—The Farmington Shale Member of the Modesto Formation (Savage, 1927, p. 309) is named for Farmington Township, Fulton County, which is the type locality (8N-4E) (Wanless, 1956, p. 11). The Farmington is the lowest named unit of the Modesto Formation in most of the state. It is commonly gray shale that becomes coarser grained upward, and the lower part generally contains marine fossils. It generally occurs immediately above the Danville (No. 7) Coal Member, but in several places a dark gray, very impure limestone, usually less than a foot thick, lies directly on the coal. In other places black fissile shale, seldom more than 2 feet thick, overlies the coal or occurs between the limestone and the Farmington Shale. The Farmington ranges from a few feet to as much as 50 feet thick in eastern, western, and southern Illinois and to as much as 100 feet or more in southeastern Illinois. It has been extensively mined for clay in the Danville region, Vermilion County.

Piasa Limestone Member—The Piasa Limestone Member of the Modesto Formation (Culver, 1925, p. 20) is named for Piasa Creek in Jersey County and the type section consists of exposures along the creek (E1/2 25, 8N-10W) (Wanless, 1956, p. 11). The Piasa, which occurs in southwestern and southern Illinois, was formerly called the Cutler Limestone in southern Illinois. In much of southwestern Illinois the Piasa lies only a few feet above the Danville (No. 7) Coal and is separated from it by either variegated claystone, gray shale, or, in places, black fissile shale. The Piasa is commonly light gray, fine-grained, argillaceous limestone containing an open-marine fauna dominated by crinoids (mainly in the lower part) and brachiopods. In many places it contains numerous fusulinids, especially at the base. It is generally less than 4 feet thick and is commonly associated with red and variegated claystone. Correlations with other units in Illinois are not definite, but the Piasa appears to be equivalent to the lower part of the West Franklin Limestone Member of southeastern Illinois and southwestern Indiana and to the Madisonville Limestone Member of western Kentucky.

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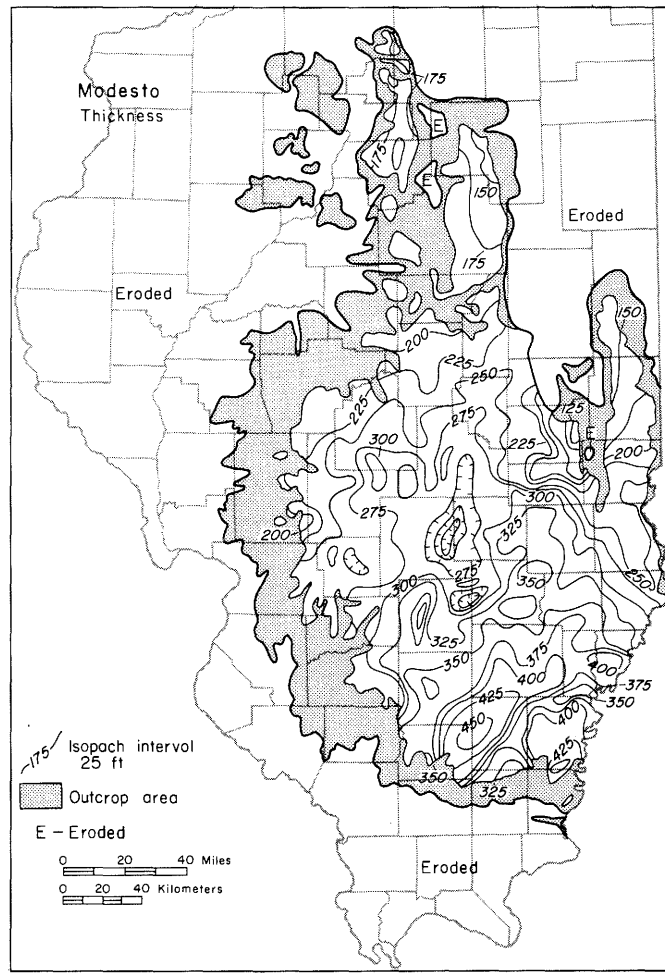

Fig. P-14—Thickness of the Modesto Formation (based on map by K. E. Clegg).

West Franklin Limestone Member—The West Franklin Limestone Member of the Modesto Formation (Collett, 1884, p. 61-62) is named for West Franklin, Posey County, Indiana. The type section consists of outcrops near the town (24, 7S-12W) (Wanless, 1956, p. 11). The member is recognized largely in southeastern Illinois. It is a fine-grained limestone generally less than 15 feet thick and occurs in one to three benches, each generally less than 10 feet thick and separated by a few feet of greenish gray to variegated claystone. The number of limestone benches decreases to the west as the underlying shale, probably the Farmington Shale, thins from east to west. In the eastern part of its area the West Franklin is closely overlain by the Chapel (No. 8) Coal, and it is likely that the West Franklin Limestone is equivalent to the entire interval from the Piasa Limestone upward through the Lake Creek Coal in southern Illinois and through the Scottville Limestone in southwestern Illinois. The Piasa Limestone also may be equivalent to the lower bench of the West Franklin (Andresen, 1956). The West Franklin is probably also equivalent to the interval including the Lonsdale and Exline Limestones of western Illinois and to the Madisonville Limestone of western Kentucky.

De Graff Coal Member—The De Graff Coal Member of the Modesto Formation (Cady, *in* Kosanke et al., 1960, p. 37) is named for De Graff School, Perry County. It previously was informally called the First Cutler Rider coal. The type section consists of exposures along Galum Creek, near De Graff School (SE cor. NE SW 21, 5S-4W). This thin, lenticular coal occurs a few feet above the Piasa Limestone in southern Illinois.

Rock Branch Coal Member—The Rock Branch Coal Member of the Modesto Formation (Kosanke et al., 1960, p. 37) is named for Rock Branch in Macoupin County. It previously was called the Scottville Coal (Payne, 1942, p. 4). The type section consists of exposures along Rock Branch (SW SW NW 16, 12N-9W). This thin coal occurs in southwestern Illinois and may be equivalent to the Pond Creek Coal of southern Illinois.

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Gimlet Sandstone Member—The Gimlet Sandstone Member of the Modesto Formation (Wanless, 1931a, p. 182, 183, 190, 192) is named for Gimlet Creek in Marshall County, and the type section consists of exposures along the creek (N1/2 SE 16, 12N-9E) (Wanless, 1956, p. 11; 1957, p. 116). The Gimlet Sandstone is locally developed as a fine- to medium-grained channel sandstone 50-60 feet thick, which cuts down from 50 feet above the Danville Coal to within a few feet of the Brereton Limestone. In other places the sandstone is only a few feet thick or is absent. The Gimlet Sandstone has been recognized principally in northern and western Illinois.

Lonsdale Limestone Member—The Lonsdale Limestone Member of the Modesto Formation (Worthen, 1873, p. 328) is named for the old Lonsdale quarries, Peoria County. The original type section in the old quarry (N1/2 6, 8N-7E) is no longer accessible, and an outcrop near by (14, 8N-7E) is a supplementary type section (Wanless, 1957, p. 194). The Lonsdale is a well developed limestone in western and northern Illinois, where it averages 6-8 feet thick and locally is as much as 25 feet thick. It is a very fine-grained, light gray limestone, conglomeratic in part. Throughout much of its area of occurrence the upper part is nodular. It contains a large and diversified marine fauna locally rich in fusulinids. It is correlative with at least a part of the West Franklin Limestone of southeastern Illinois, the Cooper Creek Limestone of Iowa, and the Madisonville Limestone Member of western Kentucky.

Pond Creek Coal Member—The Pond Creek Coal Member (Kosanke et al., 1960, p. 37) is named for Pond Creek in Williamson County. It previously was informally called the Second Cutler Rider coal. The type section of the Pond Creek Coal is at a depth of 125 feet in Consolidated Coal Company drill hole 91 (SW NE NE 21, 8S-3E). The Pond Creek is more extensive than either the De Graff Coal or the Lake Creek Coal, which, respectively, lie just a few feet above and below the Pond Creek, but the Pond Creek is recognized only in southern Illinois. It may be equivalent to the Rock Branch Coal of southwestern Illinois.

Lake Creek Coal Member—The Lake Creek Coal Member of the Modesto Formation is named for Lake Creek Township, Williamson County (Cady, *in* Kosanke et al., 1960, p. 37). It previously was informally called the Third Cutler Rider coal. The type section of the Lake Creek Coal is at a depth of 86.6 feet in the Consolidated Coal Company drill hole 91 (SW NE NE 21, 8S-3E), located in Lake Creek Township. The coal is lenticular and occurs in southern Illinois.

Athensville Coal Member—The Athensville Coal Member of the Modesto Formation (Kosanke et al., 1960, p. 37) is named for Athensville, Greene County. It previously was called Upper Scottville (Kosanke, 1950, p. 85). The type section consists of exposures near the town (SE NW SW 16, 12N-9W, Macoupin County). The Athensville Coal generally lies less than 10 feet below the Scottville Limestone. It occurs in southwestern Illinois, and it may correlate with the Lake Creek Coal of southern Illinois.

Scottville Limestone Member—The Scottville Limestone Member of the Modesto Formation (Payne, 1942, p. 4) is named for Scottville, Macoupin County. The type section consists of exposures along Apple Creek near the town (W1/2 SW 16, 12N-9W) (Wanless, 1956, p. 11). The Scottville Limestone occurs in southwestern Illinois, where it is as much as 3 feet thick. It is a light gray, fine-grained limestone that locally contains abundant *Osagia*, phylloid algae, and a diverse open-marine fauna. It is probably equivalent to part of the West Franklin Limestone of southeastern Illinois.

Exline Limestone Member—The Exline Limestone Member of the Modesto Formation (Cline, 1941, p. 65-66) is named for Exline, Appanoose County, Iowa, which is near the type section (SE 6, 67N-17W). The Exline occurs in western Illinois, where it is dark gray to black, thin- and even-bedded limestone that contains well preserved plant stems and leaves, the worm tube *Spirorbis*, and a few marine pelecypods (Wanless, 1957, p. 120). In Iowa, the Exline contains a normal marine fauna. In Illinois it usually is less than 3 feet thick, is underlain by black fissile shale, and is overlain by gray marine shale. In some places the Exline lies immediately on the Lonsdale Limestone, but in others it is as much as 30 feet above the Lonsdale.

Trivoli Sandstone Member—The Trivoli Sandstone Member of the Modesto Formation (Wanless, 1931a, p. 182, 183, 190, 192), the top of which is the Desmoinesian-Missourian Series boundary, is named for Trivoli, Peoria County. The type section consists of exposures in a ravine northeast of Pea Ridge School, near Trivoli (SW 3, 9N-5E) (Wanless, 1956, p. 11; 1957, p. 121, 193). The Trivoli Sandstone is found both as a sheet facies generally less than 20 feet thick and as a channel facies that thickens to more than 80 feet, primarily at the expense of underlying strata (Andresen, 1961). The Trivoli is present throughout much of Illinois and marks one of the periods of major stream development during Pennsylvanian time in Illinois.

(Modesto Formation continued on page 196.)

MISSOURIAN SERIES

The Missourian Series of the Pennsylvanian System (Keyes, 1893, p. 114-116; Moore, 1931) is named for the state of Missouri, where strata containing much limestone and a very little coal overlie the Desmoinesian rocks. In Illinois the Missourian includes rocks from the top of the Trivoli Sandstone Member up to a position a few feet below the coal that lies below the Shumway Limestone Member (Willman et al., 1967). It therefore includes the upper part of the Modesto Formation, all of the Bond Formation, and about half of the Mattoon Formation, all in the McLeansboro Group (fig. P-2).

Where fusulinids are present, as they are in many units in Illinois, the Missourian is characterized by earlier forms of the genus *Triticites*, which is the sub-genus *Kansanella* of Thompson. Floral zones are not as well defined in the Illinois Basin and the Midcontinent area, where the Missourian and overlying Virgilian together constitute Zones 11 and 12 (zone of *Odontopteris* sp.) (Read and Mamay, 1964). Delineation of the ranges of spore taxa in the Missourian and Virgilian Series has not been determined with the same degree of accuracy as is true for the remainder of the Pennsylvanian because the stratigraphic relation of many of the coals has not been worked out in detail. Small spores of ferns and seed ferns, many less than 30 microns in diameter, are prolific in most of the Missourian and Virgilian coals. The taxa are classified as *Punctatisporites minutus, Laevigatosporites minutus*, and species of *Cyclogranisporites* and *Apiculatisporis*. *Endosporites* is very abundant in many of the coals.

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Modesto Formation (continued)

Chapel (No. 8) Coal Member—The Chapel (No. 8) Coal Member of the Modesto Formation (Kosanke et al., 1960, p. 38), the oldest named unit in the Missourian Series, is named for Graham Chapel, Peoria County. It previously was called Trivoli (No. 8) coal (Wanless, 1931a, p. 181-182, 190, 192). The type section consists of exposures in a ravine northeast of Pea Ridge School, about 2 miles south of Graham Chapel (SW 3, 8N-5E) (Wanless, 1956, p. 11; 1957, p. 121, 193). The name "No. 8" was first given to this coal by Lesquereux (1866, p. 213) for an exposure near Shawneetown, Gallatin County. Worthen (1870) also applied the name to this coal in outcrops near Springfield, Sangamon County. The Chapel Coal is a thin, bright-banded coal that is persistent throughout most of the area of the state that is underlain by the Modesto Formation. It occurs above the widespread Trivoli Sandstone or the West Franklin Limestone and is correlated with the Ditney Coal Member of southwestern Indiana.

Cramer Limestone Member—The Cramer Limestone Member of the Modesto Formation (Kosanke et al., 1960, p. 38) is named for Cramer, Peoria County. It previously was called Trivoli Limestone (Wanless, 1931a, p. 182, 190, 192). The type section consists of exposures in a ravine northeast of Pea Ridge School, 1.3 miles northeast of the village of Cramer (Wanless, 1956, p. 11; 1957, p. 121, 193). The Cramer Limestone is normally very argillaceous and is generally less than 1 foot thick. It is lenticular but widespread and is commonly found throughout the same area as the underlying Chapel (No. 8) Coal, from which it is commonly separated by 1-2 feet of black fissile shale. The Cramer contains an abundant open-marine fauna. It is correlated with the Sniabar Limestone of southern Iowa, Missouri, and eastern Kansas.

Inglefield Sandstone Member—The Inglefield Sandstone Member of the Modesto Formation (Fuller and Ashley, 1902, p. 3) is named for Inglefield, Vanderburgh County, Indiana, and the type locality consists of exposures in a railroad cut south of the town. The sandstone occurs above the Chapel (No. 8) Coal and below the Womac Coal (Andresen, 1961). It is known primarily in eastern Illinois, but it was reported by Andresen to split into two distinct sandstones in southwestern Illinois, the lower unit occurring below the Carlinville Limestone. The Inglefield Sandstone locally exceeds 80 feet in channels oriented south-southwest, but it is relatively widespread as a much thinner sheet sandstone in most of the Illinois Basin.

Carlinville Limestone Member—The Carlinville Limestone Member of the Modesto Formation (Worthen, 1873, p. 290-301) is named for Carlinville, Macoupin County. The type section consists of outcrops along Macoupin Creek (SW SW 35, 10N-7W) (Wanless, 1956, p. 11). The limestone is recognized only in part of southwestern Illinois, where it is thick-bedded, up to 5 feet thick, and contains an open-marine fauna.

Burroughs Limestone Member—The Burroughs Limestone Member of the Modesto Formation (Ball, *in* Cooper, 1946, p. 12; 1952, p. 37, 38, 85; Kosanke et al., 1960, p. 38) is named for Burroughs Branch, a tributary of Macoupin Creek, in Macoupin County. The type section consists of outcrops along the branch on the west side of Carlinville (NW SW 27, 10N-7W). The Burroughs is recognized in only a small area in west-central Illinois, where it is a dark gray, sandy, clastic limestone that contains crinoid columnals and brachiopods and ranges from a fraction of an inch to more than 5 feet thick. Its position is 14-17 feet above the Carlinville Limestone and 18 feet or less below the Macoupin Limestone.

Womac Coal Member—The Womac Coal Member of the Modesto Formation (Kosanke et al., 1960, p. 38) is named for Womac, Macoupin County. It previously was called the Macoupin Coal (Wanless, 1931b, p. 810-811). The type section consists of exposures in a ravine draining into Macoupin Creek 3 miles southwest of Womac (Wanless, 1956, p. 11). This thin coal is widely traced in the Illinois Basin along with the overlying Macoupin Limestone, from which it is separated by 1-2 feet of black fissile shale. It is correlated with the Raben Branch Coal Member in Indiana.

Macoupin Limestone Member—The Macoupin Limestone Member of the Modesto Formation (Wanless, 1931b, p. 810-811) is named for Macoupin Creek in Macoupin County, along which the type section is exposed (NE NW 2, 9N-7W) (Wanless, 1956, p. 11; Ball, 1952, p. 85-86). It is a widespread unit, found throughout much of the Illinois Basin. The limestone is generally less than 2 but locally as much as 5 feet thick. In the type area it is composed of thin, even beds of crinoidal limestone separated in places by shale partings. Most of it is dark gray and very argillaceous.

Hall Limestone Member—The Hall Limestone Member of the Modesto Formation (Willman, *in* Cooper, 1946, p. 12) is named for Hall Township, Bureau County. The type section consists of exposures in a ravine west of the coal mine refuse pile in the western part of the town of Spring Valley (NW SW 33, 16N-11E) (Wanless, 1956, p. 12). The Hall is recognized only in northern Illinois. In the type section it lies about 45 feet below the La Salle Limestone Member and consists of a 3-foot ledge of fine-grained, green, gray, and red limestone containing numerous brachiopods, crinoid columnals, and bryozoans. It is underlain by a persistent black shale. The Hall is correlated with the Macoupin Limestone of southern and eastern Illinois.

New Haven Coal Member—The New Haven Coal Member of the Modesto Formation (Kosanke, 1950, p. 88-89), the uppermost named member of the formation, is named for New Haven, Gallatin County. The type section is an outcrop along the Little Wabash River (SE SW SE 17, 7S-10E; incorrectly given as NW 19, 7S-10E, by Kosanke, 1950). The New Haven is a thin coal, generally separated by only 1-2 feet of black fissile shale from the overlying Shoal Creek Limestone Member of the Bond Formation. It is widespread in southeastern, southwestern, and central Illinois and is absent in parts of eastern Illinois. It is correlated with a thin coal below the La Salle Limestone in northern Illinois and with the Parker Coal Member of Indiana.

Bond Formation

The Bond Formation of the McLeansboro Group (Kosanke et al., 1960, p. 39, 50, 70-73) is named for Bond County, where exposures are prominent. Seven separate outcrops in three counties constitute the type section (NE NE NE 3, 10N-2W, Montgomery County; SE NE 28, 12N-1W, Christian County; NE NW SE 7, 8N-2W, Montgomery County; east-central 24, 6N-5W, S1/2 7, 6N-4W, E edge 6, 7, 6N-4W, and SW NW 29, 7N-4W, Bond County). The Bond Formation varies from less than 150 feet thick in eastern Illinois to over 300 feet in southeastern Illinois and averages about 250 feet (fig. P-15). It includes all strata from the base of the Shoal Creek Limestone Member or the La Salle Limestone Member to the top of the Millersville Limestone Member or the Livingston Limestone Member (fig. P-2) and is characterized by a high percentage of limestone and calcareous clays and shales. The limestone members that bound the formation are the thickest and purest limestones in the Pennsylvanian System of Illinois. The upper limestone is as much as 50 feet thick and the lower is in places as much as 30 feet thick. Both are extensively quarried. In southern Illinois, south of the area of prominent development, there is no major single bench of the Millersville, and the equivalent strata are difficult to identify. Red claystones and

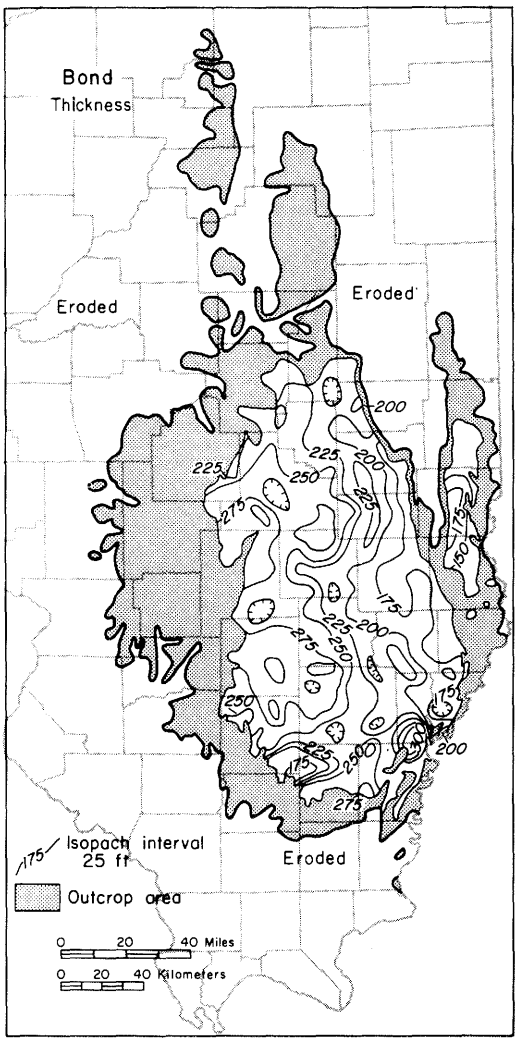

Fig. P-15—Thickness of the Bond Formation (based on map by K. E. Clegg).

shales are present in the Bond and are best developed in northern Illinois. Other units of the formation—gray shales, siltstones, and sandstones—are similar to those in the underlying Modesto Formation. Gray shales constitute the greatest portion of the formation, but thick channel sandstones are developed locally. The formation is also called Bond in Indiana, and it is equivalent to a portion of the Sturgis Formation in western Kentucky.

Shoal Creek Limestone Member—The Shoal Creek Limestone Member of the Bond Formation (Engelmann, 1868, p. 175, 177-183), the base of which is the base of the formation in all except northern Illinois, is named for Shoal Creek in Clinton County, and the type locality consists of exposures along the stream (3N-4W). The limestone is commonly 6-8 feet thick, locally as much as 20 feet. It is generally light gray, thick bedded, and fine grained, and it contains a diverse open-marine fauna. It persists throughout most of the Illinois Basin and is quarried in southwestern Illinois. The Shoal Creek is an easily recognized marker on geophysical logs in most of the deeper part of the Illinois Basin. It is locally cut out by the Mt. Carmel Sandstone or the McWain Sandstone. It is correlated with the La Salle Limestone of northern Illinois, the lower part of the Winterset Limestone Member of Missouri, and the Carthage Limestone Member of western Kentucky. The Shoal Creek Limestone Member is also recognized in Indiana.

La Salle Limestone Member—The La Salle Limestone Member of the Bond Formation (Cady, 1908, p. 128-134), the base of which is the base of the formation in northern Illinois, is named for La Salle, La Salle County. The type section consists of exposures near Bailey's Falls, south of La Salle (14, 33N-1E) (Wanless, 1956, p. 12). The La Salle Limestone is well developed in northern Illinois, where it has been quarried extensively (Cady, 1919b). It is as much as 30 feet thick in exposures near La Salle along the west flank of the La Salle Anticline, but it thins westward to about 12 feet west of Spring Valley, Bureau County. In a belt 1-2 miles wide along its eastern margin, it is a fine-grained, thick-bedded, light gray, nodular limestone containing a few shale partings and a large and diverse marine fauna, mainly brachiopods and gastropods. It grades westward to a fine-grained, argillaceous, tan, brown-weathering limestone that occurs mostly in even beds 4-8 inches thick separated by strong shale partings and containing a restricted marine fauna characterized by large brachiopods, mostly productids. It formerly was correlated with the Millersville and Livingston Limestone Members but is now correlated with the Shoal Creek Limestone.

McWain Sandstone Member—The McWain Sandstone Member of the Bond Formation (Ball, 1943, p. 150) is named for the McWain Farms, Macoupin County. The type section consists of exposures along Macoupin Creek (SE 25, 10N-7W) (Ball, 1952, p. 44). The McWain occurs as a channel sandstone in southwestern Illinois, where it locally rests on the Shoal Creek Limestone or on strata between the Shoal Creek and the Macoupin Limestone. It has been correlated with the Mt. Carmel Sandstone.

Mt. Carmel Sandstone Member—The Mt. Carmel Sandstone Member of the Bond Formation (Worthen, 1875, p. 52, 55) is named for Mt. Carmel bluff on the Wabash River at Mt. Carmel, Wabash County (W1/2 21, 1S-12W). The Mt. Carmel Sandstone is well developed in eastern and southeastern Illinois, where it is the first major channel sandstone above the Shoal Creek Limestone, and it is as much as 80 feet thick in places. It occurs about 10 feet below the Flannigan Coal. The Mt. Carmel Sandstone has been correlated with the McWain Sandstone of southwestern Illinois.

Sorento Limestone Member—The Sorento Limestone Member of the Bond Formation (Simon, *in* Wanless, 1955, p. 1764) is named for Sorento, Bond County. The type section consists of outcrops along the south-flowing tributary of Dry Fork just southwest of Sorento (NE NE 6, 6N-4W) (Kosanke et al., 1960, p. 39). The Sorento Limestone and the underlying unnamed coal have been recognized throughout much of the Illinois Basin. The limestone is generally fine grained, medium gray, less than 2 feet thick, and contains an open-marine fauna composed primarily of brachiopods, crinoids, and gastropods. In southwestern Illinois the Sorento generally lies 15-20 feet above the Shoal Creek Limestone. In the deeper part of the Illinois Basin the interval is usually 20-40 feet, but locally it may be as much as 100 feet. The Sorento is tentatively correlated with the Little Vermilion Limestone of northern Illinois.

Little Vermilion Limestone Member—The Little Vermilion Limestone Member of the Bond Formation (Willman, *in* Cooper, 1946, p. 14) is named for the Little Vermilion River in La Salle County, along which the type section is exposed (SW SW 11, 33N-1E) (Wanless, 1956, p. 12). The Little Vermilion Limestone lies about 25 feet above the La Salle Limestone and is as much as 4 feet thick locally. The limestone is dark gray, argillaceous, and shaly. It is very fossili-

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ferous, with brachiopods (particularly *Rhipidomella*), bryozoans, and crinoids abundant. In the type area a coal, generally less than 1 foot thick, is found about a foot below the limestone. The Little Vermilion is tentatively correlated with the Sorento Limestone.

Bunje Limestone Member—The Bunje Limestone Member of the Bond Formation (Simon, *in* Kosanke et al., 1960, p. 39) is named for Bunje Station, Bond County, and the type section is about 1 mile south, along Dry Fork (SE SW 7, 6N-4W). The Bunje is known only in the type locality, where it is generally less than 2 feet thick. It is very fossiliferous, having a fauna dominated by large pelecypods, and the upper few inches is characterized by cone-in-cone structure. It is underlain by an unnamed sandstone unit and is commonly about 40 feet above the Sorento Limestone. The Bunje is separated from the Flat Creek Coal above by a few feet of shale and underclay.

Flat Creek Coal Member—The Flat Creek Coal Member of the Bond Formation (Simon, *in* Wanless, 1955, p. 1764) is named for Flat Creek in Bond County, along which the type section is exposed (NE SE 24, 6N-5W) (Kosanke et al., 1960, p. 39). The Flat Creek is a thin, widespread coal readily recognized on geophysical logs in southwestern Illinois. The coal is widely overlain by a thin black shale and a marine limestone. It is correlated with the Flannigan Coal of southeastern and eastern Illinois and the Fairbanks Coal Member of Indiana.

Flannigan Coal Member—The Flannigan Coal Member of the Bond Formation (Newton and Weller, 1937, p. 9) is named for Flannigan Township, Hamilton County, where the type section is an exposure along a southwest-flowing tributary of the Middle Fork Saline River (SW NE NE 17, 7S-5E; erroneously reported as 6S-5E by Kosanke et al., 1960). In the type area, the Flannigan Coal is about 1 foot thick and is overlain by a thin, black fissile shale. The Flannigan occurs in southeastern and eastern Illinois and is correlated with the Flat Creek Coal of southwestern Illinois.

Reel Limestone Member—The Reel Limestone Member of the Bond Formation (Worthen, 1875, p. 55) is named for Reel's Corner, Wabash County (NE? 8, 1S-12W). The Reel Limestone occurs in eastern and southeastern Illinois where it is the first limestone above the Shoal Creek Limestone and lies 85-100 feet above it. The Reel Limestone is dark gray, contains many small gastropods, pelecypods, brachiopods, and incrusting Foraminifera, and is 1-3 feet thick. It is generally underlain by a thin, black fissile shale that directly overlies the Flannigan Coal.

Witt Coal Member—The Witt Coal Member of the Bond Formation (Gluskoter, *in* Kosanke et al., 1960, p. 43) is named for Witt, Montgomery County. The type section consists of exposures along the East Fork of Shoal Creek, about 6.5 miles south of Witt (NE NW SE 7, 8N-2W). The Witt Coal is generally less than 1 foot thick and is recognized only in southwestern Illinois. In the Witt type area the coal lies approximately 45 feet above the Flat Creek Coal. It has been tentatively correlated with a persistent, unnamed, thin coal that occurs about 35 feet above the Reel Limestone throughout eastern and southeastern Illinois.

Coffeen Limestone Member—The Coffeen Limestone Member of the Bond Formation (Gluskoter, *in* Kosanke et al., 1960, p. 39) is named for Coffeen, Montgomery County, and the type section consists of outcrops along the East Fork of Shoal Creek, about 4.5 miles northeast of Coffeen (NE NW SW 7, 8N-2W). The Coffeen Limestone is less than 2 feet thick in the type area and contains a varied marine fauna dominated by brachiopods, crinoids, and bryozoans. It is 8 feet above the Witt Coal in the type area and may be fairly widespread, but it has been recognized only in the northern part of southwestern Illinois. It occurs about 80 feet below the base of the Millersville Limestone. The Coffeen Limestone probably correlates with the Riverview Limestone Member, which lies about 40 feet above the Fairbanks Coal Member of Indiana.

Millersville Limestone Member—The Millersville Limestone Member of the Bond Formation (Taylor and Cady, 1944, p. 22), the top of which defines the top of the formation in central and southern Illinois, is named for Millersville, Christian County. The type locality consists of exposures near the village (SE NE 28 and NW NW 31, 12N-1W) (Payne and Cady, 1944, p. 12-13). In the type area the Millersville is 50 feet thick and is divided into two or three benches by shale partings as much as 2-3 feet thick. It is the thickest limestone in the Pennsylvanian System in Illinois. The limestone is light gray, fine grained, and contains a diversified open-marine fauna. The Millersville has been extensively quarried in central Illinois. In southern Fayette, Effingham, and Jasper Counties and farther south it is not well developed, although thin limestones in that area are considered as correlatives of part of the Millersville. East of the La Salle Anticlinal Belt, the Livingston Limestone is correlated with the Millersville, as is the Argentine Limestone Member of Missouri.

Livingston Limestone Member—The Livingston Limestone Member of the Bond Formation (Worthen, 1875, p. 11-19), the top of which forms the top of the formation in eastern Illinois, is named for Livingston, Clark County. The type section consists of exposures along Big Creek, about 2 miles northwest of Livingston (SE NW 6, 11N-11W) (Wanless, 1956, p. 12). The Livingston occurs in two or three benches separated by shale beds 1-6 feet thick and has a maximum thickness of about 25 feet. It is generally fine grained and medium to thick bedded, and each bench thins to the south as the shale partings become thicker. The Livingston is well developed in Vermilion, Edgar, Clark, and eastern Coles Counties, where it has been extensively quarried. It thins southward into Crawford County. The Livingston is correlated with the Millersville Limestone west of the La Salle Anticlinal Belt.

Mattoon Formation

The Mattoon Formation of the McLeansboro Group (Kosanke et al., 1960, p. 39, 40), the youngest Pennsylvanian formation in Illinois, is named for Mattoon, Coles County, which lies in the general outcrop area of the formation. No type section has been designated, but a good reference section of the lower 300 feet of the formation is available in a detailed sample study and an electrical log for the Illinois Geological Survey Coal Section control well 191, an oil test boring in Clay County (SE SE SE 10, 4N-5E) on file at the Survey (Kosanke et al., 1960, p. 40, 83, 84). The formation is underlain by the Bond Formation (fig. P-2), and the top is an erosional surface overlain, for the most part, by Pleistocene glacial deposits. A maximum of slightly more than 600 feet of Mattoon is preserved in the central part of the Illinois Basin in Jasper County (fig. P-16). Lithologically the Mattoon Formation is a complex unit of thin limestones, coals, black fissile shales, underclays, thick gray shales, and several well developed sandstones. Outcrops are widely scattered, and reliable subsurface data, except for electrical logs of oil tests, are scarce. Consequently, the lateral extent of many of the named units has not been determined. However, many of the coals and limestone units in the Mattoon are believed to be no less persistent than others in the McLeansboro Group. The Omega and Greenup Limestone Members are well developed and

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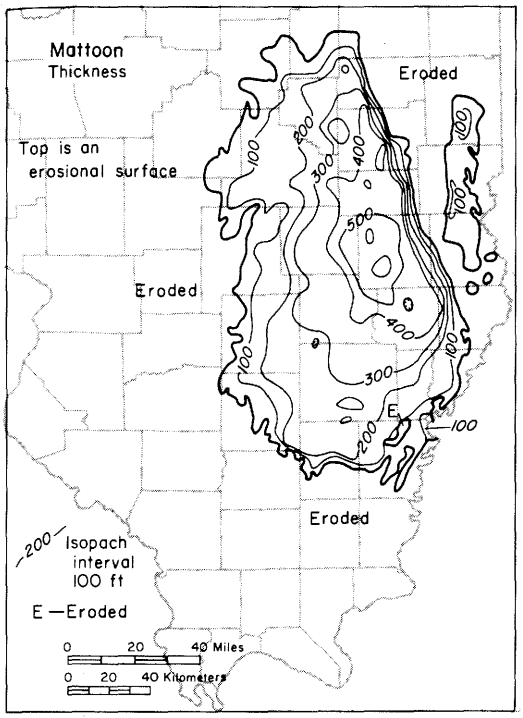

Fig. P-16—Thickness of the Mattoon Formation (based on map by K. E. Clegg).

contain abundant marine fossils, but others are thin and argillaceous. A few tan argillaceous limestones, which contain only ostracodes and *Spirorbis*, are usually less than 5 feet thick. The lower 150 feet of the Mattoon extends into Indiana. The Mattoon correlates with the upper part of the Sturgis Formation in western Kentucky but the top several hundred feet of the Sturgis is younger than the youngest Mattoon of Illinois.

Friendsville Coal Member—The Friendsville Coal Member of the Mattoon Formation (Fuller and Clapp, 1904, p. 2) is named for Friendsville, Wabash County. The type locality consists of several abandoned mines near Friendsville (13, 24, 1N-13W) (Kosanke, 1950, p. 89). The Friendsville Coal is present only in the western two-thirds of Wabash County, where it is as much as 4 feet thick. Near McCleary's Bluff in southern Wabash County it is overlain by an unnamed lenticular limestone up to 6 feet thick that contains abundant phylloid algae. The Friendsville Coal lies about 160 feet above the Reel Limestone, and its position is thought to be in the lower part of the Mattoon Formation. However, its exact relation to the Millersville (Livingston) Limestone has not been determined. In Wabash County, strata that may be equivalent to the Millersville are a complex of limestone, shale, and a few coal streaks, one of which may be equivalent to the Friendsville Coal.

Cohn Coal Member—The Cohn Coal Member of the Mattoon Formation (Newton and Weller, 1937, p. 18) is named for Cohn (now called Livingston), Clark County. The type section consists of an exposure on the south side of Big Creek, about 2.5 miles from Livingston (NE 1, 11N-12W). The Cohn Coal occurs in eastern Illinois, where it is generally less than 10 inches thick. At its type locality it is only 2 inches thick, and it lies 22 feet above the Livingston Limestone and 12 feet below the base of the Merom Sandstone. A 16-inch thick nodular limestone containing numerous *Spirorbis* occurs 2 feet above the coal. To the south in Crawford County, the Cohn Coal is correlated with a thin coal that has been mined in the vicinity of Flat Rock. In that area the Cohn Coal lies at or very near the base of the Merom Sandstone, which may have eroded the coal in some areas.

McCleary's Bluff Coal Member—The McCleary's Bluff Coal Member of the Mattoon Formation (Kosanke, 1950, p. 89; Kosanke et al., 1960, p. 40, 51) is named for McCleary's Bluff, Wabash County. The type section consists of a 3-inch coal seam exposed on the bluff overlooking the Wabash River (NW SW SE 29, 2S-13W). Its stratigraphic position is approximately 50 feet above the Friendsville Coal (Kosanke et al., 1960). It was erroneously placed below the Friendsville Coal by Kosanke (1950) and Siever (*in* Wanless, 1956). The only known exposures of the McCleary's Bluff Coal occur on McCleary's Bluff and at Keys Hill in Wabash County (NE SW 25, 1S-13W). An unnamed coal member approximately 1 foot thick lies 7 feet above the McCleary's Bluff Coal in its type area.

Merom Sandstone Member—The Merom Sandstone Member of the Mattoon Formation (Collett, 1871, p. 199) is named for Merom Hill, Sullivan County, Indiana, and the type section is along the Wabash River Bluff near the town of Merom (7, 7N-10W). At the type locality the Merom Sandstone occurs directly below glacial drift and has a maximum observed thickness of approximately 55 feet. It lies directly on top of a limestone 2-4 feet thick, which is correlated with the Livingston Limestone of eastern Illinois. The sandstone is dominantly a fluvial channel deposit, and at its type locality it has eroded the Cohn Coal, which normally lies 20-30 feet above the Livingston Limestone. The Merom Sandstone is the uppermost named member of the Pennsylvanian System in the Marshall Syncline (fig. 12), where it is approximately 100 feet thick. The stratigraphic position of the Merom Sandstone has not been definitely determined.

Dix Limestone Member—The Dix Limestone Member of the Mattoon Formation (Bradbury, 1965, p. 4) is named for Dix, Jefferson County, where it has been quarried locally. The type section consists of exposures on a southwest-flowing tributary to Casey Fork, about 2 miles south of Dix (NW SE NW 25, 1S-2E). In that area the Dix is a brownish gray argillaceous limestone as much as 6 feet thick that contains only *Spirorbis* and numerous ostracodes. It lies about 50 feet above the position of the Millersville Limestone and 300 feet above the Shoal Creek Limestone. The Dix may correlate with the fresh-water limestone found at the base of the underclay below the Opdyke Coal.

Opdyke Coal Member—The Opdyke Coal Member of the Mattoon Formation (Cady et al., 1952, p. 90-91) is named for the village of Opdyke, Jefferson County, where the type section is in small mines in the vicinity of Belle Rive and Opdyke (3S-4E). In the type locality the Opdyke is fairly extensive and as much as 2 feet thick locally. It crops out in eastern and southeastern Jefferson County and northwestern Hamilton County. It lies about 430 feet above the Shoal Creek Limestone and is tentatively correlated with a 12-inch coal that crops out on the Louden Anticline in eastern Fayette County, 60-70 feet above the Millersville Limestone, and is believed to be extensive in the subsurface of central Illinois.

Shelbyville Coal Member—The Shelbyville Coal Member of the Mattoon Formation (Broadhead, 1875, p. 169-171, used the term "Shelby"; Worthen, 1875, p. 49, used the term "Shelbyville") is named for Shelbyville, Shelby County. The type section is in natural exposures and in drift and shaft mines in the vicinity of Shelbyville (11N-3-4E) (Kay,

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1915, p. 215, 216). The coal is locally as much as 3 feet thick and can be traced in the subsurface in most of the area in which the Mattoon Formation occurs. It is normally 80-120 feet below the Omega Limestone.

Calhoun Coal Member—The Calhoun Coal Member of the Mattoon Formation (Noé, 1934, p. 103) is named for Calhoun, Richland County, and the type section is in a roadcut about 2 miles southeast of Calhoun (NE NE NE 6, 2N-14W) (Kosanke et al., 1960, p. 40, 82). The Calhoun Coal is widespread in eastern Illinois, where it is 2 feet thick or less and is overlain by the Bonpas Limestone. It lies about 525 feet above the Shoal Creek Limestone. The Calhoun is also present on the western side of the deeper part of the Illinois Basin, where it occurs a foot or two below the Omega Limestone.

Omega Limestone Member—The Omega Limestone Member of the Mattoon Formation (Weller and Wanless, *in* Lamar et al., 1934, p. 128) is named for Omega, Marion County. The type locality consists of exposures in an abandoned limestone quarry (NW NW NE 30, 3N-4W) (Weller and Bell, 1936, p. 29-32; Wanless, 1956, p. 12; Kosanke et al., 1960, p. 81, 82). The Omega is almost 11 feet thick in the type locality and reaches 15 feet in Effingham and Shelby Counties. In Shelby County it varies in thickness and character and is very argillaceous and sandy in areas where it is thick. Although sporadic in occurrence, it appears in a wide area. It is correlated with the Bonpas Limestone in eastern Illinois.

Bonpas Limestone Member—The Bonpas Limestone Member of the Mattoon Formation (Kosanke et al., 1960, p. 41) is named for Bonpas Creek, Richland County. It previously was called Calhoun Limestone (Weller, *in* Dunbar and Henbest, 1942, p. 27). The type section is in a roadcut exposure about 1.5 miles west of Bonpas Creek, the same location as the Calhoun Coal type section (Kosanke et al., 1960, p. 41, 82). The Bonpas is 3 feet thick in the type locality and is widely distributed in eastern Illinois. It contains a varied open-marine fauna and is correlated with the Omega Limestone of the western side of the area covered by the Mattoon Formation.

(Mattoon Formation continued in next column)

VIRGILIAN SERIES

The Virgilian Series of the Pennsylvanian System (Moore, 1931, correlation chart) is named for Virgil, Greenwood County, Kansas, which lies in the outcrop belt of these rocks. In Illinois it includes all Pennsylvanian strata above a position a few feet below the coal that occurs just below the Shumway Limestone Member (Willman et al., 1967). It thus includes the upper half of the Mattoon Formation of the McLeansboro Group (fig. P-2). Where marine rocks are found, as they are in Illinois and the Midcontinent Region, the Virgilian includes strata containing fusulinids of the genus *Triticites* that are more advanced than the subgenus *Kansanella* found in lower strata. The upper limit is placed just below the first appearance of the Permian genera *Pseudoschwagerina* and/or *Schwagerina*, but neither have been found in the Illinois Basin. The spores and plant-compression fossils in Virgilian rocks are not well known.

Mattoon Formation (continued)

Shumway Limestone Member—The Shumway Limestone Member of the Mattoon Formation (Weller, *in* Dunbar and Henbest, 1942, p. 28; Wanless, 1956, p. 12) is named for Shumway, Effingham County. The type locality consists of exposures along Shoal Creek about 2 miles east of Shumway (SE SE SW 26, 9N-5E) (Kosanke et al., 1960, p. 81). The Shumway is the upper, most persistent of two marine limestones. At the type locality it is 2 feet thick and contains an abundant open-marine fauna dominated by brachiopods and containing a few solitary corals. The Shumway and the thin coal a few feet under it are exposed in Effingham County. It is directly underlain by a black fissile shale and overlain by gray shale.

Effingham Limestone Member—The Effingham Limestone Member of the Mattoon Formation (Wanless, 1956, p. 7, 12) is named for Effingham, Effingham County. The type section consists of outcrops in the east-flowing tributary to Salt Creek just south of Effingham (S line NW 33, 8N-6E). This limestone has not been recognized far from the type area, where it is a 1-foot bed of granular conglomeratic limestone containing numerous brachiopods, gastropods, crinoids, and a few corals. A thin, black fissile shale occurs about 3 feet above the Effingham Limestone.

Trowbridge Coal Member—The Trowbridge Coal Member of the Mattoon Formation (Cady, 1948, p. 5, footnote 4) is named for Trowbridge, Shelby County. The type locality consists of outcrops about 1 mile northeast of the town (S line 11, 10N-6E). The Trowbridge attains a maximum thickness of 2.5-3 feet and is a normally banded coal that is high in ash. It occurs about 150-180 feet above the Omega Limestone. It has not been traced far from the type area.

Bogota Limestone Member—The Bogota Limestone Member of the Mattoon Formation (Newton and Weller, 1937, p. 9) is named for Bogota, Jasper County. The type section consists of exposures along Big Muddy Creek about 6 miles southwest of Bogota (NE NE 7, 5N-8E) (Kosanke et al., 1960, p. 44, 79, 80). The Bogota is known definitely only in the type locality, but the name has been questionably applied to many limestone outcrops in the central part of the area of the Mattoon Formation. In the type section the Bogota is 1.5 feet of gray, fossiliferous, nodular limestone in a yellowish brown clay matrix, and it overlies about 1 foot of black fissile shale.

Reisner Limestone Member—The Reisner Limestone Member of the Mattoon Formation (Kosanke et al., 1960, p. 41, 51) is named for Reisner School, Jasper County. It previously was called Newton Limestone (Newton and Weller, 1937, p. 9, 24-25). The type section consists of exposures along West Crooked Creek, 1.5 miles northeast of the abandoned Reisner School (NE NE 16, 7N-10E). Near its type locality the Reisner Limestone is argillaceous and contains fragments of small brachiopods. It is generally less than 1 foot thick, is overlain by 1.5 feet of black fissile shale, and is underlain by claystone containing argillaceous and generally unfossiliferous (with local exceptions of *Spirorbis*) limestone as much as 3 feet thick in places. The Reisner Limestone lies 60-80 feet above the Bogota Limestone Member and 40-45 feet above an unnamed coal that was mined from a few shallow shafts in the vicinity of Newton and was reported to be approximately 2 feet thick. Kosanke et al. (1960) stratigraphically placed the Reisner Limestone as the youngest named member in the Mattoon Formation. However, recent studies indicate that the Reisner Limestone occurs below the Greenup Limestone, as had been stated by Newton and Weller (1937).

Gila Limestone Member—The Gila Limestone Member of the Mattoon Formation (Newton and Weller, 1937, p. 27) is named for Gila, Jasper County. The type section consists of exposures about 1.5 miles south of Gila along Mint Creek (NE SW 31, 8N-9E) (Kosanke et al., 1960, p. 41, 51, 78,

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79). The Gila has not been recognized outside the type area, where it is a gray, fine-grained, dense limestone 2.5 inches thick in which fish scales and teeth are the only fossils found.

Woodbury Limestone Member—The Woodbury Limestone Member of the Mattoon Formation (Newton and Weller, 1937, p. 9, 28-30) is named for Woodbury, Cumberland County. The type section consists of exposures on a tributary to Webster Branch about 2 miles southwest of Woodbury (S1/2 SE 32, 9N-8E). In the type section the Woodbury is a hard, gray, calcareous ironstone layer 3-4 inches thick that contains numerous brachiopods, crinoids, and a few corals. It is separated from an underlying 5-inch coal by a few inches of black coaly shale. The Woodbury has not been recognized outside the type area.

Greenup Limestone Member—The Greenup Limestone Member of the Mattoon Formation (Newton and Weller, 1937, p. 9, 26), the youngest named member of the formation, is named for Greenup, Cumberland County. The type section consists of exposures along the valley wall of the Embarras River just west of Greenup (cen. W1/2 NE 3, 9N-9E) (Kosanke et al., 1960, p. 41, 51, 79). The Greenup is known from several outcrops in the northern part of the area of the Mattoon Formation in Jasper, Cumberland, and Coles Counties, where it is as much as 8 feet thick and has been quarried locally. The Greenup is a relatively pure limestone with an abundant open-marine fauna dominated by brachiopods and crinoids but also including a few corals and locally abundant fusulinids. It represents a major marine transgression into Illinois.

MESOZOIC ERATHEM

H. B. Willman and John C. Frye

The Mesozoic Erathem—the rocks deposited during the Mesozoic Era (Phillips, 1840)—is represented in Illinois only by the Cretaceous System, the youngest deposits of the era. As the youngest of the Paleozoic rocks (the Permian System), the Mesozoic, Triassic, and Jurassic Systems and the Comanchean Series of the Cretaceous System are not represented in Illinois, the base of the Cretaceous System is a major unconformity (fig. 1). However, the general distribution of the marine Permian rocks over the continental United States suggests that Permian seas covered much of Illinois and that their absence is attributable to erosion, either in latest Permian time or during the early and middle parts of the Mesozoic Era. There is no evidence to suggest that extensive deposits, either marine or continental, accumulated in Illinois during the pre-Cretaceous periods of the Mesozoic Era. Although such deposits could have been present and entirely eroded, the development of the sub-Cretaceous unconformity required a long interval of erosion, and it seems likely that Illinois was continuously in an erosional environment during early Mesozoic time. The Little Bear Soil, which developed on the Paleozoic rocks and is present at the base of the Cretaceous sediments in southern Illinois (fig. K-2), probably formed during the later part of this interval.

The Mesozoic rocks, which are largely unconsolidated sand incorporating some silt and clay, occur only in extreme southern Illinois and locally in western Illinois (figs. K-3, K-4). The southern Illinois Cretaceous strata are part of the deposits at the head of the Mississippi Embayment of the Gulf Coastal Plain. With the overlying Tertiary formations, they compose a distinctive unit differentiated as the Embayment Megagroup.

The Mesozoic Era, the interval of "middle life," formerly called the "Secondary Group" of rocks, is also known as the Age of Reptiles, and the huge dinosaurs of that time may have been common in Illinois, although no remains have been found. The era also saw the first appearance of birds, mammals, and angiosperms.

Little Bear Soil

The Little Bear Soil (Mellen, 1937, p. 8-20), a soil locally preserved at the base of the Cretaceous System, is named for Little Bear Creek, Tishomingo County, Mississippi. It is the only soil-stratigraphic unit that has been named in Illinois in pre-Quaternary strata (Pryor and Ross, 1962; Ross, 1963). It consists of remnants of an iron-rich residual soil developed on Paleozoic rocks. Isolated remnants have been found throughout the eastern part of the Mississippi Embayment. In Illinois it consists of red and brown clays with lenses and nodules of brown to black limonite and, generally, a few angular chert pebbles. It is included in the lower part of the Tuscaloosa Formation. It is well exposed along the Post Creek Cutoff in Pulaski County (cen. 2, 15S-2E), where it is 7 feet thick, rests on the St. Louis Limestone, and is overlain by gravel of the Tuscaloosa Formation. The Little Bear Soil was developed during early Cretaceous time, after the erosional truncation of the Paleozoic rocks by the sub-Cretaceous unconformity.

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EMBAYMENT MEGAGROUP

The Embayment Megagroup (Swann and Willman, 1961, p. 482), named for the Mississippi Embayment, the northward extension of the Gulf Coastal Plain into southernmost Illinois, consists in Illinois of the dominantly clastic formations of Cretaceous and Tertiary age that differ markedly in character from the underlying Paleozoic and the overlying Quaternary formations and are separated from both by major unconformities. The Embayment Megagroup includes seven formations (figs. K-2, T-2) that occur largely south of the Cache Valley in Pulaski and Massac Counties but also extend westward across Alexander County from the Cache River Valley to the Mississippi River Valley. The megagroup thickens rapidly southward into the Embayment area and has a maximum thickness of nearly 1000 feet in subsurface near Cairo, Alexander County.

CRETACEOUS SYSTEM

The Cretaceous System (D'Halloy, 1822), named for the chalk formations of France, is restricted in Illinois to five counties in extreme southern Illinois and to areas in Pike and Adams Counties in western Illinois.

The Cretaceous rocks in southern Illinois (Glenn, 1906; Lamar and Sutton, 1930; Stearns, 1958; Pryor, 1960; Pryor and Ross, 1962; Ross, 1963, 1964) (figs. K-1, K-2) are at the north end of the Mississippi Embayment of the Gulf Coastal Plain (fig. K-3). They are entirely clastic rocks—the nonmarine part of a large delta built where a river from the east discharged into the head of the embayment. A thin marine deposit occurs at the top. The Cretaceous rocks are as much as 500 feet thick near Cairo, where they are overlain by Paleocene sediments, but they thin rapidly northward as they are truncated by younger Tertiary and Pleistocene sediments.

The Cretaceous rocks in western Illinois (Frye et al., 1964) (fig. K-4) also are clastic rocks, largely sand, and as much as 100 feet thick. They are the easternmost outliers of Cretaceous sediments that formerly covered the region east of the Rocky Mountains and north of the Ozarks. The outliers in Illinois are nearly 200 miles from the nearest Cretaceous exposures in west-central Iowa. They appear to be beach and nearshore sediments deposited in the advancing Cretaceous sea.

Although the deposits are dominantly quartz sand in both areas, they differ noticeably in other mineral constituents. The two regions were separated by a barrier, probably a low eastern extension of the Ozark Uplift across southern Illinois.

The Cretaceous sediments in southern Illinois terminate northward as they are truncated by Tertiary deposits. The presence of Cretaceous-type gravel and white clays in possible sink holes as far north as Kaolin, northwest of Anna, Union County, suggests that Cretaceous deposits formerly were more extensive than they are now, although they probably did not extend significantly north of their present area. Cretaceous rocks in western Illinois terminate southward against an area of higher Mississippian formations, indicating that Cretaceous sediments may never have been deposited in the area between there and extreme southern Illinois.

The southern Illinois Cretaceous rocks are largely nonmarine sand containing beds of lignitic silt and clay, lignite, and gravel. The major part of the Cretaceous in this area is assigned to the McNairy Formation, but the patches of gravel at the base are assigned to the Tuscaloosa Formation, and a thin, marine sandy silt at the top is assigned to the Owl Creek Formation (fig. K-2). The heavy minerals of the sands are characterized by a high content of kyanite and by appreciable amounts of staurolite, tourmaline, sillimanite, zircon, and rutile. The clay minerals in the nonmarine sediments are largely kaolinite, whereas those in the marine sediments are dominantly montmorillonite (Pryor and Glass, 1961). The mineralogy indicates the sediments were derived from the metamorphic rocks of the Piedmont region to the east or southeast. The sediments were carried into the Embayment region by a river on the sub-Cretaceous erosional surface.

Cretaceous rocks in western Illinois, all assigned to the Baylis Formation, are largely sand and clayey sand that are generally nearly white, although they are rusty brown where weathered. They commonly contain a bed of gravel at the base and, in some localities, beds of gray to dark gray silty clay. The heavy minerals in the sands are dominantly

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zircon, tourmaline, and staurolite, in percentages close to those in the Cretaceous deposits of Iowa and Kansas. The dominant clay mineral varies from bed to bed, from montmorillonite to illite to kaolinite, indicating the mixed compositions of nearshore environments and derivation largely from northern sources. Similar compositions were found in samples of the Cretaceous in Iowa. The mineral composition and sediment characteristics distinguish these deposits from glacial deposits.

The Cretaceous rocks in western Illinois appear to have been deposited on a nearly flat surface eroded across various Mississippian and Pennsylvanian formations. In southern Illinois, variations in thickness of the Cretaceous sediments have commonly been interpreted as indicating significant relief on the pre-Cretaceous surface because the outcropping Cretaceous rocks show none of the intensive faulting found in the Paleozoic rocks immediately north of the Cretaceous area. However, Ross (1963) questioned this interpretation because subsurface information showed that the basal thin gravel and the Little Bear Soil beneath it are more widespread than originally thought and that the thickness variations of the Cretaceous parallel the structures in the Paleozoic rocks. Consequently, he related the irregularities of the sub-Cretaceous surface to Cretaceous and possibly post-Cretaceous movements of some of the major faults.

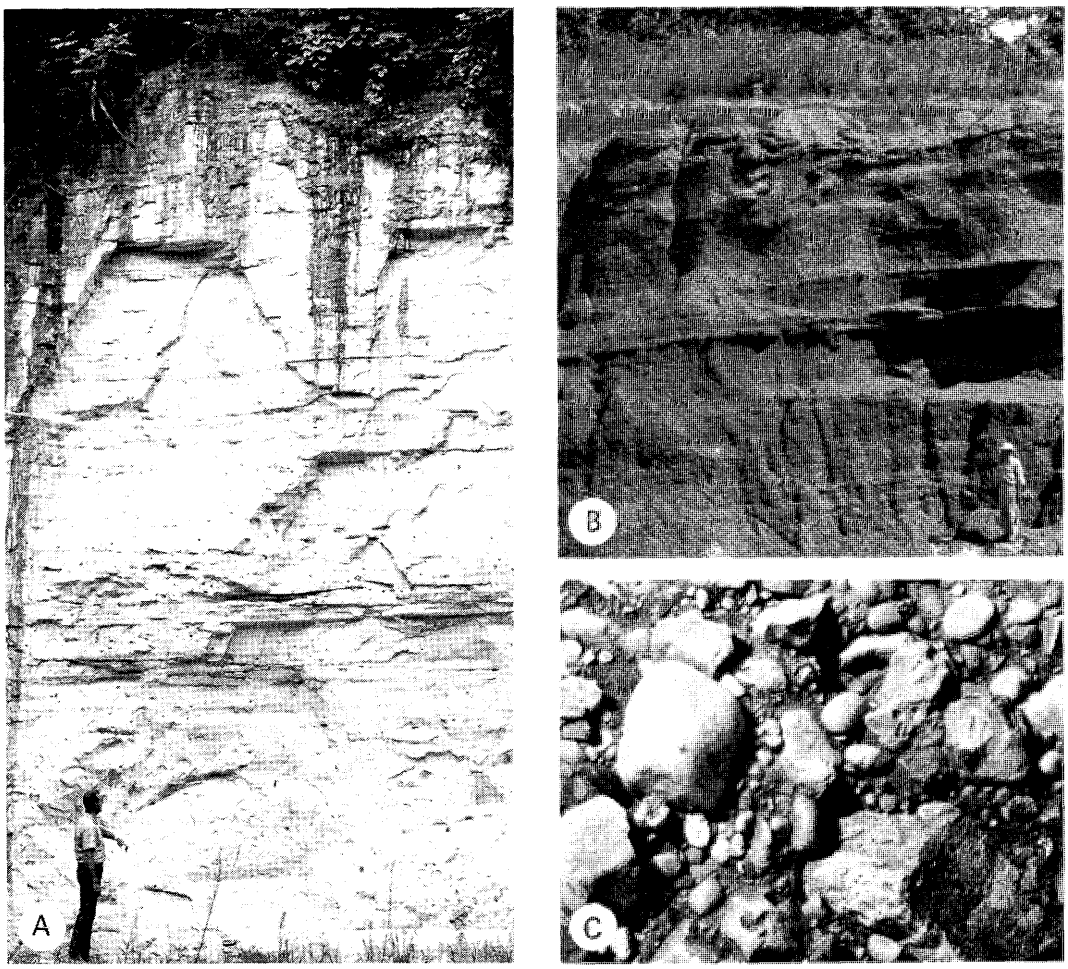

Fig. K-1—Exposures of Cretaceous and Tertiary rocks.
A—McNairy Sand in a pit near Fayville, Alexander County.
B—Mounds Gravel in pit along Illinois Highway 145, 8 miles north of Metropolis, Massac County.
C—Bedding surface of Mounds Gravel in same pit as exposure B (×1 1/2).

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The Cretaceous age of the southern Illinois deposits is indicated by the presence of a few distinctive Foraminifera in the Owl Creek Formation, by abundant plant fossils in the lignitic beds, and by the equivalence of the deposits to the abundantly fossiliferous marine sediments south of Illinois. No fossils have been found in the western Illinois deposits, but the composition of the gravels, the heavy minerals in the sands, and the clay mineral assemblages are all similar to those of the Cretaceous rocks in Iowa. From their stratigraphic position, the sediments could be Tertiary in age, but they appear to have been deeply eroded before the near-by late Tertiary gravel was deposited.

GULFIAN SERIES

The Gulfian Series (Hill, 1887, p. 298, 300) is named for its occurrence along the Coastal Plain of the Gulf of Mexico, and is presumed to include all Cretaceous rocks in Illinois. In southern Illinois most of the Cretaceous rocks were deposited during the youngest part of the Gulfian, although the basal Tuscaloosa Formation may represent early deposits of the series. Cretaceous rocks in western Illinois were probably deposited during early Gulfian time.

Tuscaloosa Formation

The Tuscaloosa Formation (Smith and Johnson, 1887, p. 18, 95-117) (fig. K-2), is named for exposures along the Tuscaloosa (Black Warrior) River near Tuscaloosa, Alabama. It is exposed only locally in extreme southern Illinois and appears to have a patchy distribution (Pryor, 1960; Pryor and Ross, 1962; Ross, 1964). It has a maximum thickness of 20 feet but is generally much thinner. The Tuscaloosa is well exposed along the Post Creek Cutoff, Pulaski County (cen. 2, 15S-2E), and in railroad cuts in the Thebes Gorge, 1 mile south of Rock Springs Hollow, Alexander County (SW 21, 15S-3W). It is largely chert gravel, generally moderately cemented with fine silica or white clay. The chert pebbles, in a matrix of coarse quartz sand, are mainly white or gray, but black pebbles are locally common. Beds of pebbly sand and white clay also are common. The clays are dominantly kaolinite (Pryor and Glass, 1961). The Little Bear Soil occurs in deposits at the base of the Tuscaloosa Formation. Gravel found northeast of Elco in northern Alexander County (SW SE 7, 14S-1W) is probably Tuscaloosa Gravel preserved in sink holes. Local concentrations of gray and black chert pebbles on the upland bedrock surfaces as far north as Kaolin, Union County (SW NW 2, 12S-2W), are probably residual or reworked from the Tuscaloosa. The Tuscaloosa in Illinois is similar in lithology and stratigraphic position to the Tuscaloosa of Kentucky and Tennessee, but it is a transgressive deposit and may be younger than the type Tuscaloosa.

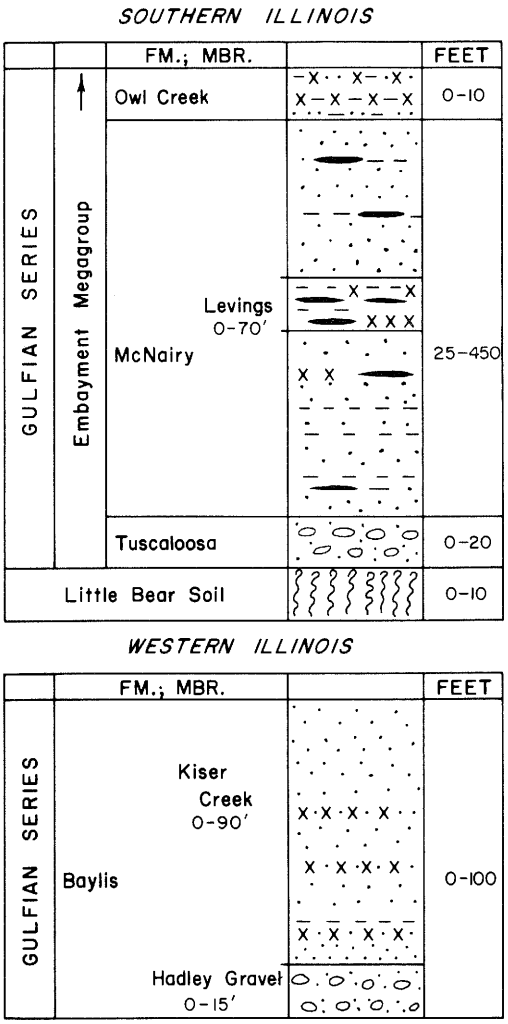

Fig. K-2—Classification of the Cretaceous System.

McNairy Formation

The McNairy Formation (Stephenson, 1914, p. 18, 22) (fig. K-2) is named for McNairy County, Tennessee, where the type section is a railroad cut 1.5 miles west of Cypress Station. It was formerly called a member of the Ripley Formation (Lamar and Sutton, 1930) but was designated a formation by Pryor (1960). The McNairy is widely exposed in extreme southern Illinois, largely south of the Cache River Valley in Massac and Pulaski Counties but also farther west in the southern part of the hills from Olive Branch to Fayville in Alexander County (fig. K-1A). The lower part of the formation is widely exposed in roadcuts in the hills 2-4 miles north of Unionville, Massac County (Ross, 1964), and the upper part in the Ohio River bluffs in the vicinity of U.S. Dam 53 in Pulaski County (Pryor and Ross, 1962). The formation is at least 450 feet thick, perhaps locally a little thicker. Along its northern limit it is truncated by the Mounds Gravel.

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The McNairy Formation is a deltaic deposit at the northern end of the Mississippi Embayment and consists largely of nonmarine sand deposited by rivers and of lignitic clays and silts deposited in interdistributary areas. The lower part consists of fine, white to light gray, cross-bedded, micaceous sand. A middle section, which is gray to black silt with beds of lignite, is named the Levings Member. The upper part is similar to the lower. In the areas where the McNairy is overlain by the Mounds Gravel, the upper 25-50 feet is commonly stained red by iron oxide. South of Illinois, the McNairy Formation grades into the marine sediments of the Selma Formation.

Levings Member—The Levings Member of the McNairy Formation (Pryor and Ross, 1962, p. 19) is named for Levings, Pulaski County, which is 1.5 miles northeast of the type section along a creek southwest of U.S. Dam 53 (NW SW 18, 15S-2E). The Levings Member is largely lignitic silt and clay with thin beds of lignite. It occurs in the middle part of the McNairy Formation, is 0-70 feet thick, and is generally present throughout the northern part of the Mississippi Embayment.

Owl Creek Formation

The Owl Creek Formation (Hilgard, 1860) (fig. K-2), named for exposures along Owl Creek, 3 miles northeast of Ripley, Tippah County, Mississippi, is the uppermost Cretaceous Formation in southern Illinois. It is exposed in Illinois only in Pulaski County along the Ohio River near U.S. Dam 53 (SE NW NE 13, 15S-1E) and along the Cache River near Unity (NE 7, S1/2 6, 16S-1W) (Pryor and Ross, 1962). It consists of glauconitic, very micaceous, sandy, silty clay and silt 0-10 feet thick. It overlies the McNairy Formation conformably. A weathered zone at its top, marked by concentrations of hematitic nodules and a sharp upper contact, indicates an unconformity that separates the Owl Creek from the overlying Tertiary Clayton Formation. The Owl Creek indicates a brief advance of the sea over the McNairy delta.

Baylis Formation

The Baylis Formation (Frye et al., 1964, p. 4) (fig. K-2), which comprises all the sediments of Cretaceous age in western Illinois, is named for Baylis, Pike County, 4 miles north of the type section, which is an exposure and small pit along a branch of Kiser Creek (NW SW SE 31, 4S-4W). The Baylis occurs in Pike and Adams Counties in a prominent ridge that extends for about 20 miles northwest of the Pittsfield area, and it also appears 10 miles farther northwest in a smaller, less prominent area south of Mendon in Adams County (fig. K-4). The Baylis has a maximum thickness of about 100 feet near Baylis, but the top of the formation is eroded and it may originally have been much thicker. The Baylis is largely fine to medium quartz sand and clayey sand. In places it contains lenses of silty clay and pebbles of chert, quartz, and quartzite. The basal few feet is generally gravel and is differentiated as the Hadley Gravel Member. The upper, sandy part of the formation is the Kiser Creek Member. The sands are generally white, but in places some beds are stained brown by limonite. The basal part of the gravel is locally strongly cemented with iron and manganese minerals, although most of the formation is uncemented and soft. The Baylis rests unconformably on Mississippian and Pennsylvanian rocks and is overlain unconformably by Pleistocene deposits, generally only loess in the main ridge northwest of Pittsfield but elsewhere by Kansan drift and, locally, by Illinoian drift (fig. K-4). Most

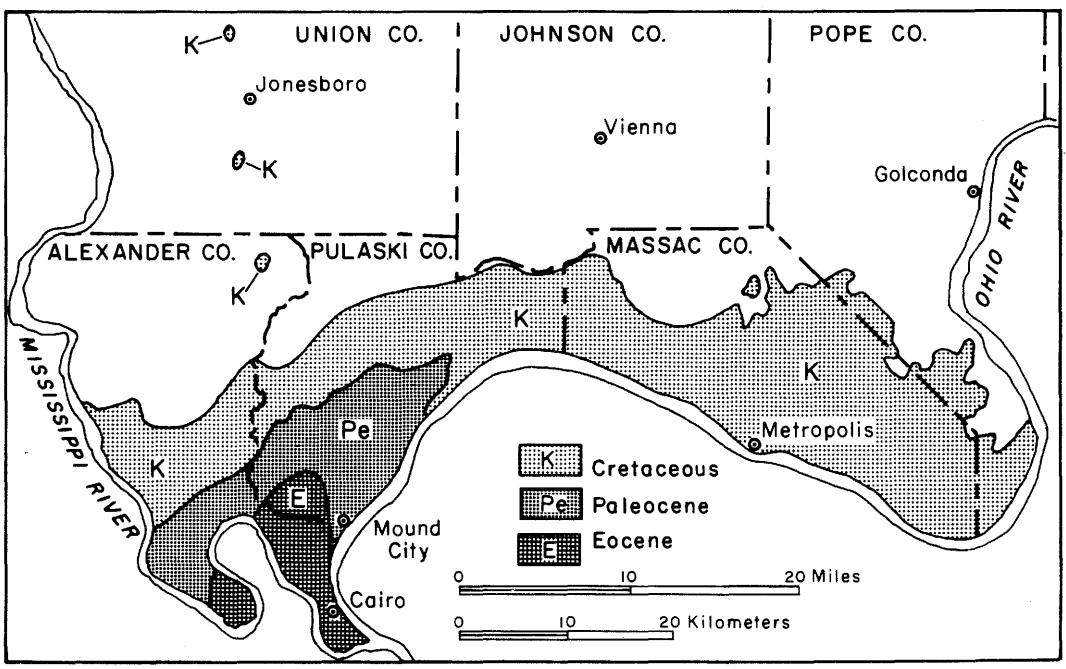

Fig. K-3—Distribution of Cretaceous, Paleocene, and Eocene strata in southern Illinois (after Willman et al., 1967).

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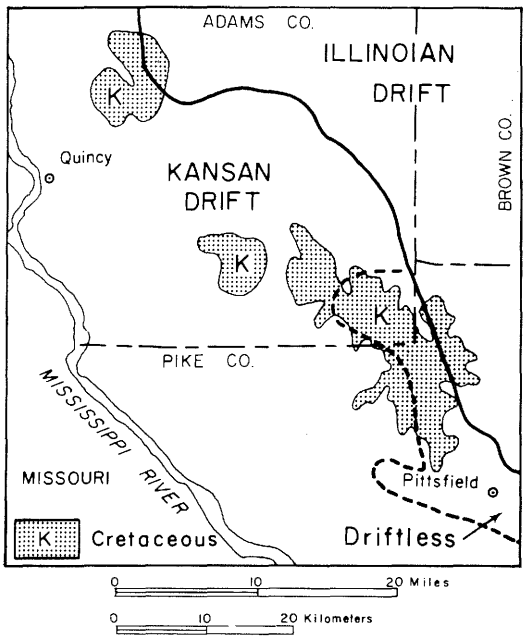

Fig. K-4—Distribution of Cretaceous strata in western Illinois (after Frye et al., 1964).

of the formation is similar in lithology to the Cretaceous Dakota Formation in west-central Iowa, but the Hadley Gravel Member closely resembles the Windrow Formation in Iowa and Wisconsin (Andrews, 1958).

Hadley Gravel Member—The Hadley Gravel Member of the Baylis Formation (Frye et al., 1964, p. 4, 8), the basal member, is named for Hadley, Pike County, 4 miles northwest of the type section, which is also the type section for the Baylis Formation. The member is generally present in the outcrop area of the formation. It is as much as 15 feet thick but is generally less than 10 feet and in places is only a layer of pebbles. It is predominantly pebbles and small cobbles of brown, dark gray, and red chert, but 20-30 percent of the pebbles are quartz, and 1-2 percent are quartzite. It differs only slightly from the Grover Gravel of the Tertiary System, which probably was largely reworked from the Cretaceous gravels, but in the Grover Gravel the brown chert pebbles are more abundant, rounder, and more highly polished. Some of the isolated patches of chert gravels long assigned to the Tertiary may be remnants of the Hadley Gravel Member, which originally may have had wide distribution in western and northern Illinois.

Kiser Creek Member—The Kiser Creek Member of the Baylis Formation (Frye et al., 1964, p. 4, 10), the upper member, is named for the East Branch of Kiser Creek, a tributary of which exposes the type section, the same section described for the Baylis Formation. The member constitutes the greater part of the formation and is dominantly sand and clayey sand, as described for the formation. The sands and clays of the Kiser Creek Member differ from glacial sands in their uniformity, lack of carbonates, distinctive clay mineral assemblages, and the absence of the variety of heavy minerals that characterizes the glacial deposits.

CENOZOIC ERATHEM

H. B. Willman and John C. Frye

The Cenozoic Erathem—the strata deposited during the Cenozoic Era (Phillips, 1840)—consists of the Tertiary and Quaternary Systems, which comprise all deposits in Illinois younger than those of the Cretaceous System of Mesozoic age, including those now being deposited. Except for small areas, mainly in western and northern Illinois, rocks of Tertiary age are restricted to extreme southern Illinois (figs. K-1, T-1), whereas deposits of Quaternary age occur throughout the state (fig. 11).

Only a minor unconformity separates the oldest Cenozoic (Tertiary) strata from the youngest Mesozoic (Cretaceous). As the Oligocene and Miocene Series are not present in Illinois, a prominent unconformity separates the oldest Tertiary (Paleocene and Eocene) from the youngest Tertiary (Pliocene) rocks. A major unconformity also separates the Tertiary from the Quaternary. However, because the Cretaceous and Tertiary Systems are missing in much of Illinois, the Quaternary System, which covers more than 95 percent of the state, lies directly and unconformably on Paleozoic rocks in most places.

The older Tertiary rocks include marine deposits of the Mississippi Embayment, whereas the younger are entirely continental. The Quaternary strata include the glacial deposits that cover 80 percent of Illinois, the loess that mantles nearly all of the state, floodplain alluvium along the rivers and streams, lake and swamp deposits in some lowland areas, sand dunes on terraces and bordering uplands, and the soils that have been developed on most of these deposits.

Many of the Cenozoic rocks are abundantly fossiliferous, and even the oldest have many species nearly like those of the present day. The term Cenozoic means "recent life."

TERTIARY SYSTEM

The Tertiary System (Arduino, 1760), a name retained from one of the earliest classifications of rocks, is extensive only in the extreme southern part of Illinois (figs. K-3, T-1), but it also occurs in small widely scattered areas in western and northern Illinois (fig. T-1). Tertiary sediments in southern Illinois are included with Cretaceous sediments in the Embayment Megagroup.

The Paleocene and Eocene Series (fig. T-2) are present as Coastal Plain sediments in extreme southern Illinois, where they are separated from overlapping Pliocene deposits by a major unconformity. Late Eocene, Oligocene, and Miocene sediments are absent, although some sediments of these series could have been deposited and later eroded during development of the sub-Pliocene unconformity. The Jackson Formation of the late Eocene occurs in Kentucky only a short distance south of Illinois, and Oligocene and Miocene deposits occur in the Coastal Plain Embayment area farther south.

Progressive sinking of the embayment area resulted in the relatively rapid southward thickening of the pre-Pliocene Cretaceous and Tertiary deposits and gave them a southward dip significantly greater than that of the Pliocene sediments. Tertiary sediments have a maximum thickness of about 400 feet in the vicinity of Cairo, Alexander County.

The Paleocene sediments are largely marine clays and sands, whereas the Eocene sands and silty clays indicate a return to nonmarine deltaic sedimentation like that operating during the Cretaceous. The Pliocene sediments are mostly fluvial deposits of a continental environment.

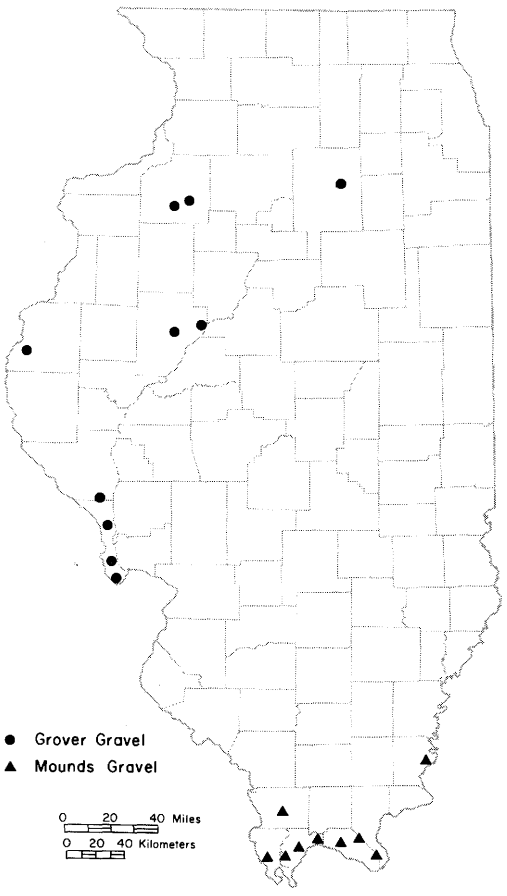

Fig. T-1—Distribution of the Mounds and Grover Gravels.

PALEOCENE SERIES

The Paleocene Series (Schimper, 1874) was differentiated from the Eocene because the floras of the sediments were believed to be sufficiently different from those of the younger Eocene to merit establishing a separate series. The floras of the Paleocene bridge the gap between typical Cretaceous and Eocene floras. Paleocene means "ancient and recent." In Illinois, the Paleocene Series occurs only in the extreme southern counties—Alexander and Pulaski. Paleocene deposits there have a maximum thickness of about 170 feet and are well exposed along the Ohio River near Olmsted and along the Cache River near Unity. The Paleocene consists of the Clayton (below) and Porters Creek Formations. Both formations include marine clays, but the Clayton is sandy and strongly glauconitic. The clays are dominantly montmorillonite (Pryor and Glass, 1961). Paleocene rocks are fossiliferous, but most of the fossils are microfossils or poorly preserved macrofossils. The heavy minerals in the Paleocene sediments are similar to those in the Cretaceous and indicate their source was the metamorphic rocks of the

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SOUTHERN ILLINOIS

SER.		FORMATION		FEET
P-P*	Embayment Megagroup	Mounds Gravel		0-50
EOCENE		Wilcox		0-250
PALEOCENE		Porters Creek		50-150
		Clayton		15-20

WESTERN AND NORTHERN ILLINOIS

SER.	FORMATION		FEET
P-P	Grover Gravel		0-10

*P-P = Pliocene - Pleistocene

Fig. T-2—Classification of the Tertiary System.

Piedmont region far to the east. South of Illinois, the two formations are classified as the Midway Group.

Clayton Formation

The Clayton Formation (Landon, 1891, p. 594) (fig. T-2), named for exposures near Clayton, Barbour County, Alabama, is persistently present at the base of the Paleocene Series in southern Illinois (Pryor and Ross, 1962). It is well exposed in a small ravine northwest of U.S. Dam 53 in Pulaski County (SE NW NE 13, 15S-1E). It is commonly 15-20 feet thick and consists of glauconitic, micaceous, green to buff silty clay that is sandy and pebbly at the base. Foraminifera are the main fossils in the Clayton Formation, but the remains of radiolarians and other plankton also are present. The Clayton is generally less sandy and more glauconitic than the Owl Creek Formation below, and the contact, which is unconformable, is marked by pebbles of white and black chert and iron oxide in the base of the Clayton.

Porters Creek Formation

The Porters Creek Formation (Stafford, 1864, p. 361, 368) (fig. T-2) is named for exposures on Porters Creek in Hardeman County, Tennessee. It is present in Alexander and Pulaski Counties in southern Illinois (Lamar, 1928b; Pryor and Ross, 1962) and is well exposed in pits south of Olmsted, Pulaski County (NE SE 27, 15S-1E), in the Ohio River bluffs near U.S. Dam 53, and along the Cache River near Unity. It is 50-150 feet thick, but north of the Cache Valley it is completely truncated by the Mounds Gravel. The Porters Creek is largely massive, compact, essentially unbedded or weakly bedded, dark gray to nearly black clay that has a blocky fracture. It is gray-tan to white where weathered. Because it does not readily become plastic when wet, it can stand in steeper faces than most clays. It is more than 80 percent montmorillonite. Microfossils (Radiolaria, Hystrichospheridae, and Foraminifera) are abundant, but fish scales, shark teeth, and casts and molds of pelecypods and gastropods are also common. The Porters Creek is overlain unconformably by the Wilcox Formation, which locally cuts deeply into the Porters Creek. The Porters Creek is a marine deposit representing an advance of the sea over essentially the entire area of the embayment. Because the clay has the absorptive and filtering properties of fuller's earth, it has been mined commercially south of Olmsted, Pulaski County.

EOCENE SERIES

The Eocene Series (Lyell, 1833) in Illinois occurs in a small area in Pulaski and Alexander Counties. It is exposed only in Pulaski County in the hills from Mounds west to Cache Valley. The Eocene sediments are all assigned to the Wilcox Formation. The Eocene, which means "dawn of the recent," was so named because its flora and fauna contained only a small proportion of recent species.

Wilcox Formation

The Wilcox Formation (Crider and Johnson, 1906, p. 5, 9) (fig. T-2) is named for Wilcox County, Alabama. It was formerly called Lagrange in Illinois (Lamar and Sutton, 1930). It is exposed in Illinois only in Pulaski County (Pryor and Ross, 1962), along the east side of the Cache River south of Unity, particularly in a pit where 20 feet of sand of the Wilcox Formation overlies the Porters Creek Formation and is overlain by the Mounds Gravel (SE SW SW 7, 16S-1W) (Pryor and Ross, 1962). The Wilcox varies from white, fine to medium, slightly micaceous sand to gray, nearly white, silty or sandy clay. It is only 20-30 feet thick in the outcrop area, but it thickens southward and is as much as 250 feet thick in subsurface near Cairo, Alexander County. The Wilcox was deposited in a delta at the head of the embayment. It probably is equivalent to only part of the Wilcox farther south in Kentucky and Tennessee.

PLIOCENE SERIES

The Pliocene Series (Lyell, 1833), translated as "more recent," was so named because the major part of the invertebrate fossils are

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referable to modern species. It is represented in Illinois by the widespread brown chert gravel deposits of southern Illinois—the Mounds Gravel—and the similar but scattered deposits in western Illinois—the Grover Gravel. All of these deposits were previously called "Lafayette," "Lafayette-type," or "Tertiary" gravel. Both formations probably contain some deposits reworked during the early Pleistocene that are not readily differentiated from those deposited during the late Tertiary. Consequently, both the Mounds and Grover Formations are assigned a Pliocene-Pleistocene age (Willman and Frye, 1970).

Mounds Gravel

The Mounds Gravel (Willman and Frye, 1970, p. 20) (fig. T-2) is named for Mounds, Pulaski County, which is 3 miles east of the type section in a gravel pit on the east side of Cache Valley (SE SW SW 7, 16S-1W). The formation is widely present and is exposed in numerous gravel pits and roadcuts in the area south of Cache Valley and westward from Cache Valley to the Mississippi River (fig. T-1). Good exposures also occur in pits in the hills 8 miles northeast of Metropolis, Massac County (SW SW 28, 14S-5E) (fig. K-1B). An isolated remnant of the gravel lies on top of the Shawneetown Hills in Gallatin County. The gravel is found in three terraces, the upper at an elevation of 580-620 feet, a middle terrace at 450-500 feet, and a lower terrace at 380-400 feet. The gravel underlying these surfaces is rarely as much as 40 feet thick, more commonly less than 20 feet. It is dominantly medium to dark brown chert pebbles with a glossy surface in a matrix of coarse red sand, but in places it is largely pebbly sand. Most of the pebbles are partly rounded and many are well rounded (fig. K-1C). Many of the chert pebbles are 2-3 inches in diameter, or even larger, in places. Quartz pebbles, also well rounded, are common and are generally less than half an inch in diameter. The lithology of the gravel has been well described by Lamar and Reynolds (1951) and Potter (1955). Crossbedding and heavy-mineral content indicate that the Mounds Gravel in southern Illinois was largely deposited by streams flowing from the east or southeast, probably down the Tennessee River Valley on the east side of the embayment area. However, the deposits near the Mississippi River at the head of the embayment and on its west side contain chert, agate, and purple quartzite pebbles characteristic of the Lake Superior region, which indicates some contribution from the north. The Mounds Gravel truncates the older Tertiary and Cretaceous sediments. It, in turn, was deeply dissected and weathered before the oldest Pleistocene deposit in the area, the Illinoian Loveland Silt, was deposited on it. The rivers and streams have entrenched themselves at least 300 feet since the earliest of the gravels was deposited on the highest bedrock surfaces. Although the highest deposits are believed to be Pliocene in age, similar deposits on the lowest surfaces may have been reworked from the higher levels during the early part of the Pleistocene. The Mounds Gravel does not contain the igneous and carbonate rocks or the heavy minerals characteristic of the glacial deposits of the Upper Mississippi and Ohio River Valleys, but such materials would not be found in sediments from the upper Tennessee River Valley. The age of the gravels is controversial (Fisk, 1944; Leighton and Willman, 1950; Potter, 1955; Willman and Frye, 1970), and the Mounds Gravel is therefore now classified as Pliocene-Pleistocene.

Grover Gravel

The Grover Gravel (Rubey, 1952, p. 61) (fig. T-2) is named for Grover, St. Louis County, Missouri, near which it is well exposed on the highest upland surface as overburden in several clay pits (SE NW SW 3, 44N-3E). The formation is as much as 50 feet thick in the type area. It also occurs widely, however, as small relict patches of chert gravel or scattered pebbles at the base of the loess on the upland surface of Calhoun County, Illinois. Isolated patches of similar chert gravel also are found in western and northern Illinois (fig. T-1). The gravel is mainly rounded, brown chert pebbles with some red hematitic chert, purple quartzite, and white and pink quartz pebbles. The matrix is largely red to tan quartz sand, the heavy minerals in which are dominantly zircon and tourmaline. Boulders of purple and pink quartzite as much as 2 feet in diameter occur in the Grover area and in one locality near Golden Eagle, Calhoun County (NE NE SE 36, 13S-2W). The isolated gravel patches included in the Grover Formation (Horberg, 1950b) because of their stratigraphic position on the bedrock in the uplands and beneath Pleistocene deposits of glacial drift or loess are probably not all of the same age. Some may be remnants of Cretaceous gravel, others of Tertiary gravel that perhaps was reworked from the Cretaceous gravel, and still others may have been reworked from the Tertiary gravel in early Pleistocene time. A few deposits contain rare pebbles of igneous and metamorphic rocks, reduced by weathering to clay with coarse mica flakes (Leighton and Willman, 1949), and these most likely are Pleistocene in age. Although the Mounds Gravel near the Mississippi River in southern Illinois contains some materials from the Upper Mississippi River Valley, similar gravel has not been found between the St. Louis area and the southern Illinois area. The connecting valley apparently has been eroded, probably as a result of uplift of the Ozark Dome. The Grover Gravel has long been interpreted as Tertiary, generally Pliocene, in age (Salisbury, 1892). Rubey (1952) considered the gravel to be as old as Miocene because of the amount of erosion that had taken place after it was deposited and because the gravel appears to be displaced more than 100 feet by movement along the Cap au Grès Faulted Flexure in Calhoun County. Because of the large quartzite boulders in the gravel, Willman and Frye (1958, 1970) suggested that the gravel may be early Pleistocene. As definitive faunal evidence is unavailable, the Grover Gravel is classified as Pliocene-Pleistocene in age.

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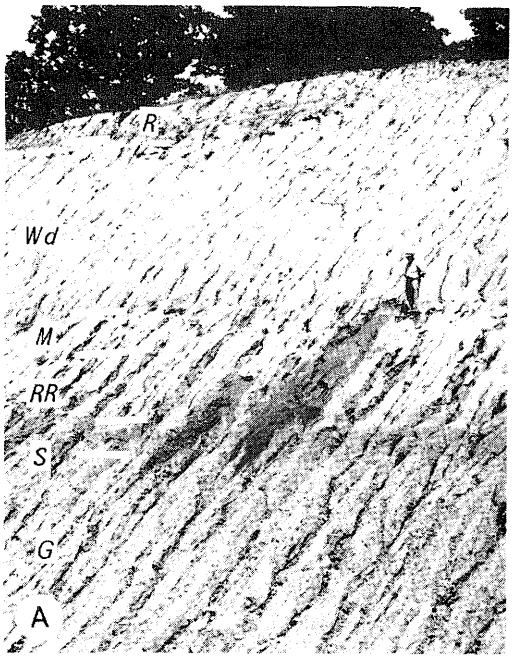

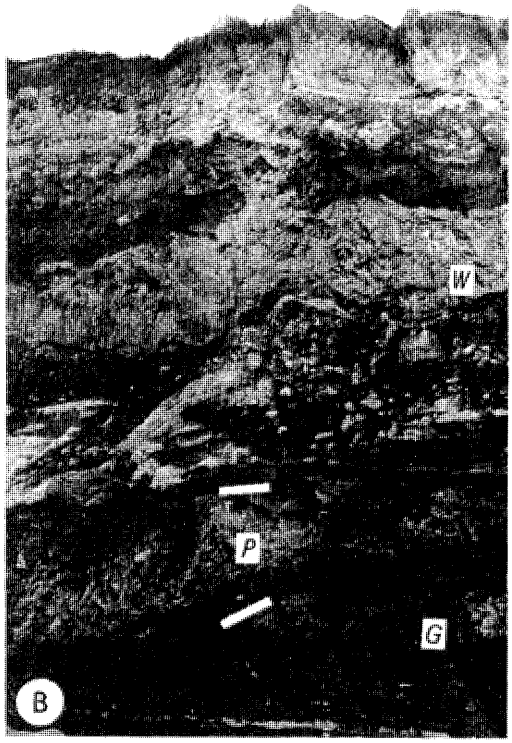

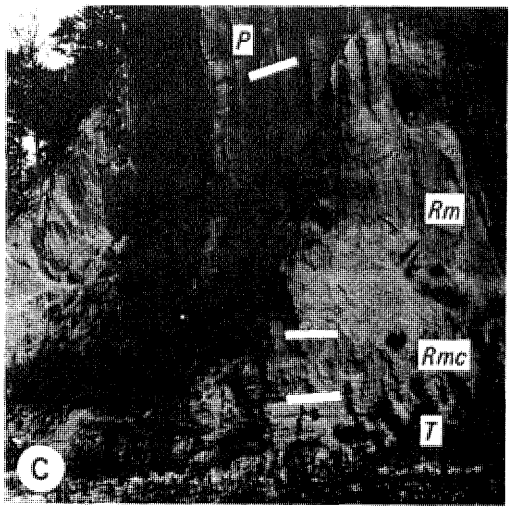

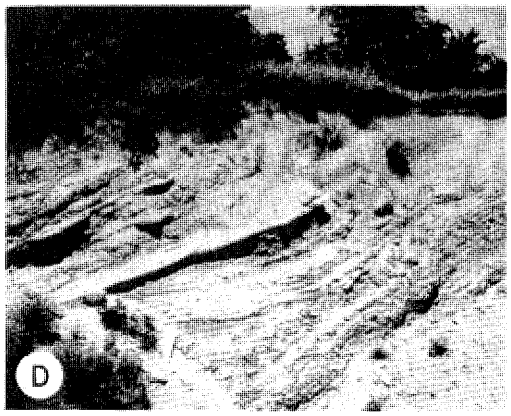

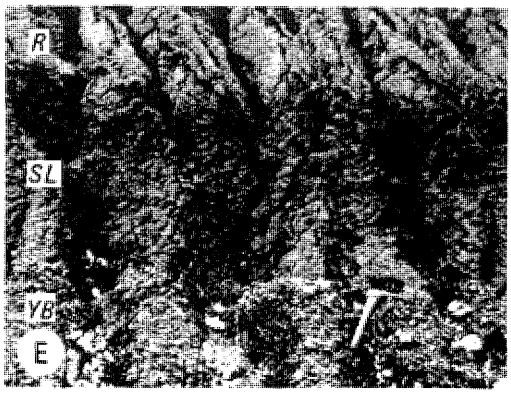

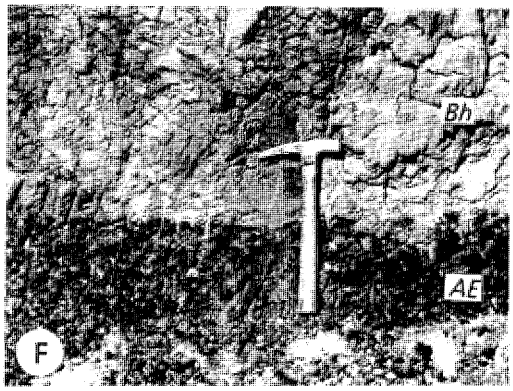

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QUATERNARY SYSTEM

John C. Frye and H. B. Willman

The Quaternary System was proposed in 1829 by Desnoyers (Wilmarth, 1925, p. 43), who recognized it as a unit distinct from the Tertiary System. Its definition depends on the placement of the end of Tertiary time. The Pleistocene Series also began at that time, and in Illinois classification the Quaternary System is equivalent to that one series. In 1925 the Pleistocene was classified as a system in Illinois, and the term "Quaternary" was not used until 1950 when the Pleistocene was reduced to a series and the Quaternary reinstated as a system. The Quaternary System includes the rocks being deposited at present.

PLEISTOCENE SERIES

The term "Pleistocene" was introduced by Lyell in 1839 (p. 616-621) as a replacement for "Newer Pliocene" (Lyell, 1833, p. 52-53) to apply to the marine strata of the Mediterranean region, in which more than 70 percent of the fossils represent living species. In 1846 Forbes applied "Pleistocene" to the "glacial epoch" in the British Isles, and in 1925 Wilmarth defined the Pleistocene in North America as including glacial and contemporaneous deposits of the "Great Ice Age." A report to the International Geological Congress in 1952 suggested worldwide adoption of a definition of the base of the Pleistocene as the base of the Villafranchian or of the equivalent marine Calabrian as exposed in Italy. However, as correlations of this proposed type area with marine strata in North America are not firmly established, the Pleistocene Series in Illinois and the rest of the continental interior continues to be defined as the glacial sequence plus the contemporaneous deposits laid down beyond the limit of continental glaciation. The Pleistocene Series includes the Holocene (Recent), which is classified as a stage rather than as a separate series, the usage accepted by many others.

Deposits of Pleistocene age are the surficial materials in virtually all of Illinois (fig. Q-1). Nearly 80 percent of the state was covered at least once by continental glaciers that left characteristic deposits (drift). Both glaciated and unglaciated areas were largely covered by wind-deposited silt (loess), by lacustrine deposits, or by deposits from streams. The only areas that were not covered by glaciers are the extreme northwestern corner, the southernmost part, and relatively small areas along the western border (fig. Q-2).

The thickness of the Pleistocene deposits in Illinois ranges from zero to approximately 600 feet (fig. Q-3), and variations in thickness occur sharply in relatively small areas. The drift is thick where major valleys in the older rocks have been filled by Pleistocene deposits and where stillstands of a glacier front have built thick ridges (moraines) of glacial debris. Drift thicknesses are greatest where glacial moraines cross the filled valleys. The loess deposits, which were derived largely from glacial outwash in the major valleys by the action of winds, are thickest along the margins of those valleys and thin rapidly away from them, in some places thinning from as much as 100 feet to less than 20 feet thick in a distance of 10 miles. Loess disappears en-

Fig. Q-1—Exposures of Pleistocene deposits.

A—Wisconsinan Richland Loess (R), Delavan Till Member of the Wedron Formation (Wd), Morton Loess (M), Robein and Roxana Silts (RR), and the Sangamon Soil (S) on till of the Illinoian Glasford Formation (C); in a railroad cut a mile east of Farmdale, Tazewell County, near the classic Farm Creek Section (Willman and Frye, 1970, p. 183).

B—The Wisconsinan Wedron (W—interbedded till and outwash) and Peddicord (P—lake sediments) Formations overlying till of the Illinoian Glasford Formation in the Wedron Silica Company pit at Wedron, La Salle County—the type sections of the Wedron and Peddicord Formations (Willman and Payne, 1942, p. 148; Willman and Frye, 1970, p. 190; Willman et al., 1971).

C—Wisconsinan Peoria Loess (P) overlying the Roxana Silt (Rm—Meadow Loess Member, Rmc—McDonough Loess Member) and the Illinoian Teneriffe Silt (T) in the Pleasant Grove School Section in the Mississippi River bluffs northwest of Collinsville, Madison County (Willman and Frye, 1970, p. 187).

D—Illinoian Glasford Formation (Hagarstown Member) showing steeply dipping sand and gravel (crevasse deposit) in a mound in the Kaskaskia Ridged Drift area, 2 miles southwest of Lakewood, Shelby County.

E—Wisconsinan Roxana Silt (R), Sangamon Soil developed in the Illinoian Loveland Silt (SL) and Yarmouth Soil developed in till of the Kansan Banner Formation (YB); in a roadcut at Independence, 5 miles south of Pittsfield, Pike County (Frye et al., 1964, p. 27).

F—Harkness Silt Member of the Kansan Banner Formation (Bh) overlying the Afton Soil developed on gravel of the Nebraskan Enion Formation (AE); in a roadcut at the Zion Church, 2 miles southeast of Marblehead, Adams County (Willman and Frye, 1970, p. 191).

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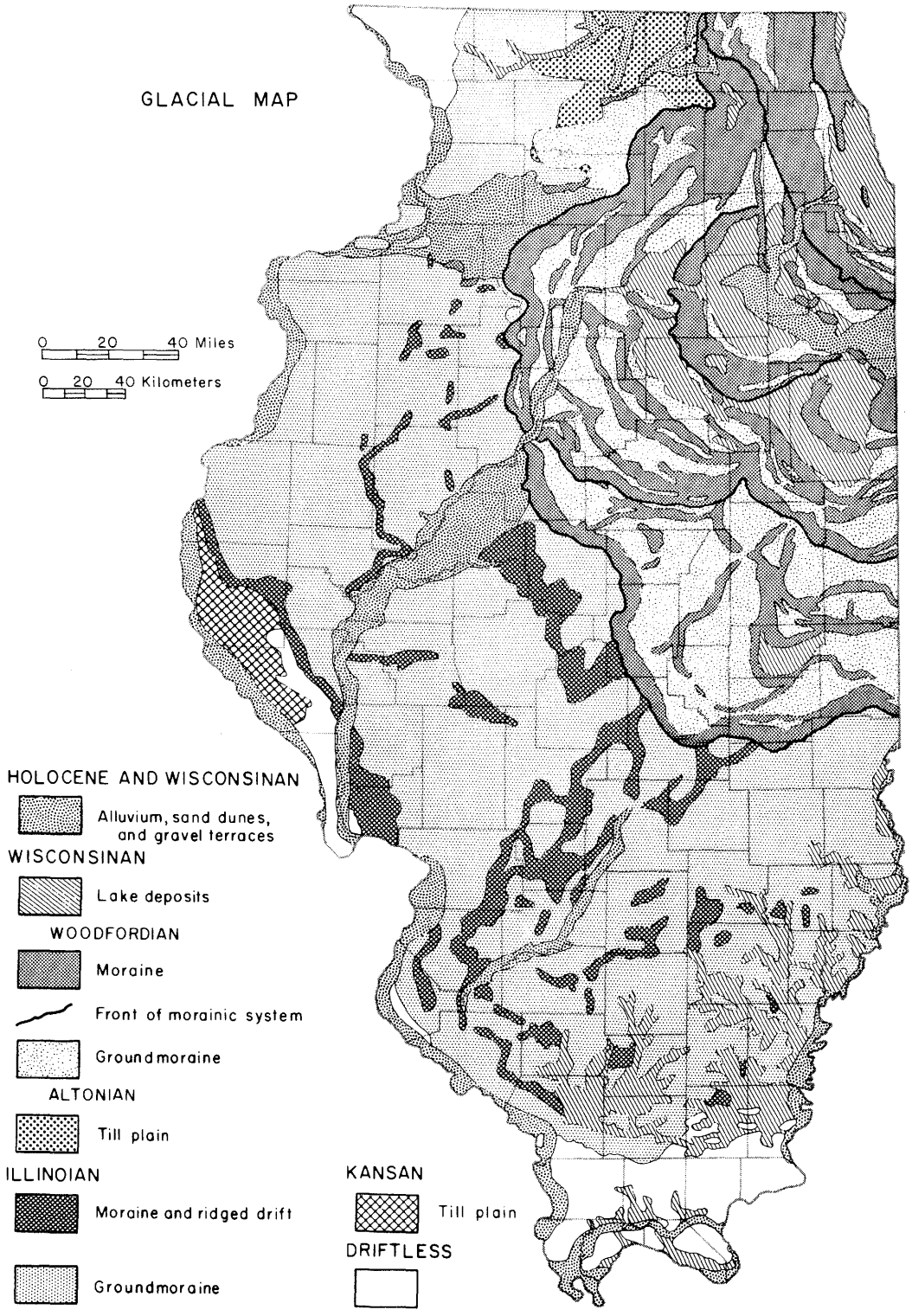

Fig. Q-2—Glacial map of Illinois (after Willman and Frye, 1970).

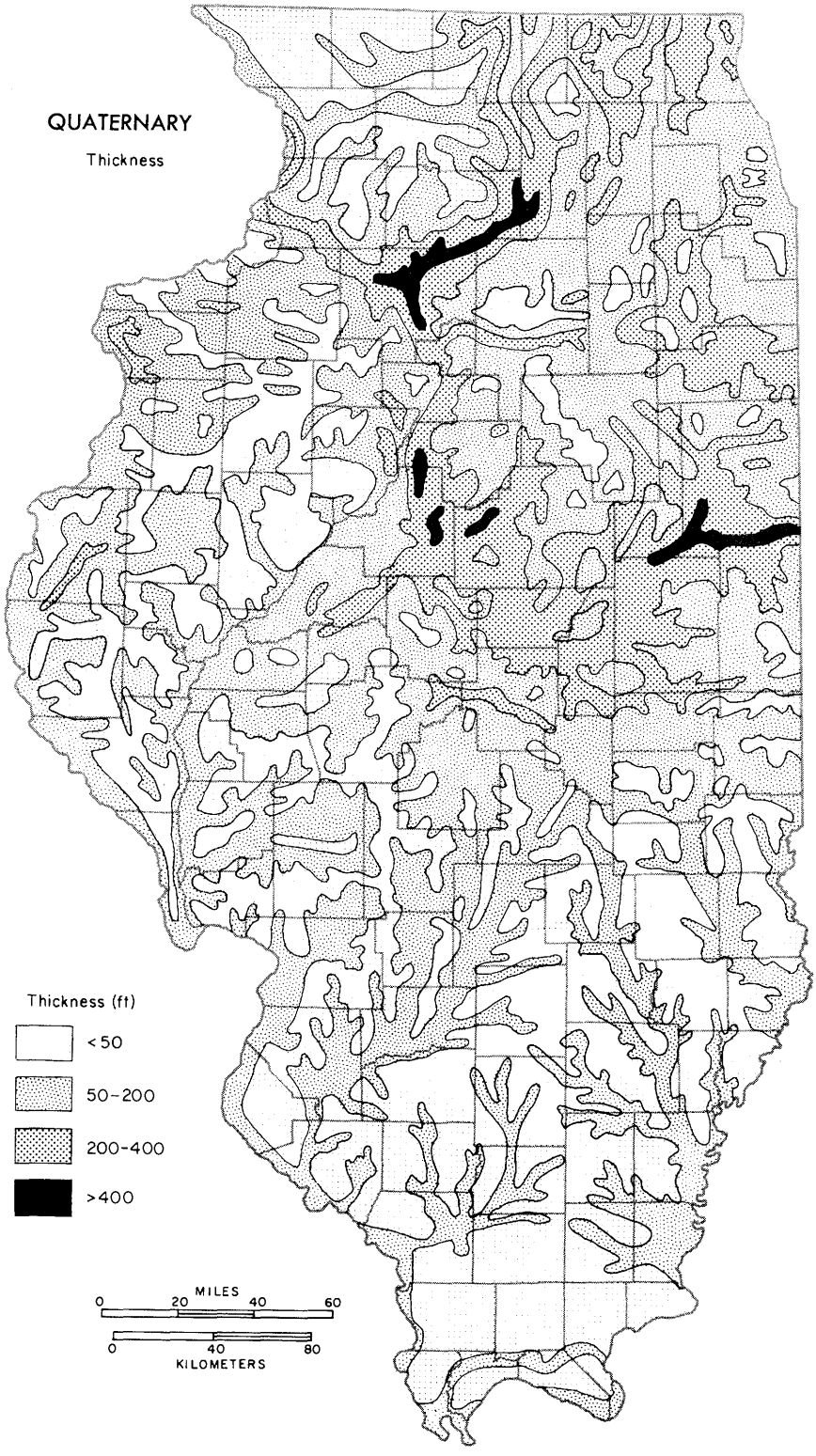

Fig. Q-3—Generalized thickness of the Quaternary deposits of Illinois (after Piskin and Bergstrom, 1967; Willman and Frye, 1970).

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tirely on the surfaces of alluvial valleys and some of the lake plains. Dune sands vary abruptly in thickness and do not display the regular, linear pattern of the loess deposits.

The Pleistocene deposits in Illinois also have a wide range in lithology—bouldery glacial tills, well sorted silts, accretion-gley, and fine-grained lacustrine clays. Glacial tills strongly reflect their mode of origin and their source areas. Glacial regimen changes with the temperature and thickness of the ice, the rate of ice flow, and the manner in which the ice disappeared. In some areas excess of marginal melting over forward motion caused retreat of the ice front. In other areas the ice lost forward motion, stagnated, and melted down from the top. All of these factors influence the resulting deposit. Glacial tills range from dominantly sand and gravel with only a small fraction of clay and silt and a few small boulders to mixtures dominantly clay or silt, with some sand, pebbles, and dispersed boulders.

Alluvial deposits are the product of normal stream action, of meltwaters in, on, or below glacial ice, or of meltwaters flowing from glaciers to a considerable distance (outwash). These deposits range from coarse, bouldery gravel to sand and silt.

Eolian deposits of loess and dune sand result from the action of winds on exposed surfaces of nonindurated materials, mostly glacial outwash. Eolian sediments are well sorted, consisting largely of medium-grained sand in the dunes and coarse to fine silt in the loess deposits. Loess deposits progressively thin and become finer grained away from their source areas in the major valleys. They range from coarse silt containing fine sand immediately adjacent to their source to fine silt containing significant amounts of clay in remote areas.

During Pleistocene time lakes formed along glacial fronts, between morainic ridges, in valleys dammed by glaciers, and in tributary valleys blocked by rapidly alluviating master streams that were receiving large quantities of outwash. The lacustrine deposits are predominantly well bedded silt, clay, and fine to medium sand. Although most lacustrine sediments are largely silt, some are predominantly sand, and others are interbedded silt, sand, and clay.

Colluvium and gravity deposits are produced by the influence of gravity on slopes. The materials in such deposits strongly reflect the local source from which they were derived, which is always up-slope from the deposit. The two categories are differentiated largely by rate of transport and particle size. Colluvial deposits move slowly down-slope, commonly contain a significant percentage of silt, clay, and some coarser fragments, and may or may not have a well defined slip plane separating them from the older rocks below. Gravity deposits are generally composed of angular fragments, are more poorly sorted, are coarser, and are associated with steeper slopes than colluvium. They include talus deposits. Both colluvium and gravity deposits are poorly sorted unless the source material is a uniform and well sorted sediment, such as loess.

Man-made deposits are extensively exposed at the surface in strip-mined areas, filled areas, and artificially created islands. Sanitary landfills also are man-made surficial deposits. Such deposits have no predictable lithology and range from refuse and stripped overburden of mines to relatively uniform sand or silt.

The mineral composition of Pleistocene deposits strongly reflects the source areas of the sediments. Source areas of colluvial and gravity deposits are close at hand, but glacial deposits reflect sources hundreds of miles away. Glacial till contains rocks and minerals picked up by the ice as the glaciers advanced; the heavy minerals of the sands were commonly derived from the crystalline rocks of southern Canada and the clay minerals and carbonates from the Paleozoic rocks farther south. The mineral compositions of the older rocks vary widely from east to west, and, consequently, the direction of ice flow and the correlation of many units can be determined by mineral analysis of the tills. As the sediments of the outwash were derived largely from the glacially transported material, their mineral composition and that of the eolian deposits derived from them also reflect the sources of the glacial deposits.

The tills from a northwestern source (Keewatin Lobe) are characterized by high montmorillonite content, more calcite than dolomite, and more epidote than garnet. Tills from the north and northeast (Lake Michigan Lobe) have a high illite content, much more dolomite than calcite, and nearly equal amounts of garnet and epidote. Tills from farther east (Saginaw, Huron, Erie Lobes) have a high illite content, generally more calcite than dolomite, and much more garnet than epidote.

Pleistocene deposits in Illinois are classified in four basic hierarchies—time-stratigraphic,

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rock-stratigraphic, soil-stratigraphic, and morphostratigraphic. Time-stratigraphic and rock-stratigraphic classifications are used for Pleistocene deposits in the same manner they are used in the rest of the stratigraphic sequence (fig. 16) and will not be redescribed here. The chart in figure Q-4 shows all time-stratigraphic, rock-stratigraphic, and soil-stratigraphic terms currently in use in Illinois and this report. The surface distribution of the dominantly till formations and members is shown in figure Q-5. Figure Q-6 shows graphically the historical development of the time-stratigraphic classification of the Wisconsinan Stage in Illinois.

Soil-stratigraphic and morphostratigraphic units are virtually unique to the Pleistocene. Soils form at the land surface as a result of the effects of weathering and of plants and animals on the sediments that underlie the surface. In most places soil forms in situ, that is, by the progressive downward alteration of sediments below a relatively stable surface. In some places, however, soils have formed by slow accumulation of fine sediment on the surface, with or without organic material. Soils buried by younger sediments are part of the stratigraphic sequence. Soil-stratigraphic classification, consisting of only one rank

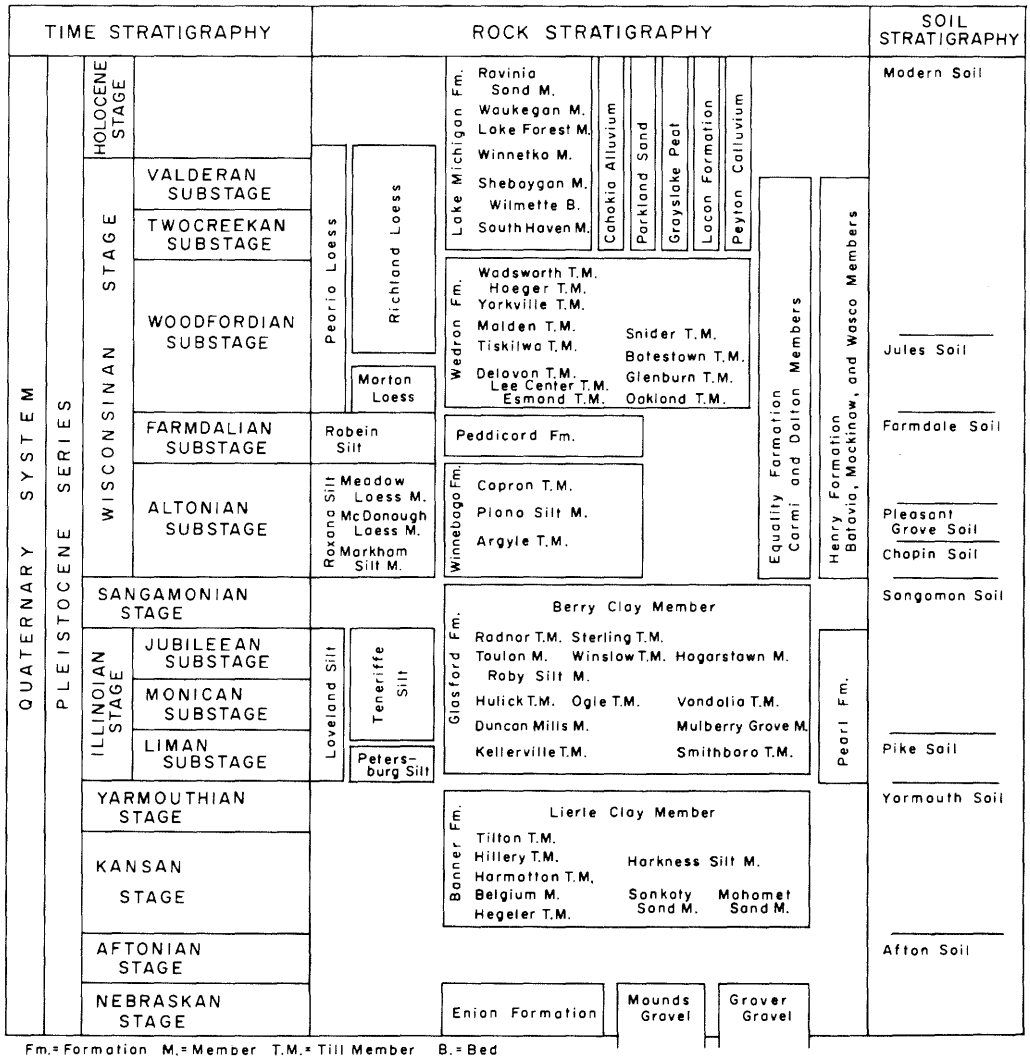

Fig. Q-4—Classification of the Pleistocene Series.

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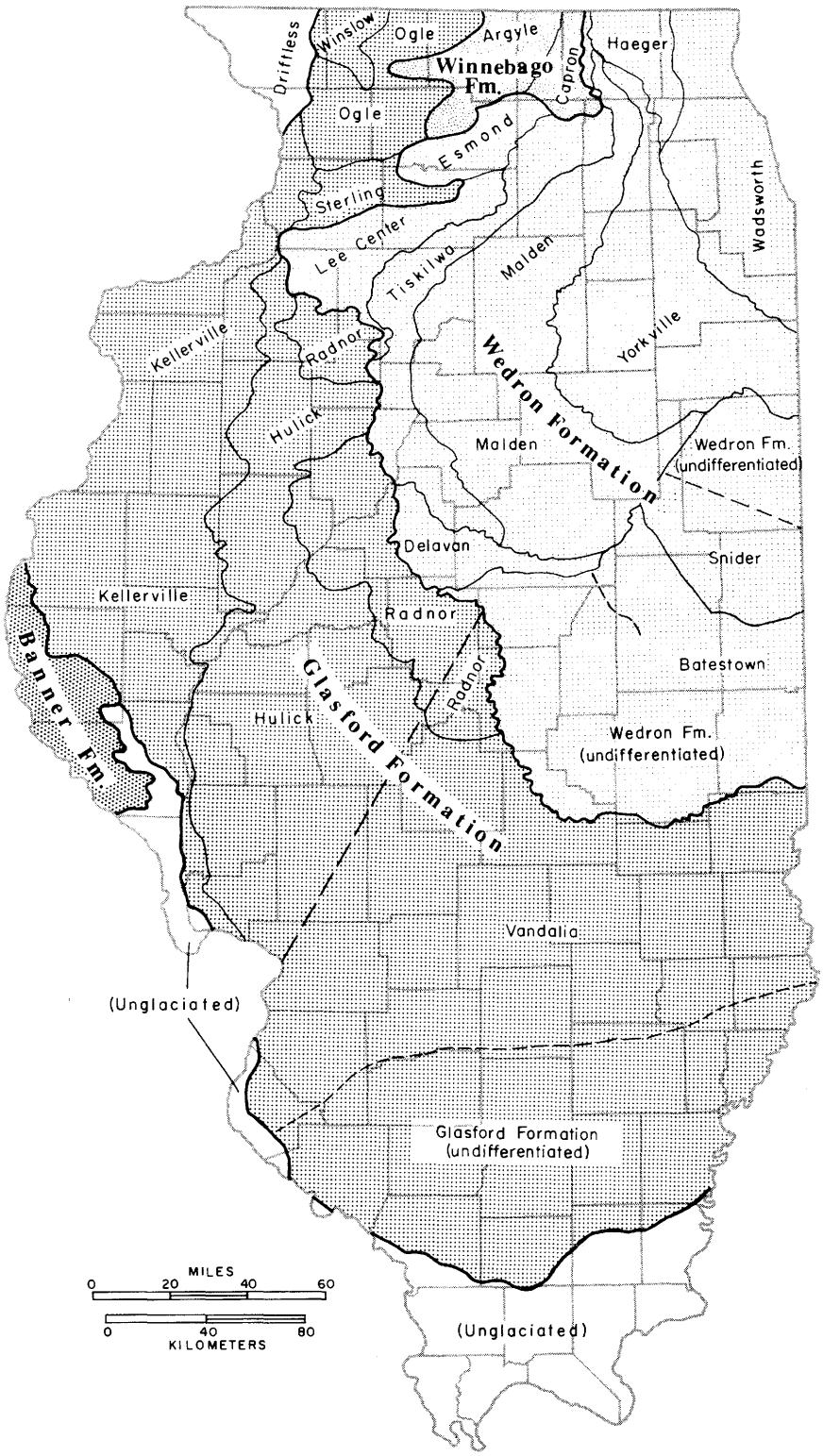

Fig. Q-5—Areal distribution of the dominantly till formations and members of Illinois (after Willman and Frye, 1970; Johnson et al., 1972).

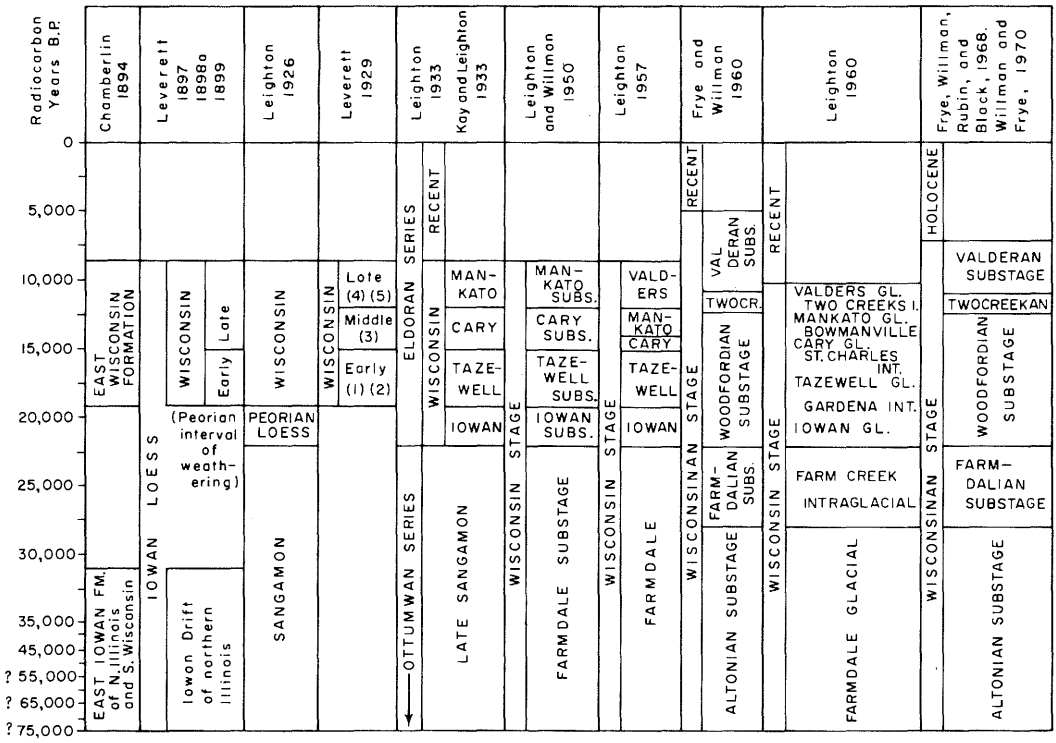

Fig. Q-6—Development of the classification of the Wisconsinan Stage in Illinois.

(soil), is a means of naming, describing, and correlating the soils in the sediment sequence. Soils do not replace the rock-stratigraphic units they are developed on; commonly, each soil is developed on several units. Only the upper surface of a soil presents a definable stratigraphic plane, because the lower part of a soil is gradational. The physical and mineral characteristics of a soil profile are generally useful in its recognition and correlation.

Morphostratigraphic units, as the name implies, are bodies of rock that are recognized and named on the basis of their surface form. Glacially produced morainic ridges, the materials in which are called drifts, and dissected alluviated surfaces, called alluvial terraces, are the two types of morphostratigraphic units recognized in Illinois. Only the drifts are formally named. Drifts are recognized not only in the surface areas but also wherever they can be identified in buried sequences. Such units are particularly useful in classification and mapping of glacial deposits in areas where a single rock-stratigraphic unit, such as glacial till, includes several morainic ridges.

The stratigraphic relations of Pleistocene deposits in Illinois are complex and contrast sharply with the more regular and uniform succession of predominantly marine Paleozoic rocks that they overlie. The complexity is caused by the different modes of deposition, the multiple sources of sediment, and the lack of regional continuity of many of the stratigraphic units. The loesses and the soil-stratigraphic units have the greatest regional continuity, although some of the glacial till units are traceable for more than 100 miles. Outwash and alluvial deposits, in general, occur along present and buried valleys, lacustrine deposits are found along segments of ponded valleys and on low areas of the till plain surfaces, and colluvium and gravity deposits are restricted to localized areas along valley margins. An idealized representation of stratigraphic relations of deposits of the Illinoian Stage in west-central and western Illinois is shown by figure Q-7, and another of Wisconsinan deposits from northeastern to west-central Illinois by figure Q-8.

Fossils are not abundant in most of the Pleistocene deposits of Illinois. None have

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thus far been found in the Nebraskan Stage, and assemblages of fossil mollusks have been collected and described from less than a dozen localities of the Kansan Stage. Several silt units of the Illinoian Stage contain relatively abundant assemblages of fossil mollusks at localities in the central and western parts of the state. The Wisconsinan and Holocene Stages contain abundant assemblages of both aquatic and terrestrial mollusks. Fossil vertebrates have also been collected from Pleistocene deposits at many localities. Although the remains of large proboscidians, such as mammoths and mastodons, have attracted the most attention, remains of smaller mammals, particularly rodents, have been recovered from several localities.

Nebraskan Stage

The name "Nebraskan" was proposed by Shimek (1909, p. 408) for the lowermost till at the Afton Junction–Thayer exposures in Union County, Iowa, based on its supposed extension into eastern Nebraska. Willman and Frye (1970, p. 118) proposed two reference sections for Illinois, the Zion Church Section in Adams County, and the Enion Section in Fulton County. The base of the Nebraskan Stage is defined by the contact of glacial or glacial-derived deposits with Tertiary or older deposits below, and its upper limit is the top of the in-situ Afton Soil that developed on the Nebraskan deposits (fig. Q-4). The Nebraskan Stage contains the deposits left by the first episode of continental glaciation in the Midwest. The deposits in western Illinois are genetically related to a glacial advance that crossed Iowa from the Keewatin center west of Hudson Bay in Canada. No Nebraskan-age glacial deposits from a northeastern center have been identified with certainty in Illinois. The Enion Formation contains deposits of Nebraskan age, and the Mounds Gravel of southern Illinois and the Grover Gravel of western and northern Illinois, described in the discussion of the Tertiary System, may be, in part, of Nebraskan age.

Enion Formation

The Enion Formation (Willman and Frye, 1970, p. 48) is named for Enion, Fulton County, half a mile east of the type section (NW SW SE 32, 4N-3E). The formation includes glacial till, outwash sand and gravel, and beds of silt that occur in both the uppermost part and at the base. It is exposed at only a few places, mostly in the west-central part of the state (fig. Q-1F). It differs from older Cretaceous and Tertiary deposits in that it contains crystalline rocks from the Canadian area and a heavy mineral suite that includes abundant ferromagnesian minerals.

Aftonian Stage

The Aftonian Stage (Chamberlin, 1894) is named for Afton Junction, Iowa, where Chamberlin interpreted deposits in a gravel pit as being interglacial. During subsequent years, usage transferred the name to accretion-gley deposits and to the deeply developed in-situ Afton Soil on the Nebraskan-age till of southern Iowa. Although there is now reasonable doubt concerning the age of Chamberlin's type gravels near Afton Junction, the name Aftonian has been retained because of its long-accepted use. The time span of the Aftonian is defined as the time of development of the in-situ Afton soil profile, and a reference section for Illinois has been designated as the Zion Church Section of Adams County (Willman and Frye, 1970).

Afton Soil

The name "Afton Soil" was proposed by Frye and Leonard (1952, p. 24, 68) for the soil on deposits of Nebraskan age in northeastern Kansas because of its presumed Aftonian age. They designated the Iowa Point Section in Doniphan County, Kansas, as a reference section, and Willman and Frye (1970, p. 82) suggested the Zion Church Section, Adams County (fig. Q-1F), as a reference for Illinois. It is a deeply developed in-situ soil profile in deposits of Nebraskan age, but it has been correlated with accretion-gley, or accretionary soils, on the Nebraskan till plain and with soils developed in older rocks that are overlain by deposits of Kansan age. It has been identified at only a few places in Illinois.

Kansan Stage

The name "Kansan" was proposed by Chamberlin (1894, p. 754), but the drift was assigned to its present stratigraphic position by Calvin (1897) and Bain (1897) because of the continuity of the deposits described by Chamberlin in Union County, Iowa, with the surface drift in northeastern Kansas. Frye and Leonard (1952, p. 74) proposed three reference sections for type Kansan in Atchison and Doniphan Counties, Kansas, and included within the stage both the proglacial sands below the till (Atchison Formation) and the retreatal outwash gravels above the till, in which the Yarmouth Soil is developed. It was defined as including the span of rocks between the top of the Afton Soil (below) and the top of the in-situ Yarmouth Soil (above). Willman and Frye (1970, p. 119) suggested as reference sections for Illinois the Enion

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Section of Fulton County, the Tindall School Section of Peoria County, and the Zion Church Section of Adams County. All the deposits of Kansan age found in Illinois are in the Banner Formation.

Banner Formation

The Banner Formation (Willman and Frye, 1970, p. 48) is named for Banner, Peoria County, near which the type section is in the Tindall School Section (SW SW NE 31, 7N-6E). It includes the glacial tills and underlying and intercalated sands, gravels, and silts overlying the Afton Soil and is terminated at the top by the top of the Yarmouth Soil (fig. Q-1E, F). In a few places the formation is as much as 300 feet thick, but it is discontinuous. In west-central Illinois it was deposited by glaciers from the northwest, but in eastern Illinois it was deposited by glaciers from the northeast. Its mineral content reflects the contrasting source areas, and in both regions its mineral content helps to distinguish it from the overlying deposits of Illinoian age. The uppermost part locally contains deposits of clay and silt that accumulated on the till plain surface as accretion-gley, in part during Yarmouthian time, but elsewhere the top of the formation is marked by the in-situ Yarmouth Soil developed in Kansan age deposits. Nine members are recognized in the Banner Formation (fig. Q-4), which is the surface drift in part of western Illinois (fig. Q-5).

Sankoty Sand Member—The Sankoty Sand Member of the Banner Formation (Horberg, 1950a, p. 34) is named for the Sankoty water-well field along the Illinois River on the north side of Peoria, Peoria County, where the type section is in a well (NW SE 15, 9N-8E). It is well sorted, medium- and coarse-grained sand, distinguished by an abundance of highly polished pink quartz grains. It occurs above Paleozoic rocks in the deepest part of the Ancient Mississippi Valley, where it is commonly 100 feet thick but locally is as much as 300 feet thick. It is overlain by tills of the Banner Formation except where they have been removed by erosion. It occurs in central and northwestern Illinois.

Mahomet Sand Member—The Mahomet Sand Member of the Banner Formation (Horberg, 1953, p. 18, 19) is named for Mahomet, Champaign County, near which it is encountered in numerous wells. The Mahomet Sand Member consists of sand and gravel with many silt beds. It lacks the pink quartz grains that occur in the Sankoty Sand. It occupies the deeper parts of the filled Mahomet Valley and its tributaries, mainly in De Witt, Macon, Piatt, and Champaign Counties. It commonly rests on Paleozoic rocks, attains a maximum thickness of 150 feet, and is overlain by till of the Banner Formation.

Harkness Silt Member—The Harkness Silt Member of the Banner Formation (Willman and Frye, 1970, p. 51) is named for Harkness Creek, Adams County, near which the type section is in the Zion Church Section (SE SE SW 9, 3S-8W) (fig. Q-1F). It consists of massive, calcareous, gray and tan silt that contains sparse molluscan fossils. It rests on the Afton Soil and is overlain by glacial till that also is of Kansan age. The member is generally less than 10 feet thick and is exposed at only a few places in central western Illinois.

Hegeler Till Member—The Hegeler Till Member of the Banner Formation (Johnson, 1971, p. 8) is named for the town of Hegeler, Vermilion County, and the type section is in the Harmattan Strip Mine No. 2 (SE SW SW 34, 20N-12W). The unit consists of two zones; the lower is outwash with gravelly till and the upper is silty till. It is up to 8 feet thick, greenish gray, weakly calcareous, generally massive, and compact. It is known in only the one locality, where it rests on rocks of Pennsylvanian age and is overlain by the Belgium Member.

Belgium Member—The Belgium Member of the Banner Formation (Johnson, 1971, p. 10) is named for the town of Belgium, Vermilion County, and the type section is in the same exposure as the Hegeler Till Member. The Belgium Member consists of two units; the lower is massive, tan to dark gray-brown, carbonaceous, calcareous, fossiliferous silt 0.5-2.5 feet thick (Leonard et al., 1971), and the upper is brown calcareous clay 0.5-1.5 feet thick. The Belgium Member is bounded below by the Hegeler Till Member or bedrock and above by the Harmattan Till Member. It is known in only the one locality in central eastern Illinois.

Harmattan Till Member—The Harmattan Till Member of the Banner Formation (Johnson et al., 1971, p. 194) is named for the Harmattan Strip Mine near Danville, Vermilion County (NE 4, 19N-12W). The member is largely gray, calcareous, dense, hard till, but the upper part contains lenticular bodies of gravelly sand. It is bounded at the base by the Belgium Member, or bedrock, and at the top by the Hillery Till Member. In the type area it is 8 feet thick, and it is known definitely only in the Danville area.

Hillery Till Member—The Hillery Till Member of the Banner Formation (Johnson et al., 1971, p. 195) is named for Hillery, Vermilion County, and its type locality is in the Power Plant Section (NW SW SW 21, 20N-12W). The Hillery Till Member is reddish brown, calcareous, massive, hard till. The lower part is slightly darker, and the upper commonly contains streaks of silt. The member is 14 feet thick in the Harmattan Strip Mine Section, where it overlies the Harmattan Till Member and is overlain by the Tilton Till Member. It is best known in the Danville area, where it generally rests directly on the bedrock.

Tilton Till Member—The Tilton Till Member of the Banner Formation (Johnson et al., 1971, p. 196) is named for Tilton, Vermilion County, and the type locality is the School House Branch Section (SE NE NE 2, 19N-12W). Where unoxidized, the Tilton Till Member is gray, calcareous, hard, silty, sandy till. The unit contains considerable silt, sand, and gravel, particularly near the upper and lower boundaries. The Tilton Till is commonly overlain at the top by a truncated weathered zone, or an oxidized zone, and in the Harmattan Strip Mine Section it overlies the Hillery Till Member. In Vermilion County the member is about 15 feet thick.

Lierle Clay Member—The Lierle Clay Member of the Banner Formation (Willman and Frye, 1970, p. 52) is named for Lierle Creek, Adams County (SE cor. SW 33, 1S-6W). It is predominantly accretion-gley consisting of gray clay, silt, and some sand. The Lierle is noncalcareous and is characterized by abundant pedogenic montmorillonite. It overlies the till of the Banner Formation and is overlain by deposits of Illinoian age. It is discontinuous, is less than 10 feet thick, and is exposed at many localities in western Illinois, where the surface drift is Kansan. The unit is part of the Yarmouth Soil but is an accretionary deposit made largely throughout Yarmouthian time.

Yarmouthian Stage

The Yarmouthian Stage is based on the Yarmouth Soil, described by Leverett (1898c, p. 176) from its occurrence in a well section near Yarmouth, Des Moines County, Iowa. It was described as the interval of weathering and organic accumulation separating the Kansan and Illinoian glacial deposits. The adjec-

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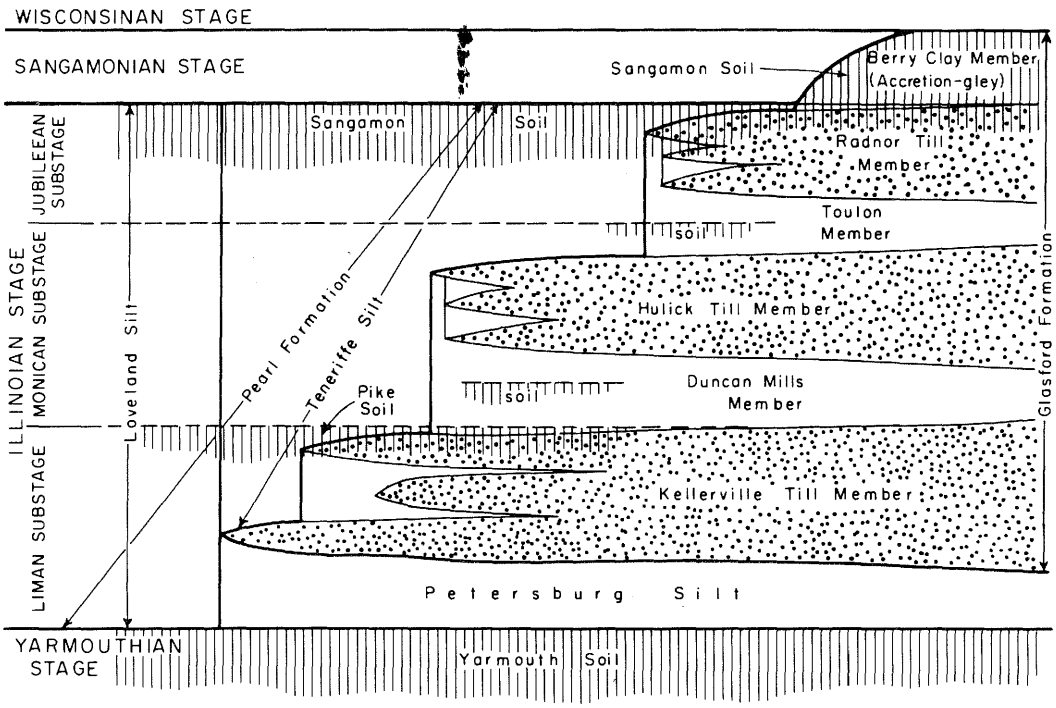

Fig. Q-7—Diagrammatic cross section showing the relations of the formations and members of Illinoian age in central and western Illinois (Willman and Frye, 1970).

tival ending was added (Frye et al., 1948) to distinguish the stage from the soil. As the original type section has not been accessible for 75 years, Willman and Frye (1970) suggested as paratype the Fort Madison Section, Lee County, Iowa (Willman et al., 1966, p. 63). The Yarmouthian Stage in Illinois is represented by the accretion-gley of the Lierle Clay Member of the Banner Formation and by the in-situ Yarmouth Soil (fig. Q-4).

Yarmouth Soil

The Yarmouth Soil was named and described by Leverett (1898c, p. 176) from its occurrence in a well at Yarmouth, Des Moines County, Iowa. He described the soil as the weathered zone on the Kansan drift, overlain by Illinoian deposits. In some places the soil is an in-situ profile developed in earlier deposits (fig. Q-1E), but in others it consists of accretionary deposits of fine sediment and organic material that accumulated in poorly drained areas on the surface of Kansan deposits. Such deposits are as much as 10 feet thick. This soil has been observed at many localities in Illinois, most of them in the western and central parts of the state.

Illinoian Stage

Leverett (*in* Chamberlin, 1896) named the Illinois till sheet for the Illinois Glacial Lobe and later introduced the name Illinoian Stage (Leverett, 1899, p. 20-23). He included within the stage all of the deposits between the Yarmouthian and Sangamonian Stages of present usage. As Leverett did not specify a type section within the lobe, Willman and Frye (1970, p. 120) designated as paratype the Tindall School Section, Peoria County (SW SW NE 31, 7N-6E) (Willman et al., 1963, p. 54-55). In this section the Illinoian Stage is bounded at the base by the truncated Yarmouth Soil and at the top by the top of the Sangamon Soil, an in-situ soil profile in the uppermost Illinoian deposits. The Illinoian Stage is subdivided into three substages—the Liman at the base, the Monican, and the Jubileean. The three substages are all present in the paratype section. The deposits are differentiated into five formations (figs. Q-4, Q-7).

Liman Substage

The Liman Substage (Frye et al., 1964, p. 16) is named for Lima Township, Adams County, and the type section is in the Pryor School Section (NE NE SE 11, 2N-8W). At the type section the substage is represented by the Petersburg Silt at the base with the Kellerville Till Member of the Glasford Formation

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above it. In the type locality its base is defined by the contact of Petersburg Silt on the Yarmouth Soil developed in Kansan deposits, and its top is the truncated surface of the Pike Soil, which is overlain by loess deposits. At the paratype section for the Illinoian Stage (the Tindall School Section), deposits of the Liman Substage are overlain by glacial deposits of the Monican Substage.

Pike Soil

The Pike Soil (Willman and Frye, 1970, p. 84) is named for Pike County, Illinois, and its type section is in the New Salem Northeast Section (NW NE SW 11, 4S-4W). In the type section the Pike Soil is developed in sediments of Liman age—the Kellerville Till Member of the Glasford Formation—and it is overlain by the Teneriffe Silt, which has the Sangamon Soil in the top. The Sangamon Soil is overlain by Wisconsinan loesses. The Teneriffe Silt at this locality is Monican and/or Jubileean in age, but from regional relations the termination of formation of the Pike Soil is inferred to be in early Monican time. The Pike Soil has a deeply developed profile, but it has been observed at only a few places in western and central Illinois.

Petersburg Silt

The Petersburg Silt (Willman et al., 1963, p. 6) is named for Petersburg, Menard County, and the type section is in the Petersburg Section (NW NW NE 23, 18N-7W). The Petersburg ranges from gray to yellow-tan to purplish tan calcareous silt. The upper part is commonly massive and loess-like and contains fossil mollusks, whereas the lower part has indistinct bedding and locally contains fine sand. It rests on the top of the Yarmouth Soil, or older deposits, and is overlain by the Glasford Formation at the many localities in central and western Illinois where it occurs. In the type section it is 20 feet thick, but at most places it is less than 12 feet thick. Beyond the area of the Glasford, deposits equivalent in age to the Petersburg are part of the Loveland Silt (fig. Q-7).

Loveland Silt

The Loveland Silt (Shimek, 1909, p. 405) is named for Loveland, Iowa, where it is exposed in the bluff of the Missouri River Valley. It is dominantly clayey silt, but locally contains some fine sand. It is tan to reddish brown, massive, and in most places is leached of carbonate minerals. It is bounded at the base by the top of the Yarmouth Soil, or older deposits, and at the top by the top of the Sangamon Soil (Willman and Frye, 1970). It commonly is entirely within the Sangamon Soil (fig. Q-1E). It occurs only beyond the limit of Illinoian glaciation—in extreme southern, western, and northwestern Illinois—and in most places is less than 10 feet thick. The Loveland Silt is continuous with both the Petersburg and Teneriffe Silts, which occur inside the glaciated area (fig. Q-7).

Pearl Formation

The Pearl Formation (Willman and Frye, 1970, p. 60) is named for Pearl, Pike County, and the type section is in the Pearl Prairie Section (SE SW NE 16, 7S-2W) (Frye and Willman, 1965, p. 14). The unit includes Illinoian outwash that occurs beyond the limit of Illinoian glaciation or overlies Illinoian till. It ranges from medium sand to gravel and sand and is commonly tan to gray-tan. It generally has more oxidized and cemented beds than the younger outwash. It is terminated upward by the top of the Sangamon Soil, which is commonly overlain by Wisconsinan loesses. In most places the formation is less than 40 feet thick, but in major valleys it may be significantly thicker. Geographic distribution is primarily along major valleys in central and western Illinois.

Glasford Formation

The Glasford Formation (Willman and Frye, 1970, p. 52) is named for Glasford, Peoria County, and the type section is in the Tindall School Section (SW SW NE 31, 7N-6E). The formation includes glacial tills, intercalated outwash deposits of gravel, sand, and silt, and the overlying accretion-gley deposits (figs. Q-1A, B, D). It overlies the Petersburg Silt or, in the absence of that formation, the top of the Yarmouth Soil or older rocks. It is terminated upward by the top of the Sangamon Soil, where the soil is an in-situ profile developed in the top of the glacial deposits and also where the soil is an accretion deposit. Fourteen members have been described within the Glasford Formation (fig. Q-4), many of which have limited regional extent. The formation is the surface drift and almost continuously present in a large part of Illinois (fig. Q-5). It is also widely present below glacial deposits in the outer 40 miles of the region covered by Wisconsinan glaciers (Horberg, 1953). The Glasford Formation is 35 feet thick in its type section, but it ranges from a few feet to more than 150 feet thick.

Kellerville Till Member—The Kellerville Till Member of the Glasford Formation (Willman and Frye, 1970, p. 55) is named for Kellerville, Adams County, and the type section is in the Washington Grove School Section, 2 miles southwest of Kellerville (NW NW SW 11, 2S-5W), an exposure at the front of the Mendon Moraine. The member is till with intercalated, discontinuous zones of sand and gravel outwash and silt. It is more varied and has a higher percentage of clay minerals and a higher ratio of calcite to dolomite than the overlying members. It is as much as 150 feet thick but commonly less than 50 feet thick. It overlies the Petersburg Silt, or older deposits, and it is overlain by the Duncan Mills Member or, where it extends beyond the margins of later Illinoian glacial advances, by the Teneriffe Silt. It is differentiated in west-central, western, and northwestern Illinois.

Duncan Mills Member—The Duncan Mills Member of the Glasford Formation (Willman and Frye, 1970, p. 56) is named for Duncan Mills, Fulton County, and the type section is in the Enion Section, 4 miles south of Duncan Mills (NW SW SE 32, 4N-3E). In the type section the Duncan Mills Member consists of outwash sand, gravel, and some silt, and is generally deeply weathered. It is recognized as a member only where it is bounded by the Kellerville Till Member below and the Hulick Till Member above. It attains a maximum thickness of 30 feet and has been observed only in central western and west-central Illinois.

Hulick Till Member—The Hulick Till Member of the Glasford Formation (Willman and Frye, 1970, p. 56) is named for Hulick School, Fulton County, and the type section is in the Lewistown Section (SW SE SE 21, 5N-3E). The member, consisting of till and intercalated sand and gravel outwash, is locally more than 100 feet thick. It is bounded at the top in various areas by the Toulon, Radnor Till, or Berry Clay Members, the Teneriffe Silt, or the Pearl Formation. At

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some places its top is the top of the Sangamon Soil. It rests on the Duncan Mills Member, the Kellerville Till Member, or older rocks. The clays and carbonates of the Hulick indicate derivation from the Paleozoic rocks of north-central and northeastern Illinois, and the heavy mineral assemblage is indicative of a source in western Ontario, Canada. The member occurs in central western and southwestern Illinois.

Toulon Member—The Toulon Member of the Glasford Formation (Willman and Frye, 1970, p. 57) is named for Toulon, Stark County, and the type section is in the Toulon Section (NW NW SW 24, 13N-5E), a borrow pit three-fourths of a mile west of Toulon. The member consists of glacially derived sand, gravel, and silt. It is differentiated only when it occurs between the Radnor Till Member above and the Hulick Till Member below. In its type section it is 9 feet thick, and it exceeds this thickness at only a few places. It has been observed in west-central and western Illinois. A minor soil in the Toulon Member forms the top of the Monican Substage.

Radnor Till Member—The Radnor Till Member of the Glasford Formation (Willman and Frye, 1970, p. 57) is named for Radnor Township, Peoria County, and the type section is in the Jubilee College Section (SW SW SW 7, 10N-7E). In the type section the Radnor Till is bounded at the top by the top of the Sangamon Soil, which is overlain by Wisconsinan loesses, and at its base by the Toulon Member. It consists of massive, calcareous, gray till characterized by a high illite content. It appears to be a stratigraphic equivalent of the Sterling Till Member of northwestern Illinois. In the type section it is 22 feet thick, and it exceeds this thickness only in the end moraine at its outer margin. The member occurs in central and east-central Illinois.

Smithboro Till Member—The Smithboro Till Member of the Glasford Formation (Jacobs and Lineback, 1969, p. 9) is named for Smithboro, Bond County, and its type locality is in the Mulberry Grove Section, 5 miles east of the town (SW SW 31, 6N-1W), where it is about 12 feet thick. The member consists of gray, compact, silty till. It is bounded below by its contact on the top of the Yarmouth Soil, or older rocks, and at the top by the overlying Mulberry Grove Member of the Glasford. It occurs widely in south-central and central eastern Illinois.

Mulberry Grove Member—The Mulberry Grove Member of the Glasford Formation (Jacobs and Lineback, 1969, p. 12) is named for Mulberry Grove, Bond County, and its type section is in the Mulberry Grove Section (SW SW 31, 6N-1W), where it is about 3 feet thick. The member is calcareous gray silt and fine sand containing some fossil mollusks (Leonard et al., 1971). It is bounded below by the Smithboro Till Member and above by the Vandalia Till Member. It occurs in south-central and central eastern Illinois.

Vandalia Till Member—The Vandalia Till Member of the Glasford Formation (Jacobs and Lineback, 1969, p. 12) is named for Vandalia, Fayette County, and the type section is in the Vandalia Bridge Section, along the Kaskaskia River, at Vandalia (NW NE SE 16, 6N-1E), where it is about 20 feet thick. The member consists of sandy till with thin lenticular bodies of silt, sand, and gravel. It is calcareous, except where weathered, generally gray, and moderately compact. It is bounded below by the Mulberry Grove, Smithboro, or older rocks, and at the top by the Hagarstown Member, younger beds, or the top of the Sangamon Soil. It commonly is 25-50 feet thick, and it occurs widely in south-central and central eastern Illinois.

Hagarstown Member—The Hagarstown Member of the Glasford Formation (Jacobs and Lineback, 1969, p. 12) is named for Hagarstown, Fayette County, 5 miles west of the type section, the Hickory Ridge Section (SW NW 30, 6N-1E). The member consists of gravelly till, poorly sorted gravel, well sorted gravel, and sand (fig. Q-1D). Stratigraphically it lies above the Vandalia Till Member and is bounded at the top by the top of the Sangamon Soil. It commonly occurs in elongate ridges in south-central Illinois. In the type locality it is about 30 feet thick, but it is more than 100 feet thick in some of the higher ridges.

Roby Silt Member—The Roby Silt Member of the Glasford Formation (Johnson, 1964, p. 8) is named for Roby, Christian County, and the type section is in the Roby Section, Sangamon County (NW SE NE 14, 15N-3W). The member consists of tan and gray calcareous silt and silty clay and contains fossil mollusks (Leonard et al., 1971). It is bounded below by the Hulick Till Member, or the Vandalia Till Member, and is overlain by the Radnor Till Member. The unit is commonly 2-5 feet thick, and it is widely distributed in central Illinois.

Ogle Till Member—The Ogle Till Member of the Glasford Formation (Frye et al., 1969, p. 24) is named for Ogle County, Illinois, and the type section is in the Haldane West Section (NE NE NE 25, 24N-7E). The member consists largely of till that varies in mineral and textural compositions. The till is generally sandy and silty, tan to gray-brown, and discontinuously interstratified with sand and gravel. The member is generally less than 20 feet thick, and it is extensively eroded. It occurs primarily in Winnebago, Stephenson, Carroll, and Ogle Counties. In most places it rests directly on bedrock. Where the Ogle Till is the surface drift, the Sangamon Soil was developed in its top, and the soil is overlain by loesses of Wisconsinan age. In many places, however, the soil was eroded before deposition of the loesses. Locally the Ogle has been found beneath the Argyle Till Member of the Winnebago Formation.

Winslow Till Member—The Winslow Till Member of the Glasford Formation (Frye et al., 1969, p. 25) is named for Winslow, Stephenson County, and the type section is in roadcuts west of Winslow (SW SE SW 21, 29N-6E). In the type section it consists of 12 feet of dark gray clayey till resting directly on bedrock and overlain by thin loesses of Wisconsinan age. At a few places the Sangamon Soil occurs in the top, but the soil has been eroded from much of the area. The Winslow is limited to Stephenson and Jo Daviess Counties. It may be a lithologic variant of the Ogle Member or a stratigraphic equivalent of the Sterling Member, but it is distinctly different from both in composition.

Sterling Till Member—The Sterling Till Member of the Glasford Formation (Frye et al., 1969, p. 25) is named for Sterling, Whiteside County, and the type section is in the Emerson Quarry Section 2 miles west of Sterling (SE NW SE 13, 21N-6E). The unit consists of gray, silty, calcareous till with an exceptionally high illite content. It overlies the Ogle Till Member, or older rocks, and is bounded at the top by the Sangamon Soil. It is overlain by the Winnebago Formation, the Wedron Formation, or loesses of Wisconsinan age. The Sterling occurs primarily in Whiteside and Lee Counties. It is as much as 40 feet thick in the Sterling area but generally is thinner. It is stratigraphically equivalent to the Radnor Till Member to the south.

Berry Clay Member—The Berry Clay Member of the Glasford Formation (Willman and Frye, 1970, p. 54) is named for Berry, Sangamon County, and the type section is in the Rochester Section, 3 miles west of Berry (NW SE NW 34, 15N-4W). The member is an accreted soil of clay and silt containing a few small pebbles. It is gray to dark gray, leached of carbonate minerals, and generally 2-5 feet thick. It is bounded at the top by the top of the Sangamon Soil and at the base by weathered till of the Glasford Formation. It occurs at isolated localities throughout the area of Illinoian drift (figs. Q-5, Q-7).

Monican Substage

The Monican Substage of the Illinoian Stage (Willman and Frye, 1970, p. 120) is

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named for Monica, Peoria County, and its type section is in the Jubilee College Section (SW SW SW 7, 10N-7E). In the type section, the deposits of the substage are the Hulick Till Member and the lower part of the Toulon Member of the Glasford Formation. The latter is outwash sand, silt, and gravel, which is oxidized and locally leached in the top. At the type section, the deposits rest unconformably on Pennsylvanian shales, but at the paratype for the Illinoian Stage (Tindall School Section) they occur between sediments of the Liman and Jubileean Substages. The Monican Substage is defined as consisting of the Illinoian deposits above the Pike Soil, and its top is a minor unnamed soil in the Toulon, which is overlain by deposits of the Jubileean Substage.

Teneriffe Silt

The Teneriffe Silt (Willman and Frye, 1970, p. 60) is named for Teneriffe School, Pike County, and the type section is in the New Salem Northeast Section (NW NE SW 11, 4S-4W). The formation contains all the silts overlying till of the Glasford Formation and is bounded at the top by the top of the Sangamon Soil. Locally it rests on the top of the Pike Soil. It is assigned to both the Monican and Jubileean Substages. The unit is fine to coarse silt and locally contains some sand and clay. The Teneriffe is not differentiated beyond the limit of Illinoian glaciation (fig. Q-7), where it is equivalent to the upper part of the Loveland Silt. The formation occurs in central western and south-central Illinois (fig. Q-1C) and at many places is overlain by the Roxana Silt.

Jubileean Substage

The Jubileean Substage of the Illinoian Stage (Willman and Frye, 1970, p. 120) is named for Jubilee College State Park, Peoria County, and its type section is in the Jubilee College Section (SW SW SW 7, 10N-7E). At the type section it consists of the upper silts of the Toulon Member and the overlying Radnor Till Member of the Glasford Formation. It overlies a minor soil developed in deposits of Monican age, and its top is the top of the in-situ Sangamon Soil, which is overlain by Wisconsinan deposits.

Sangamonian Stage

The name "Sangamon interglacial stage" was proposed by Leverett (1898b, p. 176) for exposures in Sangamon County. The name "Sangamonian Stage" was adopted in Illinois in 1960 (Frye and Willman, 1960, p. 4). The interglacial stage was based on a soil that occurs on tills of Illinoian age and is overlain by loesses of Wisconsinan age. Leverett's (1898b) type section was a locality in northwestern Sangamon County described by Worthen (1873, p. 307), but it has not been accessible for three-quarters of a century. For that reason Willman and Frye (1970, p. 121) proposed two paratype sections, the Rochester Section in Sangamon County (an accretion-gley) (NW SE NW 34, 15N-4W) and the Chapin Section in adjacent Morgan County (an in-situ soil profile) (SW NE NW 8, 15N-11W). The stage is based on the soil-stratigraphic unit, typified by these two localities, that serves to define the interval separating the Illinoian and Wisconsinan glacial stages. Sangamonian deposits are predominantly accretion-gley of the Berry Clay Member of the Glasford Formation, which also is part of the Sangamon Soil. Minor amounts of organic debris are associated with the accretion-gley deposits, but the peat and peaty silt beds called Sangamon in early reports are Wisconsinan and are assigned to the Farmdalian Substage.

Sangamon Soil

The Sangamon Soil was defined by Leverett (1898b) on the basis of a soil described by Worthen (1873) from a well in Sangamon County, Illinois. The soil is characterized by both a deeply developed in-situ profile on deposits of Illinoian age (Chapin Section) and a soil composed of accretion deposits above tills of Illinoian age (Rochester Section). The soil ranges from an in-situ solum more than 5 feet deep with a red-brown B-horizon (fig. Q-1A, E) to an accretion deposit of gray leached silt and clay containing a few small pebbles. The soil is developed in deposits of a wide range of ages and character. It is almost continuously present on the Illinoian drift (fig. Q-2), and in places it occurs on older deposits where the Illinoian is absent. It is also found in many localities where it is overlain by Wisconsinan drift.

Wisconsinan Stage

The term "Wisconsinan Stage" is derived (fig. Q-6) from the East-Wisconsin formation proposed by Chamberlin (1894, p. 763). In 1895 (p. 275) he changed the name to Wisconsin formation, and in 1899 (p. 20, 185) Leverett proposed the change to Wisconsin stage. The initial definition was based largely on the pattern of end moraines from the Lake Michigan glacial lobe and included only part of the sequence now included in the stage (fig. Q-2). In 1948 Leighton (*in* Wascher et al., 1948, p. 390) applied the name "Farmdale" to the loess previously called Late Sangamon loess and included it in the Wisconsin stage. In 1960 (p. 5) Frye and Willman proposed an expanded definition of the stage, and the present definition of the Wisconsinan

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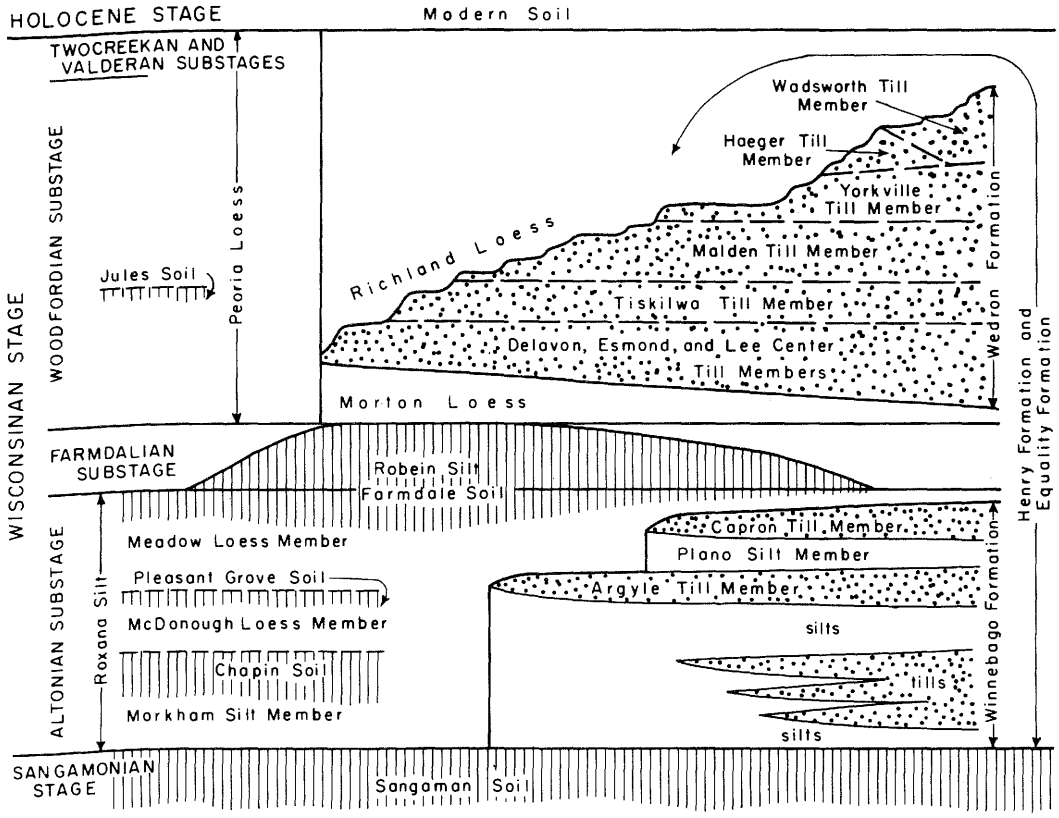

Fig. Q-8—Diagrammatic cross section showing the relations of the formations and members of Wisconsinan age in northern and western Illinois (Willman and Frye, 1970).

Stage was proposed in 1968 (Frye et al., 1968b, p. E1). The Wisconsinan Stage is bounded at the base by the contact of the Roxana Silt on the top of the Sangamon Soil (approximately 75,000 radiocarbon years B.P. [Frye et al., 1974a, p. 12]), and at the top by the contact of the youngest glacial tills with overlying lacustrine deposits in northeastern Wisconsin (approximately 7000 radiocarbon years B. P. [Frye and Willman, 1970, p. 126]). The Cottonwood School Section in Cass County (cen. E line 11, 18N-11W) was suggested by Willman and Frye (1970, p. 121) as a paratype for the stage in Illinois. The Wisconsinan Stage is subdivided into five substages, and the deposits are differentiated into 16 formations, but six of them are dominantly Holocene in age (figs. Q-4, Q-8). The Wisconsinan Stage is represented in all parts of Illinois.

Altonian Substage

The Altonian Substage (Frye and Willman, 1960, p. 5), the oldest subdivision of the Wisconsinan Stage, is named for Alton, Madison County, and the type section, which consists of Roxana Silt, is in the Alton Quarry Section (SE SW NE 10, 5N-10W) (Leonard and Frye, 1960, p. 24). In the type locality the base of the Altonian Substage is at the contact of the Markham Silt Member of the Roxana Silt with the top of the Sangamon Soil. The top of the Altonian is the contact of the Robein Silt and the Roxana Silt, or the top of the Farmdale Soil developed in Roxana Silt. Elsewhere in Illinois the substage includes deposits of till (Winnebago Formation), outwash (Henry Formation), and lacustrine deposits (Equality Formation). Deposits of Altonian age are widely distributed over Illinois.

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Roxana Silt

The Roxana Silt (Frye and Willman, 1960, p. 5) is named for Roxana, Madison County, and the type section is the Pleasant Grove School Section in the bluff of the Mississippi River Valley (SW NE SE 20, 3N-8W) (fig. Q-1C). The formation rests on the top of the Sangamon Soil (developed in Teneriffe Silt or older deposits), and it terminates upward at the base of the Robein Silt or the top of the in-situ Farmdale Soil (developed in the Roxana), which is overlain by Peoria Loess. The Roxana Silt and the overlying Robein Silt were called Late Sangamon Loess in early reports and later named Farmdale Loess and assigned to the Wisconsin Stage (Leighton, *in* Wascher et al., 1948; Leighton and Willman, 1949, 1950). The member is largely loess, but it contains some colluvium at the base and locally some eolian sand. It is pinkish tan to yellow-gray (Frye et al., 1962) and has a distinctive mineral composition (Glass et al., 1968). It is 48 feet thick in the type section, but it thins rapidly back from bluff exposures. Where thick, it contains a distinctive molluscan fauna (Leonard and Frye, 1960), and it has been subdivided into three members, the Markham Silt Member at the base, the McDonough Loess Member, and the Meadow Loess Member. Where the Roxana is thinner than 7-8 feet thick the members generally cannot be differentiated because of pedological alteration (figs. Q-1A, E). Even where only a foot or two thick, it is generally darker brown and more clayey than the Peoria Loess. The formation occurs extensively outside the limits of Woodfordian glaciation and locally is found buried by Woodfordian drift.

Markham Silt Member—The Markham Silt Member of the Roxana Silt (Willman and Frye, 1970, p. 62) is named for the town of Markham, 4 miles west of Jacksonville, Morgan County, and the type section is in the Chapin Section (SW NE NW 8, 15N-11W). The unit generally consists of colluvium of silt with some sand and a few small pebbles (Frye et al., 1974a), but locally it may be entirely silt or sand. It rests on the top of the Sangamon Soil or on an erosional surface truncating the Sangamon Soil, and it is terminated at the top by the top of the Chapin Soil, which is overlain by the McDonough Loess Member. The Markham is gray-brown, lies within the profile of the Chapin Soil, is commonly 1-3 feet thick, and is widely present in western and central Illinois.

McDonough Loess Member—The McDonough Loess Member of the Roxana Silt (Willman and Frye, 1970, p. 62) is named for McDonough Lake on the Mississippi River floodplain in Madison County, and the type section is in the Pleasant Grove School Section, the same as for the formation (fig. Q-1C). The member consists of gray to tan loess, commonly leached, bounded at the base by the top of the Chapin Soil or older deposits and at the top by the top of the Pleasant Grove Soil, which is overlain by the Meadow Loess Member. The member is generally recognizable only in the thick loess deposits adjacent to the major valleys of central, southern, and western Illinois, and it is 5 feet or less thick.

Meadow Loess Member—The Meadow Loess Member of the Roxana Silt (Willman and Frye, 1970, p. 63) is named for Meadow Heights, part of Collinsville, Madison County, and the type section, like that of the formation, is in the Pleasant Grove School Section (fig. Q-1C). The member is loess, and where thick along the bluffs of the Illinois and Mississippi Rivers of central and southern Illinois it has three recognizable zones—pink-tan zones at the top and base and a gray-tan zone in the middle. Where thick and calcareous, it contains a distinctive fauna of fossil mollusks that has been radiocarbon dated at several localities (Leonard and Frye, 1960). Its heavy mineral suite and clay mineral composition differ from those of other loess deposits (Frye et al., 1962). It rests on top of the Pleasant Grove Soil developed in the McDonough Loess Member, or on older deposits, and it is bounded at the top by the in-situ Farmdale Soil, by the Robein Silt, or by younger formations. The member is 43 feet thick at its type locality, but it thins to a few feet at distances of 15 miles or more from the source valleys.

Chapin Soil

The Chapin Soil (Willman and Frye, 1970, p. 86) is named for Chapin, Morgan County, and the type section is in the Chapin Section (SW NE NW 8, 15N-11W). It is an in-situ soil developed in the colluvium and silt of the Markham Silt Member of the Roxana Silt. The soil generally is grayish brown and rests either on the A-horizon of the Sangamon Soil or on a truncated Sangamon Soil. The profile rarely is more than 2 feet thick, in contrast to the thicker Sangamon profile below (Frye et al., 1974a). The Chapin Soil occurs in western and central Illinois.

Pleasant Grove Soil

The Pleasant Grove Soil (Willman and Frye, 1970, p. 87) is named for Pleasant Grove School and the type section, like that of the Roxana Silt, is in the Pleasant Grove Section, Madison County. The soil at the type locality is an immature, or A-C, profile developed in silt of the McDonough Loess Member of the Roxana Silt. The solum is generally gray to gray-brown and lacks a textural B-horizon. The soil has been observed only adjacent to the major valleys of central and western Illinois.

Winnebago Formation

The Winnebago Formation (Frye and Willman, 1960, p. 5; Frye et al., 1969, p. 25) is named for Winnebago County, and the type section is on the east side of Rockford in the Rock Valley College Section (SW NW SW 10, 44N-2E) and in cores of near-by borings (Nos. 2 and 5) on the Northwest Tollway (Kempton, 1963). The name Winnebago was introduced as a replacement for the term "Farmdale" (Shaffer, 1956). The formation includes glacial till and intercalated silt, gravel, and sand. It is subdivided into three named members, the Argyle Till Member at the base, the Plano Silt Member, and the Capron Till Member, which overlie unnamed till, sand, and gravel members that occur in the buried valleys and are not exposed. The formation is bounded below by the top of the Sangamon Soil, and at the top by the top of the in-situ Farmdale Soil. It ranges from a few feet to as much as 400 feet thick where it is the filling of deep bedrock valleys. The formation is exposed at the surface only in central northern Illinois (fig. Q-5). The Lemont drift (Bretz, 1955), tentatively assigned to this formation, is discussed with the Valparaiso Drift.

Argyle Till Member—The Argyle Till Member of the Winnebago Formation (Frye et al., 1969, p. 26; Willman and Frye, 1970, p. 63) is named for Argyle, Winnebago County, and the type section is in the Rock Valley College Section, the same as the type section for the formation. The till is exceptionally sandy, pinkish tan or salmon colored, massive, and calcareous. It is overlain by the Plano Silt Member, and it overlies unnamed silts and tills of the Winnebago Formation. It occurs only in central northern Illinois (fig. Q-5).

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Plano Silt Member—The Plano Silt Member of the Winnebago Formation (Kempton and Hackett, 1968, p. 31; Willman and Frye, 1970, p. 64) is named for Plano, Kendall County, and the type section is in the Big Rock Creek Section (SE NE 1, 37N-6E) where the member is 7 feet thick. The member consists of silt, silt rich in organic material, and peat. It overlies the Argyle Till and underlies the Capron Till, and it is recognized only in the area where the Capron Till is present.

Capron Till Member—The Capron Till Member of the Winnebago Formation (Frye et al., 1969, p. 26; Willman and Frye, 1970, p. 64) is named for Capron, Boone County, and the type section is in the Capron North Section (NE SE SE 23, 46N-4E). Its upper part is gray, calcareous sandy till and the lower part is silty till. It rests on Plano Silt or Argyle Till and is topped by an immature soil profile (Farmdale Soil) overlain by Peoria Loess. It occurs only in central northern Illinois (fig. Q-5).

Henry Formation

The Henry Formation (Willman and Frye, 1970, p. 70) is named for Henry, Marshall County, and the type exposure is in a gravel pit along Illinois Highway 29, 2 miles north of Henry (SE SE 32, 14N-10E), where 30 feet of sand and gravel overlain by 2 feet of the Richland Loess and the Modern Soil are exposed. The formation consists of glacial outwash of sand and gravel. In places it contains a few thin silt beds. The thickness of the formation varies greatly; in the major valleys it locally exceeds 100 feet. The formation rests on Woodfordian or older rocks, and it is overlain by Richland or Peorian Loess, the Equality Formation, or Holocene deposits. Although in some areas the formation is continuous with sand and gravel deposits that intertongue with tills of the Winnebago and Wedron Formations, vertical cut-offs are used to put the tongues in the Wedron or Winnebago Formations, and the Henry Formation is never overlain by till (fig. Q-8). Ideally, the formation is bounded at the base by the top of the Sangamon Soil, but such exposures are rarely observed; in some valleys it contains deposits older than Wisconsinan in its lower part. The formation is subdivided into three members, which are genetic units that differ in lithology—the Batavia Member (outwash plains), the Mackinaw Member (valley trains), and the Wasco Member (ice-contact deposits). The Henry Formation occurs extensively in the area of Wisconsinan glaciation and beyond that area along the outwash-carrying valleys (fig. 11).

Batavia Member—The Batavia Member of the Henry Formation (Willman and Frye, 1970, p. 71) is named for Batavia, Kane County, and the type exposure is in a gravel pit, 8 miles north of Batavia (SW 1, 40N-8E), in outwash deposited in front of the West Chicago Moraine. The Batavia Member is an upland unit of outwash sand, gravel, and silt, largely deposited along the fronts of many Wisconsinan moraines in discontinuous sheet-like deposits. The member rarely exceeds 30 feet thick, and it has sharp local variations in both thickness and texture. It rests on units of the Wedron Formation, or older deposits, and is commonly overlain only by a few feet of Richland Loess. It occurs in and bordering the area of Wisconsinan glaciation.

Mackinaw Member—The Mackinaw Member of the Henry Formation (Willman and Frye, 1970, p. 71) is named for Mackinaw, Tazewell County, and the type section is in a gravel pit on the southwest side of Mackinaw (NE NW 19, 24N-2W). The member consists of sand, pebbly sand, and gravel deposited as outwash valley trains leading outward from Wisconsinan glacier fronts and now preserved in terraces and beneath Holocene deposits. The materials are well sorted and regularly bedded. At the type locality the member is 30 feet thick, but at places it is more than 100 feet thick. The member rests on rocks ranging from the Wedron Formation to Paleozoic bedrock. It is generally overlain only by thin Richland Loess in the area of Wisconsinan glaciation and by the Peoria Loess outside that area. It occurs along many valleys throughout Illinois (fig. Q-2).

Wasco Member—The Wasco Member of the Henry Formation (Willman and Frye, 1970, p. 72) is named for Wasco, Kane County, and the type section is in a gravel pit along the Chicago Great Western Railroad (SE NW 24, 40N-7E). The Wasco consists of ice-contact sand and gravel, largely in kames, eskers, and deltas, and is characterized by lateral and vertical variations in grain size, sorting, bedding, and structure. At some localities the deposit is largely cobbles and boulders. Lenses of till and beds of silt occur in some deposits. The thickness varies greatly. The member generally rests on the Wedron Formation but locally overlies older deposits. It is commonly overlain by thin Richland Loess. It occurs discontinuously throughout the area of Wisconsinan glaciation.

Equality Formation

The Equality Formation (Willman and Frye, 1970, p. 72) is named for Equality, Gallatin County, and the type section is in the Saline River Section (SE cor. SW 27, 9S-7E). The formation consists of lacustrine silt, clay, and sand underlying a lake plain or beach complex of the present land surface. It was deposited during Wisconsinan time in (1) slackwater lakes, principally in valleys tributary to the Mississippi, Wabash, and Ohio Rivers in southern Illinois, (2) in shallow lakes produced by flooding between moraines, and (3) in ice-front lakes in northern Illinois (fig. 11). The formation is subdivided into the Carmi Member, dominantly silt and clay, and the Dolton Member, dominantly sand. It includes deposits of Altonian and Woodfordian age. Extensive molluscan faunas have been described from the lacustrine deposits (Frye et al., 1972). In the type region, the thickest sequence of Equality deposits available for study was 52 feet in the Equality Northeast Section (Frye et al., 1972), but well logs suggest that the formation may exceed 100 feet locally. The formation rests on Woodfordian or older deposits and its top is at the surface, except in local areas where Holocene formations cover it. In southern Lake Michigan it is overlain by the Lake Michigan Formation. Many individual glacial lakes, shorelines, spits, bars, and beaches have been named, but they are not stratigraphic units (Willman and Frye, 1970).

Carmi Member—The Carmi Member of the Equality Formation (Willman and Frye, 1970, p. 74) is named for Carmi, White County, and the type section is an exposure along Crooked Creek 4 miles north of Carmi (NE cor. SW 21, 4S-10E). The type section of this member occurs in the deposits of glacial Lake Little Wabash. However, the deposits, their fauna, and clay mineral composition have been much more intensively studied in the deposits of Lake Saline in Gallatin County to the south (Frye et al., 1972). The deposits there are clay and silt, with some sand, commonly 20-40 feet thick but locally as much as 100 feet. They partially fill, or drown, an extensive system of valleys that were dammed by aggradation of the Ohio and Wabash Valleys. The Carmi occurs throughout the state in large areas covered by Wisconsinan lakes and also in many smaller areas in the region of Wisconsinan glaciation in northern Illinois.

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Dolton Member—The Dolton Member of the Equality Formation (Willman and Frye, 1970, p. 74) is named for Dolton, Cook County, and the type section is an exposure of 8 feet of sand at the top of a clay pit (S1/2 NE 3, 36N-14E). The Dolton is dominantly sand with local beds of silt and gravel, and most of it was deposited in beaches and bars. It is differentiated only where it is the surficial deposit of the Equality Formation. It is best developed in Cook County, where it is associated with the several beaches of Lake Chicago (Bretz, 1955).

Farmdalian Substage

The Farmdalian Substage (Leighton and Willman, 1950, p. 602; Frye and Willman, 1960, p. 6) is named for Farmdale, Tazewell County, and the type section is in the Farm Creek Section (NE SW SE 30, 26N-3W). The substage was defined in more detail in 1968 (Frye et al., 1968b, p. E15) and in 1970 (Willman and Frye, p. 125). The substage includes the deposits made during the span of time represented by the Robein Silt at the type section (28,000-22,000 radiocarbon years B.P.), where the Robein Silt overlies the Roxana Silt and is terminated upward by the top of the Farmdale Soil. It is overlain by the Morton Loess. The substage also comprises the Peddicord Formation and the Farmdale Soil. The deposits have been extensively radiocarbon dated in Illinois.

Robein Silt

The Robein Silt (Willman and Frye, 1970, p. 64) is named for Robein, Tazewell County, and the type section is in the Farm Creek Section (NE SW SE 30, 26N-3W) (fig. Q-1B). It was called Farmdale Silt in some reports (Frye and Willman, 1960). The Robein is brown, gray, dark gray to black, leached silt. It contains abundant organic material, which differentiates it from the Roxana Silt below. It is part of the Farmdale Soil and is Farmdalian in age. It rests on the Roxana Silt, the Peddicord Formation, or the Winnebago Formation, and it is overlain by the Peoria Loess, Morton Loess, or the Wedron Formation. The Robein ranges from a few inches to more than 5 feet thick. It is discontinuous but widely distributed in Illinois.

Peddicord Formation

The Peddicord Formation (Willman et al., 1971, p. 4) is named for Peddicord School, La Salle County, and the type section is in the Wedron Section (SE SW 9, 34N-4E) (Willman and Frye, 1970) (fig. Q-1B). The formation consists of gray and pinkish tan, calcareous, lacustrine silts, and it contains fossil mollusks (Leonard and Frye, 1960). It is Farmdalian in age. The formation has been observed only in the upper Illinois Valley, where it overlies the Sangamon Soil or bedrock and is overlain by the Robein Silt or the Wedron Formation.

Farmdale Soil

The Farmdale Soil was named for Farmdale, Tazewell County (Willman and Frye, 1970, p. 87), and the type section is in the Farm Creek Section (NE SW SE 30, 26N-3W). In the type section it is an organic soil represented by the Robein Silt. It is brown to black and lacks a textural B-horizon. This unit occurs widely over Illinois and occurs both as an organic soil and as an in-situ profile developed in Roxana Silt. It is overlain by the Morton Loess, by the Peoria Loess, or by the Wedron Formation.

Woodfordian Substage

The Woodfordian Substage (Frye and Willman, 1960, p. 6-7) is named for Woodford County, Illinois, where it is the surface deposit over nearly the entire county. Glaciers of the Lake Michigan and Erie Lobes (figs. Q-9, Q-10) covered northeastern Illinois during Woodfordian time. The substage is based on the sequence of deposits above the contact of the Morton Loess on the Robein Silt in the type locality of those formations and extending upward to the base of the Two Creeks deposits, as typically exposed in east-central Wisconsin (Thwaites and Bertrand, 1957; Frye et al., 1968b). The substage includes the deposits of six formations, as well as parts of several dominantly Holocene formations (figs. Q-4, Q-8). Two of the six formations (Henry and Equality) include earlier Wisconsinan deposits and were described under the Altonian Substage. The molluscan fauna of the Woodfordian Substage, largely from the Peoria Loess, has been described (Leonard and Frye, 1960). Many radiocarbon dates have been determined from several deposits of the substage, including those adjacent to the lower and upper contacts, and they indicate a time span from 22,000 to 12,500 radiocarbon years B.P. The Woodfordian includes deposits that earlier were assigned to the Iowan, Tazewell, Cary, and Mankato Substages (fig. Q-6).

Peoria Loess

The Peoria Loess (Leverett, 1898a, p. 246; Kay and Leighton, 1933, p. 673) is named for Peoria, Peoria County, from exposures in the bluffs of the Illinois River Valley. The term "Peorian" was first used by Leverett (1898a) for an interglacial stage. Kay and Leighton (1933) restricted Peorian to the loess deposits outside the Shelbyville Morainic System, as is still the practice. Frye and Leonard (1951, p. 128) made it a rock-stratigraphic unit—Peoria Loess—which use subsequently was adopted in Illinois (Frye and Willman, 1960, p. 7). As a type section had not been described, Willman and Frye (1970, p. 65-66, 188-189) designated the Tindall School Section, south of Peoria in the west bluff of the Illinois Valley, as the type section (SW SW NE 31, 7N-6E). The formation consists of massive, well sorted silt, ranging from coarse in the valley bluffs to fine in uplands distant from the bluffs. It locally contains some fine to medium sand in the bluff areas. Where thick it is calcareous, except in the Modern Soil profile at the top; where thin it is all noncal-

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careous. The zone from which carbonates are leached varies from 3-4 feet thick at the northern end of the state to 15-20 feet at the southern end. In thick sections along the Illinois Valley, the Jules Soil occurs in the upper part, several feet below the Modern Soil. The Peoria Loess ranges in thickness from as much as 100 feet to only a foot or two, thinning away from the bluffs (figs. 11, Q-1C) (Smith, 1942; Willman and Frye, 1970). The fossil mollusks (Leonard and Frye, 1960) and clay mineral composition (Frye et al., 1962, 1968a) have been described, and a group of radiocarbon dates indicate a span of time from approximately 22,000 B.P. to 12,000 B.P. Peoria Loess is physically continuous with both the Morton Loess and the Richland Loess (fig. Q-8), which occur within the area of Woodfordian glaciation. The Peoria Loess occurs on the upland areas and valley walls of nearly all of Illinois outside the area of Woodfordian glaciation.

Morton Loess

The Morton Loess (Frye and Willman, 1960, p. 7) is named for Morton, Tazewell County, and the type section is in the Farm Creek Railroad-cut Section (cen. 31, 26N-3W) (fig. Q-1A). The unit was formerly called Peorian loess (Alden and Leighton, 1917) and later Iowan loess (Leighton, 1933; Leighton and Willman, 1950). It occurs above the Robein Silt or the Farmdale Soil developed in Roxana Silt and lies below the Wedron Formation. It is massive, calcareous silt, gray to gray-tan and locally fossiliferous (Leonard and Frye, 1960). It ranges up to 10 feet thick. It occurs only within the area of Woodfordian glaciation, but it is physically continuous with the lower part of the Peoria Loess, which lies outside that area (fig. Q-8). Radiocarbon dates indicate a time span from 20,000 to 22,000 years B.P.

Wedron Formation

The Wedron Formation (Frye et al., 1968b, p. E16) is named for Wedron, La Salle County, and the type section is in the Wedron Section (fig. Q-1B) in the Wedron Silica Company pit (SE SW 9, 34N-4E) (Willman and Payne, 1942, p. 148, 307; Willman and Frye, 1970, p. 190). The formation consists of those deposits of glacial till and outwash that extend upward from their contact on the Morton Loess to the top of the till below the Two Creeks deposits at Two Creeks, Wisconsin (Thwaites and Bertrand, 1957). Although largely till, the Wedron contains numerous intercalated beds of outwash gravel, sand, and silt (fig. Q-1A, B). In Illinois the formation is subdivided into 12 members (fig. Q-4) on the basis of the lithology of successive sheets of till. Before 1968, the deposits included in the Wedron Formation were subdivided into drifts or drift formations, lithologically distinct units named for the moraine marking the outer margin of the particular drift (Culver, 1922a; Fisher, 1925; Willman and Payne, 1942; Frye et al., 1965). The gray silty till of the Esmond, Lee Center, and Delavan Till Members was the Shelbyville drift; the pink sandy till of the Tiskilwa Till Member was the Bloomington drift; the yellow-gray silty to sandy till of the Malden Member was the Normal and Cropsey drifts; the medium to dark gray clayey till of the Yorkville Till Member was the Marseilles and Minooka drifts; and the yellow-gray gravelly to clayey till of the Haeger and Wadsworth Till Members was the Valparaiso and Lake Border drifts. The youngest, or uppermost, beds of the Wedron do not occur in Illinois but are exposed in eastern Wisconsin. The formation spans all but the earliest part of the Woodfordian Substage of the Wisconsinan Stage. Its thickness ranges widely, up to as much as 250 feet. Approximately 60 feet of deposits is exposed in the type section. The formation is widely distributed in the northeast quadrant of Illinois (fig. Q-5), where it includes most of the materials of the many prominent Woodfordian moraines, which are described as drift units in the section on morphostratigraphic classification (fig. Q-10).

Esmond Till Member—The Esmond Till Member of the Wedron Formation (Frye et al., 1969, p. 26; Willman and Frye, 1970, p. 67) is named for Esmond, De Kalb County. The type section is in roadcuts 10 miles north of Esmond (NW SW NW 27, 43N-2E, Winnebago County) and borings at Greenway School, near Esmond. The upper part of the till is silty, but the lower part is more clayey. It is gray and calcareous, and its clay mineral content is characterized by being exceptionally high in illite. The member overlies the Morton Loess, or the sandy Argyle Till Member of the Winnebago Formation where the Morton is absent. It is overlain by the pink-tan deposits of the Tiskilwa Till Member of the Wedron Formation or by Richland Loess. It is discontinuous, rarely exceeds 25 feet thick, and it is the surface drift only in the Dixon Sublobe in north-central Illinois (figs. Q-5, Q-9).

Lee Center Till Member—The Lee Center Till Member of the Wedron Formation (Frye et al., 1969, p. 26; Willman and Frye, 1970, p. 68) is named for Lee Center, Lee County, and the type section is a roadcut 5 miles northwest of Lee Center (SE SW NW 31, 21N-10E). In the type section it consists of 8 feet of calcareous, gray, silty till that underlies 4 feet of leached, brown silt of the Richland Loess. The Lee Center Till is bounded at the top by the sharply contrasting pink-tan Tiskilwa Till Member. It overlies the Morton Loess. It occurs primarily in the Green River Sublobe (figs. Q-5, Q-9), where it is thin, discontinuous, and extensively eroded by the meltwaters of Woodfordian glaciers.

Delavan Till Member—The Delavan Till Member of the Wedron Formation (Willman and Frye, 1970, p. 68) is named for Delavan, Tazewell County, and the type section is in roadcuts along Illinois Highway 121, 4 miles east of Delavan (SW 16, 22N-3W). The member consists of gray, calcareous, silty, illitic till that attains a maximum thickness of about 200 feet in the Shelbyville Morainic System. It overlies the Morton Loess and is overlain by the distinctive pinkish tan till of the Tiskilwa Till Member. It is judged to be equivalent to the Lee Center and Esmond Till Members farther north. Beyond the limit of the Tiskilwa Till Member, the Delavan is overlain by Richland Loess. It occurs in the Peoria Sublobe and is best exposed in Tazewell and McLean Counties (figs. Q-1A, Q-5).

Tiskilwa Till Member—The Tiskilwa Till Member of the Wedron Formation (Willman and Frye, 1970, p. 68) is named for Tiskilwa, Bureau County, and the type section is the Buda East Section (SE SE SW 31, 16N-8E). The till is sandy, pink-tan to reddish tan-brown, and commonly is 100-150 feet thick in the higher parts of the Bloomington Morainic System. It is bounded above by the more illitic, tan to yellow-gray till of the Malden Till Member, and below by the gray till of the Delavan, Lee Center, or Esmond Till Members. It is one of the most extensive members of the Wedron Formation, extending from Bloomington in McLean County northward to the Wisconsin state line (fig. Q-5).

Malden Till Member—The Malden Till Member of the Wedron Formation (Willman and Frye, 1970, p. 69) is named for Malden, Bureau County, and the type section is in the Malden South Section (SW SE SE 5, 16N-10E). The member consists of silty and sandy, yellow-gray to gray-tan till, with discontinuous beds and lenses of gravel and sand. In some

areas it grades upward to clayey till. It is bounded at the base by the Tiskilwa Till Member and is overlain by the clayey Yorkville Till Member or, where the Malden Member is the surface drift, by the Richland Loess. At the type locality the member is 25 feet thick, but it is 50-100 feet thick under the crests of some moraines. It is extensively exposed from McLean County northward to Kane County (fig. Q-5).

Yorkville Till Member—The Yorkville Till Member of the Wedron Formation (Willman and Frye, 1970, p. 69) is named for Yorkville, Kendall County, and the type section is in roadcuts at the intersection of Illinois Highways 47 and 71, 1 mile south of Yorkville (SE SE SE 5, 36N-7E). The member is a clayey, greenish gray to dark gray till characterized by abundant small dolomite pebbles. The Yorkville Member is as much as 200 feet thick in the Marseilles Morainic System, in and east of which it is extensively exposed (fig. Q-5). It overlies the Malden Till Member and is overlain by the Wadsworth and Haeger Till Members, the Richland Loess, or in extensive areas by the lake deposits of the Equality Formation (fig. Q-2).

Haeger Till Member—The Haeger Till Member of the Wedron Formation (Willman and Frye, 1970, p. 69) is named for Haegers Bend, a village on the Fox River in McHenry County, and the type section is in roadcuts half a mile northwest of the village (NW NE 23, 43N-8E). In the type exposure the Haeger Member consists of 12 feet of calcareous, gravelly, silty, yellow-gray till overlying the Yorkville Till Member and overlain by the Richland Loess. In some isolated hills the member may be as much as 50-100 feet thick, but it is generally thinner. It is overlain by the Wadsworth Till Member east of the area where the Yorkville is the surface drift. It occurs only in the northeastern part of the state (fig. Q-5).

Wadsworth Till Member—The Wadsworth Till Member of the Wedron Formation (Willman and Frye, 1970, p. 70) is named for Wadsworth, Lake County, and the type section is in roadcuts at the intersection of Illinois Highway 131 and Wadsworth Road (SE SE SW 30, 46N-12E). The member consists of the clayey gray tills of the Lake Border Morainic System, the Tinley Moraine, and much of the Valparaiso Morainic System. The member occurs above the Haeger and Yorkville Till Members, and it is overlain by very thin Richland Loess. It is the youngest till member of the Wedron Formation exposed in Illinois, and it is marginal to the Lake Michigan shore (fig. Q-5). It is also present under most of southern Lake Michigan, where it forms the floor of the lake east of Chicago. It is overlain by the Equality and Lake Michigan Formations in the center of the southern part of the lake.

Oakland Till Member—The Oakland Till Member of the Wedron Formation (Ford, *in* Johnson et al., 1972, p. 15) is named for Oakland, Coles County, where it is the surface drift, but it has been described only from its occurrence in the Harmattan strip mine in Vermilion County (NE NE NW 4, 19N-12W). In the Harmattan strip mine it ranges from 0 to more than 30 feet thick. It is a coarse, blocky, calcareous, brown till containing wood fragments and mollusk shells (dated at 20,800 ± 130 radiocarbon years B.P.; sample ISGS-81). It locally contains thin beds of silt, sand, and gravel at the base. It occurs above Robein Silt and is overlain by the Glenburn Till Member.

Glenburn Till Member—The Glenburn Till Member of the Wedron Formation (Johnson et al., 1971, p. 202) is named for Glenburn, Vermilion County, and the type section is in the Emerald Pond Section (NE SW SW 33, 20N-12W) (Johnson et al., 1972, p. 42). In the type section it is 17 feet thick and consists of pinkish brown to dark brown, calcareous, somewhat sandy till. At the type section it occurs above the Banner Formation of Kansan age and it is overlain by the Batestown Till Member of the Wedron Formation, but elsewhere in Vermilion and adjacent counties it has been described as overlying the Robein Silt and the Oakland Till Member of the Wedron Formation. It occurs in central eastern Illinois.

Batestown Till Member—The Batestown Till Member of the Wedron Formation (Johnson et al., 1971, p. 202) is named for Batestown, Vermilion County, and the type section is in the Emerald Pond Section (NE SW SW 33, 20N-12W) (Johnson et al., 1972, p. 42). In the type section the Batestown is 14 feet thick and consists of light olive brown to dark gray, calcareous, sandy to silty till that contains beds of sand and silt and one bed of boulders. The Batestown is bounded by the Glenburn Till Member below and the Snider Till Member above, or, where the Snider is absent, by the Richland Loess. The member occurs in central eastern Illinois (fig. Q-5).

Snider Till Member—The Snider Till Member of the Wedron Formation (Johnson et al., 1971, p. 204) is named for Snider, Vermilion County, and the type section is in the Emerald Pond Section (NE SW SW 33, 20N-12W) (Johnson et al., 1972, p. 42). In the type section the member is 16 feet thick and consists of light olive-brown to gray-brown, calcareous, blocky, jointed, clayey till and a basal zone of silt, sand, and gravel. It occurs in central eastern Illinois (fig. Q-5), where it overlies the Batestown Till Member and is commonly overlain by thin Richland Loess. The uppermost part of the Snider Till is leached and within the B-horizon of the Modern Soil.

Richland Loess

The Richland Loess (Frye and Willman, 1960, p. 7) is named for Richland Creek, Woodford County, and the type section is in a roadcut north of the creek (NW SE SW 11, 28N-3W). The formation is massive tan silt that is calcareous below the leached zone of the Modern Soil and is locally fossiliferous (Leonard and Frye, 1960). It is as much as 20 feet thick on the east bluff of the Illinois Valley north of Peoria, but it thins to 1-2 feet in the Chicago area. This loess was formerly called Tazewell loess (Leighton, 1933). It rests on deposits of the Wedron, Henry, and Equality Formations inside the area of Woodfordian glaciation (fig. Q-1A), and it is terminated upward by the Modern Soil. It is not differentiated outside that area, but it is continuous with the upper part of the Peoria Loess (fig. Q-8).

Jules Soil

The Jules Soil (Willman and Frye, 1970, p. 88) is named for Jules, Cass County, and the type section is in the Jules Section (SE SE NE 13, 18N-11W) (Frye et al., 1968a, p. 21). This soil is generally an immature, or A-C, profile with a dark gray solum that lacks a textural B-horizon. It occurs within the Peoria Loess and at a few places within the Richland Loess, but only in the thick loess sequences near the Illinois River Valley of central Illinois. It represents an interruption in loess deposition between the deposition of the Tiskilwa and Malden Till Members of the Wedron Formation (Frye et al., 1974b).

Twocreekan Substage

The Twocreekan Substage (Frye and Willman, 1960, p. 8) is named for Two Creeks, Manitowoc County, Wisconsin, and the type section is in the Two Creeks Section, 2 miles east of the town in the bluff of Lake Michi-

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gan (Thwaites and Bertrand, 1957, p. 859-864; Frye et al., 1965, p. 57). At the type locality, lake deposits of silt and sand and the forest bed overlie till and, in turn, are overlain by till. Many radiocarbon dates have been obtained from wood of the forest bed in the upper part of the Two Creeks deposits (Black and Rubin, 1968), and the time span for the substage is from 12,500 to 11,000 radiocarbon years B.P. Deposits of the Twocreekan Substage have not been specifically differentiated in Illinois, although they occur in the Equality Formation sediments of Lake Chicago and other glacial lakes and in the various surficial formations that are dominantly of Holocene age.

Valderan Substage

The Valderan Substage (Thwaites, 1943; Frye and Willman, 1960, p. 9) is named for Valders, Manitowoc County, Wisconsin, and the type section was designated as the drift in a quarry at Valders (Thwaites and Bertrand, 1957, p. 864-866). The base of the substage is defined (Frye et al., 1968b, p. E18) as the contact of the Valders till on the Two Creeks forest bed at the Two Creeks Section, eastern Wisconsin, and the top is defined as the top of the Cochrane till below post-Cochrane deposits in the James Bay Lowland of Ontario, Canada (Hughes, 1956)—a time span from 11,000 to 7,000 radiocarbon years B.P. Recent studies (Evenson, 1973) suggested that the till in the quarry at Valders is equivalent to the till beneath the Two Creeks forest bed and is therefore Woodfordian in age. If that finding is confirmed, the Two Creeks exposure, the type section of the Twocreekan Substage, should preferably be designated as the reference section for the Valderan Substage as well. The name "Valderan Substage," now well established for the drift younger than Twocreekan, as clearly intended by Thwaites (1943), Leighton (1957), and others, can then be retained. The rock-stratigraphic name for the post-Twocreekan till in eastern Wisconsin may conveniently be changed from Valders till to Two Rivers Till, as proposed by Evenson (1973) and Lineback et al. (1974). In Illinois, deposits of the Valderan Substage occur in the Equality Formation, particularly in the deposits of Lake Algonquin in the Lake Michigan Basin, in the Henry Formation along the Mississippi Valley, and in the various surficial formations that are dominantly of Holocene age.

Holocene Stage

The Holocene Stage, although based on a term and a concept that developed more than a century ago, has never been properly defined as a time-stratigraphic unit. It has been accepted as a replacement for "Recent" by the U. S. Geological Survey (Cohee, 1968) but without formal stratigraphic definition. For formal use in Illinois, Holocene Stage has replaced Recent Stage as the youngest time-stratigraphic subdivision of the Pleistocene Series (Willman and Frye, 1970, p. 126). In that sense it is defined as embracing all deposits younger than the top of the Wisconsinan Stage. The Holocene Age, therefore, extends from approximately 7000 radiocarbon years B.P. to the present. Six formations in Illinois are dominantly of Holocene age, but in many localities these surficial deposits began to accumulate and the Modern Soil began to develop as soon as the glaciers melted from the area; consequently, the lower parts of the deposits are Wisconsinan in age (fig. Q-4). These deposits are generally overlain only by the Modern Soil developed in their tops, but along marginal areas there is some overlapping and intertonguing. To avoid repetition of a formation in a single section or the occurrence of formations in different orders, each surficial formation can be overlain only by the surficial formations that are specified in the description given for that formation. The order is based on the most common relations. In complex relations the formations are terminated laterally by a vertical cut-off. Holocene deposits are abundant throughout Illinois.

Cahokia Alluvium

The Cahokia Alluvium (Willman and Frye, 1970, p. 75) is named for Cahokia, St. Clair County, which is located on the floodplain of the Mississippi River, and the type section is in a boring drilled 3 miles southwest of Cahokia (4300 feet south of lat. 38°32′30″ N and 5200 feet east of long. 90°15′ W) (Bergstrom and Walker, 1956, test hole No. 2). In the boring, the Cahokia consists of 45 feet of silt, clay, and silty sand, overlying 60 feet of sand and gravel of the Henry Formation, which rests on bedrock. The Cahokia Alluvium includes the deposits in the floodplains and channels of present rivers and streams, and the name replaces the long-used informal term "Recent Alluvium." Although largely of Holocene age, the formation in many places probably contains some deposits as old as Woodfordian. It consists mainly of poorly sorted silt, clay, and silty sand but locally contains lenses of sand and gravel. Its thickness varies greatly but rarely exceeds 50 feet. The formation rests on rocks of many ages. It generally is terminated upward by the surface of the floodplain and the Modern Soil, but locally it is overlain by the Parkland Sand, the Grayslake

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Peat, the Lacon Formation, or the Peyton Colluvium. The Cahokia Alluvium occurs throughout Illinois in valley bottoms (fig. 11),

Parkland Sand

The Parkland Sand (Willman and Frye, 1970, p. 78) is named for Parkland, Tazewell County, and the type section is in a roadcut 5 miles west of Parkland (SW SE SW 2, 23N-7W). The formation consists of windblown sand in dunes and sheet-like deposits. The thickness ranges sharply—some dunes reach 100 feet high—but the range is commonly 20-40 feet. The Parkland Sand is a surficial deposit, but it is locally overlain by the Richland Loess, the Peyton Colluvium, or the Lacon Formation. It occurs in large areas along the Illinois River Valley of central Illinois, the Green River Lowland and the Mississippi Valley of northwestern Illinois, the Kankakee Valley in northeastern Illinois, and in smaller areas elsewhere.

Grayslake Peat

The Grayslake Peat (Willman and Frye, 1970, p. 77) is named for Grayslake, Lake County, and the type section is in a pit 1 mile southeast of Grayslake (NE SE NE 2, 44N-10E), where 14 feet of peat is exposed (Hester and Lamar, 1969). The formation consists of peat, sandy and silty peat, muck rich in organic material, and a foot or two of silt at the top. In some places it contains beds of marl, silt, and clay. It rarely exceeds 20 feet thick. Although it is a surficial formation, it is locally overlain by the Cahokia Alluvium, the Parkland Sand, the Peyton Colluvium, or the Lacon Formation. It occurs as a filling of ponds and poorly drained areas, principally in the region of Wisconsinan glaciation, and in the bottomlands of the major valleys.

Lacon Formation

The Lacon Formation (Willman and Frye, 1970, p. 77) is named for Lacon, Marshall County, and the type locality is a landslip area along the bluffs of the Illinois River Valley, 2 miles northwest of Lacon (E1/2 2, 12N-9E) (Ekblaw, 1932). The formation consists of gravity-initiated deposits, such as landslides, slumps, slips, and rock falls, most of which are triggered by seasonal increases in pore-water pressure and move over surfaces lubricated by infiltrated water. The material is unsorted and reflects a local source. It is a surficial formation, and where it locally interfingers with the Cahokia Alluvium and the Peyton Colluvium it is considered part of those formations. It occurs in the many parts of the state where valley bluffs are prominent.

Peyton Colluvium

The Peyton Colluvium (Willman and Frye, 1970, p. 79) is named for Peyton Creek, Peoria County, and the type section is along the creek at the base of the Illinois Valley bluffs, 1.5 miles southwest of Glasford (NW NE 32, 7N-6E). The locality is mapped as slopewash and alluvial fans (Wanless, 1957). The formation includes the widely distributed but narrow belts of poorly sorted debris that have accumulated on the lower slopes and at the base of slopes by processes of creep, slopewash, and mudflow. The many small cones and fans that occur at the mouths of gullies and rest on floodplain or terrace surfaces, generally interfingering with colluvium, are included in the formation. The Peyton is a surficial formation and is not overlain by other formations. Where it intertongues with the Cahokia Alluvium it is included in that formation.

Lake Michigan Formation

The Lake Michigan Formation (Willman and Frye, 1970, p. 78), named for Lake Michigan, consists of the surficial lacustrine and beach deposits of the southern part of the lake. A cross section of the lake sediments along a line 12-32 miles east of Waukegan, Lake County, is the type locality (Gross et al., 1970). The formation also includes the deposits in the basins of other natural lakes in Illinois. It overlies Paleozoic rocks, glacial deposits of Wisconsinan age, or the Equality Formation, and it is overlain only by water or, on the beaches, by air. The sediments of the Lake Michigan Formation in the southern part of the lake have been described (Gross et al., 1970; Lineback et al., 1970, 1972; Lineback and Gross, 1972), and the chemical composition and trace element content of the sediments have been analyzed (Shimp et al., 1970, 1971; Ruch et al., 1970; Schleicher and Kuhn, 1970; Kennedy et al., 1971; Frye and Shimp, 1973). The formation attains a maximum thickness of more than 60 feet, but generally it is less than 40 feet thick. It is composed of clay, silt, a small proportion of sand, and local accumulations of organic matter. Seven members have been differentiated in the formation (fig. Q-4), all but one (Ravinia) of which have been defined from cores taken from the southern part of Lake Michigan.

South Haven Member—The South Haven Member of the Lake Michigan Formation (Lineback et al., 1970, p. 11) is named for South Haven, Ottawa County, Michigan, and the type section is the interval from 219.3 cm to the base of core 143 (lat. 42°21.8′ N, long. 78°10.8′ W, at a water depth of 390 feet). It is the lowest member of the formation and consists of reddish gray clay, generally less than 3.5 feet thick, on the east side of the lake. The member rests on the Wedron Formation, Equality Formation, or bedrock.

Sheboygan Member—The Sheboygan Member of the Lake Michigan Formation (Lineback et al., 1970, p. 11) is named for Sheboygan, Sheboygan County, Wisconsin, and the type section is the interval 112-219.3 cm in core 143, the same core as the type of the South Haven Member. The member consists of two reddish brown to brown clay units separated by a thin, persistent layer of gray clay. The member ranges up to 4 feet thick, is overlain by the Winnetka Member, and rests on the South Haven Member or the Equality Formation. Its maximum development is in the mid-lake area and it occurs only where water depth exceeds 230 feet. It thins shoreward to the east, south, and west. It is absent from the southwestern part of the lake.

Wilmette Bed—The Wilmette Bed of the Sheboygan Member of the Lake Michigan Formation (Lineback et al., 1970, p. 11) is named for Wilmette, Cook County, and the type section is in the type section of the Sheboygan Member. It is a bed of gray clay, with some silt and sand, in the middle of the Sheboygan Member. It is 3-9 inches thick, and it occurs only in the area of southern Lake Michigan where water depth exceeds 270 feet.

Winnetka Member—The Winnetka Member of the Lake Michigan Formation (Lineback et al., 1970, p. 8) is named for Winnetka, Cook County, and the type section is the interval 35.5-112 cm in core 143, the same core as the type of the South Haven Member. The member consists of brownish gray clay with a few interspersed black beds. It becomes somewhat sandy near the shore, but generally it is finer grained

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than the overlying members. It is 1-6 feet thick. It rests on the South Haven and Sheboygan Members and the Equality Formation, and it is overlain by the Lake Forest and Waukegan Members. The Winnetka is absent where the Wedron or Equality Formations are near the sediment surface.

Lake Forest Member—The Lake Forest Member of the Lake Michigan Formation (Lineback et al., 1970, p. 8) is named for Lake Forest, Lake County, and the type section is the interval 16-35.5 cm in core 143, the same core as the type of the South Haven Member. The member is dark gray silty clay that usually contains many thin beds of black clay. The black beds contain more organic matter than the enclosing deposits and have been radiocarbon dated at 6920 ± 200 radiocarbon years B.P. (sample ISGS-33) and 7050 ± 200 radiocarbon years B.P. (sample ISGS-36). The member is generally siltier than the Winnetka and Sheboygan Members below and less sandy and more compact than the Waukegan Member above. It is 0-4 feet thick. It is present on the western and southern sides of southern Lake Michigan but is absent from the central and eastern areas.

Waukegan Member—The Waukegan Member of the Lake Michigan Formation (Lineback et al., 1970, p. 6) is named for Waukegan, Lake County, and the type section is the interval 0-16 cm in core 143, the same core as the type of the South Haven Member. It is the surficial sediment of the formation in large areas in the center and along the eastern side of southern Lake Michigan. It is distributed widely over the offshore lake floor except at a few places where bedrock or till form the lake bottom. It consists of soft sandy silt, silty clay with a high water content, sand, and gravel. It is 0.1-30 feet thick. The member becomes sandier near shore and in the southwestern part of the lake. A gray silt facies occurs on the east side of the lake where the member is thickest, and a brown silt facies is on the west side where the member thins to less than a foot thick (Lineback and Gross, 1972).

Ravinia Sand Member—The Ravinia Sand Member of the Lake Michigan Formation (Willman and Frye, 1970, p. 78) is named for Ravinia, in the southern part of Highland Park, Lake County, where the type exposure is an accessible section of the Lake Michigan beach (W1/2 31, 43N-13E). It consists of well sorted, largely medium-grained, nearly white beach sand containing local lenses of gravel. It is relatively clean, except for man-made litter and driftwood. Smaller areas of beach sand present along the shores of other natural lakes in Illinois are included in the Ravinia. The Ravinia Member includes only beach sand and is separated from the rest of the formation at the base of the low-water swash zone. Sands occurring offshore are included in the Waukegan Member. The character of the beach sands and adjacent deposits in extreme northeastern Illinois and the history of their development have been described by Hester and Fraser (1973).

Modern Soil

As a soil-stratigraphic unit, the term "Modern Soil" (Willman and Frye, 1970, p. 89) is applied to any soil profile genetically related to the present topographic surface. It underlies the surface of most of Illinois. The soil ranges from very shallow to several feet in depth and is developed in any sediment that immediately underlies the existing land surface. The type section is the uppermost five units in the Buda East Section in Bureau County (SE SE SW 31, 16N-8E) (Frye et al., 1968a, p. 20). The term carries no implication of soil type in the soil science classification.

Morphostratigraphy

The morphostratigraphic units called drifts, which are based on glacial moraines, are described for each of the glacial lobes (fig. Q-9). A few moraines are continuous from one lobe into another, and a unit is described in the lobe where it is first mentioned. The extent of the named moraines of the Wisconsinan Stage is shown in figure Q-10. The Illinoian moraines and ridged drift areas are shown in figure Q-2. The fact that the drift is based on the moraine is not repeated in the description of each drift. The original namer of the moraine is cited as the namer of the drift. Alluvial terraces are classified as informal morphostratigraphic units. Those named were listed by Willman and Frye (1970).

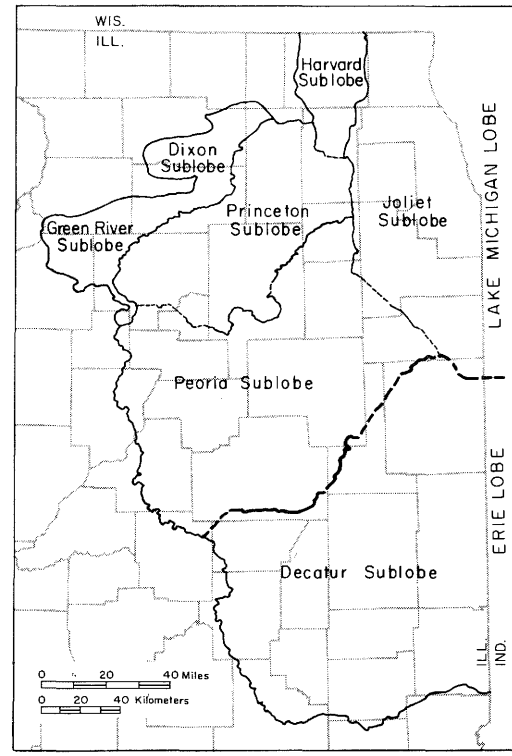

Fig. Q-9—Woodfordian lobes and sublobes in Illinois (Willman and Frye, 1970).

ERIE LOBE

Drift deposited by glaciers that invaded Illinois from the east is assigned to the Erie Lobe (fig. Q-9), although the lobe probably includes contributions by ice from the Lake Huron and Saginaw Lobes, which merged with the Erie Lobe. Erie Lobe glaciers ad-

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vanced into Illinois during the Kansan, Illinoian, and Wisconsinan Stages, and their drifts are characterized in general by larger amounts of garnet than epidote, by dominance of illite, by the presence of both kaolinite and chlorite, and by more calcite than dolomite. In the Erie Lobe, morphostratigraphic units are differentiated only in the Wisconsinan Stage and are part of the Decatur Sublobe.

Decatur Sublobe Drifts

The Decatur Sublobe drifts are related to two morainic systems and 22 named moraines (figs. Q-9, Q-10). The drift is divided into the Oakland, Glenburn, Batestown, and Snider Till Members of the Wedron Formation.

Shelbyville Drifts (Leverett, 1897, p 17)—The Shelbyville Morainic System is named for Shelbyville, Shelby County. The drift is the outer and oldest Woodfordian drift in both the Decatur and Peoria Sublobes. The massive morainic system represents successive deposits of a fluctuating ice front that in the eastern part of the Decatur Sublobe produced three closely related moraines—Westfield, Nevins, and Paris. The morainic system extends west from the Indiana state line and then northwest about 200 miles to Peoria. In the Decatur Sublobe the drift consists of pinkish gray till of the Glenburn Till Member. In the Peoria Sublobe it is gray till that, with the Le Roy Drift, forms the Delavan Till Member of the Wedron Formation, and it is generally readily distinguishable from the overlying pink till of the Tiskilwa Till Member.

Westfield Drift (Willman and Frye, 1970, p. 92)—The Westfield Moraine, named for Westfield, Clark County, is the outermost moraine of the Shelbyville Morainic System and is traced for about 40 miles.

Nevins Drift (Willman and Frye, 1970, p. 92)—The Nevins Moraine, named for Nevins, Edgar County, the middle moraine of the Shelbyville Morainic System, is separated from the other moraines by narrow depressions and is traced for about 40 miles.

Paris Drift (Willman and Frye, 1970, p. 92)—The Paris Moraine, named for Paris, Edgar County, is the inner moraine of the Shelbyville Morainic System. It is traced from near the Indiana state line westward for about 50 miles.

Heyworth Drift (Willman and Frye, 1970, p. 92)—The Heyworth Moraine is named for Heyworth, McLean County. It is a weakly morainic area east and north from Clinton. In shape and orientation it differs from other Woodfordian moraines, and it may be an Illinoian moraine mantled with Woodfordian drift.

Turpin Drift (Willman and Frye, 1970, p. 92)—The Turpin Moraine is named for Turpin, Macon County. The moraine is a sharp ridge that extends only about 6 miles from Turpin northeast to the front of the Cerro Gordo Moraine. Because its orientation is parallel to Illinoian ridges and normal to the Woodfordian moraines, it, like the Heyworth, may be a mantled Illinoian ridge.

Cerro Gordo Drift (Leverett, 1899, p. 218)—The Cerro Gordo Moraine, named for Cerro Gordo, Piatt County, is a strongly lobate ridge extending for about 80 miles. It probably represents a major readvance of the ice front.

Arcola Drift (Leighton and Brophy, 1961, fig. 1)—The Arcola Moraine, named for Arcola, Douglas County, extends for about 50 miles and forms two well defined lobes. The western lobe once enclosed a large lake called Lake Douglas.

Pesotum Drift (Leighton and Brophy, 1961, fig. 1)—The Pesotum Moraine, named for Pesotum, Champaign County, is a relatively weak ridge, in part flat-topped, that is traced for about 25 miles.

West Ridge Drift (Leverett, 1899, p. 223)—The West Ridge Moraine, named for West Ridge, a small village 3 miles southwest of Villa Grove, Douglas County, extends for about 50 miles.

Hildreth Drift (Willman and Frye, 1970, p. 94)—The Hildreth Moraine, named for Hildreth, Edgar County, extends from the Indiana state line westward for about 25 miles.

Ridge Farm Drift (Willman and Frye, 1970, p. 94)—The Ridge Farm Moraine, named for the town of Ridge Farm, Vermilion County, extends westward from the Indiana state line for about 25 miles.

Champaign Drift (Leverett, 1897, p. 18)—The Champaign Moraine, named for Champaign, Champaign County, was originally called the Champaign Morainic System and included the Pesotum, Hildreth, Ridge Farm, and Urbana Moraines. As those drifts have overlapping relations, they are now considered separate moraines (Willman and Frye, 1970). The Champaign Moraine is restricted to the ridge extending from Champaign to the Bloomington Morainic System, about 30 miles.

Rantoul Drift (Willman and Frye, 1970, p. 94)—The Rantoul Moraine, named for Rantoul, Champaign County, is a broad morainic ridge extending 15 miles southwest from the Newtown Moraine to the Champaign Moraine. Because of its alignment on the trends of earlier Woodfordian moraines, it may be a buried moraine mantled with Champaign Drift.

Urbana Drift (Ekblaw, 1941)—The Urbana Moraine, named for Urbana, Champaign County, extends from Rantoul through Urbana to the Indiana state line, about 50 miles.

Illiana Drifts (Willman and Frye, 1970, p. 95)—The Illiana Morainic System, formerly considered part of the Bloomington Morainic System, is named for Illiana, Vermilion County, on the Illinois-Indiana state line. The system consists of two closely parallel moraines differentiated as the Newtown and Gifford Moraines, and it extends eastward from the Gibson City interlobate area about 50 miles to the state line.

Newtown Drift (Willman and Frye, 1970, p. 95)—The Newtown Moraine, named for Newtown, Vermilion County, is the frontal moraine of the Illiana Morainic System.

Gifford Drift (Leighton and Brophy, 1961, p. 95)—The Gifford Moraine, named for Gifford, Champaign County, is the inner and higher moraine of the Illiana Morainic System.

Paxton Drift (Willman and Frye, 1970, p. 95)—The Paxton Moraine, named for Paxton, Ford County, extends eastward across the Decatur Sublobe from the Gibson City reentrant to the Indiana state line, about 55 miles. It previously was considered the frontal moraine of the discontinued Chatsworth Morainic System.

Ellis Drift (Willman and Frye, 1970, p. 96)—The Ellis Moraine, named for Ellis, Vermilion County, was formerly classified as part of the Chatsworth Morainic System. It is a relatively weak moraine but is traced for about 45 miles.

Chatsworth Drift (Leverett, 1899, p. 259)—The Chatsworth Moraine, named for Chatsworth, Livingston County, is a prominent moraine 75 miles long with strong relief. It occurs in both the Decatur and Peoria Sublobes.

Gilman Drift (Willman and Frye, 1970, p. 96)—The Gilman Moraine, named for Gilman, Iroquois County, is a broad but weak lobate ridge about 40 miles long, partially covered by the deposits of glacial Lake Watseka.

St. Anne Drift (Willman and Frye, 1970, p. 96)—The St. Anne Moraine, named for St. Anne, Kankakee County, is a weak morainic ridge extending only about 15 miles from Mt. Langham, a large kame, to the Iroquois Moraine.

Iroquois Drift (Leverett, 1899, p. 258, 336)—The Iroquois Moraine, named for Iroquois County, is the youngest deposit of the Erie Lobe, though possibly a contribution of

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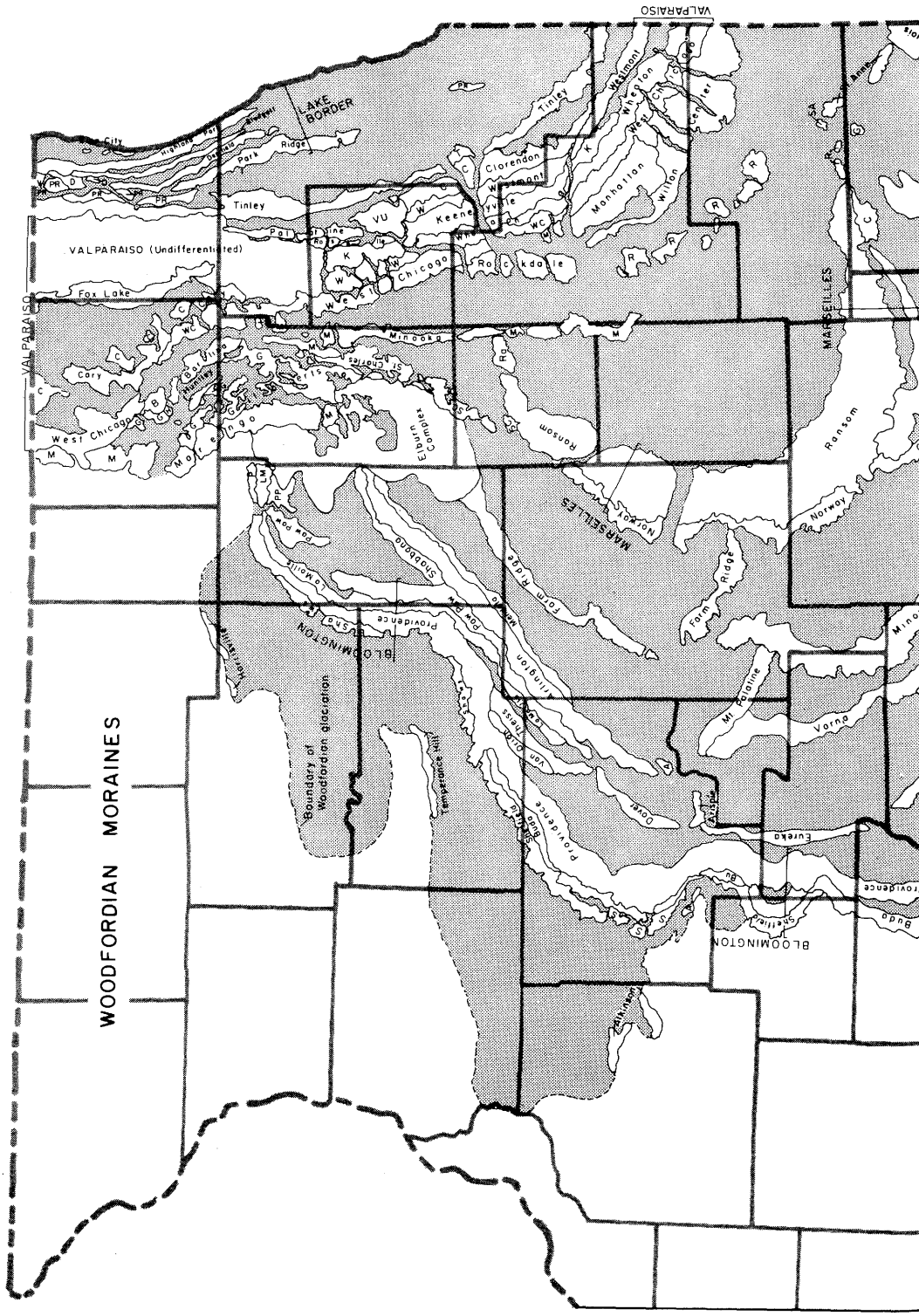

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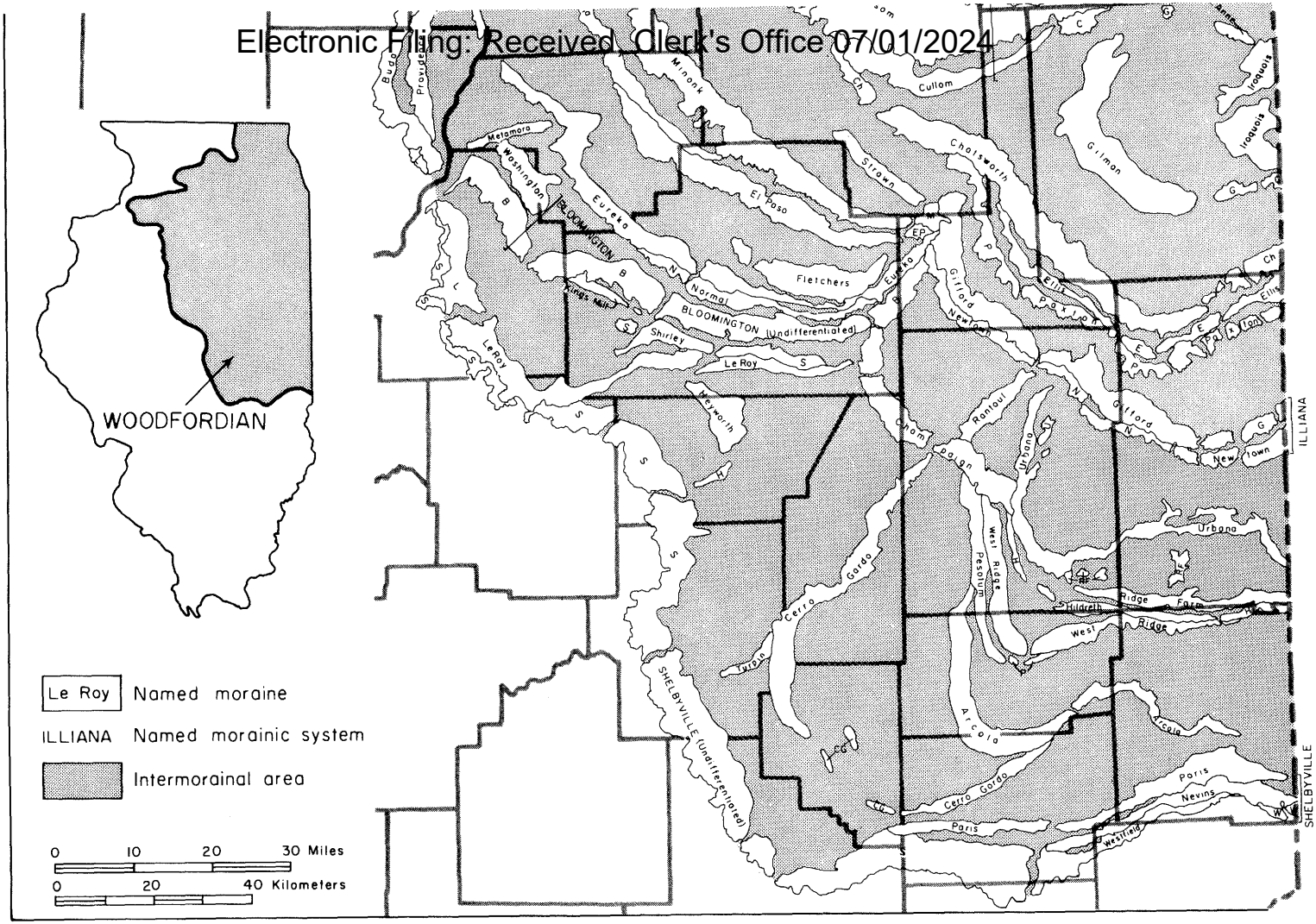

Fig. Q-10—Woodfordian glacial moraines in Illinois (Willman and Frye, 1970).

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the Saginaw Lobe, in Illinois. It is the deposit of a glacier that invaded Illinois from the east for about 8 miles along a 15-mile front.

LAKE MICHIGAN LOBE

Drift deposited by glaciers that followed the Lake Michigan Basin and spread westward and southwestward across Illinois is referred to the Lake Michigan Lobe (fig. Q-9). Morphostratigraphic units are differentiated in the Lake Michigan Lobe drifts of Illinoian and Wisconsinan age. Moraines are widely spaced and discontinuous in the Illinoian drift (fig. Q-2), but are locally useful in morphostratigraphic classification. In the Wisconsinan Woodfordian drift, the moraines are more useful in classification because of their continuity (fig. Q-10) and because many represent readvances of the ice front that produced layered sequences in the drift. After the Woodfordian ice overflowed the Lake Michigan Basin, it was diverted by topographic irregularities and contact with the Erie Lobe glaciers into several sublobes that controlled the distribution of the moraines deposited during the fluctuating withdrawal of the ice front. The major groups of nearly parallel moraines are differentiated as the Peoria, Green River, Dixon, Princeton, Harvard, and Joliet Sublobes. The drift consists of tills and interlayered water-laid deposits that, in the rock-stratigraphic classification, are assigned to the Wedron Formation and divided into eight members on the basis of differences in till composition (fig. Q-5).

Illinoian Drifts

Mendon Drift (Leighton and Brophy, 1961, pl. 1, p. 15; Frye et al., 1964, p. 14)—The Mendon Moraine, named for Mendon, Adams County, marks the outer limit of the Illinoian drift of the Lake Michigan Lobe. It extends from the Mississippi River Valley near Warsaw to the Illinois River Valley at Pearl, about 90 miles. South of Pearl it is absent along the Illinois Valley for many miles, but it is probably represented by morainic topography in Jersey County north of the confluence of the Illinois and Mississippi Rivers. However, that area may also include an extension of the Table Grove Moraine. The Mendon Drift is largely the Kellerville Till Member of the Glasford Formation.

Table Grove Drift (Willman and Frye, 1970, p. 114)—The Table Grove Moraine, named for Table Grove, Fulton County, is a distinctly morainic ridge extending through the middle part of the area of Illinoian drift in western Illinois. Although continuous for about 75 miles, its continuation east of the Illinois Valley and north of southern Knox County is uncertain. It marks the front of the Hulick Till Member of the Glasford Formation

Oneida Drift (Willman and Frye, 1970, p. 115)—The Oneida Moraine, named for Oneida, Knox County, is a weak morainic ridge traced for about 15 miles in Knox and Henry Counties.

Williamsfield Drift (Willman and Frye, 1970, p. 115)—The Williamsfield Moraine, named for Williamsfield, Knox County, is a weak morainic ridge that extends southward from Williamsfield for about 7 miles.

Oak Hill Drift (Willman and Frye, 1970, p. 115)—The Oak Hill Moraine, named for Oak Hill, Peoria County, is a continuous ridge extending northwest from the front of the Wisconsinan drift for about 20 miles. It may mark the front of a significant readvance because it is the outer limit of the Radnor Till Member of the Glasford Formation.

Jacksonville Drift (Ekblaw, *in* Ball, 1938, p. 219)—The Jacksonville Moraine, named for Jacksonville, Morgan County, is a discontinuous belt of morainic hills and crevasse deposits, without a well defined front, in Morgan and Montgomery Counties.

Buffalo Hart Drift (Leverett, 1899, p. 74-76)—The Buffalo Hart Moraine, named for Buffalo Hart, Sangamon County, is a broad area of morainic topography, crevasse deposits, and kames. It has the mineral composition of the Radnor Till and probably correlates with the Oak Hill Moraine west of the Illinois Valley.

Wisconsinan (Woodfordian) Drifts

Peoria Sublobe Drifts

The Peoria Sublobe drifts include three morainic systems and 20 individual moraines (figs. Q-9, Q-10). The outermost moraine is part of the Shelbyville Morainic System, already described as being largely in the Erie Lobe, which extends northward in the Peoria Sublobe to Peoria.

Le Roy Drift (Ekblaw, 1941)—The Le Roy Moraine, named for Le Roy, McLean County, is a lobate ridge that is traced for about 70 miles and may represent a significant readvance of the ice that was probably equivalent to the strongly lobate readvance of the Decatur Sublobe glacier that deposited the Cerro Gordo Moraine.

Shirley Drift (Willman and Frye, 1970, p. 98)—The Shirley Moraine, named for Shirley, McLean County, is a minor moraine about 25 miles long.

Kings Mill Drift (Willman and Frye, 1970, p. 98)—The Kings Mill Moraine, named for Kings Mill Creek in McLean County, is a weak morainic ridge extending for only 10 miles near the front of the Bloomington Morainic System.

Bloomington Drifts (Leverett, 1897, p. 19)—The Bloomington Morainic System, named for Bloomington, McLean County, is one of the most prominent morainic features of the Lake Michigan Lobe drift and it forms the front of the Peoria, Princeton, and Harvard Sublobes. The major part of the drift is the pink till of the Tiskilwa Member of the Wedron Formation, which distinguishes it from the older gray tills and the younger yellow-tan tills of Woodfordian age. North of Peoria the system consists of three well defined moraines, but in other places only one or two crests are recognizable. Five ridges are named in the Peoria Sublobe—the Washington, Metamora, Sheffield, Buda, and Providence Moraines.

Washington Drift (Willman and Frye, 1970, p. 99)—The Washington Moraine, named for Washington, Tazewell County, is a minor morainic area back of the main ridge of the Bloomington Morainic System and can be traced for about 10 miles in the southern part of the Peoria Sublobe.

Metamora Drift (Ekblaw, 1941)—The Metamora Moraine, named for Metamora, Woodford County, is a well defined ridge about 10 miles long that probably marks the eastern margin of a narrow lobe that extended into the Illinois River Valley during the final stages of the building of the Bloomington Morainic System.

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Sheffield Drift (MacClintock and Willman, 1959, p. 23)—The Sheffield Moraine, named for Sheffield, Bureau County, is the outermost moraine of the Bloomington Morainic System in the Peoria Sublobe and in the southern part of the Princeton Sublobe. It is about 60 miles long.

Buda Drift (MacClintock and Willman, 1959, p. 23)—The Buda Moraine, named for Buda, Bureau County, is a prominent morainic ridge about 65 miles long that extends from Peoria northward into the Princeton Sublobe. It generally is the middle ridge of the Bloomington Morainic System.

Providence Drift (MacClintock and Willman, 1959, p. 24)—The Providence Moraine, named for Providence, Bureau County, forms the crest of the Bloomington Morainic System and rises as much as 200 feet above the frontal outwash plain. In many areas it has a very rough knob and kettle topography. It is traced from Peoria northeastward for about 125 miles in the Peoria and Princeton Sublobes. It is probably equivalent to the Metamora Moraine east of the Illinois Valley.

Normal Drift (Leighton and Ekblaw, 1932, p. 13)—The Normal Moraine, named for Normal, McLean County, is the first moraine back of the Bloomington Morainic System. It is traced for about 35 miles in the southern part of the Peoria Sublobe, in which area it is the front of the gray to tan silty till differentiated as the Malden Till Member of the Wedron Formation.

Eureka Drift (Willman and Frye, 1970, p. 100)—The Eureka Moraine, named for Eureka, Woodford County, extends for about 100 miles, entirely across the Peoria Sublobe. It formerly was correlated with the Normal Moraine, but it overlaps the Normal and forms the front of the Malden Till Member.

Fletchers Drift (Willman and Frye, 1970, p. 100)—The Fletchers Moraine, named for Fletchers, a railroad siding 3 miles southwest of Cooksville, McLean County, also was formerly included in the Normal Moraine. It has a well defined front and is traced westward from the Gibson City reentrant for about 20 miles.

El Paso Drift (Leighton and Brophy, 1961, fig. 1)—The El Paso Moraine, named for El Paso, Woodford County, previously considered the frontal ridge of the discontinued Cropsey Morainic System, is traced westward from the Gibson City reentrant for about 45 miles.

Varna Drift (Willman and Frye, 1970, p. 100)—The Varna Moraine, named for Varna, Marshall County, was previously part of the discontinued Cropsey Morainic System. The Varna is traced for 40 miles but is eroded at the Illinois River Valley.

Minonk Drift (Willman and Frye, 1970, p. 101)—The Minonk Moraine, named for Minonk, Woodford County, was previously part of the discontinued Cropsey Morainic System. It extends for 65 miles, entirely across the Peoria Sublobe.

Strawn Drift (Willman and Frye, 1970, p. 101)—The Strawn Moraine, named for Strawn, Livingston County, is a weak morainic ridge between the Minonk and Chatsworth Moraines and was previously included in the discontinued Cropsey Morainic System. It is traced for only about 15 miles.

Marseilles Drifts (Leverett, 1897, p. 20)—The Marseilles Morainic System, named for Marseilles, La Salle County, is a massive ridge that generally exhibits a distinct lower frontal ridge. The frontal ridge is not continuous; the north part is named Norway and the south part Cullom. The higher, continuous crest is differentiated as the Ransom Moraine. The Ransom is largely greenish gray clayey till, which is part of the Yorkville Till Member of the Wedron Formation. It forms the innermost drift of the Peoria Sublobe and extends entirely across the sublobe.

Norway Drift (Willman and Frye, 1970, p. 102)—The Norway Moraine, named for Norway, La Salle County, extends for about 40 miles along the front of the northern part of the Marseilles Morainic System.

Cullom Drift (Leighton and Brophy, 1961, fig. 1)—The Cullom Moraine, named for Cullom, Livingston County, occupies a position similar to that of the Norway Moraine for about 35 miles along the southern part of the Marseilles Morainic System.

Ransom Drift (Willman and Frye, 1970, p. 102)—The Ransom Moraine, named for Ransom, La Salle County, forms the main crest of the Marseilles Morainic System and is traced for about 100 miles.

Green River and Dixon Sublobes Drifts

Because of their position outside the Bloomington Morainic System, the drifts of the Green River and Dixon Sublobes (figs. Q-9, Q-10) are probably equivalent to the Shelbyville Drift in the Decatur and Peoria Sublobes. The Woodfordian drift is thin, and only three areas of morainic topography along the margins of the sublobes are named.

Temperance Hill Drift (Willman and Frye, 1970, p. 103)—The Temperance Hill Moraine, named for Temperance Hill School, 3 miles northwest of Lee Center, Lee County, is a ridge traced for about 12 miles along the northern side of the Green River Sublobe.

Atkinson Drift (Willman and Frye, 1970, p. 103)—The Atkinson Moraine, named for Atkinson, Henry County, consists of patches of morainic hills along the southern side of the Green River Sublobe.

Harrisville Drift (Willman and Frye, 1970, p. 102)—The Harrisville Moraine, named for Harrisville, Winnebago County, extends for about 10 miles along the north side of the Dixon Sublobe.

Princeton Sublobe Drifts

The Princeton Sublobe (figs. Q-9, Q-10) includes one morainic system, 16 named moraines, and one complex—an area with variously oriented morainic ridges. The pink sandy till of the Tiskilwa Till Member of the Wedron Formation characterizes the outer part of the drift, followed successively eastward by the gray-tan silty till of the Malden Till Member and the gray clayey till of the Yorkville Till Member.

Bloomington Drifts—The southern moraines of the Bloomington Morainic System, the Sheffield, Buda, and Providence Moraines that were previously described for the Peoria Sublobe, extend northward into the Princeton Sublobe, but five other moraines are differentiated locally in the system in the Princeton Sublobe—the Shaws, Van Orin, Theiss, La Moille, and Paw Paw Moraines—all of which consist largely of the pink till of the Tiskilwa Till Member.

Shaws Drift (Willman and Frye, 1970, p. 105)—The Shaws Moraine, named for Shaws, Lee County, is the outermost ridge of the Bloomington Morainic System, occupying a position in the northern part of the sublobe similar to that of the Sheffield Moraine farther south. It has been traced for about 25 miles.

Van Orin Drift (Willman and Frye, 1970, p. 105)—The Van Orin Moraine, named for Van Orin, Bureau County, is a well defined ridge but is traced for only about 10 miles before it blends into the back slope of the Providence Moraine.

Theiss Drift (Willman and Frye, 1970, p. 105)—The Theiss Moraine, named for Theiss Cemetery, 3 miles southwest of Sublette, Lee County, is a distinct ridge for about 16 miles, but it, too, blends into the back slope of the Providence Moraine.

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La Moille Drift (Willman and Frye, 1970, p. 105)—The La Moille Moraine, named for La Moille, Bureau County, is a narrow ridge that is traced for about 50 miles. In its southern part it separates from the Bloomington Morainic System.

Paw Paw Drift (Willman and Frye, 1970, p. 106)—The Paw Paw Moraine, named for Paw Paw, Lee County, is the inner moraine of the northern part of the Bloomington Morainic System and is traced for about 50 miles. It is a prominent moraine that, southward, separates from the Bloomington Morainic System, and in part of that area it has a thin overlapping cover of yellow-tan till of the Malden Till Member.

Shabbona Drift (Willman and Frye, 1970, p. 106)—The Shabbona Moraine, named for Shabbona, De Kalb County, is a weakly morainic area about 18 miles long that consists largely of a thin deposit of the Malden Till Member. It marks a major readvance of the ice front.

Dover Drift (Cady, 1919b, p. 24, 81)—The Dover Moraine, named for Dover, Bureau County, is traced for about 12 miles. It marks the front of the Malden Till Member and is probably equivalent to the Shabbona Moraine, but cannot be traced directly to it.

Arispie Drift (Willman and Frye, 1970, p. 106)—The Arispie Moraine, named for Arispie Township, Bureau County, is an east-west ridge only 4 miles long, eroded at the Illinois River Valley, but it probably is a connecting link between the Varna Moraine in the Peoria Sublobe and the Dover Moraine in the Princeton Sublobe.

Arlington Drift (Cady, 1919b, p. 24, 81)—The Arlington Moraine, named for Arlington, Bureau County, is a prominent moraine that is traced northeastward from the Illinois River Valley for 55 miles.

Mt. Palatine Drift (Leighton and Brophy, 1961, fig. 1)—The Mt. Palatine Moraine, named for Mt. Palatine, Putnam County, is a prominent ridge on the south side of the Princeton Sublobe, where it is traced for about 15 miles. It probably correlates with the Arlington Moraine on the north side of the lobe.

Mendota Drift (Willman and Frye, 1970, p. 107)—The Mendota Moraine, named for Mendota, La Salle County, is a weakly morainic ridge that can be traced on the back slope of the Arlington Moraine for about 40 miles.

Farm Ridge Drift (Leverett, 1899, p. 260)—The Farm Ridge Moraine is named for Farm Ridge, which is now called Grand Ridge, La Salle County. It has a lobate configuration and extends for 35 miles north of the Illinois River Valley and for 15 miles south of the valley.

Elburn Drift (Willman and Frye, 1970, p. 107)—The Elburn Complex, named for Elburn, Kane County, is an area of variously oriented morainic ridges, kames, eskers, and lake basins at the junction of the Princeton and Harvard Sublobes.

St. Charles Drift (Willman and Frye, 1970, p. 108)—The St. Charles Moraine, named for St. Charles, Kane County, is a weakly morainic area traced for 25 miles from the front of the Marseilles Morainic System to the northern part of the Minooka Moraine. It marks the front of the very clayey till characteristic of the Yorkville Till Member.

Harvard Sublobe Drifts

The Harvard Sublobe (figs. Q-9, Q-10) includes six moraines that have a slightly westward bulge north of the Princeton Sublobe. They consist of the Tiskilwa, Malden, Yorkville, and Haeger Till Members of the Wedron Formation.

Marengo Drift (Leverett, 1899, p. 290)—The Marengo Moraine, named for Marengo, McHenry County, is a massive moraine that is largely pink till. It extends southward from the Wisconsin state line for about 40 miles, terminating at the Elburn Complex.

Gilberts Drift (Leighton and Ekblaw, 1932, p. 48)—The Gilberts Moraine, named for Gilberts, Kane County, is a low area about 30 miles long behind the Marengo Moraine and is largely pinkish gray till, gravel, and lacustrine sediments. It is assigned to the Malden Till Member, but it is pinker than the Malden in the Princeton Sublobe.

Huntley Drift (Leighton and Willman, 1953, p. 53)—The Huntley Moraine, named for Huntley, McHenry County, is a low, discontinuous ridge about 8 miles long that is largely till of the Yorkville Till Member.

Barlina Drift (Willman and Frye, 1970, p. 109)—The Barlina Moraine, named for Barlina Road, northwest of Lake-in-the-Hills, McHenry County, is a rough-surfaced ridge about 16 miles long, which, like the Huntley, consists largely of till of the Yorkville Till Member.

Valparaiso Drifts (Leverett, 1897, p. 26)—The Valparaiso Morainic System is largely in the Joliet Sublobe, but the West Chicago and Cary Moraines curve northwestward into the Harvard Sublobe, and the drifts are part of the Haeger Till Member.

Joliet Sublobe Drifts

The Joliet Sublobe (figs. Q-9, Q-10) consists of the moraines that trend essentially parallel to the Lake Michigan shore. The lobe contains two morainic systems and 19 named moraines. The moraines in the northwest part of the lobe consist of the gravelly till of the Haeger Till Member, but the others are gray clayey till of the Yorkville and Wadsworth Till Members.

Minooka Drift (Leverett, 1897, p. 20)—The Minooka Moraine, named for Minooka, Grundy County, forms the outer ridge of the Joliet Sublobe for about 50 miles. It ends at the head of Illinois River, where its southward extension was widely eroded by the Kankakee Flood. It is mainly the gray clayey till of the Yorkville Till Member.

Rockdale Drift (Fisher, 1925, p. 87)—The Rockdale Moraine, named for Rockdale, Will County, has a well defined front for 15 miles north of the Des Plaines River Valley and is represented by isolated, weakly morainic areas for 25 miles south of the valley.

Wilton Center Drift (Willman and Frye, 1970, p. 110)—The Wilton Center Moraine, named for Wilton Center, Will County, is traced for about 35 miles, from the vicinity of the Des Plaines Valley to the Indiana state line.

Manhattan Drift (Fisher and Ekblaw, *in* Fisher, 1925, p. 89)—The Manhattan Moraine, named for Manhattan, Will County, extends southward from Joliet for about 20 miles.

Valparaiso Drifts—The part of the Valparaiso Morainic System that is in the Joliet Sublobe is a complex of morainic ridges representing temporary stands of the ice front during the building of the system. Many ridges are indistinctly traced through parts of the complex but are undifferentiated in other parts. The Valparaiso Drift includes a buried drift of questionable age, informally called the Lemont drift (Bretz, 1955), which consists of yellow-gray silty till, sand and gravel, and dune sand, highly contorted in places. The Lemont drift occurs locally in the Worth, Sag Bridge, and Lemont areas in Cook County. It may be Woodfordian in age, but a leached zone on the gravel has been interpreted as possibly being the Sangamon Soil (Horberg and Potter, 1955) or the Farmdale Soil (Frye and Willman, 1970). It was tentatively assigned to the Winnebago Formation (Willman, 1971).

West Chicago Drift (Leighton, 1925, p. 69)—The West Chicago Moraine, named for West Chicago, Du Page County, forms the frontal ridge of the Valparaiso Morainic System from the Wisconsin border to the Indiana state line, about 100 miles. It is a rough-surfaced, gravelly moraine in the north but is more clayey south of West Chicago.

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Cary Drift (Leighton, 1925, p. 69)—The Cary Moraine, named for Cary, McHenry County, occurs in both the Harvard Sublobe and the northern part of the Joliet Sublobe. It is about 30 miles long and consists of gravelly till assigned to the Haeger Till Member.

Fox Lake Drift (Powers and Ekblaw, 1940, p. 1331)—The Fox Lake Moraine, named for the town of Fox Lake, Lake County, is a kame-moraine traced for about 25 miles south from the Wisconsin state line. Most of it is gravel, and it is assigned to the Haeger Till Member, although the till in places is clayey and more like that in the Wadsworth Till Member.

Wheaton Drift (Ekblaw, *in* Suter et al., 1959, fig. 5)—The Wheaton Moraine, named for Wheaton, Du Page County, is traced for about 60 miles. It may be equivalent to the Cary Moraine, but cannot be traced in the intervening area.

Keeneyville Drift (Ekblaw, *in* Suter et al., 1959, fig. 5)—The Keeneyville Moraine, named for Keeneyville, Du Page County, is traced for about 40 miles. Its position in the Valparaiso Morainic System is similar to that of the Fox Lake Moraine farther north.

Roselle Drift (Ekblaw, *in* Suter et al., 1959, fig. 5)—The Roselle Moraine, named for Roselle, Du Page County, is a narrow ridge traced for about 10 miles.

Palatine Drift (Powers and Ekblaw, 1940, p. 1331)—The Palatine Moraine, named for Palatine, Cook County, is a relatively weak moraine traced for about 18 miles.

Westmont Drift (Willman and Frye, 1970, p. 112)—The Westmont Moraine, named for Westmont, Du Page County, is a poorly defined moraine traced for about 40 miles.

Clarendon Drift (Leighton, *in* Leighton and Willman, 1953, pl. 3)—The Clarendon Moraine, named for Clarendon Hills, Du Page County, is a poorly defined moraine traced for about 25 miles. It is the innermost moraine of the Valparaiso Morainic System.

Tinley Drift (Leighton and Ekblaw, 1932, p. 15; Bretz, 1939, p. 50)—The Tinley Moraine, named for Tinley Park, Cook County, the first moraine back of the Valparaiso Morainic System, extends from Wisconsin to Indiana, about 80 miles. It has a well defined front, except in the 25 miles south of the Wisconsin state line where it overlaps the Valparaiso Morainic System.

Lake Border Drifts (Leverett, 1897, p. 42)—The Lake Border Morainic System, named for its position near the shore of Lake Michigan, consists of five closely spaced moraines that are parallel except near the Wisconsin state line where they somewhat overlap. The moraines all consist of the gray clayey till of the Wadsworth Till Member.

Park Ridge Drift (Bretz, 1939, p. 55)—The Park Ridge Moraine, named for the city of Park Ridge, Cook County, is the outermost ridge of the Lake Border Morainic System and is traced from the Wisconsin state line southward for about 40 miles, where it ends at the Lake Chicago Plain. It recurs 12 miles farther south in an isolated segment at Blue Island.

Deerfield Drift (Bretz, 1939, p. 55)—The Deerfield Moraine, named for Deerfield, Lake County, is traced about 30 miles.

Blodgett Drift (Bretz, 1939, p. 56)—The Blodgett Moraine, named for Blodgett, Lake County, is traced for about 20 miles.

Highland Park Drift (Bretz, 1939, p. 56)—The Highland Park Moraine, named for Highland Park, Lake County, is traced for about 30 miles. The moraine terminates at the Lake Chicago Plain and the Lake Michigan beach.

Zion City Drift (Ekblaw, *in* Suter et al., 1959, fig. 5)—The Zion City Moraine, named for Zion (formerly called Zion City), Lake County, consists of patches of weak morainic topography near the Wisconsin state line. It is eroded at the Lake Michigan beach and is the youngest moraine in Illinois.

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Names of certain organizations, journals, and series that are frequently cited are abbreviated more than is conventional, as follows:

AAAS—American Association for the Advancement of Science
AAPG—American Association of Petroleum Geologists
AJS —American Journal of Science
B —Bulletin
C —Circular
EGN —Environmental Geology Notes
GS —Geological Survey
GSA —Geological Society of America
J —Journal
JG —Journal of Geology
RI —Report of Investigations
USGS —United States Geological Survey

Other abbreviations are explained in *The Bibliography and Index of Illinois Geology Through 1965*, Illinois Geological Survey Bulletin 92.

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Appendix 14

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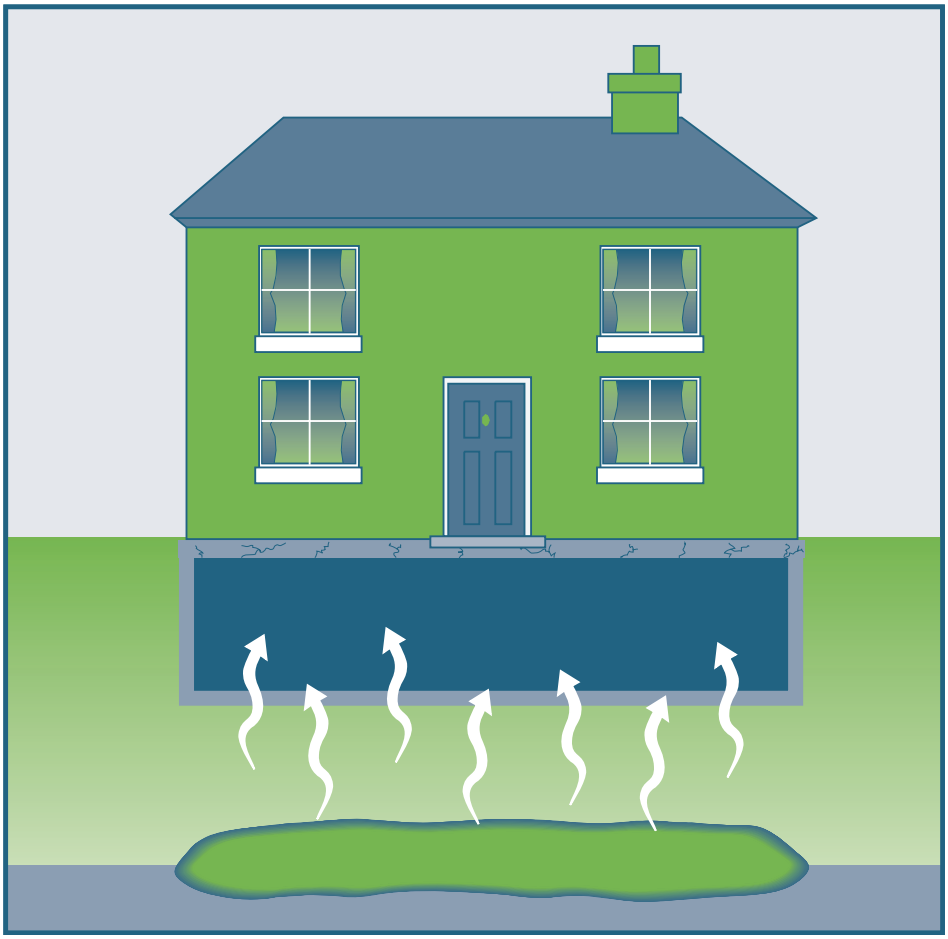
Technical and Regulatory Guidance

Vapor Intrusion Pathway: A Practical Guideline



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Prepared by
The Interstate Technology & Regulatory Council
Vapor Intrusion Team

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A Practical Guideline

January 2007

Prepared by
The Interstate Technology & Regulatory Council
Vapor Intrusion Team

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- Blayne Hartman, H&P Mobile Geochemistry
- Harley Hopkins, American Petroleum Institute
- Alana Lee, U.S. Environmental Protection Agency Region 9
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- Denise Miller, ARCADIS
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EXECUTIVE SUMMARY

This guideline was developed by the Interstate Technology & Regulatory Council (ITRC) Vapor Intrusion Team and represents the combined effort of more than 100 professionals from state and federal regulatory agencies, consultants, industry, and stakeholders. It is a practical, easy-to-read, how-to guideline for assessing the vapor intrusion pathway. Supplemental information is contained in appendices and in a companion document, *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios* (VI-1A) to assist the practitioner when using the guideline. Due to variations in policy among regulatory agencies, this document does not provide a single prescriptive approach for assessing the vapor intrusion pathway. Rather, the purpose of this guideline is to provide a generalized framework for evaluating the pathway and a description of the various tools available for investigation, data evaluation, and mitigation. The guideline is intended to be used in conjunction with any applicable federal or state vapor intrusion policy or guidance.

The ITRC *Vapor Intrusion Pathway* guidance series consists of two documents—this *Practical Guideline* and its supplement, *Investigative Approaches for Typical Scenarios*. This document, *A Practical Guideline*, consists of four chapters:

1. An overview of vapor intrusion
2. Preliminary screening of sites
3. Site investigation
4. Mitigation

Chapter 1 provides basic information on the vapor intrusion pathway. Although the document is written for the environmental professional who has some general knowledge of vapor intrusion, it is still important to discuss the essential key points that must be understood to investigate and mitigate the pathway. Thus, Chapter 1 touches on conceptual site models, multiple lines of evidence, background contamination, preferential pathways, and community outreach.

The framework of the document presents a 13-step approach that leads the investigator from Step 1 (Is there an acute exposure?) to Step 13 (Is mitigation warranted?), using a lines-of-evidence approach. The first seven steps (Chapter 2) apply to the screening of sites based upon preexisting conditions and data. The user is prompted to consider whether adequate data are available for screening, whether volatile and toxic compounds are present in the subsurface near buildings, and whether concentrations of these compounds exceed any applicable screening levels. Discussions on issues applicable to the preliminary screening process, such as development of screening levels and building design considerations, are included as appendices.

Unless the vapor intrusion pathway is determined to be incomplete during the preliminary screening steps, six steps follow that describe the vapor intrusion investigative process (see Chapter 3). The process begins with selection of an investigation strategy and development of a work plan, followed by execution of the work plan, and ending with an evaluation of the need for mitigation. Chapter 3 is augmented by detailed appendices (e.g., Appendix D. Toolbox), which

give a comprehensive treatment of the investigatory methods used for vapor intrusion assessments. Methods include groundwater sampling, active and passive soil gas sampling, subslab soil gas sampling, indoor air sampling, and supplemental tools such as flux chambers and forensics. Summary tables, charts, and checklists facilitate the use of the methods described in the toolbox.

Chapter 4 provides a comprehensive treatment of mitigation strategies. This chapter begins with an overview of three general approaches to addressing vapor intrusion—site remediation, institutional controls, and building mitigation. While the chapter focuses on building mitigation, it does include discussions on the differences between site remediation and building mitigation. The chapter also provides a description of eight building mitigation approaches, each including technology selection, design and installation considerations, operation, maintenance, performance monitoring, and mitigation system closure. Summary tables comparing the various options and costs are included.

Appendices include checklists for conceptual site models and reviewing soil gas data, a discussion of building types, a toolbox of investigative methods, quality assurance considerations, guidance for development of screening levels, an indoor air survey form, and a discussion of community stakeholder concerns. An extensive reference list is also included.

To illustrate how to use this *Practical Guideline* document, the Vapor Intrusion Team has also prepared a companion document. *Investigative Approaches for Typical Scenarios* describes applicable approaches for evaluating the vapor intrusion pathway under the following scenarios:

1. An active service station in a residential neighborhood
2. A dry cleaner in a strip mall adjacent to a neighborhood
3. A large industrial facility with a groundwater plume under several hundred receptors
4. A vacant lot with proposed brownfield development over a groundwater plume
5. A vacant large commercial building with warehouse space and office space
6. An apartment building with a parking garage over contamination

The scenarios follow the step-by-step approach described in the guidance document, focus on the decision process and alternatives chosen, identify key issues about each scenario, highlight lessons learned during process, and describe the next steps to be followed.

The ITRC *Vapor Intrusion Pathway* guidance series provides the reader with a logical, flexible framework, the variety of tools and remedial approaches, and the practical rationale for developing an investigative strategy when assessing vapor intrusion. Working within the regulatory framework, this difficult and ever-evolving pathway can be properly evaluated and the risks associated with indoor air contamination from vapor intrusion effectively mitigated.

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1. STRATEGIC OVERVIEW

This section provides a brief overview of the vapor intrusion pathway—the typical model and special factors that influence soil gas movement, the phased approach to investigation and remediation, the interpretation of the data, multiple lines of evidence, and interaction with the local community through a site-specific outreach program. Regulatory issues are identified, and key considerations are summarized for assessing the vapor intrusion pathway.

1.1 Introduction

Vapor intrusion is the migration of volatile chemicals from the subsurface into overlying buildings (USEPA 2002b). Volatile chemicals may include volatile organic compounds, select semivolatile organic compounds, and some inorganic analytes, such as elemental mercury and hydrogen sulfide. Methane should be considered where it is appropriate.

Degradation of indoor air quality causes more apprehension and anxiety among building occupants than are typically associated with other environmental problems. In a residential community, these concerns over vapor intrusion are often magnified. Regulators commonly encounter a series of questions from concerned occupants such as the following:

- Is the air that our children breathe safe, not only in our houses, but outside and in our local school or day care?
- What effect will this contamination have on our property values?

These concerns often become “hot button” issues, at times driving the strategy that regulators will take in addressing the vapor intrusion pathway. Public education and community outreach are crucial to how people react to a potential finding of vapor intrusion.

Why has vapor intrusion become such a significant environmental issue for regulators, industry leaders, and concerned residents alike? For more than a decade, environmental scientists and risk assessors viewed contaminated groundwater as a threat principally to the drinking water supply. As long as individuals didn’t drink the water, the risk of exposure to the contamination was believed eliminated. It wasn’t until investigative work of the Massachusetts Department of Environmental Protection (MassDEP) in the 1990s that regulators began to understand the significance of vapor intrusion. State and federal regulators are now in the process of examining older remedial decisions involving groundwater contamination to assess whether the vapor intrusion pathway warrants reopening closed cases. A multidisciplinary team can best evaluate and discuss the occurrence and potential impacts of the vapor intrusion pathway.

In addition, most other exposure pathways are assessed using “exterior” investigative tools to characterize and delineate contamination. While the actions to characterize and remediate contaminated groundwater or sediments may be apparent to the community, they typically are not invasive to the personal lives of individuals. Vapor intrusion, on the other hand, may involve the collection of environmental samples inside or immediately outside a structure. Thus, the process of investigating the vapor intrusion pathway often directly affects occupants.

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For example, the Redfield site in Colorado was one of the first major sites to bring the vapor intrusion issue to the attention of the U.S. Environmental Protection Agency (USEPA) and the nation in the late 1990s. Relatively low concentrations of 1,1-dichloroethene (1,1-DCE) in groundwater were found to have impacted indoor air in a large number of homes overlying the solvent plume. Indoor air testing was required in almost 800 homes and apartments at the Redfield site, leading to mitigation of almost 400 residential buildings. Subsequent monitoring of both mitigated and unmitigated homes has continued over the past eight years, resulting in more than 7000 indoor air tests to date in the site vicinity. The essential interaction with residents in this neighborhood is extensive and ongoing.

Finally, vapor intrusion is a significant issue to building occupants due to the personal public health concerns related to the degradation of indoor air quality. While a health officer can provide bottled water for occupants to drink when potable water has been contaminated, what can be done when contaminants from vapor intrusion are found in the air of their buildings?

1.2 Conceptual Model for Vapor Intrusion

Vapor intrusion is typically conceptualized as shown Figure 1-1. Chemicals volatilize from impacted soil and/or groundwater beneath a building and diffuse toward regions of lower chemical concentration (e.g., the atmosphere, conduits, basements). Soil gas can flow into a building due to a number of factors, including barometric pressure changes, wind load, thermal currents, or depressurization from building exhaust fans. The rate of movement of the vapors into the building is a difficult value to quantify and depends on soil type, chemical properties, building design and condition, and the pressure differential. Upon entry into a structure, soil gas mixes with the existing air through the natural or mechanical ventilation of the building. While Figure 1-1 schematically depicts houses and commercial/industrial buildings, other structures (e.g., apartments, schools) also can be of concern. This guidance is generally applicable to all building scenarios.

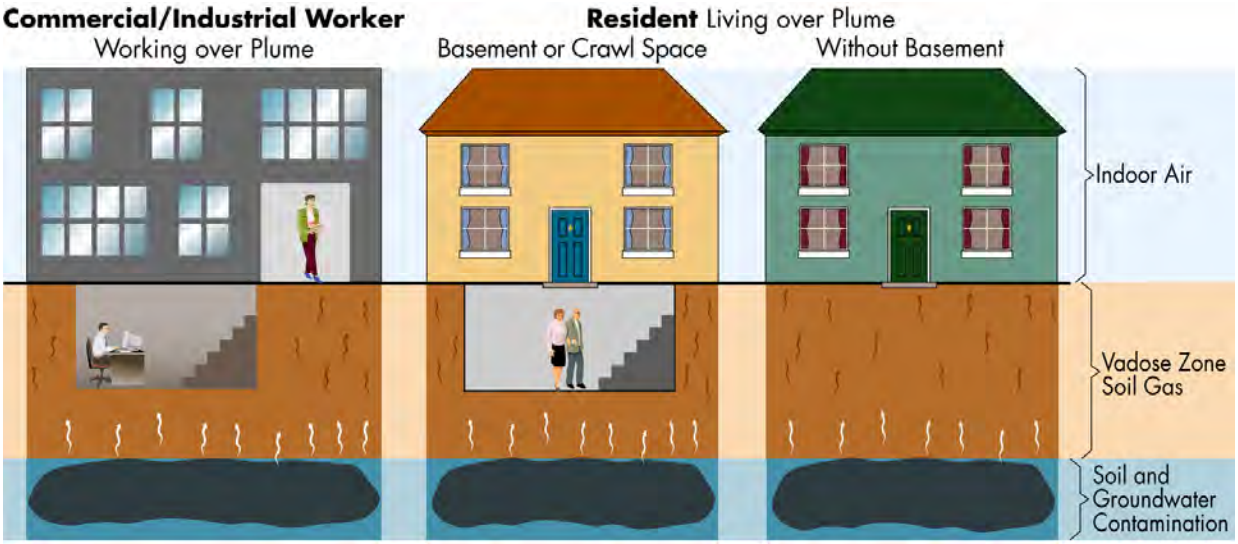

Figure 1-1. Typical conceptual model of vapor intrusion.

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Both diffusion and advection are mechanisms of transport of subsurface soil gas into the indoor air environment. Diffusion is the mechanism by which soil gas moves from high concentration to low concentration due to a concentration gradient. Advection is the transport mechanism by which soil gas moves due to differences in pressure. These pressure differences can be generated by atmospheric pressure changes, temperature changes creating natural convection in the soil, or forced pressure changes due to building ventilation systems. Advective transport is likely to be the most significant in the region very close to a basement or a foundation, and soil gas velocities decrease rapidly with increasing distance from the structure (USEPA 2004b). Once soil gases enter the "building zone of influence," they are generally swept into the building through foundation cracks by advection due to the indoor-outdoor building pressure differential. The reach of the "building zone of influence" on soil gas flow is usually less than a few feet, vertically and horizontally.

A good source of information on the conceptual model and the migration of soil gas in the subsurface can be found in the New Jersey Department of Environmental Protection (NJDEP) *Vapor Intrusion Guidance* (2005b). For additional references, see the Vapor Intrusion Resources and Links page on the Interstate Technology & Regulatory Council (ITRC) Web site (www.itrcweb.org/vaporintrusion).

1.3 Defining the Pathway

To define the vapor intrusion pathway as a complete exposure pathway, a source, migration route, and receptor must be identified (Figure 1-2). Specifically, this assessment entails the identification of all known or suspected vapor sources of contamination; consideration of the contaminant migration routes (mobility) including an evaluation of methods and manner of access, and identification of those likely to be affected by the contaminants (receptors).

The physical source of the contamination should be determined. The initial or primary sources (e.g., a leaking tank or a surface spill) or secondary sources (e.g., contaminated soil gas, soil, or groundwater) may assist in the vapor intrusion investigation. Factors in identifying likely sources include the following:

- product type, chemical composition, and location of contamination
- contaminated media
- constituents of interest present in each medium
- distribution and concentrations of contaminants in each medium

The type and location of the release can be determined by evaluating previous industrial processes employed at a site and historical site use information. The historical data can indicate chemicals used and storage locations. Also, preliminary sampling may yield analytical results that would clarify the type and location of release.

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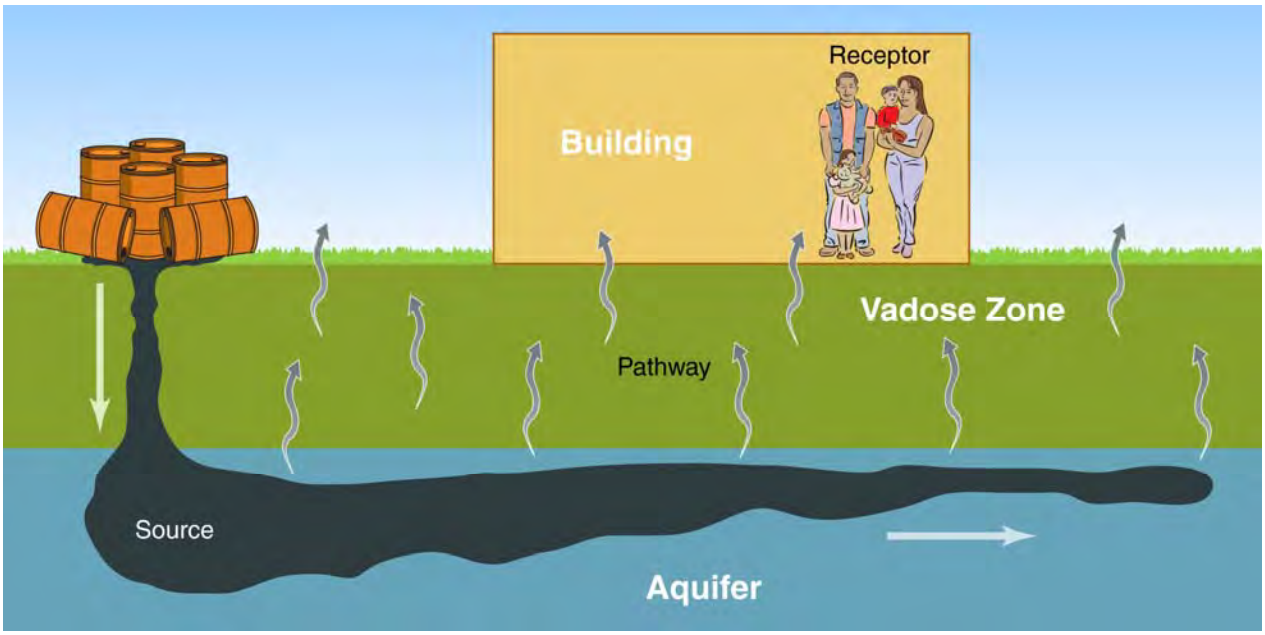

Figure 1-2 Potential source, migration route, and receptor for vapor intrusion.

The movement of contaminants from the source to the receptor is a complicated process in the vapor intrusion pathway. Building depressurization may cause soil gas from soil and/or groundwater contamination to be drawn into buildings through holes and cracks in the foundation. Heating systems, basements, and strong winds promote vapor intrusion into buildings by reducing the internal air pressure and creating a vacuum effect that enhances advective flow from underlying soils and/or groundwater into buildings ("the stack effect").

Receptors are the people that may be exposed to the site related contaminants. Typical receptors include adults and children exposed in a residential setting, adults exposed in an occupational environment, and adults and children exposed in a nonresidential setting. Other site-specific exposure scenarios (e.g., schools, day care facilities) may be identified.

Identification of possible receptors can be determined using the locality of the facility data, land use data, and demographics. Specific considerations might include the following:

- future site use and surrounding area use
- utilities in the area
- zoning criteria (commercial, industrial, residential, and industrial) and zoning exceptions (e.g., commercial zones that allow residential, multifamily residential, second-story residential)—some industrial zones allow a caretaker to live on the site; other commercial zones allow unique uses, such as day care facilities
- land use constraints
- site vicinity and conditional uses typically allowed

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1.4 General Framework for Vapor Intrusion Investigations

For the vapor intrusion pathway to be complete, there must be three components—a source of volatile compounds in the subsurface environment (groundwater and/or soil), inhabited buildings or the potential for future inhabited buildings, and a migration route to connect them (as discussed above). Once the pathway is identified, a "phased" approach is recommended to evaluate whether exposures present significant risk to the receptors, as defined by the regulatory agencies. Where there are obvious signs of vapor intrusion, such as odors or explosive hazards, these potential acute risks should be addressed immediately. For probable chronic exposure, the site may be evaluated on either a generic or site-specific basis in a timely manner. However, there may be precluding factors that limit the use of a generic screen (e.g., wet basements, sumps).

This section presents a general framework for evaluating vapor intrusion from subsurface media contamination that builds on the premise of conservative but flexible guidance, within the confines of the regulatory agency. Ultimately, the intent is to be able to differentiate sites where the pathway presents or does not present an unacceptable risk, while erring on the side of caution when there is uncertainty.

Some key principles that guide this framework are summarized below, with further detail in Chapters 2 and 3:

- implementation of a community outreach program that provides timely information to concerned citizens and property owners
- use of a phased approach that allows for the collection and use of both generic and site-specific information/data
- development of an accurate conceptual site model (CSM) that is representative of site conditions to assist with the investigative strategy and ensure proper use of the data
- application of an iterative process (i.e., starts with available data and collects additional data only to meet the needs of making informed decisions)
- allowance for a site-specific evaluation using modeling, soil gas sampling, indoor air sampling, or mitigation at any point in the process
- evaluation of multiple lines of evidence that result in decisions based on professional judgment
- consideration of current and future site use
- use of screening levels based on the appropriate exposure scenario (e.g., residential, nonresidential, occupational) consistent with the regulatory agency

1.5 Lines of Evidence

Attribution of chemicals in indoor air to vapor intrusion can become a relatively complex and difficult task. It is important to use multiple lines of evidence to reach decisions based on professional judgment. The following are some lines of evidence, listed in no particular order:

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- soil gas spatial concentrations, including subslab and exterior (some distance outside the perimeter of the foundations) soil gas data with some level of vertical profiling, if appropriate (see Appendix D)
- groundwater spatial data, with vertical profiling, if appropriate (see Appendix D)
- background, internal and external, sources (see Section 1.6.1)
- building construction and current conditions (see Appendix C)
- subslab (or crawl-space) soil gas data
- indoor air data (see Section 3.7.3)
- concurrent outdoor air data (see Section 3.7.3)
- constituent ratios (see Section 3.7.3)

Other lines of evidence may be available depending on the site-specific circumstances. Conversely, regulatory frameworks of individual states may limit the ability to use some or all of these lines.

In addition to using a phased approach, it is recommended that all available data (e.g., analytical results, building type, and ventilation rates) be used in making a determination about whether vapor intrusion is occurring and whether there are potential health concerns as a result. It should be noted there will likely be some uncertainty associated with such an assessment, regardless of the number of lines of evidence considered. Decisions should be made in consultation with the regulatory agency and based on what professional judgment deems to be reasonable and logical for the specific site.

Soil Gas and Soil Vapor
In many vapor intrusion guidance documents, "soil gas" and "soil vapor" are used interchangeably. In this document, "soil gas" refers to the gaseous elements and compounds in the small spaces between particles of soil. Once the gaseous elements or compounds migrate into a structure, they are referred to as "vapor."

It is important to point out there may be multiple sources of chemicals affecting the overall quality of the indoor air that may not be associated with the investigated chemical release, confounding the interpretation of indoor air sample results. These other sources may be from building materials, heating/cooling energy sources, residual volatile components of stored items, household activities (cooking/cleaning), and consumer products used in the building or background contaminants from ambient outdoor air (Locus Technologies 2006). Thus, indoor air sampling is generally recommended only after identifying the buildings most likely to be impacted to limit the difficult task of evaluating the data and avoiding false positive results.

1.6 Special Factors Influencing Vapor Intrusion Assessments

Numerous conditions may be important considerations either in addition to or instead of the typical conceptual model. Several are described briefly in the subsections below.

1.6.1 Background Air Concentrations

Indoor air quality often contains measurable concentrations of volatile and semivolatile compounds from household activities, consumer products, building materials, and outdoor air sources. In some cases, these background contributions exceed health-based target

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concentrations, especially for benzene, where background indoor air quality often represents an incremental cancer risk greater than 10^{-5} (one in one hundred thousand) for a residential scenario. It is generally advisable to obtain outdoor ambient air samples when collecting indoor air samples. In this way, outdoor air quality can act as a baseline, to which interior and subsurface sources are additive. In many cases, the site-specific chemicals of concern (COCs) may be limited to a few chemicals, which may not be present at significant background levels, so it may be possible to conduct indoor air monitoring for a target list of analytes and avoid complications associated with background contributions. Otherwise, a forensic analysis may be required to assess the relative contribution from subsurface and background sources, possibly requiring multiple lines of evidence and multiple methods of interpretation. Several studies (NJDEP, MassDEP, New York State Department of Health [NYSDOH]) of indoor air quality at homes unaffected by subsurface contamination are currently being conducted to provide a statistical basis for assessing background air quality. Data from such studies should prove to be valuable as one line of evidence, although personal preferences and consumer products will vary between properties. Information on New York State's background database studies can be found at www.health.state.ny.us/nysdoh/gas/svi_guidance/svi_appendc.htm.

Prior to indoor air sampling, efforts should be made to address sources of background contamination. Some background sources will occur on a fairly constant basis and are difficult to eliminate (e.g., off-gassing from furniture and treated wood surfaces, volatiles released from long-term stored chemicals or fuels). However, other sources are intermittent and have the potential to skew the data (e.g., cigarette smoke, off-gassing from dry cleaning, exhaust from attached garages). Even a simple activity like a hot shower can strip volatiles from the water, producing a spike in the concentrations of trihalomethanes. It is appropriate to conduct a building walkthrough in advance of any interior sampling events to identify potential background sources, eliminate them, and educate the occupants on those activities that should be avoided immediately before and during the sample collection. A sample building survey form can be found in Appendix G.

1.6.2 Biodegradation

Many hydrocarbons (notably petroleum-based hydrocarbons) are readily degraded to carbon dioxide (CO_2) in the presence of oxygen (O_2) by ubiquitous soil microbes. Oxygen is supplied from the atmosphere by vapor diffusion and barometric pumping and as a dissolved solute in infiltrating rainwater. Aerobic degradation is a rapid process and frequently occurs in a relatively thin (a few feet thick) zone where the concentrations of O_2 and hydrocarbons are most ideal for microbial processes. The bioattenuation of hydrocarbons can potentially reduce soil gas concentrations and vapor intrusion by several orders of magnitude.

Like petroleum hydrocarbons, chlorinated solvents also can be biodegraded, but the process tends to occur under anaerobic conditions and is slower than aerobic degradation of petroleum hydrocarbons like benzene, toluene, ethylbenzene, and xylenes (BTEX). In both cases, degradation occurs via oxidation-reduction reactions that are used by the microbes as an energy source.

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For vapor intrusion studies, the importance of biodegradation of chlorinated solvents is that additional compounds of interest are created, with obvious implications for selecting target compounds. These daughter compounds may be considered worse than the parent compound because of increased carcinogenicity.

1.6.3 Preferential Pathways

Spatially, the permeability of subsurface materials can be highly variable. Conditions such as fractured geologic media and gravel lenses or channels may allow an atypical preferential soil gas flow through high-permeability pathways (in some cases opposite to the groundwater flow). If such a migration route connects a source directly to a building or allows higher levels of groundwater contamination to migrate under a building, vapor intrusion may be exacerbated.

Most buildings have subsurface utility penetrations, so their presence alone is not considered "preferential." For this guidance (consistent with the vapor intrusion pathway in general and the Johnson and Ettinger [J&E] model specifically), some increased component of soil gas flow into the building is usually required to consider the pathway to be preferential. Anthropogenic preferential pathways include building sumps or drainage pits (that can serve as conduits for soil gas to enter buildings) or subsurface utility conduits or drains (that intersect vapor sources or soil gas migration routes and a building foundation). Natural preferential pathways include vertically fractured bedrock where the fractures are interconnected and in direct contact with the building foundation and the vapor contaminant source. Interestingly, the Georgia Environmental Protection Division had a case where rodent tracks or tunnels up to a building foundation allowed vapors to migrate into a basement.

Elevator Shafts
Elevators may constitute a vertical preferential pathway into a building since they may be constructed with subbasement perforations to allow water to drain. Elevators may also allow vapor impact on unexpected floors due to vertical migration up the shaft.

In addition, investigators must consider that preferential pathways may not be apparent based on external building inspections. According to Henry Schuver (USEPA), some communities with unexpectedly high concentrations of indoor contaminants were observed during indoor surveys to have uncapped pipes through the basement floor connected to "dry wells" designed to dispose of fluids through openings surrounded by very permeable fill materials. Thus, they served as preferential pathways by allowing an unexpected amount of vapor to migrate into the structures.

Another example is waste lines without functioning vapor traps. Petroleum compounds often biodegrade before causing vapor intrusion problems. However, one community had elevated petroleum-related concentrations in indoor air traced back to homes connected to sewer lines without vapor traps. These untrapped sewer lines formed a preferential pathway for contaminant vapors that had entered the sewer lines from openings elsewhere along the lines. It is important to note that reports of sewer odors are typically found with vapor traps that have dried out or are no longer operating properly.

The possibility of these conditions highlights the importance of an interior inspection of potentially impacted buildings before the screening process is finalized.

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1.6.4 Undeveloped Land

Assessing the potential for vapor intrusion in a future building upon land that is currently vacant poses unique challenges. Some of the investigative tools of the vapor intrusion pathway (e.g., subslab soil gas or indoor air samples) are not possible when there is no slab or structure present on the property. Alternative approaches are required in these circumstances.

Future-use exposure scenarios may involve the evaluation of municipal zoning criteria (commercial, residential) and zoning exceptions (e.g., commercial zones that allow residential, multifamily residential, second-story residential). Other considerations include commercial zones that allow day care facilities and industrial zones that allow on-site caretaker residence.

The use of institutional controls (e.g., deed restrictions, environmental covenants) may be appropriate to ensure that future use of an affected property is protective of human health through the vapor intrusion pathway. Institutional controls could include land use restrictions, future building design requirements to address the potential for vapor intrusion, notification requirements for land owners/developers, or stipulations for further investigation of the vapor intrusion pathway during evaluation of specific future use scenarios.

When institutional controls are not appropriate (or not permitted by the regulatory agency), investigators must delve deeper into their "toolbox" to assess vapor intrusion at undeveloped lands. In the end, it may be preferable to incorporate a vapor barrier and/or subslab venting system into the building design as a proactive approach.

1.7 Community Concerns

Vapor intrusion investigators must be trained to deal with community concerns. Informing residents or business owners that chemicals may have entered their buildings is a delicate situation. Usually, people are just learning that the groundwater and/or soil near their properties have been contaminated by releases from a local company or individual. Communities may be skeptical or unsure of what will happen next. How will the vapors affect their health or that of their co-workers and families? It is important to learn from experiences of other investigators who have overcome similar challenges with impacted communities.

Communication is an essential component of any community outreach program. For example, it is generally not a good idea for building occupants to learn about a vapor intrusion investigation for the first time when someone knocks on their door asking permission to drill holes in their floors or inquire about their personal activities (e.g., smoking, dry-cleaning clothes).

Redfield, Colorado Site

To facilitate public education and communication with the residents, investigators went door to door providing information packets and discussed the program directly with each resident when requesting access for testing. Testing personnel were selected, in part, for their ability to communicate and work well with the residents. Consider situations regarding language barriers and residents. Other community relation efforts included frequent public meetings, periodic mailing of project newsletters, articles published in local community newsletters, door-to-door surveys, and development of a project Web site (www.redfieldsite.org) posting fact sheets and the most recent results of groundwater and indoor air testing.

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To be successful, agencies conducting or overseeing vapor intrusion (VI) investigations need to develop a strong community outreach program to educate and reassure the local community about vapor intrusion in a meaningful, sensitive, and effective manner. Unlike any other contaminant pathway, vapor intrusion merits effective education of the affected community regarding the risk of soil gas migrating from the subsurface as well as background sources typically found in the building.

Community Advisory Groups (CAGs) may assist in this process. CAGs are generally small groups of residents who meet regularly with agencies and responsible parties. They provide an opportunity for the public to gradually gain an understanding of the complexities of vapor studies. In such settings, initial adversarial relationships usually break down, and community members often come up with constructive advice.

1.8 Remediation

Some vapor intrusion investigations will indicate that actions (remedies or mitigations) should be taken to reduce the amount of vapor intrusion into a building. "Remediation" commonly refers to an action that reduces the level of contamination in the environmental medium (e.g., groundwater) that is acting as the source of the indoor air vapors. "Mitigation," on the other hand, is generally applied to actions that prevent or minimize exposure. While the two terms are used interchangeably in this industry, the differences should be understood by the investigator. When an action is needed, a remedy or combination of remedies should be selected, implemented, operated, maintained, and monitored to properly respond to the vapor intrusion problem and bring the site to closure.

Chapter 4 of this document covers sitewide remediation, institutional controls, and building controls. Of these, building control remedies are discussed in the most detail because they include those active mitigation methods most commonly implemented at structures impacted by vapor intrusion.

1.9 Regulatory Considerations/Drivers

As indicated by the ITRC Vapor Intrusion Survey (ITRC 2004b), existing policies, regulations, and guidance regarding the methods for evaluation of the vapor intrusion pathway vary widely among jurisdictional agencies. Prior to developing a site-specific approach for the evaluation of the vapor intrusion pathway, consideration should be given to applicable local, state, and federal policies, regulatory requirements, and available guidance. Regulatory policies may offer specific approaches and screening levels for the evaluation of the vapor intrusion pathway. Coordination of vapor intrusion investigations with the appropriate jurisdictional agencies early in the planning process may allow for a more focused vapor intrusion assessment and ensure that regulatory compliance criteria are met.

Stay Ahead of the Curve

A review of the developing science relating to the vapor intrusion pathway should be conducted on a regular basis. As the state-of-the-practice for evaluating the vapor intrusion pathway develops, additional guidance, investigative tools, and case study information will be available at the ITRC Vapor Intrusion Web page (www.itrcweb.org/vaporintrusion).

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The agency with oversight responsibility will offer regulatory guidance that is applicable for a given investigation. In an ideal world, the best technical approach for any given situation is defined in the applicable regulatory guidance. In reality, vapor intrusion is an evolving science with many variables. Thus. investigators must be prepared to justify their technical approach.

Since various states express a wide range of comfort about the data types that are acceptable for screening a site from further consideration, this guidance is not prescriptive as to what data types present an appropriate methodology for screening purposes. Rather, this guidance is intended to assist the investigator in understanding the factors and methodologies that may be used to assess the vapor intrusion pathway. To refine the approach, the investigator is encouraged to consult the individual state's guidance on the subject of vapor intrusion. Check the ITRC's Vapor Intrusion Web site (www.itrcweb.org/vaporintrusion) for updated links on VI guidance documents and related information from the various states, federal government, industry and other interested parties.

2. PRELIMINARY SCREENING PHASE

The initial step in assessing the vapor intrusion pathway is developing a conceptual site model based on all available data. Once prepared, the CSM becomes a primary developmental method used by investigators when conducting a preliminary screening of a contaminated site. This chapter provides a fundamental seven-step approach to assessing the vapor intrusion pathway through this early phase of data evaluation. (The remaining six steps of the total 13-step vapor intrusion assessment are discussed in Chapter 3, Site Investigation Phase.) The role of generic screening levels and the importance of groundwater data usability are discussed as they relate to the preliminary screening phase.

As noted in Chapter 1, evaluating the potential for vapor intrusion at a site of concern should be approached as a sequential process extending from the evaluation of initially available data through the determination of no further action or mitigation. This section is intended to help the investigator evaluate existing data and make decisions regarding the need to proceed to the investigative phase to collect additional data. Given that regulator-defined screening levels are often close to background levels for many compounds and that spatial/temporal variability and sampling bias are often present, the ultimate risk management decisions should be based upon multiple lines of evidence rather than upon a single line of evidence (Section 1.5).

An appropriate initial screening process will ensure that those sites most likely to pose unacceptable risk from vapor intrusion are retained for more detailed evaluation. It is also expected that some sites will be removed from further evaluation if it is demonstrated that

- the exposure pathway is and will remain incomplete,
- the COCs are not deemed sufficiently volatile (as defined by the regulatory agency) to pose a hazard, or
- the concentrations of the volatile chemicals fall below generic screening levels.

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2.1 Developing a Conceptual Site Model

The goal for developing a CSM in the assessment of the vapor intrusion pathway is to assemble a three-dimensional concept of the site that is as comprehensive as possible. This is based on available, reliable data describing the sources of the contamination, the release/transport mechanisms, the possible subsurface migration routes, and the potential receptors, as well as historical uses of the site, cleanup concerns expressed by the community, and future land use plans. All the important features relevant to characterization of a site should be included in a CSM, and any irrelevant ones excluded. The CSM should present both a narrative and a visual representation of the actual or predicted relationships between the contaminants at the site and receptors (building occupants), as well as reflect any relevant background levels. Appendix B is a CSM checklist to assist in preparing this important component of the vapor intrusion assessment.

A CSM typically contains information on soils, geology, hydrogeology, the relative amount of heterogeneity, groundwater quality data, regional groundwater flow direction, well records, boring logs, and surficial features suggestive of whether the area is in a groundwater recharge or discharge area (e.g., ground cover, surface water bodies). Sources to check for this data are county soil surveys; state or federal water supply or geologic reports/maps; U.S. Geological Survey (USGS) topographic maps; geographic information systems; and federal, state, and local government or quasi-government agency records.

A preliminary CSM documents current site conditions, such as site geology, hydrogeology, and volatile organic compound (VOC) distribution and composition relevant to soil gas migration, and should be supported by maps, cross sections, and site diagrams. A narrative description should clearly distinguish what aspects are known or determined and what assumptions have been made in its development. The CSM should provide all interested parties with a conceptual understanding of the potential for exposure to compounds of concern at a site. It is an essential tool to aid management decisions associated with the site and also serves as a valuable communication tool both internally with the site team and externally with the community.

Sources of CSM Information

- "Conceptual Site Model Checklist" (Appendix B)
- *Vapor Intrusion Guidance* (NJDEP October 2005b)
- *Collecting and Interpreting Soil Gas Samples from the Vadose Zone: A Practical Strategy for Assessing the Subsurface Vapor-to-Indoor Air Migration Pathway at Petroleum Hydrocarbon Sites* (API 2005)

The CSM is a dynamic tool to be updated as new information becomes available, and therefore it should be amended, as appropriate, after each stage of investigation. It is especially important that the site be reasonably well characterized for the purposes of sampling plan development. The updated CSM should then contain the following information:

- Types of volatile COCs (e.g., chlorinated solvents, gasoline, jet fuel, diesel) currently or previously stored or handled at the site
- COCs and their concentrations in soil and groundwater—the future use of the data and the regulatory requirements that will be applied to the data are used to determine the appropriate laboratory analytical methods

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- Potential sources and source areas of vapors (e.g., soil; groundwater; nonaqueous-phase liquid [NAPL])
- Geology and hydrogeology in the area of the site
- Approximate location of vapor sources in the subsurface and the distances (lateral and vertical) between the sources and the building
- Current subsurface soil gas–to–indoor air migration routes (e.g., utility conduits, sewers, diffusion through vadose zone soils, see Figure 2-1)
- Construction features of existing buildings (e.g., size, age, presence of foundation cracks, entry points for utilities, and number of distinct enclosed units)
- Potential future uses for undeveloped lands based on municipal zoning laws

Appendix D of the USEPA draft vapor intrusion guidance (USEPA 2002b) explains the relationship of the CSM to the USEPA data quality objective (DQO) process.

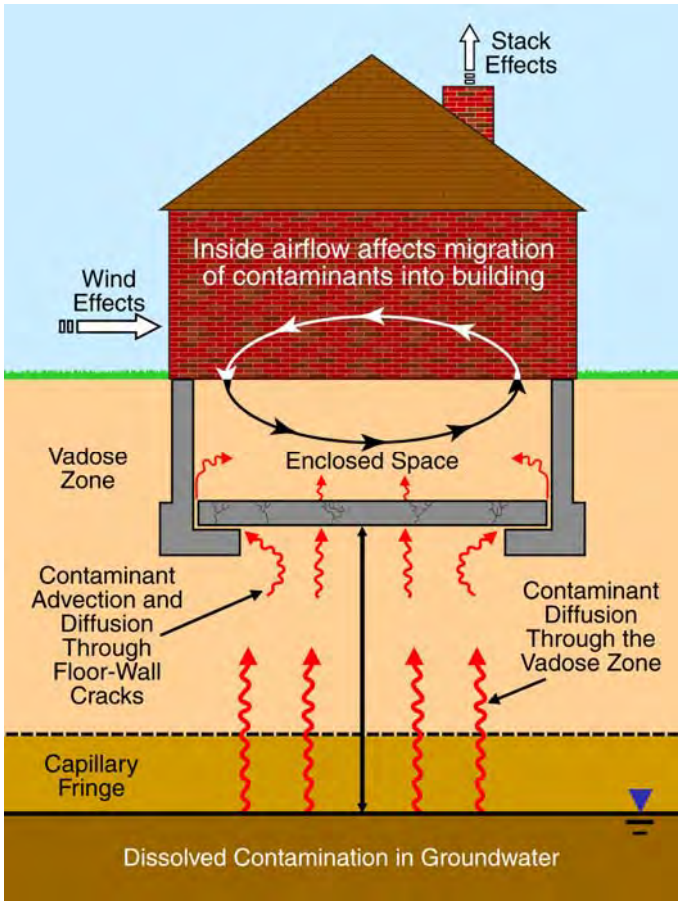

Figure 2-1. CSM illustrating vapor intrusion from groundwater contamination.

2.2 Preliminary Screening Steps

The preliminary screening process presented below comprises seven specific steps to initially assess a contaminated site. Even after the preliminary screening phase is completed, the investigator is advised that data collected in subsequent rounds of investigation may necessitate revisiting these screening steps. Thus, the iterative process discussed earlier in the document is reflected even in the preliminary stages. Refer to the preliminary screening flowchart (Figure 2-2) for additional guidance.

- Step 1: Does the site represent an acute exposure concern?
- Step 2: Are there sufficient characterization data to evaluate this pathway?
- Step 3: Are any of the site COCs both volatile and toxic?
- Step 4: Are buildings located in close proximity to volatile chemicals in soil, soil gas, or groundwater?
- Step 5: Identify the appropriate occupant exposure scenarios and generic screening levels for this site.
- Step 6: Do the data exceed the appropriate generic screening levels?
- Step 7: Does an exceedance of the generic screening level warrant further investigation?

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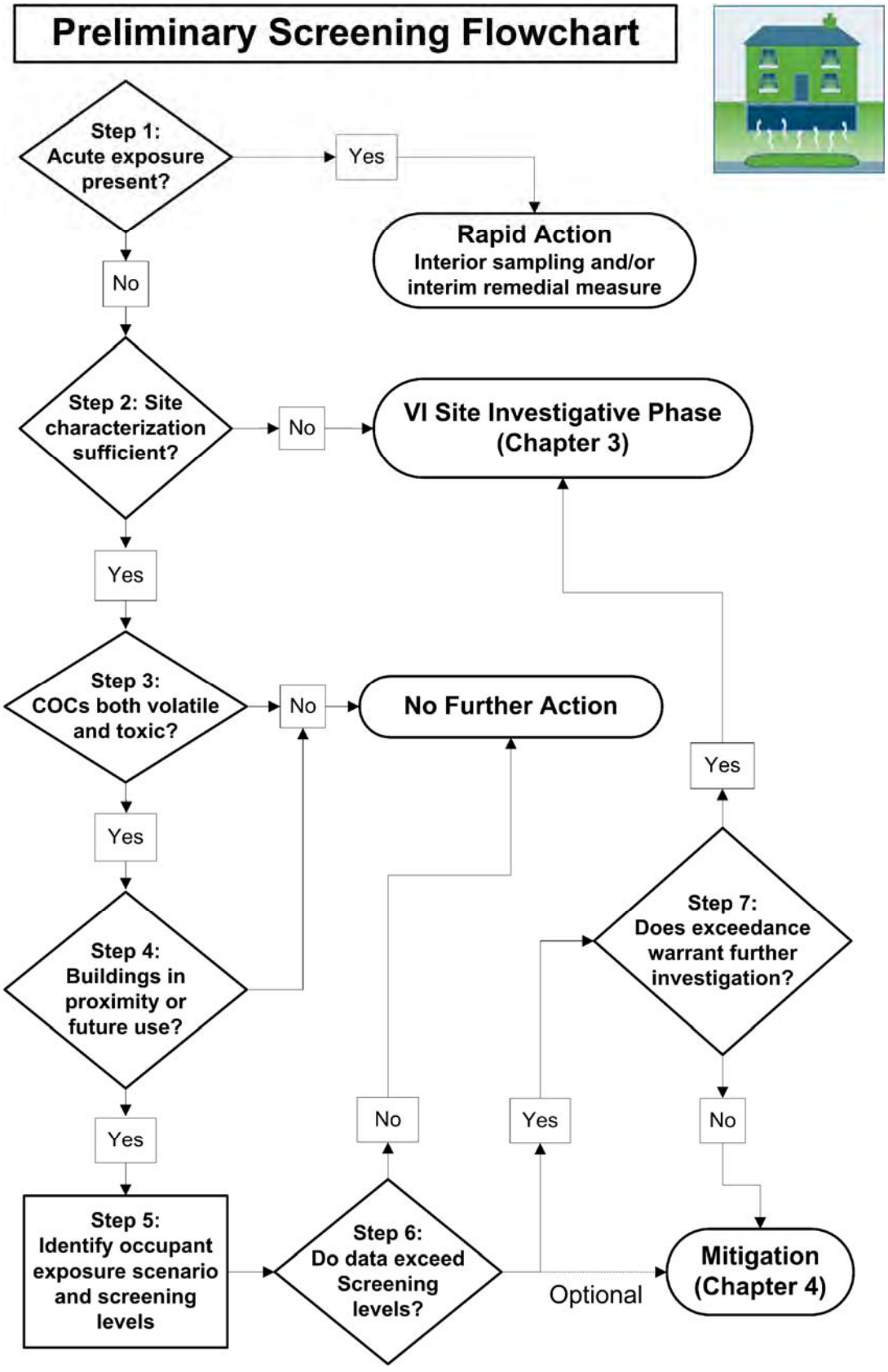

Figure 2-2. Decision-making process for VI preliminary screening.

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2.3 Step 1: Does the Site Represent an Acute Exposure Concern?

When an acute or emergency hazard resulting from vapor intrusion is suspected, the initial priority should be the immediate safety of the building occupants. Unless the indicators are unambiguous in nature (odors, physiological symptoms, etc.), it is unlikely that a significant decision such as evacuation could be made without interior measurements (subslab soil gas and/or indoor air samples). The judgment to conduct an interior investigation should be made on a site-specific basis. Each regulatory agency has its own preferences as to when subslab soil gas and indoor air sampling is warranted.

If the prompt collection of interior samples is warranted, several sampling techniques may be employed to make an acute/emergency decision. An investigator may choose to use a photoionization detector (PID), combustible gas indicator (CGI), or similar field screening device to determine whether volatile gases are present at substantial levels that could indicate an immediate hazard. Other investigative methods may be preferable to obtain more accurate determinations of VOC concentrations.

Conversely, it may be determined an interim remedial measure (IRM) would either remove the receptors from acute exposure (e.g., evacuation of the affected buildings) or disrupt the migration route (e.g., subslab depressurization or similar remedial systems).

Whichever option is selected, it must be made on a case-by-case basis, using the agencies' best judgment, and must be done rapidly. In general, vapor concentrations of this magnitude are not common.

As part of the iterative process for the vapor intrusion pathway, the investigator must always consider the potential for acute exposure when evaluating data from any subsequent investigative phases.

2.4 Step 2: Are There Sufficient Characterization Data to Evaluate this Pathway?

Preliminary screening for the vapor intrusion pathway is conducted in the context of the available data. Most contaminated sites fail to have sufficient data at this preliminary stage to conclusively eliminate the vapor intrusion pathway. Alternately, the data may not meet the quality assurance/quality control (QA/QC) level required by the regulatory agency. The investigator must determine whether adequate investigation has been conducted to identify all COCs and at their highest concentrations likely present (worst-case pathway or receptor) at the site.

If there are insufficient data to eliminate a site, then additional investigation is warranted. Thus, characterization is called for when the VI pathway may be present or inadequate results are available to make that determination. Supplemental investigation may or may not involve actual media sampling. Chapter 3 provides additional information on the investigative process of site characterization.

Investigate Source
In general, if there are no contaminants of concern at the source (e.g., soil gas at the groundwater table below a building), there may be no need for further characterization. So check the source first!

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2.5 Step 3: Are Any of the Site Chemicals of Concern Both Volatile and Toxic?

A vapor intrusion assessment typically begins with collecting information about the release. Site assessment reports, interviews with site owners and operators, spill reports from federal and state environmental agencies, and state fire marshal records may contain information and maps about sources. The COCs are typically those compounds that have been used at a site or released into the environment. The project manager should remain cognizant that some volatile chemicals may naturally degrade into other compounds (e.g., trichloroethene [TCE] can break down to vinyl chloride), so the suite of chemicals that are of potential concern may be more extensive than just the compounds released at the site.

Defining "Volatiles"

Regulatory agencies have different ways to define volatile chemicals for the VI pathway.

- The USEPA (2002b) defines volatiles as chemicals with a Henry's law constant greater than 10^{-5} atm m^3 mol^{-1} at room temperature.
- NJDEP (2005b) considers a chemical to be volatile if its Henry's law constant is greater than 10^{-5} atm m^3 mol^{-1} and its vapor pressure is greater than 1 mm Hg at room temperature.

For the most part, only compounds of sufficient volatility and toxicity are a concern for the vapor intrusion pathway. Table 1 of USEPA's draft VI guidance (2002b) lists some of the more common chemicals of sufficient volatility and toxicity. If other volatile chemicals are present at the site, Appendix D of the draft guidance presents an approach to evaluate these chemicals.

In addition, there may be other potentially explosive or toxic chemicals (e.g., methane and hydrogen sulfide) that can represent a subsurface soil gas threat and should be investigated. If the COCs do not meet these criteria, further consideration of the vapor intrusion pathway is not warranted. Otherwise, the investigator moves onto the next step in the preliminary screening phase.

2.6 Step 4: Are Buildings Located in Close Proximity to Volatile Chemicals in Soil, Soil Gas, or Groundwater?

Preliminary screening Step 4 is useful in establishing potential vapor intrusion impact areas around releases. Often, significant contaminant concentrations are found only in relatively close proximity to the original source. USEPA guidance establishes an area within 100 feet vertically or laterally from a volatile concentration of regulatory concern as a potential impact area (USEPA 2002b). Some states have established buffers of 30 feet. Others states, such as New Jersey (NJDEP 2005b), established different distance criteria based on the contaminant type (petroleum versus chlorinated hydrocarbons). Recent work (Lowell and Eklund 2004) suggests that even for sites with the presence of pure petroleum product and contamination a couple of meters below the surface, VOC emissions will tend to be insignificant at lateral distances of about 100 feet transgradient to groundwater flow from a source. Hydrocarbons probably will not migrate as far laterally if oxygen is present. Check with your local regulatory agency as to the applicable distance criterion.

Distance Criterion

USEPA (2002b) suggests that buildings within 100 feet of a contamination plume or source should be evaluated for vapor intrusion unless a significant conduit (preferential pathway) exists, in which case, the area to evaluate should extend to some unspecified distance. States have developed their own distance criterion. Check with the local regulatory agency before evaluating the existing data.

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At this step, the investigator is assumed to have sufficient information to map the subsurface contaminated soil gas distribution. Otherwise, the site has not been properly characterized (Step 2).

The length of time between the release date and the time of soil gas collection will affect the magnitude of the contaminant concentrations at a location away from a release point. The time required for soil gas to reach near-steady concentrations at any point increases with the square of the distance from the source. Soil gas concentrations measured near a source will in most cases be representative of near-steady conditions. Near-surface concentrations or soil gas concentrations measured several meters away from a source may or may not be representative of near-steady conditions. Additional information can be found in API Publication 4674 (1998).

Answering the Step 4 question requires a judgment call based on confidence in the accuracy of the data and the CSM versus the potential risk to the receptors. Investigators should consider the likely level of heterogeneity and whether or not the applicable distance criteria is conservative, given the site-specific conditions.

Finally, consider the future use of the area under investigation. While the property may be undeveloped at this time, potential developments may expose future occupants to unacceptable risk based on vapor intrusion.

2.7 Step 5: Identify the Appropriate Occupant Exposure Scenarios and Generic Screening Levels for the Site

An evaluation of the vapor intrusion pathway requires consideration of the use of the buildings in proximity of contaminated media (e.g., groundwater, soil, soil gas). For sites that have measurable sources of volatile chemicals and a viable migration route to the building, the ultimate risk decisions may depend on the use of the buildings under current conditions. Future use of current buildings and undeveloped parcels may also need to be considered in light of the probable future exposure patterns.

For preliminary screening purposes, an evaluation of building occupancy scenarios should be conducted. Occupancy scenarios include evaluating building use (e.g., residential, commercial, industrial, schools and day care) as well as potentially exposed populations (e.g., children or adults).

The approach in the USEPA draft VI guidance (2002b) is designed primarily to ensure protection of the public in residential settings but may be adjusted to evaluate nonresidential human exposures which occur in commercial, industrial, and recreational settings. Most state agencies are now making that distinction in their screening levels. According to the Vapor Intrusion Survey (ITRC 2004b), of those states that have developed vapor intrusion screening levels, 69% differentiate between residential and nonresidential values.

It is important to note that exposure to the “general public” in public buildings is usually not the most significant risk driver if there are any full-time workers in the building. USEPA’s draft VI

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guidance may be interpreted to recommend that people exposed in occupational settings should be evaluated under Occupational Safety and Health Administration (OSHA) using occupational standards rather than by current risk-based screening approaches. This position appears to be going through a reconsideration based on recent draft revisions to the USEPA VI guidance.

Many state agencies now require that occupational exposure be based on risk-based screening values and not OSHA standards when the COCs are not used in the building being investigated. Again, check with your state agency for guidance in this area. In all cases, consider the potential future use of the building, not just the current function.

2.8 Step 6: Do the Data Exceed the Appropriate Generic Screening Levels?

Existing data can be compared to generic screening levels for an initial evaluation to determine whether the pathway is complete and whether there is a potential for risk associated with the inhalation of vapors from subsurface media contamination. The generic screening levels are typically conservative, non-site-specific values. Refer to Appendix H for more information on screening levels.

USEPA included a series of groundwater, soil gas, and indoor air generic screening levels as part of its draft VI guidance (2002b). These values are still being used by the federal government and many state agencies pending revisions in the USEPA guidance document. In addition, numerous state agencies have developed their own generic screening or remediation levels for the vapor intrusion pathway.

At this stage, if the data do not exceed the applicable screening levels, no further action would be warranted (assuming proper characterization has been completed per Step 2). However, an exceedance of a generic screening level generally requires the investigator to move on to Step 7. The one exception may be the option to move directly to mitigation or long-term monitoring.

It should be noted that some state agencies allow modeling of site conditions as part of the preliminary screening to prepare site-specific screening levels.

2.9 Step 7: Does an Exceedance of the Generic Screening Level Warrant Further Investigation?

Exceedance of the applicable screening levels does not automatically mean that a remedial action is appropriate. A determination will have to be made whether additional data are necessary as part of the investigative phase (Chapter 3). Refer to the Preliminary Screening Flowchart (Figure 2-2) for further guidance.

For many regulatory agencies, an exceedance of the state's vapor intrusion criteria simply identifies the need for further investigation (especially at the preliminary screening phase). In fact, 73% of the state agencies surveyed by ITRC in January 2006 acknowledged their criteria as "screening" rather than "action" levels.

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If there is enough information to confirm VI at a concentration that adversely impacts human health (possible acute exposure), the investigator moves onto the Mitigation Phase (Chapter 4). Otherwise, further characterization is required as part of the Site Investigation Phase (Chapter 3). Of course, the investigator may elect to be proactive and move directly to the mitigation phase at any point in the process, irrespective of the information collected to date.

2.10 Data Usability for Preliminary Screening

In moving from preliminary screening to the investigative phase, it should be clear that the following questions have been answered:

- Have adequate groundwater, soil, soil gas data been collected from the applicable locations?
- Do the results meet the minimum data quality requirements of the DQOs established for the site or of the regulatory agency?

The data usability of the groundwater, soil, soil gas, and/or indoor air results is a critical consideration when making a determination on the vapor intrusion pathway.

3. SITE INVESTIGATION PHASE

This chapter continues the 13-step approach to assessing the vapor intrusion pathway with the site investigation phase. During this phase the majority of the field data are collected according to investigative strategies and work plans developed following early data evaluation.

3.1 Investigative Process

When the preliminary screening phase (Chapter 2) fails to eliminate a site from further consideration of the vapor intrusion pathway, additional evaluation may be conducted during the site investigation phase.

Before conducting a site-specific investigation and evaluation of the vapor intrusion pathway, the investigator must first decide on the general approach (i.e., the information needed and acceptable for determining whether or not the pathway is complete at a specific building or site). Different investigation approaches are available based on the environmental medium being investigated. These distinctive investigation methodologies may be followed in a progressive or phased manner.

As indicated in Table 3-1, each investigative approach has uncertainties, resulting in the potential for false positives (due to conservative assumptions) or the risk of false negatives (if less conservative assumptions are used). Specific investigation tools for each of these media and the advantages and disadvantages of each approach are discussed in more detail in Appendix D. It is common to use several investigative approaches during an investigation. The data gathered from several approaches in the decision-making process is considered as using multiple lines of evidence.

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Table 3-1. General approaches for vapor intrusion investigations

Media Investigated	Evaluation Method	Principal Issues
Groundwater	Attenuation factor or modeling based on site-specific conditions used to predict indoor air concentration	Imprecision of attenuation factors or modeling requires very conservative assumptions. Henry's law must be corrected for the aquifer temperature.
Soil gas	Attenuation factor or modeling based on site-specific conditions used to predict indoor air concentration	Fewer pathway assumptions required than groundwater, but the accuracy and representativeness of measurements may be an issue
Subslab soil gas	Attenuation factor estimated or measured (e.g., using radon) to predict indoor air concentration	Fewest pathway assumptions required, but intrusive and attenuation factors may still be conservative for many buildings.
Indoor air	Indoor air concentrations directly measured	Intrusive, and background sources may confound data interpretation. Seasonal variations are also an issue.

Many investigators and state agencies prefer to begin the investigation process outdoors (i.e., exterior groundwater or soil gas measurements) in the hope that vapor intrusion can be ruled out without having to test indoors (subslab and/or indoor air samples). An exterior assessment also allows the properties most likely affected to be identified prior to interior sampling. This approach results in less inconvenience to building occupants and avoids the complexities of potential background sources of COCs. For example, if conservative attenuation factors or modeling fail to eliminate vapor intrusion based on exterior data, then interior sampling would be the next step in the areas identified as having the highest soil gas concentrations. Alternatively, preemptive mitigation or other risk management decisions could be based on the results of any of the steps prior to interior testing.

Other investigators and some states prefer going directly to interior testing, combining indoor air and subslab soil gas sampling, or just conducting indoor air sampling. The usual reason given for adopting this approach is concern over the reliability of exterior measurements or assumptions/models used to predict indoor air concentrations versus taking direct indoor air measurements. Perhaps the most reliable approach is to base the investigation and determination of pathway completeness on site-specific conditions and multiple lines of evidence with offsetting strengths and weaknesses.

3.2 Common Vapor Intrusion Scenarios

Innumerable variations of vapor intrusion scenarios are possible, based on the multitude of COCs and sources, geologic and groundwater conditions, and potentially impacted properties and buildings. Differences in these conditions could lead to numerous investigation issues, constraints, and options, all of which impact the investigation work plan and its implementation. While it's impossible to describe each and every scenario that could result from varying circumstances, experience has shown that a few situations tend to occur more frequently than others. Therefore, *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios*

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(VI-1A, ITRC 2007), developed as a supplement to this guidance document, describes six different hypothetical, yet common vapor intrusion scenarios and the investigation approaches that might be followed. Key decision points and alternatives that may be chosen during that stage of the investigative process are identified in the scenarios.

Typical VI Scenarios

The supplement to this document, *Vapor Intrusion Pathway: Investigative Approaches for Typical Scenarios,* discusses the following VI scenarios:

1. Gas station in residential neighborhood
2. Dry cleaner in strip mall located adjacent to neighborhood
3. Large industrial facility with long plume under several hundred buildings
4. Vacant lot with proposed brownfield development over groundwater plume
5. Vacant large commercial building with warehouse space and office space
6. Apartment building with parking garage over groundwater plume

Vapor intrusion investigations can be very complex, and the scenarios are tools in themselves. The main theme of each of the scenarios is to highlight the decision process and the reasoning behind the decision, the selection of a specific tool versus an alternative investigative strategy, and how the tool was used in the hypothetical scenario. Review of the hypothetical case histories presented in the scenarios supplement may help users better understand the nuances of various investigative procedures, particularly for a site similar to one of the six scenarios.

3.3 Site Investigation Phase

For many contaminated sites, assessing vapor intrusion involves collecting additional data to make a determination on the completeness of the pathway. In the Preliminary Screening Flowchart (Figure 2-2), the decision points at Step 2 and Step 7 may lead the investigator to the site investigation phase. In both cases, further investigation is warranted due to insufficient data to properly characterize the site or delineate COCs. The site investigation process presented below continues the progressive approach to assessing a site for the vapor intrusion pathway. It comprises six specific steps to complete the evaluation of a contaminated site:

- Step 8: Choose an investigative strategy.
- Step 9: Design a vapor intrusion investigative work plan.
- Step 10: Implement the vapor intrusion investigation work plan.
- Step 11: Evaluate the data.
- Step 12: Is additional investigation warranted?
- Step 13: Is mitigation warranted?

Each of the site investigation steps (see Figure 3-1) is discussed in greater detail below.

3.4 Step 8: Choose an Investigative Strategy

Before the process can begin, investigators must decide on the technical approach that they believe is acceptable for assessing the vapor intrusion pathway and making risk-management decisions (Step 8). This decision dictates the media to be investigated and the tools that are available. Of course, investigators may have preferences for or against specific tools or evaluation procedures available for each media, as discussed later in this section.

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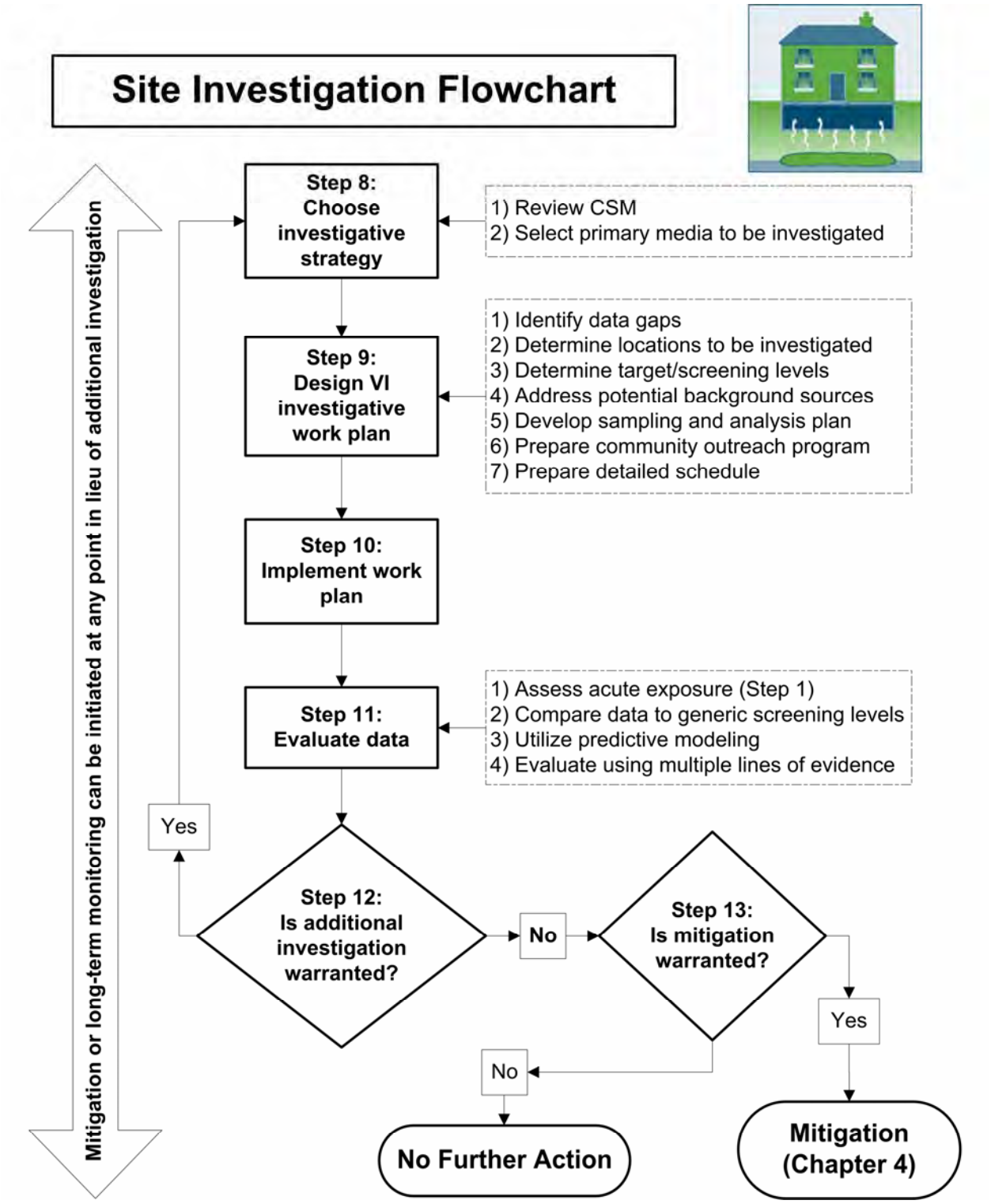

Figure 3-1. Decision-making process for VI site investigation.

The best method for a given application depends on various site-specific factors; therefore, no specific recommendations will be provided here. It should also be noted that strategic approaches

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can be altered during the investigative phase. For example, the procedures used to determine whether the worst-case building in a group of buildings is impacted may not be the same as those used to determine whether neighboring buildings are also impacted. Thus, the investigative approach used for one site may not be the best for the next site or even the next structure or neighborhood at the same site. Section 3.5.10 discusses in more detail the delineation of the nature and extent of vapor intrusion contaminants.

The investigative processes available for vapor intrusion sites are split into two broad categories—exterior and interior measurements. Supplemental data are used to enhance these two categories. Typically, investigations start with exterior measurements and then move to interior measurements to further evaluate the pathway. The choice of one of these two categories reflects the investigative strategy (Step 8) and should be based on the stage of the investigation and the guidance or policies of the regulatory agency. Appendix D further explains each of the following investigative strategies in greater detail.

3.4.1 Exterior Measurements

Groundwater

Groundwater contaminant plumes migrating under or near buildings may be a source of vapor intrusion. Because of the distance interval between groundwater monitoring wells, it is often necessary during the early stages of a site investigation to estimate the contaminant concentrations at locations that are closer to the building(s) of potential concern. While the concentrations between monitoring wells may be interpolated based on the distance between the wells, it is generally safer to use the higher concentration found in the nearby wells initially to estimate the contaminant levels that may partition into the soil pore space, possibly leading to vapor intrusion. Since water concentrations at the top of the water table are the potential source of vapor partitioning, understanding the well construction and how groundwater samples were collected can be beneficial in making more accurate determinations. The vertical profile of concentrations and water table fluctuations may be necessary data for assessing the potential for off-gassing.

Soil

Soil matrix data are less than ideal for evaluating vapor intrusion risk because of the uncertainty associated with using partitioning equations to calculate soil gas concentrations and the potential loss of VOCs during sample collection. Numerous studies have identified sampling biases, and USEPA (1993a) has determined that the scale of the biases can be as large as several orders of magnitude. Scientific studies have failed to show a good correlation between soil and soil gas sampling and analysis on a consistent basis. Consequently, soil data should be used as a screening or secondary line of evidence in vapor intrusion assessments. Soil data may be available from previous investigations and therefore assist in the development of a CSM (e.g., source location and distribution).

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Soil Gas

Measurement of soil gas is a common approach around the country for evaluating the vapor intrusion pathway. Soil gas data are reflective of subsurface properties and allow for real-time results. Risk-based screening levels for soil gas are usually higher than indoor air screening levels. Drawbacks to this method include the lack of knowledge of the proper attenuation factor to apply when interpreting soil gas data; debate over the number, location, and method of sample collection; and uncertainty over temporal and/or spatial variations in soil gas concentrations. Soil gas data are recommended over other data, specifically soil matrix and groundwater data, because soil gas data represent a direct measurement of the contaminant that can potentially migrate into indoor air.

Two methods are available to measure soil gas contamination in the unsaturated zone, active and passive soil gas sampling. More details of the soil gas measurement methods can be found in Appendix D.

Soil gas samples can be further differentiated by the location of the samples. Near-slab soil gas samples are collected outside a structure but within a short distance (usually 10 feet) of the building's foundation. Soil gas samples collected 10 feet or more from the perimeter of the building are generally referred to as "exterior" samples. Finally, subslab soil gas samples are collected from below the building foundation or slab. This interior measurement is discussed below.

3.4.2 Interior Measurements

Subslab

Subslab soil gas sampling is the preferred approach of many regulatory agencies for investigating vapor intrusion, primarily because of the proximity of the sample location to the receptor and the elimination of background interferences (when proper sampling methods are employed). Subslab soil gas sampling involves collecting soil gas from the space immediately under a slab or basement. It is distinct from shallow (e.g., 5 feet below ground surface [bgs]) soil gas samples that are collected outside and either next to (near slab) or some distance (exterior) from a slab.

Subslab soil gas concentrations, by themselves, do not necessarily indicate the extent to which vapor intrusion is occurring or, if it is occurring, whether vapor intrusion represents a health risk. However, if subslab soil gas concentrations are more than 1,000–10,000 times the target indoor air levels, the probability of unacceptable vapor intrusion is likely sufficient to warrant proactive mitigation without further investigation. Conversely, if the concentrations in the subslab soil gas are not higher than the regulatory soil gas screening levels (if available), there may be no further need for assessment. This principle alone may help to constrain the number of properties subjected to costly indoor air monitoring programs.

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Indoor Air

Measuring indoor air is the most direct approach, but may not be the simplest. It is intrusive, and background contaminant sources in the building must be considered. Many commonly used household products contain some of the same target COCs (e.g., tetrachloroethene [PCE] from dry-cleaned clothes, trichloroethane [TCA] from degreasing cleaners). In some areas, especially urban centers, outdoor ambient concentrations (e.g., benzene) may exceed allowable indoor risk based levels, further complicating this approach. When doing indoor air sampling, a household inventory should be performed to find sources of indoor air contaminants. In addition the occupants should be instructed on appropriate actions that should be taken prior to and during the sampling event. Indoor air sampling may still be the method of choice if the COC is not one commonly found in household products or ambient air (e.g., 1,1-DCE, carbon tetrachloride). Agencies may find that residents prefer indoor air sampling over other investigative methods, and the data can be directly compared to screening values rather than having to be predicted or modeled.

Crawl Space

There are several approaches to investigating crawl spaces that involve collecting either air or soil gas samples using both active and passive methods. Typically, crawl-space air samples are collected following protocols similar to those for indoor air samples for a period of up to 24 hours. Ambient air can confound analytical results because of the uncertainty of outdoor air contribution to the crawl space. Soil gas collection can also be performed in the crawl space by inserting the probe rod or sampling tube horizontally through the crawl-space access ports or vertically through the overlying structure. Additionally, flux chambers can be used to determine the surface flux of the contaminant that may be moving into the crawl space. There are little data available to assess the attenuation from crawl space to indoor air.

Ambient

When indoor air sampling is performed as part of a vapor intrusion study, coincident outdoor ambient air samples should also be collected. Ambient air samples are important to characterize site-specific outdoor air contaminants. Depending on building air exchange rates, contaminants from outdoor ambient air may make up a large percentage of indoor air contaminants. Ambient air typically contains numerous VOCs, such as benzene, PCE, and TCE, that often exceed indoor air risk-based screening levels. Some compounds, however, that are not typically found in ambient air (e.g., vinyl chloride or 1,1-DCE) may be a concern for vapor intrusion studies. For residential structures, outdoor air samples should be collected from a representative upwind location, away from wind obstructions such as trees and buildings. The typical intake would be at about 3–5 feet off the ground (at the approximate midpoint of the ground level of the building) and about 5–15 feet away from the building. For commercial structures, outdoor air samples should be collected in representative locations for the intakes of the building heating, ventilating, and air conditioning (HVAC) systems.

Representative samples should be located to minimize bias toward obvious sources of volatile chemicals (e.g., automobiles, lawn mowers, oil storage tanks, gasoline stations, industrial

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facilities). Outdoor air samples should be collected and analyzed by the same method as for indoor air samples and generally for the same time periods. Consider collecting basic meteorological data during the sampling event.

3.4.3 Supplemental Data

A number of different supplemental data collection tools may be useful when evaluating the vapor intrusion pathway to further define the site-specific CSM. Some of the available tools are listed below and discussed further in Appendix D:

- emission flux chambers
- determination of slab-specific attenuation using conservative tracers (e.g., naturally occurring radon)
- determination of room ventilation rate using tracers
- indoor/subslab differential pressure measurements
- real-time analyzers
- forensics (e.g., constituent ratios, isotopes)
- meteorological data
- pneumatic testing
- manipulating pressure differentials

3.5 Step 9: Design a Vapor Intrusion Investigative Work Plan

Once the investigative strategy is selected (or established by state policy/guidance), a work plan is developed (Step 9) to assess the vapor intrusion pathway. Key components of any vapor intrusion work plan include updating the CSM, identifying data gaps, addressing background contaminant sources, developing the sampling and analysis plan, formulating a schedule, and preparing a community relations plan.

3.5.1 Conceptual Site Model

As discussed in Section 2.1, the CSM should be considered in the preparation of the vapor intrusion investigative work plan. In addition, any deficiencies in the CSM should be identified as data gaps and incorporated into the work plan. For example, consider whether any geophysical investigative techniques are feasible and whether they would help evaluate site lithology and stratigraphic features prior to additional invasive investigations. Critical components of the CSM include the following:

- the location and nature of the source of COC found in the subsurface
- COC properties, including degradation products, solubility, vapor pressure, diffusivity in air and water, and Henry's law constant
- COC screening levels in indoor air and other media, as applicable
- a basic understanding of lithology and stratigraphic features that influence the occurrence and movement of groundwater, NAPL (if any), and soil gas
- depth to groundwater and groundwater flow directions (including vertical gradients or recharge that might lead to a clean groundwater lens at the water table

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- general nature and extent of COCs in groundwater and/or soil gas
- locations and depths of major underground utilities (particularly storm sewers)
- potential background sources of COC and typical indoor/ambient air concentration ranges
- locations, ownership, and general use of buildings (current and potential future) within the area potentially impacted

Refer to Section 2.1 for more information on CSM development. In addition, Appendix B contains a CSM checklist that should assist investigators in identifying the key components of a CSM.

3.5.2 Data Gaps

The information in the previous section is required to evaluate the potential for vapor intrusion, regardless of the investigation approach, and constitutes a data gap if not known to a reasonably conservative degree. Additional data gaps may exist based on the selected investigative strategy (Step 8). For example, approaches that rely to at least a certain extent on modeling of groundwater concentrations require site-specific information on the geology and nature/extent of COCs in groundwater below the building of concern. On the other hand, strategies that rely primarily on interior measurements for risk management decisions (including background contaminant sources) may require only general information on the nature and extent of groundwater contamination to help guide the sampling program.

3.5.3 Locations to Be Investigated

The specific properties and/or buildings that require investigation should be identified in the work plan. This is a relatively straightforward decision when only one property or building is of concern (e.g., Scenario 1 in ITRC 2007). However, when a large number of off-site buildings are potentially impacted, selection of the property or building for initial investigations can be more challenging (e.g., Scenario 3, ITRC 2007).

Spatial Patterns
It may be discovered that buildings with a specific design feature may be more susceptible to vapor intrusion and warrant closer attention or proactive mitigation. The building does not necessarily need to be located over the most highly contaminated area.

USEPA's draft VI guidance (2002b) suggests selecting the worst-case building(s)—those most likely to be impacted by vapor intrusion—for the initial investigations. The worst-case building, however, is not always readily apparent due to the large number of factors that contribute to vapor intrusion migration, including COC concentrations in groundwater or soil gas, depth to groundwater, soil types, building construction and ventilation, and groundwater flow direction.

In many cases, it may be appropriate to collect additional groundwater and/or soil gas data to narrow down the area with the highest concentrations before selecting individual properties or buildings for site-specific evaluation (e.g., Scenario 3, ITRC 2007). Select several buildings for the initial investigation to account for uncertainty and ensure that the varying factors potentially affecting soil gas migration are addressed. For example, the building overlying groundwater or soil gas with the highest concentrations, as well as the building with the most susceptible

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foundation conditions (but not necessarily overlying the highest concentrations) might both be investigated.

At some sites, a statistical approach has been adopted for selecting properties or buildings to begin investigations. Buildings might be selected based on the magnitude of underlying concentrations, with bias toward grid cells overlying higher groundwater concentrations (stratified, systematic sampling approach). This method is most appropriate when concentrations are fairly similar over a broad area and there is little to distinguish the most susceptible building or area. The investigator should work with the community outreach coordinator in these cases since the apparently random nature of properties selected for sampling will raise concerns with the local building occupants.

3.5.4 Background

Background contamination is generally defined by anthropogenic (e.g., soils) or upgradient/upstream sources (e.g., groundwater, surface water). However, background indoor air contamination is everything unrelated to the subsurface soil gas that migrates into a structure. (See Appendix G for important questions to ask during an indoor air sampling program.)

One of the initial steps when conducting an indoor air sampling program is to define which chemicals have been released into the subsurface and which are COCs with regard to the vapor intrusion pathway. These COCs may be both primary chemical constituents and their degradation products. Background indoor air sources of volatile chemicals in residential structures include consumer products, supplies used for personal hobbies, household cleaners, paints, and building supplies. These background sources should be identified and, if practical, removed prior to indoor air sampling. Information on common household products that cause measurable levels of volatile chemicals in indoor air can be found on the National Institutes of Health Household Products Database (http://householdproducts.nlm.nih.gov/) and include the following:

- adhesives (automotive, household, craft, plumbing)
- household cleaners
- lubricants
- bonders
- adhesive removers
- antistatic aerosols
- automotive parts cleaners
- paint strippers
- “spot removers” for fabrics
- jewelry polish
- water repellants
- spray paints
- dry-cleaned materials (e.g., clothing containing residual dry-cleaning solvents)

“Background” Structures

In unique circumstances, investigators can determine indoor background air concentrations as one part of a multiple-lines-of-evidence approach in the assessment of vapor intrusion. Using data from structures of similar construction but located outside the contaminant soil gas or groundwater plume, investigators can compare results with buildings impacted by VI. This is particularly useful in reoccupancy scenarios. For example, at a petroleum hydrocarbon site in Colorado, vapor intrusion caused the evacuation of two schools. Indoor air samples were collected in another school located outside of the influence of the contaminated plume. Following mitigation activities, the students were allowed to return to the formerly impacted school when contaminant concentrations in indoor air were in the range of concentrations detected in the unaffected school.

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- caulks and sealants
- cosmetics including hair spray, nail polish and nail polish remover, perfume, cologne
- air fresheners and odor eliminators
- insect repellants

As a general rule of thumb, these products should not be used inside the building at least 24–48 hours before and during the indoor air sampling activities, if practical. Investigators should consider the sorptive nature of some materials (e.g., carpeting, drapes, upholstery) to retain VOCs, slowly releasing them to the indoor environment over a period of weeks or more.

Other background sources include outdoor ambient sources such as those related to automotive exhaust, smoking indoors (e.g., benzene) and commonly emitted solvents (PCE, TCE, etc.). Before concluding that a chemical is present only as a result of background contamination, consideration should be given to the possibility that detected non-COC may also be attributed to vapor intrusion from other unknown subsurface sources. The likelihood of this possibility would largely depend on how adequately the nature and extent of contamination has been defined at a site. Subslab sampling as part of the indoor air sampling may also help with identifying chemicals migrating into the structure.

Additional information on background contamination and multiple lines of evidence can be found in Boyer 2004.

3.5.5 Sampling and Analysis Plan

Once the data gaps have been identified and the investigative locations (i.e., properties or buildings) selected, sampling methodologies and DQOs should be developed in conjunction with the preparation of the sampling and analysis plan. Keep in mind this is an iterative process and you may have to continually revise and update your investigative strategy based on new data (e.g., for larger sites preliminary soil gas samples may be used to pinpoint structure sampling). The CSM should be consulted (and updated) in parallel with the sampling and analysis plan.

Sampling plans should be reviewed to ensure that the objectives are consistent with the DQOs for the vapor intrusion pathway. Detection limits associated with the available data should be reviewed to ensure that methods chosen provide sufficient sensitivity to detect volatile chemicals at levels of concern. As previously noted, the CSM and its relationship to the USEPA DQO process are presented in Appendix B of the USEPA draft VI guidance (USEPA 2002b).

The definition of the nature and extent of contamination in groundwater and/or the vadose zone should be assessed to ensure that all COCs and areas of contamination have been identified. Groundwater concentrations should be measured or reasonably estimated using samples collected at the top of the water column from wells screened at or across the top of the water table. Soil gas, indoor air, and ambient sampling should be performed in accordance to any relevant standard operating procedures (SOPs). See Appendix D for information regarding sampling methodologies.

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3.5.6 Groundwater Sampling Issues

Preferably, groundwater monitoring data should reflect the concentration at the groundwater-vadose interface (top of the water table) as that is the point where partitioning from the groundwater to soil gas occurs. In the event that sampling shows no contamination at the groundwater-vadose interface, the project manager may correctly interpret this as indicating no vapor intrusion risk to overlying buildings unless other sources of the contaminant are known in the vadose zone sufficiently near the building of potential concern.

Surficial recharge that occurs along the predominantly horizontal flow path of a groundwater plume will tend to establish a downward vertical hydraulic gradient and cause the affected groundwater plume to also migrate downward in proportion to the amount of recharge and in relation to total flow in the hydraulic unit. This effect is often referred to as a "diving" or "sinking" plume. While it is most apparent in situations where a groundwater plume has migrated over a significant lateral distance, in some situations plumes may start to dive relatively close to their source area. The value of techniques that sample from the upper horizon (with the zone of seasonal water table fluctuations) of the groundwater cannot be minimized. Where rainfall is abundant, sinking plumes can occur even with dissolved contaminants that are traditionally thought of as "floaters." Targeting collection of groundwater samples from the top of the water table can provide significant data that will drastically reduce the extent of area over which one should consider vapor intrusion to be an issue, regardless of climate (wet, arid, etc.). For additional information, refer to NJDEP 2005b, Chapters 2 and 6.

In practice, many groundwater monitoring wells are screened in portions of the aquifer other than the interface. In addition to not revealing the conditions at the groundwater-vadose interface, purging and sampling these wells results in average contaminant concentrations that may under/overestimate soil gas concentrations and subsequently the vapor intrusion risk. Where possible, groundwater data from a relatively narrow interval across the water table should be used in the vapor intrusion assessment. The California Department of Toxic Substances Control states that a screen length of 10 feet or less will yield representative groundwater data suitable for vapor intrusion assessment (Cal DTSC 2004).

The investigator may be asked to determine whether vapor intrusion may pose a risk beyond the known plume boundaries for groundwater plumes that have not reached steady-state conditions. Information regarding the groundwater flow direction and gradient is often useful in determining the potential for contaminant migration. Groundwater characterization can entail groundwater flow direction; vertical and horizontal gradients, including as appropriate, seasonal variation, tidal influences, and the effects of groundwater withdrawal; the rate of groundwater flow movement; and the integrity of any confining units or other barriers to migration of groundwater. Groundwater movement and its associated impact upon distance from the source to the receptor should be considered. Three factors that affect contaminant levels in groundwater that affects contaminant levels in soil gas are dispersion, dilution, and recharge.

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3.5.7 Community Outreach and Information Plan

Throughout the process, investigators should keep in mind that vapor intrusion will affect communities and individuals. Learning about vapor intrusion can be stressful. In the scientific world, there are many unknowns. Communities want facts and answers. After being told about the potential for vapor intrusion in their community, homes, and businesses, it is only natural for individuals to be concerned about the air they breathe, their health and welfare, the effect of vapor intrusion on property value, and retaining clean and healthy environments. Investigators must be ready to work with communities and share findings in a respectful, understanding, and clear manner. Thus, it is critical that a community outreach plan be prepared and implemented at vapor intrusion sites. Depending on the size and complexity of the site, the plan can be anything from a one-page contact sheet to a highly detailed plan of action.

Below are some of the most common techniques for raising public awareness at contaminated sites.

- **Holding public meetings**. Public meetings may be required if further characterization is planned at any given site. This is a chance to explain the purpose as well as the potential consequences of the investigation. If there are going to be presentations about specific chemicals and risk, expect questions about how risk is calculated and what the numbers really mean. Remember, it is unrealistic to expect that people will leave the meeting with a clear understanding of the technical and policy issues associated with the site. Vapor intrusion is too "new" and complicated for many members of the general public to absorb the most important lessons in one sitting, even with the best of presentations.

- **Contacting mass media**. The mass media, including newspapers, TV, radio and the Internet, can be a positive tool to let people know about contamination issues. Take time to meet the reporters and share the facts. If there are unknowns, just state that you are unsure of certain issues (and make sure you follow up with them when you get the information). Clearly give the print media no more than three main messages. Take the time to educate the reporter on the key issues. Thus, there will be less chance of inaccuracy or sensationalism quoted in the paper. For a TV interview, consider the amount of time the broadcaster will provide to ensure that the most important message gets through.

- **Establishing Community Advisory Groups.** CAGs are generally small groups of residents who meet regularly with agencies and responsible parties. They have no decision-making authority, but they often prove influential. They provide an opportunity for the public to gradually gain an understanding of the complexities of vapor intrusion investigations. In such settings, initial adversarial relationships usually break down, and community members often come up with constructive advice.

- **Newsletters and Web Site.** An excellent tool for communicating with local residents or workers is to prepare periodic newsletters or establish a Web site with site-related information (e.g., www.redfieldsite.org).

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Investigators should also develop contingency plans for responding to public concerns as they arise. What if contamination is found in sensitive areas, such as schools or day care centers? If evidence shows that the public has been exposed to levels of contamination in drinking water or air that are considered unacceptable, will there be a way to address their likely demands for an independent health study? What if the groundwater plumes extend farther than previously believed? How are results going to be delivered to the occupants and the community as a whole?

3.5.8 Requesting Access

Effective public involvement is an important part of any environmental investigation, but because vapor intrusion investigations often require sampling near, in, or under the places where people live or work, building trust and cooperation is a critical path item for a successful project. To maximize chances of getting permission to sample in areas where existing data suggest that it should be done, it is necessary to target the outreach. This is usually a difficult, time-consuming process, but it can be made easier by a successful community-wide program of education, as described above. A typical community potentially affected by vapor intrusion contains all types of people with a variety of attitudes. Some people insist that their homes be tested even though they live a good distance from known contamination. Others refuse to permit anything that might show a health risk and/or lower their property values. Some want to cooperate, but they may find that sampling, as proposed, is impractical or inconvenient. Conversely, investigators will meet individuals that are cooperative and friendly, wanting to assist in anyway possible.

Access Issues: Be Prepared

Questions that typically need to be answered:

- Are the occupants owners or the renters?
- Who has the authority at a large commercial structure?
- Who is responsible for any common areas?
- Is access different for invasive activity, such as drilling holes in floors or wells in lawns, versus passive sampling?

Answers may vary from state to state, and in some cases the questions will not get clear answers.

The first stage in gaining permission is to determine who is authorized to give permission. The second stage is preparing materials that explain the purpose and extent of the permission. Any right-of-entry document should be written in plain language, and people should not be asked to authorize anything more than is necessary to conduct the investigation. The final stage, contacting people to gain permission, will vary from community to community. Contact by telephone or by "door knocking" is a matter of discretion. CAGs or local leaders working with the regulatory agency can often advise the best approach. They can also advise whether the outreach team should include speakers of languages other than English. In some communities, it may be best to enlist or hire a community-based organization with a continuing relationship with community members. These groups have experience in assisting with issues of mistrust, risk of deportation, and language barriers. Field personnel should be polite and considerate of the assistance that the homeowner/tenant is providing.

Once contact is made, it's essential that household members understand what is entailed in the investigation. Homeowners are likely to ask numerous questions. Will holes be drilled? Will it be necessary to remove certain household products or recently dry-cleaned clothes (background sources)? Will it be necessary to close up the house or turn on/off heating or cooling systems? Will family members or pets be moved out of the home during the sampling? A good program

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should figure out how to achieve sampling objectives while minimizing disruption of family life. The same is true in commercial structures. Will the investigation interfere with day-to-day business? Will it scare away customers or clients? Will fact sheets be necessary to inform casual entrants to the property what is going on? How long will it take to get the results, and how will they be communicated?

Finally, it should be clear from the start what the long-term implications of the study are. How many times, over what length of time, will sampling occur? What are the response options if unacceptable indoor air levels are found? Who will pay the costs? When, if ever, will things be back to normal?

3.5.9 Implementation and Scheduling

For vapor intrusion investigations, it is critical that a schedule be developed that coordinates all the various activities necessary to complete the work plan. Since the investigation is likely to involve accessing off-site properties, schedules have to be flexible, adjusting to changes that will happen. Anticipate potential pitfalls and be prepared to resolve them. It is also advisable to develop a decision logic in advance of data collection so there will no arguments over responses in the "heat of the moment."

Some of the activities that need to be reflected in the schedule are as follows:

- regulatory approvals
- permits and local approvals
- community education and access
- scheduling tests and potential logistical challenges
- evaluating data and determining if data are adequate
- reporting and communicating results
- being ready to make risk management decisions

3.5.10 Identifying Impacted Structures

The investigator may first delineate the extent of the subsurface contamination using exterior investigative tools. For a large site involving a significant number of buildings, identify primary, secondary, and tertiary buildings based on the magnitude of groundwater and/or soil gas concentrations. Then, as necessary, implement an interior investigation (e.g., subslab soil gas sampling, indoor air sampling) initially in the primary buildings. Some states may start with an interior sampling effort, targeting a primary, secondary, and tertiary zone, based solely on groundwater concentrations. If some of the primary buildings reveal evidence of unacceptable vapor intrusion, the interior investigation is expanded to the secondary buildings. This approach is referred to as a "step-out process," where buildings adjacent to impacted buildings are investigated in an

Building Triage

Sampling all structures for VI may be impractical for larger sites, so existing data can be used to determine which buildings should be targeted first. The building triage approach involves assessing the magnitude of the subsurface concentrations (e.g., soil gas, groundwater) into zones to assist in targeting initial investigations. The zones are primary, secondary, tertiary.

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outward, sequential manner until a perimeter with no impacts (or below screening levels) is established.

When vapor intrusion impacts are discovered, there is usually significant pressure from the community and other stakeholders to test and mitigate (or take other appropriate action) as quickly as possible. This should be done, of course, but not at the expense of good science or wise use of resources. For example, testing of a large number of buildings or properties beyond the known area of impact may result in unnecessary tests and wasted time and resources. This is particularly harmful when testing proceeds in the wrong direction due to a lack of data to guide the investigation. Therefore, a step-out process to delineate the impacted area should be developed, at least conceptually, prior to beginning the investigations. At some sites, a two-house rule has been followed—testing does not proceed more than two houses in any direction beyond the buildings known to be impacted. Refer to the Colorado indoor air guidance (CDPHE 2004a) for additional information.

In addition, the approach to the step-out testing program does not necessarily have to be the same as the initial testing program. Once the occurrence of vapor intrusion has been established at the initial building(s), knowledge gained from these investigations may suggest that soil gas tests, subslab soil gas tests, or other approaches may be sufficient to make risk management decisions. Testing of multiple buildings or properties often results in spatial patterns and other data correlations that can be used to evaluate the results of individual tests, potentially reducing the number of tests required to make decisions.

3.6 Step 10: Implement the Vapor Intrusion Investigative Work Plan

Once the vapor intrusion investigative work plan has been approved by the regulatory agency, it's time to implement it. The investigator needs to be prepared to adjust the schedule based on field modifications that are bound to occur. Unlike groundwater investigations where the drilling crew works consistently installing monitor wells until they're done, vapor intrusion investigations are dictated by schedules often outside the control of the field samplers. Off-site access agreements may stipulate specific hours when exterior or interior fieldwork can be completed. Collecting indoor air or subslab soil gas samples is dependent on the occupants' being available to let the field samplers into the building. Since interior sampling may involve either very early morning or late evening hours, field samplers should consider appropriate safety concerns.

Heavy rains can delay the collection of exterior soil gas samples. Thus, the investigator needs to have contingency plans in place to avoid falling too far behind in the schedule. In addition, the investigator must be responsive to the results as they are received, showing flexibility to accommodate stakeholder concerns. Verification testing may have to be implemented immediately to address unexpected data.

3.7 Step 11: Evaluate the Data

Before evaluating the analytical results for chronic risk to occupants, a review of Step 1 from the preliminary screening phase is appropriate. At all stages of the assessment, the investigator has

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to consider the potential for acute exposure of building occupants to contaminants from the vapor intrusion pathway. Although the potential for acute exposure (Step 1) is minimal, it has to be evaluated whenever additional data are obtained.

Both the preliminary screening (Step 6) and data evaluation (Step 11) stages require the use of various decision-making tools to assess the potential for human health risks. For example, in the preliminary screening step, existing site groundwater data can be compared to generic screening levels as means of evaluating whether subslab soil gas and/or indoor air samples should be collected. Similarly, as part of the data evaluation step, subslab data can either be compared to generic screening levels or used in a predictive model to determine whether indoor air samples should be collected or mitigation measures should be implemented. The regulatory agency should be consulted prior to making decisions from the data evaluation steps.

The three primary decision-making tools discussed below are generic screening, predictive modeling, and data evaluation using multiple lines of evidence. In general, generic screening will most commonly be used as part of the preliminary screening process, while predictive modeling and evaluation of multiple lines of evidence will be used to evaluate data collected during preliminary screening or site characterization phases. In addition, many states use generic screening levels in combination with the multiple-lines-of-evidence approach to make remedial decisions.

3.7.1 Comparison with Generic Screening Levels

In generic screening, it is assumed that all detected volatile chemicals in subsurface media samples above applicable generic screening levels are COCs. The applicable generic screening levels (in those states where they exist) are typically conservative, non-site-specific values. Appendix H provides a more detailed discussion of the types and sources of generic screening levels available.

If all detected chemical concentrations are less than the generic screening levels, no significant human health risks would be expected, and further assessment is not required, as long as the analytical data are sufficient and reliable. While an applicable, generic screening can indicate the absence of unacceptable health risks under many circumstances, the presence of chemical concentrations exceeding the screening levels may not definitively identify unacceptable human health risks (due to the conservative assumptions utilized in developing the screening levels). Due to the generic nature of the screening levels, an exceedance could simply be an indication that further site-specific evaluation is needed. For example, if a review of groundwater (or deep soil gas) data resulted in an exceedance of the screening level, it would be appropriate to collect subslab or indoor air samples for further evaluation.

Mitigation Versus More Investigation

Despite the lack of verifying data, choosing to mitigate based on exceeding generic screening levels may be acceptable as a proactive, protective measure.

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3.7.2 Predictive Modeling

If any of the data collected during the vapor intrusion evaluation indicate concentrations greater than generic screening levels, predictive modeling may be used to assess whether the subsurface media concentrations are high enough to potentially migrate into overlying structures. Groundwater, soil gas, and subslab data can be used to estimate indoor air concentrations in buildings using vapor intrusion contaminant transport modeling. Alternatively, indoor air samples may be collected to obtain direct measurements of chemical concentrations in indoor air. However, there are typically confounding factors when using indoor air sampling results to assess the likelihood that vapor intrusion is occurring.

Models provide predictive capability, but their reliability is difficult to defend with limited site-specific data (Johnson et al. 2002, Hers et al. 2003). The use of models should be approved by the regulatory agency. It is often be helpful to start with a screening level model using mostly generic and conservative input parameters at the early stages of a site assessment to understand, in general terms, the relative magnitude and significance of vapor intrusion. As additional site information becomes available during the course of the site investigation, these data can be incorporated into the model, yielding progressively more site-specific and typically less conservative results. It is recommended that investigators (working with regulators) determine the critical parameters (Johnson et al. 2002) and conduct sensitivity analysis whenever predictive modeling is employed. The use of extreme and nonrepresentative assumptions is the most common weakness of predictive modeling.

As noted in the Vapor Intrusion Survey (ITRC 2004b), the USEPA spreadsheet version of the Johnson and Ettinger (J&E) model is the most commonly used model for estimating chemical concentrations in indoor air (www.epa.gov/Athens/learn2model/part-two/onsite/JnE_lite.htm). With input of groundwater or soil gas concentrations, the model estimates the associated indoor air concentration. The USEPA J&E model is a simple, deterministic model, having single-point inputs and outputs. It is based on the basic principles of contaminant fate and transport, contaminant partitioning between media, and the physical and chemical properties of the contaminants themselves. The model incorporates both diffusion and advection as mechanisms of transport of subsurface soil gas into the indoor air environment. Diffusion is the dominant mechanism for vapor transport within the vadose zone. Once the soil gas enters into the "building zone of influence," the soil gas is swept into the building through foundation cracks by advection due to the indoor-outdoor building pressure differential. The distance of the building zone of influence is usually less than a few feet. The USEPA J&E model uses the conservation-of-mass principle and is based, in part, on the following assumptions:

- Steady state conditions exist.
- An infinite source of contamination exists.
- Air mixing in the building is uniform.
- Preferential pathways do not exist.
- Biodegradation of soil gas does not occur.
- Contaminants are homogeneously distributed laterally beneath the building.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.

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- Buildings are constructed on slabs or with basements.
- Ventilation rates and soil gas flow into the building are assumed to remain constant.

The USEPA J&E model is most suitable under homogeneous site conditions with uniform building construction features. Conversely, the model is weakest under variable conditions and cannot evaluate significant preferential pathways; wet basements; substantial lateral transport of soil gas; tall buildings in cold climates; large buildings with potential localized sources of vapors beneath them; and shallow, fractured-bedrock conditions. Each of these conditions has the potential to significantly increase the rate of vapor intrusion beyond the model's predictions. With an understanding of the above-mentioned limitations and the use of conservative input parameters (see USEPA 2004b for typical parameter ranges and conservative values), the USEPA J&E model can enable users to quickly screen sites for vapor intrusion risk.

To facilitate its use in evaluating potential risk due to the inhalation of vapor in indoor air, USEPA has programmed into the J&E model a health risk component that calculates the human health risk from inhaling a specific chemical at the concentration estimated in indoor air. An updated version of the spreadsheet will soon be released that offers significant advantages over versions released in 2001 and 2003. The spreadsheets allow the use of either groundwater or soil gas data; soil matrix data are not allowed). The spreadsheet contains a number of default parameters that can be changed to site-specific values. Typically, agencies customize the spreadsheet by changing the default values and putting limitations on the parameters that can be changed with site-specific data. When using the USPEA J&E model, the input parameters for a given site must be appropriately conservative and match site-specific conditions. Model details are presented in the USEPA 2004b.

The USEPA J&E model should be used only when site conditions match the model assumptions using reasonable, site-specific, or regulator-approved input parameters (USEPA 2004b). Less used, one-dimensional analytical models are also available to simulate the effects of biodegradation, source depletion of contaminants in soils, and various building construction types, such as crawl spaces. Although not included in the current (2004) version of the USEPA J&E model, future revisions are expected to include an option for evaluating buildings with crawl spaces (i.e., dirt floors). For more complex sites, multidimensional numerical models can evaluate spatial and temporal processes in the vapor intrusion pathway.

3.7.3 Evaluation of Indoor Air Data Using Multiple Lines of Evidence

Indoor air data may be collected from existing buildings at any time during a vapor intrusion evaluation. For some states, it is recommended that indoor air samples be the primary sample media and basis for evaluating vapor intrusion. In other states, indoor air sampling is not recommended or is collected as the final data type in the evaluation of vapor intrusion, if warranted based on exterior and/or subslab soil gas data. For instance, if the cumulative health risk using soil gas data and an attenuation factor calculated using the USEPA J&E model for a future building scenario is considered unacceptable, institutional or engineering controls may be warranted. If the cumulative health risk for an existing building scenario is considered unacceptable, the model results can be verified by collecting subslab and/or indoor air samples.

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If measured indoor air concentrations are greater than the screening levels, it is necessary to assess whether the measured chemical concentrations are due to subsurface vapor intrusion, interior background sources, or ambient outdoor air.

Background Concentrations

A complicating factor in evaluating the potential for vapor intrusion using indoor air data is the potential presence of some of the same chemicals at or above background concentrations separately or in combination with chemicals that may be associated with vapor intrusion. There may be multiple sources of chemicals in indoor air that are not associated with the investigated chemical release (from the ambient air and/or background sources in the building). These other sources may confound the interpretation of indoor air samples results. Thus, attribution of measured chemicals in indoor air can become a relatively complex and difficult task.

When volatile chemicals with multiple potential sources are measured in indoor air, it may be necessary to gather multiple lines of evidence to support a remedial decision either to include or exclude certain chemicals from the risk evaluation. The premise is that if it can be demonstrated through multiple lines of evidence that an indoor air concentration above a remediation goal is not derived from a subsurface source, no remediation is warranted because the indoor air concentrations are due to background source(s). The more evidence gathered to support such a conclusion, the stronger the justification for the resulting decision. Site-specific decisions should be made as to the number and types of information employed. The use of many lines of evidence may not be required if only a few or even one provide clear evidence of either background or vapor intrusion sources.

It should be noted there is some uncertainty associated with such an assessment, regardless of the number of lines of evidence considered. The relative strength or significance of each line of evidence is also a factor to consider. The importance of a line of evidence based on one or two data points (or sample results) is quite different than that of evidence using 20–30 data points. Decisions should be made based on reasonable and logical professional judgment. Clearly, a successful exit strategy is more likely if a site-specific plan is developed and consensus reached with decision makers prior to implementing the investigation.

The following lines of evidence, listed in no particular order, may be used to identify whether measured indoor air contamination is derived from subsurface impacts or background sources. Other lines of evidence may be available depending on the site-specific circumstances.

Chemicals of Concern

The easiest and probably most important line of evidence is the identification of COCs at the site. Provided sufficient characterization has occurred, the investigator should be able to establish the principal contaminants associated with the original discharge or spill. Using this information, along with any degradation products related to these chemicals, the COCs can be identified. Thus, an investigator can limit the scope of the data evaluation and the analytical parameters for any future sampling events.

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Building Construction and Current Condition

Information regarding the construction and operation of a building may be used to establish the likelihood of subsurface soil gas entering. For example, if a building's HVAC system generates positive air pressure within the structure, it may be reasonable to conclude that this system will minimize or prevent soil gas from migrating into the building from a subsurface source (if positive pressure is the remedy chosen, see Section 4.3.1.6).

Other building factors that should be considered are age; foundation and slab type; building materials; the presence of sumps, perimeter drains, elevators; the height of buildings (particularly in cold climates); basement details; crawl spaces; vapor barriers or radon remediation systems; and surface cover outside the building. Refer to Appendix C for additional information. Facts regarding the building construction and current condition may help with assessing the potential for soil gas contamination to migrate into a building.

Subslab Data

Soil gas measurements collected from beneath a building will provide a good indication of what volatile chemicals could migrate into it. If COCs in the subslab soil gas or crawl-space vapor samples are not observed to be equal to or higher than indoor air concentrations in the building, it is reasonable to conclude that any measured constituent in the indoor air samples is derived in part from other background sources. (Note: Some structures subslab samples will vary in concentration.) The difficulty with this line of evidence is ensuring that representative soil gas samples are collected from beneath the structure. Since soil gas naturally attenuates to some degree in the migration from the subsurface into an overlying structure, a detection of a chemical in the subslab soil gas sample supports, but does not necessarily confirm, that the chemical observed in indoor air is attributable to the subsurface source. Barometric pressure fluctuations can cause reversible vapor flow and can contribute vapors from interior sources to subslab samples. Thus, other lines of evidence may be important to evaluate to establish the presence of concentration gradients inside and outside the structure.

Constituent Ratios

Evaluating the ratio between concentrations of different COCs in groundwater, soil gas, subslab and/or indoor air may help to identify potential vapor intrusion contributions or to screen out background sources. For many volatile chemicals, the background concentration ratios are distinct from groundwater-derived volatile chemical ratios. This characteristic allows the volatile chemical ratios from other media to be used to eliminate indoor air constituents.

Concentration Ratios of Different Chemicals
Example: If the concentration of TCE is 10 times higher than that of PCE in groundwater, deep soil gas, and/or subslab soil gas but PCE has a higher concentration than TCE in indoor air, it is reasonable to conclude there is an interior or background source of PCE (e.g., dry-cleaned clothes, carpet spot remover). Check with the regulatory agency when using constituent ratios.

It is possible that, even if the ratio analysis suggests that indoor or ambient sources are likely responsible for some of the measured indoor air concentrations, subsurface sources may still be contributing to indoor air concentrations. Conversely, if the ratios of

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constituents in the indoor air sample are similar to the ratios observed in the subslab soil gas sample, one may conclude that the two are linked and that there is a contribution from the subsurface sources, especially if subsurface concentrations are significantly higher than indoor air concentrations.

Comparison of chemical ratios in groundwater to ratios in indoor air may also be considered. However, these ratios should be adjusted for different relative volatilities of the COC using their Henry's law constants and, if significant, different rates of retardation and/or biodegradation in the vadose zone. The comparison of soil gas ratios to Henry's law adjusted groundwater ratios may be another line of evidence for assessing background contributions or vadose zone sources. It should be recognized that background sources might result in ratios that fall within the range predicted for groundwater or measured in soil gas data. Therefore, ratios can screen out obvious background sources but will not necessarily confirm vapor intrusion or eliminate the potential for background contributions.

The presence of marker chemicals (those constituents that are associated with the subsurface contamination but not typical background air sources, such as 1,1-DCE) in indoor air samples is a good indication that intrusion is occurring and that the observed constituents are derived from the subsurface. The converse assumption may also be true—the absence of a marker chemical in indoor air samples is a good indicator that little to no contamination is coming from the subsurface, suggesting that any air contaminants observed are from background sources. However, this second assumption will depend on the relative abundance, volatility, diffusivity, and reporting limit of the marker chemical compared to other COC.

In theory, if a marker chemical is found in the subsurface and indoor air, the indoor air concentrations of other chemicals can be estimated by multiplying the subsurface concentration ratio (nonmarker/marker) by the indoor air concentration of the marker chemical. If the measured indoor air concentrations of the second chemical are greater than that predicted by this method, the additional amounts found in indoor air may be due to background contributions.

Spatial Correlation

The use of spatial correlation is another tool for differentiating vapor intrusion sources from background. For example, use of COC ratios might eliminate a number of background outliers but still leave buildings with ratios that are consistent with either vapor intrusion or background source. Spatial analysis might show that a cluster of such ratios is consistent with a groundwater plume, whereas in other area buildings the ratios appear to be randomly distributed and are more likely associated with background levels. Also, evaluate the results of the ambient (outdoor) air sample. If the data reveal measurable concentrations of multiple chemicals in ambient air, compare these concentrations and concentration ratios with similar chemicals and ratios in indoor and subsurface soil gas samples.

The spatial distribution of volatile chemicals measured within a building may also help with the identification of the source of the vapor. For instance, concentration gradients or hot spots may indicate indoor air sources. The results of air samples taken in various parts of a building can be reviewed and compared to assess whether there are any contaminant concentration gradients or

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hot spots among the various floors or rooms in a building. In general, if basement concentrations are elevated above background and there is a decreasing contamination gradient from the source (e.g., basement) area on up, there is a relatively good chance that detected concentrations are due to a subsurface source of contamination. However, it is also possible that other sources (e.g., stored products) may be present in the basement and possibly even in the living area, potentially confounding site-related concentration gradients. Ultimately, though, this approach is both expensive and not very practical.

3.7.4 Assessment of Potential Human Health Risks

Exposure to a volatile chemical due to vapor intrusion does not necessarily mean that health effects will occur. Whether or not a person experiences health effects depends on several factors, including the length of exposure, the amount of exposure, the frequency of exposure, the toxicity of the volatile chemical, and the individual's sensitivity to the chemical. The main concern is whether the chemicals may pose an unacceptable risk of chronic health effects due to long-term exposure. It should be noted that the vapor intrusion pathway may not be the only complete pathway for a particular receptor. Each potentially complete pathway (e.g., dermal contact, ingestion, etc.) may be assessed in a risk assessment prior to determining whether and what remediation may be warranted. Some regulatory agencies may mitigate a structure to interrupt completed pathways, (e.g., install a carbon system on a well or install a subslab depressurization system on the house).

Once the COCs and their representative exposure point concentrations are identified and a risk assessment is determined to be the next step, the potential for significant health risk can be assessed. The identified exposure point concentrations should be used in conjunction with appropriate exposure assumptions to complete a site-specific risk assessment. The risk assessment provides a quantitative estimate of the excess lifetime cancer risk and the potential for noncancer health effects. These estimates are then compared to USEPA and/or state-defined screening levels or are evaluated on a case-by-case basis by the regulatory agency to make a risk management decision to determine whether mitigation measures are needed. When evaluating the potential for human health risk, it is important to note that vapor intrusion may not be the only complete exposure pathway for a particular receptor. A site-specific risk assessment should consider all potentially complete exposure pathways for each receptor to make appropriately protective risk management decisions.

Extensive guidance on conducting risk assessments is available from USEPA and many state agencies. The individual state agencies should be consulted to identify any state-specific guidance and/or regulations that should be addressed. These guidance documents should be consulted when completing a site-specific risk assessment. Some of the primary references that provide guidance for the assessment of risk to public health are USEPA 1989, 1996a, 1996b, and 2002d).

3.8 Step 12: Is Additional Investigation Warranted?

Step 12 highlights the iterative process of the vapor intrusion investigation. Upon execution of the work plan and review of the results, the investigator determines whether the site has been

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adequately characterized. Have the COCs been properly delineated? Has the potential for vapor intrusion at all possibly affected buildings been assessed? Are there sufficient data to reach a remedial decision at the site?

If the answers to these and similar questions are "yes," the investigator can move on to Step 13. However, if the evaluation of the investigative results identifies data gaps that prevent reaching a final conclusion at the contaminated site, additional investigations are warranted, and the process returns to Step 8 to develop a new work plan for the next round of investigation.

To expedite this iterative process, supplemental stages of investigation can be built into the original work plan to avoid long delays while new work plans are developed and approved by the regulatory agency. For example, a standard investigative approach can be developed for assessing vapor intrusion at each building at a site where a large number of structures may be impacted. This way, the initial investigation can center on the worst-case buildings, with subsequent rounds of sampling targeting adjacent buildings (the step-out process). Keep in mind that subsequent work plans can focus on the scope of work and rely on previously approved methods.

At any point in the process, many state and federal agencies will allow a responsible party to implement a remedial action to address vapor intrusion, even prior to confirming the pathway is complete. This proactive approach can be viewed as both responsive to the concerns of public health and economically rationale when compared to the cost of a full investigation.

Alternatively, the decision may be made to conduct long-term monitoring, particularly for undeveloped parcels, until such time as the vapor intrusion pathway source is remediated or future development will likely introduce receptors (people) that could be exposed to unacceptable indoor contaminants from vapor intrusion.

3.9 Step 13: Is Mitigation Warranted?

If the vapor intrusion investigation is complete, the review of the data must be made to determine whether some form of remedial action is appropriate at the site. Step 13 is the final decision point in the assessment of the vapor intrusion pathway. The investigator must reach a conclusion on the status of the site—no further action, additional monitoring, or mitigation. This decision is often left to the regulatory agency. Mitigation is discussed further in Chapter 4.

4. REMEDIATION

Remediation of vapor intrusion impacts may be required when the results of the site investigation phase (Chapter 3) indicates that indoor air concentrations of volatile compounds exceed screening levels in existing buildings or are likely to exceed screening levels in future buildings. When remedial action is required, a remedy or combination of remedies must be selected, implemented, operated, maintained, and/or monitored to control vapor intrusion until the source of the vapors is eliminated.

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Remedies may address two possible scenarios: emergencies and nonemergencies. This document focuses on chronic exposure concerns and does not discuss appropriate responses to emergency situations where immediate safety is the primary concern. Remedies can be further separated into three types: sitewide remediation, institutional controls, and building controls. Of these, building control remedies are discussed in the most detail because they are most commonly implemented at sites impacted by vapor intrusion.

4.1 Sitewide Remedies

Sitewide remedies address the source of vapors found in buildings, such as contaminated soil and groundwater, rather than controlling the entry of vapors in buildings. Sitewide remedies may be sufficient in situations where the vapor concentrations in buildings are very low or where source remediation can be conducted very quickly. In most cases, however, sitewide remedies are considered to be the long-term solution to vapor intrusion (and other) impacts, while institutional or building control remedies are considered to be short-term or interim remedies, implemented until the long-term or sitewide remedy is complete.

Sitewide remediation of soil and groundwater contamination may include technologies to reduce contaminant concentrations in soils and soil gas, such as soil vapor extraction, or technologies which would reduce concentrations in the groundwater, such as in situ bioremediation or pump-and-treat remedies. For sitewide remedies to be protective, exposures to unacceptable levels of vapor intrusion must be controlled until concentrations in soil and/or groundwater reach acceptable levels. Therefore, until the remedy has met its cleanup goals, the vapor intrusion pathway must be effectively controlled in all potentially impacted and inhabited structures.

In general, source removal and soil vapor extraction sitewide remedies are likely to have the potential to reduce or eliminate soil gas migration in the short term and thus preempt the need for interim control (e.g., institutional or building control) remedies. Sitewide remedies are not the focus of this document.

4.2 Institutional Control Remedies

In the event that sitewide remedies are not immediately effective in reducing or eliminating the potential for vapor intrusion, institutional controls may be put in place on either an interim or permanent basis to protect human health while longer-term sitewide remedies are being developed and implemented. An example of such a control would be legal actions to limit the use of certain parcels. If risks associated with vapor intrusion were unacceptable for unrestricted use of the property, for example, restrictions could be established to allow only those land/building uses that would be associated with acceptable health risks. These legal actions can take many forms, including restrictive covenants, zoning, excavation prohibitions, and groundwater advisories.

At undeveloped sites, or at sites where land use may change in the future, institutional controls may be necessary to ensure that the vapor intrusion pathway is effectively addressed in the future. Institutional controls at undeveloped sites could include mechanisms to require the preemptive installation of vapor intrusion controls, such as subslab depressurization systems, in

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new buildings This step would avoid some of the difficulties associated with attempting to predict the potential for vapor intrusion prior to building construction (because soil gas concentrations and distributions might change due to construction of the building). Installation and operation of fans, however, might not be required unless post-construction testing or other evaluations indicated this measure to be necessary.

A significant drawback to institutional controls is that they can be difficult to implement and enforce over time in many states that do not have adequate statutory authority to implement them. Institutional controls that incorporate periodic inspections and monitoring may be required to ensure that engineering controls are operated and maintained over time to retain their effectiveness.

Institutional controls, like sitewide media remedies, are not the focus of this document; however, they are often integral to vapor intrusion remedies. The investigator should refer to other guidance documents that have been developed to address the use of institutional controls as part of environmental remediation.

4.3 Building Control Remedies

Building control remedies are typically required at vapor intrusion sites (in both existing and new buildings) until long-term, sitewide remedies reduce soil and/or groundwater concentrations to acceptable levels. The following sections discuss various vapor intrusion building control technologies, factors affecting technology selection, and design and installation issues.

4.3.1 Building Control Technologies

Several building control technologies are identified below that can reduce or eliminate the potential for vapor intrusion impacts in new and existing buildings. A brief summary of each technology is provided, along with some of the advantages and disadvantages of each system. In addition, a typical range of installed costs for each technology is provided. Because vapor intrusion controls are often added to older buildings, the potential need for and additional costs of lead paint and asbestos abatement should be considered on a case-by-case basis. In some cases, excessive costs associated with these issues could affect technology selection. For a quick summary of the typical attributes of each technology, refer to Table 4-1.

Table 4-1. Comparison of mitigation methods

Technology	Typical applications	Challenges	Range of installed costs*
Passive barrier	• New construction • Crawl spaces • Often combined with passive or active venting, sealing openings in the slab, drains, etc.	• Preventing tears, holes • May not suffice as a stand-alone technology • Some states do not accept • Ensuring caulking seals cracks in floors, etc.	• \$0.50–\$5/ft^2 • Thinner, less-expensive barriers likely to be inadequate
Passive venting	• New construction • Low soil gas flux sites • Should be convertible to active system if necessary	• Relies on advective flow of air due to wind and heat stack effects • Air flows and suction typically far less than achieved by fans	• \$0.75–\$5/ft^2

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Technology	Typical applications	Challenges	Range of installed costs*
Subslab depressurization (SSD)	• New and existing structures • Sumps, drain tiles, and block wall foundations may also be depressurized if present	• Low permeability and wet soils may limit performance • Otherwise, highly effective systems	• $1–$5/ft^2 • Residential systems typically in the $1–2/ft^2 range
Submembrane depressurization	• Existing structures • Crawl spaces	• Sealing to foundation wall, pipe penetrations • Membranes may be damaged by occupants or trades people accessing crawl space	• $1–$6/ft^2 • Residential systems typically in the $1.50–2/ft^2 range
Subslab pressurization	• Same as SSD • Most applicable to highly permeable soils	• Higher energy costs and less effective than SSD • Potential for short-circuiting through cracks	• $1–$5/ft^2
Building pressurization	• Large commercial structures, new or existing • Sensitive receptors	• Requires regular air balancing and maintenance • May not maintain positive pressure when building is unoccupied	• $1–$15/ft^2 • Heavily dependent on size and complexity of structure
Indoor air treatment	• Specialized cases only	• Typically generates a waste disposal stream • Effective capture of air contaminants may be difficult • Energy-intensive, with significant operation, maintenance, and monitoring burden	• $15K–$25K per application not atypical • Actual costs heavily dependent upon type of technology employed
Sealing the building envelope	• Cracks and holes in existing buildings	• Access to perforations • Permanence	• Highly dependent on the extent of sealing required

*Square footage costs based on building footprint.

4.3.1.1 Passive Barriers

Passive barriers are materials or structures installed below a building to physically block the entry of vapors. Passive barriers ideally cause soil gas that would otherwise enter the building under diffusion or pressure gradients to migrate laterally beyond the building footprint. In reality, it may be very difficult to completely prevent (or even substantially prevent) the entry of vapors into a building by passive barriers alone (see Table 4-2). Therefore, passive barriers are generally not recommended by themselves for vapor intrusion control, although they may enhance or increase the efficiency of other technologies, such as subslab depressurization (SSD) systems.

Table 4-2. Passive barrier pros and cons

Advantages	Disadvantages
• Low to moderate capital cost • No mechanical parts	• Even small holes can render ineffective • Likely not effective without venting • Limited applications for existing structures

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Most passive barriers consist of thermoplastic or elastomeric flexible membranes or spray-on rubberized asphalt emulsions. In new structures, barriers are placed beneath the floor slab to prevent subslab soil gas from entering the structure through cracks or construction joints in the slab. In existing structures, membranes can be used to retard the intrusion of vapors in crawl spaces or over dirt floors.

To be effective, passive barriers must provide a complete barrier to vapor intrusion since, by definition, passive barriers do not include any active measures to control the movement of soil gas. Even small imperfections in the barriers (e.g., due to holes, tears, or incomplete seals at the footings or pipe penetrations) may provide a significant migration route for soil gas when buildings are underpressurized. Occupants may accidentally penetrate the barrier as part of general building maintenance. No standard criteria have been developed for minimum passive barrier thickness or physical properties, such as puncture resistance and tear strength. Nevertheless, thin polyethylene films (often called "vapor barriers" because they have been traditionally used to prevent moisture from accumulating behind drywall walls) are easily damaged and are unlikely to survive normal construction abuse, even when cushioned by sand (ASTM 1998). Even thicker (e.g., 10–20 mil) polyvinyl chloride membranes are likely to be damaged during construction, particularly if placed below concrete slabs. Workers are likely to step onto and force aggregate and other sharp objects into the membrane and may actually poke holes into the membrane to encourage water drainage during concrete placement and curing. Studies of flexible membrane liners used for liquid containment in impoundments have shown that even placement of sand and other earth materials is likely to cause a certain amount of puncturing.

The potential for punctures may be reduced by using thicker membranes (e.g., 60–100 mil high-density polyethylene [HDPE] or similar materials); thick (e.g., ¼-inch) layers of spray-on rubberized asphalt emulsions; and cushioning materials above and/or below the membrane, such as geotextiles, sand, or fine rounded gravel (pea gravel). Some proprietary vapor barrier products incorporate cushioning, barrier, and sealing material layers in one material. Nevertheless, no specific criteria have been developed for passive vapor intrusion barriers, and some degree of imperfection (e.g., punctures, incomplete seals at seams and edges) should be expected in virtually all applications. The potential for high concentrations of certain chemicals to adversely impact membrane or solvent seam integrity should also be considered.

Key Elements of Passive Barrier Systems

- Do not expect complete elimination of vapors
- Select barriers that are thick enough to withstand normal construction abuse
- Include thorough quality control procedures to minimize barrier damage
- Inspect barrier seals at all edges, penetrations, and seams
- Test barrier integrity and performance after installation
- Have contingencies to enhance passive barriers if not adequate

In addition to specifying reasonably adequate membrane thicknesses, passive barrier designs should include QA/QC plans that address the potential for damage to the membranes during installation, subsequent concrete pours, and building construction activities and protocols for minimizing such damage. Specifications should require thorough inspection of liner seals along all edges and at penetrations, observation during concrete pouring, and detailed procedures for testing the efficacy of the passive barrier after the slab is placed (e.g., pressure tests, smoke tests,

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post-construction indoor air tests). See ASTM Standard E 1643-98 (ASTM 1998) for more information regarding the use of water vapor barriers, although these standards may not be sufficient to address chemical vapor intrusion or associated low indoor air screening levels.



Figure 4-1. Liquid Boot® being applied during construction. Courtesy LBI Technologies, Inc.

Passive barrier designs that rely on complete elimination of vapor intrusion are unlikely to succeed, for the reasons discussed above. If only low reductions in vapor intrusion rates are required, passive barriers may be sufficient; however, some method of measuring the performance of the passive barrier should be specified, and the design should allow for the addition of venting or other measures to address inadequate performance. In most cases, however, passive barriers without venting layers are not likely to be effective unless subsurface conditions are conducive to natural venting. For example, experience shows that in existing structures sealing alone reduces radon levels only 0%–50%, often due to some points of vapor entry that are obscured from view or have no access. Therefore, in most situations, at least passive venting should be combined with passive barriers, as discussed below.

Estimated costs for flexible membranes range \$4–\$50/m^2 (about \$0.50–\$5/ft^2) of building area. Less expensive (and thinner) materials are probably inadequate to be relied on alone as a passive barrier. Spray-on asphaltic emulsions (Figure 4-1) have been installed for \$21–\$32/m^2 (\$2–\$3/ft^2). Price ranges vary based on several factors, including overall area to be covered, number of protrusions that require sealing, and the material used. The barrier thickness and QC measures likely necessary for a passive barrier design to succeed on its own (e.g., without venting) may well result in costs that exceed the ranges quoted above. On the other hand, when passive barriers simply augment other active systems (see below) and are not required to be 100% effective, costs may be closer to the lower end of these ranges.

4.3.1.2 Passive Venting

Passive venting involves the placement of a venting layer below the floor slab to allow soil gas to move laterally beyond the building footprint under natural diffusion gradients (resulting from the buildup of soil gas below the building) or pressure (thermal or wind-created) gradients. Therefore, passive venting is generally feasible in only new construction (see Table 4-3). Because passive venting relies, in part, on soil gas not entering the building before it can vent laterally, passive vents should be combined with passive barriers, as discussed above. Passive venting layers must be permeable enough to allow unimpeded lateral migration of soil gas. Sands or pea gravel (i.e., nonangular materials that will not damage the membrane) are generally preferred below liners. Nonwoven geotextiles with sufficient vapor transmissivity or geogrids may also function as passive venting materials; however, care must be taken to ensure that

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concrete and fine-grained soils do not penetrate and block the pores of thin geosynthetic materials. Similarly, no venting media will function properly if saturated by water due to high groundwater tables or surface drainage problems (see Section 4.3.2.6). In addition to the venting layer, perforated collection pipes are typically routed at the periphery or through the venting media to collect soil gas and convey it to an exhaust point outside the building (Figure 4.2). Note that collection pipes are generally not required in the venting layer when active depressurization systems are installed. USEPA 1995 provides architectural drawings of passive venting systems for residential homes, including a drawing showing the additional components needed for activation of a passive system (i.e., the addition of a fan).



Figure 4-2. Passive sump mitigation system.
Courtesy Kansas Department of Health and Environment

Table 4-3. Passive venting pros and cons

Advantages	Disadvantages
• Often applied when vapor intrusion is possible but has not occurred • Can be modified to an active venting system if designed accordingly • More applicable to new than to existing buildings • Avoids the long-term operating and maintenance costs of active venting	• Not as effective as active venting • Ambient temperatures and winds can adversely impact success • Not suitable for existing structures unless very modest concentration reductions are required • Upgrade to active venting likely to be necessary for new structures when large reductions in concentrations (e.g., greater than ~90%) are required)

Passive venting designs rely on natural diffusion or pressure gradients to cause soil gas to migrate to collection pipes and exhaust to the atmosphere. Advective flow due to pressure gradients is preferred over diffusion due to chemical gradients in passive venting systems because significant concentrations of soil gas will have to build up below the building before chemical gradients will result in lateral diffusion of soil gas. The elevated concentrations that drive lateral soil gas migration may also cause vertical migration into the building through any imperfections in the passive barrier (see Section 4.3.1.1). Advective flow will occur if the venting layer is depressurized with respect to ambient or atmospheric pressures outside the building and indoor air pressures.

Passive venting systems rely on natural thermal and wind effects to achieve a lower subslab air pressure relative to indoor and outdoor air pressures. For example, by routing the vent pipe through the heated space of the building, the natural thermal stack effect of the house may create enough suction to depressurize the venting layer and draw soil gas up the pipe. However, air may sink down through vent pipes in air-conditioned houses in the summer (a reverse-stack effect). Wind blowing over the tops of exhaust pipes may also create sufficient suction to depressurize

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passive venting layers. However, air will not necessarily vent from a passive system at all times; hence the need for a sound passive barrier (see above) without significant leaks.

Passive venting systems generally result in less depressurization and lower air flow rates than active depressurization systems with fans (USEPA 1993b). As a result, passive venting systems require more permeable venting media, more suction pits for a given building area, more distributed collection pipes, and tighter passive barriers than active venting systems, all things being equal. Even so, consistent depressurization of the venting layer should not be expected, and passive venting systems are unlikely to perform as well as active systems in most buildings (USEPA 1993b). In existing buildings, where installation of venting media and passive barriers is generally not practicable (except in crawl spaces), only moderate reductions in vapor intrusion concentrations (30%–70%) are expected (USEPA 1993b). Slightly better but still variable performance is reported for some new construction passive systems, with maximum reductions still no greater than 90% (USEPA 1993b).

Key Elements of Passive Venting Systems

- Generally not adequate for existing structures (except crawl spaces)
- Do not expect complete elimination of vapors
- Should be combined with sound passive barrier
- Venting layer must be highly permeable with distributed collection pipe system
- Allow for addition of fan if necessary to meet performance objectives
- Test system integrity and performance after installation

It may be possible to rely on wind-driven ventilation to augment passive systems, particularly in areas where relatively sustained winds are common. In this case, wind-driven turbines are used to depressurize the pipe and venting layer.

Some jurisdictions may not allow the use of passive barrier designs for vapor intrusion mitigation, preferring to go directly to active designs. However, for new construction sites, where vapor intrusion has only the potential to occur, it may be reasonable to begin with a passive design (saving the cost of fans and electricity) and upgrade to an active system only if necessary. In all cases, criteria should be developed, preferably in advance of construction, for determining when passive systems need to be upgraded to active (e.g., when subslab soil gas exceeds certain concentrations based on conservative, assumed attenuation factors). Smoke or tracer gas could also be injected into the passive venting layer while the building is depressurized through operation of building ventilation fans. The detection of smoke or tracer gas inside the building would then indicate the need for an active system.

Installed passive venting system costs for new structures range \$10–\$50/m^2 (about \$1–\$5/ft^2), not including the cost of a passive barrier (see above). Most of the system cost is associated with the venting media material and installation; collection and riser pipes are generally a relatively small part of the overall cost. Some vendors have developed geosynthetic venting materials that can be applied in strips along foundation walls. In general, for roughly equivalent performance, passive venting systems cost more to install than active venting layers because passive systems rely more heavily on transmissivity of the venting layer and the integrity of the barrier layer to function. Nevertheless, when they perform adequately, passive venting systems lack the long-term operation and maintenance costs of active system fans.

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4.3.1.3 Subslab (Active) Depressurization



Figure 4-3. Active subslab depressurization system.
Courtesy Kansas Department of Health and Environment

Subslab depressurization (SSD) is widely considered the most practical vapor intrusion mitigation strategy for most existing and new structures, including those with basement slabs or slab-on-grade foundations (see USEPA 1993b). SSD systems function by creating a pressure differential across the slab that favors movement of indoor air down into the subsurface. This is accomplished by pulling soil gases from beneath the slab and venting them to the atmosphere at a height well above the outdoor breathing zone and away from windows and air supply intakes (Figure 4-3). In new construction, SSD systems are similar to passive venting systems except that a fan is used to draw soil gas through the subslab venting layer prior to discharging it to the atmosphere. In existing structures, SSD systems entail the cutting of one or more holes in the existing slab, the removal of a quantity of soil from beneath the slab to create an open hole or "suction pit" (6–18 inch radius), and the placement of vertical suction pipes into the holes. These pipes are then manifolded together and connected to a fan, which draws soil gas from the subslab area through the piping and vents it outdoors.

In new construction, permeable venting layers and passive barriers may be placed under the slab to increase the efficiency of the SSD system, essentially by extending the suction field and reducing the number of suction pits. However, venting layers and passive barriers do not have to be as robust for active SSD systems as they do for passive systems.

Key Elements of SSD Systems

- Most widely applied and effective systems for vapor intrusion control
- Applicable to new and existing construction
- One or two suction pits adequate in most existing single-family homes
- Typically combined with venting layer and passive barrier in new construction
- Performance may be limited by low-permeability subsoils
- May be combined with drain tile or block wall depressurization

Active SSD systems are the most reliable, cost effective, and efficient technique for controlling vapor intrusion in the majority of cases, with concentration reductions in the 90%–99% range (USEPA 1993b) and 99.5% or greater in carefully designed and installed systems (Folkes 2002). Subslab depressurization in the range of 0.025–0.035 inches H_2O is generally sufficient to maintain downward pressure gradients (USEPA 1993b).

Experience has shown that one or two suction pits are adequate to depressurize typical residential homes unless tight or wet soils or unusual foundation conditions inhibit the propagation of the suction field (USEPA 1993b). The suction pit location is usually not critical, but the system may perform better when pits are located near the perimeter of the home, closer to the major air entry routes (construction joints and utility penetrations). In tight

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soils, more permeable backfill materials around the footings may also allow suction fields to extend further around the slab perimeter (USEPA 1993b).

When present, sumps and associated drain tile systems may also be depressurized. Interior (i.e., inside the foundation wall) drain tile systems can help distribute the suction field under the slab. Since most drain tiles are located near the foundation wall, depressurization of the drain tile should help control vapor entry at the joint between the foundation wall and slab. Depressurization of exterior drain tile systems may also control vapor intrusion around the slab perimeter but may be less effective toward the center of the slab (USEPA 1993b).

Hollow block wall or cinder block foundation walls may act as migration routes for vapor to enter homes, particularly if the holes in the top row of blocks are open. Therefore, mitigation techniques for block wall foundations include sealing the holes at the top, as well as actual depressurization of the block wall (USEPA 1993b). Block wall depressurization is usually combined with subslab depressurization systems. However, because uniform depressurization of block walls can be difficult and, in some cases, cause basement depressurization and enhanced vapor intrusion (or back-drafting of fireplaces and combustion appliances) block wall depressurization is suggested only when subslab or drain tile depressurization prove inadequate to control intrusion (USEPA 1993b).

A number of factors must be considered when designing and installing SSDs to ensure the safe and effective performance of the systems (Table 4-4). It is beyond the scope and intent of this document to provide detailed design and construction standards. However, extensive guidance is available for the design, sizing, installation, and testing of SSDs for radon control in existing homes (USEPA 1993b, ASTM 2002b, MassDEP 1995), new residential construction (USEPA 1994a), and schools and other large buildings (USEPA 1994b). The general recommendations of these guidance documents should be followed for mitigation of vapor intrusion, with appropriate modifications for site-specific conditions and regulatory or building code permit requirements. While these guidance documents were developed specifically for radon control, experience at a number of chlorinated solvent sites has shown that SSDs can also effectively reduce VOC concentrations, achieving the relatively lower mitigation criteria currently in effect for these compounds (Folkes and Kurz 2002). SSDs should be designed and installed by qualified persons, typically consisting of environmental professionals and licensed radon contractors.

Table 4-4. Subslab depressurization pros and cons

Advantages	Disadvantages
• Successful track record of performance, 90%–99% reductions typical, 99.5% or greater reduction possible with well-designed systems • Adaptable technology, applicable to a wide variety of site conditions and geology • Simple gauges show whether the system is working	• Requires periodic maintenance • Wet and low-permeability soils retard soil gas movement • Building-specific conditions may limit options for suction pit, riser pipe, and fan locations

Although the capital cost of this technology is a function of building size and condition, a reasonable estimate of installed capital costs for these units is \$10–\$50/m^2 (\$1–\$5/ft^2). Material costs, especially for residences, are quite low and include little more than the cost of the fan,

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piping, strapping, and cement. Typical installed costs for SSDs in residential homes range about $1000–$2500, including electrical and mechanical permit fees.

Although the fans for houses are low wattage and rarely require separate electrical circuits, they are commonly installed by an electrician and usually require inspection before operation. Annual operation and maintenance costs for these systems are typically very low. Running a 90-watt fan typically costs less than $100 per year, and most fans have an expected life span of 5–15 years, with a replacement cost of about $100 plus labor.

Commercial/industrial systems may use larger, more expensive blowers, which consume more power, often requiring a separate 120 or 240 V AC circuit.

4.3.1.4 Submembrane Depressurization

Submembrane depressurization (SMD), where a membrane is used as a surrogate for a slab to allow depressurization of the soil, has been demonstrated to be the most effective mitigation method in crawl spaces (USEPA 1993b). Properly installed SMD systems have resulted in concentration reductions of up to 99.5%, similar to SSD systems (Folkes and Kurz 2002). An impermeable membrane covers the exposed dirt surface of a crawl space while the depressurization system withdraws soil gas from beneath the membrane and prevents its intrusion into the space above. Table 4-5 lists the pros and cons of this technology, and Figure 4-4 illustrates its application.

Table 4-5. Submembrane depressurization pros and cons

Advantages	Disadvantages
• Similar to SSD's • Applied in situations (e.g., crawl spaces) where SSD is not practicable • Can be combined with SSD	• Similar to SSDs • Membranes can be easily damaged and must be sealed well at edges to prevent leaks • System needs to be periodically inspected to confirm leaks are not present



Figure 4-4. Crawl-space mitigation using submembrane depressurization. Courtesy Kansas Department of Health and Environment

The membrane must be sealed well along all edges of the foundation wall or footings and to any pipe penetrations through the membrane, with enough slack to prevent tearing of the membrane under stress. Because many homes have furnaces or utilities in the crawl space, it may be necessary to place pads or other protective materials over the liner to allow residents and technicians to access the crawl space without damaging the membrane. Membranes can easily be damaged or lose their seal at the edges; therefore, periodic inspection of membranes (or other performance testing) is important for SMDs.

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When membranes are placed directly on low-permeability soils, it may be necessary to extend the soil gas extraction pipe to more than one point below the membrane using either a perforated intake pipe or a manifold system with multiple suction points (USEPA 1993b). Nonwoven geotextiles may also help extend the suction field of the system while protecting the membrane from angular objects in the soil. When the system is operating, the vacuum created by the mitigation fan should flatten the membrane against the ground. As for SSDs, USEPA guidance (1993b) for the design and installation of SMDs in crawl spaces is recommended.

Key Elements of SMD Systems

- Most widely applied and effective systems for crawl space homes
- Applicable to new and existing construction
- Suction field extension (e.g., perforated pipe) may be required for tight soils
- Liners should be sealed to foundation walls and footings
- Liners should be protected against damage where access (e.g., to service furnaces or plumbing) is expected
- Performance may be limited by low-permeability subsoils
- May be combined with SSD, drain tile, and/or block wall systems

A variation of this technology involves placing the membrane over the crawl-space surface and using a fan to gently withdraw the air within the space above (crawl-space depressurization). These systems, while presumably effective in venting portions of the crawl space, tend to be less effective than SMD systems at preventing vapor intrusion since subsurface soil gas is not actually removed. Crawl-space depressurization also typically results in higher heating and air conditioning costs. Natural crawl-space ventilation may be an option in warm climates but may result in higher heating costs and problems with freezing pipes in colder climates. The performance of natural crawl-space ventilation is variable, however, and typically does not result in more than 50% reduction in vapor intrusion (USEPA 1993b).

Costs for SMD systems are generally consistent with those of passive barriers and SSD: \$10–\$50/m^2 (\$1–\$5/ft^2). Typical costs for installation of SMDs in residential homes range about \$1000–\$2500. Annual operating and maintenance costs for these systems are similar to those for SSD, though post-mitigation monitoring, inspection, and repair costs may be higher.

4.3.1.5 Subslab Pressurization

Subslab pressurization (SSP) systems are similar to SSD systems except that fans are used to push air into the soil or venting layer below the slab instead of pulling it out. The intention is to increase the subslab air pressure above ambient levels, forcing soil gas from the subsurface to the sides of the building. USEPA 1993b suggests that this technology is most effective in highly permeable soils, where it may be difficult to pull enough air to depressurize the subslab region by SSD. SSP systems are applicable to both existing and new structures (Table 4-6).

Table 4-6. Subslab pressurization pros and cons

Advantages	Disadvantages
• Does not require soil gas to be collected within structure • May be more efficient than SSD in highly permeable soils	• More energy-intensive than SSD • Cracks or slab openings may result in short-circuiting, leading to vapors inside structure • May not be appropriate for tight soils

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Key Elements of SSP Systems
- Generally less effective than SSD systems
- May be appropriate in high-permeability subsoils
- Higher energy costs than SSD systems

Cracks or openings in the slab or foundation walls could cause short-circuiting of the system so that air forced below the slab reenters the building, potentially pulling in some of the vapors that the system intended to keep out. Since indoor air is typically used to force air below the slab, fans should be equipped with a filter to prevent buildup of debris in the vent system. Other researchers (EPA 1993b) have observed that small pits at the discharge end of the vent system have improved performance of SSP systems; however, this represents yet another design challenge associated with implementing this technology at an existing structure.

Limited cost information is available for SSP systems, but costs are expected to be similar to those for SSD systems: \$10–\$50/m^2 (\$1–\$5/ft^2. Energy costs of a SSP systems are typically higher than those of SSD systems.

4.3.1.6 Building Pressurization/HVAC Optimization

In some instances, it may be advantageous to positively pressurize the building interior (relative to the subslab), thereby preventing vapor intrusion (Table 4-7). This effect is typically achieved through mechanical means and is frequently employed at commercial buildings with "clean rooms" where no amount of outside air (or vapor intrusion) is acceptable. It may be possible to tune the building's existing HVAC system to achieve this positive pressurization, or a new system can be installed. Typically, only small increases in building pressure (e.g., <0.001 inches H_2O) are required to prevent vapor intrusion (EPA 1994b). Building pressurization is applicable to both existing and new buildings, although it may be easier to achieve and more cost-effective in new buildings.

Table 4-7. Building pressurization pros and cons

Advantages	Disadvantages
• Can be applied equally well to both new and existing structures • May be the most effective technology at preventing vapor intrusion	• Generally more costly than other techniques • Regular maintenance and air balancing needed to maintain consistent, positive pressure • Not commonly an option for single-family residences

Positive pressurization of buildings is usually practicable only when the building is relatively tight, i.e., when there are few doors or other openings. Therefore, warehouses with large bay doors are not good candidates for positive pressurization. On the other hand, well-ventilated buildings are less likely to have vapor intrusion problems. Typically, only the lower floor of the building will require positive pressurization, although this will be a benefit only if airflow between floors is limited.

This technology is effective if regular maintenance and air balancing of the system is undertaken. Appropriate pressure tests and monitoring should be incorporated in the design of HVAC remedies for vapor intrusion to ensure that sufficient positive pressures are maintained throughout the areas of the building that could be subject to vapor intrusion.

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The HVAC systems of many buildings operate during normal working hours and are shut off during the night and on weekends. In these cases, vapor intrusion could occur while the systems are off, contaminating indoor air. The degree of impact on indoor air quality during this time and the length of time the impact persists after the HVAC system is restarted must therefore be evaluated in determining the measure's effectiveness. Further, care should be taken to ensure that soil gas is not simply deflected to adjacent, unprotected areas (e.g., into a strip mall or multiunit commercial facility).

Key Elements of Building Pressurization

- Generally practicable only in commercial buildings
- Requires relatively "tight" buildings to limit airflow and energy costs
- Only the bottom floor (e.g., basement) requires pressurization
- May be cost-effective if existing HVAC equipment can be used without significant modifications
- Energy costs typically increased due to higher replacement-air flow rates

Typically applied to large commercial structures, building pressurization may be the most cost-effective method of vapor intrusion mitigation if the HVAC system already creates positive pressures. In other cases, positive HVAC pressures can be achieved with minor adjustments to existing systems, resulting in small or negligible capital costs but potentially increasing energy costs. The increased energy costs associated with positive HVAC system operation will be building-specific, depending on the additional airflow required to achieve positive pressures and heating and/or air conditioning requirements, but could exceed $\$1/ft^2$ annually. Computer-controlled systems may minimize increased energy costs by limiting the amount of airflow to that needed to maintain positive pressures.

Some new building HVAC systems range in cost $100K–$500K or more, depending on the size and complexity of the structure. Moreover, newer building designs are "tighter" and can be more cost-effectively modified than older structures.

4.3.1.7 Indoor Air Treatment

As an alternative to other forms of vapor intrusion mitigation, air within the structure can also be directed to air pollution control equipment (e.g., carbon adsorption systems) to remove toxic air contaminants from the building interior. This technique is not widely practiced since it encourages the collection of contaminant vapors within the structure and is dependent on the treatment system's uninterrupted performance to protect receptors (Table 4-8). However, it can be an effective mitigation strategy when combined with other techniques to control vapor concentrations in problem rooms. Indoor air treatment is an alternative to whole-building pressurization (see above) when subsurface depressurization and/or pressurization methods are not feasible (e.g., high water tables and wet soils). Indoor air treatment is generally only applied in existing buildings, since more cost-effective systems can generally be installed in new buildings.

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Table 4-8 Indoor air treatment pros and cons

Advantages	Disadvantages
• Results in the physical removal and disposal of the air contaminant, not simple redirection • Less susceptible to malfunction or leaks than most other technologies	• Less effective than other control methods (when applicable) • Very maintenance-intensive and costly to install and operate • System leaks, should they occur, may result in higher exposures than no control

Depending on the specific treatment method, there may be an ancillary waste stream that requires disposal. In addition, to the extent treatment of air is required, it may be more advantageous to treat the air exhausted from another treatment technique (e.g., SSD) rather than treating the indoor air of a structure. This advantage is associated with the smaller volumetric rate of air that would require treatment with SSD than if the entire indoor space required treatment.

Indoor air treatment is expensive compared to other mitigation strategies. It requires large amounts of energy and/or may present waste disposal concerns. Capital costs in the range of $20K and annual operating expenses of $15K–$20K are not uncommon (ITRC 2003). Operation and maintenance costs for these systems vary by type of equipment but can easily approach $15K–$30K or more, annually.

Key Elements of Indoor Air Treatment

- Less effective than other vapor intrusion control methods
- Expensive to install, operate, and maintain
- Typically generates waste (e.g., spent carbon)

4.3.2 Factors Affecting Building Control Technology Selection

As discussed below, a number of factors may affect technology selection for vapor intrusion mitigation of buildings, including building type and use, foundation type, subsurface conditions, the COCs, and the degree of reduction required.

4.3.2.1 New Versus Existing Buildings

More mitigation options are typically available for new buildings than for existing buildings. In general, subsurface features such as passive barriers and venting layers cannot be "installed" below existing buildings, although depressurization technologies have been shown to work well in existing buildings without the benefit of these features. In addition, the presence of lead paint or asbestos may make more intrusive technologies less cost-effective in older, existing buildings. On the other hand, new buildings may incorporate subslab venting layers, collection pipes, and vapor barriers (membranes) to enhance the performance of SSDs. These features may increase the efficiency of depressurization systems and reduce the number of suction points and fans required to achieve desired performance levels. In some cases, these enhancements may be sufficient to allow effective use of passive mitigation systems, although passive system performance will be case-specific and should be critically evaluated during system design and verified during post-mitigation diagnostic testing (see Section 4.3.3.4). New buildings can also incorporate foundation features that enhance the collection of subslab soil gas, such as conduits

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through grade beams and foundation walls (thereby reducing the number of required suction points). New construction may also incorporate design features that reduce the potential for building depressurization and/or the "stack effect," such as limiting openings that allow vertical movement of air from floor to floor, ventilation of crawl spaces, installation of HVAC systems that allow positive pressurization (commercial buildings), and outside air supply for gas furnaces and water heaters. Some of these items can be retrofitted into existing buildings. Finally, new buildings can incorporate suction points, collection and riser pipes, and other features into the design, allowing optimal location of systems without the aesthetic problems often encountered with existing buildings.

Therefore, if possible, mitigation should occur at the time that the building is constructed, rather than retrofitted after it is constructed. Such decisions may confront property owners wishing to develop property where contaminated shallow groundwater or soils pose a potential threat to indoor air quality via vapor intrusion. While the owner may choose to wait and test indoor air after the building is constructed, hoping that no mitigation will be needed, it is generally preferable for the owner and responsible parties to agree in advance on building modifications during the design phase. Costs for the mitigation can then be minimized, and it can be better integrated with other building features.

4.3.2.2 Building Size

The building size may have some effect on technology selection and system design, though in many cases larger buildings simply require larger systems, often with greater economies of scale. Larger commercial or industrial buildings, such as warehouses, may be less susceptible to poor indoor air quality resulting from vapor intrusion due to the larger building air volume, higher air exchange rates, open bay doors, positive air pressures (depending on HVAC system operation), and thicker floor slabs. These buildings or portions of these buildings, therefore, may not require mitigation. But office areas with low ceilings and a number of dividing walls may have air exchange rates and volumes that are similar to those of residential homes. So when deciding what type of mitigation is best for the building of concern, thought must also be given to which portions of the building the system must effectively mitigate.

Radon mitigation experience suggests that buildings up to 50,000 ft^2 can be mitigated by SSDs with one suction point, provided that subslab materials are permeable and the suction field is not short-circuited by cracks or other penetrations through the slab (USEPA 1993b). However, in most cases such a large building would likely require multiple SSD suction points and either multiple in-line fans or one larger blower. Multiple suction points can be connected to one large fan or blower on the roof, using interior walls or columns to locate riser pipes. However, joints between slab sections, cracks, and other penetrations through the slab between suction points should be sealed to prevent short-circuiting of the suction field.

Horizontal pipes may allow efficient depressurization and collection of soil gas over large areas below new building slabs. Horizontal pipes may also be drilled below existing large buildings, although the economies of this approach versus multiple suction points should be examined carefully. The potential impact of multiple horizontal drill holes on the foundation integrity of any shallow footings or weight-bearing slabs should also be considered.

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4.3.2.3 Building Use

Current and likely future building use should be considered when selecting mitigation technologies. Reliance on positive HVAC pressures is more suitable for commercial and industrial buildings than for residential homes because commercial HVAC systems are more readily adapted to provide continuous positive pressures and are more likely to receive routine maintenance and monitoring to ensure that positive pressures are maintained. Buildings that are occupied only for short periods or during working hours may not require the same degree of reduction, depending on the assumptions used to develop risk-based indoor air screening levels, if applicable. Building use may affect how and where mitigation piping is routed. Piping arising from the middle of warehouse areas may be in the way of operations and be at risk from damage caused by forklift or other vehicle traffic. Institutional controls—supplemental to a mitigation system or as the mitigation itself (such as building occupancy or use restrictions)—may also be feasible in commercial and industrial buildings, as long as these also ensure that any change in use will trigger a reevaluation of mitigation requirements.

4.3.2.4 Foundation Type and Condition

Foundation types include basements, crawl spaces, slabs on grade, and any number of combinations of these basic types. Foundation type affects design of only those mitigation systems that function by depressurizing soils below the building. SSD systems can be applied in any situation where a slab overlies soil, while SMD systems can be used in crawl spaces or anywhere that expanses of soil are exposed and future use of the area will not damage the membrane. Many buildings require both SSD and SMD systems, which can often be connected to the same fan.

Subslab features such as grade beams, footings, and foundation walls may interrupt the development of suction fields below the slab, requiring installation of suction points in each area. In some cases, existing drain pipes and sump systems may be used as suction points, sealed, and converted into efficient depressurization systems in existing residential and commercial/ industrial buildings. In rare cases, heating and ventilation ducts may be present below the slab, providing a preferential pathway for vapor intrusion and short-circuiting subslab depressurization fields. Building-specific designs may be necessary to overcome this situation.

Certain building features, such as elevator shafts and sumps, may enhance the potential for vapor intrusion unless properly sealed to prevent entry of both soil gas and groundwater containing VOCs. Elevator operations might enhance building depressurization and increase the rate of vapor entry into the building. Elevator shafts and other vertical conduits might also increase the movement of vapors throughout the building.

The foundation *condition* may also affect mitigation options. Excessive cracks, utility penetrations, or other openings may cause short-circuiting of the depressurization field, limiting the areal influence of a particular suction point. Solutions may include sealing of cracks and penetrations and creating additional suction points for SSD systems. Fieldstone foundation walls may be too permeable for depressurization remedies to be effective without grouting or

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otherwise sealing the wall. In extreme cases, alternative mitigation strategies may be necessary, such as building pressurization or slab replacement.

The condition of the foundation wall may also affect mitigation techniques. Cinder block foundation walls may provide vapor migration routes through the interconnected voids in the blocks, particularly if not sealed at the top of the wall. Mitigation strategies for such conditions include installation of suction points and depressurizing of the wall, as well as sealing of the openings at the top of the wall. In some homes, dugout basements may have exposed earthen walls. Typically, these must be covered by membranes or walled off to enable effective operation of depressurization systems. Basements with exposed earth or rock floors may require placement of a concrete slab or false floor with a membrane to enable depressurization.

In some cases, crawl-space areas are not accessible for installation of SMDs (Section 4.3.1.4). Options may include digging out the crawl space to allow access, installation of outside air vents to enhance natural ventilation of the crawl space (in warmer climates and where freezing of pipes in the crawl space is not a concern), installation of horizontal soil gas extraction pipes below the crawl space, and positive pressurization of the crawl space to inhibit vapor entry.

4.3.2.5 Soil Conditions

Foundation soil conditions may affect the design of depressurization systems. In the absence of a permeable venting layer below the slab, low-permeability soils restrict the extent of suction fields, increasing the number of suction points required below slabs and membranes. In some cases high-vacuum/low-flow fans may be required. Larger voids or suction pits may also be sufficient to improve SSD system operation in tight soils (Folkes and Kurz 2002).

Depressurization systems are generally very effective in permeable soils; however, large venting layers may require low-vacuum/high-flow fans to move enough air through the system. Fan selection and pipe sizing is discussed in USEPA 1993b and Fowler et al. 1990. The mitigation contractor chosen for the project should have experience installing systems in the type of subsurface soils encountered below the building(s) of concern. In very permeable soils where depressurization is difficult, subslab pressurization (where air is pumped into a permeable layer or natural soils below the slab to create positive subslab pressures that divert subsurface soil gas around the structure) may be more effective (see Section 4.3.1.5 and USEPA 1993b).

4.3.2.6 High Water Table Conditions

Saturated soils may prevent effective depressurization of the subslab region by filling soil pores and making them unavailable for vapor transport. Soils beneath the building can become saturated due to various conditions and may stay wet for relatively long periods. In these situations, it may be necessary to first solve the water problem before addressing vapor mitigation. If the wet conditions are due to a high groundwater table containing volatile COCs, actions directed to keeping the water away from the building must take precedence over intrusion concerns associated with subsurface soil gas.

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In cases where soils are damp but there is no continuing supply of water, air flow generated by an SSD system may dry the soils out sufficiently to allow effective depressurization. In cases where high water tables are controlled by drain tile or French drain systems, depressurization of the air space in the drain tile may be sufficient to control vapor intrusion (see Section 4.3.1.3). If French drain systems are retrofitted in existing structures, the drain pipes should be sufficiently large to drain the water and still leave a headspace for depressurization.

If high water table conditions are episodic, risk assessments may indicate that occasional loss of vapor intrusion control (due to loss of depressurization) does not result in a significant increase in long-term risk. Alternatively, the SSD system could be augmented by a fan that either ventilates or pressurizes the basement with outside air whenever the sump pump switches on, provided that flooding only occurs during warmer weather.

If dewatering is not practicable, then basement and/or crawl-space pressurization may be the most cost-effective method of vapor intrusion control. However, if water is actually entering the basement or crawl space, pressurization will not prevent direct partitioning of volatile compounds into the basement or crawl-space air, which would then flow into other parts of the building. In these cases, it may be necessary to depressurize the basement or crawl space, although energy costs due to heat loss may be high. In some cases, it may be possible to install a false floor above a slab or earth floor and create a thin venting layer that could be depressurized.

Finally, high water table conditions may be due to “clean water” that is infiltrating the ground after precipitation events. In this case, the water below the floor slab may actually provide a clean water lens that prevents or minimizes vapor intrusion into the building. Therefore, the SSD would need to operate during only low water table periods, when depressurization would be feasible.

4.3.2.7 Chemicals of Concern

The COCs may affect mitigation system design in at least three ways. First, potentially combustible vapors (i.e., those that may approach combustible concentrations) require intrinsically safe blowers and monitoring or alarm systems. Second, certain vapors may cause degradation of membranes, pipes, or the solvents used to join pipes. Third, COC action levels, if any, will affect the degree of concentration reduction required inside the building. Reductions of 80% or less may be possible with passive systems, while higher reductions generally require active depressurization or pressurization systems (USEPA 1993b). Standard radon SSD and SMD systems generally perform well when reductions of up to 95% are required, while more rigorous attention to installation details, enlarged suction pits, and/or increased numbers of suction points and fans may be required for higher reductions (Folkes and Kurz 2002).

4.3.3 Design and Installation of Building Controls

The following sections discuss the general approach to design of building controls, pre- and post-diagnostic testing, and other design issues, including access, owner preferences, lead-based paint and asbestos, and back-drafting potential.

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4.3.3.1 Design Approach

Design of vapor intrusion controls for new buildings should consider all of the factors discussed in the previous section. Vapor intrusion control requirements should be integrated into the overall building design process as soon as possible, since varying the locations of elevator shafts, basements, and even the building itself might help reduce the risk of vapor intrusion. Foundations can be designed to enhance, rather than inhibit, suction field extension below slabs. Similarly, building pressurization systems can be optimized by designing tighter bottom floors and installing HVAC systems capable of creating and maintaining positive pressures during all seasons. Vapor intrusion control designs should include system layout drawings, minimum material specifications, installation procedures, construction QC procedures, and post-installation testing procedures.

Design of vapor intrusion mitigation systems in existing buildings should begin with a visual inspection of the building. For existing residential homes where SSD systems are applicable and the mitigation contractor is familiar with the houses in the area, this is likely the only step required before installation (USEPA 1993b, Folkes 2002). However, for larger commercial buildings, or if subsurface or building characteristics indicate that an SSD system may not work well, premitigation diagnostic testing may be required (see Section 4.3.3.3).

For most existing residential homes, it is usually sufficient to install a relatively standard system without building-specific designs or premitigation diagnostic tests, relying on the mitigation contractor's experience in the area (USEPA 1993b). While this "standard design" approach allows systems to be installed more quickly (which may be important at larger sites with a number of homes requiring mitigation), some form of post-mitigation testing is required to verify that the standard design is adequate. Experience at the Redfield Site in Colorado indicated that only about 10% of homes requiring a 95% or less reduction in concentration needed adjustments after installation of a standard SSD system, and in most cases these adjustments were modest and inexpensive (Folkes 2002).

For larger, more complex buildings or when visual inspections indicate SSD systems may not function well, detailed diagnostic tests prior to mitigation and prepare building-specific designs may be appropriate. Commercial building owners may provide access only if they can review the mitigation design before it is installed. Some states may also require approval of building-specific designs before installation. Designs may also be needed to apply for preinstallation permits and/or to provide the public opportunity for preimplementation review and comment.

Both the standard design and custom design approaches are effective, but the best approach depends on site-specific circumstances, priorities, and to some extent, the preferences of the regulatory agency and the building owner. Table 4-9 summarizes the advantages and disadvantages of each approach.

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Table 4-9. Mitigation design approach considerations

Approach	Advantages	Disadvantages
Detailed diagnostic testing and design followed by installation and testing	• Post-installation adjustments less likely to be required • May be more effective for unique building types or unusual conditions • May be more effective when a high degree of reduction (e.g., >95%) is required • May be required if multiple reviewers/stakeholders must agree on design specifics	• Higher initial design and testing costs • More site visits required for design and initial installation • Likely to be more expensive for multiple residential mitigations (it takes longer to install systems via this approach if there are a large number of homes to be similarly mitigated)
Standard system installation based on experience and inspection followed by testing, and adjustments, if needed	• Lower initial design and installation costs • Fewer visits required to install system, less disruption to occupants • A larger number of systems can be installed per time period (although some may require adjustments) • Standard design can be adjusted over life of project based on performance of first group of systems • Most appropriate for homes and when mitigators (and regulatory reviewers) have prior experience with similar homes in the same area	• System adjustments may be required in more homes (most likely a minority of homes, if based on prior experience and standard design adjusted as necessary over life of project) • Costs for system adjustments may result in higher total costs than if these "adjustments" had been initially installed, although making such adjustments may be less expensive than detailed diagnostic testing • Additional post-mitigation tests may be necessary to demonstrate adjusted systems working adequately

4.3.3.2 Owner/Tenant Preferences

While the investigator and regulatory agency may be primarily concerned with the performance, cost-effectiveness, and reliability of any mitigation system, the tenant in the mitigated building must live (or work) with that system, and its owner will want to maintain it investment value, regardless of how many pipes, fans, and holes in the floor are deemed necessary by others. What the tenant and owner prefer, then, in terms of mitigation design features, should be taken into account as they would in any radon mitigation installation. Owners/tenants will often have strong opinions about where fans and piping are located, what level of fan noise is acceptable, how readable different system-operation gauges and meters are, and what quality of construction craftsmanship is satisfactory. If the mitigation contractor is considering an attic location for a fan, owners and tenants will need to be questioned about the current and near-future use of that space. When there are multiple mitigation options (for example, at a large commercial building where the mitigation could be based on SSD or could, alternatively, be an adjustment to the HVAC system to pressurize the building) the responsible party should fairly present the options to the building owner and tenant, explaining the advantages and disadvantages associated with each and describing why the preferred alternative should be the option installed.

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4.3.3.3 Premitigation Diagnostic Tests

When necessary, premitigation tests can be conducted in existing buildings to measure the potential extent of the suction field for SSD systems. These tests, which are often referred to as "communication" or "suction field extension" tests, indicate whether SSD systems are viable and aid in the selection of suction pit locations and fan size. They may also indicate whether any conditions (soil or building) exist that might preempt the use of active depressurization systems. The test typically involves applying suction to a centrally located hole drilled through the floor slab (using a shop vacuum or a portable radon fan) and observing the movement of smoke downward into construction joints and/or small holes drilled at locations surrounding, but distal to, the suction point. Digital micromanometers or other types of small differential-pressure monitoring devices can also be used to assess the extent to which the suction system can achieve sufficient vacuum. Diagnostics should include testing under stressed conditions, such as during operation of furnaces and vent fans that tend to depressurize the building. In most cases, suction field extension tests are the only premitigation diagnostic testing necessary prior to design and installation of SSD systems (USEPA 1993b).

Suction field extension tests may also be conducted during installation of SSD systems, rather than prior to installation, using the first suction point to apply a vacuum and determine whether additional suction points (and/or larger fans) are required.

In many cases, mitigation contractors have sufficient experience with soil conditions and building types to accurately judge the size and locations of mitigation components. If a large number of mitigation systems need to be installed as quickly as possible, it may be more expedient to install standard systems, test these systems as they are being installed, and, when necessary, enhance or modify the systems to meet performance criteria (see Section 4.3.3.4).

4.3.3.4 Post-Mitigation Diagnostic Tests and System Modifications

Post-mitigation diagnostic tests are generally recommended to ensure that mitigation systems are meeting performance objectives and criteria. Some states have required indoor air tests shortly after mitigation systems are installed to ensure that action levels are being achieved. The number and timing of required tests varies, from a minimum of two (MassDEP 2002) to long-term indoor air testing programs (CDPHE 2004). When only two post-mitigation indoor air tests are performed, at least one of the tests is generally performed during cooler months. Post-mitigation indoor air tests should not be conducted immediately after the system has been installed because time is required for vapors that have already entered the structure to dissipate. Some state guidance documents suggest that indoor air sampling not be conducted for at least 30–45 days after installation and, preferably, during the heating season, although experience at sites in Colorado suggests that indoor testing may be conducted within two weeks of system installation (unless extenuating circumstances suggest waiting for a longer period of time).

In some cases, no indoor air testing is required, and post-mitigation suction field testing is considered sufficient to demonstrate SSD performance, assuming downward pressure gradients are measured or observed at all points over the slab. Post-mitigation suction field extension testing can be conducted immediately after system installation or after a short period of

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operation. In cases of widespread contamination in the state of New York, indoor testing of a representative number of buildings may be considered (NYSDOH 2006).

When long-term indoor air testing is used to monitor mitigation system performance, other forms of diagnostic testing are generally not necessary (except when action levels are not being achieved). On the other hand, when no indoor air testing is performed, perhaps due to concerns about background sources of contamination, more rigorous suction field testing is warranted.

If post-installation diagnostic tests indicate an inadequate suction field, a number of system modifications or enhancements have been shown to be effective (Folkes and Kurz 2002), including the following:

- improved sealing of cracks, construction joints, loose membrane seals, and other penetrations in slabs or membranes that may be short-circuiting the system (as indicated by smoke tests)
- enlarging suction pits below floor slabs
- extending suction points further under membranes, using a pipe tee, perforated pipe, or nonwoven geotextiles
- adding additional suction points, with or without addition fans
- increasing fan size

4.3.3.5 Access and Scheduling

Whether the structure to be mitigated is a commercial or institutional structure or a private residence, arranging for access to the property can prove difficult. Commercial building tenants may not want construction activities disrupting business operations, and some homeowners may resist granting access to their home for a variety of reasons, including privacy issues. Scheduling indoor tests may also be difficult since access is required for both placing canisters and picking them up 24 hours later. Homeowners will often want to schedule tests before or after work. To address these concerns, it is highly advisable that an access agreement between the property owner and the investigating/mitigating entity be executed.

4.3.3.6 Lead-Based Paint/Asbestos

Depending on the age of the structure being investigated, other environmental hazards such as lead-based paint or asbestos may be present and can potentially delay mitigation activities. Generally speaking, structures built before 1990 may pose a hazard with respect to lead-based paint, while asbestos may be present in buildings built before 1980.

The presence of one or more of these materials may delay construction activities within the structure until the hazard is adequately addressed or the appropriate safeguards are in place. Addressing these hazards adds to the cost of mitigation and may negatively impact the overall project schedule. Fortunately, most SSD systems are installed in basements and crawl spaces and, whenever possible, in unfinished portions of the house, limiting the potential for disturbing lead paint or materials containing asbestos.

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4.3.3.7 HVAC Issues

When one or more ventilation techniques are used to address vapor intrusion, these systems affect the overall balance of air flow within the structure. If the ventilation equipment and combustion devices within a structure (e.g., furnaces, wood stoves, clothes dryers, and water heaters) are not properly balanced, exhaust gases from the combustion units may collect within the structure. This situation is often referred to as "back-drafting" or "spillage."

In buildings with natural draft combustion equipment, a back-draft test may be indicated prior to installation of mitigation systems involving active ventilation (e.g., SSD). If back-drafting is occurring, it should be corrected prior to installation to avoid safety hazards.

Most residential mitigations utilizing pressurization and/or ventilation techniques add little to the potential for overall building depressurization. Typically, SSD fans operate at low flow rates and induce a minimum pressure differential across the slab. SSD systems should be installed by licensed radon contractors familiar with the potential for back-drafting. Although not currently required of radon contractors, USEPA has *recommended* (USEPA 1993b) that the following procedures be undertaken to investigate the possibility of back-drafting:

- Close all windows and doors, both internal and external.
- Open all HVAC supply and return air duct vents/registers.
- Close fireplace and wood stove dampers.
- Turn on all exhaust and air distribution fans and combustion appliances except the appliance being tested for back-drafting.
- Wait five minutes.
- Test to determine the indoor/outdoor pressure differential in the room where the appliance being tested is located. If the pressure differential is –5 pascals or more, assume that a potential for back-drafting exists.
- To begin a test for actual entrainment of flue gases, turn on the appliance being tested. If the appliance is a forced-air furnace, ensure that the blower starts to run before proceeding.
- Wait five minutes.
- Using either a smoke tube or a carbon dioxide gas analyzer, check for flue gas entrainment near the vent hood.
- Repeat the last six steps for each natural draft appliance being tested for back-drafting. Extreme or unusual weather conditions need to be considered when evaluating these data.

Although cold (outside) air supply vents for gas furnaces or water heaters are typically required by building codes in newer homes, older homes may not have them, resulting in greater negative pressures when furnaces turn on and greater potential for both back-drafting and vapor intrusion. In some cases, providing cold air vents alone may mitigate very minor vapor intrusion problems and in all cases should enhance the performance of SSD systems.

4.4 Operation, Maintenance, and Monitoring

Before or shortly after mitigation systems are installed, a building or site-specific operation, maintenance, and inspection/monitoring (OM&M) plan should be prepared. The plan should

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identify what must be done following start-up of the system, as well as a schedule for conducting these activities. If a large number of systems are installed (e.g., a multihome vapor intrusion site), a standard OM&M plan could be prepared to cover all of the systems, with house-specific drawings and details contained in an appendix.

Indoor air testing is often part of a long-term performance monitoring program, although long-term indoor air monitoring may not be warranted for every system installed. Once proper operation of the system has been confirmed by physical tests and/or post-mitigation indoor air testing (see Section 4.3.3.4), indoor air testing may be warranted only in instances where the system design was complex or the construction problematic. In situations where premitigation levels were very high, however, more frequent monitoring may be necessary. Long-term indoor air testing could also be considered for a portion (e.g., 10%) of systems as QA check on installation. If, during inspections, the inspector believes that the building foundation or components of the mitigation itself have been modified by the owner/tenant since the last inspection, indoor air or suction field extension testing should be considered to ensure that performance expectations are being realized.

Mitigation systems should be inspected periodically. Maintenance should include a visual inspection to confirm the integrity of the system and (by checking manometer readings) that original suction levels are being maintained. Crawl-space membranes should look as if they are being sucked down against the soil, particularly close to suction points. Suction field extension testing may be warranted if manometer readings indicate reduced suction levels or indoor air tests show increasing trends. SSD system fans generally do not require routine maintenance; however, fans should be replaced as necessary throughout the operating life of the system. Noisy fans typically indicate problems with ball bearings and should be replaced. Routine inspections should also include an evaluation of any significant changes made to the building (e.g., remodeled basement, new floor penetrations, new furnace) that would impact the design of the mitigation system or the environment in which it is operated.

The need for air permits and/or exhaust gas controls for SSDs and SMDs should be determined on a site-by-site basis, in compliance with applicable state or local air quality control regulations. In certain cases, particularly those that involve large numbers of structures requiring mitigation within a certain area or those where the mitigation creates high vapor flux rates, it is possible that redirection of soil gases from beneath the building to the ambient air may result in unacceptably high cumulative air quality impacts at receptor points within the community. In such cases, therefore, it may be necessary to apply emission controls on mitigation systems to reduce the concentrations of VOCs being discharged to the atmosphere. Generally, when there appears to be the potential for unacceptable ambient air impacts, a dispersion modeling analysis of the emissions point(s) may be used to estimate whether resulting ambient air quality impacts exceed applicable state toxic thresholds or other health-based standards. Finally, in rare instances, a community ambient air monitoring network may be established to demonstrate that the local population is not being exposed to unacceptable levels of air contaminants resulting from the vapor intrusion mitigation processes. Evaluation of the issue to date in New York has indicated that a requirement for vapor phase controls on these systems is unnecessary, but ambient air studies are ongoing to confirm this conclusion.

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4.5. Closure

At most sites, long-term cleanup efforts will eventually reduce volatile compound concentrations in soil or groundwater to levels that no longer result in vapor intrusion impacts requiring mitigation. At this point, vapor mitigation systems could be turned off and/or removed, depending on the preferences of the building owners and obligations of responsible parties. Likewise, institutional controls could presumably be retired. This is what is meant by "closure" in the following paragraphs. For the most part this section refers to active, not passive, systems used to prevent vapor intrusion, although passive system piping could be removed if accessible. Unless there is something to "turn off" and/or take away, the concept of closure is primarily an administrative one.

Regulatory personnel and responsible parties should consider early on in the project how to determine when vapor mitigation is no longer required, as this will affect the type of data that will need to be collected during the operating period of the mitigation system. For example, the decision to stop mitigation could be based on indoor air "confirmation tests," which would be conducted after temporarily shutting down the system. The number, location, and frequency of confirmation tests could be the same as those used to identify vapor intrusion impacts; however, a smaller number of confirmation tests might be justified by an improved understanding of site conditions. In any case, the decision to no longer require vapor mitigation in a building will likely be based first on groundwater, soil, and/or soil gas concentrations, which may indicate that the vapor source has been effectively eliminated. However, just as it is difficult to predict vapor intrusion impacts in any particular building based only on media concentrations, it may also be difficult to predict when subsurface media concentrations have become sufficiently low to curtail vapor intrusion mitigation.

Therefore, responsible parties may wish to develop correlations between subsurface media and indoor air concentrations early on in the project to use as a tool for deciding when to commence closure evaluations, if consistent with applicable regulatory requirements. As long as some form of confirmation testing is eventually conducted to determine whether closure is appropriate, the decision to begin such testing could be based on a conservative but not extreme correlation values. For example, if correlation data indicated that a certain percentage of the homes at a site were not unacceptably impacted by vapor intrusion when groundwater or soil gas concentrations were below a certain level, it might be cost-effective to commence confirmation tests at this level, with the expectation that the same percentage of the time confirmatory results would indicate that continued system operation was no longer necessary to mitigate vapor intrusion. The selection of the media concentration that triggers closure (confirmation) testing is largely a matter of economics and site-specific considerations. The length of time that the media must remain below these levels will also be site-specific decision, based on judgments of whether the media has been permanently remediated and how many environmental measurements over time are needed to demonstrate this condition. Of course, if there is good documentation that the source of the contaminated vapors has been completely cleaned up (e.g., excavation of soils to below detection or conservative vapor intrusion-based screening levels), then no or limited confirmation testing may be warranted. Although the time required for soil gas fluxes to diminish after source removal vary site to site, evaluations by Johnson et al. (2002) indicate that

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soil gas concentrations (and, therefore, indoor air concentrations due to vapor intrusion) are likely to decrease in a relatively short period of time.

Mitigation systems must be shut down before confirmation tests can be conducted. Indoor air testing of mitigated buildings while the system is in operation cannot indicate whether vapor mitigation is still required. One option may be to turn off the mitigation system for a few weeks and then sample indoor air to determine whether the system is still currently needed. This approach is recommended only if the lines of evidence indicate that short-term exposures to conservatively estimated indoor air concentrations (from vapor intrusion) are not likely to result in unacceptable health impacts and if this approach is acceptable to the building occupants and owners.

Alternatively, subslab soil gas samples could be collected as a surrogate for indoor air tests. Collecting soil gas from immediately beneath the slab will reduce (but not eliminate) the potential impacts of indoor or background sources on measured COC concentrations. However, this approach requires estimation of the slab attenuation factor, as discussed in Appendix D. In some cases, comparison of soil gas profiles with baseline data may also indicate that vapor intrusion is no longer occurring. In the absence of indoor air measurements, however, subslab and soil gas to indoor air attenuation are commonly conservatively estimated. As a result indoor air concentrations and the potential for vapor intrusion based on soil gas and subslab soil gas data may be overestimated.

SSD system exhaust gases or subslab soil gas may be measured while the mitigation system is operating. However, at this point there is little if any information available indicating how well these measurements compare to subslab concentrations when the system is turned off. For example, system exhaust gases may include ambient air from outside the foundation wall, which could dilute the COC concentrations in the system exhaust stream. Subslab soil gas concentrations may be different while the system is operating due to the more rapid movement of the soil gas through the soil. Therefore, investigators may wish to develop data allowing correlations between exhaust gases and indoor air and/or subslab concentrations during the initial investigation and operation and monitoring phases of a site, to provide another potential line of evidence for closure evaluations.

The decision to close vapor mitigation systems may be made on a building-by-building basis or, in some cases, it may be made by testing only worst-case buildings at the site (or in certain areas of a larger site). If the mitigation systems at these worst-case buildings can be closed and there is high confidence in the hypothesis that if these buildings are no longer at risk, other buildings at the site will not be at risk either, then closure decisions for the entire area may be based on the results of confirmation tests for this subset of buildings.

Finally, even if regulators decide that systems may be turned off, some building owners may choose to continue operation of their mitigation systems to provide radon control, or as a preemptive measure to control vapor intrusion due to any sources that might occur in the future. Regulatory agencies may wish to promote the continued operation of vapor mitigation systems by building owners for radon control. However, the responsible party that originally installed

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and operated the vapor mitigation system would probably not be held responsible for the system under the applicable regulatory program once controls were no longer required.

4.6 Other Issues

In the case of undeveloped or redeveloped property, new construction presents an opportunity to deal with one of the more vexing VI problems: mitigating subsurface conduits that may become migration routes for soil gas. For example, sewer, water, underground cable and electrical lines are often placed on porous gravel or soil to maintain good drainage. Yet this practice also fosters inadvertent vapor transport requiring construction provisions that contain barriers to vapor transport, either through the design of the conduit or the use of nonporous materials. Currently, the National Aeronautics and Space Administration (NASA) requires this for new construction at the NASA Research Park, located at Moffett Field in California.

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APPENDIX A

Community Stakeholder Concerns

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COMMUNITY STAKEHOLDER CONCERNS

This appendix was written by stakeholders who represent communities affected by vapor intrusion to give invesitgators an understanding of the issues building occupants may be concerned with regarding vapor intrusion.

As stated in the text, when communities become aware of vapor intrusion, many concerns are raised involving not only a person's own residence, intrusive sampling, and remedies, but also the air that their children breathe while playing out of doors and at school and secondarily the retention of property values and a clean and healthy environment. At many sites, these issues become "hot button" issues, driving the discussion and sometimes the strategy that regulators will take in addressing vapor intrusion.

Based on discussions and experience of community stakeholders at various sites and the experience of stakeholder team members, the following is a brief description of major concerns that communities, property owners and others have voiced. It should be noted, however, that this list of concerns is not exhaustive. As this issue continues to develop, other issues will undoubtedly arise. It should also be noted that many of the issues below are touched on in the preceding text. However, we believe that it is important to articulate these concerns, as they would be presented from a community's point of view.

- **It is important to develop a complete CSM.** Communities want the CSM to consider all sources, receptors, and migration routes. Often, the conceptual model is restricted because the regulating agency has authority to address only some of the sources and/or migration routes. This problem requires state agencies to work together with city and county health departments, as well as with air quality management districts.

- **The quality of outdoor air is important to consider in the conceptual model and in remedy selection.** Some agencies limit their definitions of vapor intrusion to indoor exposure. To many communities, outdoor contamination through subsurface volatilization or direct discharge into the air is part of the same problem. Most guidance addresses vapors intruding into indoor spaces. Yet children spend long periods of their day in backyards, school yards, and playgrounds. This is an important consideration for communities and should be given attention at many sites. Residents also want to minimize discharges from building ventilation systems and groundwater treatment systems.

- **Communities want health-conservative analysis and standards.** Potentially impacted residents want vapor intrusion investigations and remedies to err on the side of caution. Residents want investigations to use very low screening levels and even to require mitigation and response based on the most stringent standards.

- **Cumulative and synergistic risk from multiple contaminants should be considered.** Often, more than one contaminant is the subject of vapor intrusion. Communities are concerned that the cumulative and synergistic effects of these combinations are not well understood or addressed. When it is not possible to understand or estimate these effects, risk assessment procedures should err on the side of caution.

- **Understanding transformation products and the half-lives of contaminants is often not considered in decision making.** Communities are concerned there is not enough care paid to the transformation products and the half-lives of various contaminants. For example, volatile organic compounds are transformed in groundwater and soil. Likewise, as vapors are exposed to the atmosphere, they are also converted. It is important to fully understand the half-lives of the various contaminants that are in the air, as well as considering all of the transformation products.

- **Screening programs and modeling tools are often suspect.** Initial site screening programs that eliminate sites on the basis of modeling and attenuation factors are not well understood by communities and should be used together with site-specific information. Communities are suspicious of the most common model used (J&E) as it sometimes misses the problem, either from improper use or due to shortcomings in the model. For example, there have been reports that the J&E model does not account for lateral transport of soil gas or directly consider preferential pathways. If the issue of vapor intrusion is raised, site-specific information is often required to allay a community's concerns, regardless of the models used by regulators. In addition, soil gas and groundwater plumes should be fully characterized prior to eliminating sites. There have been instances where the plume definition data indicate that no vapor intrusion could be present (assuming standard attenuation factors and vapor modeling), yet samples taken inside of residences indicate that vapor intrusion has occurred. History has reinforced many communities' distrust of models, and many want direct measurements taken.

- **Indoor air sampling is often desired by communities before a site can be eliminated.** Communities generally question findings of acceptable risk based solely on models. There has been sufficient evidence that indoor air concentrations are sometimes substantially above modeled levels. Recognizing that it would be impossible to test the air of every residence, communities that have any sign of vapor intrusion will often demand that indoor air sampling be done. Some occupants are willing to put up with the inconvenience of sampling, as well as a survey of chemicals within their homes. Indoor air samples should also include those buildings occupied by the most vulnerable among us, including day care centers and schools. Often, communities are asking that every room be sampled because of extreme variations in results due to vapor migration routes.

- **Sampling and analysis procedures should be done as quickly as possible and should follow proper procedures.** Near-real-time or real-time sampling techniques (e.g., trace atmospheric gas analyzer) that help identify sources and migration routes are preferred by community stakeholders. Stakeholders often want to know the results of any tests involving their homes as soon as possible. It's also important that good and consistent practices be followed when conducting indoor air sampling. Sometimes windows have been left open or heating systems turned off when conducting indoor air sampling, both of which cause improper readings.

- **Accelerated remediation is often the best long-term solution for vapor intrusion problems.** In most cases where vapor intrusion is caused by groundwater and soil contamination that is being actively remediated, the long-term solution to vapor intrusion is

to accelerate cleanup. At sites where subslab membranes or soil gas ventilation systems are in place to prevent indoor vapor intrusion, residents do not think of these methods as a long-term solution. Settling, earthquakes, power outages, aging, and new construction at existing buildings are barriers for these mitigation techniques. As long as there is potential exposure, health is at risk. The best way to ensure that subsurface contamination does not enter homes or other structures is to remove and/or destroy the toxic compounds. Historically, this process has been slow and difficult, but vapor intrusion sites are ideal candidates for the deployment of innovative remedial technologies.

- **Monitoring, backed by institutional controls and contingency plans, is needed to reinforce both passive and active mitigation.** In all cases where there is vapor intrusion, mitigation techniques (barriers, venting, etc.) should include a long-term monitoring plan and a contingency plan. Monitoring should be supported by institutional controls until such time that it can be shown that vapor intrusion is no longer a threat. Furthermore, the costs of such long-term management activities over the life of the contamination should be weighed against permanent treatment or removal costs (i.e., accelerated cleanup) in the selection of remedies. If in new development, consideration should be given to requiring some type of financial assurance, such as a security bond.

- **New development on sites with vapor intrusion potential should be carefully regulated.** Vapor intrusion hazards should be identified and addressed before new construction occurs. At a number of sites, new development is being proposed where vapor intrusion is likely, even in areas with ongoing vapor intrusion investigation and mitigation efforts. Regulatory agencies should work with cities and other local planning jurisdictions to screen development sites for potential vapor intrusion, ensure maximum cleanup before construction, alter building design to minimize risk, and require the installation of reliable mitigation before the fact. Potential residents should be notified of possible risks. Where necessary, notification requirements should be enforced by institutional controls. A proactive strategy toward property reuse at contaminated sites should cut down on the litigation that typically occurs once the news about vapor intrusion rises to the surface.

  Where sites have the *potential* for vapor intrusion, prophylactic measures such as requiring passive barrier systems that can be monitored and actively vented if post-construction monitoring shows the need. This “precautionary” approach would increase costs somewhat, but less than the costs of investigation and remediation. The precautionary approach also reduces downstream human health and litigation (and therefore financial) risk. Cities and developers may also take proactive measures such as ensuring that sewer and utility conduits are built to avoid typical vapor migration.

- **Retaining property values is an important component of public outreach and remedy selection.** It is apparent that many community members regard first reports of vapor intrusion as an insult not so much to their health as to their pocketbooks. It is crucial that this component of a potential vapor intrusion problem not be overlooked.

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APPENDIX B

Conceptual Site Model Checklist

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CONCEPTUAL SITE MODEL CHECKLIST

The information included in this checklist may be useful for developing a site-specific conceptual migration model and in planning soil gas sampling. The investigator may use this checklist to compile information for each site.

Utilities and Process Piping

☐ Locate and map out all underground utilities near the soil or groundwater impacts. Pay particular attention to utilities that connect impacted areas to occupied buildings.

☐ Locate and map out all underground process piping near the soil or groundwater impacts.

Buildings (Receptors)

☐ Locate and map out existing and potential future buildings.

☐ Identify the occupancy and use of the buildings (e.g., residential, commercial). You may need to interview occupants to obtain this information.

☐ Describe the construction of the building including materials (e.g., wood frame, block), openings (e.g., windows, doors), and height (e.g., one story, two story, multistory). Determine whether there is an elevator shaft in the building.

☐ Describe the foundation construction:

- Type (e.g., basement, crawl space, slab on grade)
- Floor construction (e.g., concrete, dirt)
- Depth below grade

☐ Describe the HVAC system in the building:

- Type (e.g., forced air, radiant)
- Equipment location (e.g., basement, crawl space, utility closet, attic, roof)
- Source of return air (e.g., inside air, outside air, combination)
- System design considerations relating to indoor air pressure (e.g., positive pressure is often the case for commercial buildings)

☐ Describe subslab ventilation systems or moisture barriers present on existing buildings, or identify building- and fire-code requirements for subslab ventilation systems (e.g., for methane) or moisture barriers below foundations.

Source Area

☐ Locate and map out the source area for the vapor-phase contaminants related to the subsurface vapor intrusion pathway.

☐ Describe the presence, distribution, and composition of any NAPL at the site.

☐ Identify the vapor-phase contaminants that are to be considered for the subsurface vapor intrusion pathway.

☐ Describe the status and results for the delineation of contamination in environmental media, specifically soil and groundwater, between the source area and the potential impacted buildings.

☐ Describe the environmental media (e.g., soil, groundwater, both) containing contaminants.

☐ Describe the depth to source area.

☐ Describe the potential migration characteristics (e.g., stable, increasing, decreasing) for the distribution of contaminants.

Geology/Hydrogeology

☐ Review all boring logs, monitoring well construction, and soil sampling data to understand the following:

- Heterogeneity/homogeneity of soils and the lithologic units encountered and the expected/observed contaminant migration:
  - Depth and lateral continuity of any confining units that may impede contaminant migration
  - Depth and lateral continuity of any highly transmissive units that may enhance contaminant migration
- Depth of vadose (unsaturated) zone, capillary fringe, and phreatic (saturated) zone:
  - Note any seasonal water table fluctuations and seasonal flow direction changes (hydraulic gradient).
  - Note the depth interval between the vapor source and the ground surface.

- Note the presence of any perched aquifers.
- Note where the water table intersects the well screen interval or the presence of submerged screen.

☐ Describe distinct strata (soil type and moisture content, e.g., moist, wet, dry) and the depth intervals between the vapor source and ground surface.

☐ Describe the depth to groundwater.

☐ Describe groundwater characteristics (e.g., seasonal fluctuation, hydraulic gradient).

Site Characteristics

☐ Estimate the distance from edge of groundwater plume to building.

☐ Determine nearby potential sources.

☐ Estimate the distance from vapor source area to building.

☐ Describe the surface cover between the vapor source area and the potentially impacted building.

APPENDIX C

Building Types

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BUILDING TYPES

Basements

Buildings completed below grade with a basement or partial basement may be prone to vapor intrusion for several reasons. Floor and walls may have small voids and cracks that allow soil gas to enter the building. Buildings with earthen floors (as one would find in a cellar) are especially problematic because there is a large surface area for migration of soil gas into the overlying structure and ventilation may not be present to dilute any significant vapor intrusion. Finished basements (with living spaces) are of concern because of the combination of insufficient ventilation and because the residential space is closer to the subsurface contaminant source than is living space completed at the surface. Other “red flag concerns” should be raised with basements if sumps are present or the walls are built with moisture barriers or are wet during the rainy season. Evidence of drywells, cisterns, or other voids below the basement should be identified.

Wet Basements

In areas of shallow water tables, there may not be an unsaturated zone of any significant thickness beneath the building. Building practice typically incorporates a drain around the perimeter of the footings and often a sump pump to prevent flooding of the basement. Nevertheless, this scenario is often referred to as a “wet-basement” condition. Obviously, it is not possible to assess vapor transport through the unsaturated zone beneath a building if there is no unsaturated zone. Depending on the amount of groundwater removed by the perimeter drain and sump pump, a wet-basement scenario may disrupt the formation of a clean water lens.

Slab on Grade

Slabs with cracks, utility piping, and drains may act as conduits for vapor intrusion. In some areas, homes are built with “floating slabs” where the floor is poured separately from the foundation wall. Vapors can enter the building through the perimeter crack between the wall and the floor. In areas where swelling and shrinking soils are a concern, the floor is designed to move independently of the footwalls, and the perimeter gap may be as large as 1–2 inches around the perimeter of the building.

Crawl Spaces

In some regions of the country, houses with crawl spaces may be the least likely candidates for vapor intrusion, whereas in other regions, house with crawl spaces may be especially prone to vapor intrusion problems. In warmer, humid regions, homes are often built over crawl spaces that are well ventilated to prevent the floors from rotting. While the foundation walls may have vents with movable covers, these are usually left open most of the year and may not seal tightly when closed. The extra ventilation may dilute vapor that accumulates in the crawl space. There is a further attenuation of the vapor concentration moving into the living space. Vapor transport studies of similar structures in Holland and Australia suggest that only 10%–25% of the air in the

living space enters by way of the crawl space (Turczynowicz and Robinson 2001, Waitz et al. 1996). By nature of its design, a structure such as this may have a low attenuation factor and hence may be an unlikely candidate for vapor entering the living spaces of the home, although an investigator must consider other lines of evidence as well before excluding a structure from further consideration based upon this factor alone.

In contrast, buildings in colder, dry climates may be constructed to be energy efficient for cooling and/or heating purposes and hence be more airtight. In some regions, homes may be constructed with crawl spaces that exist as large open patches of soil within an enclosed basement. Foundation walls may be built without vents or designed to seal tightly against the cold to prevent frozen pipes. Buildings of newer construction tend to be designed to allow for relatively less ambient air exchange, contributing to the problem of vapor buildup. Depending on furnace configuration, etc., most of the air in the living space enters by way of the crawl space. In these cases, vapor may easily enter the structure.

A common fallacy in evaluating vapor intrusion into crawl spaces comes in considering plastic “vapor barrier” membranes laid over the ground in the crawl space as a suitable layer of prevention against vapor intrusion. Vapor barriers may not form a complete seal and are often made of plastics that are permeable to many of the contaminants commonly encountered as vapor intrusion problems. Unless specifically designed and installed to prevent organic vapors from entering the crawl space, the presence of vapor barriers should not factor into any decision not to proceed further with evaluation.

Row Houses (Multiple Residential Units on a Single Floor Slab)

Row houses or townhouses may be constructed with multiple units on a single floor slab. It may seem reasonable to assess the potential for vapor intrusion by selecting a single unit as representative of the entire row, but experience has shown that vapor intrusion may be dominated by a discontinuity in the slab (e.g., a poorly sealed utility penetration), which may not be visible, and therefore a given unit may or may not be representative of the entire row. Additional consideration should be given to the potential for preferential pathways within the structure that may create dissimilar vapor migration routes between units.

Tall Buildings

Tall buildings in cool or cold climates generally have a significant stack effect caused by thermal convection currents. Air inside the building is heated, and hot air rises, causing a net upward flow, pressure in the upper floors, and a vacuum in the lower floors. The magnitude of the vacuum in the lower floors is proportional to the height of the building and the temperature difference between the indoor and outdoor air. This pressure differential may contribute to vapor intrusion from the subsurface and increase the potential for vapor intrusion into upper floors.

Mobile Homes and Portable Buildings

USEPA and others have offered little to no guidance on how to deal with vapor intrusion with regard to mobile homes and portable buildings. As with houses constructed over crawl spaces,

there may be a wide range of mobile-home building practices across the country, leading to a wide variation in the indoor vapor intrusion risk. The investigator evaluating vapor intrusion sites potentially affecting mobile homes should strive to factor in the building practices that are most prevalent in the area.

The undersides of mobile homes are usually sealed during manufacture with impermeable bituminous paper to protect the floor insulation during transport. Normally, this seal remains in place after the mobile home is installed at a site and can provide an extra measure of protection against vapor intrusion.

Mobile homes can be placed with or without permanent foundations. Mobile homes placed without permanent foundations or on raised concrete pilings are not likely to pose vapor intrusion risks. Even if these foundations are enclosed with metal or vinyl underskirting, which are typically attached for cosmetic purposes or to keep animals from under the mobile home, the natural ventilation though gaps and joints in the underskirting may sufficient to dilute any contaminant soil gas emanating from the subsurface.

In some areas, mobile homes are placed directly on concrete slabs, which offer more protection against vapor intrusion if no cracks are present. Even if the slab has cracks, vapor intrusion into the living space is unlikely to occur because the metal beams on the mobile home bottom typically hold the bottom of the home several inches above the slab. The resulting horizontal channels move any soil gas away from the slab instead into the overlying mobile home.

At the other end of the spectrum, mobile homes placed on permanent foundations may be somewhat susceptible to vapor intrusion depending largely on the foundation type. In some parts of the country, mobile homes are placed on raised perimeter foundations that essentially form an enclosed crawl space under the mobile home. These mobile homes are subject to many of the same considerations as conventional houses built over crawl spaces. With this construction type, the primary factor affecting vapor intrusion into the mobile home is whether the crawl space is ventilated or not, depending on local building practices. However, even mobile homes attached to unventilated crawl spaces may have less vapor intrusion than similarly constructed conventional housing by virtue of the sealed undersides. Also, air-handling systems in mobile homes typically do not draw air from the crawl spaces, as can occur with some systems in conventional construction.

Parking Structures

Buildings may contain enclosed first-floor aboveground or subsurface parking. In accordance with Unified Building Codes, the ventilation (air exchange rates) for these parking areas is generally higher than those for other occupied building floors. These parking areas also generally have ventilation systems that are separate from the overlying occupied floors, if present. In these cases, these floors of parking act as barriers to potential vapor migration into overlying occupied floors (e.g., commercial and/or residential areas). The receptors for potential vapor intrusion evaluation for these types of parking areas would be users of the parking structures and parking attendants.

Other Building Characteristics

Ventilation

The conceptual model for vapor transport assumes that vapor is drawn into the building through openings by the pressure difference between the soil and the interior of the building. The pressure differential is induced by a combination of wind and stack effects due to building heating and mechanical ventilation. Therefore, consideration should be given to the ventilation regimes within a building, including furnace/air conditioning type (e.g., forced air, radiant), furnace/air conditioning location (e.g., basement, crawl space, utility closet, attic, roof), source of return air (e.g., inside air, outside air, combination), and system design considerations relating to indoor air pressure (e.g., positive pressure is often the case for commercial buildings). Additional consideration should be given to the operational period of the ventilation systems, including daily and seasonal variations.

Vapor Barriers

Some buildings are constructed with passive vapor barriers that may reduce vapor flux into a building. More information on passive barriers can be found in Section 4.3.1.1.

Preferential Pathways

USEPA guidance (2002b) suggests that buildings within 100 feet of a contamination plume or source should be evaluated for vapor intrusion unless a significant conduit (preferential pathway) exists (in which case, the area to evaluate should extend to some unspecified distance). Refer to Section 1.6.3 for examples of preferential pathways for the vapor intrusion pathway.

Elevators may also constitute a preferential pathway, since they are typically required by building codes to have perforations to allow water to drain and the elevator may act as a piston to induce an intermittent air-pressure gradient. Most buildings have subsurface utility penetrations, so their presence alone is not considered “preferential.” Some increased component of vapor flow into the building is usually required to consider the migration route to be “preferential.”

Surface Cover

Surface cover (e.g., asphalt pavement) between the vapor source area and building should be considered for the potential vapor capping effect that may affect subsurface vapor migration.

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APPENDIX D

Toolbox

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TOOLBOX

This appendix discusses in greater detail the investigative methods or "tools" used in vapor intrusion investigations. Each section is designed to give the investigator a better understanding of how to use a tool and when it is appropriate. References are provided in case the investigator wants additional information about a tool. The tools are broken down in two categories, exterior and interior. Soil gas sampling is the principal investigative tool for potential VI sites; therefore, supplemental information regarding soil gas sampling is provided. Additional details are also provided on groundwater sampling since groundwater is often the principal source of contaminated soil gas and data are usually available on groundwater concentrations. Interior sampling generally refers to data that require entry into buildings of interest, including subslab, crawl-space, and indoor air data. Ambient outdoor air sampling is usually coupled with indoor air and crawl-space sampling. Several additional tools are also discussed.

It should be noted that during any sampling activities certain objectives should always be considered. These include using the appropriate sampling methodologies, containers, sample locations and frequency, and DQOs. Most of these objectives are defined within the discussion for the specific tools since they may vary according to the tool chosen. Basic DQO principles apply to all of the tools discussed below.

A summary of the various quantitative options utilized to evaluate the vapor intrusion pathway are provided in a matrix in Table D-4, near the end of this appendix. In addition, Table D-5, at the end of this appendix, provides the advantages and disadvantages of various investigative strategies. Please refer to these tables during the development of a vapor intrusion investigative work plan.

D.1 DATA QUALITY OBJECTIVES

It is necessary to establish DQOs before sampling is conducted. These are usually addressed during the work plan preparation. Some typical DQOs that should be addressed are listed below. This list is not complete, as special circumstances at any given site may dictate very specific DQOs.

- Define study goals.
- Identify COCs and screening levels.
- Choose sampling and analysis method with appropriate reporting limits.
- Complete presampling building survey (interior sampling).
- Establish appropriate sampling conditions, number of samples, and duration of sampling.
- Collect QC samples (e.g., field blanks, duplicates).
- Establish data validation procedures.

D.2 GROUNDWATER (EXTERIOR)

D.2.1 Use of Preexisting Groundwater Data

In many situations shallow groundwater data that are already available prior to initiation of a VI investigation are sufficient to use as part of the investigation, especially if groundwater contamination has been delineated and the plume has reached steady state conditions (i.e., is no longer expanding). In deciding whether existing data are sufficient, consideration should be given to the site-specific CSM. Groundwater data should be from wells screened across the water table at the time of sampling. In addition, the likelihood of significant vertical changes in groundwater quality near the water table, the sampling method used, the construction of existing wells sampled (e.g., screen length and placement across water table), the type of contaminants present, and heterogeneity of the vadose zone and shallow saturated zone media will likely be the most important factors in determining whether existing data are sufficient to be used for vapor intrusion assessment.

Drinking water supply wells may or may not be appropriate, depending upon how they are constructed and screened. In most situations, it is likely that few drinking water wells are screened/open across the water table. Therefore, the presence of volatiles in private or public drinking water wells should be considered a possible basis for further investigation, but in most situations the data should not be used to determine whether the pathway is complete.

D.2.2 Interpolation of Nearby Data

If groundwater data *immediately* upgradient from the structure are not available, surrounding data points can be used to construct contaminant isoconcentration maps. However, this step should be done only if data points are available on at least two sides of a structure. Complex geologic settings or the anticipated presence of steep concentration gradients warrants a denser sampling grid. Groundwater contours should consider the rate and direction of groundwater flow and the time since chemicals were released to compare the expected length of the plume to measured concentration data. In general, the distribution of chemicals in groundwater will elongate in the direction of groundwater flow (shaped like a feather, hence the term “plume”) with relatively little vertical or transverse dispersion.

D.2.3 Obtaining New Groundwater Data to Evaluate the VI Pathway

If new or additional groundwater data are needed to complete the VI investigation, the goal of the sampling effort should be to determine volatile concentrations in the uppermost groundwater beneath or near potential structures.

USEPA (2002c) and various state agencies (NJDEP 2005a) provide specific guidance and procedures for the installation of groundwater monitoring wells and the acquisition of high-quality groundwater VOC sample data. Some of the recommendations for collecting groundwater data suitable for vapor intrusion assessment (Cal DTSC 2005) are as follows:

- Proper Screen Intervals. Contaminants at the top of the water table, rather than deeper contamination, are responsible for causing potential vapor intrusion problems. Hence, monitoring wells used to make vapor intrusion evaluations should be screened across the air-water interface, meaning the well screens should not be submerged below the top of the water table.
- Proper Screen Lengths. Monitoring wells with excessively long well screens, regardless of screen placement, should not be used to make vapor intrusion evaluations. When sampling long well screens, clean water entering the well screen at depth may dilute the contaminated groundwater near the top of the screen, biasing the sampling results and the associated risk determination. Hence, short screen lengths are preferred for monitoring wells that will be used to make vapor intrusion evaluations. Ideally, the thickness of the water column in the well should be 10 feet or less. For new water table wells installed as part of a VI investigation, a 5–10-foot screen is generally recommended unless this approach conflicts with other site investigation objectives. Additional construction recommendations are discussed in NJDEP 2005b.
- Proper Well Installation. Monitoring wells should be designed and installed to yield representative samples of groundwater conditions. Monitoring wells should have proper filter packs, slot sizes, and annular seals. Direct-push sampling methods and alternative/temporary groundwater sampling techniques are often well suited for VI investigations especially if attempting to determine the depth of the interface between a shallow clean water lens and an underlying plume or for determining vertical gradients. Repeated sampling over time at the same locations may be necessary for some sites to determine whether shallow groundwater quality has changed due to water table elevation fluctuations or other factors. If bedrock wells are installed as part of a VI investigation, open hole intervals should generally be 10 feet or less and should target the most shallow water-bearing zone. In highly weathered/fractured bedrock formations, shallow groundwater flow and contaminant migration can exhibit patterns more typical of unconsolidated formations. In those situations, local heterogeneity of the bedrock may not have as much influence on whether volatiles in groundwater can off-gas into the vadose zone and diffuse up to structures at the surface. Therefore, construction of monitoring wells in such settings can be part of a VI investigation.
- Proper Well Development. Monitoring wells should be developed to create an effective filter pack around the well screen, rectify damage to the formation caused by drilling, optimize hydraulic communication between the formation and well screen, and assist in the restoration of natural water quality of the aquifer near the well.
- Proper Well Purging. Prior to sampling, monitoring wells should be purged to remove stagnant casing water from the well that is not representative of aquifer conditions. Wells can be purged by removing the traditional three casing volumes prior to sampling or the well can be purged with low-flow techniques as described below. Wells should not be purged dry because this practice will drain the filter pack and introduce potential for volatilization losses during recovery. If adequate purging cannot be conducted without excessive drawdown because of low permeability, consider using passive diffusive samplers, which do not require purging.
- Proper Well Sampling. Sampling methods that minimize the loss of VOCs during sample collection and handling, such as bladder pumps or submersible pumps, are preferred. Other methods, such as peristaltic pumps and bailers, may cause unacceptable volatilization of chemicals if not properly implemented (USEPA Technology Verification Program,

www.epa.gov/etv/verifications/verification-index.html). Passive diffusion samplers may be useful, as described below.

D.2.4 Groundwater Spatial Sampling Locations

Groundwater samples should be collected as close, horizontally and vertically, to the structures as possible because concentrations are not always uniform within a plume due to heterogeneities in source areas and in the subsurface media. Given the distance criterion between vapor source and potentially affected structures (check with your regulatory agency for the appropriate distance), a more detailed delineation of the extent of groundwater contamination may be appropriate in some situations.

Changes in surface cover that significantly affect the amount of infiltration upgradient from structures should be considered in choosing sampling locations. For example, if there is an area of groundwater recharge (e.g., storm water retention pond or a transition from a mostly paved surface to a vegetated park/open field) located between the upgradient edge of a plume and a structure, a sampling location downgradient of the recharge area should be selected to be representative of any fresh water lens that may be present.

D.2.5 Perched Water Tables and Vertical Profiles of the Groundwater

If a perched water table exists above the regional water table, it may be appropriate to collect samples from both the perched zone and regional shallow aquifer. Perched saturated zones that are laterally contiguous under/near structures, exist year-round, and are below nearby building foundations should be sampled if they are of sufficient thickness that a sample can be obtained. Professional judgment must be used in more complex situations, but in the above scenario sampling of the regional water table may not be vital to investigating the VI pathway. In some situations, vertical profiles of shallow groundwater contamination may enable a more precise evaluation of the current and potential future risk of VI.

D.2.6 Ongoing Groundwater Monitoring

After an initial VI investigation has been completed, long-term groundwater monitoring to reevaluate the VI pathway may be appropriate in some situations. Groundwater monitoring should be done where groundwater concentrations exceeding screening levels are close to, but not currently within, the applicable distance criterion to a potential receptor.

D.2.7 Groundwater Sampling Methods

Table D-1, prepared by NJDEP (2005b), summarizes some alternative groundwater sampling methods that may apply to VI investigations. Sampling guidance for VI investigations may differ from other guidance in the documents because of the objective to determine very shallow groundwater quality.

Table D-1. Groundwater sampling methods for vapor intrusion investigations

Method	Example guidance documents	Advantages or disadvantages
Direct-push and alternative groundwater sampling methods	NJDEP *Field Sampling Procedures Manual* (2005a), Section 6.9.2.1, www.nj.gov/dep/srp/guidance/fspm	• Can do vertical profiling • Can do discrete interval sampling at defined depth intervals • Rapid sampling at multiple locations • More difficult to repeat sampling in same locations • Some methods limited to unconsolidated formations
Passive diffusion bag samplers	• NJDEP *Field Sampling Procedures Manual* (2005a), www.nj.gov/dep/srp/guidance/fspm • USGS *User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells*, Part 1, www.itrcweb.org/gd_DS.asp • ITRC *Technical and Regulatory Guidance for Using Passive Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater* (2004a), www.itrcweb.org/gd_DS.asp	• Can use existing wells for ongoing monitoring • May not be adequate where/for: o VOC highly soluble in water, such as methyl tertiary-butyl ether o in-well vertical flow occurs o permeability is very low
Low-flow purging and sampling	NJDEP *Field Sampling Procedures Manual* (2005a), Sections 6.9.2.2 and 6.9.2.3, www.nj.gov/dep/srp/guidance/fspm	• May generally target interval closer to the water table in some settings • Discrete interval sample not obtained
Volume-averaged purge and sample collection	NJDEP *Field Sampling Procedures Manual* (2005a), Section 6.9.2.4, www.nj.gov/dep/srp/guidance/fspm.	• Not recommended to generate new groundwater data specifically for VI investigations because of the potential for vertical averaging

D.2.8 Passive Diffusion Samplers

Passive diffusion samplers come in several varieties, as described in ITRC 2004a. Passive diffusion bag samplers (PDBSs) may be the most common for VOCs. PDBSs should be deployed just below the water level in a well for a minimum of two weeks to equilibrate with the well water. Significant water table fluctuations during that period will affect the appropriate depth intervals for the samplers. If the water level drops below the uppermost sampler, transfer of volatiles from the sampler water into less contaminated well air space would occur. If the upper sampler is exposed to the air space, the upper sampler should be resuspended 2 feet below

the current water level and retrieved after an additional two-week equilibration period. In any event, the depth to water in the well should be measured when the PDBSs are installed and removed, and the position of the samplers relative to the water level should be clearly described in the report presenting the PDBS data. PDBSs are not applicable to all compounds (e.g., semivolatile organic compounds [SVOCs] and soluble compounds such as acetone, styrene, methyl tertiary-butyl ether [MTBE], and 4-methyl-2-pentanone [MIBK]), so the target analytes must be confirmed.

D.2.9 Low-Flow Purging and Sampling

If evaluating the VI pathway is the *only* sampling objective, it is recommended that two modifications to the typical low-flow purging and sampling procedure be employed:

- Set the pump intake level as close to the water table as possible without significant risk that the water level will drop and expose the pump intake. For wells in formations with average or high permeability, about 1.5–2 feet below the static water level should be an adequate intake location.
- The purging objective is to flush two volumes of groundwater through the sampling array (tubing and pump, etc.). While measuring water quality indicator parameters is preferred (but not necessary), drawdown should be measured and not excessive.

D.3 SOIL (EXTERIOR)

At most sites soil matrix data are available. However, these data are less than ideal for evaluating vapor intrusion risk because of the uncertainty associated with using partitioning equations and the potential loss of VOCs during sample collection. Field extraction with methanol or hexane is good for reducing volatilization losses, but it results in elevated detection limits.

To evaluate vapor intrusion, soil matrix must be converted to soil gas concentrations using assumptions about the partitioning of the contaminant into the gas phase. Soil solid–to–soil gas partitioning equations are readily available, but using them increases the uncertainty in evaluating vapor intrusion.

Hartman (2002) has found that in the case of hydrocarbons, calculated soil gas values from soil solid data often overestimate actual soil gas concentrations. Conversely, soil solid data for chlorinated hydrocarbons often underestimates soil gas concentrations.

When soil is sampled for VOCs, soil samples should be collected using procedures specifically designed to minimize volatilization losses, such as SW-846 Method 5035A and augmented USEPA Method 5035A (Cal DTSC 2004). More details on the interpretation of soil data and phase partitioning calculations can be found in the Cal DTSC vapor intrusion guidance (2005). Existing soil data should be used as part of the line-of-evidence approach. In general, soil matrix data are not recommended as a stand-alone screening tool for a vapor intrusion investigation. They can be used to delineate sources or “screen in” sites for vapor intrusion assessment, but not to eliminate sites from further assessment.

D.4 ACTIVE SOIL GAS METHODS (EXTERIOR)

Active soil gas methods consist of the withdrawal of the soil gas from the subsurface and subsequent analysis. These methods give concentration data (e.g., $\mu g/m^3$), which can be directly compared to risk-based screening levels or used in predictive models. Soil gas sampling is the preferred sampling and investigative tool for most vapor intrusion investigations.

Soil gas sample collection techniques for vapor intrusion applications require much greater care than techniques historically used for typical site assessment applications (e.g., assessing whether a underground storage tank has leaked) because risk-based concentration levels for vapor intrusion scenarios are so low (1,000–10,000 times lower than concentration levels previously of concern). The quality of soil gas data depends greatly on the collection protocols. The following overview attempts to identify alternatives, express advantages and disadvantages, and provide appropriate flexibility and cautions where warranted by the current available knowledge and experience. Some of the primary factors that can influence the measured results are summarized below. A checklist summarizing some of the key QA/QC issues is provided in Appendix E. For supplemental or up-to-date references, please refer to the ITRC Vapor Intrusion Web page (www.itrcweb.org/vaporintrusion).

Two techniques are most commonly used to install soil gas probes to collect external active soil gas samples: driven probe rod and burial of soil gas sampling tubes. Both methods have been shown to give reliable, reproducible data in moderate- to high-permeability soils (DiGiulio et. al. 2006a).

D.4.1 Driven Probe Rod (Temporary Method)

This method consists of the insertion of a hard rod (probe) driven to a target depth, collection of soil gas through the rod while it is in the ground, and subsequent removal of the rod (Figure D-1). Soil gas probes can be constructed of a variety of materials and installed by a variety of techniques. Typically, probes are constructed of hollow steel rods with an external diameter typically ranging 12.5–50 mm. Small-diameter, inert, replaceable tubing runs down the center of the drive rod to eliminate potential contamination from the inside of the rod. The probes can be driven by hand, direct-push systems, or larger drill rigs using the wire-line hammer. The driven rod method is typically faster than the buried tube method and also does not leave any materials in the ground. Probe installation can be difficult in consolidated or coarse-grained soils, especially at greater depths, where the rods are more susceptible to deflection. A surface seal is usually employed, but this does not prevent cross-flow at greater depths, so driven probes are most applicable in relatively uniform moderate- to high-permeability materials (generally not in low-permeability soils). A tracer may help to verify the absence of atmospheric air entry during sampling.



Figure D-1. Hollow rod used to collect soil gas.
Courtesy H&P Mobile Geochemistry

D.4.2 Burial of Soil Gas Sampling Tubes (Semipermanent or Permanent Method)

This method consists of the burial of a small-diameter (typically 1/8- to 1-inch outside diameter) inert (e.g., stainless steel, Teflon®, HDPE, polyetheretherketone, Nylaflow®) tube or pipe to a target depth with subsequent sampling of the soil gas after a period of time. Tubing may be buried in holes created with hand-driven rods, direct-push systems, hand augers, drills (for subfoundation samples), or drill rigs for deeper samples. Sand is used as backfill around the tip, and the remainder of the borehole annulus is sealed, usually with bentonite and water slurry. This method is sometimes referred to as the "semipermanent" method (if the tubes are removed after a short period of time) or "permanent" method (if the tubes are left in the ground for a longer period of time) but can equally be used for temporary sampling. This method offers significant advantages when repeated sampling events are needed or where the geology is not conducive to driven probes. Multiple tubes can be "nested" in the same borehole (as shown in Figure D-2), providing the seals between intervals are tight and are often referred to as "multilevel" soil gas wells or probes. They can also be installed in nearby individual boreholes (nested soil gas wells or probes).

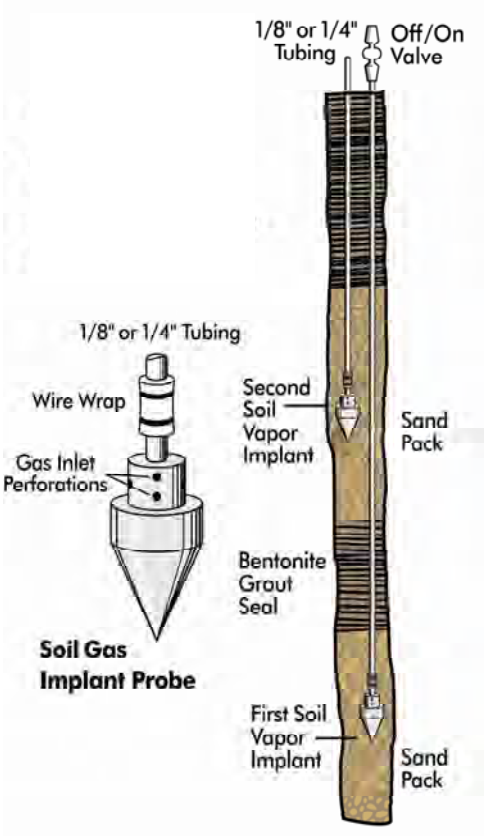

Figure D-2. Typical configuration of nested well.
Courtesy H&P Mobile Geochemistry

D.4.3 Soil Gas Sampling from Existing Groundwater Wells

Soil gas samples can be collected from groundwater wells that are screened across the water table. If 3–5 times the well casing gas volume is purged prior to sampling, the resulting soil gas sample should reflect the soil gas in the vadose zone outside of the well screen. If the casing volume is not purged, the soil gas sample will reflect contributions from both the vadose zone and from soil gas emanating from the standing water column within the lower part of the well, which is difficult to interpret and is therefore not recommended. In the first case, three to five casing volumes should be extracted prior to sampling to ensure the sample is representative. Field screening can be conducted to demonstrate stable readings before sample collection. Groundwater monitoring wells typically have vented caps, so a retrofit will be required to cap the well with an airtight cap and valve.

D.4.4 Purge Volume

Sampling systems with small internal volumes minimize potential sample-integrity problems compared to sampling systems with larger internal volumes, although reliable samples can be collected with the latter, especially when the probes are deeper than 5 feet. Stagnant air inside soil gas probes and sampling trains must be purged prior to sample collection. Three to four

system purge volumes are recommended as a minimum value. The dead volume of the sand pack should be purged if samples are collected within a few hours of installation. Larger purge volumes may result in a more integrated soil gas concentration under some conditions, providing the concentration versus purge volume is assessed using handheld meters (PID, flame ionization detector [FID], O_2, CO_2) or a mobile laboratory. If air rotary drilling is used to emplace the tubes, longer periods of time are required for the sand pack to equilibrate with the soil gas. API 2004 gives an equation to estimate the time required to reach steady state conditions. A test of concentration versus time can be used to determine when values stabilize.

D.4.5 Sample Volume and Purge Volume Tests

To reduce the uncertainty of where the soil gas sample is from and potential breakthrough from the surface, smaller volume samples (<1 L) and proper seals are recommended, especially for soil gas samples collected at shallow depths (<3 feet bgs or subslab). However, three recently published studies compared soil gas concentrations collected from volumes ranging 0.5–100 L (DiGiulio et. al. 2006a, McAlary and Creamer 2006, DiGiulio et. al. 2006b). The results of these studies, done in relatively course-grained soils, show no significant differences in concentrations. If the investigator is concerned about withdrawing larger (>3 L) sample volumes, a test of the sample concentration versus amount withdrawn might be appropriate to demonstrate there is no relationship between soil gas concentration and volume withdrawn. This can be done similar to the purge volume test described in the preceding paragraph.

D.4.6 Flow Rate and Vacuum

To minimize the potential desorption of contaminants from the soil, soil gas samples should be collected using techniques that minimize the vacuum applied to the soil. Higher vacuums also increase the potential for leaks in the sampling system. Most agencies are requiring flows less than 200 mL/min.

This conservative approach limiting flow rate may not be necessary in soils permeable enough to maintain vacuums less than 15% of atmospheric pressure (~5 inches of Hg, 60 inches of H_2O). A recent study by McAlary and Creamer (2006) actually measured soil gas concentrations over different flow rates ranging from 100 mL/min to 100 L/min at a hydrocarbon-contaminated site. They saw no significant difference in measured concentration. This study suggests that for relatively course-grained soils, flow rate does not appear to be an important variable on soil gas concentration.

D.4.7 Leak Tests

To ensure that valid soil gas samples are collected with no breakthrough of air down the probe rod or through leaks in the sampling train, a tracer compound may be applied at the base of the probe where it contacts the surface and near all connections in the sampling train. Connections can also be leak-tested using a “shut-in” test (API 2004). Seal integrity is then confirmed by analyzing collected soil gas samples for the tracer. Gaseous compounds (propane, butane, helium, SF_6) using shrouds or liquid compounds (isopropyl alcohol, pentane, freons) applied to towels are commonly used. Both types of tracers have pros and cons. Gaseous tracers offer some

advantages but are harder to use, especially to cover leakage in the sampling train. Helium offers a nice advantage in that it is readily measured on site with a field meter. Volatile liquid tracers offer logistical simplicity but are more qualitative. Liquid tracers are easily and quickly supplied at multiple locations (i.e., probe, sampling rod, sampling train, etc.) simultaneously. Liquid tracer methods are better suited for sampling through the probe rod since it can be applied to multiple leak points that may not be close to each other.

A small amount of tracer in a sample does not necessarily indicate an unreliable sample. Some agencies, such as the New York State Department of Environmental Conservation, allow tracer concentrations up to 10% of the starting concentration before considering the soil gas sample compromised. For gaseous tracers, the starting concentration is the measured concentration under the shroud. For liquid tracers, the starting concentration either is assumed as equal to the vapor pressure of the compound at ambient temperature or can be measured if on-site analysis is available. For liquid tracers such as isopropanol, a 10% leak would give a value in the sample of approximately 10,000 μg/L, assuming a starting concentration equivalent to its vapor pressure. To account for the possibility that the starting concentration is not equal to the vapor pressure, some agencies have established a specific concentration level, such as 100 μg/L, that can not be exceeded. This value corresponds to a 0.1% leak, assuming a starting concentration equal to the vapor pressure of the compound or a 1% leak if the starting concentration is only 10% of the vapor pressure, a conservative assumption. Table D-2 lists common tracers with their relative advantages and disadvantages.

Prevent Atmospheric Short-Circuiting

- Soil gas probes should be sealed above the sampling zone with a bentonite slurry for a minimum distance of 3 feet to prevent outdoor air infiltration and the remainder of the borehole backfilled with clean material.
- For multiple probe depths, the borehole should be grouted with bentonite between probes to create discrete sampling zones (Figure D-2) or separate nested probes should be installed.
- Set a protective casing around the top of the probe tubing and grout in place to the top of bentonite; slope the ground surface to direct water away from the borehole.

—from NYSDOH (2006) guidance

Table D-2. Common tracers

Tracer	Advantages	Disadvantages
Helium	• Can to check for leaks on site with handheld detector • Can quantify amount of leakage accurately • Does not interfere in TO-15 analysis	• Party-grade helium may have low ppbv VOC contamination • Process is more cumbersome than some others • Cannot be analyzed by TO-15 • Can be difficult to apply to sampling train connections
Liquid tracers	• Easy to use in identifying leaks • Can be detected by VOC analytical methods • Easier to apply to sampling train connections	• Concentration introduced to leak is estimated • Large leak may lead to VOC analysis interferences • No simple field screening method • May leave residual contamination on sampling train

Tracer	Advantages	Disadvantages
Sulfur hexafluoride	• Can check for leaks with on-site instrument with very low detection limits	• Very expensive • Field instrument subject to interference with chlorinated solvents • Cannot be analyzed by TO-15 • Is a greenhouse gas

D.4.8 Collection of Samples with Sampling Assemblies

Sampling assemblies (connecting tubing, fittings, gauges, flow controllers, etc.) should be ensured to be leak-tight using a shut-in test or tracer compound as described in the previous section and should be cleaned (and possibly blank-tested) between soil gas samples if reused. Sample tubing should generally not be reused.

D.4.9 Collection of Samples on Adsorbents

An alternative approach to collecting soil gas in a sample container is to concentrate the soil gas on an adsorbent. This type of method is required for SVOCs (generally compounds heavier than naphthalene). Typically, a pump is used to draw soil gas through the adsorbent, and the adsorbent is then analyzed by a laboratory. A variety of adsorbent cartridges and pumping systems are available from commercial vendors. All of the collection issues and criteria discussed in this section apply when using adsorbents. In addition, it is essential that the soil gas be drawn through the adsorbent by the pump, not pumped through the adsorbent to eliminate the chance for cross-contamination by the pump. It is often recommended to use two tubes in series to avoid breakthrough losses in areas of suspected higher concentrations. The adsorbent, purge rate, and sample volume must be determined by discussion with the analytical laboratory.

D.4.10 Variations in Soil Gas Values Due to Temporal Effects

Variations in soil gas concentrations due to temporal effects are principally due to temperature changes, precipitation, and activities within any overlying structure. Variations are greater in samples taken close to the surface and dampen with increasing depth. In 2006 there were a number of studies on temporal variation in soil gas concentrations, and more are under way or planned in 2007 by USEPA and independent groups. To date these studies have shown that short-term variations in soil gas concentrations at depths 4 feet or deeper are less than a factor of 2 and that seasonal variations in colder climates are less than a factor of 5 (Hartman 2006). Larger variations may be expected in areas of greater temperature variation and during heavy periods of precipitation, as described below.

IBM, Endicott, New York
Recent data from a large site in Endicott, New York collected over a 15-month period showed soil gas concentration variations of less that a factor of 2 at depths greater than 5 feet bgs.

- Temperature. Effects on soil gas concentrations due to actual changes in the vadose zone temperature are minimal. The bigger effect is due to changes in an overlying building's

heating or HVAC system and the ventilation of the structure due to open doors and windows. In colder climates, worse-case scenarios are most likely in the winter season. The radon literature suggests that temporal variations in soil gas are typically less than a factor of 2 and that seasonal effects are less than a factor of 5. If soil gas values are more than a factor of 5 below acceptable levels, repeated sampling is likely not necessary regardless of the season. If the measured values are within a factor of 5 of allowable risk levels, then repeated sampling may be appropriate.

- Precipitation. Infiltration from rainfall can potentially impact soil gas concentrations by displacing the soil gas, dissolving VOCs, and by creating a "cap" above the soil gas. In many settings, infiltration from large storms penetrates into only the uppermost vadose zone. In general, soil gas samples collected at depths greater than about 3–5 feet bgs or under foundations or areas with surface cover are unlikely to be significantly affected. Soil gas samples collected closer to the surface (<3 feet) with no surface cover may be affected. If the moisture has penetrated to the sampling zone, it typically can be recognized by difficulty in collecting soil gas samples. If high vacuum readings are encountered when collecting a sample or drops of moisture are evident in the sampling system or sample, measured values should be considered as minimum values.

- Barometric Pressure. Barometric pressure variations are unlikely to have a significant effect on soil gas concentrations at depths exceeding 3–5 feet bgs unless a major storm front is passing by. A recent study in Wyoming (Luo et al. 2006) has shown little to no relationship between barometric pressure and soil gas oxygen concentrations for a site with a water table at ~15 feet bgs.

In summary, temporal variations in soil gas concentrations, even for northern climates, are minor compared with the conservative nature of the risk-based screening levels. If soil gas values are a factor of 5–10 times below the risk-based screening levels, there likely is no need to do repeated sampling unless a major change in conditions occurs at the site (e.g., elevated water table, significant seasonal change in rainfall).

D.4.11 Choosing an Appropriate Analytical Method

A variety of analytical methods are available to measure soil gas samples, all of which can give accurate results when followed with appropriate QA/QC. Table D-3 (at the end of this appendix) summarizes the most common methods. The primary criteria for choosing the appropriate method are as follows:

- the COCs
- concentrations that may be encountered during sampling
- required detection level and other DQOs
- sampling logistics
- cost

The planning stages of the investigation should include discussions with your laboratory to ensure the appropriate analytical method is utilized.

D.4.12 Sample Containers and Storage

For fuel-related compounds (BTEX, total petroleum hydrocarbons [TPH]) and biogenic gases (CH_4, CO_2, O_2), allowable containers include Tedlar® bags, gas-tight (glass or stainless steel) vials, and passivated (Summa) stainless steel canisters. Tedlar bags are generally not considered to be reliable for more than 48 hours, but some agencies may have different requirements.

For halogenated compounds (e.g., TCE, TCA, PCE), allowable containers must be gas tight but also dark to eliminate potential photodestructive effects.

Adsorbents are suitable for most VOCs and SVOCs. However, multiple adsorbents may be required to deal with complex mixtures.

If stored samples are to be subjected to changes in ambient pressure (e.g., shipping by air), gas-tight vials or canisters are recommended. Tedlar bags to be shipped by air should be only partially filled to prevent rupture.

Allowable storage times in canisters vary among states, ranging from 3 days (Cal DTSC 2005) to 30. Most agencies require analysis within 14 days of collection.

It is not necessary to chill soil gas samples during shipping and storage.

D.4.13 On-Site Analysis

On-site analysis provides real-time detection of VOCs from any vapor migration sources or pathways, allows additional sampling locations to be added (spatially or vertically), allows recognition of spurious data, and enables measurement of the leak-test compound to ensure valid soil gas samples are collected.

Simple portable instruments can provide both qualitative and quantitative data, depending upon the compound and the required detection levels. Field screening with handheld PIDs or FIDs enable rapid screening for vapor migration routes around and into structures. However, most field-screening instruments are limited to the ppmv range, which may not provide sufficient resolution. Quantitative oxygen, carbon dioxide, and methane data are possible from handheld portable meters for concentrations in the percentage range. Helium detectors are available with a range of 0.01%–100% by volume.

For lower detection limits, mobile laboratories equipped with laboratory-grade instruments, including gas chromatographs and mass spectrometers, are capable of fully quantitative results meeting method required QA/QC and detection limits as low as 1–100 $\mu g/m^3$.

D.4.14 Recommended Soil Gas Sample Locations for Vapor Intrusion Assessments

The initial criteria to apply in determining where to collect soil gas samples for vapor intrusion assessments are the location of the contamination source relative to the receptor, the depth of the contamination source, and the type and construction of the receptor. The following sections give brief recommendations on where to collect soil gas samples both laterally and vertically for some typical situations. Additional suggestions can be found in API 2005, NYSDOH 2006, NJDEP 2005b, and EPRI 2005. For supplemental or up-to-date references, refer to the ITRC Vapor Intrusion Team Web page (www.itrcweb.org/teampublic_Vapor.asp).

D.4.15 Sample Density

Sufficient soil gas samples should be taken to make appropriate decisions. When subsurface contamination is encountered near buildings, soil gas samples should be collected to assess the contaminant distribution in sufficient detail to identify buildings that may have unacceptable levels of vapor intrusion. Characterization should continue until concentrations of VOCs meeting acceptable risk-based levels are encountered in the subsurface laterally and vertically between the source and potential receptors.

The exact number and spacing of samples (i.e., sample density) will vary on a site-specific basis. Ideally, there should be a soil gas sample for every existing or future building for smaller sites (i.e., houses surrounding a dry cleaner or a gas station) and sufficient spatial coverage to be representative for larger distributions (e.g., groundwater plume under hundreds of houses). For sites where current and future land use will be restricted by a land use covenant, the soil gas sampling density can be modified as a function of the size of the current and future buildings pursuant to the covenant.

When sampling near or under individual structures, collect enough samples to get a representative value of the soil gas concentration (analogous to placing enough borings on a typical site). If statistical averaging methods are being used to process the data, a minimum number of locations might be required depending upon the statistical method employed.

D.4.16 Selection of Lateral Soil Gas Sampling Locations

It is important to consider the following parameters when selecting lateral sample locations.

Subsurface Contamination Adjacent to a Structure: If the contamination source is not directly below the structure, collect samples on the side of the structure closer to the source. Collect samples in any known subsurface migration routes, such as sewers or utility lines that extend towards the contamination. If concentrations exceeding screening levels are detected, it may be appropriate to proceed to interior sampling (e.g. subslab).

Subsurface Contamination underneath a Structure: If the contamination source is directly below the structure, collect samples directly underneath the structure foundation if possible and/or indoor air samples. If possible, collect enough samples to get a representative value under the footprint of the structure and locate them to provide an indication of the spatial distribution of

the contamination. If subslab samples are not possible, collect near slab soil gas samples around all sides of the structure to determine the concentration distribution and get an idea of the possible concentration under the structure. An alternative approach may be required for very large buildings.

Surface Contamination Within or Immediately Adjacent to a Structure: This situation is most likely applicable to commercial facilities with adjoining businesses (e.g., dry cleaners at strip malls) or industrial settings with partitioned or immediately adjacent buildings. The contamination enters the shallow vadose zone from the surface, as a dense vapor or as a liquid spill, and then migrates laterally underneath the building slab. Collect samples directly underneath the structure slab covering the area of concern in the structure.

D.4.17 Selection of Vertical Soil Gas Sampling Locations Exterior to the Building

The closer to the ground surface or structure foundation, the greater the chance that surface processes such as atmospheric pumping, precipitation, and advective flow induced from the overlying structure will affect the soil gas concentration. In general, the effects due to these processes are considered to be minimized at depths 3–5 feet below the ground surface or building foundation, and measured soil gas concentrations are less likely to fluctuate. However, some processes, such as bioattenuation, oxygen replenishment, and substructure flushing, occur primarily at shallower depths (<3 feet), so sampling in this zone should not necessarily be precluded. If soil gas data from depths <3–5 feet bgs or below the level of the foundation are collected, additional sampling events may be appropriate to ensure representative values, especially if the measured values yield risks that are near acceptable levels.

Multiple-depth samples should be collected as needed to define vertical trends in soil gas concentrations or to determine maximum concentrations at the contamination source. Deeper samples tend to minimize temporal variations. The tension-saturated zone above the water table (capillary fringe) should be avoided if possible because high water saturation makes soil gas sampling difficult.

Exterior soil gas samples collected from just above the source or about 10 feet below the lowest floor slab are expected to provide a conservative estimate of subslab concentrations, as described further in Section D.6.

Some general recommendations regarding selection of vertical samples follow:

Subsurface Contamination Adjacent to a Structure. Collect samples between the structure and the source at about 3–5 feet below the lowest floor or shallower if the contamination source is shallower. For structures with basements, at least one vertical profile along the basement wall facing the contamination is advised.

Subsurface Contamination Underneath a Structure. If accessible, collect samples immediately below the structure’s foundation. For hydrocarbons, collect near-structure samples at about 3–5 feet below the lowest floor or shallower if the contamination source is shallower. For chlorinated hydrocarbons, collect samples near the source and at least 10 feet below the foundation (but no

deeper than the top of the capillary fringe). If concentrations exceeding screening levels are detected, either collect additional samples around the structure to allow better determination of the concentration distribution around the structure or proceed to interior sampling (subslab and/or indoor air).

Surface Contamination Within or Immediately Adjacent to Structure. As described in the prior section, this situation is most likely applicable to commercial facilities with adjoining businesses (e.g., dry cleaners at strip malls) or industrial settings with partitioned or immediately adjacent buildings. Collect samples directly underneath the slab covering the area of concern in the structure.

D.4.18 Applications of Vertical Profiles of Soil Gas Concentrations

Vertical profiles of soil gas concentrations can be useful for the following situations:

- determining the source of the contamination if not previously known
- determining the attenuation of contaminants in the soil gas in the vadose zone due to bioattenuation or other processes

Depending on the depth of groundwater, vertical profiles should consist of a minimum of three sampling depths, fewer for shallower aquifers. If repeated data are desired, install soil gas monitoring tubes for easy re-sampling.

D.5 PASSIVE SOIL GAS METHODS

Passive soil gas methods consist of the burial of an adsorbent in the ground (Figure D-3) with subsequent retrieval and measurement of the adsorbent. With passive sampling, there is no forced movement of soil gas. Instead, as the vapors migrate, the sorbent acts as a sink for the organic compounds in the soil gas. This method gives a time-integrated measurement and therefore reduces the uncertainty due to temporal variations.

Passive soil gas methods directly measure a mass of contaminant that has diffused onto an adsorbent media. Reporting units are typically in terms of mass (e.g., micrograms). Using relative mass levels, passive soil gas can be a viable, cost-effective, and simple screening tool to determine potential areas of concern. While published methods exist that describe the procedures to generate contaminant concentration data from a passive sorbent-based sampler in air in the absence of soil (ASTM 2002a, 2003), no published data or documents have demonstrated the applicability of the



Figure D-3. Installing a passive soil gas module.
Courtesy W.L. Gore & Associates, Inc.

method to soil gas. The fundamental difference is that the gas-phase diffusivity is known in the air, enabling a calculation of concentration from the adsorbed mass, but it is unknown in the vadose zone.

Field studies to calibrate the passive method to actual soil gas concentrations are still too limited to validate the use of this method for quantitative soil gas concentrations. For this reason, passive soil gas is not presently considered to be applicable for stand-alone assessment of vapor intrusion risk. However, passive soil gas sampling does have applications in vapor intrusion assessments. Passive methods offer a quick and relatively inexpensive method to find vapor migration pathways into a structure or around a structure, such as utility corridors. The composition of subsurface soil gases can be determined from passive soil gas samples, and the location of sources and subsurface plumes can be mapped, particularly edges of plumes to determine whether contamination is near current or future buildings. Passive soil gas sampling methods can also be useful in situations where active methods may not be applicable, e.g., low-permeability areas and high-moisture settings. Further, they are capable of detecting and reporting compounds present in very low concentrations.

Special considerations for passive soil gas surveys include the following:

- The adsorbent material should be hydrophobic to minimize water vapor uptake.
- Exposure time—The sampler must be deployed long enough to adsorb a detectable mass, but not so much as to allow the adsorbent to become saturated.
- Desorption and analytical method—The adsorbed compounds can be removed from the adsorbent by thermal desorption or solvent extraction and analyzed using gas chromatography (GC) or GC-mass spectrometry (GC/MS). Methods using thermal desorption have the benefit of greater method sensitivity than those using solvent extraction.
- Sampler installation—For subslab sampling, a narrow-diameter hole is drilled through the slab, and the sampler is slipped into the hole beneath the slab, while the hole itself is sealed. Deeper soil gas sampling generally involves drilling a narrow-diameter hole at least 3–5 feet bgs. The passive sampler is inserted to depth and the installation hole is secured. (See Section 6.0 below for special considerations regarding drilling through slabs.)
- Passive samplers should be transported in a sealable container to preserve cleanliness prior to use and to prevent additional adsorption during return shipment to the analytical laboratory.

Appendix E provides a checklist summarizing additional QA/QC issues.

D.6 SUBSLAB SOIL GAS SAMPLES (INTERIOR)

Subslab samples are soil gas samples collected from immediately below a slab on grade or a basement floor slab. The procedure involves drilling through the concrete slab and collecting a soil gas sample for field or laboratory analysis. Subslab soil gas samples are sometimes collected concurrently with indoor air samples so that the subslab concentrations can be directly compared to indoor air concentrations collected at the same time.

A typical subslab probe is constructed from small-diameter (e.g., ⅛- or ¼-inch outside diameter) stainless steel or another inert material and stainless steel compression fittings. The probes are

cut at a length to either float in the slab or to extend just to the base of the slab (Figure D-4). If repeated sampling is anticipated, surface completions may need to be flush with the surface (trip-proof) and cosmetically clean, especially in residences.



Figure D-4. Installation of subslab soil gas sample port. Courtesy Kansas Department of Health and Environment

Special considerations for subslab soil gas samples include:

- Subslab samples should be avoided in areas where groundwater might intersect the slab.
- Underground utilities (e.g., electric, gas, water, tension rods or sewer lines) should be located and avoided.
- If a vapor barrier already exists under the slab, subslab sampling might puncture the barrier, so the hole must be carefully resealed after monitoring is complete.
- For basements, primary entry points for vapors might be through the sidewalls rather than from below the floor slab, so subslab samples might need to be augmented with samples through the basement walls.
- Sample collection and analysis are analogous to those in other types of soil gas sampling; however, risk-based screening levels for subslab samples are lower than those for deeper soil gas samples, requiring an analytical method with lower detection limits.
- Recent studies have confirmed that temporal variations in subslab soil gas concentrations are usually minimal.

USEPA published an SOP for subslab sampling (USEPA 2006) in March 2006. The NJDEP guidance document (2005b) has a modified version of these procedures. There is also an SOP in the EPRI (2005) handbook. For supplemental or up-to-date references, please refer to the ITRC Vapor Intrusion Web site (www.itrcweb.org/vaporintrusion).

D.7 NEAR-FOUNDATION (EXTERIOR) VERSUS SUBSLAB (INTERIOR) SAMPLING

Subslab sampling is intrusive and sometimes impossible due to access limitations or disturbances to the occupants. In many situations, soil gas samples near the foundation at a depth of ~3–5 feet below the lowest floor may be an appropriate surrogate for subslab sampling for screening purposes, with approval of the regulatory agency. However, there is no consensus regarding the conditions under which near-slab soil gas samples collected around a structure can be used to predict subslab concentrations beneath a structure. Data presented by Diguilio, Wertz, and Abreu at the March 2006 Association for Environmental Health and Sciences workshop indicate that exterior shallow soil gas samples (<10 feet below foundation) may underestimate subslab concentrations for nonbiodegradable compounds. Existing data for hydrocarbons (Davis 2006) suggest otherwise. More studies are currently in progress comparing exterior soil gas concentrations at various depths to subfoundation concentrations.

When subslab soil gas sampling is not possible, it is conservatively recommended to collect multiple near-slab soil gas samples at some depth below the bottom of the lowest floor of the building. See presentations posted at the Indoor Air Vapor Intrusion Database (http://www.iavi.rti.org/WorkshopsandConferences.cfm).

In general, the subslab soil gas concentration cannot be higher than the source concentration. If the soil gas concentrations at the source are below acceptable levels for subslab samples, then subslab samples should not be necessary. In areas of shallow (<25 feet) groundwater, soil gas samples from just above the capillary fringe should be readily obtainable.

For biodegradable hydrocarbons, recent data compiled by Utah Department of Environmental Protection (Davis 2006) indicate that if oxygen levels in the vadose zone are >5% and the source is at least 3–5 feet below the receptor, than the vapor pathway is complete in less than 6% of the sites. Hence, in this situation, if adequate soil porosity exists and areas for air penetration (e.g., lawns and gardens) exist around the structure, it is likely that bioattenuation is occurring under the slab, and near-slab data might be considered to adequately reflect subslab levels, especially for structures with small slabs such as single-family homes.

D.8 MEASUREMENT OF INDOOR AIR (INTERIOR)

Indoor air samples are normally collected after subsurface soil gas characterization and other environmental samples (e.g., groundwater and/or soil gas) indicate the need to conduct an internal site-specific assessment. The analyte list should minimally focus on compounds identified in subsurface samples at concentrations above screening levels, their possible breakdown products, and potentially compounds that may be useful as marker compounds. Since some state agencies require full parameter analysis, confirm the parameter list with the appropriate regulators.

Temporal variability will depend on the duration of the sample. Grab (instantaneous) samples are generally not recommended. For residential settings, air samples are typically collected over a 24-hour period. Air samples for commercial and industrial settings are normally collected over 8 hours to correspond to an average workday. The sample duration should be evaluated and agreed upon during work plan preparation. In addition, confirm the appropriate ventilation conditions with the regulatory agency. Some states require that sampling be performed only in areas where windows and doors have not been opened and air-handling systems have not been operating for several hours.

Short-term temporal variability in subsurface vapor intrusion occurs in response to changes in weather conditions (temperature, wind, barometric pressure. etc.), and the variability in indoor air samples generally decreases as the duration of the sample increases because the influences tend to average out over longer intervals. Published information on temporal variability in indoor air quality shows concentrations with a range of a factor of 2–5 for 24-hour samples (Kuehster, Folkes, and Wannamaker 2004; McAlary et al. 2002). If grab samples are used to assess indoor air quality, a factor of safety (at least a factor of 5) should be used to adjust for short-term fluctuations before comparing the results to risk-based target concentrations. Long-term integrated average samples (up to several days) are technically feasible, using a slower flow rate

(this is the USEPA recommended approach for radon monitoring). Indoor air sampling during unusual weather conditions should generally be avoided.

Specific situations may warrant the need to collect indoor air samples before completing the subsurface soil gas characterization due to an immediate need. Examples of such situations may include, but are not limited to, the following:

- in response to a spill event when there is a need to qualitatively and/or quantitatively characterize the contamination
- if high readings are obtained in a building when screening with field equipment (e.g., PID, organic vapor analyzer, or explosimeter) and the source is unknown
- if significant odors are present and the source is unknown
- if groundwater beneath the building is contaminated, the building is prone to groundwater intrusion or flooding (e.g., sump pit overflows), and subsurface soil gas sampling is not feasible
- regulatory agency requires indoor air sampling
- presence of light, nonaqueous-phase liquid directly below the building
- fractured bedrock potentially creating a preferential pathway into the structure

D.8.1 Presampling Building Surveys

Assessing the vapor intrusion pathway using indoor air analysis may be complicated by the impact of background contaminant sources. Differentiating the common household sources of poor indoor air quality from those associated with contaminated groundwater or subsurface soil is a legal and fiscal dilemma facing both regulatory agencies and potential responsible parties throughout the country.

One of the tools used to identify background sources in the indoor air environment is the “Indoor Air Quality Questionnaire and Building Inventory” prepared by NYSDOH (2006) and provided herein as Appendix G. The questionnaire enables the investigator to document various information on the building, the occupants, and potential sources of indoor air contamination. The questionnaire has been revised and updated over the years by numerous state agencies, including NJDEP, New Hampshire Department of Environmental Services, Vermont Department of Health, and MassDEP. Handheld field screening instruments can be useful to evaluate these types of VOC sources that are unrelated to vapor intrusion.

As part of the presampling site visit, typical entry points should also be evaluated for each building that is to be sampled. Utility corridors can act as contaminant migration pathways allowing VOCs to travel long distances. Any foundation penetrations such as water, sewer, gas, electric and telecommunication lines, as well as sumps, should be screened during the presampling site visit.

D.8.2 Sample Collection Methods

Time-integrated sampling is typically used when conducting indoor air exposure assessments associated with vapor intrusion investigations. A time-integrated sample represents a sample taken at a known sampling rate over a fixed period of time. Two methods are commonly employed: collection of samples in an evacuated canister and collection of samples on adsorbent media.

Collection of Samples in an Evacuated Canister

The sampling canister (Figure D-5) is a passivated or specially lined inert container (e.g., Summa, Silco®) sent to the field under vacuum and certified clean and leak-free. The canister fills with air at a fixed flow rate over a preset period of time with use of a flow controller calibrated and set in the laboratory. Initial and final vacuums are recorded for each canister. The main advantages of canister sample collection are the capability of analyzing multiple samples from the same canister and the ease of deployment and retrieval. Canister methods are most commonly employed in North America. To ensure the canisters are filling at the proper rate, they should be rechecked after deployment. Canisters with dedicated vacuum gauges facilitate this effort and are strongly recommended. The canister must be retrieved prior to being completely filled (with some residual vacuum remaining) to ensure proper collection period.



Figure D-5. Stainless steel canisters.

Collection of Samples on Adsorbents

Sample collection on an absorbent—an option for VOCs and a requirement for SVOCs—can be done actively or passively. Active sampling requires drawing air at a calibrated flow rate through a tube containing adsorbent media over a specified time period. The flow rate and sampling volume used are determined based on the adsorbent used, the COCs, and the amount (mass) of adsorbent contained in the tube. The samples are taken to the laboratory for thermal or chemical desorption and subsequent analysis. Reporting limits are based upon the amount of air that is passed through the tube. It is important to use a sorbent that is certified clean and that can be reliably used for the collection and analysis of the COCs. A primary disadvantage of adsorbent sampling is that typically only one analysis is possible from a tube. Other complications of sorbent sampling are potential compound breakthrough and sorbent contamination from passive adsorption of VOCs.

Passive sampling of indoor air is similar to active sampling methods in which vapor constituents are collected onto adsorbents, but the collection of constituents is based on the diffusion of the compound onto the adsorbent and does not rely on pumps. As an advantage, the passive sampler is simply hung in the indoor air space to be sampled and left for a predetermined period of time. After the exposure period the sampler is placed into an airtight container until analysis of the

media. Exposure times must be determined based on estimated sample concentrations such that the sampler does not reach a state of equilibrium (or saturation) with the environment, a common source of low bias.

D.8.3 Sample Locations and Frequency

A typical single-family residential dwelling (approximately 1500 ft^2) should have one indoor air sample collected from the first floor and one from the basement or crawl space (if present). Significantly larger buildings may require additional samples, especially if there are separate air spaces or separate air-handling units. Multifamily residential units and commercial or retail buildings require a careful review of the building features. Subsurface structures may be present that would facilitate VI and thus degrade indoor air quality in one portion of the building and not another (e.g., partial crawl spaces, sumps, elevators). Any sampling approach should take into account the different exposure scenarios (e.g., day care, medical facilities) that exist within the building and any sensitive populations that may be exposed to the contaminated vapors. Multiple indoor air sample locations are necessary for multifamily residential units and commercial or retail buildings.

Additional sampling considerations include the following:

- Samples should be collected in the breathing zone, ~3–5 feet off the ground, in high-use areas.
- In structures with basements, both the occupied living areas and basement areas may be sampled from a risk management perspective.
- For multistory residential buildings, consideration should be given to collecting one sample on each floor or other appropriate sample locations.
- If indoor air samples are being collected as a stand-alone determination of the VI pathway, a second confirmation sample may be necessary in colder climates due to seasonal variations. One of the two sampling events should take place during the months between November and March, since these are generally worst-case conditions for VI.
- However, in those cases where the results are an order of magnitude below the appropriate screening levels, a second round of sampling is likely not necessary.

D.8.4 Analysis Methods

The most common contaminants of potential concern for VI investigations are VOCs though SVOCs are also of concern. Table D-3 (at the end of this appendix) lists available methods for VOCs and SVOCs.

The TO-14A and TO-15 methods are commonly used for VOCs in indoor and ambient air samples. A driver behind using these methods is the ability to achieve very low reporting limits (RLs). Using the method that can achieve the lowest RLs is not always the best or most viable option. TO-15 utilizes a GC/MS as the detector. The MS can be run in two different modes: full scan and selective ion monitoring (SIM). (Note: Some compound selectivity and the ability to identify unknowns may be lost in the use of SIM analysis due to limiting the masses scanned.) Standard TO-15 is normally run in the full-scan mode and can give a large list of approximately

70 compounds with RLs ranging 0.2–0.5 ppbv. This analyte list and RLs are generally more than sufficient when analyzing soil gas. In the SIM mode, TO-15 has the ability to reach RLs ranging 0.002–0.010 ppbv for a smaller list of (12–15) compounds. (Check with your laboratory, which may have its own list of compounds.) Because soil gas samples generally have COCs at higher concentrations than the SIM method can calibrate to, the SIM method is appropriate for only indoor and ambient air samples.

It is important to note that QA/QC protocols may vary greatly among laboratories, so the practices should be reviewed and specified in the work plan prior to data collection. Data validation methods (when required by the regulatory agency) should also be specified and approved in advance.

D.9 SAMPLING OF CRAWL SPACES (INTERIOR)

Many crawl spaces are designed with vents and may allow outdoor air exchange, so the concentration in the crawl space may be inversely proportional to the ventilation rate, which is not usually controlled. This effect can influence sampling results, as well as the vapor intrusion migration pathway analysis. Other types of crawl spaces have limited access, making it more difficult to collect samples.

Typically, crawl-space samples are collected following protocols similar to those for indoor air samples. For crawl spaces with limited access, a sampling tube is typically inserted horizontally through the crawl-space sidewall access ports or vertically through the overlying floor. As with soil gas or indoor air samples, enough measurements should be collected to get a representative value in the crawl space.

There are several options for sampling air from the crawl space. Crawl spaces can be sampled by collecting soil gas samples (active or passive), air samples (with canisters or adsorbents), or soil gas samples with flux chambers (identified as a supplemental data tool later in this appendix).

D.10 AMBIENT (OUTDOOR) AIR SAMPLING

When sampling indoor air as part of a vapor intrusion study, outdoor ambient air samples should be also collected to characterize site-specific outdoor air background conditions. Ambient air could possibly contain numerous volatile compounds, especially in highly populated or industrialized areas. The outdoor ambient air levels of some volatile compounds can often exceed indoor air risk-based screening levels.

Outdoor air samples should be collected from a representative location, preferably upwind and away from wind obstructions such as trees and buildings. The intake should be at ~3–5 feet off the ground (at the approximate midpoint of the ground-story level of the building) and ~5–15 feet away from the building.

Representative samples should be placed to minimize bias toward obvious sources of volatile chemicals (e.g., automobiles, lawn mowers, oil storage tanks, gasoline stations, industrial

facilities, etc.). Outdoor air samples should be collected and analyzed by the same method as indoor air samples.

For determining ambient air concentrations, USEPA recommends that ambient sampling begin at least 1 hour and preferably 2 hours before indoor air monitoring begins and continue until at least 30 minutes before indoor monitoring is complete. This practice is recommended since most buildings have an hourly air exchange rate in the range of 0.25–1.0, and thus air entering the building in the period before indoor sampling remains in the building for a long time.

D.11 SUPPLEMENTAL TOOLS/DATA USEFUL FOR VI INVESTIGATIONS

D.11.1 Emission Flux Chamber Method

Flux chambers are enclosures placed directly on the surface (e.g., ground, floor) for a period of time, and the contaminant concentration in the enclosure is measured. In theory an effective room concentration can be calculated from the measured flux by assuming the measured flux is constant over time and over the floor area of the room and assuming a room ventilation rate. The calculated room concentration can be compared directly to allowable room concentrations for the volatiles of interest. This method offers advantages in some cases because it yields the actual flux of the contaminant out of the ground, which eliminates some of the assumptions required when using other types of subsurface data. The method has long been used by regulatory agencies at hazardous waste sites and it is widely used for measuring trace emissions from natural soils, but its application to vapor intrusion assessments is relatively limited.

The testing is typically conducted in one of two modes: dynamic or static. In dynamic systems, a sweep gas is introduced into the chamber to maintain a large concentration gradient across the emitting surface. The effluent air from the chamber is collected using canisters and analyzed for COCs. This method is best suited for situations where large fluxes are anticipated. In static systems, a chamber is emplaced, and the contaminant concentration buildup is measured over time. This method is best suited for situations where lower fluxes are anticipated.

Flux chambers are not well suited for structures with covered floor surfaces such as single family residences because the primary entry points of soil gas into the structure (cracks, holes, sumps, etc.) are often concealed by floor coverings, walls, stairs, etc. For structures, the method has more application to larger industrial and commercial buildings with slab-on-grade construction where the slab is mostly uncovered. A building survey using a real-time analyzer or on-site GC can be used to attempt to identify the primary locations of vapor intrusion.

Flux chambers are best suited for situations where measurement from bare soils is desired, such as the following:

- homes with dirt basements or crawl spaces
- mobile homes above unfinished slabs or soil
- evaluation of future-use scenarios at sites without existing buildings
- to demonstrate the occurrence of bioattenuation from areas with shallow soil gas contamination (<5 feet bgs)

Flux chambers can also be used as a qualitative tool to locate surface fluxes of VOC contamination and entry points into structures.

Regardless of the method used, enough chamber measurements should be collected to get a representative value under the footprint of the building (analogous to placing enough borings on a typical site), near edges where the slab meets the footing, over any zones with cracks or conduits, and over the center of the contamination if known. In all cases, it is recommended that chambers be deployed for long enough periods to enable temporal variations to be assessed, similar to indoor air measurements (8–24 hours depending upon the conditions; 24 hours if large temperature differences exist between day and night (County of San Diego *Site Assessment Manual*).

More details on the flux chamber method can be found in Kienbusch 1986, Eklund 1992, and Hartman 2003.

D.11.2 Determination of Slab-Specific Attenuation Factor Using Tracers

Measurement of a conservative tracer inside the structure and in the subslab soil gas can enable calculation of a site-specific attenuation factor. The calculated attenuation factor can then be used to estimate the indoor air concentration of other COCs by multiplying the measured subslab soil gas concentration by the attenuation factor for the tracer (or "marker compound"). This method assumes that all subslab vapor phase contaminants are entering the building at equal rates, a relatively safe assumption for most situations. Naturally occurring radon is the most commonly used conservative tracer. Other potential tracers include breakdown products such as 1,1-DCE or cis-1,2-DCE, which are generally not found in consumer products, building materials, or outdoor air. Complications to this technique include the presence of indoor sources of the tracer (if any) and any temporal variations. However, if subslab samples are being collected, concurrent collection of radon or another tracer data may prove useful and is generally not too expensive. Determination of radon concentration using adsorbents is possible for indoor air samples but not for soil gas samples including subslab samples. Soil gas methods exist for the collection of subslab radon concentration measurements (USEPA 2006), but analysis of the samples may not be readily available from most commercial laboratories.

D.11.3 Determination of Room Ventilation Rate Using Tracers

The indoor air concentration is inversely proportional to the room ventilation rate: doubling the ventilation rate halves the indoor air concentration. The default ventilation rates used by USEPA and many other agencies are conservative: room exchange rates of once every 1–4 hours for residences and once every hour for commercial buildings. For some structures, typically commercial buildings, the actual ventilation rate can be determined from the HVAC system or building design specifications, keeping in mind that the air exchange rate should be calculated from the make-up volume, not the total air-handling volume. For other structures, typically residences, this information is not readily available, so the ventilation rate must be either measured or assumed at the default value. ASTM Method E 741 describes techniques for measuring ventilation rates using gaseous tracers such as helium or sulfur hexafluoride (SF_6).

Typically, a pulse input of tracer gas is applied, and the decay in concentration versus time is measured. The inverse of the air exchange rate is the slope of a plot of natural logarithm of the normalized concentration (Ct = n / Ct = 0) versus time. If a subsurface tracer gas is used, this can serve as the pulse input. Alternatively, a tracer gas can be released at a constant rate and the concentration measured once steady state conditions are reached (i.e., typically after three or four air exchanges).

The techniques are quick and relatively inexpensive. For colder climates, measurement during the cold and warm seasons may be prudent if the ventilation rate during the more conservative case (cold season) suggests unacceptable indoor air concentrations.

D.11.4 Differential Pressure Measurements

Models and look-up values used by USEPA and many state regulatory agencies are based on assumed advective flow into the structure due to a pressure gradient of 4 pascals. This assumption can be checked in the field to provide another line of evidence to evaluate vapor intrusion using a digital micromanometer attached to a subslab soil gas probe. It is often advisable to use one with data-logging capabilities and assess the response to wind speed and barometric pressure changes if these data are collected.

Measurement of the pressure gradient between the structure and outdoors can assist in interpreting measured indoor concentrations of contaminants. A correlation between indoor air concentration and relative pressure could provide information on the contaminant source. For example, if a building is overpressured relative to the subsurface, measured indoor concentrations might be more likely attributable to aboveground sources. Conversely, if the building is underpressured relative to the subsurface, measured indoor concentrations might be more likely attributable to subsurface sources. Commercial buildings with large HVAC systems, and perhaps residences with air-conditioning units, may fall into the former category. Many structures in cold environments, especially residences, will fall into the latter category when the heaters are running. These data will usually be used as a secondary line of evidence in support of indoor air quality data or other lines of evidence.

D.11.5 Real-Time and Continuous Analyzers

As with any type of site investigation, it is difficult to reach any conclusions with any degree of confidence with only a handful of data points. Vapor intrusion data sets consisting of one soil gas and/or indoor air analysis per structure may be very difficult to interpret, but cost and access limitations often preclude multiple analyses. Real-time analyzers can be used less expensively to collect multiple sampler that can be used to locate problem structures, vapor migration routes into structures, and volatile sources inside the structures. Continuous analyzers that collect data automatically over a period of time can sort out background scatter and determine temporal variations both indoors and below ground. Larger data sets allow trends in the results to be recognized and correlated to other variables such as pressure differentials, wind speed, and HVAC systems. Larger data sets allow forensic approaches to be applied.

A variety of real-time analyzers exist, including handheld logging instruments (PID, FID, thermal conductivity detector [TCD], infrared analyzers, z-Nose®, and ppbRAE), automated GCs, portable MSs, and USEPA's own Trace Atmospheric Gas Analyzer (TAGA). Many of these will have applicability that is limited by their sensitivity or cost.

D.11.6 Forensic Data Collection and Analysis

Forensic approaches attempt to determine the source of any detected volatiles through a detailed study of the nature of contamination with focus on lines of evidence to potential sources. Traditional environmental site assessments focus on the nature and extent of contamination as determined by common methodologies developed to provide data for regulatory purposes. The environmental forensics approaches are more sophisticated analytical techniques that have the ability to produce chemical fingerprints that are source specific. Potential fingerprinting strategies include the following:

Forensics Used at Colorado's Redfields Site

Forensic approaches were used at the Redfield Rifles site in Colorado to determine whether the source of subslab contaminants was in the vadose zone or the overlying structure (McHugh, De Blanc, and Pokluda 2006).

- Using compound ratios (e.g., DCE/TCE) and comparing them in the soil gas and indoor air results
- Distinguishing between different types of hydrocarbons (e.g., diesel, gasoline, jet fuels) using comprehensive analysis of the samples, including total chromatographic patterns
- Using isotope ratios (e.g., Cl-36, C-13) to distinguish between chlorinated solvent manufacturers and identify multiple sources in comingled groundwater plumes

Environmental forensics is a developing approach that will likely be increasingly important in regulatory enforcement actions and cost-recovery litigation.

D.11.7 Soil Physical Properties

Site-specific soil properties such as bulk density, grain density, total porosity, moisture content, and fraction organic carbon can be measured from soil samples and the results used to replace default input parameters when models are employed. Air permeability of the vadose zone can be determined from either in situ or laboratory measurements. In situ measurements test a larger portion of the subsurface than a laboratory measurement of a small core sample. In situ measurements of air permeability should be conducted in the shallow vadose zone, the area of the vadose zone subject to advection by building-driven depressurization, or to assess the presence of low-permeability layers in the unsaturated zone, which may act as partial vapor barriers.

D.11.8 Meteorological Data

A variety of weather conditions can influence soil gas or indoor air concentrations. The radon literature suggests that temporal variations in the soil gas are typically less than a factor of 2 during a season and less than a factor of 5 from season to season). Recent soil gas data from

Endicott, New York and Casper, Wyoming are in agreement with the radon results. For soil gas, the importance of these variables will be greater the closer the samples are to the surface and are unlikely to be important at depths greater than 3–5 feet below the surface or structure foundation.

Indoor air may be more susceptible to weather conditions, so collection of meteorological data can be helpful to assessing the vapor intrusion risk:

- Rainfall events—Precipitation can affect vapor intrusion rates and possible soil gas concentrations. Percolation of water through the soil can displace soil gas and lead to a short-term spike in vapor intrusion. The increased soil moisture after a rain event can reduce vapor transport through the soil due to reduced effective porosity and permeability. Measurements made during or immediately after a significant rain event (e.g., >1 inch) may not be representative of long-term average conditions. For other sites, however, frequent rainfall is common, and testing soon after a rain event is both representative and inevitable.

- High wind speed—High wind speed can create pressure differentials around a structure causing an advective flow in the shallow soil gas around and beneath a structure. This condition can create a number of situations including an inflow of air into the vadose zone on the windward side of a building, outflow of soil gas on the leeward side, and overpressurization of the area under the building versus the building itself. Such a flow pattern can lead to higher oxygen concentrations at deeper depths on one side of a building than on the other, which is relevant at sites with hydrocarbon contamination. Recent studies by the American Petroleum Institute suggest that horizontal flow of the soil gas under slab-on-grade foundations can be rapid in areas with sandy soils, which is also likely coupled to wind speed. Unusually windy conditions should be avoided for sampling to the extent possible.

- Frozen ground or permafrost—The inflow of air into the vadose zone or soil gas out of the vadose zone may be restricted if the ground surface is frozen and snow-covered, so these conditions should be noted where applicable.

- Major storm events—Changes in barometric pressure can create movement in the near surface vadose zone, a process known as “barometric pumping.” For most normal climatic conditions, the effect on soil gas concentrations will be minimal; however it may be significant near or during major storm events or for sites with very deep unsaturated zones, especially if the geologic materials are fractured (Parker 2003).

D.11.9 Pneumatic Testing

In some cases, geologic layers can form partial or complete barriers to upward vapor transport toward overlying buildings, particularly laterally continuous, fine-grained soil layers that retain sufficient moisture to be saturated or nearly saturated. It may be possible to identify the presence of such geologic barriers using pneumatic testing, analogous to a groundwater pumping test, where one well is used for extraction and other wells are used for monitoring the vacuum response. If the extraction well is screened below the fine-grained layer and the monitoring probe is screened above the fine-grained layer, the pneumatic test can be analyzed to assess

whether and to what extent there is pneumatic connection between the intervals. Alternatively, a test can be conducted using two wells screening in the geologic layer below the fine-grained unit, where the vacuum versus time data collected at the monitoring well is analyzed using the Hantush-Jacob (1955) leaky-aquifer solution to calculate the vertical leakage (or absence thereof) through the fine-grained "confining" layer, as described by Thrupp, Gallinatti, and Johnson (1996). These pneumatic tests provide information within the subsurface region that is stressed during the test, which can span hundreds of feet, but knowledge of the geology is important prior to inferring conditions farther from the test location.

D.11.10 Manipulating Pressure Differentials

One possible method for distinguishing subsurface vapor intrusion from background sources is to collect indoor air samples with and without manipulating the pressure differential from the subsurface to indoor air. This can be accomplished by pressurizing the building or depressuring the region beneath the floor slab. In both cases, if the applied pressure differential is sufficient to prevent subsurface vapor intrusion, the concentrations of chemicals intruding from the subsurface will be reduced and the concentrations of chemicals from background sources will be largely unaffected. Folkes (2000) reported measured indoor air concentrations for several chlorinated hydrocarbons before and after the operation of a subsurface depressurization system to mitigate subsurface vapor intrusion.

Table D-3. Summary of analytical methods for soil gas, indoor and ambient air samples[a]

Parameter	Method	Sample media/storage	Description[b]	Method holding time	Reporting limit[c]
VOCs					
BTEX, MTBE, TPH	TO-3	Tedlar bag or canister/ambient temperature	GC/FID	30 days for canister	1–3 μg/m^3
Nonpolar VOCs	TO-14A	Canister/ambient temperature	GC/ECD/FID or GC/MS	30 days for canister	1–3 μg/m^3
Polar and nonpolar VOCs	TO-15	Canister/ambient temperature	GC/MS	30 days for canister	1–3 μg/m^3
Low-level VOCs	TO-15 SIM	Canister/ambient temperature	GC/MS	30 days	0.011–0.5 μg/m^3
Polar and nonpolar VOCs	TO-17[d]	Sorbent tube, chilled <4°C	GC/MS	30 days	1–3 μg/m^3
VOCs	8021B modified[e]	Syringe, Tedlar bag, glass vial/ ambient temperature	GC/PID	On-site analysis or up to 30 days (depending on container)	10–60 μg/m^3
VOCs	8260B modified[e]	Syringe, Tedlar bag, glass vial/ ambient temperature	GC/MS	On-site analysis or up to 30 days (depending on container)	50–100 μg/m^3
SVOCs					
SVOCs	TO-13A[d]	High-volume collection (may require large sample volume, e.g., 300 m^3)/PUF/XAD media, chilled <4°C	GC/MS	Extracted within 7 days of collection and analyzed within 40 days of extraction	5–10 μg/sample
Low-level olycyclic aromatic hydrocarbons (PAHs)	TO-13A SIM[d]	High-volume collection (may require large sample volume, e.g., 300 m^3)/PUF/XAD media, chilled <4°C	GC/MS	Extracted within 7 days of collection and analyzed within 40 days of extraction	0.5–1 μg/sample
Pesticides and polychlorinated biphenyls (PCBs)					
Pesticides and PCBs	TO-4A[d] or TO-10A[d]	High-volume collection (may require large sample volume, e.g., 300 m^3)/PUF media, chilled <4°C	GC/ECD	Extracted within 7 days of collection and analyzed within 40 days of extraction	Pesticides: 0.5–1 μg/sample, PCBs: 1–2 μg/sample
Fixed gases					
Fixed gases (methane, nitrogen, oxygen)	USEPA 3C	Canister or Tedlar bag/ambient temperature	GC/FID	3 days for Tedlar bag, 30 days for canister	1000–2000 μg/m^3

Parameter	Method	Sample media/storage	Description[b]	Method holding time	Reporting limit[c]
Fixed gases (methane, nitrogen, oxygen, carbon dioxide, carbon monoxide)	ASTM D-1946	Canister or Tedlar bag/ambient temperature	GC/TCD/FID	3 days for Tedlar bag, 30 days for canister	1000–2000 μg/m^3
Natural gases	ASTM D-1945	Canister or Tedlar bag/ambient temperature	GC/FID	3 days for Tedlar bag, 30 days for canister	1000–2000 μg/m^3
TPH–alkanes					
C4–C24	8015 mod.	Canister or Tedlar bag/ambient temperature	GC/FID	3 days for Tedlar bag, 30 days for canister	10 ppmv
C4–C12	8260	Canister or Tedlar bag/ambient temperature	GC/MS	3 days for Tedlar bag, 30 days for canister	1 ppmv[d]
C4–C12	TO-15	Canister or Tedlar bag/ambient temperature	GC/FID	3 days for Tedlar bag, 30 days for canister	0.1 ppmv

[a] This is not an exhaustive list. Some methods may be more applicable in certain instances. Other proprietary or unpublished methods may also apply.

[b] ECD = electron capture detection, FID = flame ionization detection, GC = gas chromatography, MS = mass spectrometry, PID = photoionization detection, TCD = thermal conductivity detection

[c] Reporting limits are compound specific and can depend upon the sample collection and the nature of the sample. Detection limits shown are for the range of compounds reported by the analytical methods.

[d] The indicated methods use a sorbent-based sampling technique. The detection limits will depend on the amount of air passed through the media.

[e] Method is generally applicable only for on-site analysis of soil gas samples.

Table D-4. Matrix of various quantitative options to evaluate vapor intrusion

Measurement approach	Source at depth (> 5 feet) directly under building				Shallow source (<5 feet) under building				Source in vadose zone adjacent to building				Special conditions			
	Undeveloped site	Residential with basement or slab-on-grade floor	Residential with dirt floor or crawl space	Commercial/ industrial	Undeveloped site	Residential with basement or slab-on-grade floor	Residential with crawl space or dirt floor	Commercial/ industrial	Undeveloped site	Residential with basement or slab-on-grade floor	Residential with crawl space or dirt floor	Commercial/ industrial	Petroleum hydrocarbons	Vapor migration routes	Wet basement	Very-low-permeability soils
Shallow groundwater (near water table)	P	P	P	P	P	O	O	O	O	O	O	O	S	O	P	O
Deep (> 5 feet) soil gas	P	P	P	P	N	N	N	N	P	P	P	P	P	O	N	N
Shallow (5 feet) soil gas	P	P	P	P	P	P	P	P	P	P	P	P	P	P	N	N
Subslab soil gas	N	P	N	P	N	P	N	P	N	S	N	S	P	O	N	P
Vertical profile of soil gas	O	O	O	O	N	N	N	N	O	O	O	O	P	O	N	N
Indoor air	N	S	S	S	N	S	S	S	N	S	S	S	S	P	S	S
Ambient (outdoor) air	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Passive soil gas sampling	S	S	S	S	S	S	S	S	S	S	S	S	S	S	N	S
Emission flux chambers	O	N	S	O	O	N	S	O	O	N	S	O	O	N	N	O
Tracer testing for alpha factor	N	O	O	O	N	O	O	O	N	N	N	S	O	O	N	O
Tracer testing for ventilation rate	N	O	O	S	N	O	O	S	N	O	O	O	O	O	O	O
Pressure differential monitoring	N	O	O	O	N	O	O	O	N	O	O	O	O	O	N	O
Real-time analyzers	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
Meteorological data	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O

This rating indicates that each tool can be used for the category lower in the hierarchy.

P = primary investigative tool, can potentially be used as a principal tool for assessing VI.

S = secondary investigative tool, can be used to develop CSM and/or as a line of evidence in support of another line of evidence.

O = Optional investigative tool, may be useful to further define VI pathway or as means to focus primary investigative tools.

N = not usually appropriate as an investigative tool for vapor intrusion assessment.

Table D-5. Pros and cons of various investigative strategies

Measurement	Relative Advantages	Relative Disadvantages	Comments
Deep soil gas (>5 feet below slab)	• Existing data may already be available for some sites • Less chance of short-circuiting by atmospheric air • Temporal variations in concentration minimal	• Data may not be representative of soil gas concentrations at shallower depths due to intervening soil layers • Does not account for aerobic biodegradation in shallower soil layers	When combined with other data, deep soil gas data can provide evidence of attenuation as a function of vertical transport distance. However, deep soil gas sampling is conservative for screening purposes.
Shallow soil gas (<5 feet below slab or basement floor)	• Standard equipment and approaches have been developed • Media most likely to intrude into receptors • Data can be collected outside the building	• Rate of vapor transport to the building must be estimated • May not reflect subslab concentrations • Greater temporal variability than deeper soil gas data	Building zone of influence must be taken into consideration in sampling design. Shallow soil gas sampling may not be conservative for screening purposes.
Subslab soil gas	• Provides more representative subsurface data for sites with surface releases (e.g., spills and leaks) • Gives concentrations immediately below building and receptors	• May contain contaminants from interior sources • Highly intrusive; requires building access and drilling through slab/floor • Rate of vapor transport into the building must be estimated • Conservative screening levels	Preferred approach of many regulatory agencies. Concurrent determination of slab-specific attenuation factor may be useful to interpret data.
Emission flux	• Measure actual contaminant emissions from subsurface • Takes into account all subsurface processes such as biodegradation, advection, sorption • Eliminates interpretation using attenuation factor or model	• Equipment and experienced staff may be difficult to find • Selection of representative sampling locations may be difficult • Biased low results if emission “hot spots” are not sampled • Not considered by most regulatory agencies	This approach is best suited for evaluating future-use scenarios on undeveloped land, houses with dirt floor basements or crawl spaces, and to confirm bioattenuation in shallow vadose zone (<3 feet bgs).
Soil gas attenuation (α) factors	• Quick and very easy	• Attenuation factors used for this purpose tend to be very conservative (e.g., $<50^{th}$ percentile) • Empirical attenuation factors may be biased high due to sources other than vapor intrusion • No agreed-upon attenuation factors for many regulatory jurisdictions	Attenuation factors may be based on empirical measurements of concentration ratios at other sites or on assumed Q_{soil} and building ventilation flow rates.

Measurement	Relative Advantages	Relative Disadvantages	Comments
Slab-specific attenuation factor determination (from subsurface tracer)	• Naturally occurring compounds (e.g., Rn-222) can be used in some cases • Provides a direct measure of attenuation across a slab • Typical values often >10 times lower than default values	• Usually requires separate analytical method than that used for target compounds • If radon is used, investigator may find indoor concentrations exceeding health-risk levels • Radon not present everywhere at levels distinguishable from background	Method assumes that the tracer and subsurface contaminants move into the building at the same rate.
Indoor air	• Relatively simple to collect samples • Direct measurement of contaminant concentrations in buildings • May be more convincing to occupants	• Background sources complicate data interpretation • Requires access to indoor space • For residential sites, a building survey prior to sampling is often necessary • Very low reporting limits may be required for some compounds (e.g., TCE) • One-time sampling results may not be representative of long-term average concentrations • Poor sample control	Time-integrated samples are typically collected (e.g., 24-hour samples for residential sites and 8-hour samples for industrial sites).
Crawl-space air	• Simple to measure	• Background sources from overlying structure may complicate data interpretation	Most guidance uses an attenuation factor of 1.0 between crawl space and indoor air.
Pressure differential	• Relatively simple to measure • Can provide evidence of direction of vapor transport (in or out)	• Requires subslab port or other subsurface sampling point • Temporal variations complicate interpretation and often requires multiple sampling events	Detection levels down to 1 pascal can be obtained using inexpensive 0–0.25 inch H_2O magnahelic gauge.
Building ventilation rate	• Very simple to measure (standard ASTM method exists) • For many commercial buildings, rate is already known from design specifications • Value can be >10 times default parameters allowed in models	• For residences, seasonal variations may be large	Fewer sampling locations are needed if additional mixing of air within building is provided. Most commonly used for commercial receptors.

Measurement	Relative Advantages	Relative Disadvantages	Comments
Forensics	• Can differentiate sources of contaminants	• Typically requires a significant amount of data • Methods still being developed • Background sources can complicate interpretation	Forensic approaches are not likely to be used until later rounds of an investigation.
Continuous analyzers	• Provide large amounts of data • Can help sort out temporal variations and background scatter	• Limited use	Larger data sets allow correlation to other variables such as pressure differentials, wind speed, and HVAC systems.
Soil physical properties	• Easy to measure • Enable site-specific values to be used in predictive models • Values can be >10 times default parameters in models	• Data collected near a building may not be representative of zone beneath building • Difficult to get rig near most residential buildings (e.g., lawns, landscaping, trees)	Most sensitive soil physical properties to measure are percentage of water content and permeability.
Groundwater data	• Monitoring wells already exist for many sites (previous data) • Acceptable to most agencies • Familiar media to most investigators • Temporal effects minimal	• Look-up values, attenuation factors, or models tend to be extremely conservative, so VI risk is often overestimated • Existing data may be from a well that is not optimally screened for upper water table	This approach often used as an initial screen.
J&E model with groundwater or soil gas data	• Quick and easy • Model can account for various site-specific factors • Potential future scenarios can be evaluated	• Default input values to model tend to be very conservative • Pressure differential always assumed to be present (i.e., Q_{soil} assumed to be positive value) • Model does not account for biodegradation of BTEX or other compounds • Model is designed to evaluate residential scenarios and has some added limitations if used for other scenarios • Regulators may not accept results if depth to groundwater is <5 feet	The accuracy of the model output is best if the pollutant transport distance is at a minimum (i.e., shallow soil gas is better than deep soil gas) and no partitioning calculations are needed (soil gas data are better than groundwater data).

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APPENDIX E

Quality Assurance Considerations

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QUALITY ASSURANCE CONSIDERATIONS

Quality assurance and quality control procedures should be implemented in every step of the assessment process to ensure the collection of data of acceptable quality. This appendix discusses some general QA/QC considerations for field and laboratory activities.

QA/QC for Active Sampling

The majority of the soil gas and indoor air sampling conducted for the investigation of the vapor intrusion pathway is for VOCs. This section focuses on USEPA Method TO-15, which uses specially treated, certified clean, leak-free canisters for the collection of air samples in the field. Canisters are shipped to the field under vacuum of approximately –30 inches Hg. Flow controllers, calibrated in the laboratory, are sent with the canisters to allow the canisters to collect the samples over a set time period.

Below are *examples* of QA/QC procedures that should be considered. This list is not meant to be exhaustive:

- Analyte list and reporting limits—Discuss your program-required analyte list and reporting limits with the laboratory to ensure they will be met.
- Determine from the laboratory whether its reporting limit refers to a method detection limit (MDL), practical quantitation limit (PQL), or some other reporting limit.
  - MDL = 99% confidence that data is distinguishable from background noise
  - PQL = an estimated value usually 3–5 times the MDL
  - RL = concentration ≥ the lowest calibration standard > MDL

  (www.depweb.state.pa.us/landrecwaste/lib/landrecwaste/land_recycling/workshops/usingyourlabwisely.ppt#349,14,How)
- Laboratory certification—Many regulatory agencies across the country require laboratories to be certified to conduct air analysis.
- Certified canisters—The laboratory must certify that the canister is leak-free and clean below the RL for the VOCs of concern.
- Flow controllers—The laboratory provides a flow controller that is clean and calibrated to collect a sample over a specified time frame (e.g., 30 minutes to 24 hours).
- SOPs—Ensure that the sampling crew follows documented, reproducible field procedures.
- System leak checks for soil gas samples–Use a tracer gas to check for leakage around the sampling probe and analytical sampling train.
- Initial and final vacuum readings—The sampler should take the canister vacuum reading before and after sampling to ensure that the canister was leak-free upon receipt in the field and that the flow controller collected the sample over the specified amount of time.
- Precautions should be taken to avoid sample interference such as fueling vehicles prior to sampling or using permanent marking pens in the field.
- Required laboratory QC samples—Mass spectral tuning, initial calibration, continuing calibration verification, laboratory control spike, and method blank.

- Additional QC samples (if needed):
  - Trip blanks refer to canisters sent out with the canister batch to test for the presence of contaminants introduced during transit and storage.
  - Method blanks refer to purified gas (air, nitrogen) samples collected through the sampling system to test for the presence of contaminants introduced by the sampling methods.
- Analytical holding time per USEPA TO-15—Analysis of canister samples for VOCs must be completed within 30 days from collection; check with the state or region to verify holding time requirements.

QA/QC for Passive VOC Sampling

As with any site investigative tool, passive sampling requires adequate QA/QC to provide data of sufficient quality to ensure proper decision making. Modified USEPA Methods 8260 and 8270 may be used for analysis, or USEPA TO-17 using thermal desorption followed by GC/MS may be used. QA/QC requirements are based more on DQOs than on prescriptive procedures. Specific QA/QC procedures vary depending on the manufacturer of the sampler and on the analytical laboratory. Therefore, it is important to understand what procedures will be used and to determine whether they are adequate to meet DQOs.

At a minimum QA/QC procedures should consider the following:

- Passive sampler installation, retrieval, and handling—To ensure consistency of deployment and sample integrity prior to analysis.
- Units of measure—Concentration or mass (or some other relative) units. If concentration data are to be provided, are there sufficient data to verify sampling rates, indifference to changing air flow, and sampler capacity?
- Detection limit—Are the sampler and analytical method of sufficient sensitivity?
- Cleanliness of sampler—Are procedures in place to verify the cleanliness of the sampler? The sampler background must be sufficiently less than RLs.
- Instrument tuning—Applicable if MS detection is used.
- Instrument calibration—Are target compounds used for calibration and concentration ranges adequate to cover COCs and suspected sample levels?
- Control samples—Method, trip, and field blanks to verify integrity of samples during shipment and potential levels of background.
  - Method blanks are clean adsorbent material analyzed by the applicable analytical method to determine any potential background levels of target compounds contributed by the analytical method.
  - Trip blanks are unexposed passive samplers that accompany samplers during transport to the field and then to the laboratory to determine any potential background levels of target compounds that may have been contributed during transport.
  - Field blanks (for soil gas sampling only) are passive samplers exposed to ambient conditions for the same amount of time field-exposed samplers are exposed to ambient conditions prior to installation in the subsurface, intended to determine the potential

contribution of background levels of target compounds contributed by ambient air and not soil gas.

- Replicate analyses—If replicate analysis is required, does that sampler allow for multiple analyses or do multiple samplers need to be co-located?
- Are matrix spikes required?

Other QA/ QC Considerations

- Passive samplers should be transported in a sealable container to preserve cleanliness prior to use and to prevent additional adsorption during return shipment to the analytical laboratory.
- For subsurface applications, the samplers should also have a design that keeps soil, microbes, liquid water, and other contaminants from coming in direct contact with the adsorbent.
- The adsorbent material should be hydrophobic to minimize water vapor uptake.
- Accurate time recording is essential for comparison of results, and all samplers in a given medium should be deployed for a consistent amount of time. The time may vary for different media. For example, if soil gas concentrations are expected to be higher than indoor air concentrations, the soil gas samplers may approach saturation before the indoor air samplers have sufficient mass to reach analytical detection limits, in which case, the indoor air samplers should be deployed for a longer period than the subsurface samplers.

APPENDIX F

Regulator’s Checklist for Reviewing Soil Gas Data

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REGULATOR'S CHECKLIST FOR REVIEWING SOIL GAS DATA

ITRC Vapor Intrusion Pathway Overview

SAMPLE COLLECTION ISSUES

Active Soil Gas Surveys

- □ Did the probe rod have an inert internal tube (stainless steel, Teflon®, nylon)?
- □ Was the probe adequately decontaminated between samples?
- □ Were at least three dead volumes of the probe purged?
  - ⇨ *Avoid excessive purging, unless field screening (O_2, CO_2, PID, or FID and tracer gas) conducted to demonstrate absence of atmospheric air intrusion.*
- □ Were samples collected deep enough to minimize air infiltration?
  - ⇨ *At least 5 feet bgs unless special precautions used to minimize purge volume and confirm absence of atmospheric air.*
- □ Did it rain shortly before the sampling event?
  - ⇨ *Soil gas sampling should be avoided following significant precipitation.*
  - ⇨ *Generally, there is no consensus on how much rain can fall or how long you should wait. It depends on soil type, amount of rain, and previous soil moisture content.*
- □ Was a reliable method used to ensure the absence of atmospheric air leakage?
  - ⇨ *Probe sealed at the surface and throughout the borehole annulus?*
  - ⇨ *Tracer compound used to demonstrate no leakage down or around probe and at all sample train fittings?*
- □ Were samples collected close to the surface (<3 feet bgs) repeated?
- □ Were small sample volumes collected?
- □ Were samples collected in appropriate containers for the COC(s)?
- □ If canisters were used, was each canister certified clean or batch-tested?
- □ Were flow controllers and sample trains reused?
  - ⇨ *If yes, they should be cleaned between samples.*
- □ Were vacuum pumps used in the sample collection?
- □ Were excessive vacuums required to obtain a sample?
  - ⇨ *>10 inches of H_20 should be avoided.*
- □ Were samples collected upstream of the vacuum pump?
- □ Were samples analyzed on or off site?
- □ For canisters, were samples stored at ambient air temperature?
- □ Were samples analyzed within recommended holding times?
- □ If both on-site and off-site analyses were performed, do the results generally agree?

Passive Soil Gas Surveys

- □ Were method and trip blanks analyzed?
  - ⇨ *Needed to show absence of contaminants from laboratory or transportation back and forth to site.*
- □ Were samplers left in the ground for consistent and sufficient time?
  - ⇨ Generally a few days to two weeks.
  - ⇨ Collect in same sequence as deployed.
- □ Were duplicate samples collected, and how do they compare?
- □ Are data used appropriately?
  - ⇨ For what purpose?
  - ⇨ Were active soil gas samples collected for comparison?
  - ⇨ How well do passive and active samples compare?
- □ Could measured values be from infiltration of contaminated atmospheric air or from an overlying surface (e.g., asphalt, dirty soil)?
- □ Are relative concentrations of compounds detected consistent with expectations from other media (soil gas, groundwater, bulk soil)?

Flux Chamber Surveys

- □ Were the sample locations representative?
  - ⇨ Near vapor migration routes?
  - ⇨ Open ground, covered ground, cracked ground covers?
- □ How long was the deployment time? Was it long enough to average temporal variations?
  - ⇨ Match indoor air default collection times.
- □ Was a sweep gas used? Was the outflow balanced to the inflow to ensure no leaks?
  - ⇨ If outflow lower than inflow, sweep gas exiting bottom.
  - ⇨ Pressure measurements not adequate to test this.
- □ Did the chamber concentration reach high enough values to influence the flux?
  - ⇨ Should be no more than 20% of risk-based maximum flux value.
- □ What volume of vapor was collected from the chamber?
  - ⇨ Volume collected should be less than 20% of chamber volume.
- □ How fast was it collected? Did it create advective flow from the subsurface or sides?
  - ⇨ Flow should be less than 200 mL/min.
- □ Was the chamber subjected to temperature extremes?
  - ⇨ Shield from direct sunlight.
  - ⇨ Chamber surface must stay above dew point.

SAMPLE ANALYSIS ISSUES

The following questions should be asked when examining the analysis of any type of soil gas sample—active, passive, or flux chambers.

- □ What methods are being used? Can they detect the target compounds at the required levels of sensitivity?
- □ Have the method required calibration standards been analyzed?
- □ Are the reported values within the documented calibration range of the instrument?
- □ Are any compounds coeluting on a non-halogen-specific detector?
- □ Have the method required QA/QC samples been analyzed (blanks, duplicates, etc.)?
- □ Are the calibration standards within method-required holding times and traceable to a certified source?
- □ In what units are the data reported (μ/L, μg/m^3, ppbv, ppmv)?
- □ For high concentrations, have large dilutions been performed?

Passive Soil Gas Samples

In addition to the analytical issues summarized above, the following issues should be examined with passive soil gas samples:

- □ How are the samples desorbed from the collector?
- □ Is the desorption process quantitative, and does it fractionate?
- □ What units are the data reported in (mass, concentration in headspace, etc.)?

Surface Flux Chamber Samples

In addition to the analytical issues summarized above, the following issues should be examined with surface flux chamber samples:

- □ Is the method detection limit low enough to reach the expected chamber concentrations for the acceptable flux?

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APPENDIX G

Indoor Air Sampling Questionnaire

NEW YORK STATE DEPARTMENT OF HEALTH
INDOOR AIR QUALITY QUESTIONNAIRE AND BUILDING INVENTORY
CENTER FOR ENVIRONMENTAL HEALTH

This form must be completed for each residence involved in indoor air testing.

Preparer's Name _____ Date/Time Prepared _____

Preparer's Affiliation _____ Phone No._____

Purpose of Investigation_____

1. OCCUPANT:

Interviewed: Y / N

Last Name: _____ First Name: _____

Address: _____

County: _____

Home Phone: _____ Office Phone: _____

Number of Occupants/persons at this location _____ Age of Occupants _____

2. OWNER OR LANDLORD: (Check if same as occupant ___)

Interviewed: Y / N

Last Name: _____ First Name: _____

Address: _____

County: _____

Home Phone: _____ Office Phone: _____

3. BUILDING CHARACTERISTICS

Type of Building: (Circle appropriate response)

Residential	School	Commercial/Multi-use
Industrial	Church	Other: _____

If the property is residential, type? (Circle appropriate response)

Ranch	2-Family	3-Family
Raised Ranch	Split Level	Colonial
Cape Cod	Contemporary	Mobile Home
Duplex	Apartment House	Townhouses/Condos
Modular	Log Home	Other:_____

If multiple units, how many? _____

If the property is commercial, type?

Business Type(s) _____

Does it include residences (i.e., multi-use)? Y / N If yes, how many? _____

Other characteristics:

Number of floors_____ Building age_____

Is the building insulated? Y / N How air tight? Tight / Average / Not Tight

4. AIRFLOW

Use air current tubes or tracer smoke to evaluate airflow patterns and qualitatively describe:

Airflow between floors

_____

_____

_____

Airflow near source

_____

_____

_____

Outdoor air infiltration

_____

_____

_____

Infiltration into air ducts

_____

_____

_____

5. **BASEMENT AND CONSTRUCTION CHARACTERISTICS** (Circle all that apply)

a. Above grade construction:	wood frame	concrete	stone	brick
b. Basement type:	full	crawlspace	slab	other _____
c. Basement floor:	concrete	dirt	stone	other _____
d. Basement floor:	uncovered	covered	covered with _____	
e. Concrete floor:	unsealed	sealed	sealed with _____	
f. Foundation walls:	poured	block	stone	other _____
g. Foundation walls:	unsealed	sealed	sealed with _____	
h. The basement is:	wet	damp	dry	moldy
i. The basement is:	finished	unfinished	partially finished	
j. Sump present?	Y / N			
k. Water in sump?	Y / N / not applicable			

Basement/Lowest level depth below grade: _____(feet)

Identify potential soil vapor entry points and approximate size (e.g., cracks, utility ports, drains)

_____

_____

6. **HEATING, VENTING and AIR CONDITIONING** (Circle all that apply)

Type of heating system(s) used in this building: (circle all that apply – note primary)

Hot air circulation	Heat pump	Hot water baseboard	
Space Heaters	Stream radiation	Radiant floor	
Electric baseboard	Wood stove	Outdoor wood boiler	Other _____

The primary type of fuel used is:

Natural Gas	Fuel Oil	Kerosene
Electric	Propane	Solar
Wood	Coal	

Domestic hot water tank fueled by: _____

Boiler/furnace located in:	Basement	Outdoors	Main Floor	Other_____
Air conditioning:	Central Air	Window units	Open Windows	None

Are there air distribution ducts present? Y / N

Describe the supply and cold air return ductwork, and its condition where visible, including whether there is a cold air return and the tightness of duct joints. Indicate the locations on the floor plan diagram.

_____

_____

_____

_____

7. OCCUPANCY

Is basement/lowest level occupied? Full-time Occasionally Seldom Almost Never

Level	General Use of Each Floor (e.g., familyroom, bedroom, laundry, workshop, storage)
Basement	_____
1st Floor	_____
2nd Floor	_____
3rd Floor	_____
4th Floor	_____

8. FACTORS THAT MAY INFLUENCE INDOOR AIR QUALITY

a. Is there an attached garage?	Y / N	
b. Does the garage have a separate heating unit?	Y / N / NA	
c. Are petroleum-powered machines or vehicles stored in the garage (e.g., lawnmower, atv, car)	Y / N / NA	Please specify_____
d. Has the building ever had a fire?	Y / N	When?_____
e. Is a kerosene or unvented gas space heater present?	Y / N	Where? _____
f. Is there a workshop or hobby/craft area?	Y / N	Where & Type? _____
g. Is there smoking in the building?	Y / N	How frequently? _____
h. Have cleaning products been used recently?	Y / N	When & Type? _____
i. Have cosmetic products been used recently?	Y / N	When & Type? _____

j. Has painting/staining been done in the last 6 months? Y / N Where & When? _____

k. Is there new carpet, drapes or other textiles? Y / N Where & When? _____

l. Have air fresheners been used recently? Y / N When & Type? _____

m. Is there a kitchen exhaust fan? Y / N If yes, where vented? _____

n. Is there a bathroom exhaust fan? Y / N If yes, where vented? _____

o. Is there a clothes dryer? Y / N If yes, is it vented outside? Y / N

p. Has there been a pesticide application? Y / N When & Type? _____

Are there odors in the building? Y / N
If yes, please describe: _____

Do any of the building occupants use solvents at work? Y / N
(e.g., chemical manufacturing or laboratory, auto mechanic or auto body shop, painting, fuel oil delivery, boiler mechanic, pesticide application, cosmetologist

If yes, what types of solvents are used? _____

If yes, are their clothes washed at work? Y / N

Do any of the building occupants regularly use or work at a dry-cleaning service? (Circle appropriate response)

Yes, use dry-cleaning regularly (weekly) No
Yes, use dry-cleaning infrequently (monthly or less) Unknown
Yes, work at a dry-cleaning service

Is there a radon mitigation system for the building/structure? Y / N Date of Installation: _____
Is the system active or passive? Active/Passive

9. WATER AND SEWAGE

Water Supply: Public Water Drilled Well Driven Well Dug Well Other: _____

Sewage Disposal: Public Sewer Septic Tank Leach Field Dry Well Other: _____

10. RELOCATION INFORMATION (for oil spill residential emergency)

a. Provide reasons why relocation is recommended: _____

b. Residents choose to: remain in home relocate to friends/family relocate to hotel/motel

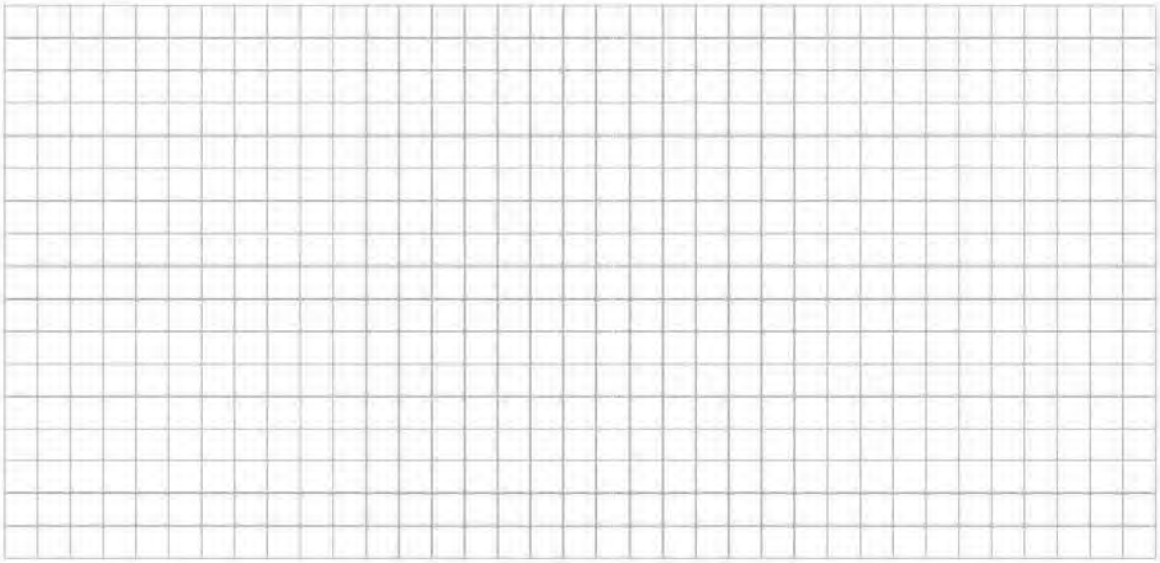
c. Responsibility for costs associated with reimbursement explained? Y / N

d. Relocation package provided and explained to residents? Y / N

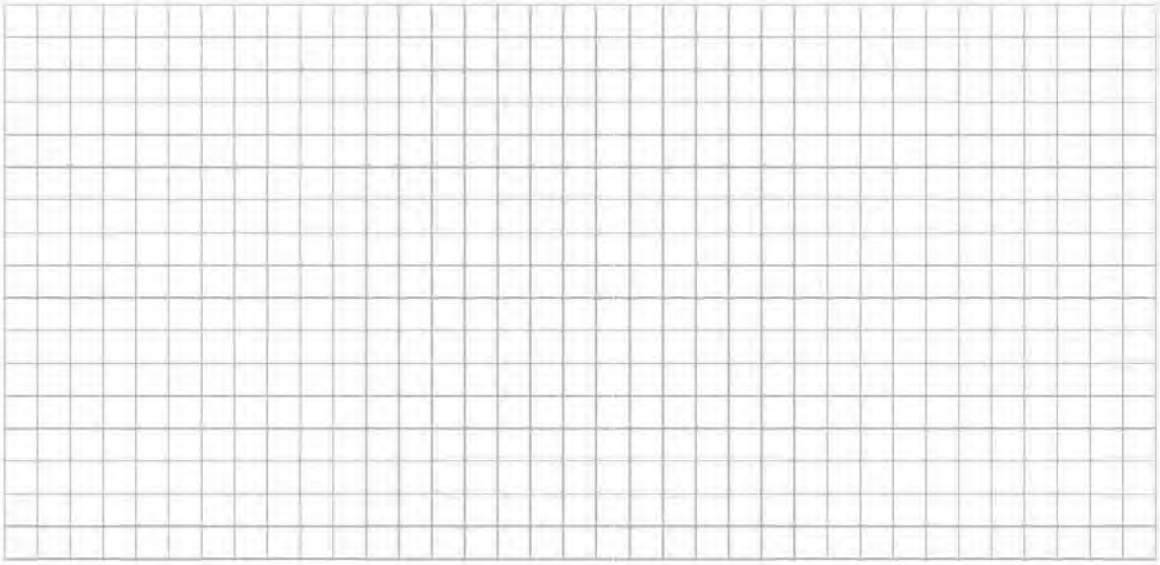
11. FLOOR PLANS

Draw a plan view sketch of the basement and first floor of the building. Indicate air sampling locations, possible indoor air pollution sources and PID meter readings. If the building does not have a basement, please note.

Basement:



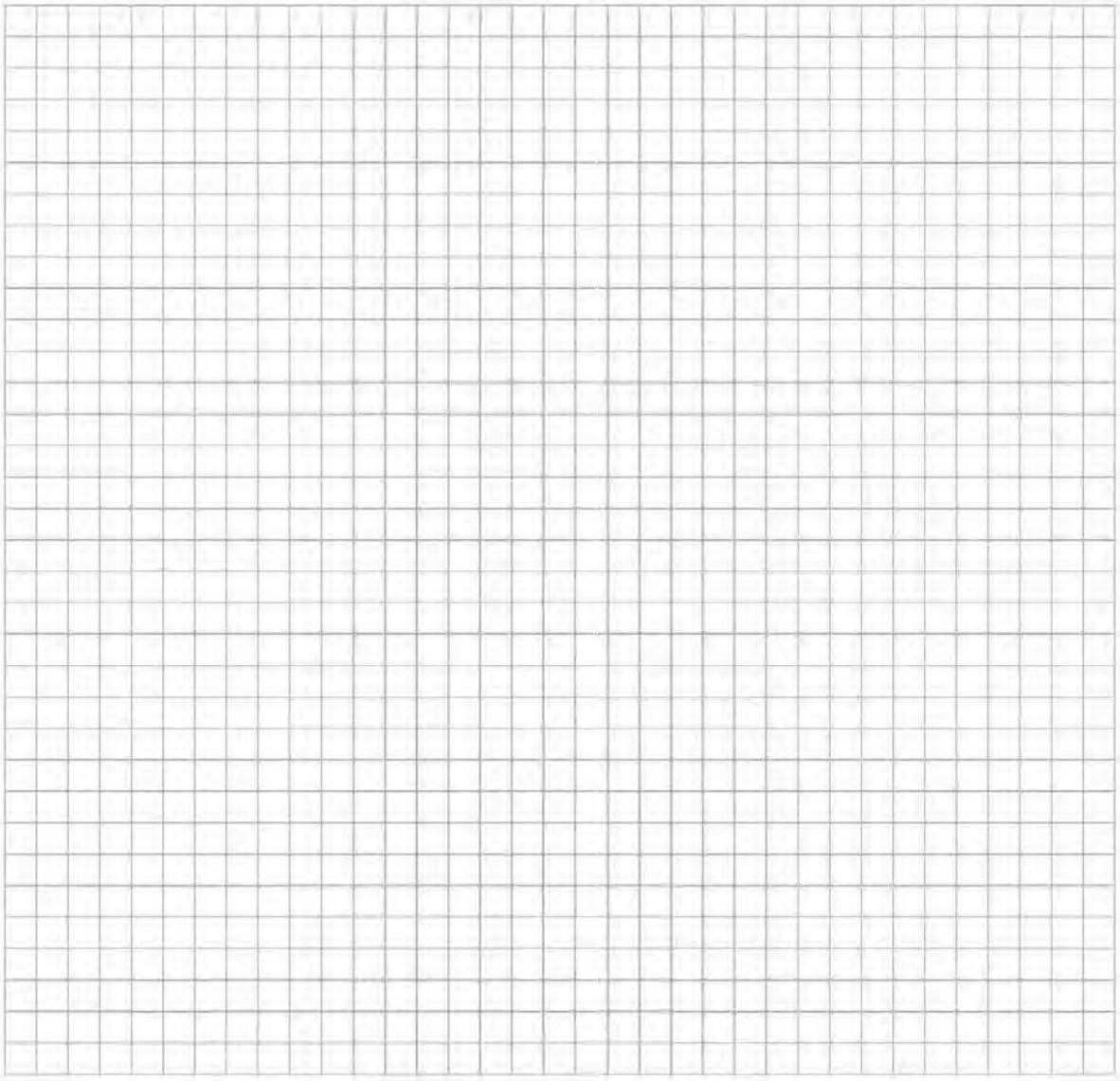
First Floor:



12. OUTDOOR PLOT

Draw a sketch of the area surrounding the building being sampled. If applicable, provide information on spill locations, potential air contamination sources (industries, gas stations, repair shops, landfills, etc.), outdoor air sampling location(s) and PID meter readings.

Also indicate compass direction, wind direction and speed during sampling, the locations of the well and septic system, if applicable, and a qualifying statement to help locate the site on a topographic map.



13. PRODUCT INVENTORY FORM

Make & Model of field instrument used: _____

List specific products found in the residence that have the potential to affect indoor air quality.

Location	Product Description	Size (units)	Condition*	Chemical Ingredients	Field Instrument Reading (units)	Photo** Y / N

* Describe the condition of the product containers as **Unopened (UO), Used (U), or Deteriorated (D)**
** Photographs of the **front and back** of product containers can replace the handwritten list of chemical ingredients. However, the photographs must be of good quality and ingredient labels must be legible.

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APPENDIX H

Development of Screening Levels

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DEVELOPMENT OF SCREENING LEVELS

H.1 GENERIC SCREENING LEVELS

In general, generic screening levels are used to determine whether the potential exists for subsurface contaminants to be present in indoor air at levels that could result in adverse health effects to exposed receptors. If the screening levels for the selected medium are not exceeded, then it is possible that no further evaluation of the vapor intrusion pathway is necessary. A screening approach should be protective of human health, while limiting unnecessary investigative cost. This appendix describes methodologies for the development of generic screening levels for various environmental media, including indoor air, crawl-space air, subslab soil gas, soil gas, groundwater, and soil.

Typically, the development of a screening level begins with a target concentration in indoor air. Indoor air target concentrations can be risk-based indoor air concentrations derived using USEPA consensus toxicity criteria, indoor air literature background values, or other agency-established values. Target indoor air concentrations can be used as a basis to establish screening levels in soil, soil gas, and groundwater. Indoor air target levels can be developed for residential and nonresidential exposure scenarios. For industrial sites, the OSHA-acceptable workplace levels (e.g., permissible exposure levels [PELs]) or other acceptable workplace levels may be applicable as indoor air target concentrations, depending on the circumstances and established policies of the regulatory agency. (As previously stated, the oversight regulatory agency should be consulted when determining any value or other actions at sites within their oversight.)

Next, an allowable concentration in a subsurface medium is calculated from a target indoor air concentration, assuming a certain amount of attenuation and dilution through the vadose zone and the building floor slab. The amount of vapor attenuation/dilution from the subsurface media concentration to the indoor air concentration, known as the “attenuation factor,” can be based on either a model or empirical data. Generic attenuation factors derived using a vapor intrusion model—primarily the USEPA version of the Johnson and Ettinger model (USEPA 2004b) or variations—incorporate default soil and building parameters. In addition, specific considerations may be applicable to petroleum hydrocarbons due to biodegradation.

Existing numerical criteria developed by various federal and state agencies to evaluate potential indoor air impacts were reviewed. While this appendix focuses on the development of values to be used in a screening-level evaluation of the vapor intrusion pathway, it is important to note that the existing numerical criteria are developed to serve different purposes. More conservative assumptions are included in screening levels that, when exceeded, indicate the potential for risk and a need for further evaluation (USEPA 2002b). More realistic assumptions specific to an exposure scenario may be made in the development of risk-based cleanup standards (CTDEP 2003) or action levels (CDPHE 2004) that, when exceeded, trigger remedial action or mitigation. A point-by-point comparison (in other words, comparison of maximum site data) may be appropriate for a screening-level evaluation using generic screening levels, while cleanup standards are typically compared with an exposure point concentration (such as an average concentration or 95th percentile upper concentration limit of the mean). Some agencies conduct

screening-level evaluations using vapor intrusion models instead of or in addition to numerical screening levels. Other agencies provide generic attenuation factors (discussed below), which are used with subsurface media concentrations to predict indoor air concentrations (Cal DTSC 2004). In addition to a generic screening phase, some agencies have a more site-specific or semi-site-specific screening phase in which generic numerical criteria can be modified using site-specific soil and building parameters and the J&E model (Health Canada 2004, MassDEP 2004, USEPA 2002b).

H.1.1 Attenuation Factors

The attenuation factor represents the ratio of the target indoor air concentration within a building to the vapor-phase concentration in subsurface media underlying or adjacent to a building. Attenuation factors are used by a number of agencies to calculate media-specific screening levels or predict indoor air concentrations. These attenuation factors can be derived either empirically or through the use of vapor intrusion models.

An alpha factor is a unitless empirical attenuation factor relating the indoor air concentration to either a subsurface soil gas concentration (α_{sg}) or to a groundwater concentration (α_{gw}) as follows:

$$(\alpha_{sg}) = C_{indoor}/C_{soil\ gas}$$

and

$$(\alpha_{gw}) = C_{indoor}/(C_{water} \times H) \ ,$$

where H = the compound's unitless Henry's law constant.

In a more practical sense, the attenuation factor is the measure of how soil and building properties can limit the intrusion of organic vapors as they migrate into a structure (Gerrard 2006).

Generic screening levels and attenuation factors generally assume the following conditions for use in evaluating the potential for vapor intrusion into an existing, or in some cases, future building:

- The site is adequately characterized.
- The subsurface is reasonably homogeneous.
- No significant fractures exist in the subsurface.
- Groundwater is greater than a certain depth (varies by agency).
- There is no standing water inside the building.
- NAPL is not present on the water table.
- Preferential pathways for soil gas migration do not exist.
- Biodegradation of soil gas contaminants is not occurring.
- Contaminants are homogeneously distributed.

- The building does not have a dirt floor.
- Contaminant vapors enter a building primarily through cracks in the foundation and walls.
- Building ventilation rates and the indoor-outdoor pressure differentials are constant.
- Model assumptions are representative of site conditions.

USEPA has conducted some testing of the reliability of the attenuation factors to estimate indoor air concentrations (Dawson 2005). Selected data sets of indoor air, groundwater data, and subsurface soil gas concentrations were compared, and an attenuation factor calculated. It was found that for volatile chlorinated hydrocarbons, an attenuation factor of 1000 is a conservative estimate of actual indoor air concentrations from calculated soil gas concentrations derived from volatilization from groundwater. This attenuation factor may not be applicable for very shallow groundwater (<5 feet below foundation) or shallow groundwater (<feet below foundation) if there are significant openings to the subsurface (e.g., earthen floors, crawl spaces, sumps), preferential pathways, low building air exchange rates, or very high sustained indoor/outdoor pressure differentials. It was also found that there are insufficient data to draw definite conclusions about generic soil gas–indoor air attenuation factors.

H.1.2 Key Differences

Key differences in the numerical screening levels used to evaluate the vapor intrusion pathway may include the following:

- receptor-specific screening levels (some agencies have developed residential screening levels only, so levels specific to nonresidential exposure scenarios can be derived)
- toxicity values (some states have approved toxicity value that differ from the approved federal toxicity values)
- use of modeled or empirical data to develop attenuation factors and numerical screening levels
- incorporation of background quantitatively into screening levels
- consideration of hypothetical future buildings (California specifies different modeling or exposure point concentrations assumptions depending on whether the building being evaluated is an existing or future structure)

Target indoor air concentrations can vary by several orders of magnitude due to differences in target carcinogenic and noncarcinogenic risk levels, toxicity values, indoor air background values, odor thresholds, analytical quantitation limits, exposure factors (e.g., exposure duration, inhalation rate, body weight), and not-to-exceed ceiling values, if used. Target indoor air concentrations serve as an input in the development of screening levels for subsurface media. In addition to the variability in target indoor air concentrations, groundwater-to-indoor air, soil gas–to–indoor air, and soil–to–

Application of Screening Levels

- There may be state-specific screening levels, as opposed to defaulting to federal values
- Screening levels are promulgated values in some states, so there is little or no ability for site-specific revision.
- States may have different hierarchies for media preference.
- Consideration of possible future land use changes may be required when identifying the most appropriate receptor-specific screening levels.

indoor air numerical screening levels can vary for a number of other reasons. Regional geology, hydrogeology, climate, and building construction vary and therefore affect default assumptions and model input parameters regarding depth to groundwater, soil type, building air exchange rate, building-outdoor pressure differential, building size, and other variables. Some agencies include a dilution or degradation factor for certain petroleum hydrocarbons to account for the biodegradation in the vadose zone.

H.2 INDOOR AIR TARGET VALUES

Risk-based concentrations are concentrations of chemicals within a building that are not expected to cause adverse health effects from long-term exposure. Risk-based indoor air concentrations are generally developed for chronic exposures to generally low-level vapor concentrations. This appendix does not specifically address acute hazards.

Target indoor air screening levels are generally risk-based and are derived using standard risk assessment equations and the following input parameters:

- acceptable target risk thresholds for individual chemicals or cumulative effects
- appropriate toxicity values (federal or state toxicity values for carcinogenic and noncancer toxicity endpoints)
- exposure assumptions such as inhalation rate, exposure duration, and exposure frequency

Standard risk assessment equations and typical default assumptions are identified in various USEPA and state risk assessment guidance such as USEPA 1989, 1996a, 1996b and 2002d. The following equations generally apply:

- For noncarcingens:

$$\text{target indoor air concentration } (\mu g/m^3) = \frac{THQ \times RfD \times BW \times AT \times 1000\ \mu g/mg}{EF \times ED \times IRA},$$

where

THQ = target hazard quotient (see Section 2.1)
RfD = reference dose (mg/kg-day, see Section 2.2)
BW = body weight (kg)
AT = averaging time (days)
EF = exposure frequency (days/year)
ED = exposure duration (years)
IRA = inhalation rate (m^3/day)

- For carcinogens:

$$\text{target indoor air concentration } (\mu g/m^3) = \frac{TR \times BW \times AT \times 1000\ \mu g/mg}{EF \times ED \times IRA \times CSF},$$

where

TR = target incremental lifetime cancer risk (see Section 2.1)
BW = body weight (kg)
AT = averaging time (days)
EF = exposure frequency (days/year)
ED = exposure duration (years)
IRA = inhalation rate (m^3/day)
CSF = cancer slope factor ($[mg/kg\text{-}day]^{-1}$, see Section 2.2)

Alternatively, the indoor air target concentration may be established as the practical quantitation limits using standard methods or indoor air literature background values. For buildings regulated under OSHA, the indoor air target concentrations may be OSHA-derived screening levels (PELs). Consideration of background concentrations is important in the evaluation of potential subsurface media contributions to indoor air given the presence of other sources of VOCs inside buildings. Some agencies use literature or agency-collected indoor air background values as target indoor air concentrations (NYSDOH 2006), while others use a background value if it exceeds a risk-based concentration on a compound-specific basis (CTDEP 2003, MassDEP 2004). Most agencies set the target indoor air concentration at the PQL if it is higher than a risk-based concentration. Some agencies evaluate PQLs on a chemical-specific basis, while others select one value to represent the PQL for all compounds for a specific medium. For example, the Connecticut Department of Environmental Protection sets a "floor" for the soil gas volatilization criteria at 0.5 ppb (CTDEP 2003).

H.2.1 Acceptable Target Risk Thresholds

Cancer risk is generally described as an incremental lifetime cancer risk (ILCR), and noncancer risk is generally described as a hazard quotient (HQ) or total hazard index (HI), which is the sum of HQs for evaluating noncancer effects for multiple chemicals. Acceptable ILCR values are also identified as individual chemical risk or multiple (cumulative) chemical risk. There is some variability in acceptable target ILCRs established by various regulatory agencies, although the acceptable target level for HQ or total HI is less $\leq$1.0. Most target cumulative ILCRs considered acceptable lie within the risk range of 10^{-6}–10^{-4}.

A total HI of less than 1.0 indicates that it is unlikely that adverse human health affects will occur during a lifetime in an exposed population, including sensitive subpopulations (USEPA 1989). Cumulative ILCRs of 10^{-6}–10^{-4} correspond to theoretical probabilities of 1 chance in 1 million to 1 chance in 10 thousand in addition to or in excess of the background cancer risk. It is generally widely accepted in the regulatory community that cumulative ILCR estimates that are equal or less than 10^{-6} do not require remediation or mitigation measures. Risk estimates that are greater than 10^{-4} generally require remediation or mitigation to reduce potential exposures. Under the Resource Conservation and Recovery Act Corrective Action Environmental Indicators (EI) program (USEPA 2005), USEPA indicates that "For the purposes of making Current Human Exposure under Control EI determinations with respect to vapor intrusion, EPA generally

recommends the use of 10^{-5} levels for carcinogens (incremental individual lifetime cancer risk), and a Hazard Quotient (HQ) of 1 for noncancer risk."

H.2.2 Toxicity Values

Commonly, the equations that are used to calculate risk, screening levels, or acceptable concentrations use the inhalation cancer slope factor, CSF $(mg/kg\text{-}day)^{-1}$ and the inhalation reference dose, RfD (mg/kg-day) as the main indicators of potency or toxicity. Some years ago the Integrated Risk and Information System (IRIS) and the USEPA Office of Air Programs began using, and advocating the use of, a reference concentration (RfC) in $\mu g/m^3$ to describe an acceptable airborne concentration protective of the general public and sensitive subpopulations and a unit risk factor (URF) in $(\mu g/m^3)^{-1}$ is to represent the risk of exposure from 1 $\mu g/m^3$. RfCs and URFs are toxicity values developed assuming only an adult receptor. Adult exposure assumptions are included in their derivation, whereas RfDs and CSF may be used to estimated risk or develop screening levels for adults or children.

H.2.3 Receptors and Exposure Parameters

USEPA 1989 provides general guidance on how to characterize exposures and risks when conducting risk assessments. Characterization of potentially exposed populations involves the identification of the current populations at the site in question, activity patterns of these populations, consideration of future land usage at the property, and an evaluation of sensitive populations (i.e., potentially at an increased risk from exposure to a contaminant due to activity and/or behavioral patterns). The following land use categories may be applicable for the development of screening levels for generic exposure scenarios:

- residential
- nonresidential (e.g., commercial/industrial)
- recreational

The exposure assumptions for different exposure scenarios can change, for example in terms of: hours per day, days per year, and years of exposure as well as inhalation rates and body weights, depending on the applicable receptor(s). Screening levels for a residential receptor is generally considered to be the most conservative and thus protective of sensitive populations as well as adults and children in a residential land use scenario. The exposure assumptions for nonresidential receptors (e.g., commercial and industrial workers) are generally less conservative than those in a residential exposure scenario since for nonresidential exposure scenarios only adult receptors with lesser exposure durations are typically considered. Exposure assumptions may be modified to account for regional conditions.

<u>Residential</u>

This category applies if the primary activity of the property is residential in nature and includes single-family dwellings, condominiums, or apartment buildings. Residential screening levels may also apply to facilities deemed to have similar exposure potential as a residence (such as a day care center, school, or elderly care facility). Receptors for the residential land use must

include the general population, including adults and children of various ages. A pregnant female may also be considered a relevant receptor. Default exposure assumptions for the residential scenario are typically 30-year residence time, daily exposure for 350 days/year, with an inhalation rate of 20 m^3/day for a 70-kg adult over 24 years and 10 m^3/day for a 15-kg child over 6 years.

Nonresidential (Commercial)

Activities and uses are extremely variable within the nonresidential land use category. Nonresidential/commercial land uses may range from more sensitive uses such as day care centers and schools to less sensitive uses such as gas stations and warehouse operations. Potential exposures to children are considered for day care centers and schools. For other commercial scenarios, a commercial worker is considered to be the most sensitive receptor. Default exposure assumptions for the commercial worker are typically 25-year employment time, daily exposure for 250 days/year, with an inhalation rate of 20 m^3/day for a 70-kg adult. Some agencies reduce the default inhalation rate per day to reflect a shorter exposure time during the time the worker is in the work place (e.g., from 20 m^3/day to 10 m^3/day, CTDEP 2003).

Nonresidential (Industrial)

Industrial land use is typically applied when the primary activity at the property is and will continue to be industrial in nature. Inactive or abandoned properties can be included in this category if the use was and/or will be industrial and access is controlled as necessary to ensure unacceptable exposures (i.e., exposures more consistent with a residential exposure setting) do not occur. The industrial category does not typically include establishments where children may commonly be present. For industrial sites, the OSHA-acceptable workplace levels (PELs) or other acceptable workplace levels may be used as indoor air target concentrations. Note: Many regulatory agencies use a risk-based value rather than OSHA PELs when vapor intrusion is occurring and the COC is not being used in the facility.

Default exposure assumptions for the industrial worker are generally similar to a commercial worker: 25-year employment time, daily exposure for 250 days/year, with an inhalation rate of 20 m^3/day for a 70-kg adult. However, some agencies may adjust the inhalation rate to account for increased breathing rates during the workday exposure period.

Recreational

Receptors in structures used for recreational purposes may also include adult and child receptors. Default exposure assumptions for the recreational worker are generally similar to a commercial or industrial worker: 25-year employment time, daily exposure for 250 days/year, with an inhalation rate of 20 m^3/day for a 70-kg adult. Default exposure assumptions for the child recreator may be similar to those for a residential child with shorter exposure durations. However, as above, some agencies may adjust the inhalation rate to account for increased breathing rates during typical recreational activities.

Sensitive Populations

The potential for sensitive populations at a vapor intrusion site should be considered. Facilities where sensitive populations may be located include day care centers, schools, and elderly care facilities. The target indoor air concentration for a residential scenario, which includes children, is often considered adequately protective for sensitive populations. Some agencies include adjustments to screening levels based on adult receptors for the derivation of appropriate screening levels for children. For example, the Connecticut Department of Environmental Protection includes in its residential volatilization criteria (CTDEP 2003) a twofold adjustment factor for children's increased inhalation exposure rate relative to adults (due to a greater respiratory rate per body weight and lung surface area) and a twofold adjustment factor for children's increased sensitivity when exposed to genotoxic carcinogens.

H.3 CRAWL-SPACE AIR SCREENING LEVELS

Few agencies currently have generic screening levels for air within building crawl spaces. Screening levels for crawl-space air may only be applicable in certain regions of the country where crawl-space construction is common for residential buildings. Based on the preliminary results of the agency's vapor intrusion database review process, USEPA has concluded there is limited empirical data from which to develop an attenuation factor for crawl-space air (Dawson 2004).

The following equation can be used to calculate generic screening levels for crawl-space air:

$$C_{CA} = C_{IA}/\alpha \ ,$$

where

C_{CA} = crawl-space air screening concentration ($\mu g/m^3$)
C_{IA} = target indoor air concentration ($\mu g/m^3$)
α = crawl-space air attenuation factor (dimensionless)

The crawl-space air screening levels reviewed are based on empirical attenuation factors and generally range 0.1–1.0. An attenuation factor of 1.0 assumes no attenuation of compound concentrations from crawl-space air to indoor air and is considered to be an upper bound value (Dawson 2004).

H.4 SUBSLAB SOIL GAS SCREENING LEVELS

For both subslab soil gas and soil gas measured at deeper depths beneath a building or outside a building footprint, the soil gas screening levels are the target indoor air concentrations multiplied by an attenuation factor. The attenuation factors should be supported by empirical observations and represent the attenuation of vapors as they migrate from the source through the vadose zone to beneath the floor slab, through the floor slab, or from the exterior into the interior of a building and equilibrating in the indoor air space. Specific considerations may be applicable to petroleum hydrocarbons due to biodegradation.

Several agencies, including USEPA, include soil gas collected from a depth of 5 feet or less (outside a building or below a building floor slab) and subslab soil gas collected below a building floor slab in the same category (typically designated "shallow soil gas") when evaluating the vapor intrusion pathway.

The following equation can be used to calculate subslab soil gas screening levels:

$$C_{SS} = C_{IA}/\alpha \ ,$$

where

C_{SS} = subslab soil gas screening concentration ($\mu g/m^3$)
C_{IA} = target indoor air concentration ($\mu g/m^3$)
α = subslab soil gas attenuation factor (dimensionless)

Attenuation factors for subslab soil gas are typically based on empirical data and generally range 0.01–0.1 for residential buildings. As part of its ongoing review of the agency's vapor intrusion database, USEPA has determined that its current OSWER draft subslab attenuation factor of 0.1 may be overly conservative and is reportedly revisiting this number (Dawson 2004).

H.5 SOIL GAS SCREENING LEVELS

As discussed above, several agencies currently include soil gas collected from a depth of 5 feet or less (outside a building or below a building floor slab) and subslab soil gas collected below a building floor slab in the same category (typically designated "shallow soil gas") when evaluating the vapor intrusion pathway. Due to differences in the nature of sampling, and the need to gain access into a building to conduct subslab sampling, it may be preferable to have soil gas screening levels apply to all soil gas samples collected outside a building at a certain depth below ground surface.

The following equation can be used to calculate soil gas screening levels:

$$C_{SG} = C_{IA}/\alpha \ ,$$

where

C_{SG} = soil gas screening concentration ($\mu g/m^3$)
C_{IA} = target indoor air concentration ($\mu g/m^3$)
α = soil gas attenuation factor (dimensionless)

Both empirical and modeled attenuation factors are available for soil gas. The reported range of attenuation factors, both empirical and modeled, for a residential building scenario is 0.002–0.1. These attenuation factors apply to either shallow (typically <5 feet bgs) or deep (>5 feet) soil gas samples taken at or in proximity to the current structures. Attenuation factors for future

residential buildings are also available for some agencies and typically range 0.0009–0.01. The attenuation factors used by the agencies for nonresidential/commercial buildings typically range 0.0005–0.1. One agency, California Environmental Protection Agency, provides a soil gas attenuation factor for future commercial buildings of 0.0004 (Cal DTSC 2004). Health Canada provides semi-site-specific soil gas attenuation factors for residential and commercial buildings (Health Canada 2004).

H.6 GROUNDWATER SCREENING LEVELS

The groundwater screening levels include established groundwater standards, such as maximum contaminant levels, as well as health-based groundwater concentrations calculated to be protective of indoor air quality.

Groundwater screening levels developed for the vapor intrusion pathway are applicable to groundwater concentrations obtained from monitoring wells screened at or near the water table. Groundwater samples collected from deeper aquifers or well screen intervals are not appropriate for evaluating the vapor intrusion pathway and should not be compared with groundwater screening levels for the purposes of site screening since chemical volatilization and subsequent upward vapor migration occur from chemical concentrations in groundwater at the water table. When nonimpacted shallow groundwater lies above an impacted groundwater zone, the shallow groundwater acts as a barrier for volatilization from groundwater at deeper depths. However, the application of groundwater screening levels is state specific. For instance, Michigan requires that groundwater screening levels be compared to concentrations throughout the affected aquifer.

The following equation is often used to develop generic screening levels to evaluate the groundwater–to–indoor air exposure pathway:

$$C_{GW} = C_{IA}/(H \times \alpha \times 1000\ L/m^3) \ ,$$

where

C_{GW} = groundwater screening level (μg/L)
C_{IA} = target indoor air level (μg/m^3)
H = Henry's law constant (dimensionless)
α = groundwater attenuation factor (dimensionless)

Henry's law constant is used to convert the groundwater concentration in the aqueous phase to a vapor-phase concentration at equilibrium. According to USEPA (2002b), "Field data suggest that this conversion may result in over prediction of the soil gas concentration (by as much as a factor of ten) directly above the contaminated groundwater. However, this is not always the case and consequently Henry's Constant is used [in the USEPA-OSWER Draft Vapor Intrusion Guidance] without a correction factor." Henry's law constants can be obtained from USEPA for many VOCs (USEPA 2004a).

Both empirical and modeled attenuation factors are available from the various agencies for groundwater. Some states calculate chemical-specific attenuation factors using the J&E model

(MassDEP 2004). The range of groundwater–to–indoor air attenuation factors is typically 0.0007–0.0008 (chemical specific) to 0.001 for residential buildings. Generic groundwater attenuation factors are not available for nonresidential/commercial buildings. Health Canada provides semi-site-specific groundwater attenuation factors for residential and commercial buildings (Health Canada 2004). Additional information regarding the use of the J&E model can be found in the EPA 2005.

H.7 SOIL SCREENING LEVELS

Screening levels based on soil concentrations are generally not derived for assessing the vapor intrusion pathway. Most states and USEPA regions do not use or encourage the use of soil–to–indoor air screening levels. The USEPA Office of Solid Waste and Emergency Response draft guidance cites uncertainties related to soil partitioning calculations and analytical limitations when sampling and evaluating VOCs in the soil matrix which reduce the defensibility of soil screening levels (USEPA 2002). Further, nondetect analytical soil concentration results do not necessarily indicate a lack of a soil gas source (due to potential volatilization during sample collection, handling, and analysis) but may be interpreted as such.

Generally, soil gas measurements are recommended as an alternative to bulk soil measurements to evaluate potential vapor migration from a soil medium. There are situations, though, in which it is not feasible to collect a defensible soil gas sample. For instance, the presence of a shallow water table or clay-rich soils may preclude soil gas sampling. In these situations, where contaminants originate from a soil source (as compared to a groundwater source), bulk soil measurements may be used to evaluate the vapor intrusion pathway.

Few states have derived soil–to–indoor air screening levels. Pennsylvania Department of Environmental Protection (PADEP 2004) has developed and promulgated soil screening levels based on the application of the J&E model.

H.8 BIODEGRADABLE COMPOUNDS

Some agencies include a dilution or degradation factor in the development of screening levels for certain petroleum hydrocarbons to account for the biodegradation in the vadose zone. Several apply a dilution/degradation factor of 0.1 (or 10-fold dilution) to petroleum compounds, including BTEX (Health Canada 2004, NJDEP 2005, MADEP 2004). USEPA generic attenuation factors are based largely on data for less-degradable chlorinated compounds (USEPA 2002b). Empirical data suggests that a 3- to 10-fold decrease in the attenuation factor is appropriate for biodegradable BTEX compounds compared with chlorinated compounds (USEPA 2002b, Appendix F, Section 5). Recent American Petroleum Institute guidance suggests 0.01 as a low-end soil gas attenuation factor and that soil gas–to–indoor air attenuation factors of 0.0001–0.00001 may be reasonable for BTEX compounds (API 2004).

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APPENDIX I

ITRC Vapor Intrusion Team Contacts

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ITRC VAPOR INTRUSION TEAM CONTACTS

Co-Leaders

John Boyer
NJ Department of Environmental Protection
609-984-9751
609-292-0848
john.boyer@dep.state.nj.us

Bill Morris
KS Department of Health and Environment
785-296-8425
785-296-1686
bmorris@kdhe.state.ks.us

Program Advisor

Steve R. Hill
RegTech, Inc
208-442-4383
208-442-1762
Srhill1@mindspring.com

Team Members

Leah Alejo
NFESC, ESC – 411
805-982-1753
805-982-4304
leah.alejo@navy.mil

Vanessa J.Bauders
U.S. Army Corps of Engineers
816-983-3567
816-426-5550
vanessa.j.bauders@nwk02.usace.army.mil

Delonda Alexander
NC Dept. of Environment and Natural Res.
919-508-8444
919-733-4811
cdsca@hotmail.com

Ramesh Belani
PA DEP
484-250-5756
484-250-5961
rbelani@state.pa.us

Harry Anderson
W.L. Gore & Associates, Inc.
410-506-4852
410-506-4780
handerso@wlgore.com

Greg Braun
MassDEP
617-292-5718
greg.braun@state.ma.us

Jean Balent
USEPA, Technology Innovation Program
703-603-9924
703-603-9135
balent.jean@epa.gov

Anita Broughton
Haley & Aldrich, Inc
619-285-7104
619-280-9415
ABroughton@haleyaldrich.com

Andre Brown
W.L. Gore & Associates, Inc.
415-648-0438
415-648-0398
abrown@wlgore.com

Tonia R. Burk
GA Environmental Protection Division
404-657-8642
404-651-9425
tonia_burk@dnr.state.ga.us

Richard Burns
Connestoga Associates
610-280-0277
rburns@craworld.com

Mary Camarata
Oregon DEQ
541-686-7839 x259
541-686-7551
camarata.mary@deq.state.or.us

Douglas N. Cox
Mitretek Systems
210-408-5554
210-479-0482
douglas.cox@mitretek.org

Craig Dukes
SC DEHEC
803-896-4057
dukescv@dhec.sc.gov

Diane Easley
USEPA Region 7
913-551-7797
913-551-7063
easley.diane@epa.gov

Peter Eremita
Maine Dept. of Environmental Protection
207-822-6364
207-822-6303
pete.m.eremita@maine.gov

Mark J. Fisher
U.S. Army Corps of Engineers
402-697-2587
402-697-2595
mark.j.fisher@usace.army.mil

Douglas M. Fitton
LFR Inc.
850-254-2229
850-422-2624
douglas.fitton@lfr.com

David J. Folkes
EnviroGroup Limited
303-790-1340 x111
303-790-1347
dfolkes@envirogroup.com

Richard Galloway
DNREC-SIRB
302-395-2614
302-395-2615
rick.galloway@state.de.us

Kimberly Gates
U.S. Navy NFESC
805-982-1656
805-982-4304
kimberly.gates@navy.mil

Sandra Gaurin
BEM Systems, Inc.
908-598-2600 ext.154
SGaurin@bemsys.com

Johnathan Gledhill
Policy Navigation Group
888-312-4119
jgledhill@policynavigation.com

Jerry Grimes
Virginia DEQ
804-698-4207
gjgrimes@deq.virginia.gov

Jeanene Hanley
Arizona Dept. of Environmental Quality
602-771-4314
602-771-4346
jph@azdeq.gov

Jim Harrington
NY Dept. of Environmental Conservation
518-402-9755
518-402-9722
jbharrin@gw.dec.state.ny.us

Blayne Hartman
H&P Mobile Geochemistry
858-793-0401
858-793-0404
bhartman@handpmg.com

Tom Higgins
Minnesota Pollution Control Agency
651-282-9880
651-296-9707
tom.higgins@pca.state.mn.us

Jay W. Hodny
W.L. Gore & Associates, Inc.
410-506-4774
410-506-4780
jhodny@wlgore.com

Stephen Hoffine
Burns & McDonnell Engineering Co., Inc.
816-822-3892
shoff@burnsmcd.com

Greg Johnson
Colo. Dept. Labor and Employment
303-318-8536
303-318-8546
greg.johnson@state.co.us

Alan V. Jones
Utah Department of Environmental Quality
801-536-4287
ajones@utah.gov

Bheem R. Kothur
Florida DEP/S&HW/Regulation Section
850-245-8781
850-245-8810
bheem.kothur@dep.state.fl.us

Alana Lee
USEPA Region 9
415-972-3141
415-947-3528
lee.alana@epa.gov

Diedre Lloyd
Florida DEP
850-245-8954
850-2 45-8975
Diedre.Lloyd@dep.state.fl.us

Alexander MacDonald
Regional Water Quality Control Board
916-464-4625
916-464-4797
amacdonald@waterboards.ca.gov

Ronald J. Marnicio
Tetra Tech, EC
617-457-8262
ronald.marnicio@tteci.com

Diana Y. Marquez
Burns & McDonnell Engineering Co., Inc.
816-822-3453
816-822-3494
dmarque@burnsmcd.com

Todd A. McAlary
GeoSyntec Consultants, Inc.
519-822-2230 x239
519-822-3151
Tmcalary@geosyntec.com

Rafael McDonald
MassDEP
617-292-5713
rafael.mcdonald@state.ma.us

William McKercher
MS DEQ
601-961-5731
601-961-5300
willie_mckercher@deq.state.ms.us

John S. Mellow
PA DEP
570-826-2064
570-820-4907
jmellow@state.pa.us

Denise Miller
ARCADIS
865-675-6700
dmiller@arcadis-us.com

Robin Mongeon
State of New Hampshire
603-271-7378
rmongeon@des.state.nh.us

Evelina Morales
OK Department of Environmental Quality
405-702-5108
405-702-5101
evelina.morales@deq.state.ok.us

Eric M. Nichols
LFR Inc.
Eric.Nichols@lfr.com

Richard Olm
AZ Department of Environmental Quality
602-771-4223
602-771-4272
olm.richard@azdeq.gov

Ian T. Osgerby
USACE, New England District
978-318-8631
978-318-8614
ian.t.osgerby@usace.army.mil

Jeffrey J. Painter
Pennsylvania DEP
717-783-9989
717-783-2703
jepainter@state.pa.us

Gina M. Plantz
Newfields
781-264-4950
781-681-4048
gplantz@newfields.com

Henry Schuver
USEPA OSW
703-308-8656
703-308-8609
Schuver.Henry@epamail.epa.gov

Lenny Siegel
Center for Public Environmental Oversight
650-961-8918
lsiegel@cpeo.org

Susan Ann Skye
Florida Dept. of Health
850-245-4444 x2310
850-487-0864
Susan_Skye@doh.state.fl.us

Nelly F. Smith
Alabama DEM
334-271-7750
nfsmith@adem.state.al.us

Peter M. Strauss
PM Strauss & Associates
415-647-4404
415-647-4404
petestrauss1@comcast.net

Neil B. Taylor
Utah Department of Environmental Quality
801-536-4102
801-536-4242
nbtaylor@utah.gov

Fred Tillman
USEPA Ecosystems Research Division
706-355-8309
706-355-8302
tillman.fred@epa.gov

Jim Whetzel
W.L. Gore & Associates, Inc
410-506-4779
410-506-4780
jwhetzel@wlgore.com

Yvonne Walker
Navy Environmental Health Center
757-953-0941
757-953-0675
walkery@nehc.med.navy.mil

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APPENDIX J

Acronyms

ACRONYMS

API	American Petroleum Institute
BTEX	benzene, toluene, ethylbenzene, and xylenes
bgs	below ground surface
CAG	Community Advisory Group
CGI	combustible gas indicator
COC	chemical of concern
CSF	cancer slope factor
CSM	conceptual site model
1,1-DCE	1,1-dichloroethene
DQO	data quality objective
EI	environmental indicator
FID	flame ionization detector
GC	gas chromatography
GC/MS	gas chromatography/mass spectrometry
HDPE	high-density polyethylene
HI	hazard index
HQ	hazard quotient
HVAC	heating, ventilating, and air conditioning
ILCR	incremental lifetime cancer risk
IRIS	Integrated Risk Information System
IRM	interim remedial measure
ITRC	Interstate Technology & Regulatory Council
J&E	Johnson and Ettinger model
MassDEP	Massachusetts Department of Environmental Protection
MDL	method detection limit
MIBK	4-methyl-2-pentanone
MTBE	methyl tertiary-butyl ether
NAPL	nonaqueous-phase liquid
NASA	National Aeronautics and Space Administration
NJDEP	New Jersey Department of Environmental Protection
NYSDOH	New York State Department of Health
OM&M	operation, maintenance, and monitoring
OSHA	Occupational Safety and Health Administration
PAH	polyaromatic hydrocarbon
ppbv	parts per billion by volume
PCB	polychlorinated biphenyls
PCE	tetrachloroethene (also called perchloroethene)
PDBS	passive diffusion bag sampler
PEL	permissible exposure limit
PID	photoionization detector
PQL	practical quantitation limit
QA/QC	quality assurance/quality control
RfC	reference concentration
RfD	reference dose

RL	reporting limit
SIM	selective ion monitoring
SMD	submembrane depressurization
SOP	standard operating procedure
SSD	subslab depressurization
SSP	subslab pressurization
SVOC	semivolatile organic compound
TAGA	Trace Atmospheric Gas Analyzer
TCA	trichloroethane
TCD	thermal conductivity detector
TCE	trichloroethene
TPH	total petroleum hydrocarbons
URF	unit risk factor
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VI	vapor intrusion
VOC	volatile organic compound

Soil Gas Unit Conversion Factors		
Unit	**To convert to:**	**Multiply by:**
µg/L	mg/m^3	1
$\mu g/m^3$	mg/m^3	0.001
ppbv	$\mu g/m^3$	MW/24
$\mu g/m^3$	ppbv	24/MW
ppmv	mg/m^3	MW/24
ppbv	mg/m^3	MW/24,000
µg/L	$\mu g/m^3$	1000
$\mu g/m^3$	µg/L	0.001
µg/L	ppbv	24,000/MW
µg/L	ppmv	24/MW
ppbv	ppmv	0.001
ppmv	ppbv	1000

At standard temperature and pressure

µg/L	micrograms per liter
mg/m^3	milligrams per cubic meter
$\mu g/m^3$	micrograms per cubic meter
ppbv	parts per billion by volume
MW	molecular weight
ppmv	parts per million by volume

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Appendix 15

Electric Power Research Institute (EPRI), 2022. Evaluation and Comparison of Leach Test and Porewater Variability for Multiple Coal Combustion Product Management Units. EPRI, Palo Alto, CA: 2022. 3002024214.

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EPRI

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2022 TECHNICAL REPORT

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Evaluation and Comparison of Leach Test and Porewater Variability for Multiple Coal Combustion Product Management Units

3002024214

Final Report, November 2022

EPRI Project Manager
B. Hensel

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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THE FOLLOWING ORGANIZATIONS PREPARED THIS REPORT:

Ramboll

EPRI

NOTE

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ACKNOWLEDGMENTS

The following organizations prepared this report:

Ramboll
243 W. Florida Street
Fifth Floor
Milwaukee, WI 53204

Principal Investigators
N. Keller
A. O'Connor
R. Banoff
S. Meyer
S. Shock

EPRI
3420 Hillview Ave.
Palo Alto, CA 94304

Principal Investigator
B. Hensel

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ABSTRACT

EPRI is researching coal combustion product (CCP) porewater chemistry to improve predictions of chemical evolution over the long term, particularly post-closure. An EPRI-member company made a large volume of porewater chemistry data available to EPRI, which was used to improve our understanding of porewater chemistry and how it varies between and within CCP units. This data set also provided information on the efficacy of USEPA's SW-846 1313 and 1316 leaching methods (also known as *LEAF 1313* and *LEAF 1316*) for evaluating porewater chemistry.

The objective of this research was to provide information on the chemistry of CCP porewater and how it may vary to help inform decision making on porewater evaluations. The specific objectives of this project were to:

- Evaluate the relationship of total (unfiltered) concentrations versus dissolved (filtered) concentrations in CCP porewater
- Assess the variability of porewater properties within and between CCP units
- Identify whether there are relationships between the laboratory leaching tests and measured porewater concentrations

Keywords

CCP porewater
Coal combustion products (CCPs)
LEAF
Porewater variability

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Deliverable Number: 3002024214

Product Type: Technical Report

Product Title: Evaluation and Comparison of Leach Test and Porewater Variability for Multiple Coal Combustion Product Management Units

PRIMARY AUDIENCE: Subject matter experts and project managers responsible for closure or groundwater remediation at coal combustion product (CCP) management units.

SECONDARY AUDIENCE: Groundwater and geochemical modelers responsible for predicting the long-term effects of closure or groundwater remediation at CCP management units.

KEY RESEARCH QUESTION

EPRI is researching CCP porewater chemistry to improve predictions of chemical evolution over the long term, particularly post-closure. The objective of this research was to provide information on the chemistry of CCP porewater and how it may vary to inform decision making when characterizing porewater concentration for groundwater and geochemical models. The specific objectives of this project were to:

- Evaluate the relationship of total (unfiltered) concentrations versus dissolved (filtered) concentrations in CCP porewater
- Assess the variability of porewater properties within and between CCP units
- Identify whether there are relationships between the laboratory leaching tests and measured porewater concentrations

RESEARCH OVERVIEW

CCP porewater data were collected and provided by an EPRI-member company. The porewater data were collected from porewater monitoring points (PMPs) installed at 29 CCP management units between 2015 and 2021. In addition, CCP solids samples from the same location and depth as the PMPs at four units were subjected to leach testing using USEPA SW-846 methods 1313 (LEAF 1313) and 1316 (LEAF 1316). EPRI researchers used graphical and statistical methods to evaluate the data with respect to the project objectives.

KEY FINDINGS

- A comparison of total versus dissolved porewater sample results indicated:
  - Total and dissolved measurements are generally more comparable at concentrations elevated well above the reporting limit where laboratory analytical variability is less significant relative to concentration.
  - Major ions (Ca, Mg, Na, K), certain minor ions (Ba, B, Mn, Mo, Sr, Li), and elements with low detection frequency (Cd, Hg) were least likely to be affected by sample filtration.
  - Elements most likely to be affected by sample filtration were Al, Cr, Cu, Fe, and V.
- A comparison of intra-unit and inter-unit porewater variability results indicated:
  - There does not appear to be an overall pattern to define which parameters exhibit high or low variability. However, parameters of interest—either because they are CCP tracers (B and SO_4) or potential remediation drivers (As, Sb, B, Cr, Co, Li, Mo, and Se)—mostly have medium to high intra-unit variability, which suggests that more extensive porewater evaluation may be helpful to characterize a unit when developing a source term to model these parameters. Lithium was the only remediation driver with low intra-unit variability.

  - As, B, Co, Li, Mo, Se, and SO_4 had high inter-unit variability. Sb and Cr had medium and low inter-unit variability, respectively, which was attributed to their relatively low concentration in the porewater samples.
- Comparing leach test eluates to porewater samples, EPRI researchers observed:
  - LEAF 1313 and 1316 eluate concentrations were usually more than 25% higher or 25% lower than their paired median porewater concentrations. This observation was made for 1313 eluates at natural pH and the broader pH range for all porewaters as well as for 1316 results at low and high L/S.
  - Elements often controlled by available content—such as B, Ca, Cl, Li, Sr, and SO_4—tended to be underpredicted by the LEAF tests.
  - As, Fe, and Mn were also underpredicted, even though they tend to be solubility controlled, because the LEAF testing was performed under oxic conditions when the solubility of these elements is low.
  - Conversely, Se and Cr, which are most soluble under oxic conditions, tended to be overpredicted by the LEAF testing performed under oxic conditions.
  - Sb, Tl, and V tended to be overpredicted by the leach tests while other elements were overpredicted or underpredicted depending on test-specific and site-specific factors.

WHY THIS MATTERS

This research helps stakeholders understand that LEAF tests produce valuable information for comparing CCPs and understanding their geochemistry but are not reliable for predicting in-field porewater quality. This research also helps stakeholders understand CCP porewater variability, which can be used to improve characterization of source terms used in fate and transport or geochemical models and resulting predictions of groundwater quality in response to closure or remediation alternatives evaluated with these models.

HOW TO APPLY RESULTS

The conclusions of this research are stated in this executive summary. Readers interested in more detailed information for specific constituents can reference the body of this report.

LEARNING AND ENGAGEMENT OPPORTUNITIES

Previous research results published by EPRI related to porewater variability and the ability of leach tests to predict porewater chemistry are:

- *Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment: Capped Unit*. EPRI, Palo Alto, CA: 2020. 3002017363.
- *Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit: Plant 42197*. EPRI, Palo Alto, CA: 2021. 3002018780.

EPRI CONTACTS: Bruce Hensel, Technical Executive, bhensel@epri.com; Benjamin Gallagher, Principal Technical Leader, bgallagher@epri.com

PROGRAM: CCP Land and Groundwater Management, P242; Coal Combustion Products Management, P241

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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1 INTRODUCTION

EPRI is researching coal combustion product (CCP) porewater chemistry to improve predictions of chemical evolution over the long term, particularly post-closure. The objective of this research was to provide information on the chemistry of CCP porewater and how it may vary to inform decision making when characterizing porewater concentration for groundwater and geochemical models. The specific objectives of this project were to:

- Evaluate the relationship of total (unfiltered) concentrations versus dissolved (filtered) concentrations in CCP porewater
- Assess the variability of porewater properties within and between CCP units
- Identify whether there are relationships between the laboratory leaching tests and measured porewater concentrations

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2
SUMMARY OF DATA

Coal Combustion Product Units

CCP porewater and leach test data were provided for 14 power plants in North Carolina (Synterra, 2021). The 14 power plants and 29 associated CCP management units are summarized in Table 2-1. Porewater data were collected from porewater monitoring points (PMPs) installed at all 29 units between 2015 and 2021. Additional data from laboratory leaching tests were provided for four plants (Allen, BCSS, Cliffside, and Marshall), based on cores collected at the time of PMP installation in 2018. Operational periods are summarized in Table 2-1 and illustrated in Figure 2-1.

All units contain coal ash and are primarily a mix of fly ash and bottom ash. Several units were excavated within the last 15 years (that is, Asheville units 1964 and 1982, Cliffside units 1–4 and ash storage area, Dan River ash basin, Riverbend ash basin and cinder storage area, and Weatherspoon 1979 ash basin).

Leach test data were obtained by LEAF 1313[1] and LEAF 1316.[2] Synthetic precipitation leaching procedure (SPLP) was also performed, but final values for eluate pH were not available, so the SPLP results are not further considered.

Data Preparation and Refinement

Data were provided in two separate files: one containing the porewater data and the other containing LEAF leach test eluate data. Due to differences in how these two files reported data, slightly different data preprocessing and quality assurance steps were taken for the porewater data file and the LEAF eluate data file. For both data files, concentrations reported in units of µg/L were converted to mg/L for consistency across the data set. Radium activities reported as negative values were set to zero for both data files. Quality control replicate sample analyses were removed from the porewater data set to avoid bias because those results are not independent.[3] In the porewater data, non-detect results were identified as those samples flagged with a "U" qualifier, and the method detection limit was used as the result. QA/QC samples were excluded from the LEAF eluate data. In the LEAF eluate data, non-detect results were identified

[1] LEAF 1313 (SW-846, USEPA 2019) is a standardized, parallel batch extraction method used to evaluate the liquid-solid partitioning (LSP) of inorganic constituents as a function of eluate pH.
[2] LEAF 1316 (SW-846, USEPA 2019) is an equilibrium-based leaching test intended to provide eluate solutions over a range of liquid-to-solid ratios (L/S). This method consists of five parallel batch extractions of a particle-size-reduced solid material in reagent water over a range of L/S values from 0.5 to 10 mL/g-dry material.
[3] The data set included four categories of duplicate samples, which combined represented a small fraction of the data set. In the absence of information about the nature of those duplicate sample categories, they were excluded from the data set used in this analysis.

as those samples with analytical results less than method detection limit (MDL), and the MDL was used as the result.

Table 2-1
Summary of sites and CCP units with available porewater and leachate data

Site	Unit(s)	PMPs	Years in Operation	Dry Ash Handling?[1]	Excavation?[2]
Allen	Ash Basin	21	1957–2019	Y	
Asheville	1964 Basin	2	1964–1982		Complete
Asheville	1982 Basin	1	1982–2020		Complete
BCSS	Ash Basin	9	1974–2019	Y	
Buck	Ash Basin, Cell 1	3	1982–2013		In Progress
Buck	Ash Basin, Cell 2	4	1957–2013		
Buck	Ash Basin, Cells 2 and 3	2	1957–2013		
Buck	Ash Basin, Cell 3	1	1957–2013		
Cape Fear	1963 Basin	2	1963–1970		
Cape Fear	1970 Basin	2	1970–1978		
Cape Fear	1985 Basin	2	1985–2012		
Cliffside	Active Ash Basin	6	1975–2018		
Cliffside	Ash Pore Water[3]	2	1975–2018		
Cliffside	Ash Storage Area	1	1970–1978		In Progress
Cliffside	Former Units 1–4 Basin	3	1957–1977		Complete
Cliffside	Inactive Unit 5 Basin	3	1972–1980		In Progress
Dan River	Ash Basin	3	1956– 2012		Complete
Lee	Lay of Land Area	2	<1951		
Lee	Inactive Ash Basin	2	1962–1982		
Marshall	Ash Basin	14	1965–1984	Y	
Marshall	Dry Ash Landfill	1	1984–1999	Y	
Mayo	Ash Basin	3	1983–2016	Y	
Riverbend	Ash Basin	3	1957–2013		Complete
Riverbend	Cinder Storage Area	1	1929–1957		Complete
Roxboro	East Ash Basin	2	1966–1983		
Roxboro	West Ash Basin	2	1973–2018	Y	
Sutton	1971 Basin	1	1971–2013		
Sutton	Former Ash Disposal Area	1	1954–1972		
Weatherspoon	Ash Basin	1	1958–2011		In Progress

Notes:

[1] Dry ash handling may include units constructed on top of the footprint of ash basins.

[2] Excavation of the unit has been performed (complete) or is ongoing (in progress) as of the date the information was provided.

[3] Based on review, these locations are likely within the Active Ash Basin but were kept separate because of their distinction in the database.

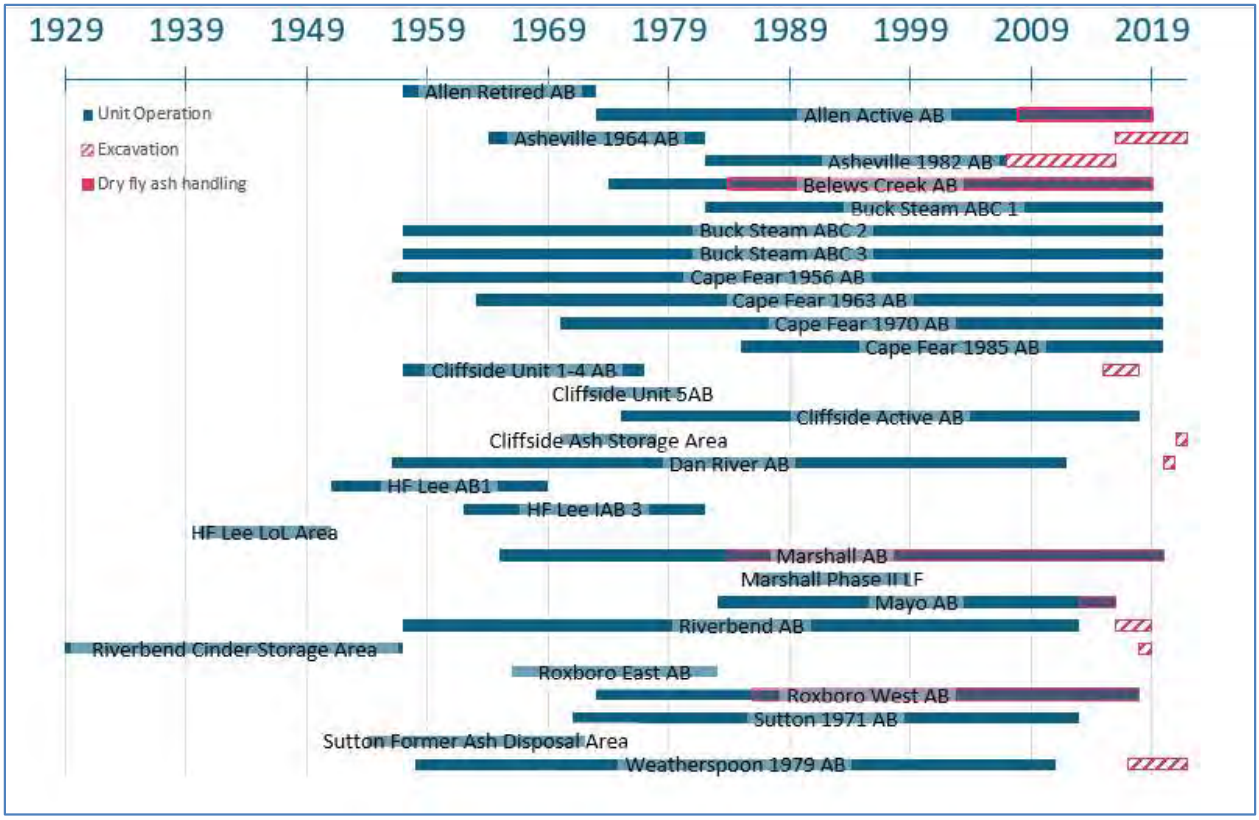

Figure 2-1
Operational history CCP units with available porewater data

Porewater Data

The porewater data set contained 111 parameters (including both total and dissolved fractions for most inorganic parameters) reported at a total of 100 individual PMPs. The porewater data set was refined prior to further analysis based on number of measurements for each parameter and degree of relevance in CCP porewater. Most parameters with fewer than 1,000 measurements were excluded from this analysis. This included redox speciation measurement, dissolved samples filtered at a 0.1 µm level, and some radioactive parameters. Some parameters with fewer than 1,000 total measurements were retained due to their relevance for CCP (fluoride, lithium, and isotopes of radium) or to facilitate comparisons between total and dissolved concentrations. In addition, dissolved oxygen (often unreliable due to contamination during sampling) and oxidation-reduction potential (ORP) (redundant with Eh) measurements were excluded. After refinement, the porewater data set contained 71 parameters measured at 100 PMPs (see Table 2-2 for a list of parameters analyzed in porewater and Appendix A for sample counts and basic statistics).

Table 2-2
Summary of units with observations for each parameter

Parameter	Units	
	Total	Dissolved
Alkalinity (ALK)	29	
Aluminum (Al)	29	29
Antimony (Sb)	29	29
Arsenic (As)	29	29
Barium (Ba)	29	29
Beryllium (Be)	29	29
Bicarbonate Alkalinity (ALK-HCO_3)	29	
Boron (B)	29	29
Cadmium (Cd)	29	29
Calcium (Ca)	29	19
Carbonate Alkalinity (ALK-CO_3)	29	
Chloride (Cl)	29	
Chromium (Cr)	29	29
Hexavalent Chromium (Cr(VI))	26	
Cobalt (Co)	29	29
Copper (Cu)	29	29
Eh	29	
Fluoride (F)	23	
Iron (Fe)	29	29
Lead (Pb)	29	29
Lithium (Li)	23	20
Magnesium (Mg)	29	19
Manganese (Mn)	29	29
Mercury (Hg)	29	29
Molybdenum (Mo)	29	29
Nickel (Ni)	29	29
Nitrate + Nitrite (NO_2+NO_3)	29	
pH	29	
Potassium (K)	29	19
Total Radium (Ra)	8	
Radium-226 (^{226}Ra)	23	
Radium-228 (^{228}Ra)	23	
Selenium (Se)	29	29
Sodium (Na)	29	19

Table 2-2 (continued)
Summary of units with observations for each parameter

Parameter	Units	
	Total	Dissolved
Specific Conductance (EC)	29	
Strontium (Sr)	29	29
Sulfate (SO_4)	29	
Sulfide (S^{2-})	29	
Temperature (TEMP)	29	
Thallium (Tl)	29	29
Total Dissolved Solids (TDS)		29
Total Organic Carbon (TOC)	29	
Total Suspended Solids (TSS)	29	
Turbidity (TURB)	29	
Vanadium (V)	29	29
Zinc (Zn)	29	29

Leach Test Data

The LEAF data set contained 30 parameters and final eluate pH values for tests performed on CCP samples from 18 PMP boreholes. The LEAF and porewater data were paired based on co-location of station and depth of sample (Table 2-3).[4] For cases in which multiple LEAF samples were collected from multiple depths within the borehole spanning the corresponding porewater screen interval, the LEAF results were paired with the same porewater data. Parameters with no corresponding results in the porewater data set (U), three or fewer samples (Hg), and indicator parameters (ORP, specific conductance, and total dissolved solids [TDS]) were not included in the analysis. The combined leach test data set contained 25 parameters and final eluate pH values reported at 18 PMPs. LEAF 1313 testing was performed at pH values of about 4, 6, 8, and 10 and at natural pH. LEAF 1316 testing was performed at L/S ratios of 0.5, 1, 2, 4, 5, 6, 8, and 10.

[4] LEAF test data that did not have porewater data available from the same PMP and at the screened depth interval are not included in the analysis.

Table 2-3
Summary of leach test and porewater pairings for each PMP and depth interval

Site Name	Station ID	LEAF 1313 Sample Depths (ft)	LEAF 1316 Sample Depths (ft)	Porewater Screen Intervals (ft)
Allen[1]	AB-21SL	34–44	34–44	35–45
Allen	AB-25S	7–20	7–20	5–20
Allen	AB-25SL	30–45	30–45	30–45
Allen	AB-29S	9–17	9–17	5–20
Allen	AB-29SL	37–47	37–47	36–46
Allen	AB-35S	42–51	42–51	35–50
BCSS	AB-04S	3–18	3–18	3–18
BCSS	AB-04SL	51–61	51–61	51–61
Cliffside	AB-03S	30–50	30–50	22–37
Cliffside	AB-03SL	54–59	54–59	Unknown[2]
Cliffside	AB-04S	10–21	10–21	5–20
Cliffside	AB-04SL	35–39	35–39	29–39
Cliffside	AS-07S	30–40	30–40	28.5–43.5
Cliffside	U5-02S	47–57	47–57	50–65
Cliffside	U5-02S	57–66.5	57–66.5	50–65
Marshall	AB-12SL	43–45	43–45	43–53
Marshall	AB-15S	3–15	3–15	8–23
Marshall	AB-15S	18–20	18–20	8–23
Marshall	AB-15SL	47–49	47–49	43–53
Marshall	AB-18S	8–13	8–13	6–16

Notes:

[1] Each row represents one set of paired porewater and leach test data.

[2] Assumed to be a relevant comparison in the absence of depth interval information.

Porewater Results

An overview of the refined porewater data set is presented in Table 2-4. Sample sizes for each parameter varied from 70 samples (dissolved measurements for major ions), to between 100 and 1,000 samples (Ra isotopes, F, and Li), to over 1,000 samples (the rest of the parameters). Most of the major ions were detected in more than 90% of samples, except for NO_2+NO_3, (detected in 49% of samples) and ALK-CO_3 (detected in 12% of samples). Many minor and trace elements (total Al, total and dissolved As, Ba, B, Co, Fe, Li, Mn, Mo, Ni, Sr, and V) were detected in more than 75% of samples. Other minor trace elements were detected in between 25% and 75% of samples, including dissolved Al; total Cd and Pb; and both total and dissolved Sb, Be, Cr, Cr(VI), Cu, Se, Tl, and Zn. Total organic carbon (TOC) and total suspended solids (TSS) were also detected in between 25% and 75% of samples. Dissolved Cd, dissolved Pb, and both total and dissolved Hg were detected in 25% or fewer samples. Sulfide (S^{2-}) was also detected in very few samples (8%).

Table 2-5 shows the results of comparing porewater concentrations to a threshold value based on a regulatory standard, specifically the maximum contaminant level (MCL; 40 C.F.R.§141), secondary maximum contaminant level (SMCL; USEPA, 2022a), or regional screening level (RSL; USEPA, 2022b), where a standard was available. Although **these standards are not directly applicable to porewater data,** they provide useful thresholds for evaluating porewater concentrations. For example, if porewater concentrations are consistently below the threshold value for a parameter, the CCP unit would be an unlikely source of downgradient groundwater protection standard (GWPS) exceedances for that parameter. The statistics presented in this table are comparable to a similar tabulation by EPRI (2021a) for a larger, more widely distributed, porewater data set. However, there are differences in the tabulations. The current data set was compiled to determine the percentage of all samples with a concentration higher than a benchmark. The EPRI (2021a) data set is based on the average concentration of all porewater samples collected at a unit (range from as few as 1 to more than 100 samples per unit).

Both data sets show that As and Li have concentrations higher than a GWPS-based threshold in more than 50% of the sample and site average tabulations. In addition, Mn is greater than its SMCL-based threshold in more than 50% of the two tabulations.[5] Conversely, many of the tested constituents (Al, Sb, Ba, Be, Cr, Cu, F, Pb, Hg, Ra, Sr, Tl, and Zn) were unlikely (<15%) to have a concentration higher than their respective thresholds in both tabulations.

[5] The SMCL is based on aesthetic considerations to drinking water quality rather than on health-based considerations.

Table 2-4
Summary of porewater data

Parameter	Unit	Total			Dissolved		
		Sample Count	Detection Frequency (%)	Median	Sample Count	Detection Frequency (%)	Median
Field Parameters							
Eh	mV	1390	100	132	--	--	--
pH	SU	1390	100	7.01	--	--	--
EC	µmhos/cm	1390	100	640	--	--	--
TEMP	Deg C	1390	100	19.695	--	--	--
TURB	NTUs	1388	100	4.8	--	--	--
Major Ions							
ALK	mg/L	1375	94	139	--	--	--
ALK-HCO_3	mg/L	1361	91	137	--	--	--
Ca	mg/L	1383	100	76.5	84	99	75.9
ALK-CO_3	mg/L	1355	12	5	--	--	--
Cl	mg/L	1377	100	10.1	--	--	--
F	mg/L	440	94	0.33	--	--	--
Mg	mg/L	1382	100	15.55	70	99	19.45
NO_2 + NO_3	mg-N/L	1333	49	0.02	--	--	--
K	mg/L	1381	96	10.6	70	91	9.845
Na	mg/L	1383	99	12.5	70	99	10.65
SO_4	mg/L	1376	98	103	--	--	--
Minor and Trace Elements							
Al	mg/L	1357	79	0.128	1199	57	0.1
Sb	mg/L	1343	60	0.00099	1190	54	0.0007385
As	mg/L	1382	99	0.2215	1216	99	0.1965
Ba	mg/L	1288	98	0.172	1173	99	0.158
Be	mg/L	1297	43	0.0001	1178	37	0.0001
B	mg/L	1383	98	1.25	1216	98	1.245
Cd	mg/L	1247	27	0.00008	1159	24	0.00008

Table 2-4 (continued)
Summary of porewater data

Parameter	Unit	Total			Dissolved		
		Sample Count	Detection Frequency (%)	Median	Sample Count	Detection Frequency (%)	Median
Minor and Trace Elements (continued)							
Cr	mg/L	1381	66	0.00076	1211	58	0.0005
Cr(VI)	mg/L	1188	31	0.00003	--	--	--
Co	mg/L	1382	83	0.001095	1213	80	0.001
Cu	mg/L	1117	59	0.00069	1116	50	0.000605
Fe	mg/L	1383	95	2.57	1209	83	2.22
Pb	mg/L	1130	36	0.000105	1115	15	0.0001
Li	mg/L	515	95	0.118	142	96	0.182
Mn	mg/L	1383	95	0.7	1216	93	0.659
Hg	mg/L	1145	6	0.0002	1130	2	0.0002
Mo	mg/L	1287	93	0.0253	1176	93	0.02585
Ni	mg/L	1317	86	0.0023	1185	86	0.00205
Se	mg/L	1353	47	0.00089	1199	46	0.000756
Sr	mg/L	1383	100	1.78	1216	100	1.675
Tl	mg/L	1368	63	0.00018	1208	59	0.00012
V	mg/L	1381	95	0.00312	1214	90	0.0025
Zn	mg/L	1135	51	0.01	1120	41	0.01
Other							
S^{2-}	mg/L	1105	8	0.1	--	--	--
TDS	mg/L	--	--	--	1375	99	411
TOC	mg/L	1281	72	1	--	--	--
TSS	mg/L	1118	62	5.6	--	--	--
Radiologic							
^{226}Ra	pCi/L	393	92	0.333	--	--	--
^{228}Ra	pCi/L	393	88	0.564	--	--	--
Ra	pCi/L	114	100	0.8225	--	--	--

Table 2-5
Comparison of porewater data to reference regulatory standards

Parameter	Unit	Threshold Value	Threshold Basis	Samples Above Threshold (%)	Site Averages Above Threshold (%)[1]
Al	mg/L	20	RSL	3.6	4
Sb	mg/L	0.006	MCL	12	17
As	mg/L	0.01	MCL	84	71
Ba	mg/L	2	MCL	0.16	0
Be	mg/L	0.004	MCL	5.2	6
B	mg/L	4	RSL	24	68
Cd	mg/L	0.005	MCL	1.6	24
Cl	mg/L	250	SMCL	4.1	23
Cr	mg/L	0.1	MCL	0.94	10
Co	mg/L	0.006	RSL	24	27
Cu	mg/L	1.3	MCL	0	0
F	mg/L	4	MCL	5	---
Fe	mg/L	14	RSL	26	4
Pb	mg/L	0.015	MCL	0.62	4
Li	mg/L	0.04	RSL	76	74
Mn	mg/L	0.05	SMCL	83	72
Hg	mg/L	0.002	MCL	0.17	4
Mo	mg/L	0.1	RSL	33	78
Se	mg/L	0.05	MCL	3.1	47
Sr	mg/L	12	RSL	1.8	2
SO_4	mg/L	250	SMCL	24	91
Tl	mg/L	0.002	MCL	8.6	15
Ra	pCi/L	5	MCL	0	---
V	mg/L	0.086	RSL	6.8	31
Zn	mg/L	6	RSL	0.26	0

Note:
[1] The site averages are from EPRI (2021a); --- indicates parameters not listed in EPRI (2021a).

Leach Test Results

An overview of the LEAF test eluates is presented in Tables 2-6 (LEAF 1313) and 2-7 (LEAF 1316). Each individual sample represents the result for one test condition (that is, a specific pH for LEAF 1313 or a specific liquid-to-solid ratio for LEAF 1316) applied to one CCP solid sample. For summary purposes, the LEAF 1313 natural pH values (no acid/base added; sometimes referred to as the *natural pH*) and LEAF 1316 results at liquid-to-solid ratio (L/S) = 1.0 are compiled for table statistics. The proportion of detected results for all parameters in both LEAF tests is higher than those reported in the porewater measurements due to lower detection

limits used for most analytes in the LEAF tests. However, Cd was usually not detected and Hg was not detected in the LEAF 1313 samples, and Be was usually not detected and Pb and Hg were not detected in the LEAF 1316 samples.

Table 2-6
Summary of LEAF 1313 data

Param	Units	All LEAF 1313 Samples		LEAF 1313 @ Natural pH					
		Sample Count	PMP Count	Sample Count	PMP Count	Detection Frequency	Min	Median	Max
Sb	mg/L	93	18	20	18	95%	0.0011	0.0099	0.02
As	mg/L	93	18	20	18	100%	0.0025	0.12	0.25
Ba	mg/L	93	18	20	18	100%	0.025	0.098	0.35
Be	mg/L	93	18	20	18	10%	0.000057	0.000057	0.00016
B	mg/L	93	18	20	18	100%	0.043	0.093	1.2
Cd	mg/L	93	18	20	18	5%	0.00013	0.00013	0.00016
Ca	mg/L	93	18	20	18	100%	1.9	10	32
Cl	mg/L	93	18	20	18	40%	0.71	0.71	48
Cr	mg/L	93	18	20	18	100%	0.001	0.0035	0.022
Cr(VI)	mg/L	83	16	18	16	28%	0.0032	0.0032	0.022
Co	mg/L	93	18	20	18	55%	0.000075	0.00013	0.002
F	mg/L	93	18	20	18	100%	0.1	0.29	0.73
Fe	mg/L	93	18	20	18	80%	0.014	0.048	0.21
Pb	mg/L	93	18	20	18	40%	0.000094	0.000094	0.0032
Li	mg/L	93	18	20	18	95%	0.0026	0.012	0.03
Mn	mg/L	93	18	20	18	75%	0.0014	0.0037	0.28
Hg	mg/L	93	18	20	18	0%	0.000065	0.000065	0.000065
Mo	mg/L	93	18	20	18	100%	0.0031	0.024	0.18
Ni	mg/L	49	10	11	10	82%	0.00031	0.00067	0.011
^{226}Ra	pCi/L	34	7	7	7	100%	0	0.13	0.255
^{228}Ra	pCi/L	34	7	7	7	100%	0.109	0.16	0.344
Se	mg/L	93	18	20	18	100%	0.011	0.040	0.23
Sr	mg/L	93	18	20	18	100%	0.04	0.21	0.53
SO_4	mg/L	93	18	20	18	100%	2.3	12	49
Tl	mg/L	93	18	20	18	75%	0.000063	0.00012	0.00062
V	mg/L	83	16	18	16	100%	0.0023	0.092	0.3

Table 2-7
Summary of LEAF 1316 data

Param	Units	All LEAF 1316 Samples		LEAF 1316 @ L/S = 1					
		Sample Count	PMP Count	Sample Count	PMP Count	Detection Frequency	Min	Median	Max
Sb	mg/L	100	18	20	18	100%	0.004	0.043	0.14
As	mg/L	100	18	20	18	100%	0.004	0.11	0.67
Ba	mg/L	100	18	20	18	100%	0.034	0.11	0.21
Be	mg/L	100	18	20	18	5%	0.000057	0.000057	0.000074
B	mg/L	100	18	20	18	100%	0.15	0.53	11
Cd	mg/L	100	18	20	18	30%	0.00013	0.00013	0.0007
Ca	mg/L	100	18	20	18	100%	7.8	48	210
Cl	mg/L	100	18	20	18	100%	1.3	3.9	520
Cr	mg/L	100	18	20	18	100%	0.00081	0.0038	0.11
Cr(VI)	mg/L	90	16	18	16	50%	0.0032	0.0044	0.12
Co	mg/L	100	18	20	18	90%	0.000075	0.00024	0.0099
F	mg/L	100	18	20	18	100%	0.12	0.61	3.6
Fe	mg/L	100	18	20	18	15%	0.014	0.014	0.08
Pb	mg/L	100	18	20	18	0%	0.000094	0.000094	0.000094
Li	mg/L	100	18	20	18	100%	0.0064	0.044	0.21
Mn	mg/L	100	18	20	18	90%	0.0014	0.020	1.4
Hg	mg/L	100	18	20	18	0%	0.000065	0.000065	0.000065
Mo	mg/L	100	18	20	18	100%	0.0065	0.14	1.5
Ni	mg/L	55	10	11	10	100%	0.00054	0.0023	0.072
^{226}Ra	pCi/L	30	5	6	5	100%	0.0611	0.19	0.533
^{228}Ra	pCi/L	30	5	6	5	100%	0	0.25	0.462
Se	mg/L	100	18	20	18	100%	0.025	0.12	0.85
Sr	mg/L	100	18	20	18	100%	0.21	1.0	2.6
SO_4	mg/L	100	18	20	18	100%	13	100	420
Tl	mg/L	100	18	20	18	100%	0.00013	0.00066	0.0029
V	mg/L	90	16	18	16	100%	0.0038	0.099	0.71

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3
POREWATER ANALYSIS

Summary

This section presents an evaluation of the porewater data set that included a comparison of total and dissolved concentrations as well as an evaluation of the variability observed in porewater concentrations.

Total versus dissolved sample results:

- Total and dissolved measurements are generally more comparable at concentrations elevated well above the reporting limit where laboratory analytical variability is less significant relative to concentration.
- Major ions (Ca, Mg, Na, K), certain minor ions (Ba, B, Mn, Mo, Sr, Li), and elements with low detection frequency (Cd, Hg) were least likely to be affected by sample filtration.
- Elements most likely to be affected by sample filtration were Al, Cr, Cu, Fe, and V.

Intra-unit and inter-unit variability results:

- There does not appear to be an overall pattern to define which parameters exhibit high or low variability. However, parameters of interest—either because they are CCP tracers (B and SO_4) or potential remediation drivers (As, Sb, B, Cr, Co, Li, Mo, and Se)—mostly have medium to high intra-unit variability, which suggests that more extensive porewater evaluation may be helpful to characterize a unit when developing a source term to model these parameters. Li was the only remediation driver with low intra-unit variability.
- As, B, Co, Li, Mo, Se, and SO_4 had high inter-unit variability. Sb and Cr had medium and low inter-unit variability, respectively, which, as previously noted, can be attributed to their relatively low concentration (medians lower than 0.001 mg/L; see Appendix A) in the porewater samples reviewed in this analysis.

Analysis of Total Versus Dissolved Concentrations

Background

Porewater samples from CCP may be unfiltered or filtered[6] in the field, resulting in determinations of total or dissolved concentrations, respectively. The presence of suspended solids in porewater samples has the potential to affect total porewater measurements and can cause analytical results to not be representative of actual porewater concentrations. Geochemical modeling studies generally assume that the samples are field-filtered, while samples collected for

[6] Dissolved data represent field filtration using a 0.45-µm filter.

other purposes may not be filtered. Therefore, it is useful to understand the similarity and dissimilarity between total and dissolved measurements in CCP porewater samples.

A dissolved concentration lower than the total concentration suggests desorption of chemical constituents from small particles (>0.45 µm) in the sample when a total sample is acidified. There is no environmental explanation for a dissolved concentration higher than a total concentration. However, additional variability could be a result of heterogeneity in the samples themselves. Although paired total and dissolved samples are collected from the same location in the same sample event, they are often collected sequentially and therefore may represent slightly different fractions of porewater.

Methods

The porewater data set described in Section 2 was refined to include only samples that had both total and dissolved fractions analyzed (that is, samples with paired total and dissolved data). For samples in which either result was a non-detect, the MDL was used to calculate the ratio. The total versus dissolved concentration comparison plots are provided in Appendix B.

Data were evaluated by determining if total and dissolved concentrations were effectively similar for each sample. Total and dissolved concentrations for a sample were considered similar when the difference was within a predefined range of error. A difference of up to 20% was set as the predefined error—a percentage that is typically acceptable to meet quality control standards in a laboratory for a set of duplicate samples (USEPA, 2020). Therefore, a difference of 20% between the total and dissolved measurements was considered similar because it is within the range of accepted typical analytical variability. The overall degree of similarity for a parameter was then quantified by the percent of samples in the entire data set that had a difference of less than 20% between the total and dissolved concentrations.

Results and Discussion

The results of the total versus dissolved concentration comparison are presented in Table 3-1. For each parameter, the percentage of samples for which dissolved results were similar to totals is presented as well as the percent of samples above and below the defined range. The degree to which dissolved and total concentrations were similar ranged from 42% to 97% (Table 3-1). When there was a difference, the dissolved sample usually (63% of sample pairs with a difference) had the lower concentration, but this was not always the case.

Table 3-1
Summary of total versus dissolved concentration comparison

Parameter	Number of Samples Compared	Number Where Total and Dissolved Both Non-Detect	Dissolved Lower Than Total	Dissolved Higher Than Total	Similar Total and Dissolved Concentrations[1]
Al	1199	236	39%	10%	50%
Sb	1185	440	11%	11%	78%
As	1215	6	14%	6%	80%
Ba	1157	8	6%	2%	93%
Be	1164	560	20%	18%	62%
B	1216	19	3%	2%	95%
Cd	1140	794	7%	7%	86%
Ca	84	0	6%	0%	94%
Cr	1209	311	36%	22%	42%
Co	1212	163	21%	9%	71%
Cu	1076	330	28%	28%	44%
Fe	1209	64	35%	6%	59%
Pb	1078	653	19%	9%	72%
Li	136	5	2%	6%	92%
Mg	70	0	4%	0%	96%
Mn	1216	57	6%	3%	90%
Hg	1108	1037	2%	4%	95%
Mo	1162	67	6%	6%	88%
Ni	1176	122	17%	13%	70%
K	70	2	0%	4%	96%
Se	1194	569	14%	11%	75%
Na	70	0	1%	1%	97%
Sr	1216	1	2%	1%	97%
Tl	1204	403	17%	11%	72%
V	1213	41	40%	9%	52%
Zn	1081	448	18%	20%	62%

Note:

[1] Percentages may not add up to 100% due to rounding.

The similarity between total and dissolved results is visualized by plotting the dissolved concentration (y axis) against the total concentration (x axis) (Figure 3-1; Appendix B). Each sample pair is represented by one data point. If total and dissolved concentrations are identical in a sample, that point will fall on the 1:1 line. The 20% range of variability is illustrated by the dashed lines surrounding the 1:1 line. Any points that fall outside of the area between those lines are considered to have different total and dissolved concentrations. Points below the defined range of comparability have lower dissolved than total concentrations, while points above the defined range have higher dissolved than total concentrations (which, as discussed previously, is likely an artifact of sample and/or laboratory variability). The color of each point reflects the turbidity measured for that sample.

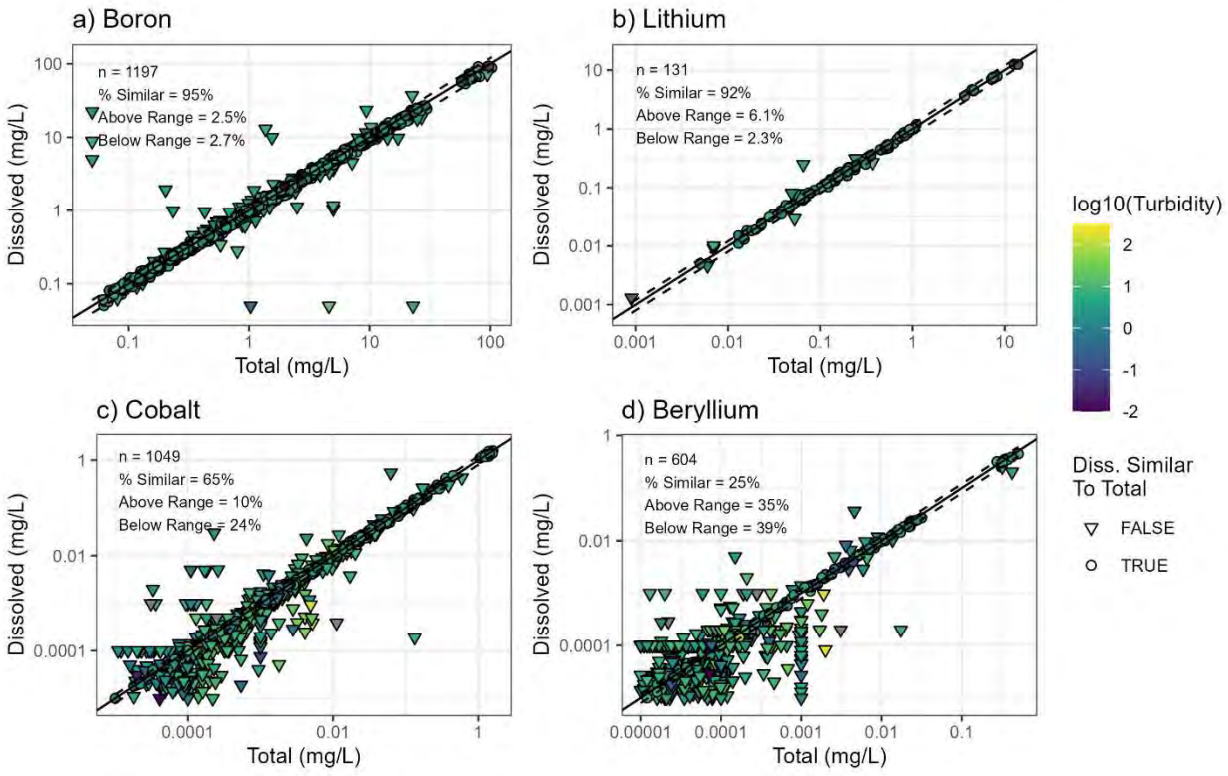

Figure 3-1
Comparison of total versus dissolved measurements for selected parameters when detected in one or both of the paired samples

The statistics on the graphs are for sample pairs where a concentration is detected in one or both samples and differs from Table 3-1 because samples where both results are non-detect were not considered.

Parameters such as Co, which sorb strongly to particulates and therefore have total concentrations more heavily influenced by the presence of turbidity, tend to have a greater proportion of samples below the defined range used for comparison. In contrast, Be does not sorb as strongly to particulates and instead has relatively equivalent proportions of points above and below the defined range. For both Co and Be, fewer samples fall outside the defined range of similarity at higher total concentrations. This suggests that total and dissolved measurements are generally more comparable at concentrations elevated well above the reporting limit (that is, where laboratory analytical variability is less significant relative to concentration).

For both Co and Be, the samples with the highest turbidity typically fall below the defined range. This observation is consistent with turbidity potentially contributing to higher total than dissolved concentrations due to the presence of sorbed ions, although this relationship is qualitative, and turbidity is not the only factor causing differences between dissolved and total concentrations (because not all samples with lower dissolved concentrations compared to totals have elevated turbidity).

Table 3-2 groups the results presented in Table 3-1. This grouping shows that major ions (Ca, Mg, Na, K), certain minor ions (Ba, B, Mn, Mo, Sr, Li), and elements with low detection frequency (Cd, Hg) were least likely to be affected by sample filtration. It is worth noting that Cd and Hg have much lower percentages for similarity (54% and 17%, respectively) when detected in one or both of the total and dissolved samples (see Appendix B). Elements most likely to be affected by sample filtration were Cr, Cu, Al, Fe, and V.

Table 3-2
Grouping of total vs. dissolved sample results

Concentration Tendency for Pairs That Were Not Similar	Percent of Paired Total and Dissolved Samples with Similar Concentration					
	40% to 50%	50% to 60%	60% to 70%	70% to 80%	80% to 90%	>90%
Dissolved more often had lower concentration	Cr	Al, Fe, V	Be, Ni	As, Co, Pb, Se, Tl		Ca, Mg, Ba, B, Mn, Sr
Similar frequency for lower and higher concentration	Cu			Sb	Cd, Mo	Na
Dissolved more often had higher concentration			Zn			K, Li, Hg

Analysis of Variability in Porewater

Background

Porewater composition variability between different CCP units (inter-unit variability) and within the same CCP unit (intra-unit variability) was evaluated in this task. Variability between different units may be due to different operational histories and different CCP source materials. Variability within a single unit may reflect different CCP composition if more than one CCP is managed in the unit (particularly for landfills), differences associated with chemical evolution over time for older vs. newer portions of the unit (particularly for landfills), and, in the case of

sluiced CCPs, the differences in chemistry associated with particle size, because coarse CCP particles will settle near the discharge pipe into the pond, and fine CCP particles will settle near the outfall structure where water exits the pond. This section uses porewater data from 29 CCP units of different sizes and ages (Section 2) to characterize inter-unit and intra-unit variability for a wide range of porewater parameters. The aim of this analysis is not to identify individual causes of variability within and between each of these CCP units; instead, the goal is to describe the variability of different parameters to help inform the characterization of porewater variability within other CCP units.

Methods

Figure 3-2 illustrates how inter-unit and intra-unit variability were evaluated for each parameter. Inter-unit differences were quantified by comparing the highest and lowest medians calculated at the units. Intra-unit differences were quantified using the 25th and 75th percentiles of the data. The 25th and 75th percentiles of the data are visually represented by the lower and upper bounds of the box in a boxplot, and the interquartile range (the difference between the 25th and 75th percentiles) is often used to characterize variability of data.

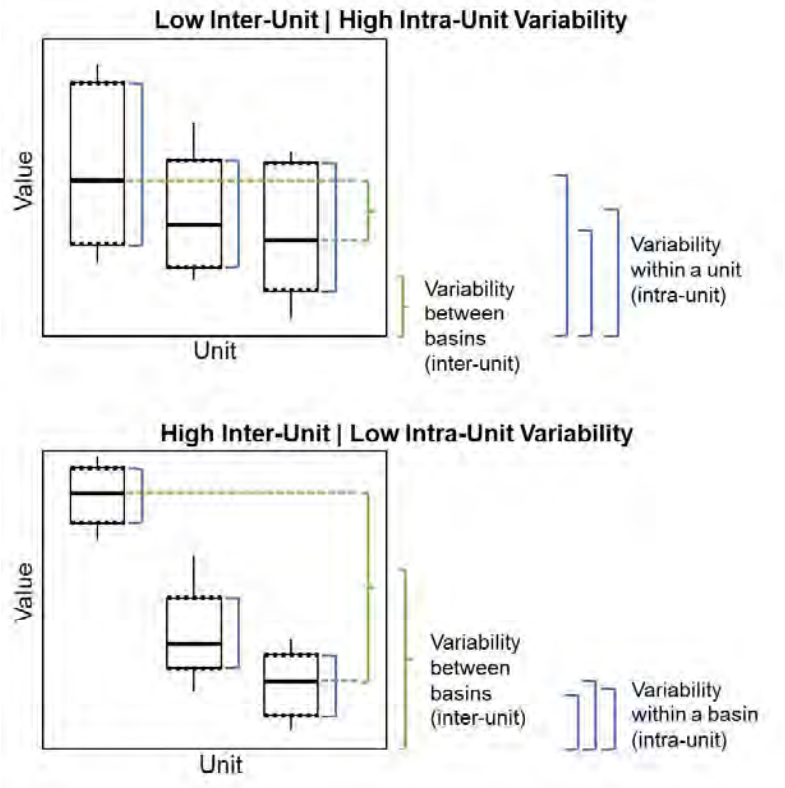

Figure 3-2
Conceptual drawing illustrating how inter- and intra-unit variability were assessed

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A median range ratio (MRR) was calculated by taking the ratio between highest and lowest medians to allow for comparison of inter-unit variability across different parameters. For example, an MRR of 10 indicates an order of magnitude difference between the highest and lowest medians regardless of the actual concentrations of a given parameter. One MRR was calculated for each parameter based on the medians for all the units. An MRR could not be meaningfully calculated for Eh because the lowest median was a negative value, resulting in a negative ratio.

Intra-unit variability was quantified by taking the ratio between the 25th and 75th percentile of the data (interquartile ratio [IQR]). By calculating the IQR instead of the interquartile range, differences due to absolute concentration measurements are removed. Because IQRs were calculated by unit, as many as 29 IQRs are calculated for each parameter. The median IQR for each parameter is used in this comparison to represent the overall intra-unit variability.

For parameters with both total and dissolved concentrations available, this analysis uses only total concentrations. Data for most parameters were available for all 29 units, although some parameters were not available for all units (Table 3-3).

Results and Discussion

A summary of inter- and intra-unit variability is presented in Table 3-3. The MRR ranges from 1.6 to 80,000, with half the parameters having an MRR between 14.75 and 150. The IQR ranges from 1.0 to 5.0, with half the parameters falling between 1.4 and 2.6. High, moderate, and low variability were categorized based on approximately the top, middle, and bottom third of results, as shown in Table 3-4.

Table 3-3
Results of inter- and intra-unit variability analysis

Category	Parameter	Number of Units	Sample Count	MRR[1]	Median IQR
Field parameters	Eh	29	1390	NA	2.8
	pH	29	1390	2.0	1.1
	EC	29	1390	15	1.4
	TEMP	29	1390	1.6	1.3
	TURB	29	1388	5.9	2.4
Major ions	F	23	440	82	1.5
	NO_2 + NO_3	29	1333	16	2.0
	ALK	29	1375	130	1.9
	ALK-HCO_3	29	1361	130	1.6
	Ca	29	1383	22	1.5
	ALK-CO_3	29	1355	3.1	1.0
	Cl	29	1377	15	1.5
	Mg	29	1382	210	1.8
	K	29	1381	46	1.2
	Na	29	1383	68	1.4
	SO_4	29	1376	29000	1.9

Table 3-3 (continued)
Results of inter- and intra-unit variability analysis

Category	Parameter	Number of Units	Sample Count	MRR[1]	Median IQR
Minor ions and trace elements	Al	29	1357	400	4.1
	Sb	29	1343	74	2.3
	As	29	1382	1500	2.5
	Ba	29	1288	65	2.3
	Be	29	1297	14	1.8
	B	29	1383	580	1.7
	Cd	29	1247	51	1.1
	Cr	29	1381	7.6	2.6
	Cr(VI)	26	1188	14	4.6
	Co	29	1382	1200	4.5
	Cu	29	1117	12	2.6
	Fe	29	1383	1000	5.0
	Pb	29	1130	44	1.2
	Li	23	515	1800	1.4
	Mn	29	1383	2200	3.6
	Hg	29	1145	4.0	1.0
	Mo	29	1287	80000	2.2
	Ni	29	1317	65	3.1
	Se	29	1353	130	1.9
	Sr	29	1383	17	1.7
	Tl	29	1368	46	2.3
	V	29	1381	360	4.7
	Zn	29	1135	18	1.8
Other	S^{2-}	29	1105	22	1.0
	TOC	29	1281	74	1.3
	TSS	29	1118	54	2.1
Radiologic	^{226}Ra	23	393	26	3.0
	^{228}Ra	23	393	9.8	2.9
	Ra	8	114	3.3	2.4

Note:

[1] The MRR describes the inter-unit variability, and the median IQR describes the intra-unit variability. A higher value indicates greater variability. Dark green indicates low variability, light green indicates moderate variability, and yellow indicates high variability according to the ranges described in Table 3-4.

Table 3-4
Values for variability group cutoff

Value Type	Range[1]	Quantitative Assessment	Parameter Count
Median IQR	[1 to 1.5]	Low intra-unit variability	15
	(1.5 to 2.3]	Medium intra-unit variability	15
	(2.3 to 5]	High intra-unit variability	15
MRR	(1 to 20]	Low inter-unit variability	16
	(20 to 100]	Medium inter-unit variability	14
	(100 to 80,000]	High inter-unit variability	14

Note:

[1] Square brackets are inclusive of the number shown; round brackets are exclusive

Figure 3-3 illustrates examples of low and high values of inter- and intra-unit variability using boxplots for the results from each unit, ordered based on each unit's median value. The units are identified in the x axis by numerical code (the numbers are non-sequential and were derived from the database provided to EPRI). Results for selected parameters are presented and discussed in the text. Similar figures for all parameters that were evaluated are provided in Appendix C.

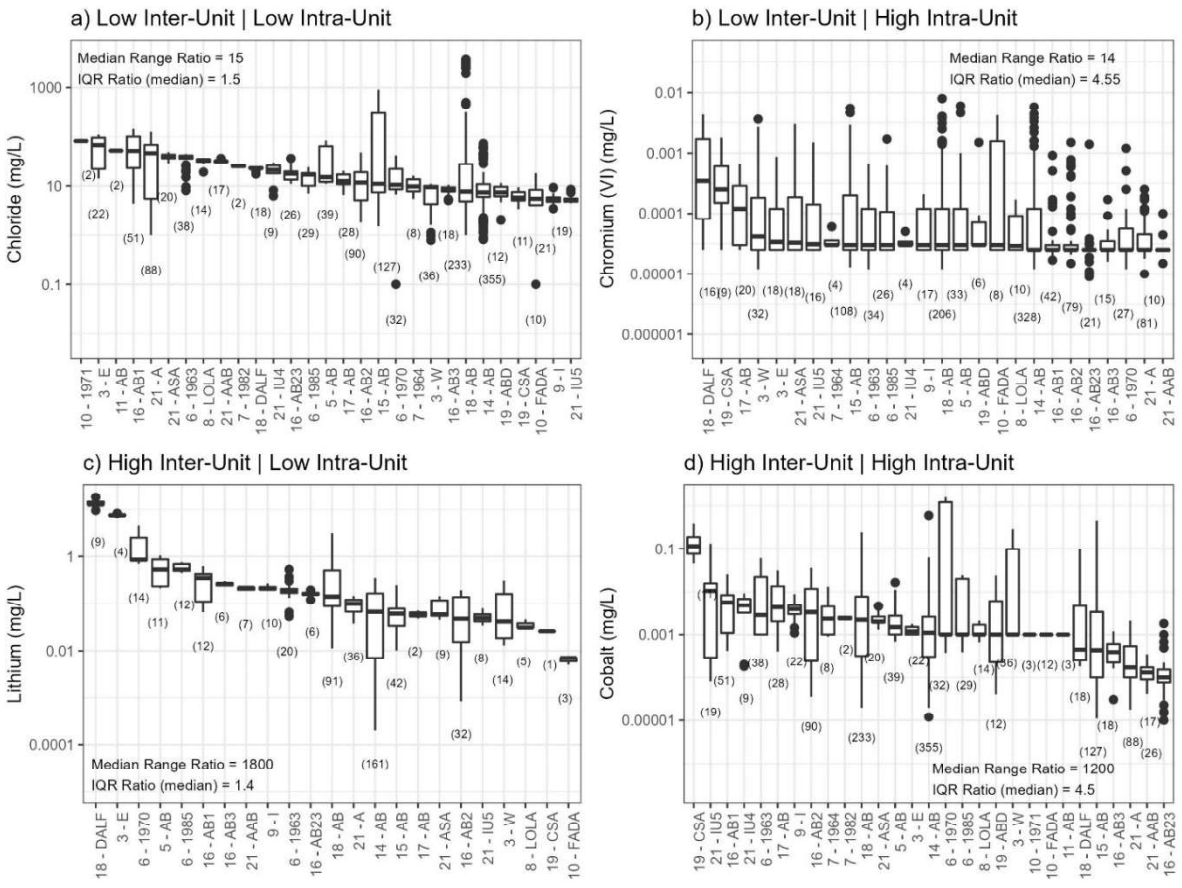

Figure 3-3
Boxplots illustrating both high and low inter- and intra-unit variability for selected parameters

Cl is presented as an example of low inter-unit and low intra-unit variability. An MRR of 15 indicates less than two orders of magnitude variability across all the units. A median interquartile ratio of 1.5 shows that Cl concentrations are relatively consistent within each unit, with units having less than twofold difference in concentration. Few parameters have low inter-unit and intra-unit variability; others with low variability include several field parameters (pH, specific conductance, and temperature) in addition to ALK-CO_3 and Hg, both of which were detected infrequently (Table 3-5).

Cr (Figure 3-3) and Cr(IV) have low inter-unit variability but high intra-unit variability, which may be attributed to the very low concentrations of these parameters. Other parameters with this pattern of variability include Cu, ^{228}Ra, and total Ra (Table 3-5). The maximum and minimum medians are similar because most individual sample results are non-detects, while the occasional detection creates high variability within each unit.

Li is presented as an example of high inter-unit and low intra-unit variability (Figure 3-3). The highest and lowest medians span three orders of magnitude (MRR of 1,800), while concentrations within a unit generally have less than a twofold difference in concentration. This indicates that within a unit there is generally little variability in Li concentration, so a small number of porewater samples may sufficiently characterize Li concentrations. Although no other parameters were observed to have high inter-unit and low intra-unit variability (suggesting that it may be an artifact of a small Li sample size), B and SO_4 (common CCP indicators) along with Mo, alkalinity, and Se had high inter-unit variability and medium intra-unit variability (Table 3-5).

Co is presented in Figure 3-3 as an example of high inter-unit and high intra-unit variability. The medians span three orders of magnitude (MRR of 1,200), and there is over fourfold variation within most units. This suggests that concentrations of Co in porewater may be difficult to predict for a CCP unit and that they may change over time or vary spatially throughout the unit. Other parameters with this distribution include As, Fe, V, Al, and Mn (Table 3-5).

Table 3-5
Inter-unit and intra-unit variability parameter groups

Intra-Unit Variability	Inter-Unit Variability		
	Low (MRR <=20)	**Medium (MRR >20 and <=100)**	**High (MRR >100)**
Low (IQR <=1.5)	pH, EC, TEMP, ALK-CO_3, Cl, Hg	F, Ca, K, Na, Cd, Pb, S^{2-}, TOC	Li
Medium (IQR >1.5 and <=2.3)	NO_2+NO_3, Be, Sr, Zn	Sb, Ba, Tl, TSS	ALK, ALK-HCO_3, Mg, SO_4, B, Mo, Se
High (IQR >2.3)	TURB, Cr, Cr(VI), Cu, ^{228}Ra, Total Ra	Ni, ^{226}Ra	Al, As, Co, Fe, Mn, V

Note: Eh is not shown because MRR was not calculated for this parameter.

There does not appear to be an overall pattern to define which parameters exhibit high or low variability, likely because the porewater concentrations are determined by a combination of the composition of the stored CCP, the operating history of the unit (for example, degree of sluicing), and the *in situ* geochemical conditions as well as the geochemical characteristics of each parameter. Of particular interest are the results for the common CCP tracers (B and SO_4), as well as potential remediation drivers (As, Sb, B, Cr, Co, Li, Mo, and Se; as defined by EPRI, 2021b).

Most of the tracers and remediation drivers have medium to high intra-unit variability, suggesting that more extensive porewater evaluation may be helpful to characterize a unit when developing a source term to model these parameters. Li was the only remediation driver with low intra-unit variability. Except for Sb and Cr, the tracers and potential remediation drivers had high inter-unit variability. Sb and Cr had medium and low inter-unit variability, respectively, which, as previously noted, can be attributed to their relatively low concentration (medians lower than 0.001 mg/L; see Appendix A) in the porewater samples reviewed in this analysis.

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4
COMPARISON OF LEAF LEACH TEST ELUATE CONCENTRATIONS TO POREWATER CONCENTRATIONS

Summary

LEAF 1313 (pH-dependent) and 1316 (L/S-dependent) eluate concentrations were compared to median porewater concentrations taken from PMPs screened at the same location and depth as samples used in the LEAF testing for 18 PMPs spread across four CCP management units. This analysis indicated:

- LEAF 1313 and 1316 eluate concentrations were usually more than 25% higher or 25% lower than their paired median porewater concentrations. This observation was made for 1313 eluates at natural pH and the broader pH range for all porewaters and for 1316 results at low and high L/S.
- Elements often controlled by available content—such as B, Ca, Cl, Li, Sr, and SO_4—tended to be underpredicted by the leach tests.
- As, Fe, and Mn were also underpredicted, even though they tend to be solubility controlled, because the LEAF testing was performed under oxic conditions when the solubility of these elements is low.
- Conversely, Se and Cr, which are most soluble under oxic conditions, tended to be overpredicted by the LEAF testing performed under oxic conditions.
- Sb, Tl, and V tended to be overpredicted by the leach tests while other elements were overpredicted or underpredicted depending on test-specific and site-specific factors.
- No bias was detected for Hg because most porewater and all the LEAF test results were non-detect.
- Overall, these observations confirm the observations from EPRI 2020 and 2021c that LEAF tests do not reliably predict porewater concentrations observed in the field.

Background

Laboratory leaching tests can be used to estimate how environmental conditions, the length of exposure to leaching conditions, and material composition affect the release of inorganic constituents from CCP. However, the ability of leaching tests to predict concentrations of inorganic constituents in field porewater depends on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field (EPRI, 2020 and 2021c).

Traditional leach tests expose a solid material to a single eluent, which is intended to be representative of *in situ* porewater concentrations. These traditional leach tests include USEPA Method 1311 (Toxicity Characteristic Leaching Procedures; TCLP), USEPA Method 1312 (Synthetic Precipitation Leaching Procedure; SPLP), and ASTM D3987 (Shake Extraction of Solid Waste with Water; ASTM). A more robust approach to leaching tests is the Leaching Environmental Assessment Framework (LEAF) (USEPA, 2019), which uses a gradient of eluent compositions designed to evaluate leaching behavior across a range of environmental conditions. Different LEAF methods alter different controlling variables (for example, pH, liquid-to-solid ratio [L/S]) in their experimental design.

In 2020 and 2021, EPRI published research that compared the results of traditional leaching tests (TCLP, SPLP, and ASTM) to two of the four LEAF leaching methods: USEPA Method 1313 (Liquid-Solid Partitioning as a Function of Eluate pH Using a Parallel Batch Procedure) and USEPA Method 1314 (Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-Flow Percolation Column Procedure) (EPRI, 2020 and 2021c). The 2020 and 2021 research compared porewater to leach test eluates from samples collected from the screened intervals of the PMPs. The results indicated that traditional leaching tests were not reliable predictors of measured porewater concentrations because of the relatively high L/S used in these tests and because they do not necessarily reproduce field pH and redox conditions within a CCP unit.

LEAF testing is designed to span the range of pH and L/S encountered in the field although it can be difficult to determine in advance which pH or L/S will best predict the field concentration—and that point varies by element. In general, EPRI (2020 and 2021c) found that low L/S eluates from USEPA Method 1314 were better indicators for constituents where liquid-solid partitioning (LSP) is limited by the content in the CCP solids (available content LSP). Examples of constituents controlled by available content LSP are B, Cl, Mo, and SO_4. Traditional leaching methods and USEPA Method 1313 use higher L/S ratios and tended to underpredict these constituents. Constituents with porewater concentrations controlled by their solubility (solubility-controlled LSP), such as As and Sb, were better predicted by USEPA Method 1313 although the pH at which the test best predicted field conditions did not always correspond to the field pH, in part because redox also affects leaching of these elements and because it is challenging to duplicate field redox conditions in the laboratory—especially for strongly reducing conditions. EPRI (2020 and 2021c) also found that site-specific conditions influence whether some constituent concentrations are available content–controlled, solubility-controlled, or controlled by wash-off (present in an easily dissolved form that is rapidly removed by initial contact with water).

This research expands on the previous findings by evaluating the effectiveness of two LEAF test methods (1313 and 1316) at predicting porewater concentration across multiple CCP storage units using paired LEAF and porewater data (as described in Section 2). Similar to EPRI (2020 and 2021c), the laboratory leaching tests were performed on solid samples extracted from the location and depth interval within the CCP deposit where the screened interval of the PMP was placed.

Methods

Eluate concentrations from the LEAF tests were normalized by dividing by the median porewater concentration for the paired samples. Due to the high variability in the resulting ratios, the $\log_{10}$ of each ratio was used for analysis and visualization. If a leach method predicted a porewater concentration to complete accuracy, the ratio between the eluate concentration and porewater concentration would be equal to one (for a $\log_{10}$ ratio of zero).

To quantitatively assess how well the LEAF methods predicted porewater concentrations at any pH or L/S, a predefined range of variability between leach test eluate and porewater concentrations was established. Concentrations in leach test eluates and porewater samples were considered "within range" if the $\log_{10}$ of the ratio was within half an order of magnitude of zero (that is, a $\log_{10}$ ratio between -0.5 and 0.5, or approximately a threefold difference in concentrations between the leach test and median porewater results). Note that this criterion was applied to all pH and L/S eluates from Methods 1313 and 1316, respectively, and therefore provides insight on whether the leach test was comparable to field porewater concentrations at any point in the tested pH or L/S range. This criterion provided a broad measure of leach test performance relative to porewater concentrations.

However, being "within range" is not necessarily a reasonable approximation of field conditions. For example, a plus or minus threefold difference (half an order of magnitude) for a porewater constituent with a concentration of 1,000 mg/L would mean that the leach test eluate was either within or outside a range between about 320 mg/L and 3,100 mg/L. Therefore, a follow-up tabulation was performed following the approach of EPRI (2020, 2021c) using the following criteria:

- For LEAF 1313, was the natural pH (no acid or base added) eluate within 25% of the median porewater concentration?
- For LEAF 1316, were eluates at low (<1.0) or high (>1.0) L/S within 25% of the median porewater concentration?

Results and Discussion

Evaluation of LEAF Test Bias

The comparison of LEAF test results to observed porewater concentrations for all pH and L/S is presented in Table 4-1. The proportion of samples with LEAF 1313 test results within half an order of magnitude around the median porewater concentration ranged from 0% (Cr(VI)) to 100% (Hg) although the "within range" result for Hg is a reflection on detection limits because most porewater and all leach test results were lower than detection limits. The proportion of samples with LEAF 1316 test results within half an order of magnitude around the median porewater concentration spanned a range, from 0% (Cr(VI)) to 100% (Be and Hg), although the Be and Hg results were mostly non-detect.

F was the only commonly detected element with more than two-thirds of LEAF results within range for both the 1313 and 1316 tests, while Sb, Cl, Cr(VI), Fe, Mn, Se, and V had fewer than one-third of the results within range for both tests.

Table 4-1
Summary of LEAF 1313 and LEAF 1316 comparison to porewater results

Param	LEAF 1313				LEAF 1316			
	Sample Count	Samples in Range (%)	Samples Above Range (%)	Samples Below Range (%)	Sample Count	Samples in Range (%)	Samples Above Range (%)	Samples Below Range (%)
Sb	88	33	66	1.1	95	8.4	92	0
As	88	34	4.5	61	95	32	4.2	64
Ba	88	44	38	18	95	73	3.2	24
Be	88	76	24	0	95	100	0	0
B	88	19	0	81	95	38	4.2	58
Cd	88	59	31	10	95	79	9.5	12
Ca	88	45	2.3	52	95	47	3.2	49
Cl	88	11	0	89	95	26	8.4	65
Cr	88	23	77	0	95	34	66	0
Cr(VI)	78	0	100	0	85	0	100	0
Co	88	38	33	30	95	43	13	44
F	88	73	4.5	23	95	86	8.4	5.3
Fe	88	18	6.8	75	95	12	1.1	87
Pb	88	59	30	11	95	83	1.1	16
Li	88	30	0	70	95	37	1.1	62
Mn	88	24	15	61	95	13	2.1	85
Hg	88	100	0	0	95	100	0	0
Mo	88	25	8	67	95	46	25	28
Ni	49	49	41	10	55	67	22	11
^{226}Ra	29	59	17	24	30	67	10	23
^{228}Ra	29	59	10	31	30	53	0	47
Se	88	10	90	0	95	4.2	96	0
Sr	88	36	2.3	61	95	39	0	61
SO_4	88	18	0	82	95	43	14	43
Tl	88	59	36	4.5	95	62	35	3.2
V	78	18	81	1.3	85	2.4	98	0

Note: A green highlight indicates that >67% of the tests were within range, a yellow highlight indicates 33% to 66% within range, and no highlight indicates <33% within range.

The leach test to median porewater ratios are graphically illustrated in Figure 4-1. Each bar on the histogram shows the number of sample points within a given range of $\log_{10}$ median porewater ratio. If a particular leach method sample perfectly predicted porewater concentrations, the data point would fall on the x = zero line (equivalent to a ratio of 1). The half an order of magnitude range of defined variability is illustrated by the dashed lines at x = -0.5 and x = 0.5. The distribution of samples outside the area between those lines indicates bias. The color of the boxes represents results from the two LEAF tests (because the total number of samples differed between leach test methods, the absolute height of the bars will be different). Figures for selected parameters are presented in Figure 4-1 to illustrate a range of observed outcomes. Similar figures for all parameters are provided in Appendix D.

Sb provides an example where both LEAF 1313 and LEAF 1316 results are biased high (more of the ratios fall to the right of 0.5 than to the left of -0.5 in Figure 4-1a). Most of the LEAF 1316 results for Sb fall outside the half order of magnitude criterion.

Ba is an example in which LEAF 1313 is biased high and LEAF 1316 is biased low (Figure 4-1b). For both tests, the distribution of data is centered close to zero and most samples have a $\log_{10}$ ratio between -0.5 and 0.5, but there are substantially more ratio results to one side of the range compared to the other side.

The distribution for Mo LEAF 1316 data is centered close to zero (Figure 4-1c), with a similar number of ratios on either side of the range, indicating no bias. LEAF 1313 results are mostly to the left of the range, indicating a bias low in the 1313 testing.

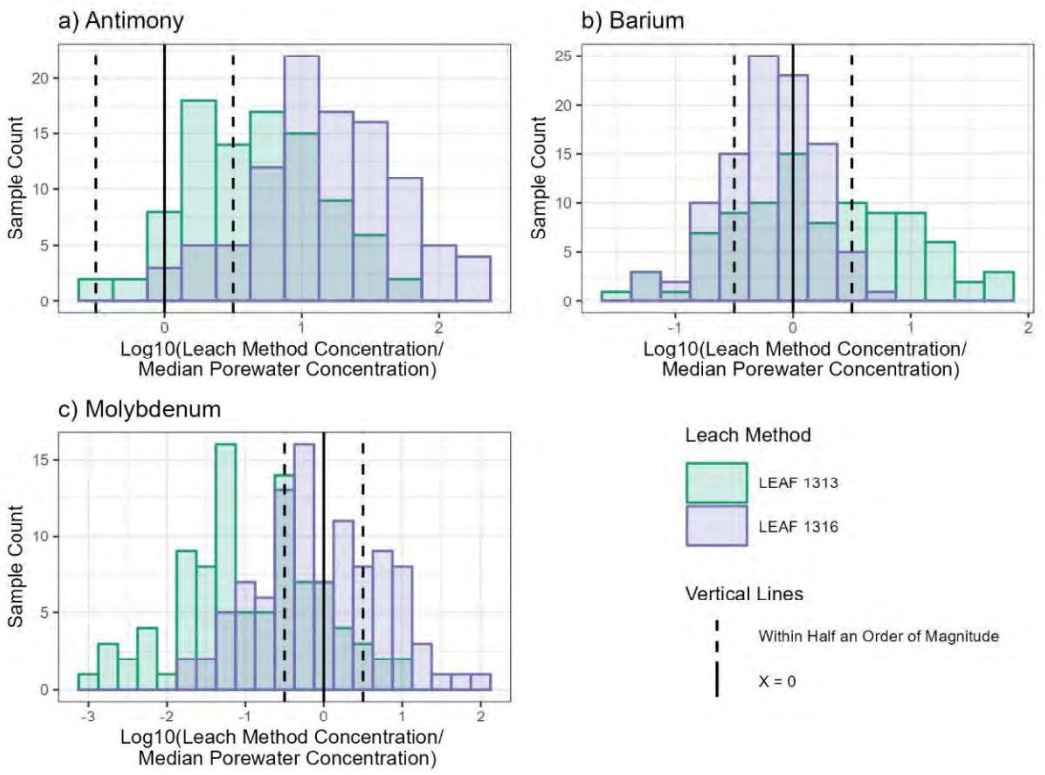

Figure 4-1
Histograms comparing the concentrations predicted by the LEAF 1313 and LEAF 1316 to the median observed porewater concentrations

Sample bias is summarized by element in Table 4-2. A test was considered to impart a bias toward higher concentration (overpredict porewater concentrations) if more than 50% of the samples were above range **or** if at least 20% of the results were above range and there were more than twice as many results above range compared to results below range. Bias low (test underpredicts porewater concentration) was assigned if more than 50% of the samples were below range **or** if at least 20% of the results were below range and there were more than twice as many results below range compared to results above range. The results of this comparison show:

- Elements often controlled by available content—such as B, Ca, Cl, Li, Sr, and SO_4—tend to be underpredicted (bias low) by the leach tests.
- As, Fe, and Mn were also underpredicted, even though they tend to be solubility controlled, because the LEAF testing was performed under oxic conditions when the solubility of these elements is low.
- Conversely, Se and Cr, which are most soluble under oxic conditions, tended to be overpredicted by the LEAF testing performed under oxic conditions.
- Sb, Tl, and V tend to be overpredicted (bias high) by the leach tests while other elements may be overpredicted or underpredicted depending on test-specific and site-specific factors.
- No bias was detected for Hg because most porewater and all the LEAF test results were non-detect.

Table 4-2
Summary of LEAF test bias compared to porewater concentrations

	Bias Low	No Bias	Bias High
LEAF 1313	As, B, Ca, Cl, F, Fe, Li, Mn, Mo, ^{228}Ra, Sr, SO_4	Co, Hg, ^{226}Ra	Sb, Ba, Be, Cd, Cr, Cr(VI), Pb, Ni, Se, Tl, V
LEAF 1316	As, B, Ba, Ca, Cl, Co, Fe, Li, Mn, ^{226}Ra, ^{228}Ra, Sr, SO_4	Be, Cd, F, Pb, Hg, Mo, Ni	Sb, Cr, Cr(VI), Se, Tl, V

Direct Comparison of LEAF Eluate Concentrations to Porewater Concentrations

Figures 4-2 and 4-3 illustrate how leach test concentration varied under the range of pH and L/S conditions imposed by the LEAF 1313 and LEAF 1316 leach tests, respectively. The $\log_{10}$ ratios of leach test sample to median porewater concentrations (y axis) are plotted against the measured sample pH (Figure 4-2) or against the L/S ratio (Figure 4-3). As shown in Figure 4-1, the zero line and predefined range of $\log_{10}$ ratios (-0.5 to 0.5) are shown. In addition, shaded areas represent the order of magnitude and 25% criteria used in EPRI (2020 and 2021c). The same three analytes discussed previously are shown in Figures 4-2 and 4-3 to illustrate a range of potential outcomes. These same figures for all analytes are presented in Appendix E (LEAF 1313, pH dependent) and Appendix F (LEAF 1316, L/S dependent).

Figure 4-1a indicates a tendency for Sb to be overpredicted by LEAF 1313. Figure 4-2a shows this to be the case across the pH range, with some underpredictions at the lowest pH tested. Figure 4-3a shows that porewater Sb tended to be overpredicted at all L/S, especially at low L/S.

Figure 4-1b indicates that Ba was overpredicted by LEAF 1313 and underpredicted by LEAF 1316. Figure 4-2b shows that the 1313 tests for Ba tended to be biased high at low pH and biased

low at high pH. Figure 4-3b shows that Ba can be underpredicted at any L/S and can also be overpredicted at higher L/S.

Figure 4-2c shows that Mo, while biased low across the LEAF 1313 pH range, had more results within range at pH >7.0 SU than at lower pH. Figure 4-3c illustrates that even though the sum of results for Mo testing using Method 1316 showed no bias, the samples at low L/S were biased high, and the samples at high L/S were biased low.

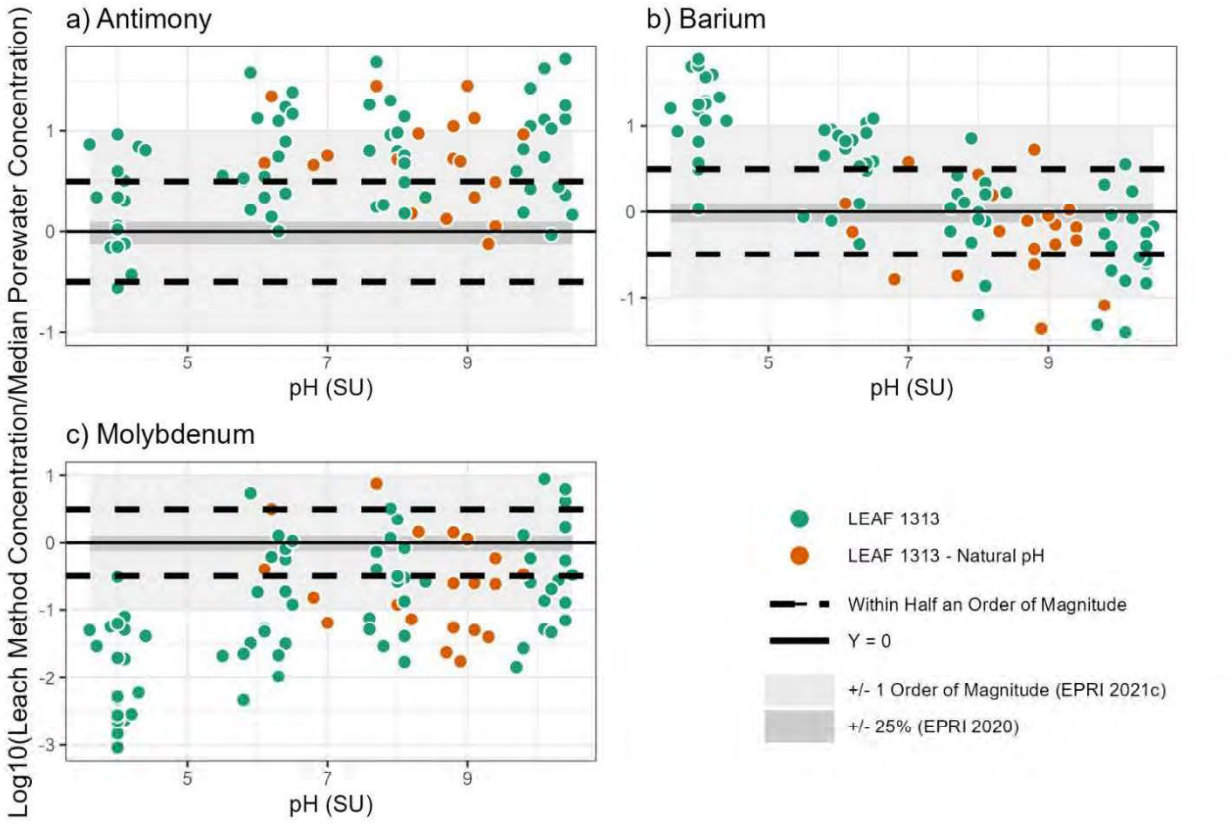

Figure 4-2
Comparison of LEAF 1313 results (normalized to median porewater concentration) across the range of pH levels tested

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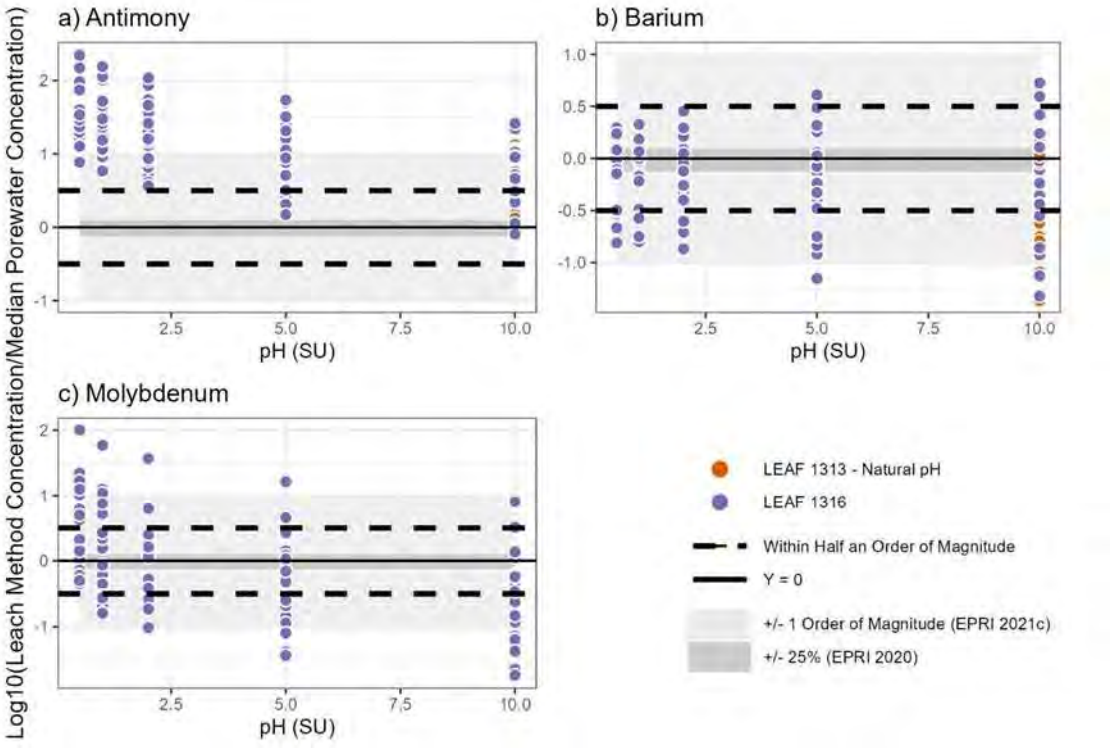

Figure 4-3
Comparison of LEAF 1316 results (normalized to median porewater concentration) across the range of L/S levels tested

Results from the LEAF 1313 test measured at natural porewater pH are included for comparison.

Focusing on natural pH results, the LEAF 1313 tests usually yielded eluate concentrations at natural pH that were higher (>25%) or lower (<25%) than the median porewater concentrations from their paired PMPs (Table 4-3). Taking this comparison a step further, examination of the plots in Appendix E indicates that all LEAF 1313 eluates (natural pH or not) at pH between 6 and 10 were more likely to be outside than inside the ±25% range.[7] The only exception to this observation is for lead, because it was often not detected and the detection limits for the porewater analysis and LEAF 1313 analysis were similar. Similarly, the 1316 eluate concentrations were usually not within ±25% of their paired porewater concentrations. Lead was most likely to yield a concentration within the ±25% criteria but only because the MDLs used for the LEAF 1316 analysis and porewater analyses were similar for this element, which was usually not detected in either porewater or eluates. These results confirm the observations from EPRI 2020 and 2021c that LEAF tests do not reliably predict porewater concentrations observed in the field.

[7] The median porewater concentrations for the ash basins were mostly between 6 and 10 (see pH plot in Appendix C), and the natural pH range for all PMPs was between 6 and 10.

Table 4-3
Tabulation of LEAF 1313 and 1316 eluate concentrations at natural pH and low or high L/S

Parameter	1313 Natural pH Eluates Within ±25%	1313 Natural pH Eluates Outside ±25%	1316 Eluates at L/S <1 Within ±25%	1316 Eluates at L/S >=1 Within ±25%	1316 Eluates Outside ±25%
Sb	10	90	0	3	97
As	5	95	3	9	88
Ba	15	85	5	15	80
Be[1,2,3]	10	90	2	8	90
B	0	100	5	3	92
Cd[1,2,3]	0	100	0	2	98
Ca	0	100	4	7	89
Cl[2]	5	95	5	2	93
Cr	10	90	2	7	91
Cr(VI)[1,2,3]	0	100	0	0	100
Co	10	90	2	11	87
F	10	90	6	19	75
Fe[3]	5	95	0	2	98
Pb[1,2,3]	45	55	15	52	33
Li	0	100	4	2	94
Mn	0	100	1	1	98
Hg[1,2,3]	0	100	0	0	100
Mo	5	95	1	6	93
Ni	0	100	4	9	87
^{226}Ra	29	71	7	23	70
^{228}Ra	14	86	7	17	77
Se[1]	5	95	0	3	97
Sr	0	100	4	6	90
SO_4	5	95	6	6	88
Tl	30	70	2	12	86
V	6	94	0	1	99

Notes:

[1] Low detection frequency (<=50%) in porewater

[2] Low detection frequency (<=50%) in LEAF 1313 eluate at natural pH

[3] Low detection frequency (<=50%) in LEAF 1316 eluate at L/S = 1

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5
ADDITIONAL DATA EXPLORATION

This report has discussed porewater composition on a parameter-by-parameter basis. Advanced statistical methods could be used in the future to help characterize entire porewater signatures. Multivariate statistical methods can evaluate the relationships between more than two variables simultaneously, allowing for easier interpretation of entire porewater signatures. Potentially applicable multivariate statistical methods include principal component analysis (PCA), cluster analysis, and linear discriminant analysis (the use of which is discussed in detail in EPRI, 2022).

PCA is a common dimensionality reduction method (Abdi and Williams, 2010; Shlens, 2014). The principal components calculated are essential new "variables," which are linear combinations of the original data that separate the data points and reduce redundancy in the data. In EPRI 2022, PCA was used to distinguish CCP porewater from coal pile runoff water (a potential alternative source of downgradient exceedances). Similar multivariate analyses could be used to assess how parameters co-vary within and between units as well as how successful laboratory leach testing is at determining entire porewater signatures.

6
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A
SUMMARY OF POREWATER DATA

Parameter	Unit	Sample Count	Number of Units	Detection Frequency (%)	Min	Max	Mean	Median
Field Parameters								
Eh	mV	1390	29	100	-244.3	863	166	132
pH	SU	1390	29	100	2.5	11.5	7.17	7.01
EC	µmhos/cm	1390	29	100	0.2	12002	1060	640
TEMP	Deg C	1390	29	100	1.87	35	19.7	19.695
TURB	NTUs	1388	29	100	0	624	6.43	4.8
Major Ions								
ALK	mg/L	1375	29	94	1.4	1690	168	139
ALK-HCO_3	mg/L	1361	29	91	1.2	837	162	137
Ca	mg/L	1383	29	100	0.0628	1830	120	76.5
Ca (Diss)	mg/L	84	19	99	0.1	461	102	75.9
ALK-CO_3	mg/L	1355	29	12	1	1640	9.87	5
Cl	mg/L	1377	29	100	0.1	3650	69.5	10.1
F	mg/L	440	23	94	0.0398	50	0.908	0.33
Mg	mg/L	1382	29	100	0.0654	1030	35.1	15.55
Mg (Diss)	mg/L	70	19	99	0.1	275	28.8	19.45
NO_2 + NO_3	mg-N/L	1333	29	49	0.00002	13.6	0.13	0.02
K	mg/L	1381	29	96	0.893	566	19.8	10.6
K (Diss)	mg/L	70	19	91	0.913	270	20.2	9.845
Na	mg/L	1383	29	99	1.7	445	23.2	12.5
Na (Diss)	mg/L	70	19	99	2.47	246	21.6	10.65
SO_4	mg/L	1376	29	98	0.1	28000	425	103
Other								
S^{2-}	mg/L	1105	29	8	0.0001	10	0.151	0.1
TDS	mg/L	1375	29	99	8.7	15000	849	411
TOC	mg/L	1281	29	72	0.085	56	1.82	1
TSS	mg/L	1118	29	62	0.0025	909	20.7	5.6
Trace Elements								
Al	mg/L	1357	29	79	0.004709	1160	9.26	0.128
Al (Diss)	mg/L	1199	29	57	0.001835	1140	8.81	0.1
Sb	mg/L	1343	29	60	0.000089	0.104	0.00285	0.00099
Sb (Diss)	mg/L	1190	29	54	0.000077	0.0968	0.00271	0.0007385
As	mg/L	1382	29	99	0.000065	6.38	0.422	0.2215
As (Diss)	mg/L	1216	29	99	0.000041	5	0.394	0.1965
Ba	mg/L	1288	29	98	0.000024	3.52	0.238	0.172
Ba (Diss)	mg/L	1173	29	99	0.000023	3.37	0.226	0.158

Summary of Porewater Data

Parameter	Unit	Sample Count	Number of Units	Detection Frequency (%)	Min	Max	Mean	Median
Trace Elements (continued)								
Be	mg/L	1297	29	43	0.00001	0.507	0.00442	0.0001
Be (Diss)	mg/L	1178	29	37	0.00001	0.449	0.0038	0.0001
B	mg/L	1383	29	98	0.0067	103	5.03	1.25
B (Diss)	mg/L	1216	29	98	0.05	92.8	4.89	1.245
Cd	mg/L	1247	29	27	0.000025	0.0457	0.000672	0.00008
Cd (Diss)	mg/L	1159	29	24	0.000025	0.024	0.000567	0.00008
Cr	mg/L	1381	29	66	0.000091	0.263	0.00387	0.00076
Cr (Diss)	mg/L	1211	29	58	0.000091	0.245	0.00317	0.0005
Cr(VI)	mg/L	1188	26	31	0.000009	0.008	0.00022	0.00003
Co	mg/L	1382	29	83	0.00001	1.58	0.0231	0.001095
Co (Diss)	mg/L	1213	29	80	0.00001	1.57	0.0222	0.001
Cu	mg/L	1117	29	59	0.00011	0.245	0.00341	0.00069
Cu (Diss)	mg/L	1116	29	50	0.00011	0.241	0.00368	0.000605
Fe	mg/L	1383	29	95	0.003841	2480	46.4	2.57
Fe (Diss)	mg/L	1209	29	83	0.003389	2500	42.1	2.22
Pb	mg/L	1130	29	36	0.000028	0.0207	0.000658	0.000105
Pb (Diss)	mg/L	1115	29	15	0.000028	0.016389	0.000477	0.0001
Li	mg/L	515	23	95	0.0002	18.3	0.528	0.118
Li (Diss)	mg/L	142	20	96	0.0011	12.6	0.726	0.182
Mn	mg/L	1383	29	95	0.001852	36.7	2.27	0.7
Mn (Diss)	mg/L	1216	29	93	0.002599	37.4	2.13	0.659
Hg	µg/L	1145	29	6	0.000621	4.6	0.17	0.2
Hg (Diss)	µg/L	1130	29	2	0.02	3.0	0.17	0.2
Mo	mg/L	1287	29	93	0.000085	55.6	0.902	0.0253
Mo (Diss)	mg/L	1176	29	93	0.000095	44	0.759	0.02585
Ni	mg/L	1317	29	86	0.00013	3.22	0.0412	0.0023
Ni (Diss)	mg/L	1185	29	86	0.00011	3.19	0.0388	0.00205
Se	mg/L	1353	29	47	0.000063	1.1	0.00929	0.00089
Se (Diss)	mg/L	1199	29	46	0.000074	0.897	0.0091	0.000756
Sr	mg/L	1383	29	100	0.005	29.5	2.49	1.78
Sr (Diss)	mg/L	1216	29	100	0.005	22	2.3	1.675
Tl	mg/L	1368	29	63	0.000016	0.02	0.000752	0.00018
Tl (Diss)	mg/L	1208	29	59	0.000015	0.0733	0.000684	0.00012
V	mg/L	1381	29	95	0.000073	3.26	0.0461	0.00312
V (Diss)	mg/L	1214	29	90	0.000058	2.22	0.0412	0.0025
Zn	mg/L	1135	29	51	0.001873	7.13	0.0846	0.01
Zn (Diss)	mg/L	1120	29	41	0.001674	6.45	0.0711	0.01
Radiologic								
^{226}Ra	pCi/L	393	23	92	0	2.09	0.41	0.333
^{228}Ra	pCi/L	393	23	88	0	3	0.668	0.564
Total Ra	pCi/L	114	8	100	0	3.84	0.903	0.8225

B
TOTAL VERSUS DISSOLVED CONCENTRATION COMPARISON

The figures in this appendix (Figures B-1 through B-26) compare total vs. dissolved concentrations in filtered and unfiltered sample pairs when a concentration is detected in one or both samples. For clarity, samples where concentrations are below detection limits in both samples are not shown. The statistics on the graphs are for sample pairs where a concentration is detected in one or both samples and will therefore differ from the statistics shown in Table 3-2.

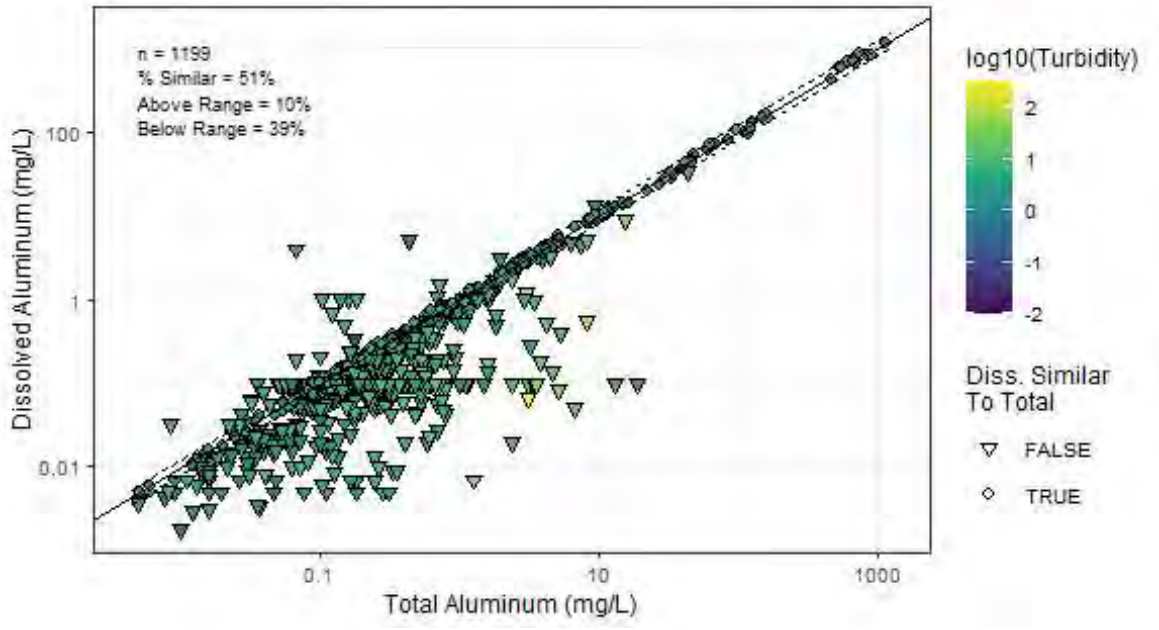

Figure B-1
Aluminum

Total versus Dissolved Concentration Comparison

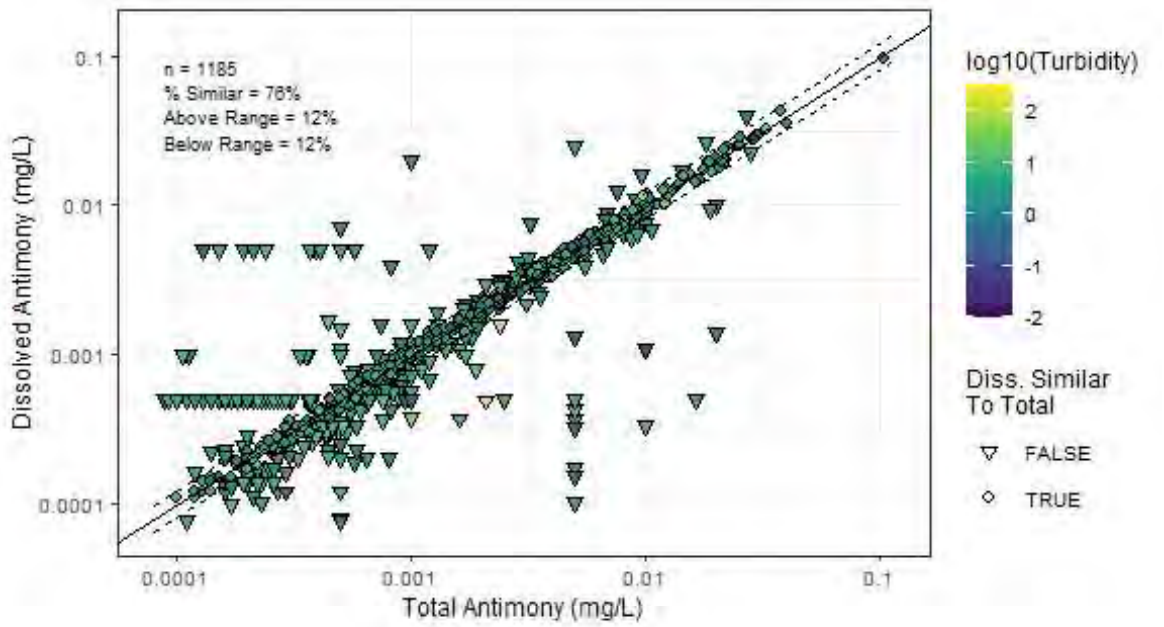

Figure B-2
Antimony

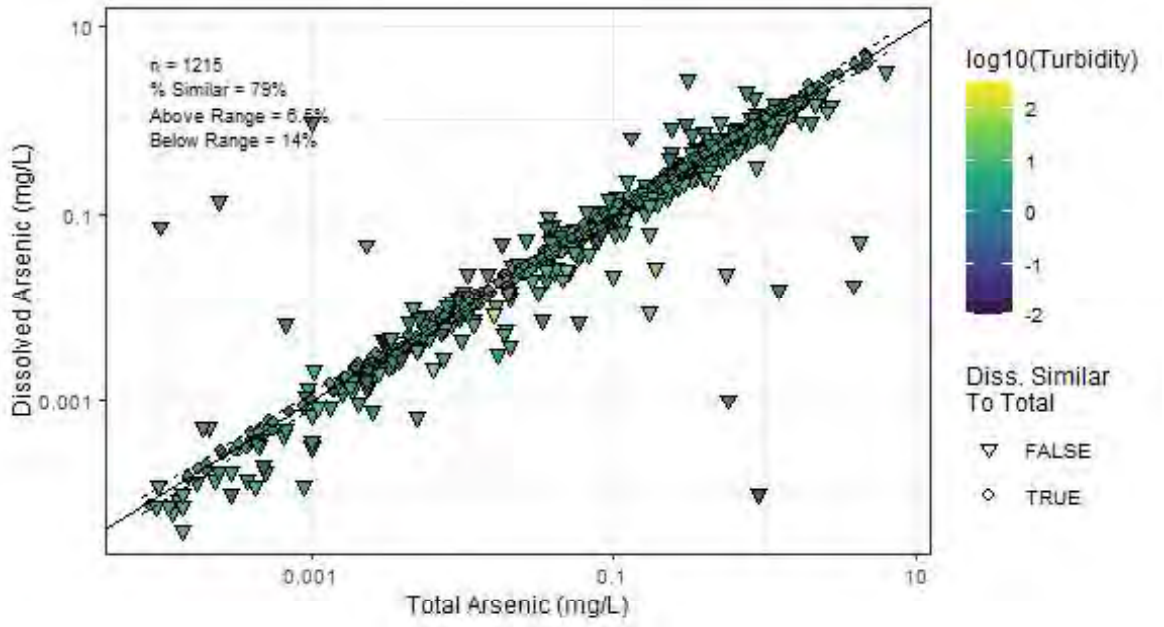

Figure B-3
Arsenic

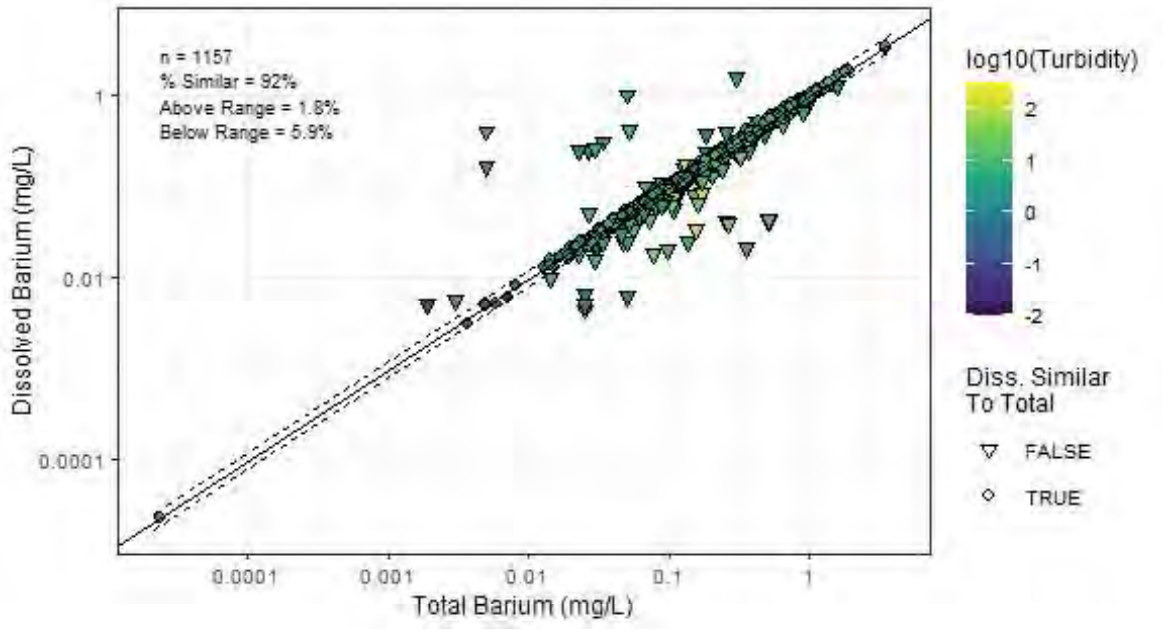

Figure B-4
Barium

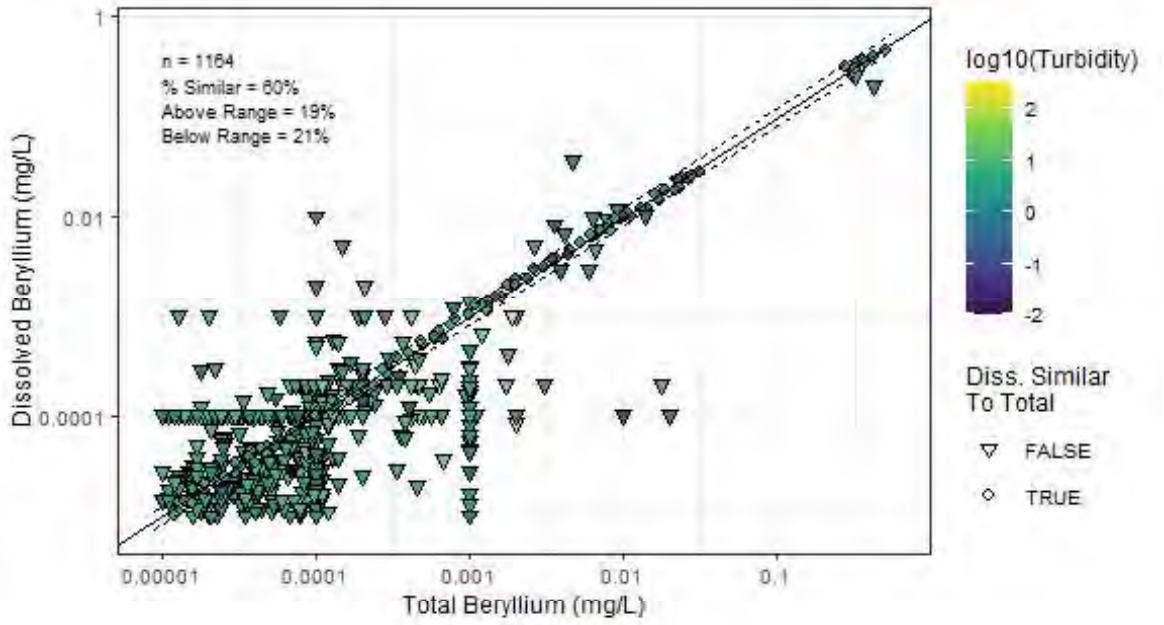

Figure B-5
Beryllium

Total versus Dissolved Concentration Comparison

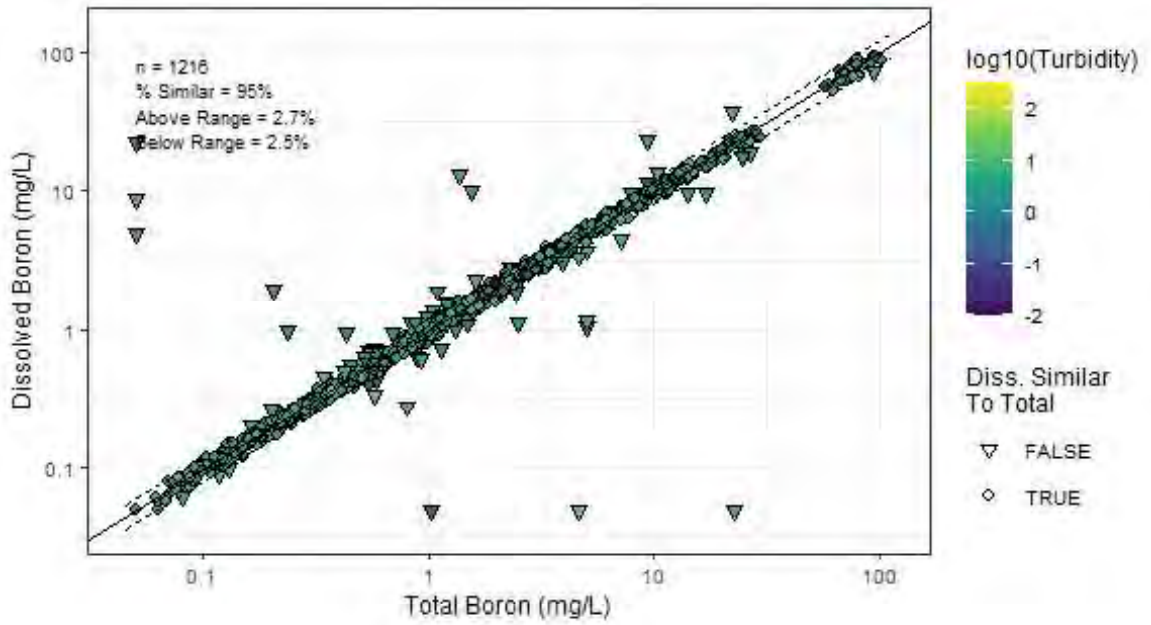

Figure B-6
Boron

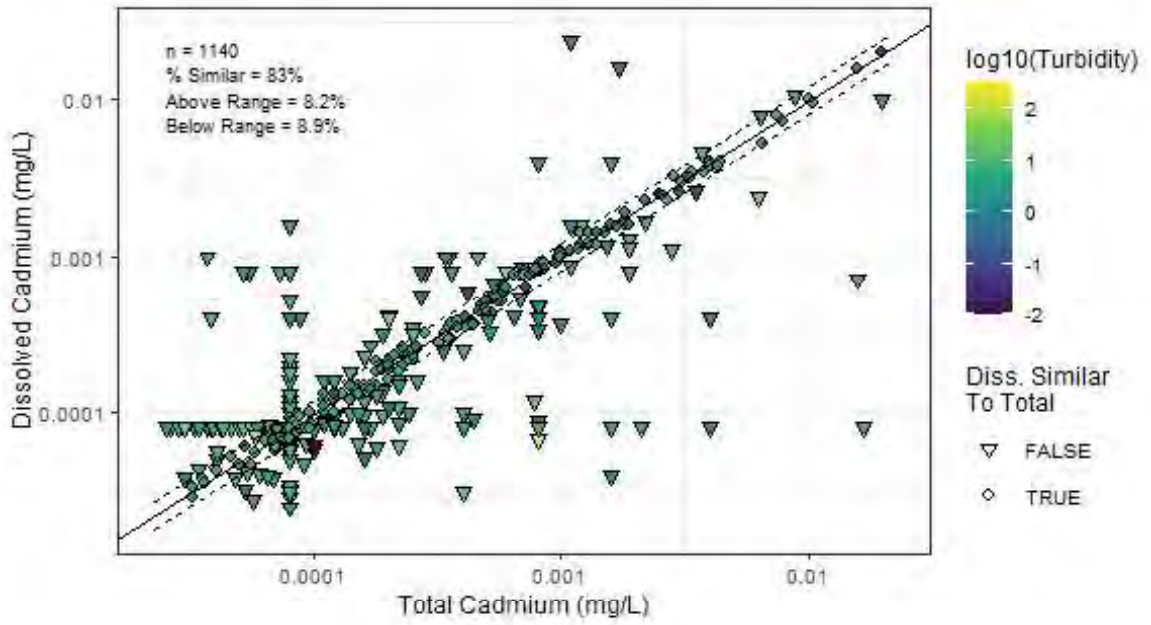

Figure B-7
Cadmium

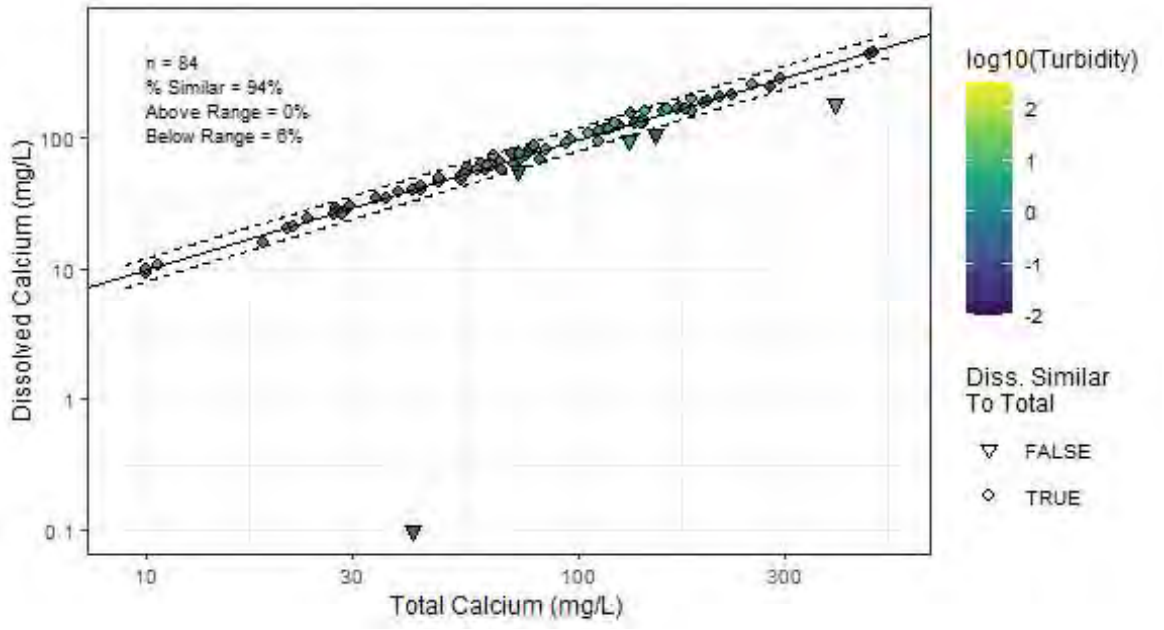

Figure B-8
Calcium

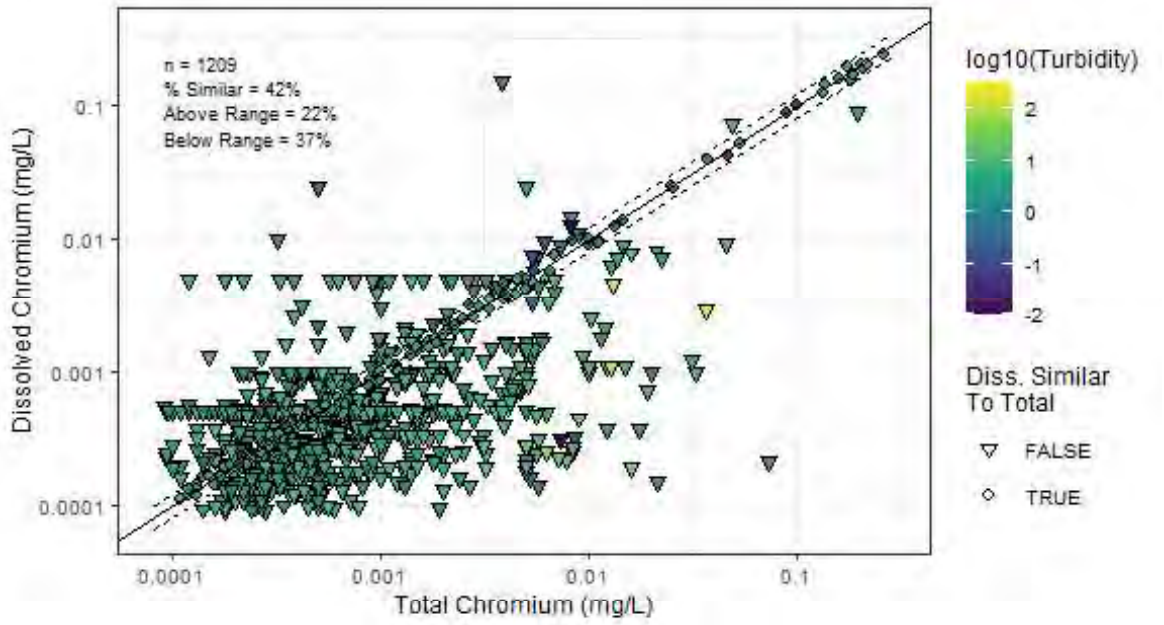

Figure B-9
Chromium

Total versus Dissolved Concentration Comparison

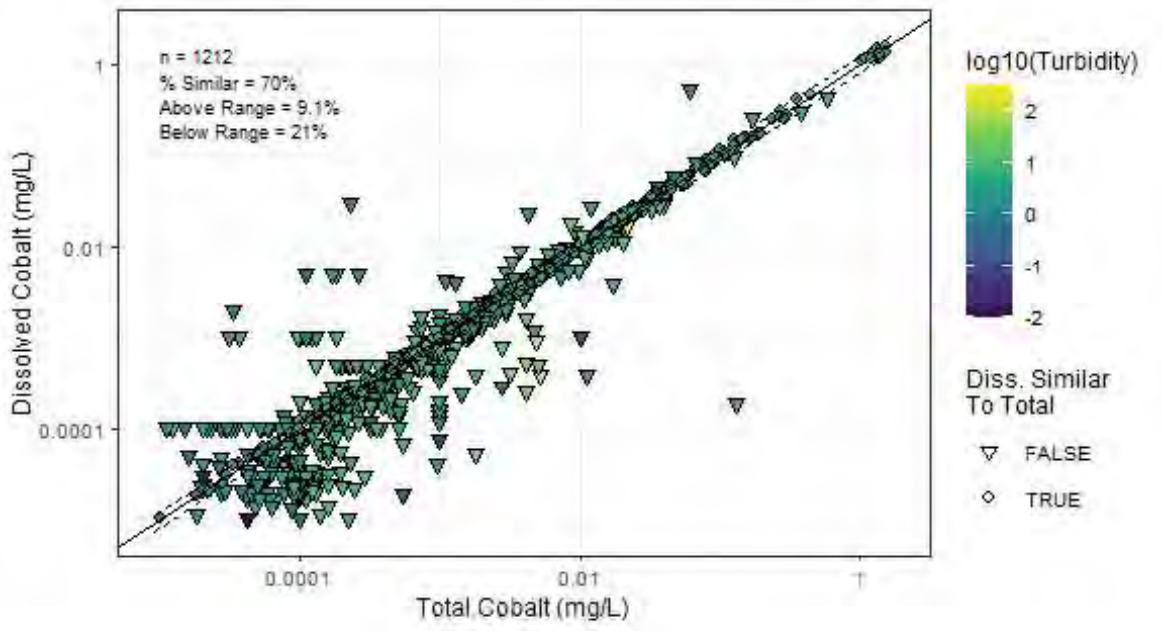

Figure B-10
Cobalt

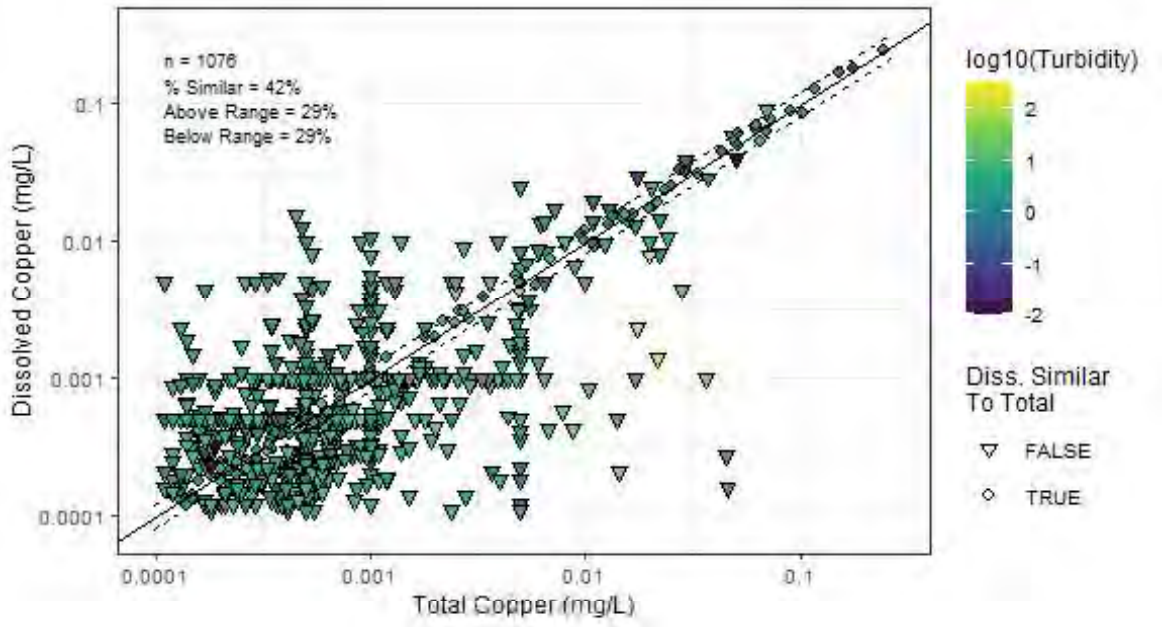

Figure B-11
Copper

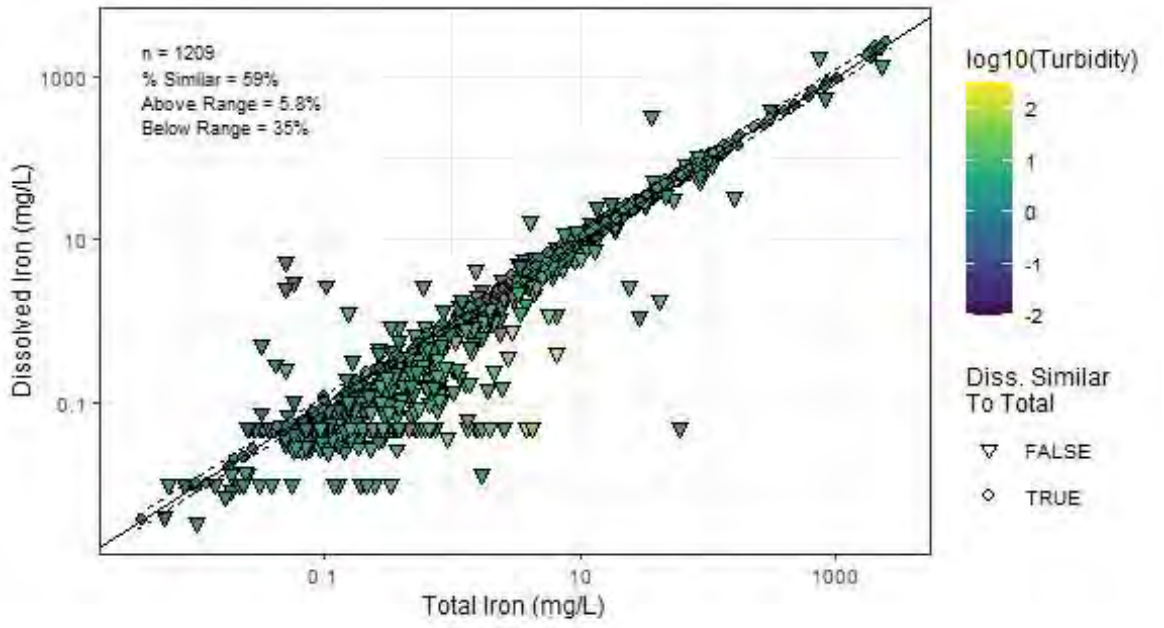

Figure B-12
Iron

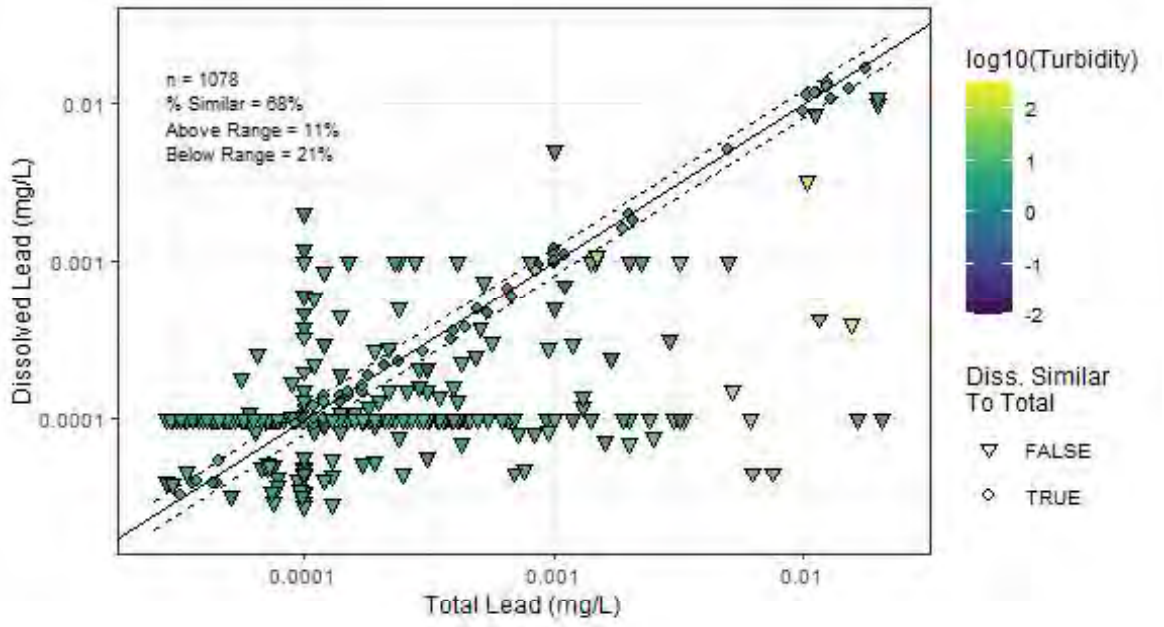

Figure B-13
Lead

Total versus Dissolved Concentration Comparison

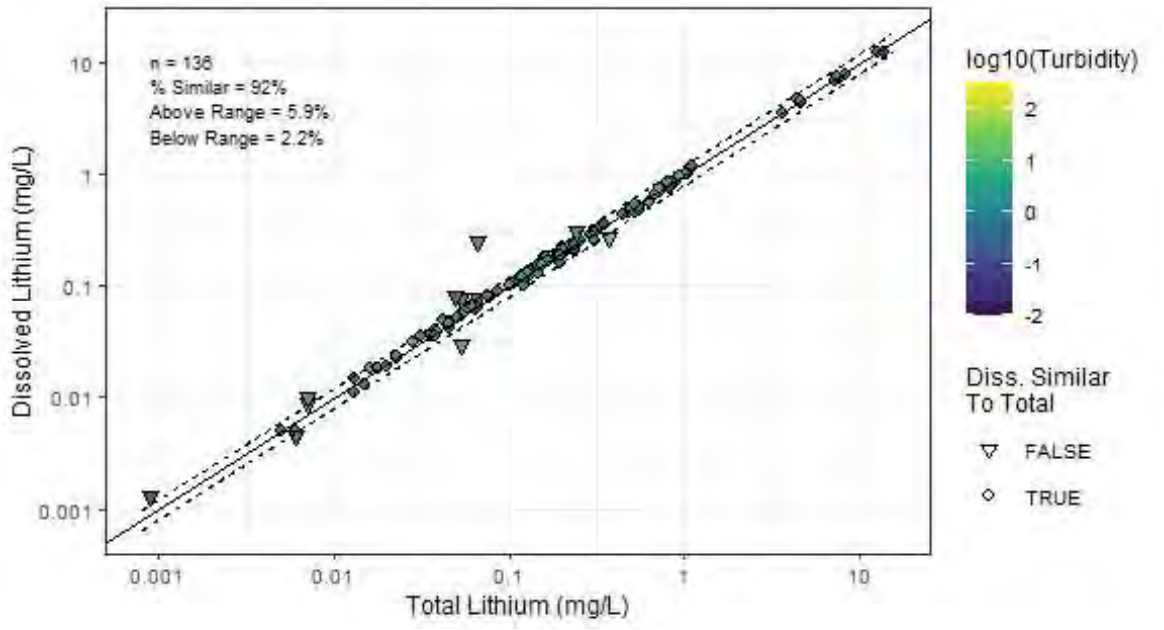

Figure B-14
Lithium

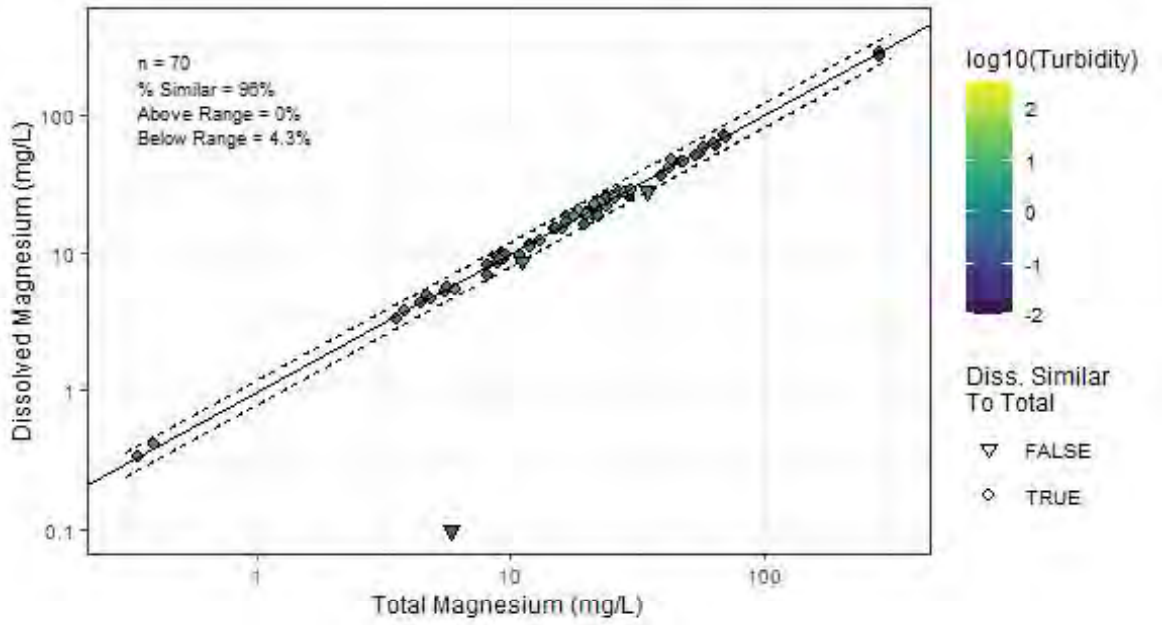

Figure B-15
Magnesium

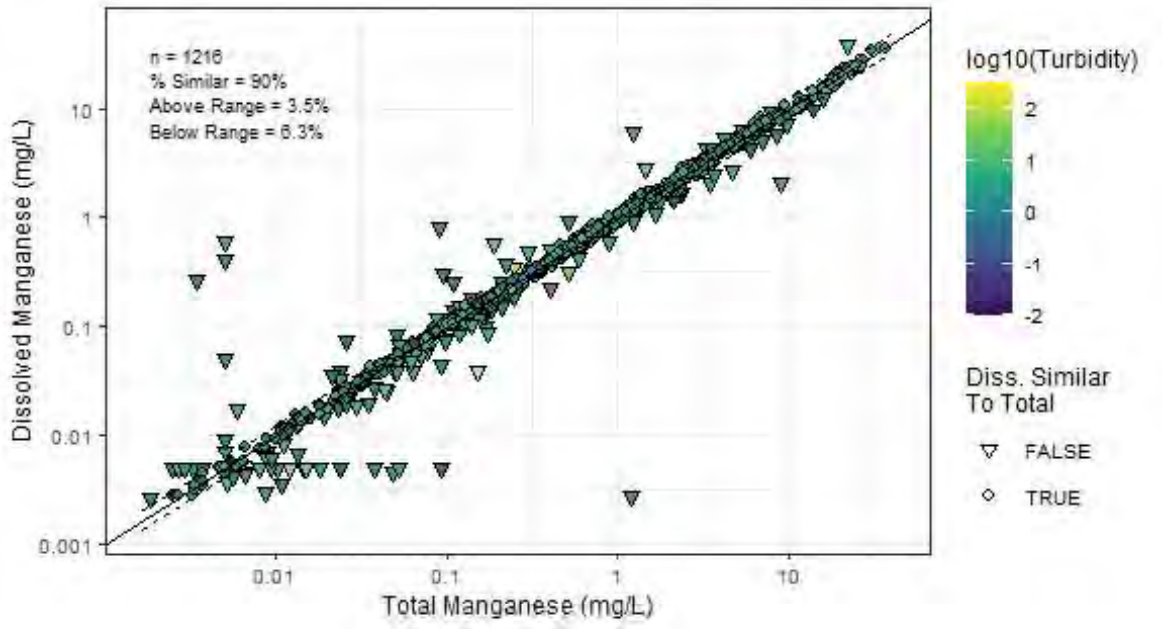

Figure B-16
Manganese

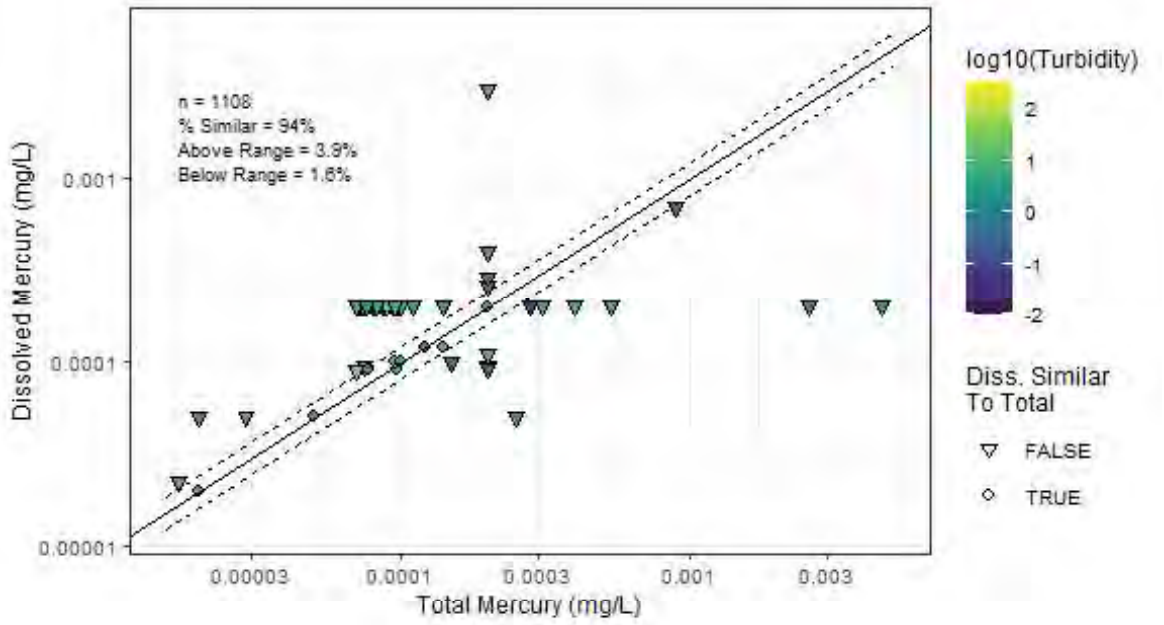

Figure B-17
Mercury

Total versus Dissolved Concentration Comparison

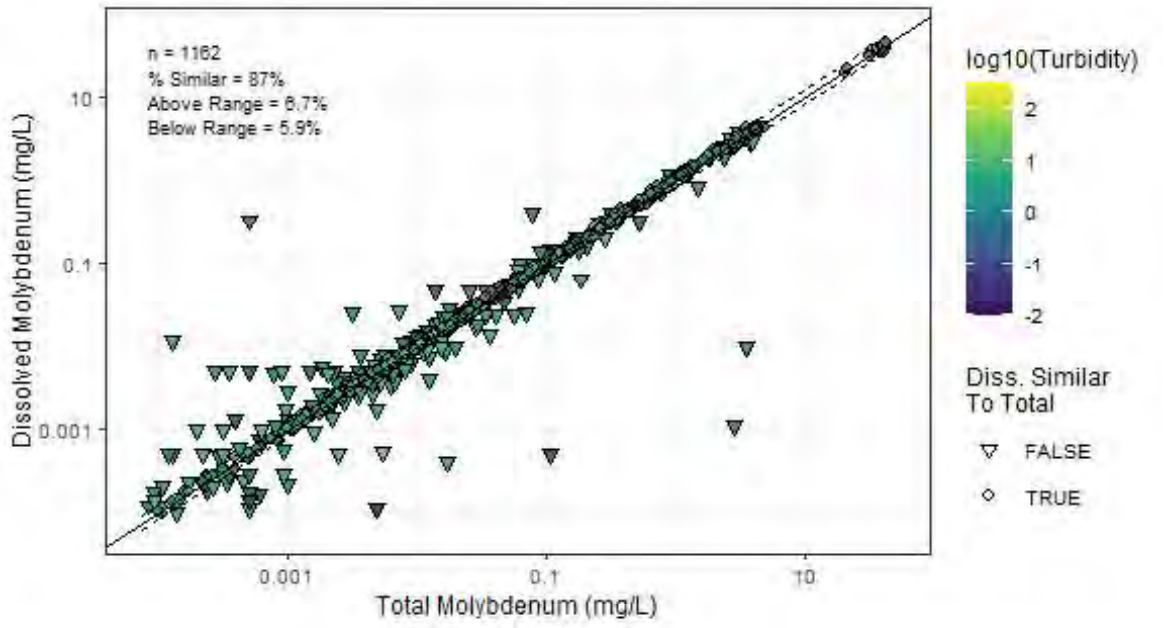

Figure B-18
Molybdenum

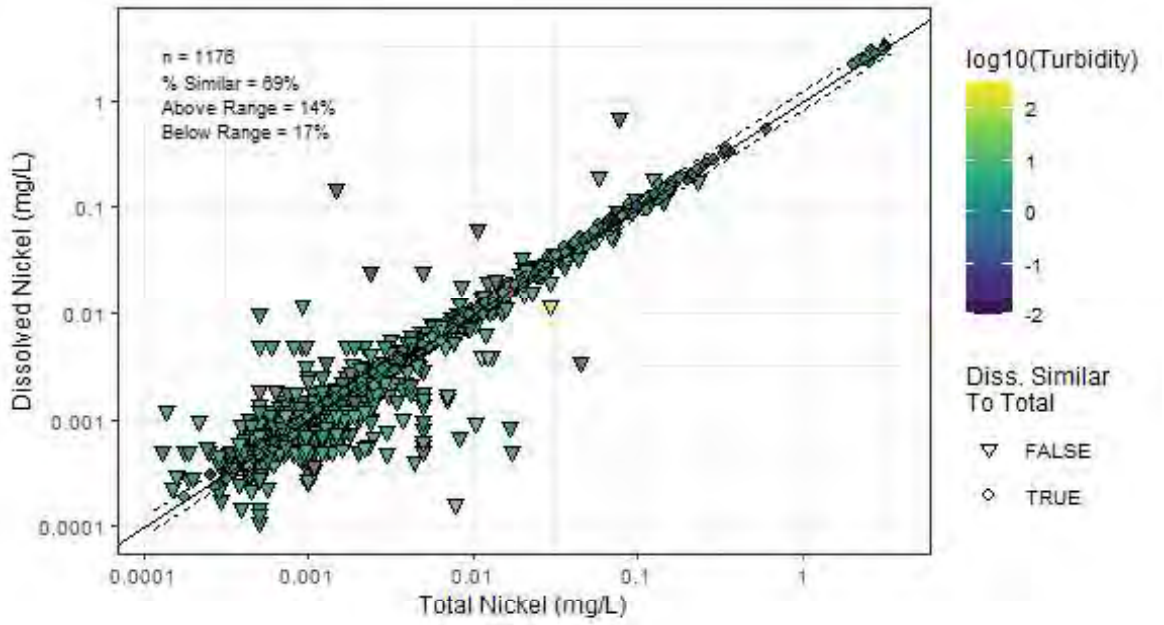

Figure B-19
Nickel

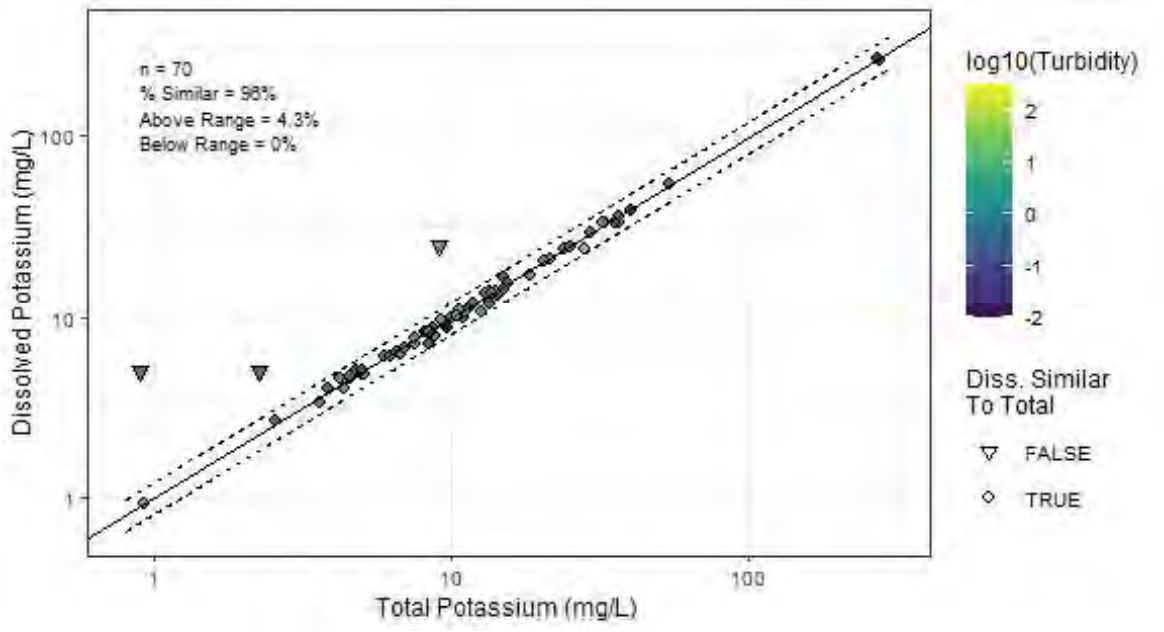

Figure B-20
Potassium

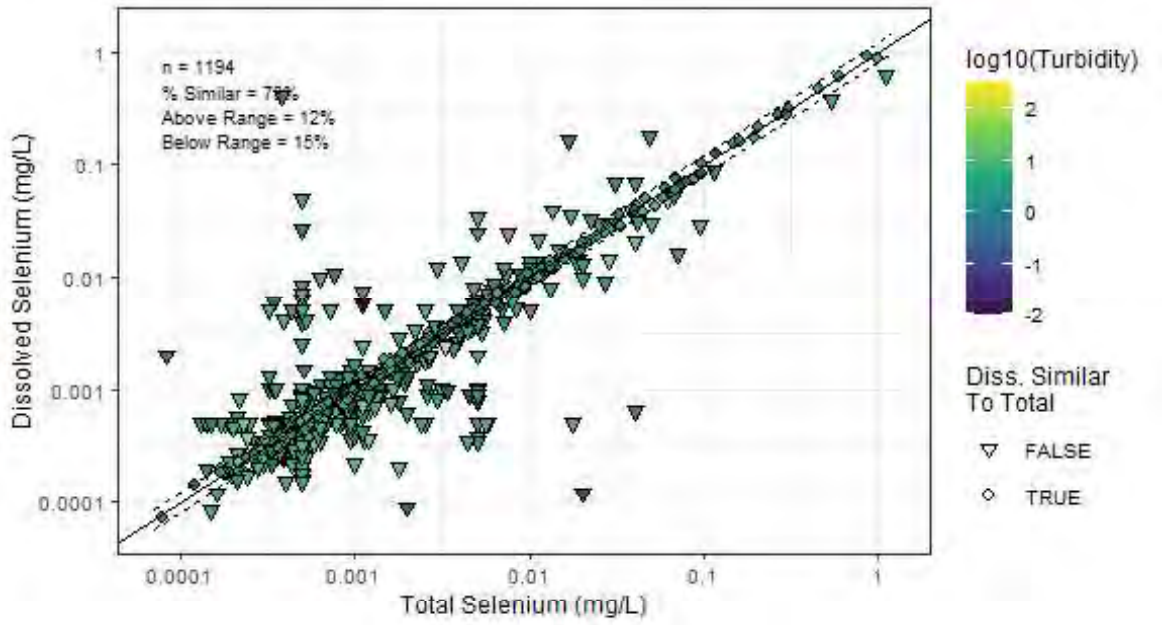

Figure B-21
Selenium

Total versus Dissolved Concentration Comparison

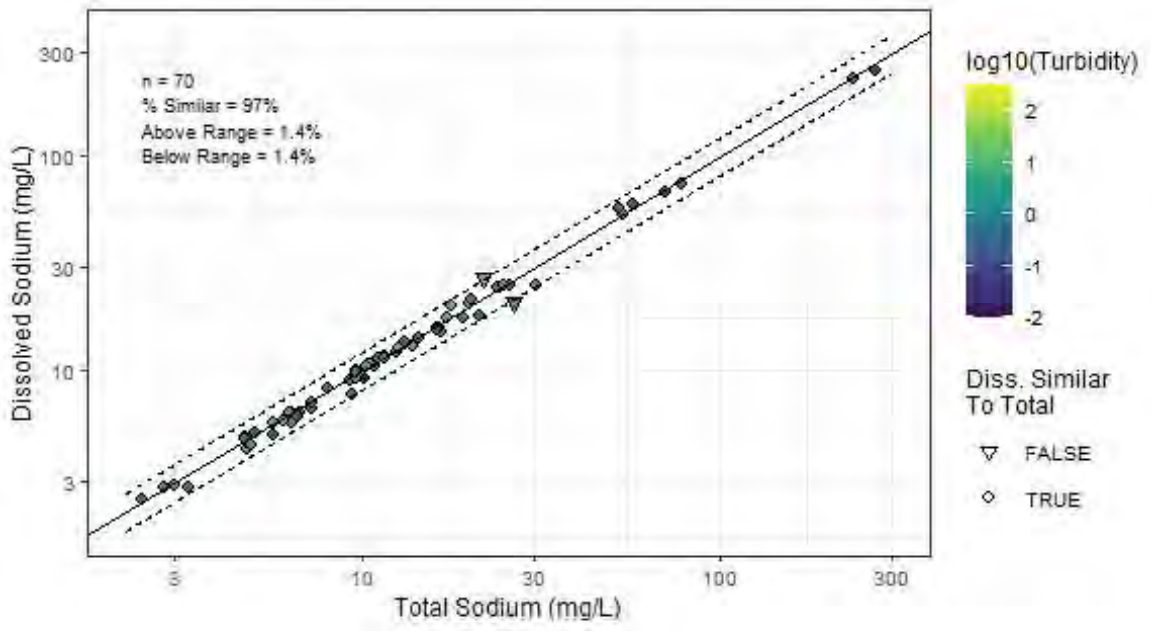

Figure B-22
Sodium

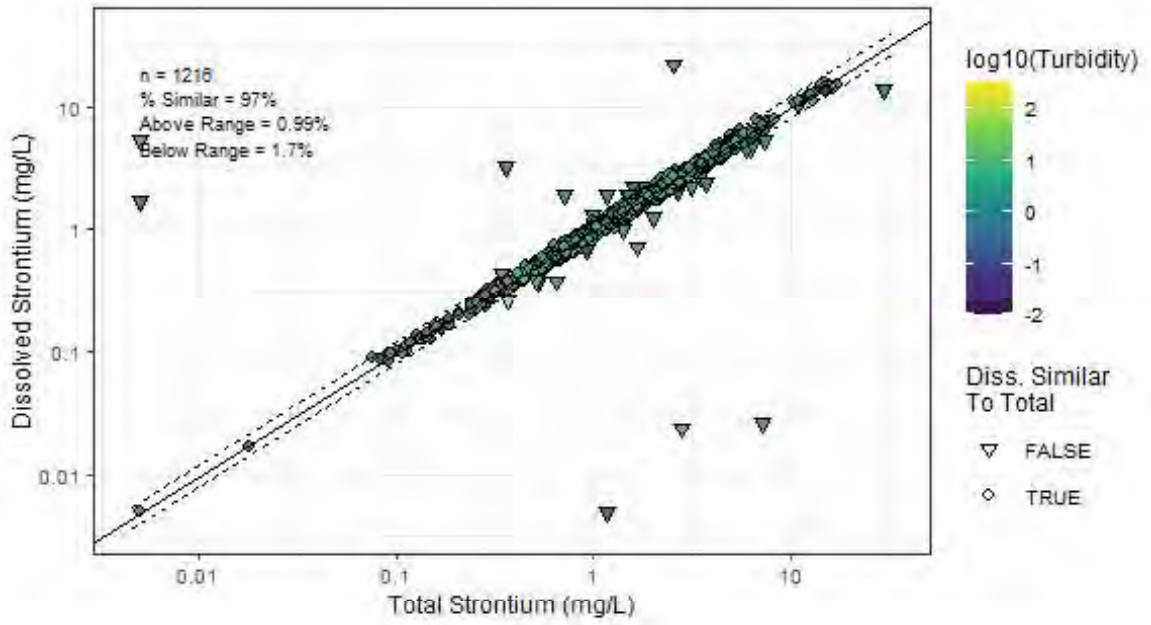

Figure B-23
Strontium

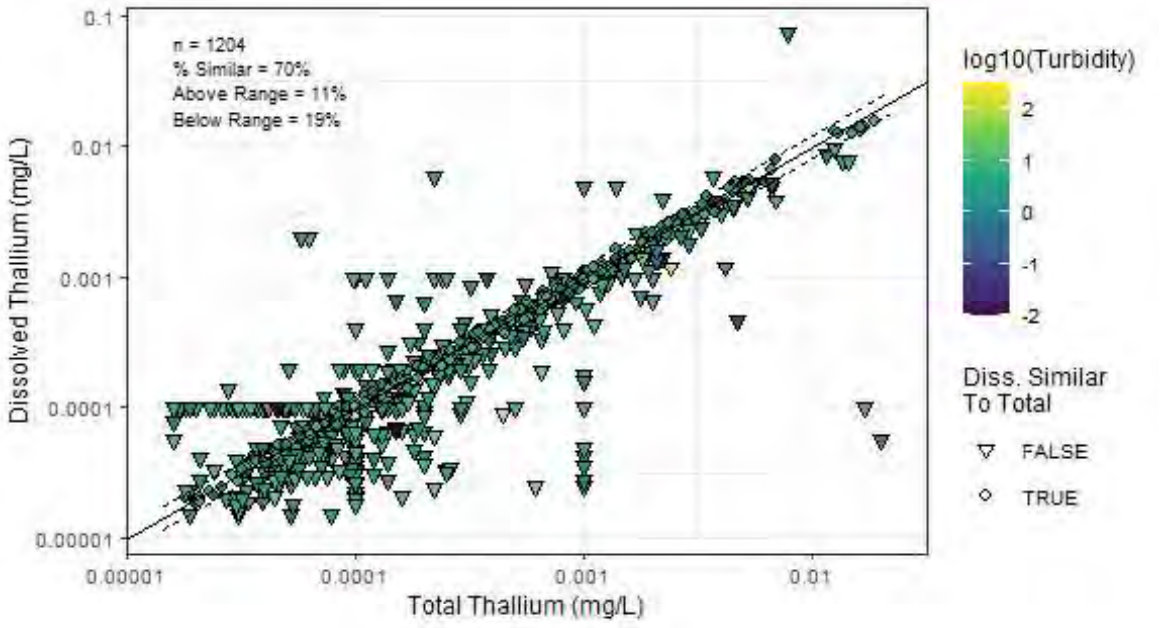

Figure B-24
Thallium

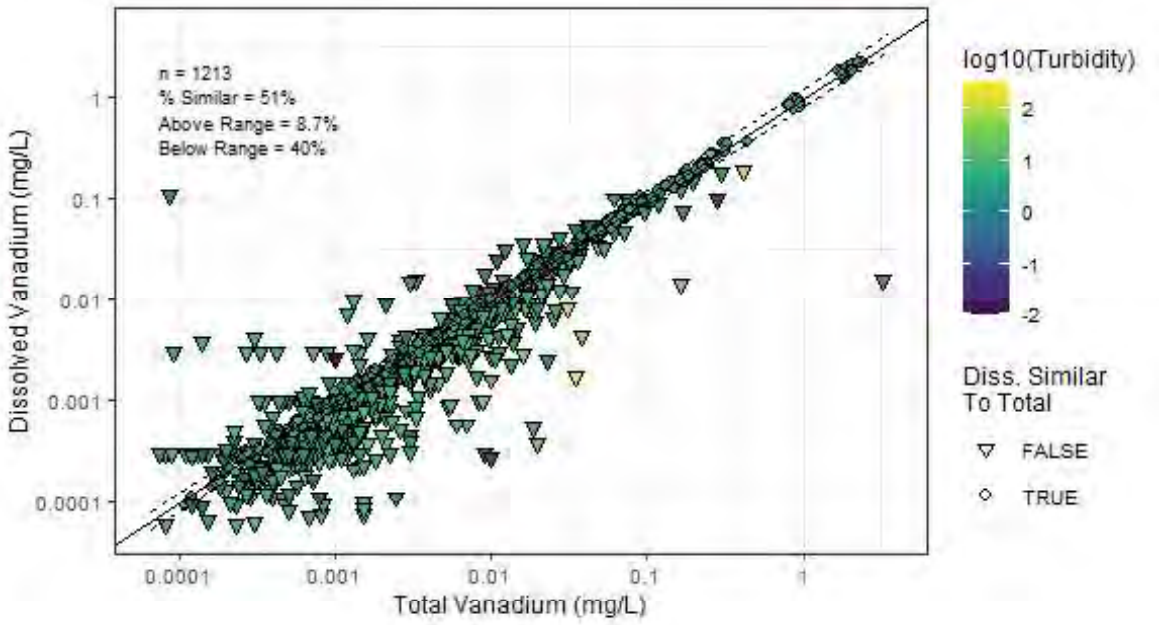

Figure B-25
Vanadium

Total versus Dissolved Concentration Comparison

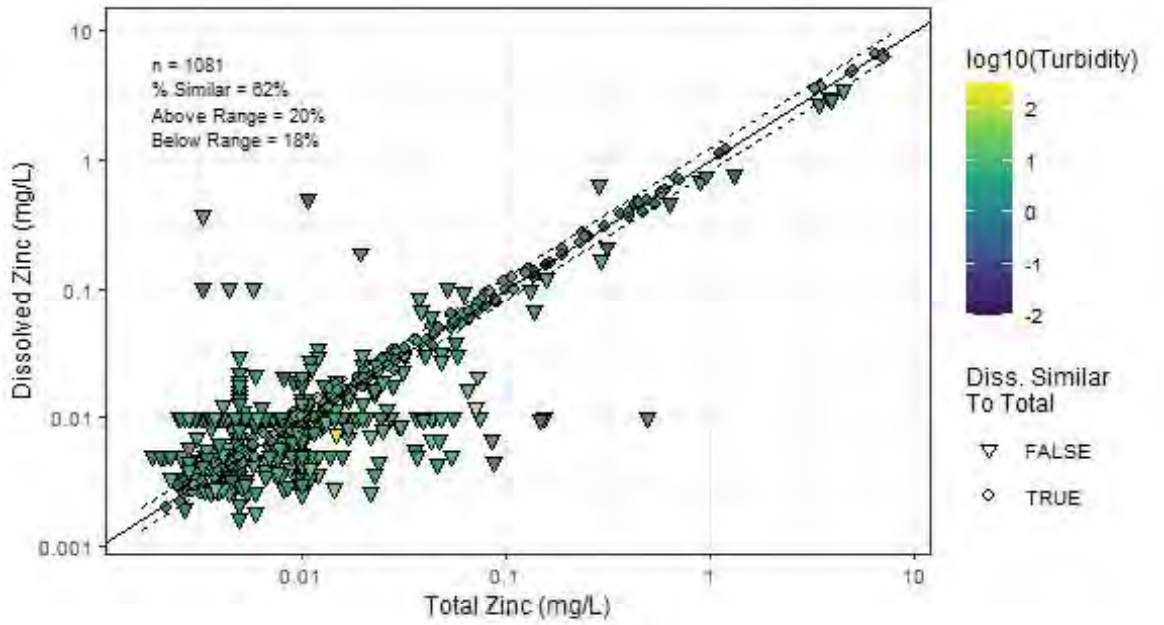

Figure B-26
Zinc

C
POREWATER VARIABILITY

The figures in this appendix illustrate inter- and intra-unit variability using boxplots. Intra-unit variability was based on the ratio of the 75th to 25th percentile (as illustrated by each individual box; a longer box indicates greater intra-unit variability than a shorter box). Inter-unit variability was determined based on the difference between median concentrations (horizontal line within each box) for each parameter across all sites.

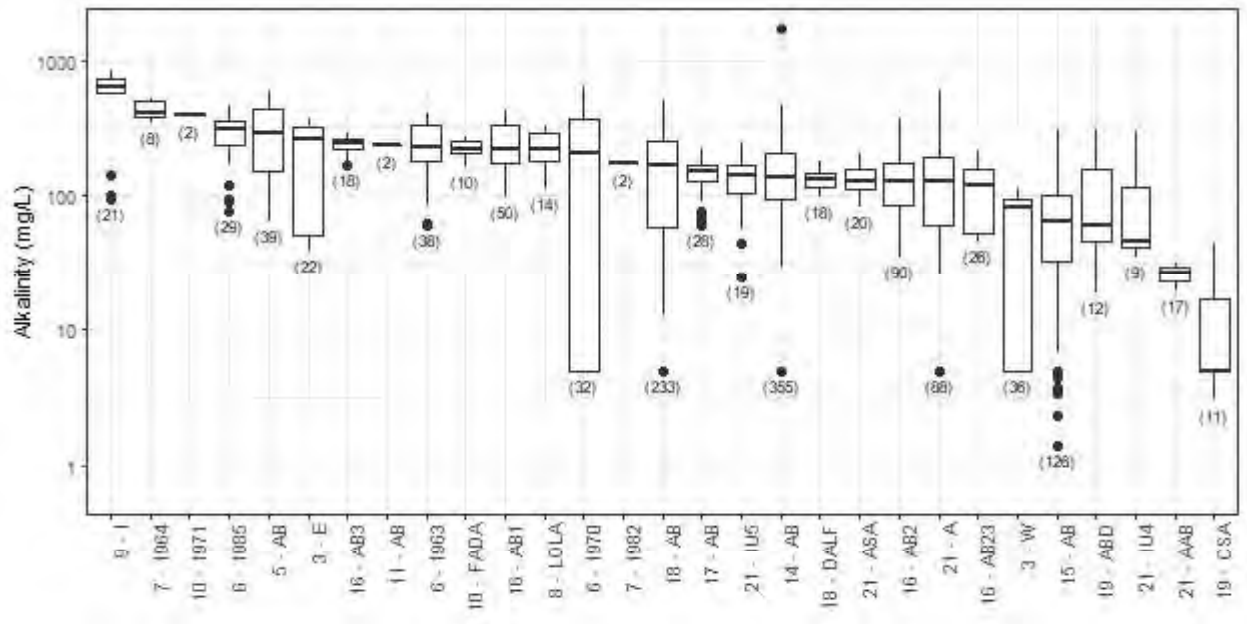

Figure C-1
Alkalinity

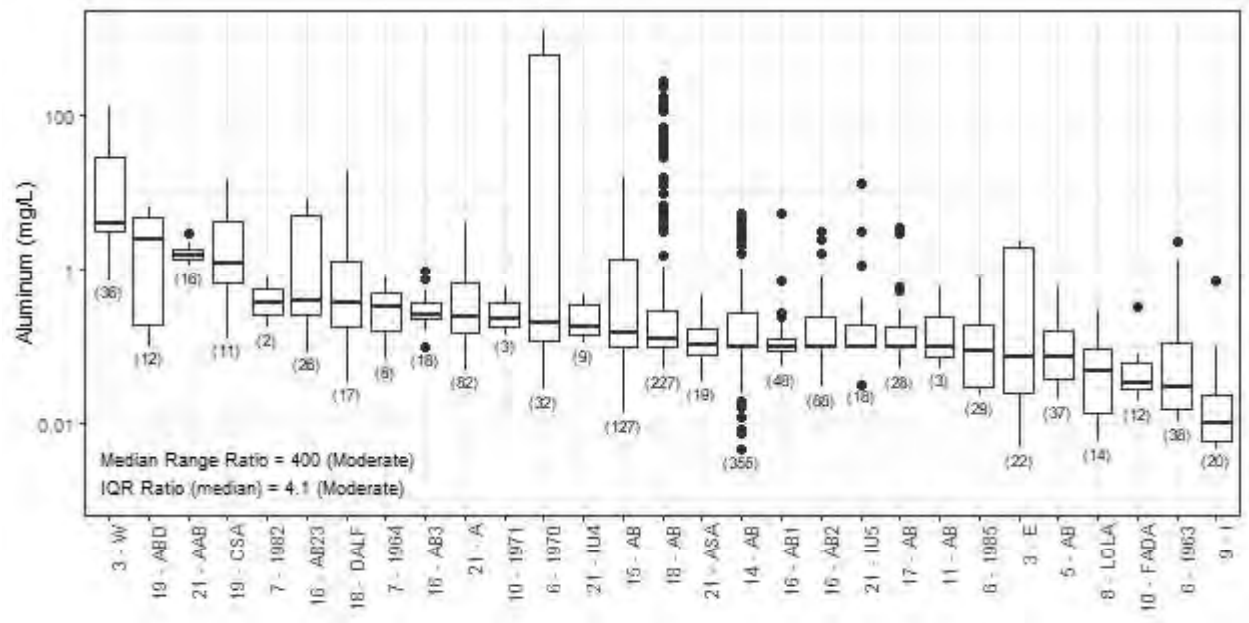

Figure C-2
Aluminum

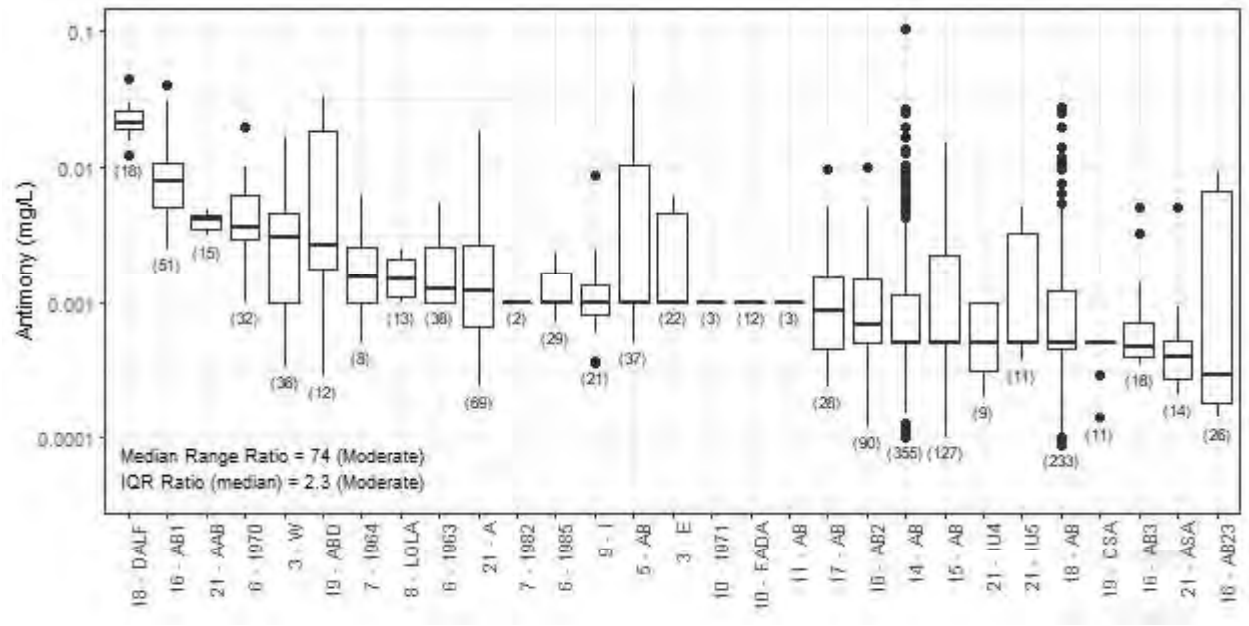

Figure C-3
Antimony

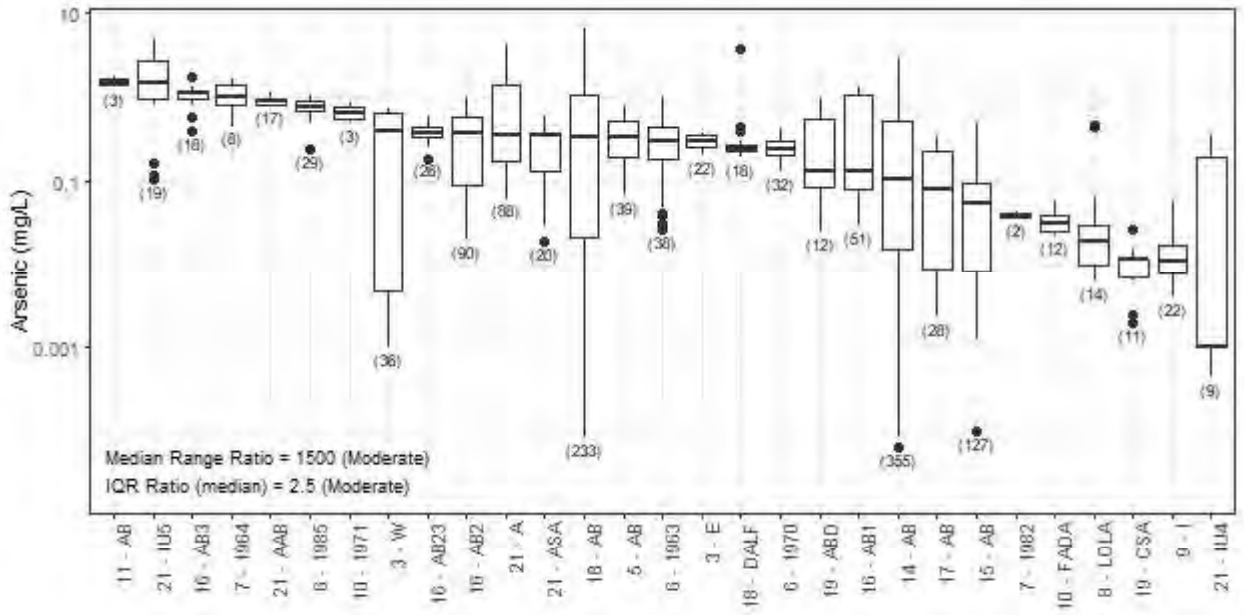

Figure C-4
Arsenic

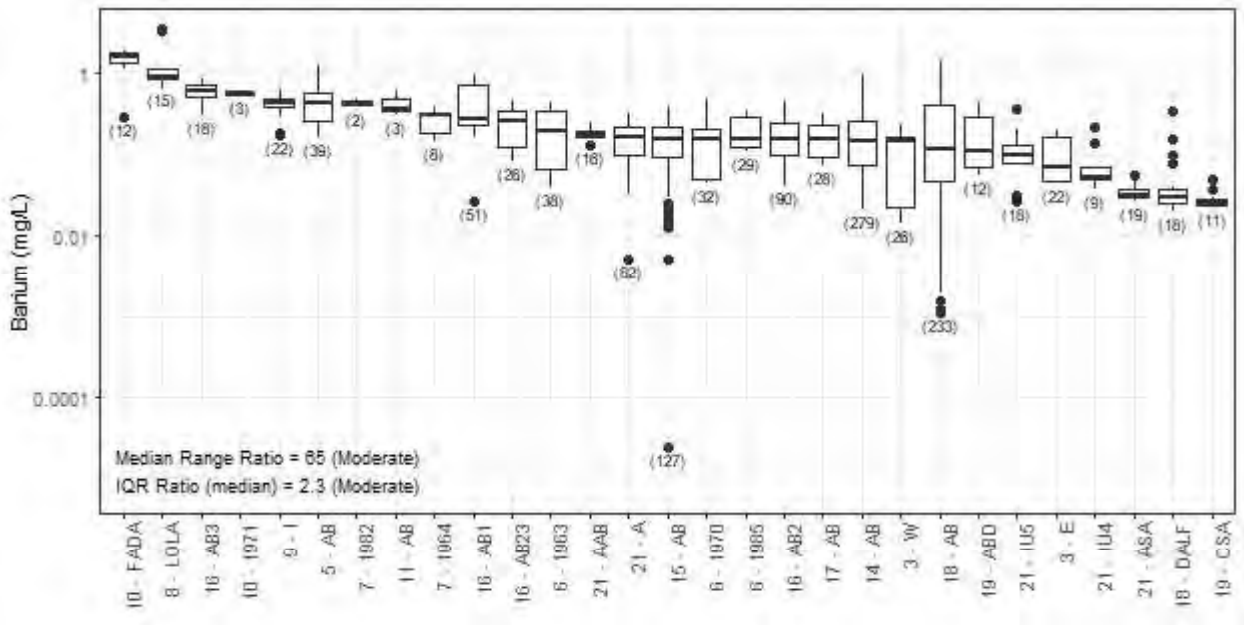

Figure C-5
Barium

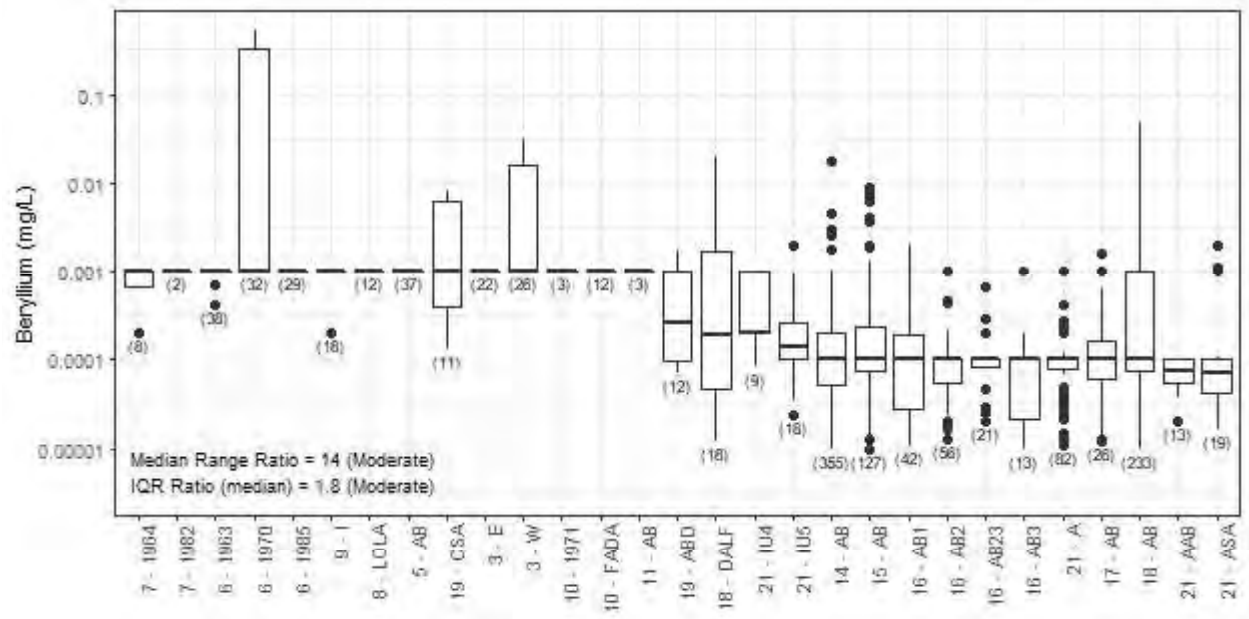

Figure C-6
Beryllium

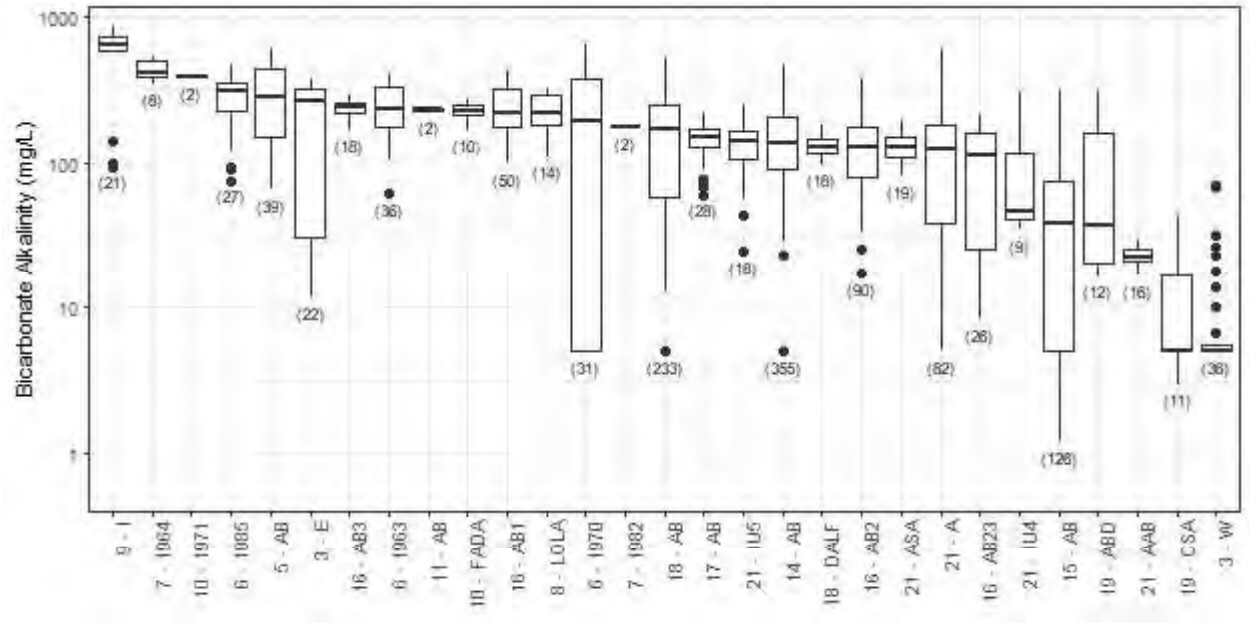

Figure C-7
Bicarbonate alkalinity

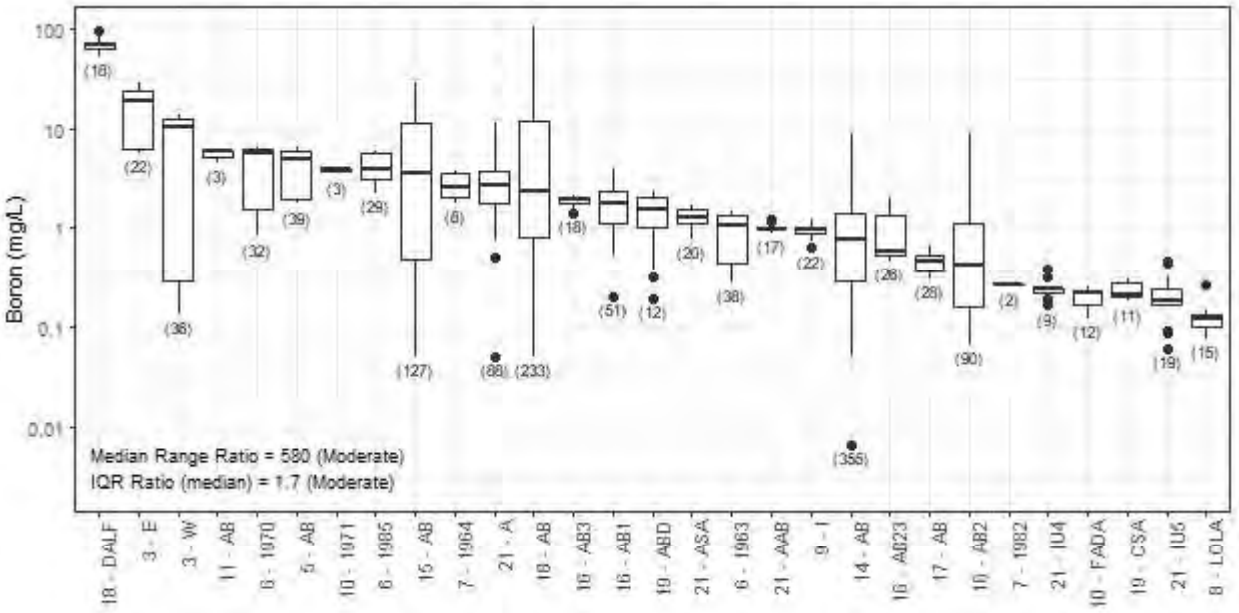

Figure C-8
Boron

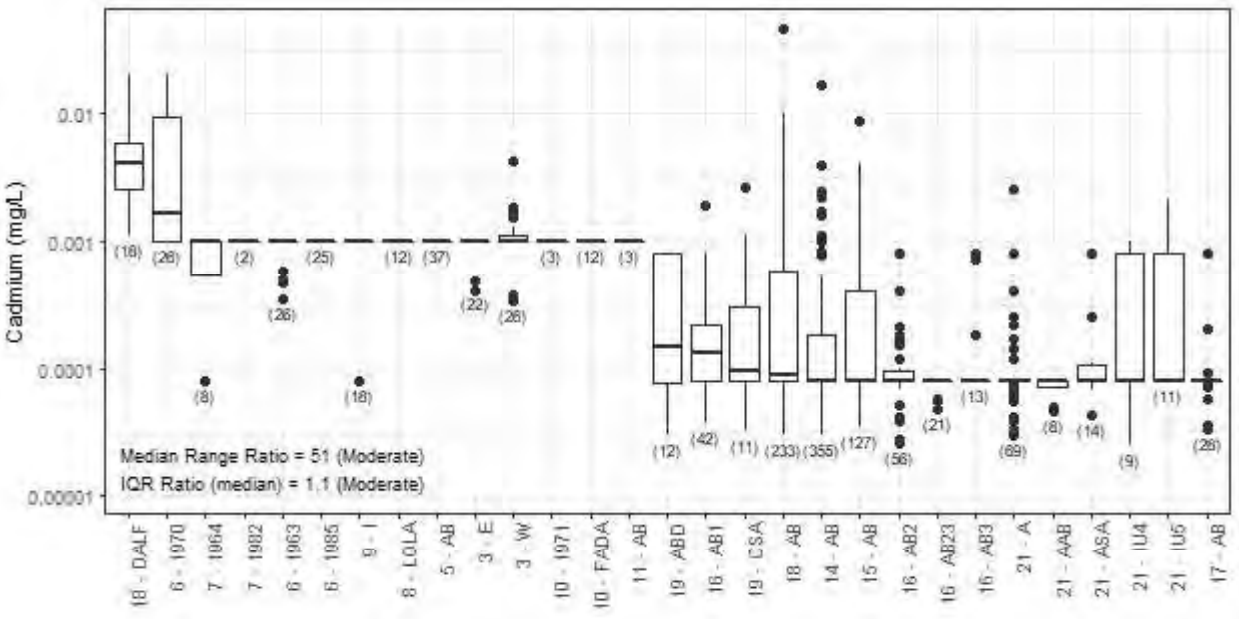

Figure C-9
Cadmium

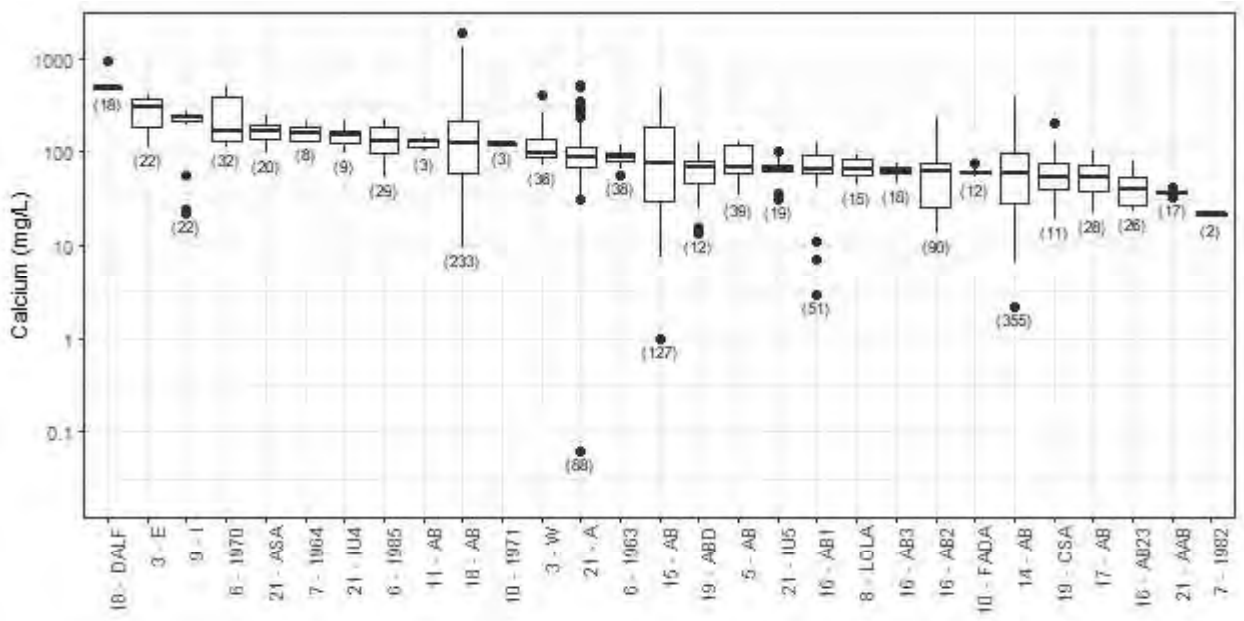

Figure C-10
Calcium

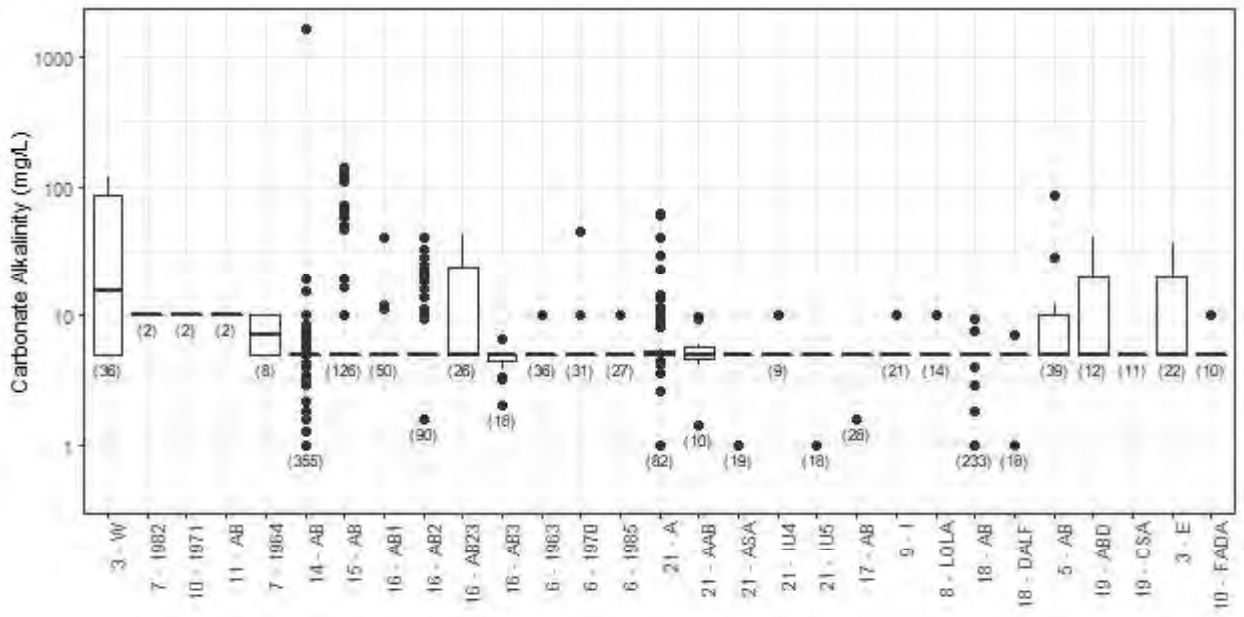

Figure C-11
Carbonate alkalinity

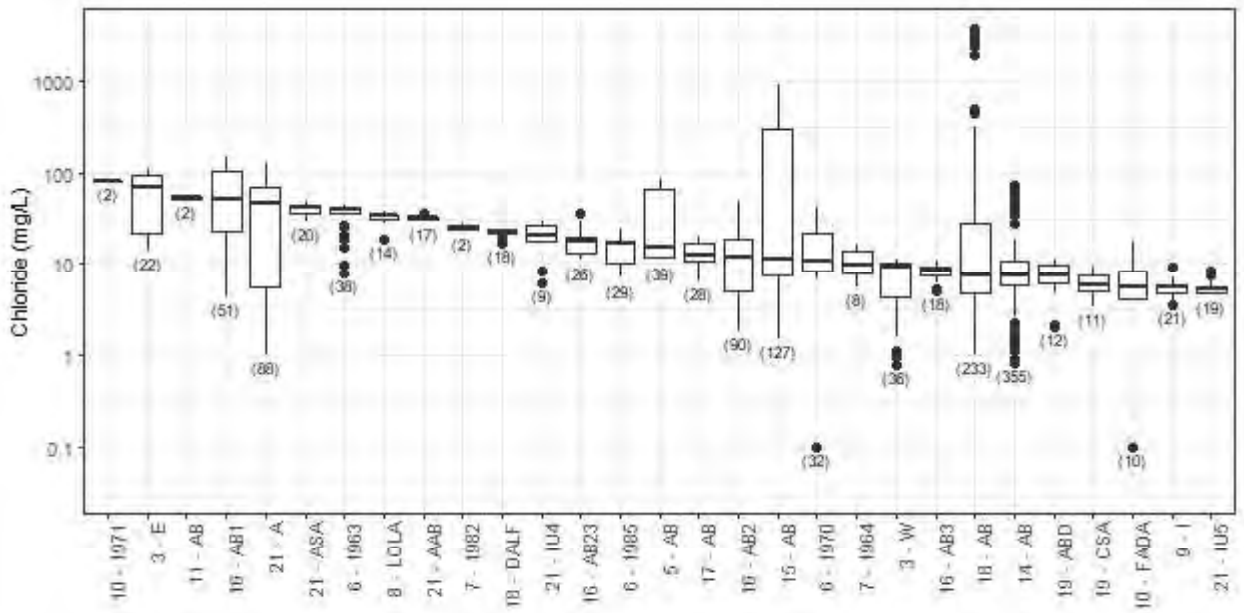

Figure C-12
Chloride

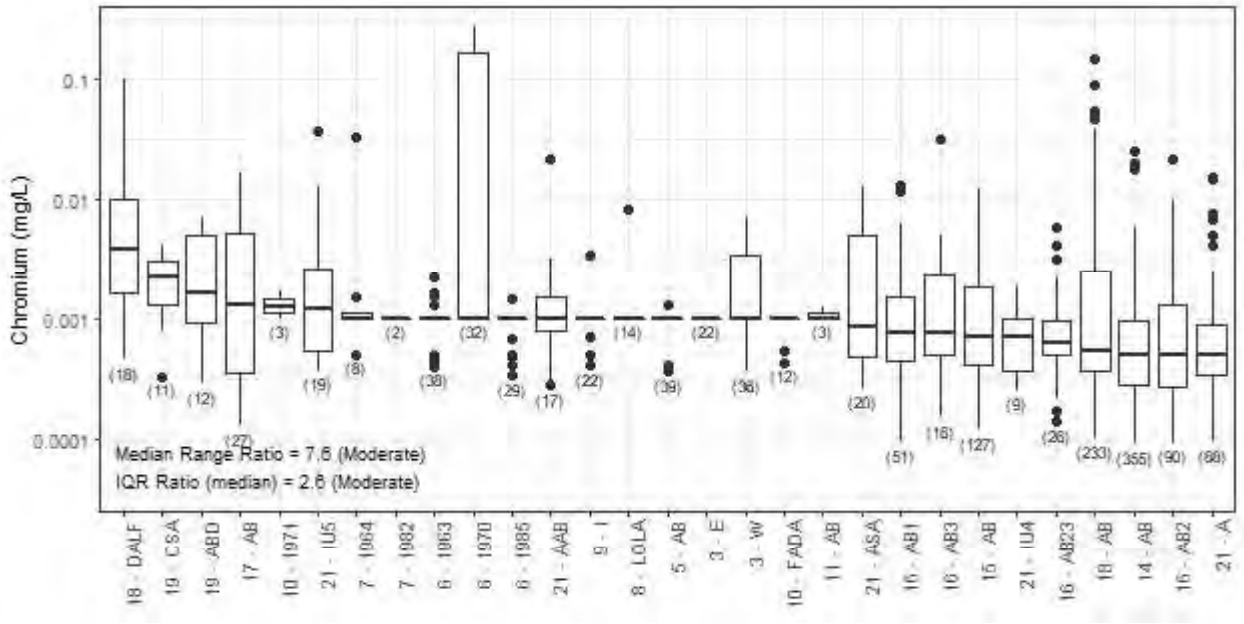

Figure C-13
Chromium

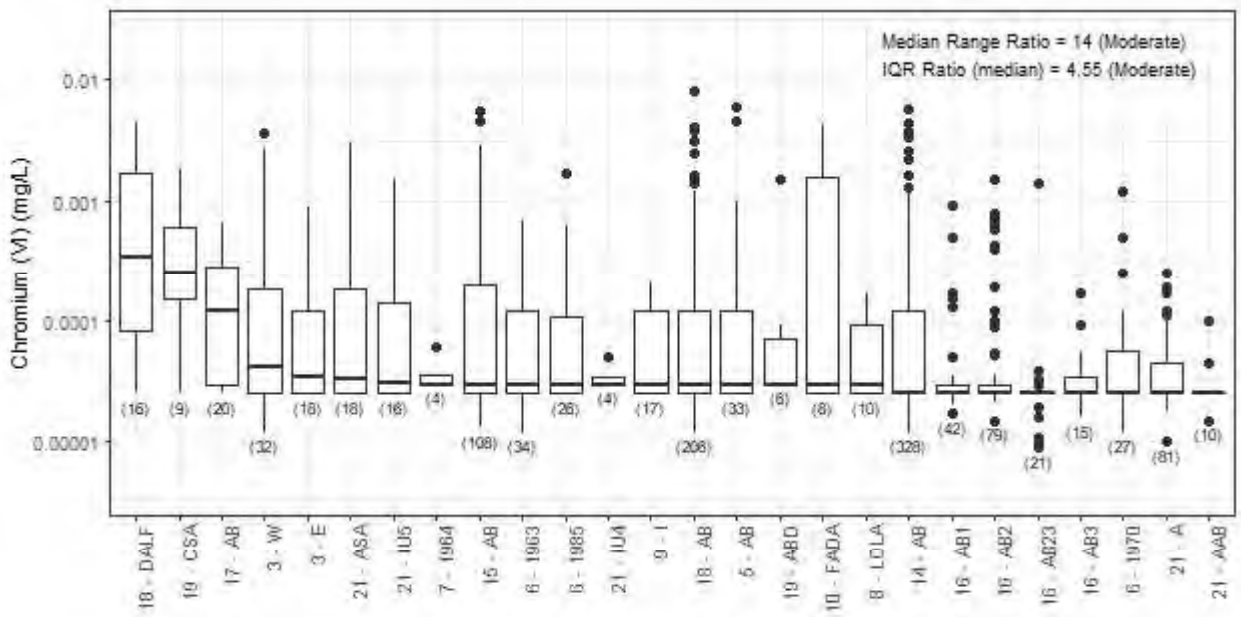

Figure C-14
Chromium (VI)

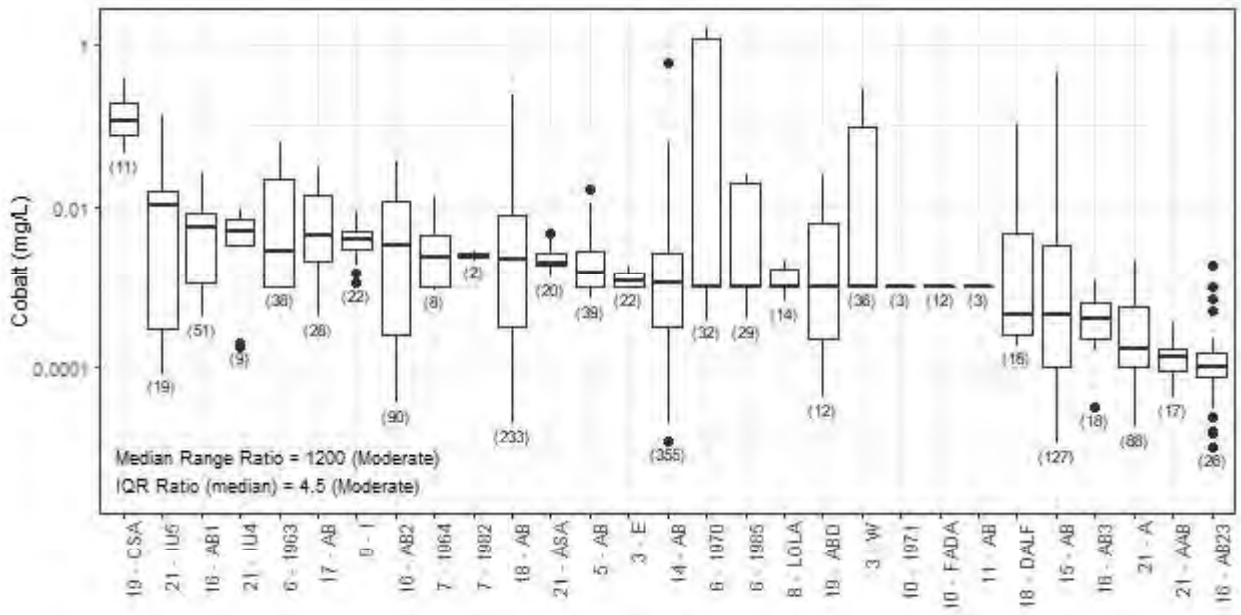

Figure C-15
Cobalt

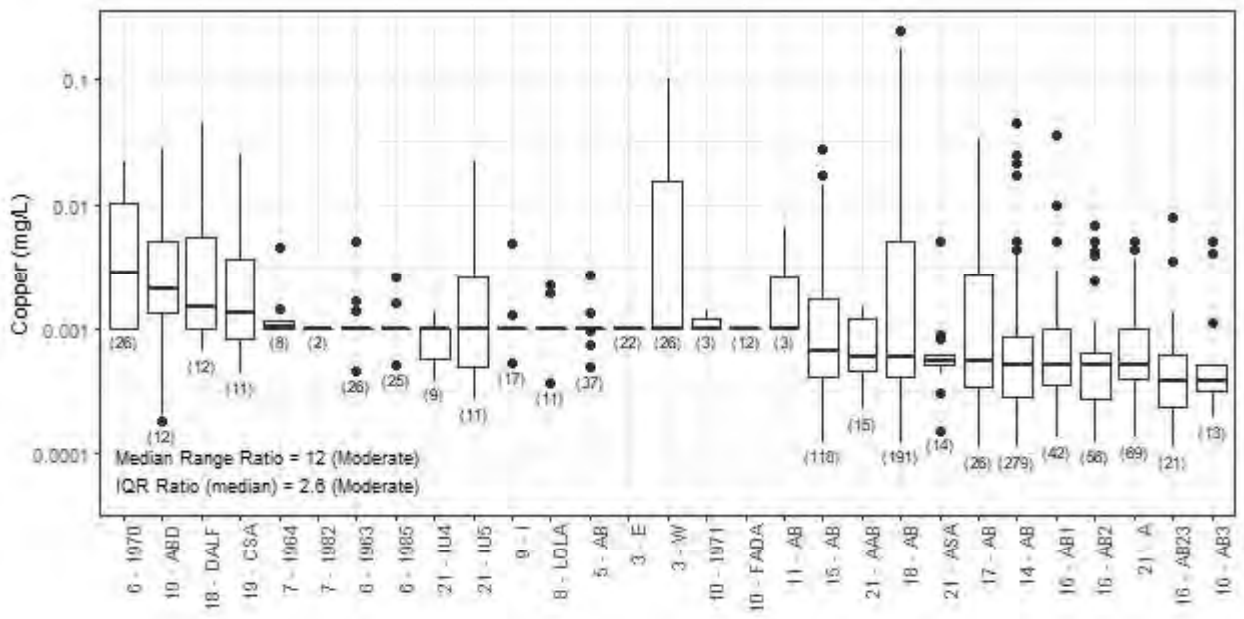

Figure C-16
Copper

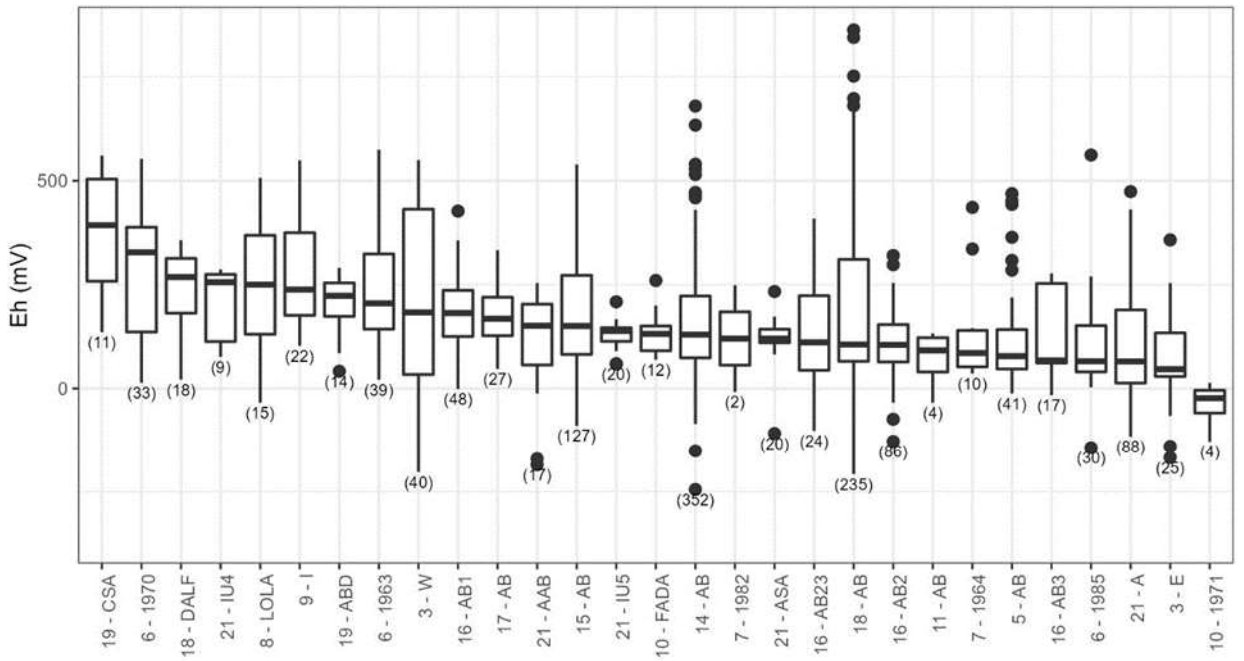

Figure C-17
Eh

Porewater Variability

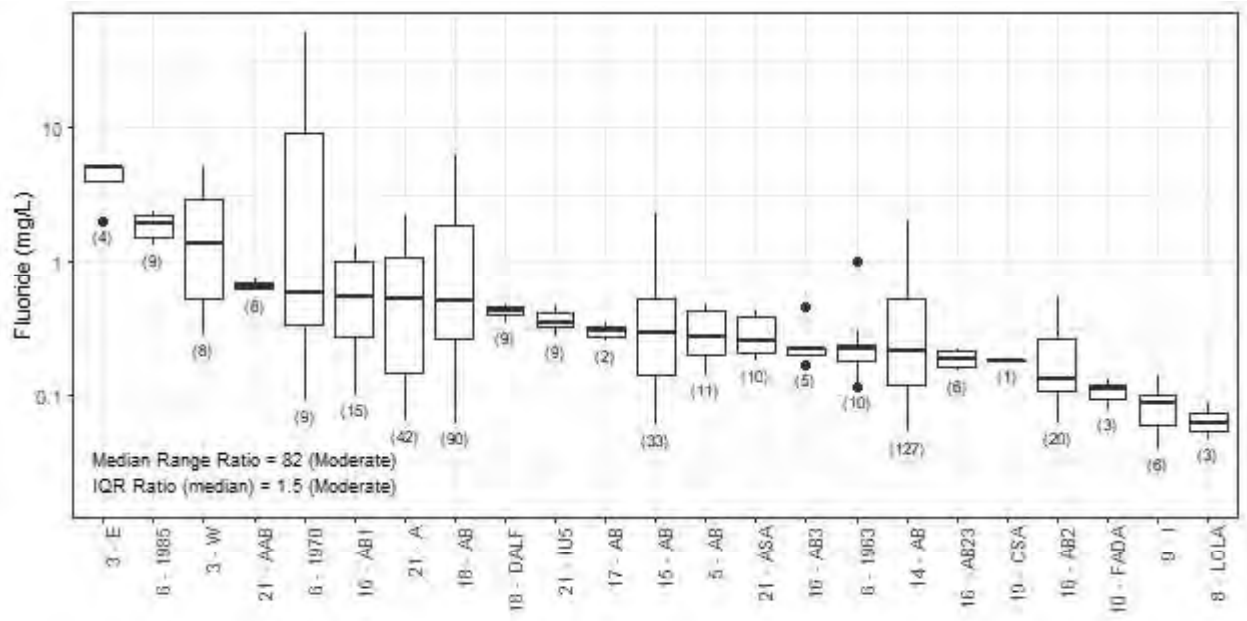

Figure C-18
Fluoride

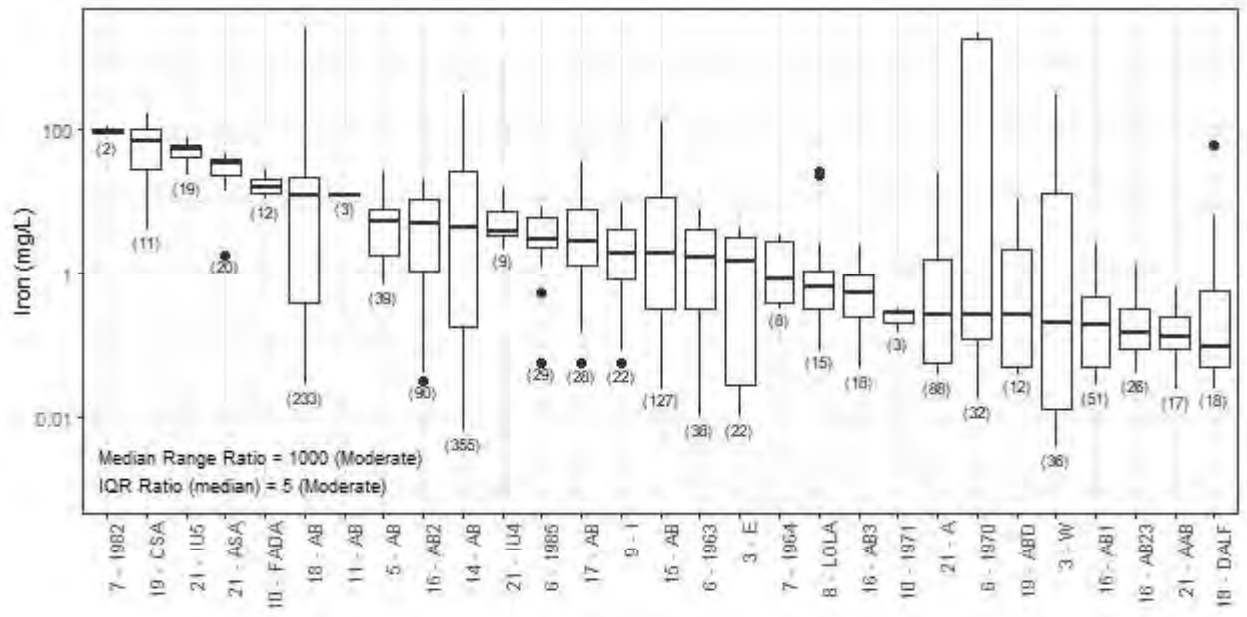

Figure C-19
Iron

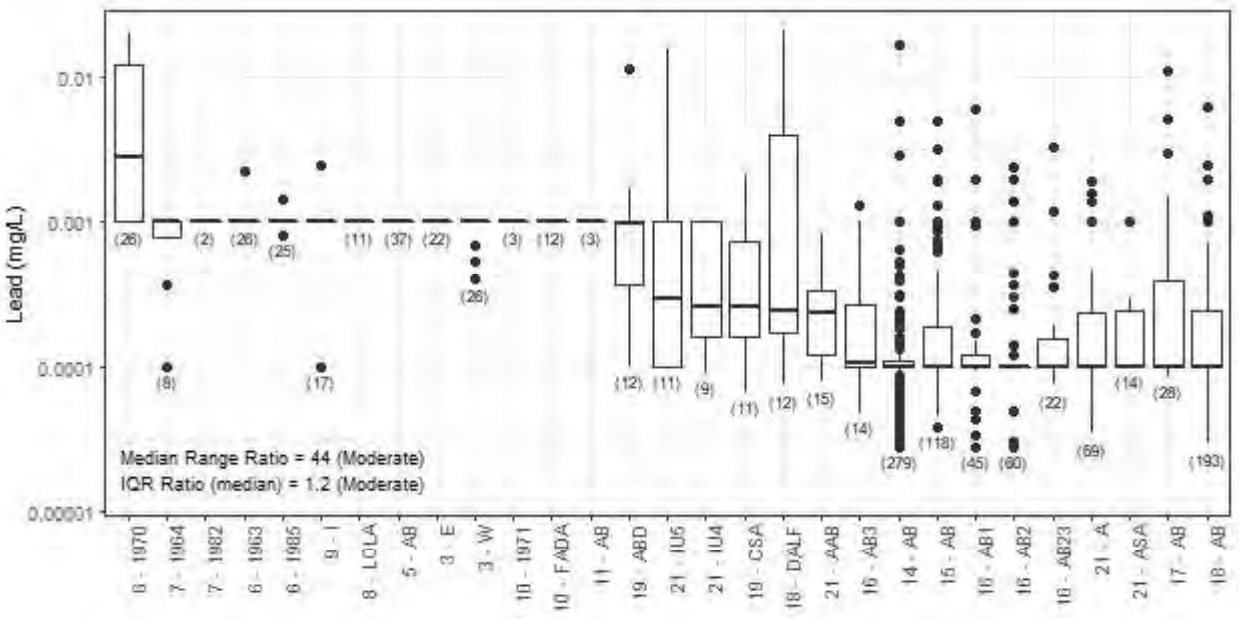

Figure C-20
Lead

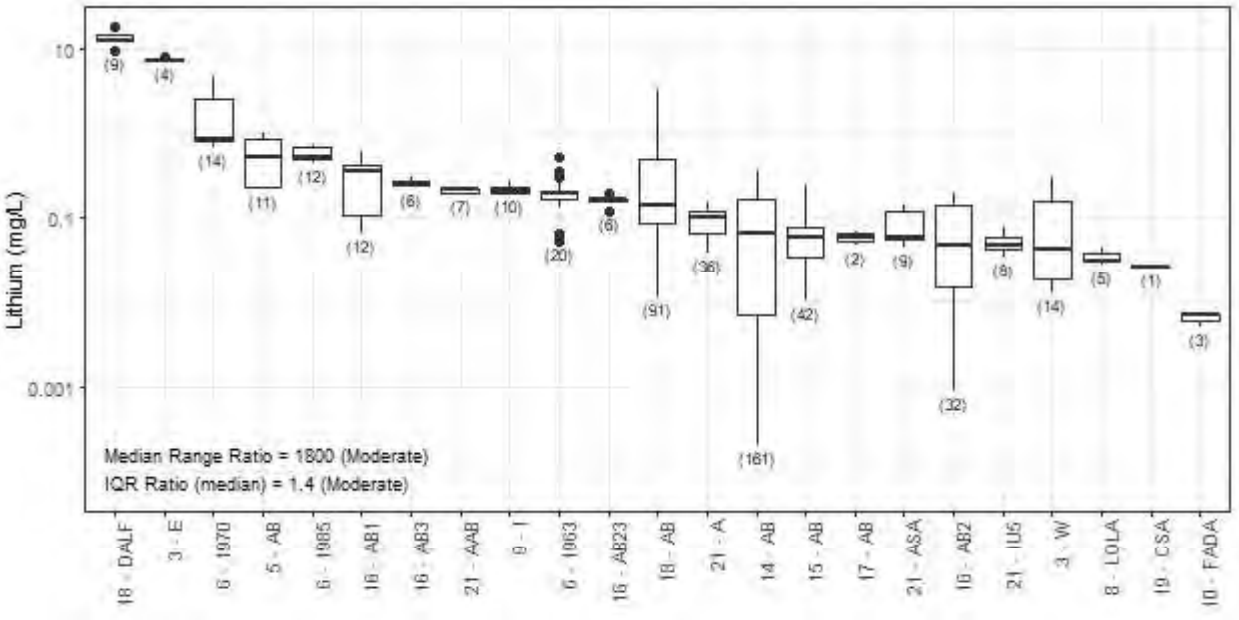

Figure C-21
Lithium

Porewater Variability

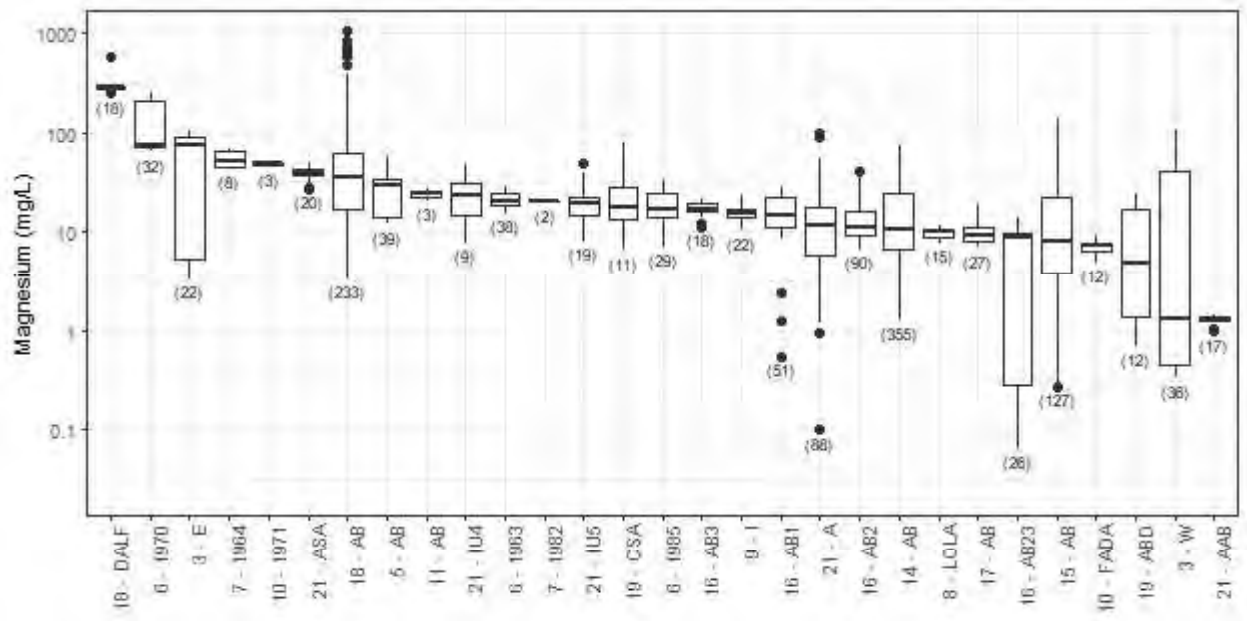

Figure C-22
Magnesium

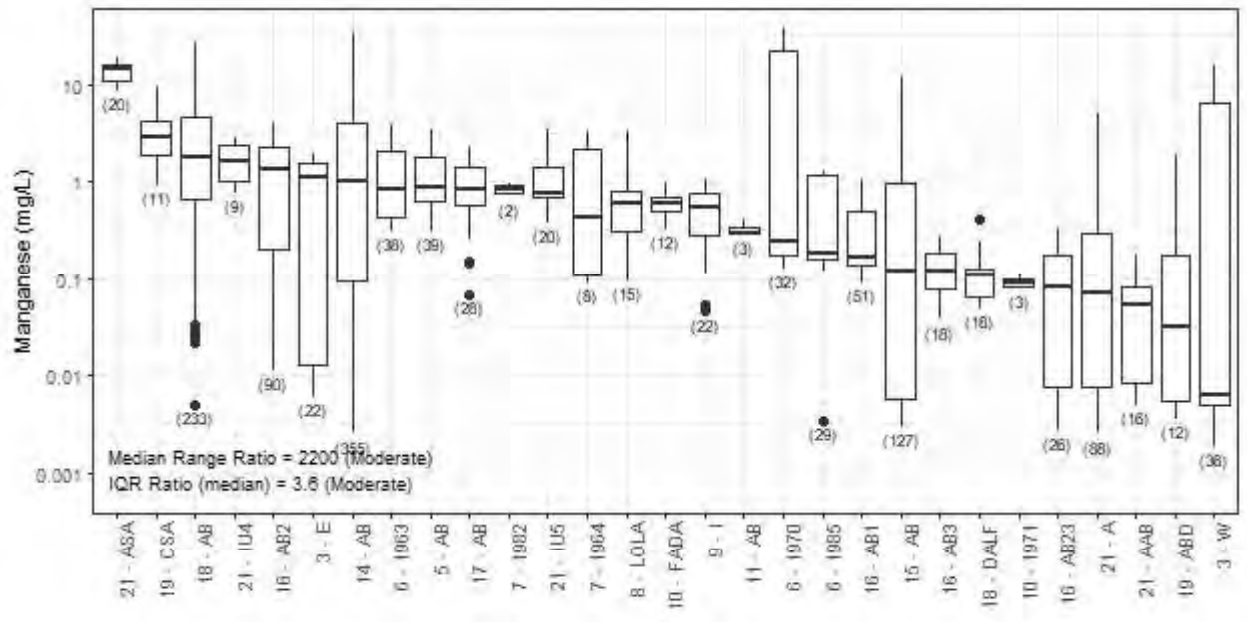

Figure C-23
Manganese

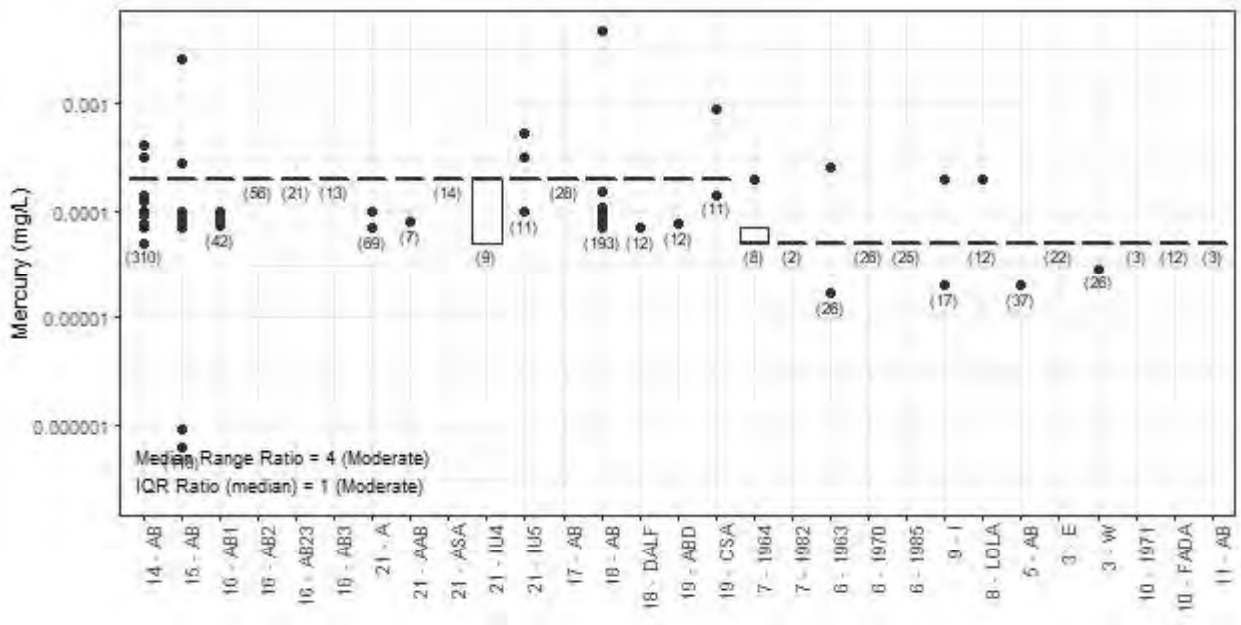

Figure C-24
Mercury

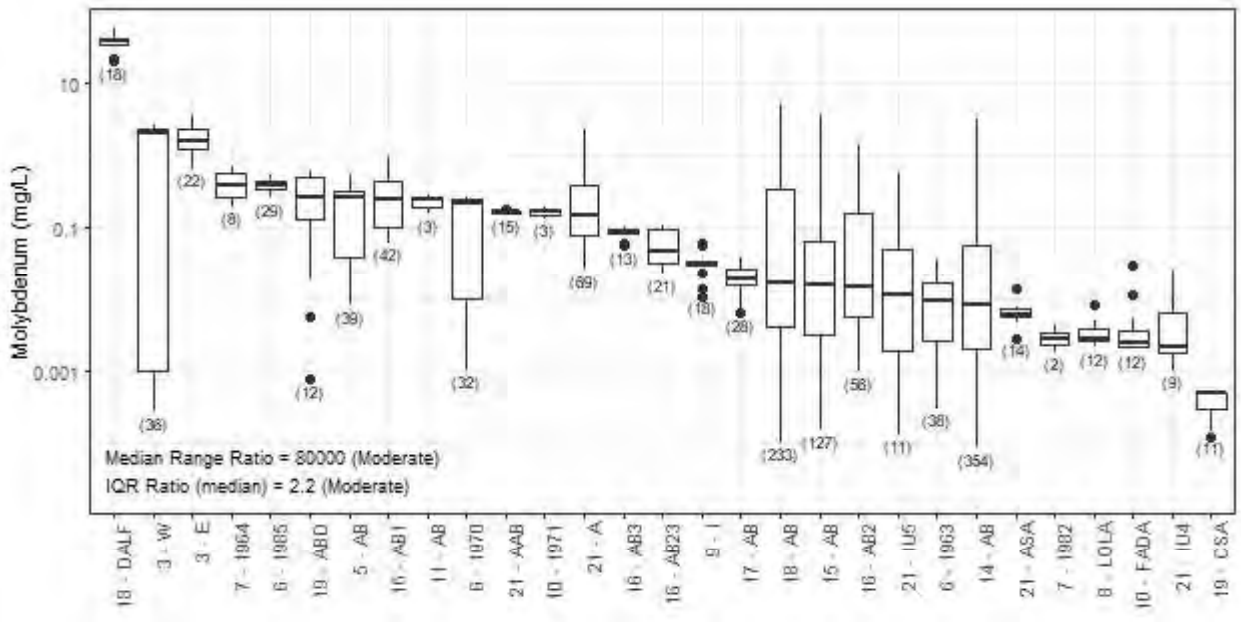

Figure C-25
Molybdenum

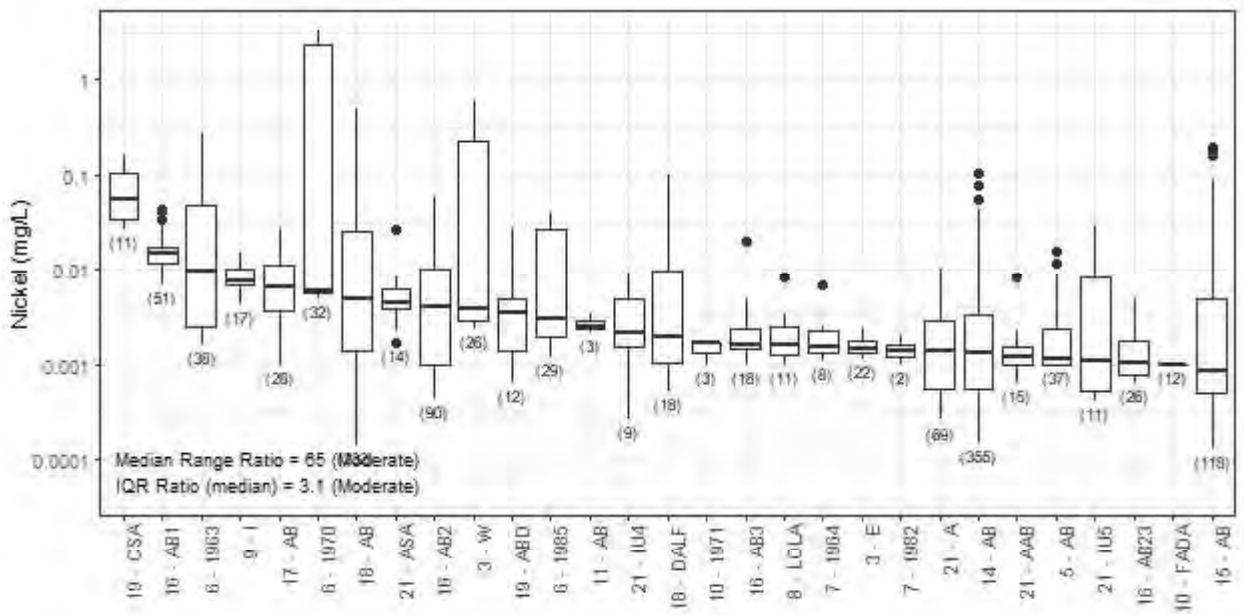

Figure C-26
Nickel

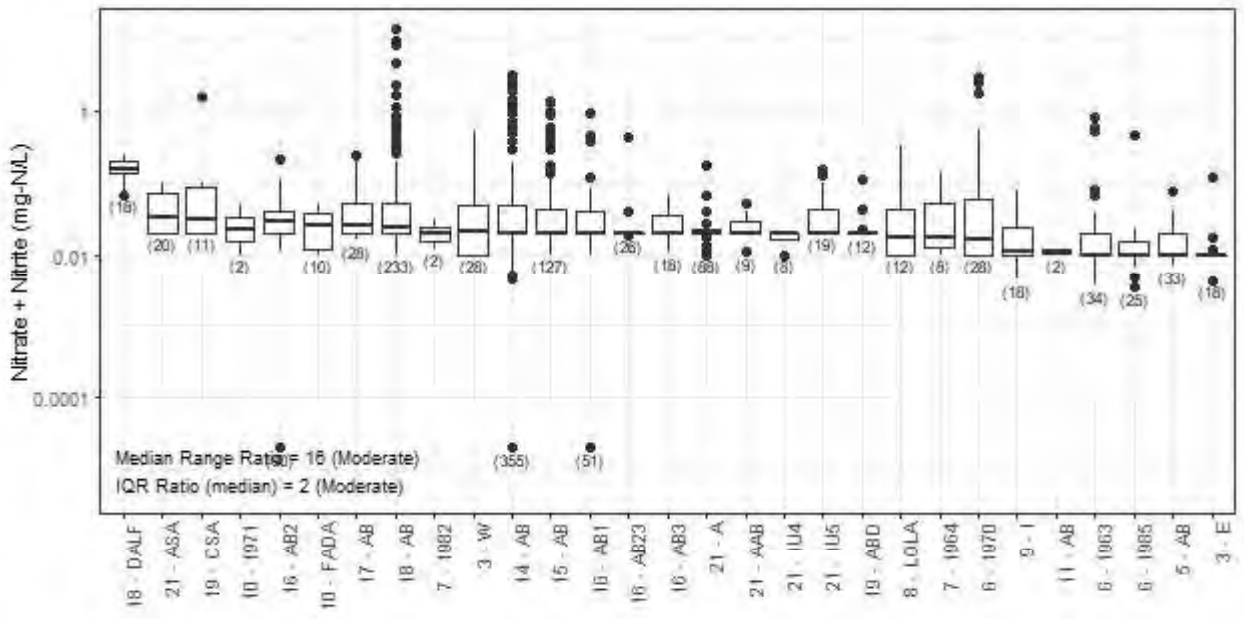

Figure C-27
Nitrate + Nitrite

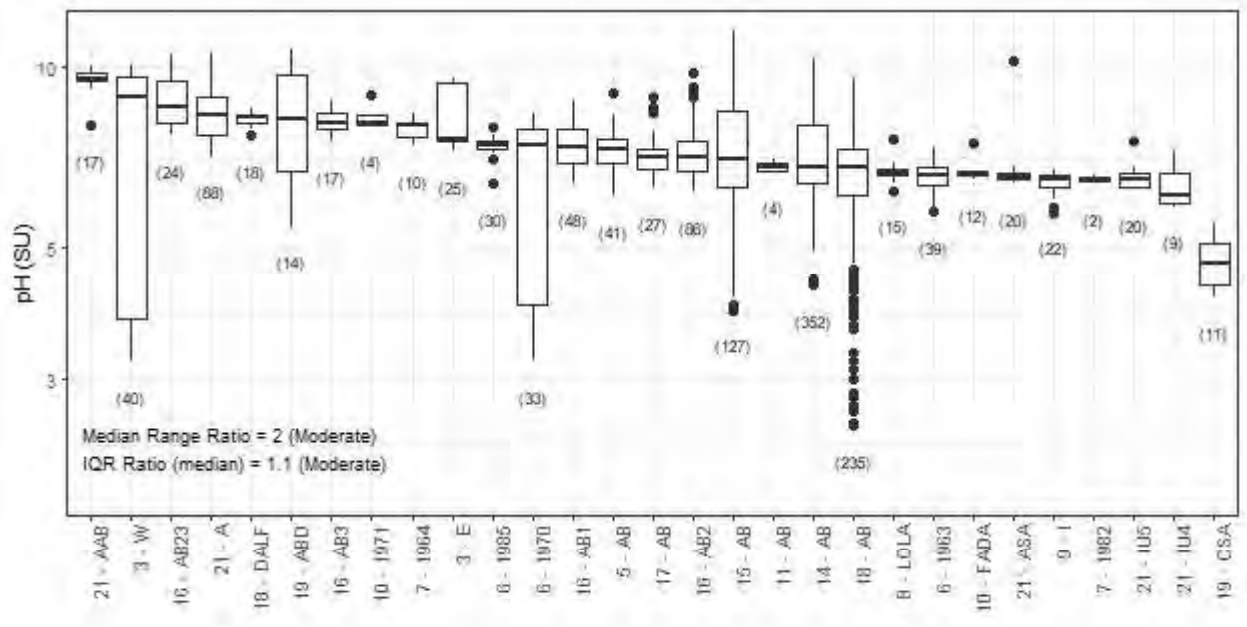

Figure C-28
pH

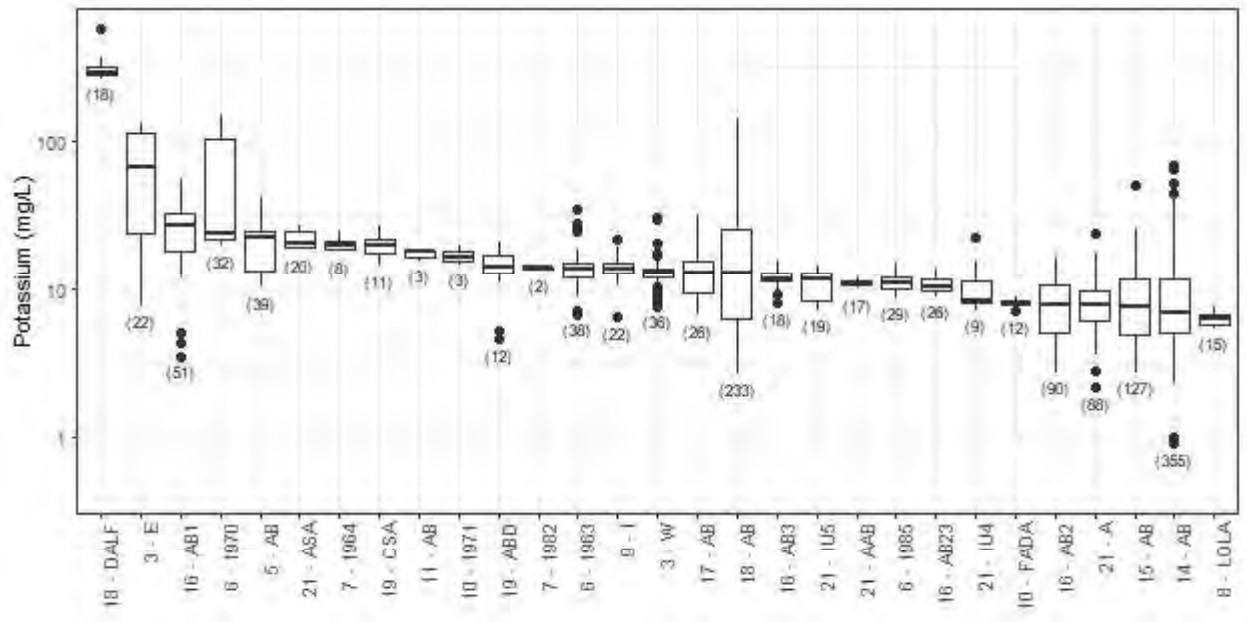

Figure C-29
Potassium

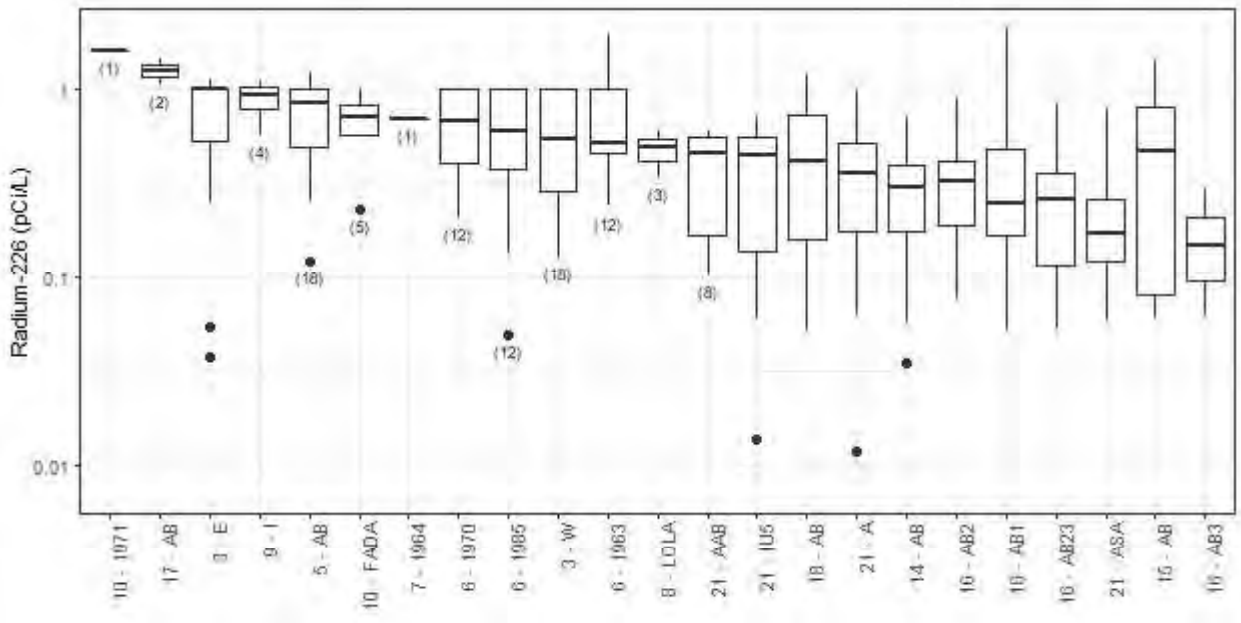

Figure C-30
Radium-226

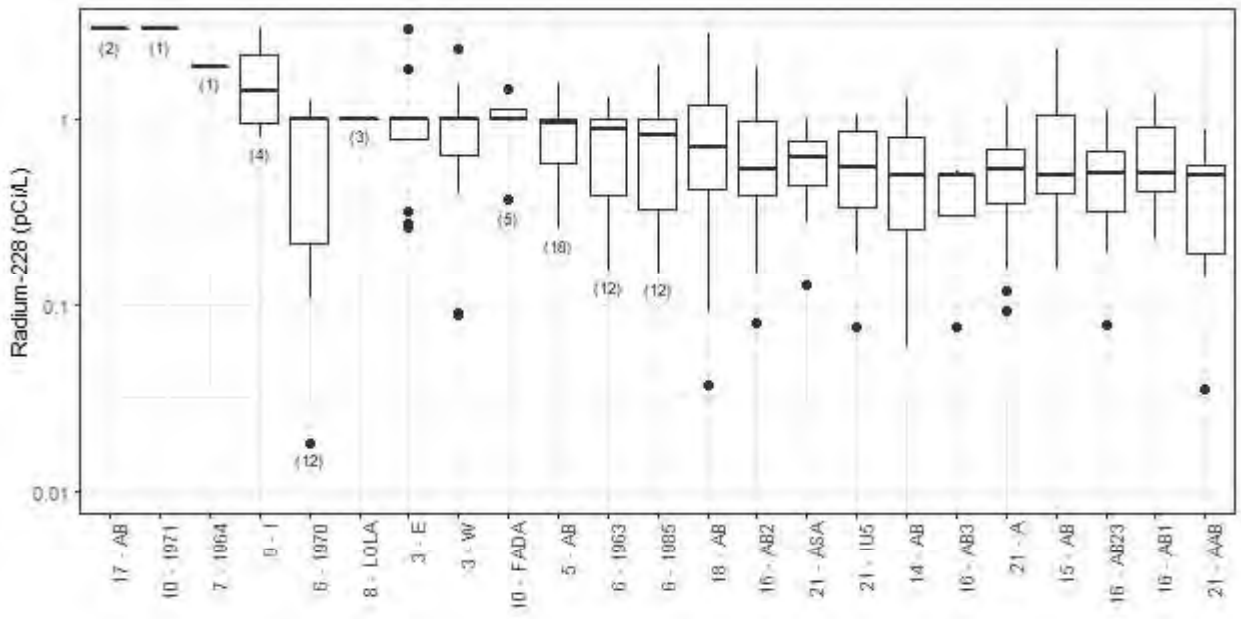

Figure C-31
Radium-228

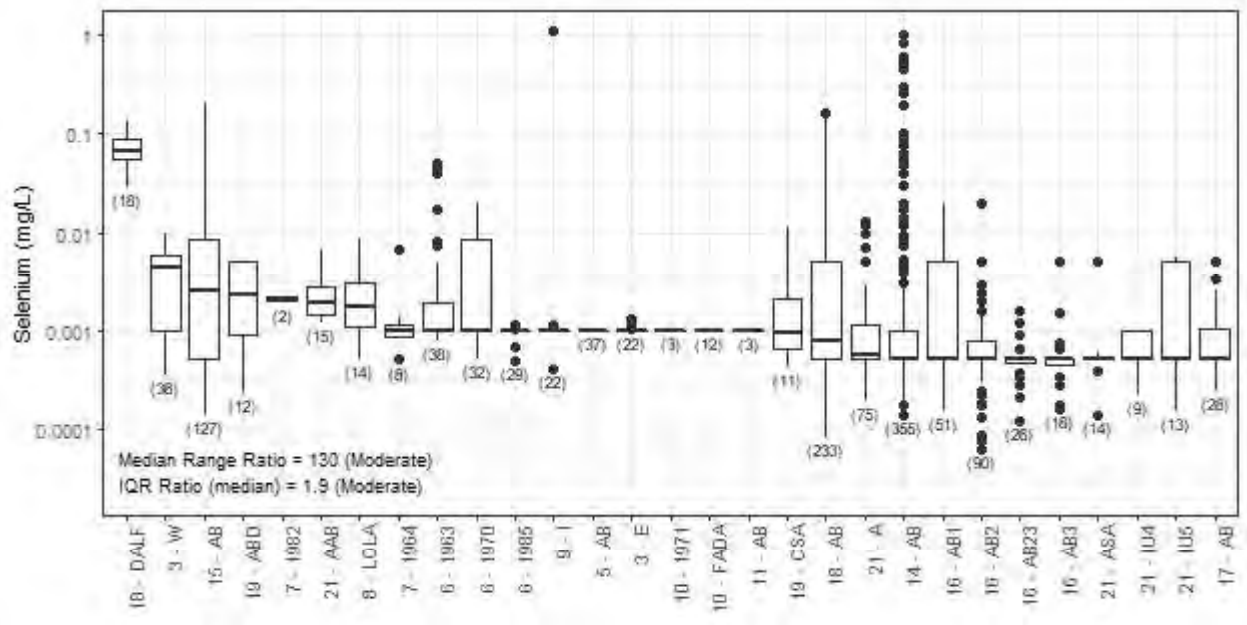

Figure C-32
Selenium

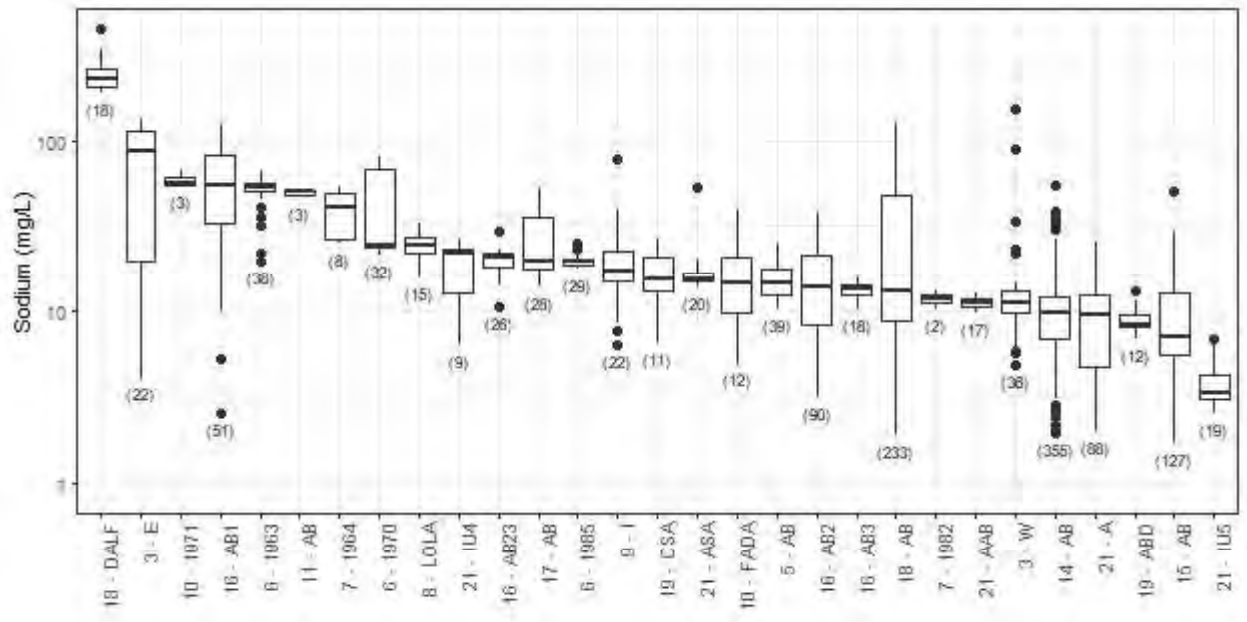

Figure C-33
Sodium

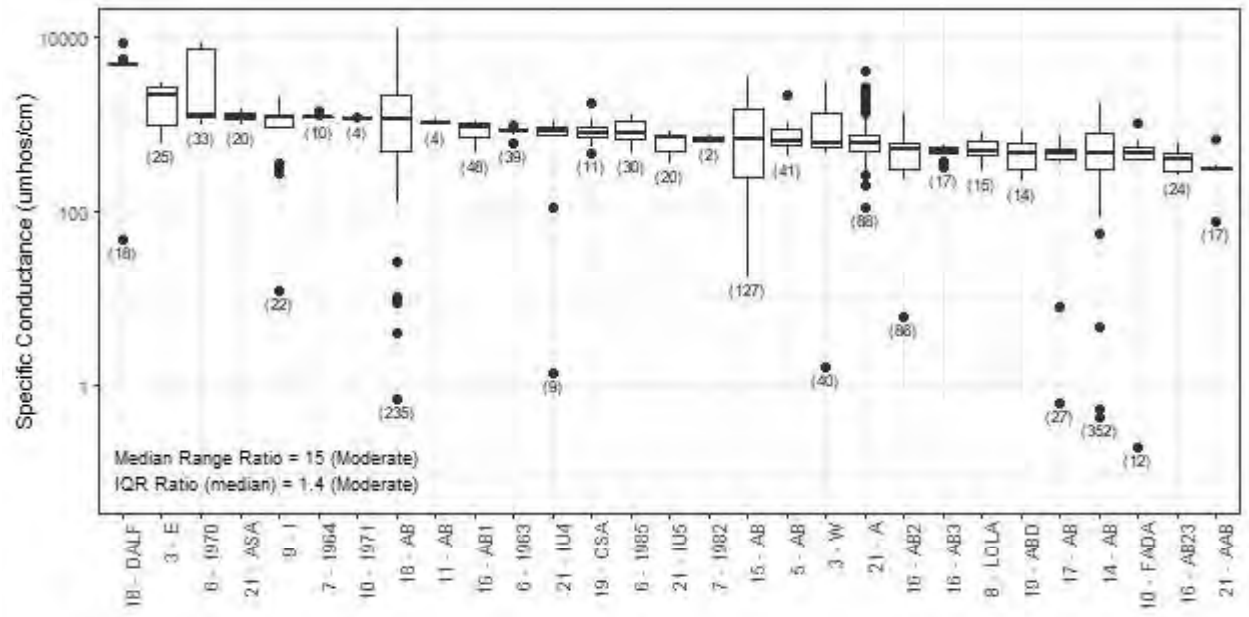

Figure C-34
Specific conductance

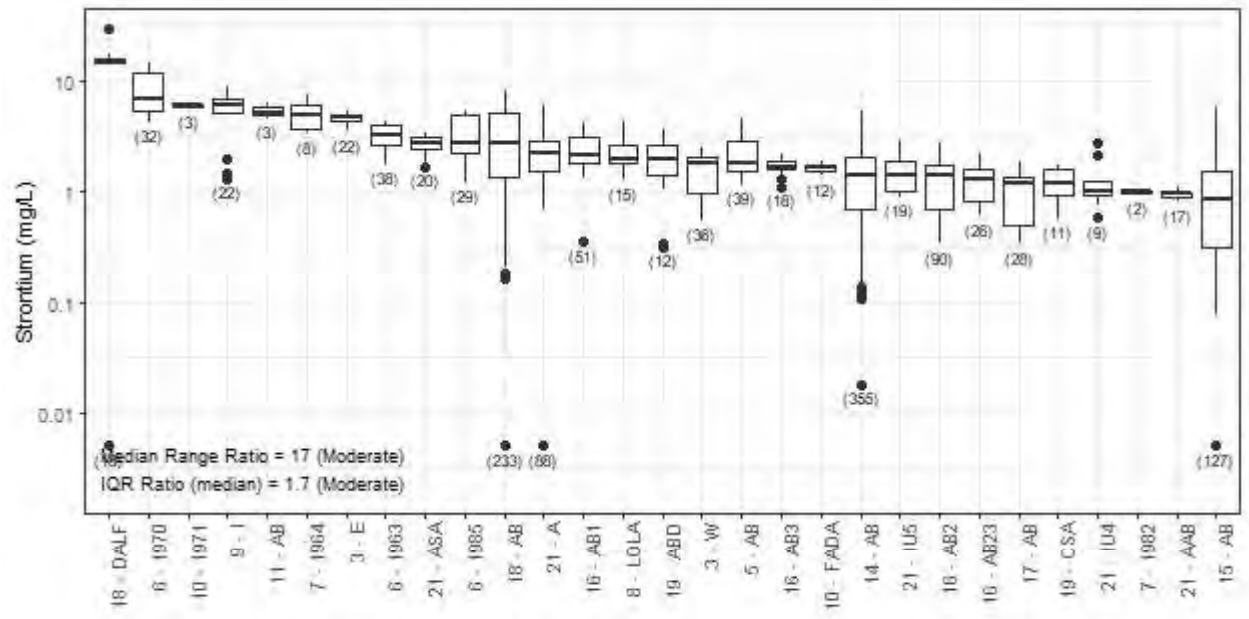

Figure C-35
Strontium

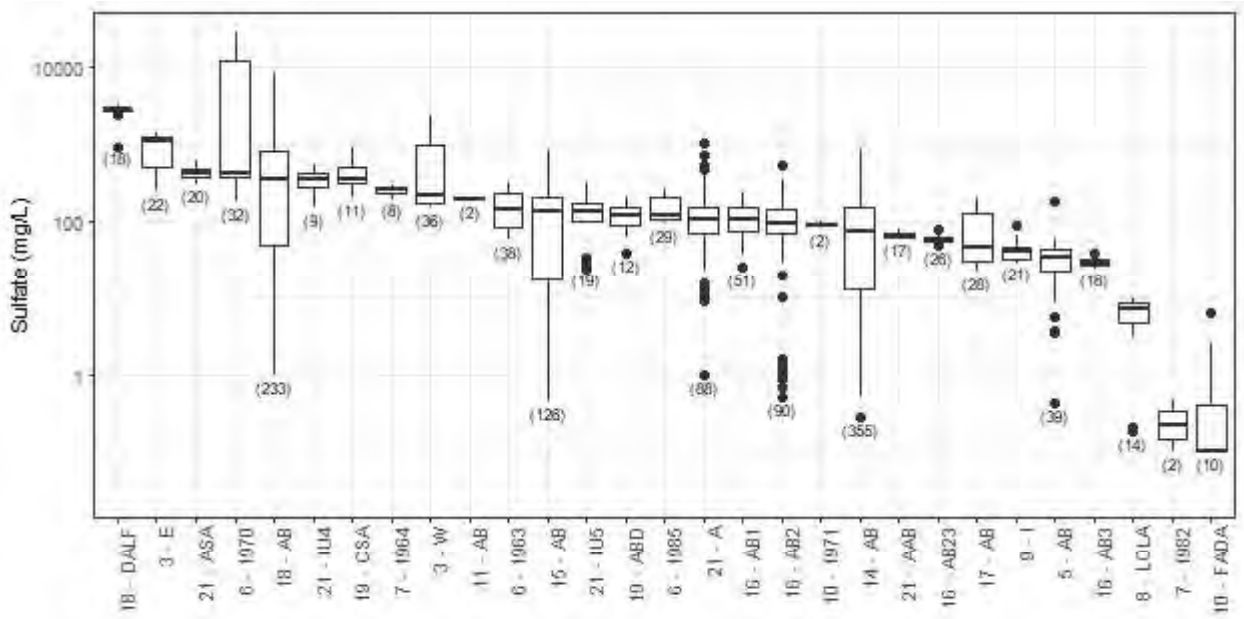

Figure C-36
Sulfate

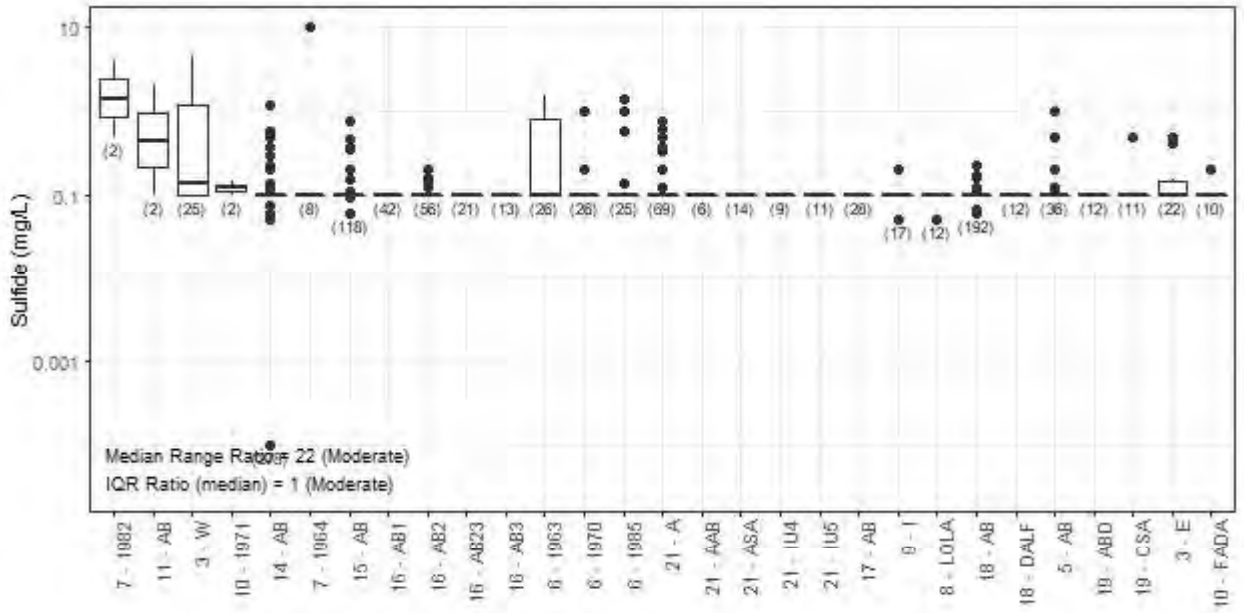

Figure C-37
Sulfide

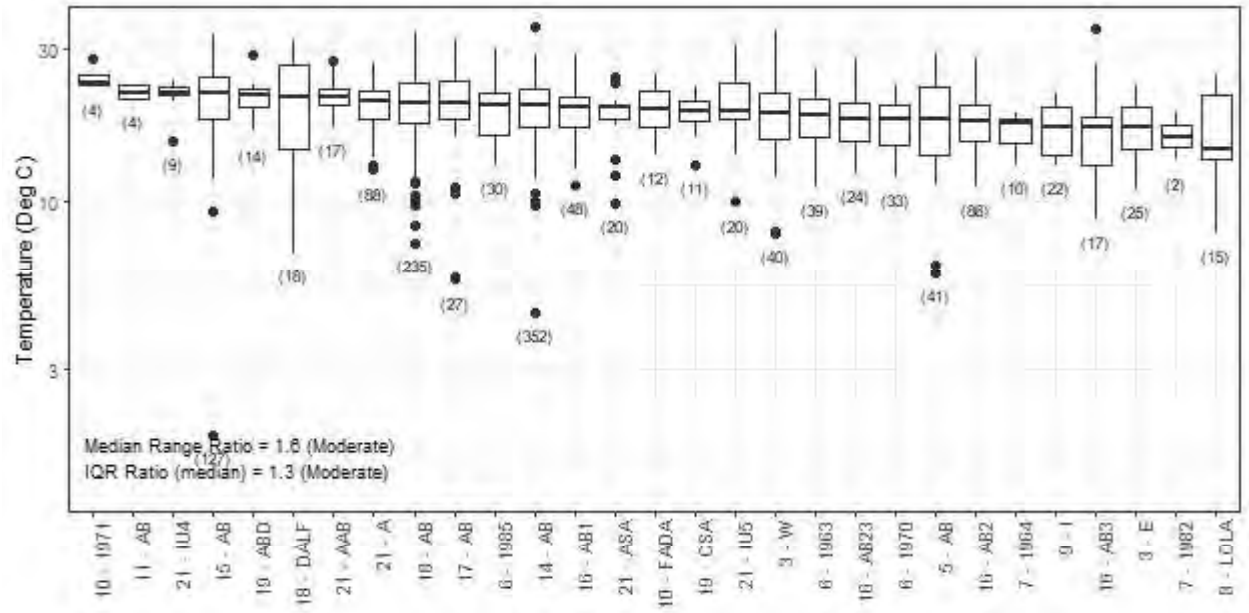

Figure C-38
Temperature

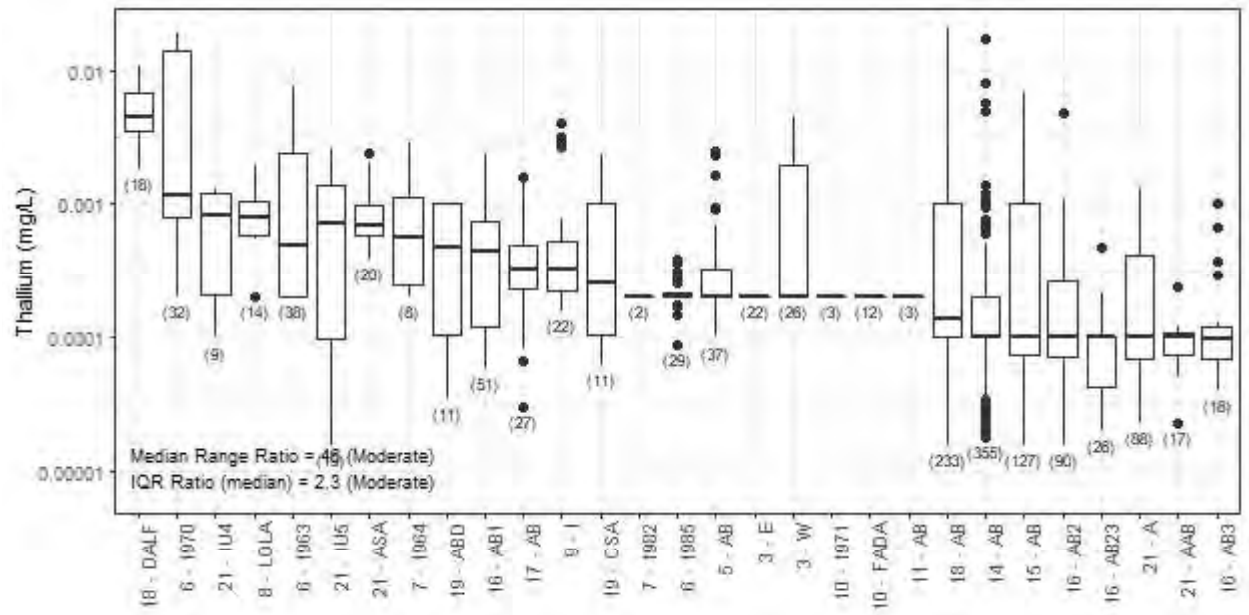

Figure C-39
Thallium

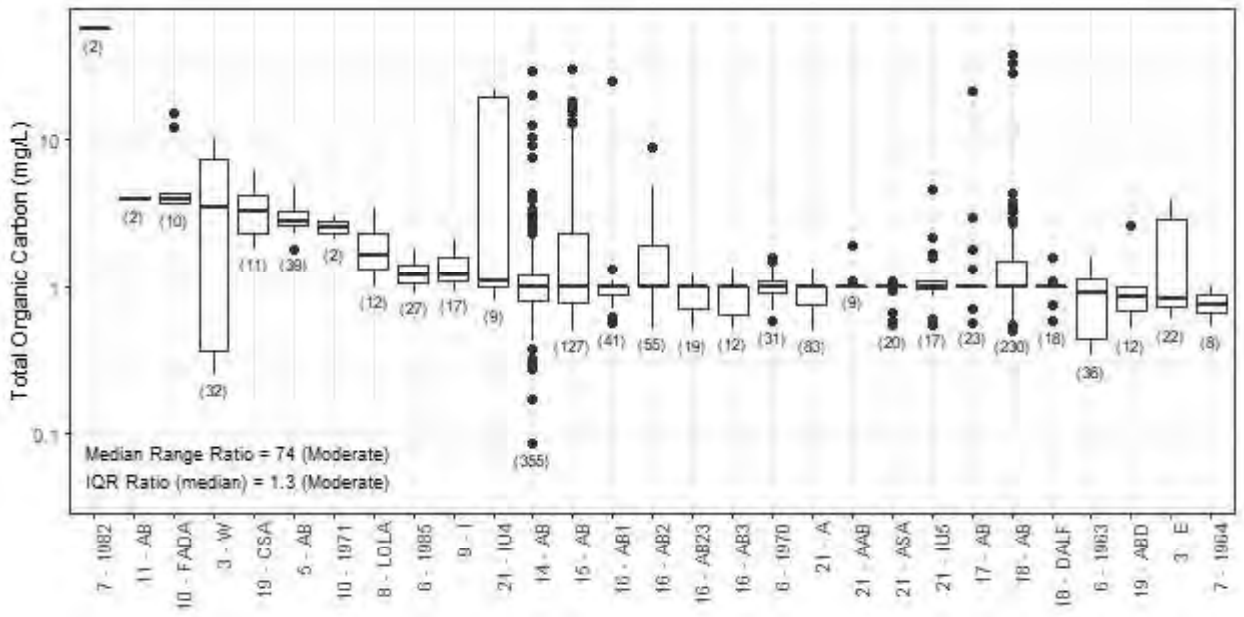

Figure C-40
Total organic carbon

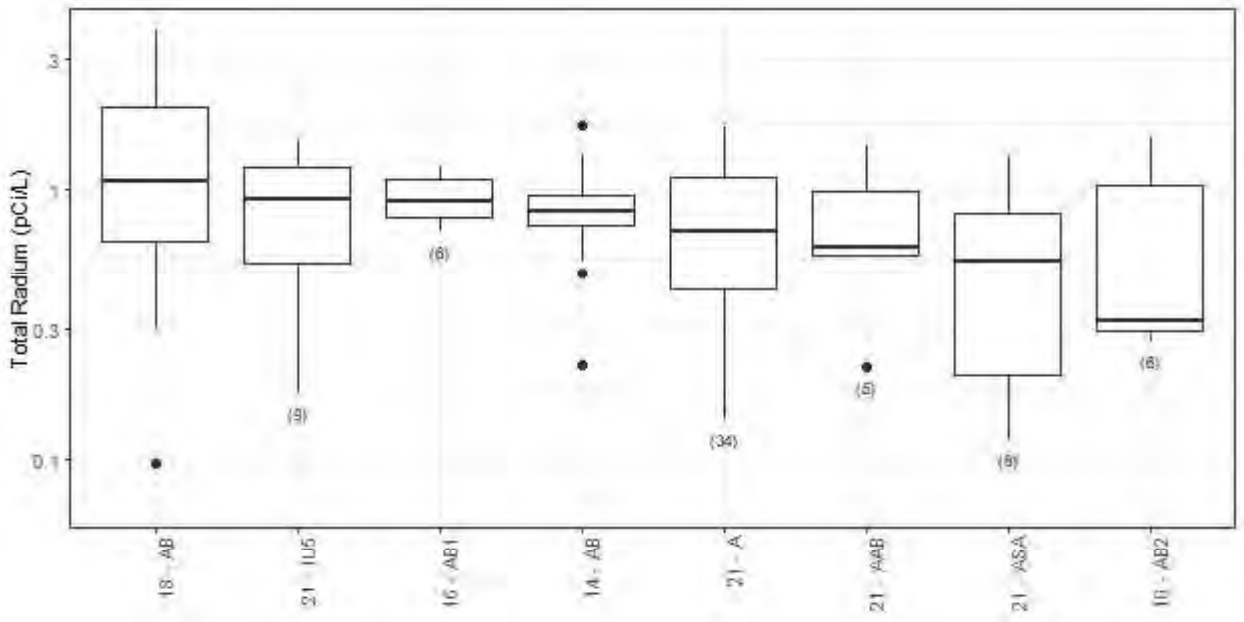

Figure C-41
Total radium

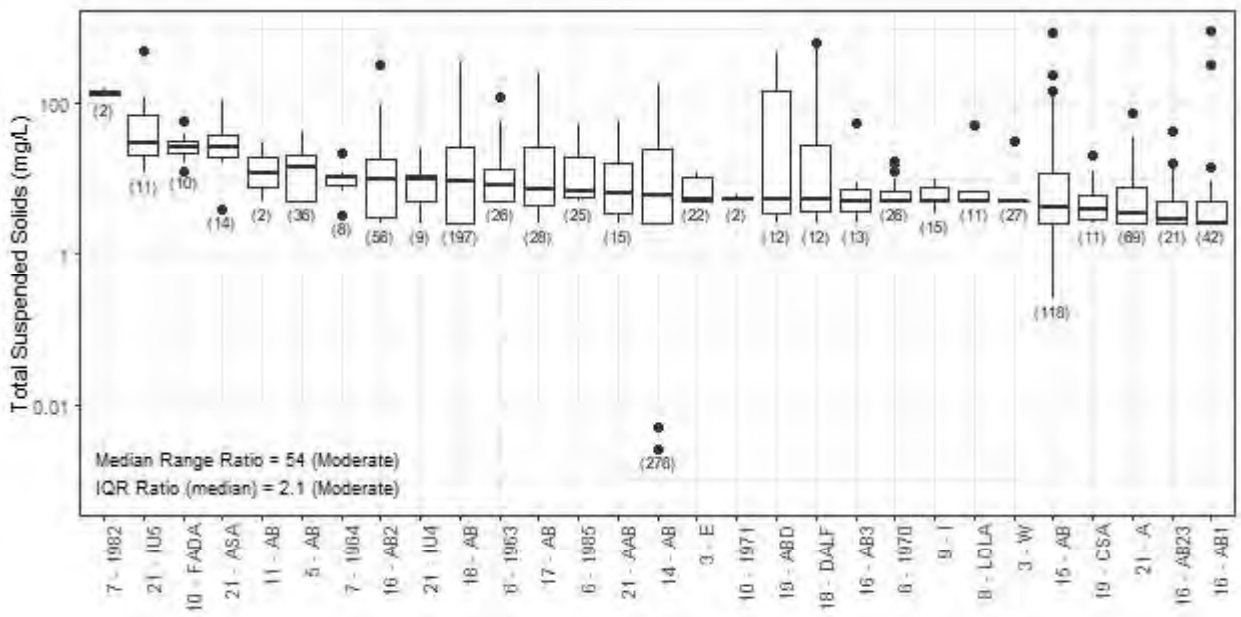

Figure C-42
Total suspended solids

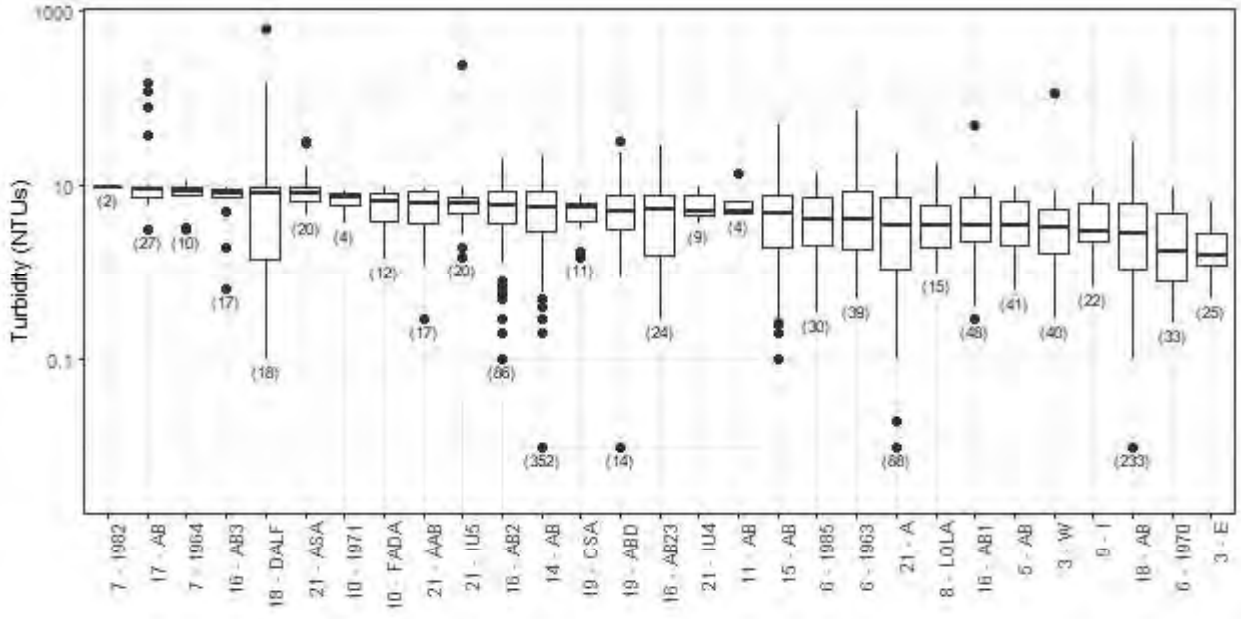

Figure C-43
Turbidity

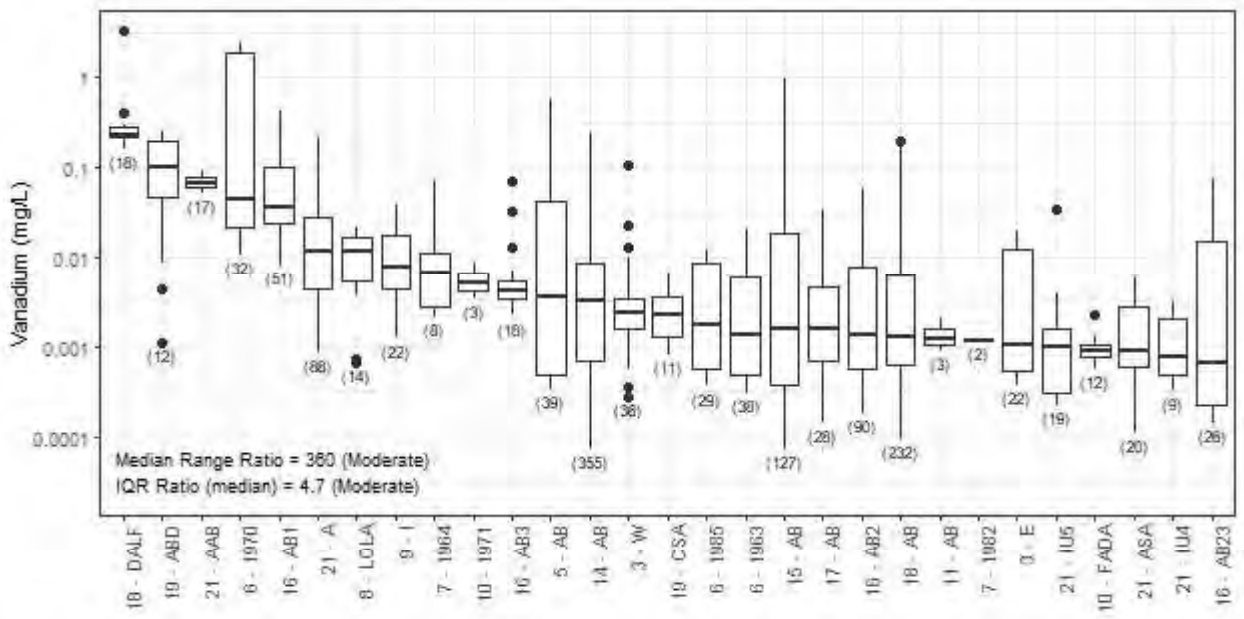

Figure C-44
Vanadium

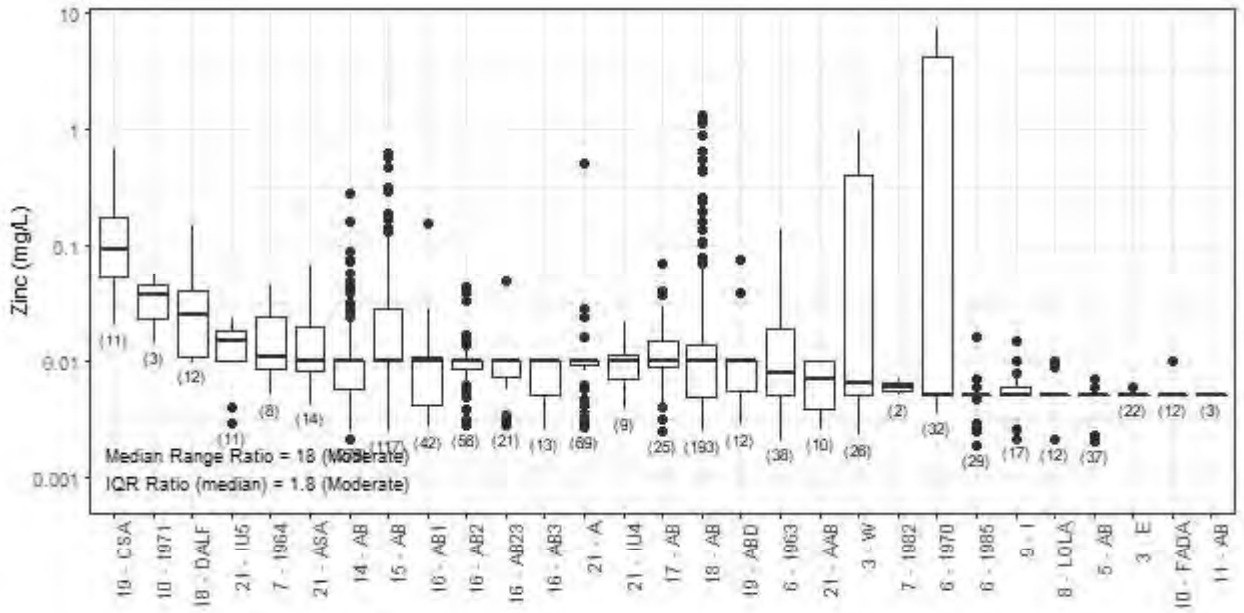

Figure C-45
Zinc

D
HISTOGRAM COMPARISON OF LEAF 1313 AND LEAF 1316 LEACH TEST METHODS

Figures D-1 through D-26 use histograms to compare results of the LEAF 1313 and LEAF 1316 leach test methods. The position of the distribution indicates LEAF test bias. A distribution centered within the vertical dashed lines with a similar sample count to either side indicates little bias, while a distribution that extends more to the left or more to the right of the dashed lines indicates that the leach test results were biased low or biased high, respectively.

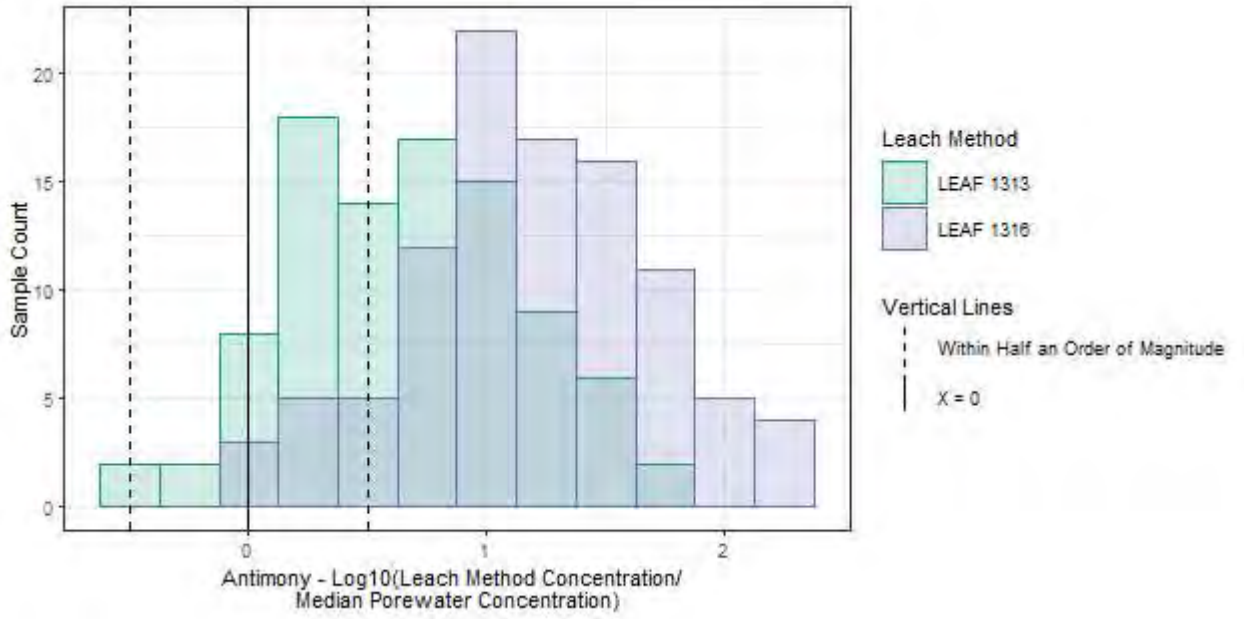

Figure D-1
Antimony

Histogram Comparison of LEAF 1313 and LEAF 1316 Leach Test Methods

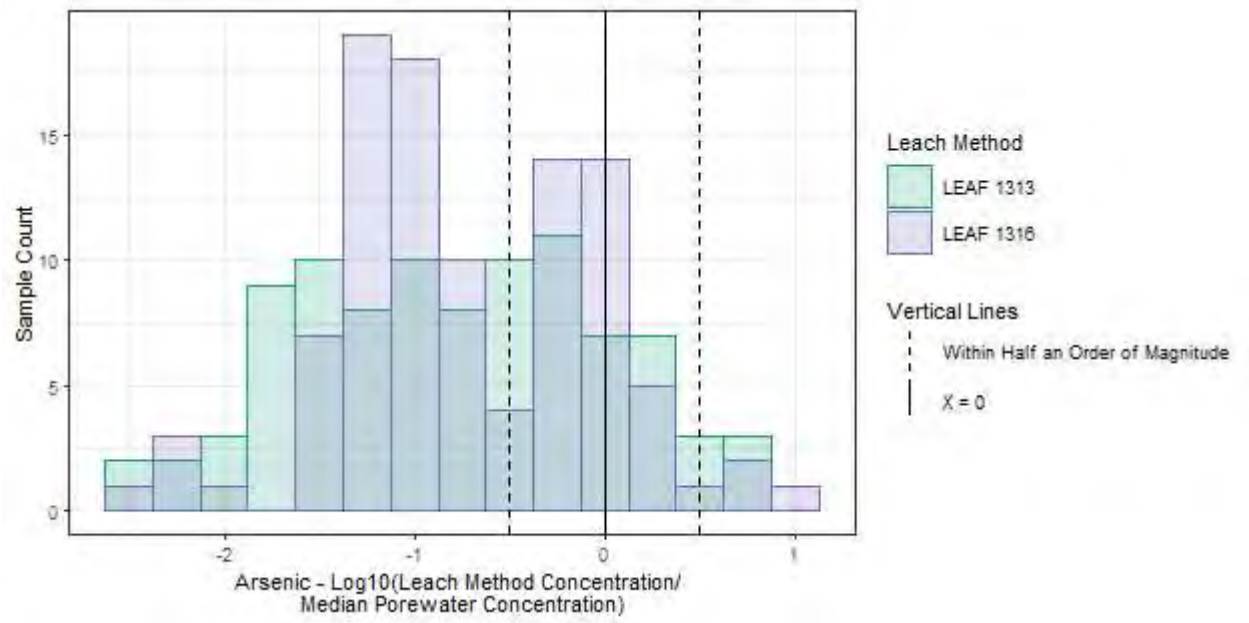

Figure D-2
Arsenic

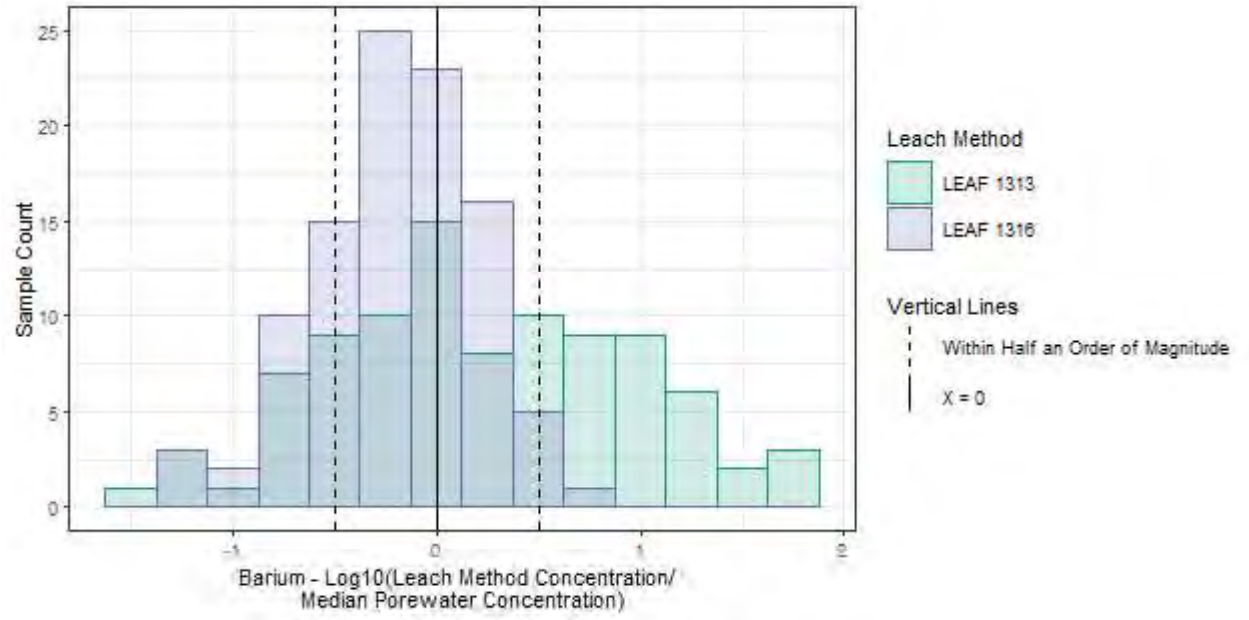

Figure D-3
Barium

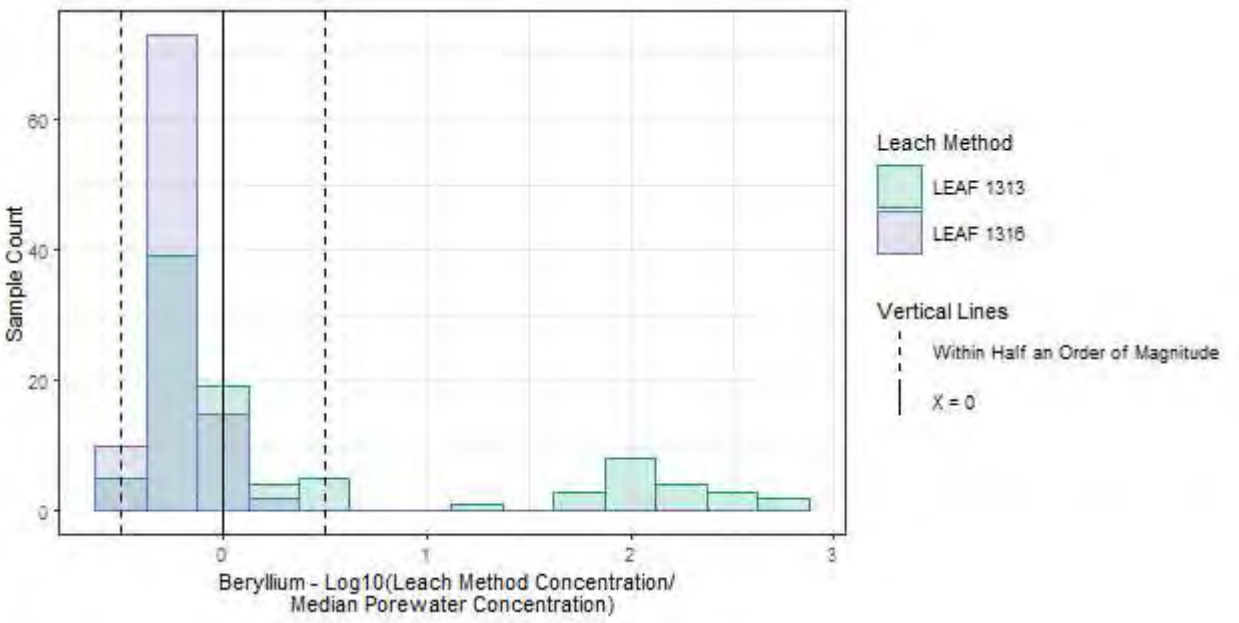

Figure D-4
Beryllium

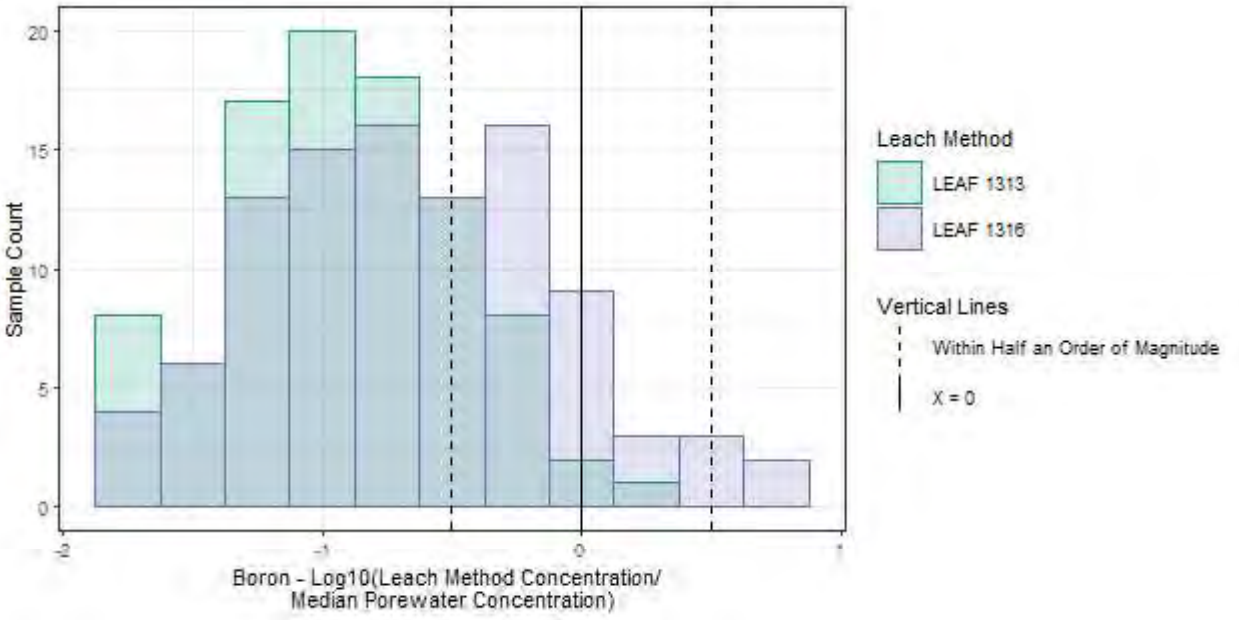

Figure D-5
Boron

Histogram Comparison of LEAF 1313 and LEAF 1316 Leach Test Methods

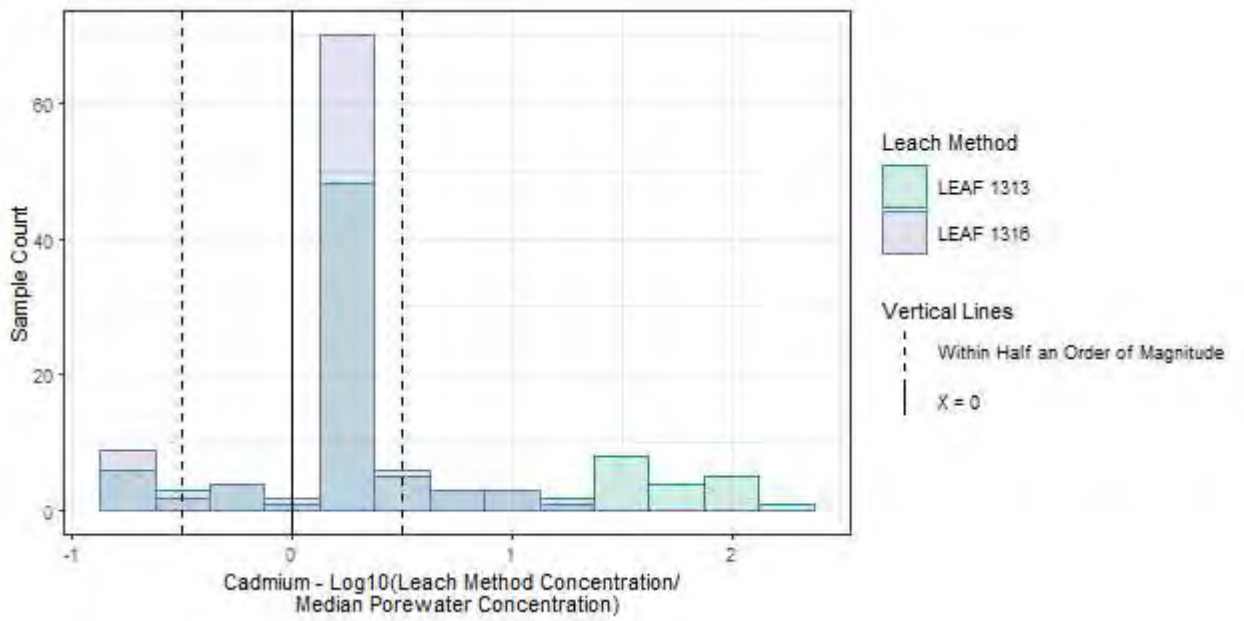

Figure D-6
Cadmium

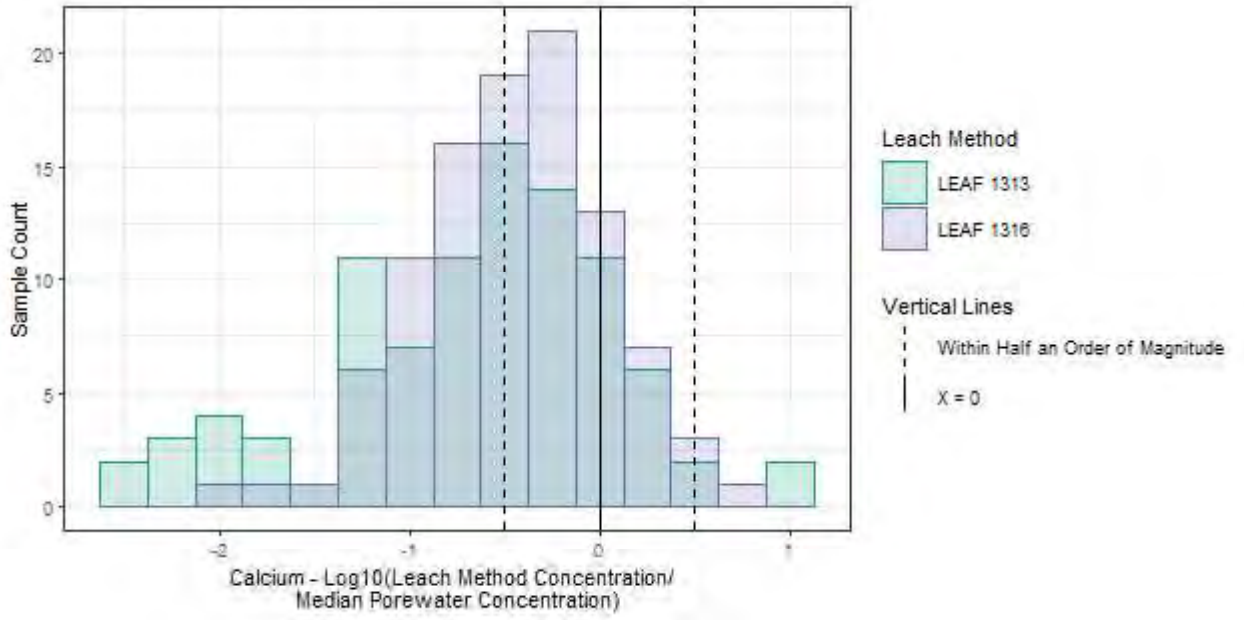

Figure D-7
Calcium

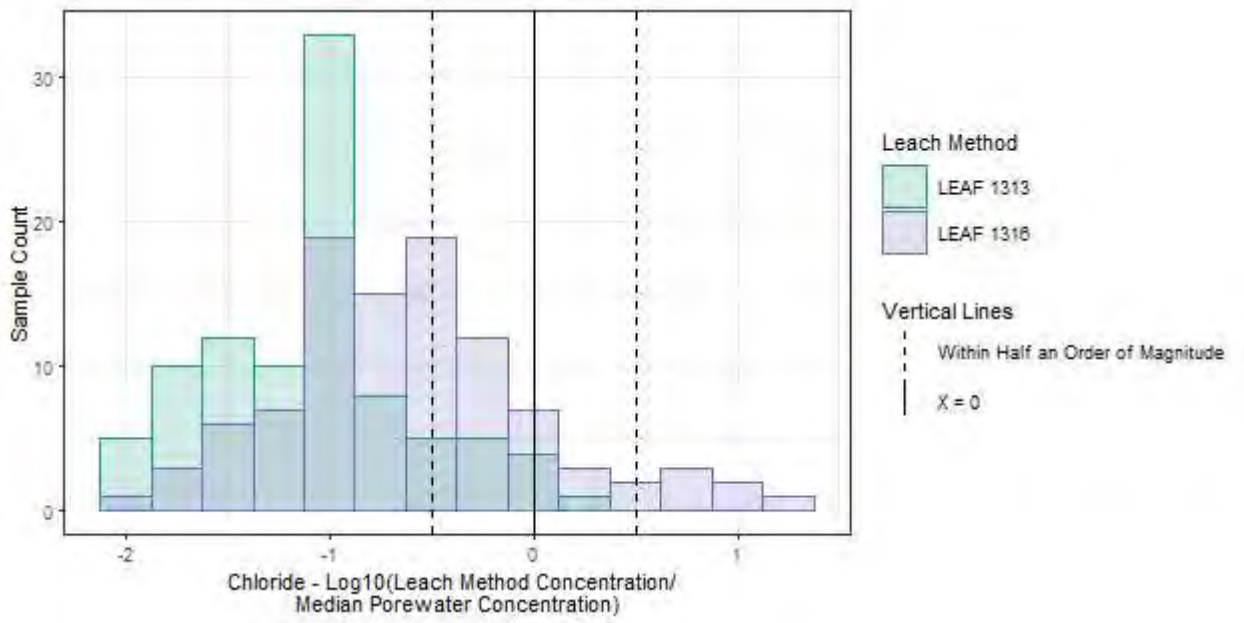

Figure D-8
Chloride

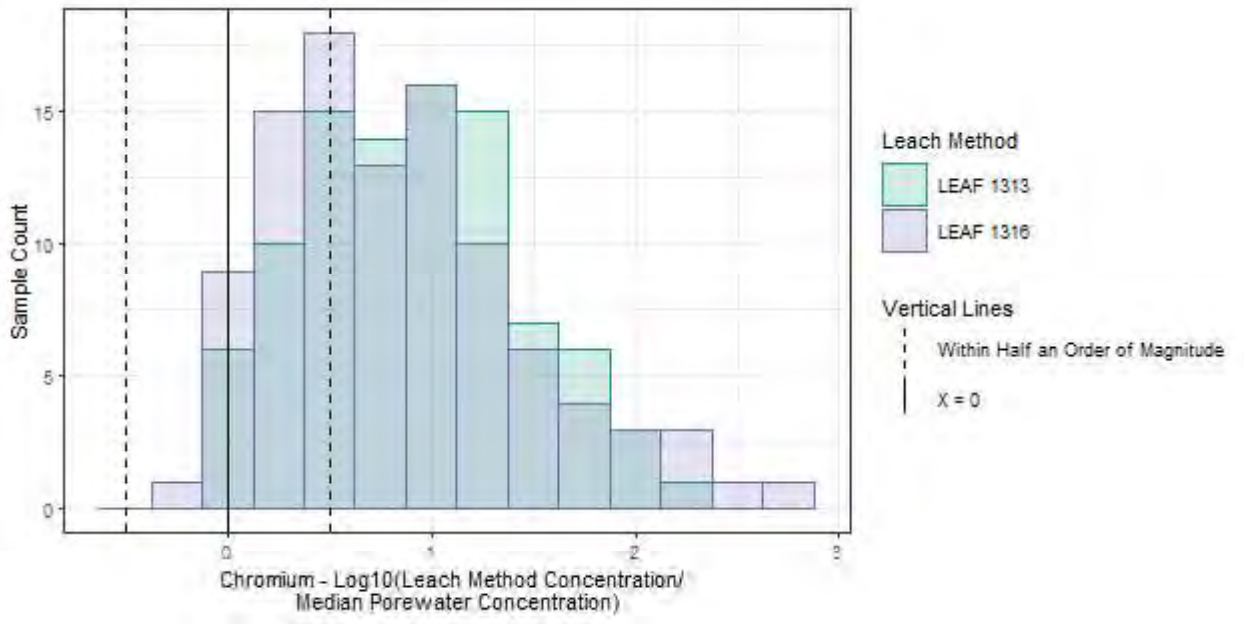

Figure D-9
Chromium

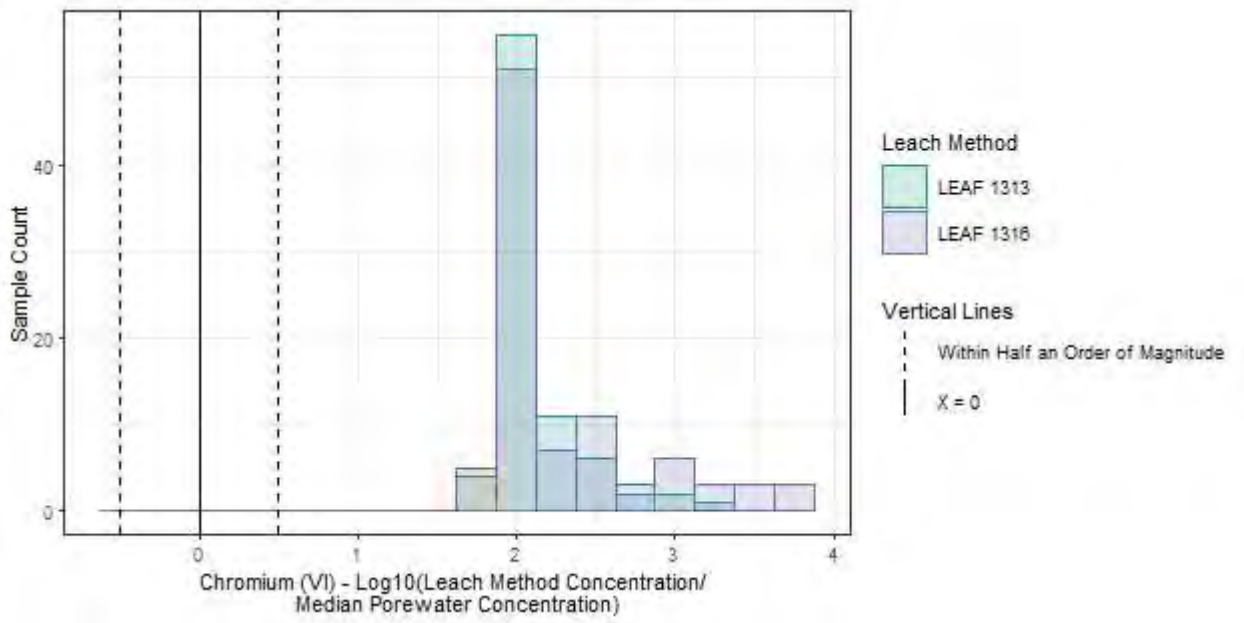

Figure D-10
Chromium (VI)

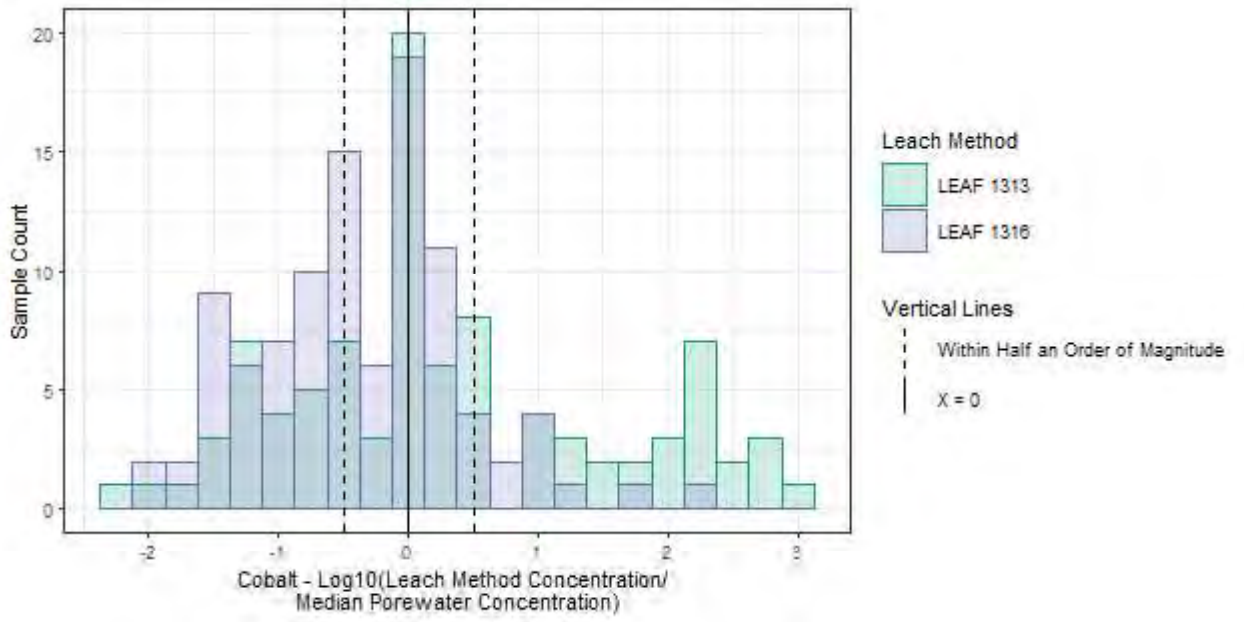

Figure D-11
Cobalt

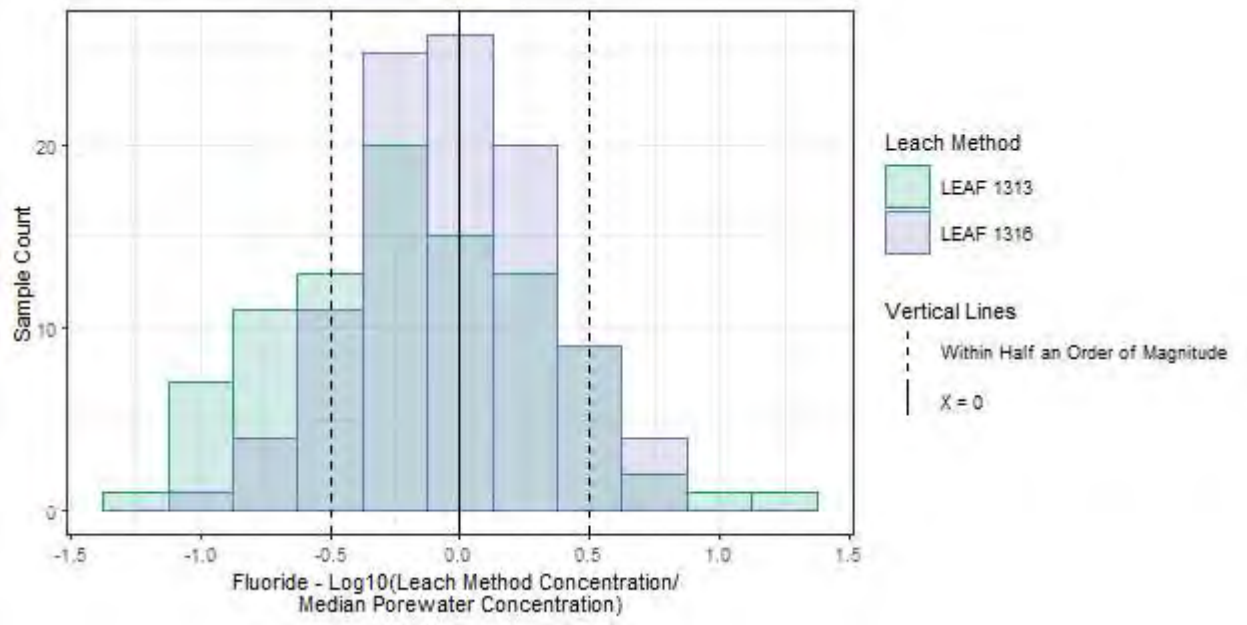

Figure D-12
Fluoride

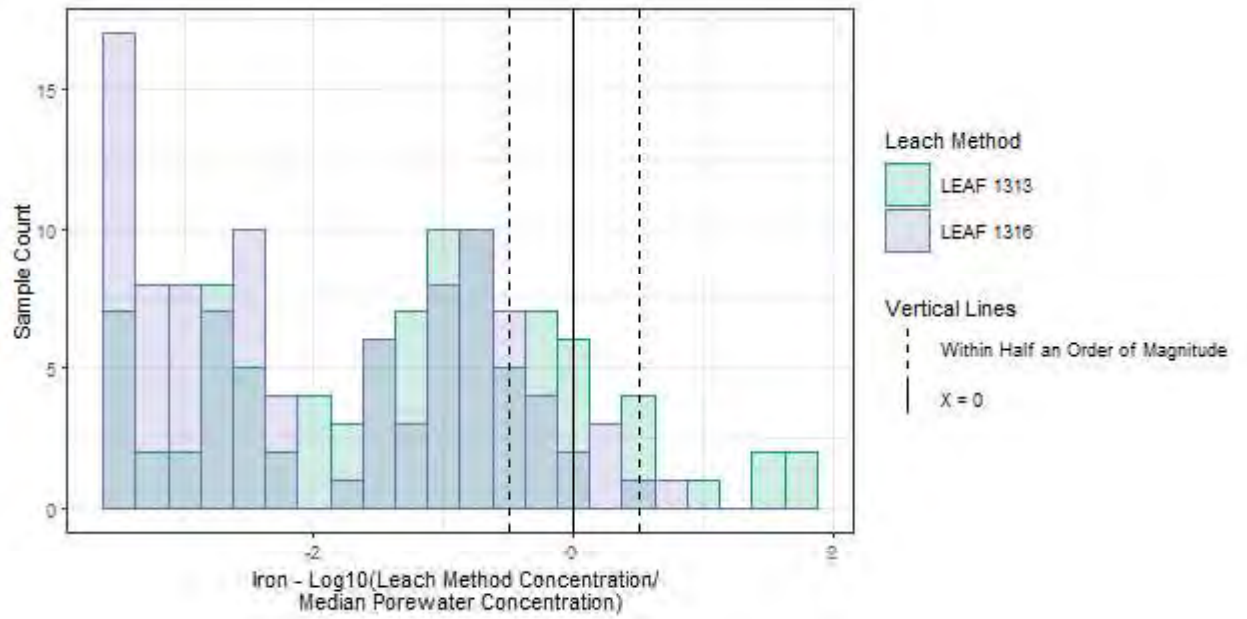

Figure D-13
Iron

Histogram Comparison of LEAF 1313 and LEAF 1316 Leach Test Methods

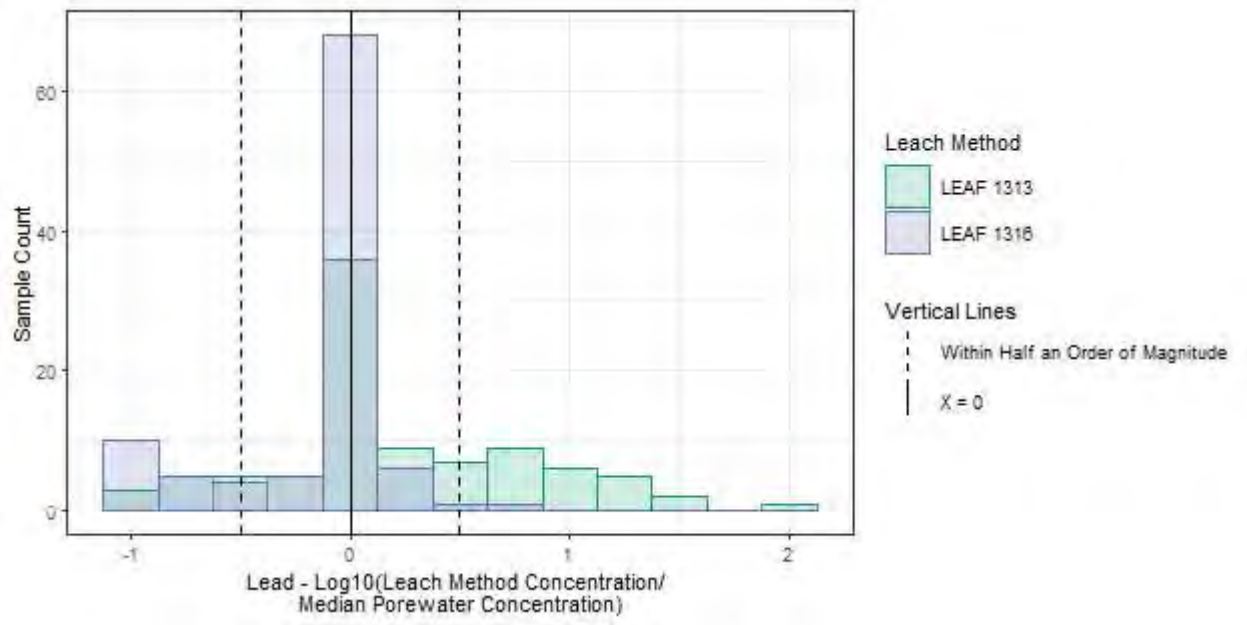

Figure D-14
Lead

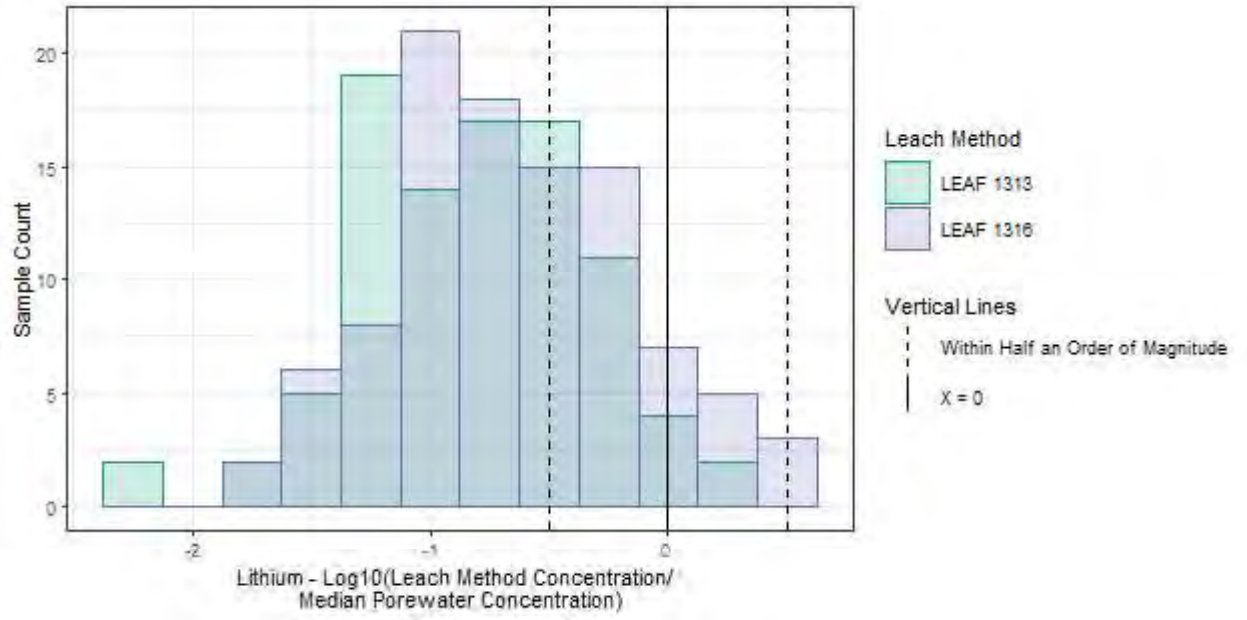

Figure D-15
Lithium

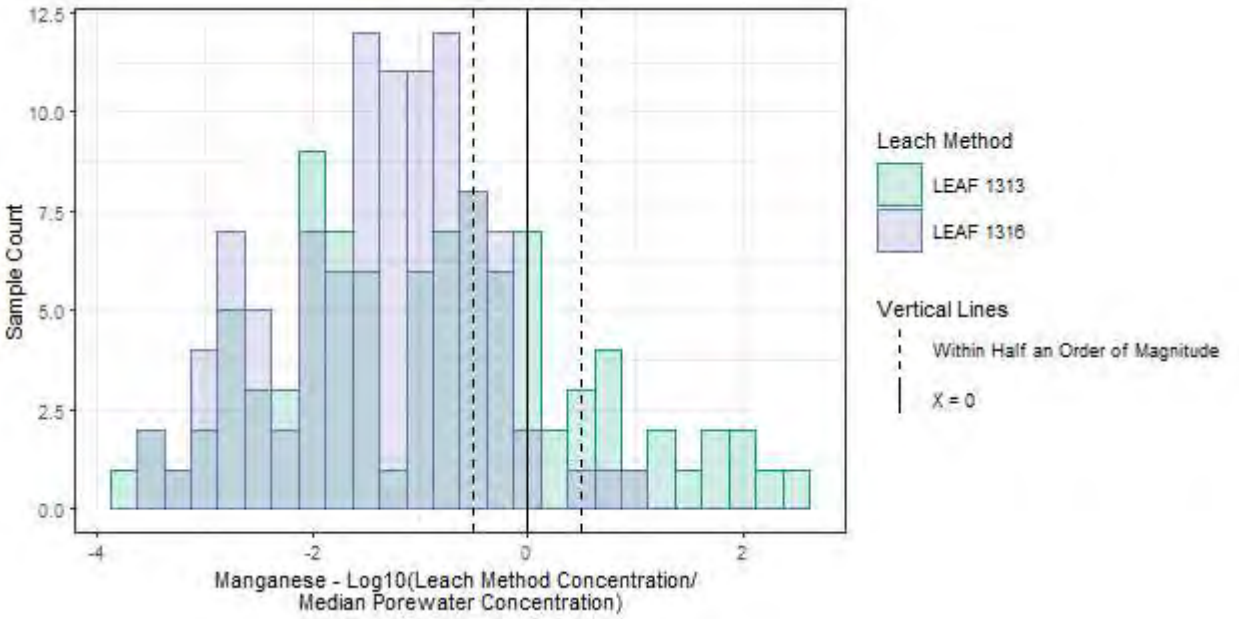

Figure D-16
Manganese

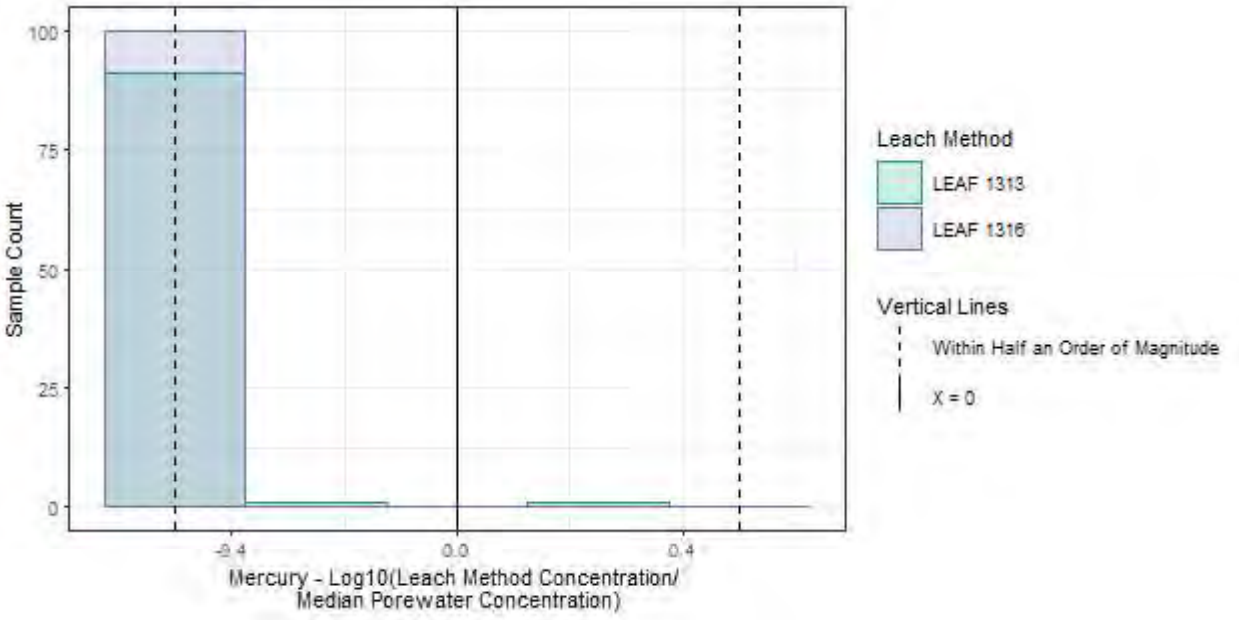

Figure D-17
Mercury

Histogram Comparison of LEAF 1313 and LEAF 1316 Leach Test Methods

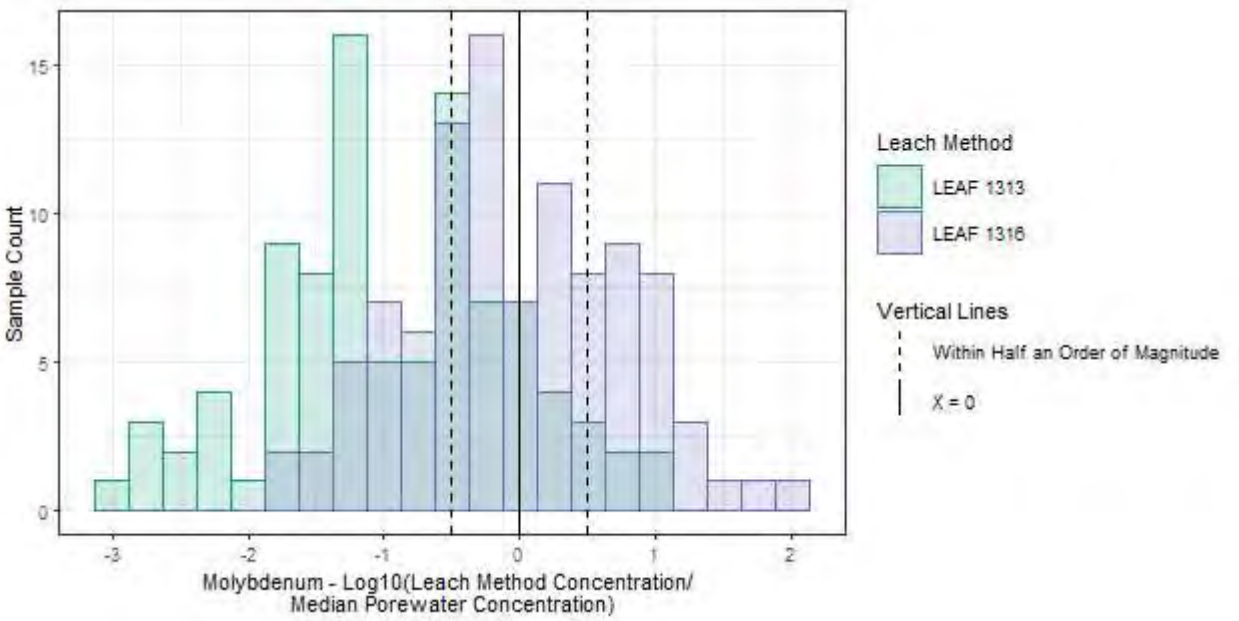

Figure D-18
Molybdenum

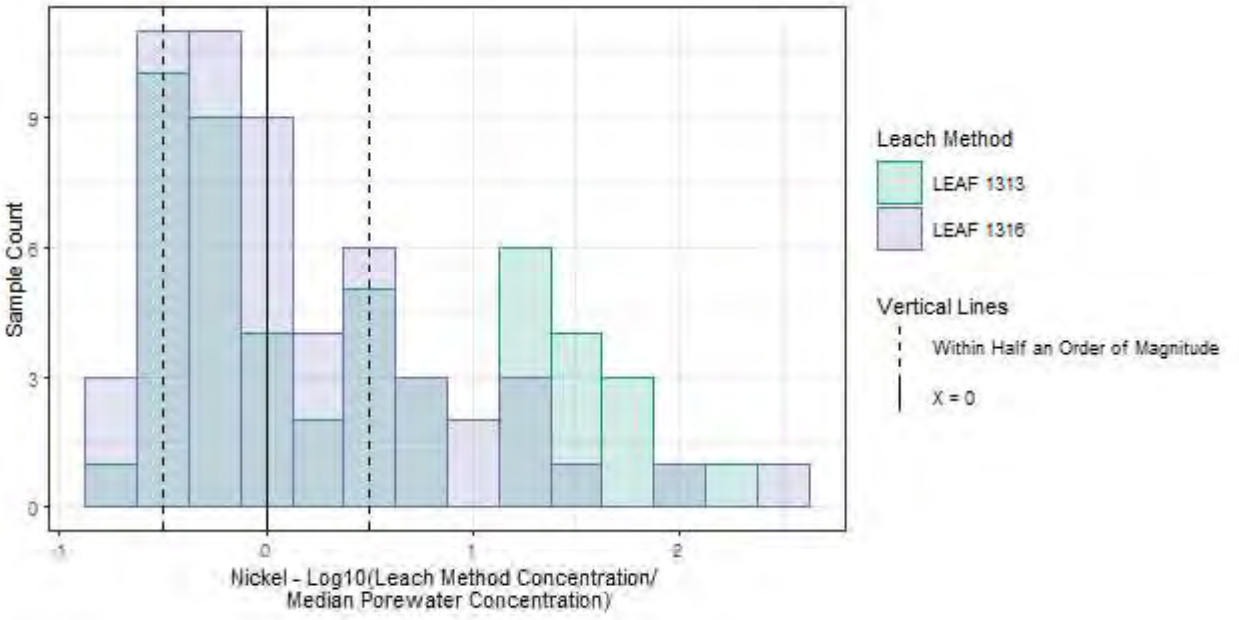

Figure D-19
Nickel

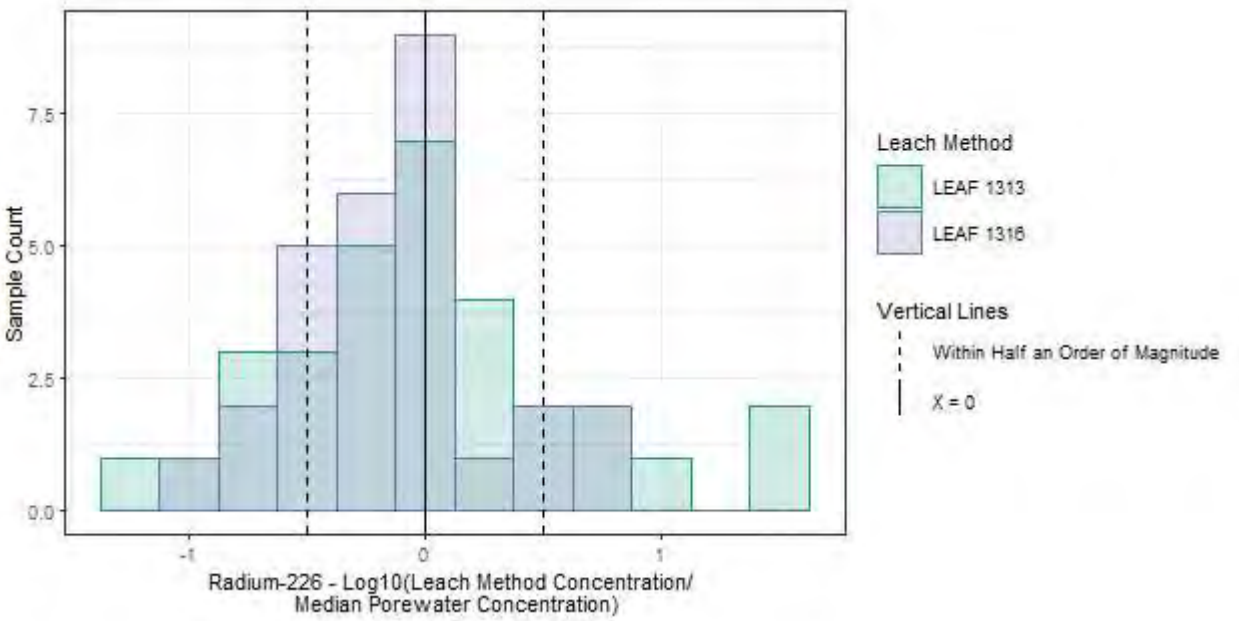

Figure D-20
Radium-226

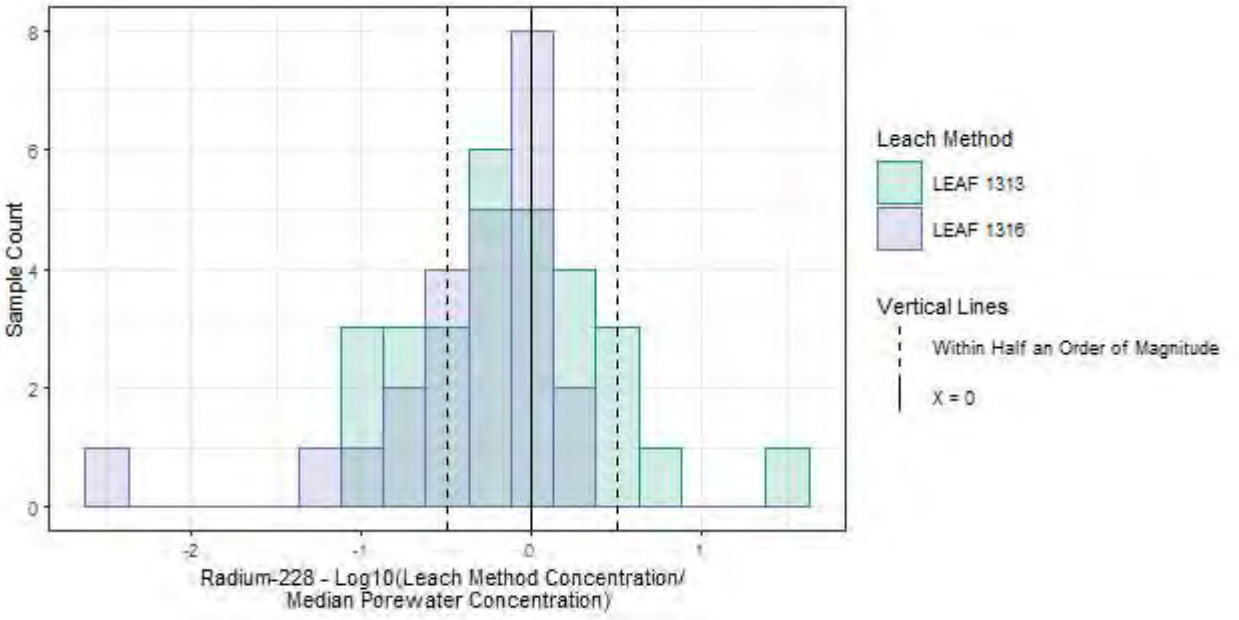

Figure D-21
Radium-228

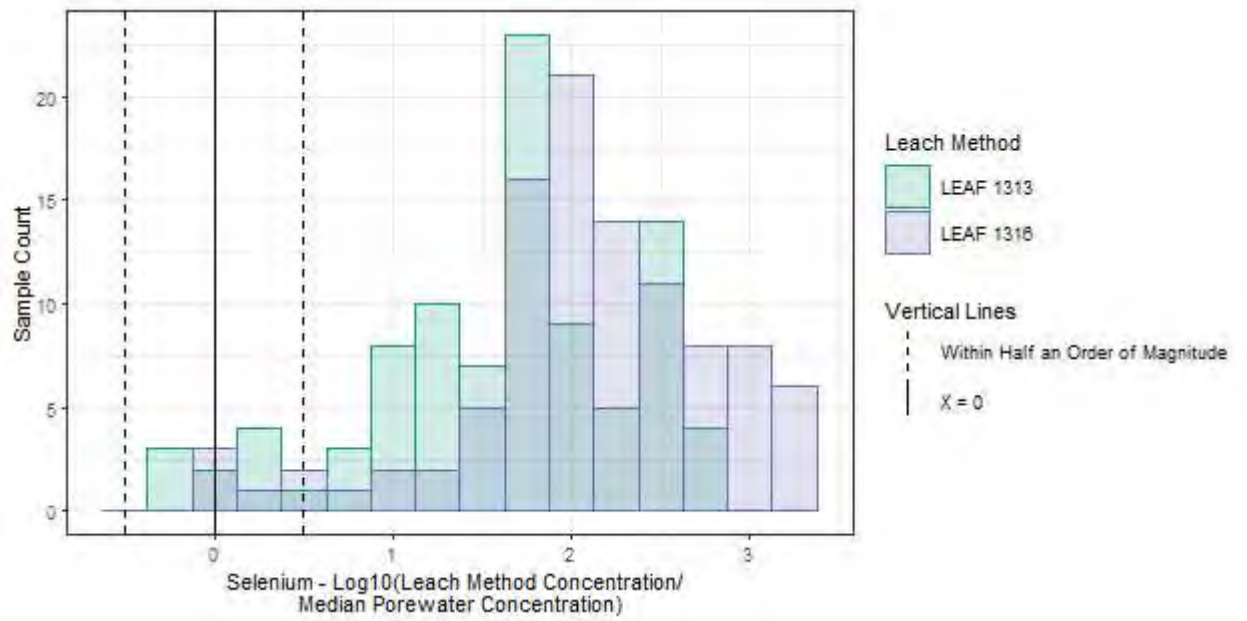

Figure D-22
Selenium

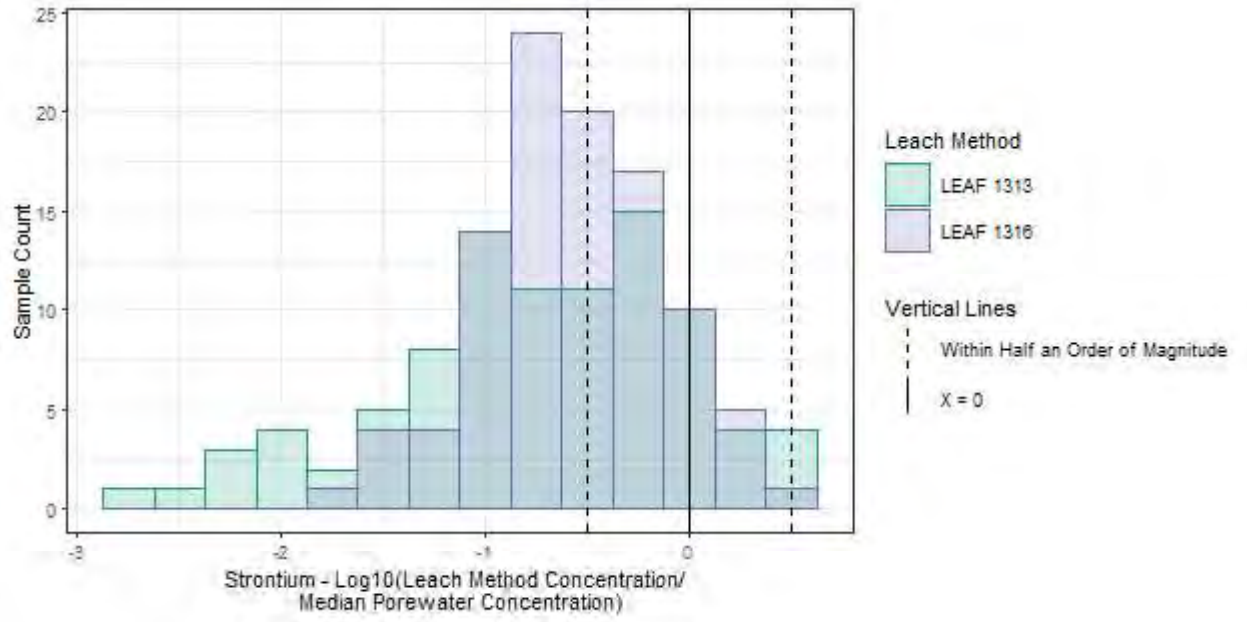

Figure D-23
Strontium

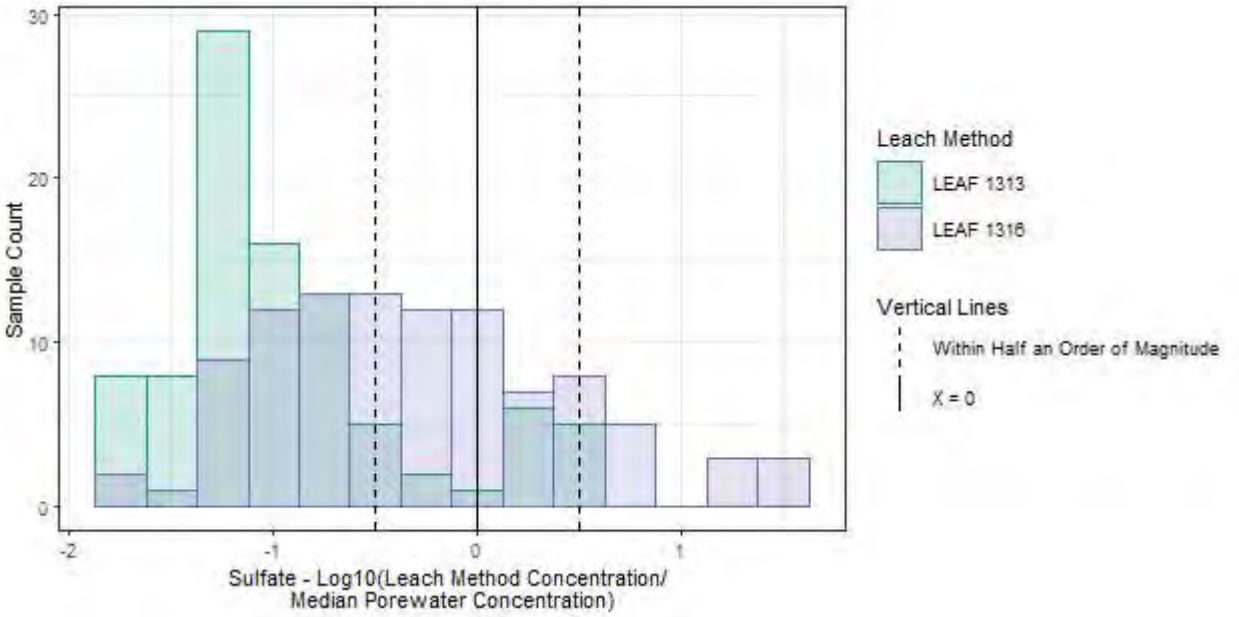

Figure D-24
Sulfate

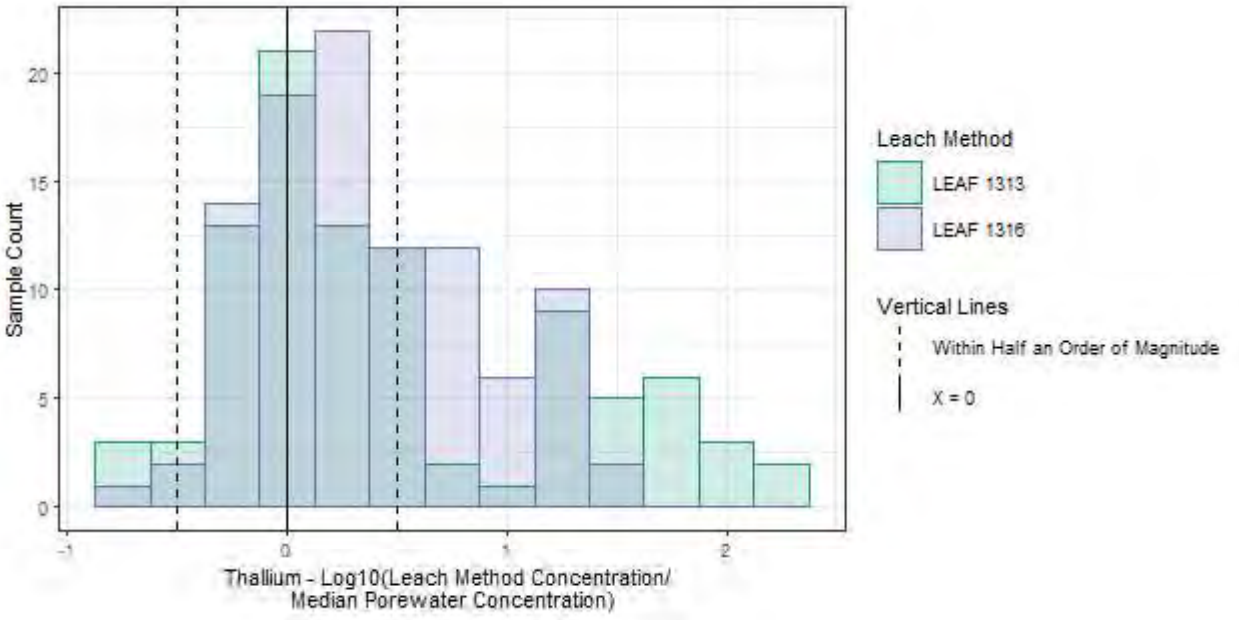

Figure D-25
Thallium

Histogram Comparison of LEAF 1313 and LEAF 1316 Leach Test Methods

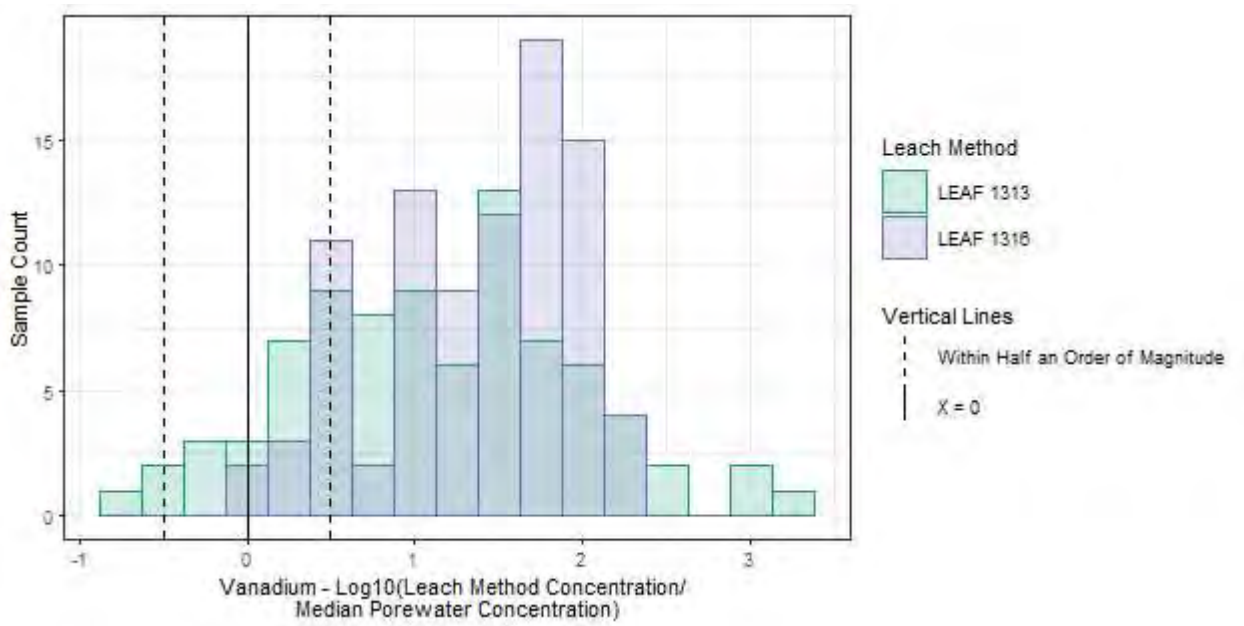

Figure D-26
Vanadium

E
PLOTS SHOWING NORMALIZED LEAF 1313 TO POREWATER RESULTS ACROSS THE RANGE OF pH LEVELS TESTED

Figures E-1 through E-26 show normalized LEAF 1313 test results, where the results were normalized by dividing by the median porewater concentration (because results are displayed as $\log_{10}$, a value of zero indicates exact agreement). The ability of the 1313 test to reproduce porewater concentrations was evaluated based on how many results at natural pH plotted within the dark-shaded ±25% range.

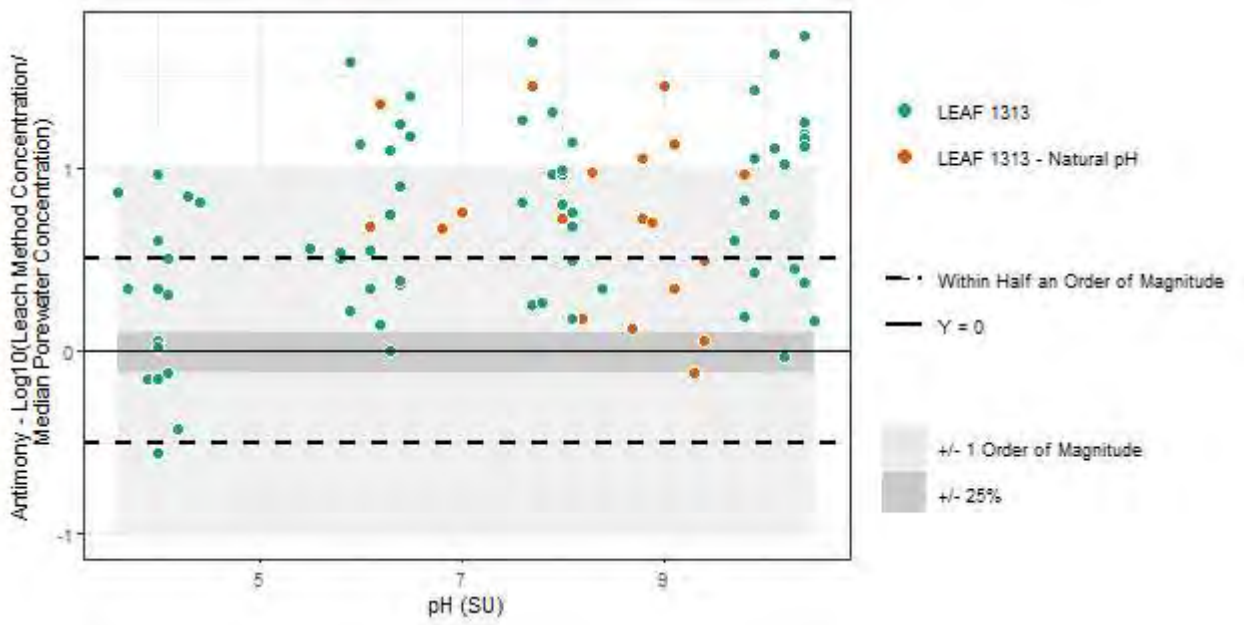

Figure E-1
Antimony

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

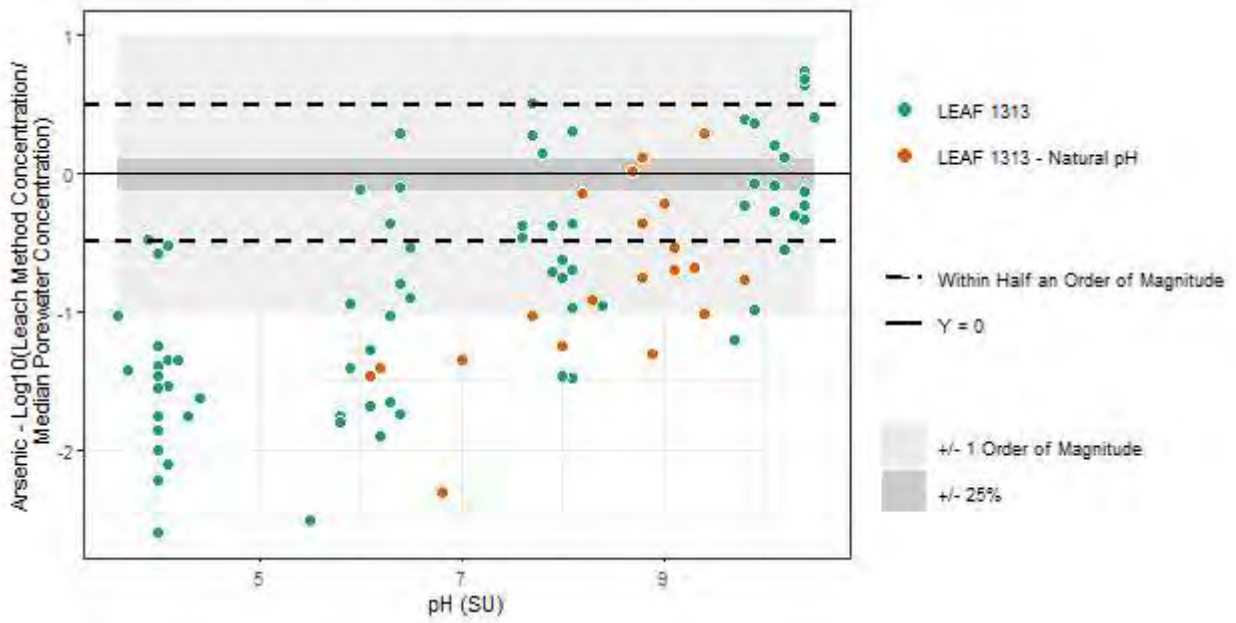

Figure E-2
Arsenic

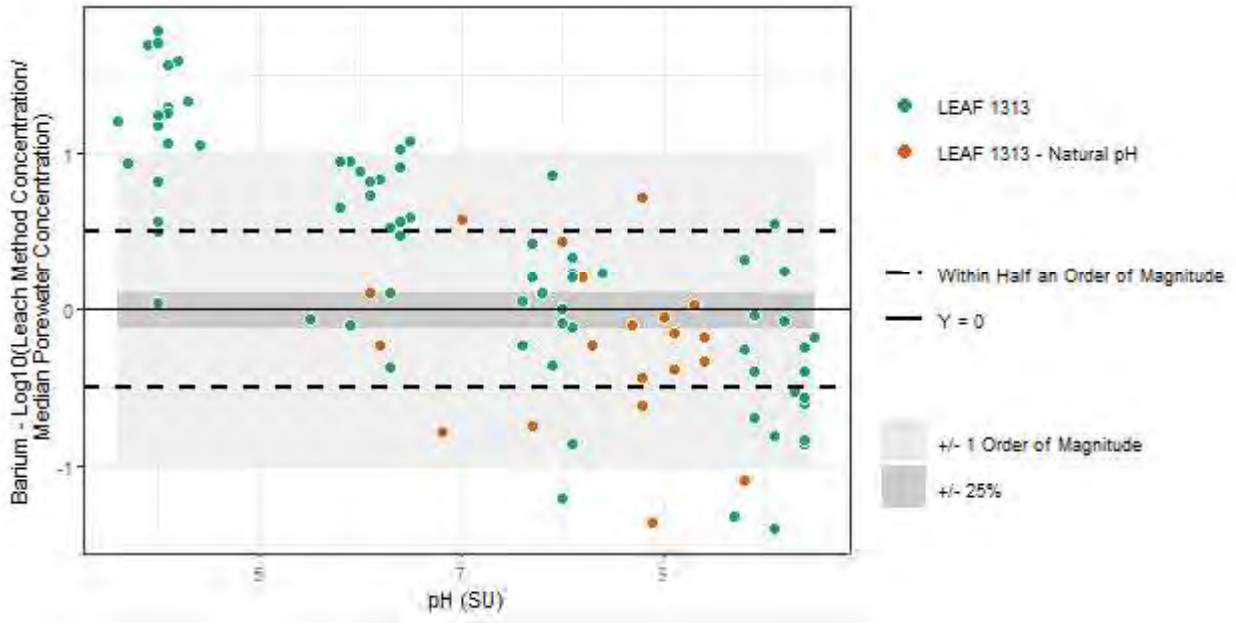

Figure E-3
Barium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

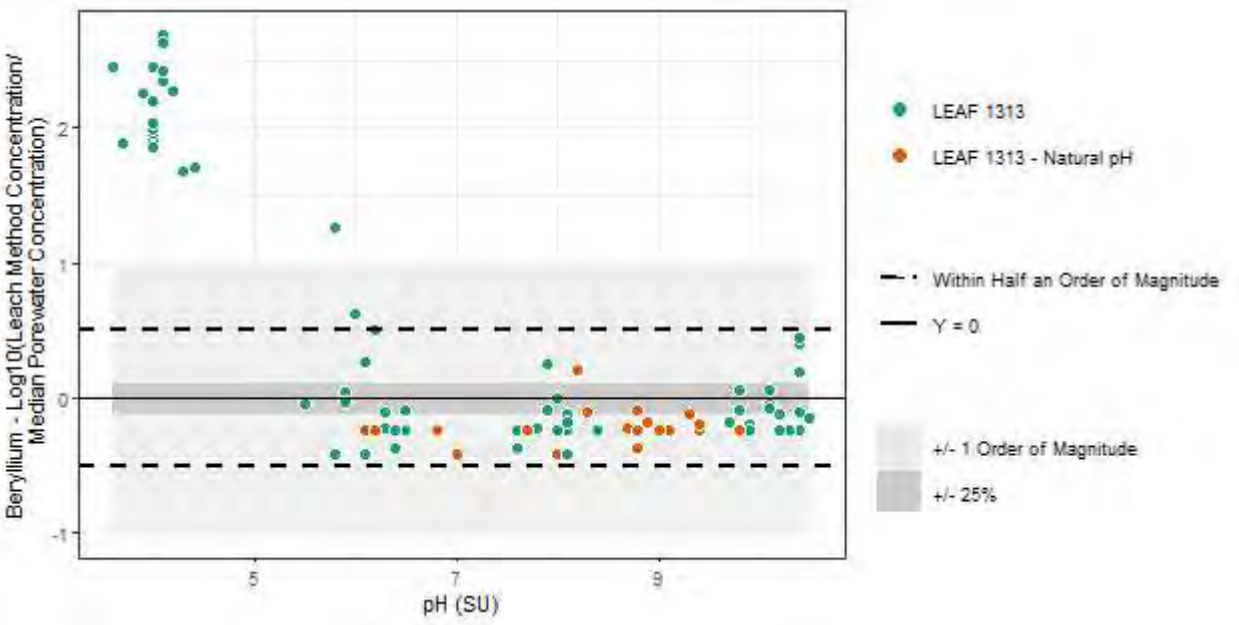

Figure E-4
Beryllium

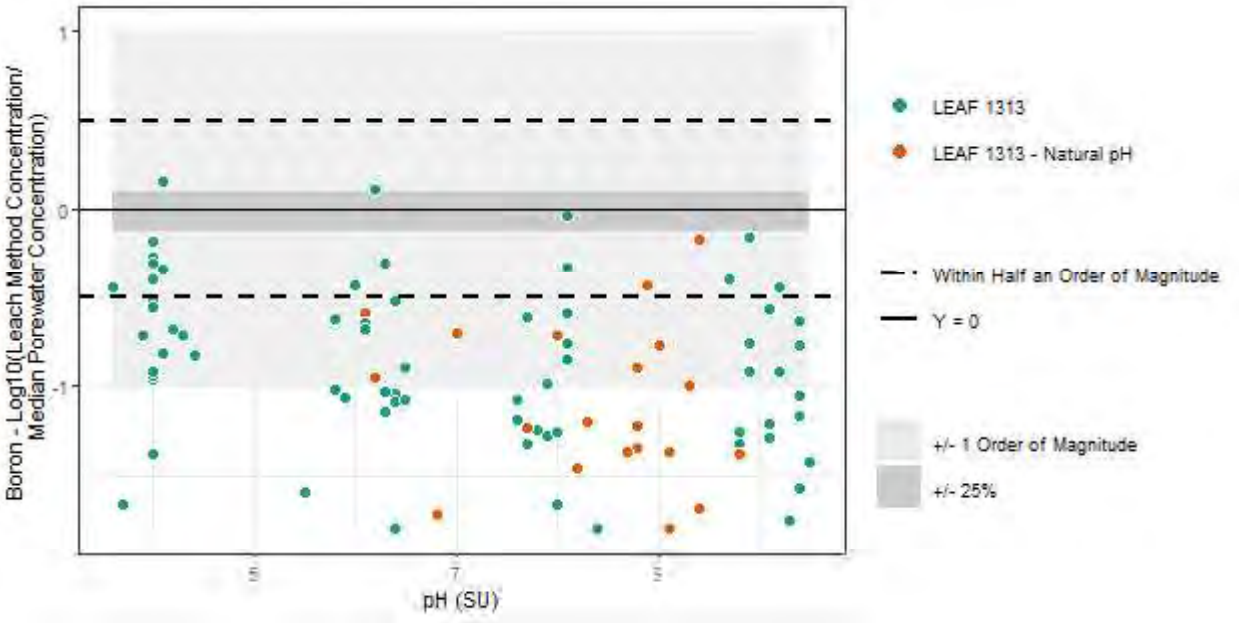

Figure E-5
Boron

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

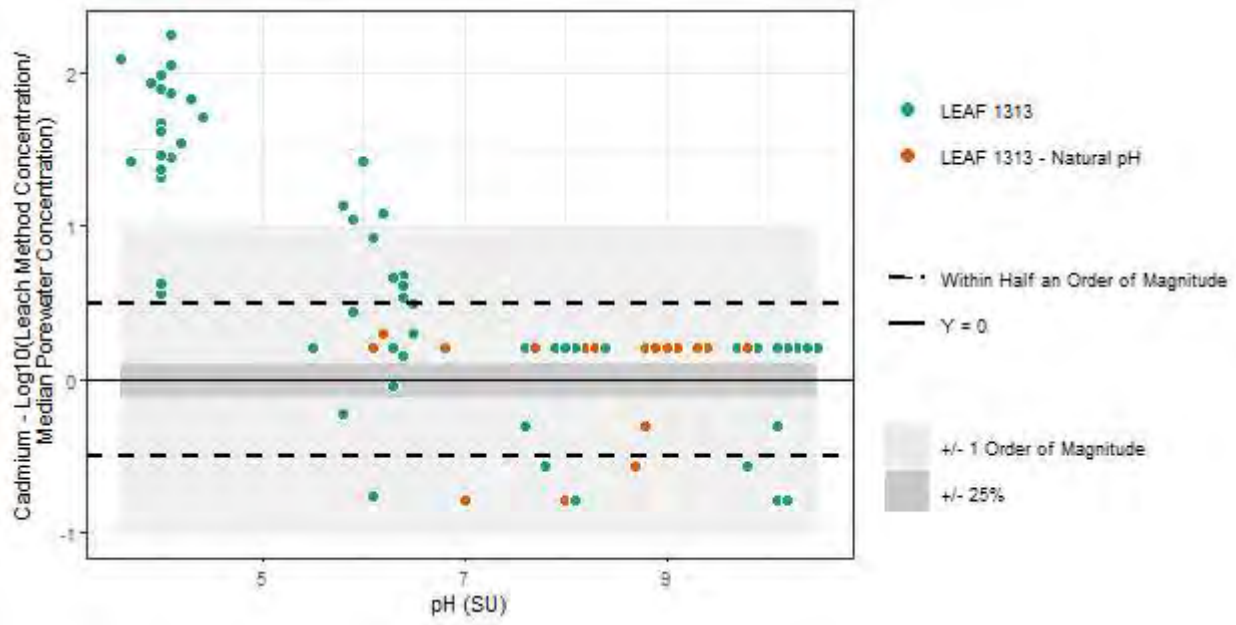

Figure E-6
Cadmium

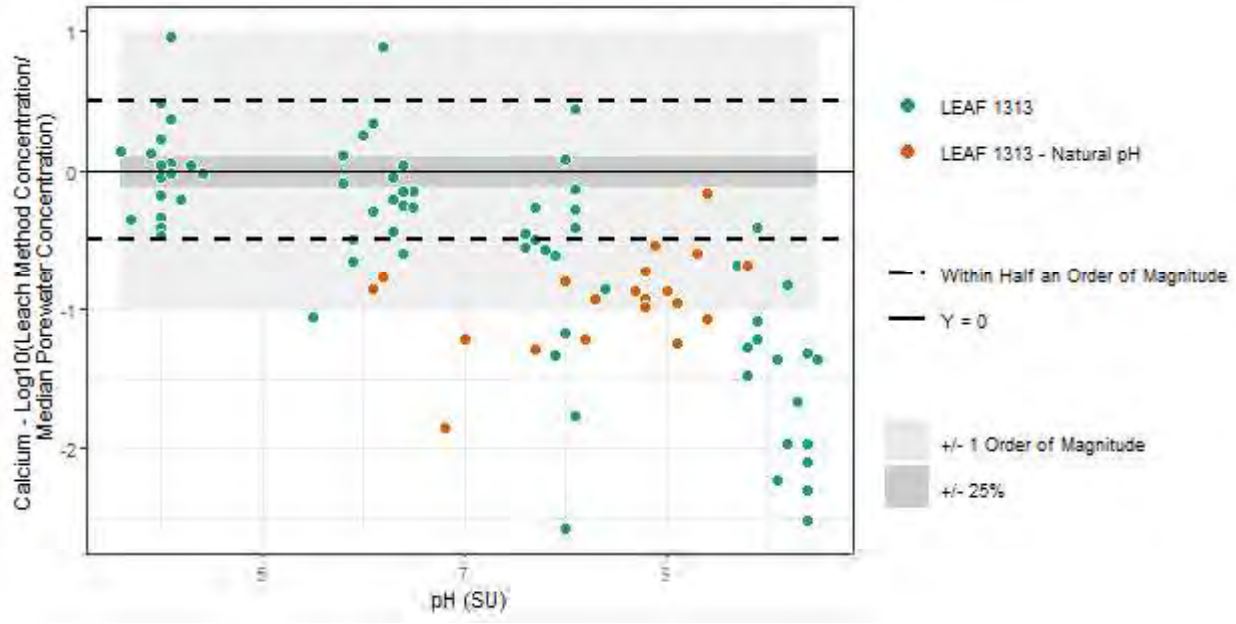

Figure E-7
Calcium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

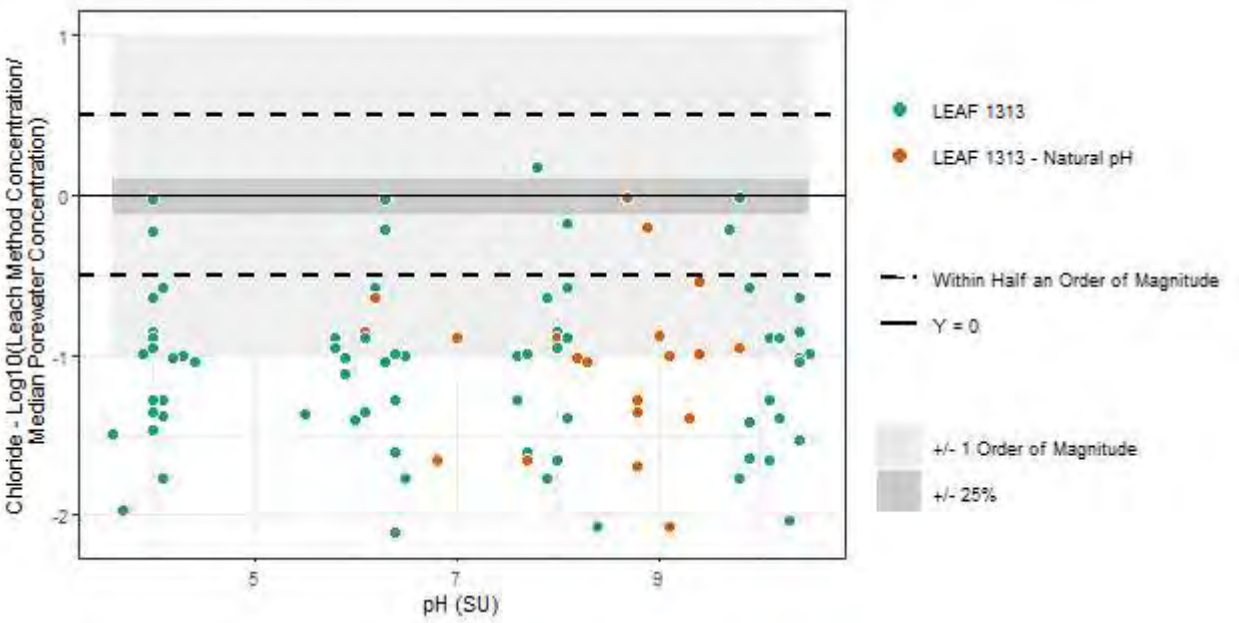

Figure E-8
Chloride

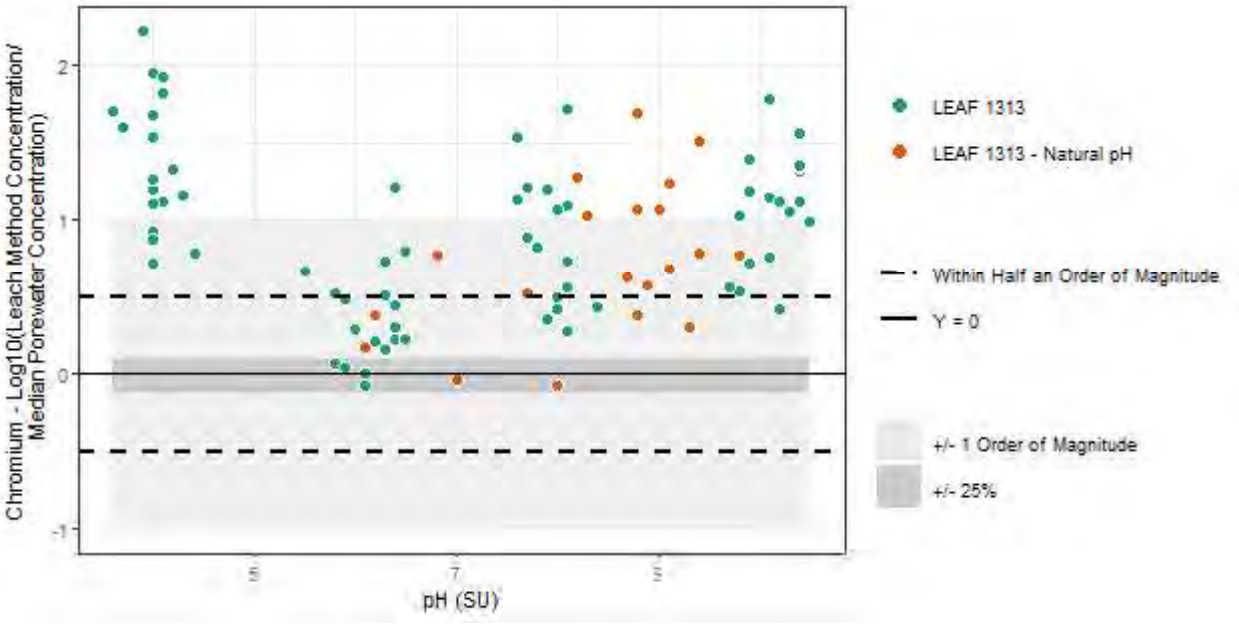

Figure E-9
Chromium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

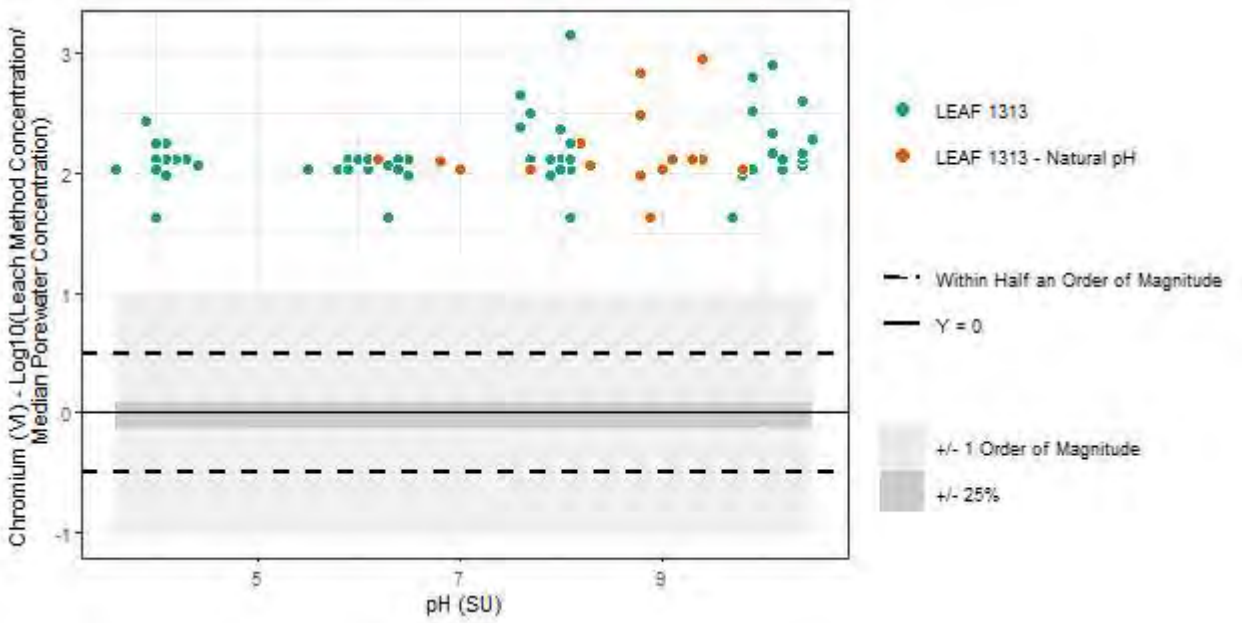

Figure E-10
Chromium (VI)

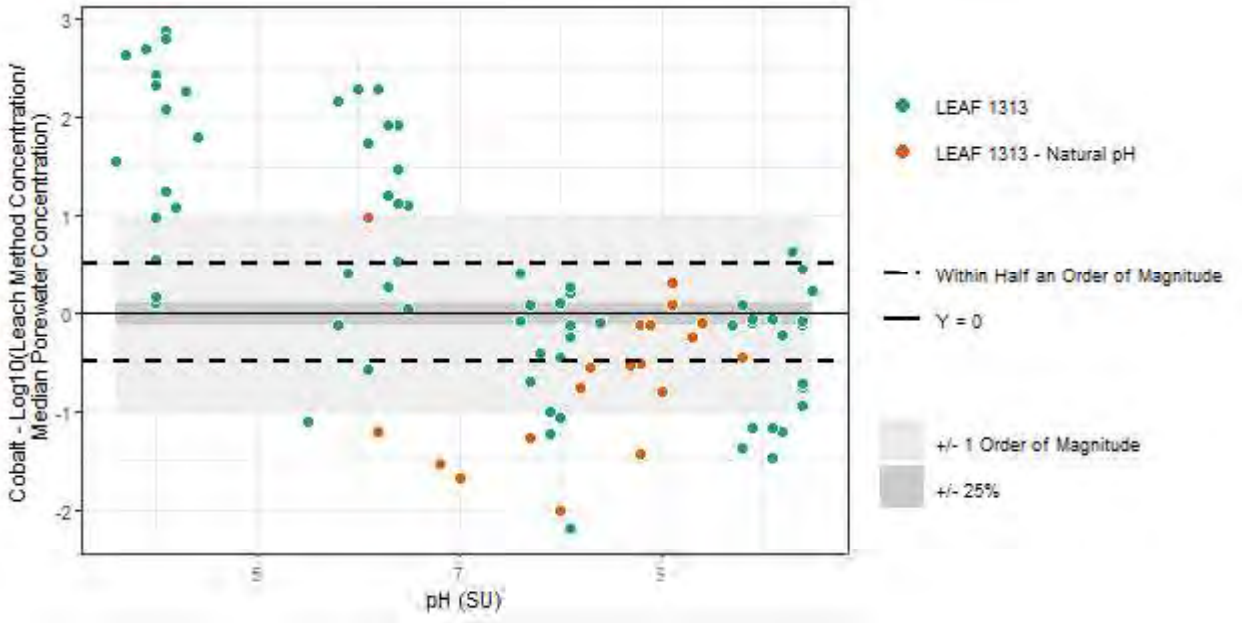

Figure E-11
Cobalt

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

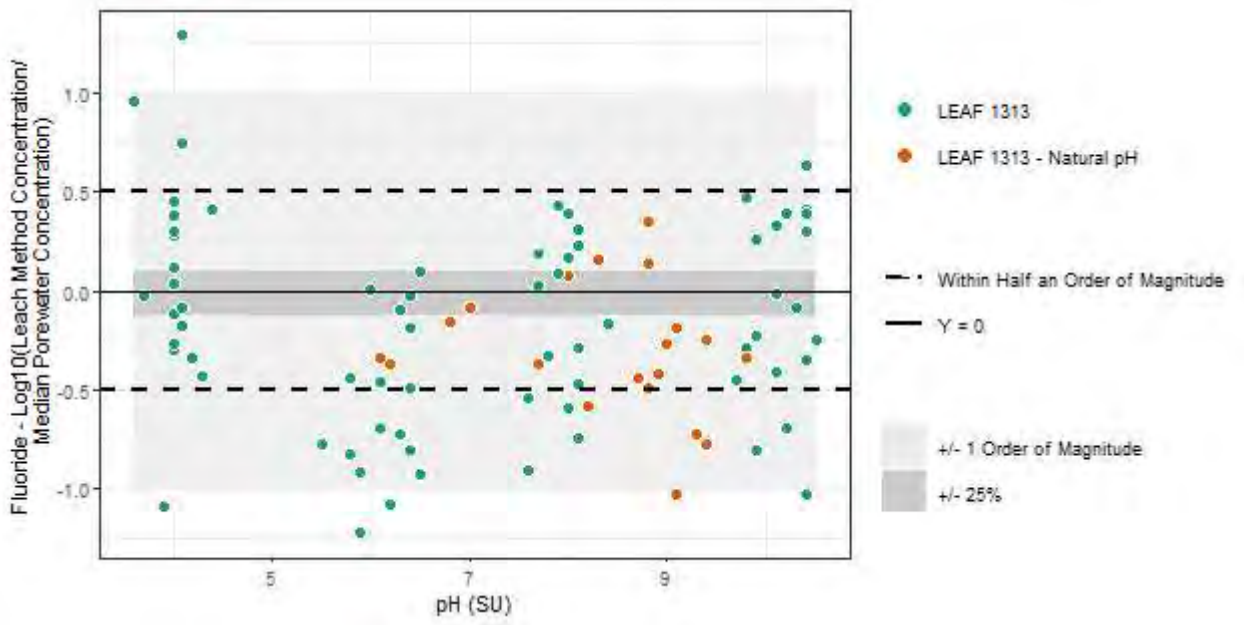

Figure E-12
Fluoride

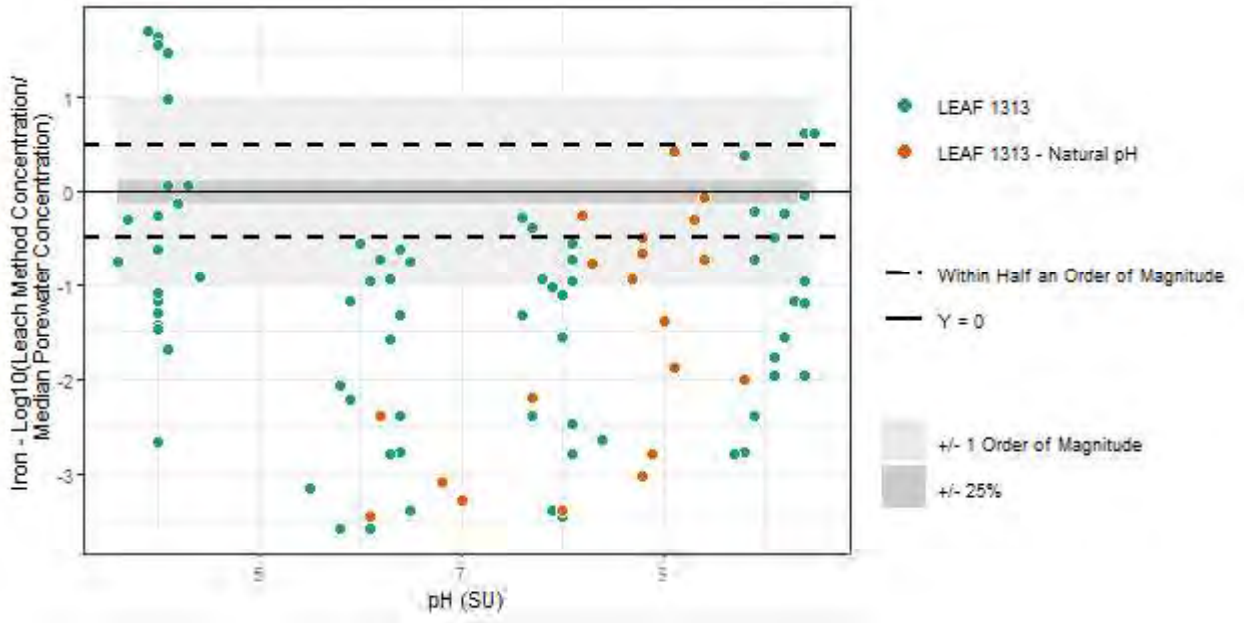

Figure E-13
Iron

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

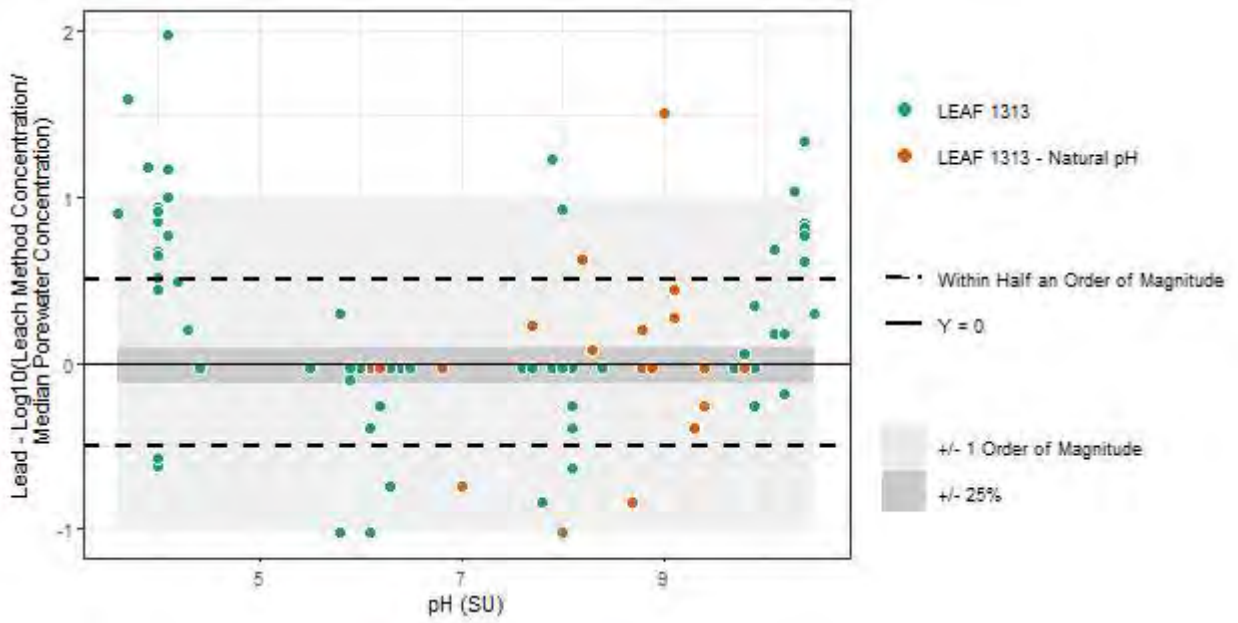

Figure E-14
Lead

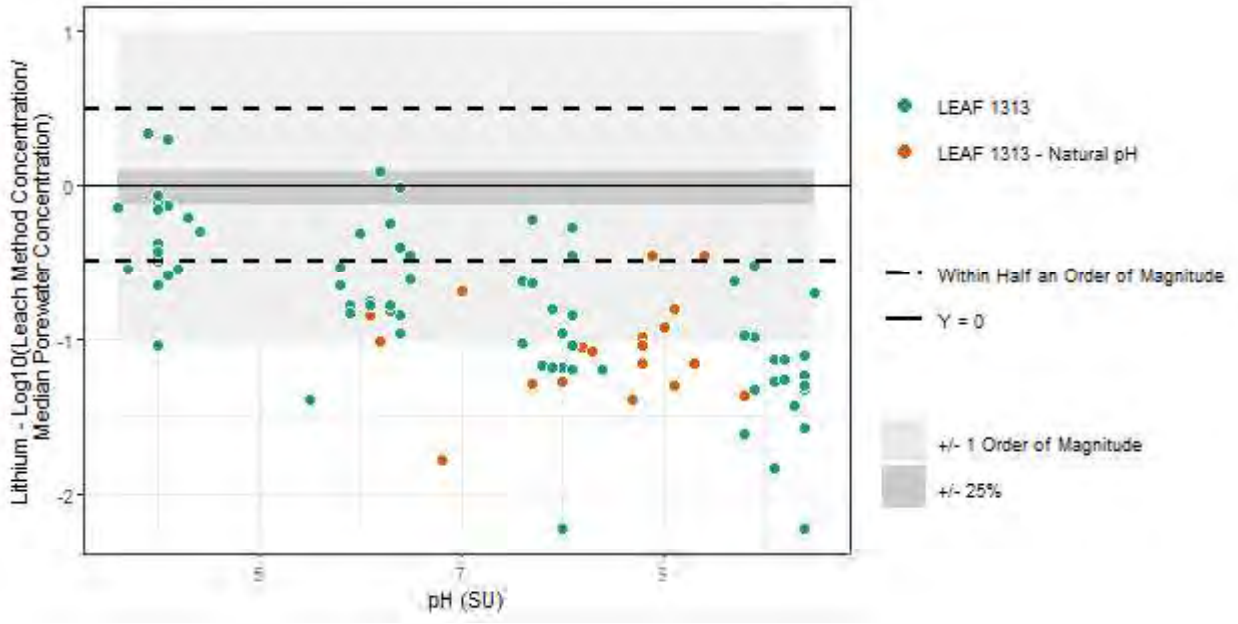

Figure E-15
Lithium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

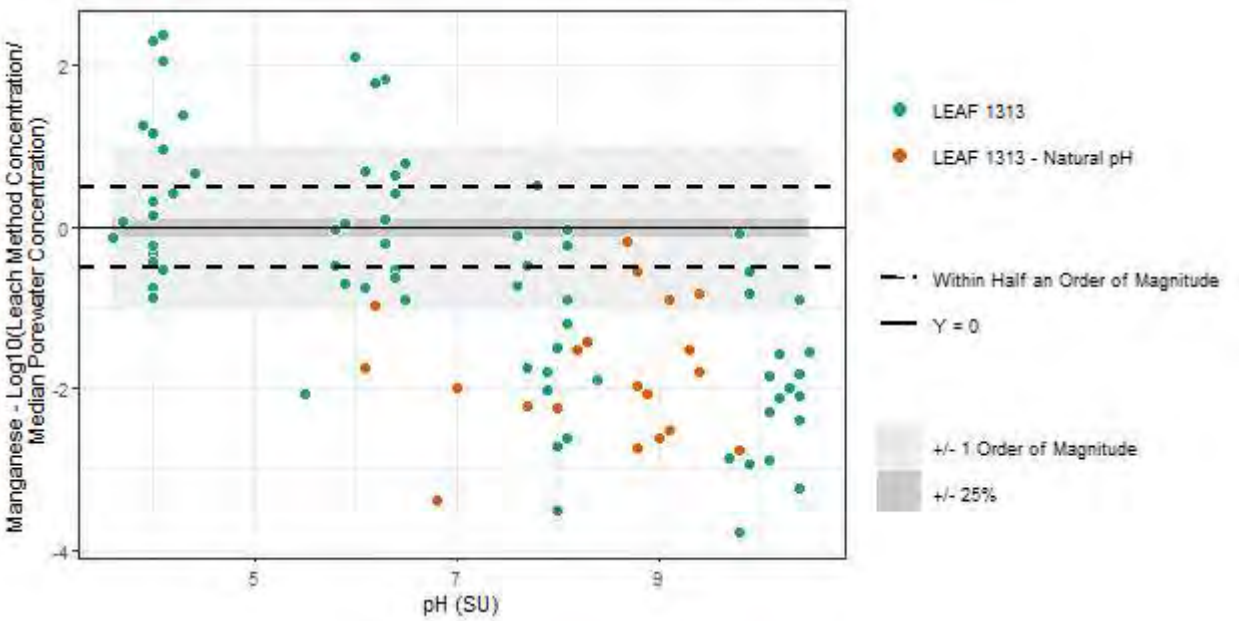

Figure E-16
Manganese

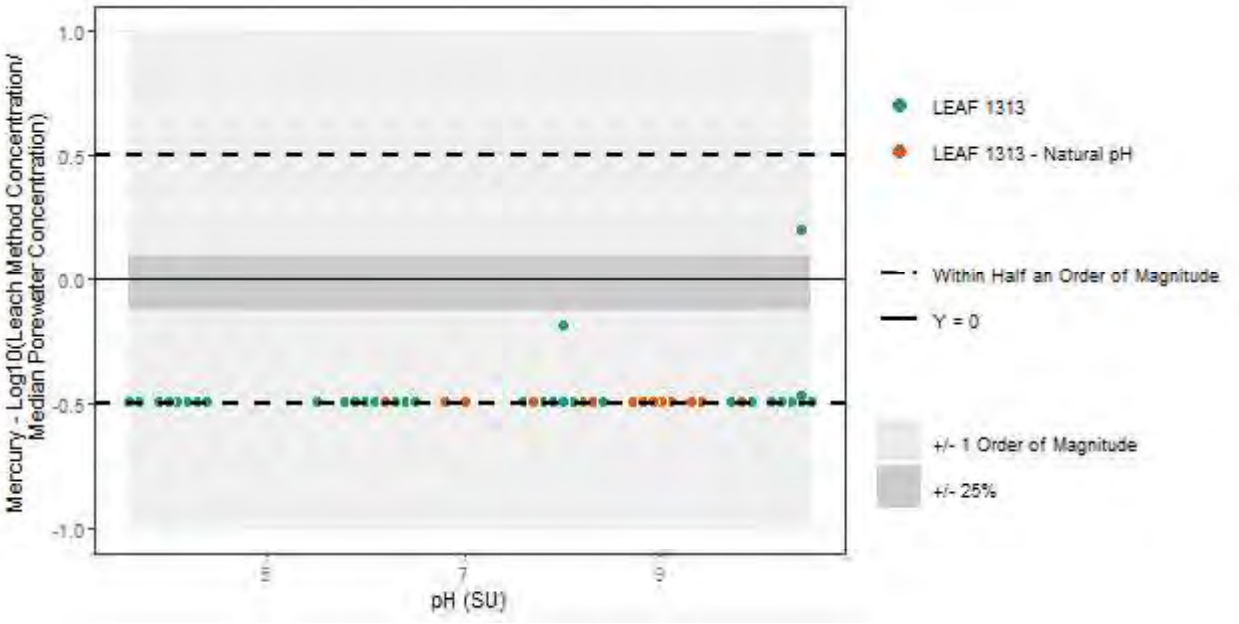

Figure E-17
Mercury

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

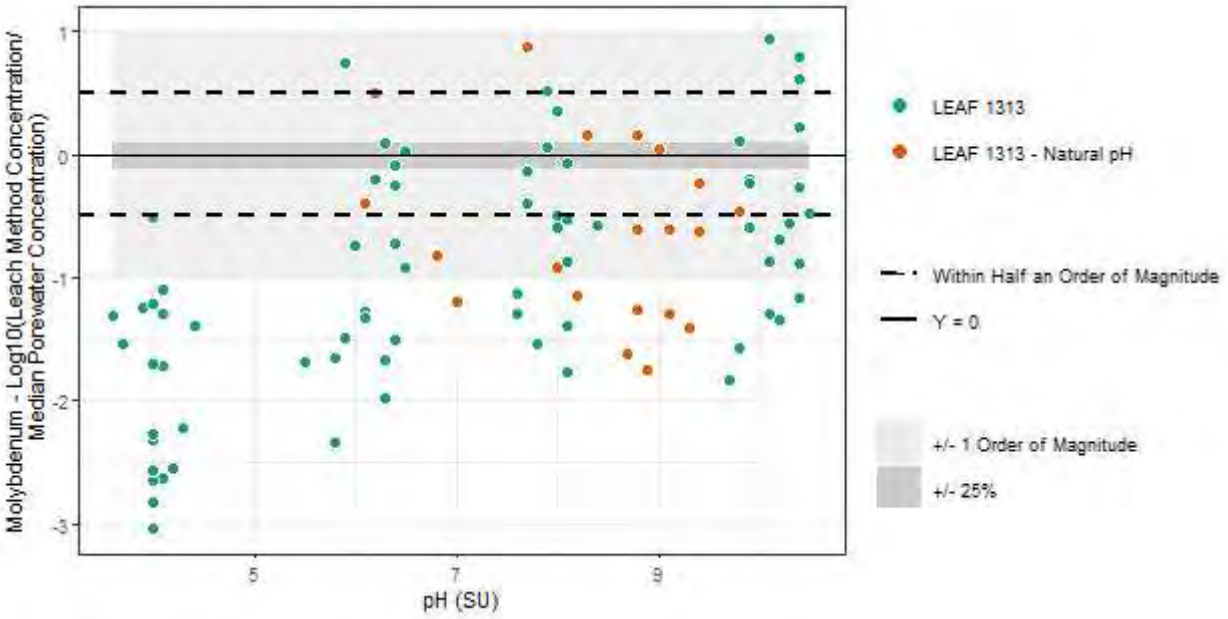

Figure E-18
Molybdenum

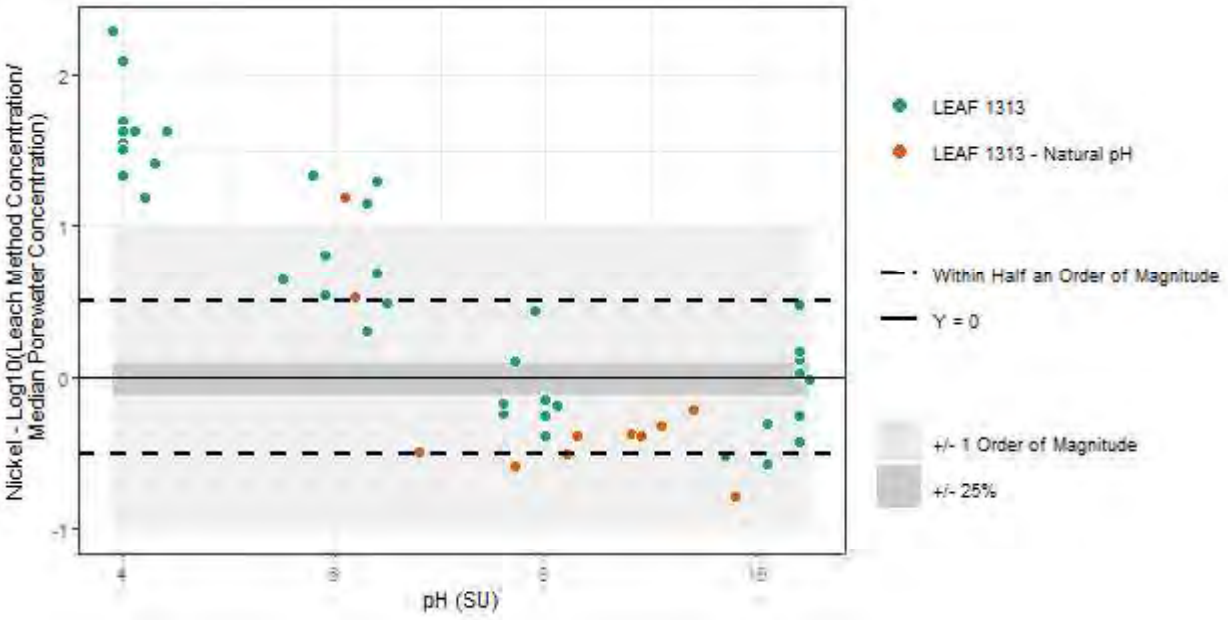

Figure E-19
Nickel

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

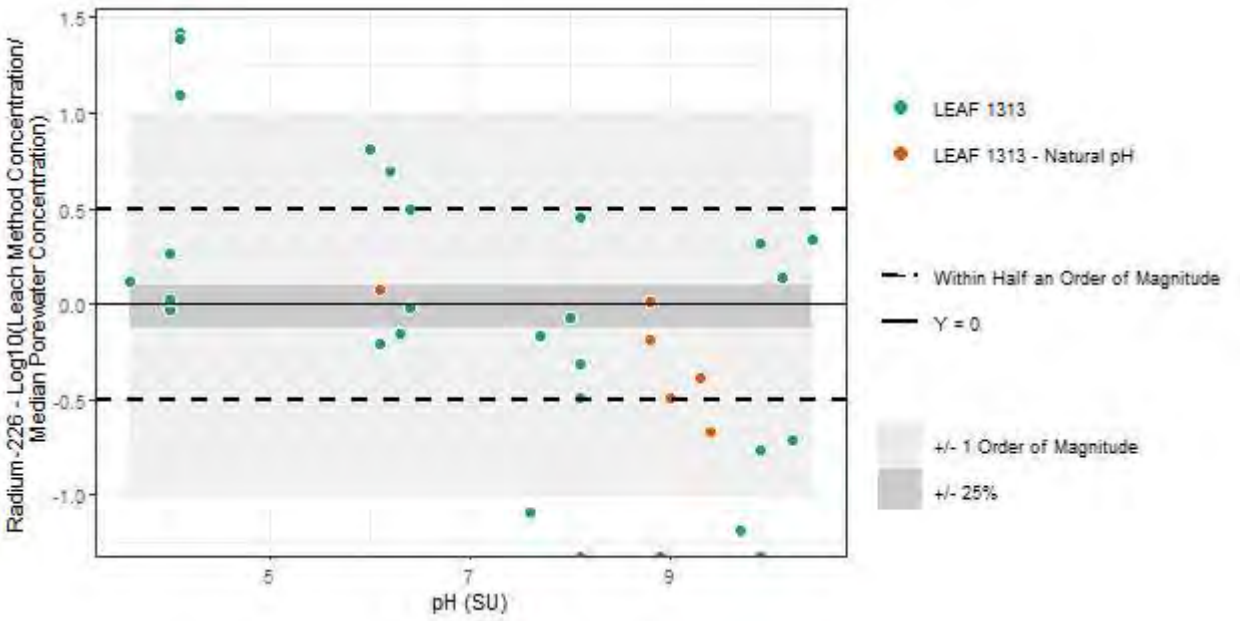

Figure E-20
Radium-226

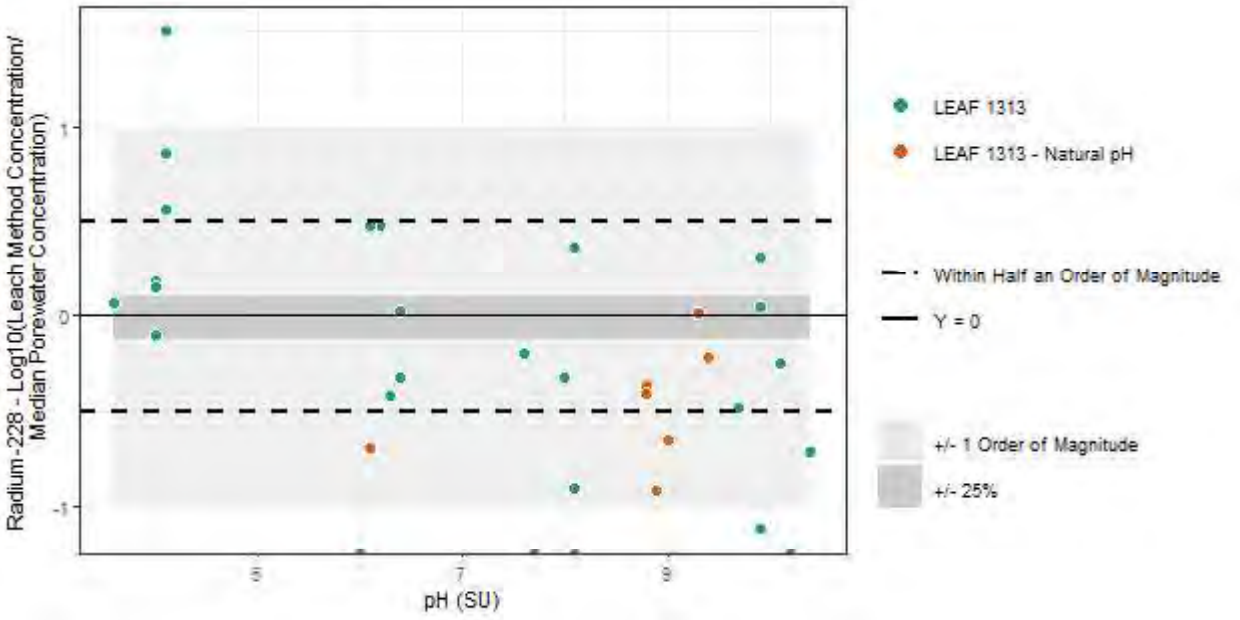

Figure E-21
Radium-228

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

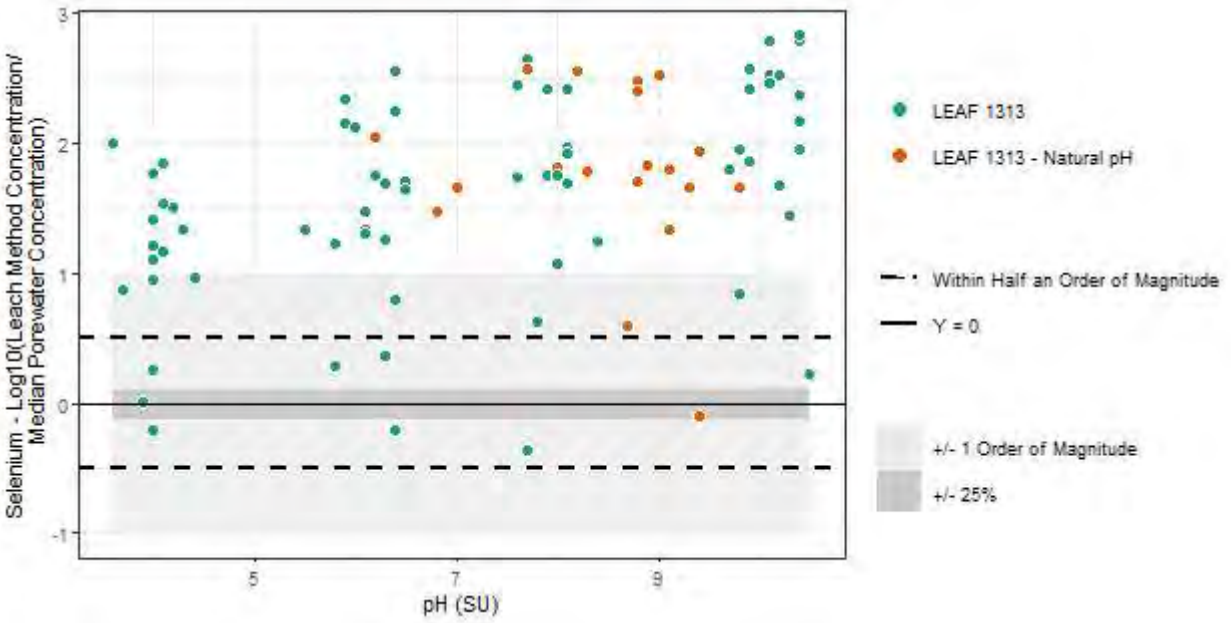

Figure E-22
Selenium

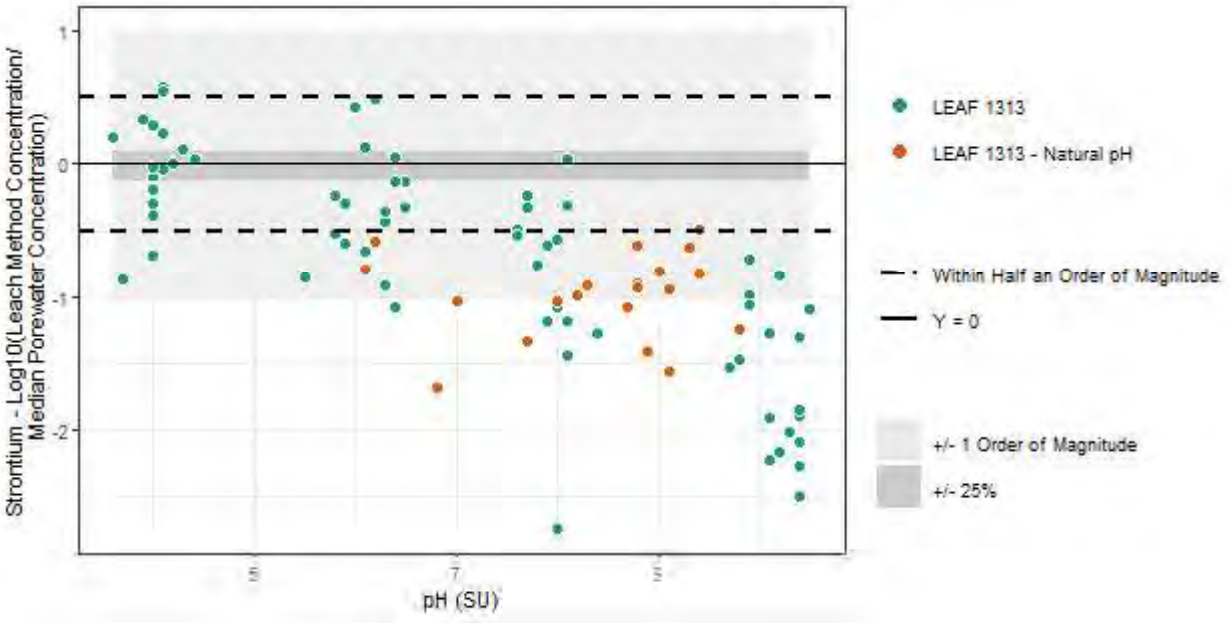

Figure E-23
Strontium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

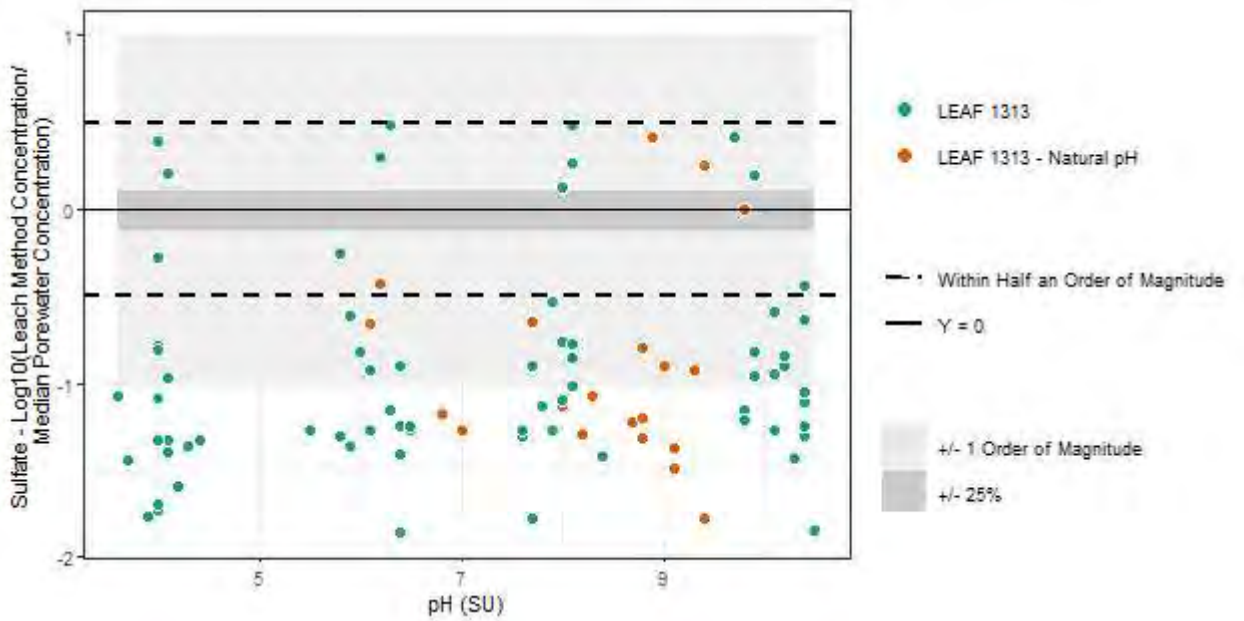

Figure E-24
Sulfate

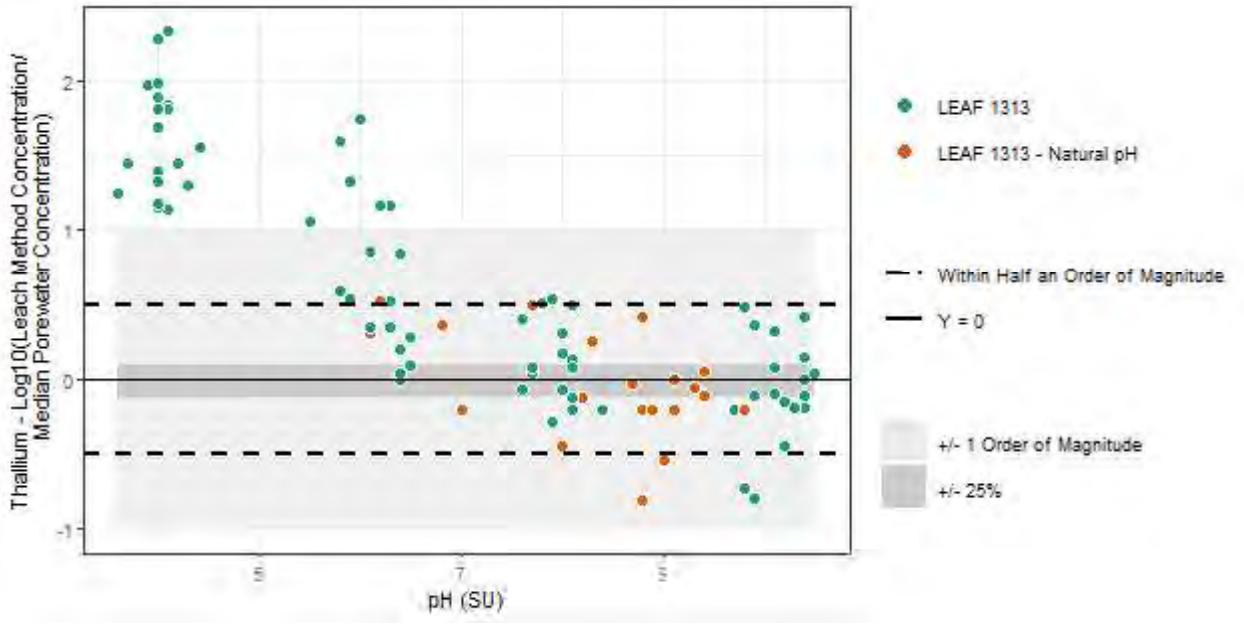

Figure E-25
Thallium

Plots Showing Normalized LEAF 1313 to Porewater Results across the Range of pH Levels Tested

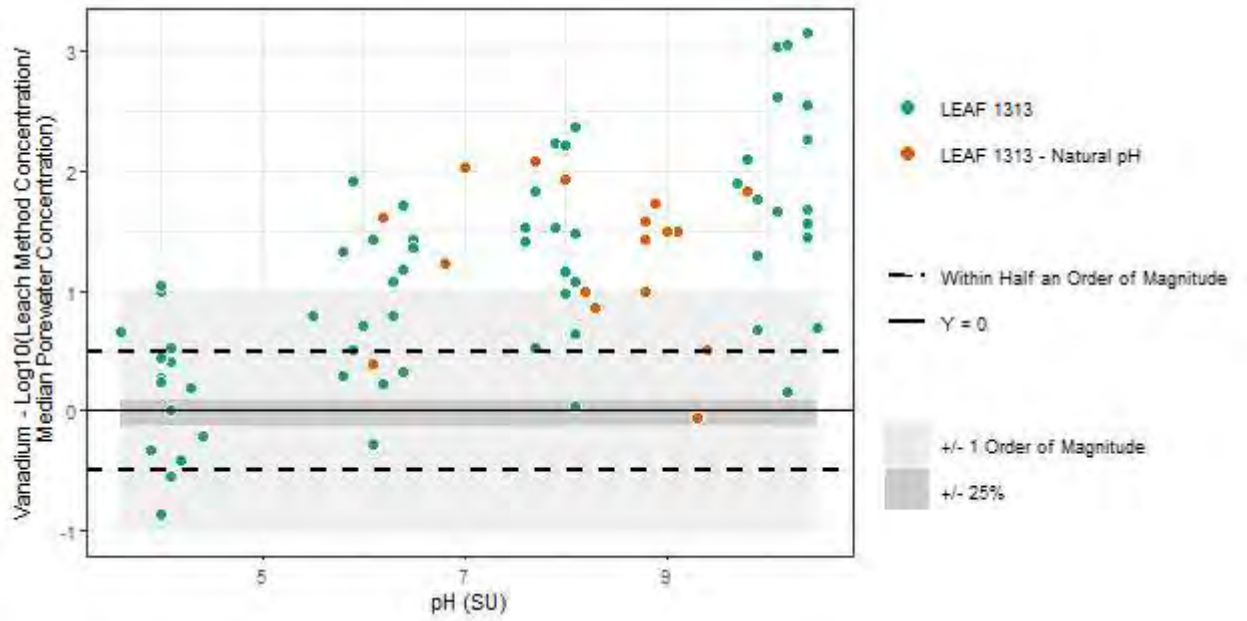

Figure E-26
Vanadium

F

PLOTS SHOWING NORMALIZED LEAF 1316 TO POREWATER RESULTS ACROSS THE RANGE OF L/S VALUES TESTED

Figures F-1 through F-26 show normalized LEAF 1316 test results (and 1313 at natural pH) as a function of L/S ratio. The results were normalized by dividing by the median porewater concentration (because results are displayed as $\log_{10}$, a value of zero indicates exact agreement). The ability of the 1316 test to reproduce porewater concentrations at any given L/S was evaluated based on how many results plotted within the dark-shaded ±25% range.

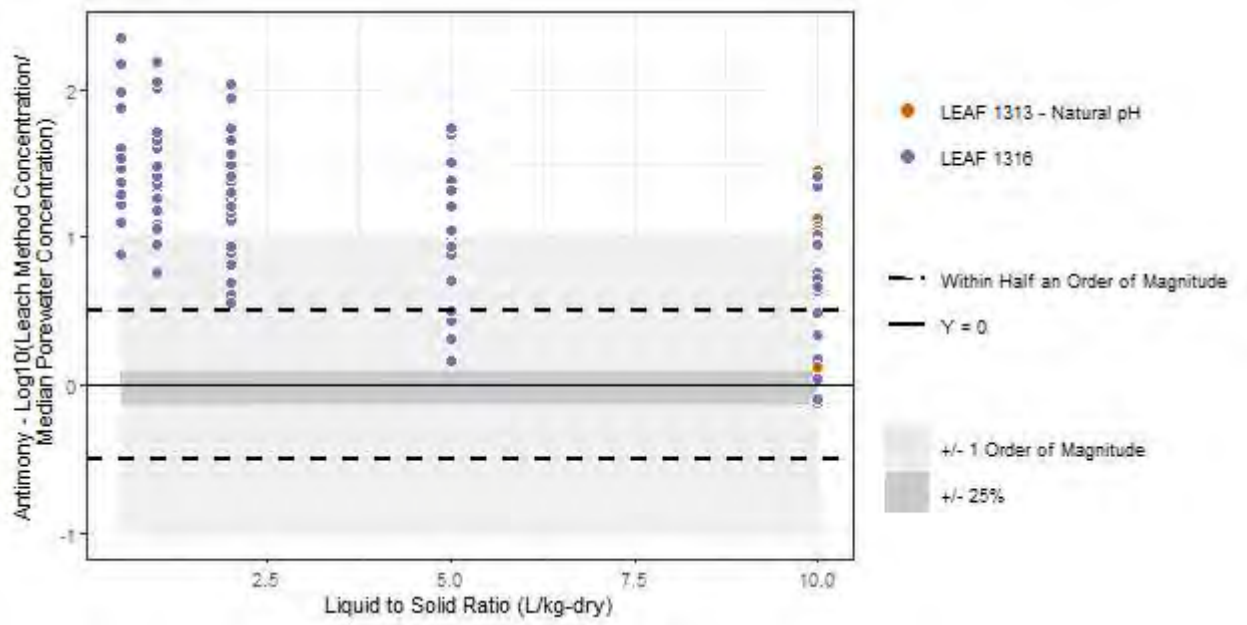

Figure F-1
Antimony

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

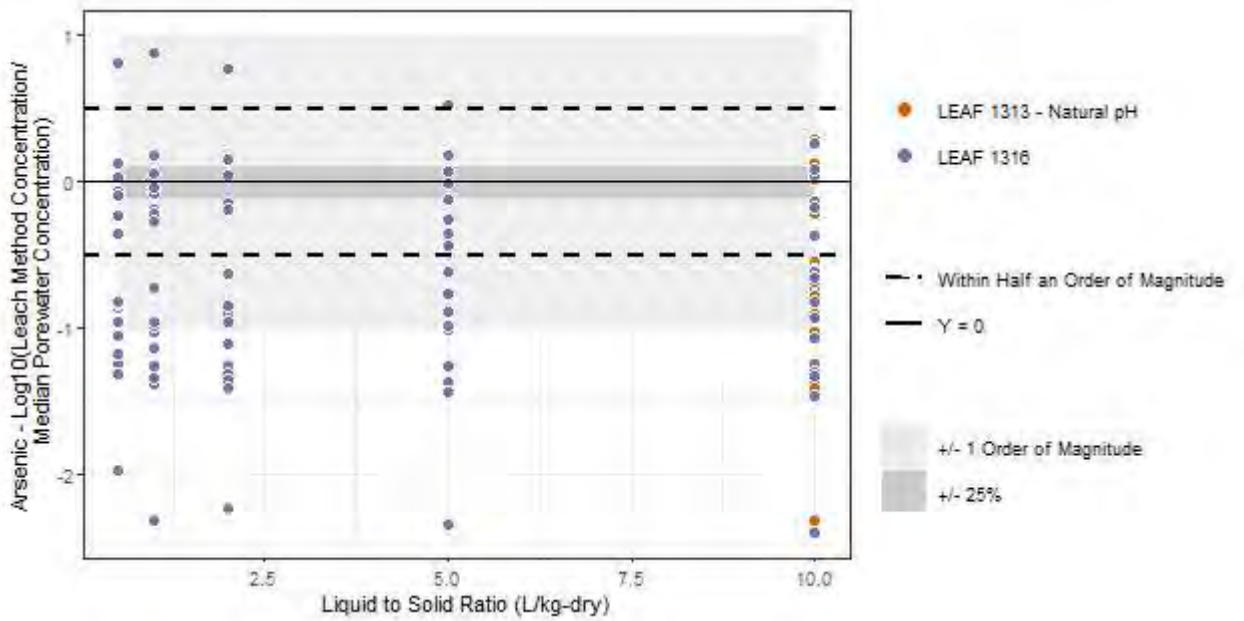

Figure F-2
Arsenic

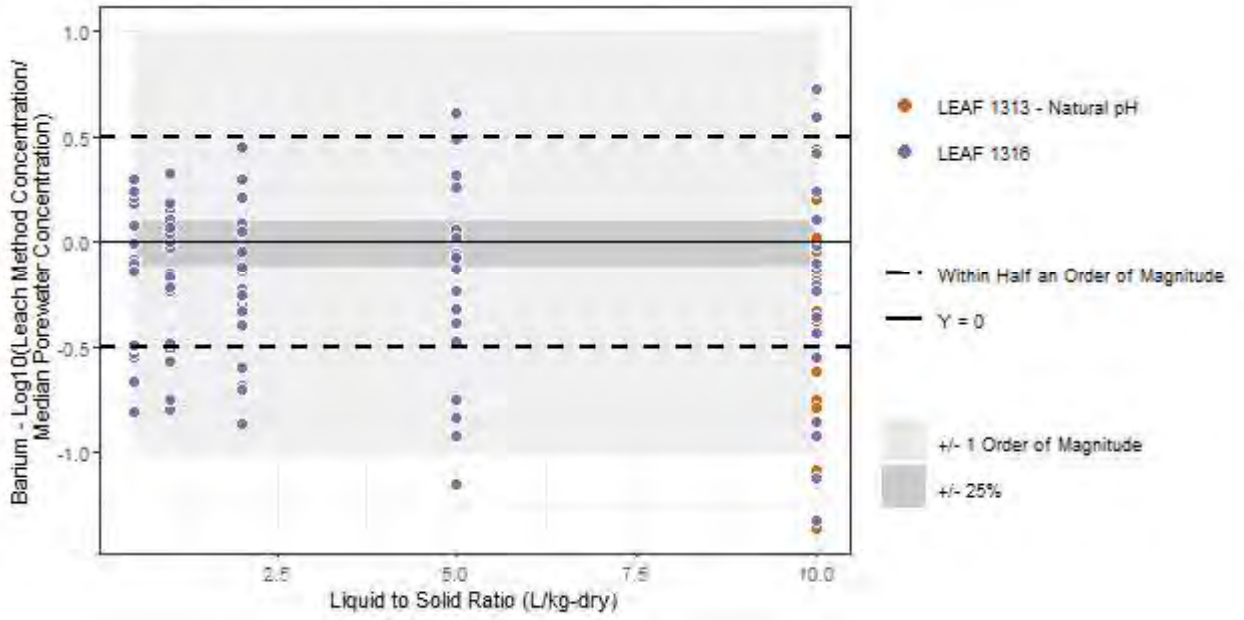

Figure F-3
Barium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

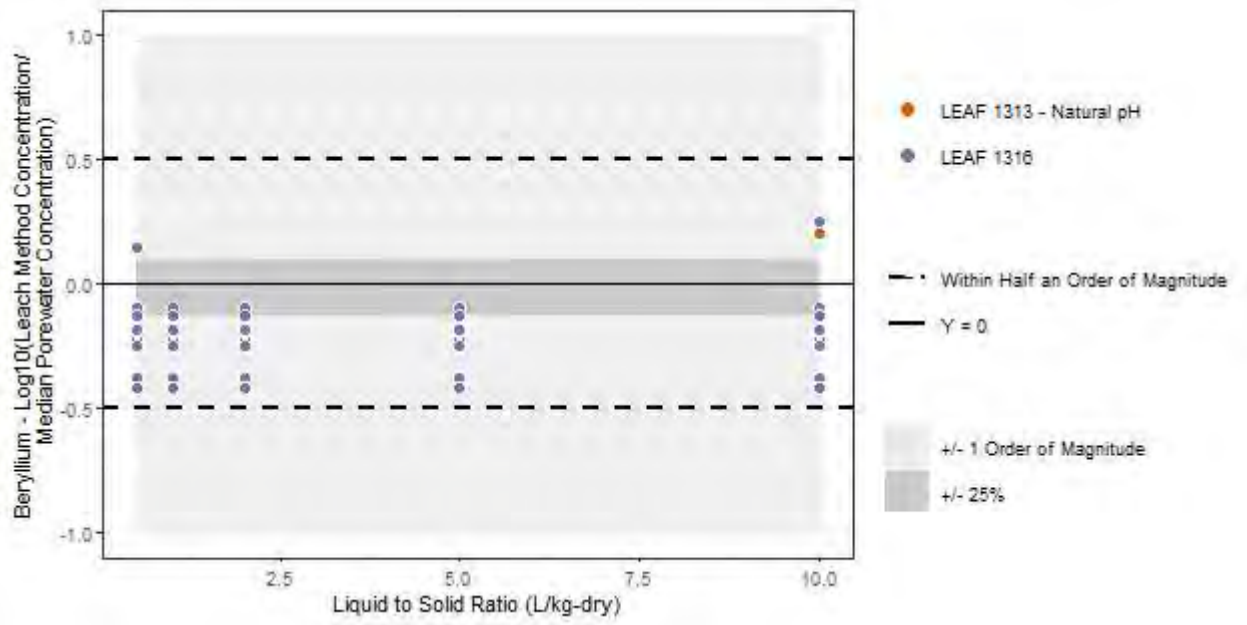

Figure F-4
Beryllium

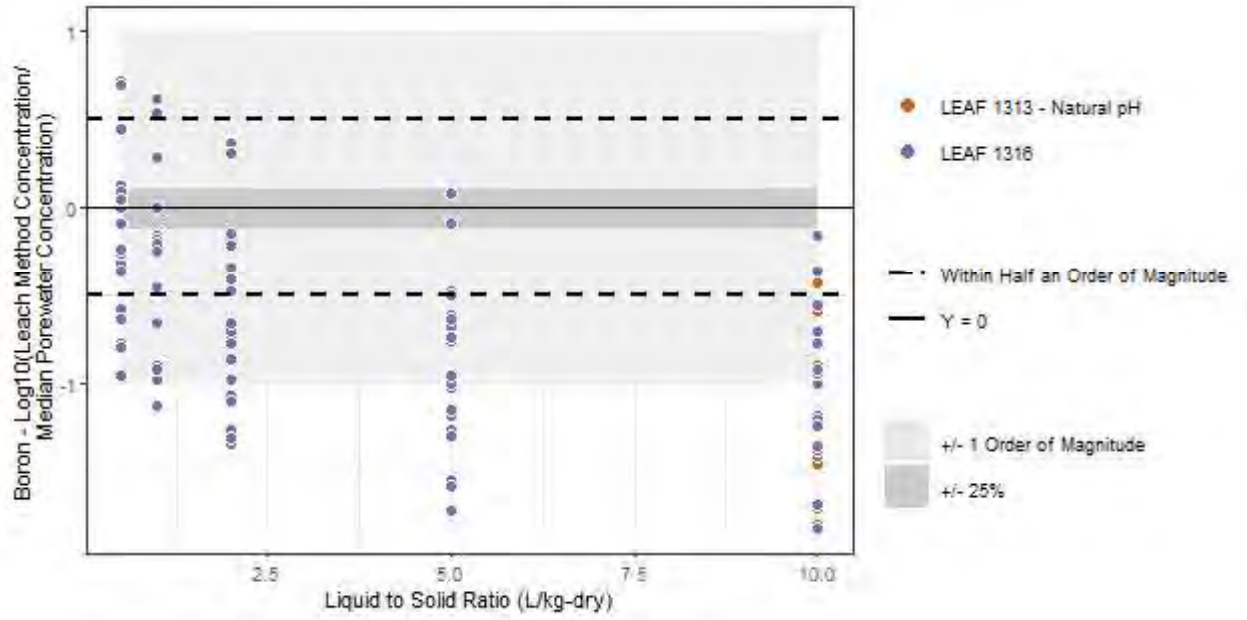

Figure F-5
Boron

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

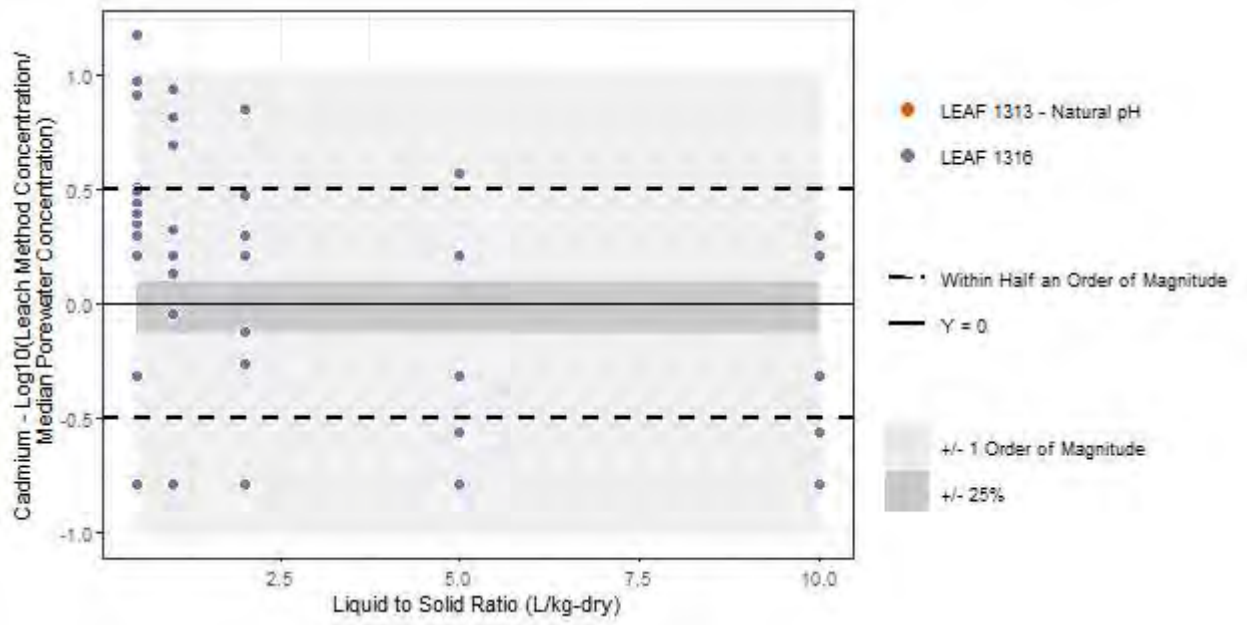

Figure F-6
Cadmium

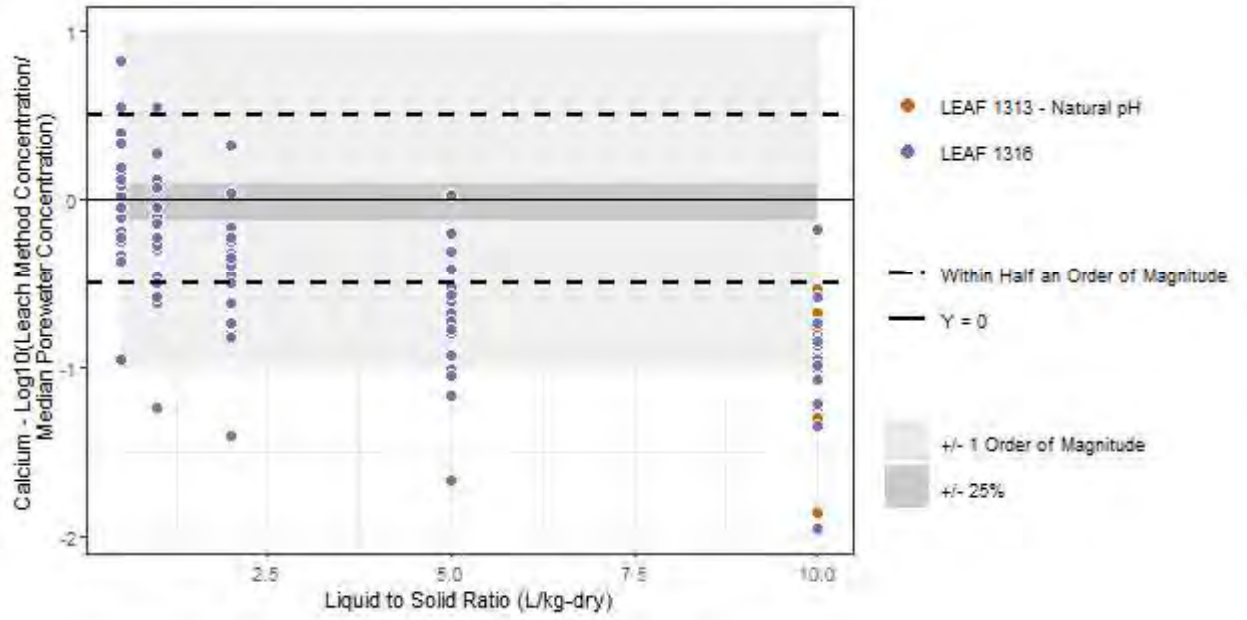

Figure F-7
Calcium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

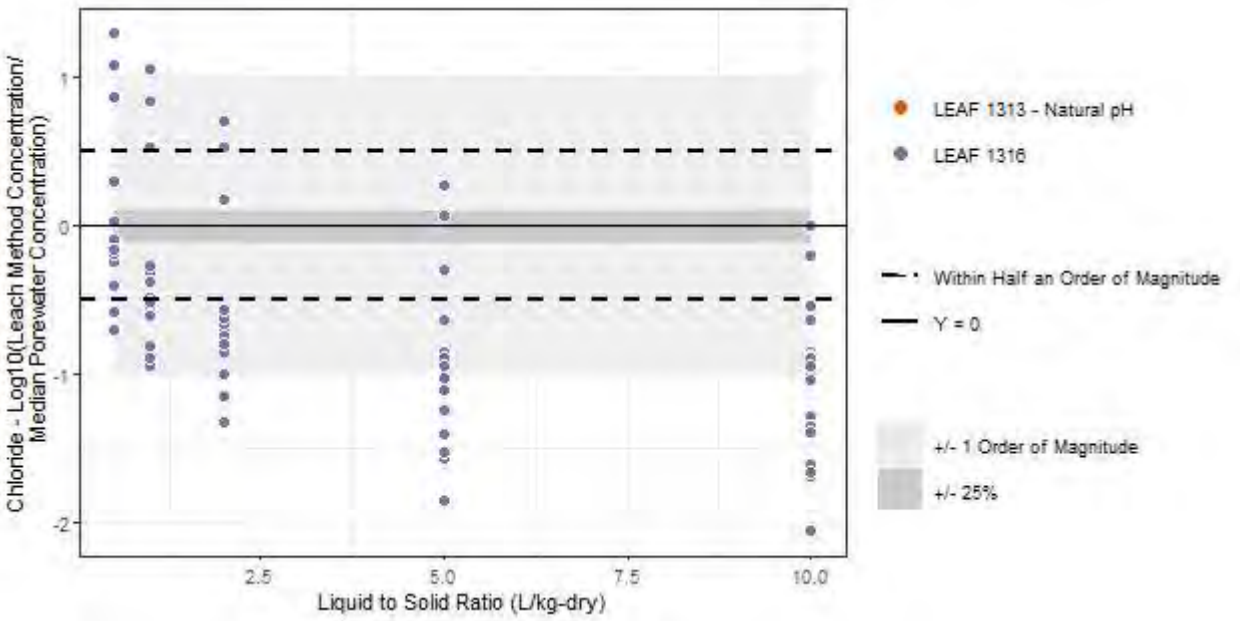

Figure F-8
Chloride

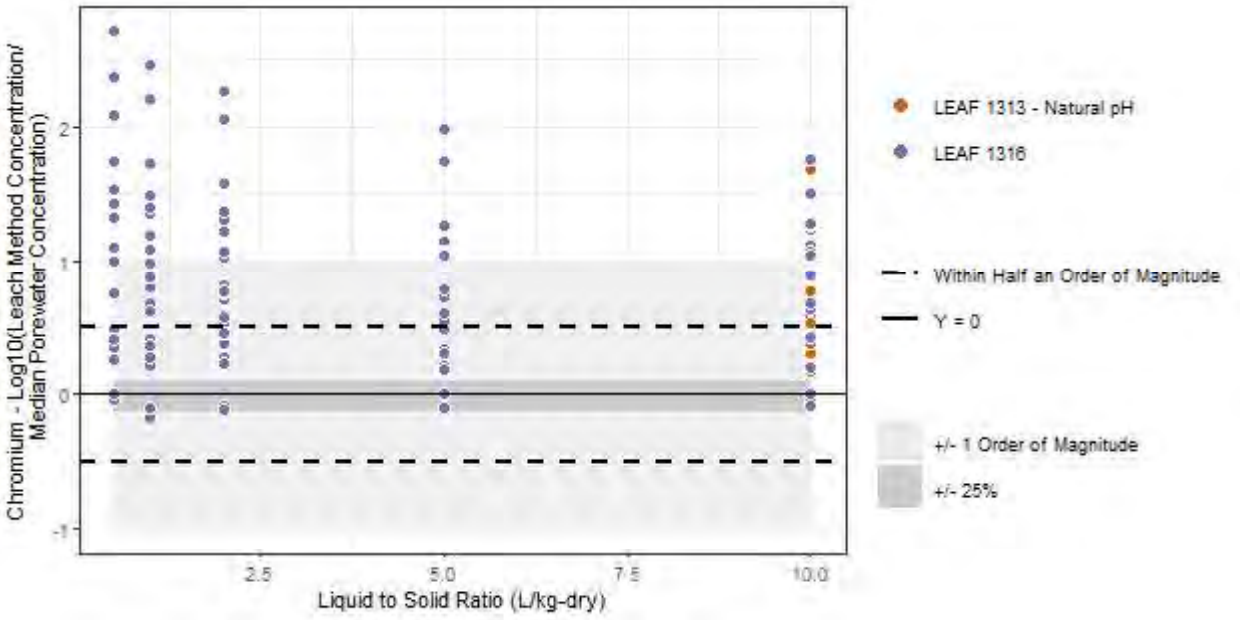

Figure F-9
Chromium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

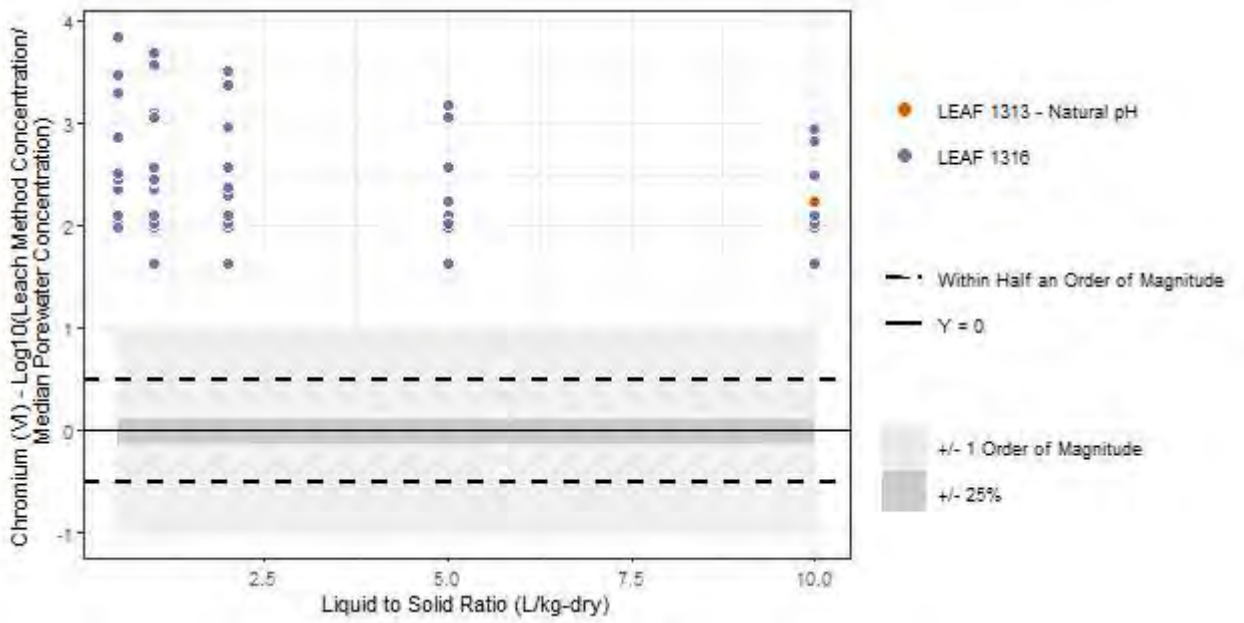

Figure F-10
Chromium (VI)

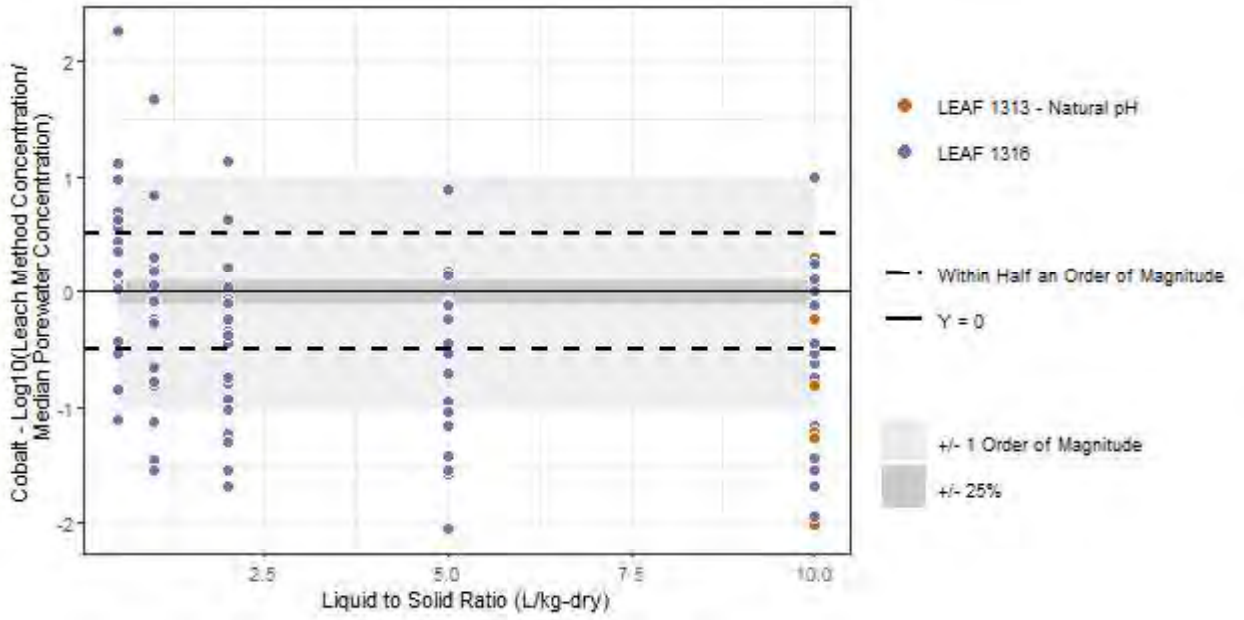

Figure F-11
Cobalt

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

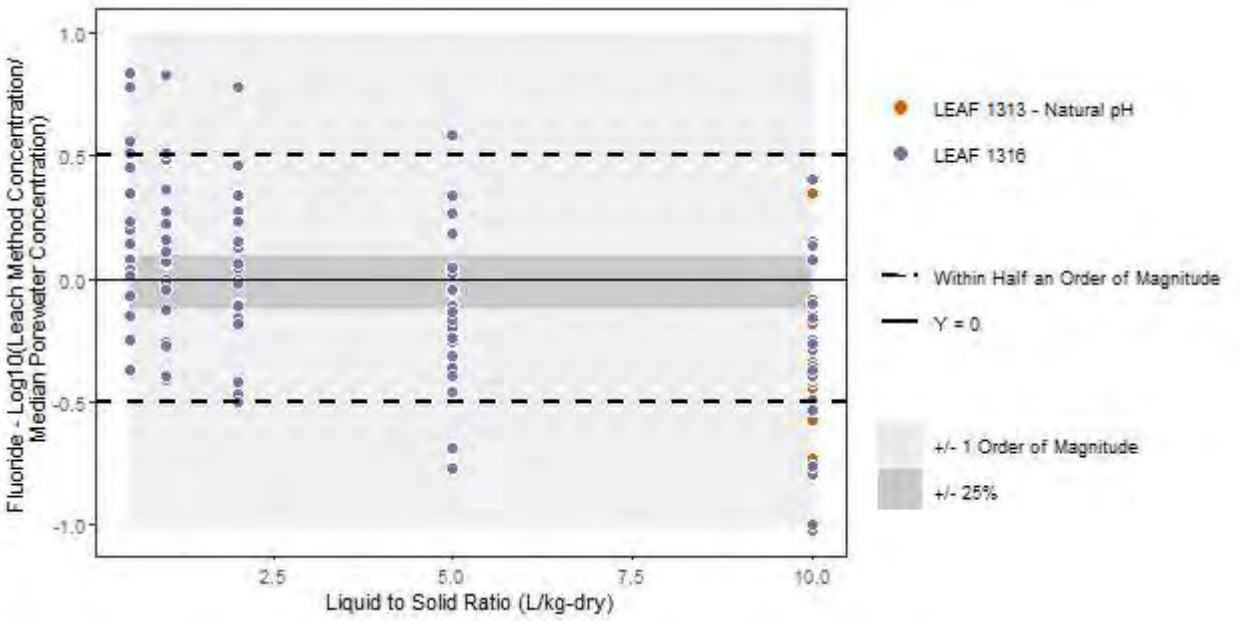

Figure F-12
Fluoride

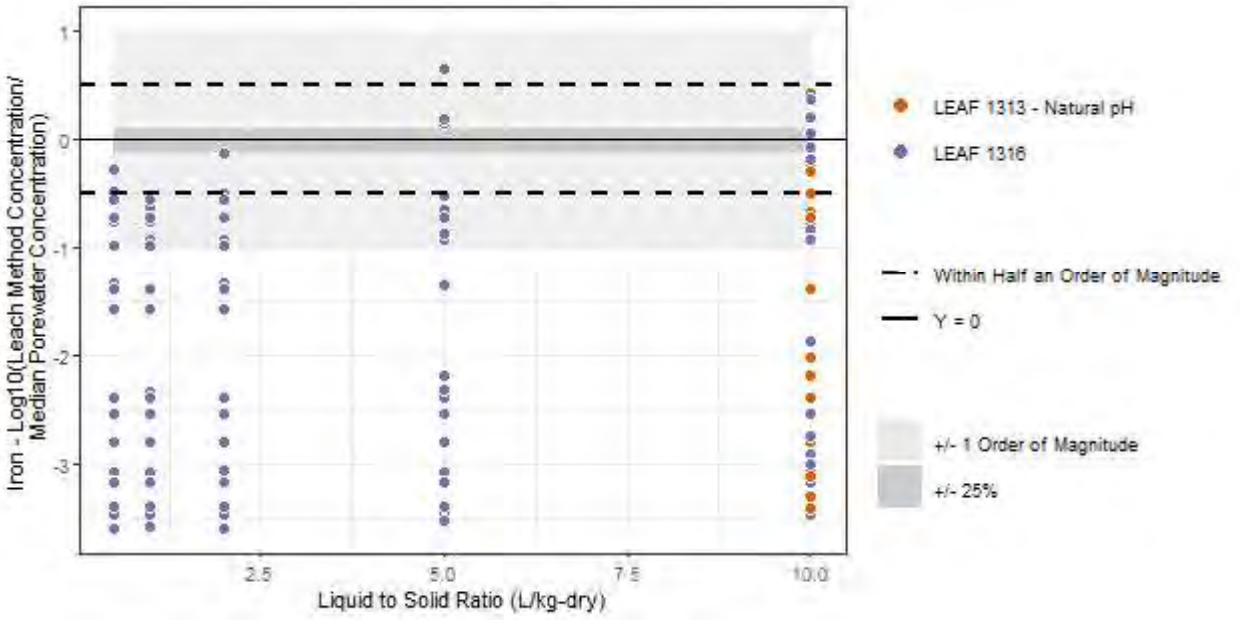

Figure F-13
Iron

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

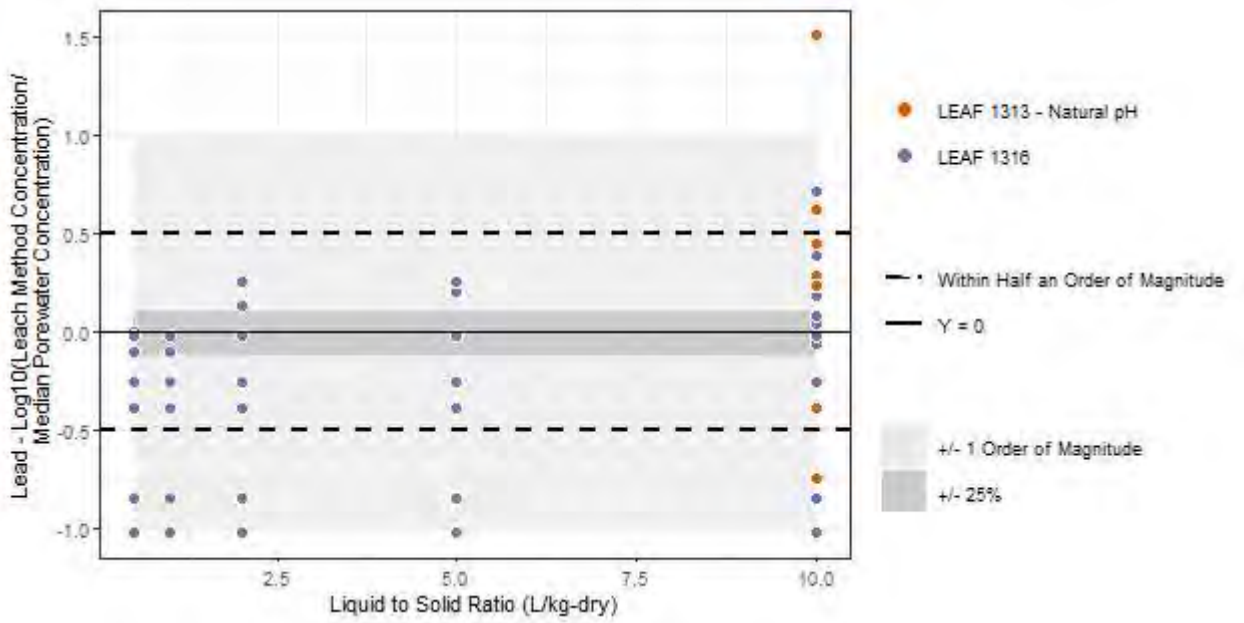

Figure F-14
Lead

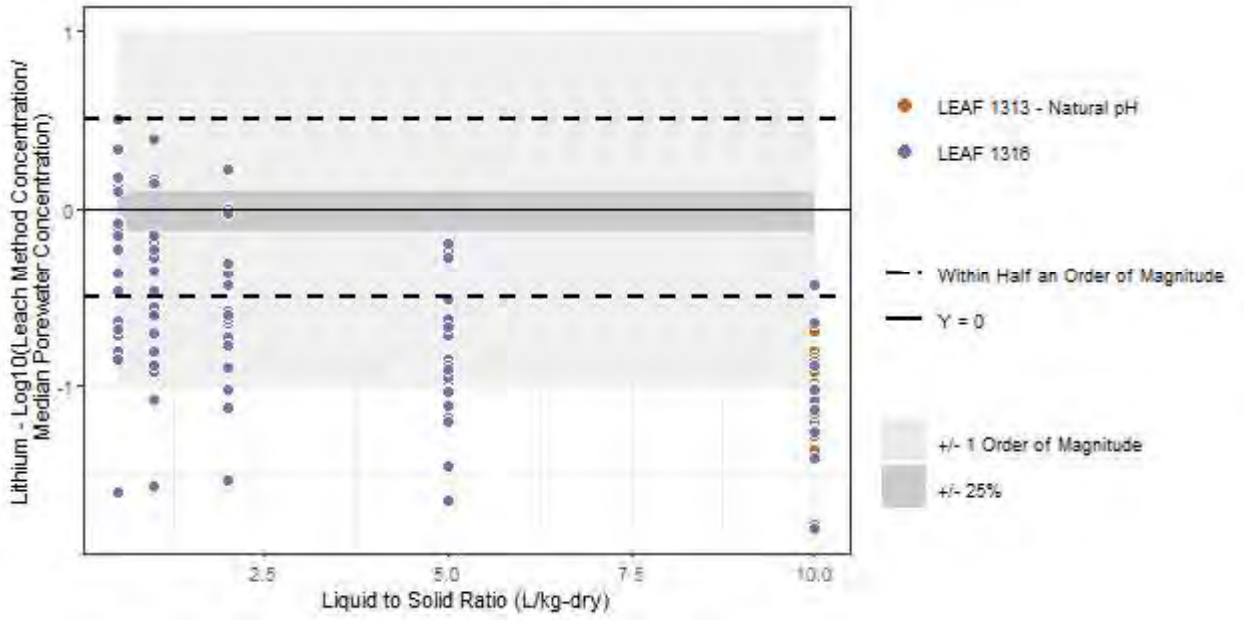

Figure F-15
Lithium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

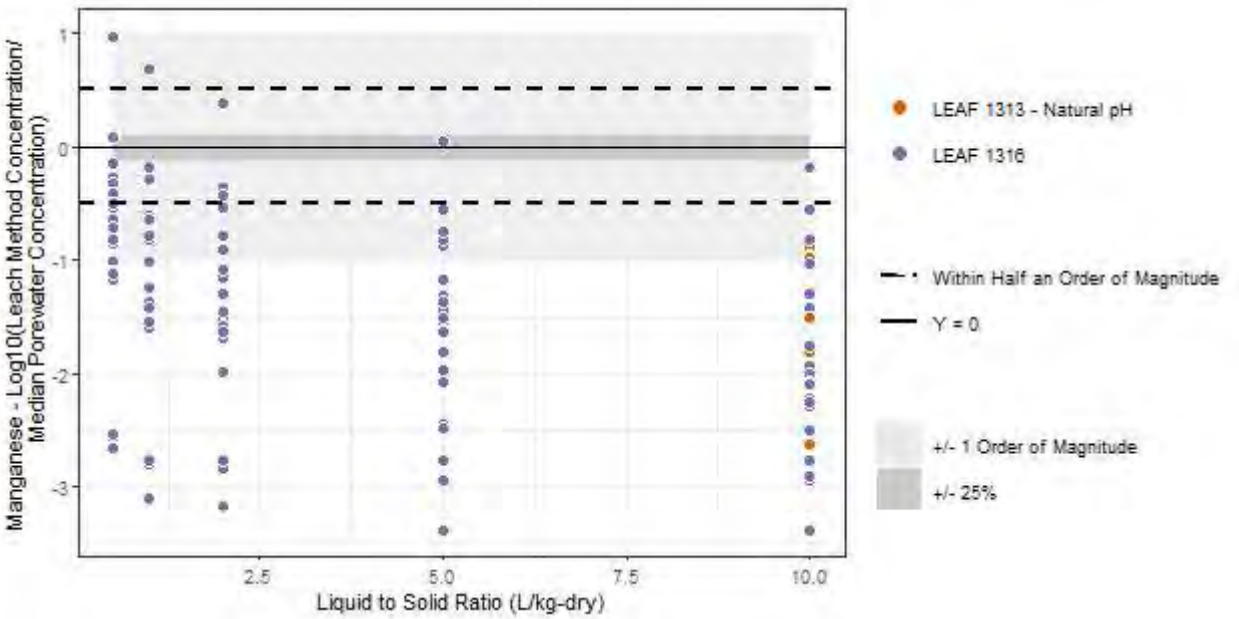

Figure F-16
Manganese

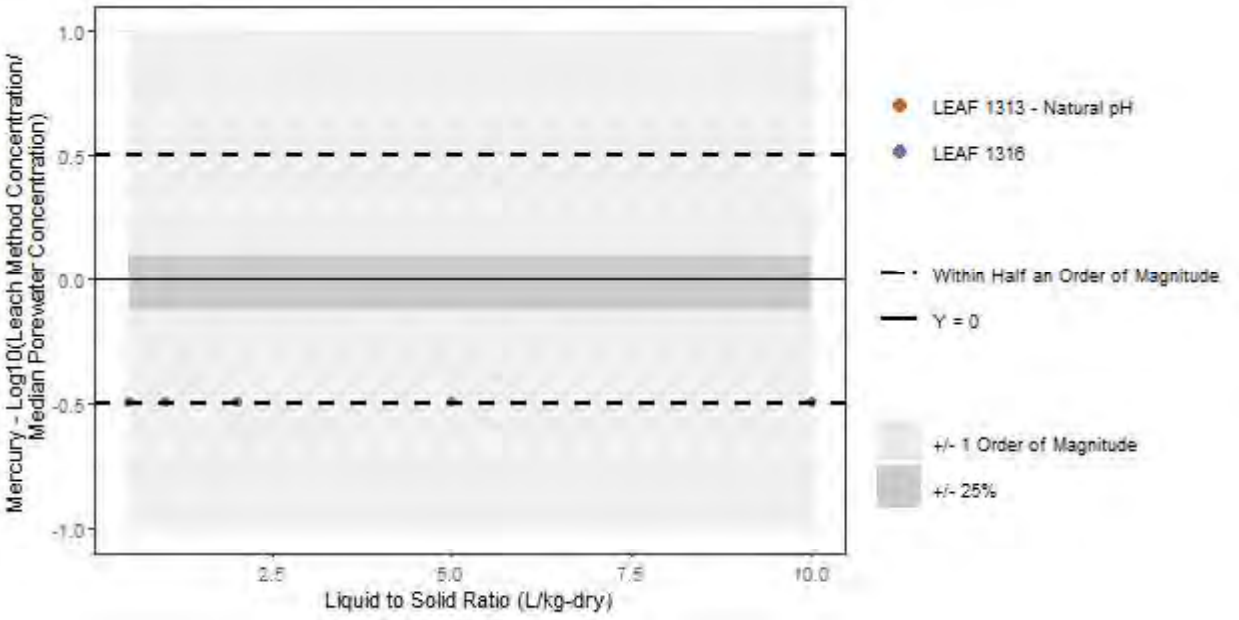

Figure F-17
Mercury

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

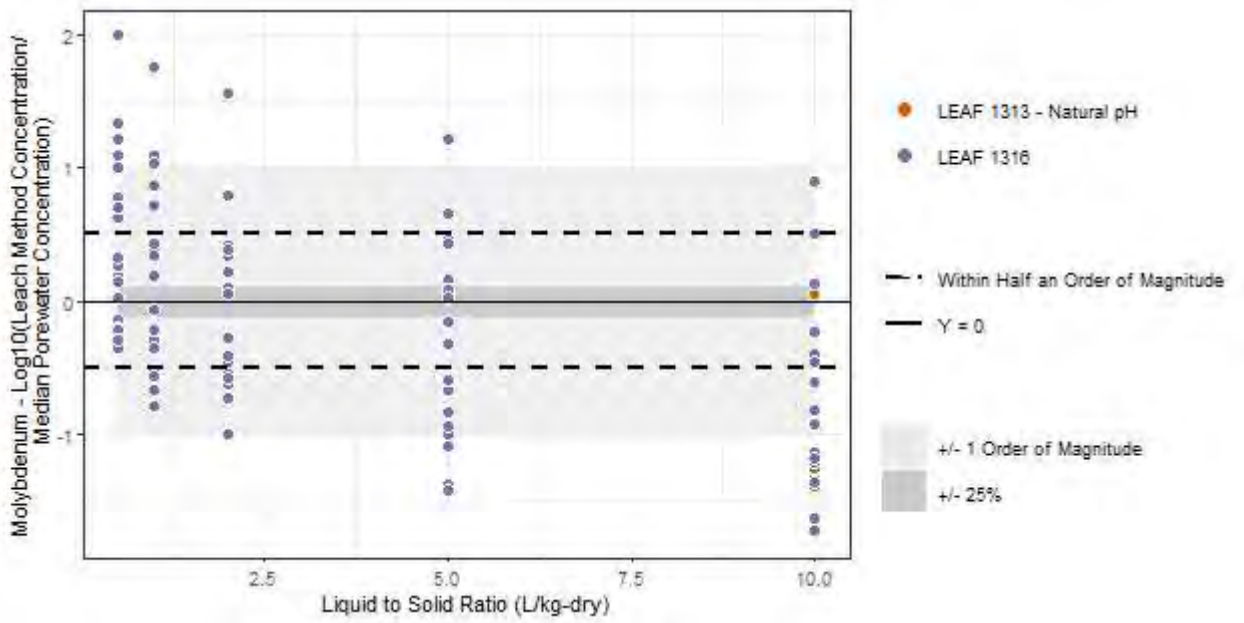

Figure F-18
Molybdenum

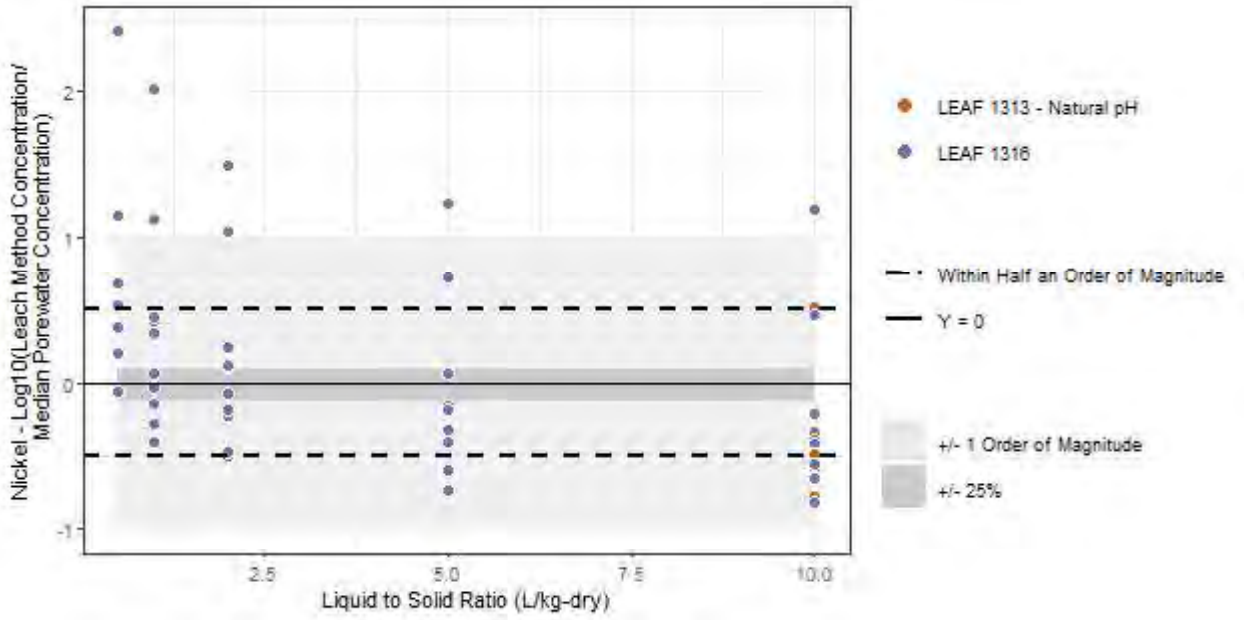

Figure F-19
Nickel

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

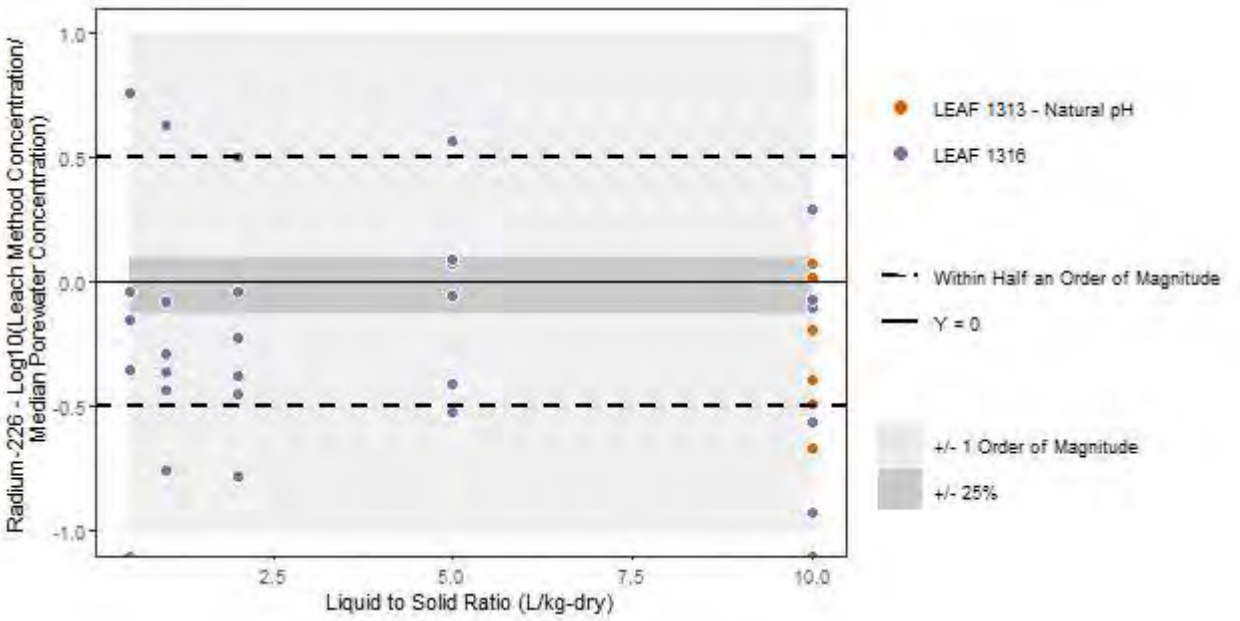

Figure F-20
Radium-226

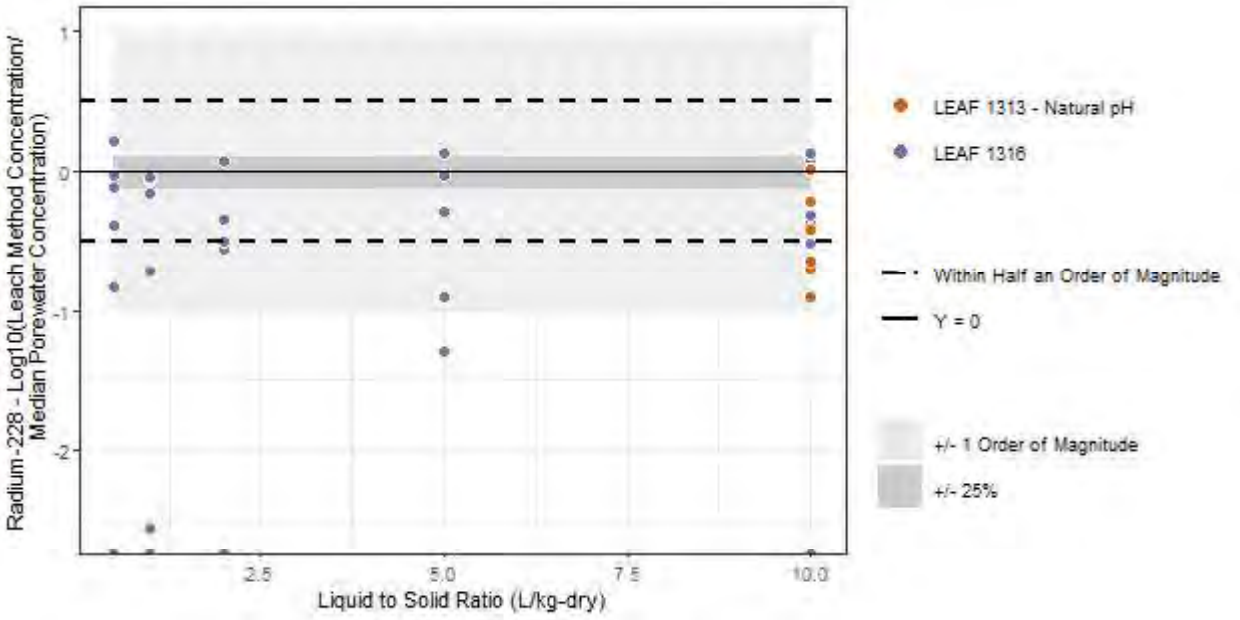

Figure F-21
Radium-228

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

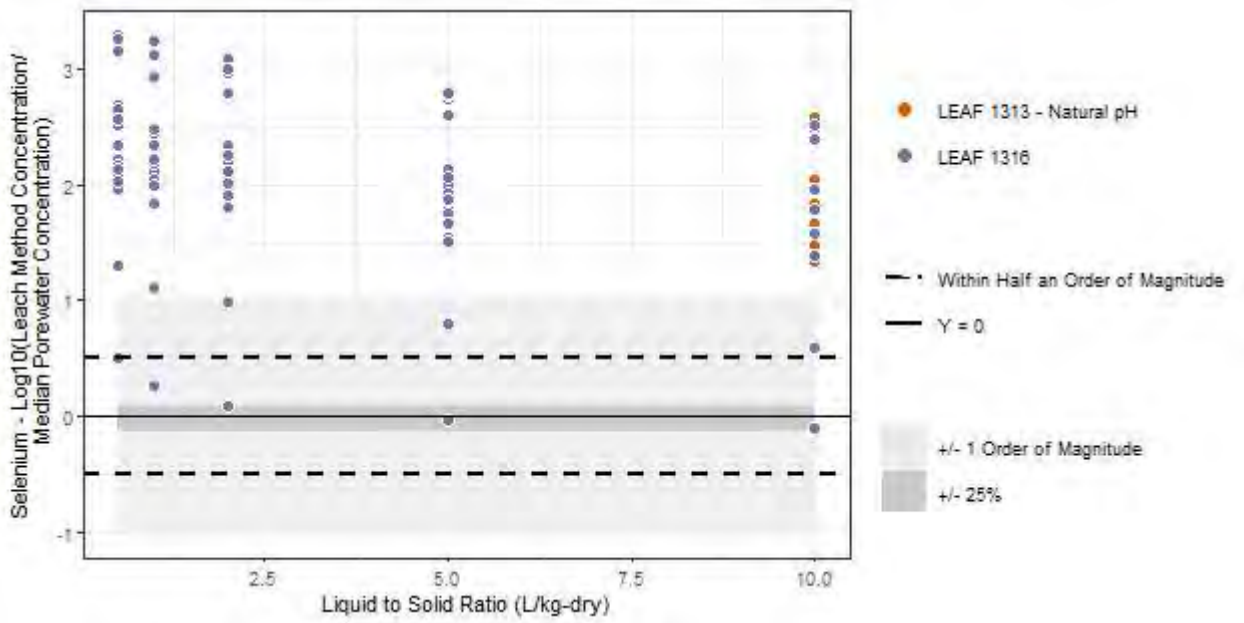

Figure F-22
Selenium

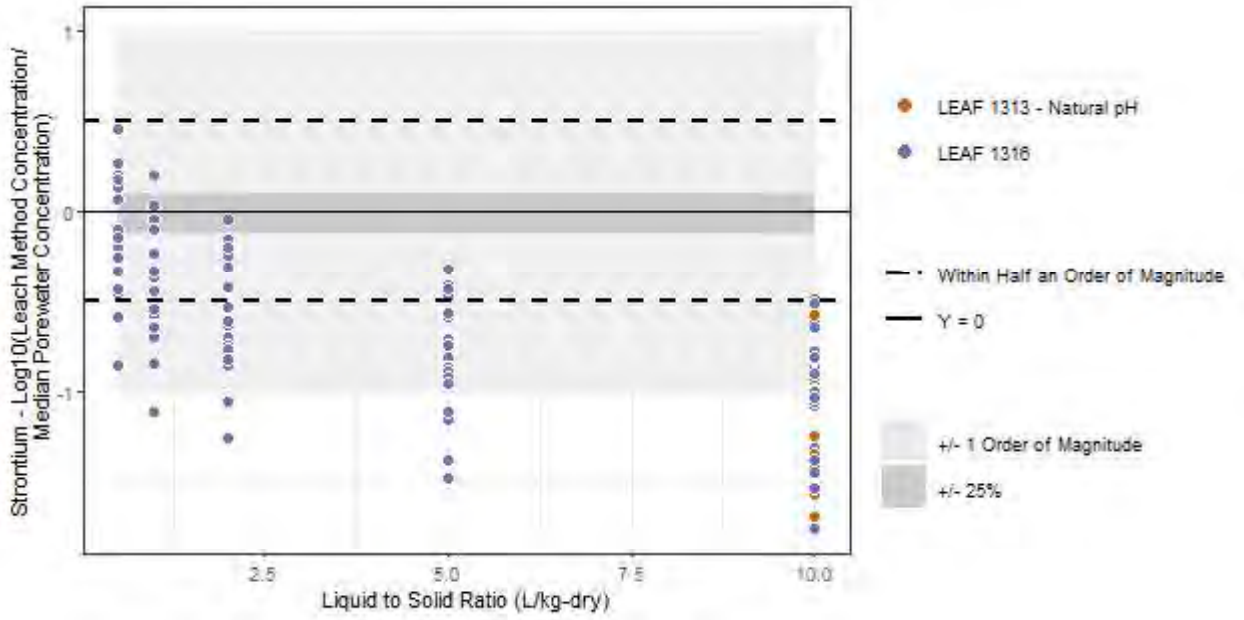

Figure F-23
Strontium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

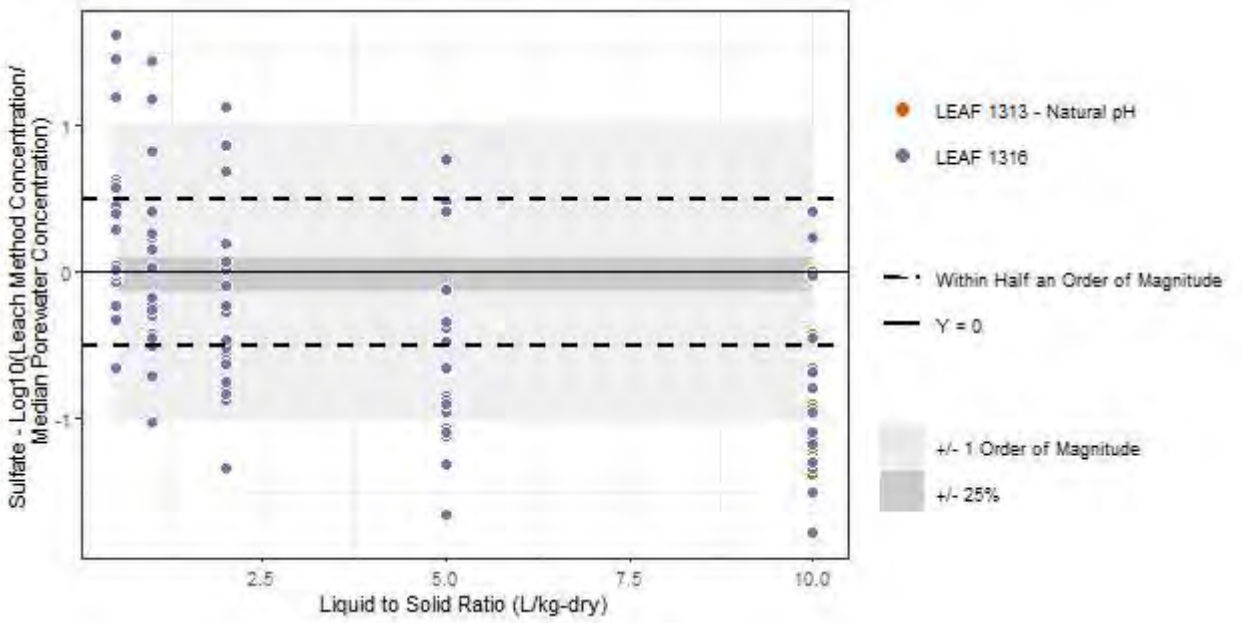

Figure F-24
Sulfate

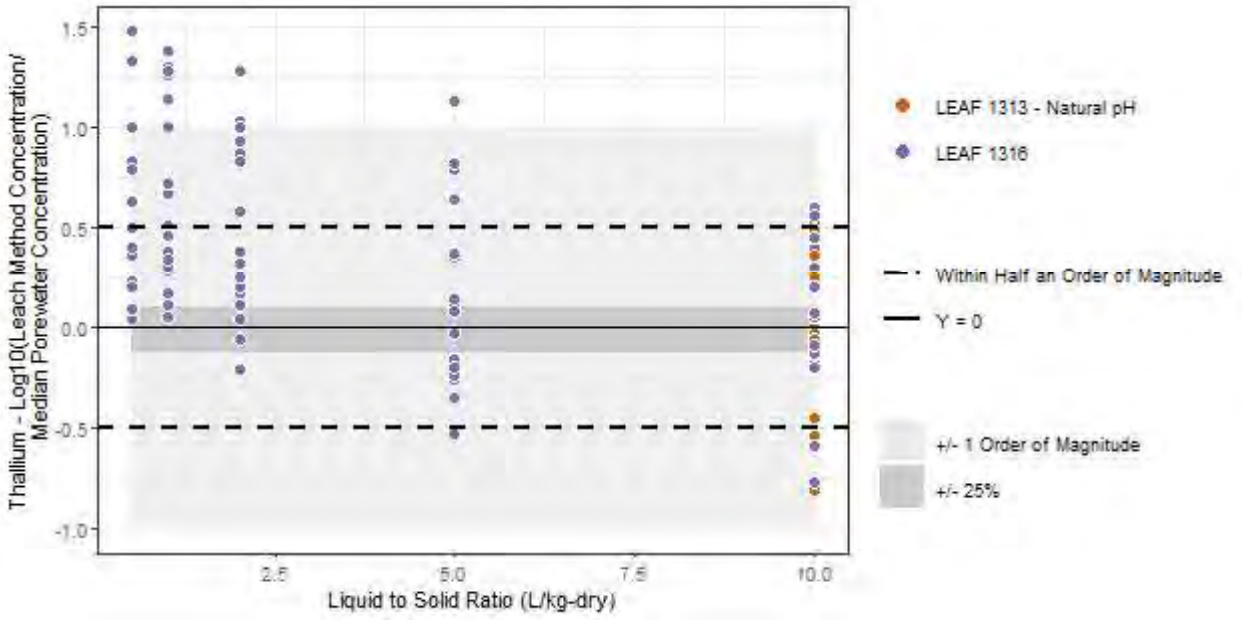

Figure F-25
Thallium

Plots Showing Normalized LEAF 1316 to Porewater Results across the Range of L/S Values Tested

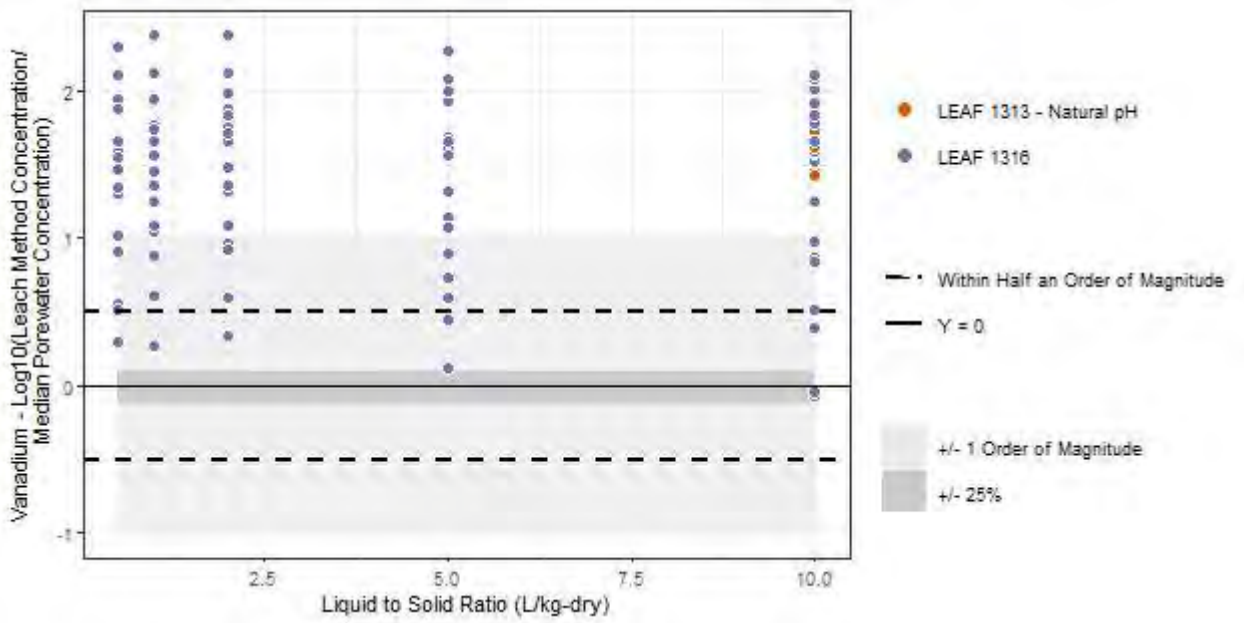

Figure F-26
Vanadium

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EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Appendix 16

Electric Power Research Institute (EPRI), 2021. Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit: Plant 42197. EPRI, Palo Alto, CA: 2021. 3002018780.

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Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit

Plant 42197

2021 TECHNICAL REPORT

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Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit

Plant 42197

3002018780

Final Report, February 2021

EPRI Project Manager
B. Hensel

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Vanderbilt University Department of Civil and Environmental Engineering

Hans van der Sloot Consultancy

University of Virginia School of Engineering

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The following organizations, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Vanderbilt University Department of Civil and Environmental Engineering
Nashville, TN 37235

Principal Investigators
D.S. Kosson (PI)
A.C. Garrabrants (Co-PI)
X. Wang
R. DeLapp

Hans van der Sloot Consultancy
Hoorn, the Netherlands

Principal Investigator
H.A. van der Sloot

University of Virginia School of Engineering
Charlottesville, VA

Principal Investigators
C.H. Benson
J. Chen
J.M. Benavides

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ABSTRACT

The appropriate selection and use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is highly dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field.

This report presents the results of geotechnical, hydrologic, and leaching characterization of samples of coal ash collected from an active coal ash disposal unit where dry-handled coal ash is placed over a portion of a former sluiced (i.e., wet-handled) coal ash deposit. The hydraulic conductivity of intact cores from the saturated coal ash was measured in context of the distribution of particles in the coal ash samples and the overburden pressure associated with disposal at depth within the facility. The leaching test results for LEAF tests (i.e., EPA Methods 1313 and 1314) were compared to the results for traditional tests (i.e., ASTM, TCLP, SPLP). In addition, porewater estimates derived directly from leaching tests were compared to measured porewater concentrations, and measured porewater concentrations were compared to groundwater concentrations.

Keywords
Coal ash
Leaching tests
Porewater
Leaching Environmental Assessment Framework (LEAF)
Hydrogeochemistry

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Deliverable Number: 3002018780

Product Type: Technical Report

Product Title: Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from an Active Coal Ash Management Unit: Plant 42197

PRIMARY AUDIENCE: Electric utility environmental professionals responsible for landfill and impoundment management of CCPs

SECONDARY AUDIENCE: Researchers and regulators interested in CCP leaching and chemistry

KEY RESEARCH QUESTION

The appropriate use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is highly dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field. The objectives of this research were (i) to determine the most appropriate approach for estimating porewater concentrations at CCP disposal facilities, and (ii) to highlight the potential connection between the CCP leaching performance of a disposal facility, based on porewater measurements or leaching tests, and sentinel monitoring of groundwater exterior to the disposed material.

RESEARCH OVERVIEW

The Electric Power Research Institute (EPRI), Vanderbilt University (VU), and University of Virginia (UVA) performed a study to develop relationships between the geochemistry of the disposed CCPs and the measured concentrations for inorganic constituents in the porewater of CCP disposal units. In addition, this study investigates the potential relationship between porewater concentrations and concentration in groundwater measured at adjacent monitoring wells.

CCP materials were collected at four locations from an active CCP disposal unit where coal ash was initially sluiced (wet-handled), and is now dry-handled. During field activities, porewater access points and subsurface gas access points were established for eight monthly sampling events. Collected materials were characterized for leaching and geotechnical/hydrologic properties. The hydraulic conductivity of intact cores from the ash deposit was measured in context of the distribution of particle sizes in the CCP samples and the overburden pressure associated with disposal at depth within the unit. The leaching test results for the Leaching Environmental Assessment Framework (LEAF) (i.e., EPA Methods 1313 and 1314) were compared to those for traditional tests (i.e., ASTM, TCLP, and SPLP). In addition, porewater estimates derived directly from leaching tests were compared to measured porewater concentrations, and measured porewater concentrations were compared to groundwater concentrations.

KEY FINDINGS

- Despite differences in coal ash placement (dry-handled ash in the upper portion and wet-handled ash in the lower portion), there was little observed variability in vertical concentration profiles. This observation suggest that infiltration moving through the unsaturated dry-handled ash (e.g., from precipitation, liquid dumps, water spray for dust management) results in migration of readily dissolved constituents from the dry-handled material into the underlying wet-handled coal ash. Downward movement of soluble constituents results in the pH and porewater composition within the saturated material being similar to the low L/S extraction fractions of composited dry material.
- The ratio of the available content to the total content shows that only a small fraction of total content of most trace constituents is leachable over a broad pH range.
- Suboxic to anoxic conditions are established at relatively shallow depths (> 5 m) below the surface of the dry-handled material.
- The high pH within the porewater of deposited material prevents development of significant microbial activity at depths greater than 5 m below the surface.
- Hydraulic conductivity of the ashes typically was within the range of 10^{-5} to 10^{-6} cm/s. Hydraulic conductivity diminished as the effective stress increased, but only modestly.
- Some parameters in the porewater (e.g., pH, temp, B, Co, Ni, and Zn) exhibited temporal variability due to factors such as seasonal changes or impacts of damage and repair of porewater access points. Other constituents (e.g., Cd, Ca, Cu, Mo, and Se) remained relatively constant within each porewater access point throughout the 8-month monitoring period. Spatial variability was observed for some constituents between porewater access points; however, no consistent pattern was observed.
- The limited data collected from downgradient monitoring wells and porewater access points suggest that porewater concentration alone is an unreliable indicator that a constituent has had an impact on elevated groundwater concentrations or for prediction of downgradient concentrations at this site.
- Traditional leaching tests, such as TCLP, SPLP, and ASTM, are poorer indicators of measured porewater concentrations than LEAF tests. Low liquid-to-solid ratio (L/S) eluates from EPA Method 1314 are better indicators than the traditional tests and EPA Method 1313 for concentrations for available content-limited constituents (e.g., B, Cd, Cl^-, Mo, Se, and SO_4^{-2}) because of the strong L/S-dependence. The data presented here showed that the traditional tests, with an L/S greater than 20 L/kg-dry, and EPA 1313 at L/S=10 L/kg-dry often under-predicted field porewater concentrations by an order of magnitude or more. These results indicate that additional information (e.g., available content and porewater L/S) is needed to provide a reasonable approximation of porewater concentrations. For constituents with solubility-controlled liquid-solid partitioning (e.g., As, Sb, and Tl), EPA 1313 tests at L/S=1 L/kg-dry provide an estimate of porewater concentrations generally within a factor of 2. The combination of pH-dependent leaching data (EPA 1313) with percolation column test results (EPA 1314) provides valuable information for geochemical modeling.

- For field environments that are oxidizing to slightly reducing, leaching test data approximated field porewater concentrations of solubility-controlled constituents within an order of magnitude. Because of the oxic to suboxic subsurface conditions at this site, sampling, laboratory handing, and testing conditions did not appear to significantly influence the redox condition of the field material. This in contrast to impoundments with highly reducing subsurface conditions, where material handling in the presence of oxygen during sampling and laboratory testing can significantly impact test results. The only constituent not well defined by any of the LEAF tests was chromium, the result for which may have been influenced by oxidization of materials during collection from a suboxic environment and testing in an oxic laboratory. The leaching results for chromium indicate that laboratory testing results for redox-sensitive elements (e.g., As, Cr, Sb, Se, V) may not directly reflect the leaching anticipated in porewater when the field environment is reducing, in part due to oxidation incurred during sampling, handling, and testing.

WHY THIS MATTERS

This research provides a unique opportunity to compare a statistically valid field porewater sample set to laboratory leaching test results on samples collected from the same location and depth interval as the porewater sampling point and provides information to guide appropriate use of these tests. It also provides information on, and comparison of, the spatial and temporal/seasonal variability in both porewater quality and laboratory leachate quality at a CCP site. Data collected during this research will inform EPRI physical and geochemical modeling of leaching within coal ash landfills and impoundments.

HOW TO APPLY RESULTS

The results of this research are site-specific, yet when considered with known differences in L/S associated with different leaching tests, and geochemical differences between the field and laboratory environment, they provide information for generalizing the best uses of different leaching tests and porewater data. Companies interested in performing similar comparisons between leaching tests and porewater will be interested in the field and laboratory methodologies described in Sections 2 and 3. Companies and stakeholders interpreting leaching test and porewater results will be interested in the results summarized in Sections 6 and 7.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- A framework using geochemical modeling and porewater data to predict long-term leaching at CCP sites is being developed under EPRI Program 242's hydrogeochemistry project. A series of reports published from 2018 through 2021 describe results of this research. These reports can be accessed by searching epri.com for "Hydrogeochemical Assessment of Long-Term Leaching Characteristics at Coal Combustion Product Sites."
- Stakeholders, including regulatory agencies, reviewing leaching test analyses may be interested in results of this research to understand the relationship between the different leaching tests, and the relationship between leaching tests and porewater within CCPs.

EPRI CONTACT: Bruce Hensel, Principal Technical Leader, bhensel@epri.com

PROGRAMS: Coal Combustion Products Management, P241, P242 and 2020 PS49A.

ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviations and Acronyms

AMSL	above mean sea level
BGS	below ground surface
CCP(s)	coal combustion product(s)
CFR	Code of Federal Regulations
CH_4	methane gas
CO_2	carbon dioxide gas
DIW	deionized water
DIC	dissolved inorganic carbon
DO	dissolved oxygen
DOC	dissolved organic carbon
EC	electrical conductivity (mS/cm)
EPA	U.S. Environmental Protection Agency (Washington, DC)
EPRI	Electric Power Research Institute (Palo Alto, CA)
GAP(s)	gas access point(s)
HDPE	high-density polyethylene
HFO	hydrous ferric oxides
HNO_3	nitric acid
HSA	hollow-stem auger
H_2S	hydrogen sulfide gas
H_2SO_4	sulfuric acid
IC	ion chromatography
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma – mass spectrometry
ICP-OES	inductively coupled plasma – optical emission spectroscopy
ID	internal diameter
KOH	potassium hydroxide

LEAF	Leaching Environmental Assessment Framework
LLOQ(s)	lower limit(s) of quantitation
LOI	loss on ignition
LSP	liquid-solid partitioning
L/S	liquid-to-solid ratio (mL/g-dry)
MDL(s)	method detection limit(s)
NDIR	non-dispersive infrared
NH_3	ammonia gas
NIST	National Institute of Standards and Technology (Gaithersburg, MD)
NTU	nephelometric turbidity unit
OD	outer diameter
ORP	oxidation-reduction potential (mV)
O_2	oxygen gas
PAP(s)	porewater access point(s)
pe	electron concentration (-log mol e^-/L)
PSD	particle size distribution
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act of 1986
SAP	sampling and analysis plan
SU	standard unit
TC	total carbon
UVA	University of Virginia (Charlottesville, VA)
VU	Vanderbilt University (Nashville, TN)
wt%	weight percent (percent by mass)
XRF	x-ray fluorescence
ΣL/S	cumulative liquid-to-solid ratio

Groundwater/Porewater Sample Points

VC-1	porewater access point in the CDL landfill
VC-2	porewater access point in the CDL landfill
VC-3	porewater access point in the CDL landfill
VC-4	porewater access point in the CDL landfill
209	downgradient groundwater monitoring well

931	downgradient groundwater monitoring well

Leaching/Extraction Tests

ASTM	ASTM D3987: Practice for Shake Extraction of Solid Waste with Water
1313	EPA Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH Using a Parallel Batch Procedure
1314	EPA Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-Flow Percolation Column Procedure
1313_L/S=1	EPA Method 1313 modified for L/S=1 mL/g-dry and abbreviated to 5 target endpoint pH values about the own pH of the material
SPLP	EPA Method 1312: Synthetic Precipitation Leaching Procedure
TCLP	EPA Method 1311: Toxicity Characteristic Leaching Procedure

Equation and Parameter Variables

AC	available content (mg/kg-dry)
$C_{1313(\max pH\ 2,9,13)}$	max concentration from EPA 1313 at pH 2, 9, or 13 (mg/kg-dry)
F	Faraday constant (23,061 cal/(V mol))
Eh	redox potential (mV)
L/S	liquid-to-solid ratio for fully saturated pores (L/kg-dry)
$(L/S)_{1313}$	liquid-to-solid ratio for EPA 1313 extractions
PW	mean porewater concentration from monthly PAP monitoring (mg/L)
R	1.987 (cal/(K mol))
s	global standard deviation of a profile parameter in all “known ash samples”
T	temperature (K)
WC	water content (%)
x	parameter measurement (e.g., pH, concentration) from the low L/S extraction test
$\bar{x}$	global mean of a profile parameter in all “known ash samples” for all boreholes
z	concentration of a constituent in a leaching test (mg/L)
%D	percentage difference between leaching and porewater concentrations
ρ_{dry}	dry unit density (kg-dry/m^3)
θ_s	saturated water content (m^3_{water}/m^3)

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1 INTRODUCTION

The appropriate use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field. For example, traditional leaching tests, including EPA Method 1311: Toxicity Characteristic Leaching Procedures (TCLP), EPA Method 1312: Synthetic Precipitation Leaching Procedure (SPLP), and ASTM D3987: Shake Extraction of Solid Waste with Water (ASTM), provide only a snapshot of leaching performance under conditions that often deviate substantially from current or anticipated future field conditions.

In 2012, the United States Environmental Protection Agency (EPA) published four leaching methods from the Leaching Environmental Assessment Framework (LEAF) as draft methods available for use. The four methods have since been validated (Garrabrants et al., 2012a; 2012b) and incorporated as final methods into the Agency's compendium of laboratory methods for solid wastes (SW-846, 2019). The four LEAF methods are:

- EPA Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH Using a Parallel Batch Procedure
- EPA Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-Flow Percolation Column Procedure
- EPA Method 1315: Mass Transport Rates of Constituents in Solid Materials Using a Tank Leaching Procedure
- EPA Method 1316: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Procedure

The LEAF approach differs from traditional leaching assessment methodologies in that the leaching tests are designed to provide a series of eluates characteristic of leaching behavior dependent on one or more controlling factors rather than a single eluate that is representative of field leachate from a designed scenario. The EPA has provided a guide for how LEAF tests may be incorporated into common leaching assessment practices (EPA, 2019; Garrabrants et al., 2020a; 2020b).

There remains uncertainty as to the selection of specific test methods and interpretation of testing results to represent (i) the range of pH and liquid-to-solid ratio (L/S) within a waste mass and (ii)

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the current and long-term geochemical conditions of the porewater of CCP impoundments and landfills. Thus, leaching tests have been widely applied, but often without consideration of their inherent limitations for providing information suitable for evaluation of long-term leaching performance. In addition, little information is available that directly compares measured field porewater concentrations at CCP disposal sites to the results of various leaching test results.

The Electric Power Research Institute (EPRI), Vanderbilt University (VU), and University of Virginia (UVA) initiated a study to develop relationships between the geochemistry of the disposed CCPs and the measured and predicted concentrations for inorganic constituents in the porewater of CCP disposal units. In addition, this study investigates the potential relationship between porewater concentrations and the concentrations in groundwater measured at adjacent downgradient monitoring wells; although this evaluation was limited because there were no upgradient or background monitoring wells that could be used for comparison. This research was accomplished by collecting CCP materials from an active disposal unit where dry-handled coal ash overlies wet-handled ash. During field activities, subsurface materials were collected during borings, and porewater access and subsurface gas access points were installed and sampled for eight monthly monitoring events. Collected materials were characterized for leaching and geotechnical/hydrologic properties. A framework for integrating these data is being developed under a separate EPRI project. This report provides the methodology for sampling and characterization of disposed CCPs collected from an ash management unit at Plant 42197, also referred to as "CDL." The report summarizes the results of characterization CCP samples, including leaching tests and geotechnical/hydrologic data, and monitoring data with respect to groundwater and coal ash porewater collected at the facility as well as vadose-zone subsurface gas concentrations monitored within the coal ash deposit.

Project Goals and Objectives

The goals of this research are (i) to determine the most appropriate approach for estimating porewater concentrations at CCP disposal facilities, and (ii) to highlight the potential connection between the CCP leaching performance of a disposal facility and monitoring of groundwater exterior to the disposed material, based on porewater measurements and leaching tests.

The specific objectives of this project include:

- Collecting field materials to qualify the spatial variability of materials disposed in the management unit and measurements of spatial and temporal variability of porewater and pore gas composition, and to allow for characterization of leaching and geotechnical/hydrologic properties;
- Characterizing the hydraulic properties of coal ash for use in hydrologic/reactive transport modeling of CCP impoundments and landfills;
- Establishing the relationships between the characterization of leaching from bulk samples using traditional leaching tests (i.e., TCLP, SPLP, and ASTM) and LEAF pH- or L/S-dependence leaching tests with measured porewater concentrations monitored at the site;
- Assessing the ability of leaching tests (traditional or LEAF tests) to directly estimate coal ash porewater concentrations; and

- Identifying the relationship, if any, between porewater concentrations within the saturated zone of the management unit and downgradient groundwater concentrations.

Site Description

The active landfill at Plant 42197 covers a 110-acre area that was part of a larger 300-acre CCP management unit constructed around 1970 and used to collect storm water and process water from the plant. Starting in the mid-1990s, the unit was divided into sections for sluicing/consolidation of bottom ash, storage of gypsum, and landfilling of dry-handled fly and bottom ash. A 5-ft layer of bottom ash with a permeable geomembrane was laid as a capillary break over the lower wet-handled coal ash deposit to separate this older material from the landfill. Fly ash is collected in a dry state and conditioned with moisture prior to spreading and compacting the ash on the landfill. Bottom ash from the bottom ash settling area is deposited and compacted into the unit primarily to provide surface stability for transport and construction equipment. Starting in October 2019, approximately one-quarter of the surface area of the landfill was covered with 1-2 feet of topsoil and seeded for final cover.

Sampling and Testing Approach

Fieldwork for this project included: (i) advancement of boreholes into the coal ash deposit to improve the understanding of the ash stratigraphy and to obtain samples of the unsaturated and saturated ash layers; (ii) installation of porewater access points (PAPs) within the saturated ash layer and subsurface gas access points (GAPs) within the unsaturated ash; and (iii) sampling of groundwater and porewater and subsurface gas on a monthly basis.

Figure 1-1 shows the relative locations of four boreholes (VC-1, VC-2, VC-3, and VC-4) drilled into the coal ash for material sampling at the site and for installation of PAPs. Additionally, the figure indicates the locations of two groundwater monitoring wells (209 and 931) that allow for sampling of downgradient groundwater in the alluvium that extends beneath the management unit. No upgradient groundwater monitoring well was identified that would provide data on the condition of groundwater prior to reaching the disposal facility. At each of the four borehole locations, bulk ash samples were collected at approximately 10-foot intervals by split spoon sampling. This material was tested in the field and in the laboratory to evaluate the homogeneity of material in the disposal facility and to characterize the leaching properties of the collected ash. In parallel, intact ash cores were collected by tube sampling to determine geotechnical characteristics and hydraulic conductivity of the disposed ash. On a monthly basis for eight months following the completion of the initial fieldwork, samples were collected from each PAP and from the two downgradient groundwater monitoring wells to provide points of comparison to PAP porewater samples. During monthly sampling, the composition of subsurface gas was monitored.

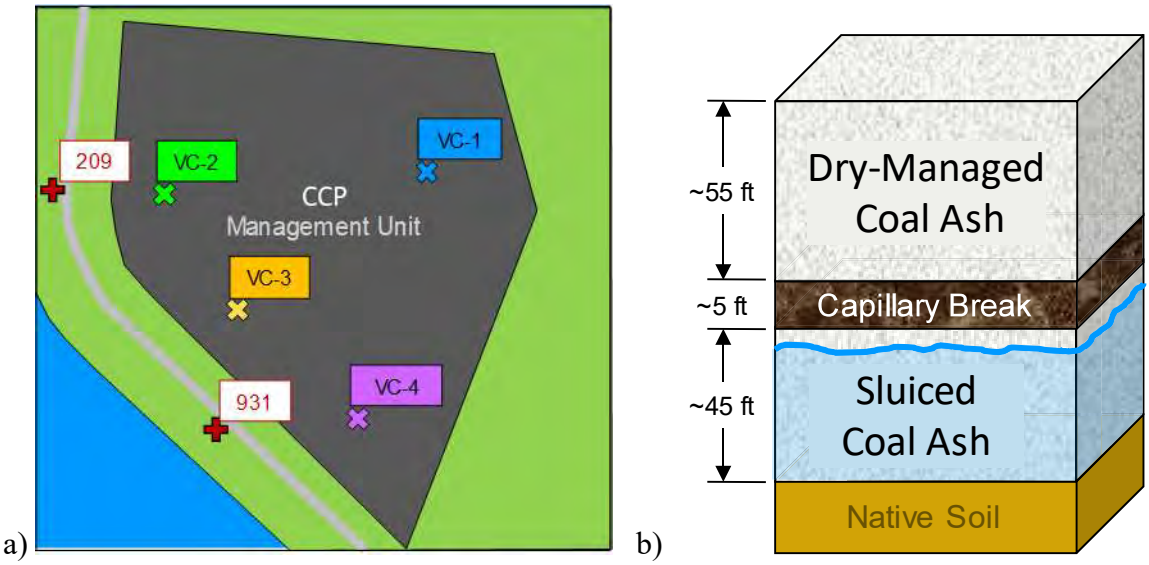

Figure 1-1
Schematic representations of the CDL management unit: a) plan view showing boreholes (VC-1 through VC-4) and groundwater monitoring wells; b) cross-section of disposal unit with approximate layer depths

Bulk samples of collected ash were shipped to the Department of Civil and Environmental Engineering at VU for characterization of leaching properties using the following tests:

- EPA Method 1313 to determine leaching behavior as a function of eluate pH at L/S values of 10 and 1 mL/g-dry,
- EPA Method 1314 to evaluate L/S-dependent leaching from a percolation column, and
- A trio of single-batch extraction tests (i.e., TCLP, SPLP, and ASTM) commonly used to estimate leaching concentrations.

The eluate pH for all leaching tests was measured and recorded so that comparisons could be made between leaching evaluations. The reported constituents include most of those found in the Code of Federal Regulations, Title 40, Section 257 (40 CFR 257), Appendix III for detection monitoring and Appendix IV for assessment monitoring, as well as several additional constituents. Although listed in 40 CFR 257 App III and IV, radium and total dissolved solids were not analyzed. Approximately 40 constituents were quantified in leachates and porewater/groundwater samples to provide a comprehensive basis for geochemical modeling of leaching test results.

The geotechnical and hydrologic properties of intact core samples were determined at the School of Engineering at UVA. Hydraulic conductivity of intact samples was measured using flexible-wall permeameters following the methods in ASTM D5084. Tests were conducted over a range of effective stresses to evaluate how hydraulic conductivity varies with packing configuration and overburden found at depth. Particle size analysis was conducted on each sample using the methods in ASTM D6913 to understand how the hydraulic conductivity varies with the composition of the ash.

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2
COLLECTION OF FIELD MATERIALS

The locations of the four boreholes (VC-1, VC-2, VC-3, and VC-4) shown in Figure 1-1 were selected to be within the footprint of the saturated ash deposits, but out of the way of active ash placement. Thus, materials obtained from these boreholes were considered to capture the vertical and horizontal heterogeneity of ash materials above and below the water table. Prior to the 1990s, coal ash was sluiced from the main plant using process water to an outfall near the location of VC-1. Records indicate that the wet-handled ash is approximately 45-feet deep, covered by a 5-foot thick bottom ash capillary break, and, at the time of field sampling, approximately 55 feet of unsaturated dry-handled material consisting of fly ash mixed with bottom ash. The description of historical ash placement in this unit, and the lack of any significant known spatial variations in material types within the unit, indicated that the four locations would be representative of materials across the 110-acre disposal facility.

Initial Site Sampling

Field sampling included collection and testing of bulk ash samples from two to three consecutive split spoons interspersed with thin-wall tube sampling to obtain samples of undisturbed ash. This sequence was repeated at 10-foot intervals starting at five feet below ground surface (BGS). All drilling operations were conducted by a contracted drilling/engineering company. Boreholes were advanced using an 8.25-inch internal diameter (ID) hollow-stem auger (HSA) drilling a 13-inch diameter hole. Collected samples included small samples used in field-testing, bulk material preserved for leaching characterization at VU, and core samples for hydraulic property testing at UVA. Figure 2-1 shows a schematic of the samples collected at depth along with a summary of the number and type of samples collected at each borehole. In this figure, the depths BGS for each sample recorded during collection have been converted to elevations in feet above mean sea level (AMSL) after surveying of the PAP casings and ground elevations. An inventory of the collected samples is provided in Appendix A.

When the borehole depth reached a target level below the water table, prepacked PVC well screen was set in a sand layer for porewater recovery, and the borehole was sealed with bentonite pellets and then backfilled with bentonite chips to the target level for GAP placement. GAPs were set within a 1-foot interval of round river stone and sealed with a wetted and expanded bentonite cap (bentonite pellets) above and below the GAP layer. After the completion of initial site sampling (i.e., advancing borings and installation of monitoring points), the PAP wells were developed and readied for sampling. The finalized bore logs are maintained as electronic files available upon request.

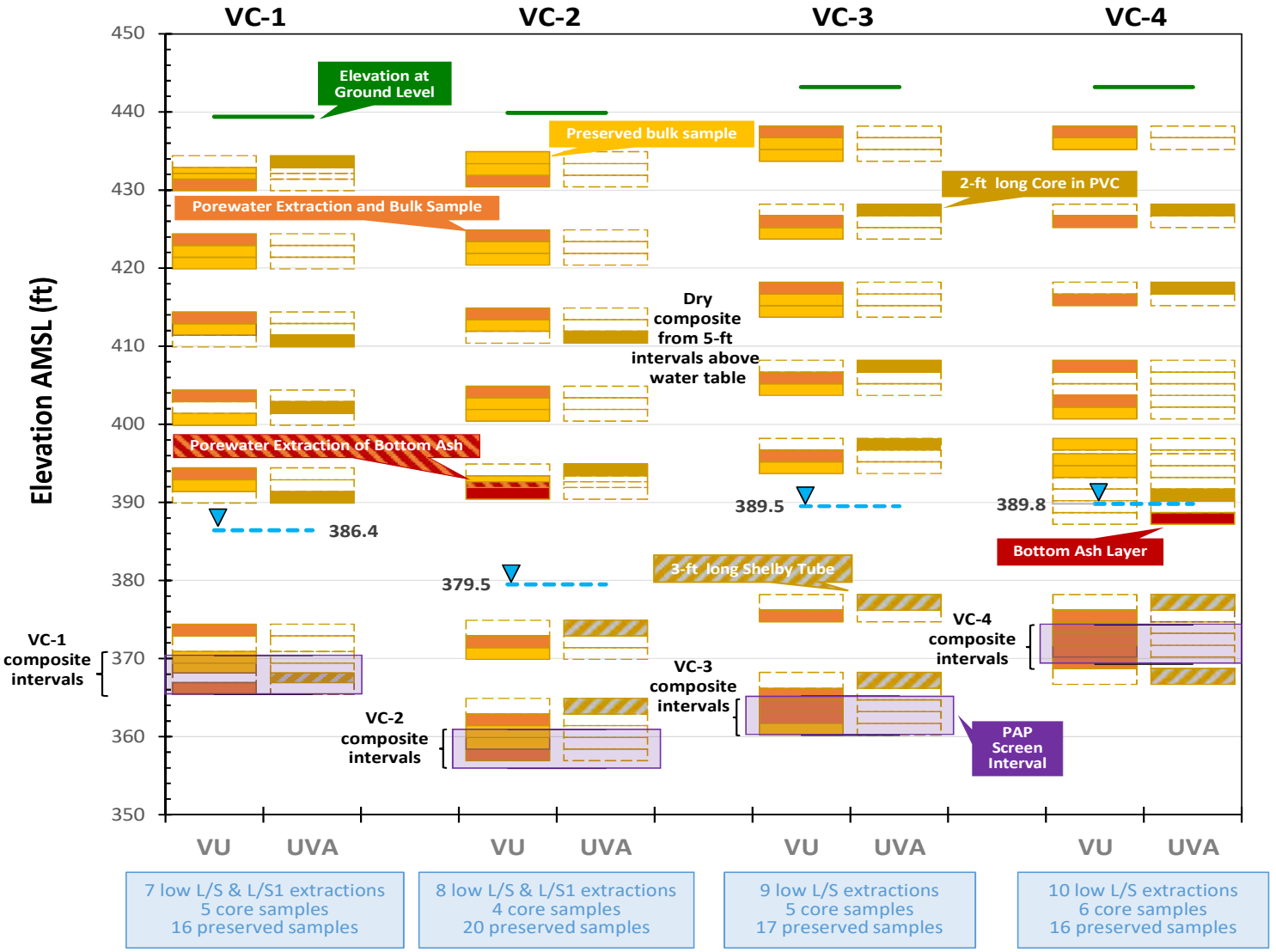

Figure 2-1
Ash sample collection and field testing for VC-1, VC-2, VC-3, and VC-4 boreholes

Bulk Material (Split Spoon Samples)

At each borehole location, 3-inch OD x 24-inch long split spoon samplers were advanced into the coal ash starting at 5 feet BGS (Figure 2-1). Upon retrieval by the drilling contractor, each split spoon sample was opened, recorded, and examined by a licensed geologist prior to release to VU for sample packaging, distribution, and laboratory analysis. VU field activities included preparation of samples for the following:

- Low L/S Field Extractions: Approximately 120 grams of ash from a split spoon was moderately packed into a 3.8-cm ID x 11-cm long acrylic cylinder equipped with a filtration stage and a 0.45-m polypropylene filtration membrane (Figure 2-2a). To ensure extractable moisture in visually dry samples, 10 to 20 mL of de-oxygenated, deionized water (DIW) was added to the cylinder prior to capping, sealing, and storage under an argon blanket (Figure 2-2b). In the laboratory, these samples were centrifuged at 1,000 revolutions-per-minute (rpm) for 5 minutes to extract the pore solution for analysis. During field operations, the porewater extraction tubes were stored in a pressure vessel that was purged with argon gas immediately after each sampling session. This unique field sampling and extraction technique was specifically designed for this project to optimize control of L/S ratio and maintenance of field reduction-oxidization (redox) conditions based on previous field sampling experience (EPRI, 2020).

a)  b) 

Figure 2-2
Low L/S Field Extraction: a) capped apparatus with sample and b) collected samples stored in pressure vessel prior to purging with argon

- Moisture Content Samples: In parallel to porewater testing, a known mass of ash (~20 g) was collected in a certified, pre-tared 125-mL high-density polyethylene (HDPE) bottle (Nalgene I-Chem #N311-0125) for moisture content analysis at VU.
- L/S≈1 Extractions: A known mass of ash (~150 g) from VC-1 and VC-2 split spoons was placed into a certified, pre-tared 50-mL HDPE DigiTube (SCP Science #010-500-253). The bottle was filled with de-oxygenated DIW and weighed to record the mass of added water. In the laboratory, these tubes were tumbled for 24 hours followed by filtration through 0.45-µm HDPE membrane and analysis of extracted fluid.

- Bulk Ash Collection: Remaining ash from each split spoon was vacuum-sealed in plastic bags (Figure 2-3) with oxygen scavenger packets (zero-valent iron) to preserve the redox conditions of the material. The preserved bulk material was maintained in its original cylindrical shape with the top and bottom of the core marked on the vacuum bag. Bulk samples were stored in coolers for shipment to VU.

Labels used for samples included "CDL" as a site identifier, the borehole number (VC-1, VC-2, VC-3, or VB-4), and the depth BGS from which the samples were taken. For example, the sample labeled "CDL_VC-3_16.5-18" in Figure 2-3 was collected from the split spoon at 16.5 to 18 feet BGS at borehole VC-3. For split spoons that penetrated an interface (e.g., between ash with visually different properties), the separate materials were collected as separate bulk samples in two vacuum-sealed bags. The upper portion was labeled with an "A" extension, while the lower portion was labeled with "B" at the same split spoon interval. All samples were stored at <5 °C and transported to the VU lab within 48 hours of collection, where they were stored in an environmentally controlled room at 5 °C prior to processing for leaching tests.

a) 

b) 

Figure 2-3
Examples of split spoon cores: a) as recovered and photo-documented in the field and b) as a vacuum-sealed bulk sample from borehole VC-3 (CDL_VC-3_16.5'-18') preserved for testing

Intact Cores (Tube Samples)

Thin-walled tube sampling of unsaturated ash was attempted, but the tubes would not penetrate the compacted unsaturated material without crumpling. Therefore, split spoon samples of unsaturated ash were extruded into 2-inch OD diameter x 24-inch long PVC tubes, maintaining the sample orientation, so that materials could be consolidated at UVA for testing. Oxygen scavenger packets were included within the tubes, and PVC endcaps were sealed to the tube with duct tape.

Below the water table, in the wet-handled ash, 3-inch OD by 36-inch long thin-wall tube samplers were pushed into the ash layer to obtain intact cores at locations targeted to collect samples near the PAP elevations. Each recovered thin-walled tube was sealed at both ends using plastic expanding inserts, capped with plastic endcaps, and sealed with duct tape. Oxygen scavenger packets were included in each thin-walled tube before sealing. Sample identification was based on the interval BGS from which the samples were recovered (e.g., the tube sampler recovered from the interval from 65 to 67 feet BGS at borehole VC-2 was labeled "CDL_VC-2_65-67").

Porewater Access Points

Once the 8.25-inch ID HSA was advanced to the target depth for placement of a PAP, a 2-inch OD Schedule 40 PVC pipe was installed through the HSA. At each well location, the contractor installed pre-packed, 5-foot screened section in agreement of the field team leads for VU, EPRI, and CDL. Each 13-inch diameter borehole was backfilled with 1 foot of clean sand before the well screen was set, and after setting the screen, was backfilled with sand to 2 feet above the top of the well screen. The sand pack was sealed with bentonite clay pellets, and bentonite chips were used to backfill the borehole to within ½ foot of the GAP depth.

Subsurface Gas Access Points

GAPs were established for monthly monitoring of subsurface gas at nominally 5-, 15-, and 50-feet BGS (50-foot deep GAPs were established at VC-1 and VC-3 only). Each GAP consisted of a ¼-inch diameter stainless steel tube set at depth within a 1-foot thick layer of round river rock and sealed from above and below with a 1-foot thick layer of expanded bentonite clay. The lower end of the GAP tubing was protected from rock, ash, and clay debris with an inverted steel cup. The stainless steel tubing was zip-tied to the PVC well and finished with a 2-way shut-off valve. The bed of river rock, nominal size of between ¾ inch and ¼ inch, ensures sufficient subsurface gas volume for measurement. A detail of the conceptual design of an installed GAP is illustrated in Figure 2-4.

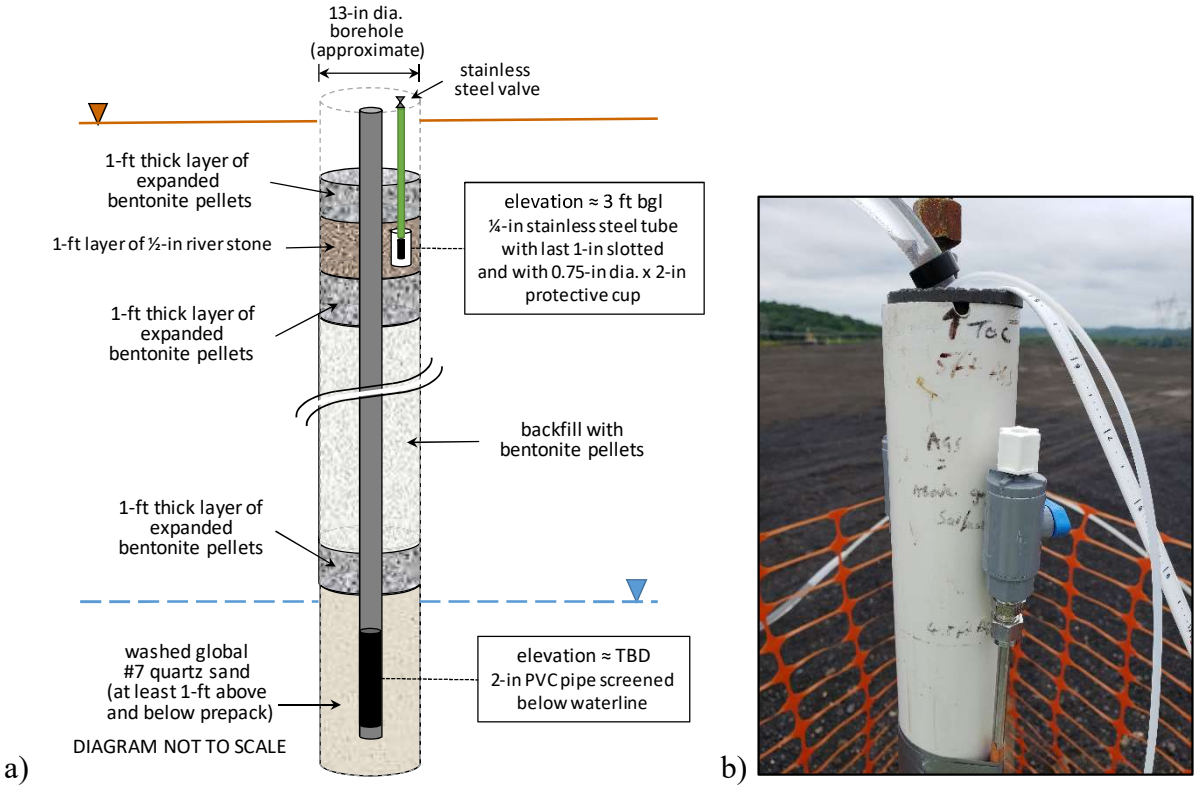

Figure 2-4
Porewater and gas access points: a) conceptual design of PAP and GAP installation and b) picture of installed PAP and GAP

Summary of Borehole and PAP/GAP Elevations

Within two weeks of field sampling, the drilling contractor installed dedicated pumps, developed the wells, and protected the borehole locations with a construction mesh. The horizontal location of the PAP and the elevations of the PVC tubing and ground surface level were surveyed by a professional land surveyor. A summary of the elevation survey results and elevation of pertinent sampling locations for the VC-1, VC-2, VC-3, and VC-4 boreholes is tabulated in Table 2-1. Figure 2-5 graphically shows the elevation relationships between the boreholes and the two downgradient monitoring wells (209 and 931), as well as porewater and groundwater elevations measured during the field study.

Table 2-1
Elevations Above Mean Sea Level (AMSL) for CDL Boreholes

	Elevations AMSL (ft)			
	VC-1	**VC-2**	**VC-3**	**VC-4**
Top of Well Casing	444.46	445.06	448.92	447.63
Ground Surface	439.4	439.9	443.2	443.2
GAP #1 (green)	434.4	435.0	438.4	438.1
GAP #2 (red)	424.4	425.0	427.7	428.3
GAP #3 (blue)	391.0	-	393.5	-
Water Level *	386.4	379.5	389.5	389.8
Top of PAP Well Screen	370.4	360.9	365.2	374.3
Bottom of PAP Well Screen	365.4	355.9	360.2	369.3

Note: (-) indicates that no GAP was placed adjacent to the water table at VC-2 or VC-4.

* water level measured on the date of well construction. Monthly water table elevations are provided in Figure 7-1.

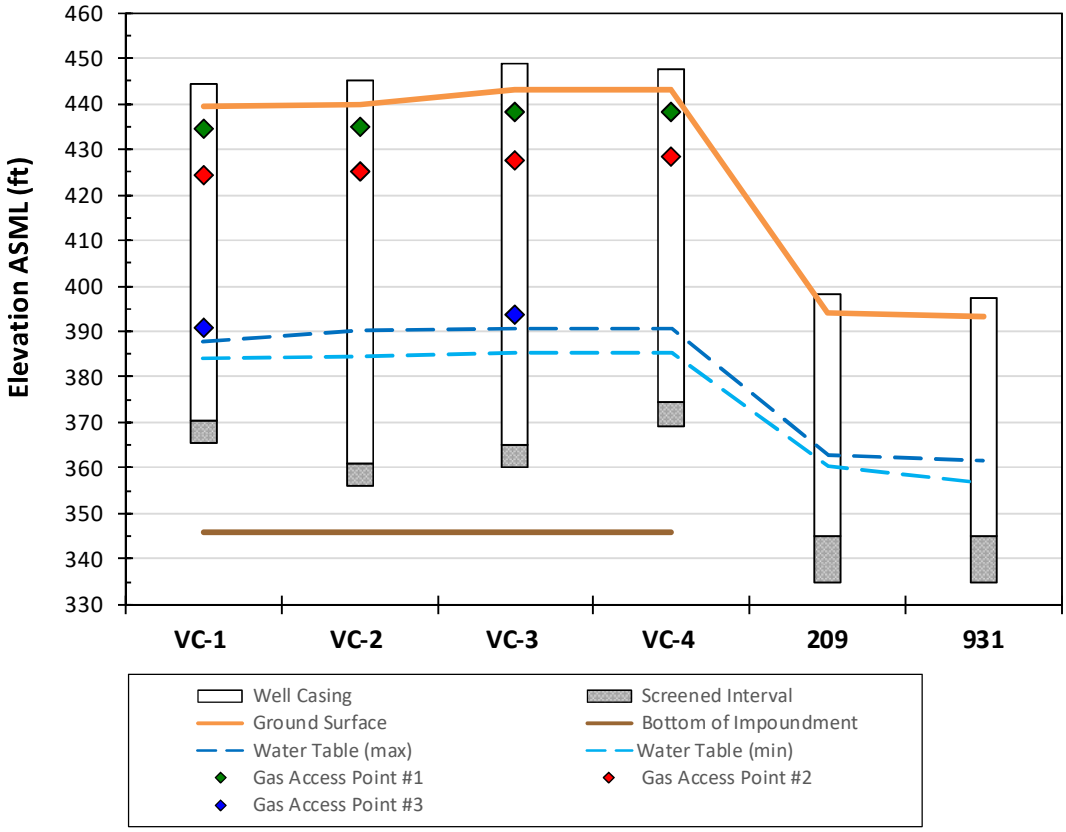

Figure 2-5
Summary of borehole and monitoring well elevations including screened intervals and GAPs. Maximum and minimum water table measurements from monthly measurements (Figure 7-1) are also shown. Figure does not depict horizontal monitoring point placement.

Monthly Field Monitoring

Porewater and subsurface gases were monitored monthly at each borehole location over eight months from June 2019 through January 2020. In addition, groundwater samples from monitoring wells 209 and 931 downgradient of the CCP landfill were collected.

Collection of Groundwater and Porewater

The relative locations of the four installed PAPs (VC-1, VC-2, VC-3, and VC-4) and the two existing groundwater sampling wells were shown previously in Figure 1-1. CDL field personnel accessed each well, stabilized the well using low-flow sampling techniques according to company standard operating procedures, and allowed VU field team access to the effluent line for collection of groundwater and porewater samples. At no time did the site owners' personnel retain custody of any samples used for this analysis.

The sampling flow rates for porewater and groundwater wells were approximately 150 mL/min and 50 mL/min, respectively. At 5-minute intervals, the pH, dissolved oxygen (DO), electrical conductivity (EC), oxidation-reduction potential (ORP), temperature, and turbidity of the sampled water were monitored using a flow-through multi-parameter sonde and separate

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turbidity meter while water level was measured with a portable electronic water level meter. The criteria used to determine well stability were (i) turbidity less than 10 NTUs and (ii) pH stable within 0.1 standard unit over three consecutive 5-minute readings.

Groundwater and porewater samples were collected in 50-mL Digitubes including duplicate samples collected for anion analysis via ion chromatograph (IC) and duplicate samples collected for metals and other cation analysis via inductively coupled plasma (ICP) techniques (see *Chemical Analysis of Eluates, Groundwater, and Porewater* in Section 3 for details). Samples for ICP analysis were preserved in the field by addition of 1.5 mL of Tracemetal® grade nitric acid (3% total acid addition) using a 100-1000 µL Oxford Benchmate manual pipette and disposable tips. A set of four samples was collected unfiltered followed by a set of samples passed through a QuickFilter 609 cm^2, 0.45-mm inline filter. In total, eight 50-mL Digitubes were collected at each sampling location. All liquid samples were stored in a cooler of ice with an Elitech RC-5 USB temperature data logger to record the temperature within the cooler. Samples were transported by the field team to VU for immediate storage at 5 ºC prior to analysis. Analysis of the sample results showed negligible differences between the filtered and unfiltered samples, and the results from the unfiltered samples are used in the following analysis.

Subsurface Gas Monitoring

A description of the monitoring process for subsurface gas and a picture of gas monitoring apparatus are provided in Section 3.

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3
MATERIALS AND METHODS

The following sections include brief descriptions of the test methods and analytical methods used in this study. Also described are the quality assurance/quality control (QA/QC) samples and criteria for each analytical method.

Collected Materials

Materials recovered during initial sample collection included bulk samples from split spoons and intact cores contained in PVC tubes or thin-wall stainless steel tubes. Laboratory processing of bulk material for leaching tests included (i) homogenization within each split spoon sample, (ii) compositing saturated ash samples from each borehole from materials collected near the screening level, and (iii) compositing unsaturated ash into one sample across the disposal facility.

Homogenization of Bulk Samples

Each recovered split spoon sample was crushed with a rolling pin and homogenized by hand through the plastic bag until the contents were well mixed. From this homogenized split spoon material, composite samples were created.

Material Composites

For each of four boreholes (VC-1, VC-2, VC-3, and VC-4), saturated ash homogenized from split spoons collected at the PAP screen elevation was used to develop a composite test material representative of the bulk ash deposited at the PAP. Table 3-1 shows the specific homogenized split spoon materials used to create each composite sample for the four boreholes. In addition, a fifth composite material of unsaturated ash was created by blending homogenized material above the water table from all boreholes collected; however, the intervals used in this composite, hereafter referred to as "Dry," varied with the intervals of unsaturated ash at each borehole.[1]

The composite material was created by mixing equal dry mass equivalents (i.e., the mass of "as received" material that equates to a prescribed mass of dry material) from each homogenized split spoon in a plastic bag under a N_2-purged environment in a Coy chamber (an anoxic glove box) to minimize air exposure. The composite material was homogenized by hand through the plastic bag until well mixed. This composited sample was used for total content analysis and characterization using LEAF leaching tests and traditional leaching tests (i.e., ASTM, TCLP, and SPLP).

[1] In other words, five composites are discussed in Section 4 – composites VC-1, VC-2, VC-3, and VC-4, which represent the lower wet-handled coal ash deposit and have corresponding PAP porewater samples, and the composite referred to as Dry, which represents the upper dry-managed coal ash deposit and does not have corresponding porewater samples.

Table 3-1
Below Ground Surface (BGS) and Top Elevations Above Mean Sea Level (AMSL) of Homogenized Split Spoon Intervals Used to Create Borehole Composites (VC-1, VC-2, VC-3, and VC-4)

VC-1		VC-2		VC-3		VC-4	
Interval BGS (ft)	Elevation AMSL (ft)	Interval BGS (ft)	Elevation AMSL (ft)	Interval BGS (ft)	Elevation AMSL (ft)	Interval BGS (ft)	Elevation AMSL (ft)
PAP Screen	367.9	PAP Screen	358.4	PAP Screen	362.7	PAP Screen	371.8
68.5-70.0	370.9	78.5-80.0	361.4	78.5-80.0	364.7	68.5-70.0	374.7
70.0-72.5	369.4	80.0-81.5	359.9	80.0-81.5	363.2	70.0-71.5	373.2
72.5-74.0	366.9	81.5-83.0	358.4	81.5-83.0	361.7	71.5-73.0	371.7
-	-	-	-	-	-	73.0-74.5	370.2

Notes: PAP Screen elevation to middle of 5-ft screen.
All elevations shown at the top of the 2-ft split spoon sample.

Material Properties

Total Content by EPA Method 3052

The total elemental content of composite samples was determined by acid digestion following EPA Method 3052, with subsequent analysis of the digestate by Eurofins TestAmerica (Knoxville, TN). According to the Method 3052, a solid sample of up to 0.5 g (wet) is digested in 9 mL of nitric acid and 3 mL of hydrofluoric acid for 15 minutes in a microwave to accelerate the digestion reactions. Additional acid and reagent combinations, including hydrochloric acid and hydrogen peroxide, are added to ensure that the solid is dissolved. The microwave temperature profile includes reaching 180±5 ºC in approximately less than 5.5 minutes and remaining at 180±5 ºC for 9.5 minutes for the completion of specific reactions. After cooling, the vessel contents were centrifuged and decanted. The small volume of remaining digestate was diluted to a volume of 100 mL and chemically analyzed. Inductively coupled plasma–optical emission spectrometry (ICP-OES) following EPA Method 6010A was used to determine digestate concentrations for 26 constituents (i.e., Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Sr, Tl, V, and Zn). Boron was not included in this total content analysis because metaborate is added to the digestion process for Method 3052. Mercury concentrations in the digestate were measured by using cold vapor atomic absorption following EPA Method 7470A. The total content (mg/kg) is calculated by multiplying the concentration measured in the digestate (mg/L) by the L/S of the extraction procedure (L/kg). For this study, the resultant total content is effectively on a dry mass basis (mg/kg-dry) because the material submitted to the laboratory for testing was oven-dried prior to submission to the laboratory.

X-Ray Fluorescence Analysis

The elemental composition of coal ash samples was determined at UVA using x-ray fluorescence (XRF) quantitative analysis on an Epsilon 3X energy-dispersive XRF spectrometer (PANalytical, Malvern, UK) with a silver anode X-ray tube and 50-micron beryllium window.

Five-gram subsamples of coal ash were taken from the undisturbed core samples, air-dried for 24 hours at room temperature, and ground by hand to less than 0.075 mm using an agate mortar and pestle. For analysis, ground samples were packed into an 18-mL sample cup (28 mm ID x 30 mm). Each subsample was analyzed in duplicate following ASTM D8064 (2016) for the XRF analytical method of silicate rocks.

Loss on Ignition

Loss on ignition (LOI) was measured at UVA for subsamples of undisturbed coal ash material to quantify total organic matter content. LOI was conducted in accordance with ASTM D2974-14 by heating a pre-weighed sample at 550 °C using a Lindberg/Blue M 1200 °C Box Furnace (ThermoFisher Scientific, Waltham, MA).

Moisture Content

As part of the leaching test characterization using the LEAF methods, the moisture content of each study material was determined following the ASTM D2216 (2010). Moisture content on a dry mass basis was calculated as the difference in the mass of a "wet" subsample compared to the sample after oven drying to constant mass at 105±5 °C. The solids content is defined as the mass of solid material in an "as-tested" or "wet" subsample, measured on a "wet" basis. The determination of moisture content and solids content provides uniform bases for reporting of total content and leaching behavior results, allowing for comparison between moist and dry materials.

Porosity or Saturated Volumetric Water Content

Dry density and porosity of each material were determined at UVA using weight-volume computations, following the procedure in ASTM D7263 (2018). Under saturated conditions (i.e., when all voids are filled with water), the saturated volumetric water content equals the porosity.

Particle Size Distribution

Particle size distribution (PSD) of each CCP sample was determined at UVA by a combination of mechanical analysis following ASTM D6913-17 and sedimentation analysis following ASTM D7928-17. For mechanical analysis, a 100-g sample was oven-dried at 110±5 °C and passed through a series of US standard sieves: No. 10 (2 mm), No. 20 (0.85 mm), No. 60 (0.25 mm), No. 100 (0.15 mm), and No. 200 (0.075 mm). The fraction of the 100-g mass retained on each sieve was measured gravimetrically. Particle size distribution of the fraction coarser than the No. 200 sieve (0.075 mm) was calculated as the weight of solid retained on each sieve.

For sedimentation analysis, 50 g of dry solid that had passed the No. 200 (0.075 mm) sieve was soaked in 4% sodium metaphosphate, $(NaPO_3)_6$, solution for 12 hours and then transferred to a 1-L graduated cylinder. The graduated cylinder was capped, then agitated end-over-end for 60 seconds, and then settling of particles was monitored using a hydrometer. Stokes law was used to compute the PSD from the hydrometer data for the fraction of particles finer than the No. 200 sieve.

Saturated Hydraulic Conductivity

Hydraulic conductivity tests were conducted in flexible-wall permeameters following the methods in ASTM D5084-16. Sections of undisturbed coal ash were extruded from thin-wall sampling tubes (Figure 3-1) and cut into 76-mm long specimens. Non-woven geotextile disks and porous stones were placed on both ends of each coal ash specimen (Figure 3-2a) to ensure uniform flow distribution and to retain particles. Specimens were wrapped in a latex membrane and placed into a flexible-wall permeameter (Figure 3-2b).

In lieu of the more traditional tap water or 0.01 M $CaCl_2$ solution suggested in ASTM D5084, DIW was used as the permeant solution to ensure that the water entering the specimen had no ionic species that might alter the hydraulic conductivity or the leachable constituents in the coal ash. Effluent from the permeameter was collected following the procedure in ASTM D7100-11. Effluent samples were collected from the tests, stored in Teflon® sample bottles with minimal headspace, and shipped under chain of custody to VU for chemical analysis.

The falling headwater-constant tailwater method was used with an average hydraulic gradient of 15. No backpressure was applied to simulate field conditions and to minimize alterations in geochemistry. All tests were conducted at an initial effective stress of 20 kPa and continued until the hydraulic conductivity reached hydraulic equilibrium as defined in ASTM D5084 (steady hydraulic conductivity, incremental outflow divided by steady inflow within 1.0±0.25). At the conclusion of the test, weight-volume calculations were conducted to confirm that all specimens were saturated during testing.

After testing at 20 kPa was complete, three specimens, representing higher, lower, and intermediate hydraulic conductivity, were consolidated to an effective stress of 100 kPa and permeated again until hydraulic equilibrium was established (steady hydraulic conductivity, steady flow ratio 1.0±0.25). This procedure was repeated at effective stresses of 250, 400, and 500 kPa. The initial stress (20 kPa) was selected to replicate the stress condition of shallow coal ash in the basin. The higher stresses represent conditions at greater depths. Effluent samples from the higher-stress tests were not collected for chemical analysis.

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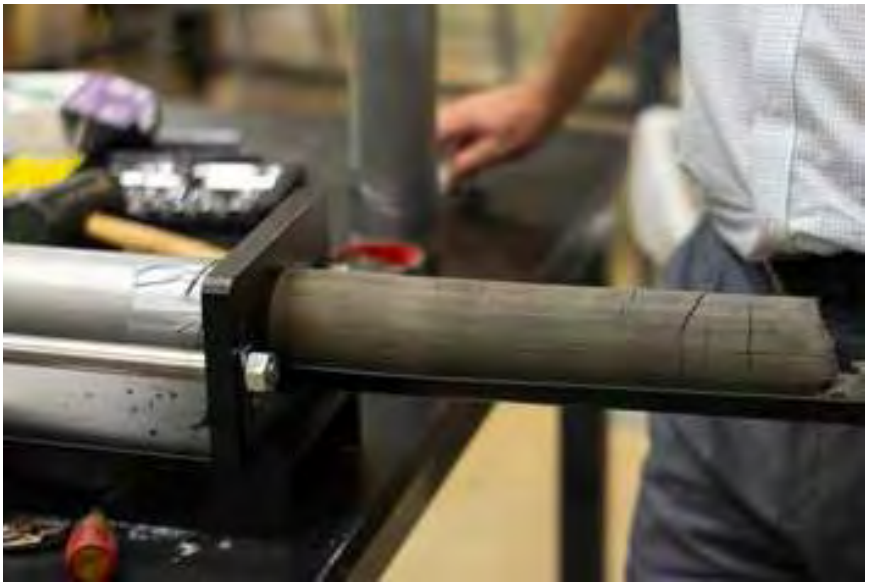

Figure 3-1
Extrusion of undisturbed coal ash sample from a thin-wall sampling tube conducted at UVA

a)  b) 

Figure 3-2
Hydraulic conductivity test specimen and permeameter setup: a) test specimen (brown, gray cylinder) between two geotextile filter disks (thin black disks) and two porous stones (blue-gray disk on each end); b) test specimen installed in flexible wall permeameter

Traditional Extraction Tests

EPA Method 1311 – Toxicity Characteristic Leaching Procedure

EPA Method 1311, or TCLP, is a single-point batch leaching test used to determine the toxicity characteristic of a material and the disposal options for a material under the Resource

Conservation and Recovery Act of 1986 (RCRA). TCLP was designed to simulate eluate concentrations for a plausible mismanagement scenario where hazardous waste is disposed in a municipal solid waste landfill. Thus, a solution of acetic acid in DIW is the extraction fluid to represent the primary acidity in municipal solid waste landfill leachate. Based on a pretest of the buffering capacity of test sample for acetic acid, either Extraction Fluid #1 (dilute acetic acid with a NaOH buffer at a pH of 4.93±0.05) or Extraction Fluid #2 (dilute acetic acid at a pH of 2.88±0.05) is selected for the test. Since the method allows for analysis of samples with filterable water (e.g., slurries), the specified L/S of 20 mL/g is based on the mass of moist sample recovered from pressure filtration at 15 lb/in^2 (103 kPa). The filtrate from pressure filtration was preserved and chemically analyzed in parallel to TCLP extracts. Therefore, the final dry-basis extraction L/S is typically greater than 20 mL/g-dry when filterable water is considered.

For TCLP analysis, 100 g of solid was pressure-filtered and the moist solid was mixed with Extraction Fluid #1 at an L/S of 20 mL/g-dry. The mixture was tumbled at 28±2 rpm for 18±2 hours. Although not specified in the method, the pH of the final eluate was measured and recorded so that test results could be compared to other leaching methods. The eluate from the extraction was pressure-filtered through a 0.22-µm borosilicate glass fiber filter and preserved for analysis. Filtrate from pressure filtration and the extraction eluate were analyzed separately, and an "effective" extraction concentration was calculated for each constituent as a volume-weighted average concentration of the two liquids. For QA/QC purposes, a method blank, with the filter paper and extraction fluid only, and duplicate samples for the composite at VC-3 were conducted in parallel using the same reagents.

EPA Method 1312 – Synthetic Precipitation Leaching Procedure

EPA Method 1312, or SPLP, is a single-batch leaching test used to evaluate the leaching behavior of a waste material in contact with acidic rain. The test is performed in the same manner as the TCLP, but with extraction fluids of 60/40 weight percent (wt%) sulfuric acid (H_2SO_4) and nitric acid (HNO_3) in DIW (Extraction Fluids #1 and #2) or DIW (Extraction Fluid #3). The selection of extraction fluid depends on the location of the site under investigation and the constituents being tested. Extraction Fluid #1 is used for sites east of the Mississippi River, Extraction Fluid #2 is used for sites west of the Mississippi River, and Extraction Fluid #3 is used only when cyanides or volatiles are to be analyzed.

Approximately 100 g of ash was pressure-filtered and the moist solid was mixed with Extraction Fluid #1 at an L/S of 20 mL/g. The mixture was tumbled at 28±2 rpm for 18±2 hours. Although not specified in the method, the pH of the final eluate was measured and recorded so that test results could be compared to other leaching methods. The eluate from the extraction was pressure-filtered through a 0.22-µm borosilicate glass fiber filter and preserved for analysis. Filtrate from pressure filtration and the extraction eluate were analyzed separately and an "effective" extraction concentration for each constituent was calculated as a volume-weighted average of the two liquids. A method blank, extraction fluid with no solid carried through test process, and duplicate samples for the composite at VC-4 were analyzed.

ASTM D3987 – Shake Extraction of Solid Waste with Water

ASTM D3987, or ASTM, is a single-point extraction test that is used to estimate leaching concentrations when no acid or base is added to the extraction. Since the method is patterned

after TCLP, the procedure is similar to the EPA method; however, DIW is used as the extraction fluid. A subsample of ash (70±0.1 g) was tumbled at 28±0.2 rpm with DIW at an L/S of 20 mL/g for 18±0.25 hours. After tumbling, the extract was separated from the solid by vacuum filtration through a 0.45-µm polypropylene membrane and the pH of the final eluate was measured and recorded. Reagent blanks, method blanks, and duplicate samples for the composite at VC-2 were analyzed.

Leaching Environmental Assessment Framework (LEAF) Methods

EPA Method 1313 – Liquid-Solid Partitioning as a Function of Eluate pH Using a Batch Extraction Procedure

EPA 1313 (SW-846, 2019) is a standardized, parallel batch extraction method used to evaluate the liquid-solid partitioning (LSP) of inorganic constituents as a function of eluate pH. The general procedure consists of nine batch extractions of a particle-size reduced subsample material contacted with leaching solution at an L/S of 10 mL/g-dry material and tumbled end-over-end over a specified contact interval. The leaching solution is DIW with additions of HNO_3 or potassium hydroxide (KOH) to adjust the final pH of the eluate to a target of nine specific pH values (i.e., pH values of 2, 4, 5.5, 7, 8, 9, 10.5, 12, and 13). An additional extraction without addition of acid or base was carried out to measure constituent leaching at the natural pH of the material.[2] After 24 hours of tumbling, the contact time associated with a sample particle size of 85 wt% less than 300 µm, the solid and liquid phases were separated by settling or centrifugation, and the pH, EC, and ORP of the clarified eluate were measured. The remaining slurry was vacuum-filtered through 0.45-µm pore size membranes prior to chemical analysis by ICP-OES, IC, and carbon analysis.

EPA 1313 provides (i) a titration curve of the pH response to additions of acid or base, (ii) the available content of constituents in the solid material, and (iii) the LSP curve for constituents over the tested pH range. Furthermore, the results of EPA Method 1313 are suitable for use in geochemical speciation modeling for the estimation of the solid-phase mineralogy and surface chemistry that controls constituent release.

Variants of EPA 1313 Methods

In this program, the full EPA 1313 method and variants of EPA 1313 were carried out on ash materials for different purposes:

- Full EPA 1313 was conducted on all composite samples (i.e., saturated ash composite from each borehole plus the site-wide unsaturated composite). The procedure was modified slightly to include an extra extraction filling the gap in pH between pH < 2.0 and pH = 4.
- For all composite materials, a variant of EPA 1313 was carried out using an L/S of 1 mL/g-dry and abbreviated to the natural pH and four other pH target values distributed over the range of pH 6 to 13 (i.e., five pH values in total). This modified 1313 test, referred to as

[2] The "natural pH," sometimes referred to as "own pH," is defined as the eluate pH in response to extraction in deionized water (i.e., no acid or base added) at an L/S of 10 mL/g-dry. To distinguish the natural pH at L/S=10 mL/g-dry (Method 1313 or 1313_3pt) from the pH response to DIW at L/S of 1 mL/g-dry measured using 1313_L/S=1, the former will continue to be called with "natural pH," while latter will be referred to as "own pH."

1313_L/S=1, was used to evaluate how changes in L/S may influence LSP concentrations and to provide verification data for development of geochemical speciation models.

EPA Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio using a Percolation Column Procedure

EPA 1314 (SW-846, 2019) is a standardized, up-flow column procedure used to evaluate release of inorganic constituents from percolating solid materials as a function of cumulative L/S (i.e., the volume of liquid that passes through the column relative to the dry mass of material in the column). In this study, EPA 1314 was used to characterize the L/S-dependent leaching of constituents in 250-400 g-dry composited ash samples (e.g., VC-1, VC-2, VC-3, VC-4, and Dry). A 5-cm diameter by 30-cm glass column was packed with coal ash in a series of five lifts with moderate tamping between lifts. DIW was used as the eluent solution since the coal ash had relatively low organic carbon and clay contents compared to soils. The eluent was pumped at a flowrate of 0.75±0.25 L/S per day through the material in an up-flow direction to minimize air entrapment and flow channeling. Eluates were collected at predetermined cumulative L/S values (i.e., 0.2, 0.5, 1.0, 1.5, 2.0, 4.5, 5.0, 9.5, and 10 mL/g-dry). For each eluate fraction, the pH and conductivity were recorded prior to filtration and preservation for chemical analysis. To present the results, the eluate pH, and concentrations of constituents in the eluates (mg/L), and the cumulative release through the end of each eluate fraction (mg/kg-dry) were plotted as functions of L/S in separate graphs.

Comparison of Leaching Test Parameters and Conditions

All leaching tests conducted for this program are designed to measure the LSP of constituent release from a material under the specified test conditions shown in Table 3-2. TCLP, SPLP, and ASTM are single-batch leaching tests that yield only one result; thus, test duplicates were conducted as shown in the table to ensure the quality of test results. The EPA 1313 test and its variants are batch procedures, but with parallel extractions to provide data over a range of test conditions. These batch tests, however, differ in the chemical makeup of extraction fluid as well as in the specified L/S. Moving from left to right in Table 3-2, the leaching test conditions are presented in order of increasing L/S. In the last column are the test conditions for EPA 1314, designed to measure LSP as a function of cumulative L/S.

Table 3-2
Leaching Test Parameters and Test Conditions

Parameter	TCLP	SPLP	ASTM	1313	1313_L/S=1	1314
Method Type	Single-batch	Single-batch	Single-batch	Parallel batch	Parallel batch	Column
Number of Eluates	1	1	1	11**	5	9
Extraction Fluid	Acetic acid in DIW	H_2SO_4/HNO_3 in DIW	DIW	HNO_3 or KOH in DIW	HNO_3 or KOH in DIW	DIW
Extraction Fluid pH	#1: 4.93±0.05* #2: 2.88±0.05	#1: 4.20±0.05* #2: 5.00±0.05 #3: DIW	-	-	-	-
L/S	20 mL/g-filtered	20 mL/g-filtered	20 mL/g-wet	10 mL/g-dry	1 mL/g-dry	0.2-10 mL/g-dry (cumulative)
Eluate pH	-	-	-	<2, 3**, 4, 5.5, 7, 8, 9, 10.5, 12, 13, natural pH	5.5, 7, 8, 9, own pH	based on solid buffering capacity
Eluate Filtration	0.22-µm via pressure	0.22-µm via pressure	0.45-µm via vacuum	0.45-µm via vacuum	0.45-µm via vacuum	0.45-µm via vacuum
Eluate Measurements	pH, EC	pH, EC	pH, EC	pH, EC	pH, EC	pH, EC
Reagent Blank	No	No	Yes	No	No	Yes
Method Blank	Yes	Yes	Yes	Yes	Yes	No
Duplicate Test	VC-3	VC-4	VC-2	None	None	None
Chemical Analysis	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC
Samples Tested	VC-1, VC-2, VC-3, VC-4, Dry composites	VC-1, VC-2, VC-3, VC-4, Dry composites	VC-1, VC-2, VC-3, VC-4, Dry composites	VC-1, VC-2, VC-3, VC-4, Dry composites	VC-1, VC-2, VC-3, VC-4, Dry composites	VC-1, VC-2, VC-3, VC-4, Dry composites

Note: * indicates the TCLP and SPLP extraction fluids used for these tests.
** the 1313 procedure calls for 9 pH extractions + natural pH. An additional extraction at pH 3 was performed for this testing.

Chemical Analysis of Eluates, Groundwater, and Porewater

For each eluate from a leaching test, the following parameters were measured.

Eluate pH

Eluate pH was measured on all aqueous extracts following EPA 9040C (SW-846, 2019) using an Accumet XL20 meter and a combined pH electrode on approximately 5 mL of eluate. Prior to testing, the electrode was calibrated with two National Institute of Standards and Technology (NIST) traceable pH buffer solutions that bounded the anticipated range of pH to be measured. A third mid-range NIST buffer was used to verify the calibration.

Specific Conductance

Specific conductance, or EC, is a measure of the ability of an aqueous solution to carry an electrical current. The property is dependent on (i) the presence of ions; (ii) total concentration, mobility, and variance of ions in solutions; and (iii) the temperature of the measurement. Conductivity of all leaching test eluates was determined following EPA Method 9050A (SW-846, 2019) using a standard conductivity probe calibrated to an appropriate standard conductivity solution for the conductivity range of concern.

Oxidation-Reduction Potential

ORP is a voltage differential related to the redox state of a solid-liquid solution and its effect on chemical composition (e.g., reduced/oxidized iron, dissolved oxygen, biological activity). ORP voltage of all eluate solutions was measured with a probe, consisting of a platinum electrode and a reference electrode, placed in contact with the soil solution. In laboratory tests, the ORP voltage reading was converted to redox potential (Eh) by addition of a probe-specific correction factor of 228 mV at 25 °C. In field measurements, however, the probe correction factor was automatically compensated for by the instrument to produce output as Eh values.

Since redox reactions vary with pH and the mineral species present, redox is parameterized in geochemical modeling as the pH+pE, where pE is the negative logarithm of the free electron concentration, or –log([e^-]). The corrected Eh values of leachates and eluates were converted to a pE value using the following equation:

$$pE = \frac{F}{2.303RT}(Eh/1000)$$

where F is the Faraday constant (23,061 cal/(V mol)),
Eh is the redox potential of the solution (mV),
2.303 is a conversion (ln[e^-]/2.303 log[e^-]),
R is the gas constant (1.987 cal/(K mol)),
T is the temperature (K), and
1000 is a units conversion (1,000 mV = 1 V).

Inductively Coupled Plasma Spectrometry

The eluate concentrations of trace elements and material major species (e.g., Al, Ca, Si) were determined using a combination of ICP-OES and inductively coupled plasma–mass spectrometry (ICP-MS). The choice of instrumentation was determined based on detection limits, expected concentrations, and environmental threshold values. Table 3-3 provides the method detection limits (MDLs) and lower limits of quantitation (LLOQs) used in this project.

Major species and trace elements present at higher concentrations were determined using a Varian Model 720-ES ICP-OES (Agilent Technologies, Santa Clara, CA) following EPA Method 6010D (SW-846, 2019). The ICP-OES was calibrated to a 5-point standard curve with an analytical range of 25 to 25,000 µg/L. For some high-concentration trace elements, the standard curve was extended up to 500,000 µg/L using a 7-point standard curve. For low-level trace analysis, concentrations were determined by ICP-MS using a Perkin Elmer Elan DRC II (Perkin Elmer, Waltham, MA) following EPA Method 6020A (SW-846, 2019). The ICP-MS was calibrated to a 5-point standard curve with range between approximately 1 and 250 µg/L and extended with a 7-point calibration curve to 1,000 µg/L for some constituents.

Analytical QA/QC included initial and continuing calibration checks and blanks, matrix spikes, and method blanks. Calibration check standards and matrix blanks were evaluated every 10 to 20 samples with the requirements that check standards were within 15% of the specified value and blanks were below LLOQs. Matrix spikes were required to have recoveries within 20% of the calculated concentration considering the spiked mass. Initial and continuing calibration check standards for ICP-OES and ICP-MS were 0.5 mg/L and 0.050 mg/L, respectively. Analyte concentrations measured at less than the MDL were reported as <MDL and graphed at one-half the MDL values to indicate that the measurement was conducted. Analytical results measured at less than the LLOQ but greater than the MDL are estimated values.

Table 3-3
Methods, MDLs, and LLOQs for Analysis of Eluates by ICP-OES and ICP-MS

Analyte	Symbol	Method	MDL (mg/L)	LLOQ (mg/L)
Aluminum	Al	ICP-OES	0.0034	0.025
Antimony	Sb	ICP-MS	0.000013	0.001
Arsenic	As	ICP-MS	0.000036	0.001
Barium	Ba	ICP-OES	0.0016	0.025
Beryllium	Be	ICP-MS	0.000035	0.001
Boron	B	ICP-OES	0.0023	0.025
Cadmium	Cd	ICP-MS	0.00018	0.001
Calcium	Ca	ICP-OES	0.0065	0.025
Chromium	Cr	ICP-MS	0.000053	0.001
Cobalt	Co	ICP-MS	0.000023	0.001
Copper	Cu	ICP-MS	0.00004	0.001
Iron	Fe	ICP-OES	0.0022	0.025
Lead	Pb	ICP-MS	0.000027	0.001
Lithium	Li	ICP-OES	0.0047	0.025
Magnesium	Mg	ICP-OES	0.0035	0.025
Manganese	Mn	ICP-MS	0.000032	0.001
Molybdenum	Mo	ICP-OES	0.0018	0.025
Nickel	Ni	ICP-MS	0.000032	0.001
Phosphorus	P	ICP-OES	0.0068	0.025
Potassium	K	ICP-OES	0.0032	0.025
Selenium	Se	ICP-MS	0.000062	0.001
Silicon	Si	ICP-OES	0.0038	0.025
Silver	Ag	ICP-MS	0.000042	0.001
Sodium	Na	ICP-OES	0.0056	0.025
Strontium	Sr	ICP-OES	0.0037	0.025
Sulfur	S	ICP-OES	0.0058	0.025
Thallium	Tl	ICP-MS	0.000019	0.001
Vanadium	V	ICP-OES	0.0012	0.0025
Zinc	Zn	ICP-MS	0.000091	0.001

Ion Chromatography

The concentrations of anions in leaching test eluates were determined by IC using a Metrohm 881 Compact IC Pro (Metrohm USA, Riverview, FL) with a Metrosep A Supp 5 column and a conductivity detector following EPA Method 9056A (SW-846, 2019). A seven-anion calibration standard was diluted to form a 5-point calibration curve with the MDLs and LLOQs shown in Table 3-4. Since the calibration standards are diluted from a bulk multi-analyte standard, the calibration range differs for each analyte (e.g., 0.050-50 mg/L for Cl^- and 0.150-150 mg/L for SO_4^{-2}). Calibration check standards were required to be within 15% of the specified value, while acceptable analytical blanks were measured below the quantitation limits.

Table 3-4
MDLs and LLOQs for Analysis of Eluates by IC

Analyte	Symbol	MDL (mg/L)	LLOQ (mg/L)
Bromide	Br^-	0.0064	0.025
Chloride	Cl^-	0.0101	0.05
Fluoride	F^-	0.0063	0.02
Nitrate	NO_3^-	0.0112	0.1
Nitrite	NO_2^-	0.0108	0.05
Phosphate	PO_4^{-3}	0.0247	0.15
Sulfate	SO_4^{-2}	0.0254	0.15

Carbon Analysis

Carbon analysis for eluate samples included analyses for dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC). Carbon analysis was conducted using a Shimadzu TOC-V CPH/CPN (Shimadzu Scientific Instruments, Inc., Columbia, MD) by catalytic oxidation/non-dispersive infrared detection (NDIR) following EPA Method 9060A. Total carbon (TC) in the eluate is converted to carbon dioxide via oxidation or decomposition, carried by a zero-CO_2 air stream into the NDIR. For analysis of DIC, liquid samples are acidified with 2-molar hydrochloric acid to liberate carbonates and other forms of inorganic carbon from solution as carbon dioxide, which is sparged from the liquid sample into the NDIR by the zero-CO_2 carrier gas. DOC is determined by measuring the TC of a sample after purging of inorganic carbon. The instrument was calibrated using sodium hydrogen carbonate and potassium hydrogen phthalate over a 5-point calibration curve for DIC and DOC, respectively. The resultant analytical range was between 0.1 and 100 mg/L, with MDL and LLOQ values shown in Table 3-5. Checks on QA/QC at a frequency of every 10 analytical samples included calibration checks with a required recovery within 15% of the specific value, and method blanks with a requirement that the concentration was less than quantifiable limits.

Table 3-5
MDLs and LLOQs for Eluate Analysis for Carbon

Analyte	Symbol	MDL (mg/L)	LLOQ (mg/L)
Inorganic carbon	DIC	0.15	0.5
Organic carbon	DOC	0.18	0.5

Subsurface Gas Analysis

The composition of subsurface gas was monitored monthly from June 2019 through January 2020. Subsurface gas was monitored for oxygen (O_2), carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S) using a Ventis Pro 5 meter (Figure 3-3a) rented monthly from Industrial Scientific, Pittsburgh, PA. Table 3-6 shows the measurement units and calibration ranges for the five gases. To avoid any moisture from subsurface gas fouling the vacuum pump, the subsurface gas was drawn through a 250-mL syringe filled with desiccant (Figure 3-3b).

a) 

b) 

Figure 3-3
Subsurface gas monitoring apparatus: a) Ventis Pro 5 meter and b) connected tubing and desiccant syringe

Table 3-6
Calibration Ranges for Subsurface Gas Monitoring

Analyte	Symbol	Units	Calibration Range	
Ammonia	NH_3	ppm	0	500
Hydrogen sulfide	H_2S	ppm	0	500
Carbon dioxide	CO_2	%	0	5
Methane	CH_4	%	0	5
Oxygen	O_2	%	0	30

Data Management with LeachXS™

Laboratory and analytical information for leaching tests was recorded by the laboratory technician in Microsoft Excel® spreadsheets specifically designed for each test for use as templates for data collection and archiving. Analytical data documenting concentrations of constituents from each leaching test were entered into the same spreadsheets. These data templates were used as the interface for loading laboratory and analytical data into LeachXS™ (VU, 2019), a database-driven data management and reporting software program. LeachXS was used to (i) archive the laboratory and analytical data from leaching tests; (ii) compare test results between composite materials (e.g., VC-1, VC-2, VC-3, or VC-4) and between test types (e.g., TCLP, SPLP, ASTM, and LEAF); and (iii) generate the Excel plots used for this report. These data have also been added to EPRI's CPInfo database.

4
PHYSICAL AND HYDRAULIC PROPERTIES

Physical properties of the fly ash samples used for measurement of hydraulic properties are summarized in Table 4-1, composition of the solids is summarized in Table 4-2, and the hydraulic conductivities are summarized in Table 4-3.

Particle size distributions of the coal ash samples are shown in Figure 4-1. All of the ashes contained a broad range of particle sizes ranging from coarse-to-fine sand, silt, and clay-size (<2 μm) particles. Fines is the predominant fraction for all of the samples. Each has a broadly graded particle size distribution. The fines content (i.e., particles finer than 75 μm) ranges from 61.5% to 96.8%, and the clay-size (i.e., finer than 2 μm) ranges from 7.0% to 19.4%. No particles coarser than sand-size were observed.

Table 4-1
Physical Properties of Coal Ash Samples Used for Hydraulic Conductivity Testing

Sample ID	Sample Elevation at Top (ft AMSL)	Sample Elevation at Bottom (ft AMSL)	Water Content (%)	Dry Unit Weight (kg/m^3)	Pore L/S of Intact Cores (L/kg-dry)	Particle Size Fractions			
						% Gravel	% Sand	% Fines	% Clay
CDL-VC2-65	374.9	371.9	39.5	1,090	0.36	0	12.1	87.9	13.1
CDL-VC2-75	364.9	361.9	35.4	1,110	0.32	0	38.5	61.5	7.3
CDL-VC3-65	378.2	375.2	35.7	1,390	0.26	0	3.2	96.8	14.3
CDL-VC3-75	368.2	365.2	41.5	1,150	0.36	0	7.8	92.2	7.0
CDL-VC4-65	378.2	375.2	39.8	1,150	0.35	0	23.3	76.7	19.4
CDL-VC4-75	368.2	365.2	36.6	1,290	0.28	0	6.2	93.8	11.6

An estimate of the pore L/S ratio of intact cores was made from the water content and the dry unit density assuming a fully saturated 1 m^3 volume of ash:

$$L/S = \frac{WC/100}{\rho_{dry}} \times 1000$$

where L/S is the liquid-to-solid ratio for fully saturated pores (L/kg-dry);
WC is the water content (%) from Table 4-1;
ρ_{dry} is the dry unit density (kg-dry/m^3) from Table 4-1; and,
1000 is a unit conversion factor for volume (1000 L = 1 m^3).

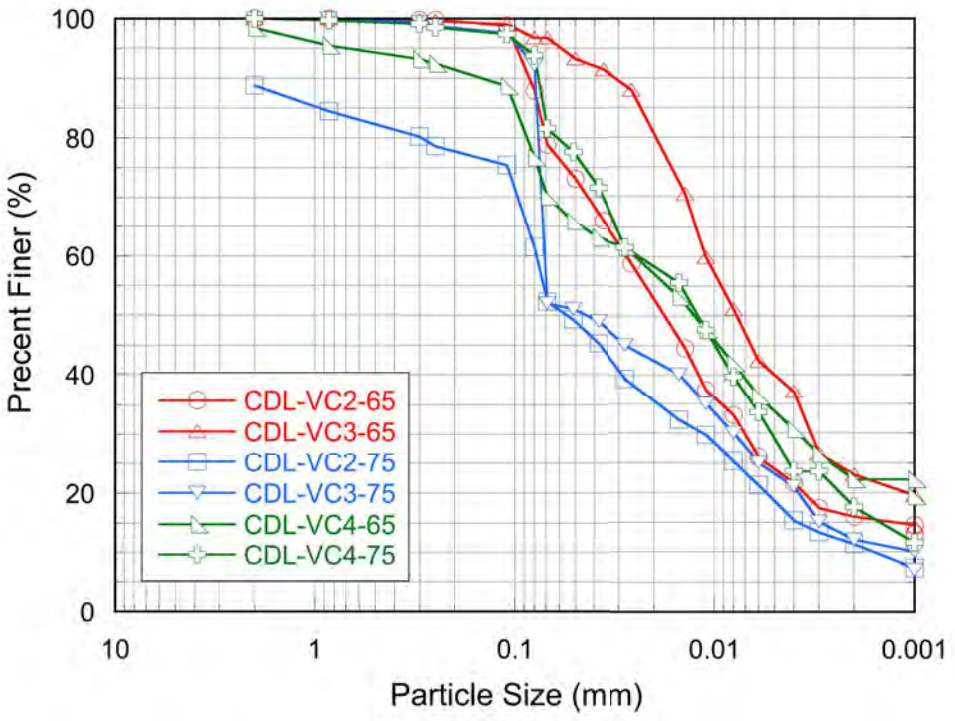

Figure 4-1
Particle size distribution of coal ash samples on which hydraulic conductivity tests were conducted

Table 4-2 indicates that all of the ash samples are predominantly composed of Al, Fe, and Si oxides, which reflects the predominant alumino-silicate mineral structure of the particulate. All samples contain modest amounts of Ca, K, and Ti. The LOI varies considerably, from 1.9% to 13.1%, with all but one sample having an LOI > 3.3%. The variability in composition of major elements appears to reflect the nature of the deposited ash as layers of fly ash and bottom ash.

Table 4-2
Composition of Solids (%) from LOI and XRF of Coal Ash Samples Used for Hydraulic Conductivity Assessment (elements exceeding 1.0%). Measurements were not conducted for CDL-VC3-65.

Composition	VC-2		VC-3		VC-4	
	65	75	65	75	65	75
LOI	2.0	2.7	-	1.9	13.1	3.3
Al_2O_3	15.8	16.1	-	17.2	15.6	17.5
CaO	7.9	8.9	-	6.6	8.4	5.3
Fe_2O_3	32.6	29.0	-	27.5	32.6	31.0
K_2O	3.7	4.2	-	4.5	3.7	4.0
SiO_2	35.2	36.4	-	39.2	34.6	37.3
TiO_2	1.3	1.3	-	1.4	1.2	1.4

The hydraulic conductivities fall into two groups (Table 4-3): more permeable samples (CDL-VC2-65, CDL-VC2-75, and CDL-VC3-75) and less permeable samples (CDL-VC3-65, CDL-VC4-65, and CDL-VC4-75). The more permeable ashes have hydraulic conductivities in the range of 10^{-5} cm/s, whereas the less permeable ashes have hydraulic conductivities in the range

of 10^{-6} cm/s. The differences in hydraulic conductivity between these groups cannot be attributed to particle size characteristics such as fines content or 2 -μm clay content (Figure 4-2). However, the less permeable ashes have higher dry density, and therefore lower void ratio (Figure 4-3).

Table 4-3
Hydraulic Conductivity of Coal Ash Samples

Sample ID	Effective Stress (kPa)	Hydraulic Conductivity (cm/s)
CDL-VC2-65	20	4.18×10^{-5}
	100	2.40×10^{-5}
	250	2.02×10^{-5}
	400	1.82×10^{-5}
	500	1.81×10^{-5}
CDL-VC2-75	20	2.43×10^{-5}
	100	1.90×10^{-5}
CDL-VC3-65	20	8.28×10^{-6}
	100	6.22×10^{-6}
	250	4.83×10^{-6}
	400	4.32×10^{-6}
	500	3.75×10^{-6}
CDL-VC3-75	20	1.54×10^{-5}
	100	1.26×10^{-5}
	250	1.09×10^{-5}
	400	8.15×10^{-6}
CDL-VC4-65	20	4.98×10^{-6}
	100	4.47×10^{-6}
CDL-VC4-75	20	2.07×10^{-6}
	100	1.96×10^{-6}

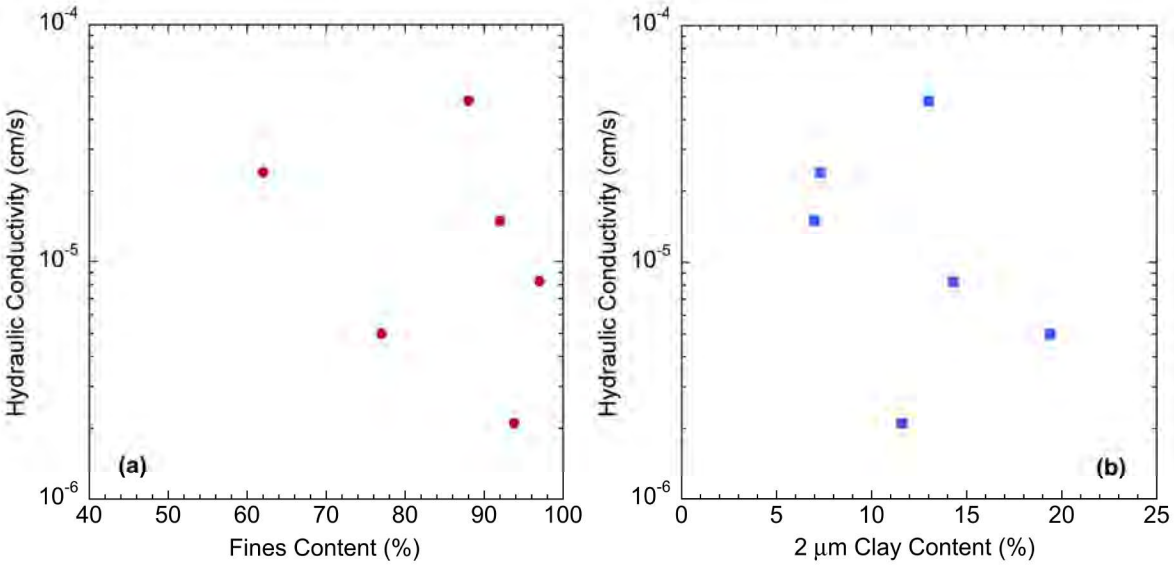

Figure 4-2
Hydraulic conductivity of coal ashes at 20 kPa effective stress as a function of (a) fines content and (b) 2-μm clay content

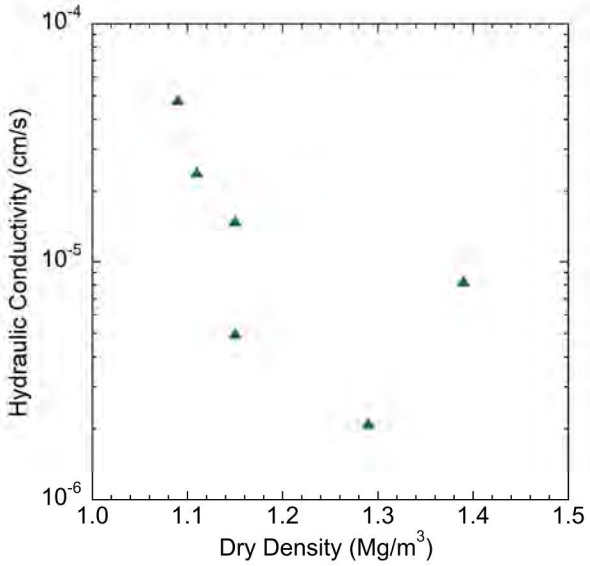

Figure 4-3
Hydraulic conductivity of coal ashes as a function of dry unit weight

Hydraulic conductivity of the coal ash samples as a function of confining stress is shown in Figure 4-4. The hydraulic conductivity diminishes only modestly with increasing stress, decreasing approximately by a factor of 2 as the effective stress is increased from 20 to 500 kPa. The insensitivity to stress is most likely due to the ash being predominantly comprised of silt-size and sand-size particles.

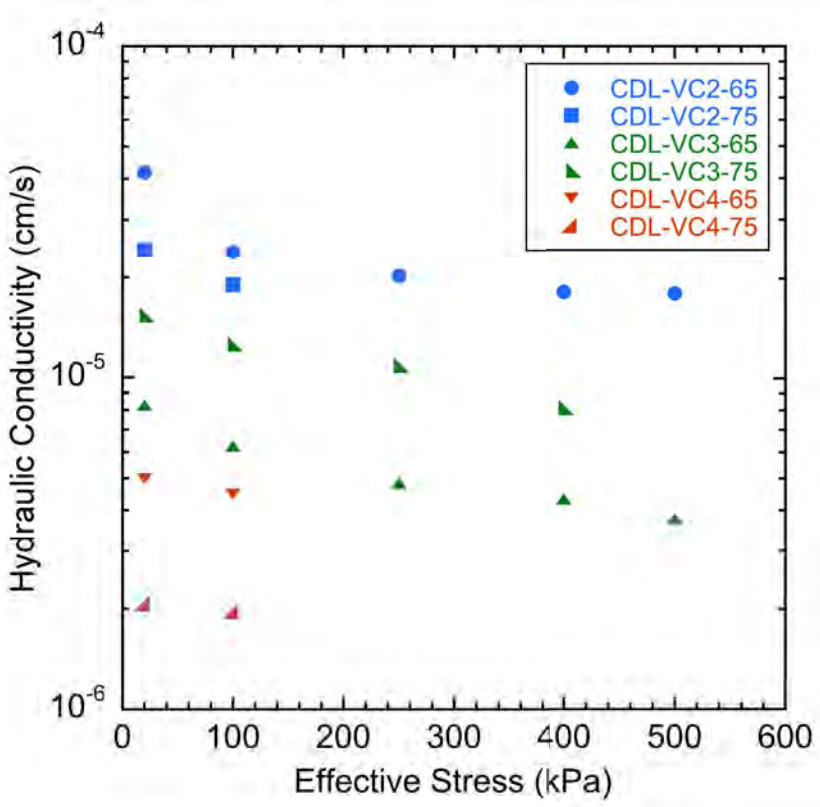

Figure 4-4
Hydraulic conductivity of coal ash samples as a function of effective stress

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5
INDIVIDUAL SPLIT SPOON SAMPLE TESTING

Evaluation of Field Extractions (Low L/S and L/S ≈ 1)

During field sampling, grab samples of ash from each split spoon were extracted by centrifugation of the moisture content (i.e., Low L/S Field Extractions). Because the moisture content of the unsaturated split spoon material varied with depth and texture, a small amount of DIW was added to each extraction to ensure that a sufficient amount of liquid could be recovered and analyzed. The resultant L/S of Low L/S Field Extractions varied between 0.28 and 0.67 mL/g-dry, consistent with the L/S of porewater from intact core samples (Table 4-1).

Vertical Heterogeneity Within and Between Boreholes

Profile Plots of Field and Laboratory Extraction Data

After surveying of the borehole and PAP locations and elevations, depths BGS measured during sample recovery were converted to elevations ASML. The concentration from Low L/S Field Extractions of individual split spoon materials was plotted as a function of elevation to provide a visual indication of material heterogeneity with depth within a borehole. Examples of these borehole profile plots are presented in Figure 5-1 and Figure 5-2.

Each figure represents the concentration profiles for a measured constituent in the Low L/S Field Extractions for VC-1 (blue), VC-2 (green), VC-3 (orange), and VC-4 (purple). The constituent concentration is plotted along the x-axis, while the elevation for the center of the split spoon is plotted on the y-axis. The red horizontal line shows the surface elevation at the time of drilling. The 5-foot wide shaded area indicates the screening interval for the PAP in each borehole. The light-colored data points in each profile indicate the intervals from which material was taken to create the composite ash sample for each borehole used in detailed characterizations.

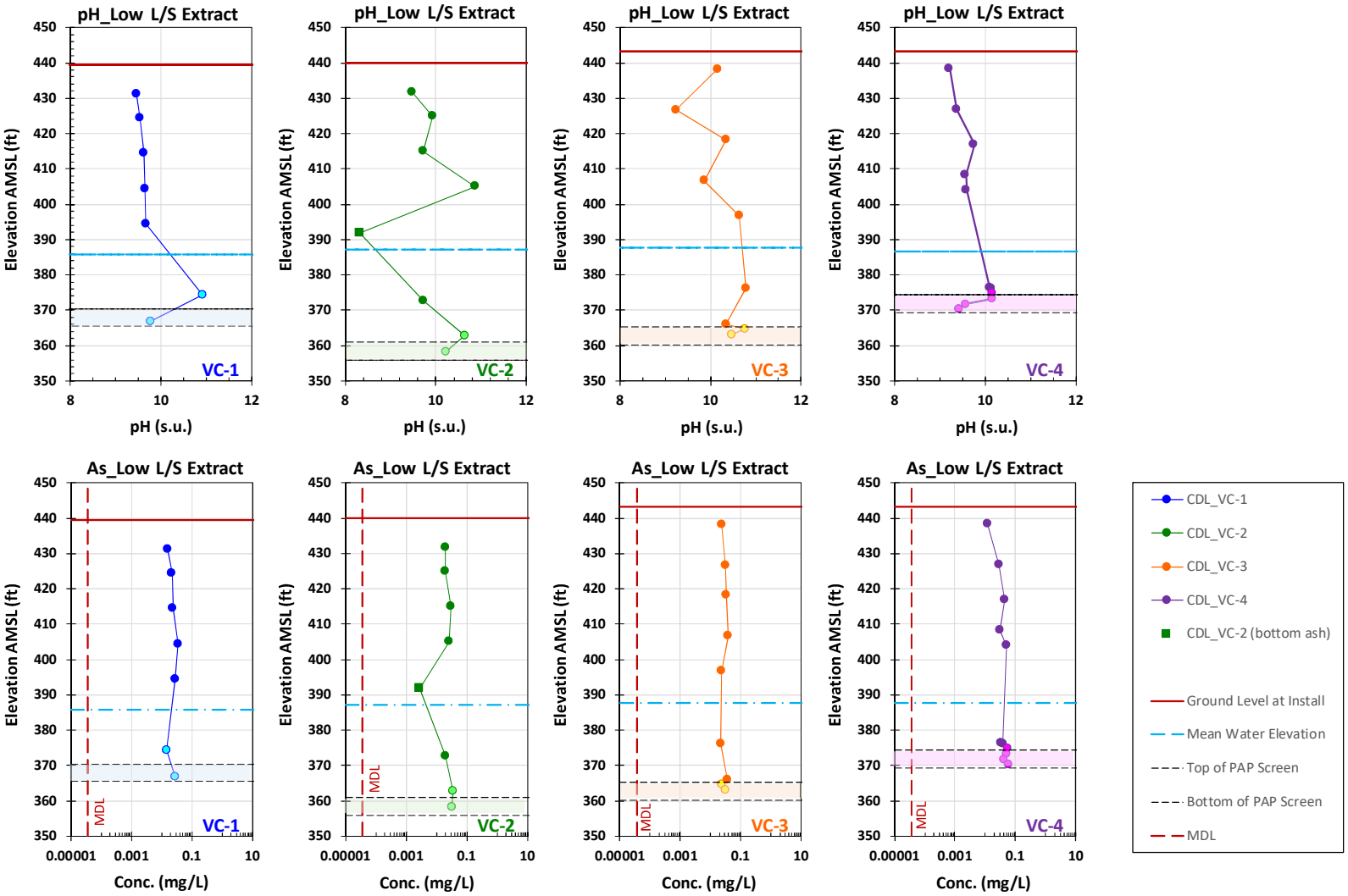

Figure 5-1
Low L/S Field Extraction concentration profiles within boreholes (VC-1, VC-2, VC-3, and VC-4): pH and arsenic; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL

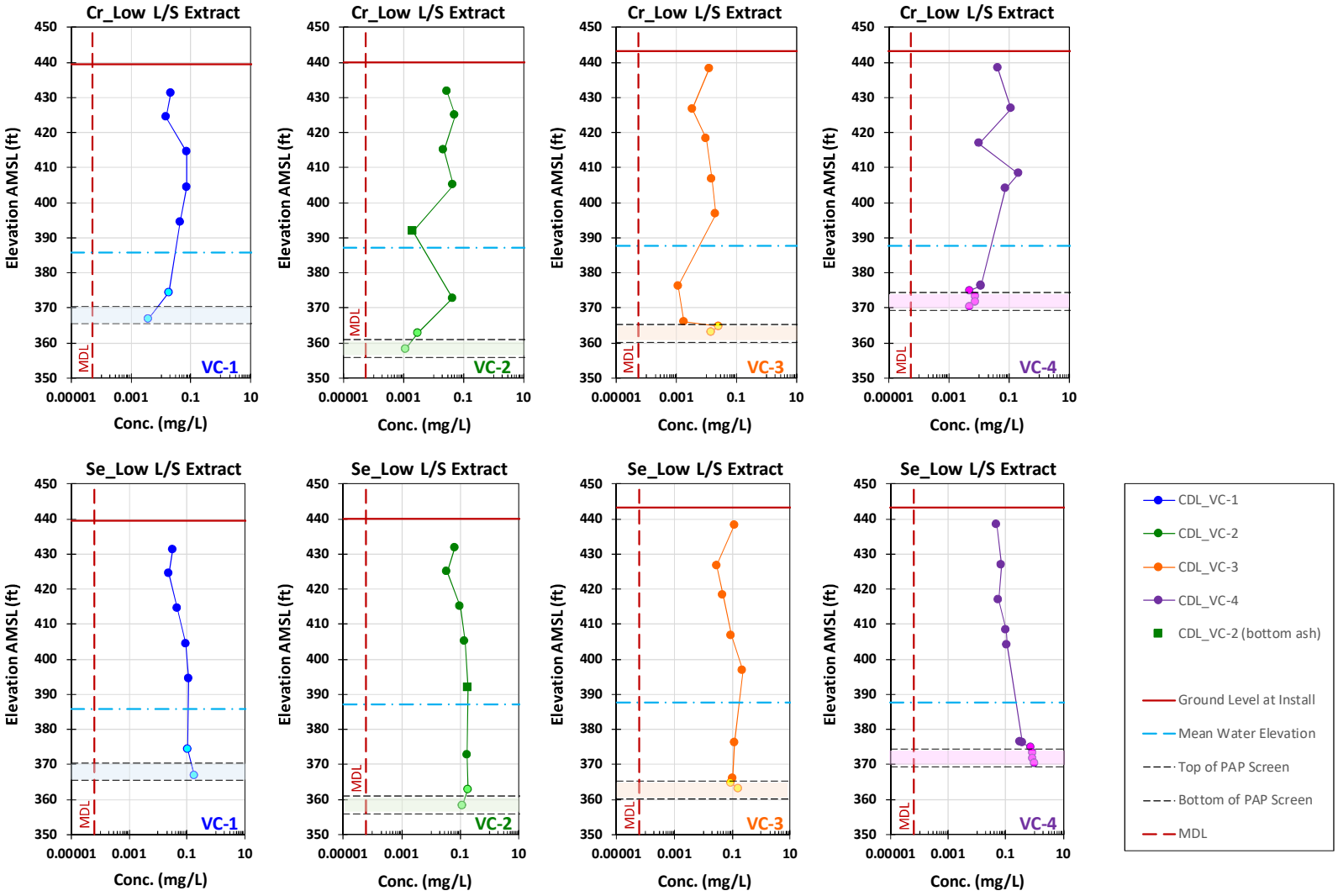

Figure 5-2
Low L/S Field Extraction concentration profiles within boreholes (VC-1, VC-2, VC-3, and VC-4): chromium and selenium; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL

Standardized Borehole Profiles of Low L/S Field Extractions

The concentration data for Low L/S Field Extractions were converted to standardized profile plots using the global mean and standard deviation for "known ash samples" in all boreholes as characterized by the geologist notes. The standardized concentration is calculated as:

$$\frac{x - \bar{x}}{s}$$

where x is the parameter (e.g., pH, concentration) from the extraction test,
$\bar{x}$ is the global mean of all "known ash samples" for all boreholes, and
s is the global standard deviation of all "known ash samples."

The global mean and standard deviation for all constituents are tabulated in Table 5-1. The standardized concentration provides a measure of the difference between the measured concentration and the mean as a number of standard deviations from the mean concentration. A homogenous material, for example, may have measurements within 2 standard deviations of the mean, while measurements greater than 4 standard deviations may have more than random variations such as influence from cover or underlying material. Justification for use of ash sample global statistics, rather than within-borehole statistics, was based on the results of t-test for pairwise comparisons assuming unequal variances, which showed no statistical difference in means between boreholes. In addition, the use of global statistics in standardized concentration profiles allows for comparison between boreholes on the same basis.

The standardized borehole profiles for the example constituents presented in Figure 5-1 and Figure 5-2 are presented in Figure 5-3 and Figure 5-4. The standardized profiles for all constituents are presented Appendix B-2. In general, the concentration profiles for most constituents are vertically consistent within the ash deposit and show no evidence of difference between the upper dry-handled coal ash and lower wet-handled coal ash.

Table 5-1
Global Mean and Standard Deviation of Laboratory Extractions (L/S=1) Concentrations

		Global "Ash" Statistics		
Analyte	**Units**	**Mean**	**Std. Dev**	**Coefficient of Variation**
Moisture Content	g_{H2O}/g	0.24	0.07	29%
EC	mS/cm	4.29	1.48	35%
pH	S.U.	9.96	0.49	4.9%
ORP	mV	78.4	23.3	30%
pH+pE	-	15.14	0.32	2.1%
Aluminum	mg/L	0.78	0.89	110%
Antimony	mg/L	0.002	0.001	50%
Arsenic	mg/L	0.03	0.01	33%
Barium	mg/L	0.11	0.05	46%
Beryllium	mg/L	ND	-	-
Boron	mg/L	16.1	15.8	98%
Cadmium	mg/L	0.02	0.01	50%
Calcium	mg/L	570	250	44%
Chromium	mg/L	0.31	0.04	13%
Cobalt	mg/L	0.0006	0.0002	33%
Copper	mg/L	0.011	0.001	9.1%
Iron	mg/L	0.01	0.02	200%
Lead	mg/L	ND	-	-
Lithium	mg/L	1.4	1.0	71%
Magnesium	mg/L	0.96	1.0	100%
Manganese	mg/L	0.0017	0.0011	65%
Molybdenum	mg/L	10.4	8.6	83%
Nickel	mg/L	0.0047	0.0012	26%
Phosphorus	mg/L	ND	-	-
Potassium	mg/L	300	88	29%
Selenium	mg/L	0.21	0.26	120%
Silicon	mg/L	4.1	2.2	54%
Silver	mg/L	ND	-	-
Sodium	mg/L	280	130	46%
Strontium	mg/L	3.2	2.0	63%
Sulfur	mg/L	590	280	48%
Thallium	mg/L	0.02	0.02	100%
Vanadium	mg/L	1.8	1.1	61%
Zinc	mg/L	0.01	0.01	100%

Notes: ND = all or most of the L/S=1 concentrations were less than the MDL

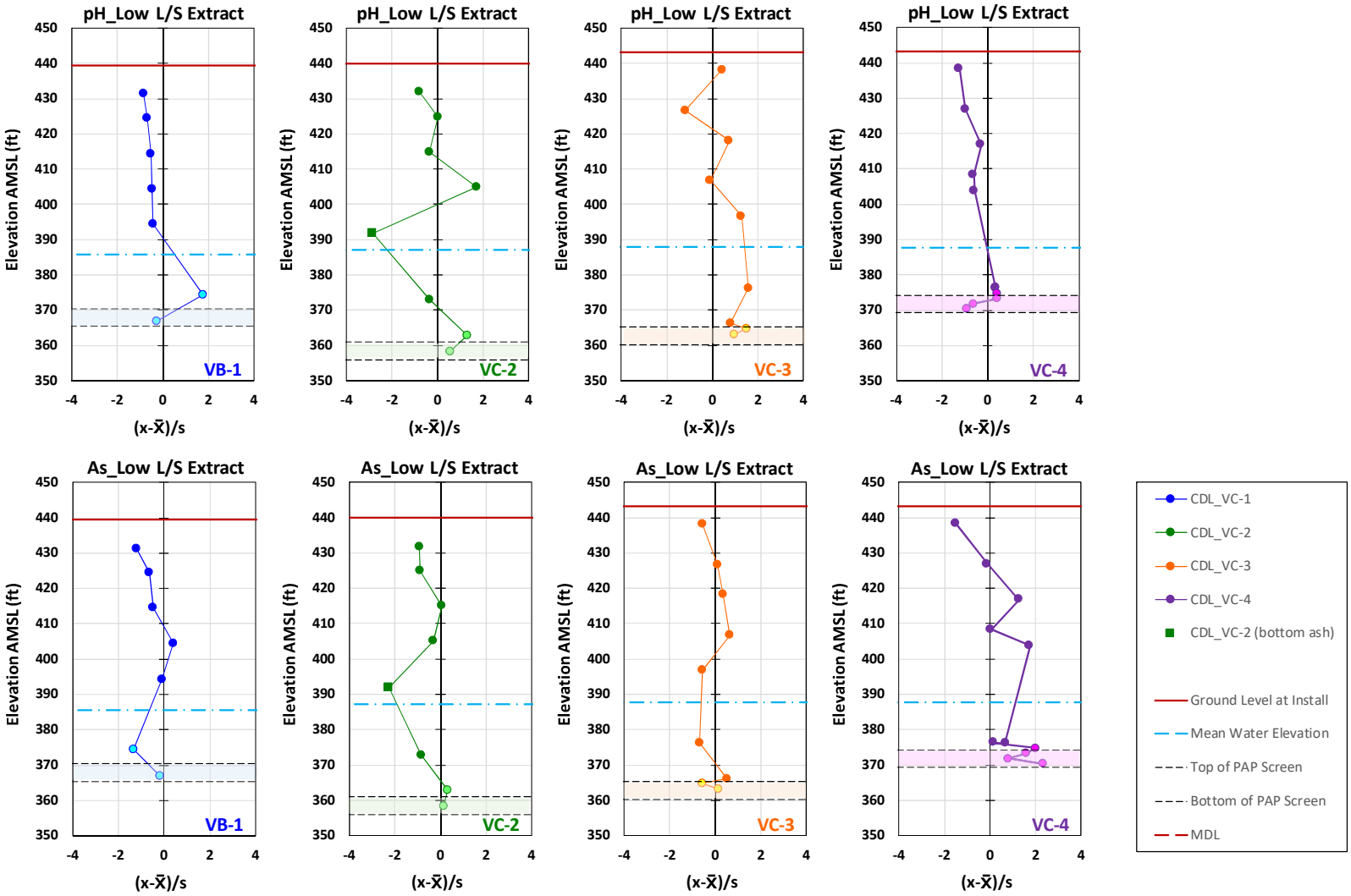

Figure 5-3
Standardized Low L/S Field Extraction profiles within boreholes (VC-1, VC-2, VC-3, and VC-4) standardized to the global mean (X̄) and standard deviation (s) of known ash samples: pH and arsenic; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL

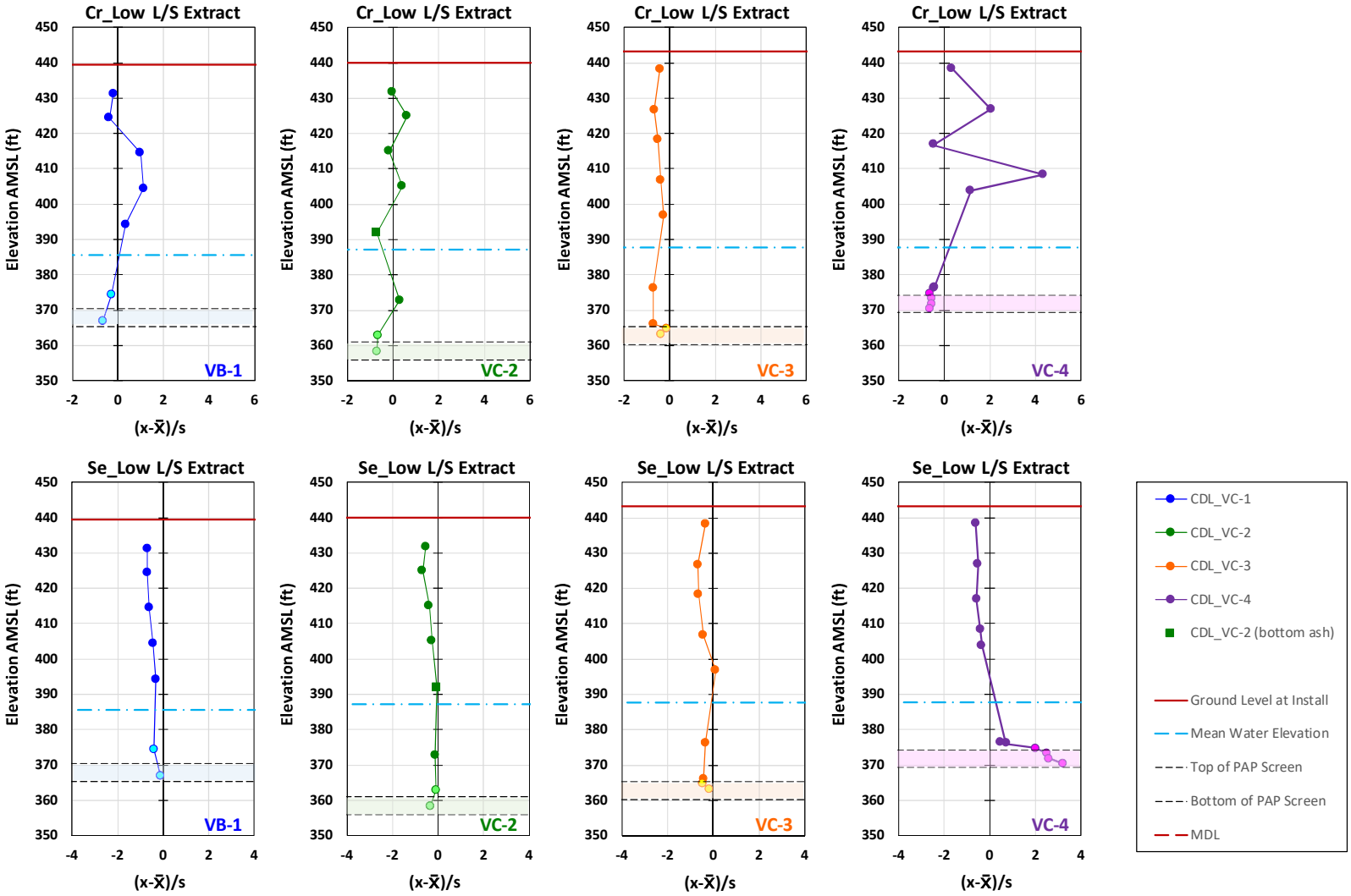

Figure 5-4
Standardized Low L/S Field Extraction profiles within boreholes (VC-1, VC-2, VC-3, and VC-4) standardized to the global mean (x̄) and standard deviation (s) of known ash samples: chromium and selenium; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL

Comparison of Standardized Borehole Profiles for Low L/S and L/S≈1 Field Extractions Based on Mass Release (mg/kg)

For boreholes VC-1 and VC-2, L/S≈1 Field Extractions were conducted as a comparator to the unique Low L/S Field Extractions. Example comparisons of standardized borehole variability graphs are presented in Figure 5-5 and Figure 5-6, while the complete results for all measured constituents are presented in Appendix B-3. In general, the variability between field extraction methods is negligible; however, the unique Low L/S Field Extraction technique provided data that are somewhat less variable than the L/S≈1 Field Extractions. The Low L/S extractions are considered to provide better control of redox conditions and L/S values that are more consistent with porewater values.

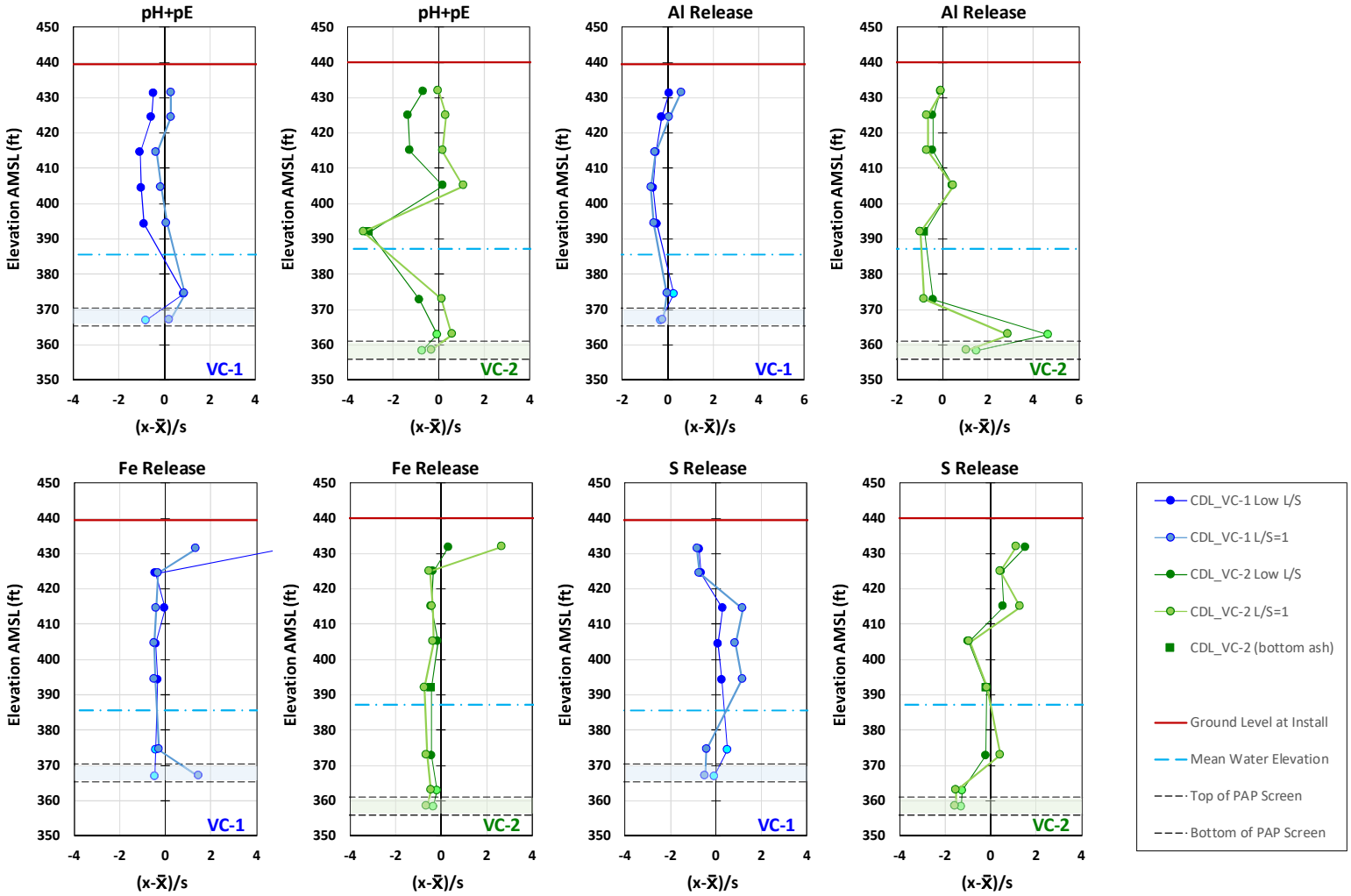

Figure 5-5
Comparison of standardized mass release profiles for Low L/S Field Extractions and L/S ≈ 1 Field Extractions of major constituents from VC-1 and VC-2: pH+pE, aluminum, iron, and sulfur; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL

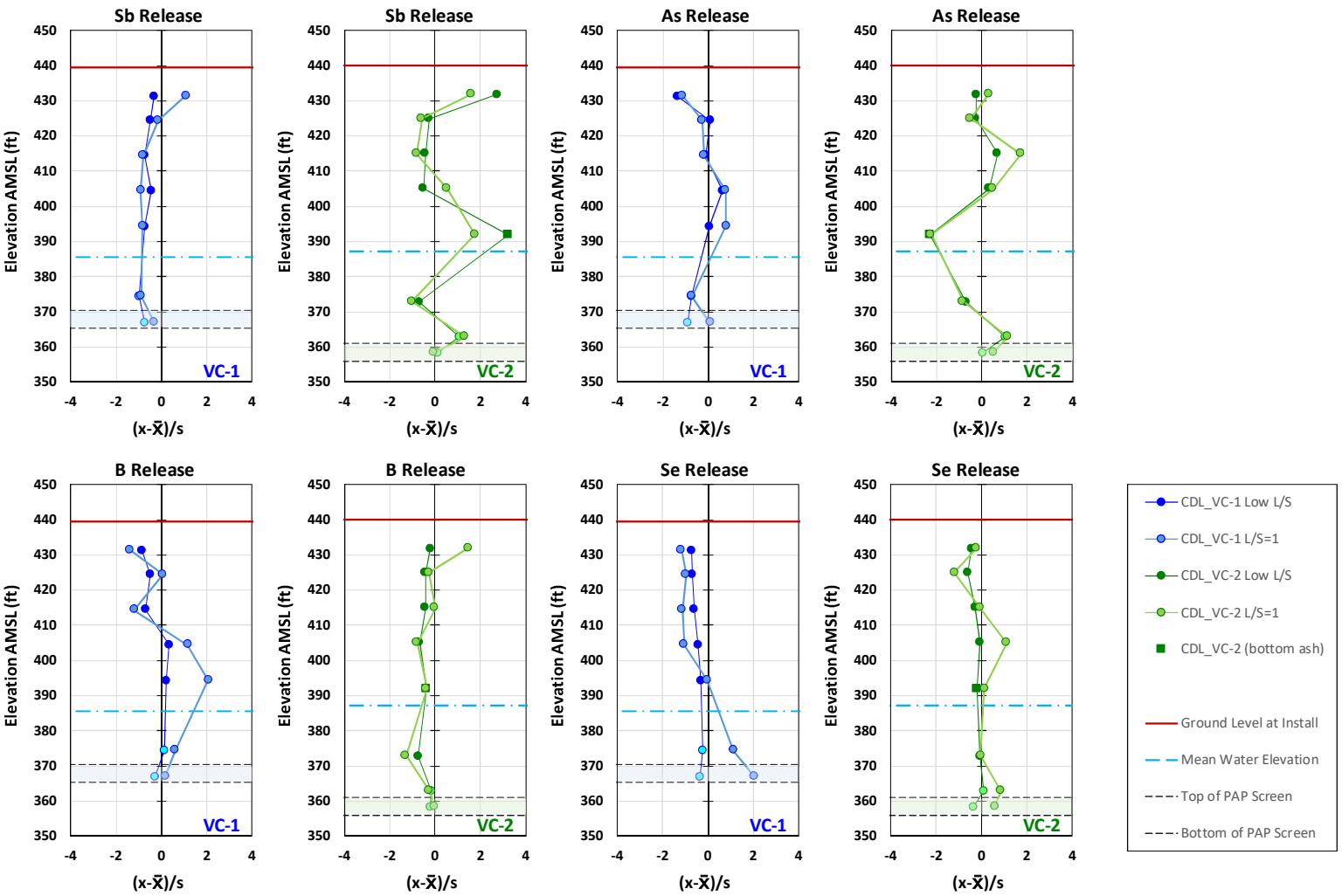

Figure 5-6
Comparison of standardized mass release profiles for Low L/S Field Extractions and L/S ≈ 1 Field Extractions of trace constituents from VC-1 and VC-2: antimony, arsenic, boron, and selenium; interface between dry- and wet-handled ash occurs at approximately 390 ft AMSL.

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6
COMPOSITE ASH SAMPLE TEST RESULTS

Subsamples of bulk material collected from split spoon sampling were homogenized within each bulk storage packet. For borehole composites, the material in the storage packets around the PAP screening intervals was composited by equal dry mass from each packet as shown in Table 3-1. These composites of wet-handled ash were labeled for their respective borehole locations (i.e., VC-1 through VC-4). An additional site-wide composite of unsaturated material, labeled as "Dry," was created by equal mass from split spoon samples from dry-handled material in all boreholes collected above the water table. The five composites were subject to detailed investigation of total content, available content, and leaching characteristics as a function of pH and L/S.

Total Content

The total content analysis results for the five composite materials are shown in Table 6-1.[3] In preparation for EPA Method 3052, ash samples were dried under nitrogen and ground to pass a No. 100 (150 μm) sieve. Therefore, the total content results are reported on a dry-mass basis (mg/kg-dry), whereas typical EPA Method 3052 results would be based on "as received" solid sample (mg/kg), which can include the inherent moisture in the solid sample.

The coal ash composites are comprised mainly of Al, Ca, Fe, K, Na, and Si (not measured). Of the 26 constituents analyzed, Sb, Co, Mg, Mn, Hg, Ag, and Tl were reported for at least one of the five composites to have low total content relative to the commercial laboratory's reporting limit. Mercury was detected above reporting limit only in the "Dry" composite and, therefore, was not considered in the analysis of test leachates or the comparison to groundwater concentrations. The remaining low-concentration constituents were retained because preliminary testing indicated that leaching concentrations were low, but quantifiable in LEAF leaching tests.

For most elements analyzed (16 of 26), the dry-handled ash composite had a total content value within the range of values for the wet-handled composites. Only Pb, Hg, and Mo had a total content a factor of 1.5 or more higher than the highest wet-handled composite value within the range, while Cd, Li, Sr, and Zn had total contents slightly higher (within a factor of 1.0 to 1.5) than the highest wet-handled value. Total content values for Mn, K, and Na were slightly lower than the lowest wet-handled total content value.

[3] As noted in the test description in Section 3, boron was not analyzed for total content because metaborate is added to the digestion process for Method 3052.

Table 6-1
Total Contents for Composite Samples (VC-1, VC-2, VC-3, VC-4, and Dry) Based on EPA Method 3052

Analyte	Symbol	MDL (mg/kg)	VC-1 (mg/kg)	VC-2 (mg/kg)	VC-3 (mg/kg)	VC-4 (mg/kg)	Dry (mg/kg)
Aluminum	Al	2.9	21,000	17,000	27,000	18,000	27,000
Antimony	Sb	1.9	6.2	4.5 J	5.0 J	7.7	7.4
Arsenic	As	1.3	51	63	48	94	54
Barium	Ba	0.22	370	480	820	390	360
Beryllium	Be	0.014	11	7.9	5.9	13	9.5
Cadmium	Cd	0.74	4.4	3.5	5.1	3.8	6.0
Calcium	Ca	10	13,000	9,400	24,000	9,300	21,000
Chromium	Cr	0.13	170	140	130	180	160
Cobalt	Co	2.8	32	23 J	20 J	42	29
Copper	Cu	3.6	81	72	64	92	78
Iron	Fe	65	120,000	99,000	100,000	130,000	110,000
Lead	Pb	1.0	62	70	67	74	160
Lithium	Li	0.27	68	55	50	66	71
Magnesium	Mg	3.4	340 J	430 J	610	300 J	490 F1
Manganese	Mn	0.10	380 B	390 B	430 B	330 B	280 B
Mercury	Hg	0.058	ND	ND	ND	0.058 J	0.46
Molybdenum	Mo	0.15	27	26	18	37	62
Nickel	Ni	2.1	130	93	89	160	120
Potassium	K	240	12,000	16,000	14,000	12,000	11,000
Selenium	Se	1.6	14	10	9.3	17	16
Silver	Ag	0.10	1.2 J	1.0 J	0.93 J	1.3 J	1.1 J
Sodium	Na	240	5,400	5,200	4,900	5,100	3,800
Strontium	Sr	0.054	68	57	67	95	130 F1
Thallium	Tl	9.3	13 J	14 J	9.7 J	14 J	9.4 J
Vanadium	V	0.056	670	450	480	660	620
Zinc	Zn	4.6	410	430	410	420	460

Notes:
B the compound was found in the blank and sample.
F1 the matrix spike recovery is outside of acceptance limits
J the result is less than the reporting limit but greater than or equal to the MDL; estimated concentration.
ND the compound was not detected at a concentration above the MDL.

Leaching Test Results

For this project, leaching test results included LEAF test results (EPA 1313, 1313_L/S=1, EPA 1314) and traditional leaching tests (TCLP, SPLP, ASTM). All leaching data are presented in Appendix C for each composite sample as a function of pH and L/S. The graphs used in the following discussion of leaching test results were derived from the appendix figures either by combining data series (e.g., comparisons between composites) or by limiting axis domains. In

some cases, discussion graphs are presented as graphs of mass release (mg/kg-dry), which were derived from eluate concentrations (mg/L) multiplied by the associated L/S value (L/kg-dry). Mass release graphs are not presented in the appendix.

pH-Dependent Leaching Tests (EPA 1313, 1313_L/S=1)

Titration Curves

Titration curves from pH-dependent tests conducted on composite samples are presented in Figure 6-1. The titration curve indicates the amount of acid or base (shown as acid additions less than zero) required to provide a specific eluate pH, sometimes referred to as the acid/base neutralization capacity of the material. This data may be useful when leachates or materials from other processes or natural environments are introduced to a storage facility (e.g., pyritic tailings co-disposed with fly ash).

In LEAF nomenclature, the pH response when no acid or base is added to the extraction at an L/S of 10 mL/g-dry is referred to as the "natural pH" of the material. Because the natural pH is defined at an L/S of 10 mL/g, the term "own pH" will be used to differentiate the pH response at other L/S values (e.g., 1313_L/S=1) from the natural pH. The natural pH (EPA 1313) and own pH (1313_L/S=1) are tabulated for the five composite materials in Table 6-2 and represented in Figure 6-1 as large color-coded circles about a data point. The values for natural pH for the five composites are generally the same (average value of 10.41±0.18). The composite of the unsaturated ash (Dry) is the least alkaline (pH_{nat}=10.21), but not much more so than the composite of saturated ash at VC-2 (pH_{nat}=10.29). The most alkaline composite is the saturated ash composite at VB-3 (pH_{nat}=10.67). In comparison to natural pH, the own pH values are essentially the same as their associated natural pH values (within approximately 0.2 standard units).

Table 6-2
Natural pH (EPA 1313) and own pH (1313_L/S=1) of composite samples

	Method	L/S (mL/g-dry)	VC-1 pH (SU)	VC-2 pH (SU)	VC-3 pH (SU)	VC-4 pH (SU)	Dry pH (SU)
Natural pH	EPA 1313	10	10.44	10.29	10.67	10.43	10.21
Own pH	1313_L/S=1	1	10.66	10.64	10.71	10.29	10.01

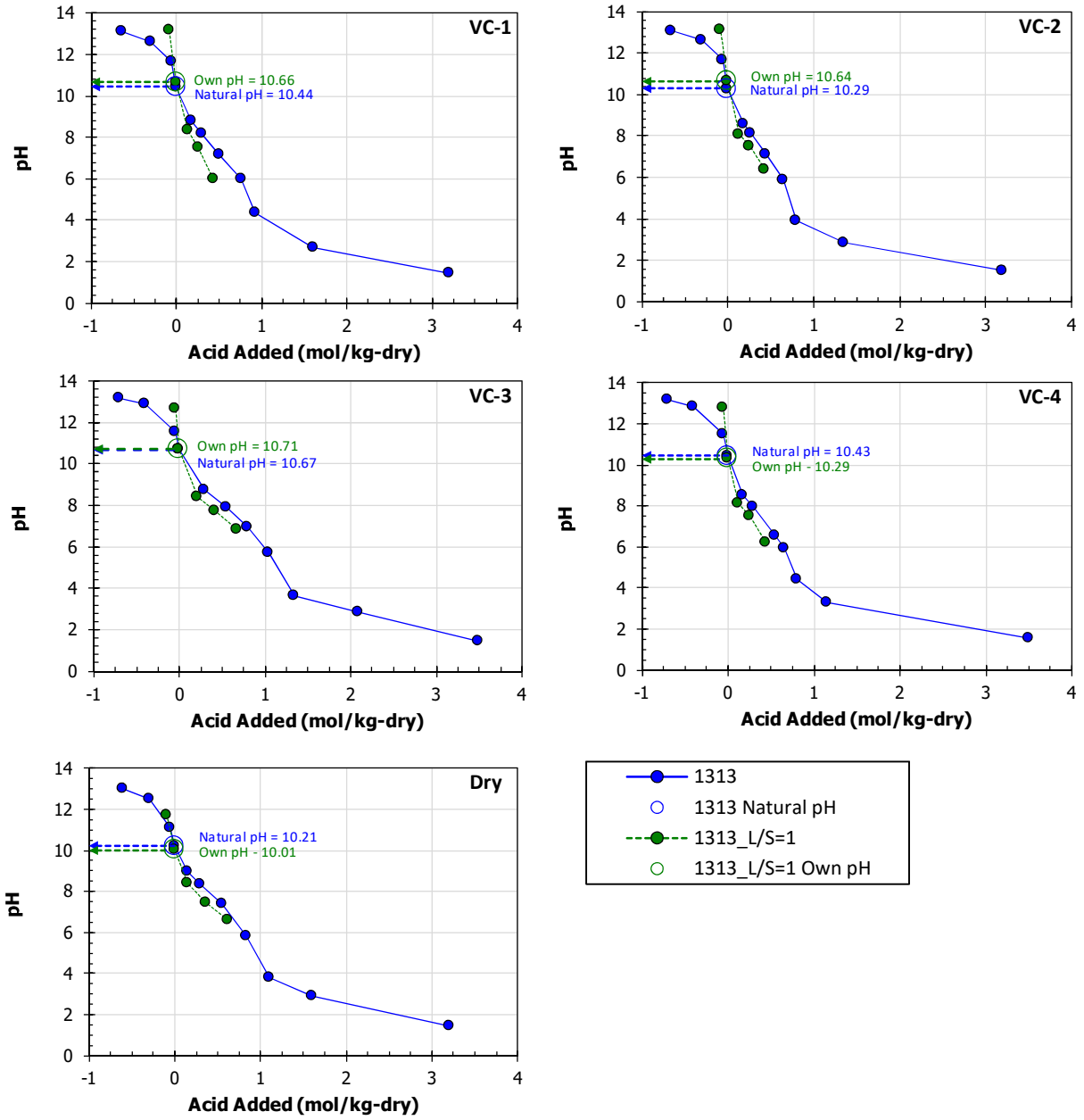

Figure 6-1
Titration curves from EPA 1313 test results from five composite samples (VC-1, VC-2, VC-3, VC-4, and Dry)

Constituent Concentrations

The concentration of a constituent in each eluate of a pH-dependent leaching test (i.e., EPA 1313 and 1313_L/S=1) is indicative of the speciation of the constituent and the LSP in equilibrium with the L/S, pH, EC, and ORP of the contacting fluid. Eluate concentrations are typically plotted as a function of eluate pH to indicate how LSP changes over a broad range of pH values. These data also can be used to parameterize controlling mineral sets in geochemical speciation models, for example, LeachXS™/ORCHESTRA (Meeussen, 2015), to create a source term for

fate and transport modeling. The pH-dependent leaching behavior of a constituent is useful when disposed materials may be contacted with water containing significant amounts of acid or base (e.g., pyrite-impacted groundwater or alkali process wastewaters).

However, for many field assessments, evaluation of LSP may be limited to an applicable pH domain. The applicable pH domain is typically centered about the natural pH of the material but should consider the potential for leachate pH values to shift with aging or external influences (EPA, 2019). For example, alkaline materials that may be exposed to the environment can carbonate, which neutralizes the pH toward the equilibrium pH of calcium carbonate (pH ~ 8.2). Therefore, an applicable pH domain that is inclusive of critical pH values and is based on target eluate pH values from EPA 1313 would be $8 \leq pH \leq 12$. Example test results from EPA 1313 are shown in Figure 6-2 with the applicable pH domain shaded. These examples show that LSP behavior can vary significantly between constituents (e.g., boron vs. lead) but that the behavior for a constituent is very consistent between composite samples. The concentrations within the applicable pH domain are often, but not always, considerably lower than the maximum concentration over the entire EPA 1313 test pH range.

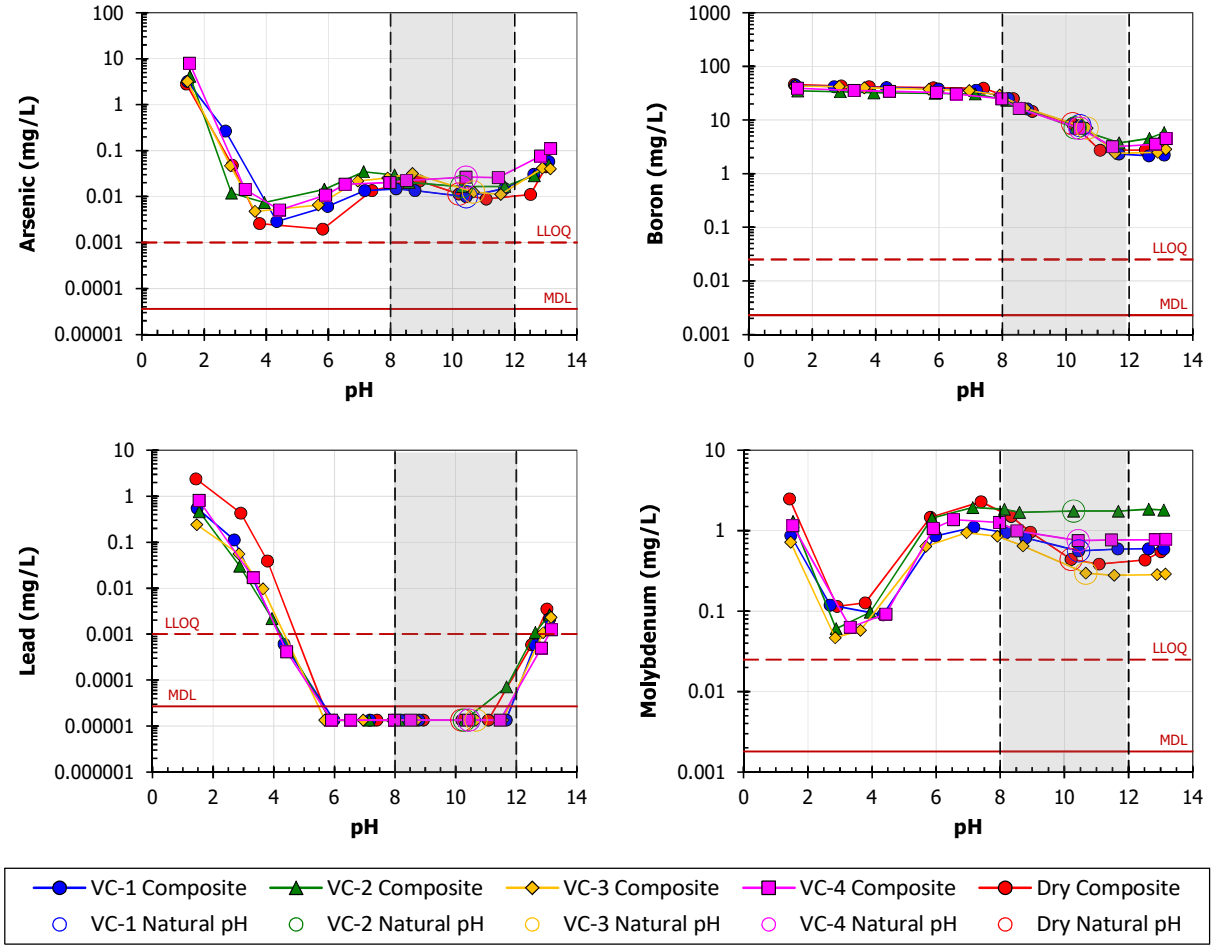

Figure 6-2
Example LSP behaviors from composite samples (VC-1, VC-2, VC-3, VC-4, and Dry) showing applicable pH range ($8 \leq pH \leq 12$) for alkaline materials

Available Content Determination Using EPA 1313

The broad pH range of data provided by EPA 1313 data allows for evaluation of content of leachable constituent, known as the available content (EPA, 2019). The standard EPA methodology (EPA, 2019) for determination of available content is to identify the maximum leaching concentration (mg/L) from EPA 1313 test results at pH value of 2, 9, and 13 and calculate the mass release (mg/kg-dry) at the maximum LSP concentration:

$$AC = C_{1313(\max pH\ 2,9,13)} \cdot (L/S)_{1313}$$

where AC is the available content (mg/kg-dry);
$C_{1313(\max pH\ 2,9,13)}$ is the maximum concentration from EPA 1313 data at pH 2, 9, or 13 (mg/kg-dry); and,
$(L/S)_{1313}$ is the liquid-to-solid ratio for the EPA 1313 extractions of 10 mL/g-dry (10 L/kg-dry).

Values for the available content of constituents for the five composite samples (VC-1, VC-2, VC-3, VC-4, and Dry) are reported in Table 6-3. The ratio of the available content to the total content (Table 6-4) indicates that for most constituents only a fraction (< 20%) is leachable over a broad pH range. In some cases, the available fraction is less than 1% of the total content. In Table 6-4, the high ratios (> 1) for Ca and Mg suggest either that digestion by EPA 3052 was not complete or that there is inherent error associated with multiplying a relatively small digestate concentration by a large effective L/S of 500 or more.

Table 6-3
Available Content for Composite Samples VC-1, VC-2, VC-3, VC-4, and Dry Based on the Maximum Concentration from EPA Method 1313

Analyte	Symbol	VC-1 (mg/kg-dry)	VC-2 (mg/kg-dry)	VC-3 (mg/kg-dry)	VC-4 (mg/kg-dry)	Dry (mg/kg-dry)
Aluminum	Al	4,900	4,900	6,200	4,700	5,100
Antimony	Sb	2.5	2.2	4.6	2.0	3.8
Arsenic	As	32	42	32	79	28
Barium	Ba	4.5	5.5	4.1	6.3	2.7
Beryllium	Be	2.1	1.4	1.3	2.5	1.9
Boron	B	440	350	430	390	460
Bromide	Br^-	< 0.064	< 0.064	< 0.064	< 0.064	< 0.064
Cadmium	Cd	2.5	1.5	2.7	2.3	3.4
Calcium	Ca	17,000	17,000	19,000	15,000	19,000
Chloride	Cl^-	620	460	360	620	470
Chromium	Cr	9.4	11	11	8.0	8.3
Cobalt	Co	1.1	1.5	1.5	2.0	1.9
Copper	Cu	3.5	4.2	2.2	3.8	7.5
Dissolved Inorganic Carbon	DIC	130	140	210	160	67
Dissolved Organic Carbon	DOC	190	180	240	170	24
Fluoride	F^-	< 0.063	83	68	< 0.063	77
Iron	Fe	2,200	2,100	2,200	2,200	2,100
Lead	Pb	5.5	4.6	2.4	8.1	24
Lithium	Li	1.8	1.0	1.7	1.1	3.4
Magnesium	Mg	490	580	760	410	710
Manganese	Mn	80	75	120	57	54
Molybdenum	Mo	8.7	19	9.0	14	25
Nickel	Ni	4.0	4.0	3.9	4.9	4.3
Nitrate	NO_3^-	< 0.11	0.2	< 0.11	< 0.11	< 0.11
Phosphate	PO_4^{-3}	780	1,300	600	830	750
Potassium	K	670	820	730	540	820
Selenium	Se	2.1	1.0	1.3	2.6	2.4
Silicon	Si	5,100	4,900	7,700	4,500	5,700
Silver	Ag	< 0.0004	< 0.0004	< 0.0004	< 0.0004	< 0.0004
Sodium	Na	430	330	260	440	300
Strontium	Sr	25	20	24	35	48
Sulfate	SO_4^{-2}	9,500	7,000	13,000	9,100	19,000
Thallium	Tl	5.1	4.2	3.6	6.3	5.6
Vanadium	V	190	140	150	190	150
Zinc	Zn	10	8.0	13	10	19

Notes: All available contents determined at a pH of 2 except DOC and DIC at pH 13.

Table 6-4
Ratio of Available Content (EPA 1313) to Total Content (EPA 3052) for Composite Samples VC-1, VC-2, VC-3, VC-4, and Dry

		Available Content / Total Content (-)				
Analyte	**Symbol**	**VC-1**	**VC-2**	**VC-3**	**VC-4**	**Dry**
Aluminum	Al	0.23	0.29	0.23	0.26	0.19
Antimony	Sb	0.40	0.49 J	0.92 J	0.26	0.051
Arsenic	As	0.63	0.67	0.67	0.84	0.52
Barium	Ba	0.012	0.012	0.0050	0.016	0.0075
Beryllium	Be	0.19	0.18	0.22	0.19	0.20
Cadmium	Cd	0.57	0.43	0.53	0.61	0.57
Calcium	Ca	1.3	1.8	0.79	1.6	0.91
Chromium	Cr	0.055	0.079	0.085	0.044	0.052
Cobalt	Co	0.034	0.065 J	0.075 J	0.048	0.066
Copper	Cu	0.043	0.058	0.034	0.041	0.096
Iron	Fe	0.018	0.021	0.022	0.017	0.019
Lead	Pb	0.089	0.066	0.036	0.11	0.15
Lithium	Li	0.026	0.018	0.034	0.017	0.048
Magnesium	Mg	1.4 J	1.3 J	1.2B	1.4 J	1.4 F1
Manganese	Mn	0.21 B	0.19 B	0.28 B	0.17 B	0.19 B
Molybdenum	Mo	0.41	0.73	0.50	0.38	0.40
Nickel	Ni	0.031	0.011	0.044	0.031	0.036
Potassium	K	0.056	0.051	0.052	0.045	0.075
Selenium	Se	0.15	0.10	0.14	0.15	0.15
Sodium	Na	0.080	0.063	0.053	0.086	0.079
Strontium	Sr	0.37	0.35	0.36	0.37	0.37 F1
Thallium	Tl	0.39 J	0.30 J	0.37 J	0.45 J	0.60 J
Vanadium	V	0.28	0.31	0.28	0.29	0.24
Zinc	Zn	0.024	0.019	0.031	0.022	0.041

Notes: B the compound was found in the blank and sample of the total content analysis extract.
F1 the matrix spike recovery for the total content analysis extract is outside of acceptance limits.
J the total content result is less than the LLOQ but greater than or equal to the MDL; estimated value.

Alternatively, the available content may be presented graphically as the maximum mass release from EPA 1313 data (Figure 6-3). These figures show that the maximum release for many constituents is often determined at pH $\leq$ 2, but that mass release may be similar at other pH values (see Mo). These figures also show that the absolute value determined for the available content may be dependent on the pH value used to determine the maximum concentration from EPA 1313. For example, the maximum mass release values for arsenic and boron are determined at a pH $\leq$ 2; however, the boron data plateaus in the acidic range, while the arsenic data is still on a steep increasing slope as pH decreases. Therefore, a minor change in the EPA 1313 eluate pH

will not significantly impact the available content determination for boron, while the same minor change may significantly alter the determined available content for arsenic.

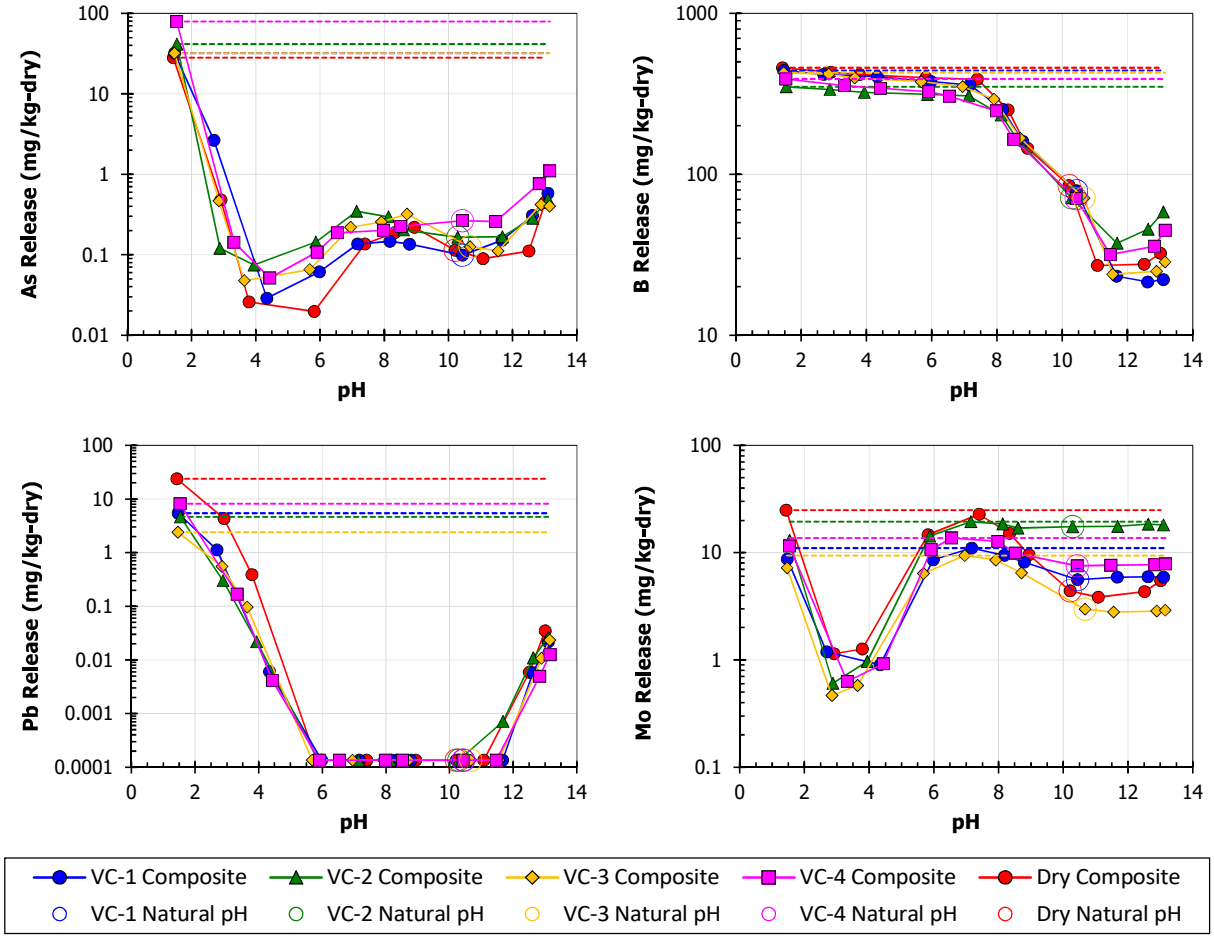

Figure 6-3
Example mass release from composite samples (VC-1, VC-2, VC-3, VC-4, and Dry) showing available content (dashed horizontal lines)

L/S-Dependent Leaching Test Results (EPA 1314)

The results of EPA 1314 indicate how the LSP of constituents changes as the amount of water passing through a bed of material increases (i.e., the cumulative L/S, or ΣL/S). In general, soluble minerals are dissolved and removed from the column at low ΣL/S values; therefore, different minerals and processes (e.g., dissolution vs. desorption) may control the release of constituents at various points along the percolation column elution curve. As leaching progresses, the ionic strength of the porewater decreases, leading to changes in controlling minerals and, in some cases, the controlling LSP mechanisms (e.g., a constituent with an LSP limited by the available content at high concentration may show signs of solubility-controlled LSP at low concentration). In cases where the ΣL/S can be related to the rate of field infiltration, column test data can provide an estimate of leaching concentration as a function of time (Kosson et al., 2014; Garrabrants et al., 2020a, 2020b; EPA, 2019).

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pH in Column Eluates

The measured pH values of eluates from the column test (EPA 1314) for the five composite samples (VC-1, VC-2, VC-3, VC-4, and Dry) are presented in Figure 6-4. These graphs also indicate the natural pH (EPA 1313) and the own pH (EPA 1313_L/S=1) as dashed lines, and the range of pH values measured in the PAPs.

For the saturated composites (VC-1, VC-2, VC-3, and VC-4), the evolution of pH in the percolation column shows an initially increasing trend followed by a plateau at an approximate pH of 10, with the starting pH and the plateau varying slightly between composites. However, the evolution of pH for the Dry composite taken from samples above the water table shows a different trend, with an initially high pH that decreases by about 0.5 pH units to plateau at a pH of approximately 9.0. The increase in pH at low L/S for the saturated composites (VC-1 through VC-4) may be due to surficial oxidation or carbonation resulting from contact of moist, alkaline ash with air during sample handling.

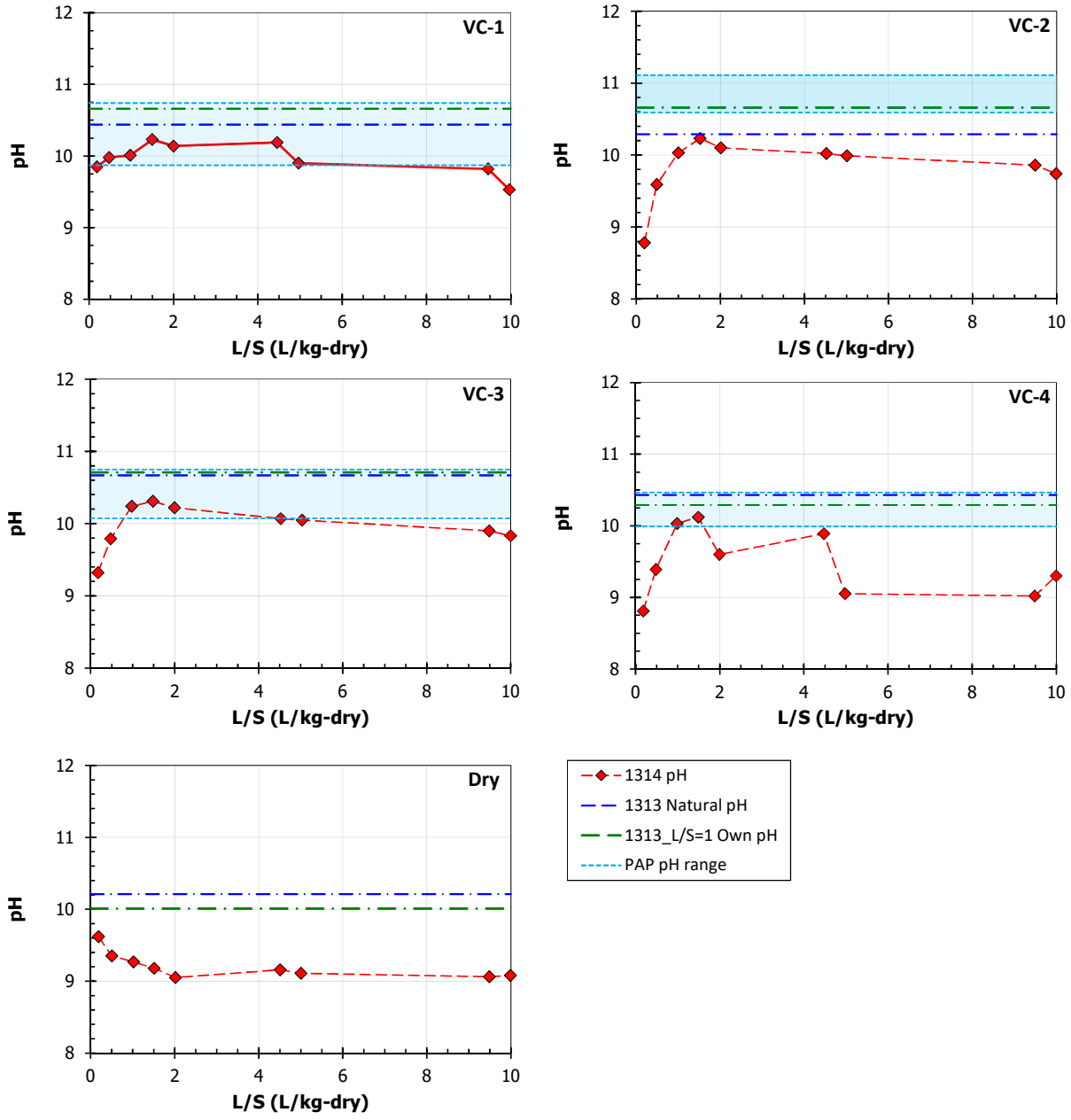

Figure 6-4
Evolution of pH in column eluates (EPA 1314) from five composite samples (VC-1, VC-2, VC-3, VC-4, and Dry) compared to natural pH (EPA 1313), own pH (EPA 1313_L/S1), and range of porewater pH measurements

Table 6-5 compares the eluate pH values from the lowest L/S fraction of EPA 1314 to the range of pH values at higher L/S values, to the natural pH and own pH measured in batch leaching tests (EPA 1313 and 1313_L/S-1), and to the range of pH in porewater samples from the PAPs. In general, column test eluates at low L/S are approximately 1.5 pH units lower than measured in batch leaching tests. The difference may be explained predominantly by ionic strength changes with increasing L/S and interactions with dissolved constituents in equilibrium at the L/S values.

Table 6-5
Comparison of Eluate pH from Low L/S Column Fraction (EPA 1314) to the Natural pH (EPA 1313) and Own pH (1313_L/S=1) of Composite Samples

	Method	L/S (mL/g-dry)	VC-1 pH (SU)	VC-2 pH (SU)	VC-3 pH (SU)	VC-4 pH (SU)	Dry pH (SU)
1st Fraction	EPA 1314	0.2	9.85	8.78	9.32	8.81	9.62
Range	EPA 1314	2-10	9.5-10.1	9.7-10.1	9.8-10.2	9.0-9.9	9.0-9.2
Own pH	1313_L/S=1	1	10.66	10.64	10.71	10.29	10.01
Natural pH	EPA 1313	10	10.44	10.29	10.67	10.43	10.21
Porewater	-	0.35	9.9-10.7	10.6-11.1	10.1-10.8	10.0-10.5	-

Note: Porewater L/S estimated from porosity and density of intact cores collected at the elevation of the PAP.

Constituent Results

The concentration of a constituent's percolation column eluates (EPA 1314) indicates how the LSP changes as water passes through the material. Eluate concentrations and mass release are typically plotted as a function of the cumulative L/S (i.e., the cumulative amount of eluent passing through the column relative to the mass of material in the column).

Examples of typical L/S-dependent behavior from EPA 1314 conducted on the VC-1 composite are shown in Figure 6-5, presented as eluate concentration (mg/L) on the left and cumulative mass release (mg/kg-dry) on the right. In mass release graphs, the gray dashed line indicates the mass release proportional to the cumulative L/S expected if concentration is controlled by constant solubility. The following behaviors are shown in Figure 6-5:

- The eluate concentrations for Sb (top) are essentially constant as a function of L/S and, thus, the mass release is proportional to the cumulative L/S and the mass release curve follows the solubility indicator line. This L/S-dependent behavior is consistent with ***solubility-controlled LSP***.
- EPA Method 1314 data indicate that the constituent concentration of Co (middle) decreases rapidly up to an L/S of 2 L/kg-dry, indicating an ***available content-limited LSP***. Eluate concentrations that are a strong function of L/S may decrease to less than quantitation limits within the test cumulative L/S range, indicating depletion of the available content.
- The L/S-dependent leaching of Se (bottom) is a good example of rapid release of a soluble fraction of the available content without depletion. This differs from the example behavior of Co because, after an initial "wash off" of a highly soluble fraction, leaching concentrations remain detectable and relatively constant, suggesting the constituent exists in ***both content-limited (highly soluble mineral phase) and solubility-controlled (low-solubility mineral phase) LSP*** fractions.

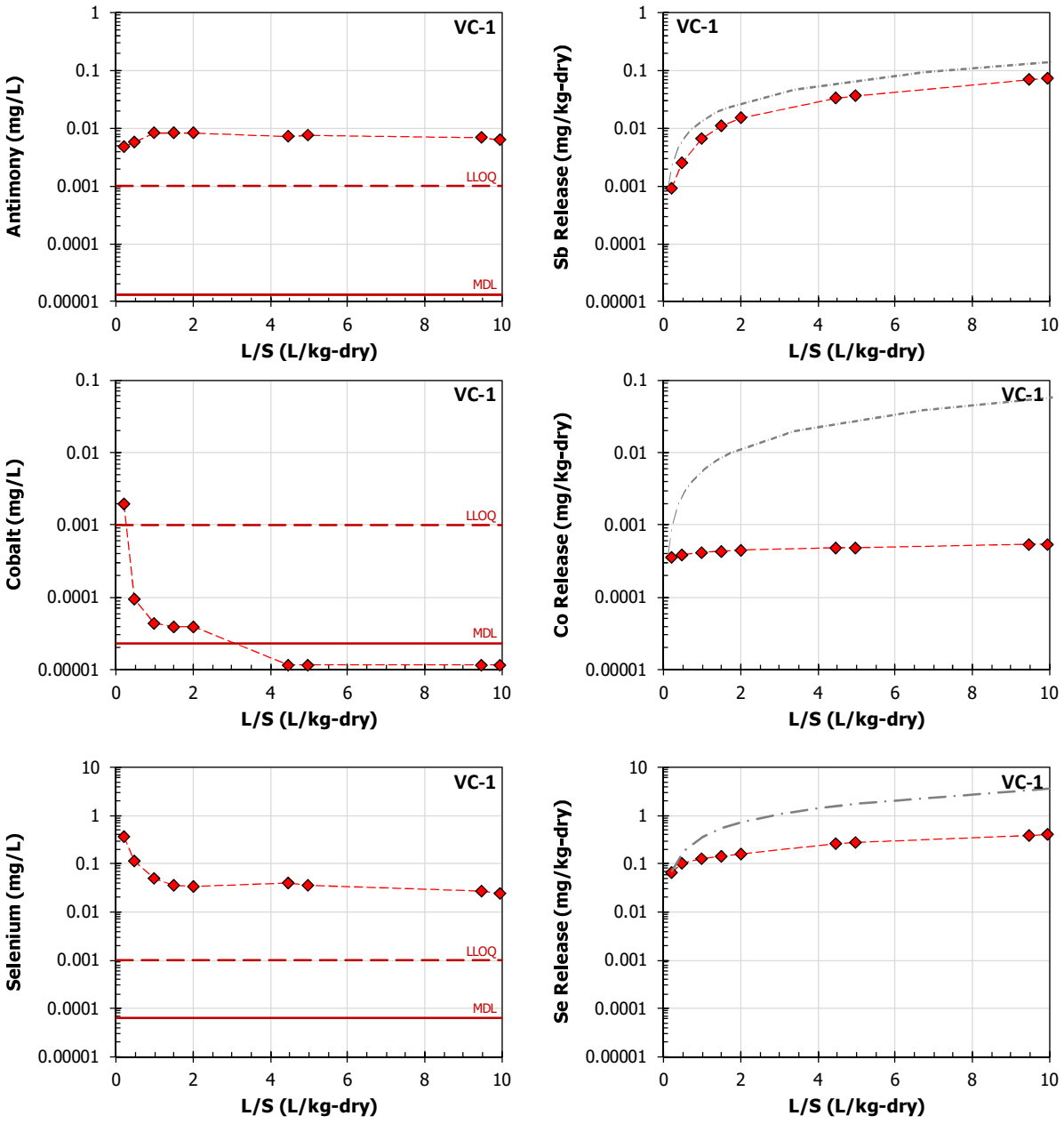

Figure 6-5
Example 1314 test results from VC-1 showing a solubility-controlled constituent (antimony) and depletion of the available content (cobalt) and wash-off of a soluble constituent fraction without depletion (selenium). The gray dot-dashed line indicates prototypical solubility-controlled release fitted to the first EPA 1314 data point.

Determining LSP Behavior

Solubility-Controlled LSP vs. Available Content-Limited LSP

Comparing the impacts of changing pH (e.g., within an EPA 1313 test) with the impact of changing L/S (e.g., within an EPA 1314 test) can be a helpful methodology for distinguishing

the LSP behavior of constituents. Often, the distinction of "solubility-controlled LSP" or "adsorption-controlled" behavior from those with "available content-limited LSP" is a useful classification for grouping large lists of constituents.

The following LSP leaching behaviors were observed from comparison of pH-dependent (EPA 1313) leaching data to L/S-dependent (EPA 1314) leaching data. The focus of the following classifications is limited to the applicable pH domain about the natural pH. Outside of those pH bounds, constituents that were classified as available content-limited may show solubility-controlled LSP or vice versa.

- Solubility-Controlled LSP – When the eluate concentrations are limited by mineral solubility, sorption to mineral phases, and precipitation/dissolution, eluate concentrations are considered ***solubility-controlled.*** Eluate concentrations are a strong function of pH and a weak function of L/S. The LSP for Sb (Figure 6-6) provide a good example of solubility-controlled LSP, as eluate concentrations change by orders-of-magnitude with pH (EPA 1313) but do not change with L/S over the range up to L/S=10 mL/g-dry (EPA 1314). However, the distinction between adsorption and solubility as a controlling mechanism within this classification may be unclear, as both mechanisms are strongly influenced by pH and the patterns for these mechanisms may look similar. Geochemical speciation modeling (not included in this scope) can be useful to discern specific pH-dependent mechanisms.
- Available Content-Limited LSP – When eluate concentrations are limited by the amount of leachable mass in the solid, the characteristic LSP behavior is considered ***available content-limited***. Eluate concentrations are a weak function of pH and a strong function of L/S. Over the applicable pH range ($8 \leq pH \leq 12$), the LSP behavior of Mo (Figure 6-6) presents a good example of available content-limited LSP, as the pH-dependent concentrations (EPA 1313) are relatively stable compared to the significant change in LSP (EPA 1314).
- Wash-Off with Depletion – When a percentage of a constituent is present in porewater or in an easily dissolvable form, there can be a significant initial flush of constituent from a column (i.e., orders-of-magnitude decrease through a $\Sigma L/S$ of 2 L/kg-dry). This behavior is typical for a ***wash-off release mechanism***. The pH-dependent leaching data alone may not indicate this behavior, and the L/S-dependent data become crucial. The endpoint of wash-off can result in depletion of the constituent from the material, evidenced by L/S-dependent concentrations below quantitation limits as presented for Mg in Figure 6-6.

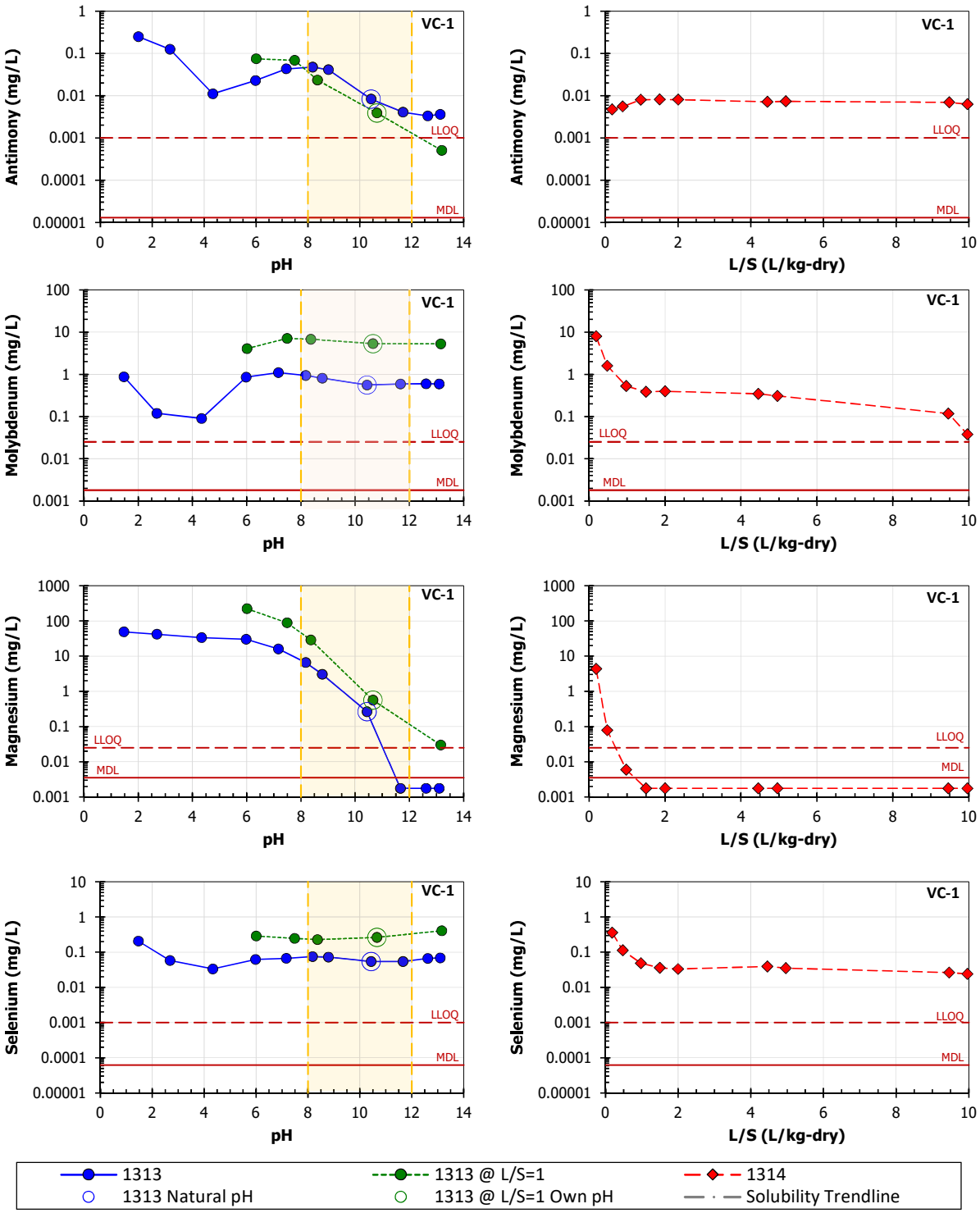

Figure 6-6
Examples of EPA 1313 and EPA 1314 data showing solubility-controlled LSP (antimony); available content-limited LSP (molybdenum); wash-off of soluble fraction leading to depletion (magnesium); and wash-off followed by solubility-controlled LSP (selenium)

- Wash-Off Followed by Solubility Control – In some cases, a secondary fraction of a constituent in the solid material may control eluate concentrations after the initial wash-off. This mechanism results in a relatively constant, detectable eluate concentration following wash-off. In Figure 6-6, Se LSP is a good example of this behavior.
- Non-Detected – For some constituents, eluate concentrations over the applicable pH domain ($8 \leq pH \leq 12$) are below the MDL of the analytical method. Therefore, LSP behavior cannot be determined.

The constituents that are included in each observed behavior are summarized in Table 6-6.

Table 6-6
LSP Behavior over Applicable pH Domain Based on Comparison of EPA 1313 and EPA 1314

LSP Behavior	Constituents
Available Content-Limited	Cl^-, Mo, K, Na
Wash-Off to Depletion	Mg, Mn, NO_3^-
Wash-Off Fraction/Solubility-Controlled	Ba, B, Cd, Cr, Cu, DOC, Li, Ni, Se, Si, Sr, SO_4^{-2}, V
Solubility-Controlled	Al, Sb, As, Ca, DIC, Tl
Non-Detect (values < MDL)	Be, Br^-, Co, F^-, Fe, Pb, PO_4^{-3}, Ag, Zn

The high number of constituents with wash-off followed by a low concentration of solubility-controlled LSP suggest a systematic controlling mechanism in the landfill. Figure 6-7 compares the L/S-dependent data between all composite samples. The data in this figure show that the eluate concentrations for the dry composite are often initially higher than the eluate concentrations of the saturated borehole composites (VC-1 through VC-4). In some cases (e.g., SO_4 in Figure 6-7), the LSP behavior in unsaturated ash is solubility-controlled whereas the LSP behavior in the saturated ash indicates a mobile constituent. These observations suggest that constituents leached from dry-handled ash penetrate into the saturated ash, providing the dissolved or easily solubilized fraction of a constituent in the observed wash-off behavior. Once the overburden constituents are released, the LSP behavior is controlled by the dissolution of more recalcitrant constituents in the saturated ash.

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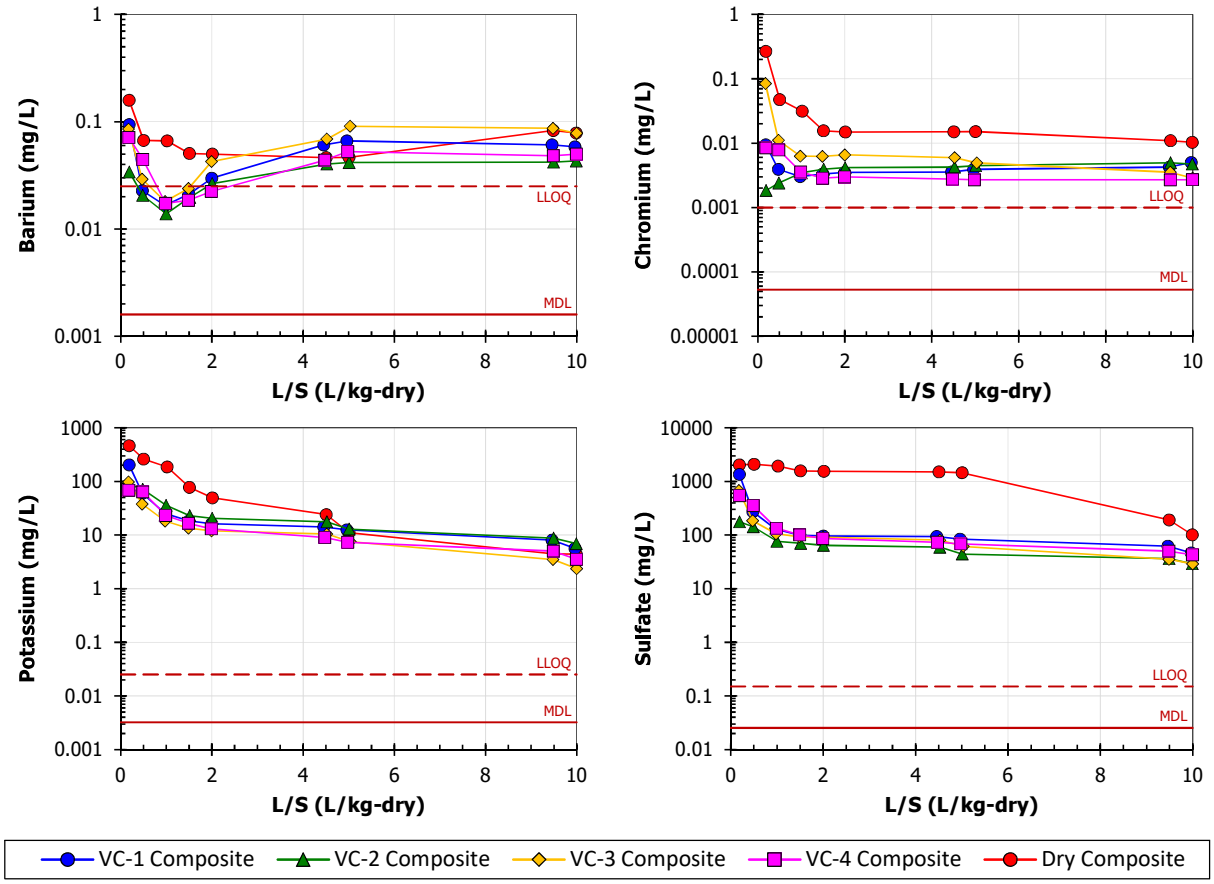

Figure 6-7
Comparison of L/S-dependent (EPA 1314) data showing influence of dry-handled ash (Dry composite) on eluate concentrations of wet-handled ash (VC-1, VC-2, VC-3, and VC-4)

Traditional Extraction Test Results

The L/S and measured pH from the extractions using the traditional leaching tests (TCLP, SPLP, and ASTM) are presented in Table 6-7.

Table 6-7
Liquid-to-Solid Ratio and Measured Extraction pH for Traditional Leaching Tests

Material	TCLP		SPLP		ASTM	
	L/S (mL/g-dry)	pH	L/S (mL/g-dry)	pH	L/S (mL/g-dry)	pH
VC-1	26.8	5.74	26.8	10.47	27.8	10.48
VC-2	28.8	5.39	28.8	10.40	30.0	10.51
VC-3	28.4	6.27	28.4	10.38	29.7	10.60
VC-4	26.9	5.47	26.9	10.32	28.1	10.51
Dry	24.8	5.78	24.8	10.04	24.8	10.20

The amount of extraction fluid for ASTM is determined as the mass of the "as received" test material in grams divided by the test-specific L/S of 20 mL/g. The resultant L/S on a dry basis is greater than 20 because of the water inherent in the pores of the "as received" material. The procedures for TCLP and SPLP require a pressure filtration preconditioning of the test sample to remove excess liquid, which is analyzed separately. The extraction fluid is based on the mass of the pressure-filtered solid material in grams divided by the same L/S of 20 mL/g. Therefore, the calculated L/S for TCLP and SPLP is lower than the L/S for the ASTM test that includes extra water. The measured pH for ASTM, which uses DIW as an extraction fluid, is consistent with the natural pH (1313) and own pH (1313_L/S=1) of the composites at VC-1, VC-2, VC-3, VC-4, and Dry reported in Table 6-2. For SPLP, the measured pH is slightly lower than the ASTM pH, consistent with the small amount of acid used in the extraction fluid. The stability of the measured pH for TCLP extracts across different composites reflects the buffering provided by the organic acetic acid.

The eluate constituent concentrations for TCLP, SPLP, and ASTM tests are presented in Table 6-8, Table 6-9, and Table 6-10, respectively. Since pH is an important factor for solubility-controlled LSP, these tables also include the final eluate pH. Recording of eluate pH allows for comparison of the results of these traditional tests to the pH- and L/S-dependent LEAF test results. In general, SPLP and ASTM concentrations were comparable to each other but were lower than TCLP concentrations, sometimes by orders-of-magnitude. In many cases, the increases in TCLP concentrations were caused by the lower pH of TCLP eluates. Exceptions for this site (which may not be generalizable) include As, Mo, and SO_4^{-2}, where similar concentrations were measure in all three procedures, and PO_4^{-2}, Se, and V, where SPLP and ASTM eluates had higher concentration than TCLP. All of these observations are consistent with the pH-dependent LSP curves discussed above.

Table 6-8
TCLP (EPA Method 1311) Eluate Concentrations

Analyte	Symbol	VC-1 (mg/L)	VC-2 (mg/L)	VC-3 (mg/L)	VC-4 (mg/L)	Dry (mg/L)
	pH	5.74	5.39	6.28	5.47	5.78
Aluminum	Al	1.7	1.8	0.41	2.1	1.1
Antimony	Sb	0.049	0.053	0.073	0.046	0.078
Arsenic	As	0.0056	0.012	0.0097	0.012	0.0064
Barium	Ba	0.55	0.085	0.40	0.84	0.14
Beryllium	Be	0.001 J	0.0019	0.0001 J	0.0023	0.0015
Boron	B	15	13	16	15	19
Bromide	Br^-	ND	ND	ND	ND	ND
Cadmium	Cd	0.019	0.013	0.010	0.018	0.032
Calcium	Ca	650	500	750	550	860
Carbon, Inorganic	DIC	4.5	5.5	13	8.1	2.1
Chloride	Cl^-	2.7	3.7	2.3	7.5	7.6
Chromium	Cr	0.037	0.081	0.13	0.048	0.0071
Cobalt	Co	0.017	0.014	0.010	0.028	0.029
Copper	Cu	0.018	0.021	0.013	0.022	0.017
Fluoride	F^-	ND	ND	ND	ND	ND
Iron	Fe	0.19	0.14	0.017 J	0.19	0.060
Lead	Pb	0.0002 J	0.0003 J	0.0001 J	0.0002 J	0.0009 J
Lithium	Li	0.009 J	0.011 J	0.012 J	0.008 J	0.014 J
Magnesium	Mg	4.8	5.7	8.5	6.2	13
Manganese	Mn	2.6	2.4	1.9	2.1	0.68
Molybdenum	Mo	0.32	0.45	0.35	0.38	0.82
Nickel	Ni	0.085	0.071	0.057	0.11	0.13
Nitrate	NO_3^-	ND	ND	ND	ND	ND
Phosphate	PO_4^{-3}	ND	ND	ND	ND	ND
Phosphorus	P	ND	ND	ND	ND	ND
Potassium	K	22	24	17	17	35
Selenium	Se	0.054	0.059	0.077	0.071	0.093
Silicon	Si	31	42	21	36	30
Silver	Ag	ND	ND	ND	ND	ND
Sodium	Na	540	530	540	530	530
Strontium	Sr	0.75	0.58	0.66	1.0	1.6
Sulfate	SO_4^{-2}	380	280	480	290	970
Sulfur	S	130	96	160	98	350
Thallium	Tl	0.028	0.031	0.013	0.041	0.034
Vanadium	V	0.28	0.26	0.37	0.26	0.26
Zinc	Zn	0.31	0.27	0.11	0.36	0.52

Notes: Data for VC-3 shown as mean of duplicate tests (TCLP-A, TCLP-B).
J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.
ND the compound was not detected at a concentration above the MDL.
Organic carbon is not reported, as the results are dominated by the organic carbon in the TCLP extraction fluid.

Table 6-9
SPLP (EPA Method 1312) Eluate Concentrations

Analyte	Symbol	VC-1 (mg/L)	VC-2 (mg/L)	VC-3 (mg/L)	VC-4 (mg/L)	Dry (mg/L)
	pH	10.47	10.40	10.38	10.32	10.04
Aluminum	Al	6.8	6.4	4.9	6.7	3.5
Antimony	Sb	0.010	0.014	0.011	0.0093	0.0074
Arsenic	As	0.0066	0.0091	0.0091	0.016	0.0080
Barium	Ba	0.11	0.070	0.12	0.098	0.085
Beryllium	Be	ND	ND	ND	ND	ND
Boron	B	2.5	2.0	1.9	2.1	1.6
Bromide	Br^-	ND	ND	ND	ND	ND
Cadmium	Cd	0.0004 J	0.0015	0.0001 J	0.0006 J	0.0004 J
Calcium	Ca	47	40	47	47	150
Carbon, Inorganic	DIC	3.6	4.7	3.9	3.9	6.0
Carbon, Organic	DOC	2.9	3.0	2.7	2.6	2.5
Chloride	Cl^-	9.0	5.5	5.9	9.8	9.5
Chromium	Cr	0.0026	0.0033	0.0069	0.0022	0.0082
Cobalt	Co	0.0001 J	0.0002 J	0.0001 J	0.0001 J	0.0003 J
Copper	Cu	0.0017	0.0011	0.0018	0.0013	0.0026
Fluoride	F^-	ND	ND	ND	ND	ND
Iron	Fe	0.001 J	0.0077 J	0.0077 J	0.014 J	ND
Lead	Pb	ND	ND	ND	ND	ND
Lithium	Li	0.012 J	0.009 J	0.016 J	0.008 J	0.011 J
Magnesium	Mg	0.0022 J	0.016 J	0.030	0.043	0.16
Manganese	Mn	0.0014	0.0015	0.0014	0.0013	0.0014
Molybdenum	Mo	0.18	0.51	0.10	0.25	0.14
Nickel	Ni	0.0019	0.0017	0.0012	0.0012	0.0054
Nitrate	NO_3^-	250	250	250	220	150
Phosphate	PO_4^{-3}	ND	ND	ND	ND	ND
Phosphorus	P	ND	ND	ND	ND	ND
Potassium	K	7.5	73	5.1	4.9	13
Selenium	Se	0.052	0.041	0.028	0.040	0.028
Silicon	Si	2.0	2.0	3.0	1.8	1.7
Silver	Ag	ND	ND	ND	ND	ND
Sodium	Na	8.6	4.8	5.2	8.2	7.3
Strontium	Sr	0.10	0.059	0.08	0.12	0.42
Sulfate	SO_4^{-2}	76	52	62	63	360
Sulfur	S	27	19	22	22	130
Thallium	Tl	0.0013	0.0015	0.0008 J	0.0017	0.0010
Vanadium	V	0.28	0.24	0.34	0.27	0.24
Zinc	Zn	0.0025	0.0022	0.0013	0.0016	0.0015

Notes: Data for VC-4 shown as mean of duplicate tests (SPLP-A, SPLP-B).
J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.
ND the compound was not detected at a concentration above the MDL.

Table 6-10
ASTM (ASTM D3987) Eluate Concentrations

Analyte	Symbol	VC-1 (mg/L)	VC-2 (mg/L)	VC-3 (mg/L)	VC-4 (mg/L)	Dry (mg/L)
	pH	10.48	10.51	10.60	10.51	10.20
Aluminum	Al	6.9	6.6	4.9	7.0	3.2
Antimony	Sb	0.010	0.015	0.012	0.0098	0.0067
Arsenic	As	0.0058	0.0088	0.0085	0.0076	0.0089
Barium	Ba	0.11	0.075	0.12	0.10	0.086
Beryllium	Be	ND	ND	ND	ND	ND
Boron	B	3.9	2.5	1.8	1.9	1.6
Bromide	Br^-	ND	ND	ND	ND	ND
Cadmium	Cd	0.0005 J	0.0012	0.0001 J	0.0006 J	0.0004 J
Calcium	Ca	47	41	46	49	140
Carbon, Inorganic	DIC	29	2.8	4.9	5.5	5.2
Carbon, Organic	DOC	2.2	2.3	2.4	2.2	2.0
Chloride	Cl^-	10	6.8	5.1	12	9.9
Chromium	Cr	0.0084	0.0070	0.011	0.0029	0.0059
Cobalt	Co	0.0003 J	0.0003 J	0.0002 J	0.0002 J	0.0003 J
Copper	Cu	0.001	0.0013	0.0013	0.0025	0.0024
Fluoride	F^-	ND	ND	ND	ND	ND
Iron	Fe	0.012 J	0.0054 J	0.0027 J	0.0053 J	ND
Lead	Pb	ND	0.0004 J	ND	ND	ND
Lithium	Li	0.013	0.0079 J	0.013 J	0.014 J	0.0081 J
Magnesium	Mg	0.039	0.013 J	0.024 J	0.038	0.16
Manganese	Mn	0.0031	0.0053	0.0026	0.0022	0.0020
Molybdenum	Mo	0.18	0.514	0.095	0.25	0.14
Nickel	Ni	0.0018	0.0015	0.0016	0.0018	0.0035
Nitrate	NO_3^-	ND	ND	ND	ND	ND
Phosphate	PO_4^{-3}	ND	ND	ND	ND	ND
Phosphorus	P	ND	ND	ND	ND	ND
Potassium	K	7.5	7.3	5.1	5.1	13
Selenium	Se	0.047	0.038	0.026	0.039	0.037
Silicon	Si	2.1	2.1	3.1	1.9	1.9
Silver	Ag	ND	ND	ND	ND	ND
Sodium	Na	8.0	5.9	3.8	9.1	7.3
Strontium	Sr	0.095	0.06	0.07	0.12	0.41
Sulfate	SO_4^{-2}	77	55	60	67	390
Sulfur	S	27	19	22	24	130
Thallium	Tl	0.0018	0.0022	0.0011	0.0028	0.0013
Vanadium	V	0.26	0.21	0.32	0.25	0.25
Zinc	Zn	0.0071	0.0025	0.0017	0.0028	0.0024

Notes: Data for VC-2 shown as mean of duplicate tests (ASTM-A, ASTM-B).
J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.
ND the compound was not detected at a concentration above the MDL.

Comparison of Traditional and LEAF Test Results

When the pH and L/S of leaching tests are recorded, the test results from different leaching tests can be compared based on eluate pH or L/S. An example comparison is shown in Figure 6-8 for Mo leaching from the VC-2 composite. In Figure 6-8, the eluate concentrations (mg/L) are shown in the left column, and mass release values (mg/kg-dry) are shown in the right column. The upper row presents data as a function of pH, with L/S-dependence shown in the bottom row.

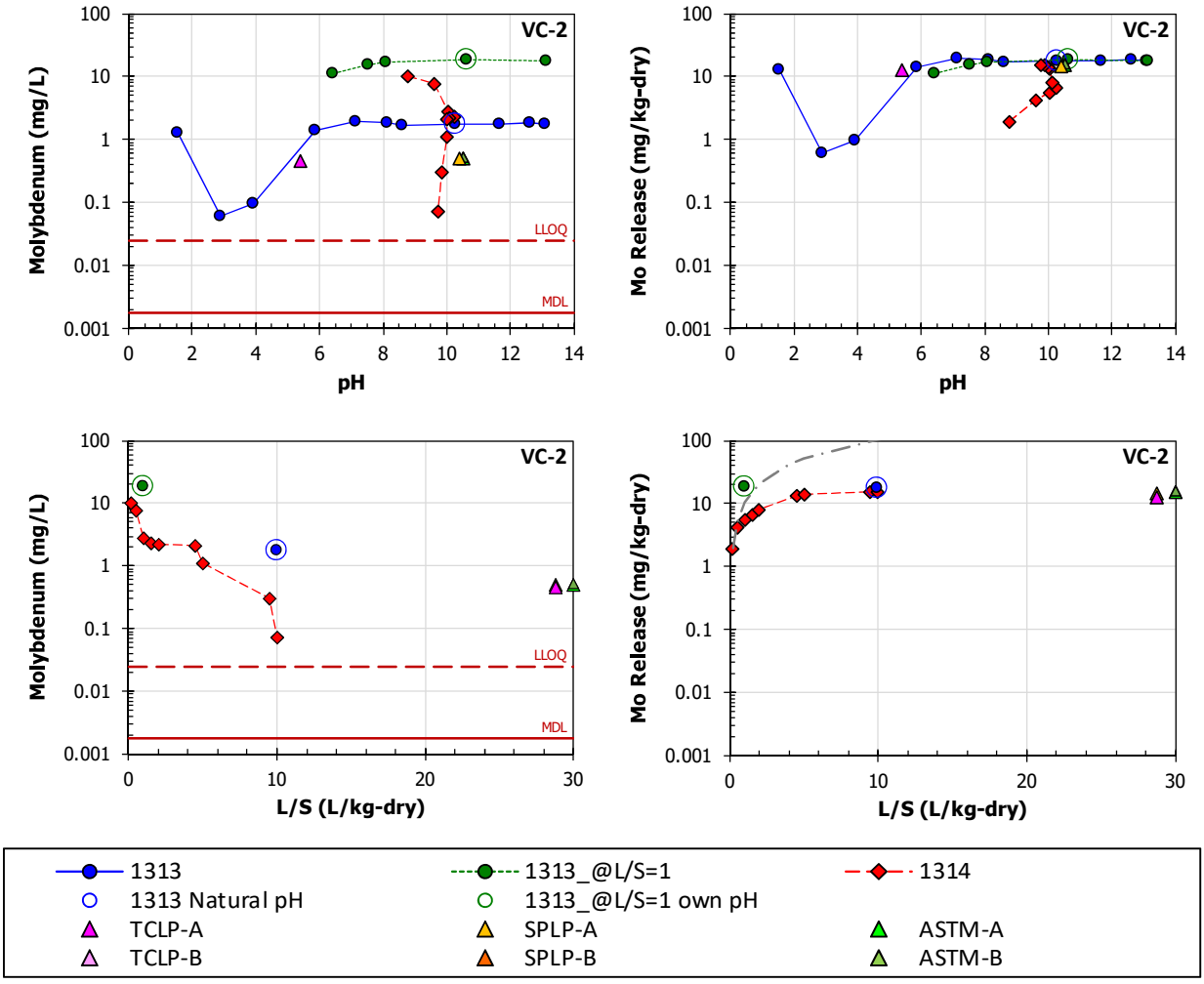

Figure 6-8
Comparison of molybdenum concentration (left) and mass release (right) using traditional (TCLP, SPLP, and ASTM) and LEAF tests (1313, 1313_L/S=1, and 1314); replicates indicated by "-A" and "-B"

For a constituent with available content-limited LSP, for example Mo, the concentrations obtained from the traditional leaching test data are slightly lower than those in EPA Method 1313 and consistent with the higher L/S for the traditional tests. The data for SPLP and ASTM are very close to the leaching response at natural pH measured in EPA Method 1313 due to the little to no acidity added. Conversely, the buffered solution of TCLP leads to a significant lower eluate pH. However, on a mass release basis (Figure 6-8 upper right) all of the results are consistent.

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When data for a constituent with available content-limited LSP are compared as a function of L/S, the eluate concentrations of any single extraction at a fixed L/S are unlikely to match the column elution curve. The concentrations in the column test reflect a “progressive” leaching case where material is removed from the column, rather than a batch leaching case represented by single extractions. However, mass release as a function of L/S should be consistent between all tests because the basis of the data is the solid mass. Of course, the L/S of traditional tests are much higher than the L/S of either the LEAF tests or field conditions, so the data are not readily compared or applicable to leaching scenarios with low L/S values.

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7
GROUNDWATER, POREWATER, AND SUBSURFACE GAS MONITORING

Measured field parameters for groundwater and porewater sampling as well as graphical presentation of groundwater and porewater concentrations from unfiltered samples are provided in Appendix D-1. These data represented the sampling period from June 2019 through January 2020. Monthly analysis of groundwater wells and PAPs focused on 17 constituents from 40 CFR 257 (As, B, Ba, Be, Ca, Cd, Cl^-, Co, Cr, F^-, Li, Mo, Pb, Sb, Se, SO_4^{-2}, and Tl) and 13 additional constituents (Ag, Br^-, Cu, DIC, DOC, Fe, K, Na, Ni, PO_4^{-3}, Sr, V, and Zn).

Groundwater and Porewater Parameters

Plots of field measurements are shown in Figure 7-1 and Figure 7-2. Within each bar chart, data for the porewater sampled at the four boreholes are presented in solid colors (i.e., blue for VC-1, green for VC-2, gold for VC-3, and purple for VC-4). The downgradient groundwater is presented as stripe-filled bars that are color-coded to their nearest PAP (i.e., the groundwater monitoring well at 209 is associated with VC-2 while the groundwater monitoring well at 931 is more directly opposite VC-4). Due to physical activity at the landfill during sampling (ongoing deposits and grading), not all PAPs were sampled each month.

The data in Figure 7-1 show that the water table elevation, pH, and electrical conductivity remain relatively constant over time at each sample point. The mean water table in the PAPs (386.8 ft AMSL) is approximately 27 feet higher in elevation than the mean water table of the downgradient wells (360.2 ft AMSL). The pH of the porewater in the PAPs is more alkaline ($pH_{ave\text{-}VCs}$=10.5±0.3) than in the downgradient monitoring wells (pH_{ave}=6.7±0.2).

Figure 7-2 presents measured values of water temperature, ORP, and DO, showing seasonal trends for all parameters. The ORP values of the PAP porewater appear to have significant variability, which may be indicative of the nature of the ORP measurement. The mean dissolved oxygen for the two downgradient monitoring wells (DO_{ave}=0.9±0.3 mg/L) is somewhat lower than in the PAPs ($DO_{ave\text{-}VCs}$=1.5±0.3 mg/L). The dissolved oxygen data for all of the porewater and groundwater measurements are notably less than the 9.1 mg/L for saturated surface water at 20 ºC (USGS, 1998) and, therefore, the porewater is considered to be suboxic.

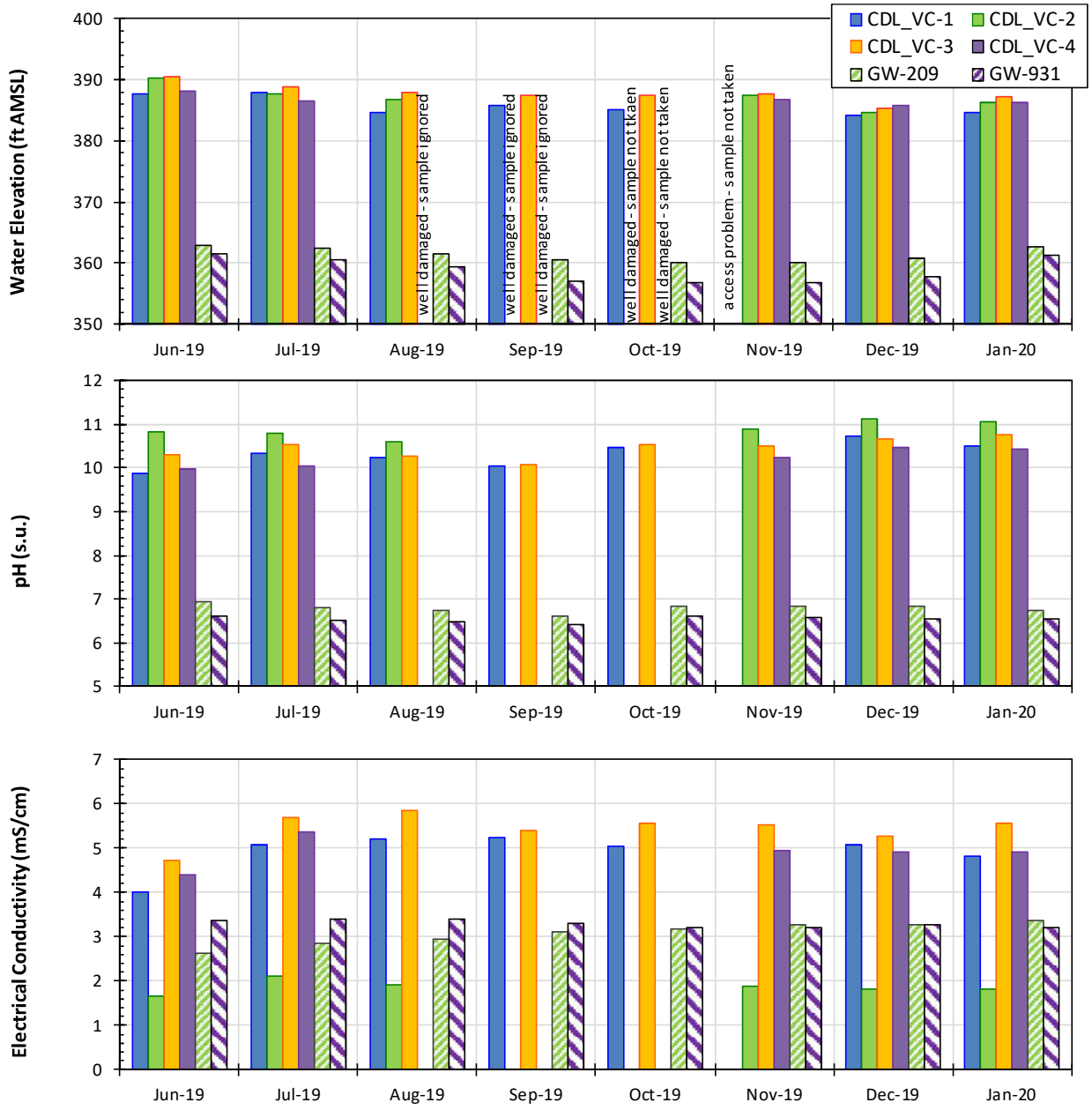

Figure 7-1
Groundwater and porewater field parameters from monthly sampling: water table elevation, pH, and EC

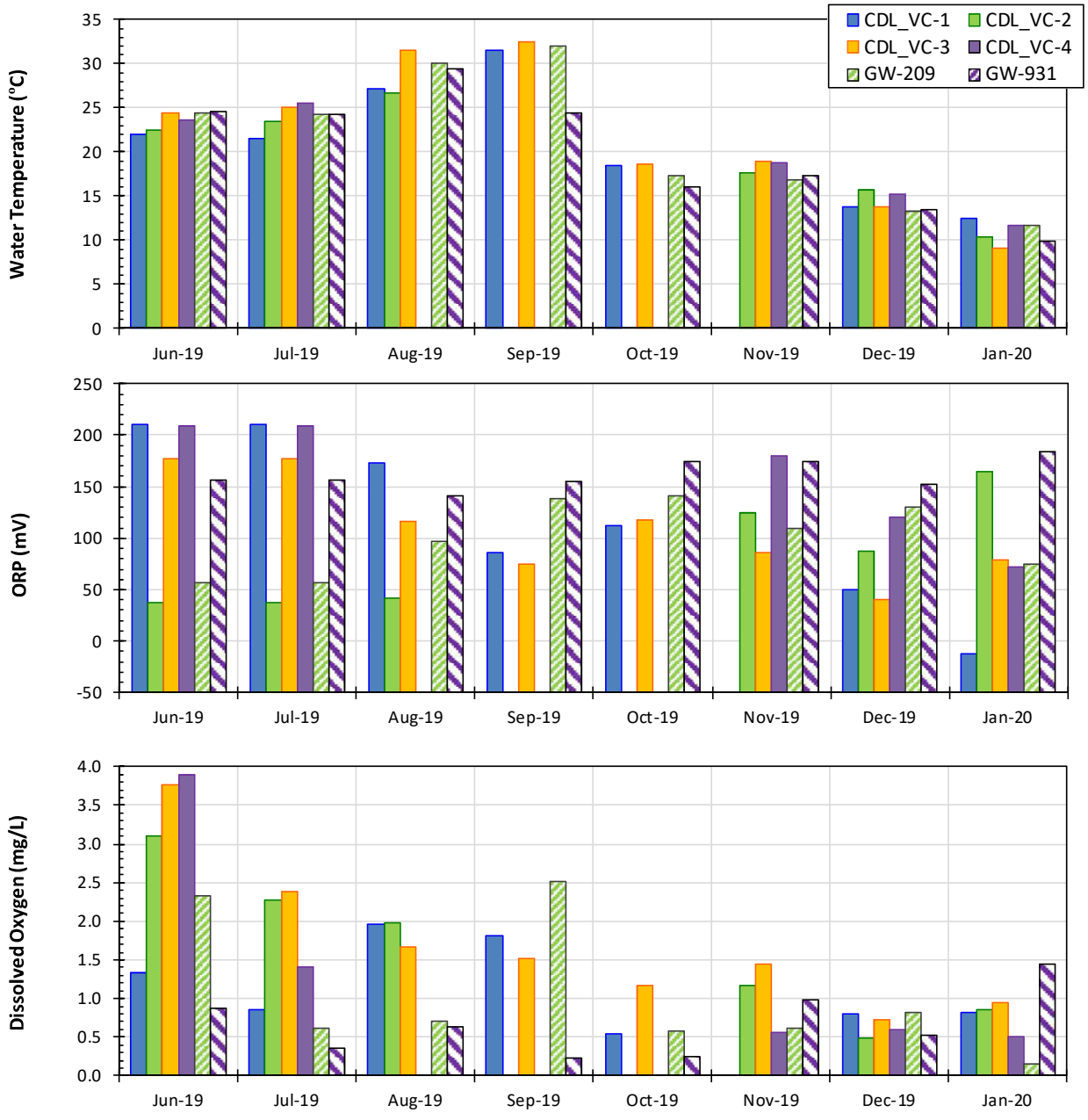

Figure 7-2
Groundwater and porewater field parameters from monthly sampling: water temperature, ORP, and DO

Concentrations in Groundwater and Porewater

Monthly analysis of groundwater wells and PAPs focused on 30 constituents, including 17 from 40 CFR 257 (As, B, Ba, Be, Ca, Cd, Cl^-, Co, Cr, F^-, Li, Mo, Pb, Sb, Se, SO_4^{-2}, and Tl). Thirteen additional constituents that were analyzed were Ag, Br^-, Cu, DIC, DOC, Fe, K, Na, Ni, PO_4^{-3}, Sr, V, and Zn. Examples of the results for selected constituents are presented in Figure 7-3 and Figure 7-4, while the graphical results for all 30 constituents are presented in Appendix D-1.

Given the geography and groundwater flow patterns at this site, there was not an upgradient monitoring well that could be used in a comparison to determine whether or not there were any impacts to groundwater from this CCP unit; therefore this analysis will not attempt to determine whether or not the groundwater quality represents releases from the coal ash. The discussion that follows allows for either possibility as the relationship between porewater and downgradient groundwater is explored.

An analysis of variance (ANOVA) was initially attempted to compare the groundwater and porewater datasets, but in most cases low p-values indicated that groundwater and porewater concentrations were not from the same statistical population. Instead, downgradient concentrations were directly compared to porewater concentrations using means and standard deviations. Table 7-1 summarizes the standard deviation analysis as follows:

- "GW >> PW" and "GW << PW" indicate that the mean groundwater concentration (GW) for a groundwater monitoring well was greater than or less than the mean porewater concentration (PW) at the associated PAP by a difference of three standard deviations or more;
- "GW > PW" and "GW < PW" indicate that the mean groundwater concentration at a groundwater monitoring well was greater than or less than the mean porewater concentration at the associated PAP by a difference of greater than one standard deviation, but less than three standard deviations; and,
- "GW ≈ PW" indicates that the mean groundwater concentration from a groundwater monitoring well was within one standard deviation of the mean porewater concentration of the associated PAP.

In Table 7-1, Ag, Be, Cr, F^-, and Pb are not included because the concentrations of these constituents were below the analytical MDL in both porewater and groundwater. The summary in the table assumes the potential for a connection between specific PAPs and specific groundwater monitoring wells (e.g., VC-2 and Well 209), based solely on geography and a general understanding of groundwater flow direction.

Table 7-1
Relationships between Groundwater and Porewater Based on PAP-Downgradient Groundwater Pairs (Well 209 and PAP at VC-2; Well 931 and PAP at VC-4)

	Monitoring Well 209 (GW) to PAP at VC-2 (PW)	Monitoring Well 931 (GW) to PAP at VC-4 (PW)
GW >> PW	B, Ca, Cl^-, Co, Fe, SO_4^{-2}	Co, Fe
GW > PW	-	Ni, Zn
GW ≈ PW	Ba	Ba, Cl^-,
GW < PW	As, Cu*, V	-
GW << PW	Cd*, Li, Mo, Ni, Sb*, Se, Tl*, Zn*	As, B, Ca, Cd*, Cu, Li, Mo, Sb*, Se, SO_4^{-2}, Tl*, V

Notes * Indicates that groundwater concentrations were all or mostly below the MDL

The following are observations from this summary.

- Co and Fe have higher concentrations in groundwater than in porewater for all comparisons, while Ba and Cl^- concentrations were similar or much higher in groundwater depending on the comparison. Higher groundwater concentrations suggest that porewater from the coal ash is not the primary source of the groundwater concentration and a limited relationship exists between recent porewater concentration and the downgradient groundwater concentrations at this site. Similar concentrations could be indicative of a release, especially if the constituent is environmentally conservative (e.g., B, Cl^-, and SO_4^{-2}); however, it is unlikely that there would be no dilution when leachate would be released to groundwater. The history and variety of residual storage at this site (e.g., underlying large area of sluiced ash, bottom ash collection ponds, gypsum storage stacks) confounds the ability to use boron as an indicator species for release from this landfill.
- Nine constituents (As, Cd, Cu, Li, Mo, Sb, Se, Tl, and V) have higher concentration in porewater than in both downgradient monitoring wells for all comparisons. Higher concentrations in coal ash porewater suggest that porewater has the potential to affect downgradient groundwater quality; however, porewater concentrations for several of these constituents (Cd, Li, Mo, Sb, Tl, and V) are 2 to 3 orders-of-magnitude higher in the coal ash deposit than in the downgradient wells, suggesting limited impact from porewater on downgradient monitoring well concentrations at this site.

Overall, these observations indicate that at this site, high porewater concentrations cannot be assumed to indicate impacts on downgradient groundwater concentrations.

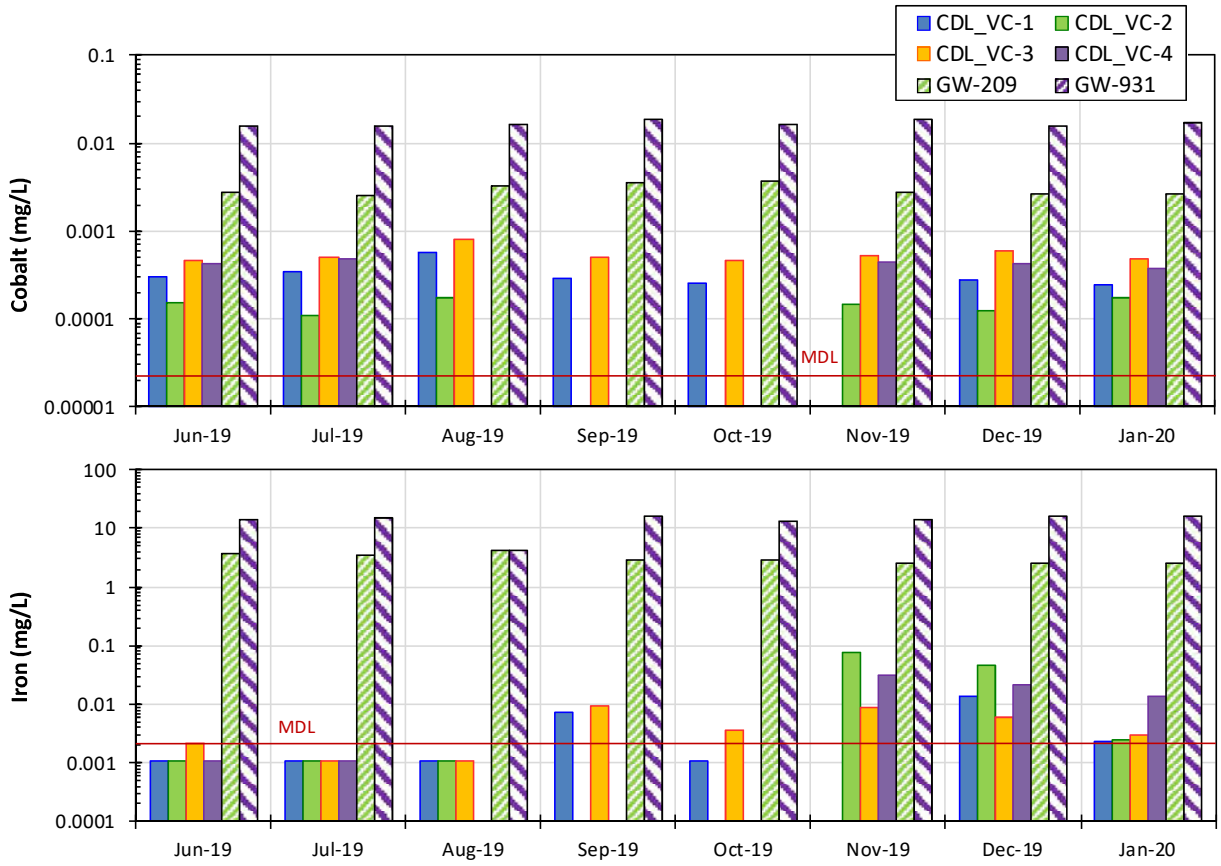

Figure 7-3
Groundwater and porewater monitoring from monthly sampling showing lower concentrations in coal ash porewater (VC-1, VC-2, VC-3, and VC-4) than in downgradient groundwater wells (209 and 931); concentrations plotted on a logarithmic axis

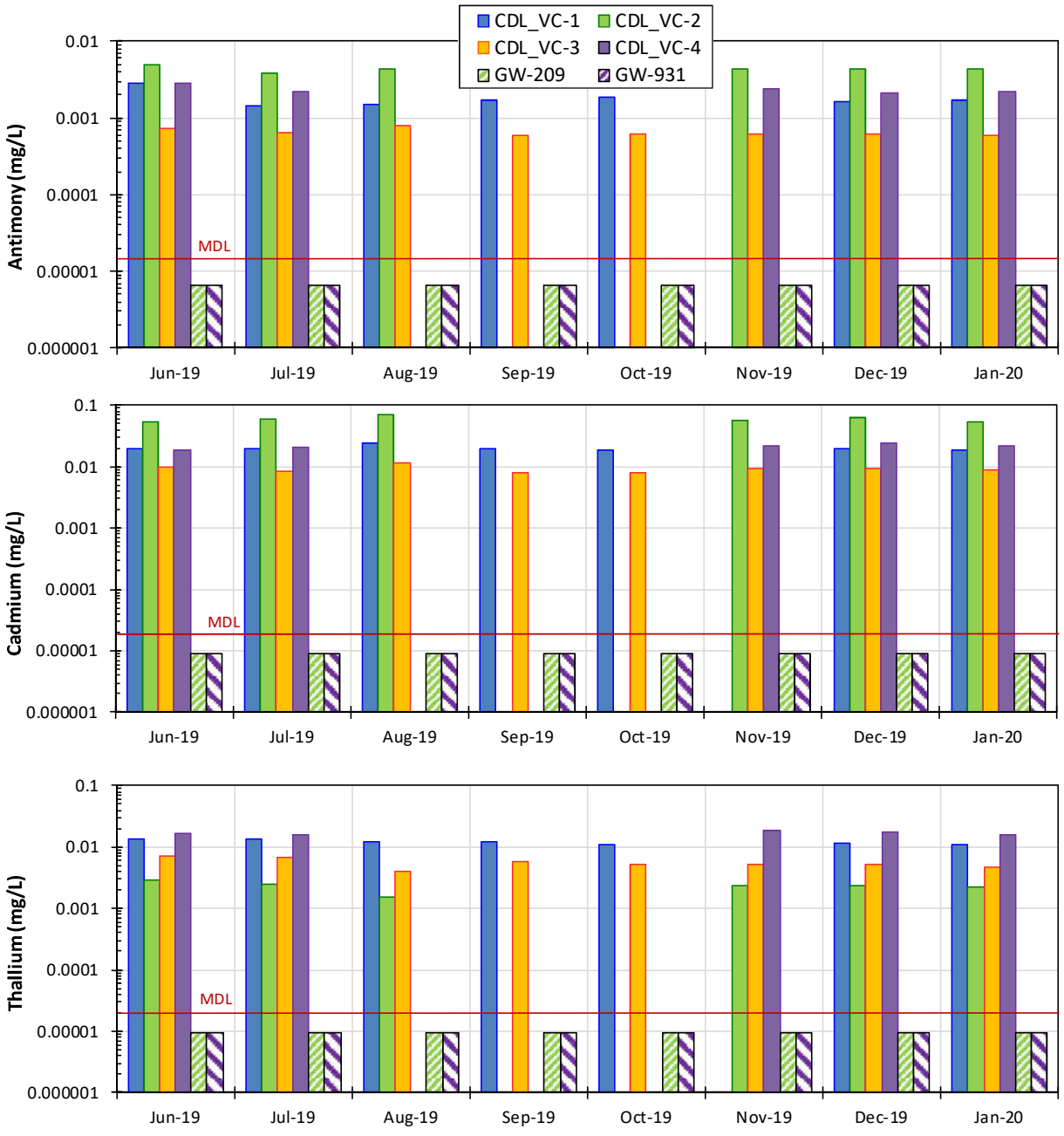

Figure 7-4
Groundwater and porewater monitoring from monthly sampling showing significantly higher concentrations in coal ash porewater (VC-1, VC-2, VB-3, and VC-4) than in groundwater from the downgradient wells (209 and 931); concentrations plotted on a logarithmic axis

Temporal and Spatial Variability in Porewater Parameters

Data reflecting the temporal variability of porewater parameters from monthly monitoring are presented as time-series plots as a function of date. The shapes of the time series distinguish porewater properties that are relatively constant over the sampling period from porewater properties that vary with time. Time-series plots are presented in Appendix D-2. Examples of time series plots for field parameters (Figure 7-5) indicate that variability over the sampling period may be primarily attributed to seasonal changes (e.g., temperature, redox conditions as seen by pH+pE). The trends in porewater constituent concentrations (Figure 7-6) show that many parameters remained relatively constant throughout the monitoring period. The trend lines for VC-2 (green) and VC-4 (pink) were interrupted due to activity on the landfill that caused damage to the PAP. The damage was repaired and the PAPs redeveloped prior to continuation of data collection.

The spatial variability between PAP concentrations was evaluated based on the differences between mean constituent concentrations. Concentrations of a constituent in a PAP were deemed systematically different if the mean concentration in that PAP was more than a factor of five higher or lower than the mean of other PAPs. Based on this analysis, the following observations were made:

- The mean concentrations of Ag, Be, Cr, F^-, and Pb were below the MDL for the analysis and, therefore, no spatial variability could be determined.
- The mean concentrations of Cl^-, Cu, Fe, SO_4^{2-}, Tl, and Zn in VC-2 and Cd and Sb in VC-3 were lower than the mean concentrations in the other PAPs; however, some of this variability may be explained by the damage to wells VC-2 and VC-4.
- The mean concentrations of Cl^- in VC-4, Li in VC-1, and Mo in VC-2 (Figure 7-6) were higher than the mean concentrations in the other PAPs.

Of the 23 constituents evaluated, only Cu and Zn had mean concentrations between PAPs that varied by more than an order-of-magnitude; however, no pattern in spatial variability was observed.

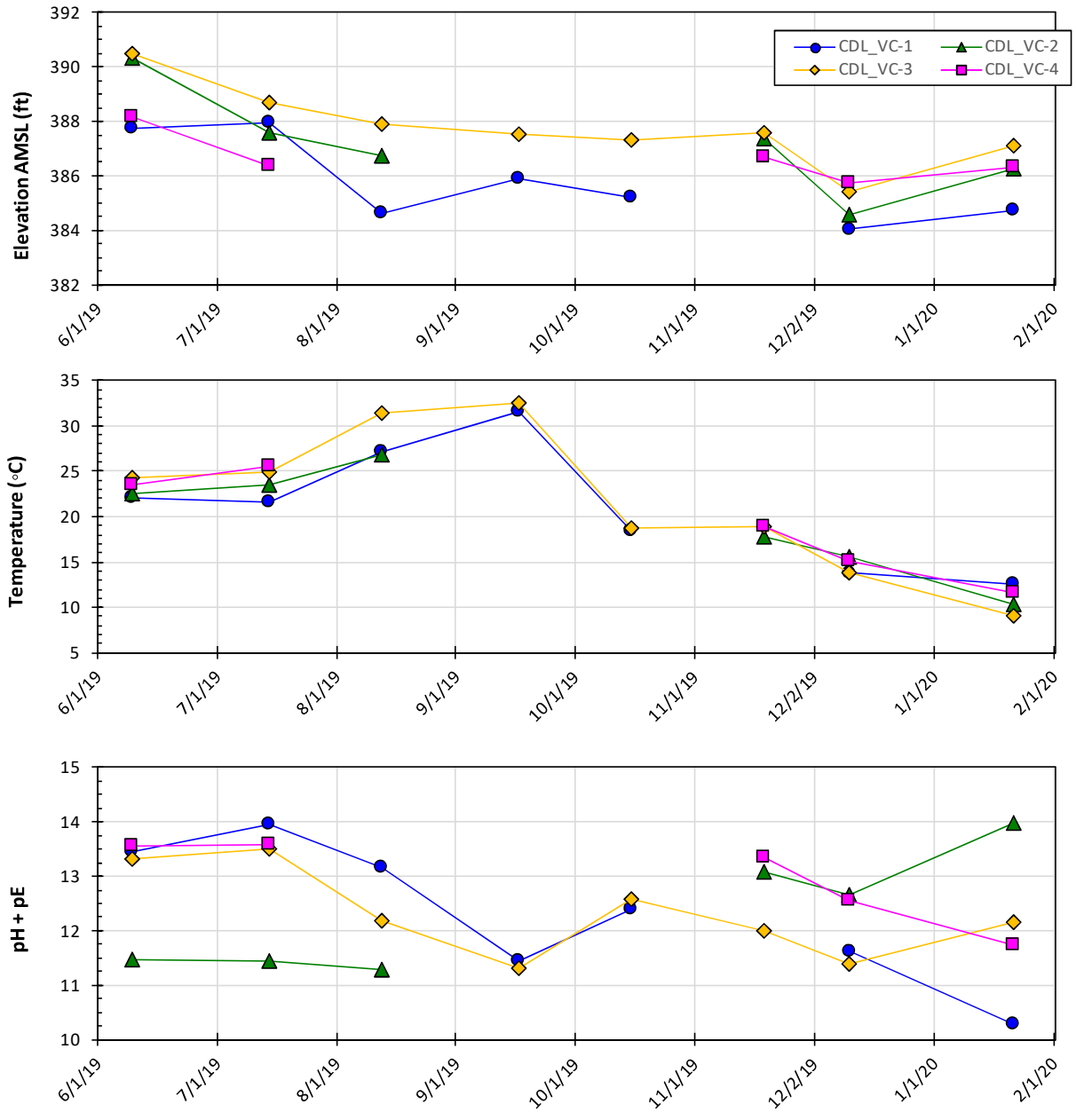

Figure 7-5
Example temporal porewater data showing seasonal or other variability: elevation, temperature, and pH+pE

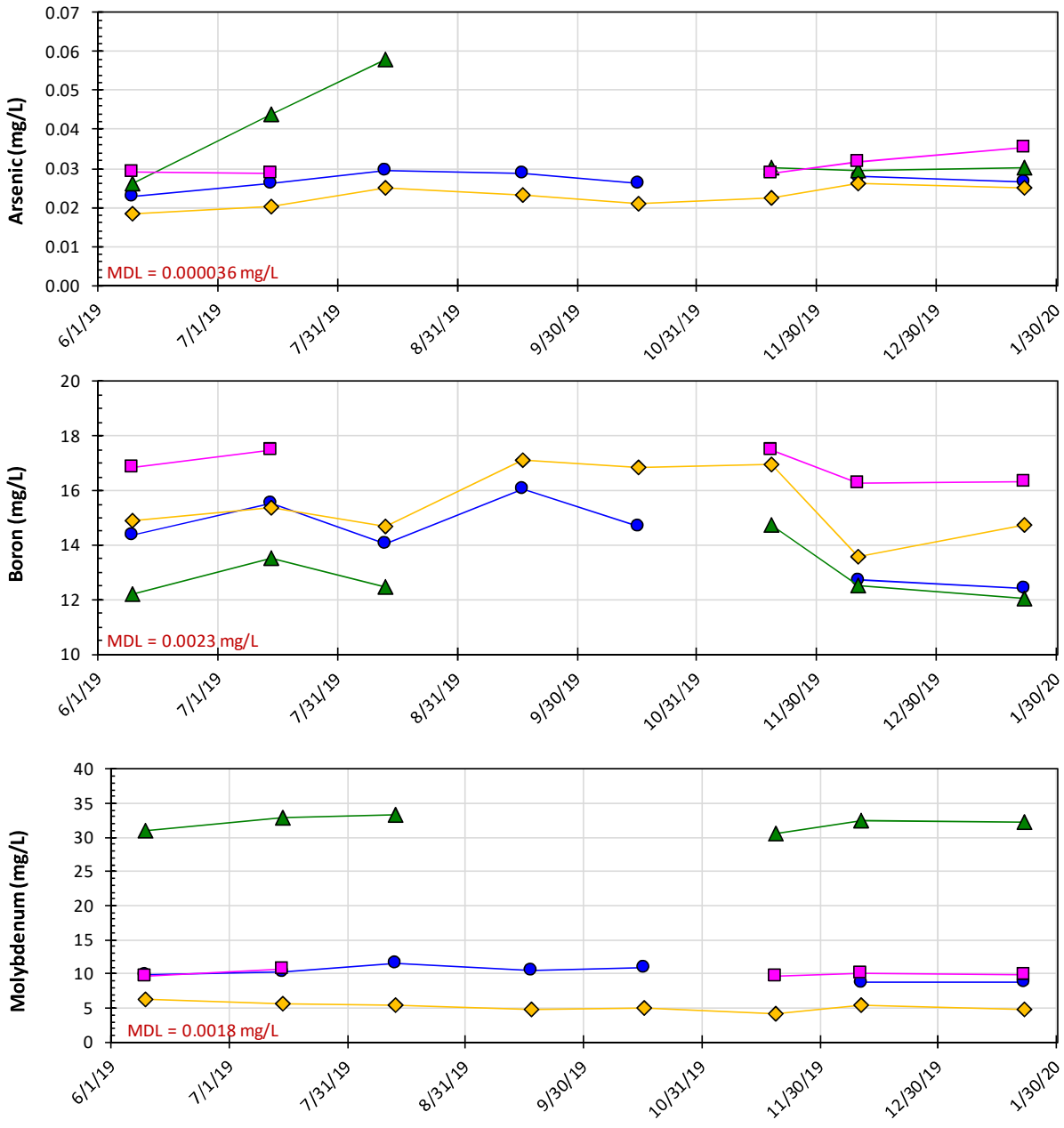

Figure 7-6
Example temporal porewater data showing relatively constant conditions: arsenic, boron, and molybdenum

Subsurface Gas Monitoring

Concentrations of O_2, CO_2, CH_4, NH_4, and H_2S were measured in the four boreholes using gas access points (GAPs). GAPs were installed at VC-1 and VC-3 at three depths (5, 15, and 50 feet BGS), while VC-2 and VC-4 had GAPs installed at 5 and 15 feet BGS. Full tabular data for subsurface monitoring are presented along with graphical comparisons in Appendix D-3.

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The results of monthly gas monitoring varied to some degree by borehole:

- VC-1 consistently had higher subsurface O2 concentrations at a depth of 5 feet BGS than at 15 or 50 feet BGS (Figure 7-7). The data at this borehole suggest that oxygen is quickly depleted in the subsurface. At VC-3 and VC-4, there appears to be period of instability as initial O2 concentrations were significantly higher than after the first two months.
- CO2 levels were generally low and variable as a function of depth and time (Figure 7-8).
- CH4 concentration in subsurface gas was detected in VC-1 only at very low concentrations at depth (Figure 7-9). In this scenario, methane detection is likely indicative of localized decay of organic matter rather than a strongly reduced subsurface environment as noted in the closed impoundment discussed in EPRI (2020).
- Subsurface NH4 and H2S concentrations were negligible, detected very sporadically and at very low concentrations (Appendix D-3).

These data are indicative of a heterogeneous redox environment. At depth (> 5 feet BGS), O_2 concentrations, in particular, confirm the suboxic environment indicated by DO measurements in the porewater.

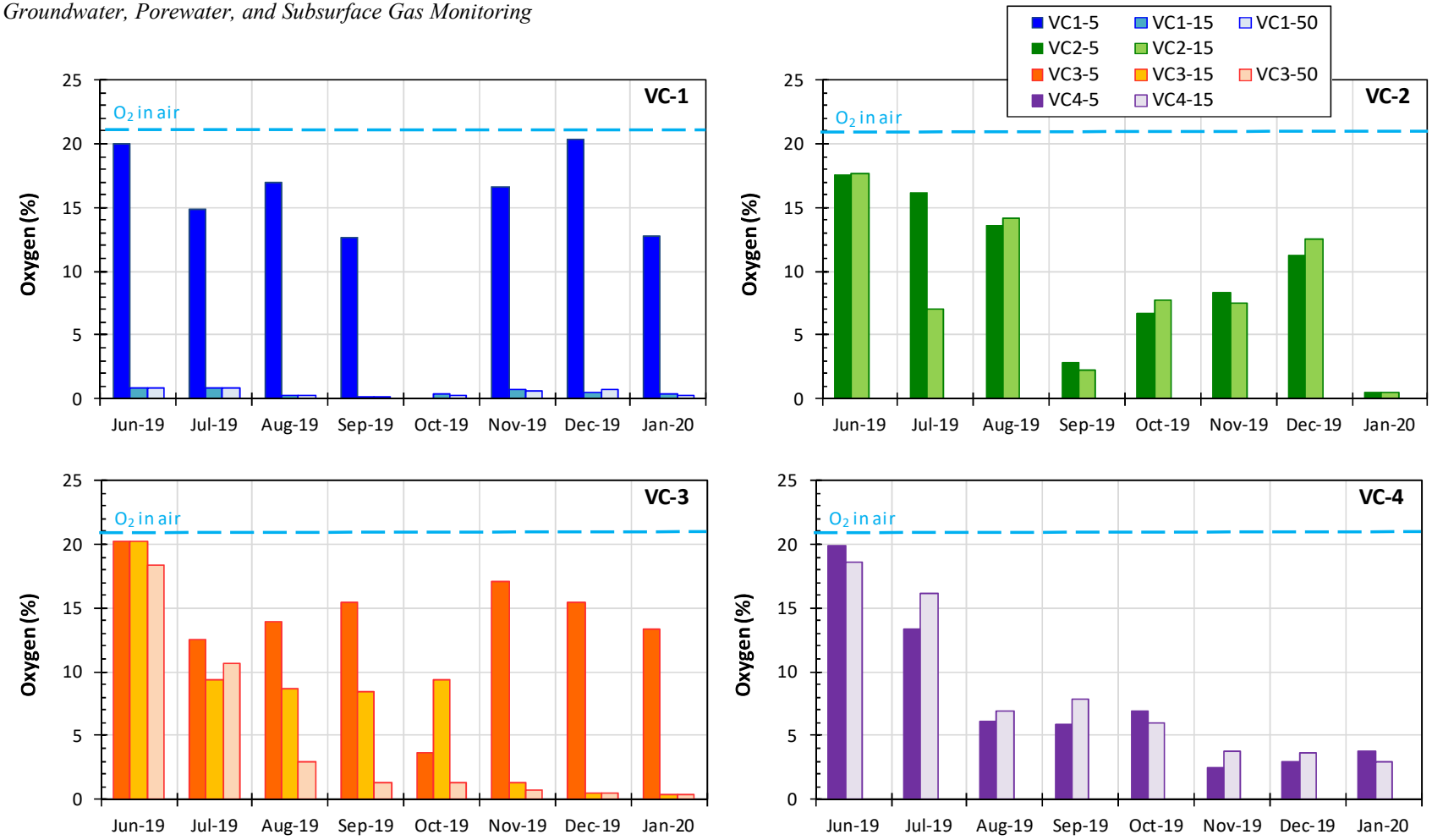

Figure 7-7
Concentration (%) of oxygen (O_2) from GAPs at boreholes VC-1, VC-2, VC-3, and VC-4 in the subsurface of the dry-handled landfill

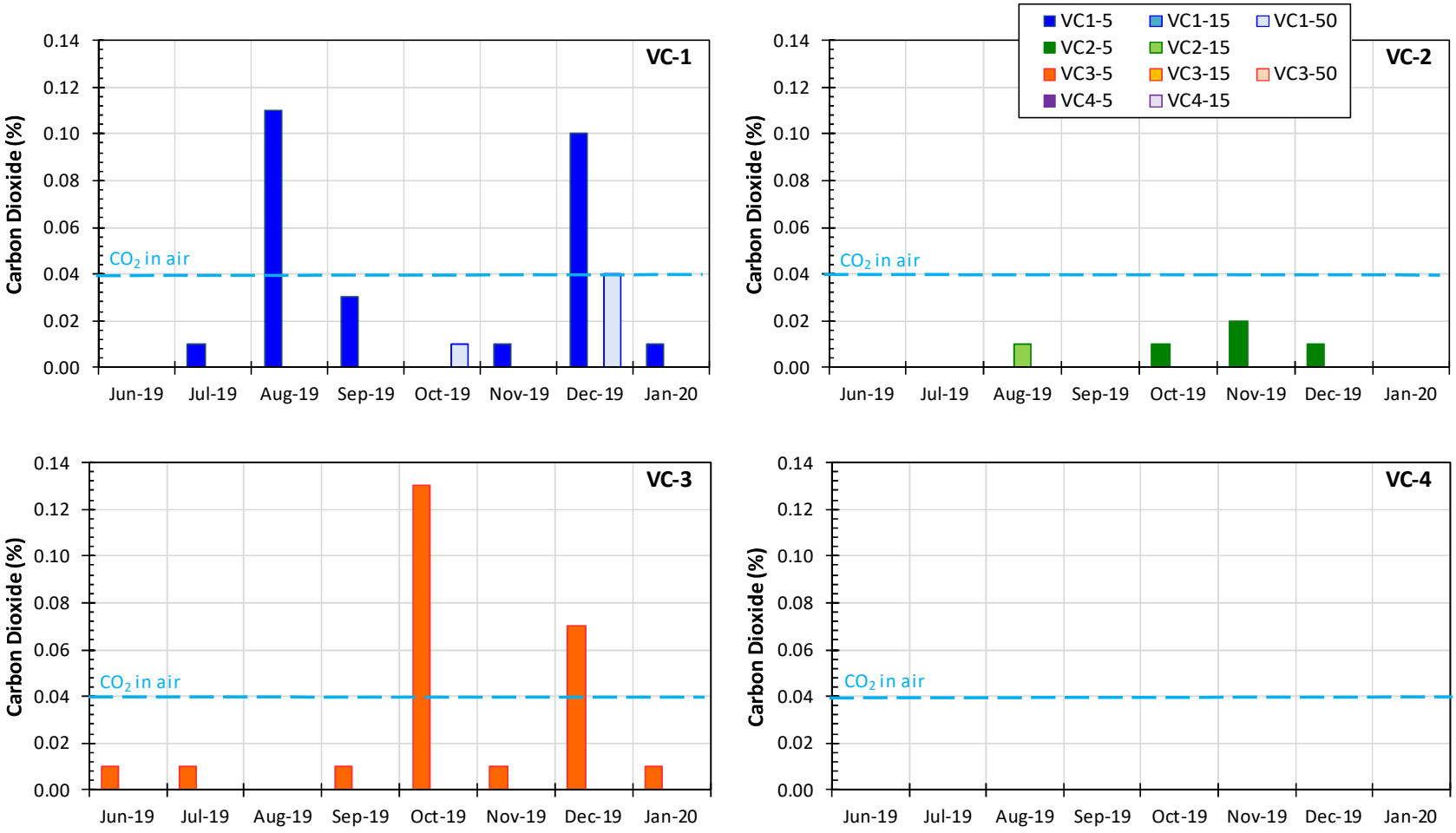

Figure 7-8
Concentration (%) of carbon dioxide (CO_2) from GAPs at boreholes VC-1, VC-2, VC-3, and VC-4 in the subsurface of the dry-handled landfill

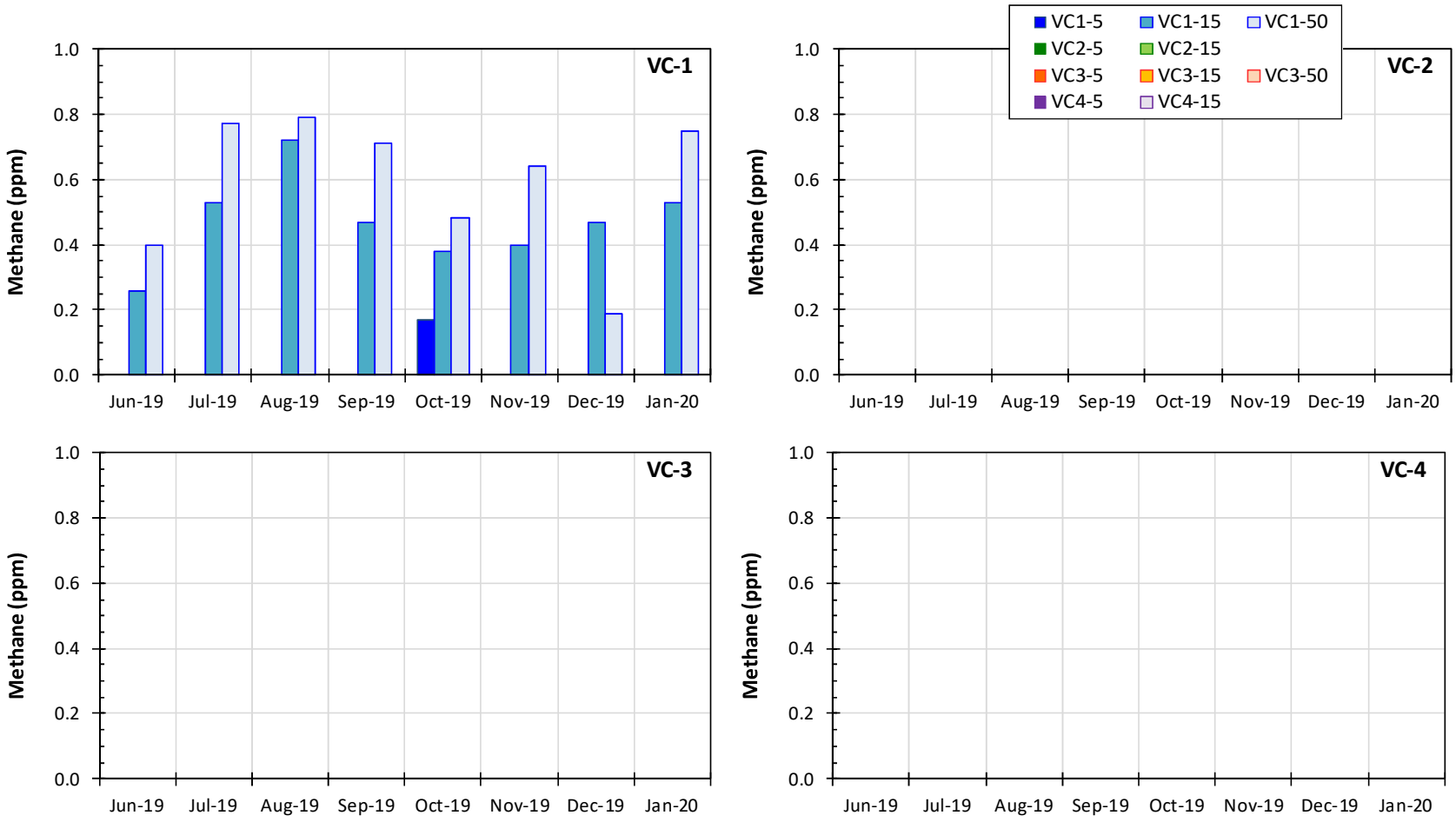

Figure 7-9
Concentration (ppm) of methane (CH_4) from GAPs at borehole VC-1, VC-2, VC-3, and VC-4 in the subsurface of the dry-handled landfill

Comparison of Leaching Tests to Monthly Porewater Samples

The results of LEAF leaching tests and traditional tests (TCLP, SPLP, and ASTM) were plotted as a function of pH along with the porewater concentrations measured at the corresponding borehole (VC-1, VC-2, VC-3, or VC-4). Examples of these comparisons are shown in Figure 7-10 through Figure 7-12, while a full set of results is presented in Appendix E. In the pH-dependence graphs, monitored porewater data are presented both as data points representing monthly measured porewater concentrations and as dashed lines representing the mean pH and mean concentration of all measured values.

To the right of each pH-dependence graph, bar charts show the ratio of the leaching test concentration to the mean porewater concentration. The seven ratios are shown in increasing order of L/S, including:

- the 1st eluate from EPA 1314 at ΣL/S=0.2 mL/g-dry,
- the 2nd eluate from EPA 1314 at cumulative ΣL/S=0.5 mL/g-dry (displayed as L/S=0.3)[4],
- the 1313_L/S=1 concentration at own pH at L/S=1 mL/g-dry,
- the 1313 concentration at natural pH at L/S=10 mL/g-dry,
- TCLP conducted at an average L/S of 23 mL/g-dry,
- SPLP conducted at an average L/S of 22 mL/g-dry, and
- ASTM at an average L/S of 27 mL/g-dry.

The eluate-to-porewater-concentration ratios indicate how closely leaching test concentrations can predict measured field concentrations. For example, Figure 7-10 shows that B porewater concentrations are well predicted by low L/S batch leaching (1313_L/S=1) and, coincidently, by TCLP; however, the test-specific L/S of TCLP and resultant eluate pH are not representative of that in the coal ash porewater. For boron, all leaching test data estimate porewater concentrations within an order-of-magnitude. These observations are consistent with available content-limited LSP where eluate concentration is a strong function of L/S. Since the L/S of ASTM and SPLP is significantly greater than the L/S in the field, these traditional tests tend to underestimate the porewater concentrations for available content-limited LSP constituents by an order-of-magnitude or more.

[4] The first eluate is taken at L/S=0.2, the second is taken 0.3 pore volumes later, so the L/S is 0.3 and ΣL/S=0.5.

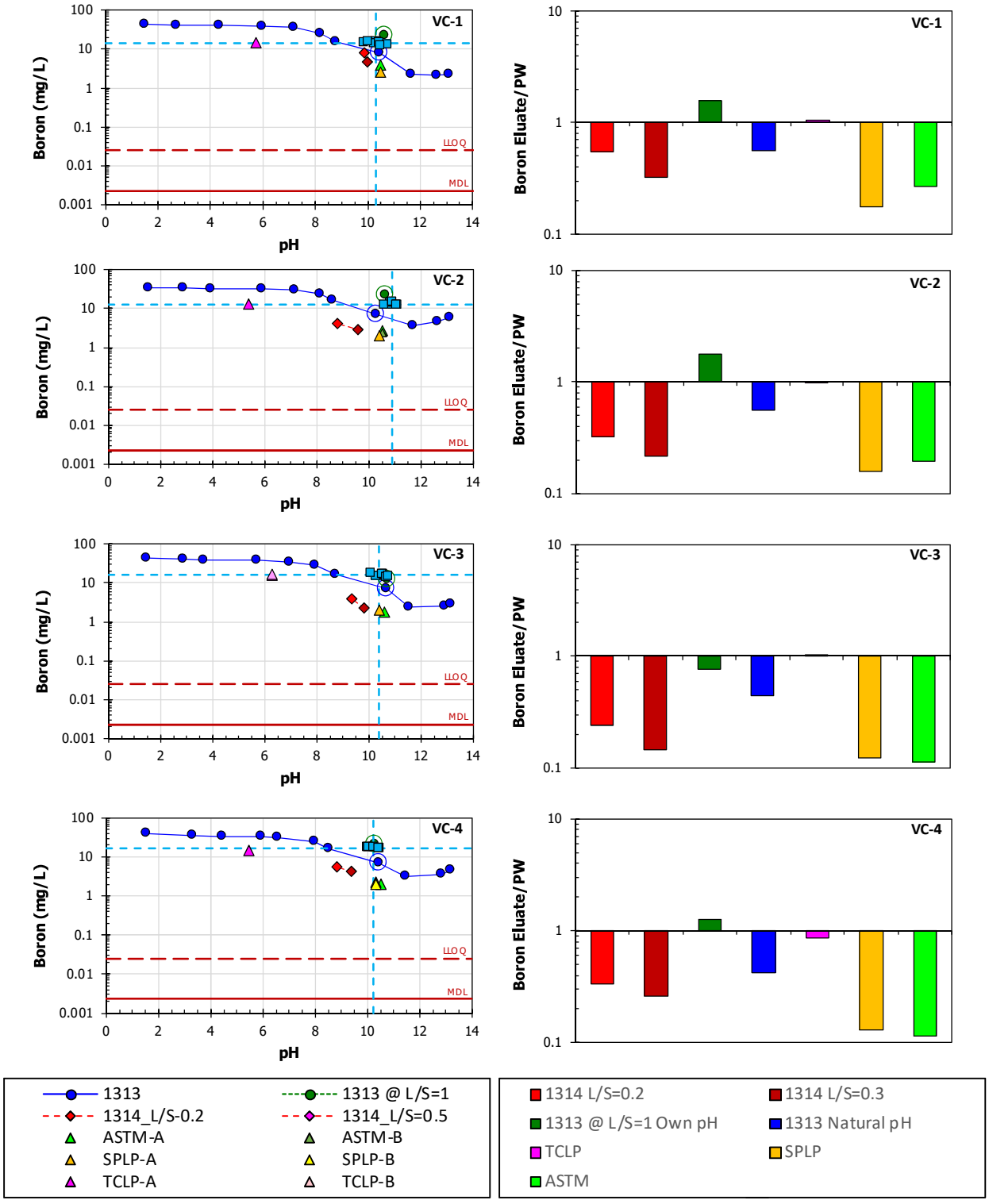

Figure 7-10
Boron concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

Of the 30 evaluated constituents, only chromium compared poorly to all of the leaching test concentrations. The porewater concentrations of Cr were less than the analytical MDL of 0.000053 mg/L in all four PAPs, while leaching tests returned concentrations between 0.001 and 0.1 mg/L (Figure 7-11). Subsurface gas measurements indicated a deficit of oxygen (Figure 7-7) without generation of carbon dioxide (Figure 7-8) or significant methane (Figure 7-9), which suggests suboxic conditions. Under these conditions, Cr is reduced to Cr(III), which would be insoluble at the porewater pH conditions. When samples are collected from the field, homogenized in the laboratory, and exposed to laboratory conditions during testing, the material oxidizes enough to convert a portion of Cr(III) to Cr(IV), leading to increased chromium concentrations in leaching test eluates. Conversely, arsenic, also a redox-sensitive constituent, is predicted within an order of magnitude in all leaching test approximations (Figure 7-12). The ability of leaching tests to approximate arsenic concentrations in the porewater is most likely due to the speciation of arsenic and the subsurface conditions. In literature, arsenic retained in fly ash as calcium-arsenate and arsenate hematite was less susceptible to changes due to redox conditions (Deonarine et al., 2016). In addition, the subsurface conditions here, while suboxic, are not sufficiently reducing to be affected by short-term exposures of the solid materials to oxygen in laboratory leaching tests.

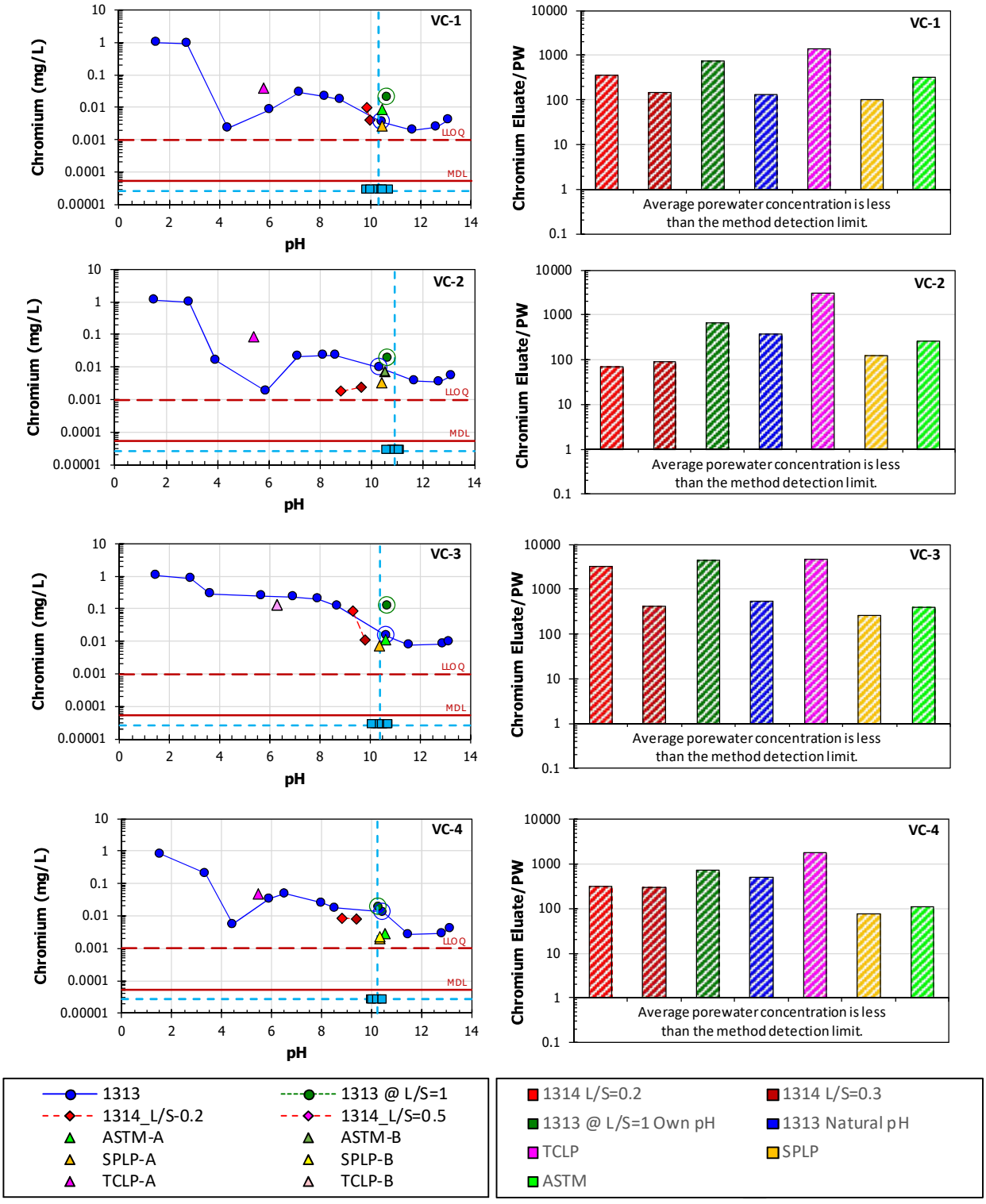

Figure 7-11
Chromium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

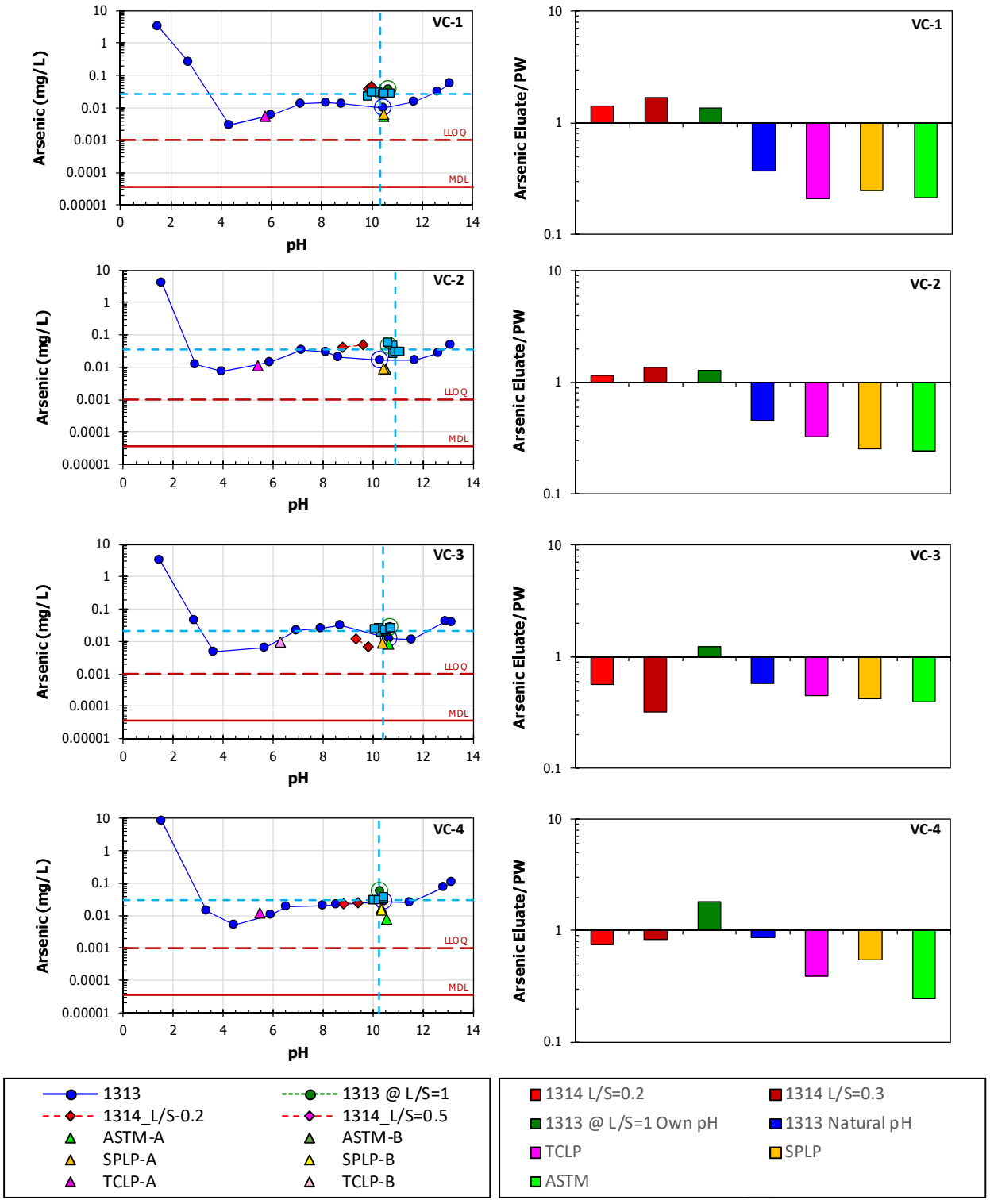

Figure 7-12
Arsenic concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

A qualitative summary of the ability of different leaching tests to estimate the measured porewater concentrations at each of the PAPs is shown in Table 7-2 for constituents with solubility-controlled LSP, Table 7-3 for constituents with wash-off followed by solubility control, Table 7-4 for constituents with available content-limited LSP, and Table 7-5 for constituents with non-detected data. In these tables, shading is used to indicate if the leaching test estimate is within 25% of the mean porewater concentration (green), within an order-of-magnitude of the mean porewater concentration (orange), or greater than an order-of-magnitude from the mean porewater concentration (red). These classifications are based on a percentage difference:

$$\%D = \frac{(z - PW)}{PW}$$

where %D is the percentage difference between leaching and porewater concentrations;
z is the leaching tests concentration (mg/L); and
PW is the mean porewater concentration from monthly PAP monitoring (mg/L).

When "GW <MDL" appears in the Notes column, the mean porewater concentration was less than the analytical MDL. Within the field of the table, an asterisk is used to indicate that the leaching test results were less than the MDL.

These tables provide an overview of the ability of leaching tests, conducted on materials collected from a suboxic environment and tests at mildly oxidizing conditions in a laboratory setting, to estimate porewater concentrations. This comparison indicated that the ability of leaching tests, conducted under specific test conditions, to predict porewater concentration varied by constituent and test. While no single leaching test consistently predicted concentrations within 25% of porewater concentrations for all constituents, the following observations were made:

- TCLP tends to over-predict porewater concentrations in alkaline ash (average pH_{nat}~10.4) by more than an order-of-magnitude for many constituents, in part, due to the pH (pH~5) imposed by the acetic acid leaching solution;
- EPA 1313, ASTM, and SPLP were usually within an order-of-magnitude for the solubility-controlled constituents where pH is the critical factor in LSP concentration and the leaching solution (i.e., deionized water for EPA 1313 at natural pH and ASTM, weak acid solution for SPLP) does not significantly alter eluate pH;
- EPA 1313 (L/S=10 L/kg-dry), ASTM (L/S~30 L/kg-dry), and SPLP (L/S~30 L/kg-dry) often under-predicted porewater concentrations by more than an order-of-magnitude for available content-controlled constituents because of the high L/S ratio relative to porewater L/S (0.35 L/kg-dry); and,
- EPA 1313_L/S=1 and low L/S 1314 column fractions usually yielded results within an order-of-magnitude of the porewater concentrations for both solubility-controlled and available content-controlled constituents.

When summarized by constituent, leaching test predictions *typically*:

- Over-predicted porewater concentrations for Sb and Cr;

- Under-predicted porewater concentrations for Ba, B, Cd, Ca, Cl^-, DOC, Li, Mo, Ni, K, Na, Sr, and SO_4^{-2};
- Over-predicted at L/S=0.2 and under-predicted at higher L/S for Co;
- Over-predicted at L/S<1.0 and under-predicted at higher L/S for P;
- Over-predicted at L/S<=1.0 and under-predicted at higher L/S for V; and,
- Did not consistently over- or under-predict porewater concentrations for As, Cu, DIC, Fe, Se, Tl, and Zn.

The above constituent evaluation does not include TCLP tests where leaching concentrations were primarily higher than porewater or those constituents where eluates and porewater concentrations were both usually less than MDL (i.e., Be, Br^-, F^-, Pb, and Ag).

The results of this qualitative summary should not be used without consideration of the redox conditions of the field and should always be shown along with the graphical data (e.g., Figure 7-10 through Figure 7-12) that indicate the pH result for the tests. For example, the table indicates that TCLP would provide a good estimate of porewater concentration for B; however, this is somewhat of a coincidence because the pH of TCLP is more than four pH units less than the natural pH of the ash.

Table 7-2
Summary of Leaching Tests to Porewater Concentrations – Solubility-Controlled LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP	SPLP	ASTM	Notes
Antimony	VC-1								
	VC-2								
	VC-3								
	VC-4								
Arsenic	VC-1								
	VC-2								
	VC-3								
	VC-4								
Calcium	VC-1								
	VC-2								
	VC-3								
	VC-4								
Dissolved Inorganic Carbon	VC-1								
	VC-2								
	VC-3								
	VC-4								
Thallium	VC-1								
	VC-2								
	VC-3								
	VC-4								

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

Table 7-3
Summary of Leaching Tests to Porewater Concentrations – Wash-off / Solubility-Controlled LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20 +	SPLP L/S=20 +	ASTM L/S=20 +	Notes
Barium	VC-1								
	VC-2								
	VC-3								
	VC-4								
Boron	VC-1								
	VC-2								
	VC-3								
	VC-4								
Cadmium	VC-1								
	VC-2								
	VC-3								
	VC-4								
Chromium	VC-1								GW
									<MDL
	VC-2								GW
									<MDL
	VC-3								GW
									<MDL
	VC-4								GW
									<MDL
Copper	VC-1								
	VC-2								
	VC-3								
	VC-4								
Dissolved Organic Carbon	VC-1								
	VC-2								
	VC-3								
	VC-4								
Lithium	VC-1								
	VC-2				*				
	VC-3				*				
	VC-4				*				
Nickel	VC-1				*				
	VC-2				*				
	VC-3				*				
	VC-4				*				
Selenium	VC-1								
	VC-2								
	VC-3								
	VC-4								
Strontium	VC-1								
	VC-2								
	VC-3								
	VC-4								

Table 7-3 (continued)
Summary of Leaching Tests to Porewater Concentrations – Wash-off / Solubility-Controlled LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20 +	SPLP L/S=20 +	ASTM L/S=20 +	Notes
Sulfate	VC-1								
	VC-2								
	VC-3								
	VC-4								
Vanadium	VC-1								
	VC-2								
	VC-3								
	VC-4								

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

Table 7-4
Summary of Leaching Tests to Porewater Concentrations – Available Content-Limited LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S=10 Nat pH	TCLP L/S=20 +	SPLP L/S=20 +	ASTM L/S=20 +	Notes
Chloride	VC-1								
	VC-2								
	VC-3								
	VC-4								
Molybdenum	VC-1								
	VC-2								
	VC-3								
	VC-4								
Potassium	VC-1								
	VC-2								
	VC-3								
	VC-4								
Sodium	VC-1								
	VC-2								
	VC-3								
	VC-4								

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

Table 7-5
Summary of Leaching Tests to Porewater Concentrations – Non-detected Constituents

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20+	SPLP L/S=20+	ASTM L/S=20+	Notes
Beryllium	VC-1	*	*	*	*		*	*	GW <MDL
	VC-2	*	*	*	*		*	*	GW <MDL
	VC-3	*	*	*	*		*	*	GW <MDL
	VC-4	*	*	*	*		*	*	GW <MDL
Bromide	VC-1	*	*	*	*	*	*	*	GW <MDL
	VC-2	*	*	*	*	*	*	*	GW <MDL
	VC-3	*	*	*	*	*	*	*	GW <MDL
	VC-4	*	*	*	*	*	*	*	GW <MDL
Cobalt	VC-1				*				
	VC-2				*				
	VC-3				*				
	VC-4				*				
Fluoride	VC-1	*	*	*	*	*	*	*	GW <MDL
	VC-2	*	*	*	*	*	*	*	GW <MDL
	VC-3	*	*	*	*	*	*	*	GW <MDL
	VC-4	*	*	*	*	*	*	*	GW <MDL
Iron	VC-1	*	*		*				
	VC-2	*			*				
	VC-3	*			*				
	VC-4		*		*				
Lead	VC-1	*	*	*	*		*	*	GW <MDL
	VC-2	*	*	*	*		*		GW <MDL
	VC-3	*	*	*	*		*	*	GW <MDL
	VC-4	*	*	*	*		*	*	GW <MDL
Phosphorus	VC-1			*	*	*	*	*	
	VC-2				*	*	*	*	
	VC-3				*	*	*	*	
	VC-4				*	*	*	*	
Silver	VC-1	*	*	*	*	*	*	*	GW <MDL
	VC-2	*	*	*	*	*	*	*	GW <MDL
	VC-3	*	*	*	*	*	*	*	GW <MDL
	VC-4	*	*	*	*	*	*	*	GW <MDL

Table 7-5 (continued)
Summary of Leaching Tests to Porewater Concentrations – Non-detected Constituents

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20+	SPLP L/S=20+	ASTM L/S=20+	Notes
Zinc	VC-1				*				
	VC-2			*	*				
	VC-3			*	*				
	VC-4				*				

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

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8
SUMMARY OF OBSERVATIONS

The data presented in this report represent the results of geotechnical, hydrologic, and leaching characterization of samples of coal ash collected from an active CCP management unit at Plant 42197. The hydraulic conductivity of intact cores from the coal ash deposit was measured in context of the distribution of particles in the coal ash samples and the overburden pressure associated with disposal at depth within the coal ash deposit. The leaching test results for LEAF tests (i.e., EPA Methods 1313 and 1314) were compared to the results for traditional tests (i.e., ASTM, TCLP, and SPLP). In addition, porewater estimates derived from leaching tests were compared to measured porewater concentrations, and measured porewater concentrations were compared to groundwater concentrations.

Based on the presented data and analysis, the following general observations can be made:

- Despite differences in coal ash placement (dry-handled ash in the upper portion and wet-handled ash in the lower portion), ***there was little observed variability in vertical concentration profiles***. This observation, in combination with initial concentration from percolation column test results, suggest that infiltration moving through the unsaturated dry-handled ash (e.g., from precipitation, liquid dumps, water spray for dust management) results in migration of readily dissolved constituents from the dry-handled material into the underlying wet-handled coal ash. ***Downward movement of soluble constituents results in the pH and porewater composition within the saturated material similar to the low L/S extraction fractions of composited dry material***.
- The ratio of the available content to the total content shows that ***only a small fraction of total content of most trace constituents is leachable*** over a broad pH range.
- ***Suboxic to anoxic conditions are established at relatively shallow depths (> 5 m) below the ground surface of the dry-handled material***. Oxygen penetration from the surface is limited because of abiotic and biotic reactivity of the freshly deposited fly ash in conjunction with pore filling due to water additions to maintain dust control and compaction of additionally added materials (e.g., bottom ash) for structural workability (truck access).
- ***The high pH within the porewater of deposited material prevents development of significant microbial activity at depths greater than 5 m below the ground surface*** (or potentially even at shallower depths). This is in contrast to observations in some impoundments of only wet-handled material (EPRI, 2020), which showed nearly neutral porewater pH and indicators of robust microbial reduction of iron and sulfate along with methanogenesis.
- ***Hydraulic conductivity of the ashes typically was within the range of 10^{-5} to 10^{-6} cm/s***, with the lower hydraulic conductivities corresponding to higher dry unit weight. Fines content and 2-mm clay content had no consistent influence on hydraulic conductivity, in contrast to

previous experience (EPRI, 2020). Hydraulic conductivity diminished as the effective stress increased, but only modestly.

- ***Some parameters in the PAP porewater (e.g., pH, temp, B, Co, Ni, and Zn) exhibited temporal variability*** due to factors such as seasonal changes or impacts of damage and repair of porewater access points. Other constituents remained relatively constant within each porewater access point throughout the 8-month monitoring period. ***Spatial variability was observed for some constituents between PAPs; however, no consistent pattern was observed***. With the exception of Cu and Zn, concentrations between PAPs were within an order of magnitude.
- There were insufficient data from limited collection points to identify relationships between porewater and downgradient groundwater concentrations. For example, no upgradient groundwater well was identified to provide groundwater conditions in the flow path prior to the landfill. ***The limited data collected from downgradient monitoring wells and PAPs suggest that porewater concentration alone is an unreliable indicator that a constituent has had an impact on elevated groundwater concentrations or for prediction of downgradient concentrations at this site***.
- Traditional leaching tests, such as TCLP, SPLP, and ASTM, are poorer indicators of measured porewater concentrations than LEAF tests. ***Low liquid-to-solid ratio (L/S) eluates from EPA Method 1314 are better indicators than the traditional tests and EPA 1313 for concentrations for available content-limited constituents (e.g., B, Cd, Cl^-, Mo, Se, and SO_4^{-2}) because of the strong L/S-dependence.*** The data presented here showed that the traditional tests, with an L/S greater than 20 L/kg-dry, and EPA 1313 at L/S=10 L/kg-dry often under-predicted field porewater concentrations by an order of magnitude or more. These results indicate that additional information (e.g., available content and porewater L/S) is needed to provide a reasonable approximation of porewater concentrations. ***For constituents with solubility-controlled liquid-solid partitioning (e.g., As, Sb, and Tl), EPA 1313 tests at L/S=1 L/kg-dry provide an estimate of porewater concentrations generally within a factor of 2.*** The combination of pH-dependent leaching data (EPA 1313) with percolation column test results (EPA 1314) provides valuable information for geochemical modeling.
- For field environments that are oxidizing to slightly reducing, leaching test data usually approximated field porewater concentrations of solubility-controlled constituents within an order of magnitude. ***Because of the oxic to suboxic subsurface conditions at this site, sampling, laboratory handing, and testing conditions did not appear to significantly influence the redox condition of the field material.*** This is in contrast to impoundments with highly reducing subsurface conditions, where material handling in the presence of oxygen during sampling and laboratory testing can significantly impact test results. The only constituent not well defined by any of the LEAF tests was chromium, the result for which may have been influenced by oxidization of materials during collection from a suboxic environment and testing in an oxic laboratory. The leaching results for chromium indicate that laboratory testing results for redox-sensitive elements (e.g., As, Cr, Sb, Se, V) may not directly reflect the leaching anticipated in porewater when the field environment is highly reducing, in part due to oxidation incurred during sampling, handling, and testing.

9
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A
MATERIAL COLLECTION SAMPLE INDEX

Borehole CDL_VC-1, Collected 3/19/19

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
5'-6.5'	CDL_VC-1_5'-6.5'	Dry stack	Tube sample for UVA	-	-	-
6.5'-8'	CDL_VC-1_6.5'-8' (A)	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,732.0	-
6.5'-8'	CDL_VC-1_6.5'-8' (B)	Dry stack	Bulk Material	1-gal. vacuum-seal bag	552.0	-
8'-9.5'	CDL_VC-1_8'-9.5'	Dry stack	PW Extractor (+ 18.4 mL H2O); L/S=1 Extraction; Moisture Content	No bulk material collected	-	0.16
15'-16.5'	CDL_VC-1_15'-16.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content	No bulk material collected	-	0.23

Borehole CDL_VC-1, Collected 3/19/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
16.5'-18'	CDL_VC-1_16.5'-18'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	2,131.6	-
18'-19.5'	CDL_VC-1_18'-19.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,367.0	-
25'-26.5'	CDL_VC-1_25'-26.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	571.3	0.21
26.5'-28'	CDL_VC-1_26.5'-28'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	881.0	-
28'-29.5'	CDL_VC-1_28'-29.5'	Dry stack	Tube Sample for UVA	-	-	-

Borehole CDL_VC-1, Collected 3/19/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
35'-36.5'	CDL_VC-1_35'-36.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	360.0	0.18
36.5'-38'	CDL_VC-1_36.5'-38'	Dry stack	Tube sample for UVA	-	-	-
38'-39.5'	CDL_VC-1_38'-39.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	849.0	-
45'-46.5'	CDL_VC-1_45'-46.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	490.8	0.18
46.5'-48'	CDL_VC-1_46.5'-48'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	656.1	-

Borehole CDL_VC-1, Collected 3/19/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
48'-49.5'	CDL_VC-1_48'-49.5'	Dry stack/bottom ash layer	Tube sample for UVA	-	-	-
65'-66.5'	CDL_VC-1_65'-66.5'	Impoundment	PW Extractor (+ 10 mL H2O); L/S=1 Extraction; Moisture Content	No bulk material collected	-	0.33
66.5'-68.5'	CDL_VC-1_66.5'-68.5'	Impoundment	Shelby tube for UVA (no recovery)	-	-	-
68.5'-70'	CDL_VC-1_68.5'-70'	Impoundment	Bulk Material	1-gal. vacuum-seal bag	2,485.2	-
70'-72.6'	CDL_VC-1_70'-72.6' (A)	Impoundment	Bulk Material	1-gal. vacuum-seal bag	1,257.1	-

Borehole CDL_VC-1, Collected 3/19/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
70'-72.6'	CDL_VC-1_70'-72.6' (B)	Impoundment	Tube Sample for UVA	-	1,257.1	-
72.5'-74'	CDL_VC-1_72.5'-74'	Impoundment	Low L/S extractor; L/S=1 digit tube; Moisture content; Bulk	1-gal. vacuum-seal bag	1,323.7	0.23

Material Collection Sample Index

Borehole CDL_VC-2, Collected 3/14/19

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
5'-6.5'	CDL_VC-2_5'-6.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	625.91	-
6.5'-8'	CDL_VC-2_6.5'-8'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	757.99	-
8'-9.5'	CDL_VC-2_8'-9.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content	-	-	0.21
15'-16.5'	CDL_VC-2_15'-16.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content	1-gal. vacuum-seal bag	848.07	0.20
16.5'-18'	CDL_VC-2_16.5'-18'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1281.9	-

Borehole CDL_VC-2, Collected 3/14/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
18'-19.5'	CDL_VC-2_18'-19.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1050.75	-
25'-26.5'	CDL_VC-2_25'-26.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1815.3	0.19
26.5'-28'	CDL_VC-2_26.5'-28'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,065.3	-
28'-29.5'	CDL_VC-2_28'-29.5'	Dry stack	Tube Sample for UVA	-	-	-
35'-36.5'	CDL_VC-2_35'-36.5'	Dry stack	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,423.5	0.21

Borehole CDL_VC-2, Collected 3/14/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
36.5'-38'	CDL_VC-2_36.5'-38'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,243.4	-
38'-39.5'	CDL_VC-2_38'-39.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,863.5	-
45'-46.5'	CDL_VC-2_45'-46.5'	Dry stack	Tube sample for UVA	-	-	-
46.5'-48'	CDL_VC-2_46.5'-48'	Dry stack/bottom ash layer	Bulk Material	1-gal. vacuum-seal bag	1,081.4	-
46.5'-48'	CDL_VC-2_46.5'-48'	Dry stack/bottom ash layer	Bulk Material	1-gal. vacuum-seal bag	1,217.0	-

Borehole CDL_VC-2, Collected 3/14/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
48'-49.5'	CDL_VC-2_48'-49.5'	Dry stack/bottom ash layer	PW Extractor (+ 20 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,372.4	0.11
65'-67'	CDL_VC-2_65'-67'	Impoundment	Shelby Tube for UVA	-	-	-
67'-68.5'	CDL_VC-2_67'-68.5'	Impoundment	PW Extractor (+ 10 mL H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,372.3	0.25
68.5'-70'	CDL_VC-2_68.5'-70'	Impoundment	Bulk Material	1-gal. vacuum-seal bag	2,184.4	-
75'-77'	CDL_VC-2_75'-77'	Impoundment	Shelby Tube for UVA	-	-	-

Borehole CDL_VC-2, Collected 3/14/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
77'-78.5'	CDL_VC-2_77'-78.5'	Impoundment	PW Extractor (no H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,529.1	0.35
78.5'-80'	CDL_VC-2_78.5'-80'	Impoundment	Bulk Material	1-gal. vacuum-seal bag	2,553.4	-
80'-81.5'	CDL_VC-2_80'-81.5'	Impoundment	Bulk Material	1-gal. vacuum-seal bag	2,589.9	-
81.5'-83'	CDL_VC-2_81.5'-83'	Impoundment	PW Extractor (no H2O); L/S=1 Extraction; Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,597.8	0.29

Borehole CDL_VC-3, Collected 3/7-8/19

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
5'-6.5'	CDL_VC-3_5'-6.5'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	874.3	0.22
6.5'-8'	CDL_VC-3_6.5'-8'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,467.7	-
8'-9.5'	CDL_VC-3_8'-9.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,069.9	-
15'-16.5'	CDL_VC-3_15'-16.5'	Dry stack	Tube Sample for UVA	-	-	-
16.5'-18'	CDL_VC-3_16.5'-18'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,897.2	0.16

Borehole CDL_VC-3, Collected 3/7-8/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
18-19.5	CDL_VC-3_18-19.5	Dry stack	Bulk Material	1-gal. vacuum-seal bag	2519.2	-
INVENTORY OF FIELD-COLLECTED ASH SAMPLES **CDL_VC-3** Collection Date: **March 8, 2019**						
Depth Below Ground Level (ft)	**Sample ID**	**Material Type (Dry Stack or Impoundment)**	**Target Test**	**Container & Size**	**Bulk Weight in bag (g)**	**Moisture Content (gH2O/g)**
25'-26.5'	CDL_VC-3_25'-26.5'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	652.7	0.16
26.5'-28'	CDL_VC-3_26.5'-28'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	649.8	-
28'-29.5'	CDL_VC-3_28'-29.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,121.6	-

Borehole CDL_VC-3, Collected 3/7-8/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
35'-36.5'	CDL_VC-3_35'-36.5'	Dry stack	Tube Sample for UVA	-	-	-
36.5'-38'	CDL_VC-3_36.5'-38'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,844.4	0.15
38'-39.5'	CDL_VC-3_38'-39.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	702.8	-
45'-46.5'	CDL_VC-3_45'-46.5'	Dry stack	Tube Sample for UVA	-	-	-
46.5'-48'	CDL_VC-3_46.5'-48'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,147.3	0.21

Borehole CDL_VC-3, Collected 3/7-8/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
48'-49.5'	CDL_VC-3_48'-49.5'	Dry stack	Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,351.8	0.20
65'-67'	CDL_VC-3_65'-67'	Impoundment	Shelby Tube for UVA	-	-	-
67'-68.5'	CDL_VC-3_67'-68.5'	Impoundment	PW Extractor (no H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,599.1	0.33
75'-77'	CDL_VC-3_75'-77'	Impoundment	Shelby Tube for UVA	-	-	-
77'-78.5'	CDL_VC-3_77'-78.5'	Impoundment	PW Extractor (no H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,173.3	0.28

Borehole CDL_VC-3, Collected 3/7-8/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
78.5'-80'	CDL_VC-3_78.5'-80'	Impoundment	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,431.6	0.34
80'-81.5'	CDL_VC-3_80'-81.5'	Impoundment	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,727.2	0.32
81.5'-83'	CDL_VC-3_81.5'-83'	Impoundment	Bulk Material	1-gal. vacuum-seal bag	1,352.4	-

Material Collection Sample Index

Borehole CDL_VC-4, Collected 3/5-6/19

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
5'-6.5'	CDL_VC-4_5'-6.5'	Dry stack	PW Extractor (+ 20 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,643.2	0.21
6.5'-8'	CDL_VC-4_6.5'-8'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	1,135.4	-
15'-16.5'	CDL_VC-4_15'-16.5'	Dry stack	Tube Sample for UVA	-	-	-
16.5'-18'	CDL_VC-4_16.5'-18'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,086.8	0.18
25'-26.5'	CDL_VC-4_25'-26.5'	Dry stack	Tube Sample for UVA	-	-	-

Borehole CDL_VC-4, Collected 3/5-6/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
26.5'-28'	CDL_VC-4_26.5'-28'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,013.7	0.17
35'-36.5'	CDL_VC-4_35'-36.5'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,103.2	0.15
36.5'-38'	CDL_VC-4_36.5'-38'	Dry stack	Sample discarded due to poor recovery	-	-	-
38'-39.5'	CDL_VC-4_38'-39.5'	Dry stack	Sample discarded due to poor recovery	-	-	-
39.5'-41'	CDL_VC-4_39.5'-41'	Dry stack	PW Extractor (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	713.7	0.16

Borehole CDL_VC-4, Collected 3/5-6/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
41'-42.5'	CDL_VC-4_41'-42.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	799.5	-
45'-46.5'	CDL_VC-4_45'-46.5'	Dry stack	Bulk Material	1-gal. vacuum-seal bag	715.4	-
47'-48.5'	CDL_VC-4_47'-48.5'	Dry stack	Bulk Material (only bottom part preserved)	1-gal. vacuum-seal bag	601.7	-
48.5'-50'	CDL_VC-4_48.5'-50'	Dry stack	Moisture Content; Bulk Material	1-gal. vacuum-seal bag	795.7	0.19
50'-51.5'	CDL_VC-4_50'-51.5'	Dry stack	Sample discarded due to poor recovery	-	-	-

Borehole CDL_VC-4, Collected 3/5-6/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
51.5'-53'	CDL_VC-4_51.5'-53'	Dry stack	Tube Sample for UVA	-	-	-
53'-54.5'	CDL_VC-4_53'-54.5'	Dry stack	Sample discarded due to poor recovery	-	-	-
54.5'-56'	CDL_VC-4_54.5'-56'	Dry stack/bottom ash layer	Tube sample for UVA/ Moisture content		-	0.16

INVENTORY OF FIELD-COLLECTED ASH SAMPLES
CDL_VC-4
Collection Date: **March 6, 2019**

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
65'-67'	CDL_VC-4_65'-67'	Impoundment	Shelby Tube for UVA	-	-	-

Borehole CDL_VC-4, Collected 3/5-6/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
67'-68.5'	CDL_VC-4_67'-68.5'	Impoundment	PW Extractor A (no H2O); PW Extractor B (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,412.5	0.27
68.5'-70'	CDL_VC-4_68.5'-70'	Impoundment	PW Extractor A (no H2O); PW Extractor B (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	1,956.2	0.35
70'-71.5'	CDL_VC-4_70'-71.5'	Impoundment	PW Extractor A (no H2O); PW Extractor B (+ 7 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,050.7	0.33
71.5'-73'	CDL_VC-4_71.5'-73'	Impoundment	PW Extractor A (no H2O); PW Extractor B (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,361.2	0.25
73'-74.5'	CDL_VC-4_73'-74.5'	Impoundment	PW Extractor A (no H2O); PW Extractor B (+ 10 mL H2O); Moisture Content; Bulk Material	1-gal. vacuum-seal bag	2,499.3	0.25

Borehole CDL_VC-4, Collected 3/5-6/19 (continued)

Depth Below Ground Level (ft)	Sample ID	Material Type (Dry Stack or Impoundment)	Target Test	Container & Size	Bulk Weight in bag (g)	Moisture Content (gH2O/g)
74.5'-76.5'	CDL_VC-4_74.5'-76.5'	Impoundment	Shelby Tube for UVA	-	-	-

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B
INDIVIDUAL SPLIT SPOON SAMPLE ANALYSIS

Table of Appendices

B-1 Concentration Profiles from In-Field Low L/S Extractions

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B-1 Concentration Profiles from In-Field Low L/S Extractions

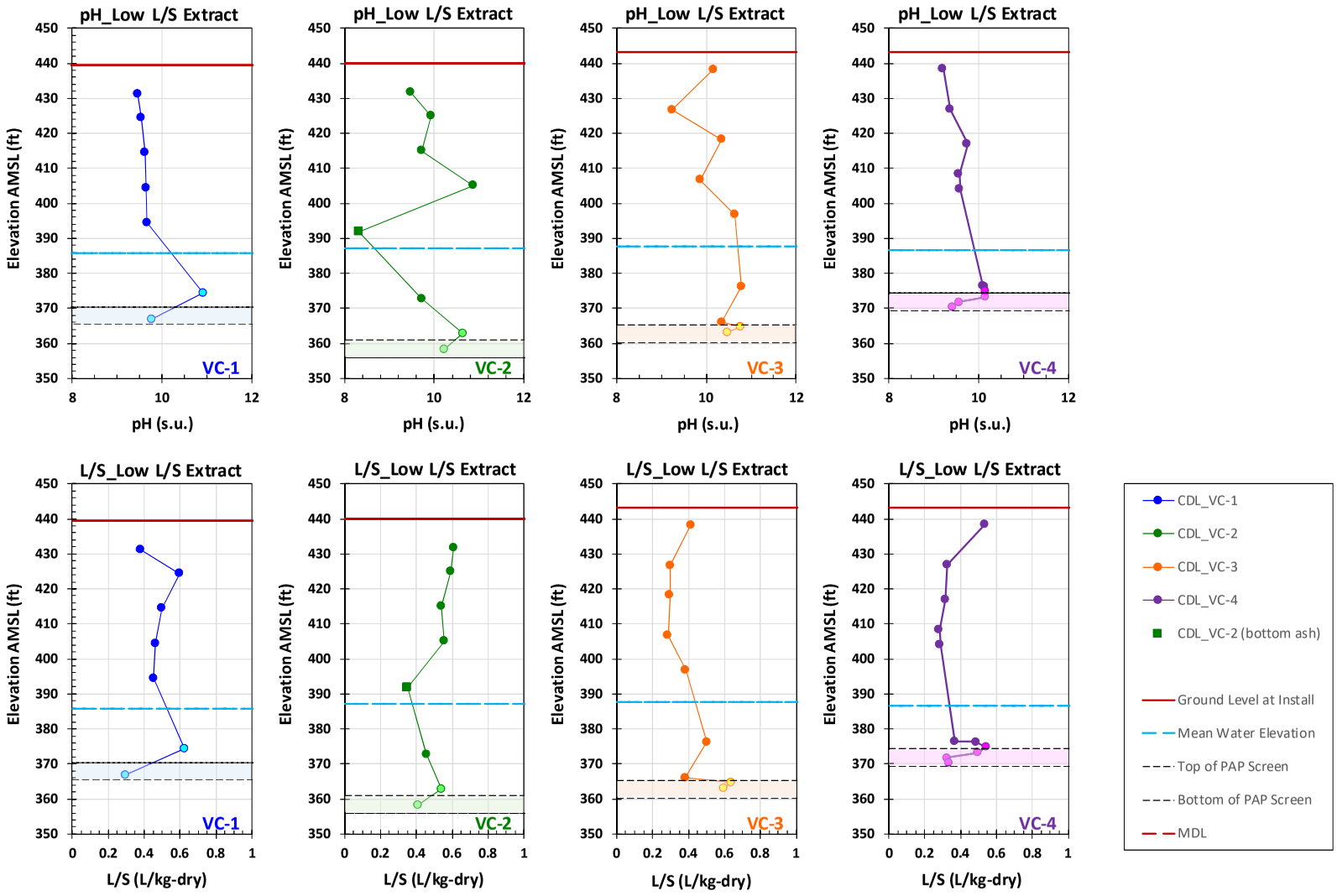

Figure B-1
Concentration profiles from in-field low L/S extractions: pH and liquid-to-solid ratio (L/S)

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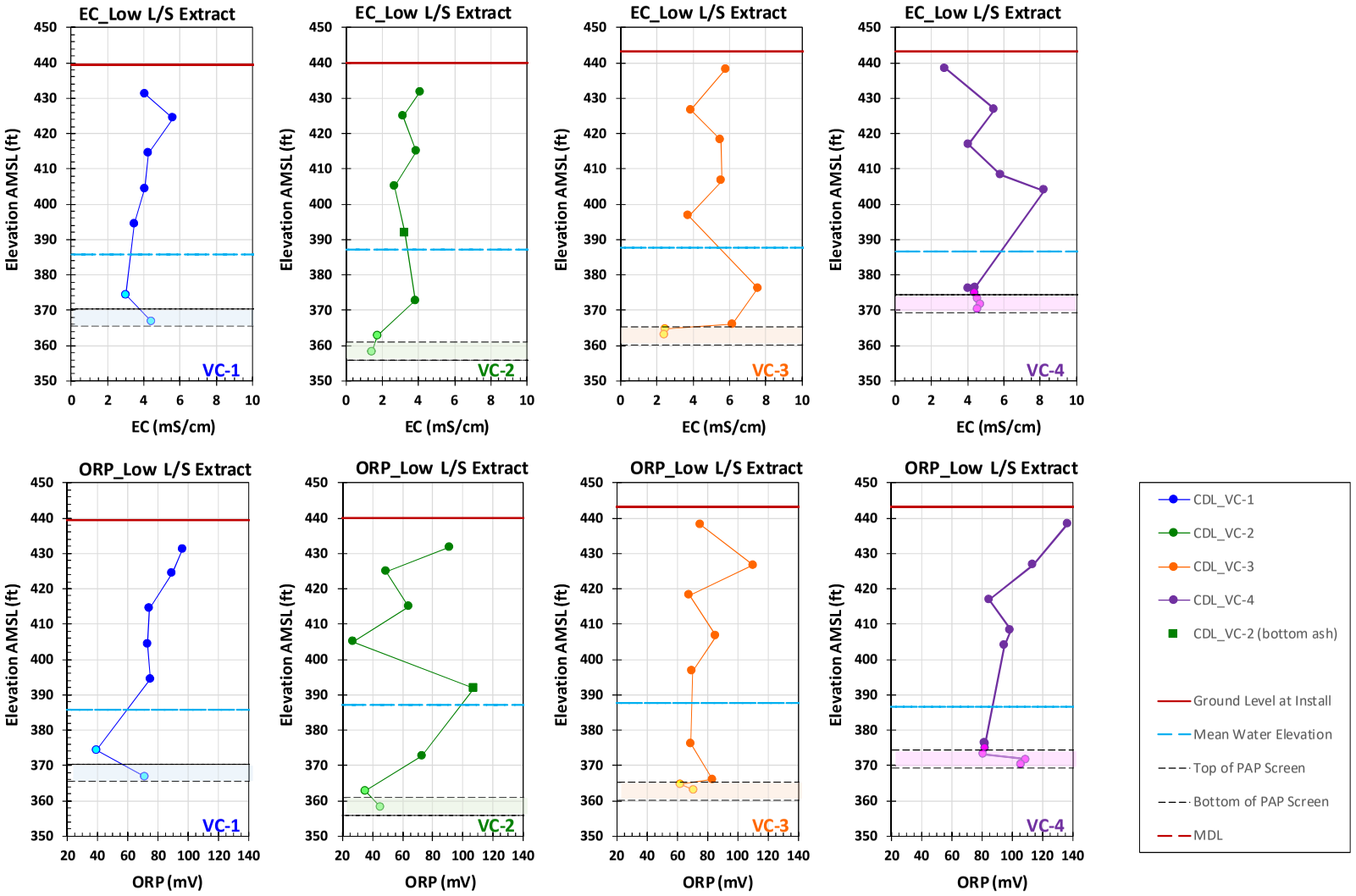

Figure B-2
Concentration profiles from in-field low L/S extractions: electrical conductivity (EC) and oxidation-reduction potential (ORP)

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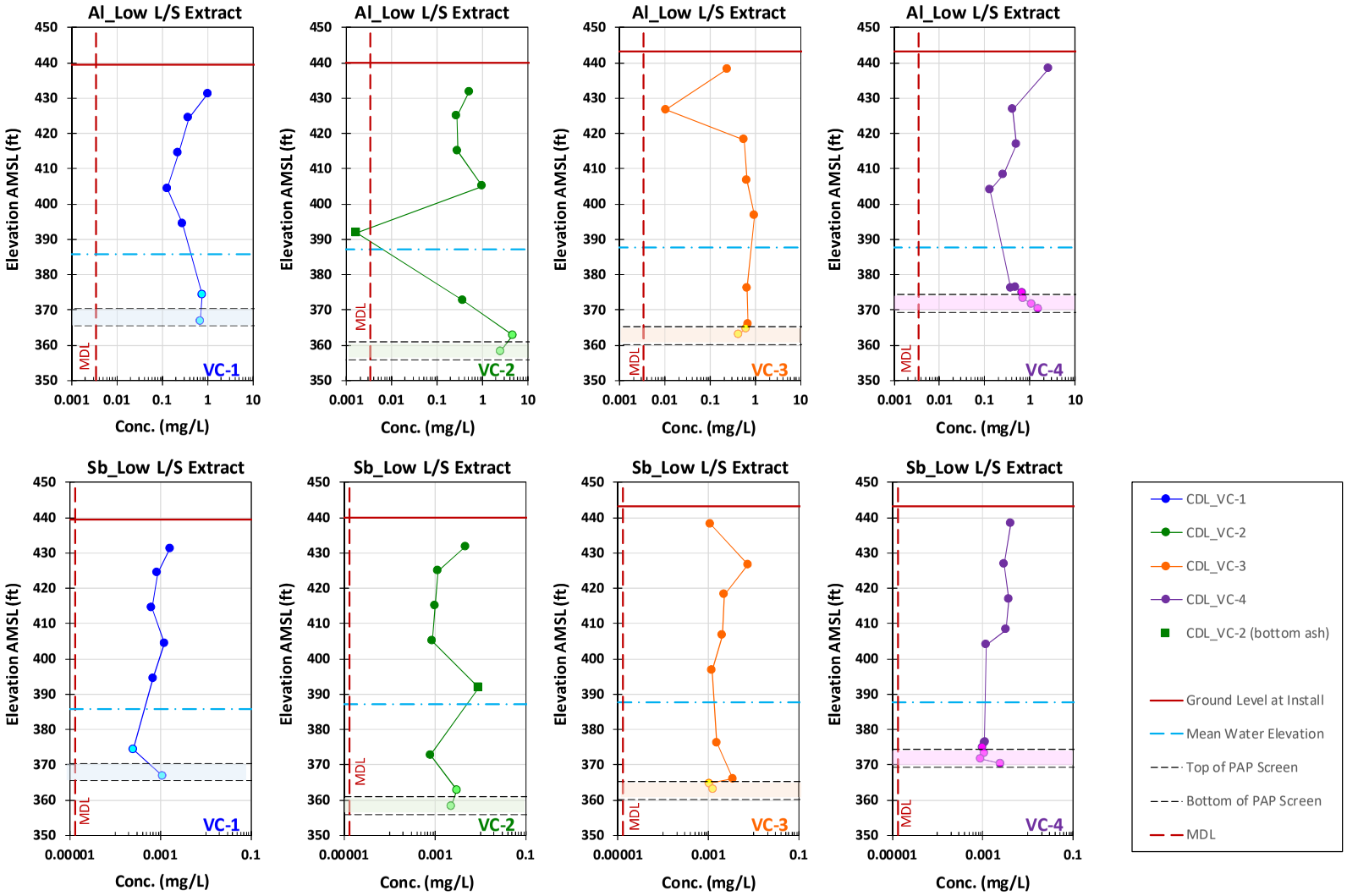

Figure B-3
Concentration profiles from in-field low L/S extractions: aluminum and antimony

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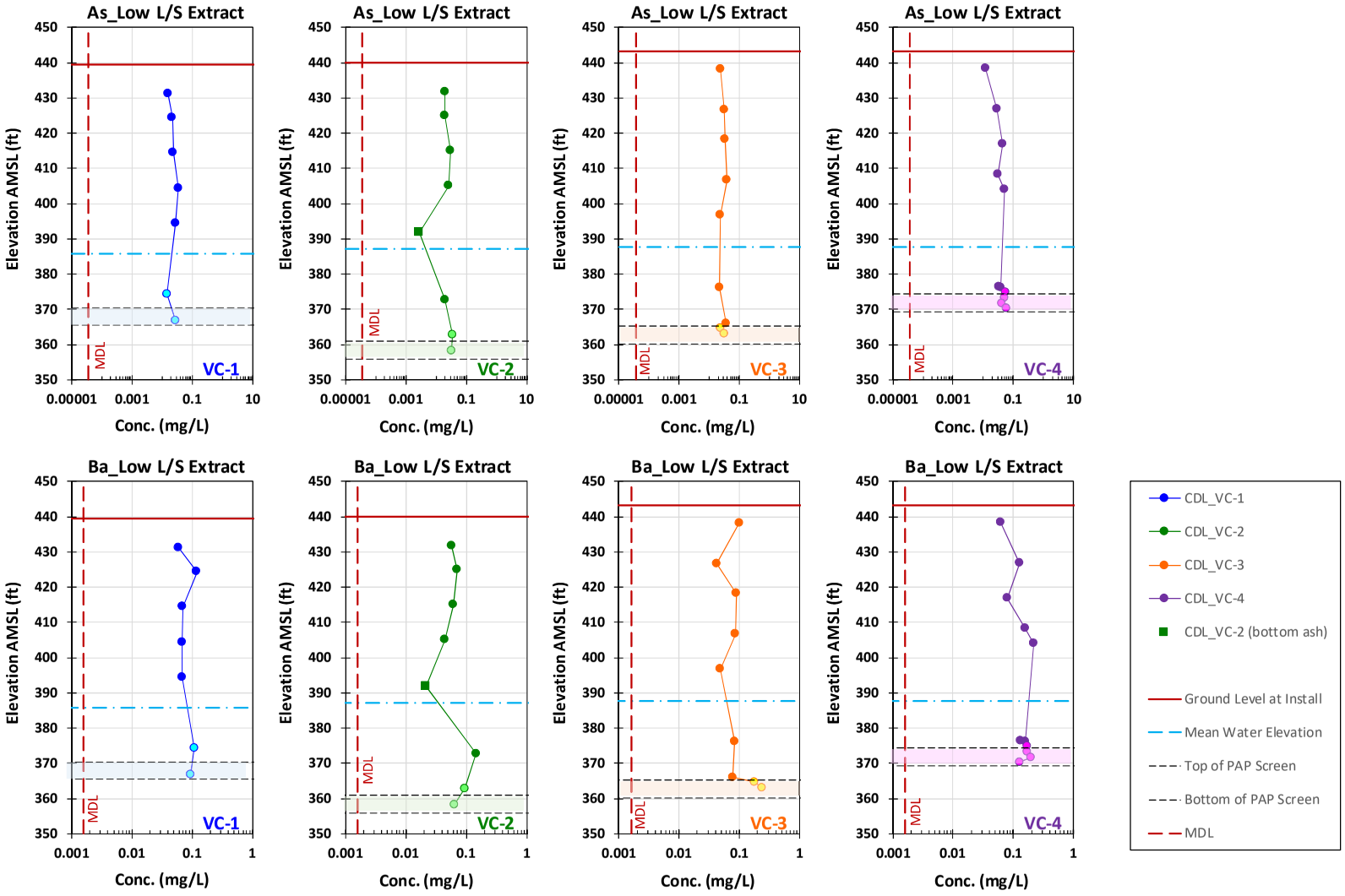

Figure B-4
Concentration profiles from in-field low L/S extractions: arsenic and barium

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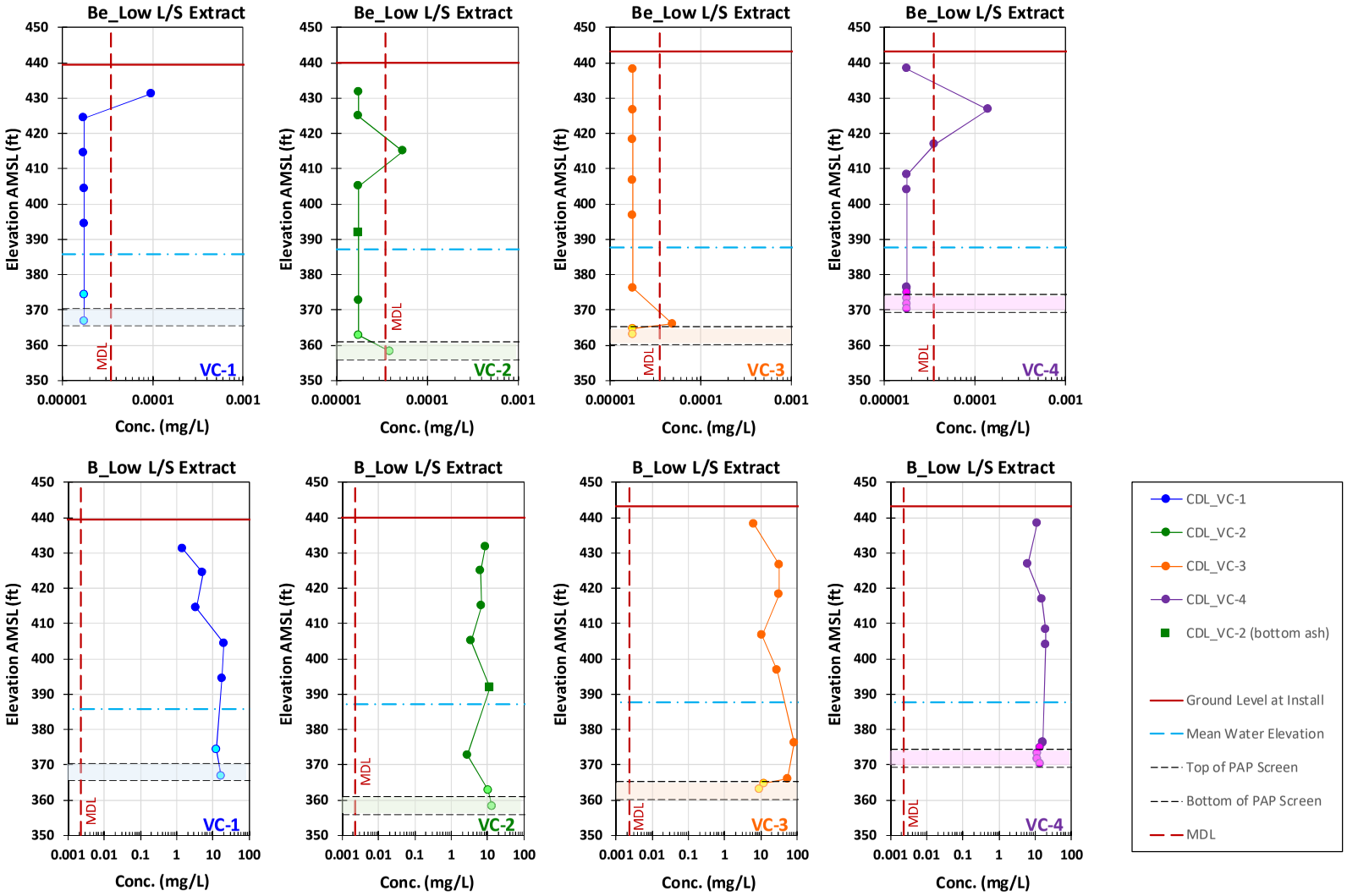

Figure B-5
Concentration profiles from in-field low L/S extractions: beryllium and boron

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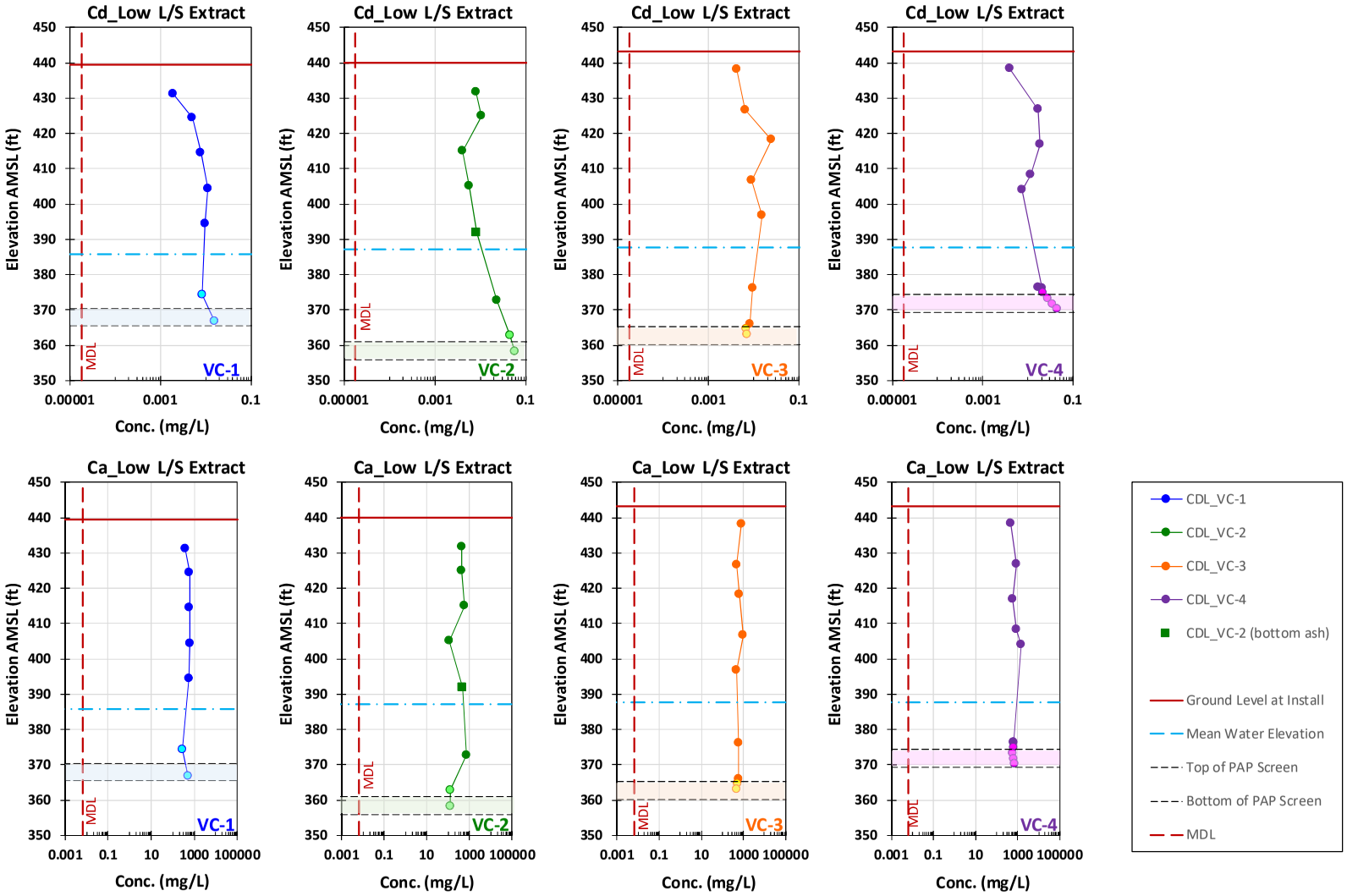

Figure B-6
Concentration profiles from in-field low L/S extractions: cadmium and calcium

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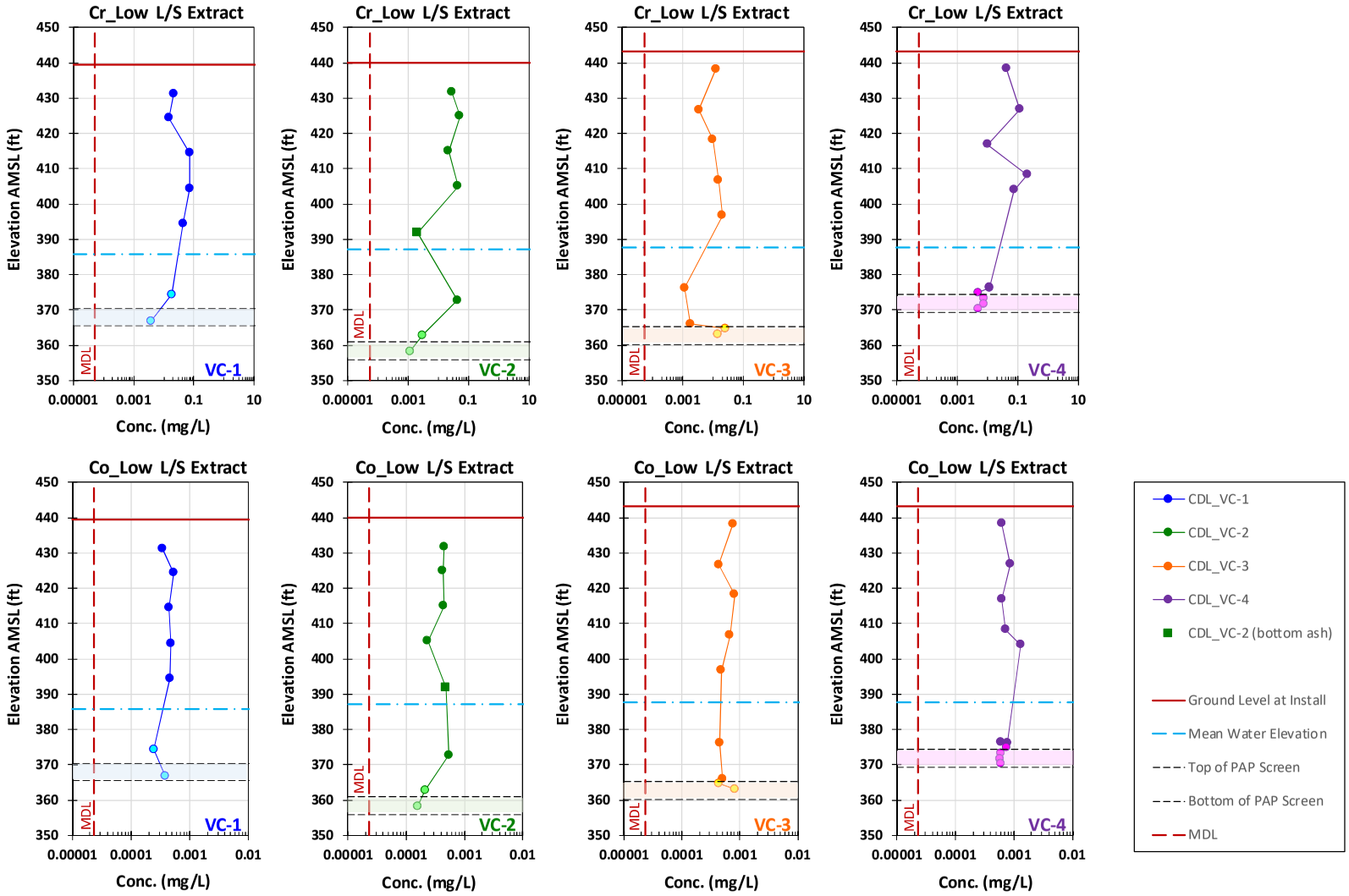

Figure B-7
Concentration profiles from in-field low L/S extractions: chromium and cobalt

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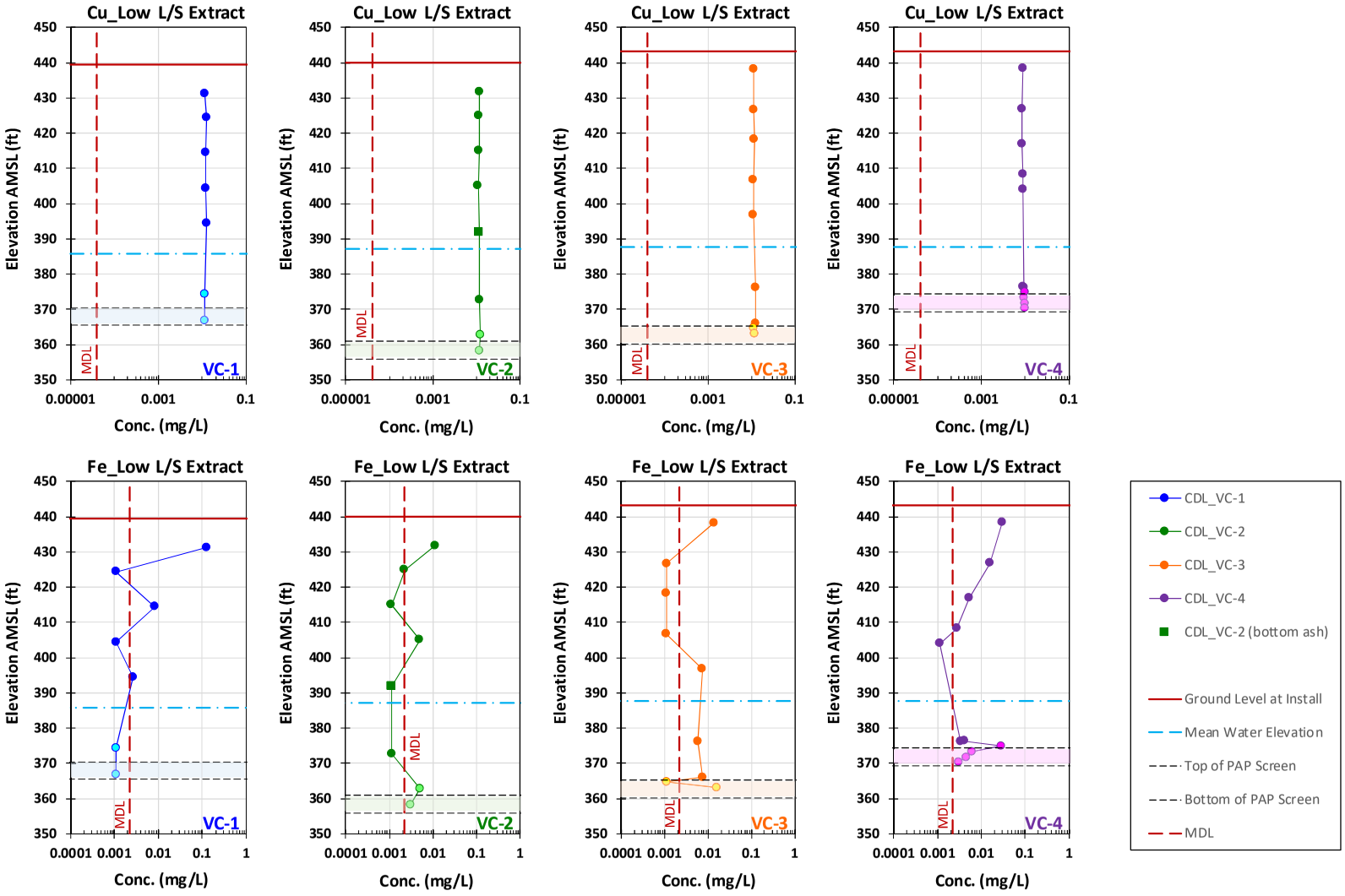

Figure B-8
Concentration profiles from in-field low L/S extractions: copper and iron

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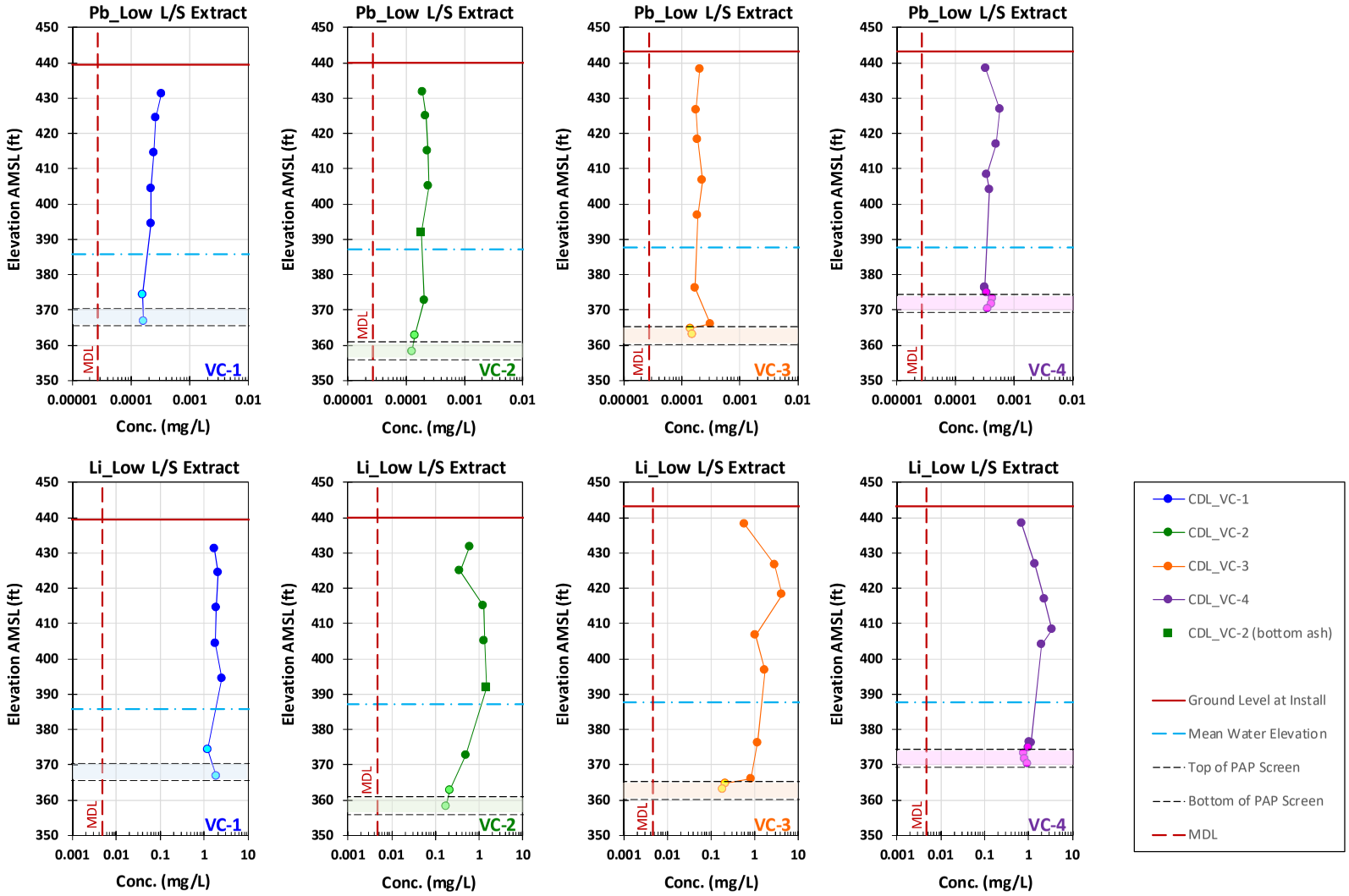

Figure B-9
Concentration profiles from in-field low L/S extractions: lead and lithium

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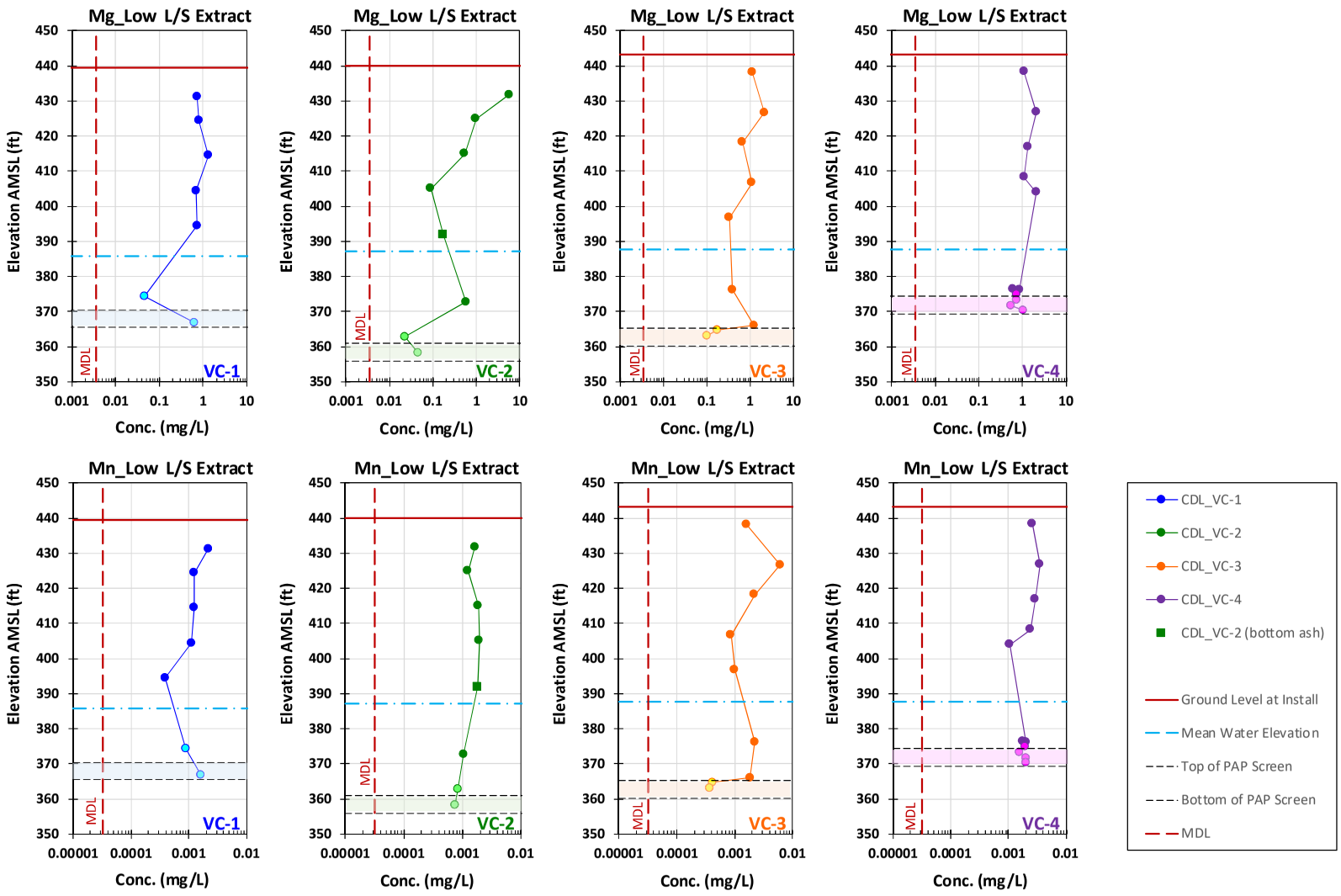

Figure B-10
Concentration profiles from in-field low L/S extractions: magnesium and manganese

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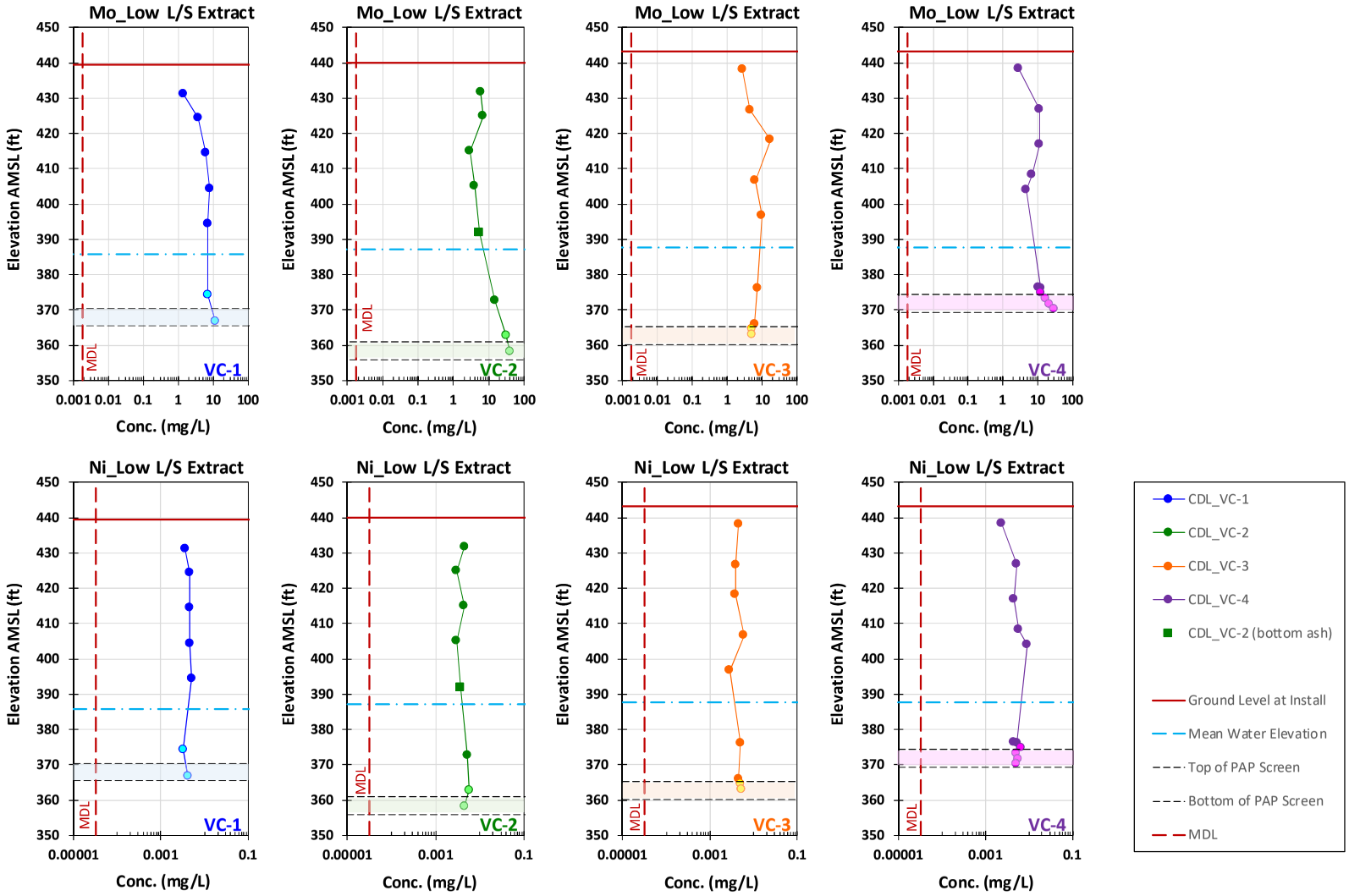

Figure B-11
Concentration profiles from in-field low L/S extractions: molybdenum and nickel

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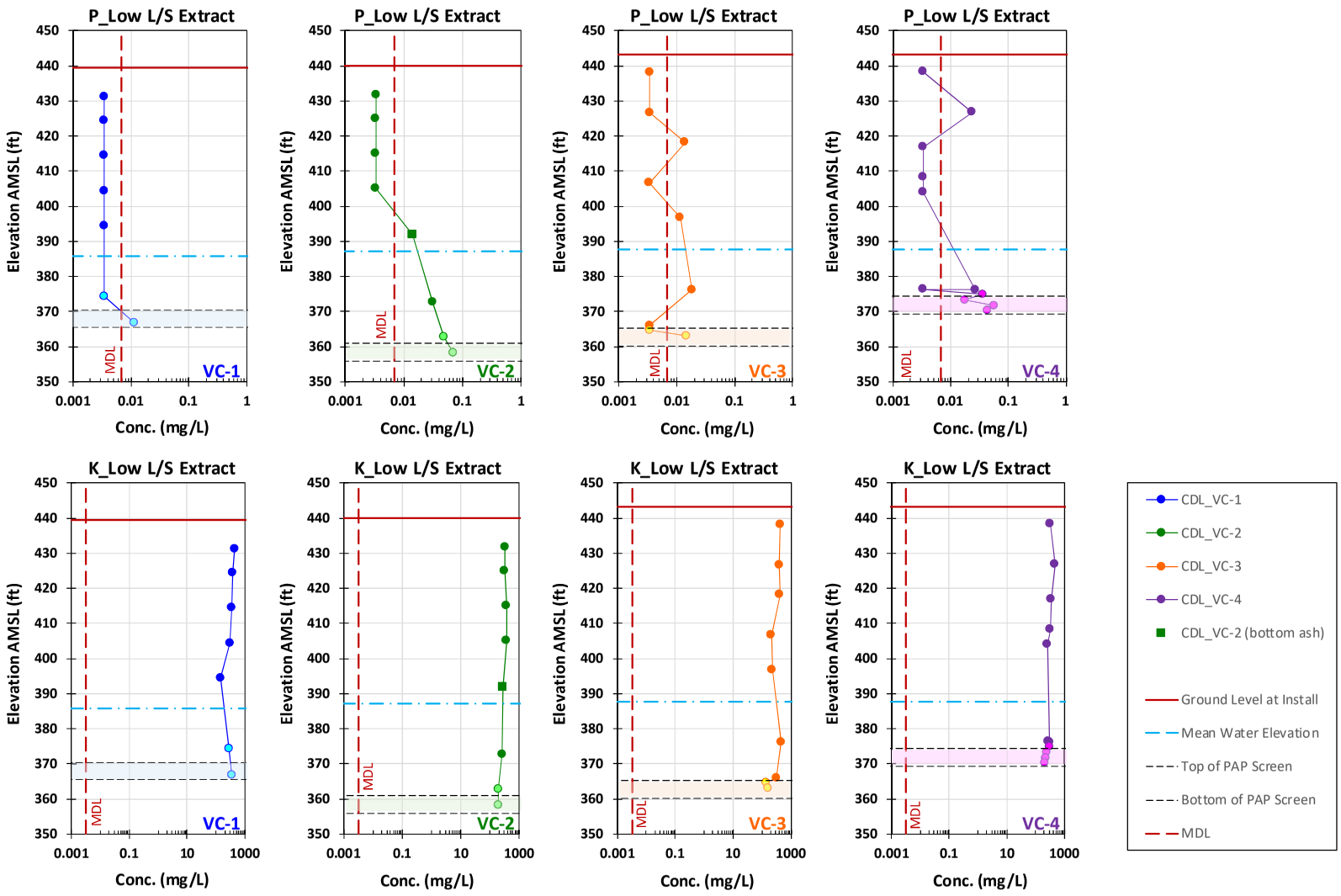

Figure B-12
Concentration profiles from in-field low L/S extractions: phosphorus and potassium

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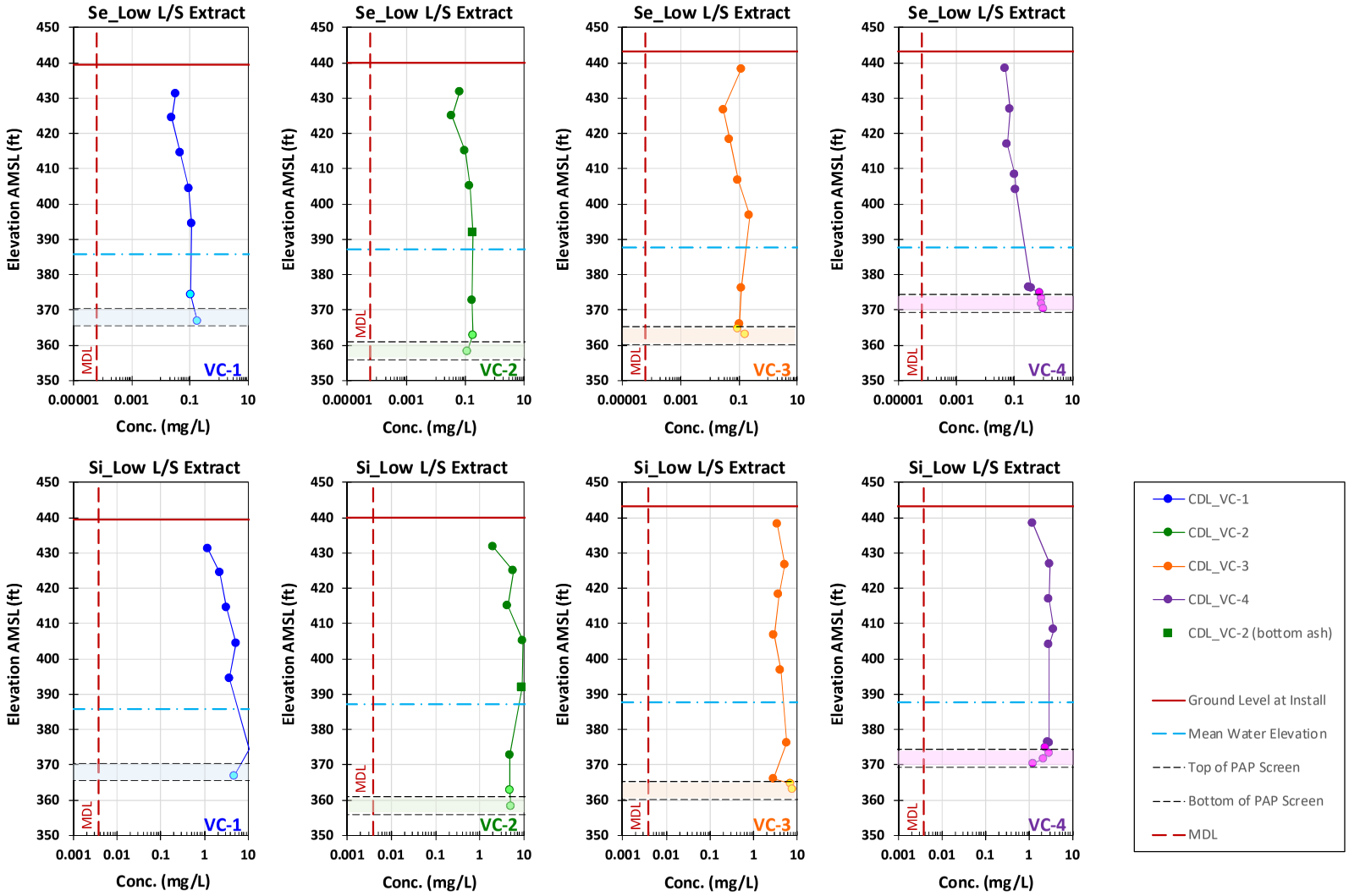

Figure B-13
Concentration profiles from in-field low L/S extractions: selenium and silicon

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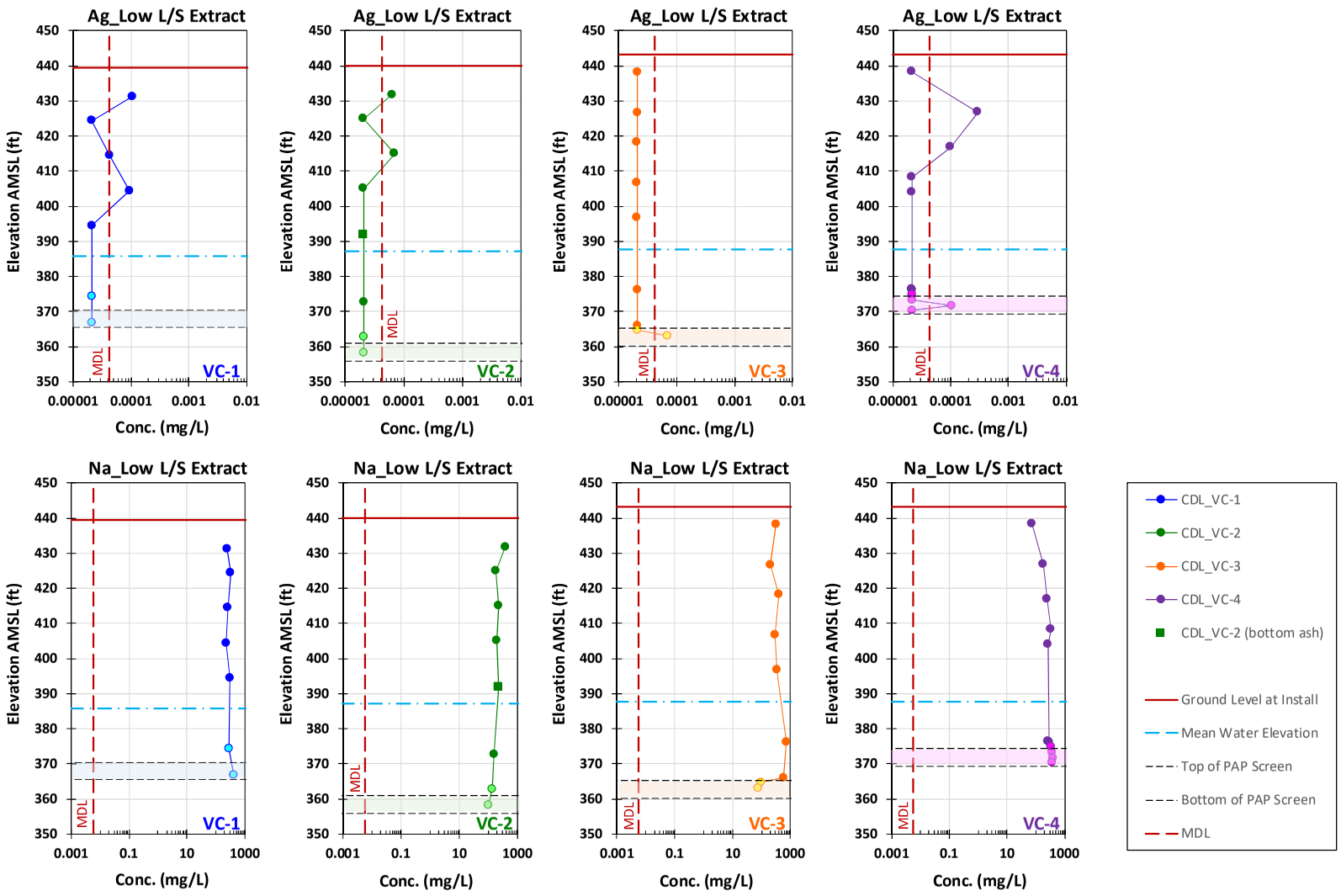

Figure B-14
Concentration profiles from in-field low L/S extractions: silver and sodium

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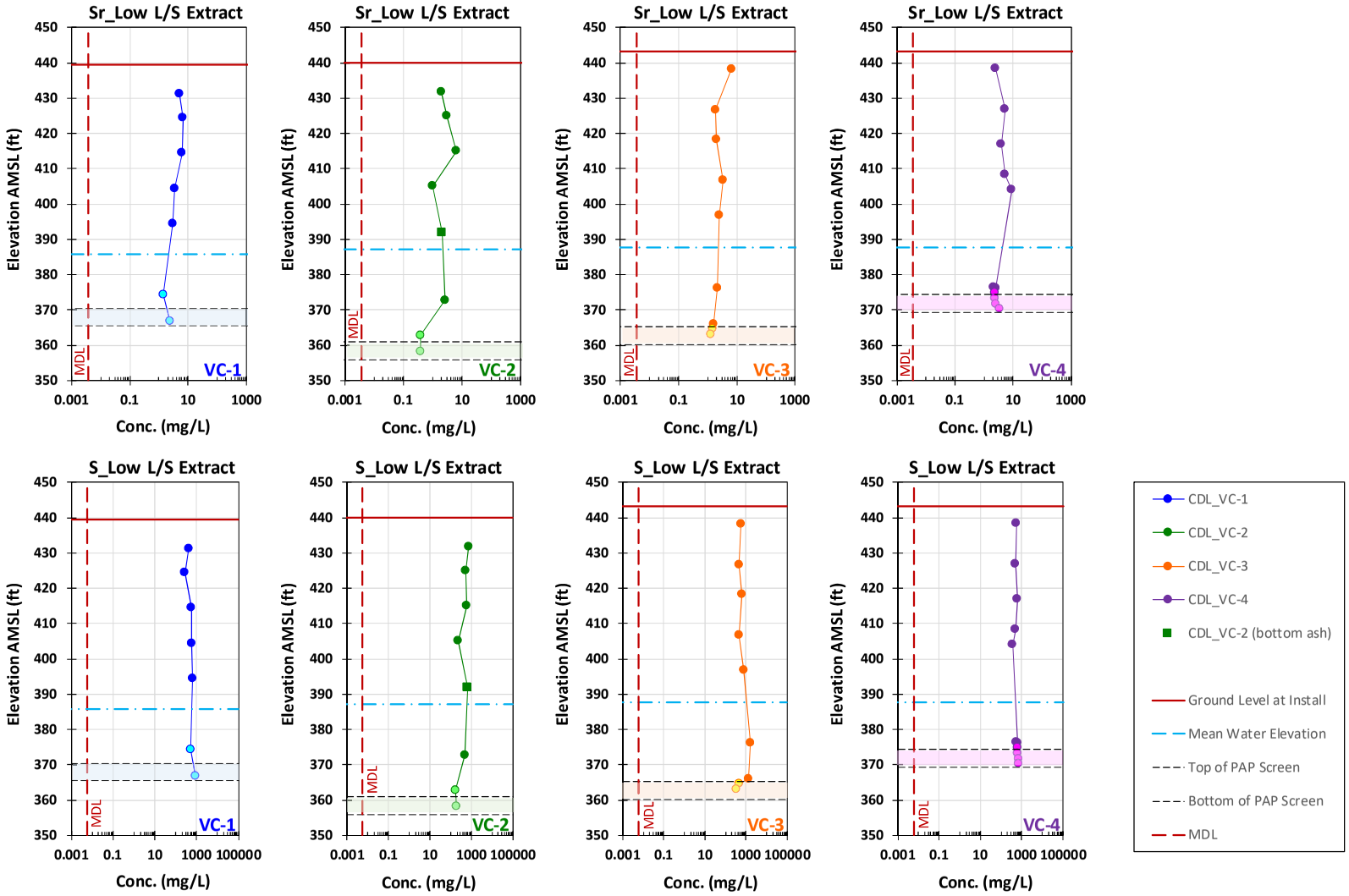

Figure B-15
Concentration profiles from in-field low L/S extractions: strontium and sulfur

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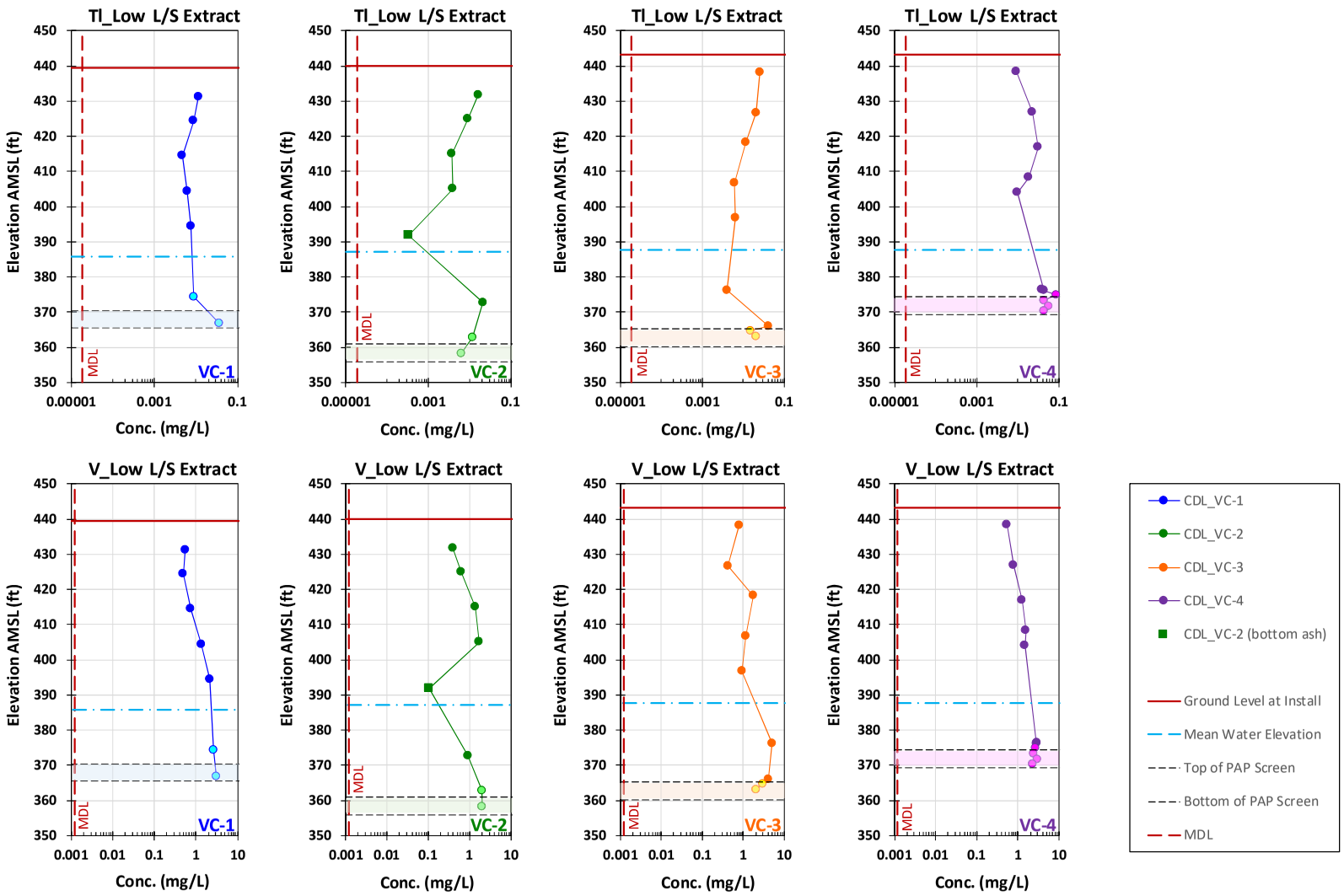

Figure B-16
Concentration profiles from in-field low L/S extractions: thallium and vanadium

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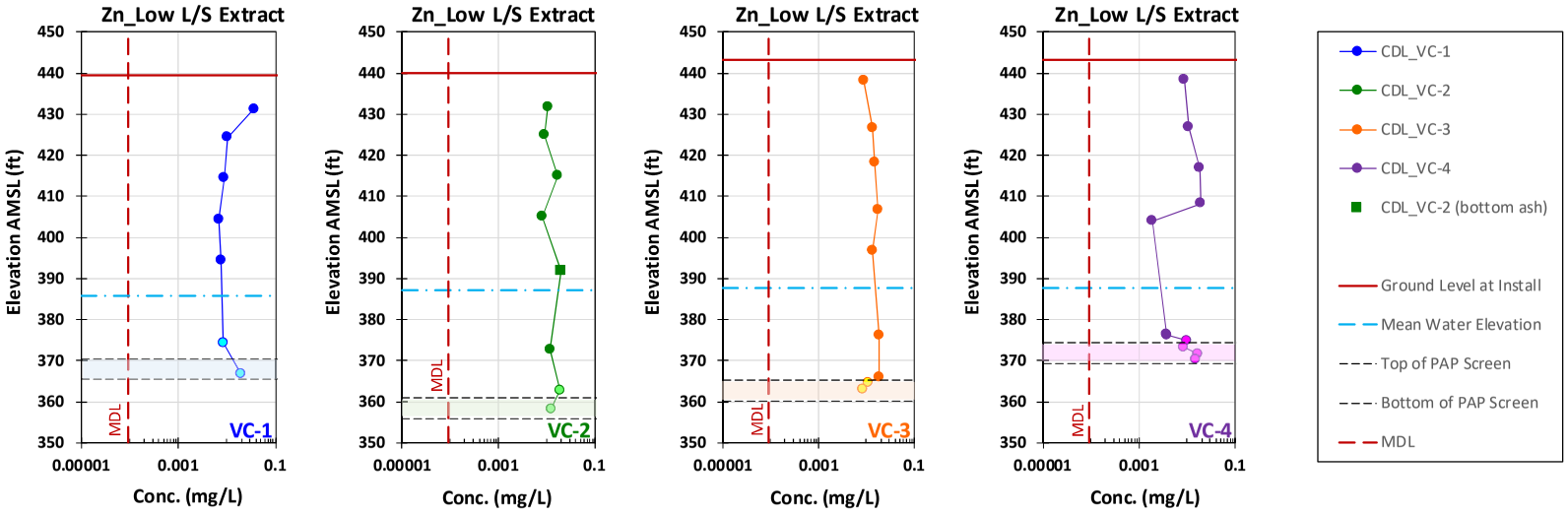

Figure B-17
Concentration profiles from in-field low L/S extractions: zinc

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B-2 Standardized Concentration Profiles of In-field Low L/S Extractions Using the Global Material Mean and Standard Deviation

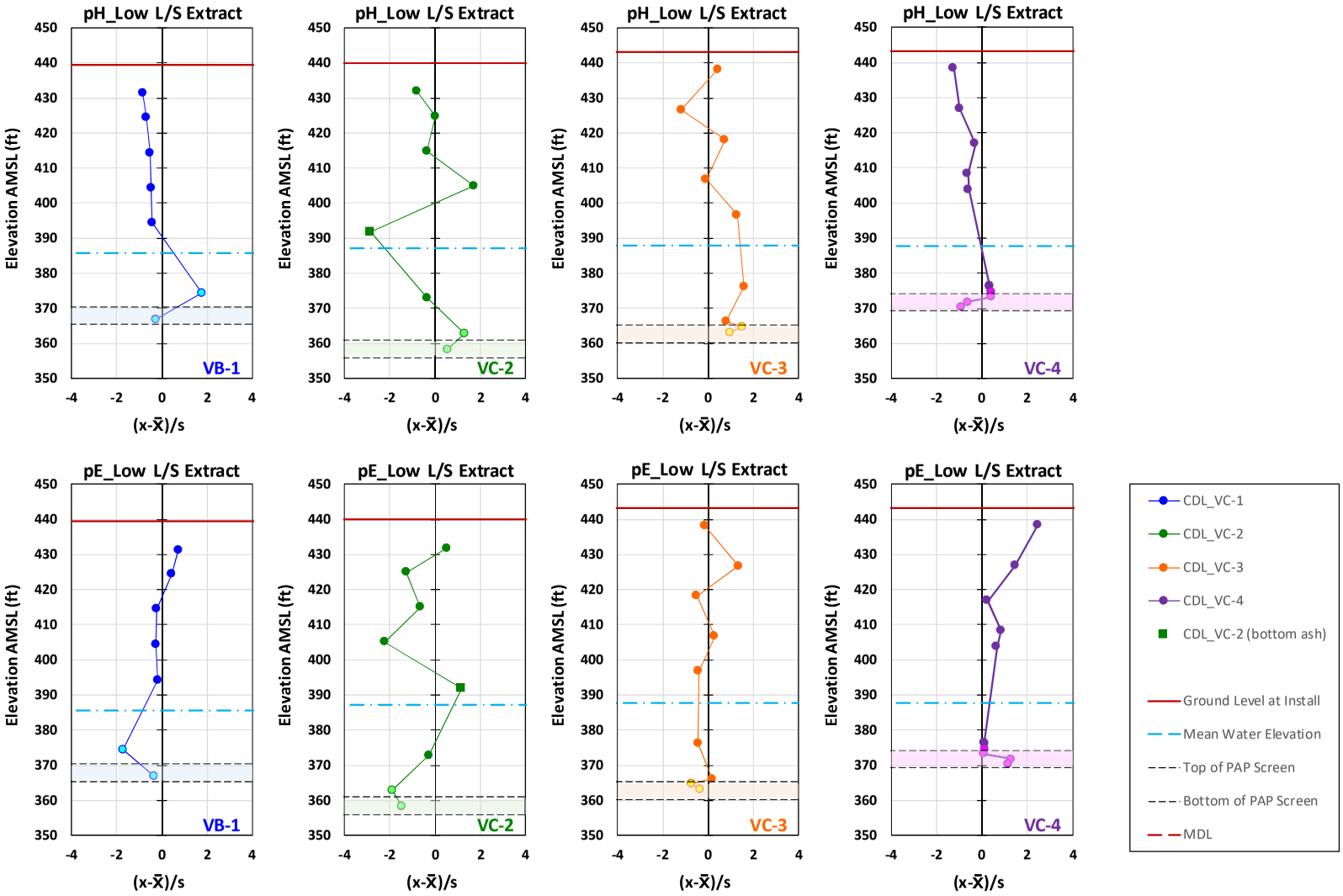

Figure B-18
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: pH and pE

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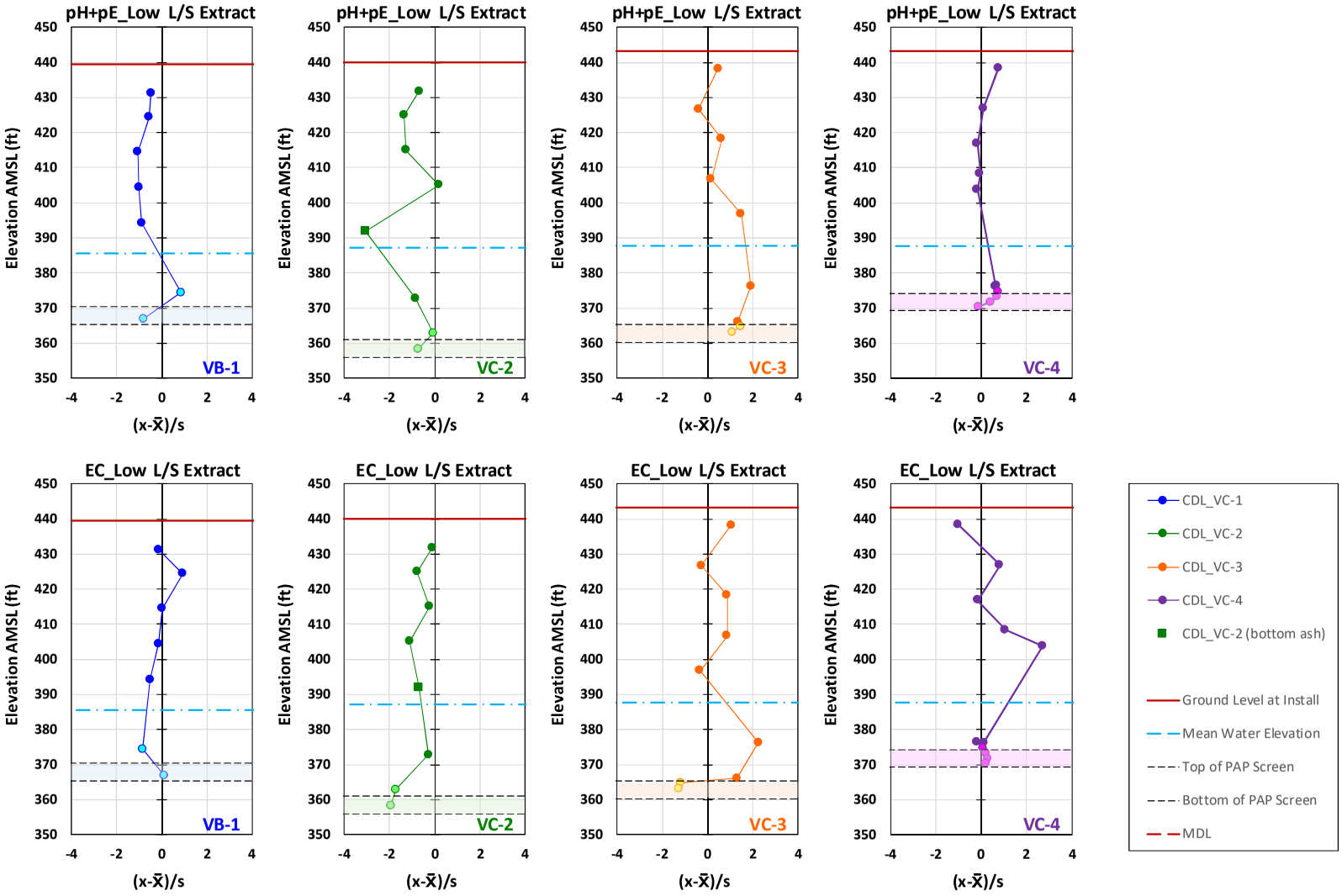

Figure B-19
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: pH+pE and electrical conductivity

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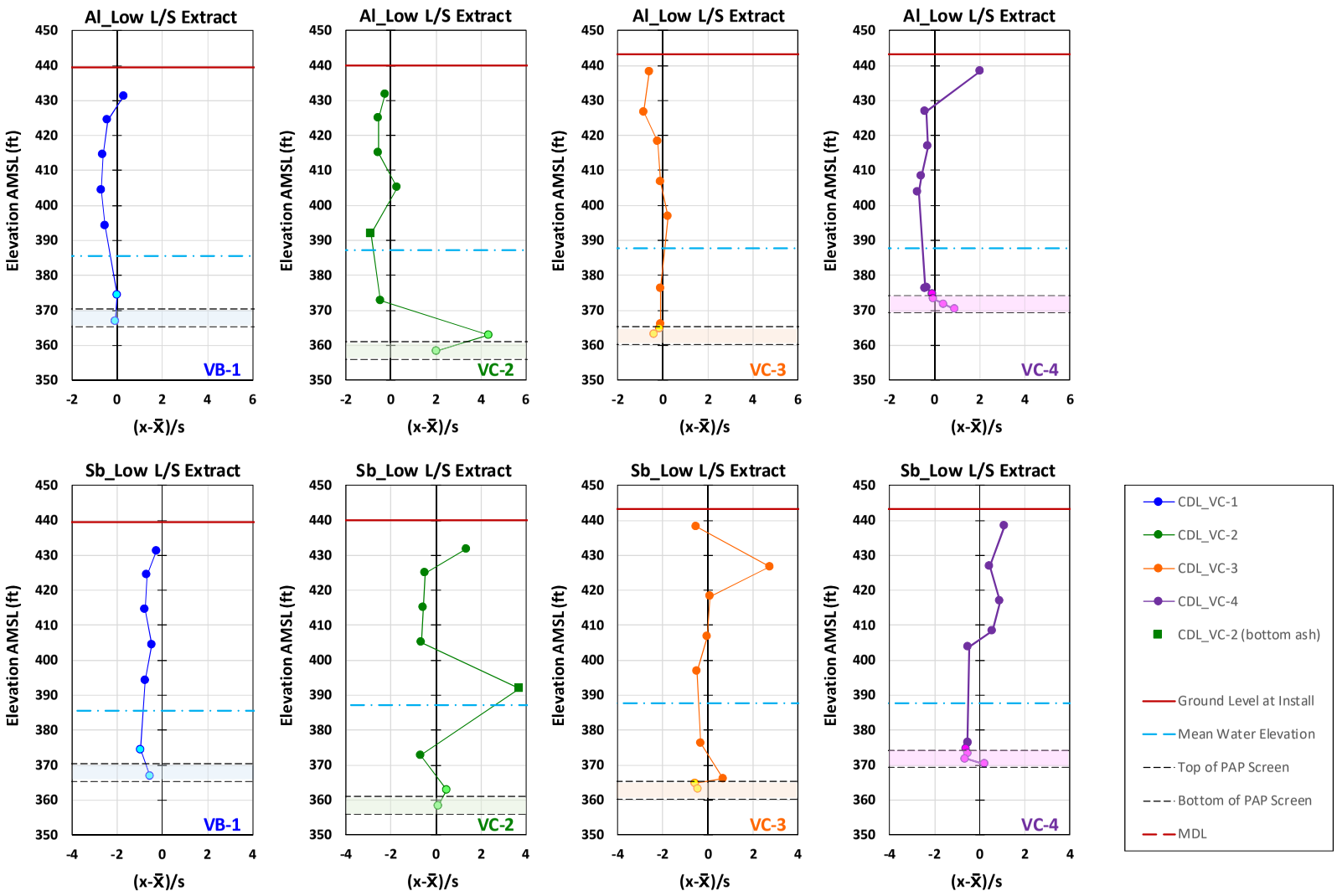

Figure B-20
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: aluminum and antimony

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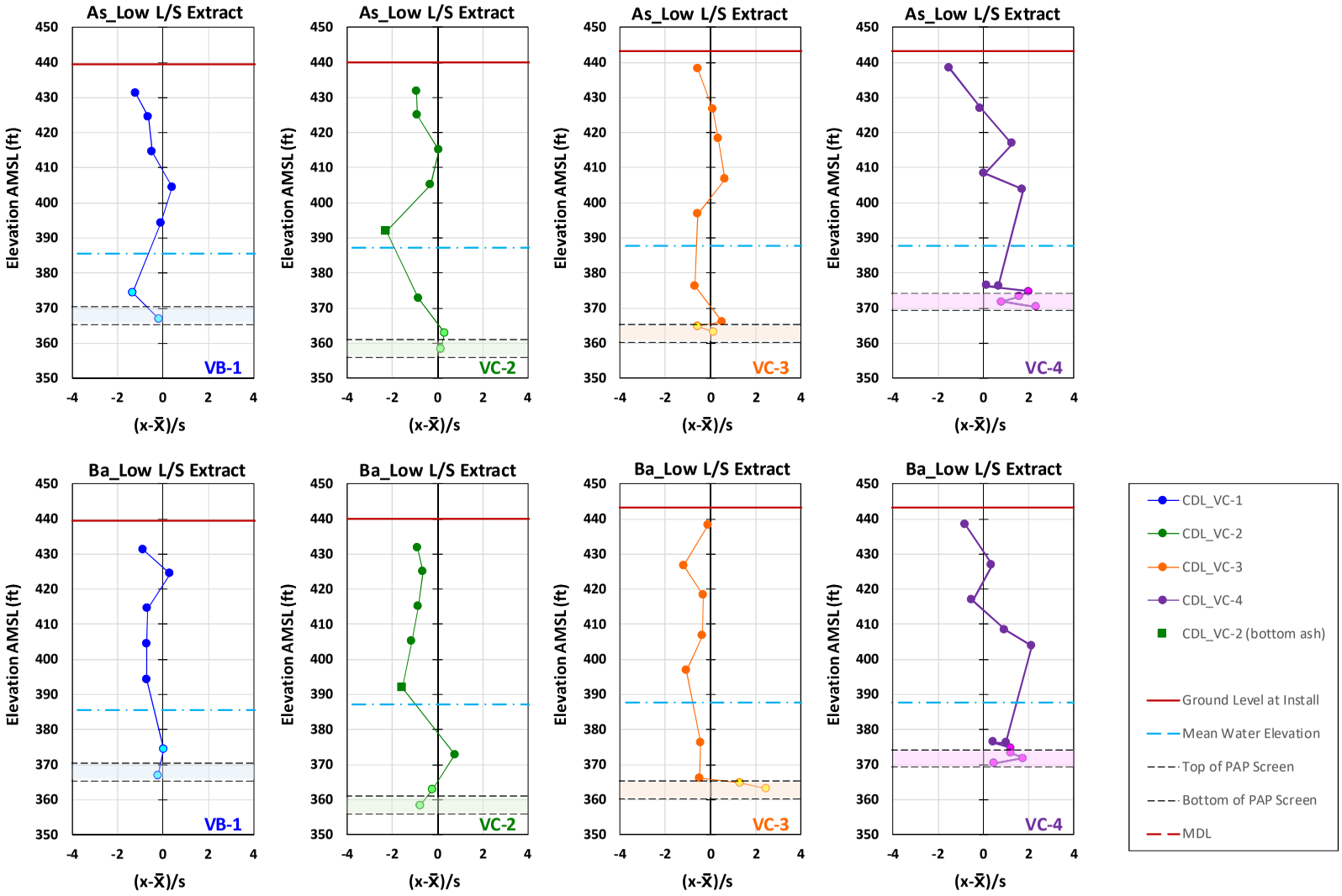

Figure B-21
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: arsenic and barium

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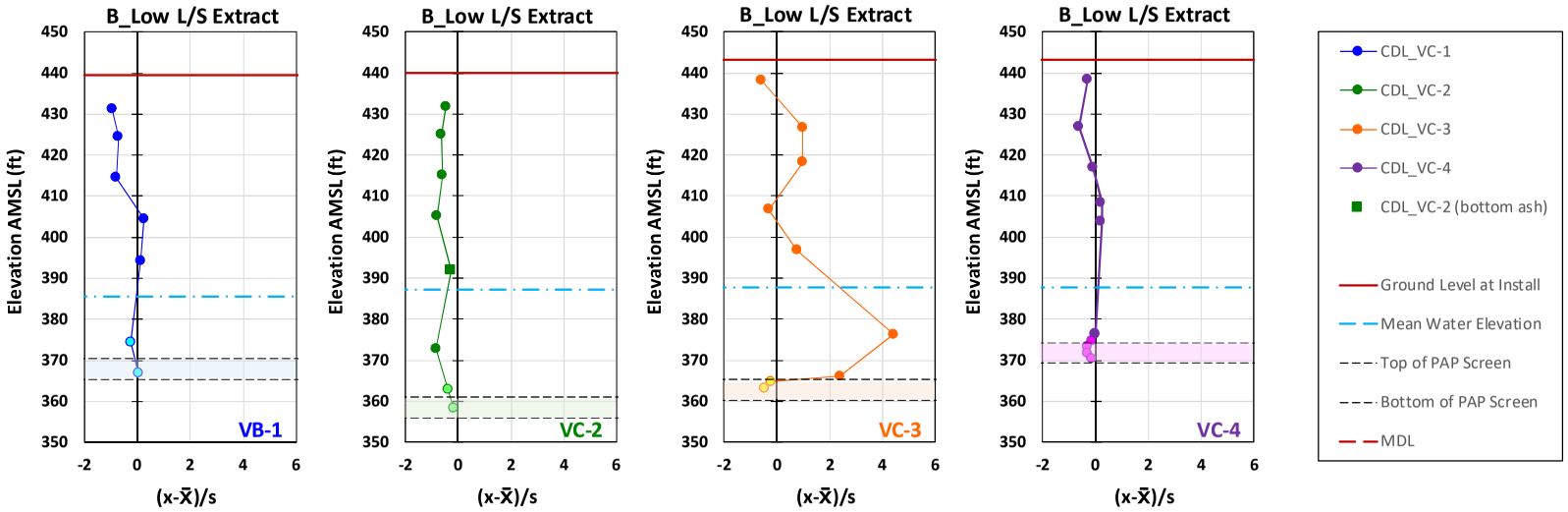

Figure B-22
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: beryllium and boron

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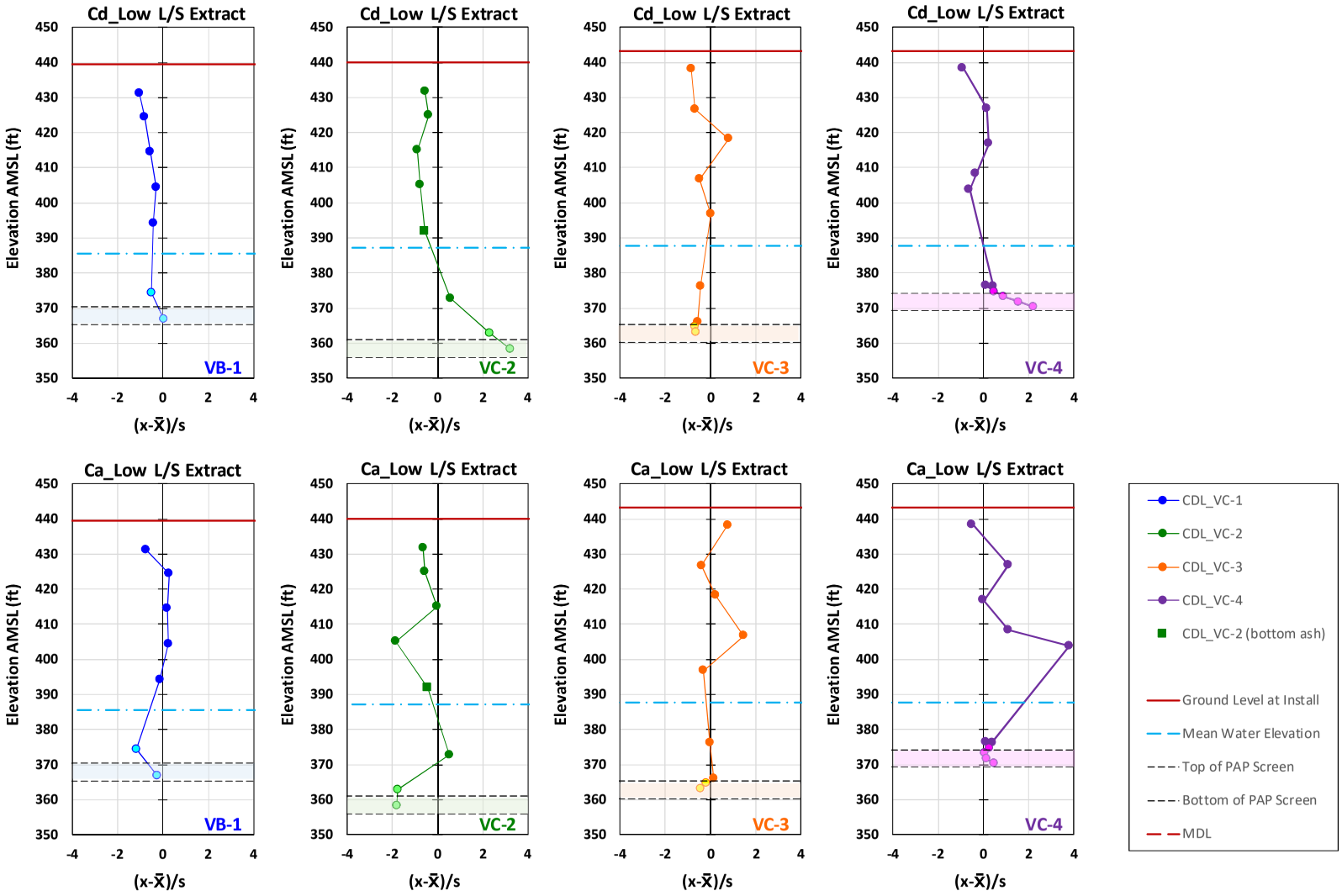

Figure B-23
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: cadmium and calcium

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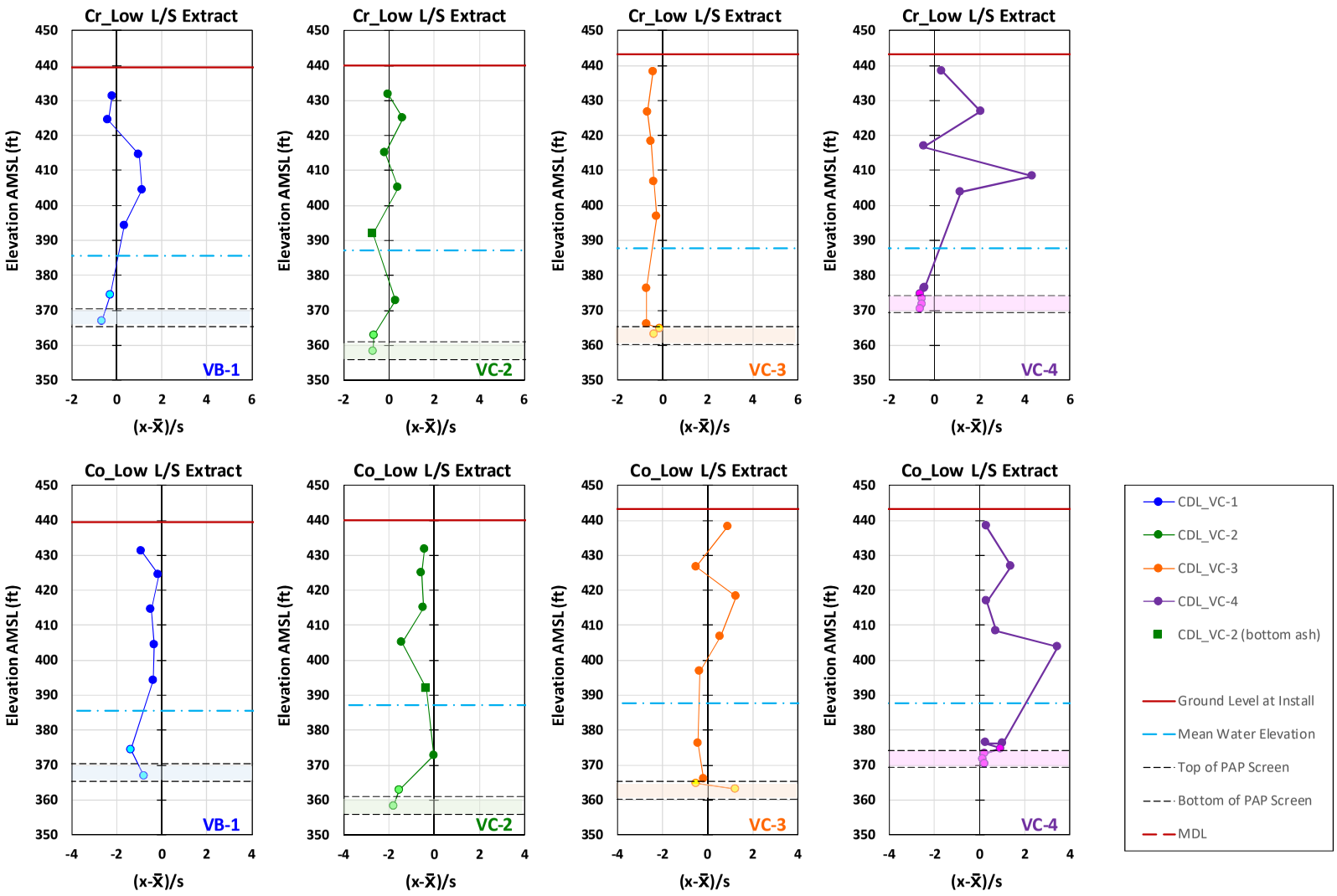

Figure B-24
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: chromium and cobalt

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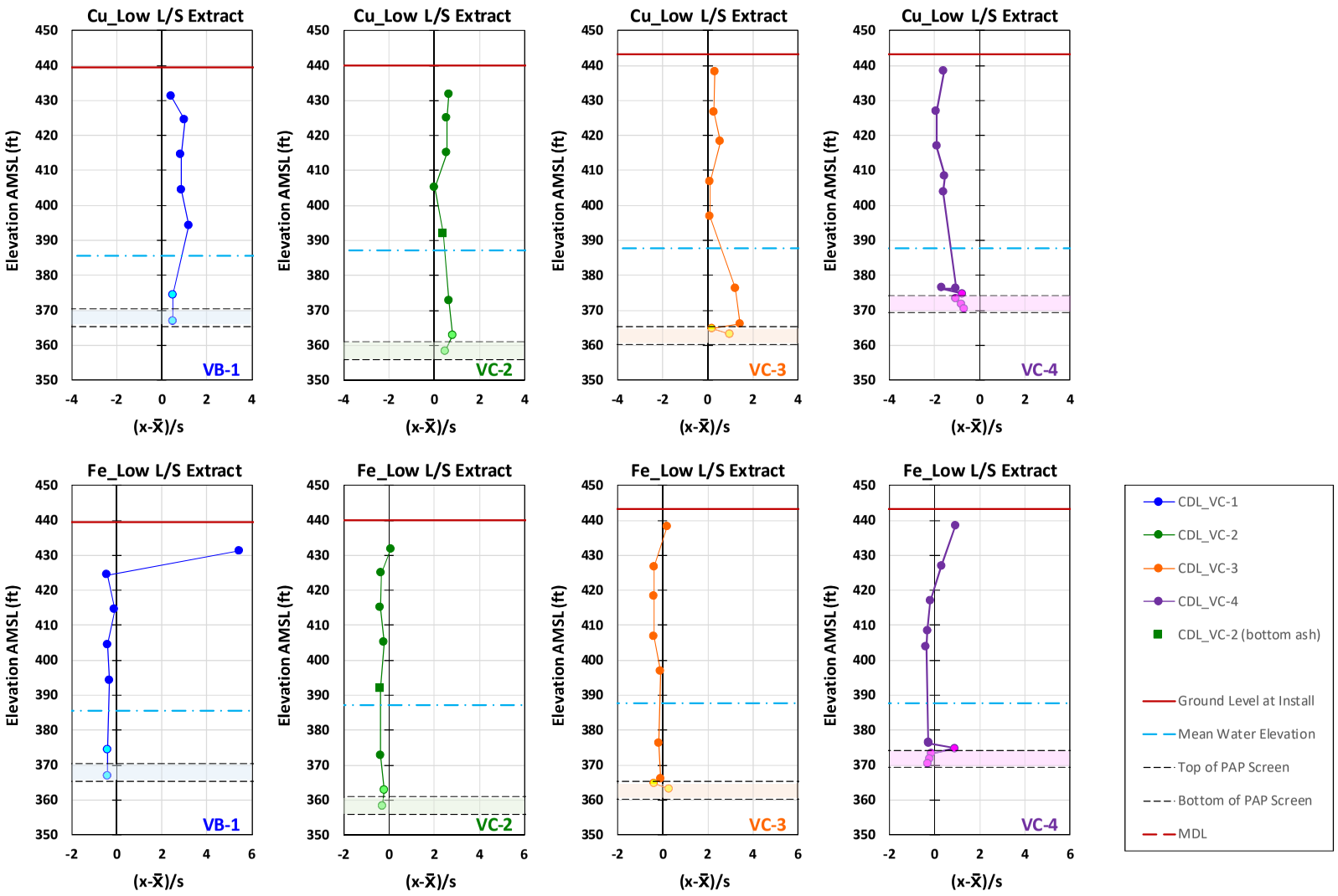

Figure B-25
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: copper and iron

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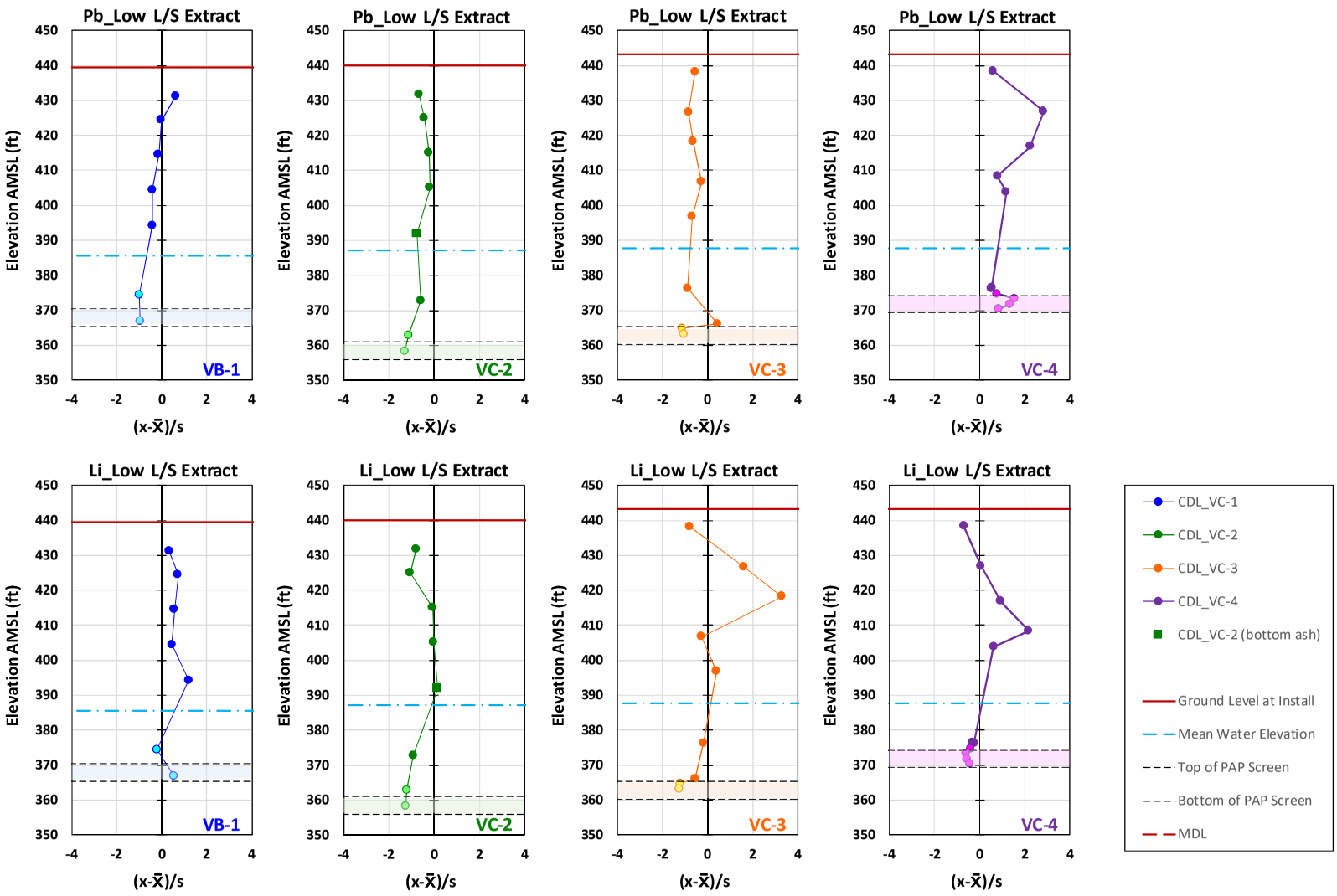

Figure B-26
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: lead and lithium

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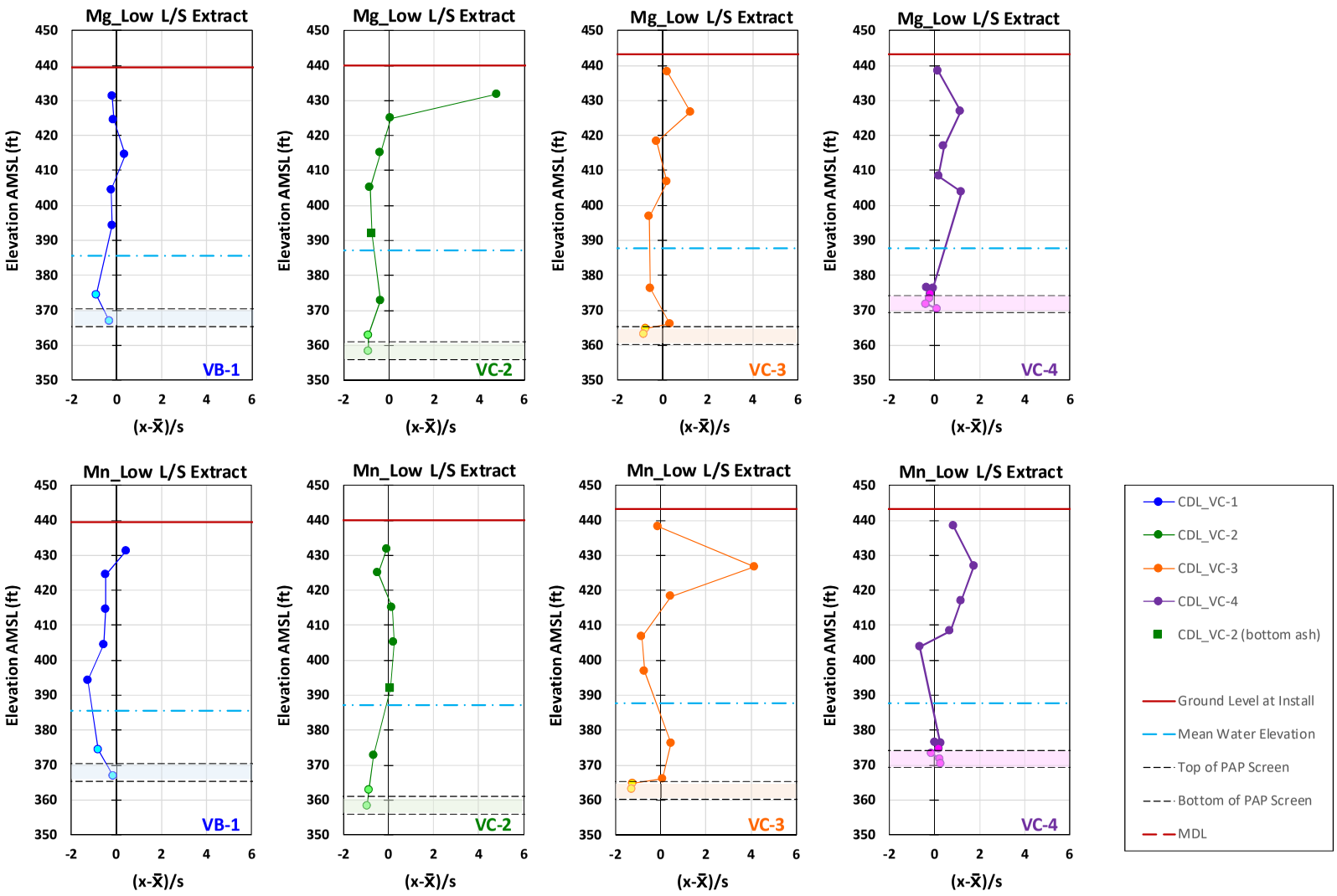

Figure B-27
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: magnesium and manganese

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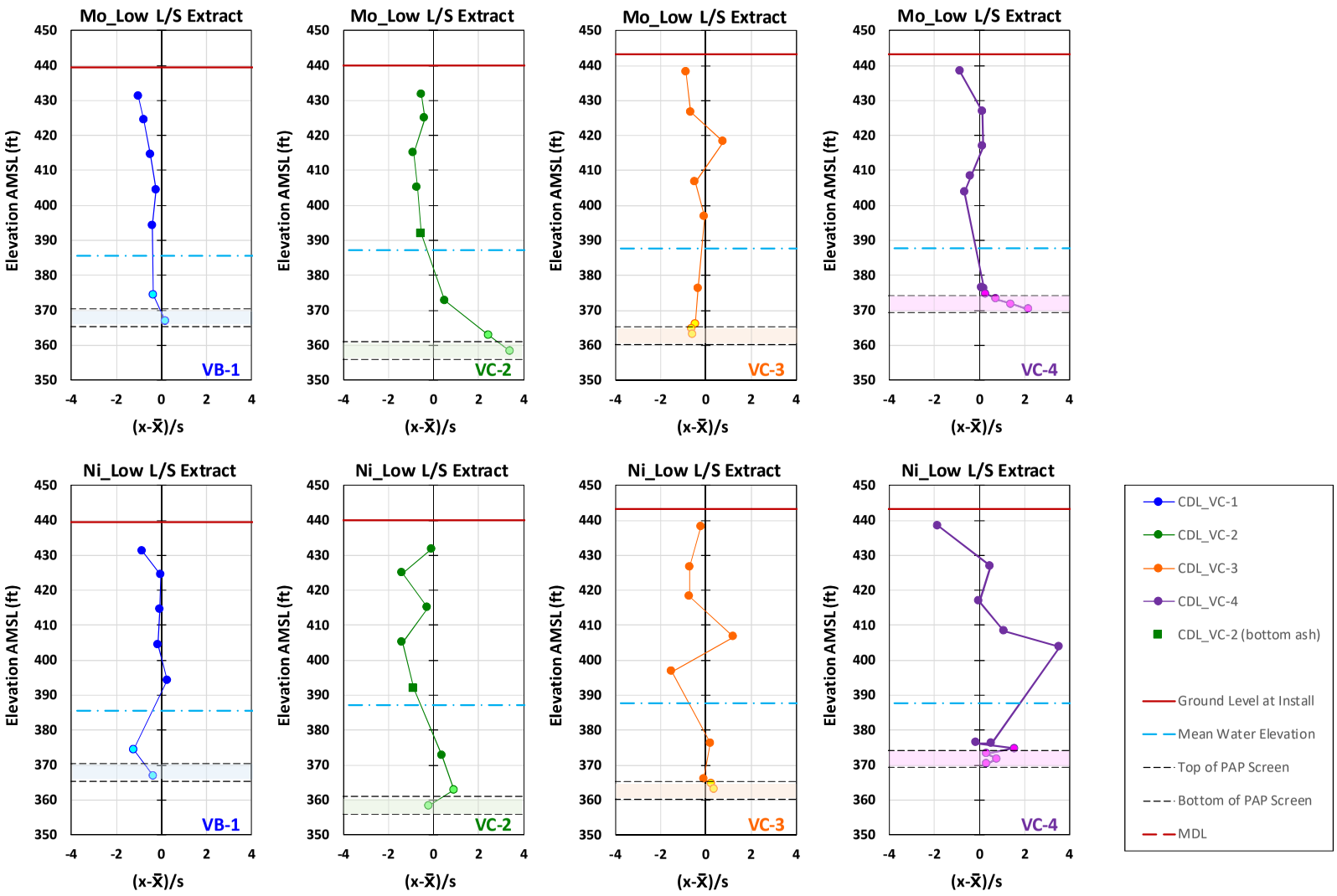

Figure B-28
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: molybdenum and nickel

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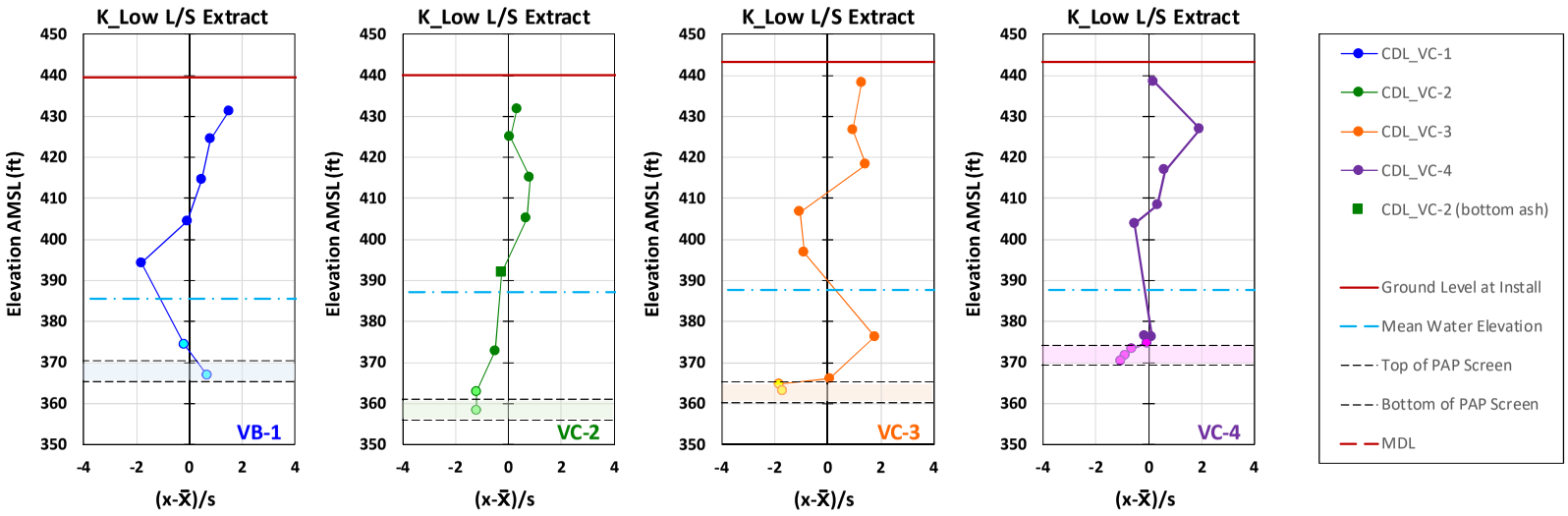

Figure B-29
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: potassium

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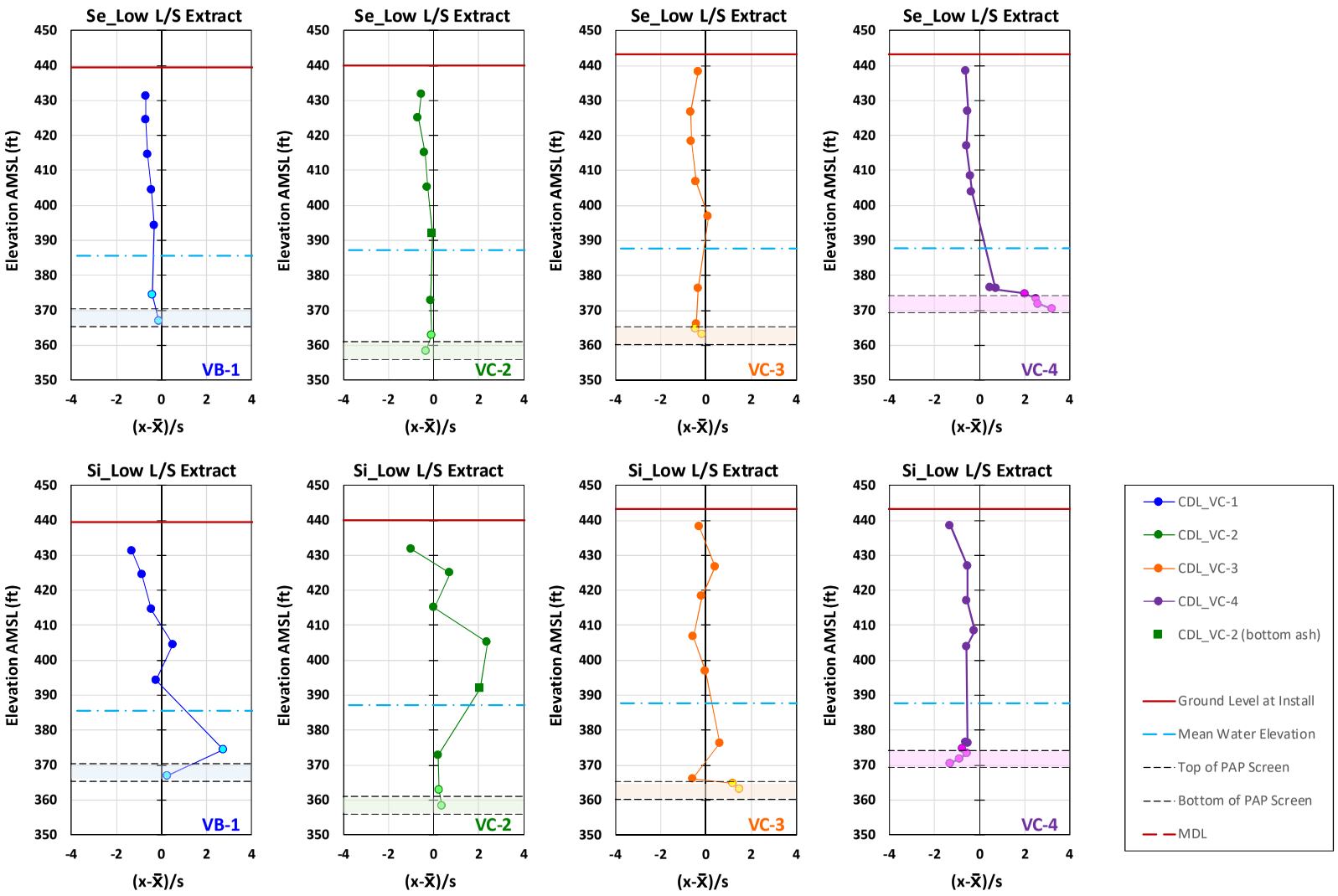

Figure B-30
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: selenium and silicon

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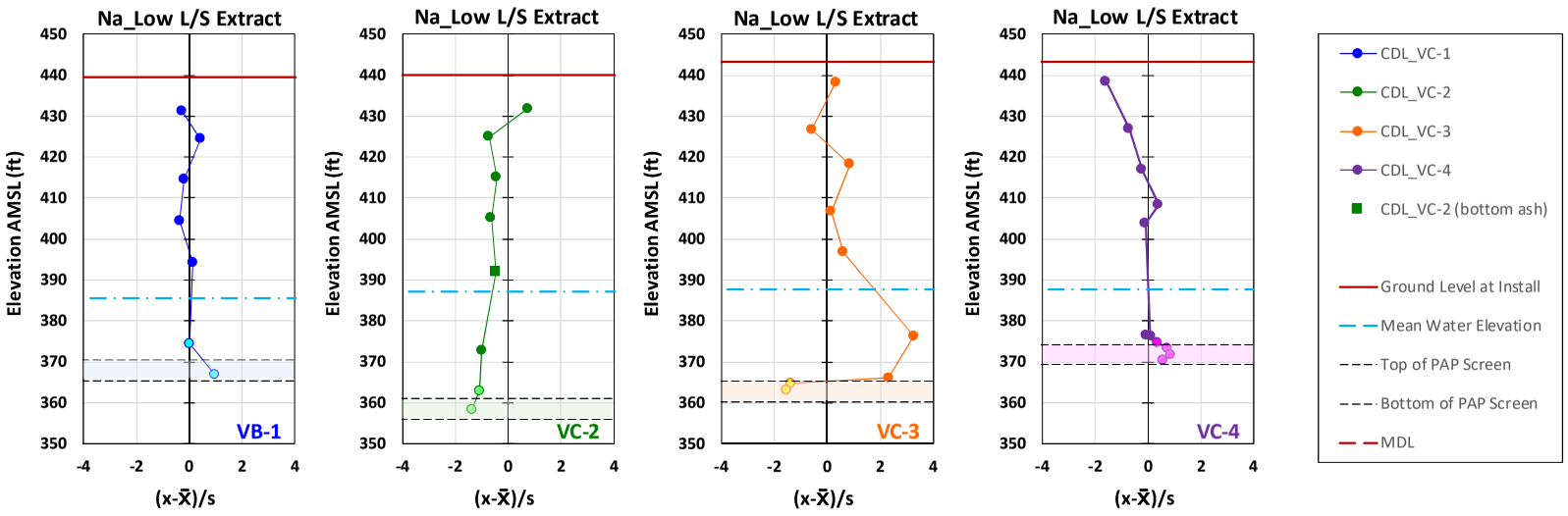

Figure B-31
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: sodium

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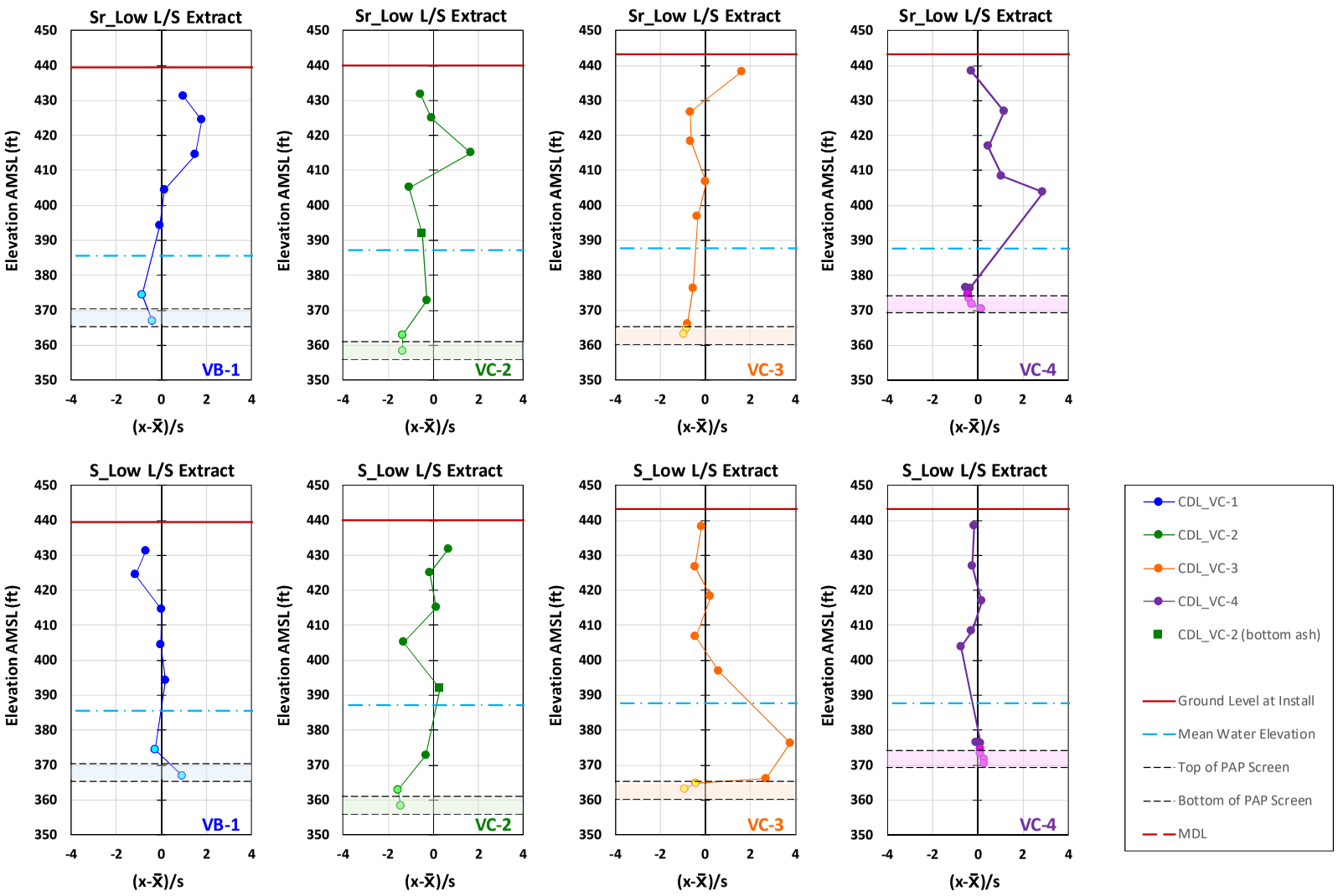

Figure B-32
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: strontium and sulfur

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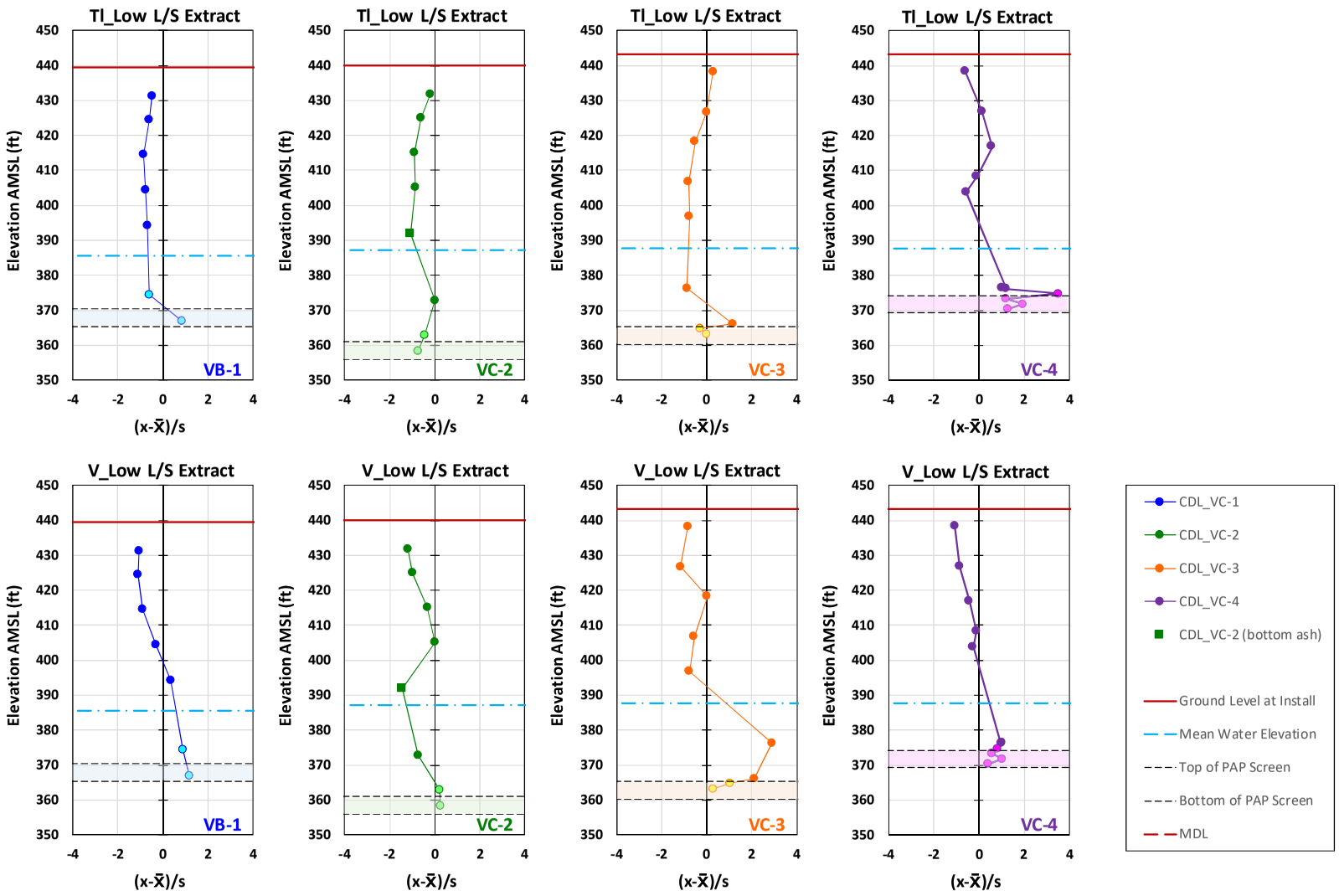

Figure B-33
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: thallium and vanadium

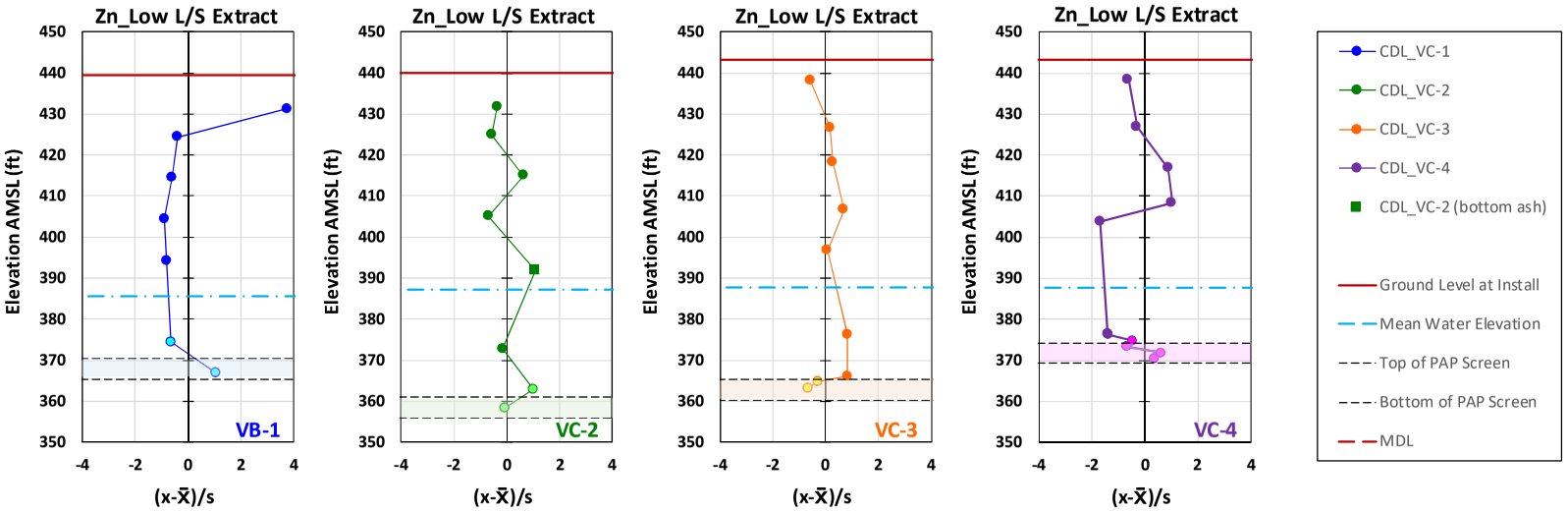

Figure B-34
Profiles from in-field low L/S extractions standardized using the global material mean and standard deviation: zinc

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B-3 Comparison of Standardized Release Profiles for Low L/S and L/S≈1 Extractions

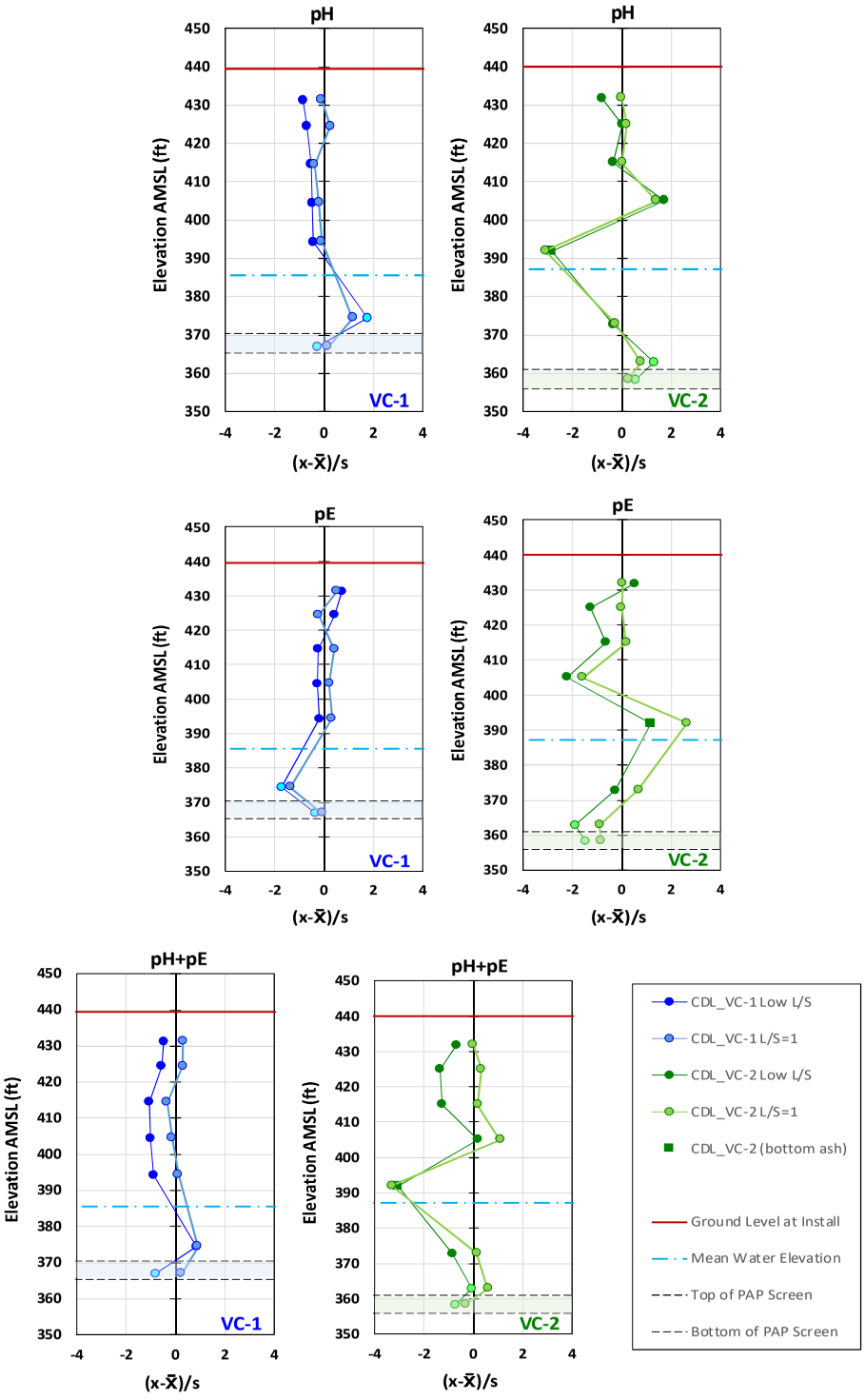

Figure B-35
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: pH, pE, and pH+pE

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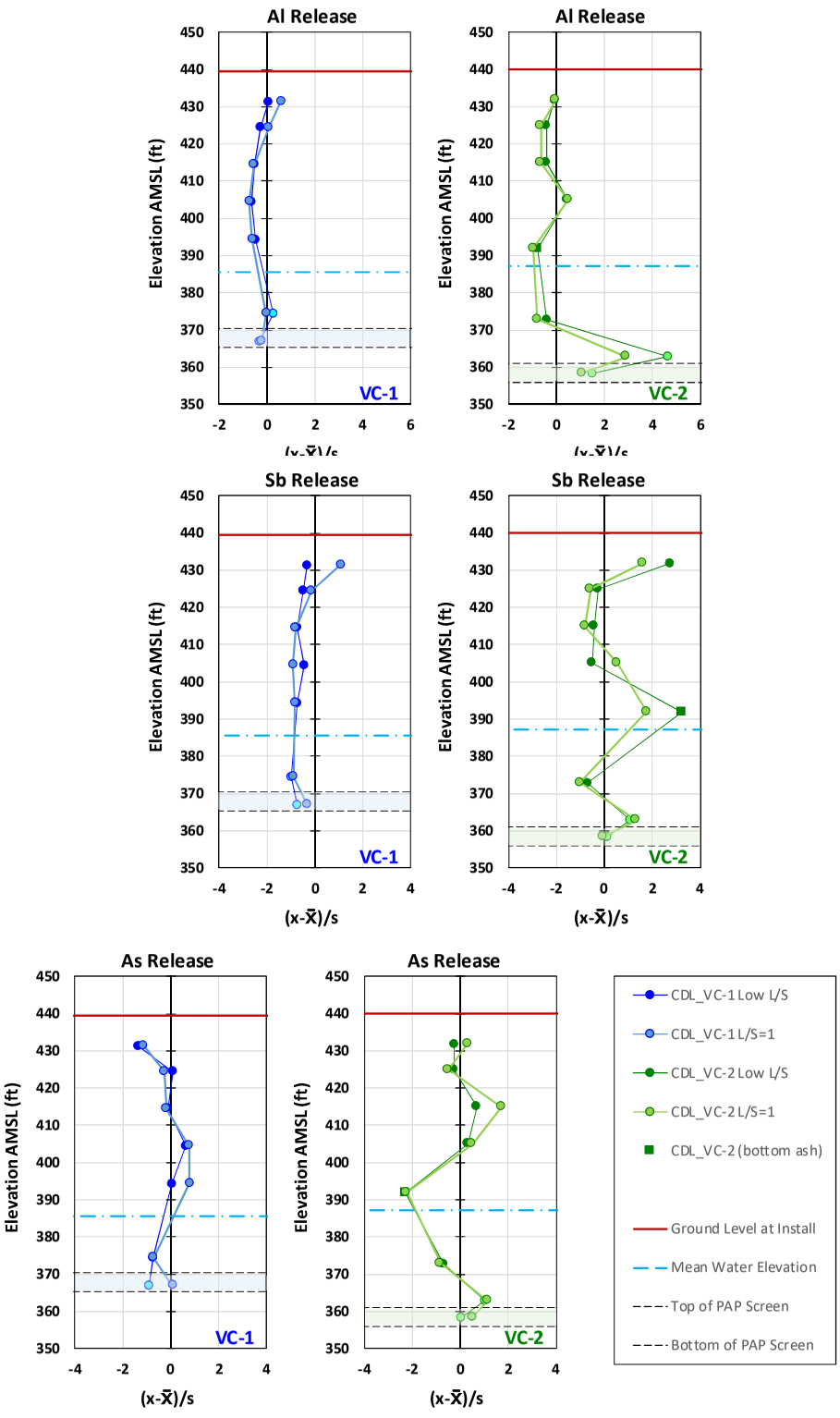

Figure B-36
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: aluminum, antimony, and arsenic

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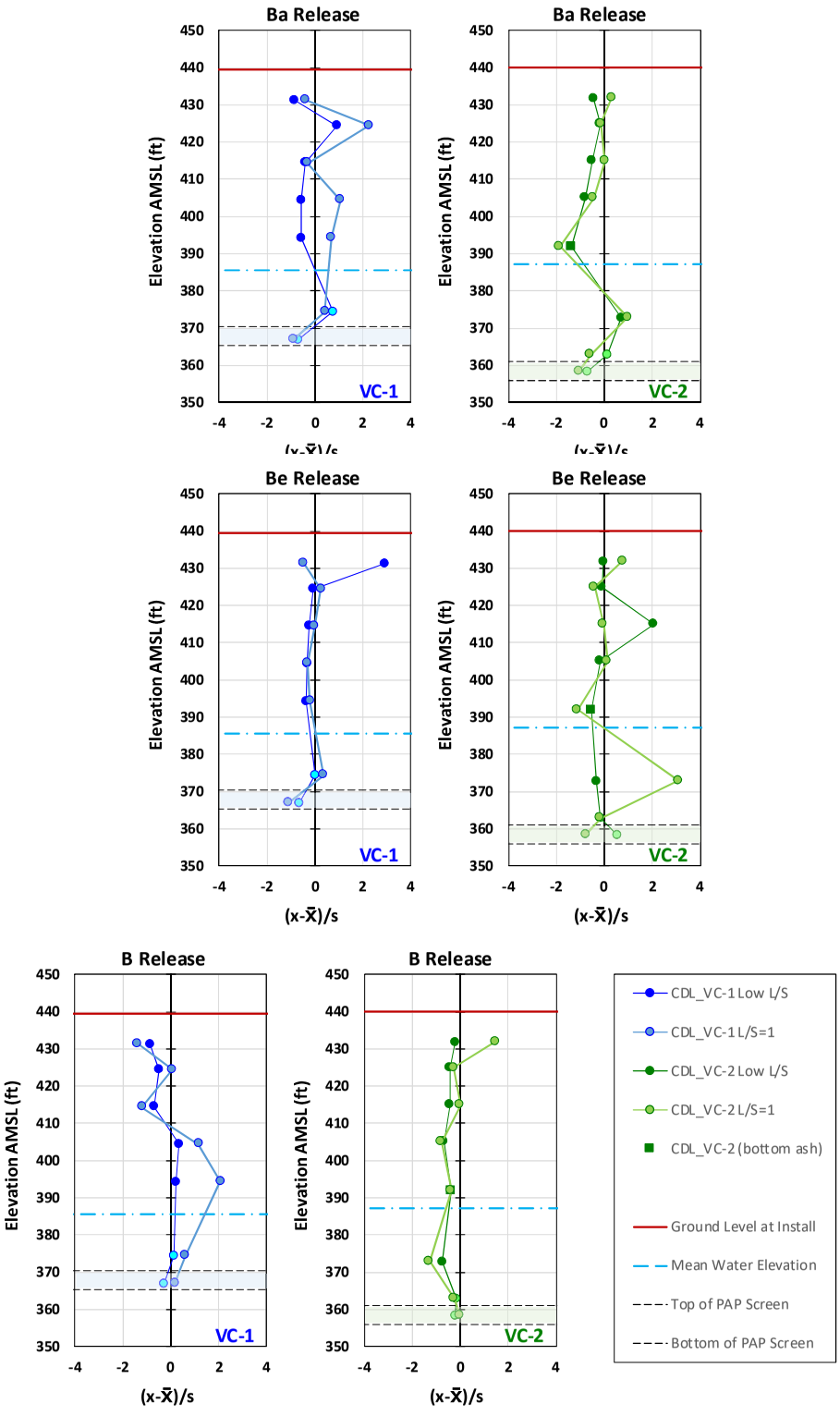

Figure B-37
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: barium, beryllium, and boron

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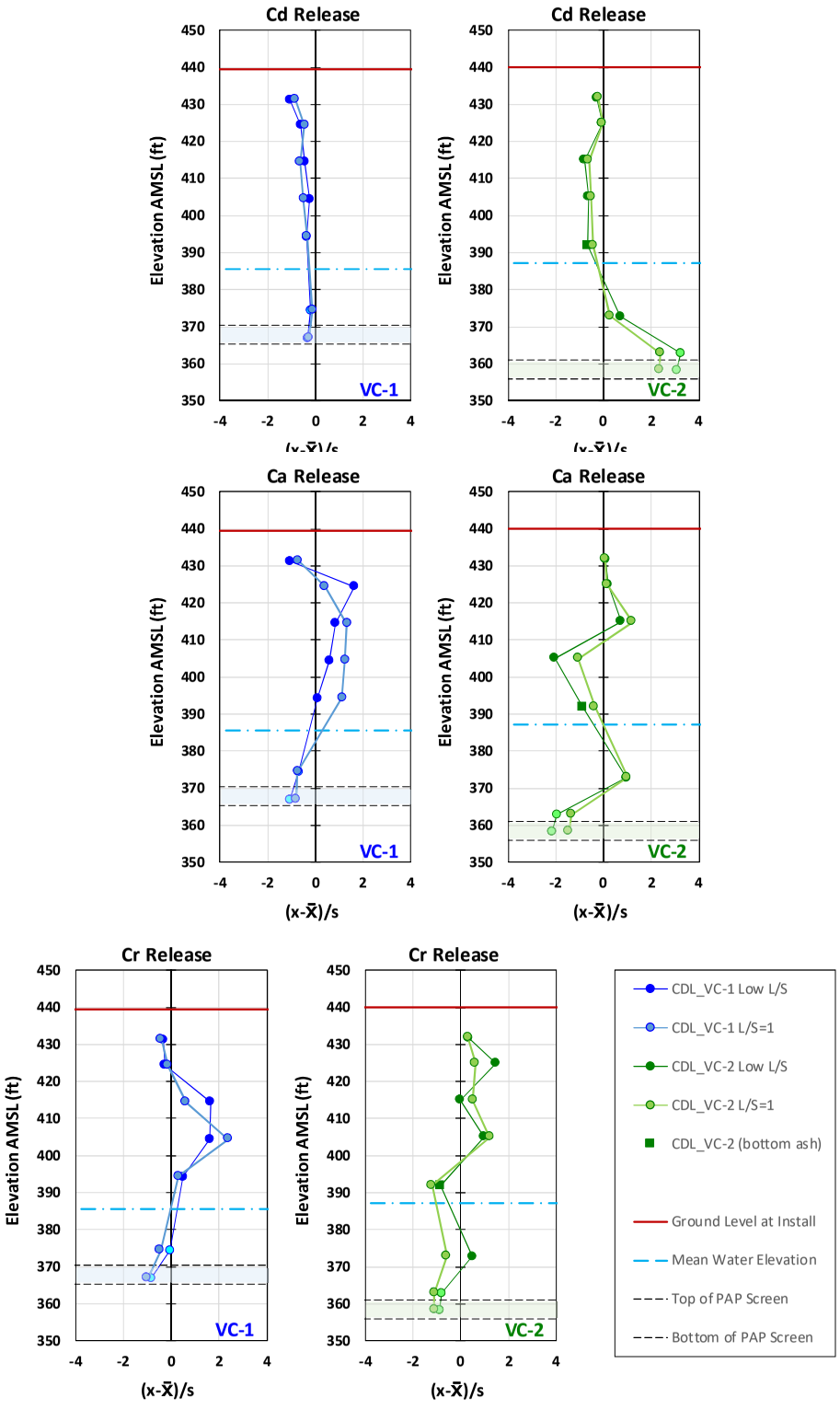

Figure B-38
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: cadmium, calcium, and chromium

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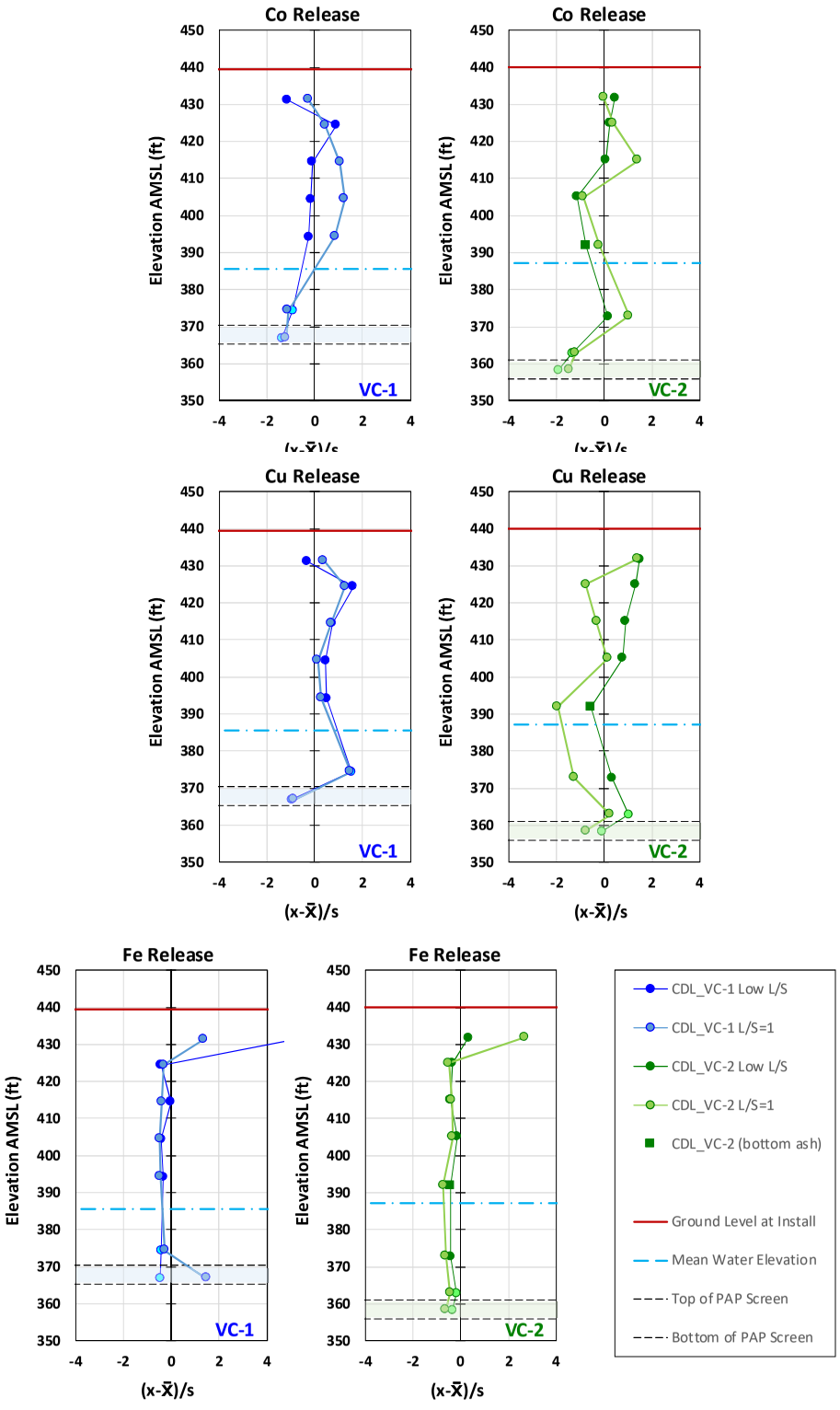

Figure B-39
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: cobalt, copper, and iron

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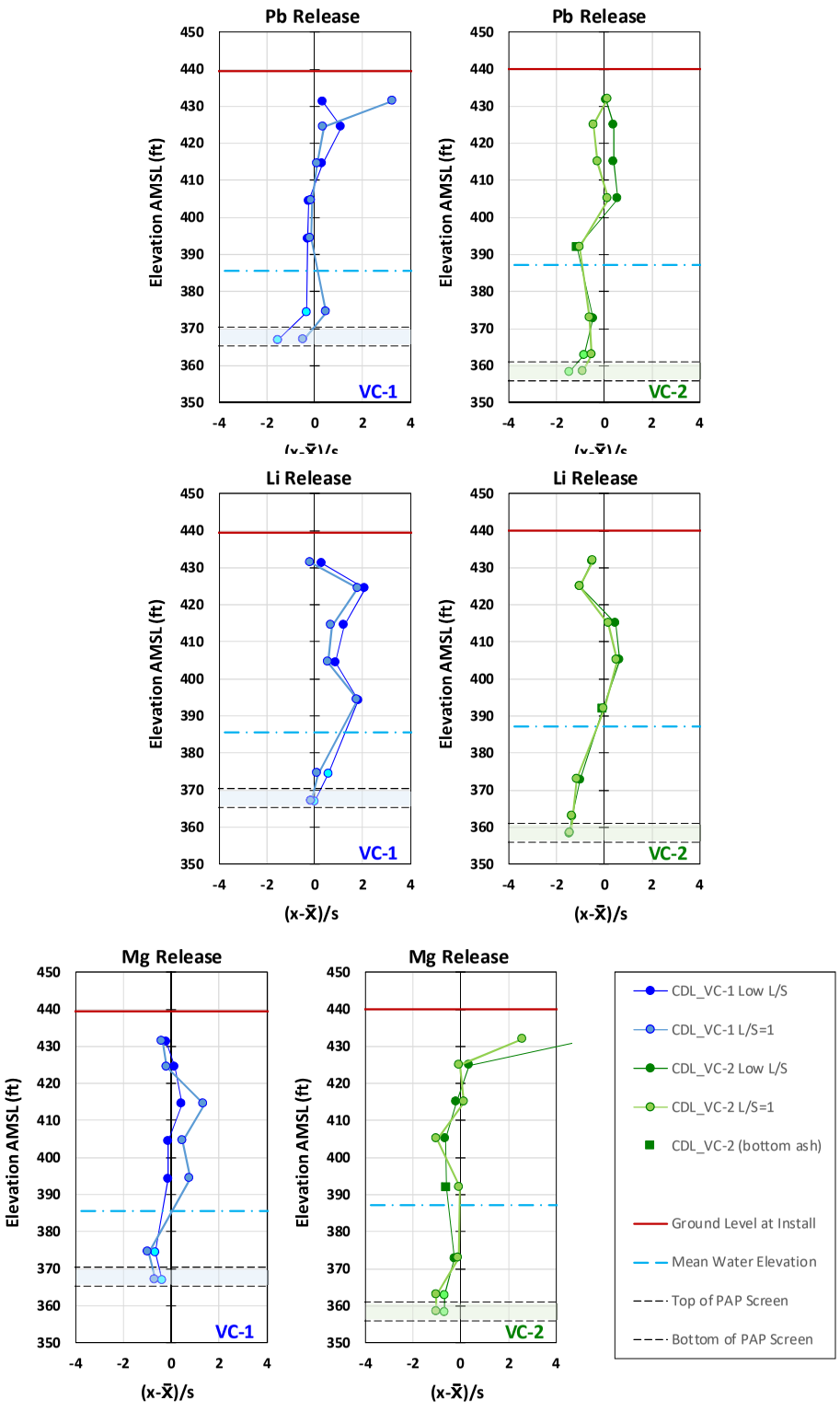

Figure B-40
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: lead, lithium, and magnesium

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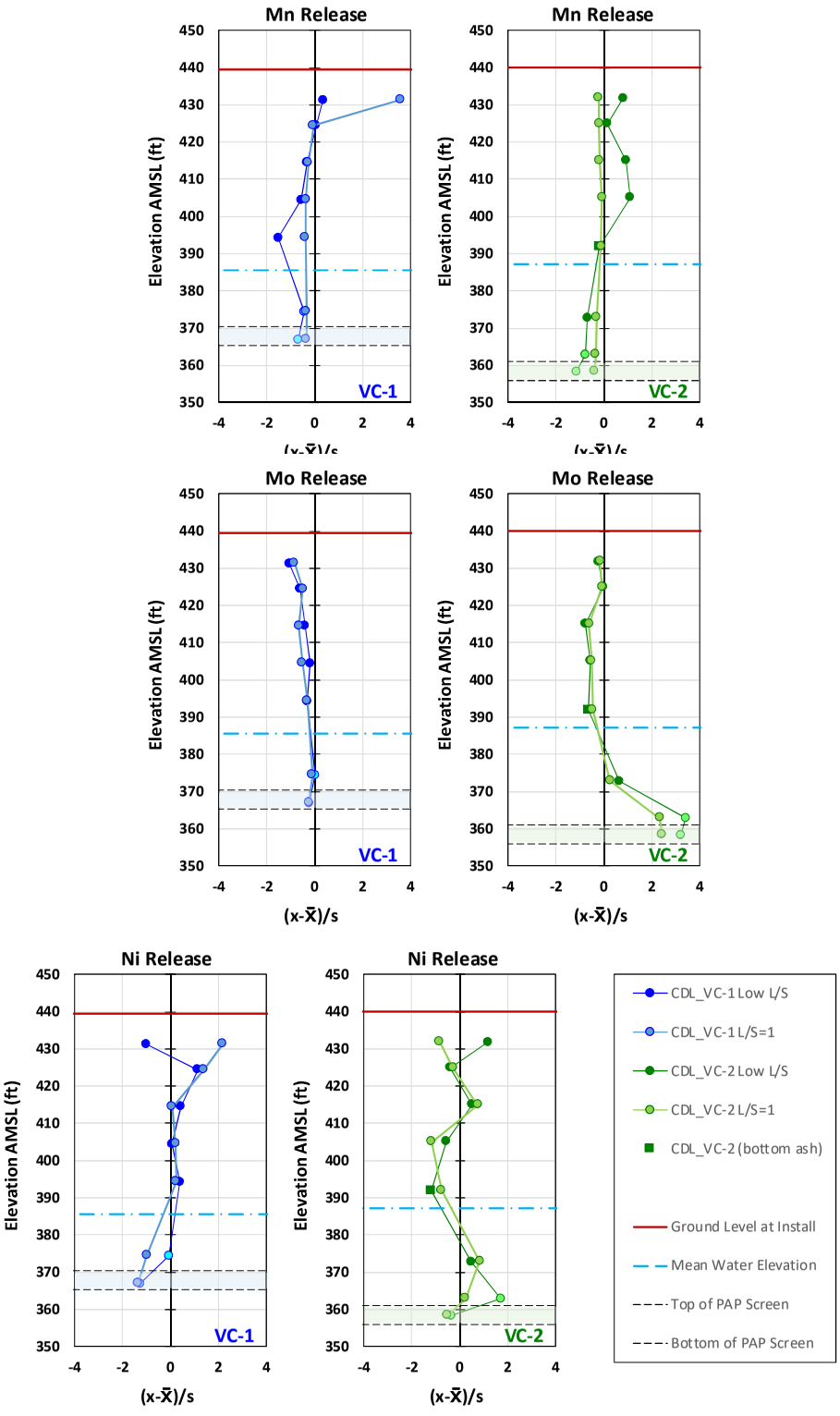

Figure B-41
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: manganese, molybdenum, and nickel

Electronic Filing: Received, Clerk's Office 07/01/2024

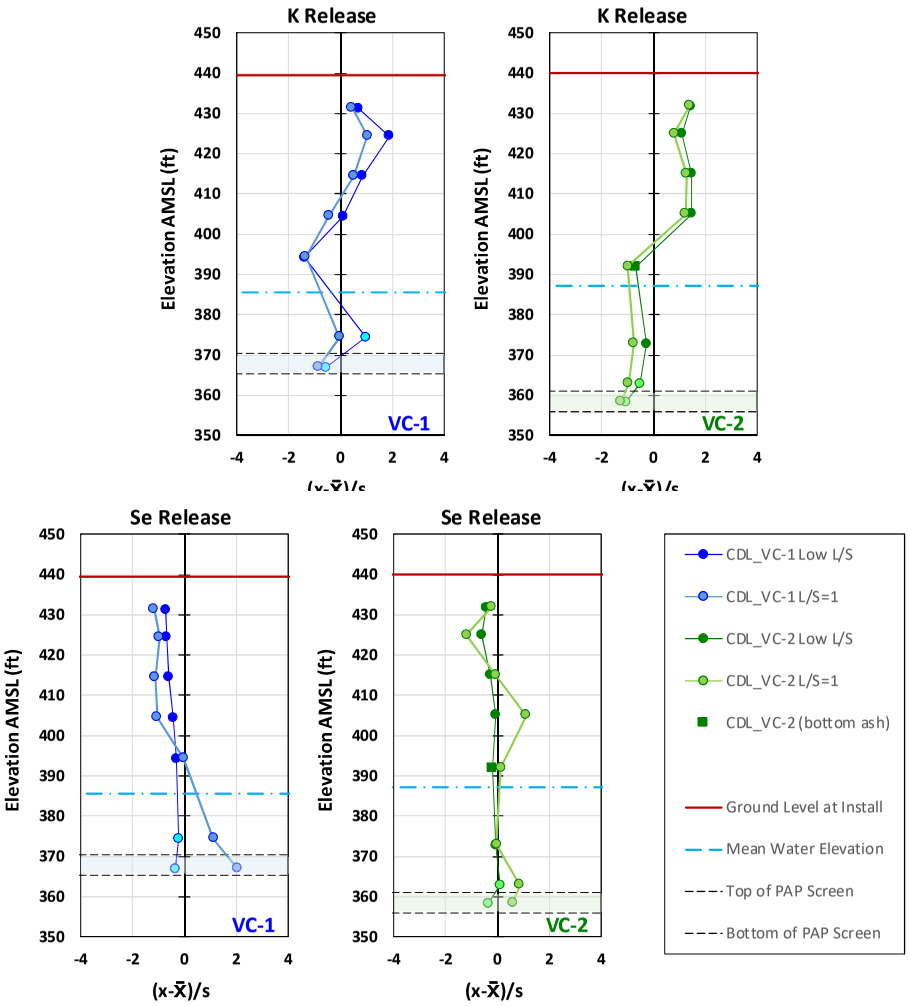

Figure B-42
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: potassium and selenium

Electronic Filing: Received, Clerk's Office 07/01/2024

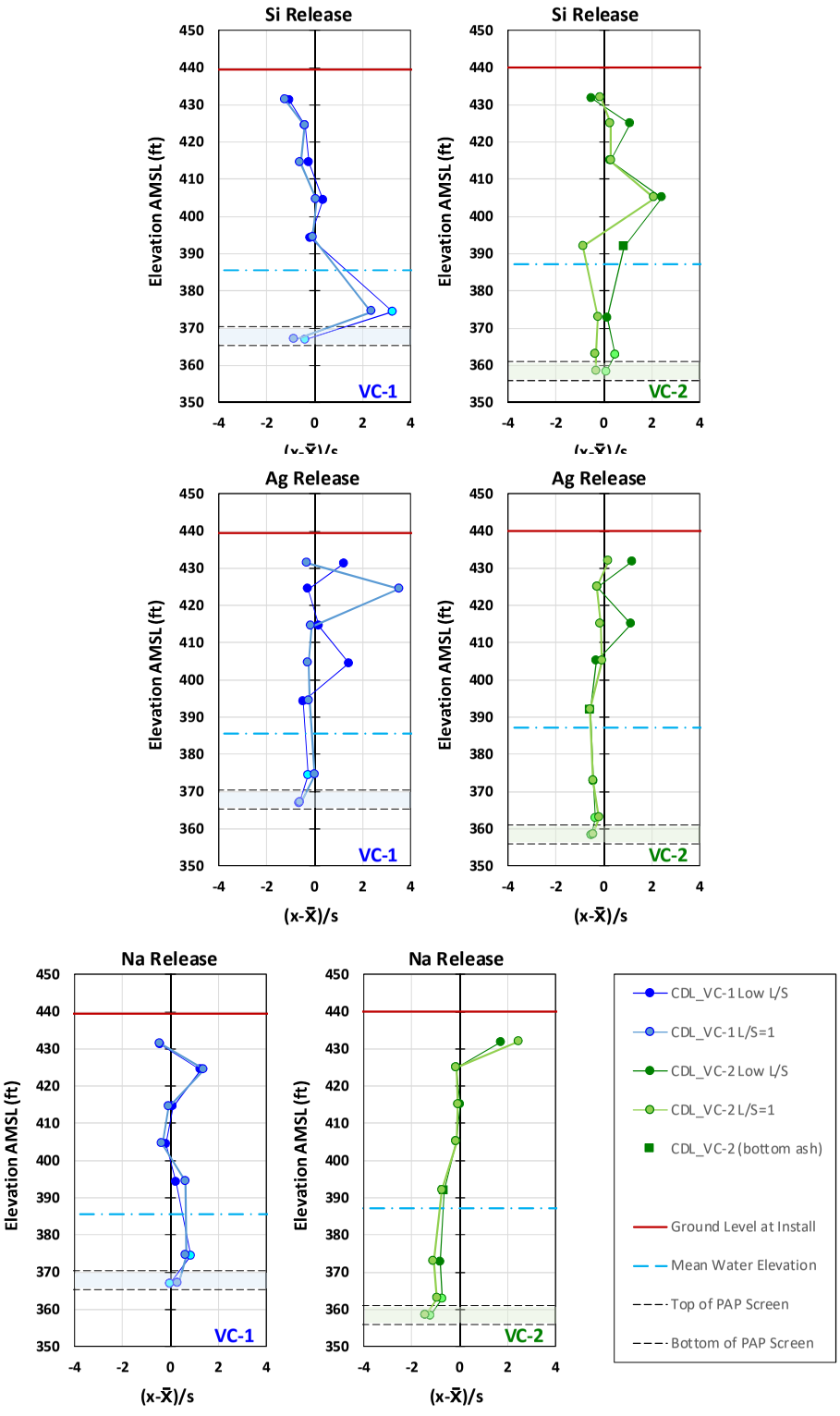

Figure B-43
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: silicon, silver and, sodium

Electronic Filing: Received, Clerk's Office 07/01/2024

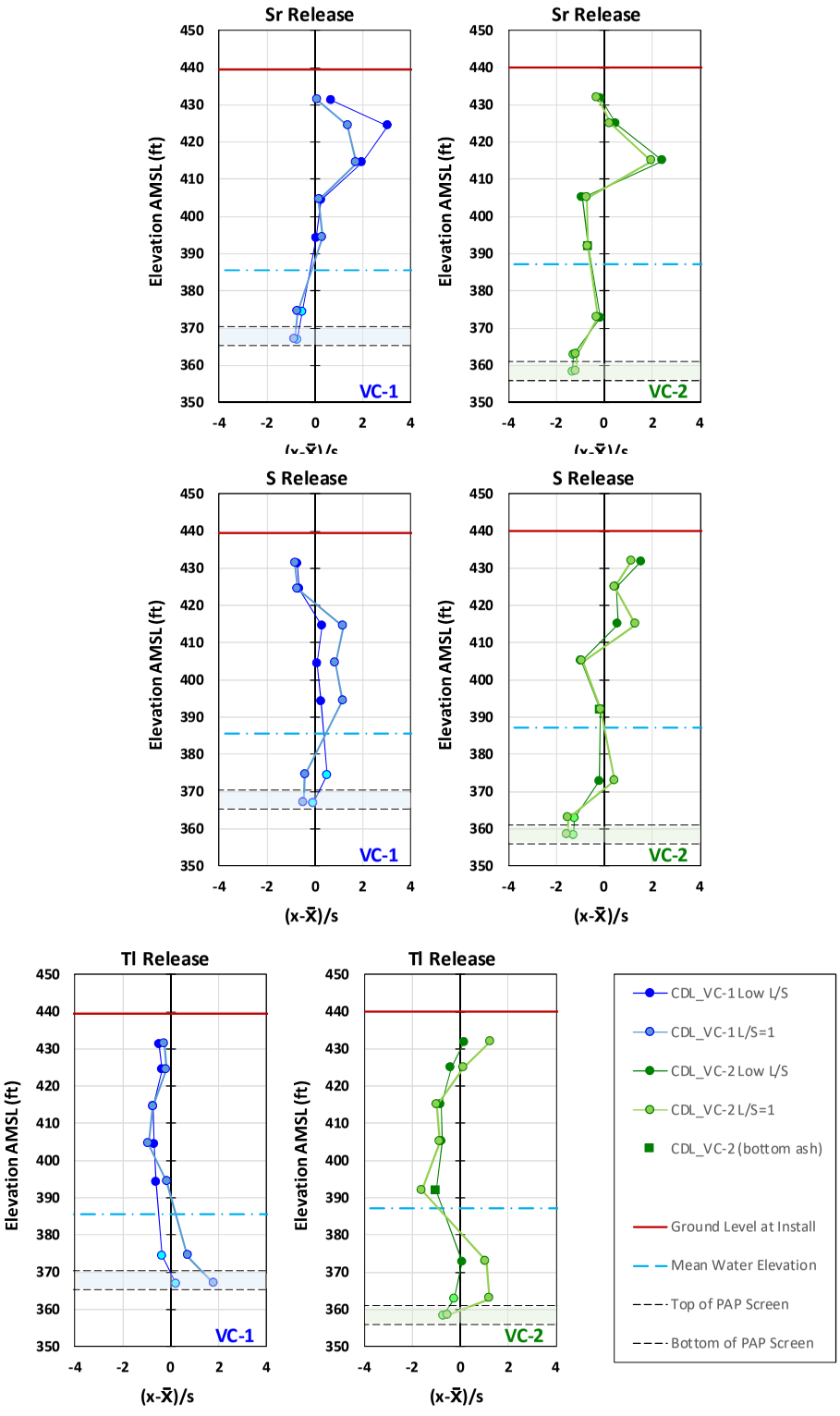

Figure B-44
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: strontium, sulfur, and thallium

Electronic Filing: Received, Clerk's Office 07/01/2024

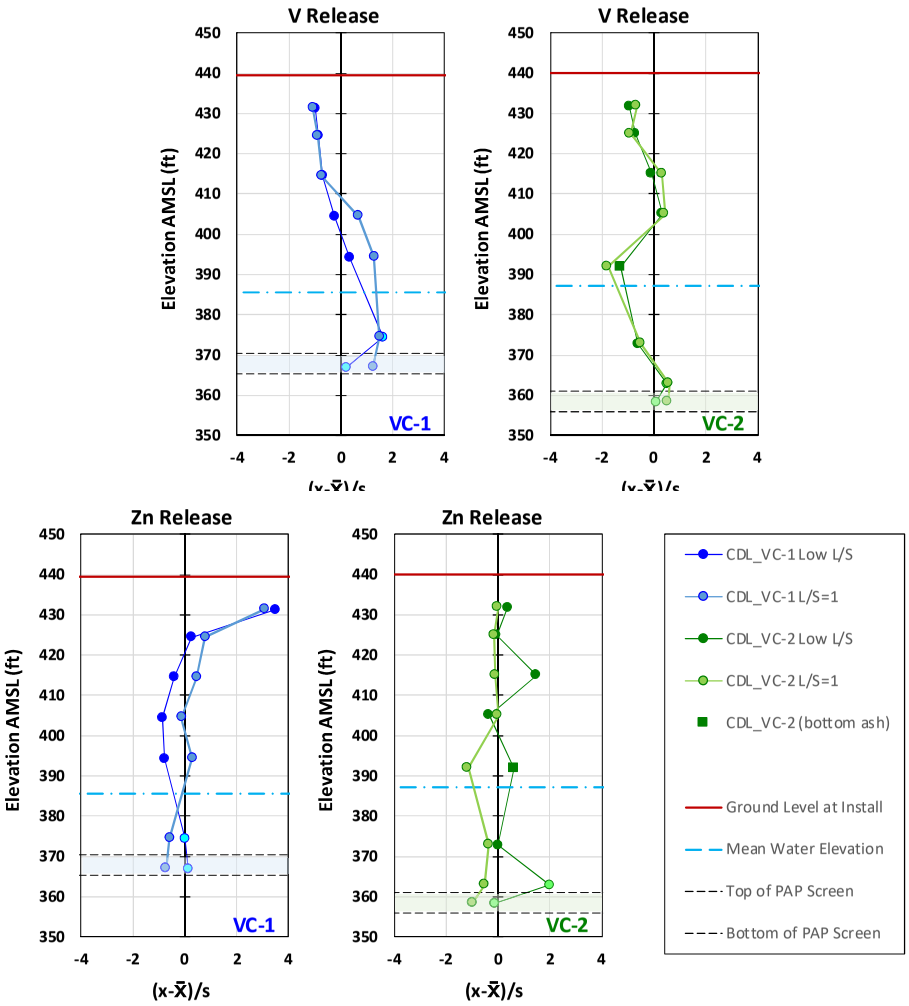

Figure B-45
Comparison of release (mg/kg-dry) from in-field extractions at low L/S and at L/S~1: vanadium and zinc

C
LEACHING TEST METHOD RESULTS

Leaching Test Method Results

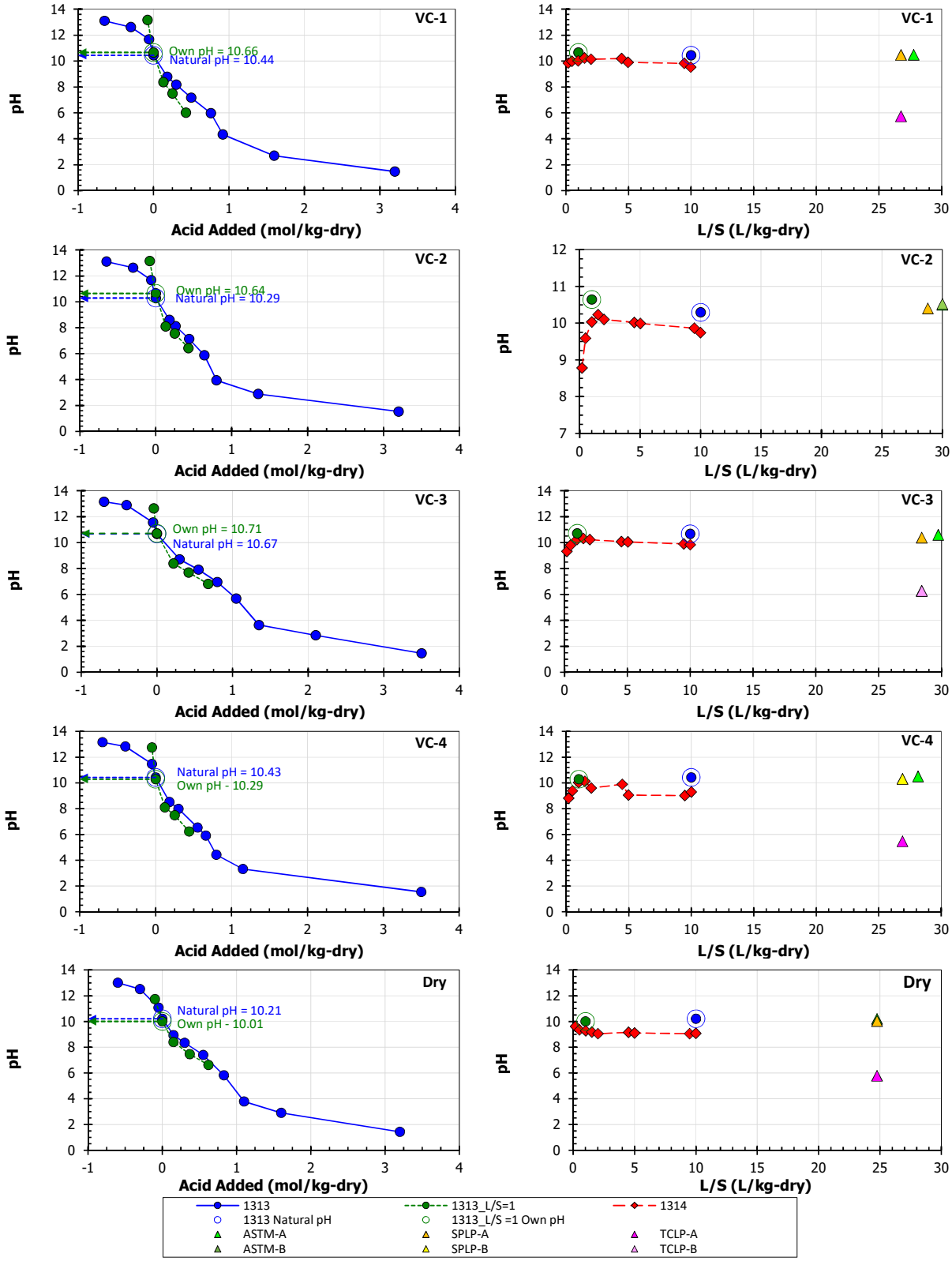

Figure C-1
Titration curve and pH results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

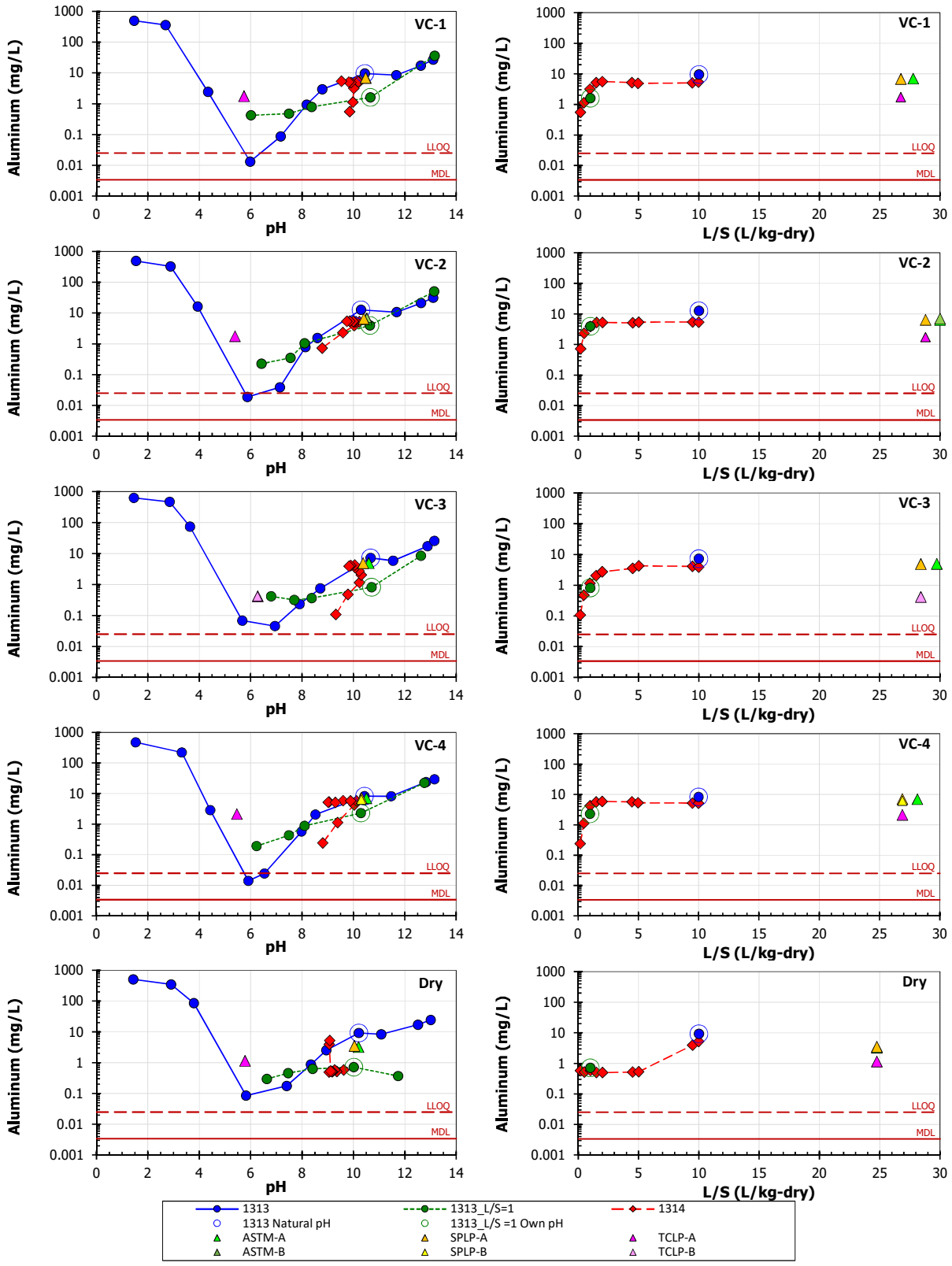

Figure C-2
Aluminum leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Electronic Filing: Received, Clerk's Office 07/01/2024

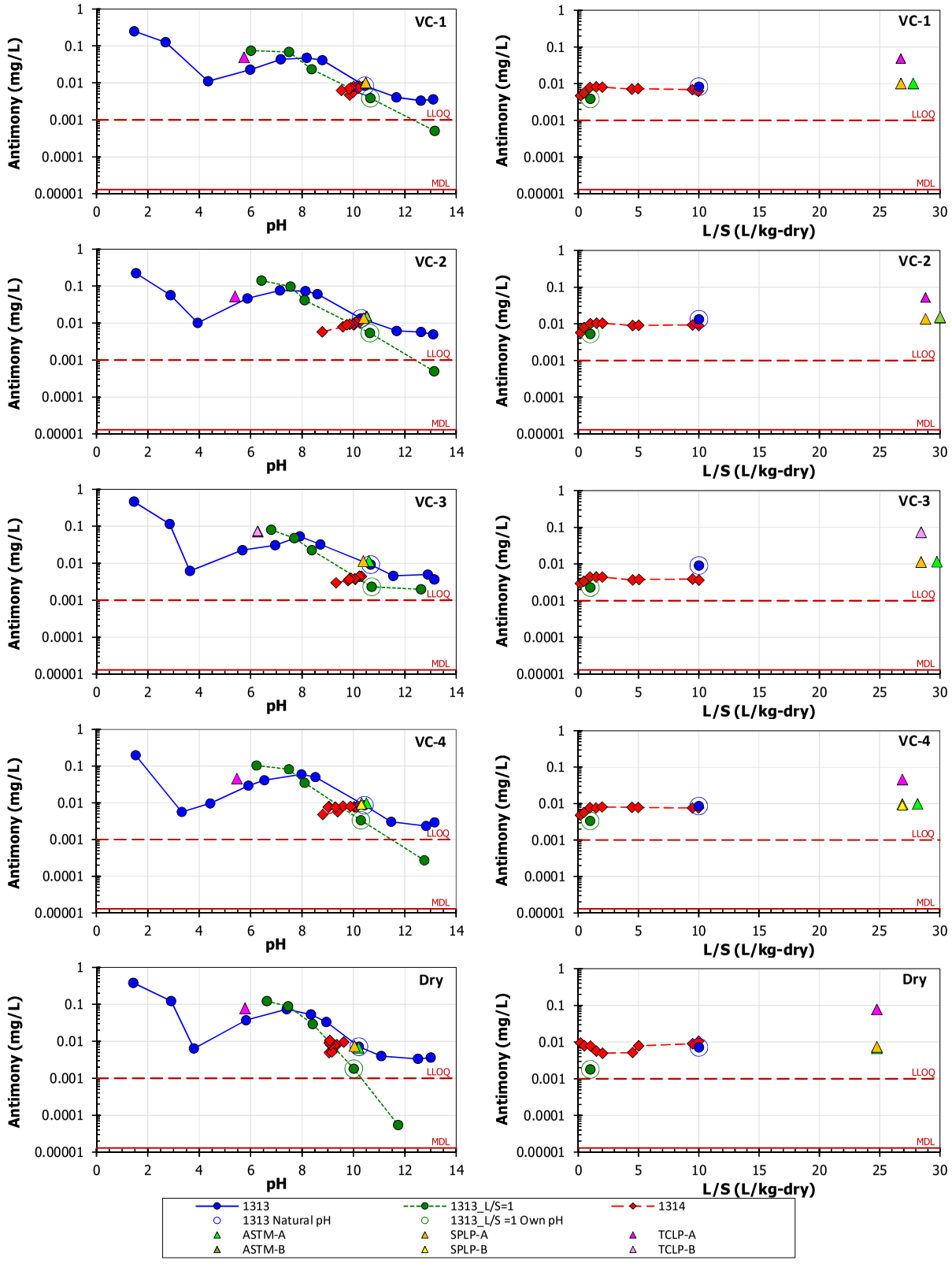

Figure C-3
Antimony leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Electronic Filing: Received, Clerk's Office 07/01/2024

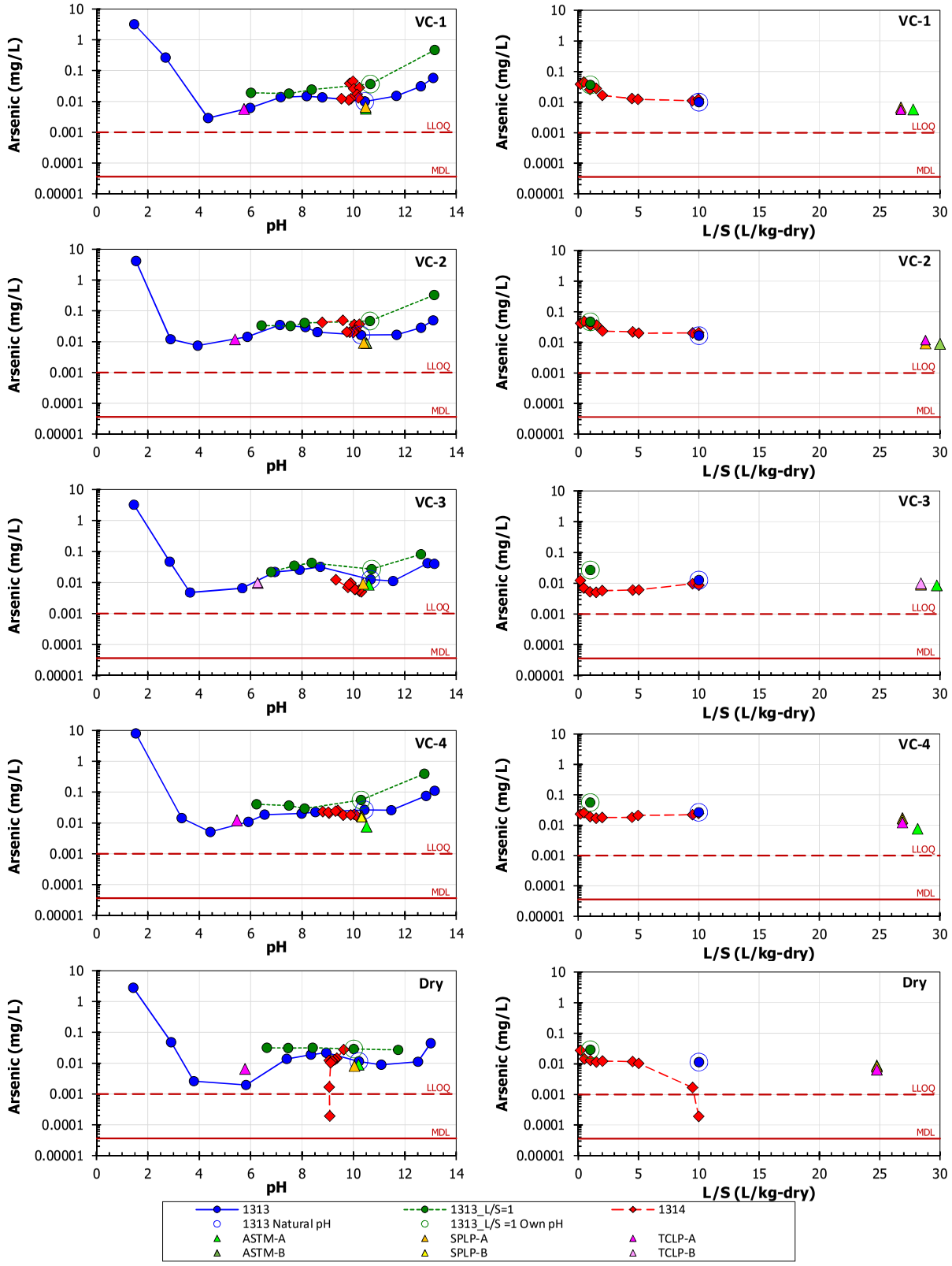

Figure C-4
Arsenic leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

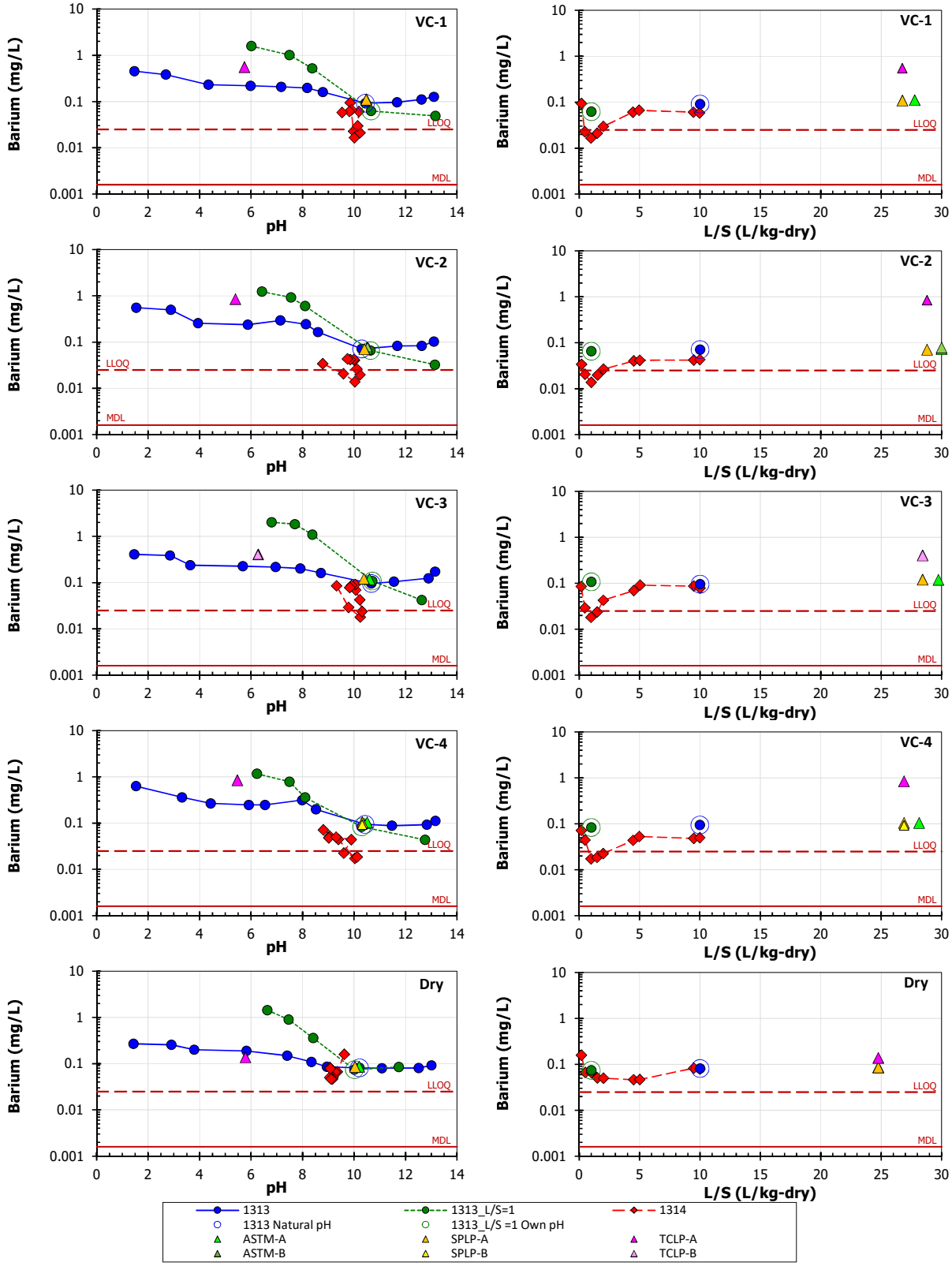

Figure C-5
Barium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Electronic Filing: Received, Clerk's Office 07/01/2024

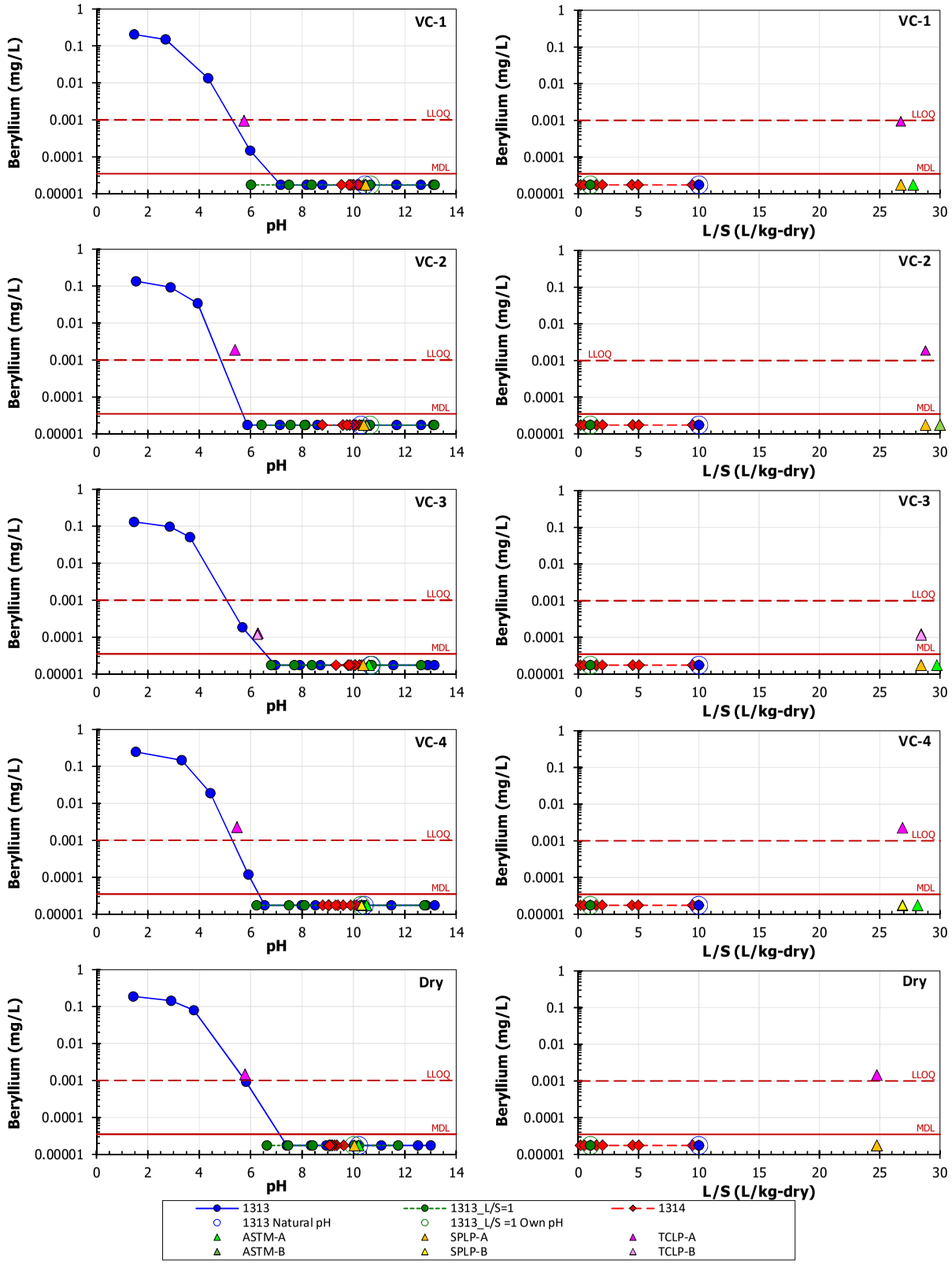

Figure C-6
Beryllium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

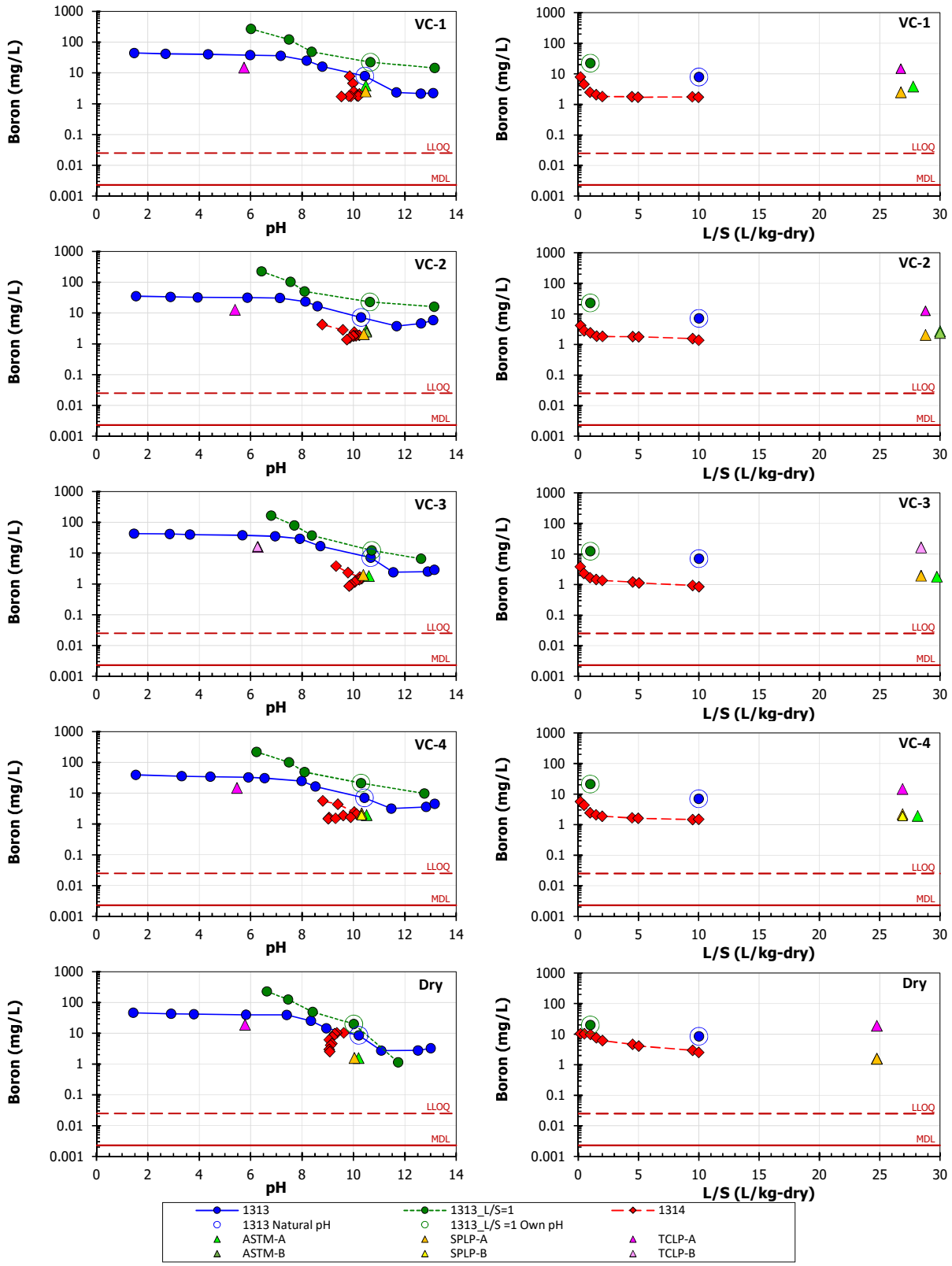

Figure C-7
Boron leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

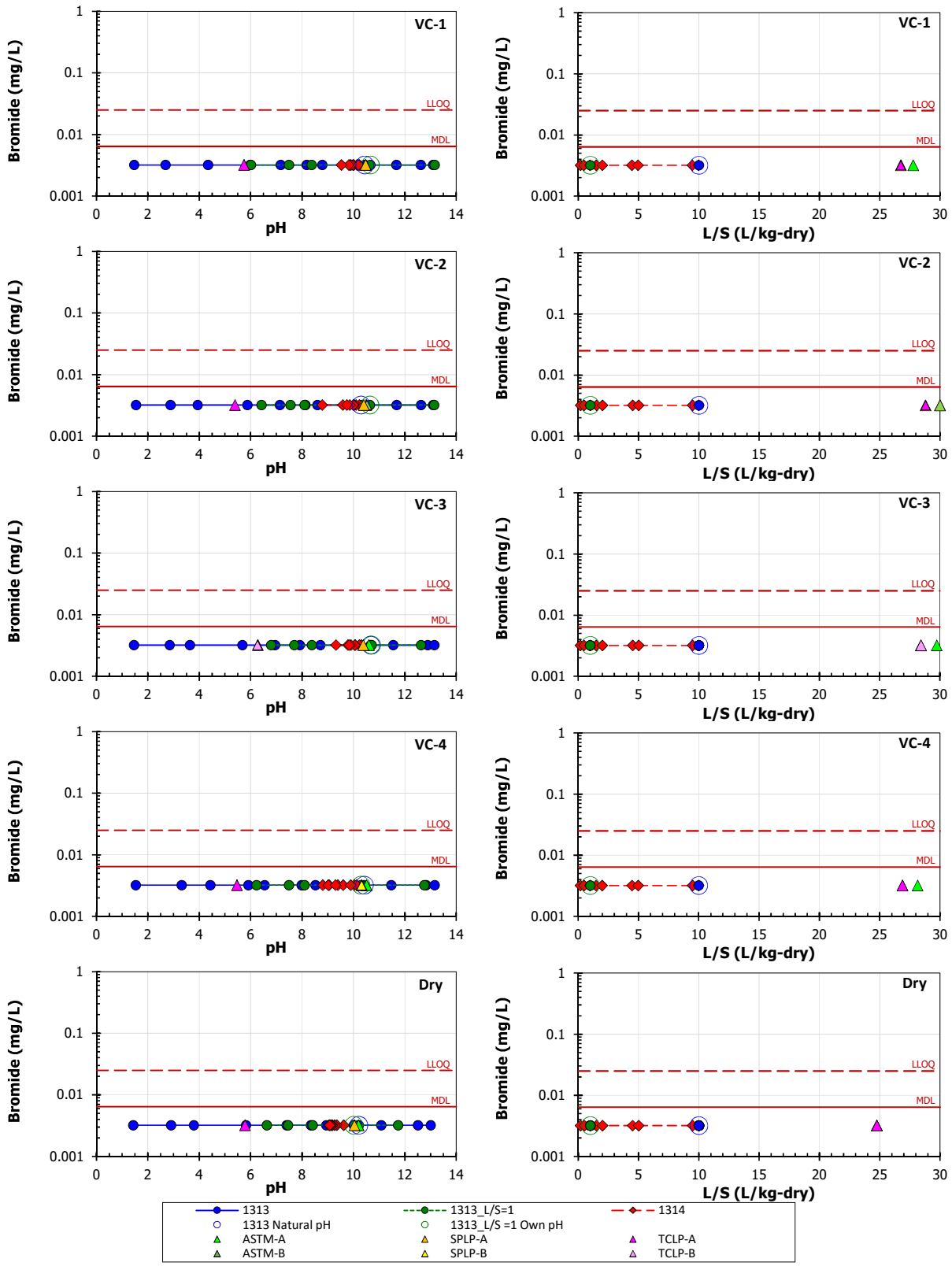

Figure C-8
Bromide leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

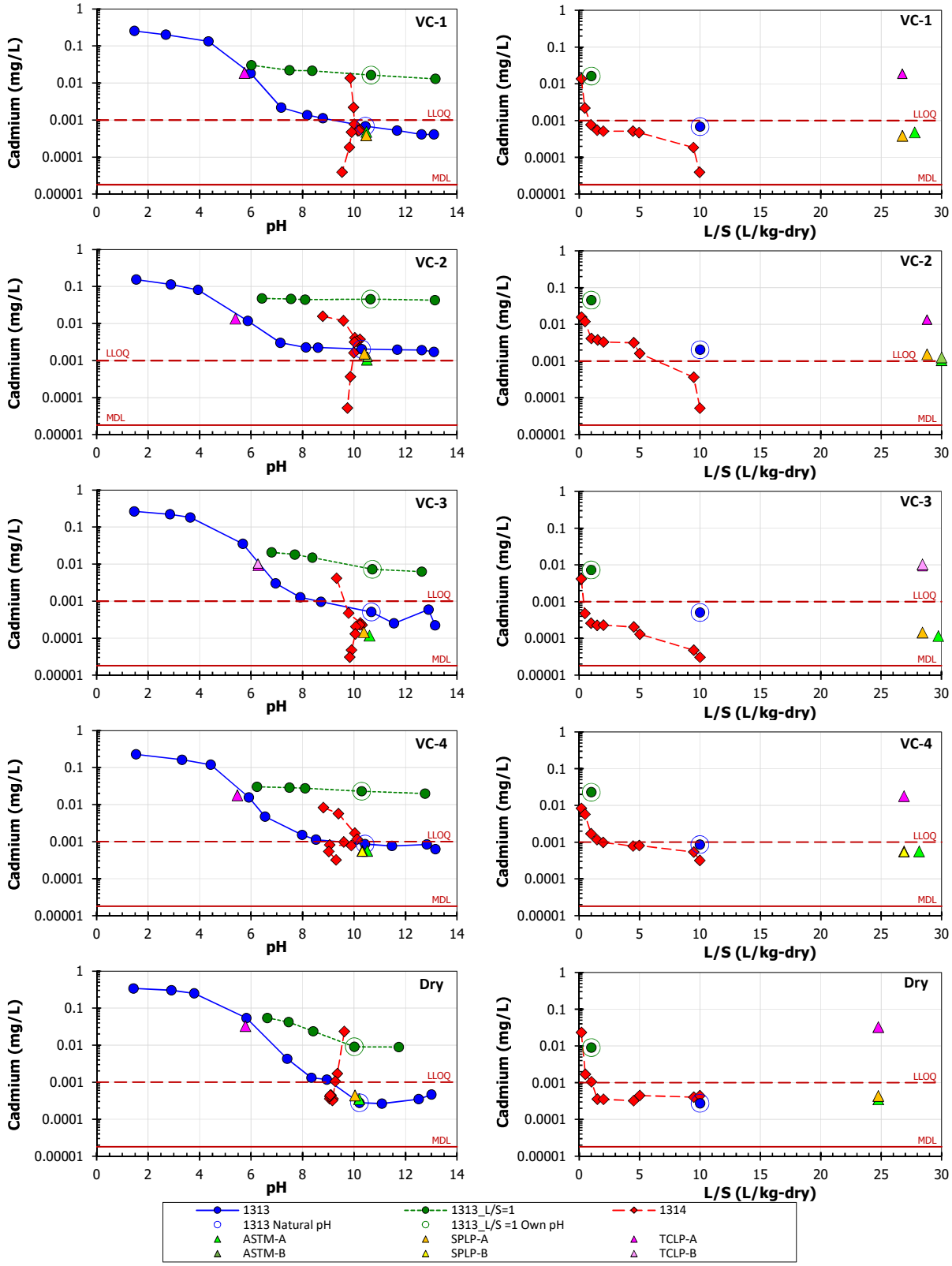

Figure C-9
Cadmium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

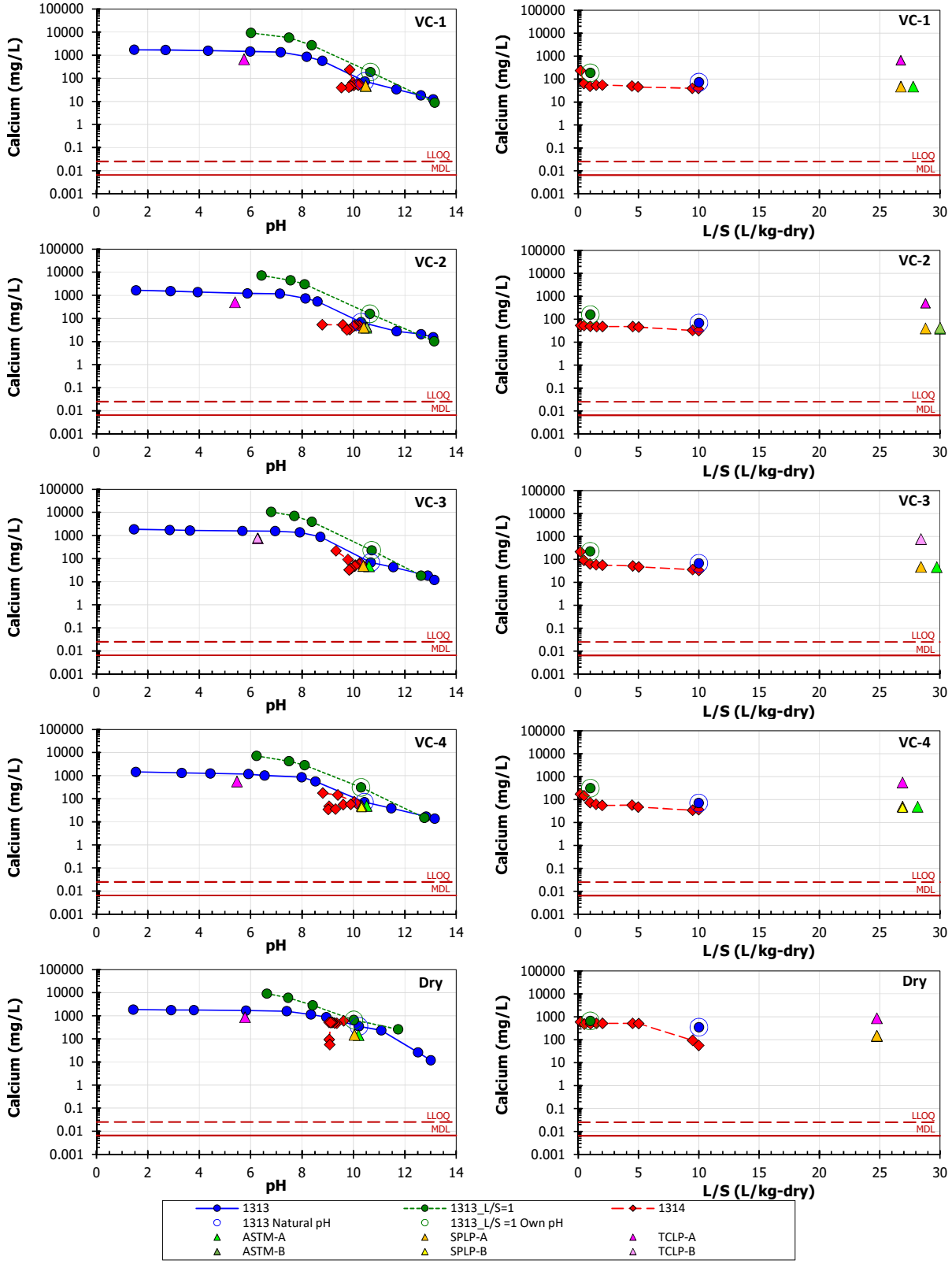

Figure C-10
Calcium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

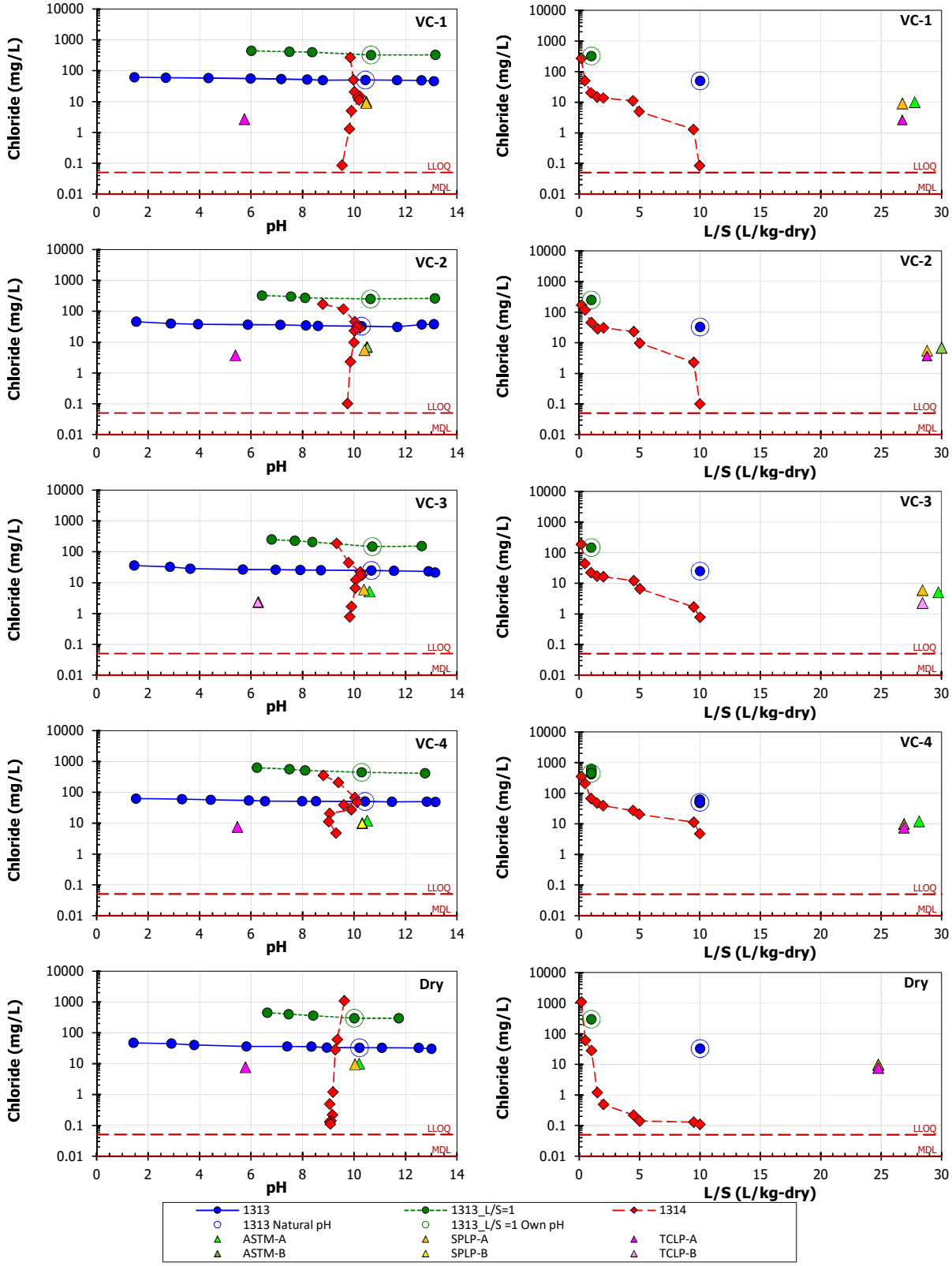

Figure C-11
Chloride leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

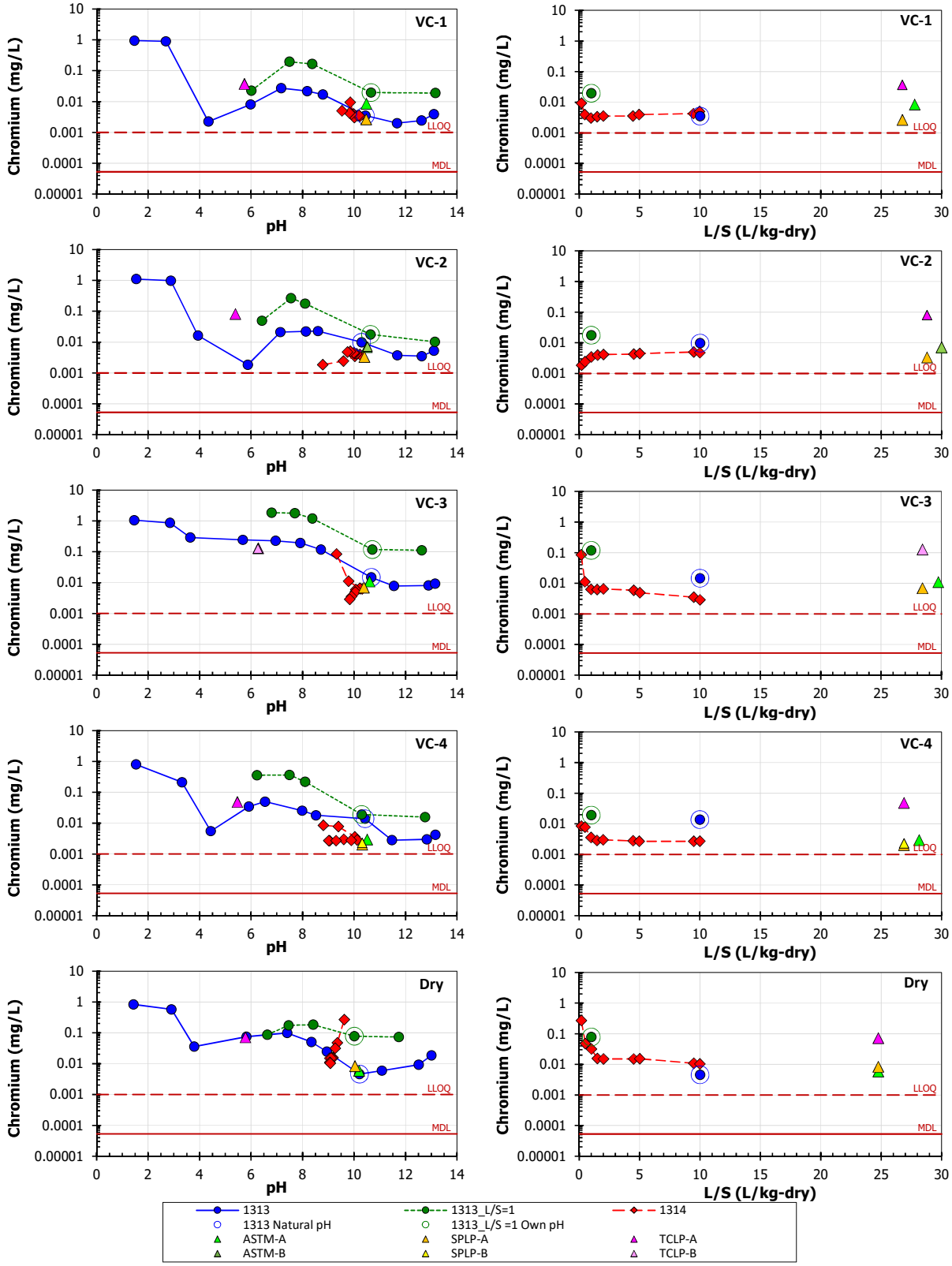

Figure C-12
Chromium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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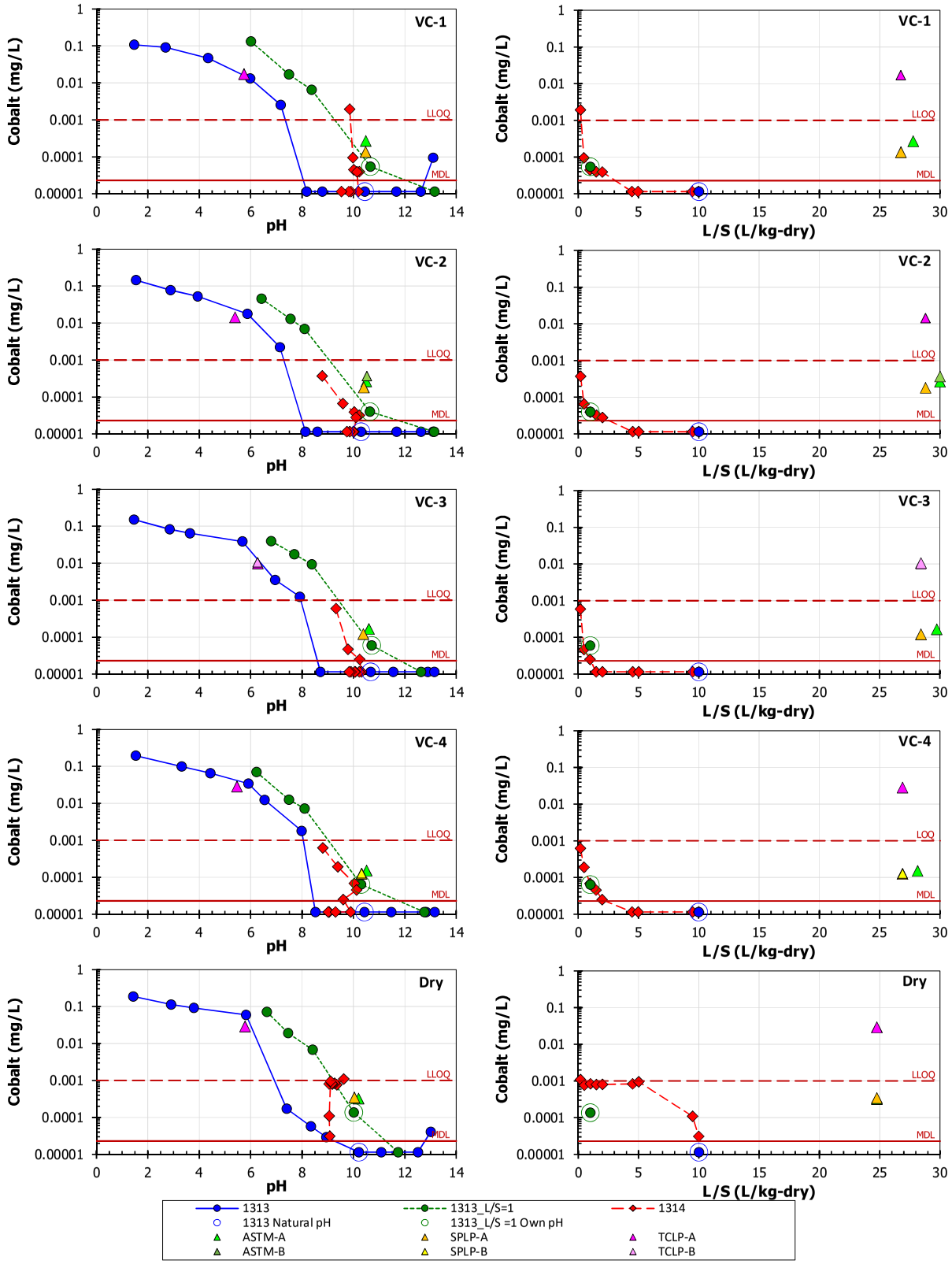

Figure C-13
Cobalt leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

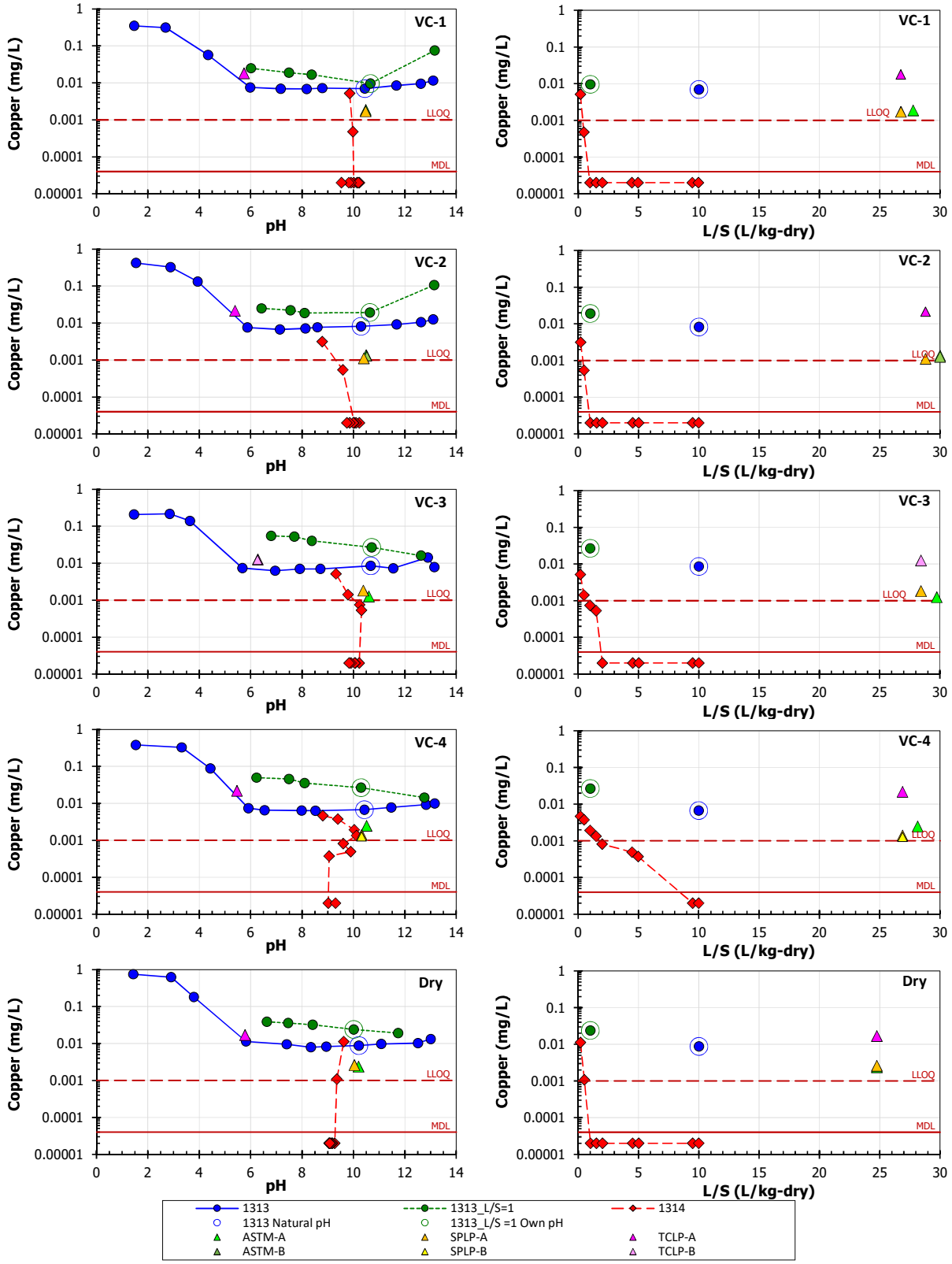

Figure C-14
Copper leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Electronic Filing: Received, Clerk's Office 07/01/2024

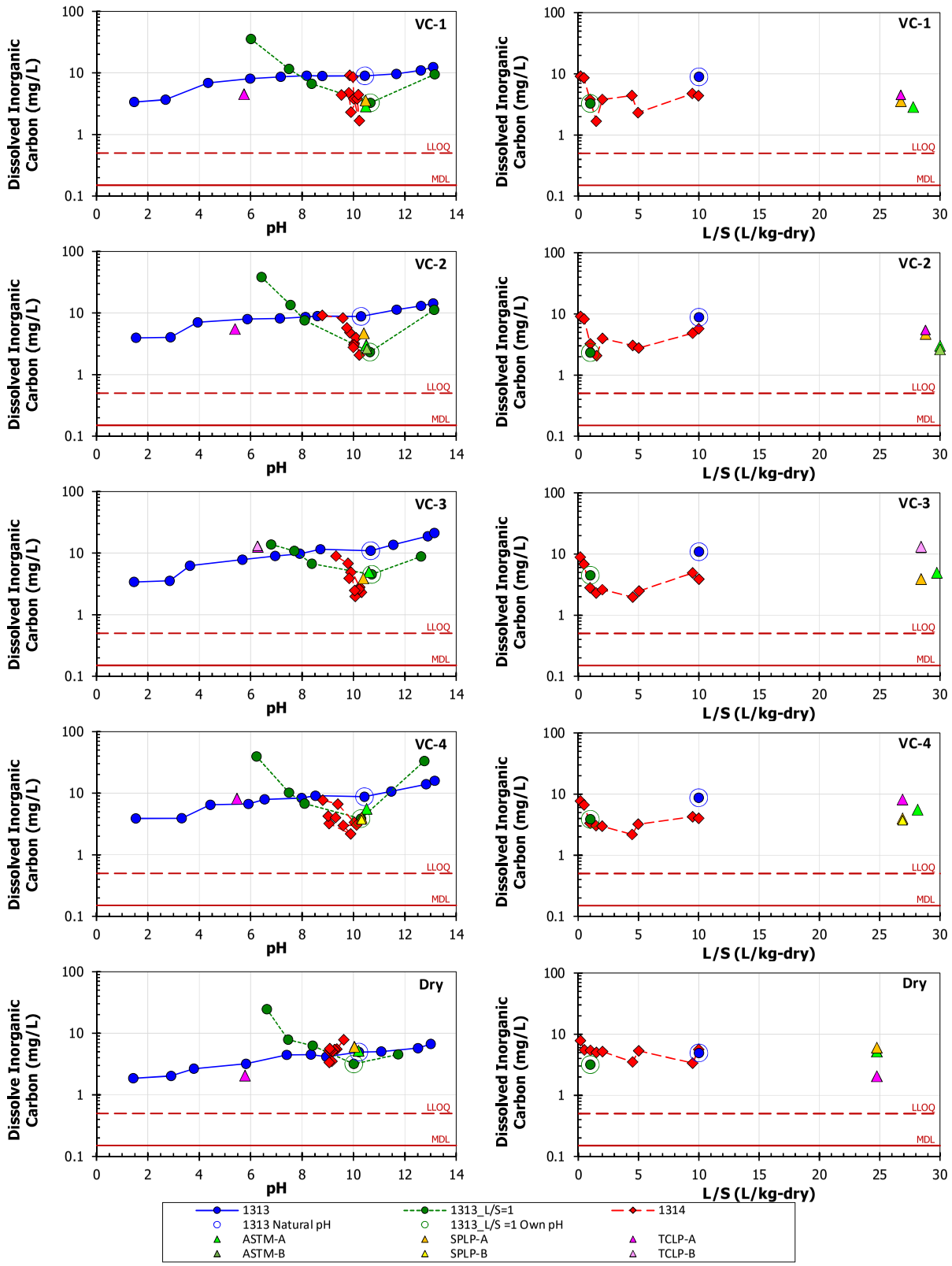

Figure C-15
Dissolved inorganic carbon leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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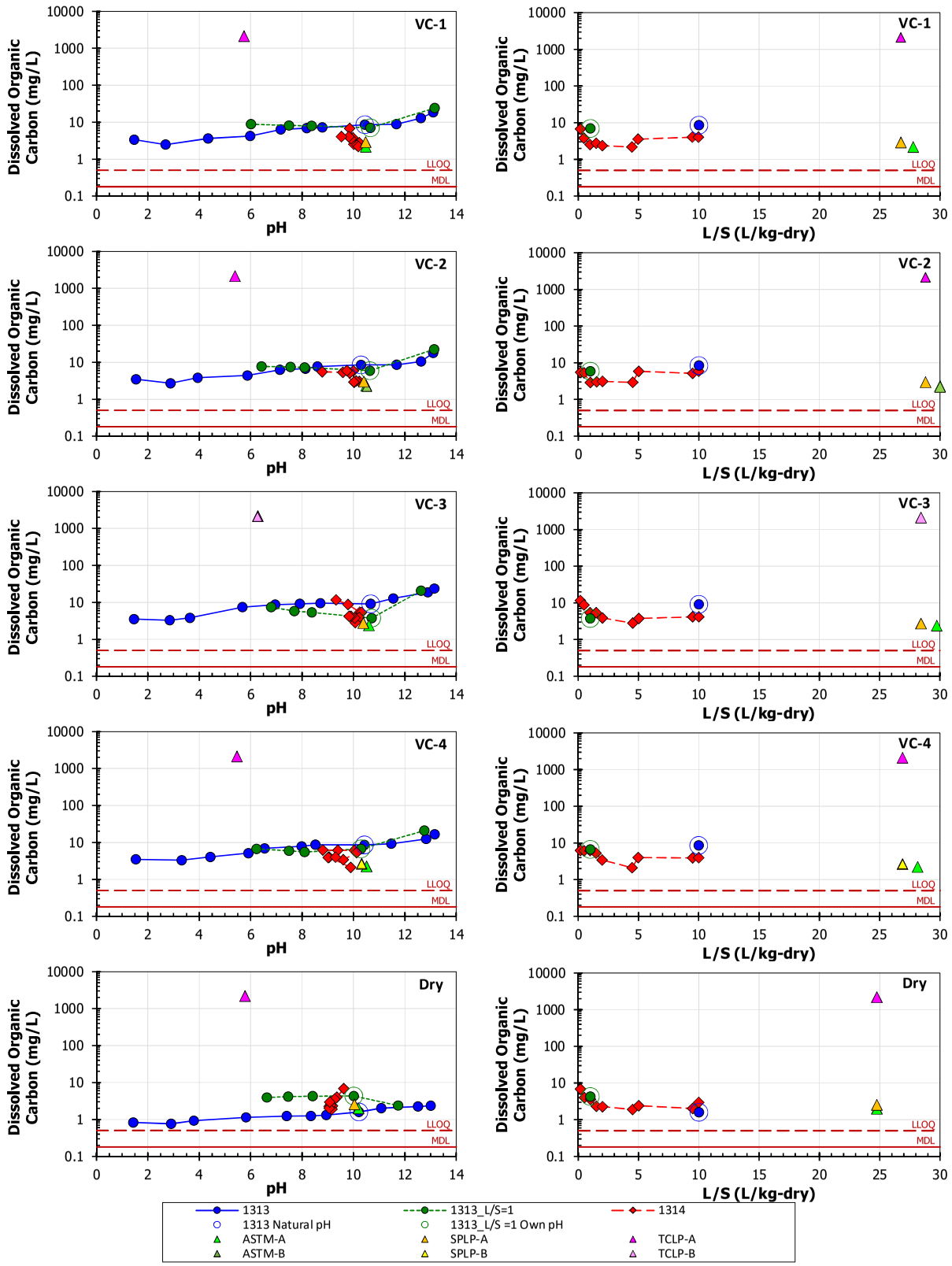

Figure C-16
Dissolved organic carbon leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

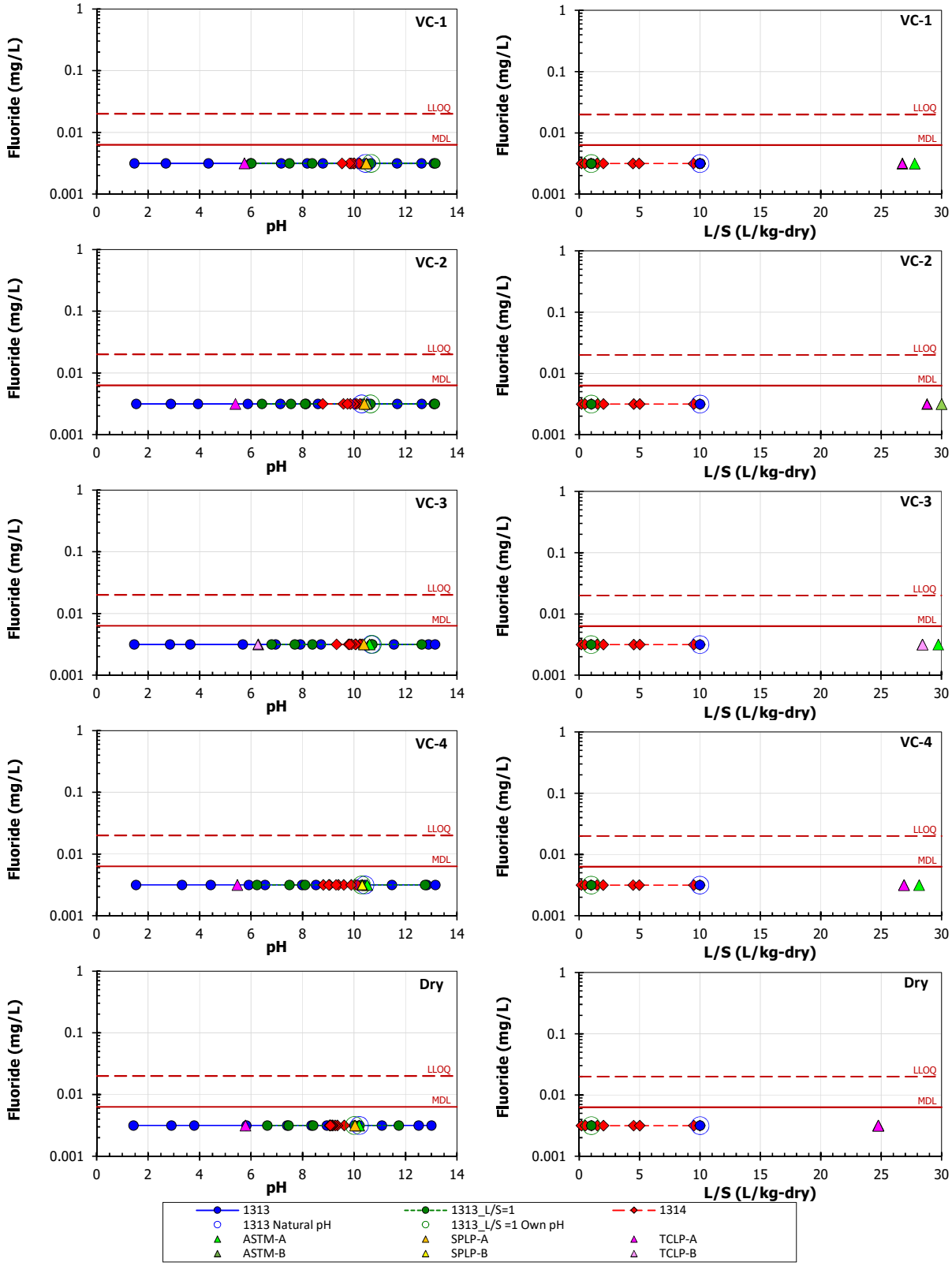

Figure C-17
Fluoride leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

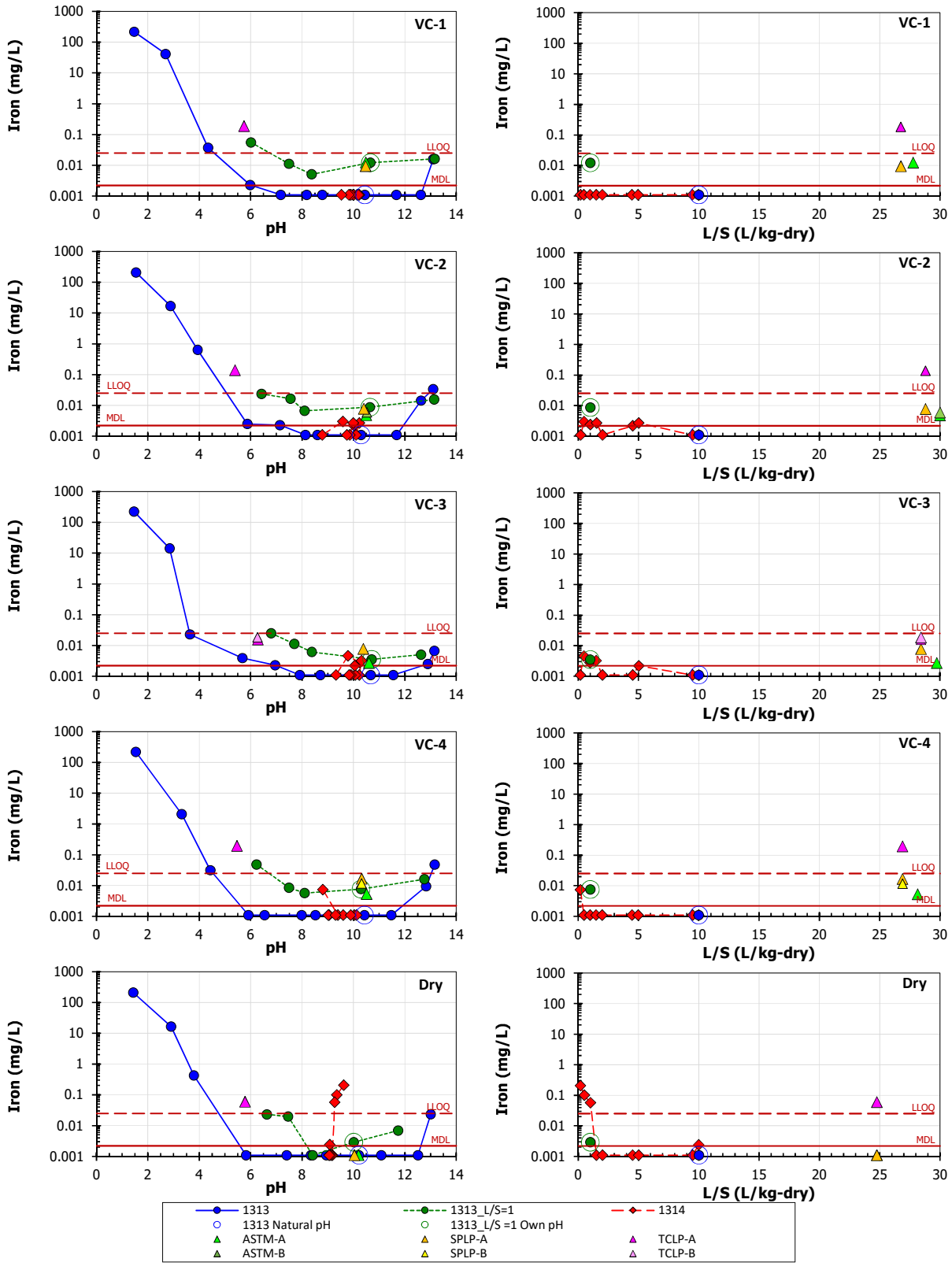

Figure C-18
Iron leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

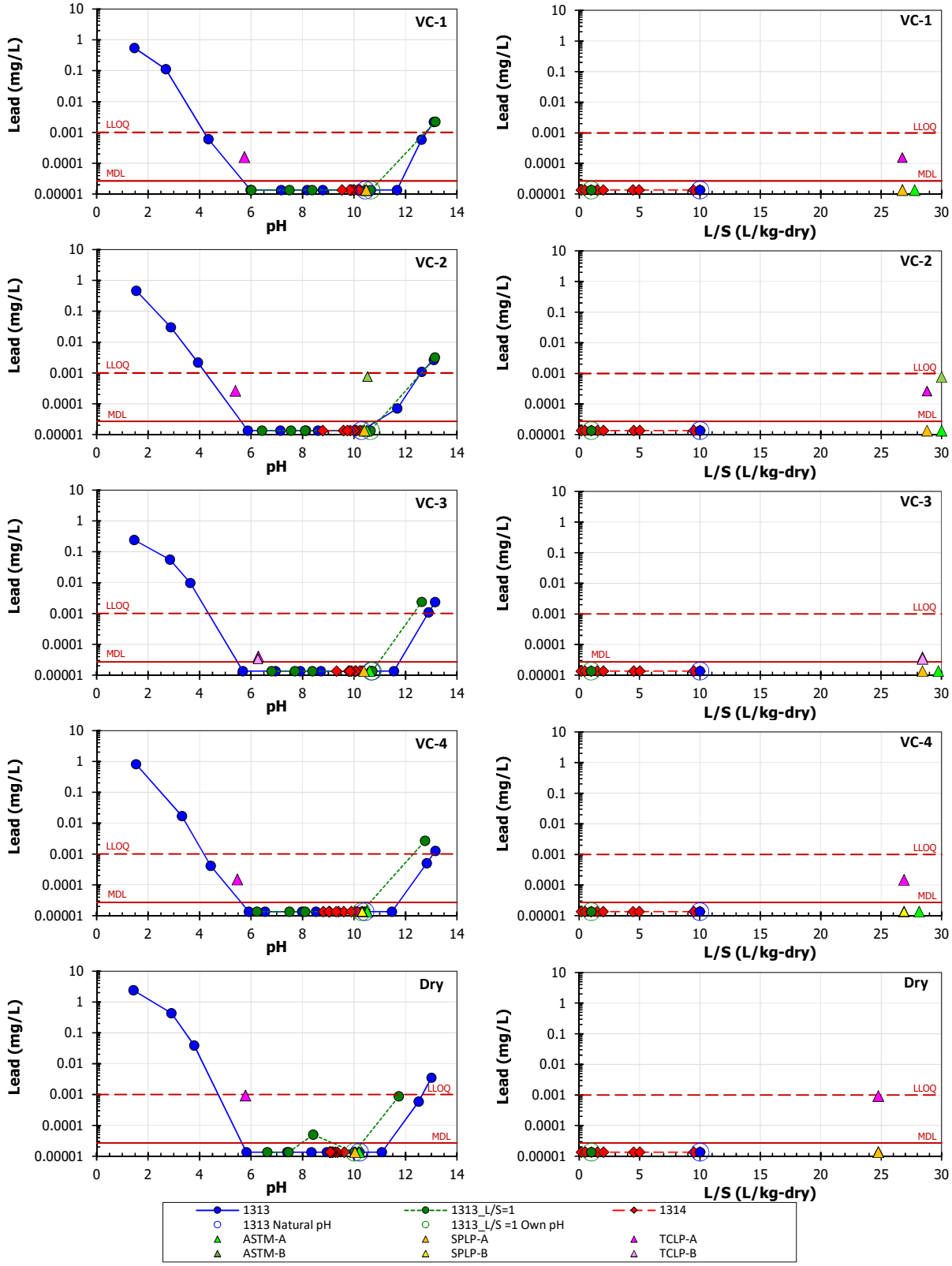

Figure C-19
Lead leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

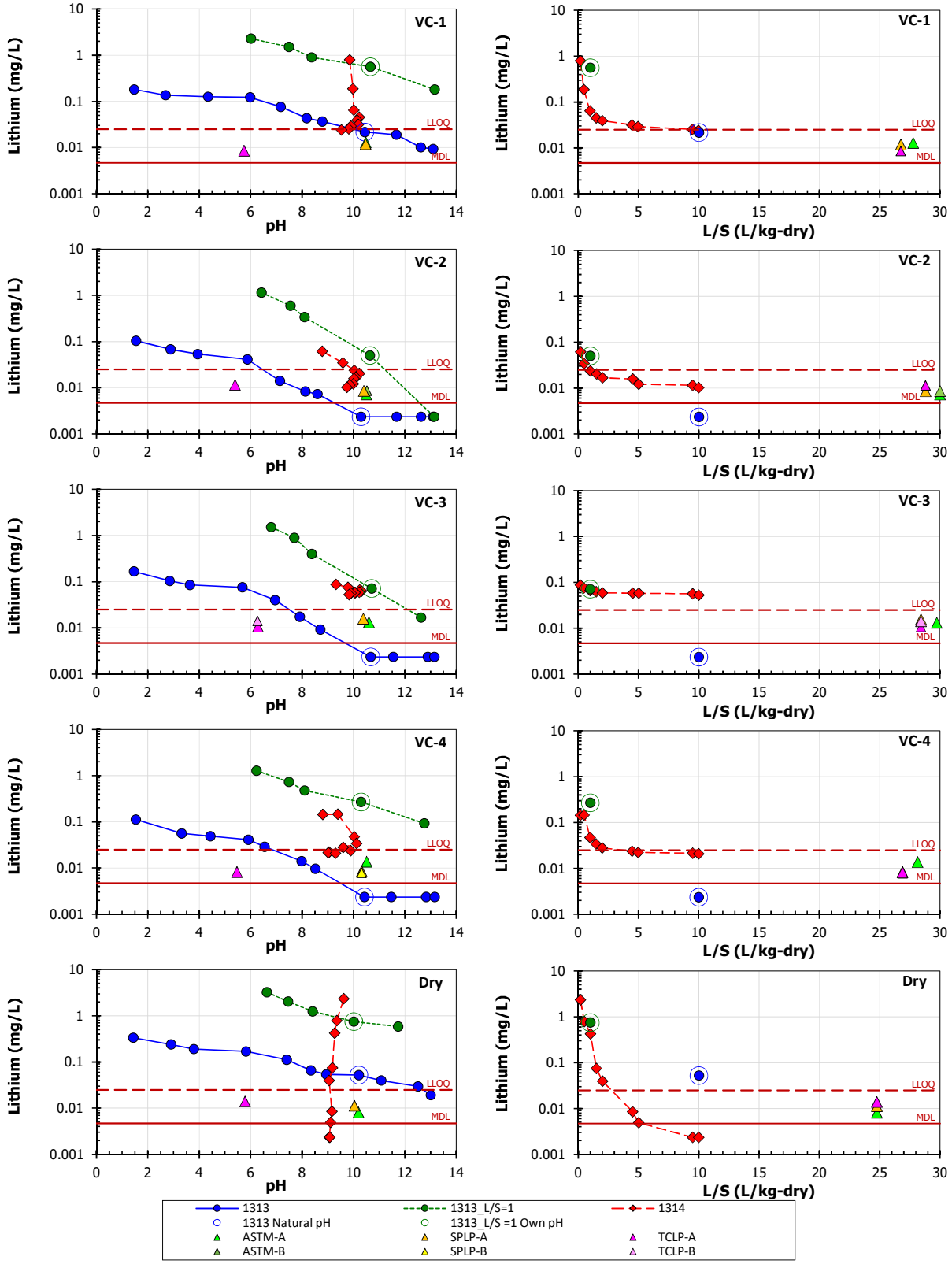

Figure C-20
Lithium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

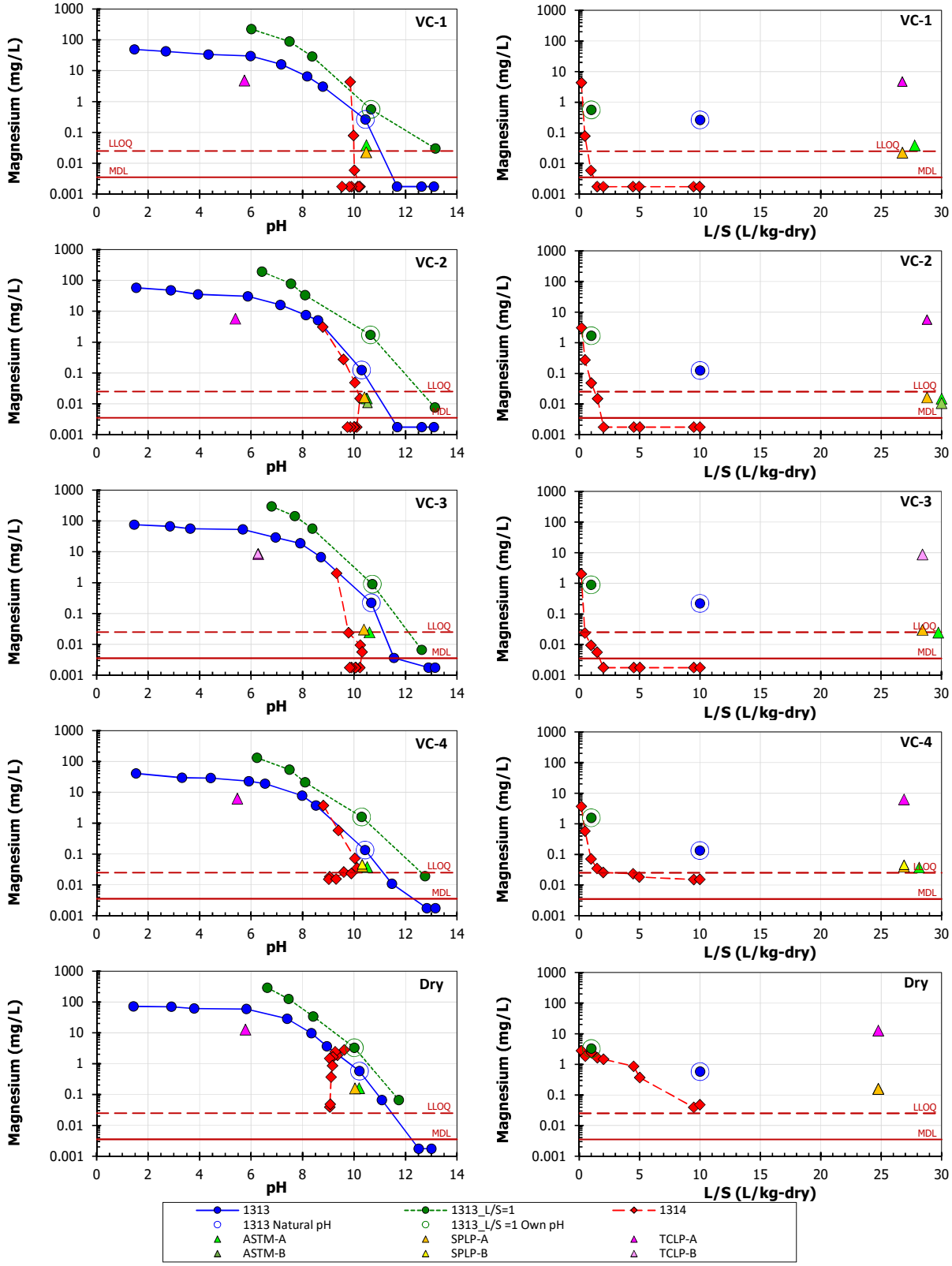

Figure C-21
Magnesium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

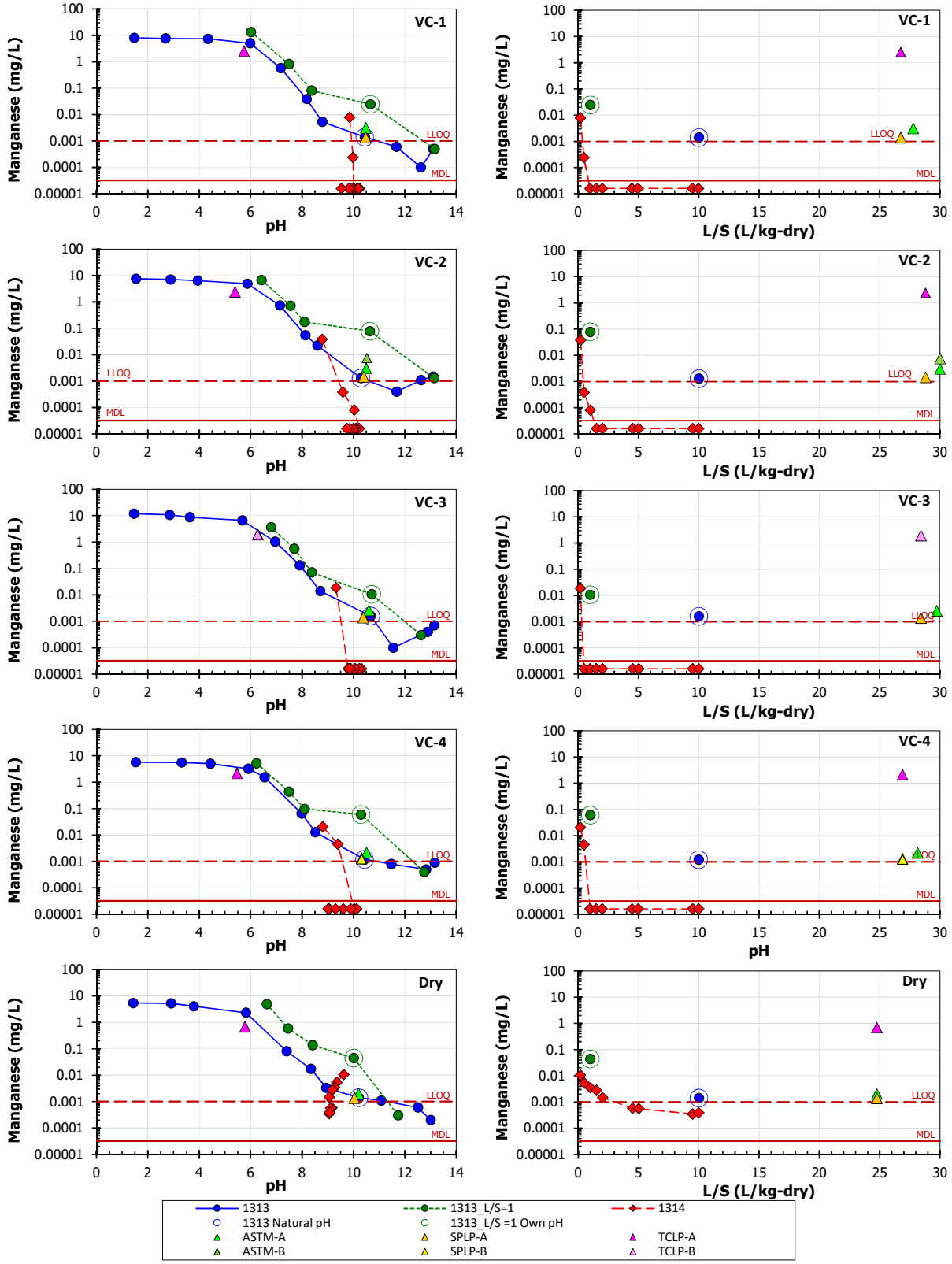

Figure C-22
Manganese leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

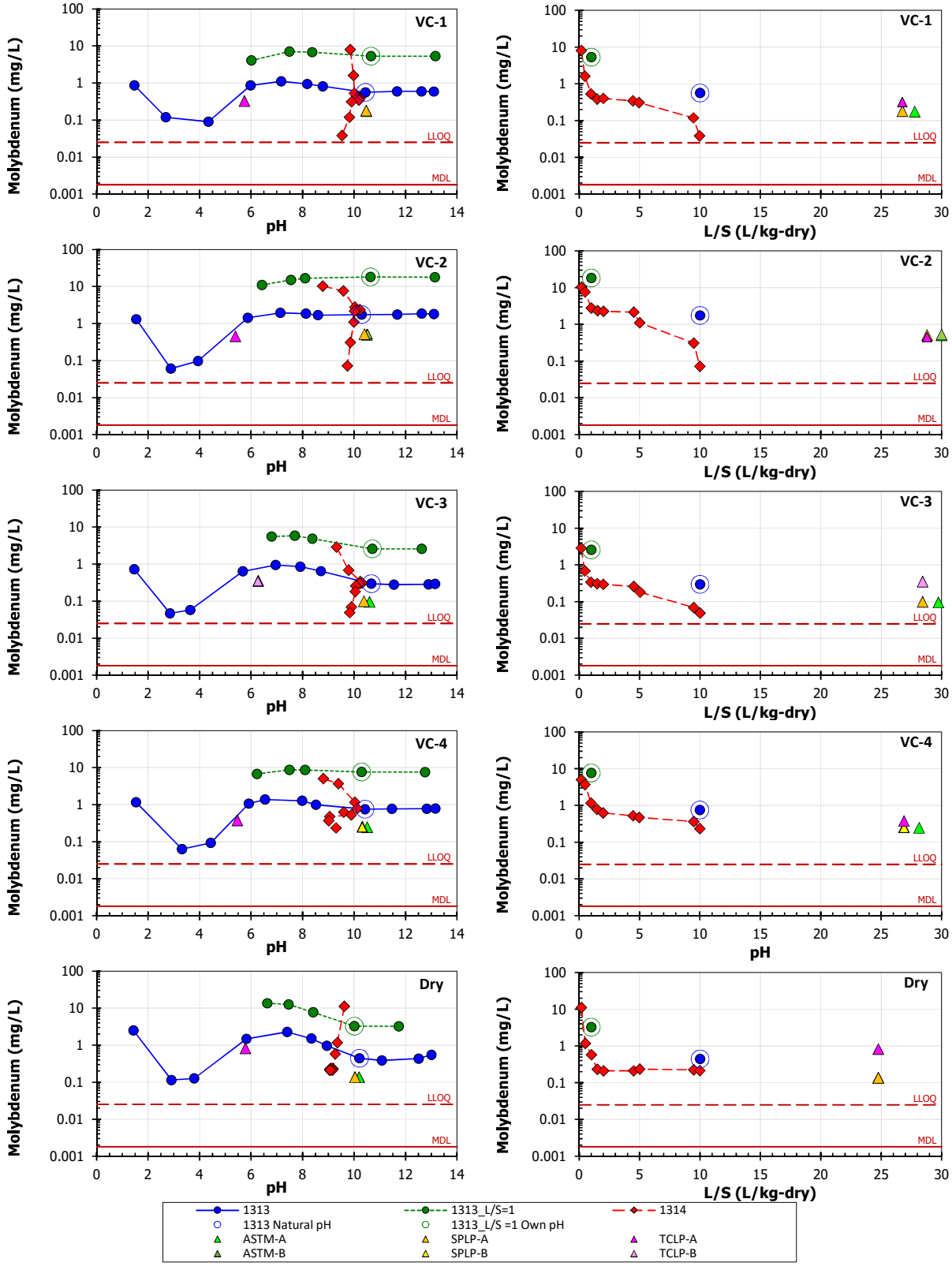

Figure C-23
Molybdenum leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

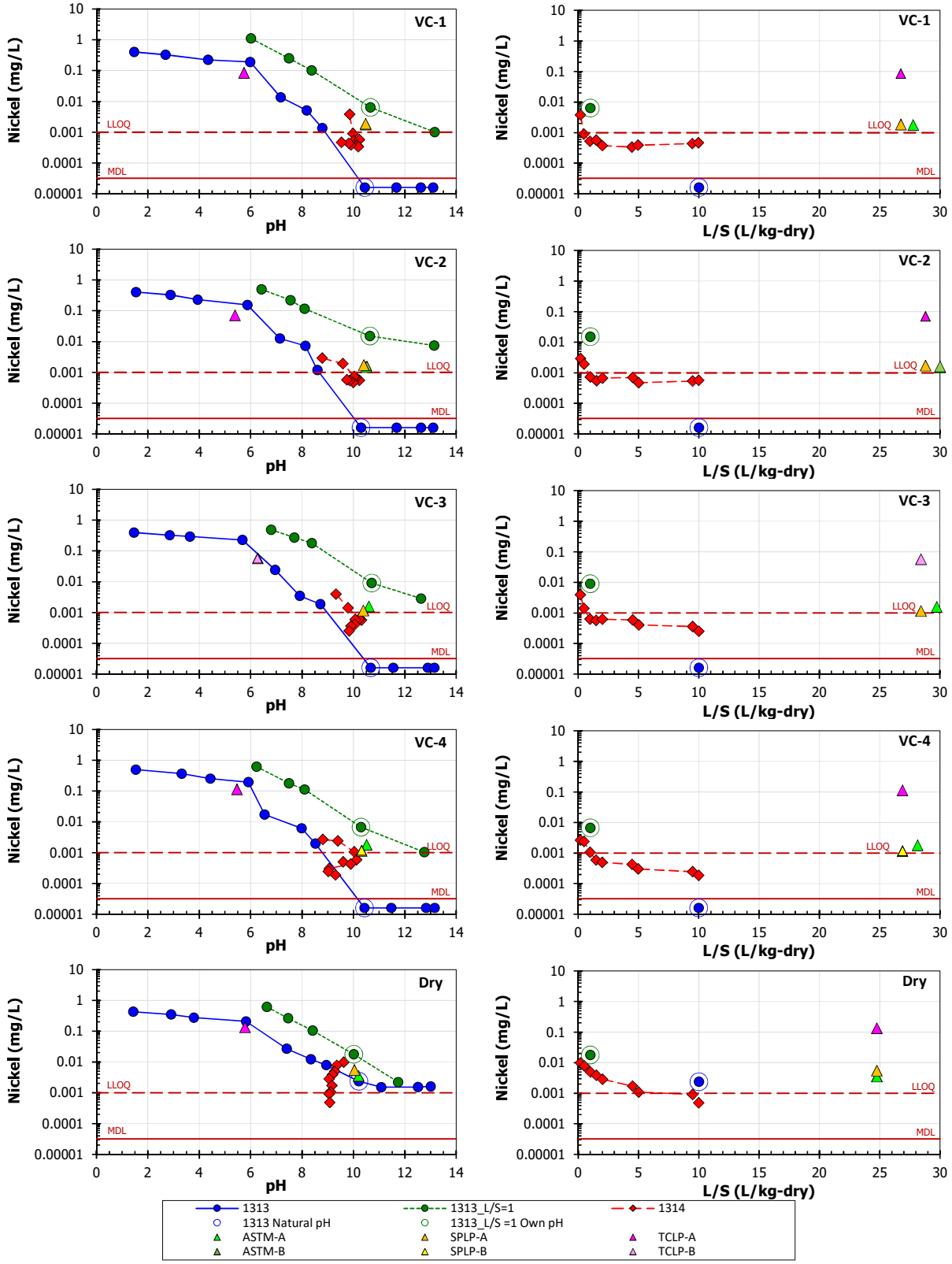

Figure C-24
Nickel leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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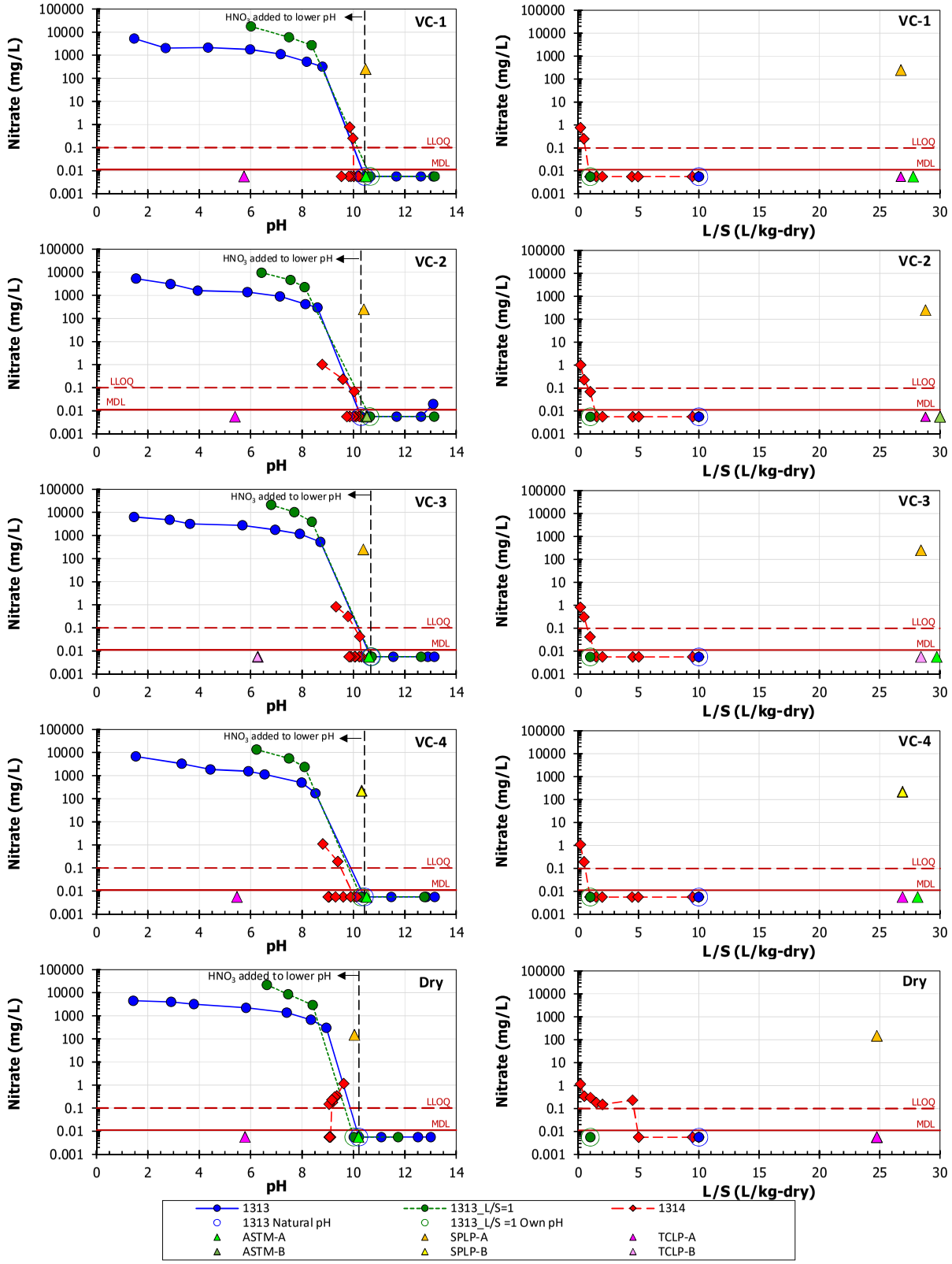

Figure C-25
Nitrate leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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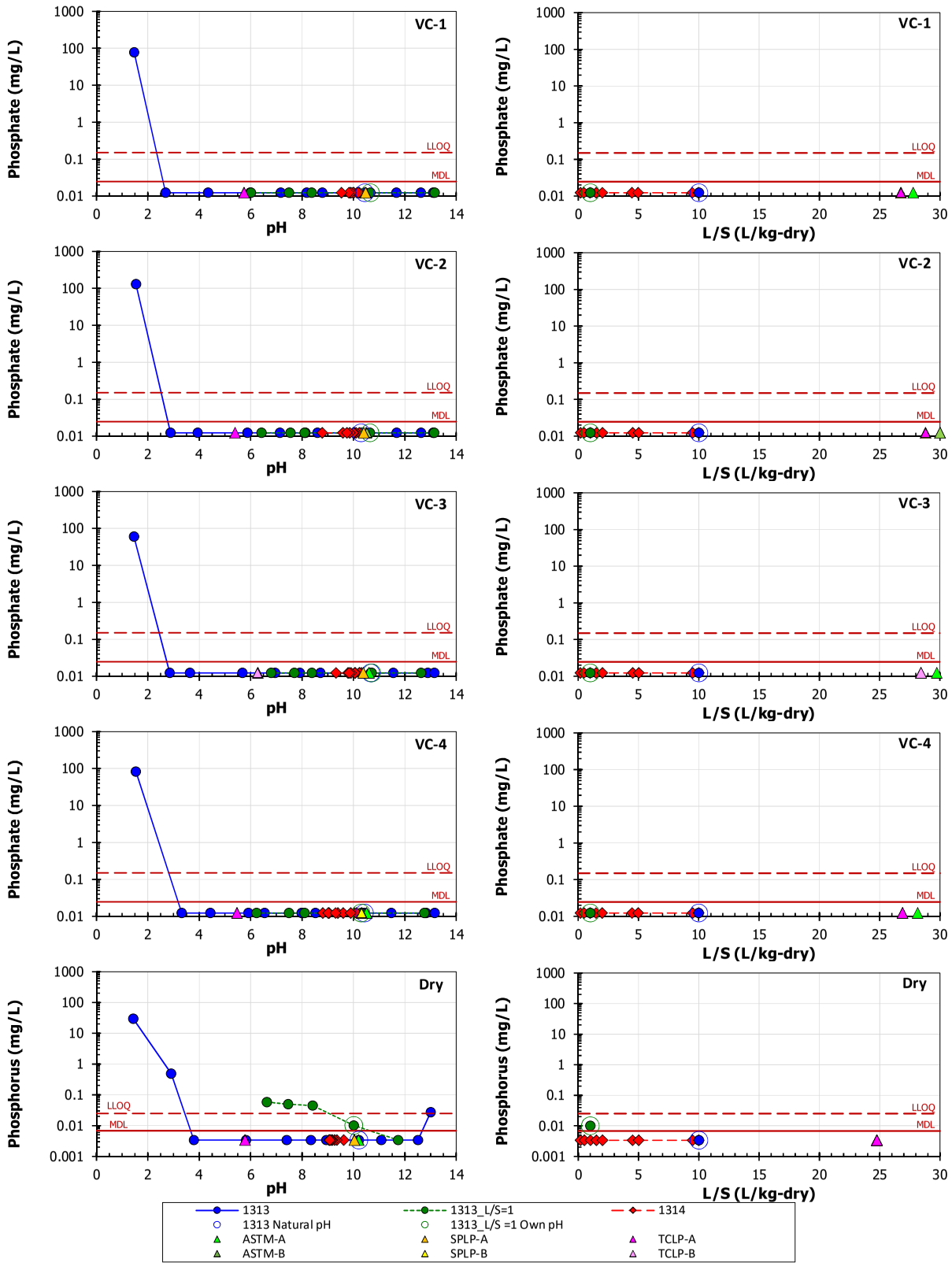

Figure C-26
Phosphate leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

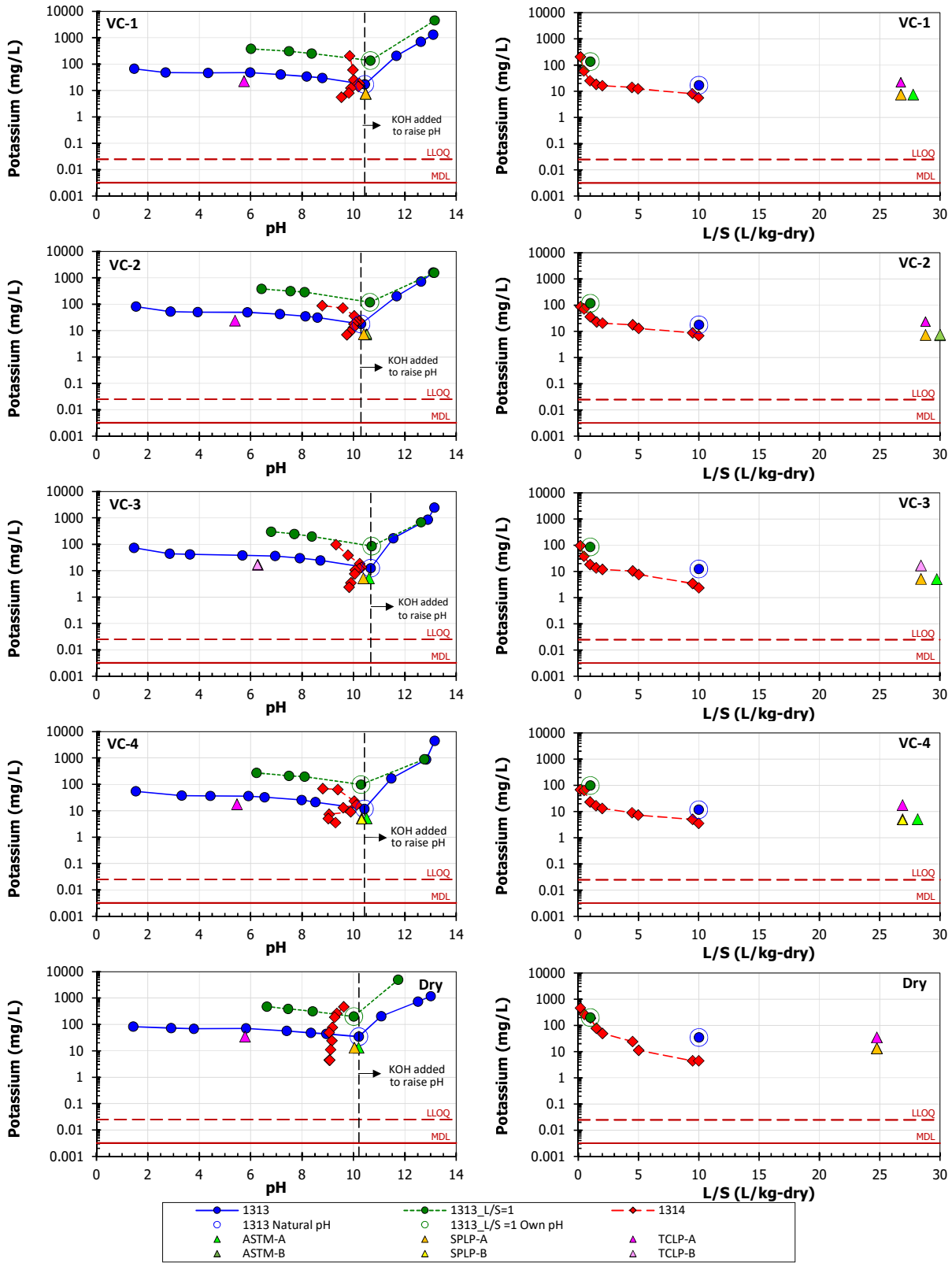

Figure C-27
Potassium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

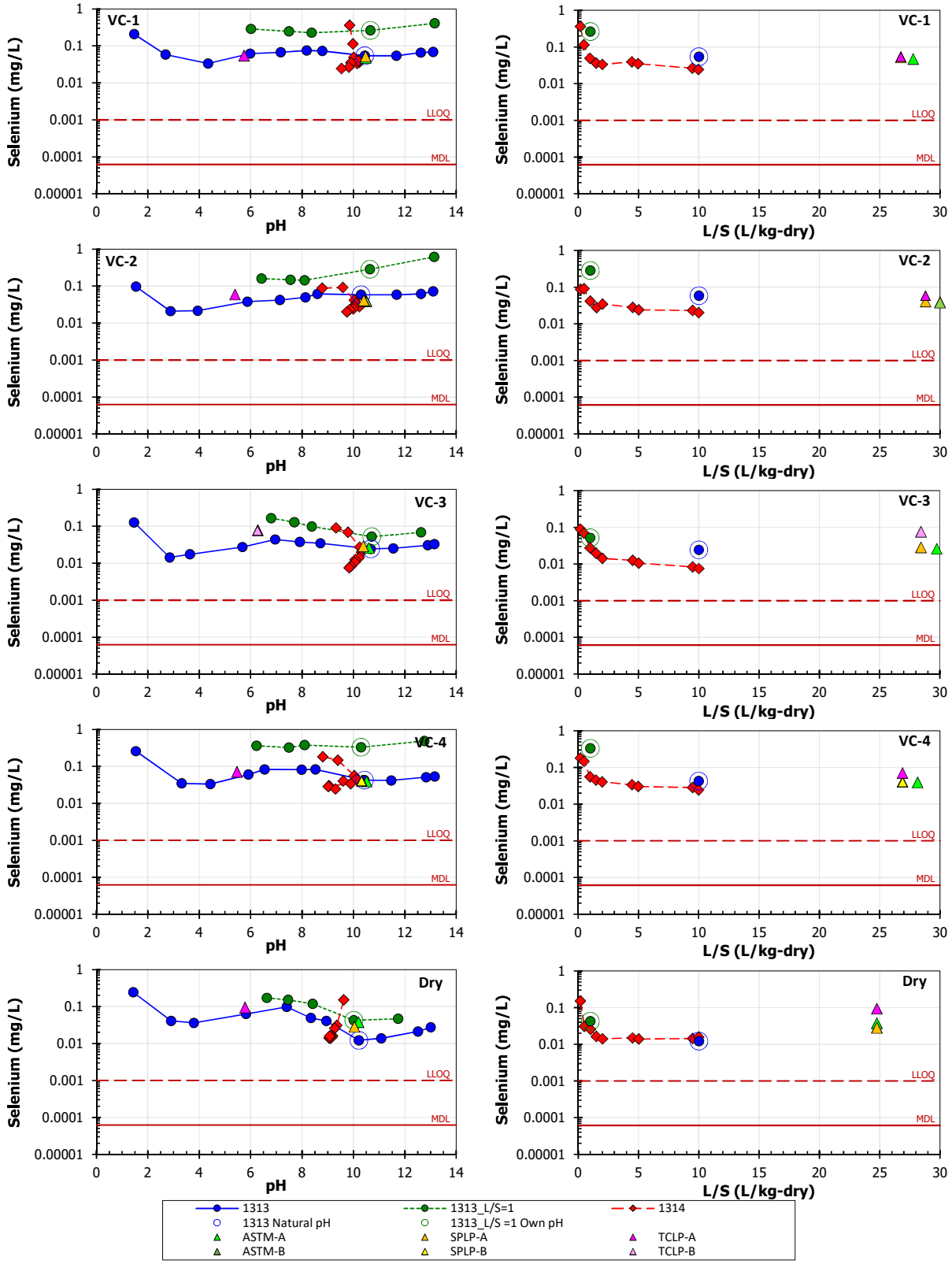

Figure C-28
Selenium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

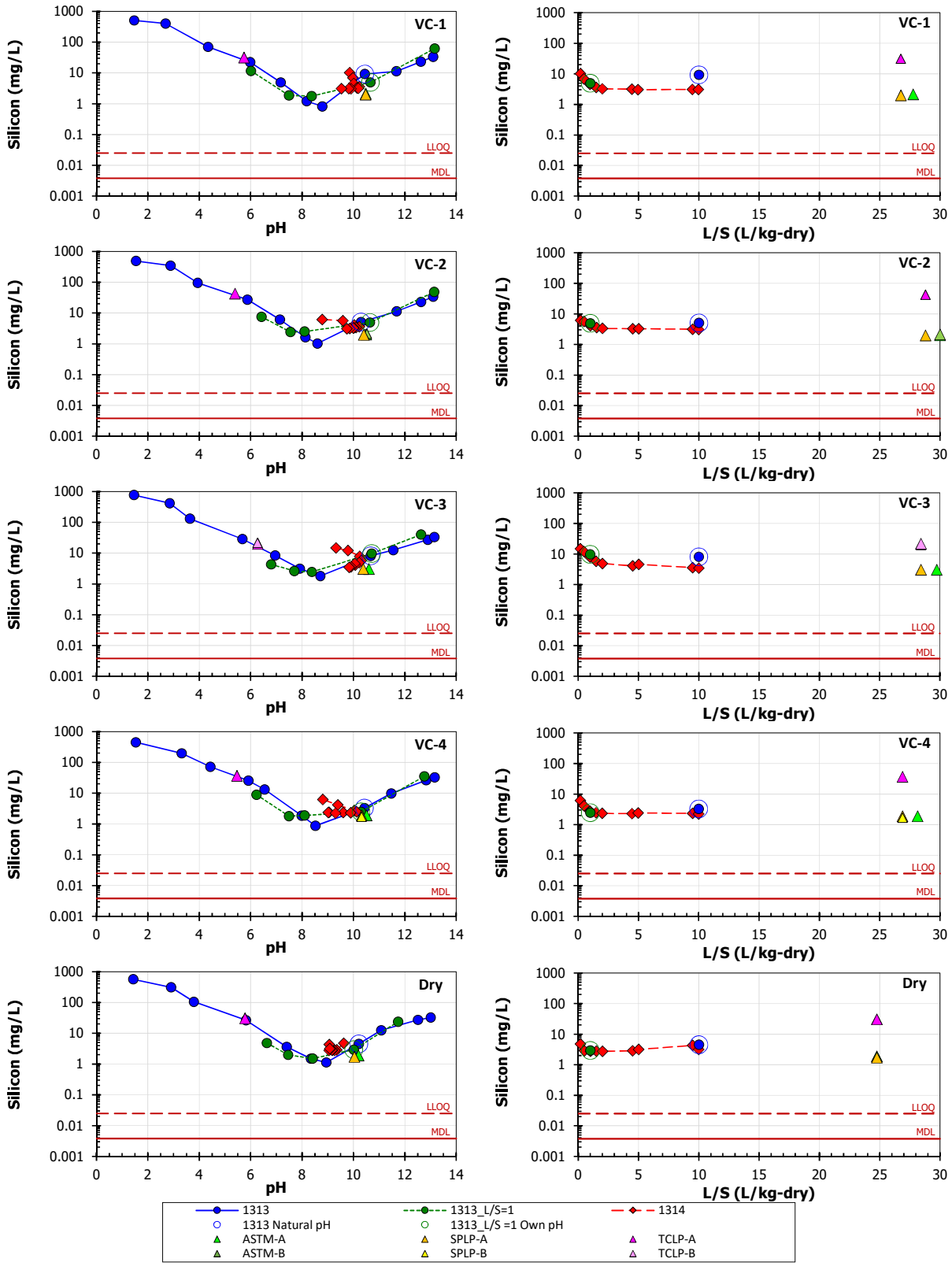

Figure C-29
Silicon leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

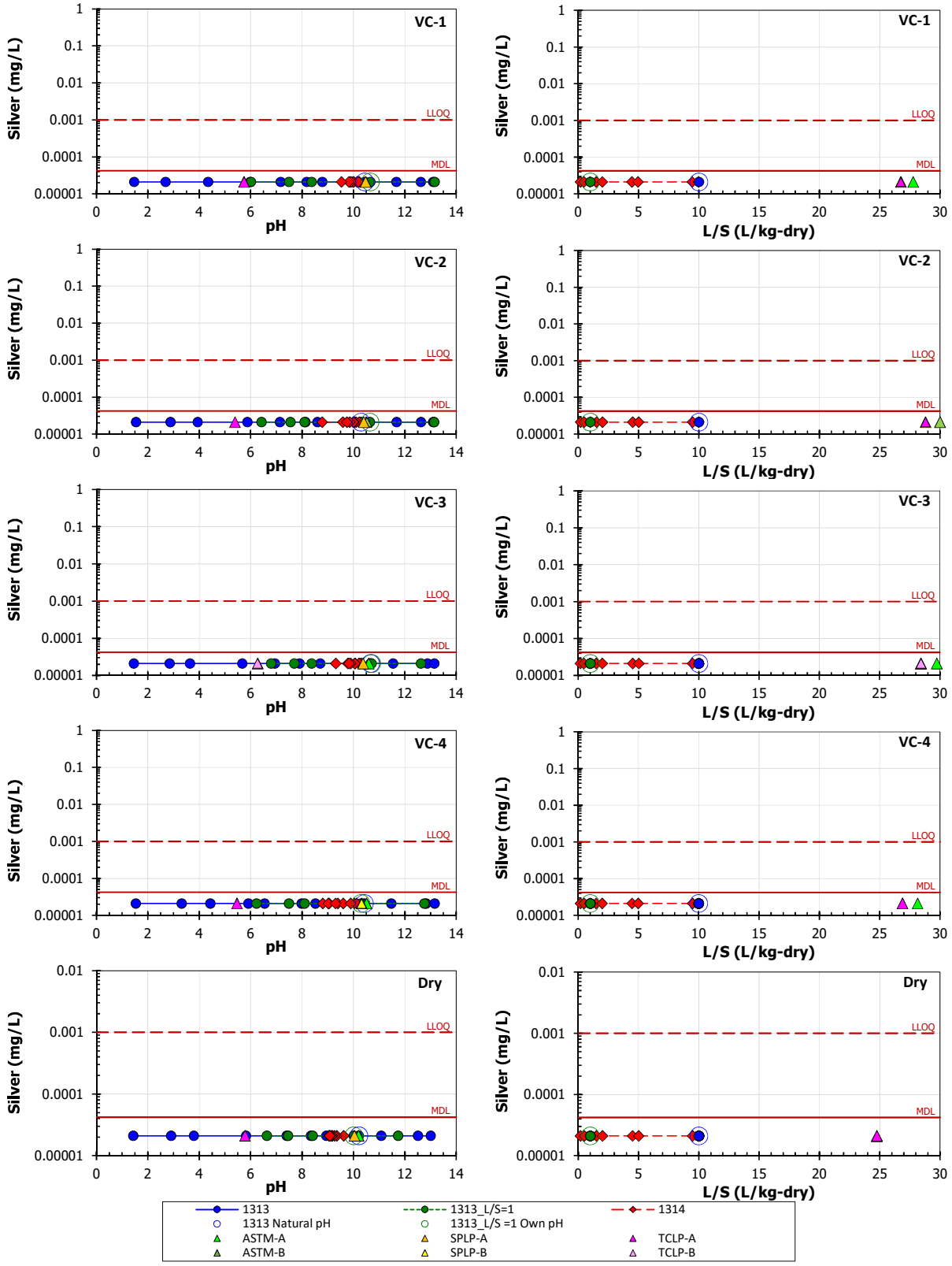

Figure C-30
Silver leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

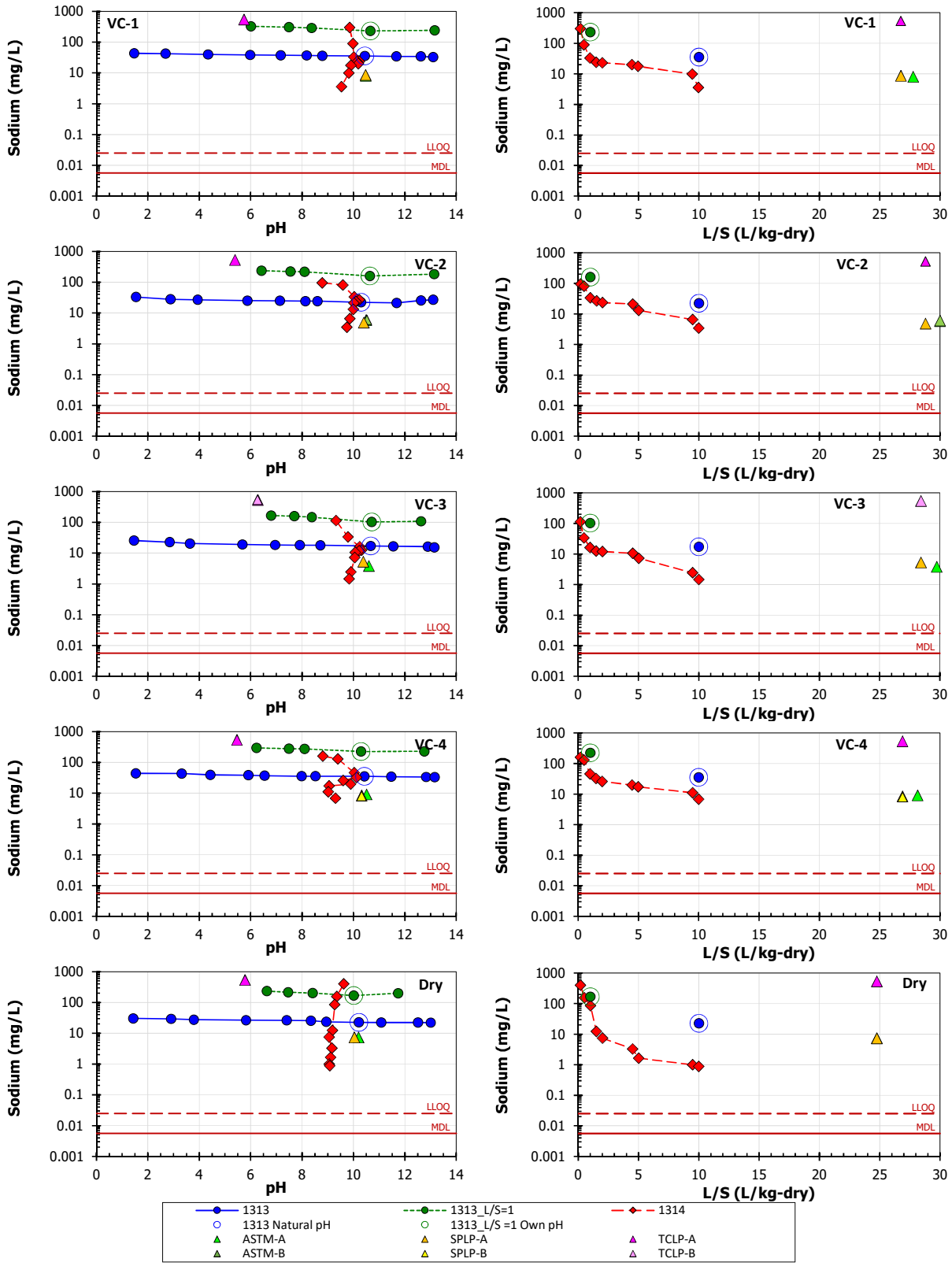

Figure C-31
Sodium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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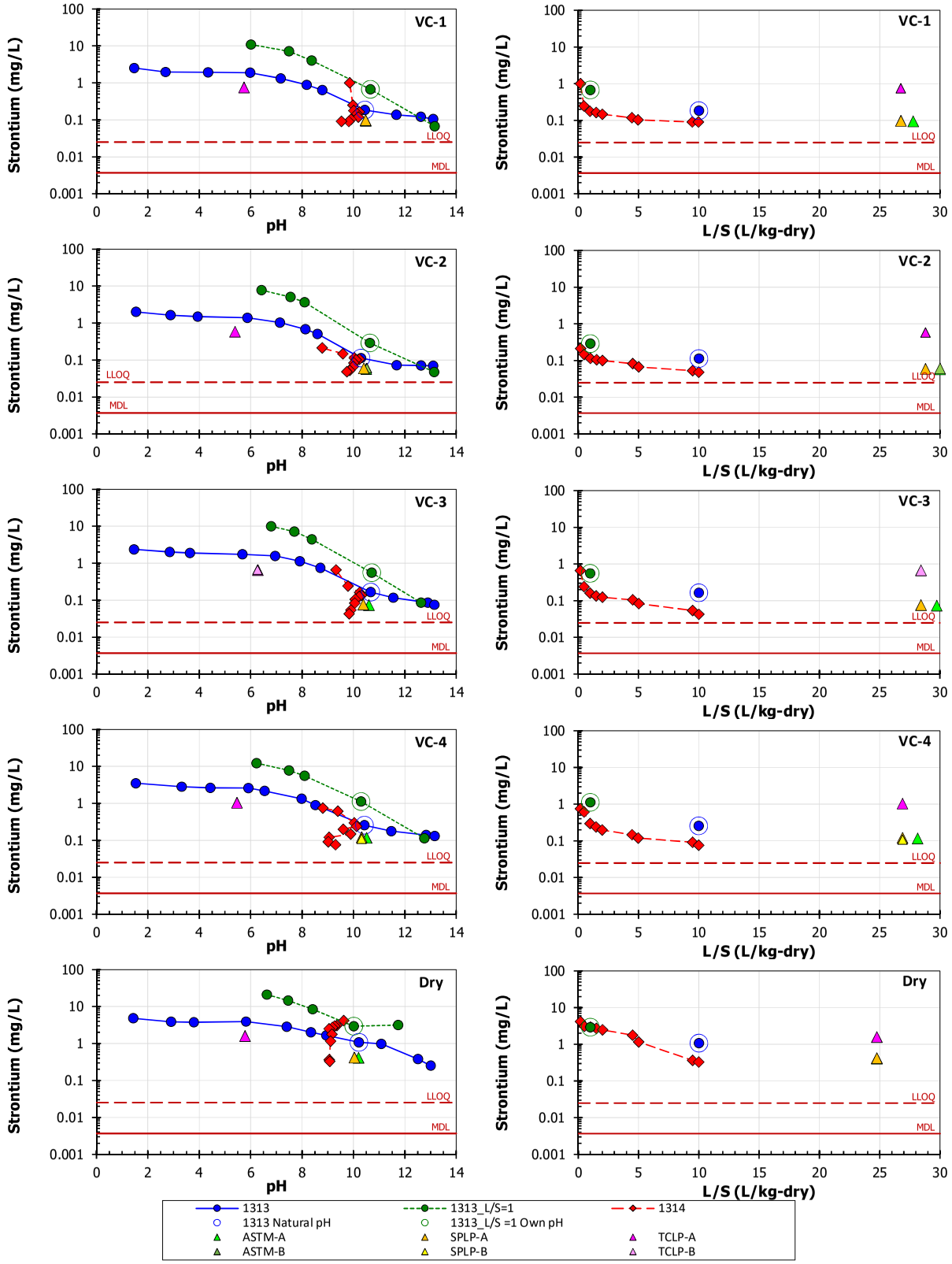

Figure C-32
Strontium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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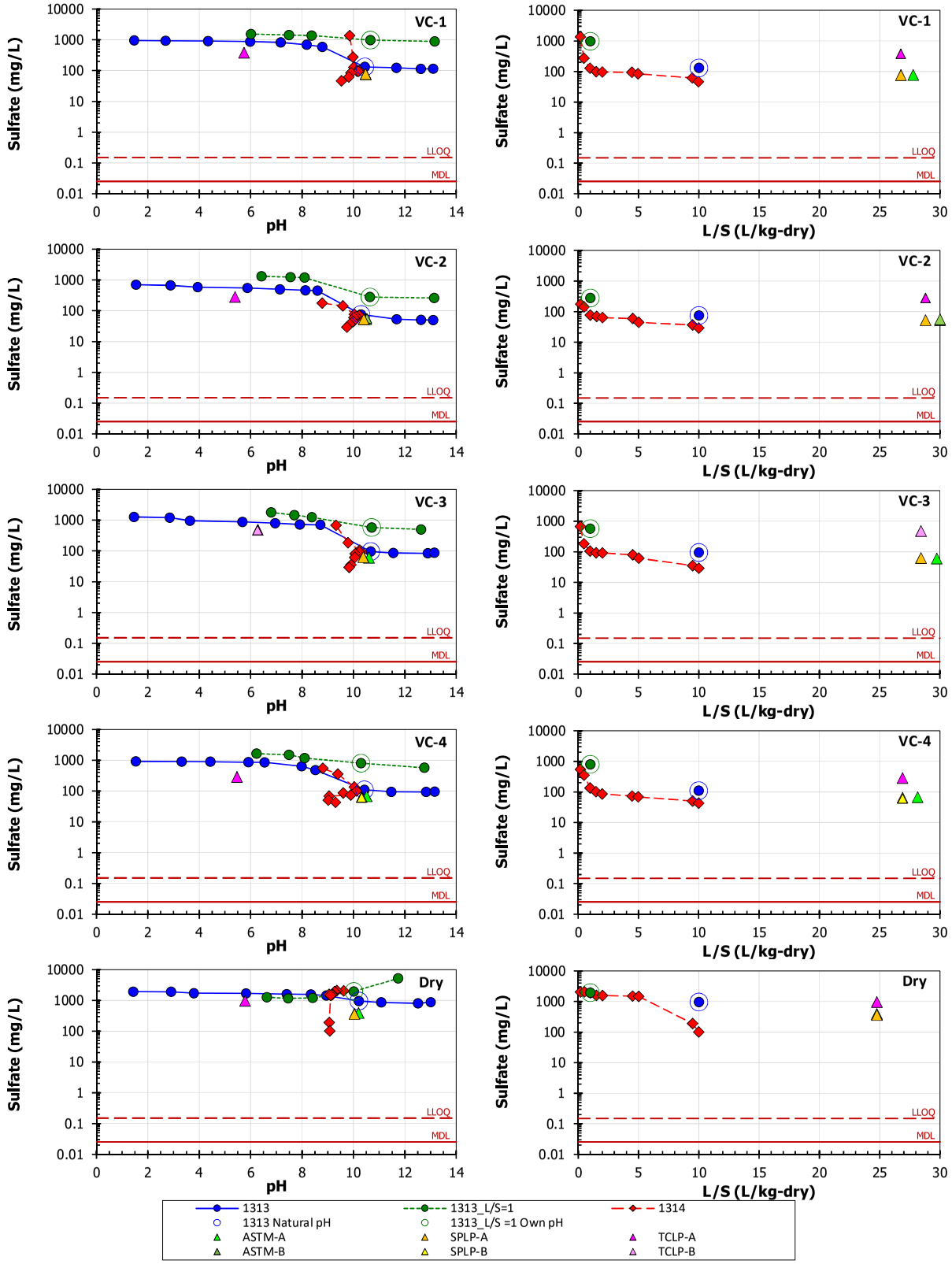

Figure C-33
Sulfate leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

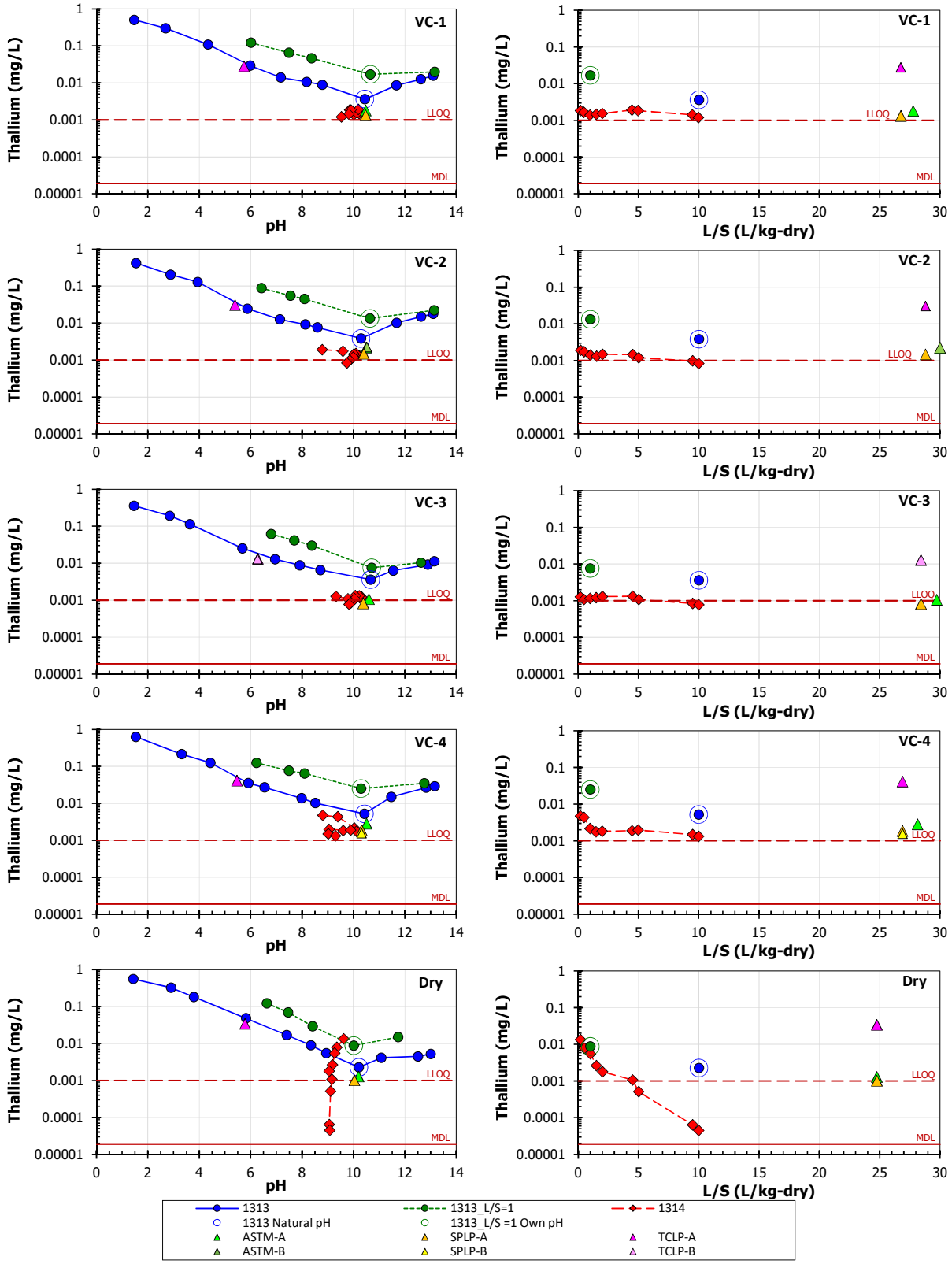

Figure C-34
Thallium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

Leaching Test Method Results

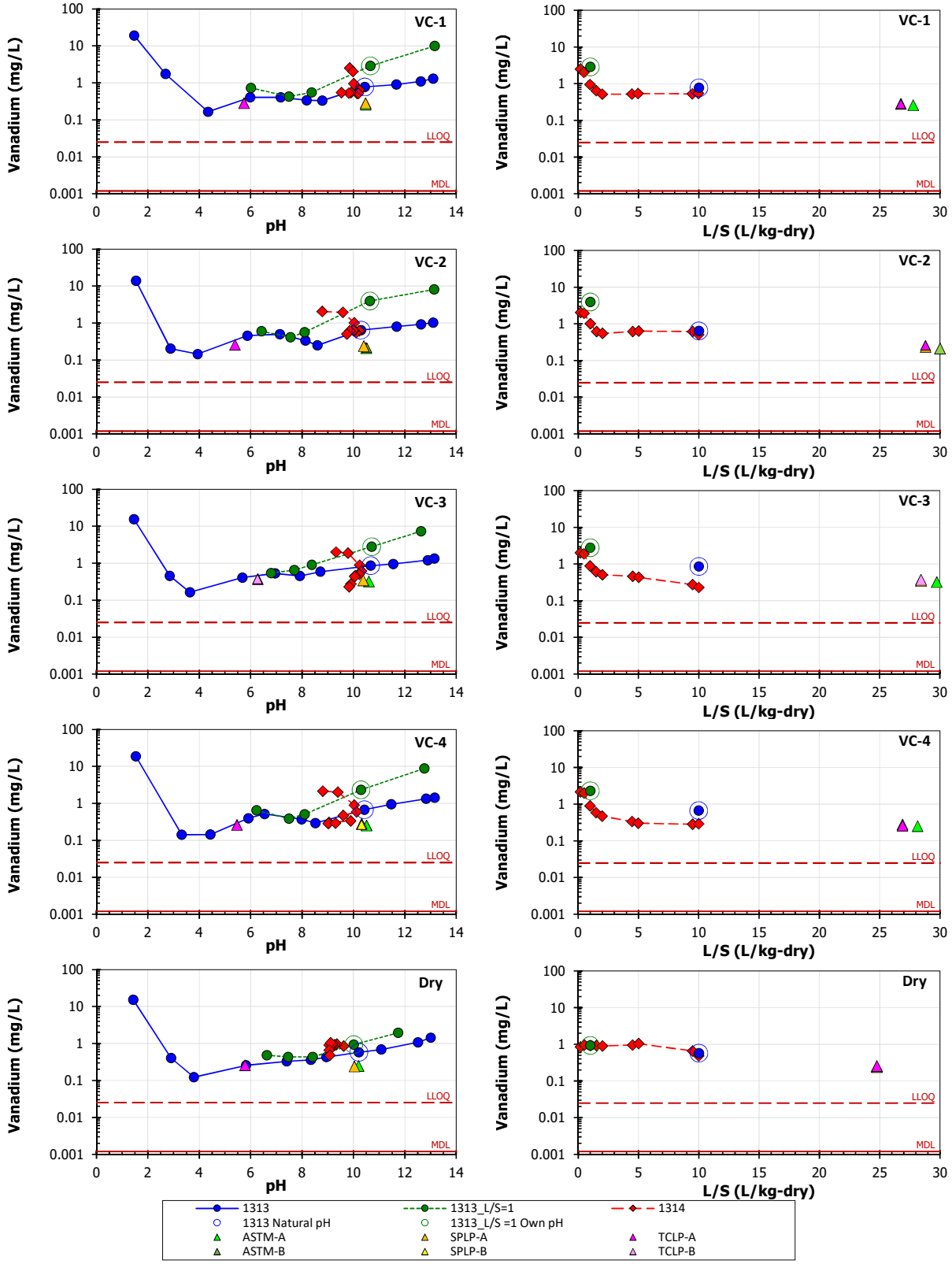

Figure C-35
Vanadium leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

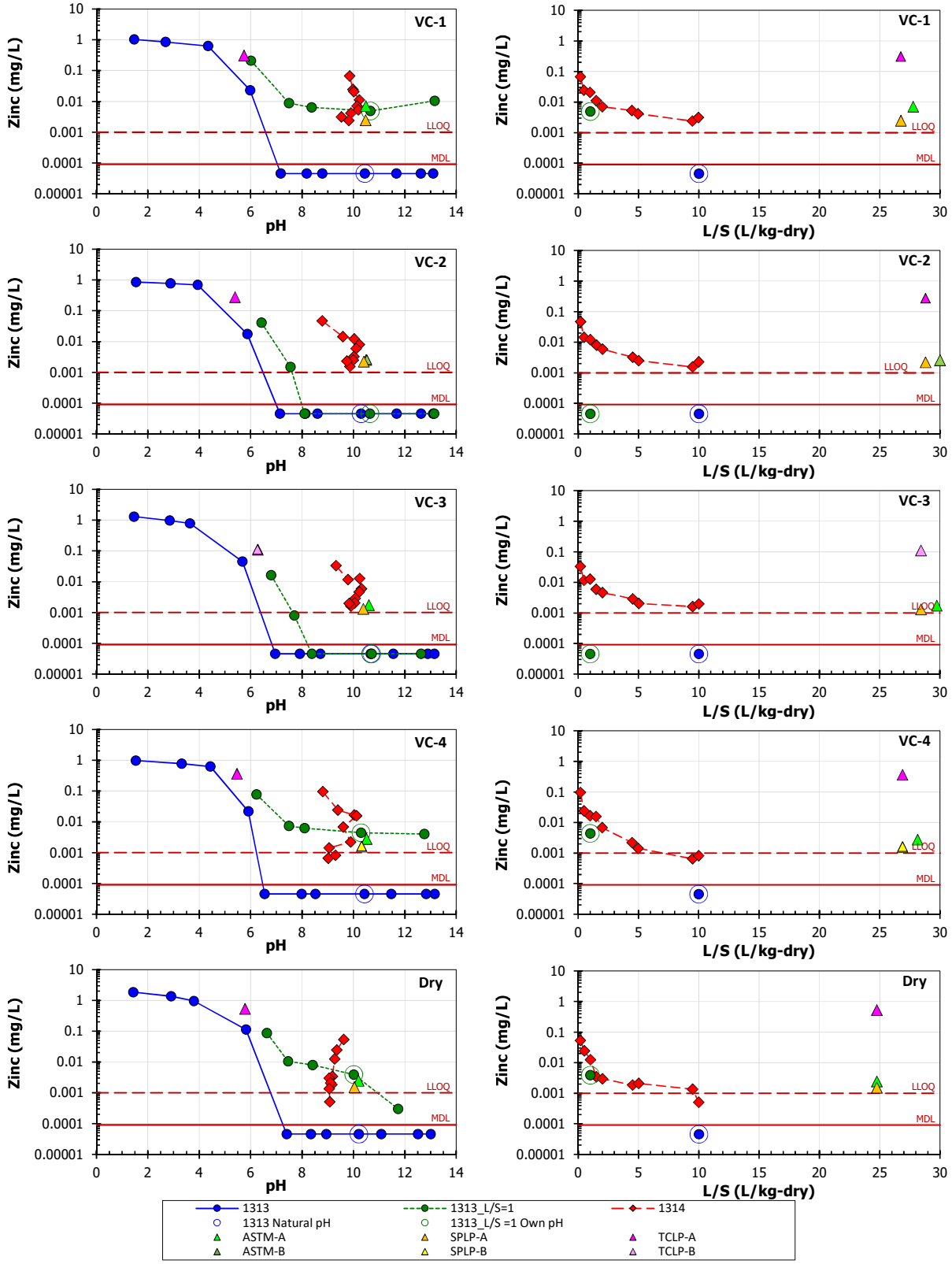

Figure C-36
Zinc leaching results for LEAF tests (1313, 1313@L/S=1, 1314) and traditional tests (TCLP, SPLP, ASTM) for Plant 42197 landfill composites

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D
GROUNDWATER AND POREWATER DATA

Table of Appendices

D-1 Groundwater and Porewater Data Tables and Graphs

D-2 Time Series Graphs for Porewater Data

D-3 Subsurface Gas Data Tables and Graphs

D-1 Groundwater and Porewater Data Tables and Graphs

CDL_VC-1 (ash porewater borehole)

	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	9:28	9:32	9:21	16:00	12:41	Groundwater sampling equipment unable to access borehole due to soft ground. Samples were not collected.	11:17	14:00
Water Table AMSL (ft)	56.71	56.51	59.85	58.58	59.27		60.40	59.73
Temperature (°C)	22.05	21.56	27.15	31.58	18.46		13.85	12.50
pH (s.u.)	9.87	10.35	10.24	10.03	10.47		10.74	10.50
DO (mg/L)	1.33	0.86	1.96	1.81	0.54		0.80	0.81
EC (mS/cm)	4.008	5.063	5.208	5.240	5.039		5.077	4.815
ORP (mV)	211	211	174	86	112		50	-13
Turbidity (NTU)	0.15	0.15	3.70	1.00	0.05		1.20	0.00
Time at end	9:37	9:34	9:27	16:06	12:46		11:24	14:08

CDL_VC-2 (ash porewater borehole)

	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	10:36	10:37	10:16	PVC borehole casing was damaged by heavy equipment. Collected samples were not analyzed. Casing repaired by CDL contractor during October sampling event.		16:05	13:52	10:55
Water Table AMSL (ft)	54.75	57.50	58.30			57.67	60.51	58.81
Temperature (°C)	22.55	23.42	26.74			17.71	15.63	10.30
pH (s.u.)	10.83	10.81	10.59			10.91	11.11	11.05
DO (mg/L)	3.10	2.27	1.97			1.16	0.50	0.85
EC (mS/cm)	1.648	2.111	1.900			1.878	1.829	1.830
ORP (mV)	38	38	42			125	88	165
Turbidity (NTU)	3.40	3.40	2.30			13.40	4.10	0.05
Time at end	10:42	10:45	10:26			16:10	13:58	11:02

CDL_VC-3 (ash porewater borehole)

	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	11:31	11:44	11:24	14:27	12:00	13:46	12:10	11:55
Water Table AMSL (ft)	58.46	60.21	61.00	61.40	61.60	61.33	63.50	61.80
Temperature (°C)	24.34	24.98	31.46	32.54	18.66	18.94	13.75	9.10
pH (s.u.)	10.32	10.53	10.26	10.08	10.53	10.51	10.68	10.75
DO (mg/L)	3.77	2.39	1.67	1.52	1.18	1.45	0.72	0.95
EC (mS/cm)	4.730	5.692	5.854	5.388	5.574	5.523	5.279	5.565
ORP (mV)	177	177	117	76	118	87	41	79
Turbidity (NTU)	1.25	1.25	2.10	1.80	0.00	1.50	1.65	0.00
Time at end	11:40	11:55	11:32	14:36	12:06	13:53	12:17	12:05

CDL_VC-4 (ash porewater borehole)

	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	12:29	12:40				12:48	14:51	1:00
Water Table AMSL (ft)	59.49	61.25				60.97	61.90	61.34
Temperature (°C)	23.53	25.57				18.84	15.14	11.60
pH (s.u.)	9.99	10.04				10.24	10.47	10.45
DO (mg/L)	3.90	1.40				0.56	0.60	0.50
EC (mS/cm)	4.399	5.356				4.960	4.907	4.903
ORP (mV)	210	210				180	120	73
Turbidity (NTU)	0.80	0.80				5.10	1.80	0.00
Time at end	12:34	12:46				12:54	14:58	1:05

PVC borehole casing was damaged by heavy equipment. Collected samples were not analyzed. Casing repaired by CDL contractor during October sampling event.

Groundwater and Porewater Data

GW_209 (downgradient groundwater well)

	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	13:32	13:44	14:50	10:55	10:55	10:19	10:26	15:00
Water Table AMSL (ft)	35.36	35.88	36.68	37.70	38.04	38.01	37.50	35.45
Temperature (°C)	24.46	24.27	30.03	32.00	17.32	16.83	13.28	11.60
pH (s.u.)	6.93	6.80	6.74	6.61	6.85	6.86	6.85	6.75
DO (mg/L)	2.33	0.62	0.71	2.52	0.59	0.62	0.83	0.16
EC (mS/cm)	2.629	2.854	2.954	3.093	3.159	3.279	3.282	3.363
ORP (mV)	57	57	97	138	141	109	131	75
Turbidity (NTU)	0.75	0.75	7.55	1.25	0.00	1.75	0.70	0.00
Time at end	13:37	13:50	14:57	11:03	11:00	10:25	10:31	15:08

GW_931 (downgradient groundwater well)

	Jun-19	**Jul-19**	**Aug-19**	**Sep-19**	**Oct-19**	**Nov-19**	**Dec-19**	**Jan-20**
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
Time at start	15:14	15:03	15:59	10:05	9:55	9:32	9:42	9:40
Water Table AMSL (ft)	35.61	36.49	37.75	40.05	40.30	40.25	39.43	35.90
Temperature (°C)	24.53	24.27	29.49	24.46	16.00	17.39	13.52	9.90
pH (s.u.)	6.62	6.50	6.48	6.42	6.60	6.58	6.55	6.54
DO (mg/L)	0.87	0.36	0.63	0.23	0.24	0.98	0.52	1.45
EC (mS/cm)	3.368	3.385	3.410	3.312	3.212	3.205	3.266	3.196
ORP (mV)	157	157	142	155	174	174	153	184
Turbidity (NTU)	9.40	9.40	9.70	9.65	17.45	14.35	7.75	38.40
Time at end	15:25	15:16	16:07	10:10	10:04	9:39	9:49	9:48

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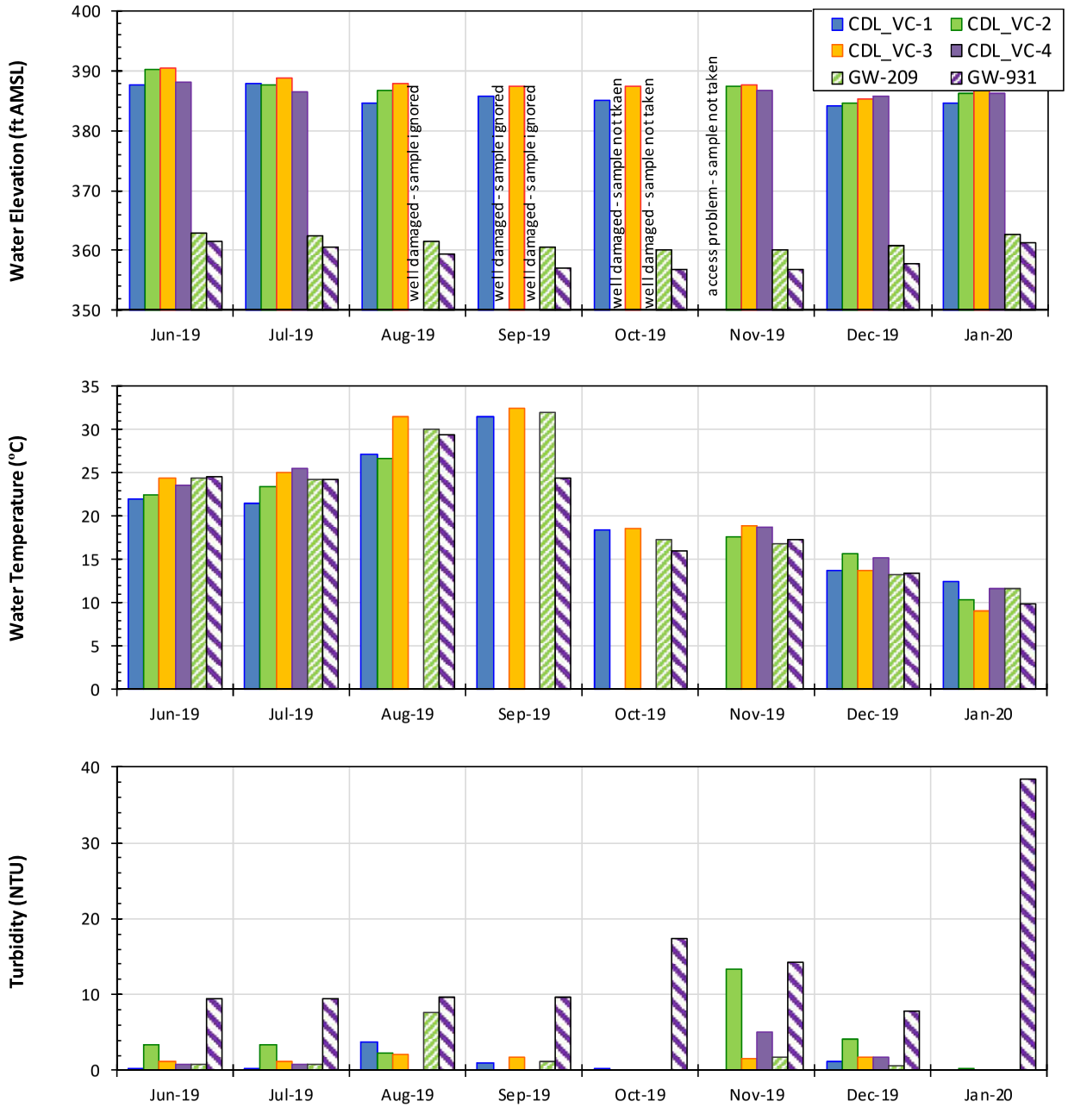

Figure D-1
Groundwater and porewater conditions during monthly sampling: water table elevation ASML, water temperature, and turbidity

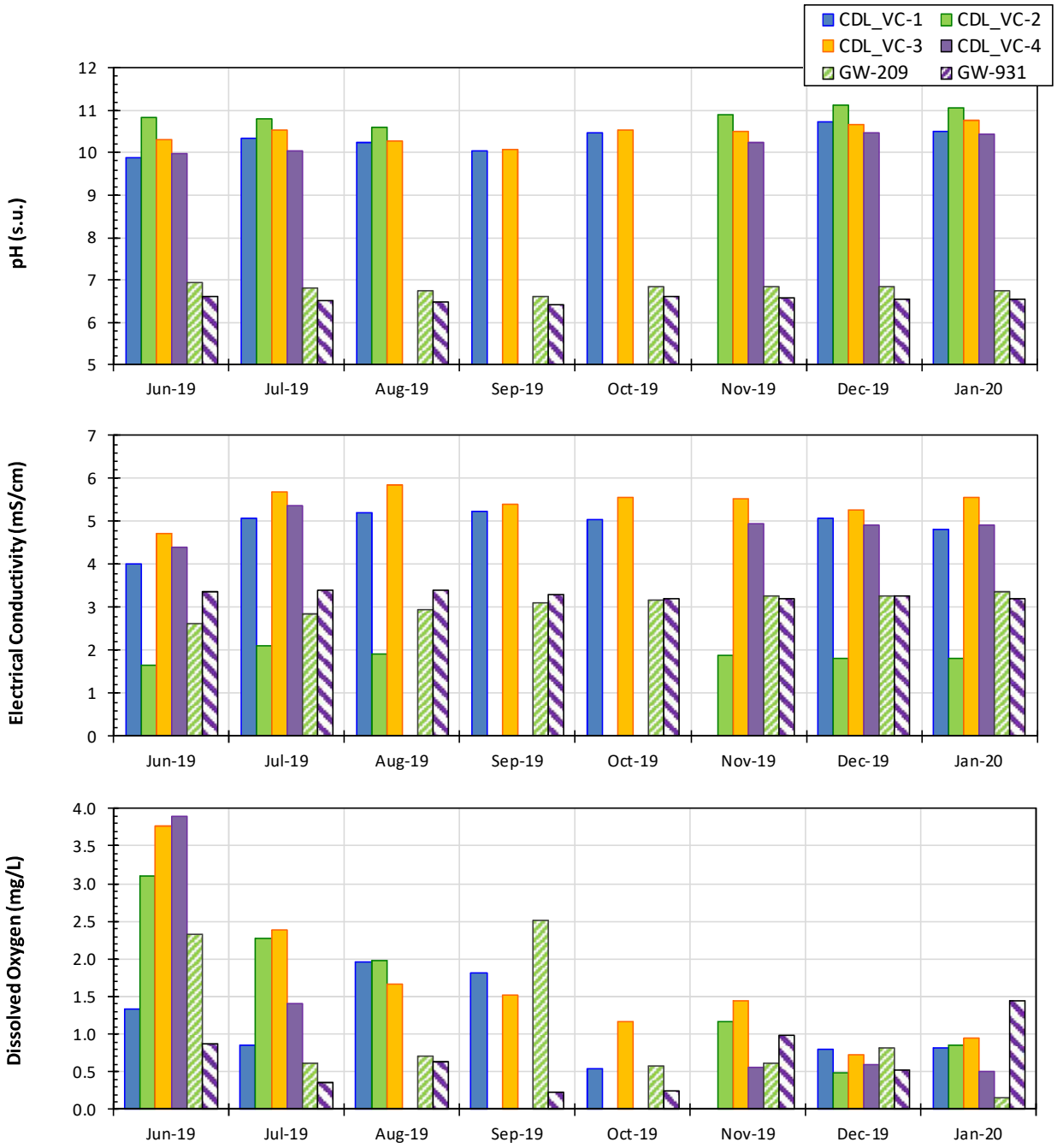

Figure D-2
Groundwater and porewater conditions during monthly sampling: pH, electrical conductivity, and dissolved oxygen

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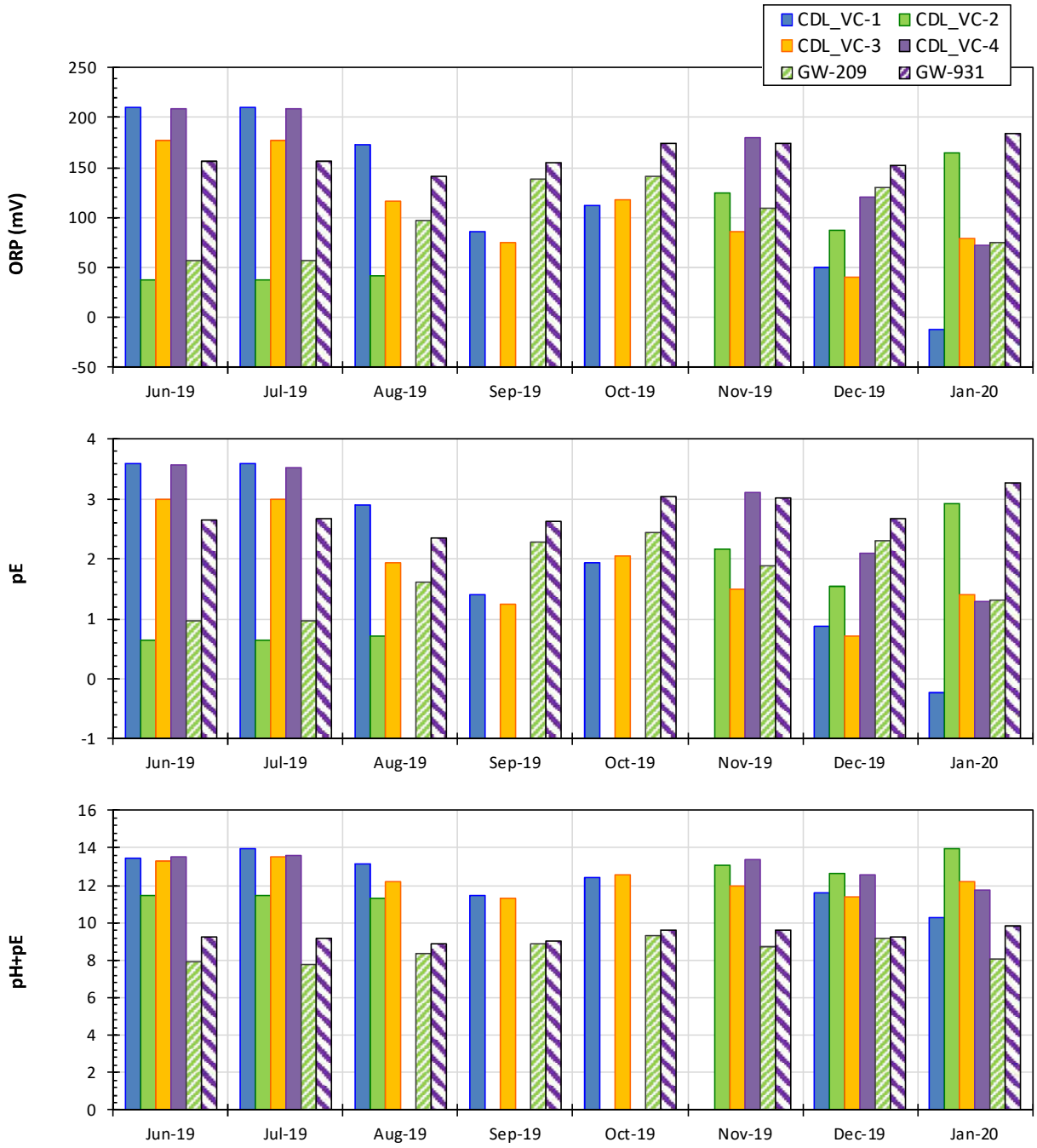

Figure D-3
Groundwater and porewater conditions during monthly sampling: ORP, pE (derived from ORP), and pH+pE (derived from ORP and pH)

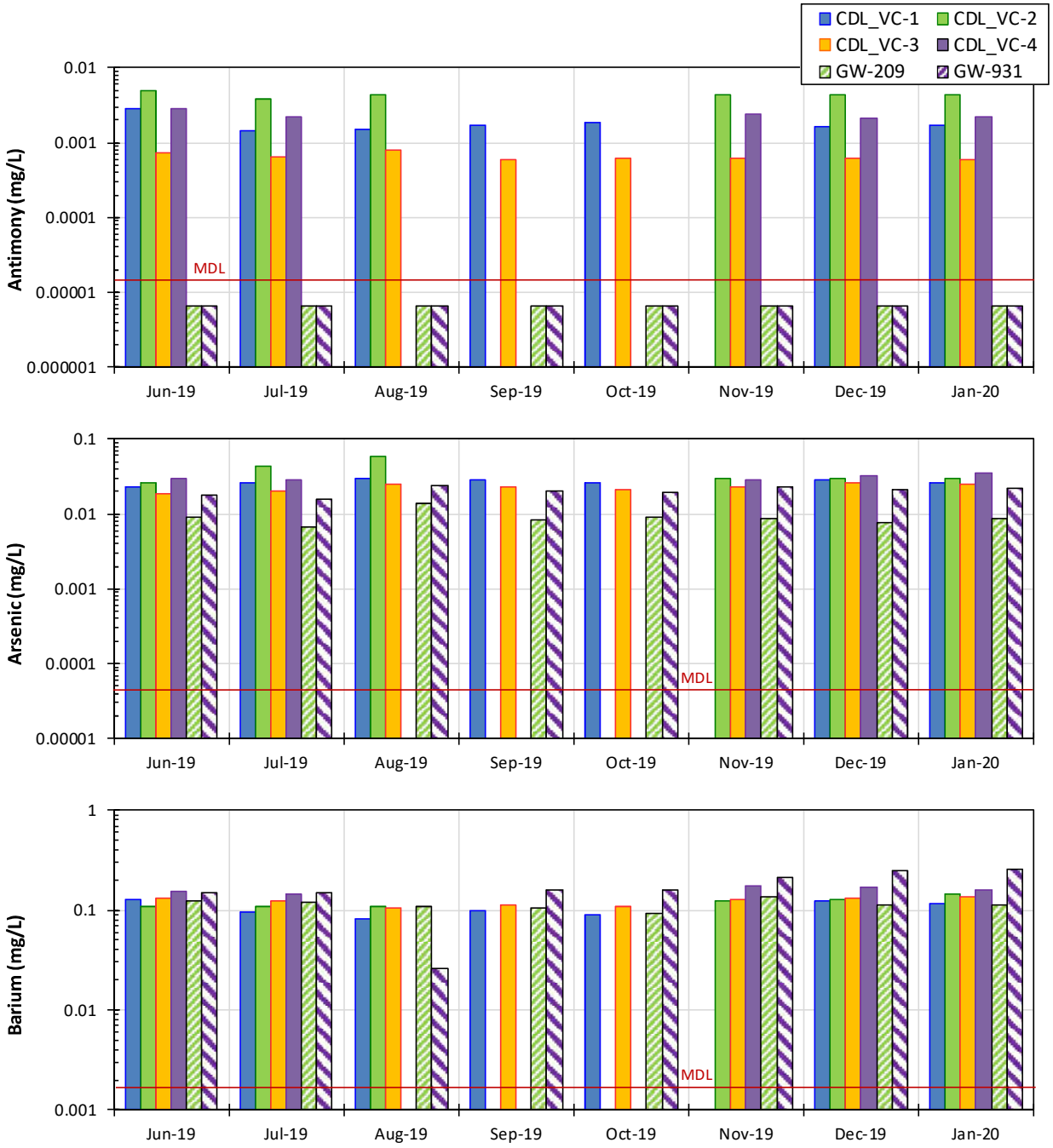

Figure D-4
Measured groundwater and porewater concentrations plotted on a logarithmic axis: antimony, arsenic, and barium

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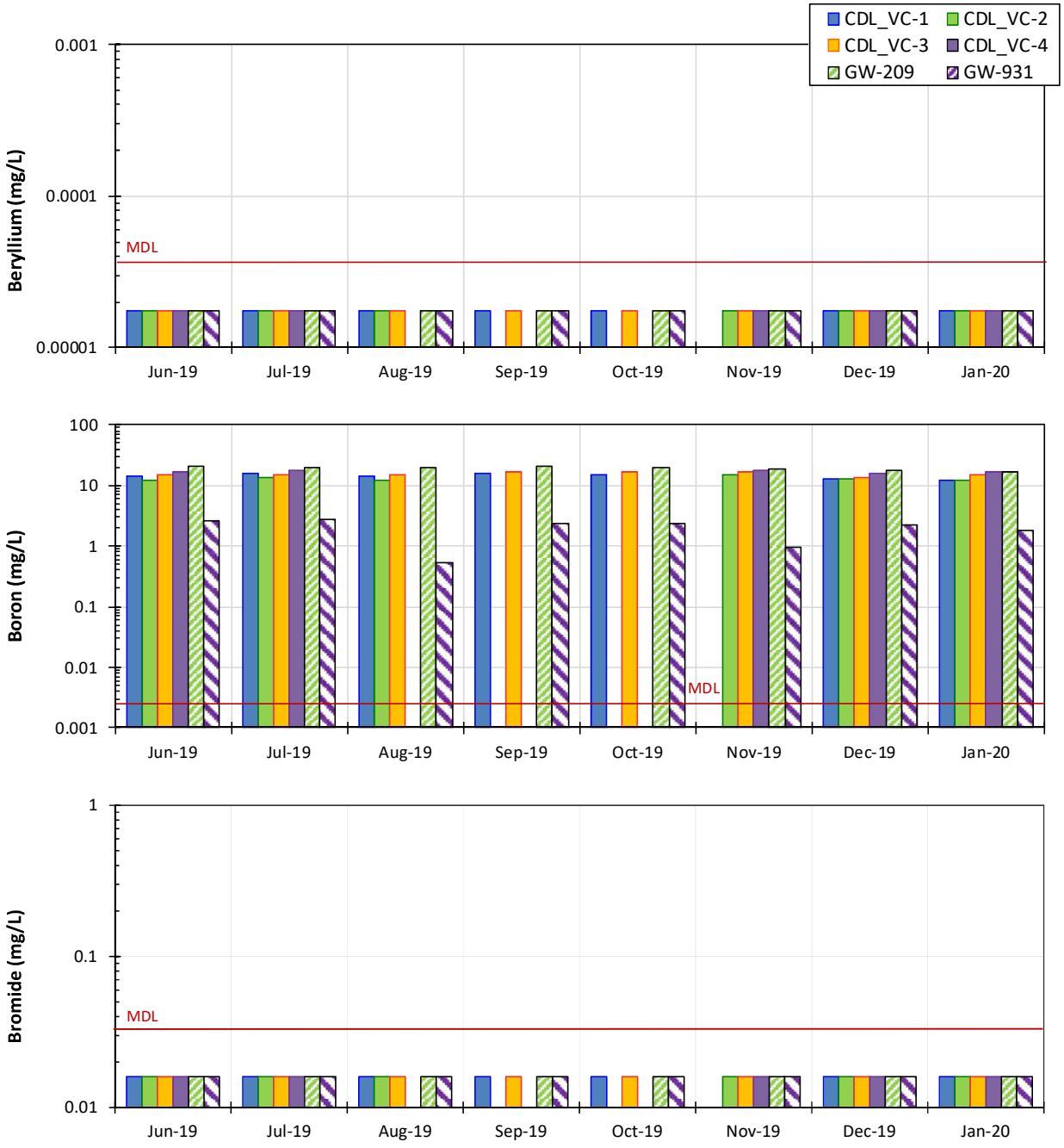

Figure D-5
Measured groundwater and porewater concentrations plotted on a logarithmic axis: beryllium, boron, and bromide

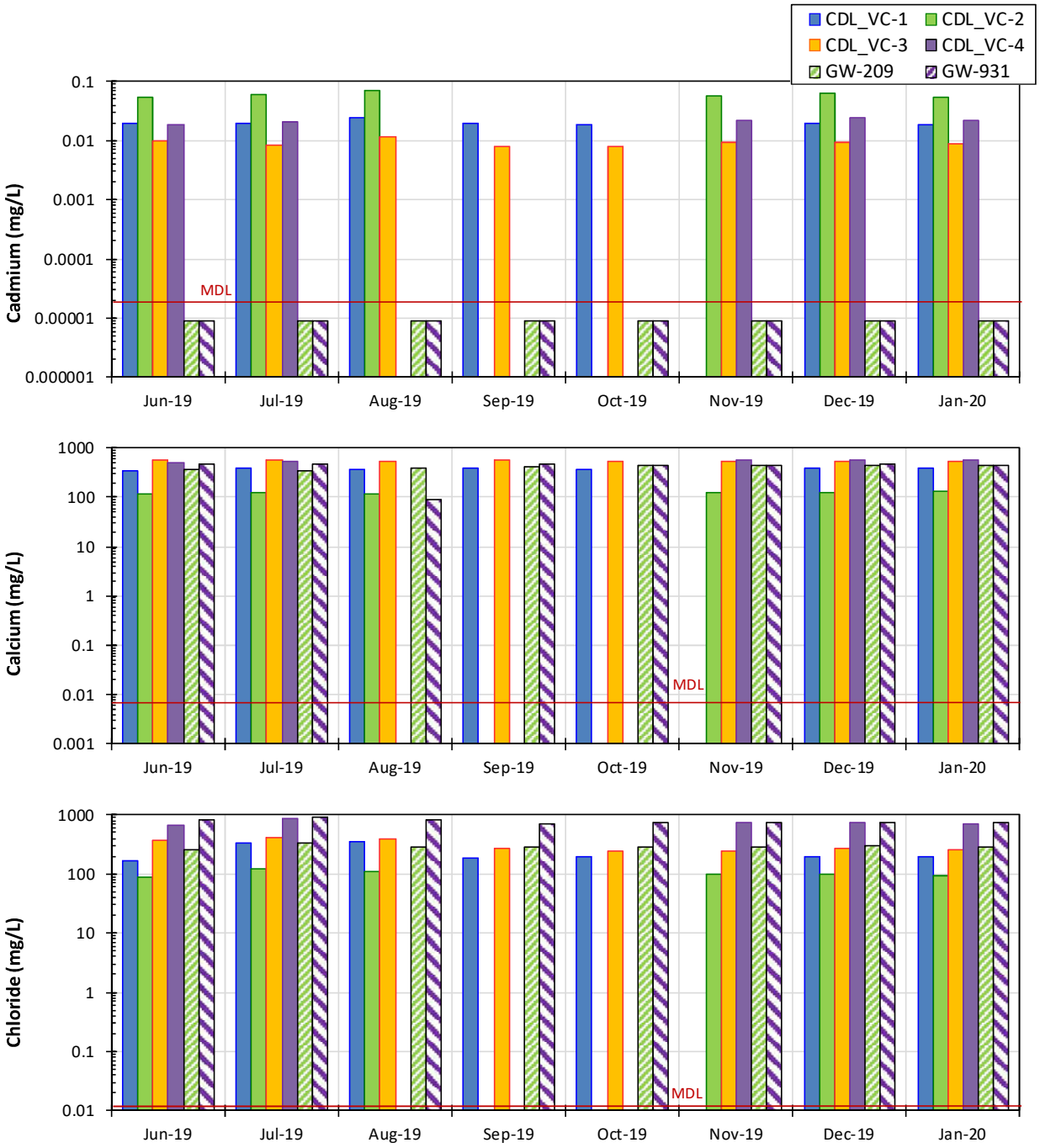

Figure D-6
Measured groundwater and porewater concentrations plotted on a logarithmic axis: cadmium, calcium, and chloride

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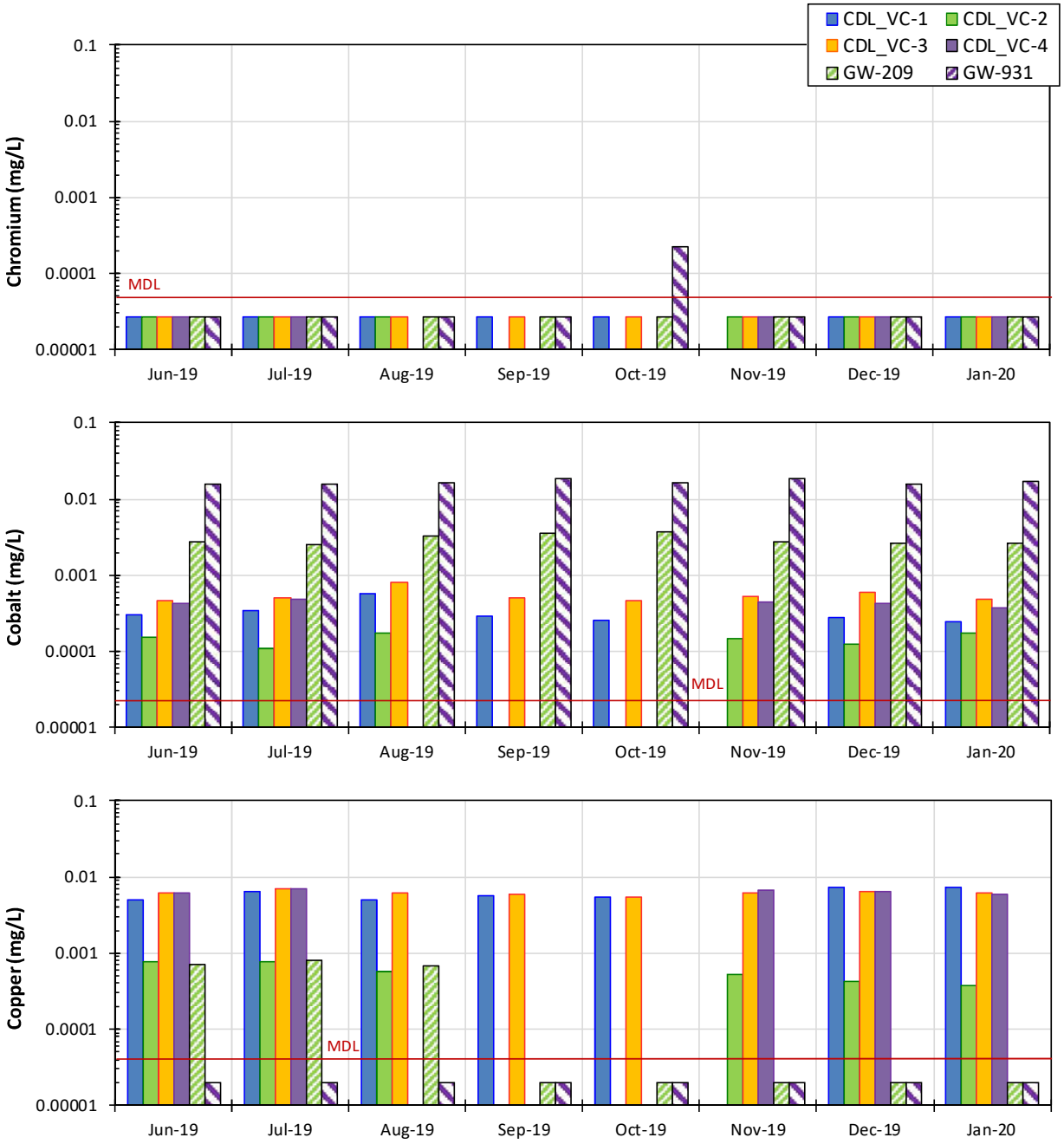

Figure D-7
Measured groundwater and porewater concentrations plotted on a logarithmic axis: chromium, cobalt, and copper

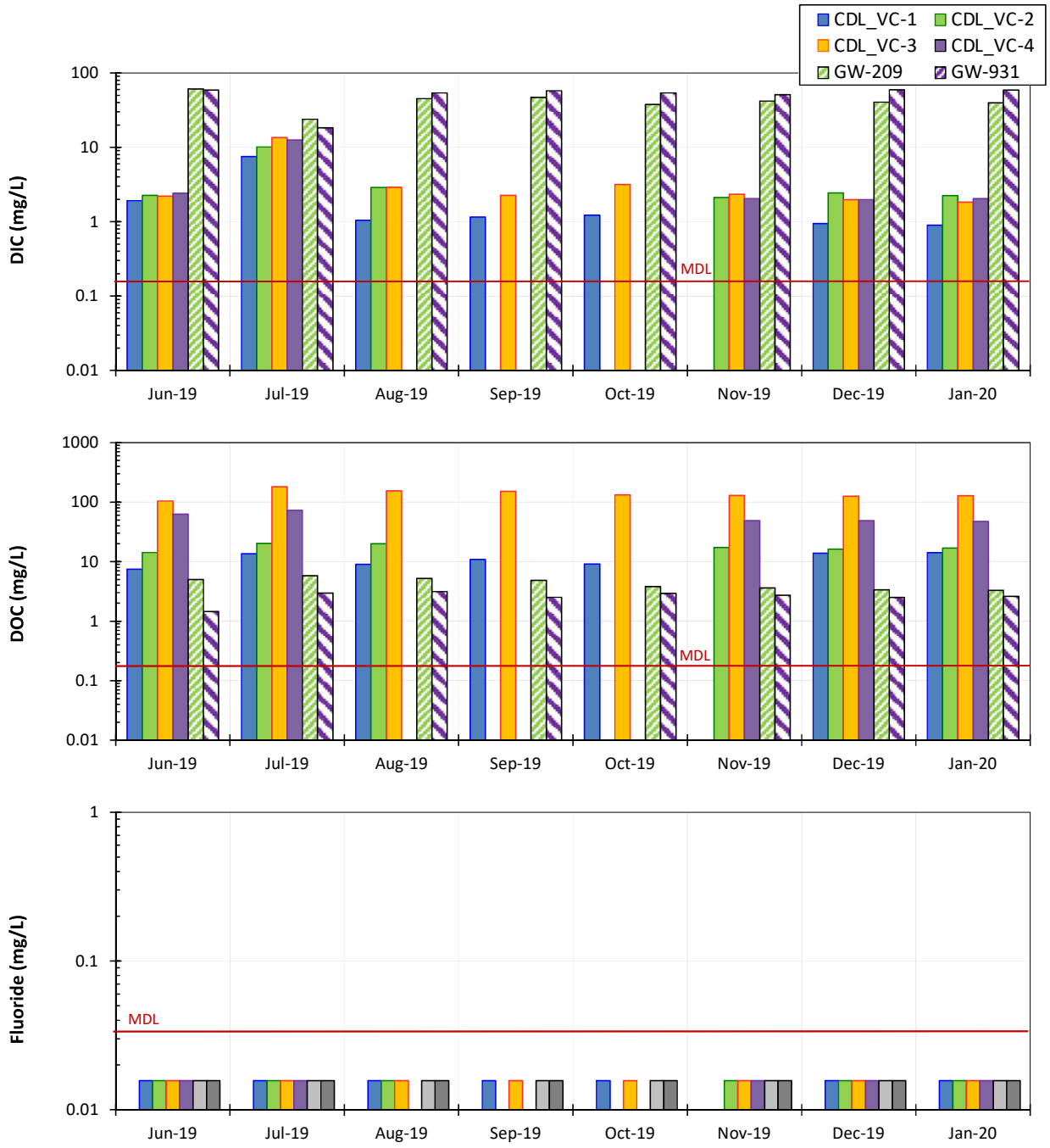

Figure D-8
Measured groundwater and porewater concentrations plotted on a logarithmic axis: dissolved inorganic carbon, dissolved organic carbon, and fluoride

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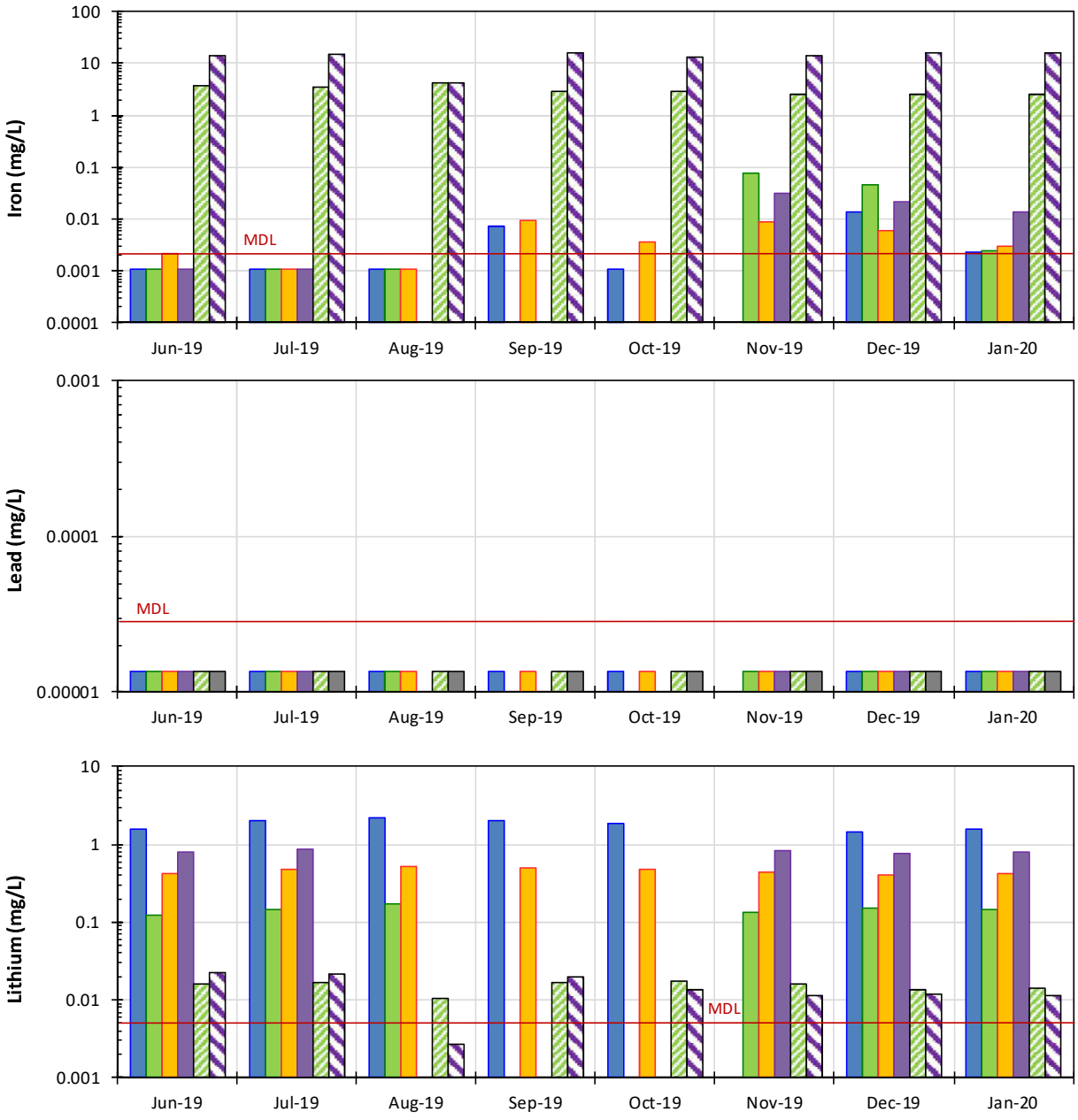

Figure D-9
Measured groundwater and porewater concentrations plotted on a logarithmic axis: iron, lead, and lithium

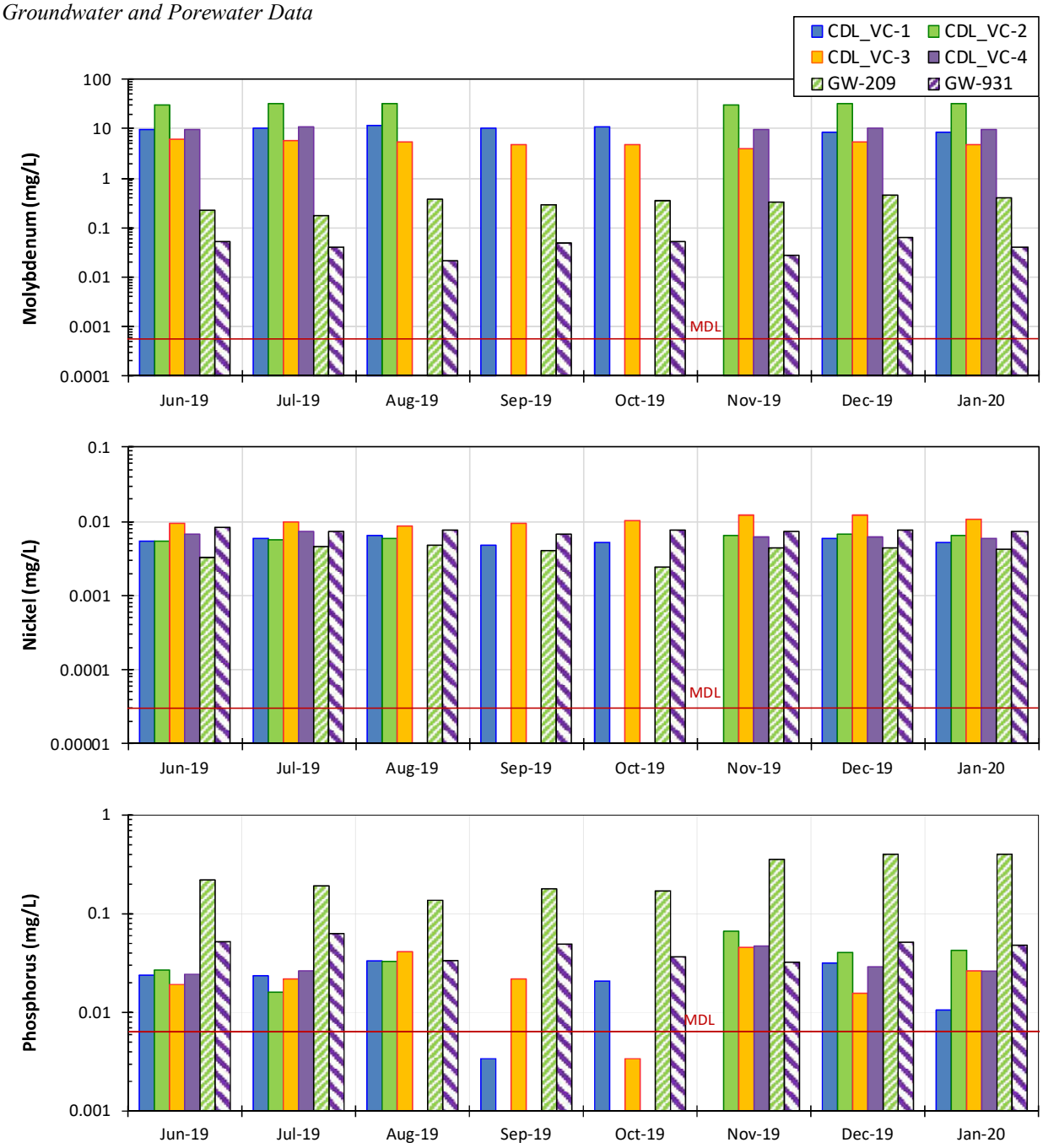

Figure D-10
Measured groundwater and porewater concentrations plotted on a logarithmic axis: molybdenum, nickel, and phosphorus

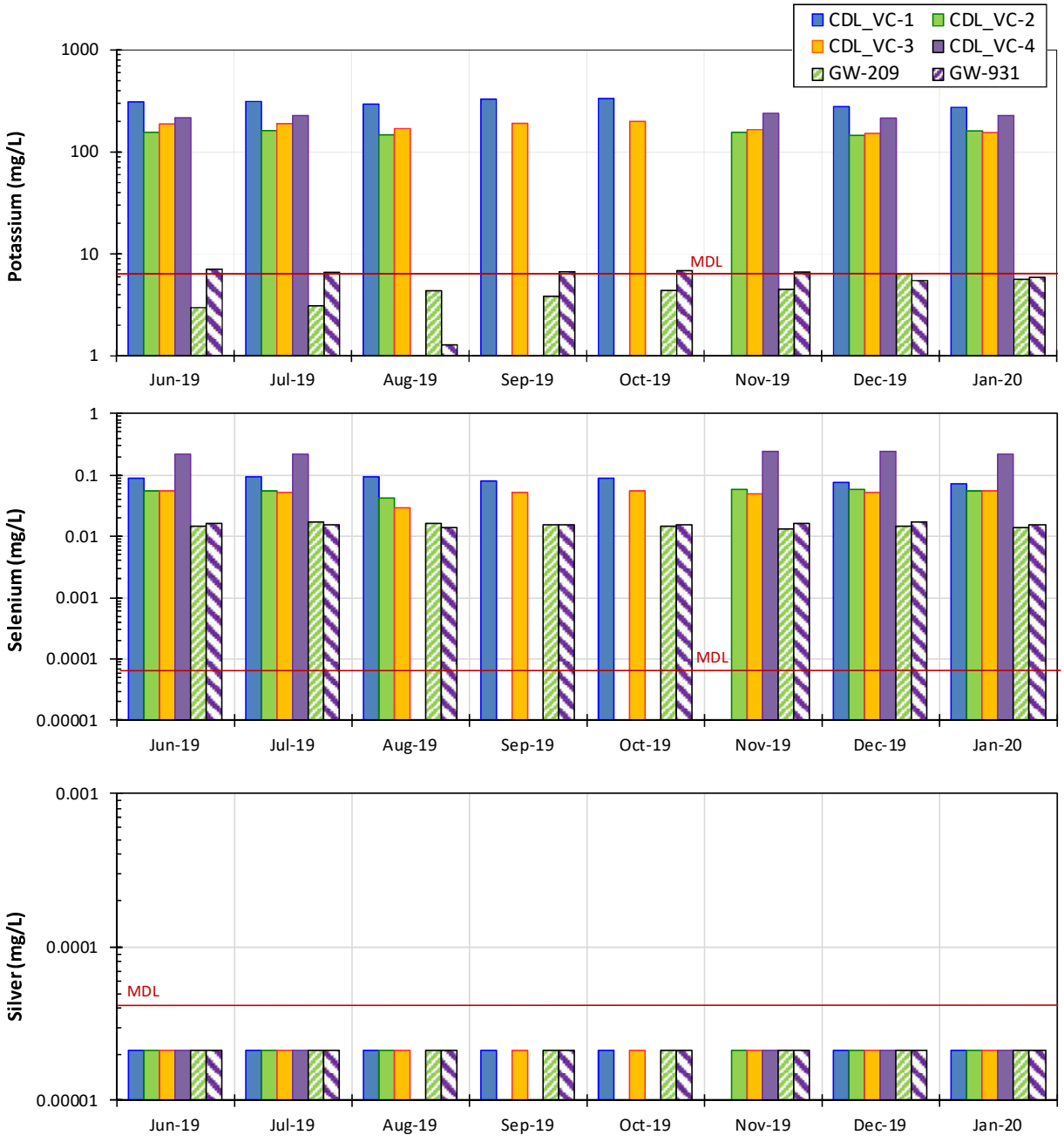

Figure D-11
Measured groundwater and porewater concentrations plotted on a logarithmic axis: potassium, selenium, and silver

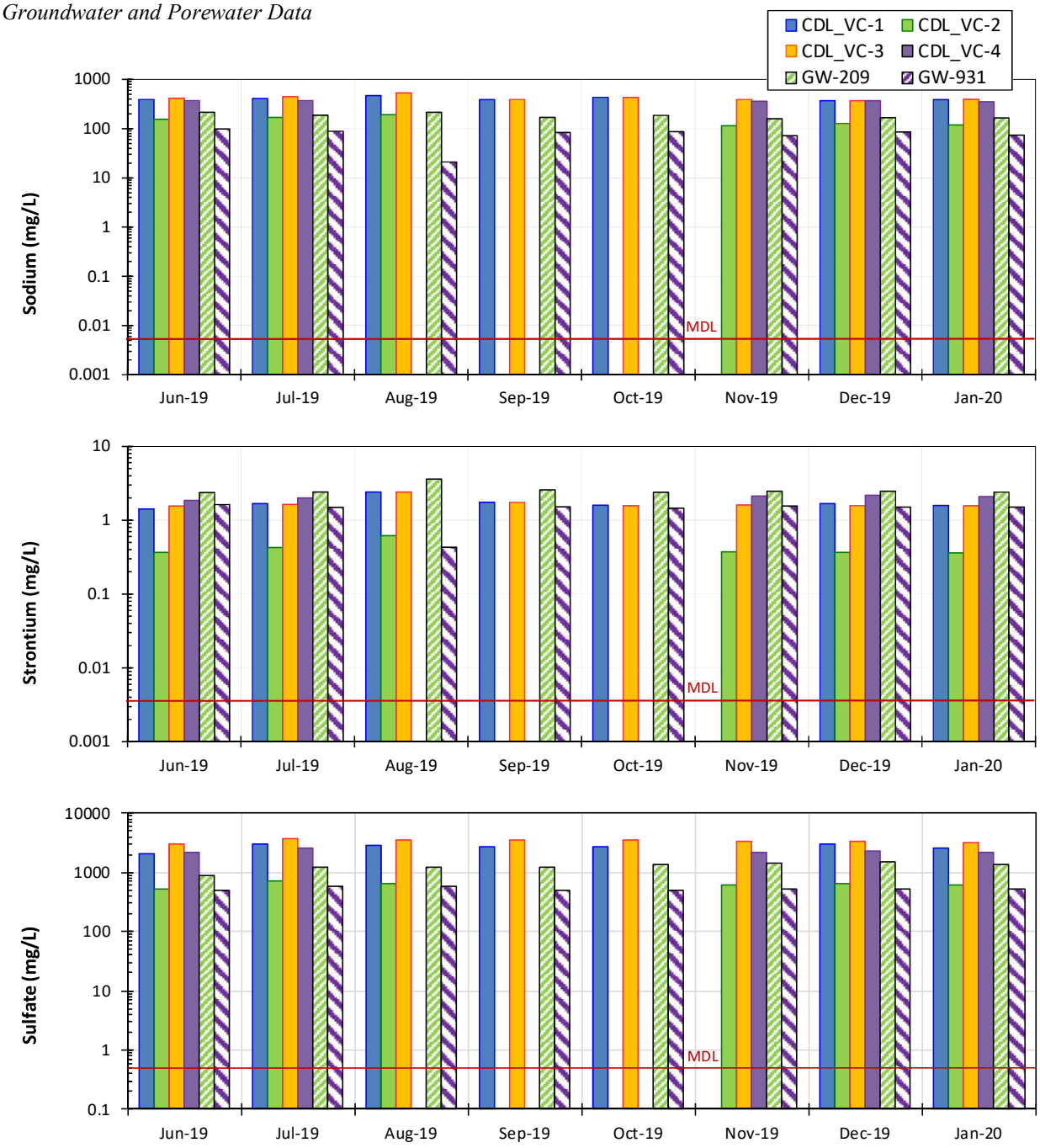

Figure D-12
Measured groundwater and porewater concentrations plotted on a logarithmic axis: sodium, strontium, and sulfate

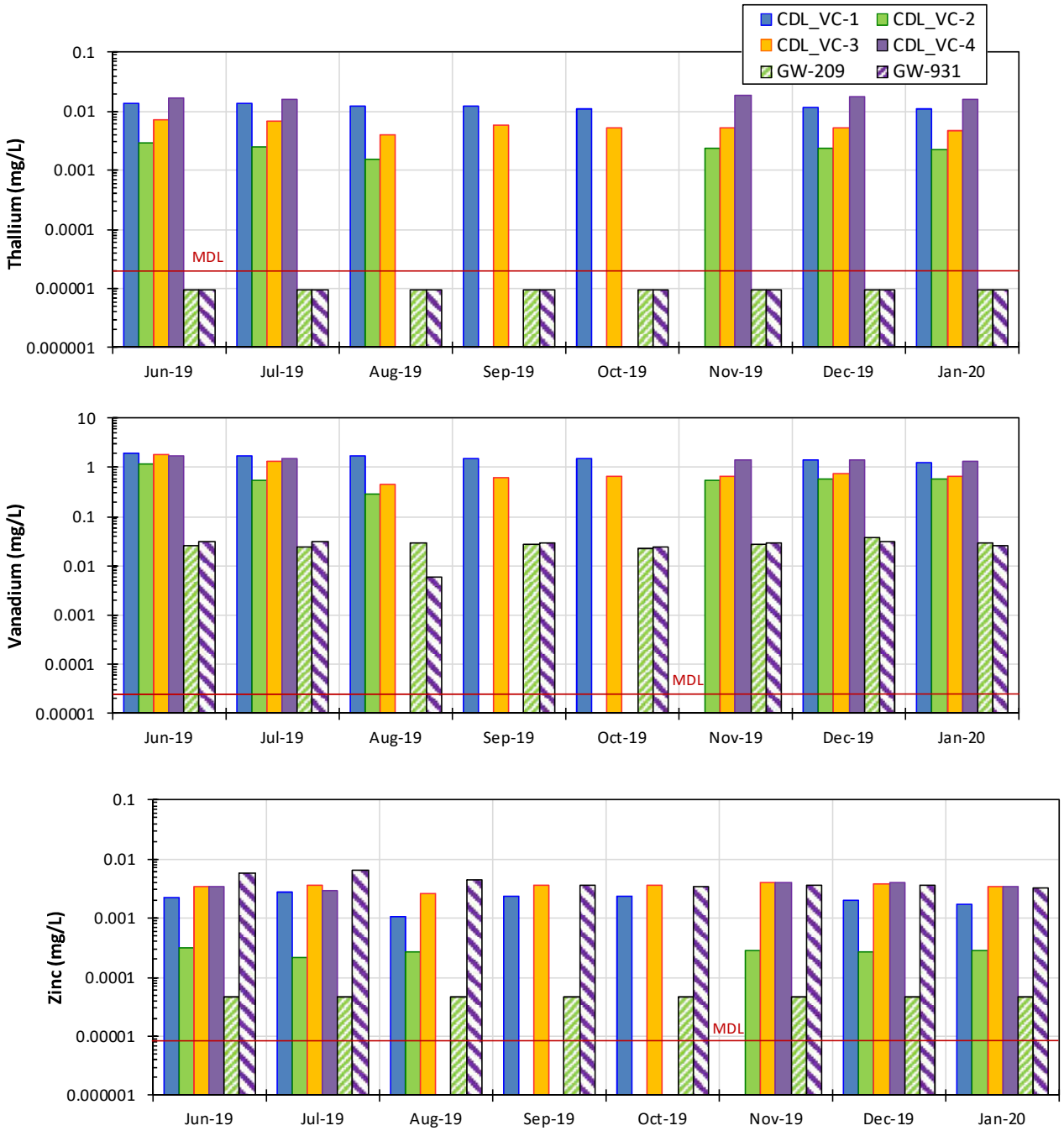

Figure D-13
Measured groundwater and porewater concentrations plotted on a logarithmic axis: thallium, vanadium, and zinc

D-2 Time Series Graphs for Porewater Data

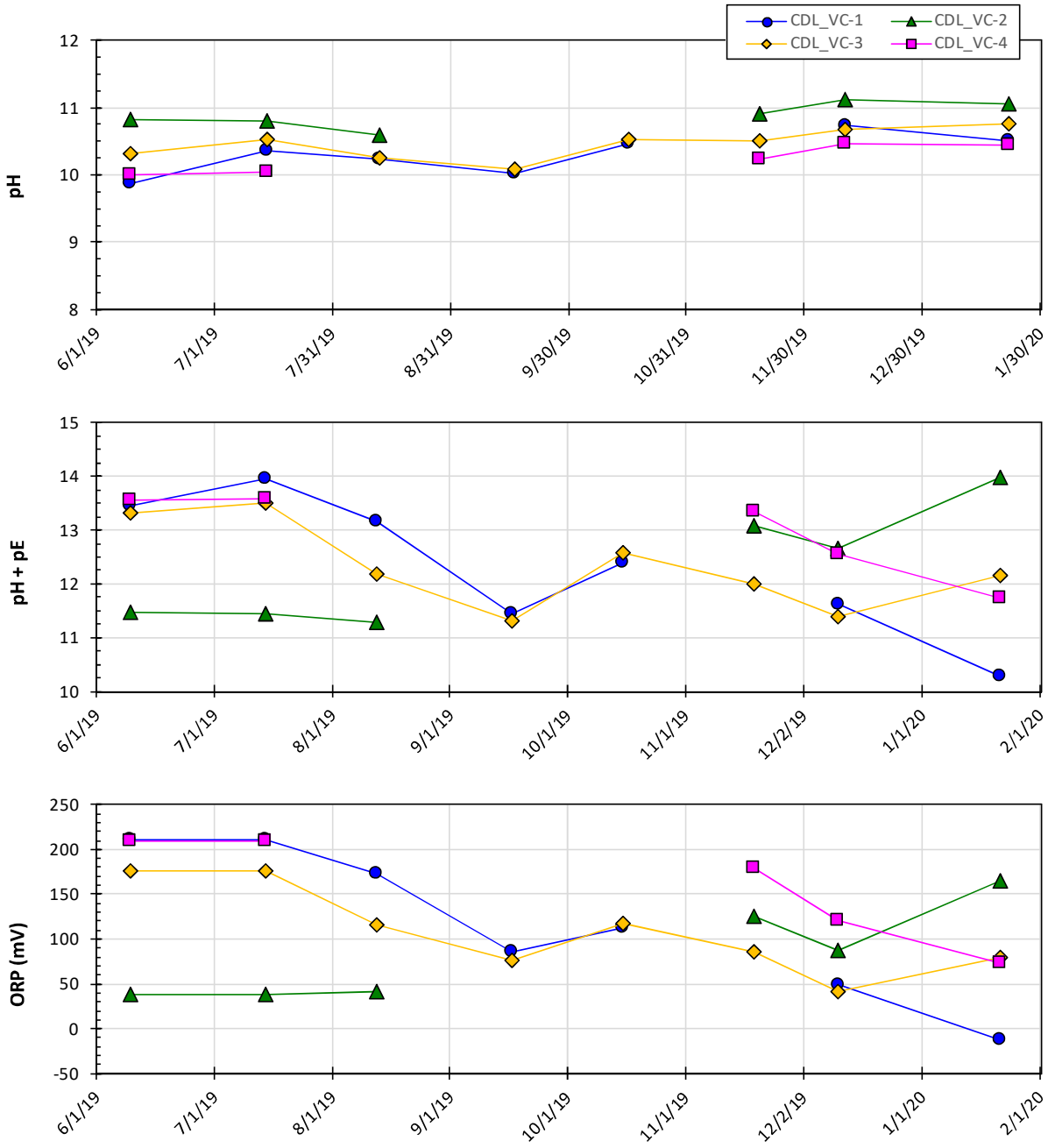

Figure D-14
Time-series plots of porewater conditions: pH, pH+pE, and ORP

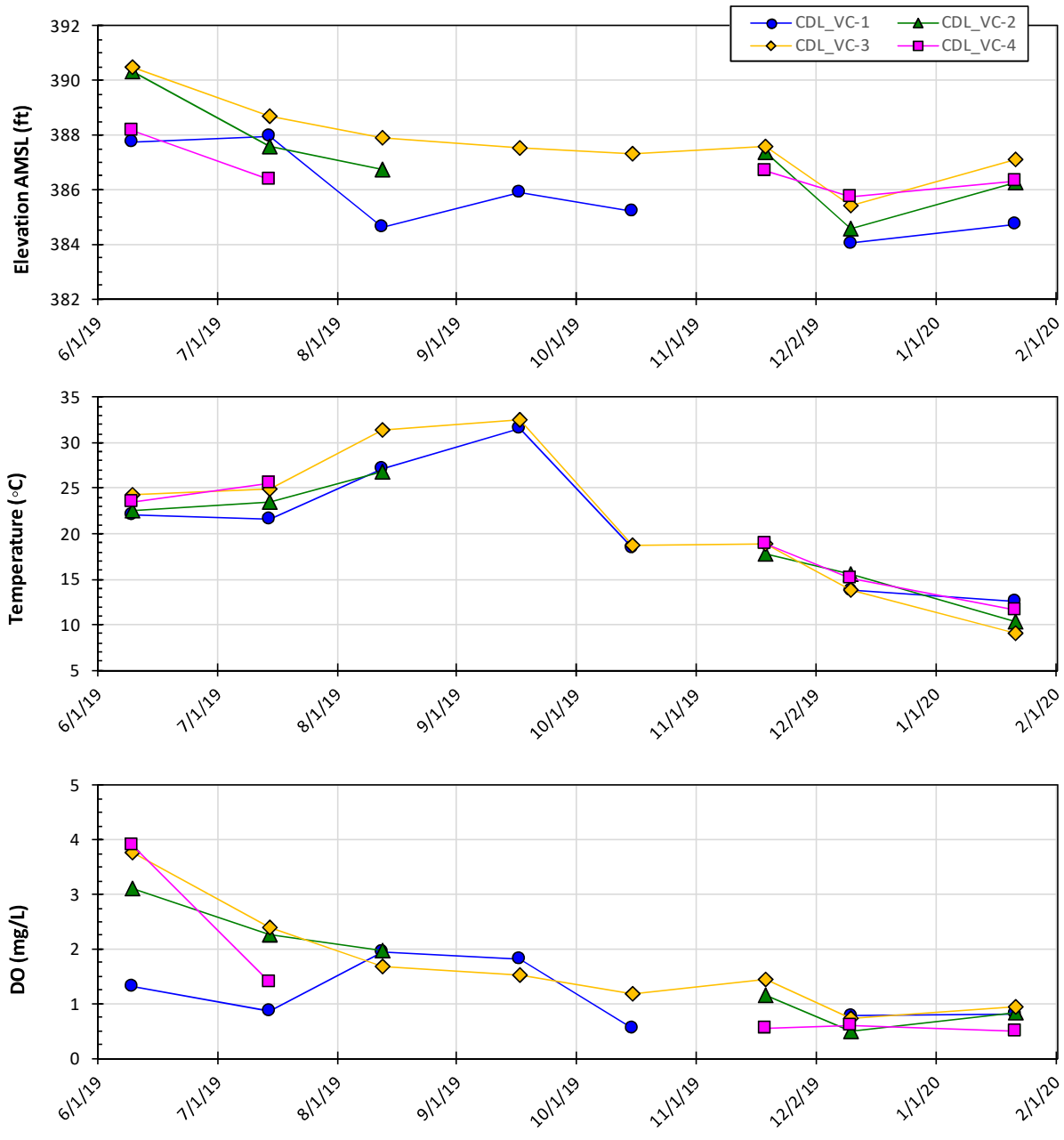

Figure D-15
Time-series plots of porewater conditions: porewater elevation, temperature, and dissolved oxygen

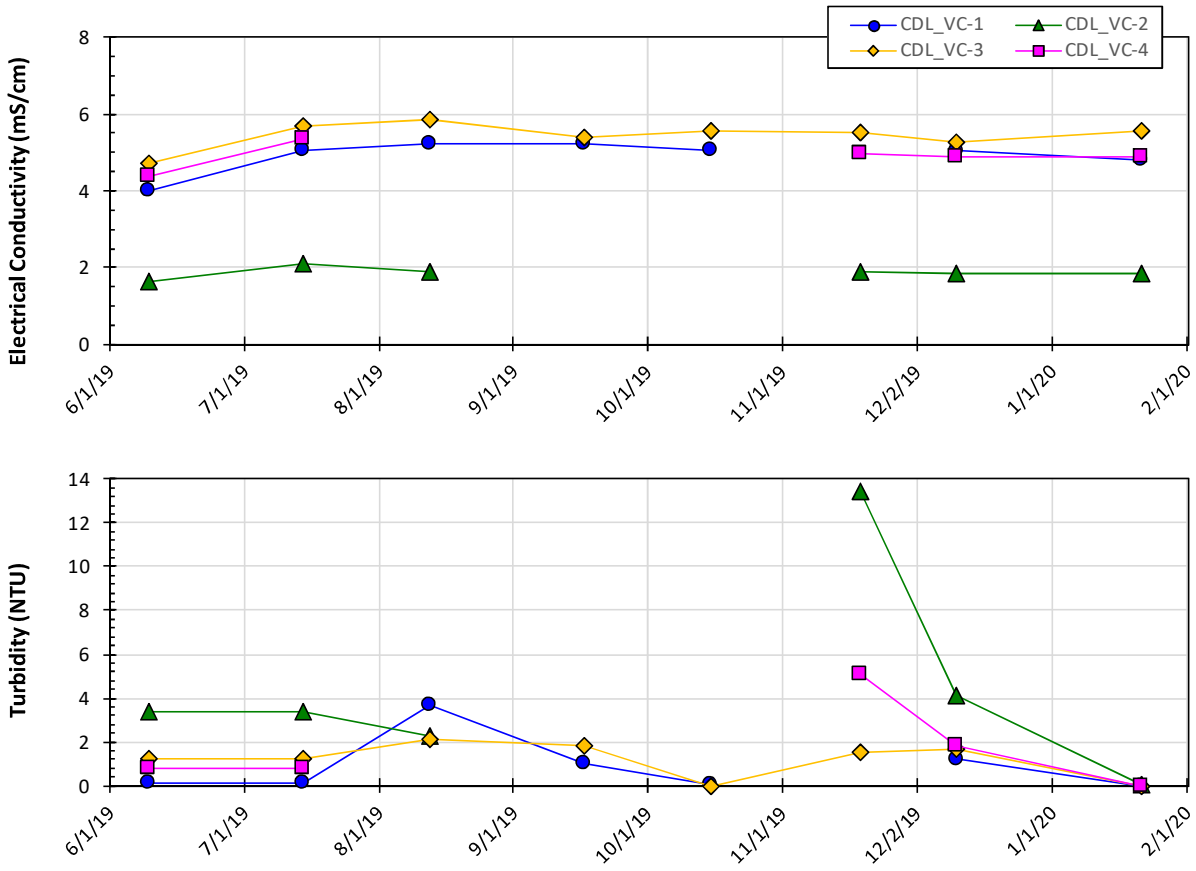

Figure D-16
Time-series plots of porewater conditions: electrical conductivity and turbidity

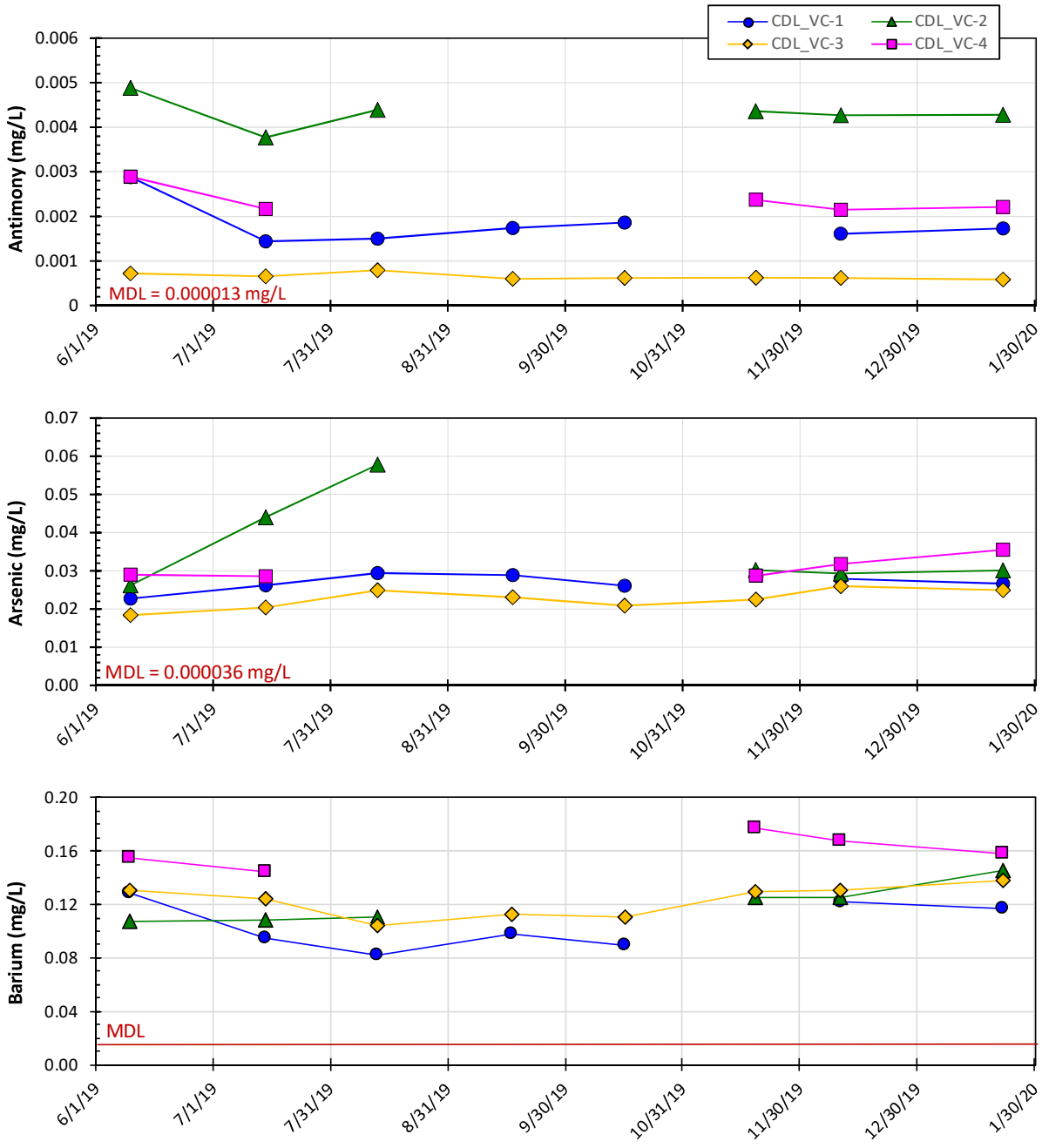

Figure D-17
Time-series plots of porewater conditions: antimony, arsenic, and barium

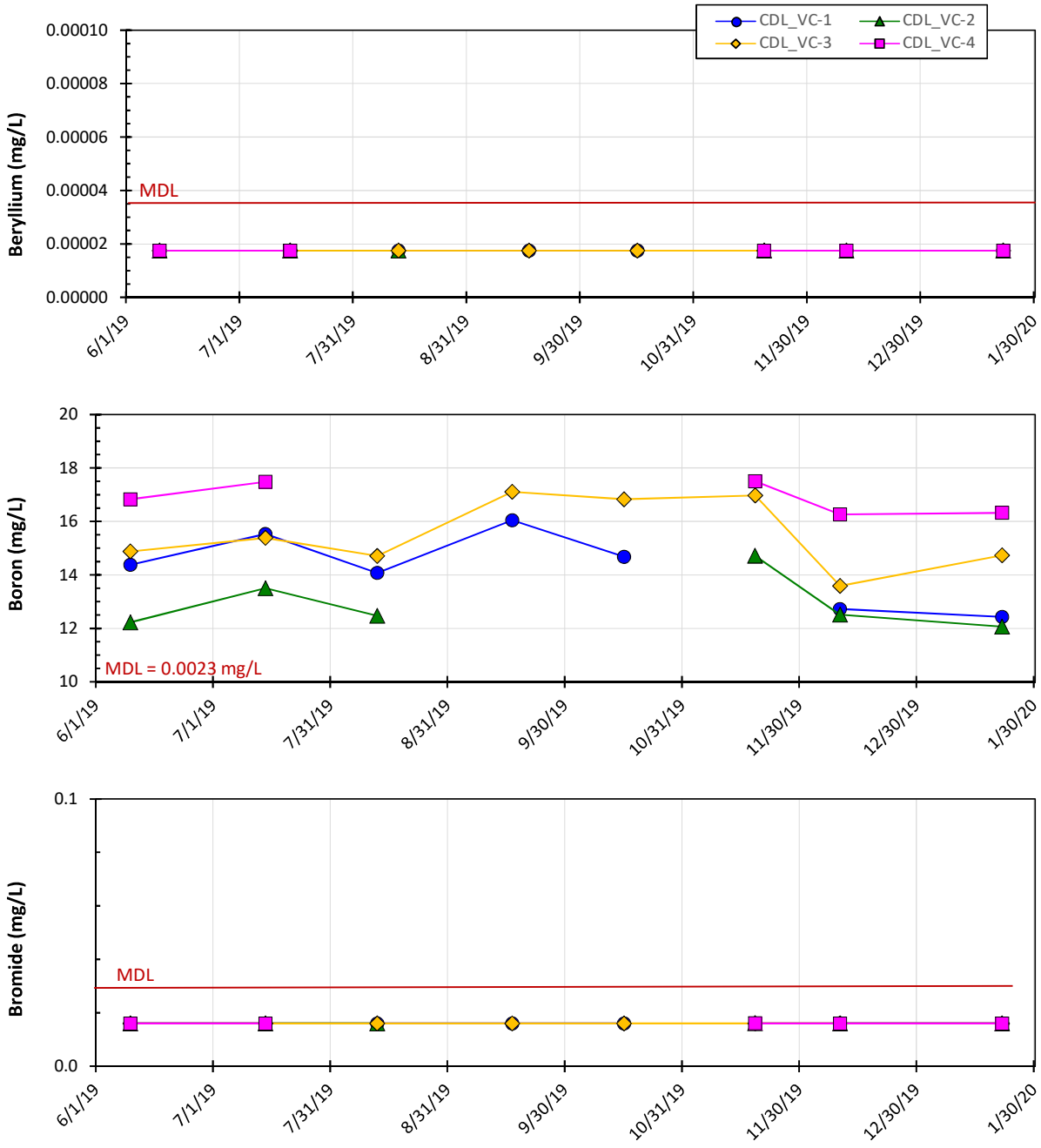

Figure D-18
Time-series plots of porewater conditions: beryllium, boron, and bromide

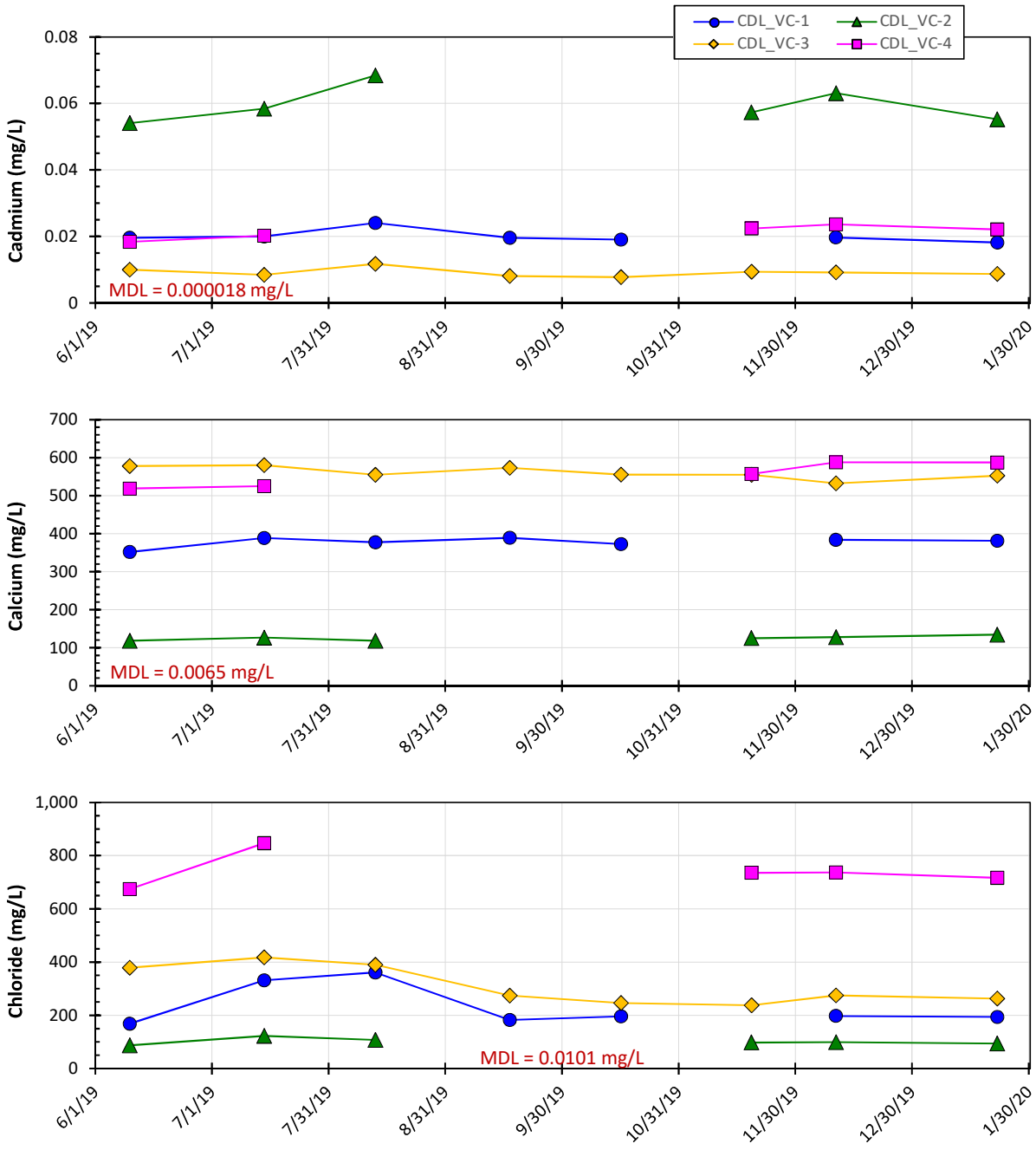

Figure D-19
Time-series plots of porewater conditions: cadmium, calcium, and chloride

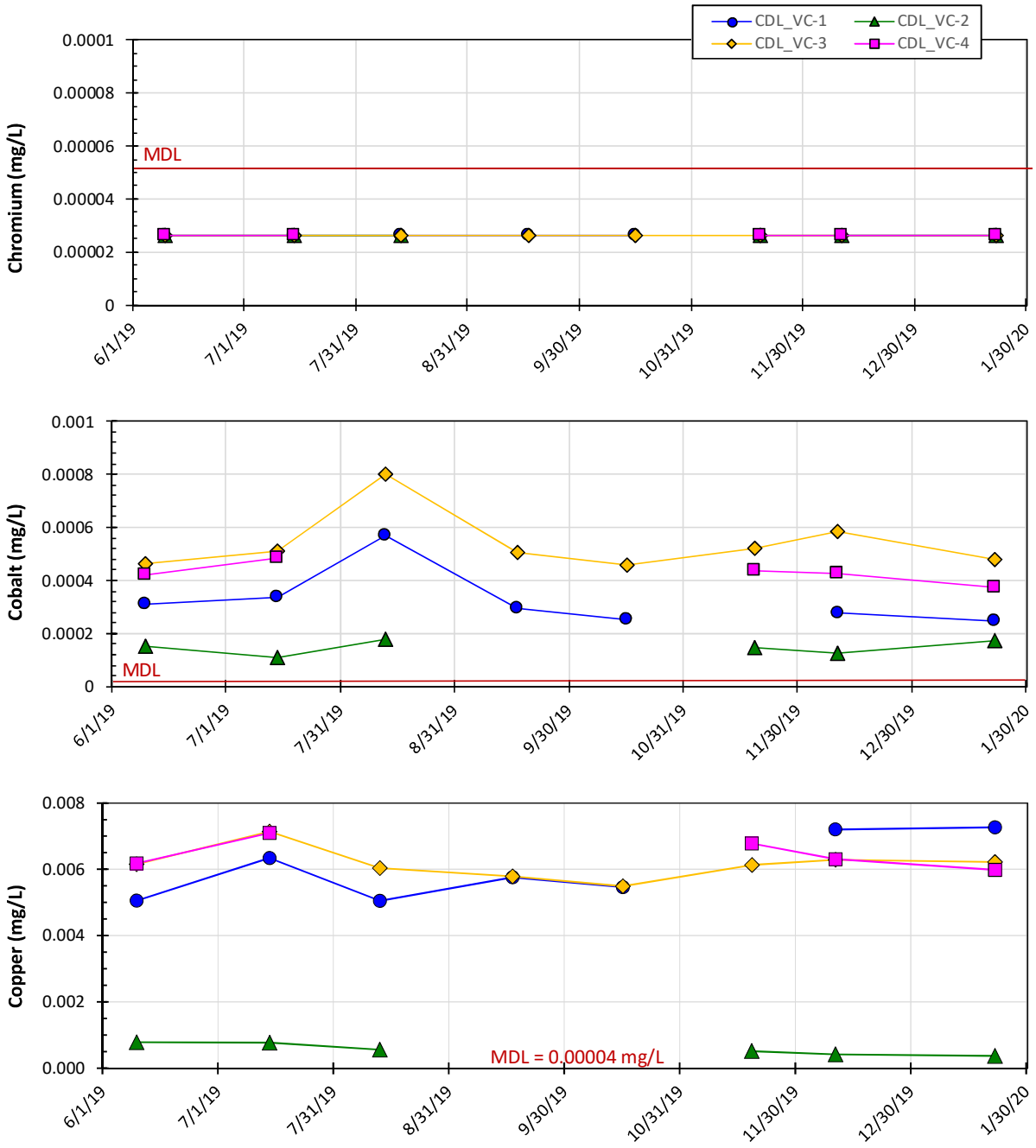

Figure D-20
Time-series plots of porewater conditions: chromium, cobalt, and copper

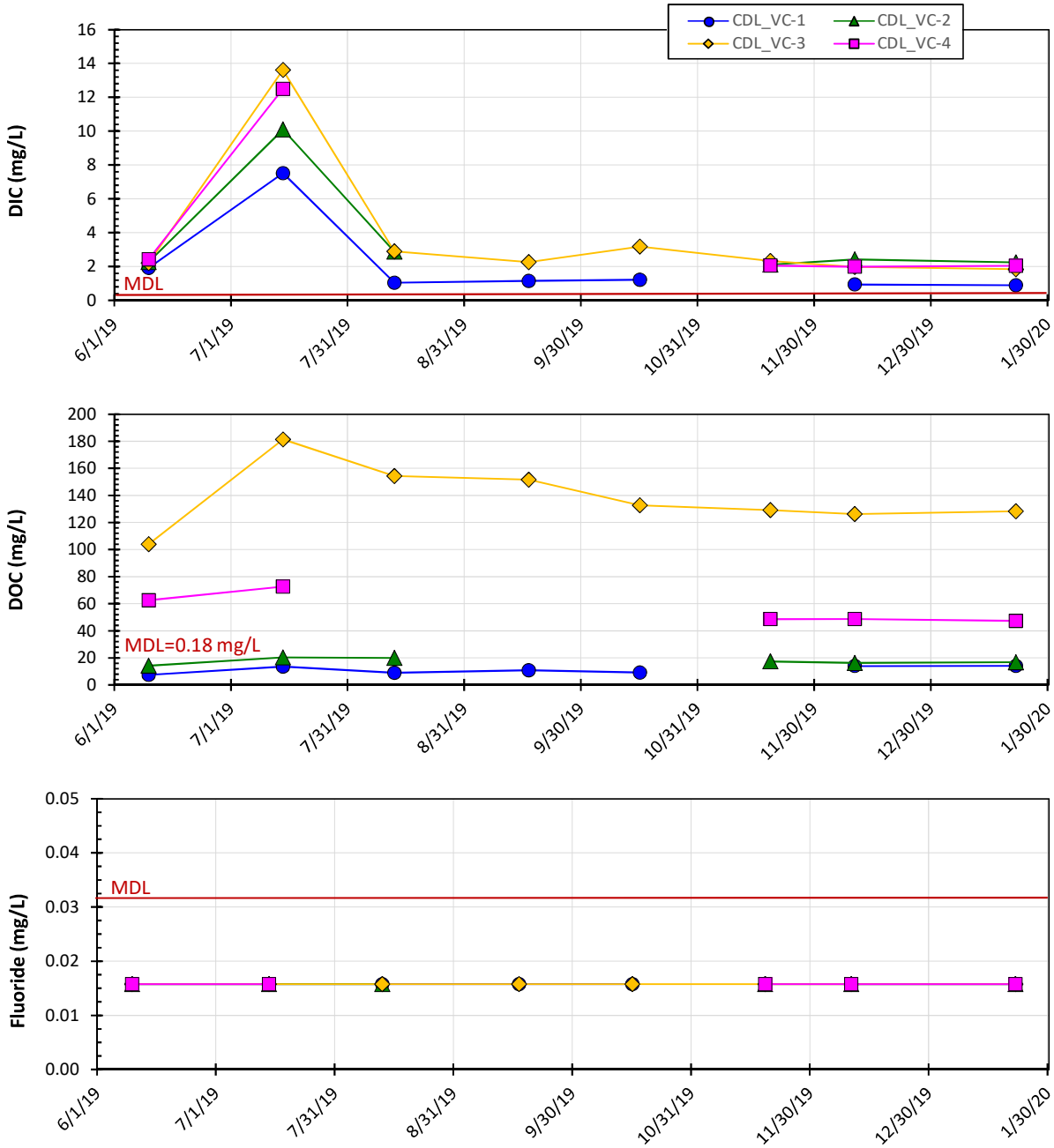

Figure D-21
Time-series plots of porewater conditions: dissolved inorganic carbon, dissolved organic carbon, and fluoride

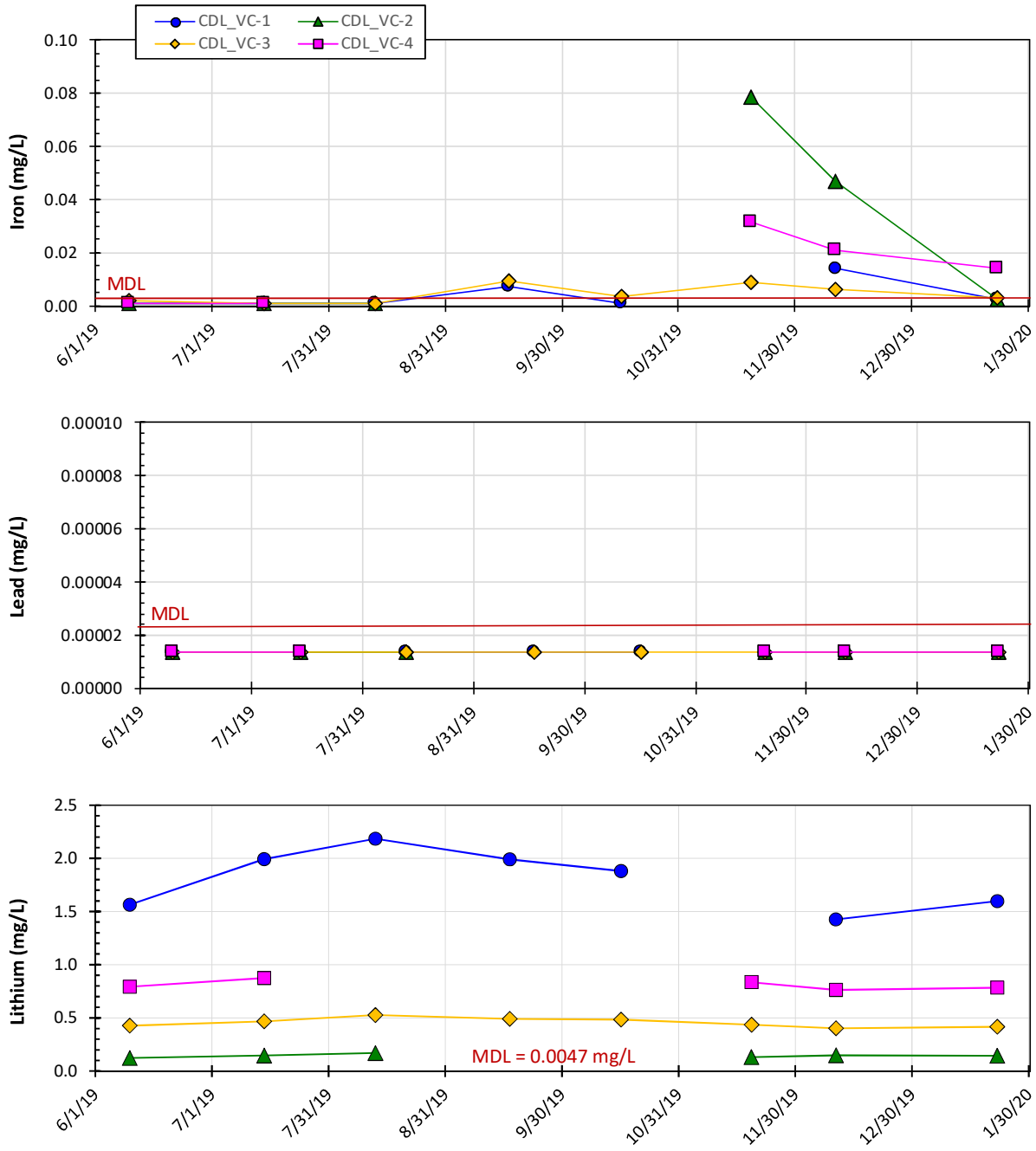

Figure D-22
Time-series plots of porewater conditions: iron, lead, and lithium

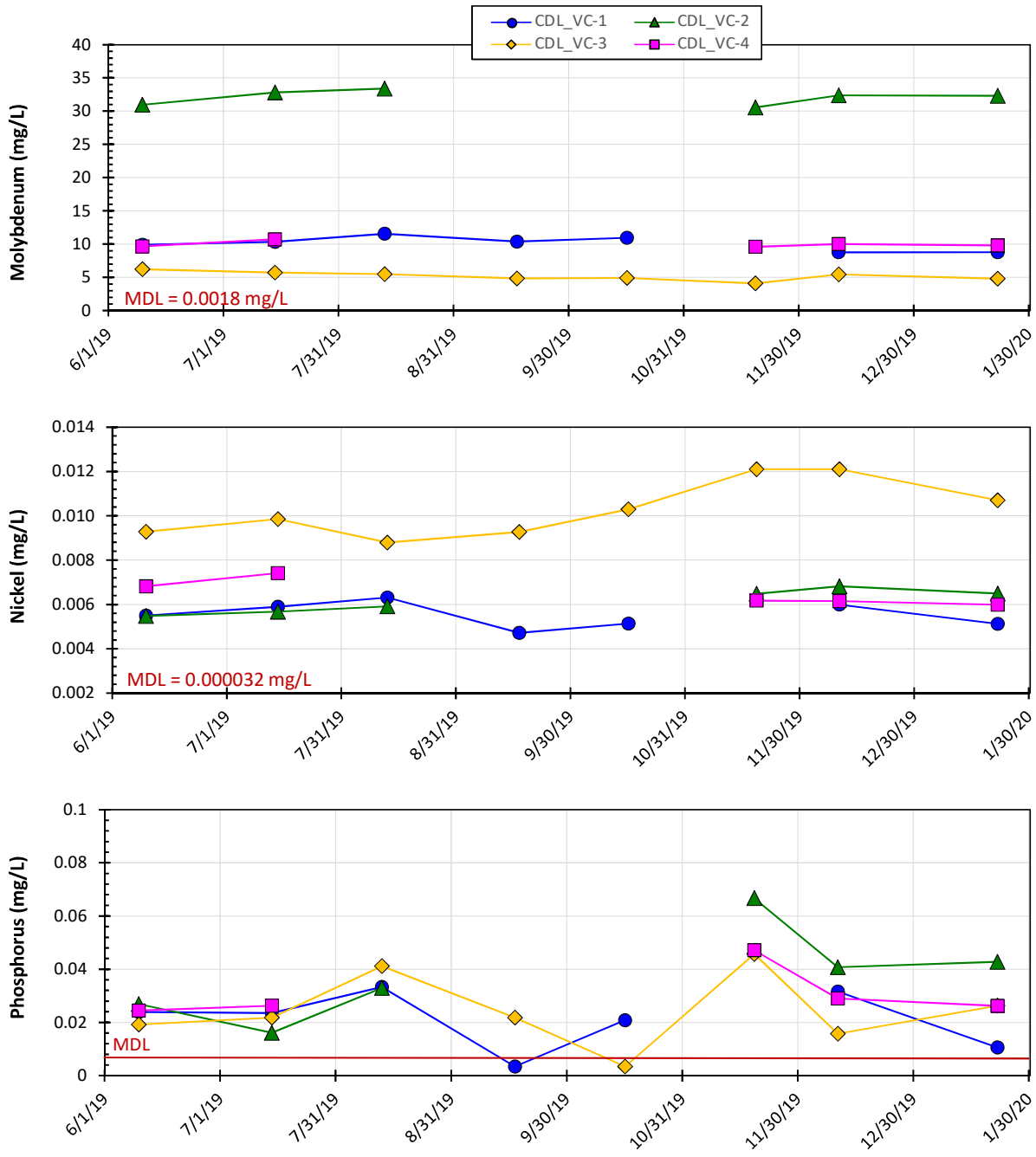

Figure D-23
Time-series plots of porewater conditions: molybdenum, nickel, and phosphorus

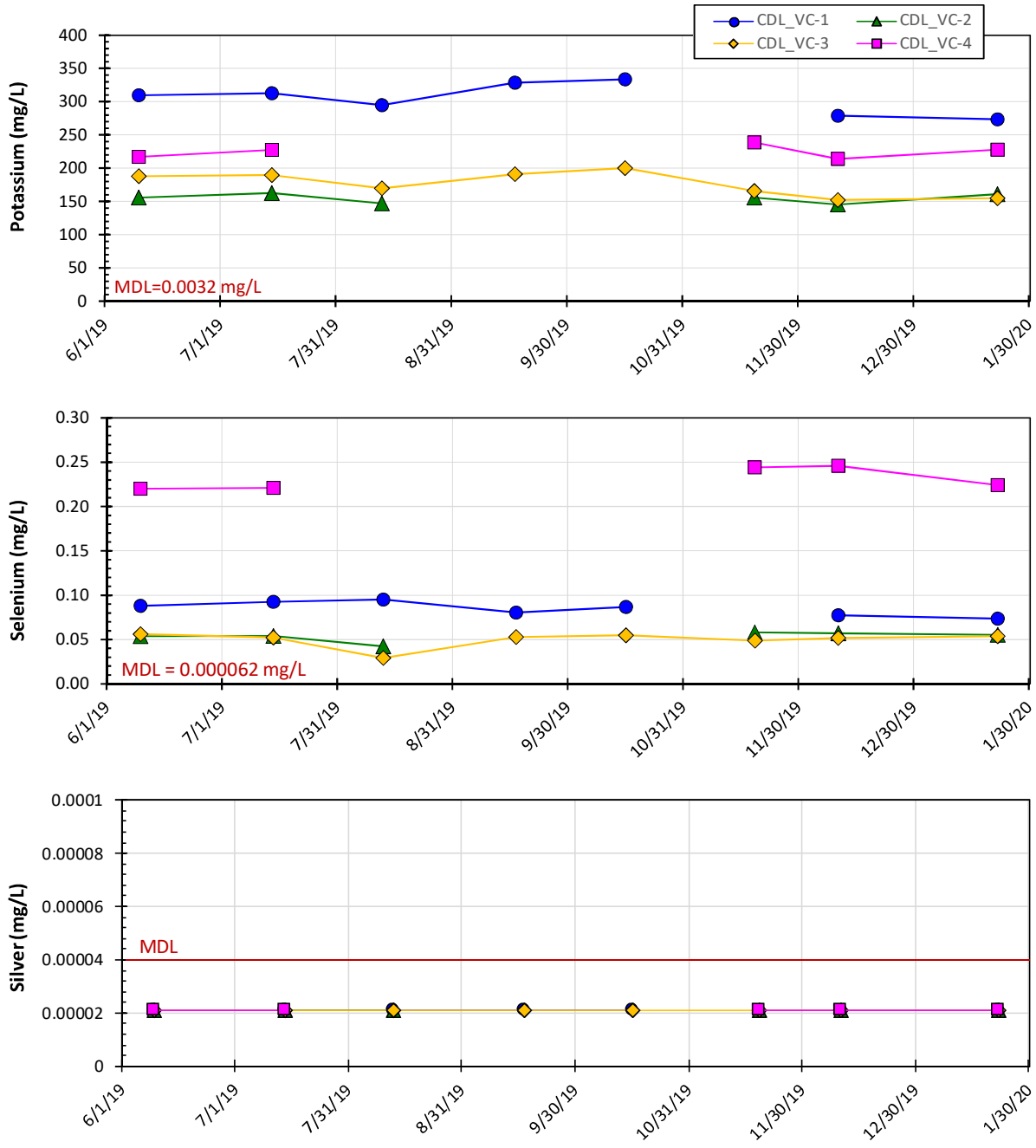

Figure D-24
Time-series plots of porewater conditions: potassium, selenium, and silver

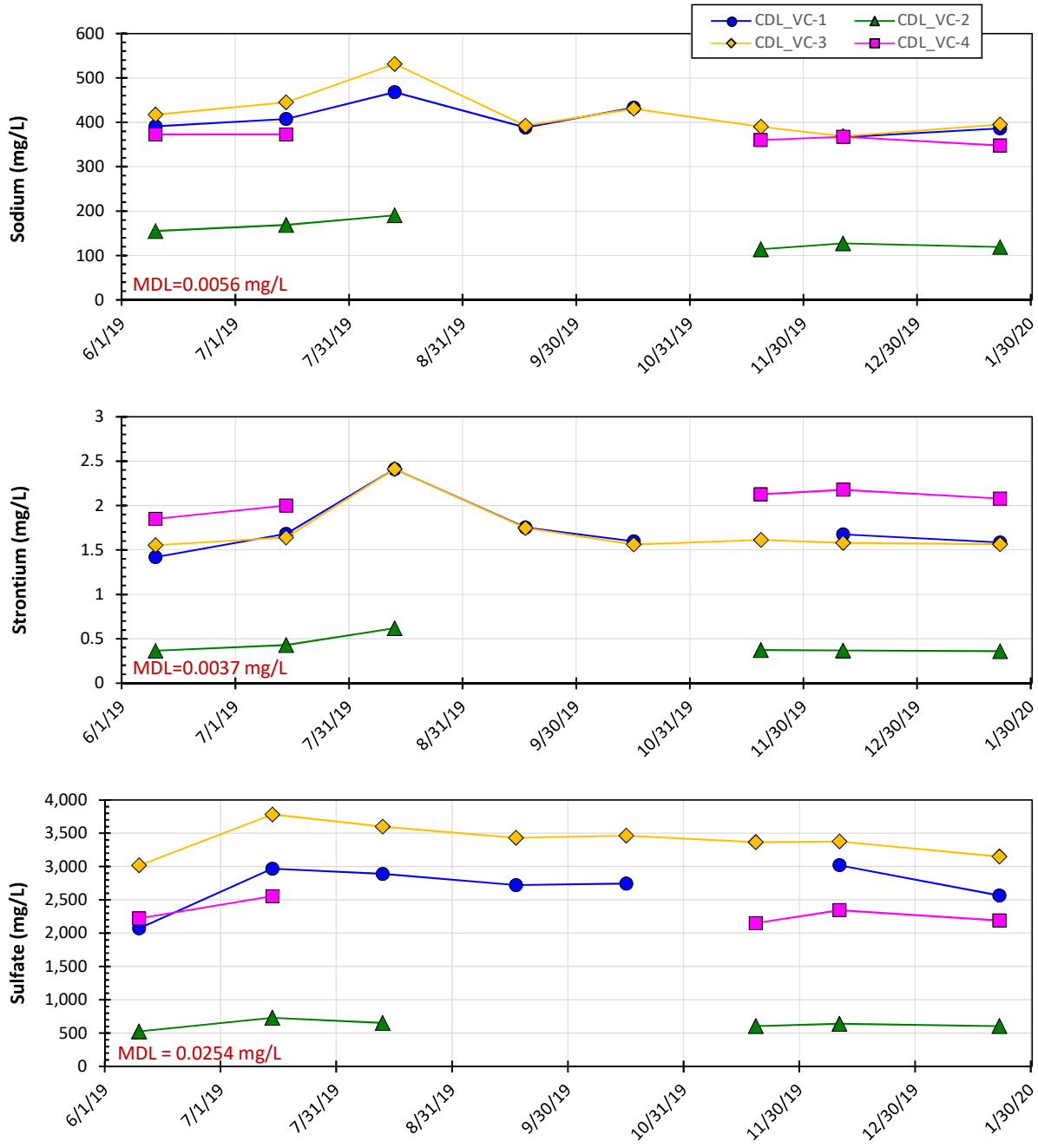

Figure D-25
Time-series plots of porewater conditions: sodium, strontium, and sulfate

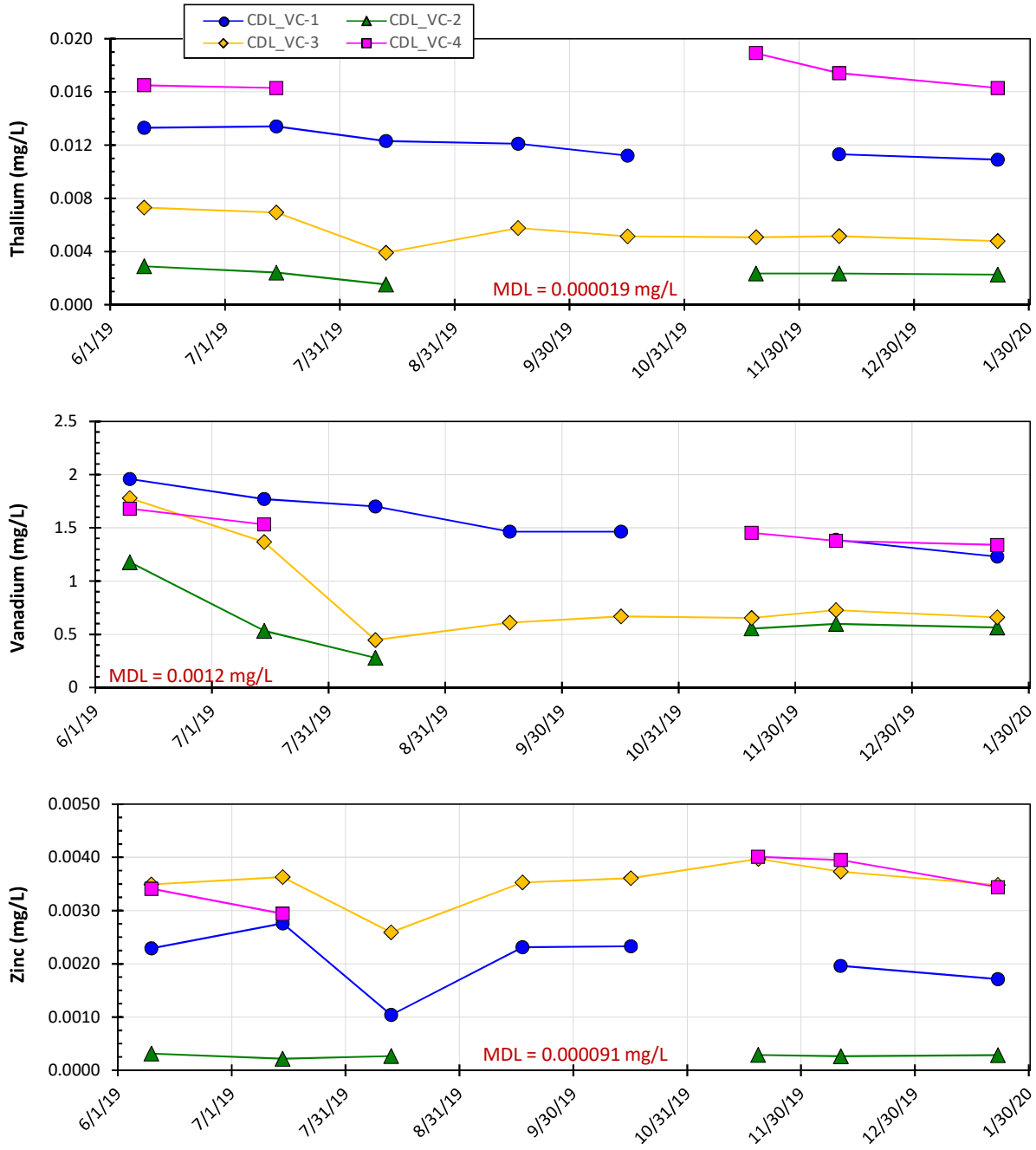

Figure D-26
Time-series plots of porewater concentrations: thallium, vanadium, and zinc

D-3 Subsurface Gas Data Tables and Graphs

VC-1 (gas access points)

5-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	20.0	14.9	17.0	12.6	0	16.6	20.4	12.7
CO_2 (%)	0	0.01	0.11	0.03	0	0.01	0.1	0.01
CH_4 (%)	0	0	0	0	0.17	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

15-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	0.9	0.9	0.3	0.2	0.4	0.7	0.5	0.4
CO_2 (%)	0	0	0	0	0	0	0	0
CH_4 (%)	0.26	0.53	0.72	0.47	0.38	0.40	0.47	0.53
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

50-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	0.9	0.9	0.3	0.1	0.3	0.6	0.7	0.3
CO_2 (%)	0	0	0	0	0.01	0	0.04	0
CH_4 (%)	0.40	0.77	0.79	0.71	0.48	0.64	0.19	0.75
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

VC-2 (gas access points)

5-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	17.5	16.1	13.6	2.8	6.7	8.3	11.2	0.5
CO_2 (%)	0	0	0	0	0.01	0.02	0.01	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

15-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	17.7	7.0	14.2	2.2	7.7	7.5	12.5	0.5
CO_2 (%)	0	0	0.01	0	0	0	0	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0.3	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

VC-3 (gas access points)

5-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	20.2	12.5	13.9	15.5	3.6	17.1	15.5	13.4
CO_2 (%)	0.01	0.01	0	0.01	0.13	0.01	0.07	0.01
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

15-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	20.2	9.4	8.7	8.4	9.4	1.3	0.5	0.4
CO_2 (%)	0	0	0	0	0	0	0	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

50-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	18.4	10.6	2.9	1.3	1.3	0.7	0.5	0.4
CO_2 (%)	0	0	0	0	0	0	0	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

VC-4 (gas access points)

5-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	19.9	13.4	6.1	5.9	6.9	2.5	2.9	3.8
CO_2 (%)	0	0	0	0	0	0	0	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

15-ft Below Grade	Jun-19	Jul-19	Aug-19	Sep-19	Oct-19	Nov-19	Dec-19	Jan-20
Sampling Date	6/10/19	7/15/19	8/13/19	9/17/19	10/16/19	11/19/19	12/11/19	1/22/20
O_2 (%)	18.6	16.2	6.9	7.8	6.0	3.8	3.6	2.9
CO_2 (%)	0	0	0	0	0	0	0	0
CH_4 (%)	0	0	0	0	0	0	0	0
NH_3 (mg/L)	0	0	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0	0	0

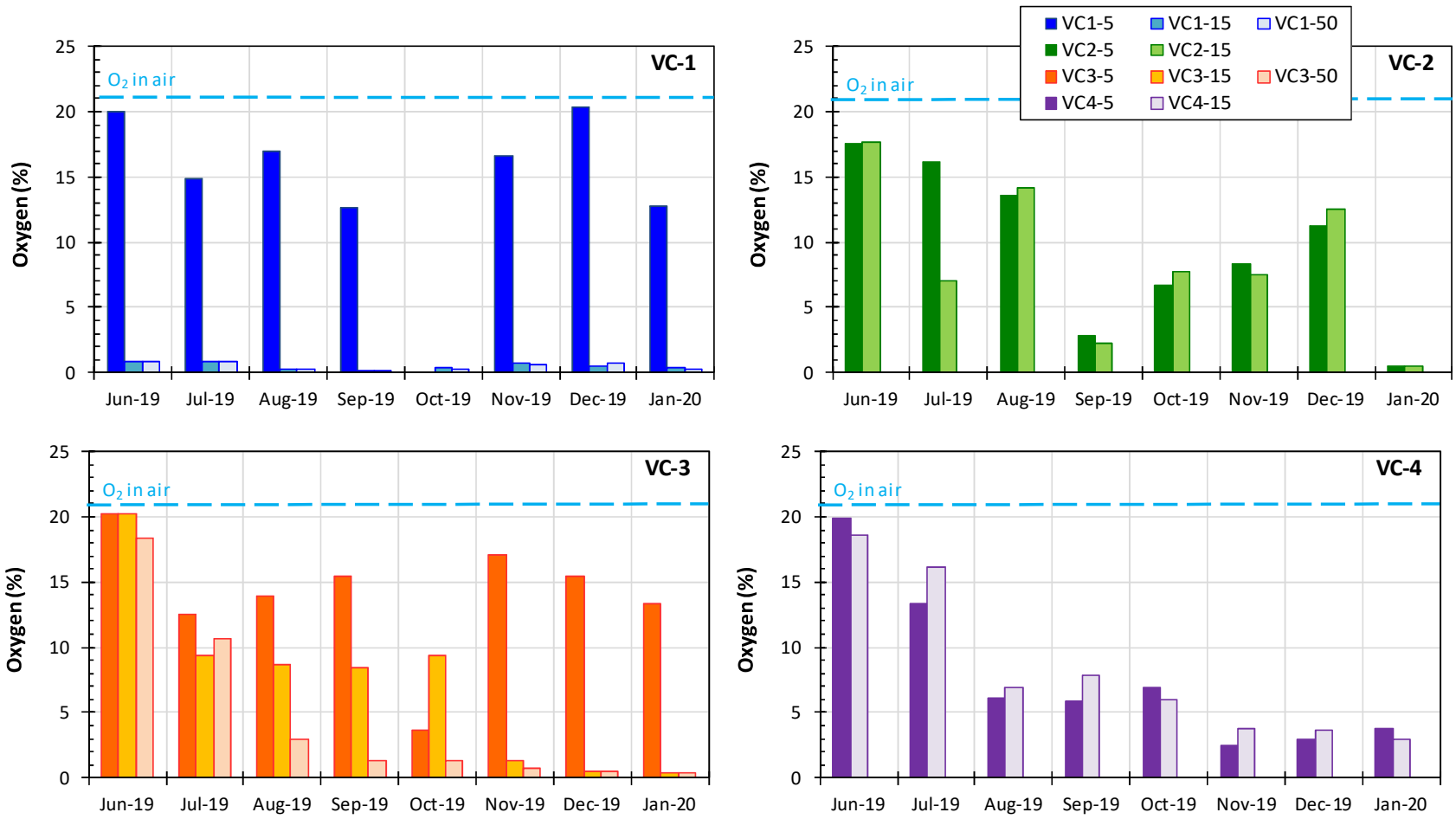

Figure D-27
Measured subsurface oxygen composition by depth below original ground level

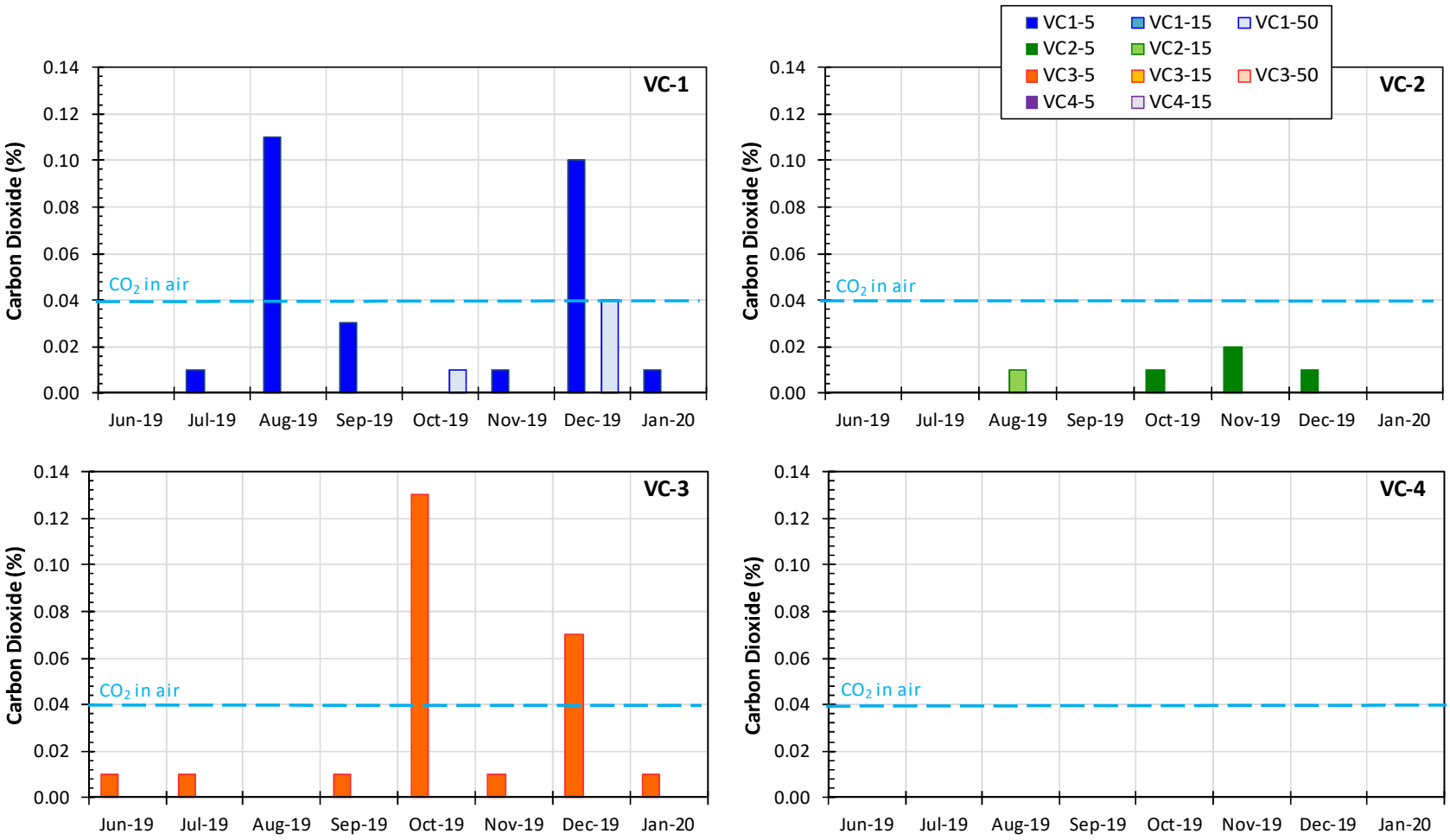

Figure D-28
Measured subsurface carbon dioxide composition by depth below original ground level

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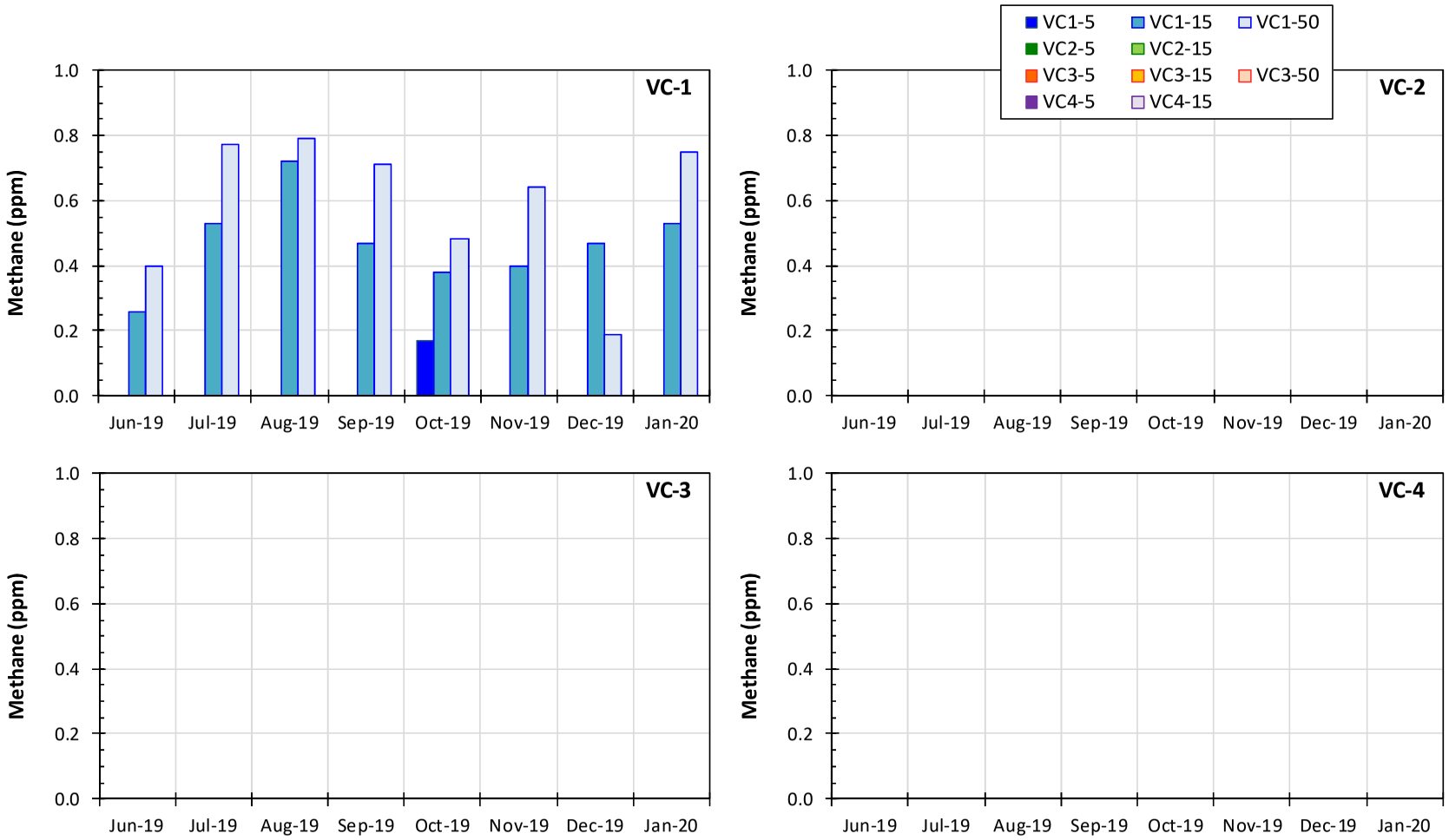

Figure D-29
Measured methane oxygen composition by depth below original ground level

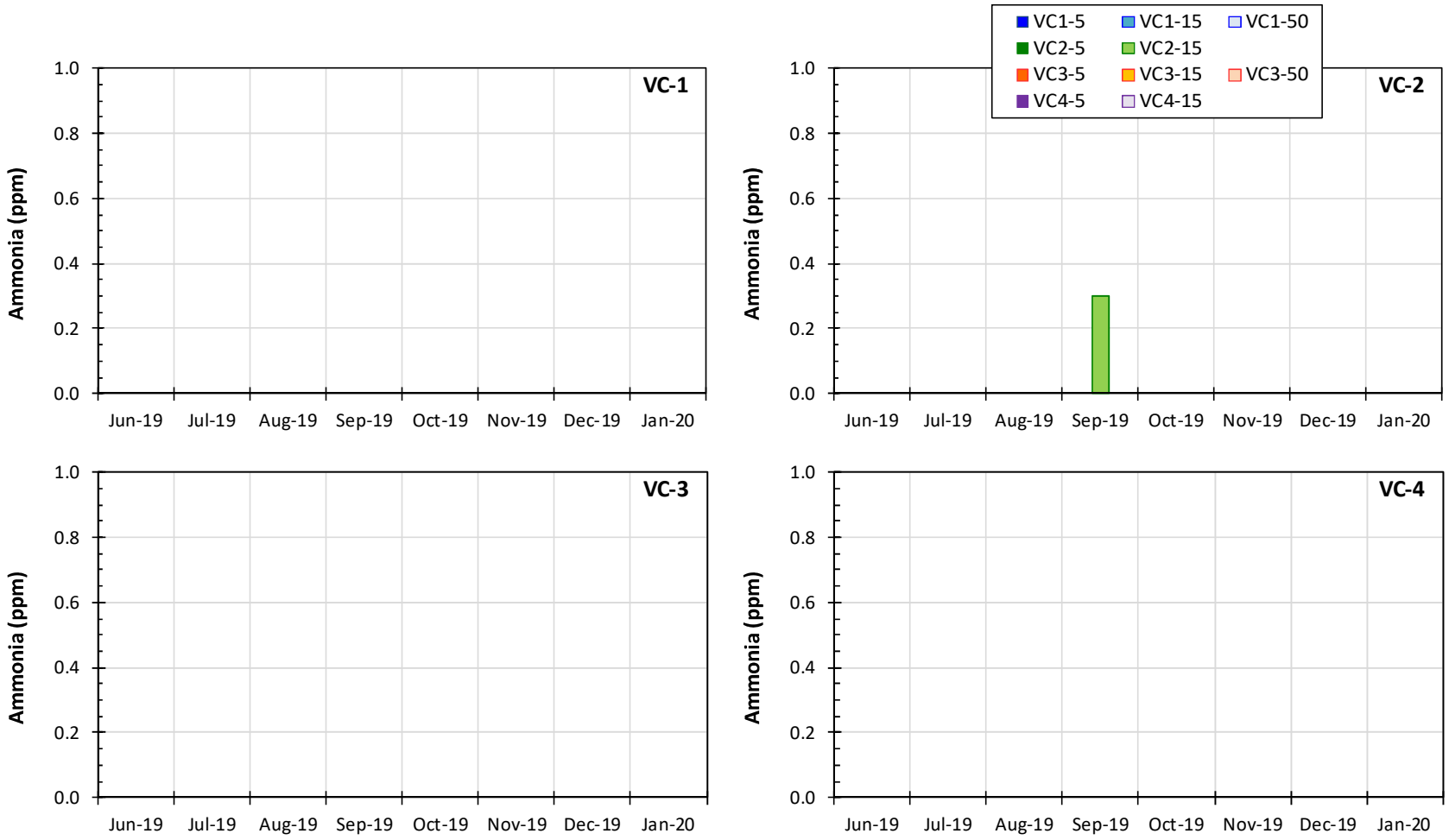

Figure D-30
Measured subsurface ammonia composition by depth below original ground level

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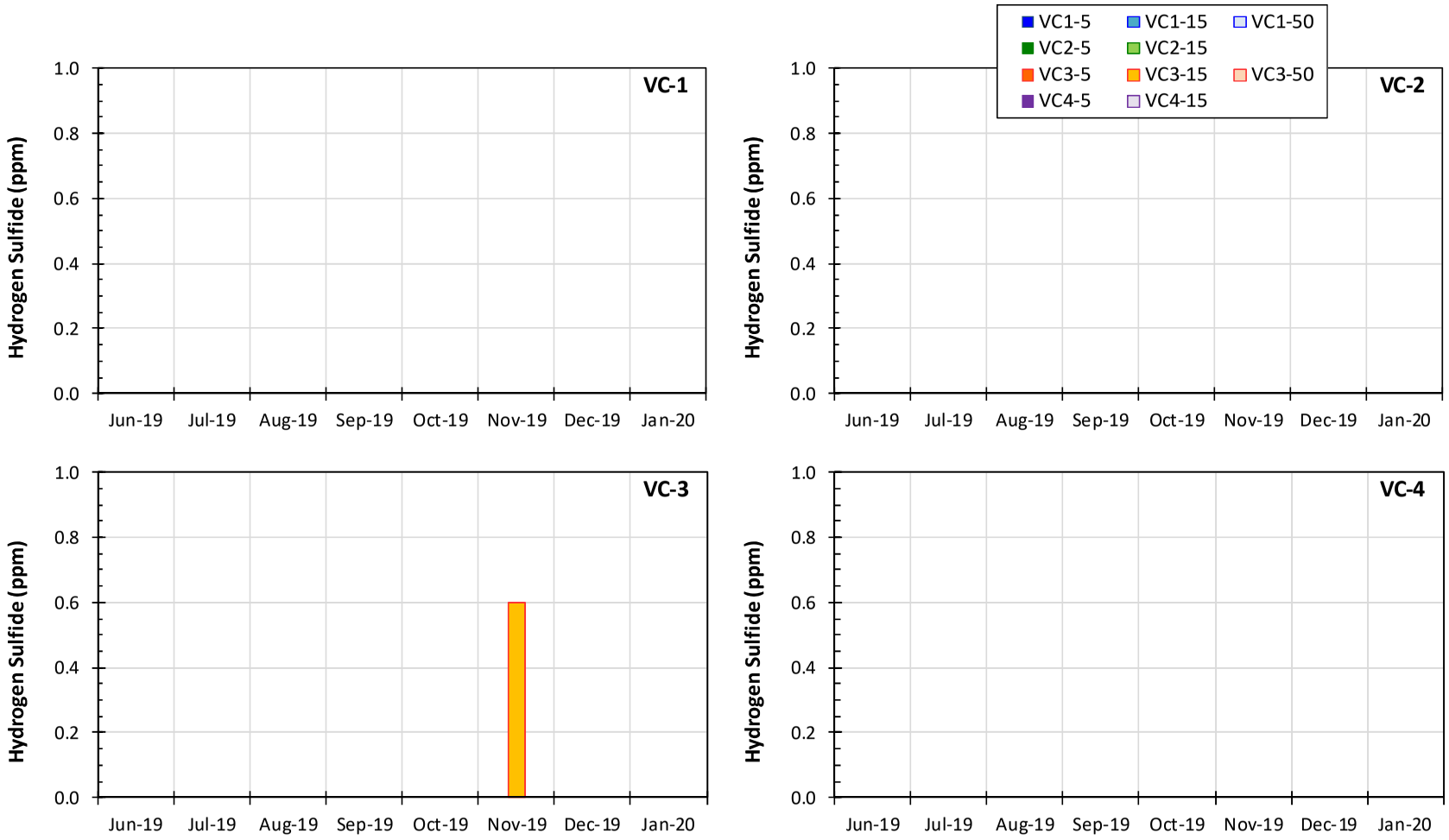

Figure D-31
Measured subsurface hydrogen sulfide composition by depth below original ground level

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E
COMPARISON OF POREWATER ESTIMATES FROM LEACHING TESTS WITH MEASURED VALUES

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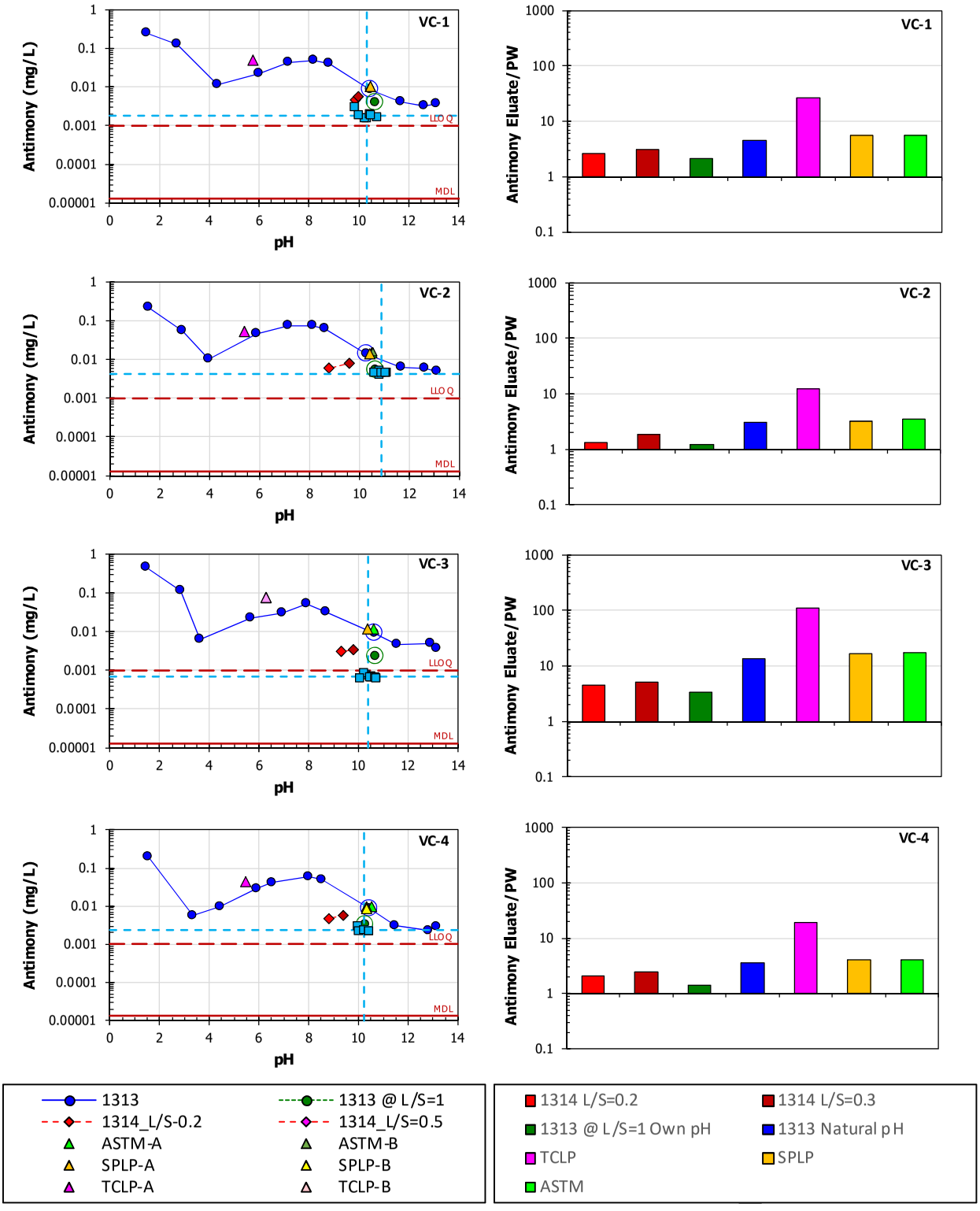

Figure E-1
Antimony concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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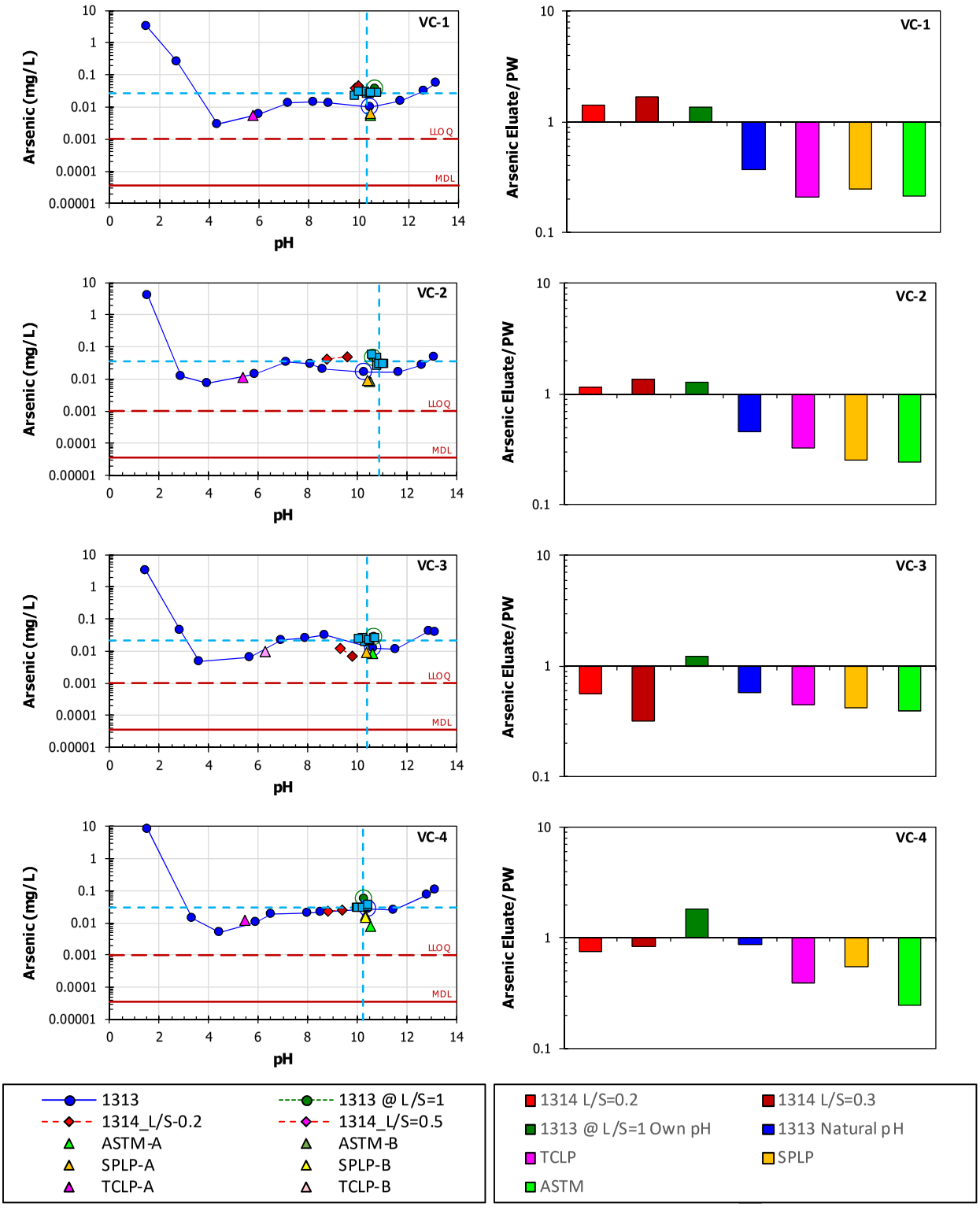

Figure E-2
Arsenic concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

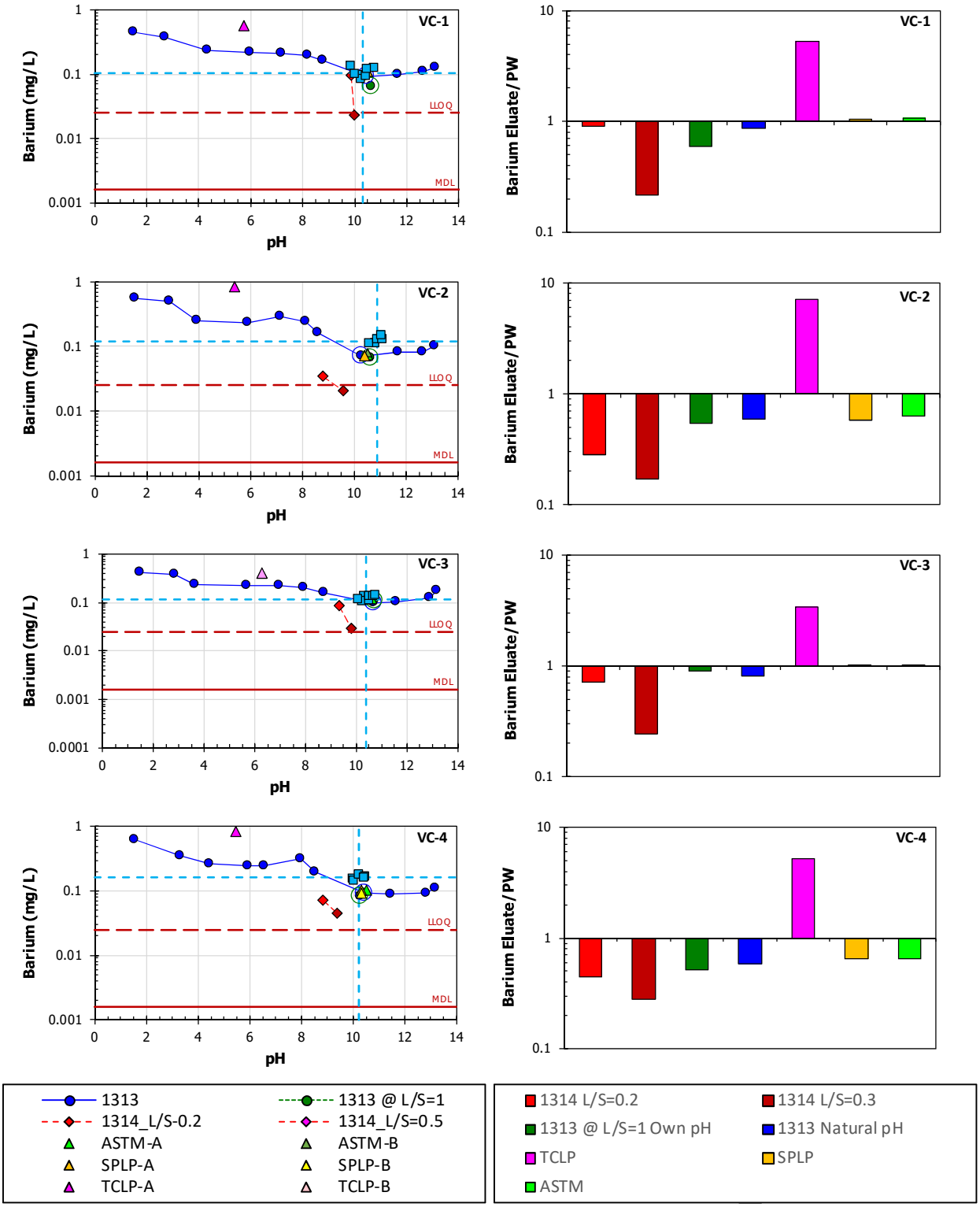

Figure E-3
Barium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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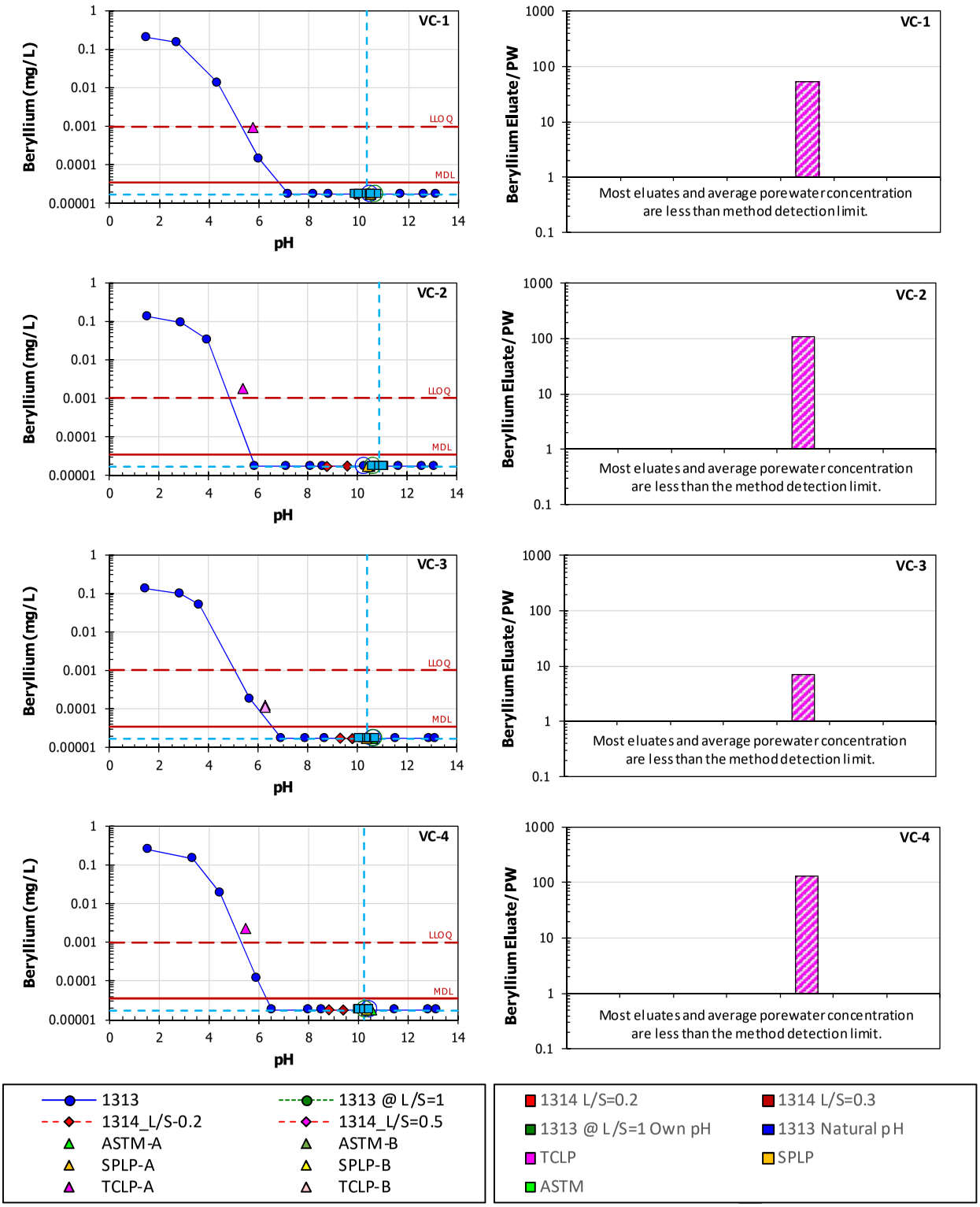

Figure E-4
Beryllium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Comparison of Porewater Estimates from Leaching Tests with Measured Values

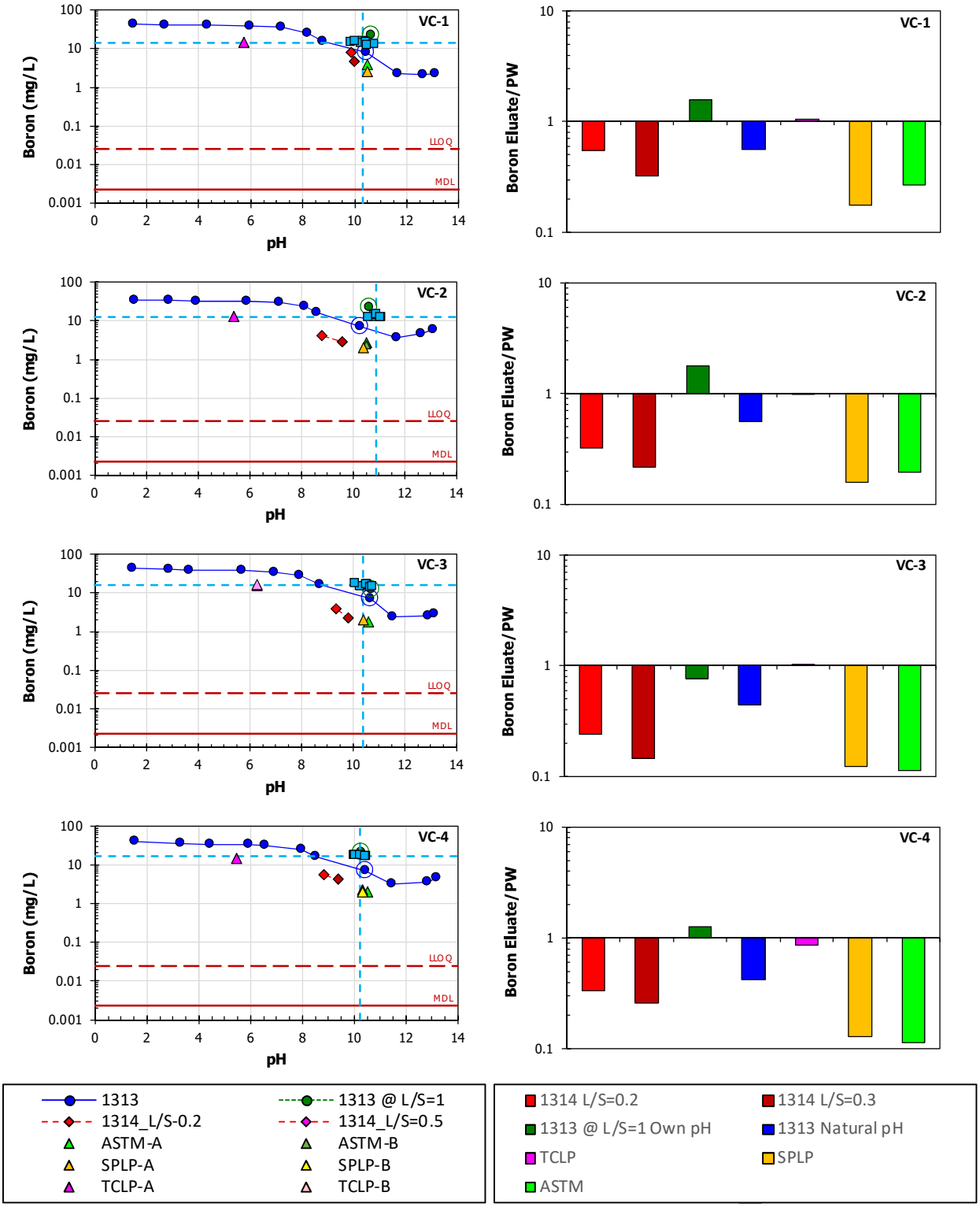

Figure E-5
Boron concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

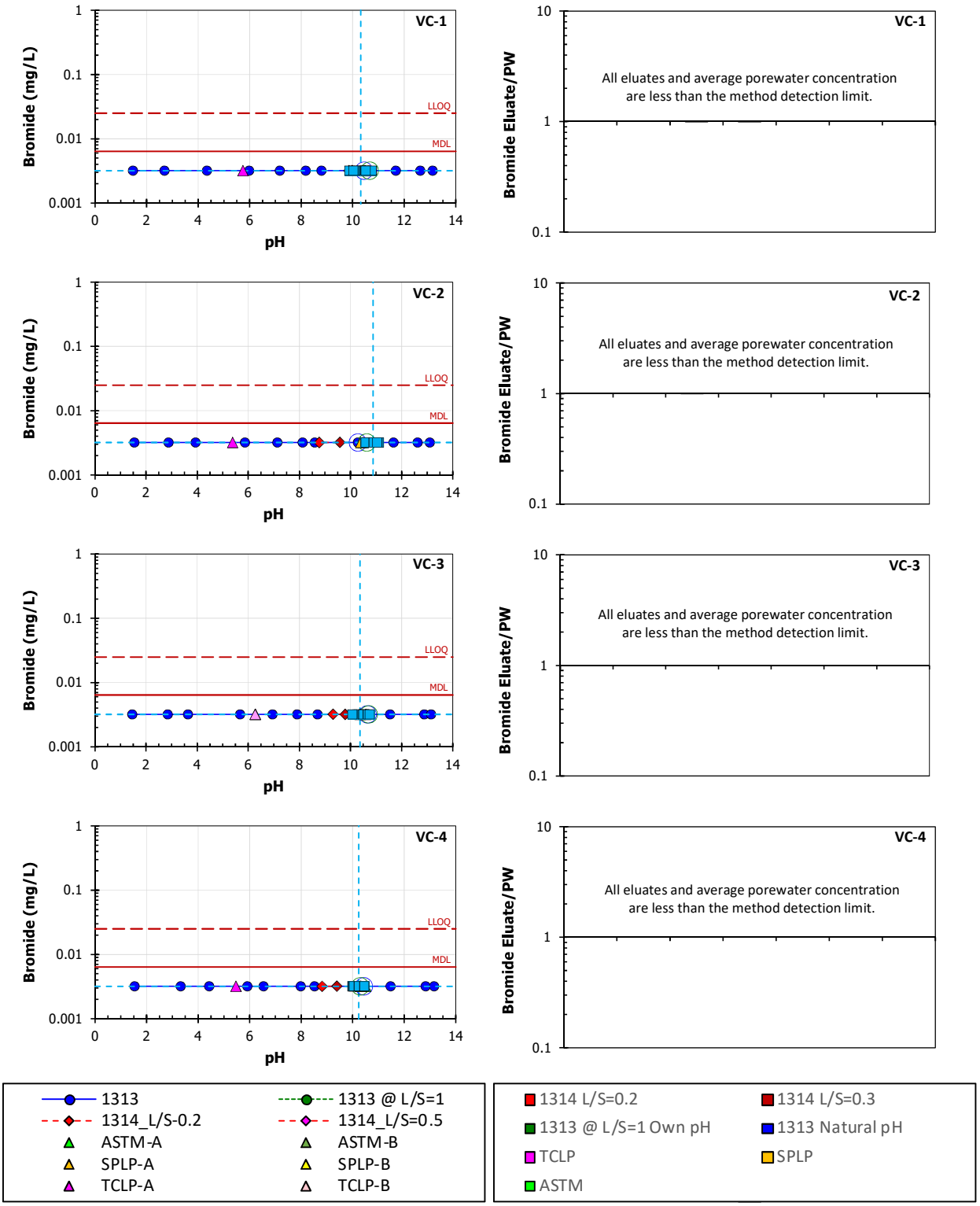

Figure E-6
Bromide concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

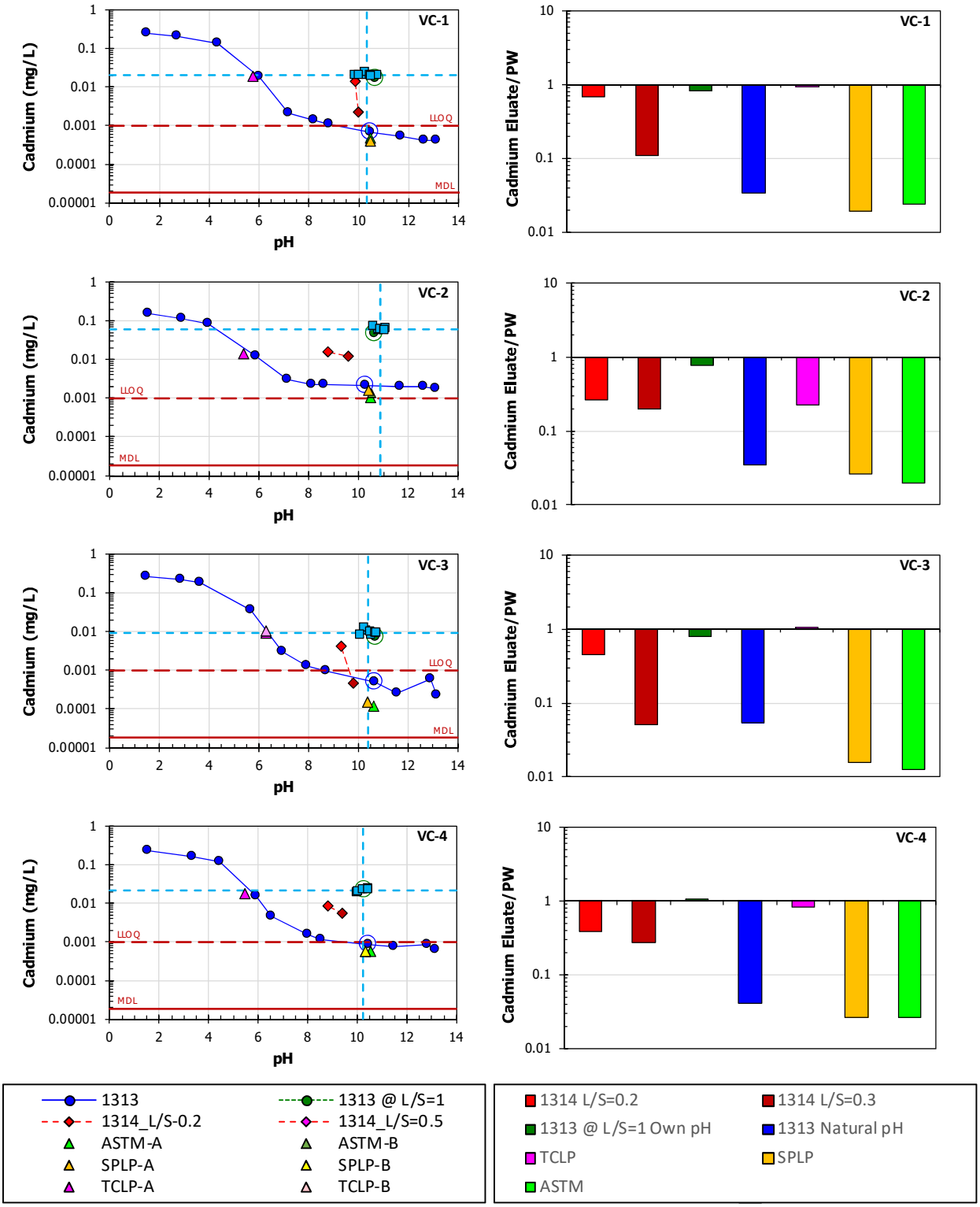

Figure E-7
Cadmium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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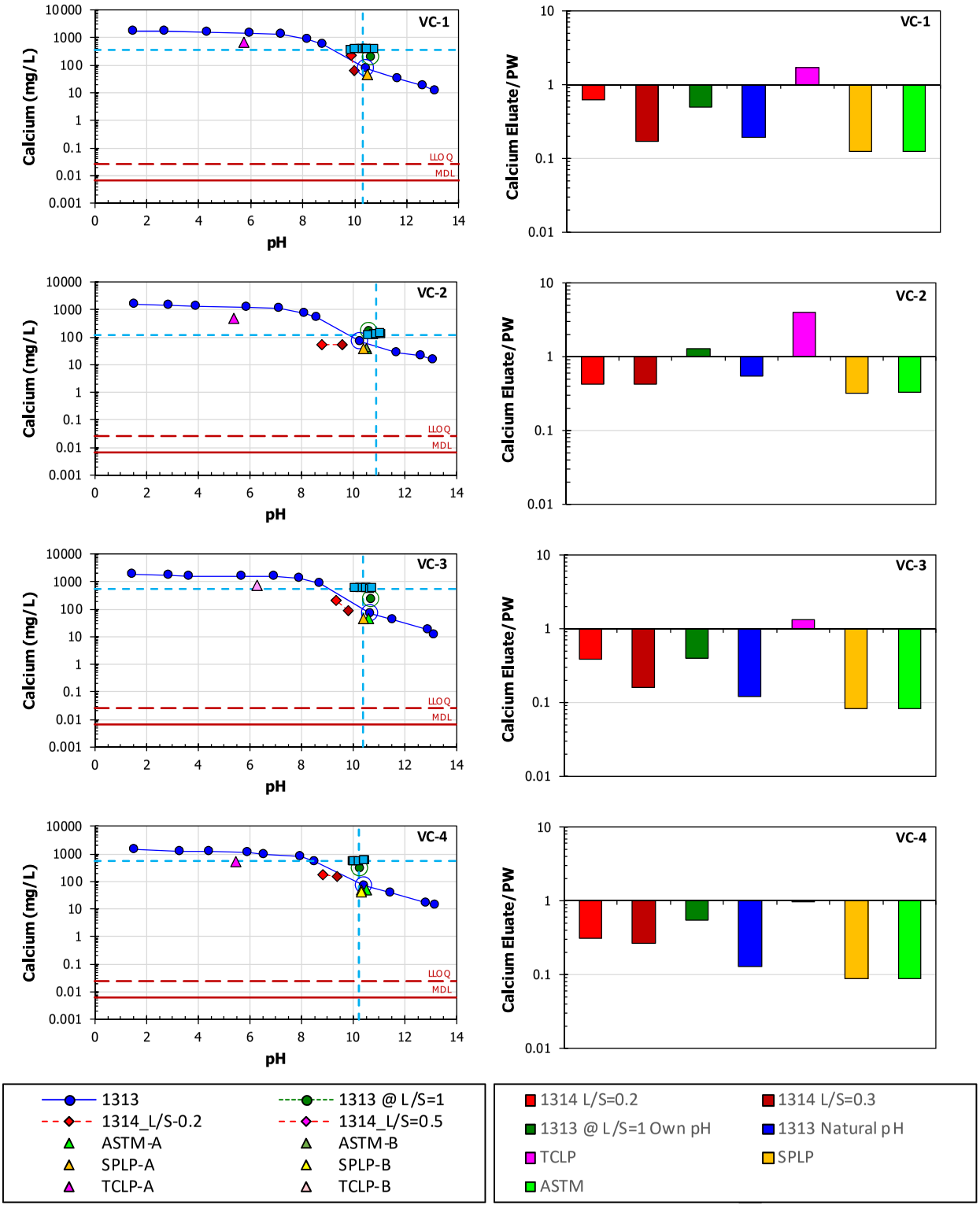

Figure E-8
Calcium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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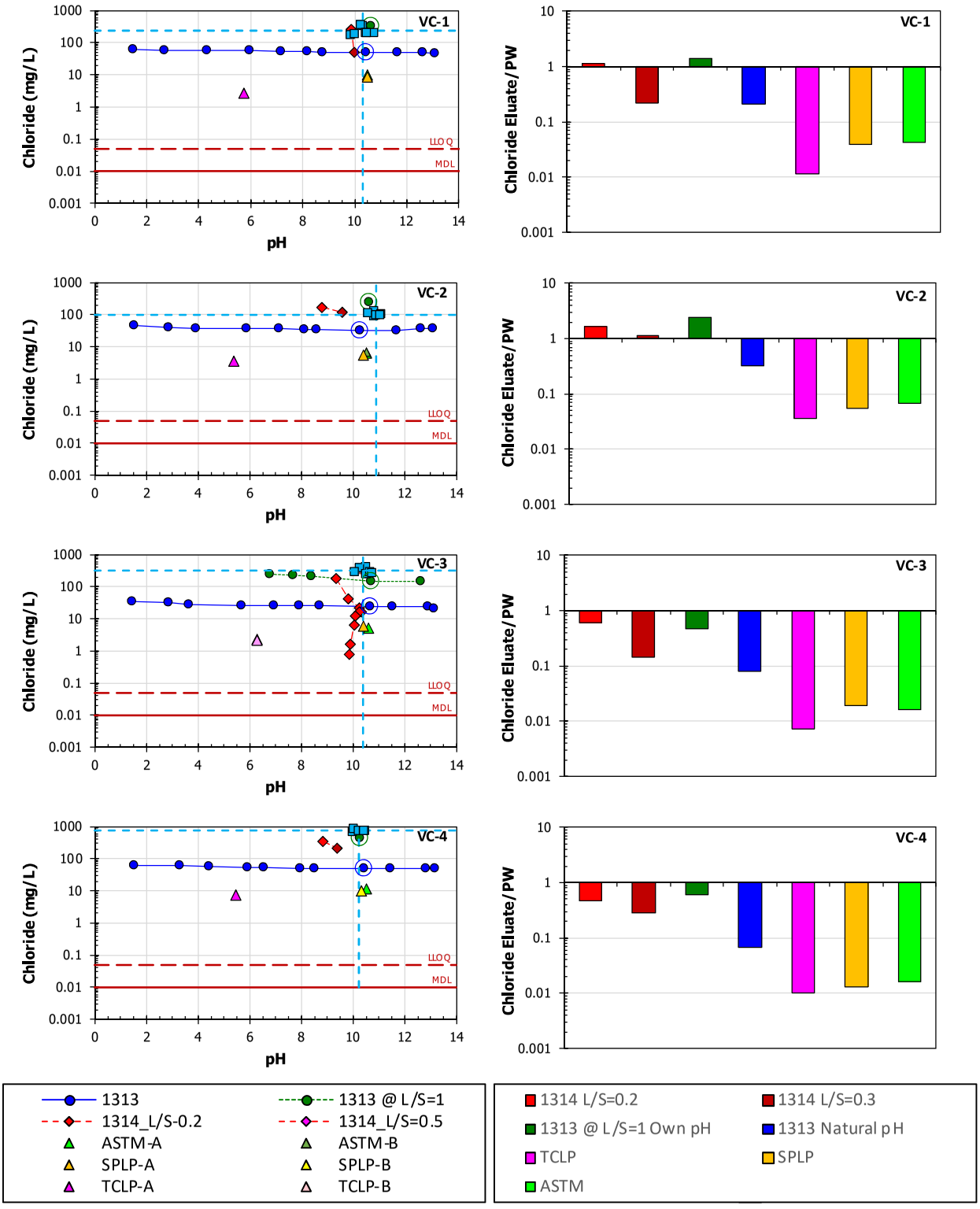

Figure E-9
Chloride concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

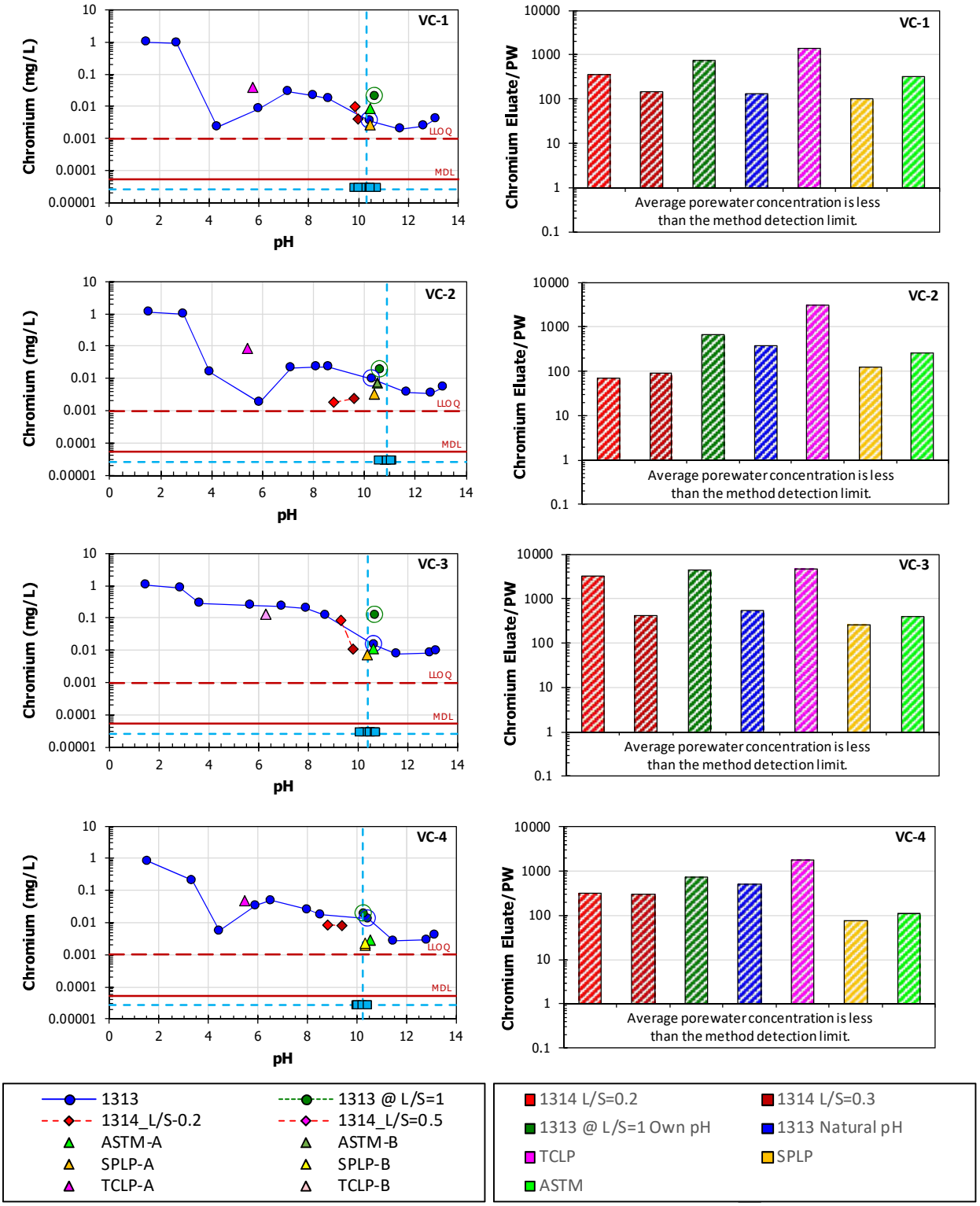

Figure E-10
Chromium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

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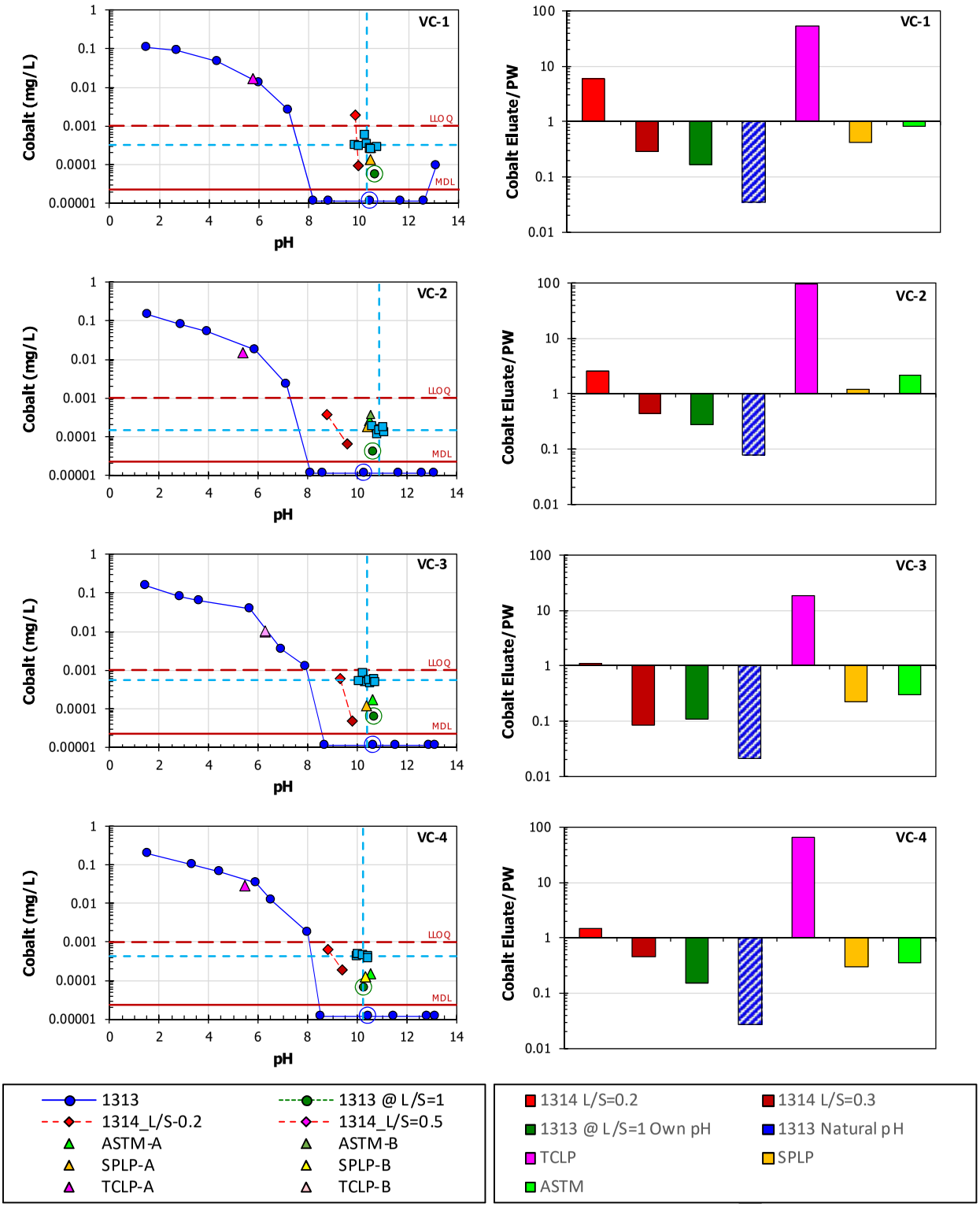

Figure E-11
Cobalt concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

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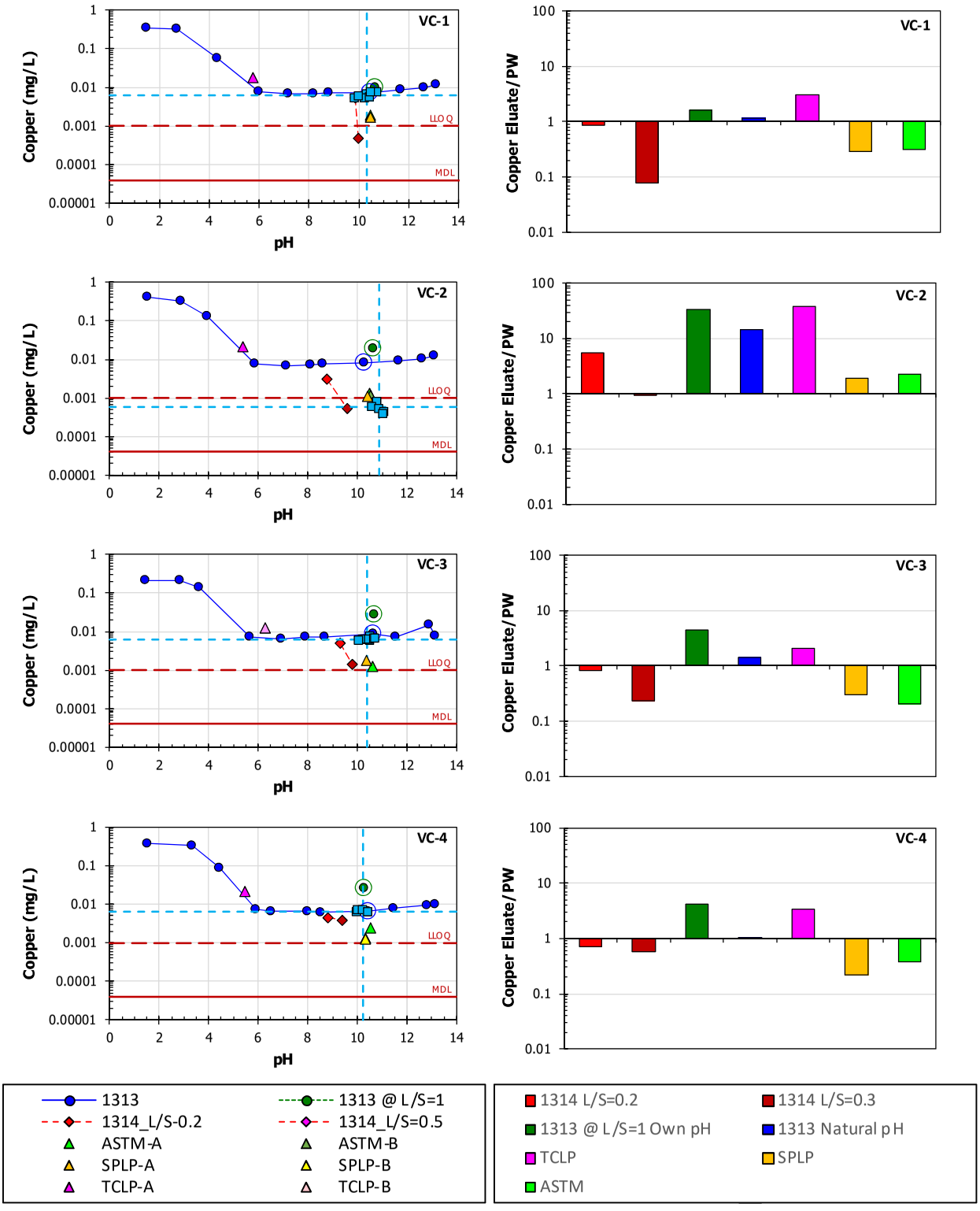

Figure E-12
Copper concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Electronic Filing: Received, Clerk's Office 07/01/2024

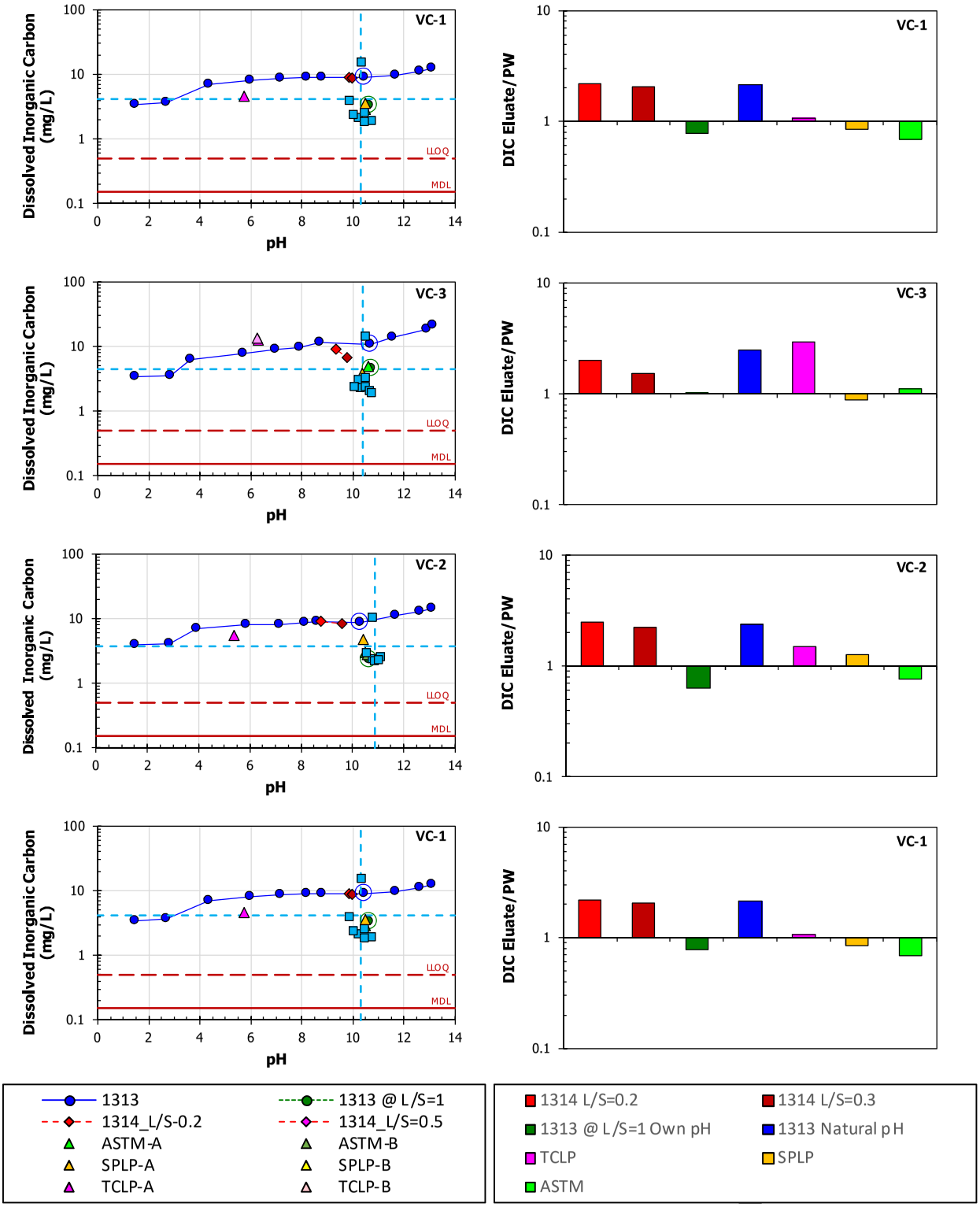

Figure E-13
Dissolved inorganic carbon concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Electronic Filing: Received, Clerk's Office 07/01/2024

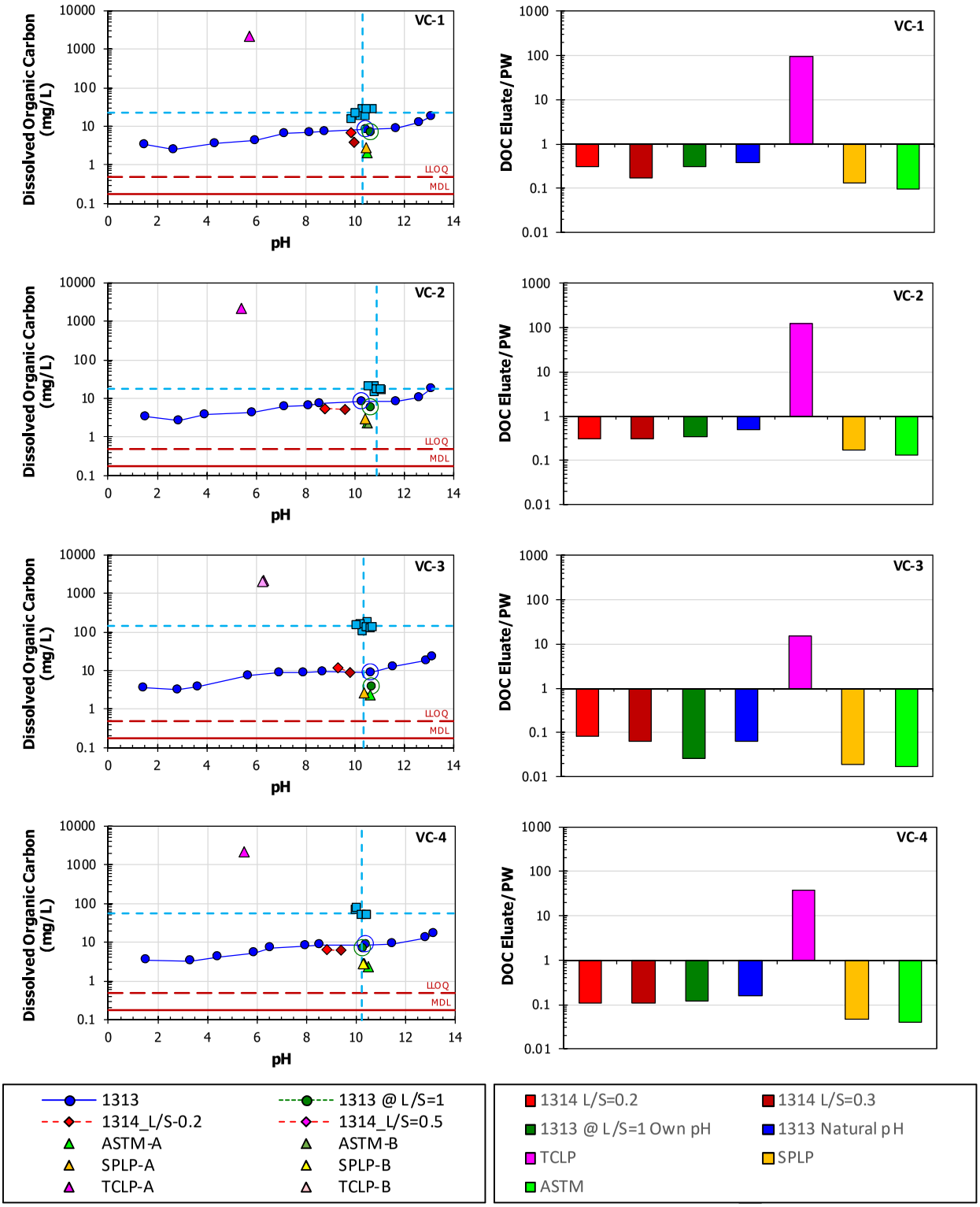

Figure E-14
Dissolve organic carbon concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

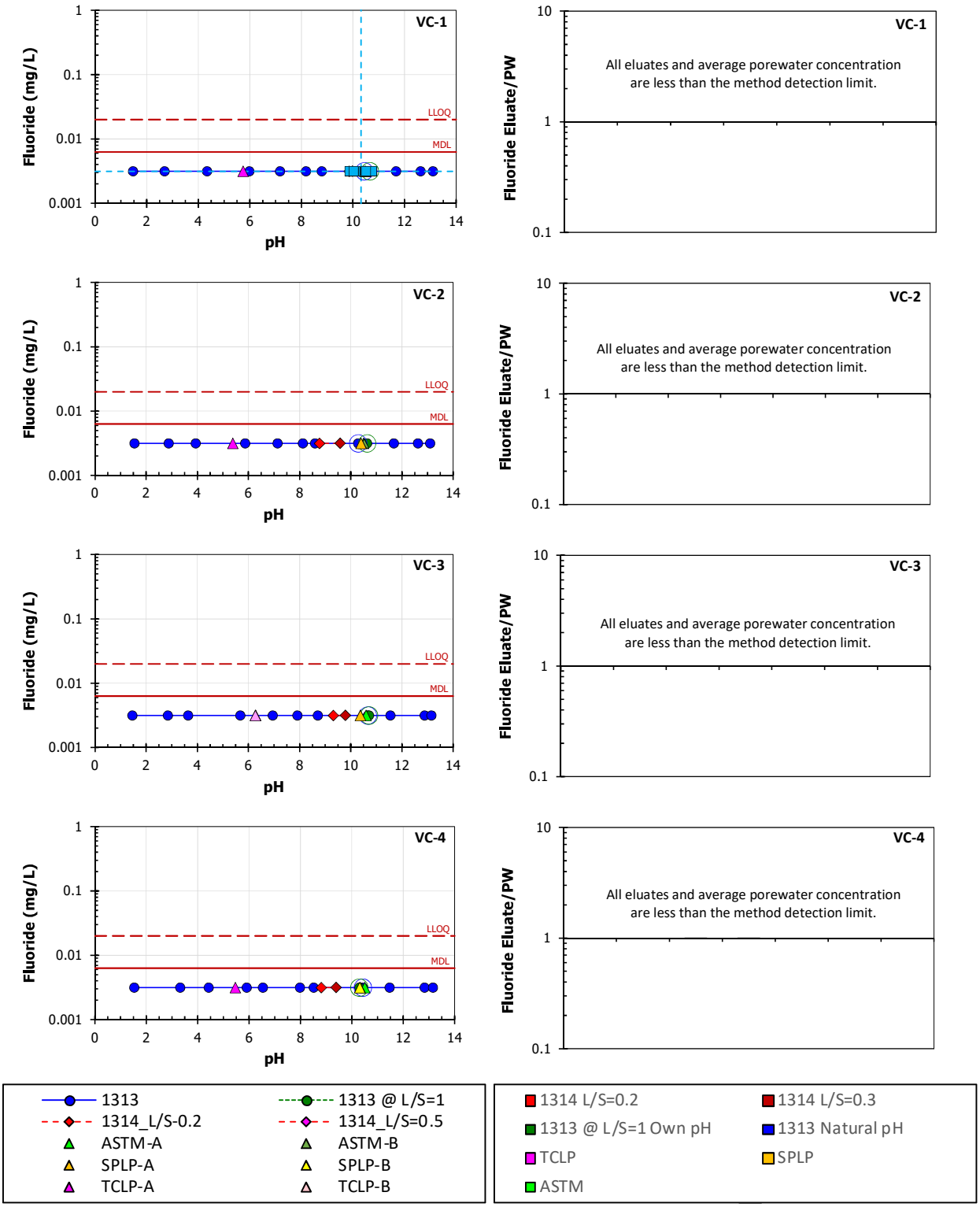

Figure E-15
Fluoride concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

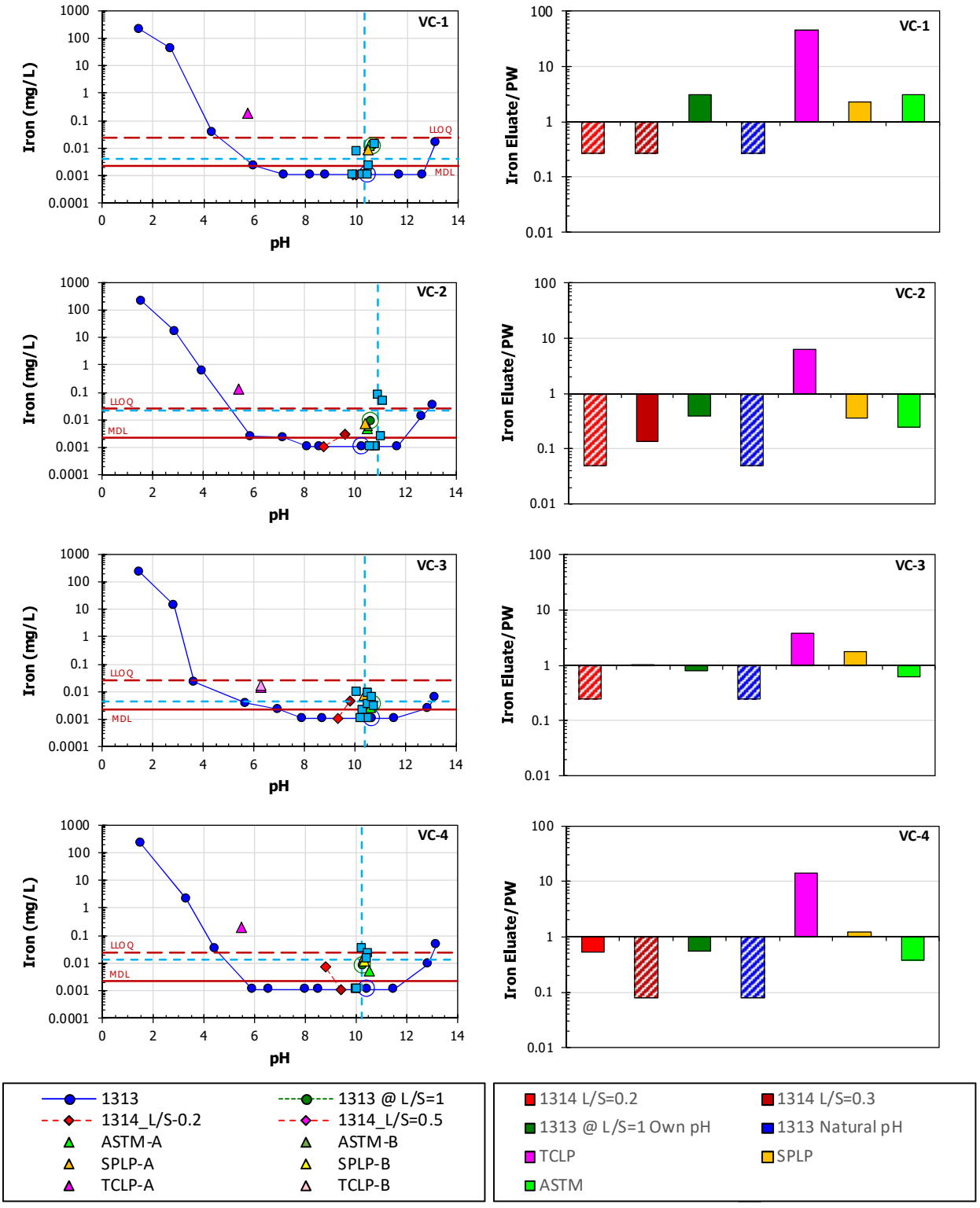

Figure E-16
Iron concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Comparison of Porewater Estimates from Leaching Tests with Measured Values

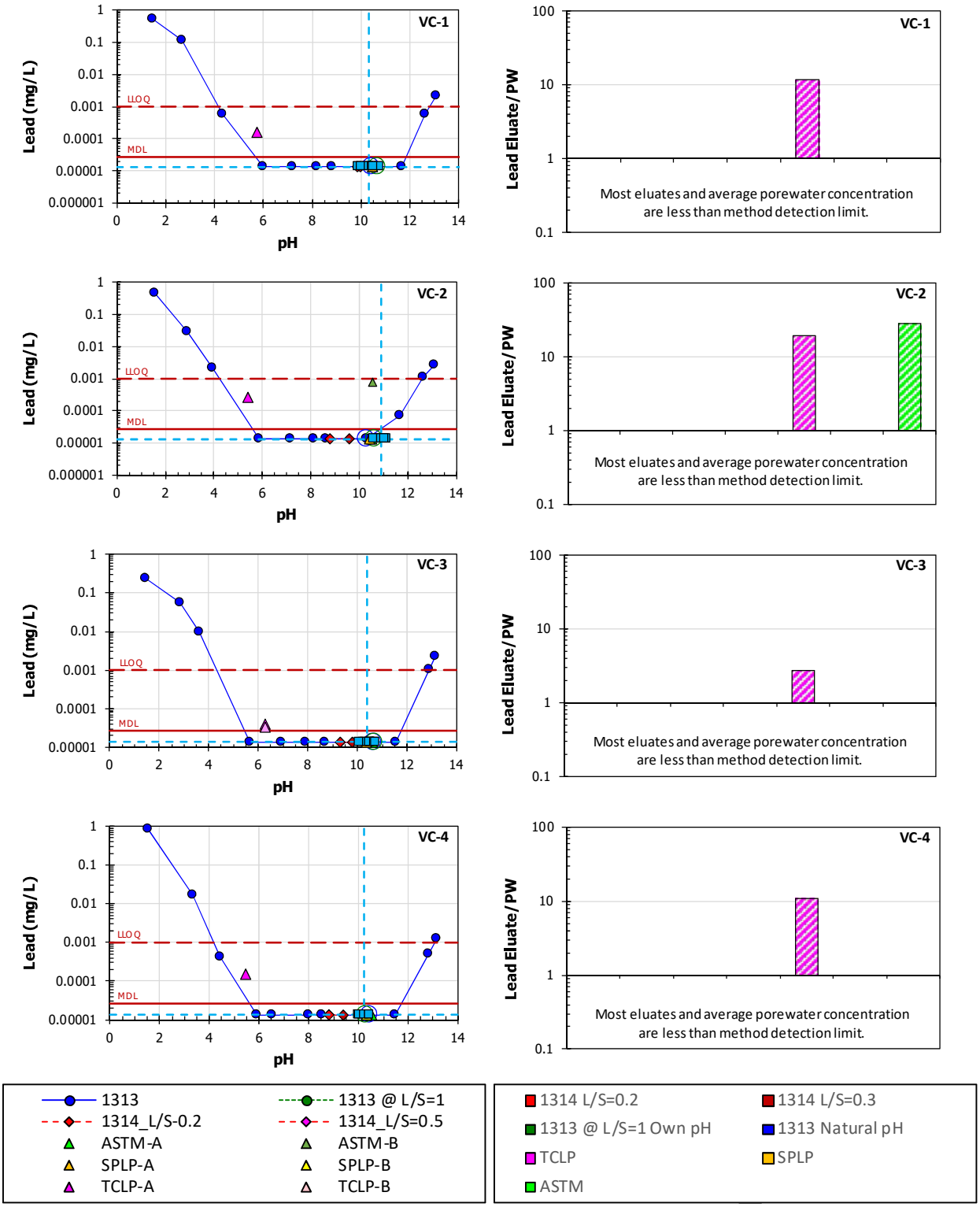

Figure E-17
Lead concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Electronic Filing: Received, Clerk's Office 07/01/2024

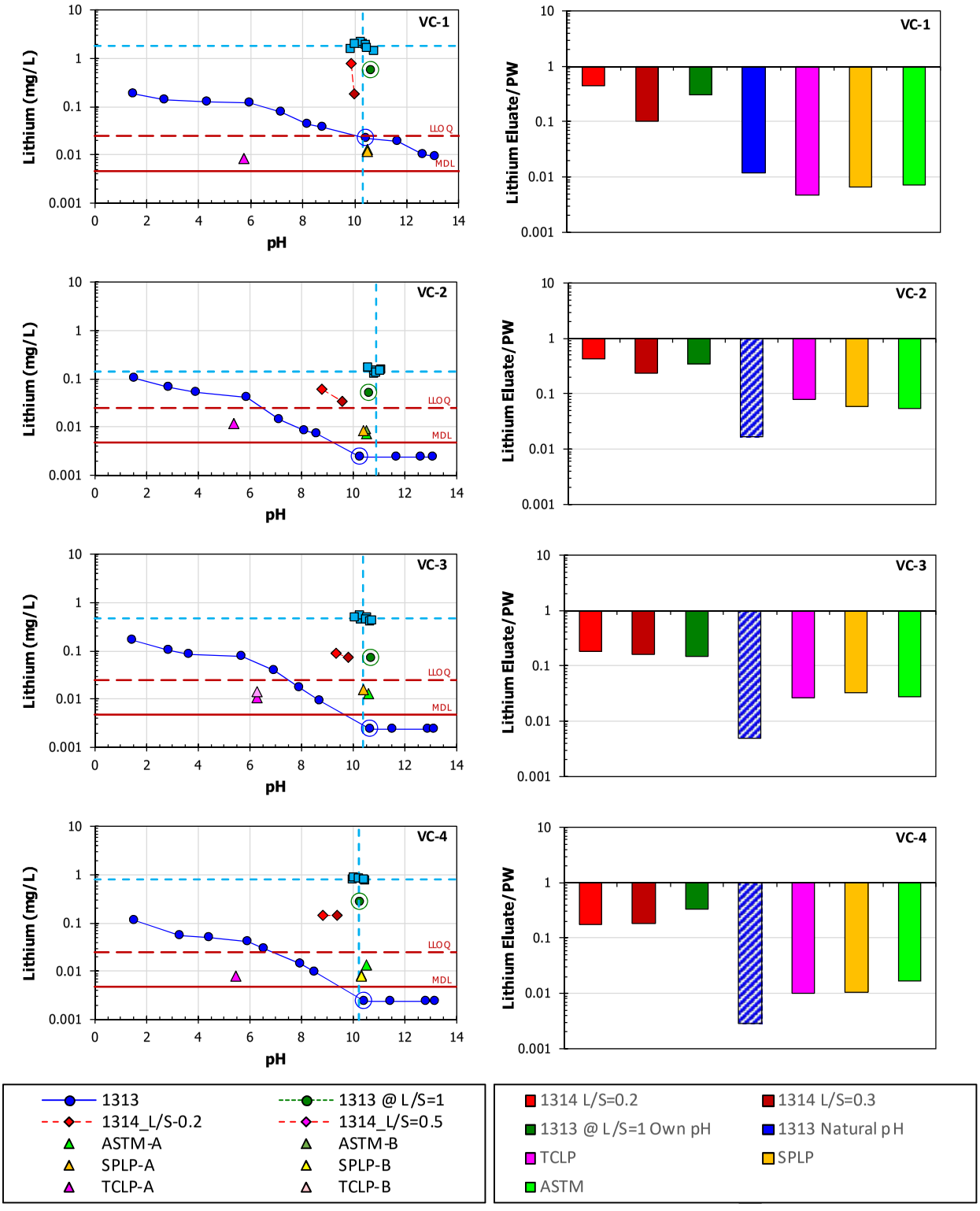

Figure E-18
Lithium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Electronic Filing: Received, Clerk's Office 07/01/2024

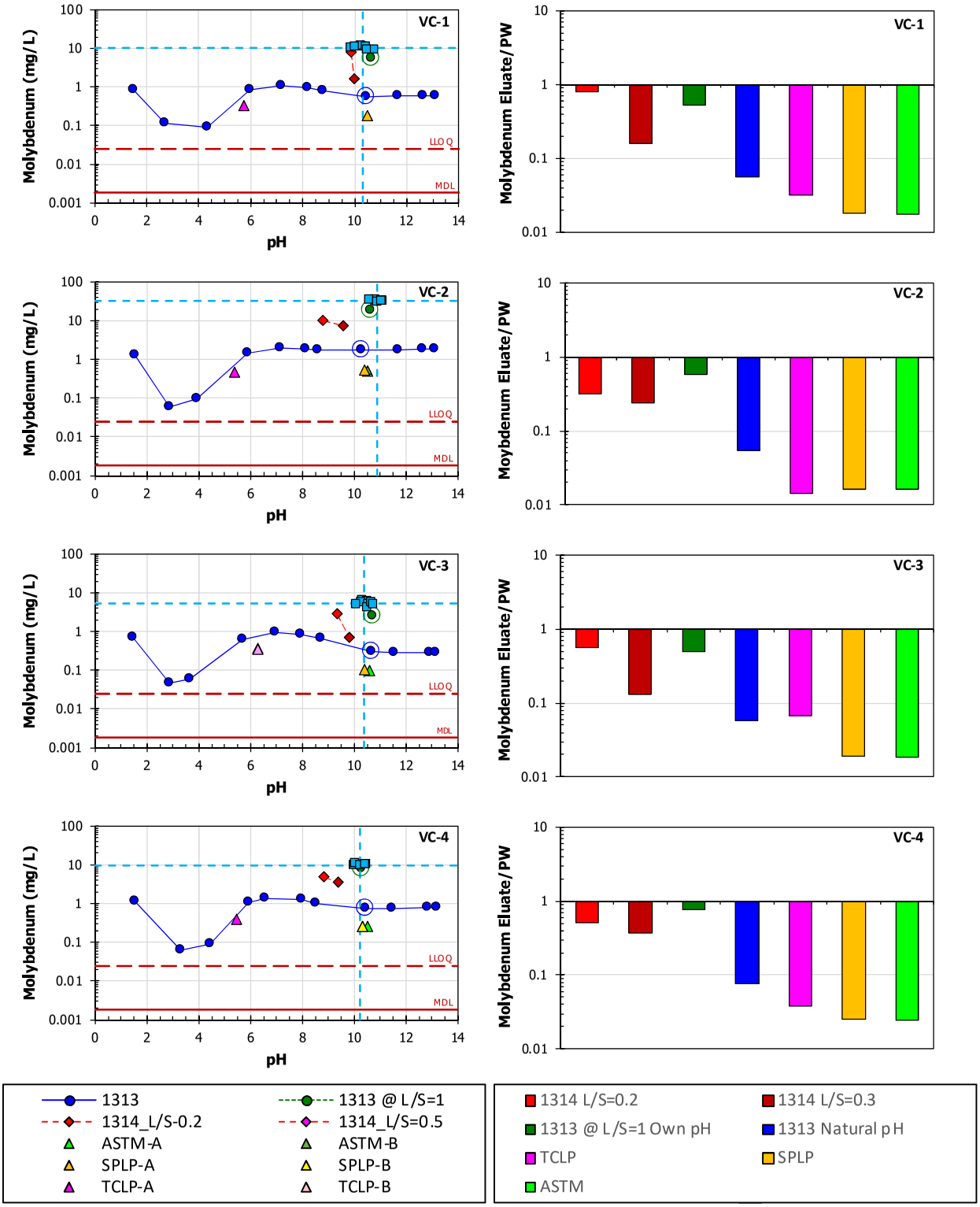

Figure E-19
Molybdenum concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Electronic Filing: Received, Clerk's Office 07/01/2024

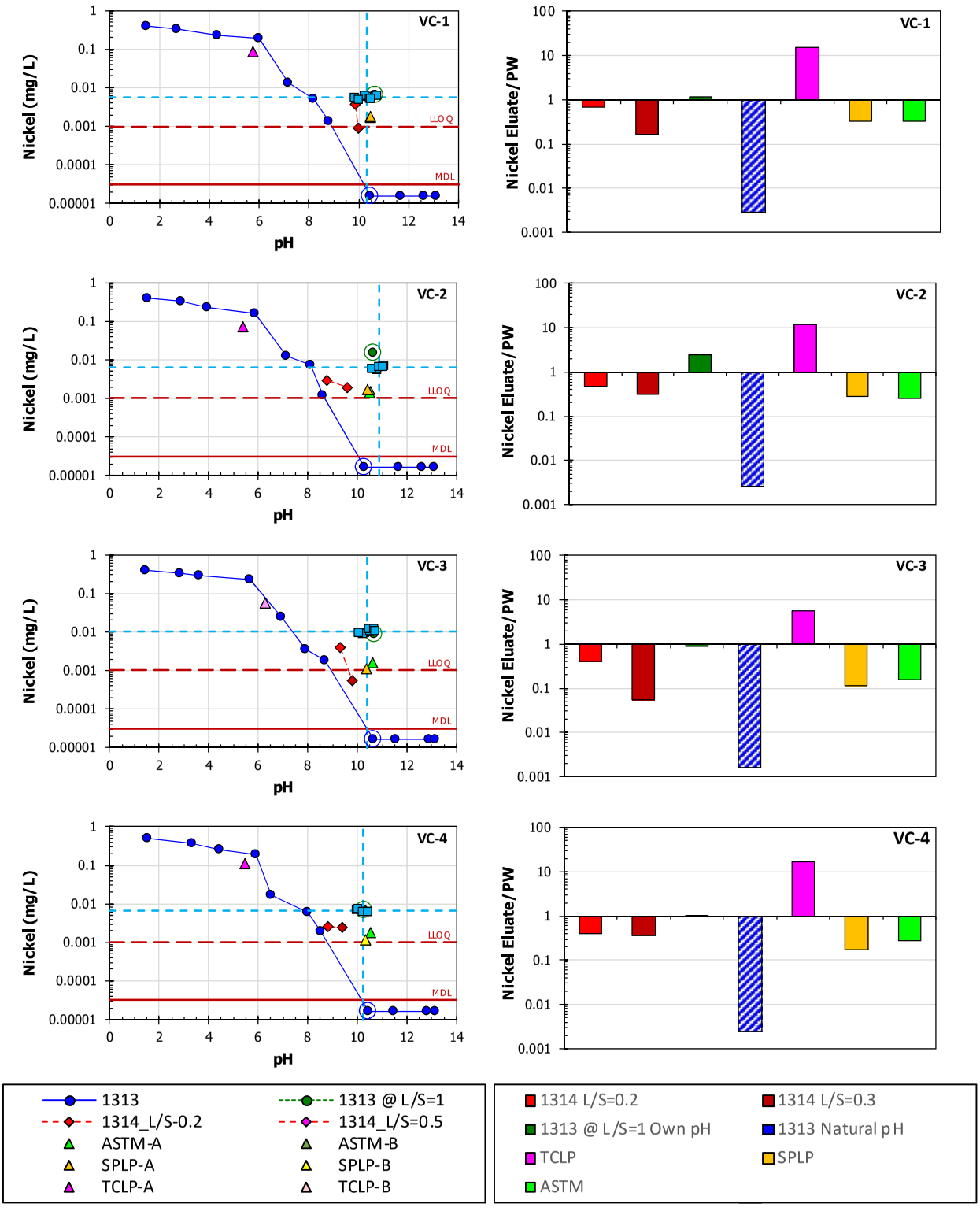

Figure E-20
Nickel concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Comparison of Porewater Estimates from Leaching Tests with Measured Values

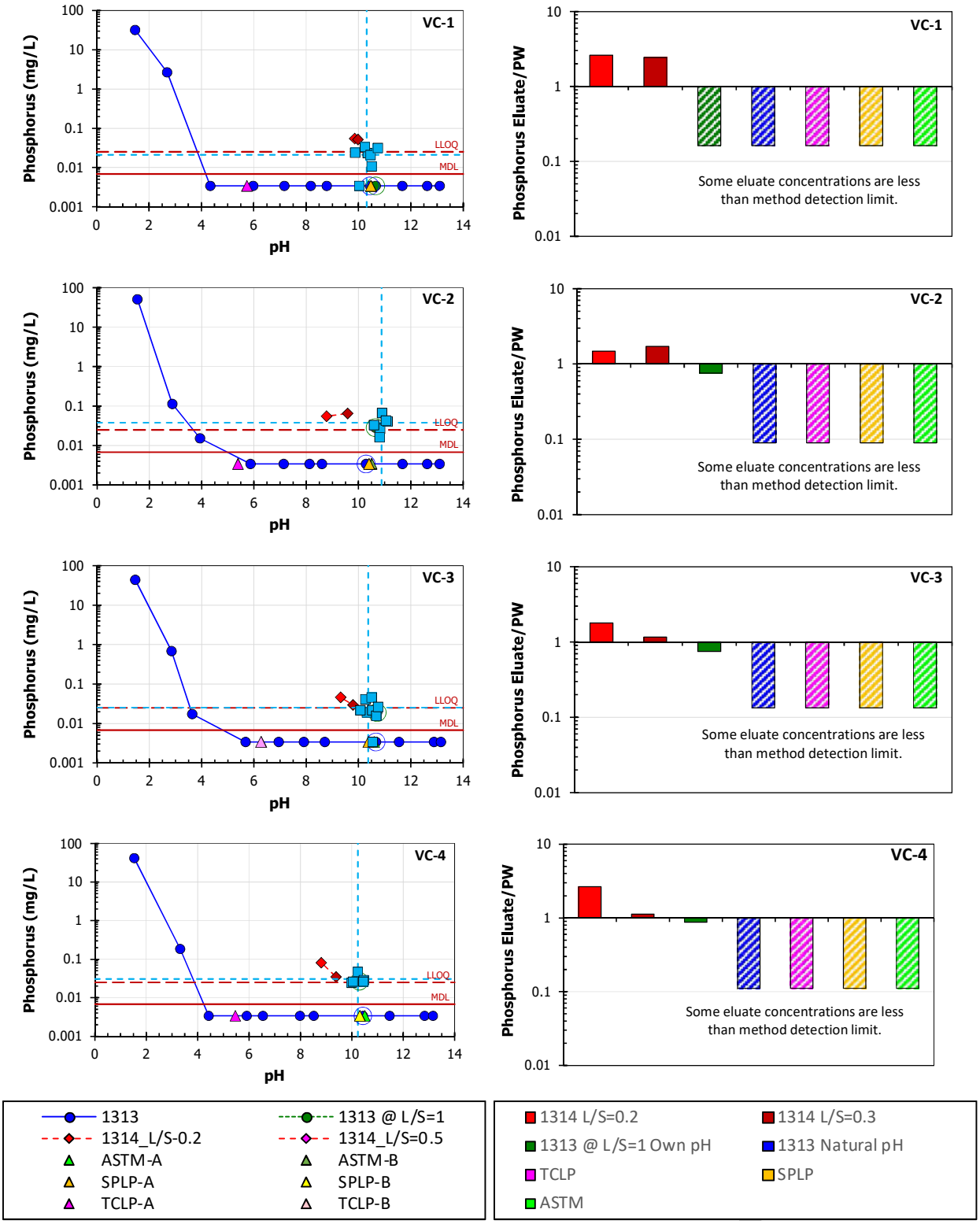

Figure E-21
Phosphorus concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Electronic Filing: Received, Clerk's Office 07/01/2024

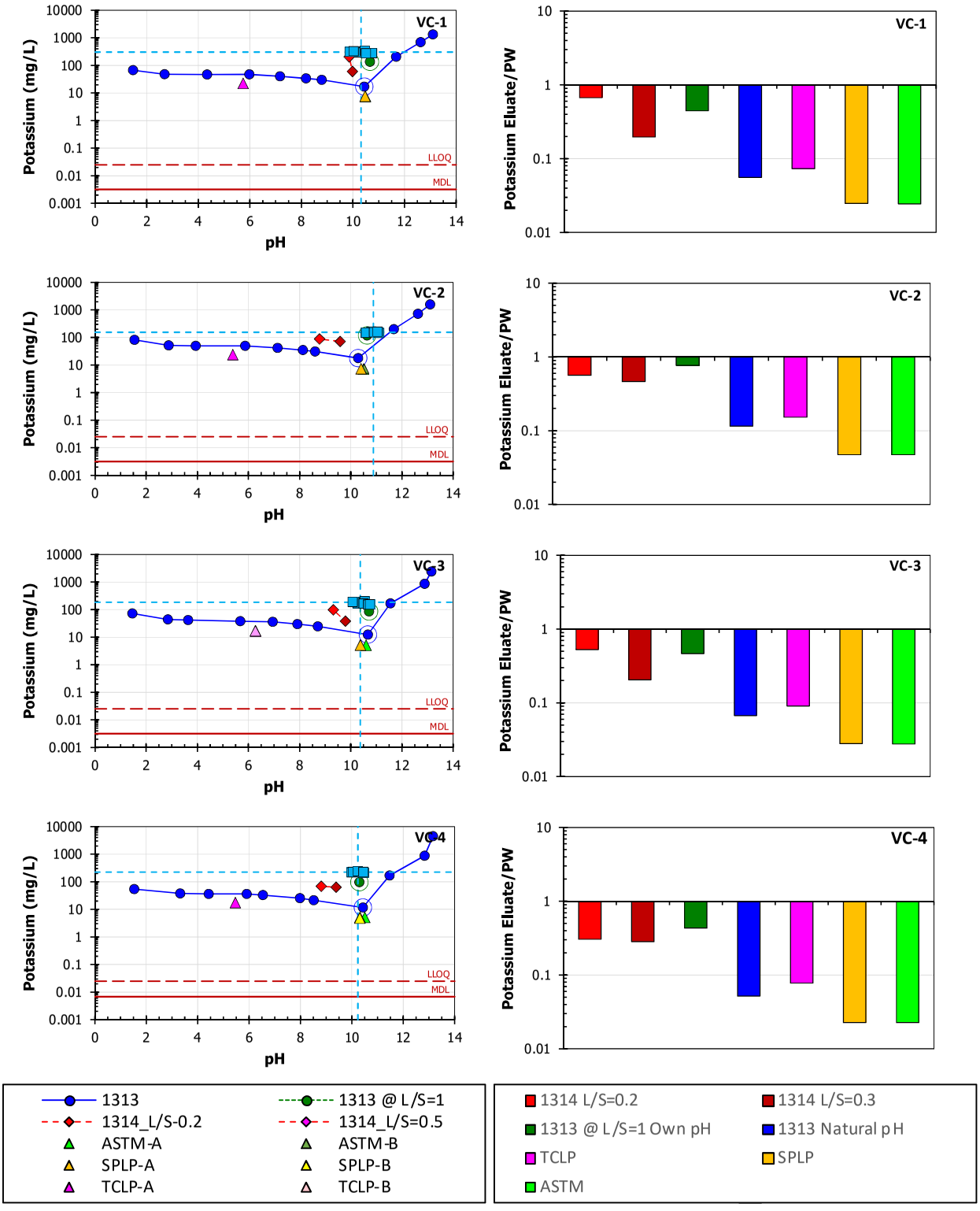

Figure E-22
Potassium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Electronic Filing: Received, Clerk's Office 07/01/2024

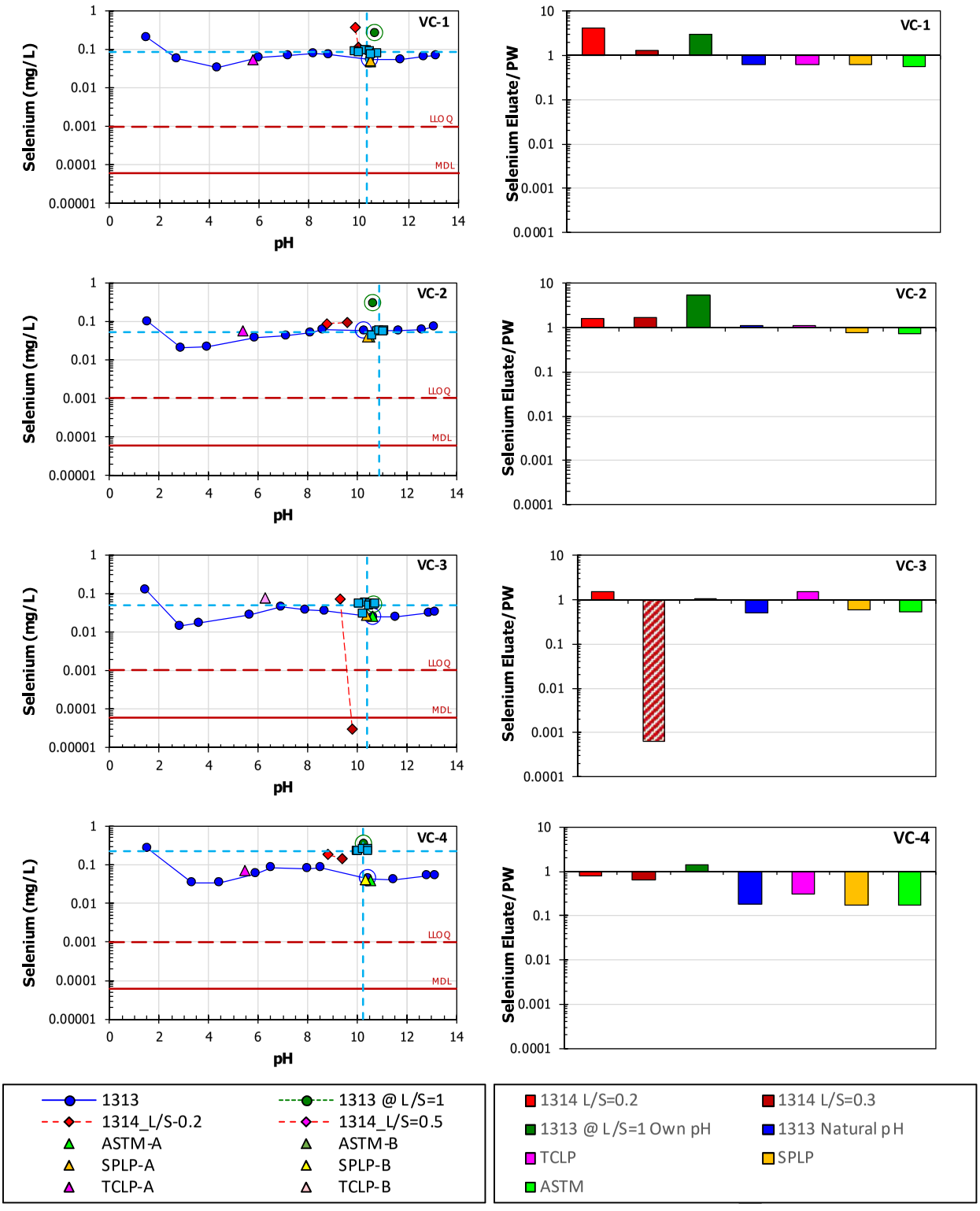

Figure E-23
Selenium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

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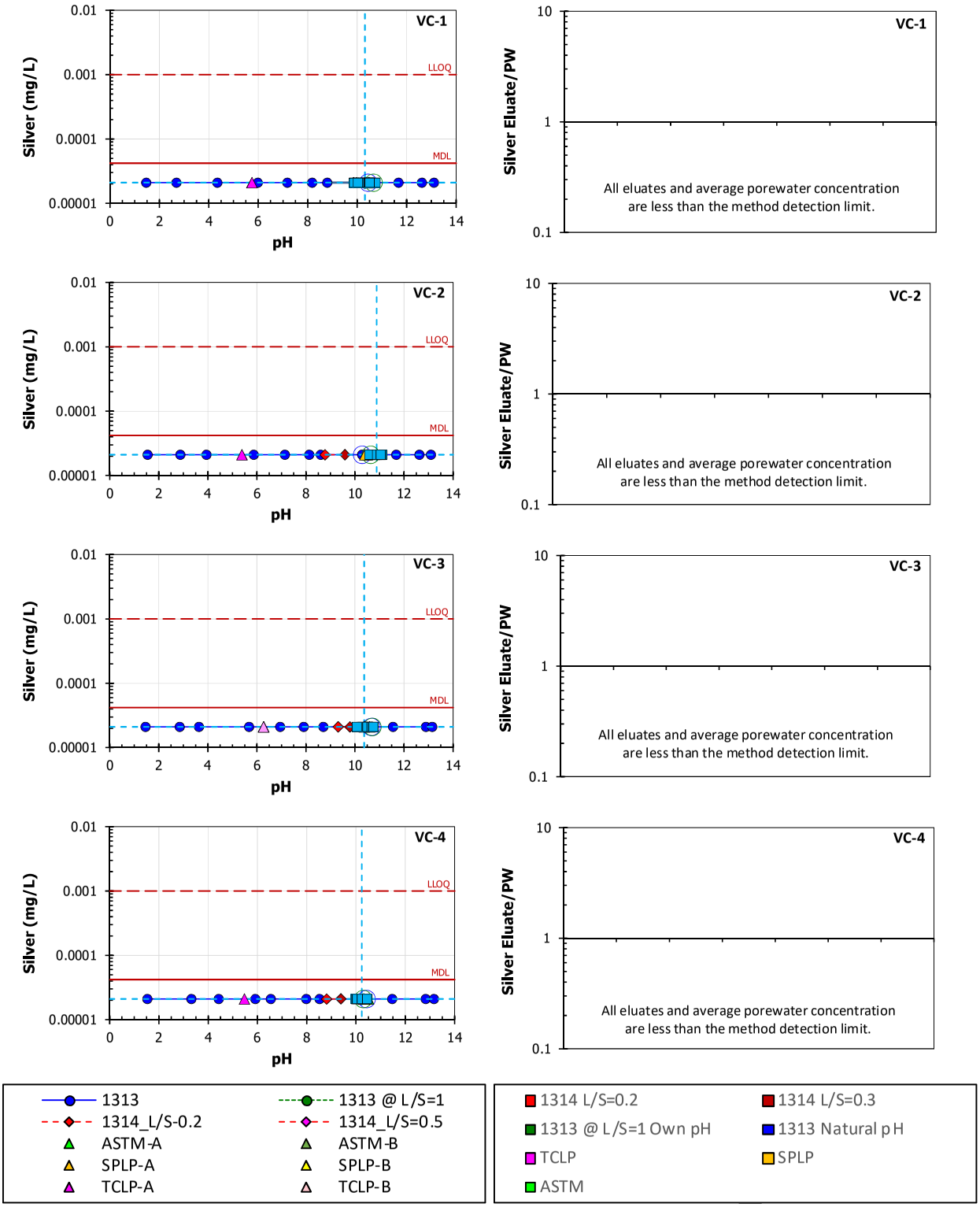

Figure E-24
Silver concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

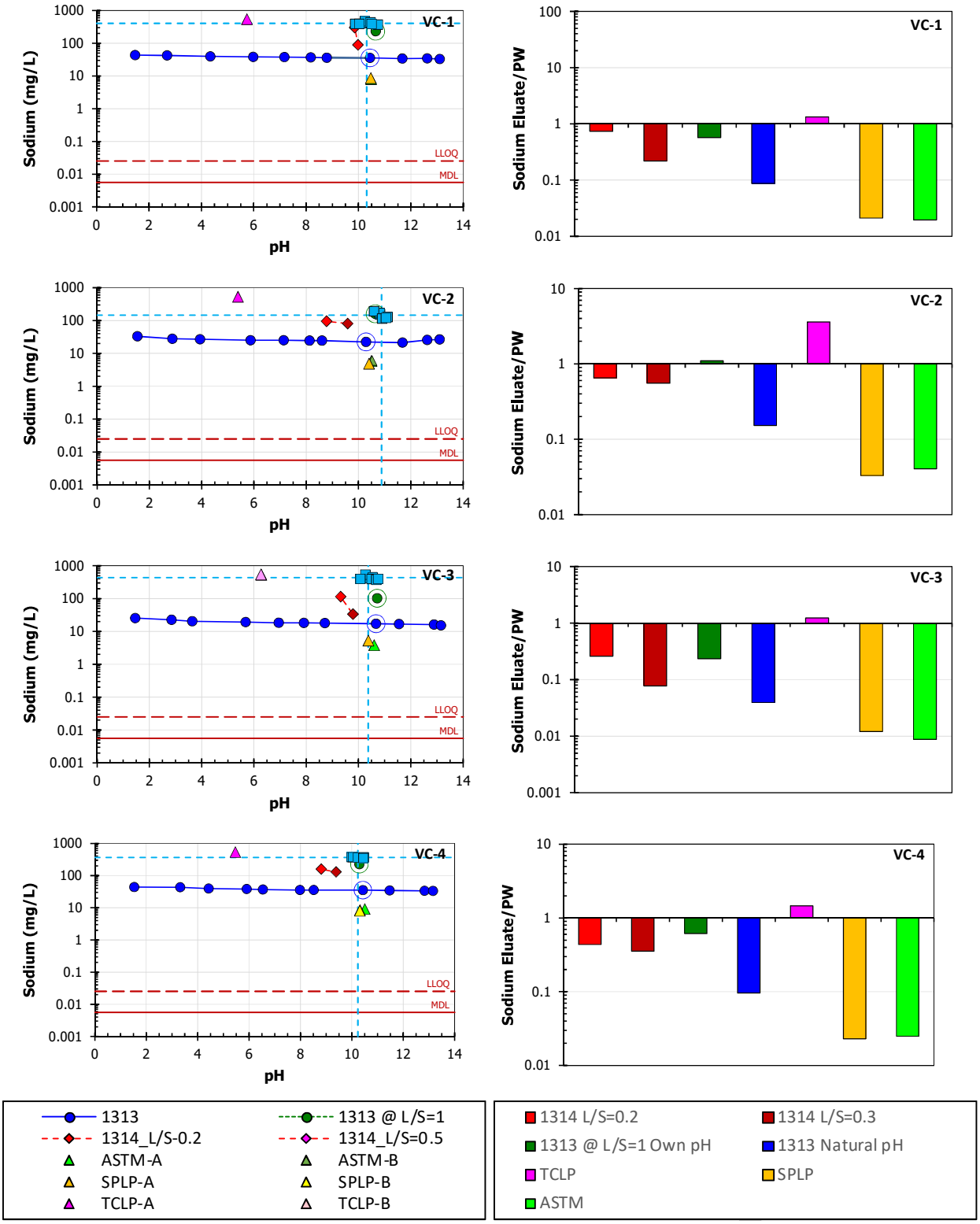

Figure E-25
Sodium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

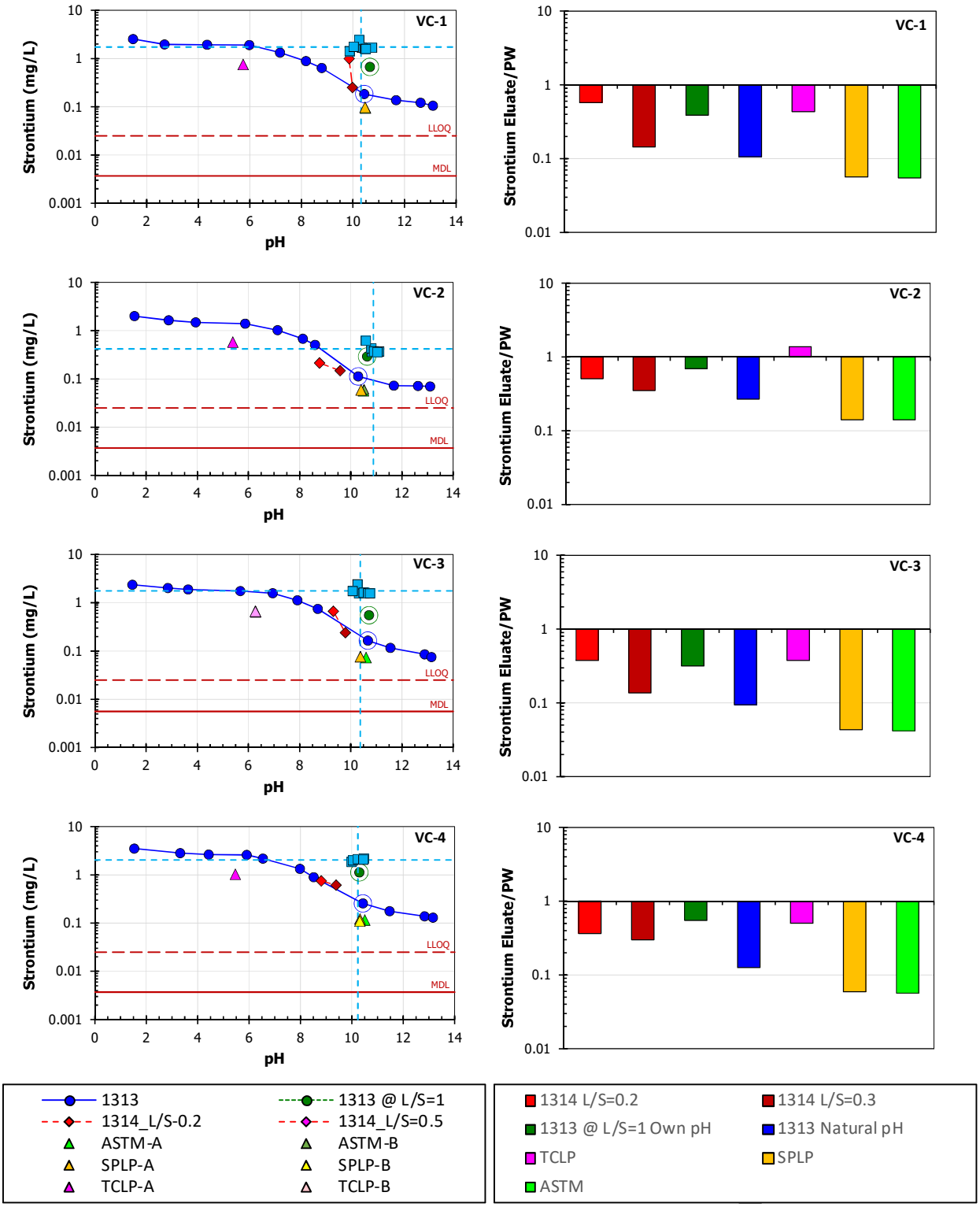

Figure E-26
Strontium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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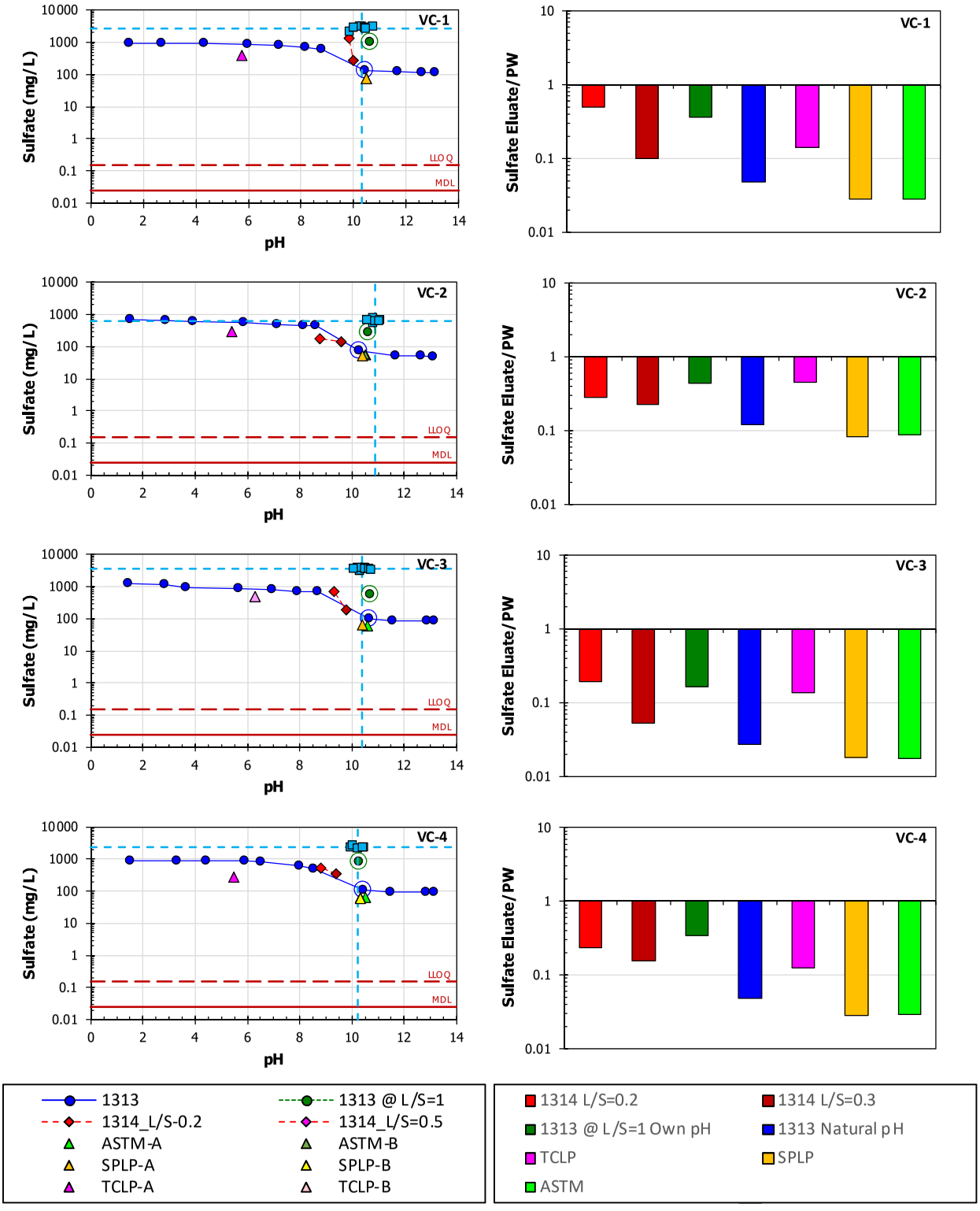

Figure E-27
Sulfate concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

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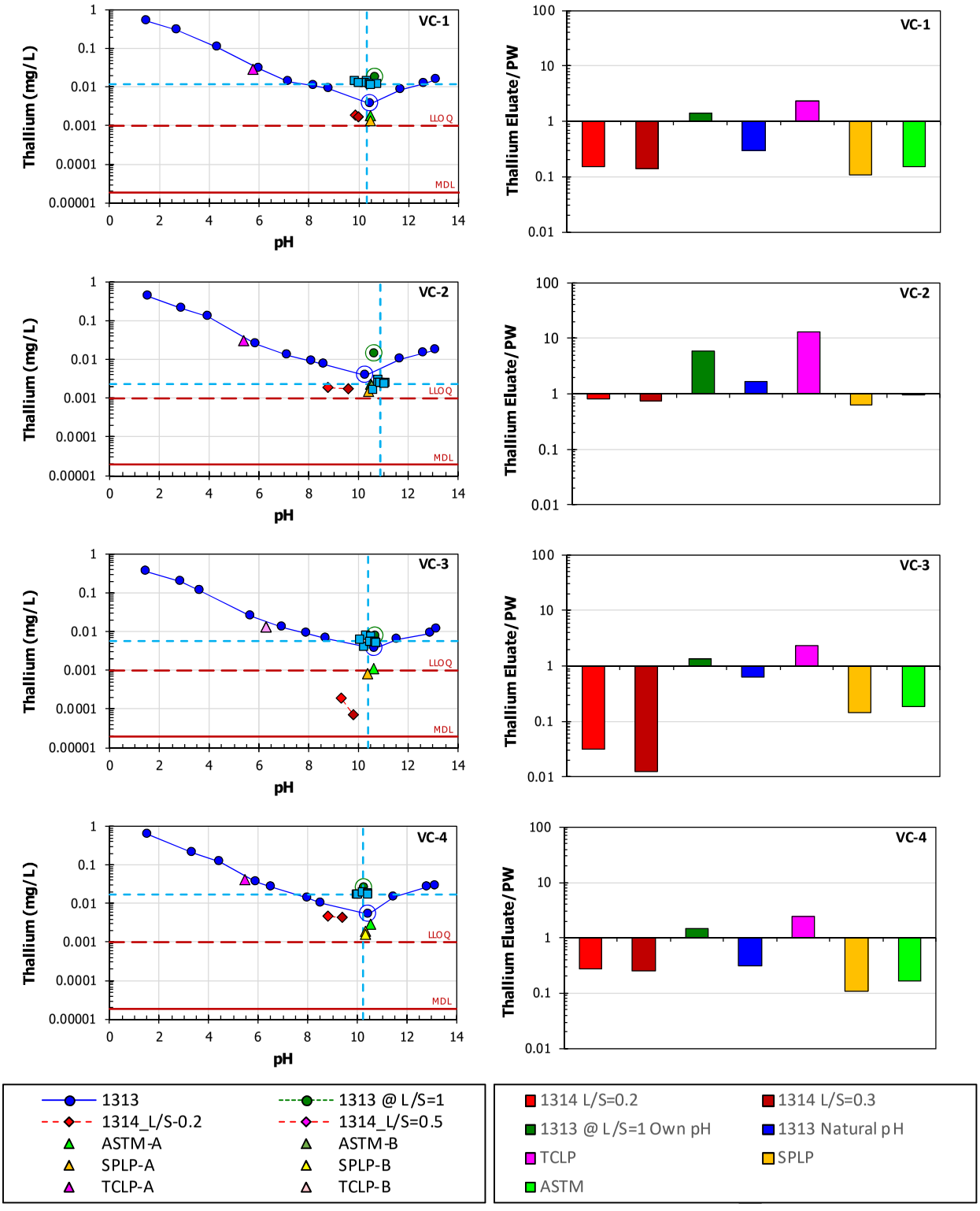

Figure E-28
Thallium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

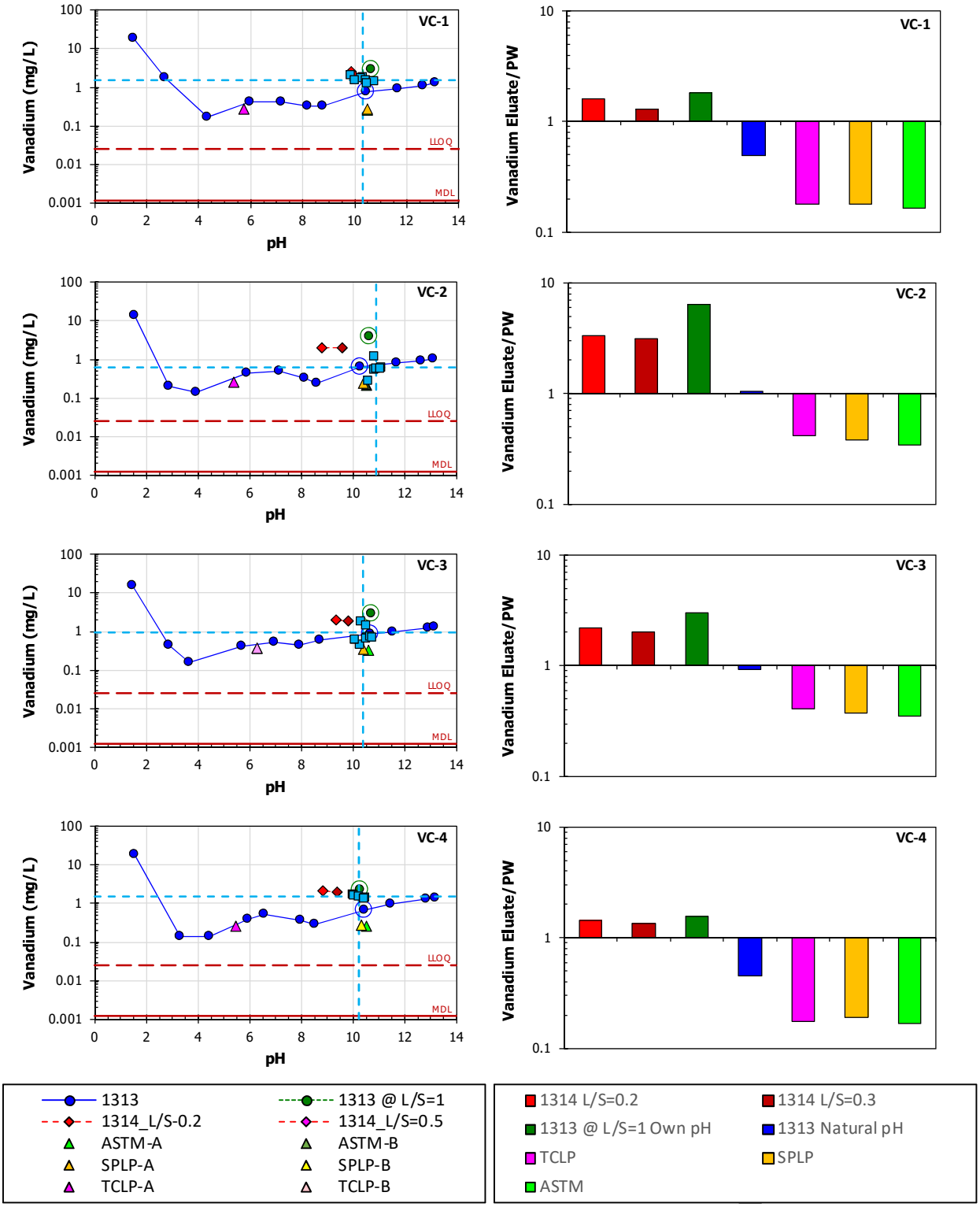

Figure E-29
Vanadium concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right)

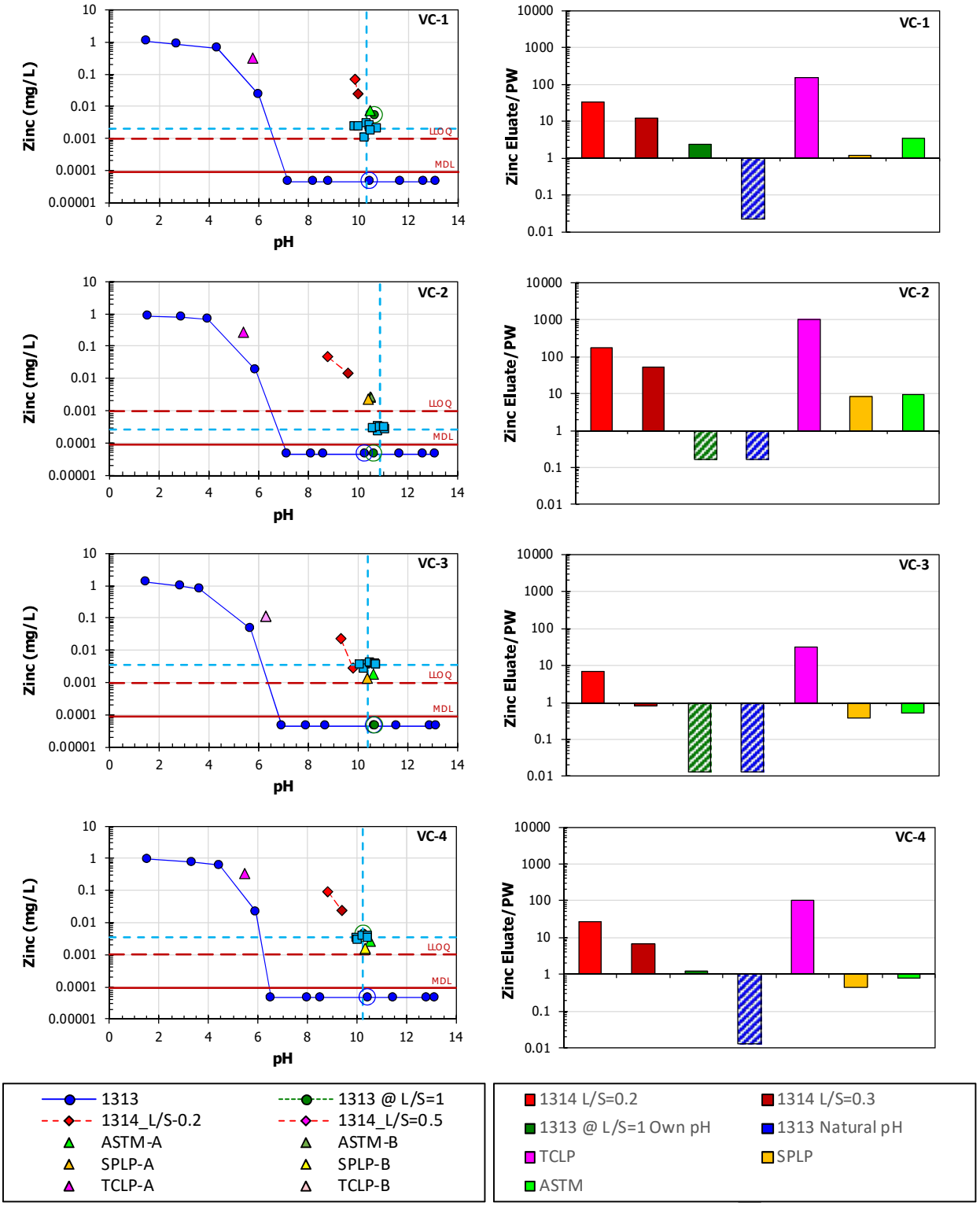

Figure E-30
Zinc concentration from leaching tests compared to measured and mean porewater concentrations as a function of pH (left) and as a ratio of eluate-to-porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

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F
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Program:

Coal Combustion Products Management

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Appendix 17

Electric Power Research Institute (EPRI), 2020. Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment: Capped Unit. EPRI, Palo Alto, CA: 2020. 3002017363.

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Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment

Capped Unit

2020 TECHNICAL REPORT

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Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment

Capped Unit

3002017363

Final Report, June 2020

EPRI Project Manager
B. Hensel

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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Vanderbilt University Department of Civil and Environmental Engineering

Hans van der Sloot Consultancy

University of Virginia School of Engineering

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The following organizations, under contract to the Electric Power Research Institute (EPRI), prepared this report:

Vanderbilt University
Department of Civil and Environmental Engineering
Nashville, TN 37235

Principal Investigators
D.S. Kosson (PI)
A.C. Garrabrants (Co-PI)
X. Wang
Q. Qui
Z. Chen
R. DeLapp

Hans van der Sloot Consultancy
Hoorn, The Netherlands

Principal Investigator
H.A. van der Sloot

University of Virginia
School of Engineering
Charlottesville, VA 22904

Principal Investigators
C.H. Benson
J. Chen
J.M. Benavides

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ABSTRACT

The appropriate use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field.

This report presents the results of geotechnical, hydrologic, and leaching characterization of samples collected from a closed and capped coal ash impoundment. The hydraulic conductivity of intact cores from the pond was measured in context of the distribution of particles in the coal ash samples and the overburden pressure associated with disposal at depth within the pond. The leaching test results for LEAF tests (i.e., EPA Methods 1313 and 1314) were compared to those for traditional tests (i.e., ASTM, TCLP, SPLP). In addition, concentrations derived from leaching tests were compared to porewater concentrations determined from field samples, and field-sampled porewater concentrations were compared to groundwater concentrations, to evaluate similarities and dissimilarities between these results.

Keywords

Coal ash
Leaching tests
Porewater
Leaching Environmental Assessment Framework (LEAF)
Hydrogeochemistry

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EXECUTIVE SUMMARY

Deliverable Number: 3002017363

Product Type: Technical Report

Product Title: Leaching, Geotechnical, and Hydrologic Characterization of Coal Combustion Products from a Closed Coal Ash Impoundment: Capped Unit

PRIMARY AUDIENCE: Electric utility environmental professionals responsible for landfill and impoundment management of CCPs.

SECONDARY AUDIENCE: Researchers and regulators interested in CCP leaching and chemistry.

KEY RESEARCH QUESTION

The appropriate use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field. The goals of this research were (i) to evaluate approaches for estimating porewater concentrations at CCP disposal facilities, and (ii) to explore potential connections between the CCP leaching performance of a disposal facility, based on porewater measurements or leaching tests, and monitoring of groundwater exterior to the facility.

RESEARCH OVERVIEW

Coal ash samples were collected at three locations from a closed and capped disposal impoundment. During field activities, porewater access and subsurface gas access points were established and monitored for 13 months. Collected solids were characterized for leaching and geotechnical/hydrologic properties. The hydraulic conductivity of intact cores was measured in context of the distribution of particle sizes in the coal ash samples and the overburden pressure associated with disposal at depth within the pond. The leaching test results for the Leaching Environmental Assessment Framework (LEAF) (i.e., EPA Methods 1313 and 1314) were compared to those for traditional tests (i.e., ASTM, TCLP, and SPLP). In addition, leaching test results were compared to porewater concentrations determined from field samples, and field-sampled porewater concentrations were compared to groundwater concentrations, to evaluate similarities and dissimilarities between these results.

KEY FINDINGS

- The hydraulic conductivity of intact ash samples is strongly dependent on the fraction of fines in the material. The measured hydraulic conductivity of finer, less permeable coal ash samples was lower (ranging from approximately $7x10^{-4}$ cm/s to $1x10^{-5}$ cm/s) than the hydraulic conductivity of coarser, more permeable samples (approximately $1x10^{-3}$ cm/s). In general, the measured hydraulic conductivity decreased with increasing effective stress, or overburden pressure; however, the hydraulic conductivity of coarser, more permeable coal ash samples decreased three times as much as that of finer, less permeable coal ash.

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- The subsurface gas measurements and concentrations of redox-sensitive constituents in field porewater samples suggest that reduction-oxidation conditions of the closed disposal impoundment were more bio-chemically reduced than indicated by porewater analysis alone. Monitoring of subsurface gas concentrations shows the presence of hydrogen sulfide and methane, indicating strongly reducing conditions. Monthly data indicate that reducing conditions are spatially variable in extent and may be seasonally dependent. In addition, arsenic concentrations in the porewater are at the high end of previously reported ranges for coal ash. At intermediate reducing conditions, elevated concentrations of arsenic are likely due to loss of hydrous ferric oxides as ferric oxides are reduced and solubilized (conversion of insoluble Fe^{3+} to soluble Fe^{2+}). Under very low redox conditions, arsenic porewater concentrations decrease due to conversion of As(V) to As(III) and likely precipitation as sulfides. Conversely, the porewater concentrations of antimony and selenium in the reduced pond environment are suppressed due to formation of reduced species with lower solubility.
- Traditional leaching tests (i.e., TCLP, SPLP, and ASTM) are poor indicators of measured porewater concentrations. Low liquid-to-solid ratio (L/S) eluates from EPA Method 1314 were better indicators than the traditional tests for concentrations for available content-limited constituents (B, Ca, Cl, Mo, SO_4, Tl) because of the strong L/S-dependence. However, additional information (e.g., available content and porewater L/S) would be needed to provide a reasonable approximation of porewater concentrations. For constituents with solubility-controlled liquid-solid partitioning (Sb, As, Ba, Cr, F^-, Se, V, Zn), pH-dependence tests (e.g., EPA Method 1313) may provide valuable information for geochemical modeling, but, for this site, the natural or own pH responses did not reliably estimate field porewater concentrations, in part due to differences in redox as noted in the next bullet.
- When the field environment is highly reducing, laboratory leaching results for redox-sensitive elements (e.g., As, Cr, Sb, Se, and Fe) do not directly reflect the leaching anticipated in porewater. This is, in part, because reduced materials collected in the field are inevitably partially oxidized during sampling, handling, and testing.
- Porewater concentrations were not a reliable indicator for which constituents would have elevated concentrations, relative to background, in downgradient groundwater or for future prediction of downgradient concentrations at this site.

WHY THIS MATTERS

This research provides a unique opportunity to compare a field porewater sample set to laboratory leaching test results on samples collected from the same location and depth interval as the porewater sampling point and provides information to guide appropriate use of these tests. It also provides information on, and comparison of, the spatial and temporal/seasonal variability in both porewater quality and laboratory leachate quality at a CCP site. Data collected during this research will inform EPRI physical and geochemical modeling of leaching within coal ash landfills and impoundments.

HOW TO APPLY RESULTS

The results of this research are site-specific, yet when considered with known differences in L/S associated with different leaching tests, and geochemical differences between the field and laboratory environment, they provide information for generalizing the best uses of different leaching tests and porewater data. Companies interested in performing similar comparisons between leaching tests and porewater will be interested in the

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field and laboratory methodologies described in Sections 2 and 3. Companies and stakeholders interpreting leaching test and porewater results will be interested in the results summarized in Sections 4 and 5, as well as the detail provided in Appendices C through G.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- A framework using geochemical modeling and porewater data to predict long-term leaching at CCP sites is being developed under EPRI Program 49A's hydrogeochemistry project. A series of reports published from 2018 through 2020 describe results of this research. These reports can be accessed by searching epri.com for "Hydrogeochemical Assessment of Long-Term Leaching Characteristics at Coal Combustion Product Sites."
- Stakeholders, including regulatory agencies, reviewing leaching test analyses may be interested in results of this research to understand the relationship between the different leaching tests, and the relationship between leaching tests and porewater within CCPs.

EPRI CONTACTS: Bruce Hensel, Principal Technical Leader, bhensel@epri.com

PROGRAM: Coal Combustion Products—Environmental Issues, PS49A

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
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ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Abbreviations and Acronyms

AMSL	above mean sea level
BGS	below ground surface
CCP(s)	coal combustion product(s)
CFR	Code of Federal Regulations
CH_4	methane gas
CO_2	carbon dioxide gas
DIW	deionized water
DIC	dissolved inorganic carbon
DO	dissolved oxygen
DOC	dissolved organic carbon
EC	electrical conductivity (mS/cm)
Eh	redox potential (mV)
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
GAP(s)	gas access point(s)
HDPE	high-density polyethylene
HFO	hydrous ferric oxides
HNO_3	nitric acid
HSA	hollow-stem auger
H_2S	hydrogen sulfide gas
H_2SO_4	sulfuric acid
IC	ion chromatography
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma – mass spectrometry
ICP-OES	inductively coupled plasma – optical emission spectroscopy

ID	internal diameter
KOH	potassium hydroxide
LEAF	Leaching Environmental Assessment Framework
LLOQ(s)	lower limit(s) of quantitation
LOI	loss on ignition
LSP	liquid-solid partitioning
L/S	liquid-to-solid ratio
MDL(s)	method detection limit(s)
NDIR	non-dispersive infrared
NH_3	ammonia gas
NIST	National Institute of Standards and Technology
OD	outer diameter
ORP	oxidation-reduction potential
O_2	oxygen gas
PAP(s)	porewater access point(s)
pe	electron concentration
PSD	particle size distribution
QA/QC	quality assurance/quality control
RCRA	Resource Conservation and Recovery Act of 1986
SU	standard unit(s)
TC	total carbon
UVA	University of Virginia (Charlottesville, VA)
VU	Vanderbilt University (Nashville, TN)
wt%	weight percent (percent by mass)
XRF	x-ray fluorescence

Groundwater/Porewater Sample Points

AD1	upgradient, background groundwater well
VB-1	porewater access point in the closed impoundment
VB-2	porewater access point in the closed impoundment
VB-3	porewater access point in the closed impoundment
6AR	downgradient compliance groundwater well

Leaching/Extraction Tests

ASTM	ASTM D3987: Practice for Shake Extraction of Solid Waste with Water
1313	EPA Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH Using a Parallel Batch Procedure
1314	EPA Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-Flow Percolation Column Procedure
1313_L/S=1	EPA 1313 modified for L/S=1 mL/g-dry and abbreviated to 5 target endpoint pH values about the own pH of the material
1313_3pt	EPA 1313 abbreviated to 3 target endpoint pH values (<2, natural pH, and 9)
SPLP	EPA Method 1312: Synthetic Precipitation Leaching Procedure
TCLP	EPA Method 1311: Toxicity Characteristic Leaching Procedure

Equation and Parameter Variables

F	Faraday constant (23,061 cal/(V mol))
MC	moisture content on a dry basis (%)
m_{wet}	mass of “wet” solid (g)
m_{dry}	mass of oven-dried solid (g-dry)
n	porosity (m^3_{pore}/m^3)
SC	solids content on a wet basis (%)
R	1.987 (cal/(K mol))
T	temperature (K)
ρ_d	dry density (mg-dry/m^3)
θ_s	saturated water content (m^3_{water}/m^3)

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1 INTRODUCTION

The appropriate use of laboratory leaching tests to describe the leaching characteristics of disposed or beneficially used coal combustion products (CCPs) is an ongoing concern. Leaching tests can provide information to estimate the release of inorganic constituents for (i) comparison of the effects of environmental conditions on leaching characteristics of a material, (ii) evaluation of the effects that chemical changes over time may have on leaching, and (iii) comparison of leaching characteristics between different materials. However, the ability of leaching test results as a tool or input used to predict field porewater concentrations is highly dependent on the intended purpose of the leaching test, the applied test conditions, individual constituent geochemistry, and the ability of the test to address the principal conditions that control leaching in the field. For example, traditional leaching tests, including EPA Method 1311: Toxicity Characteristic Leaching Procedures (TCLP), EPA Method 1312: Synthetic Precipitation Leaching Procedure (SPLP), and ASTM D3987: Shake Extraction of Solid Waste with Water (ASTM), provide only a snapshot of leaching performance under conditions that often deviate substantially from current conditions and anticipated future field conditions.

In 2012, the United States Environmental Protection Agency (EPA) published four leaching methods from the Leaching Environmental Assessment Framework (LEAF) as draft methods available for use. The four methods have since been validated (Garrabrants et al., 2012a; 2012b) and incorporated as final methods into the Agency's compendium of laboratory methods (SW-846). The four LEAF methods are:

- EPA Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH Using a Parallel Batch Procedure
- EPA Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using an Up-Flow Percolation Column Procedure
- EPA Method 1315: Mass Transport Rates of Constituents in Solid Materials Using a Tank Leaching Procedure
- EPA Method 1316: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Parallel Batch Procedure

The LEAF approach differs from traditional leaching assessment methodologies in that the leaching tests are designed to provide a series of eluates characteristic of leaching behavior dependent on one or more controlling factors rather than a single eluate that is representative of field leachate from a designed scenario. The EPA has provided a guide for how LEAF tests may be incorporated into common leaching assessment practices (EPA 2019, Garrabrants et al., 2019a, 2019b).

There remains uncertainty as to the selection of specific test methods to represent (i) the range of pH and liquid-to-solid ratio (L/S) within a waste mass and (ii) the current and long-term geochemical conditions of the porewater of CCP impoundments and landfills. Thus, leaching

tests have been widely applied, but often without consideration of their inherent limitations for providing information suitable for evaluation of long-term leaching performance. In addition, little information is available that directly compares measured field porewater concentrations at CCP disposal sites to the results of various leaching test results.

The Electric Power Research Institute (EPRI), Vanderbilt University (VU), and University of Virginia (UVA) collaborated on a study to evaluate relationships between the geochemistry of the disposed CCPs and the measured and predicted concentrations for inorganic constituents in the porewater of CCP disposal units. In addition, this study investigates the potential relationship between porewater concentrations and the concentrations in groundwater measured at adjacent monitoring wells. CCP materials were collected from two disposal sites. During field activities, porewater access and subsurface gas access points were established for eight to twelve months of monthly monitoring. Collected materials were characterized for leaching and geotechnical/hydrologic properties. A framework for integrating these data is being developed under a separate EPRI project. This report provides the methodology for sampling and characterization of disposed CCPs collected from a closed ash impoundment at Plant 42201, also referred to as "KSP." This report summarizes the results of leaching tests and monitoring data with respect to groundwater and impoundment porewater collected at the facility as well as vadose zone subsurface gas concentrations monitored within the impoundment.

Project Goals and Objectives

The goals of this research were (i) to evaluate approaches for estimating porewater concentrations at CCP disposal facilities, and (ii) to explore potential connections between the CCP leaching performance of a disposal facility, based on porewater measurements or leaching tests, and monitoring of groundwater exterior to the facility.

The specific objectives of this project include:

- Collecting field materials to qualify the spatial and temporal variability of materials disposed in the closed impoundment and to allow for characterization of leaching and geotechnical/hydrologic property determination.
- Correlating the characterization of leaching from bulk samples using traditional leaching tests (i.e., TCLP, SPLP, and ASTM) and LEAF pH- or L/S-dependence leaching tests with measured porewater concentrations monitored at the site.
- Assessing the ability of leaching tests (traditional or LEAF tests) to directly estimate porewater concentrations within the closed impoundment.
- Identifying the relationship, if any, between porewater concentrations within the closed impoundment and downgradient groundwater concentrations.

Site Description

The closed impoundment, represented in Figure 1-1a, is a triangular 25-acre area divided from a larger coal ash landfill constructed in the 1950s. The impoundment was used to collect storm water and process water from Plant 42201 before discharge into an adjacent river. Between 2012 and 2015, the impoundment received sluiced CCPs from the plant. In 2016, the inactive impoundment was closed, with the closure project completed approximately one month prior to

the field collection of field samples and establishment of groundwater sampling points. The closure project involved removal of free water from the impoundment, regrading of the coal ash to level the surface, and installation of a composite geosynthetic soil cover system as illustrated in Figure 1-1b. The cover is typically about 5 feet thick; however, the thickness of the cover system varies based on the ash layer elevations. At the time of the field investigation, phreatic porewater occurred approximately 6 feet below the surface of the ash layer. At the center of the impoundment, the ash layer is approximately 20 feet thick.

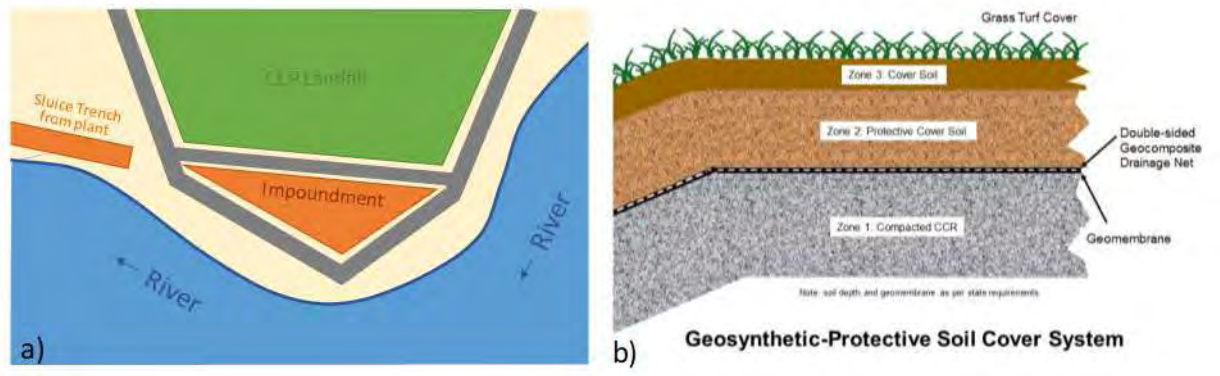

Figure 1-1
Schematic representations of the KSP closed impoundment: a) plan view of impoundment relative to the adjacent coal ash landfill and river; b) cross-section of typical geosynthetic soil cover

Sampling and Testing Approach

Fieldwork for this project included: (i) advancement of boreholes into the coal ash deposit to improve the understanding of stratigraphy and to sample contained solids (i.e., ash, cover fill, and native clay liner); (ii) installation of porewater access points (PAPs) and subsurface gas access points (GAPs) within boreholes in the ash deposit; and (iii) monthly sampling of groundwater and porewater and subsurface gas compositions. At each of three locations within the closed impoundment, bulk ash samples were collected from continuous split spoon sampling to evaluate the constituency of material in the ash deposit and leaching properties of the collected ash. In parallel, intact ash cores were collected to determine geotechnical characteristics and hydraulic conductivity of the disposed ash. At monthly intervals after the completion of initial field work, porewater was collected from each PAP along with groundwater collection at upgradient (background) and downgradient wells to provide points of comparison to porewater samples.

Characterization of leaching properties was carried out by personnel in the Department of Civil and Environmental Engineering at VU. Leaching characterization tests included EPA Method 1313 to determine leaching behavior as a function of eluate pH, EPA Method 1314 to evaluate L/S-dependent leaching from a percolation column, and a trio of single-batch extraction tests (i.e., TCLP, SPLP, and ASTM). For all leaching tests, the pH of all eluates was measured and recorded so that comparisons could be made between leaching evaluations. The reported constituents include most of those found in the Code of Federal Regulations, Title 40, Section 257 (40 CFR 257), Appendix III for detection monitoring and Appendix IV for assessment monitoring, as well as several additional constituents as listed in Table 3-3, Table 3-4, and Table

3-5 of this report. Relative to 40 CFR 257 App III and IV, a broader suite of approximately 40 constituents was quantified to provide a comprehensive basis for geochemical modeling of leaching test results. Although listed in 40 CFR 257 App III and IV, radium and total dissolved solids were not analyzed.

The geotechnical and hydrologic properties of intact core samples were determined at the School of Engineering at UVA. Hydraulic conductivity of intact samples was measured using flexible-wall permeameters following the methods in ASTM D5084. Tests were conducted over a range of effective stresses to evaluate how hydraulic conductivity varies with packing configuration and overburden found at depth. Particle size analysis was conducted on each sample using the methods in ASTM D6913 to understand how the hydraulic conductivity varies with the composition of the ash.

At UVA, a complementary series of tests to that of EPA Method 1314 was conducted on undisturbed samples collected in thin-wall sampling tubes for hydraulic conductivity testing in flexible-wall permeameters. Although the primary purpose of these tests was to measure the hydraulic conductivity of the coal ash samples, eluates collected from hydraulic conductivity testing served as a point of comparison to percolation leaching tests on composite samples according to EPA Method 1314. These tests on undisturbed samples in flexible-wall permeameters contrasted with conventional Method 1314 tests conducted on remolded (including partially oxidized) samples in rigid-wall columns, providing a direct assessment of the impacts of sample handling, column packing, and potential sidewall flow on percolation leaching. Additional discussion of these tests is included in the section on hydraulic conductivity test methods.

2
COLLECTION OF FIELD MATERIALS

Sample Locations

Ash, porewater, and gas samples were obtained at three boring locations (VB-1, VB-2, and VB-3). The approximate locations of these boreholes are shown in Figure 2-1 relative to the closed impoundment and the adjacent river. These locations were selected to be within the area of the closed impoundment and were considered to capture the vertical and horizontal heterogeneity of ash materials. When the impoundment was active, coal ash was sluiced from the main plant using process water into the impoundment near the location of VB-1. The water flowed toward VB-3 and onto the outfall to the river near location VB-2. Ash chemistry of the three locations is assumed representative of materials across the closed impoundment.



Figure 2-1
Schematic representation of the closed KSP ash impoundment, showing the approximate locations of three porewater access points (PAPs), VB-1, VB-2, and VB-3, and existing groundwater wells, 6AR and AD1 (out of frame).

Initial Site Sampling

The field sampling included continuous split spoon sampling to obtain bulk ash for leaching characterization and to provide an understanding of the ash deposit after closure, followed by discrete Osterberg sampling to obtain intact ash cores at approximate 5-ft intervals. All drilling

operations were conducted by a contracted drilling/engineering company. Prior to sampling, the top vegetation cover and geosynthetic cover in a 100-ft^2 area (10 ft by 10 ft) at each sampling location were removed by contractors. Bulk ash material was collected using 3-inch outside diameter (OD) x 24-inch long split spoons advanced through a 4.25-inch internal diameter (ID) hollow-stem auger (HSA) drilling a 9-inch diameter hole. Intact cores were collected at discrete depth intervals using thin-wall tube samplers pushed through an 8.25-inch ID HSA drilling a 13-inch hole. After the completion of the borings and installation of monitoring points, the geosynthetic cover was repaired and the cover fill replaced.

Bulk Material (Split Spoon Samples)

Split spoons were advanced from the upper cover-ash interface into the underlying native clay material (Table 2-1). Upon retrieval by the drilling contractor, each split spoon sample was opened and recorded by a licensed geologist and released to VU for documentation and collection. The borehole logs and an index with photographs of recovered split spoon material are provided in Appendix A and Appendix B, respectively. During field sampling, the activities included (i) preparation of ash extractions with de-oxygenated, deionized water (DIW) targeting an L/S of approximately 1 mL of water per estimated gram of dry ash and (ii) collection and preservation of bulk material for subsequent laboratory testing.

- L/S ≈ 1 Extractions: To protect the redox conditions of the sample and characterize the porewater composition for a screening analysis within each borehole, about 150-200 g of ash was placed into a certified, pre-tared 250-mL high-density polyethylene (HDPE) bottle (Nalgene I-Chem #N311-0250). The mass of the ash grab sample was measured and recorded. The bottle was filled with de-oxygenated DIW and weighed to quantify the mass of added water. The location of the ash grab sample within the split spoon was selected based on visual representativeness of ash.
- Bulk Ash Collection: Remaining ash from each split spoon was vacuum-sealed in plastic bags (Figure 2-2) and stored on ice for transport to the laboratory. To the extent possible, the bulk ash was maintained in its original split spoon shape and the top and bottom of the core were marked on the plastic bag.

Sample labels included “KSP” as a site identifier, the borehole number (VB-1, VB-2, or VB-3), and the depth below ground surface (BGS) from which the samples were taken. For example, the sample labeled “KSP_VB-3_15-17” in Figure 2-2 was collected from the split spoon at 15 to 17 feet BGS at borehole VB-3. For split spoons that penetrated an interface (e.g., between ash and the bottom native clay layer or between coal ash layers with visually different properties), the separate materials were collected as separate bulk samples in two vacuum-sealed bags. The upper portion was labeled with an “A” extension, while the lower portion was labeled with “B” at the same split spoon interval. All samples were preserved in coolers with ice and transported to the VU lab within 48 hours. During transport, the cooler temperature was monitored and recorded by an Elitech RC-5 USB temperature data logger. At the VU lab, all bulk materials were stored in an environmentally controlled room at 5 °C prior to processing for leaching tests.

a) 

b) 

Figure 2-2
Examples of split spoon cores: a) as recovered and photo-documented and b) vacuum-sealed bulk sample from borehole VB-3 (KSP_VB-3_15-17) preserved for testing

A schematic summary of the split spoon samples and the numbers of total samples preserved at each location are shown in Figure 2-3. In this figure, the depths BGS for each sample have been converted to elevations in feet above mean sea level (AMSL) after surveying of the PAP casings and ground elevations.

Intact Cores (Tube Samples)

Immediately following completion of the continuous split spoon borehole, the drilling rig was moved forward in its tracks 5 feet to advance an 8.25-inch HSA for push core sampling of ash. At each boring location, 3-inch OD by 36-inch long thin-wall tube samplers were pushed into the ash layer and obtained intact cores at intervals according to the observations from split spoon boring. The locations of the cores were targeted to collect samples across interfaces with the cover material and clay liner as well as major ash deposits within the ash column. Each recovered thin-walled tube was sealed at both ends using plastic expanding inserts, capped with plastic endcaps, and sealed with duct tape. The thin-walled tubes were vacuum-sealed in plastic bags and kept upright for transport. Sample identification was based on the interval BGS from which the samples were recovered. For example, the tube sampler recovered from the interval from 12 to 14.5 feet BGS at borehole VB-1 was labeled "VB-1_OST_12-14.5." The associated elevations for the three tube samples collected at each borehole are summarized in Table 2-1.

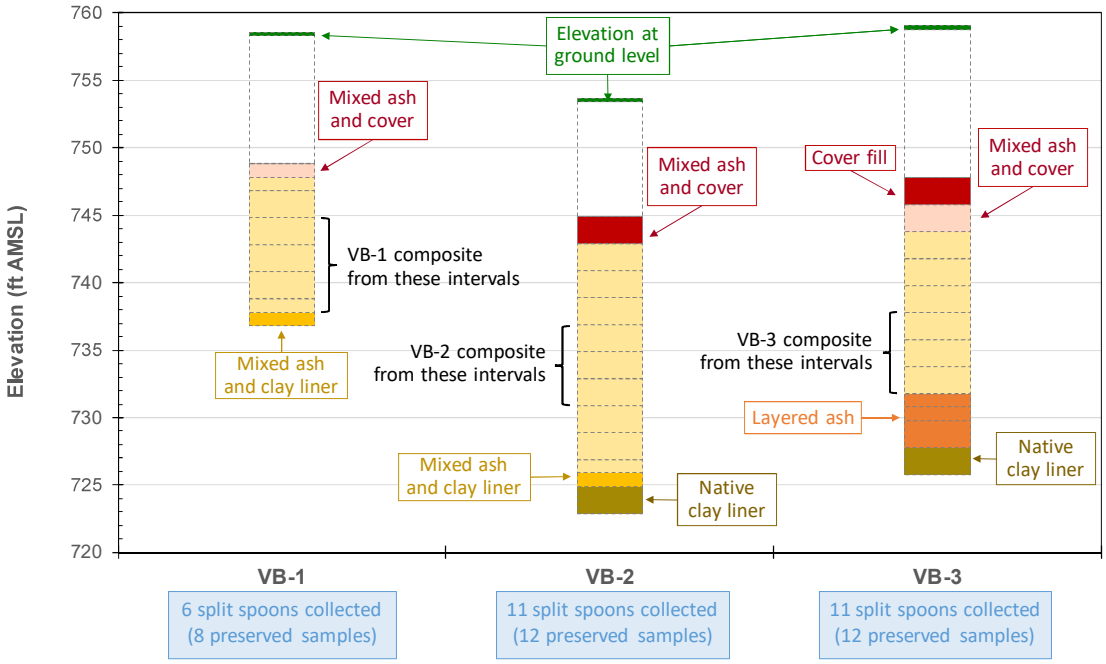

Figure 2-3
Collection of bulk material samples by split spoon, showing bulk samples composited around well screening levels

Porewater Access Points

Once the 8.25-inch ID HSA was advanced to the target depth for placement of the PAP, a 2-inch OD Schedule 40 PVC pipe was installed through the HSA. At each well location, the contractor installed a pre-packed, 2-foot screened section in agreement of the field team leads for VU, EPRI, and KSP after review of saturated zone observed for the continuous sampling borehole. Each 13-inch diameter borehole was backfilled with 1 foot of clean sand before the well screen was set, and after setting the screen, was backfilled with sand to 2 feet above the top of the well screen. The sand pack was sealed with bentonite clay pellets, and bentonite chips were used to backfill the borehole to within ½ foot of the GAP depth. Boring logs are presented in Appendix A.

Subsurface Gas Access Points

The composition of subsurface gas within the ash pond was sampled through GAPs set between 2 and 3 feet below the top of the ash deposit. Each GAP consisted of a ¼-inch diameter stainless steel tube set at depth within a 1-foot thick layer of round river rock and sealed from above and below with a 1-foot thick layer of expanded bentonite clay. The lower end of the GAP tubing was protected from rock, ash, and clay debris with an inverted steel cup. The stainless steel tubing was zip-tied to the PVC well and finished with a 2-way shutoff valve. The bed of river rock, nominal size of between ¾ inch and ¼ inch, ensures sufficient subsurface gas volume for measurement. A conceptual diagram and photograph are presented in Figure 2-4.

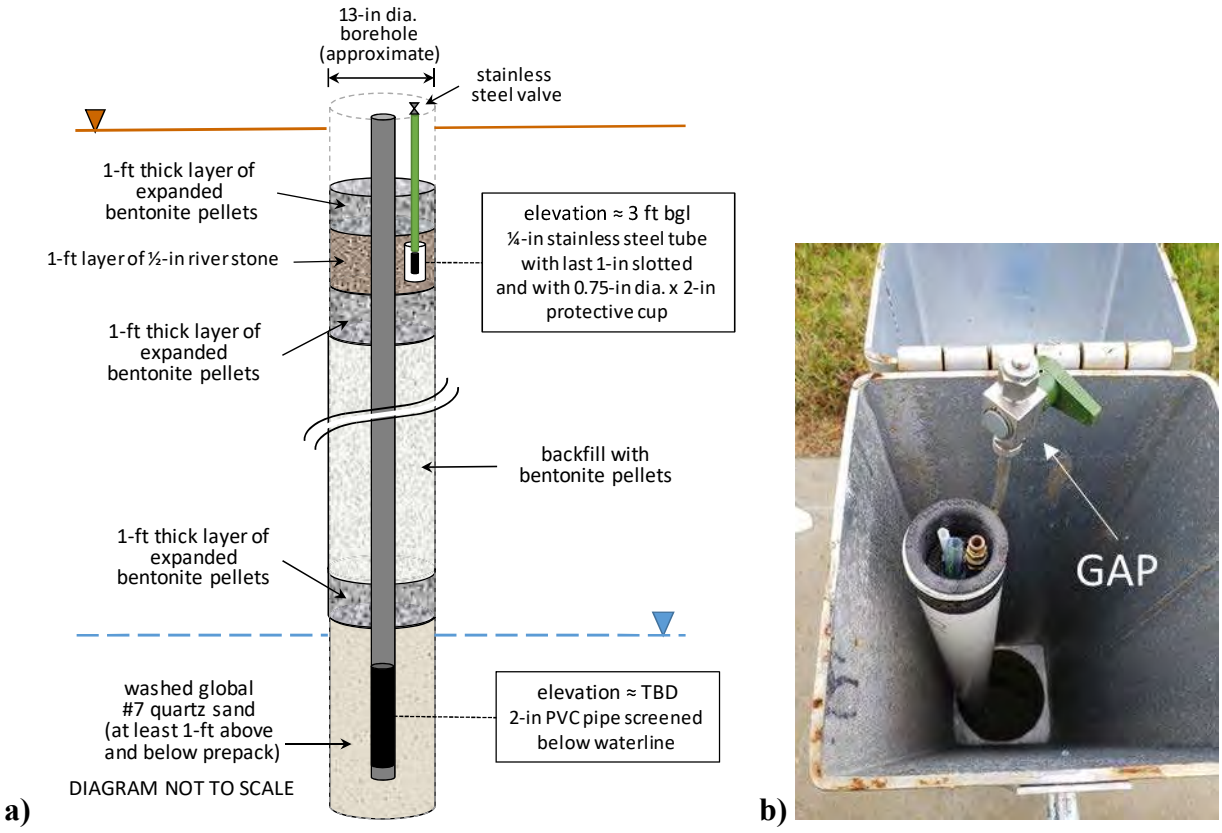

Figure 2-4
Porewater and gas access points: a) conceptual design of PAP and GAP installation and b) picture of installed PAP and GAP within a metal riser

Summary of Borehole Stratigraphy, Ash Collection, and PAP/GAP Installation

Within two weeks of field sampling, the drilling contractor installed dedicated pumps, developed the wells, and protected the borehole locations with a metal riser and concrete base. As part of this process, the horizontal location of the PVC riser, as well as the elevations of the well riser and ground level, were surveyed by a professional land surveyor. A summary of the elevation survey results and elevation of pertinent strata and sampling locations for the VB-1, VB-2, and VB-3 boreholes are tabulated in Table 2-1 and presented graphically in Figure 2-5 along with the stratigraphy for the upgradient background well (AD1) and downgradient compliance well (6AR).

Table 2-1
Elevations Above Mean Sea Level (AMSL) for KSP Boreholes Including the Range of Continuous Bulk Ash Sampling and Discrete Tube Samples

	VB-1	VB-2	VB-3
	Elevation (ft AMSL)	Elevation (ft AMSL)	Elevation (ft AMSL)
Top of Well Casing	761.60	756.78	762.04
Ground Level	758.3	753.4	758.8
Cover Fill Interface	748.8	744.9	753.8
Top of Ash Bed	748.8	743.9	745.4
GAP Placement	746.3	741.4	743.8
Water Level	742.3	741.9	738.8
PAP Well Screen	738.8 to 740.8	733.4 to 735.4	733.8 to 735.8
Bottom of Ash Bed	737.3	725.6	731.3
Clay Liner Interface	737.3	725.6	728.0
Bulk Ash Samples	737.8 to 747.8	725.9 to 744.9	731.8 to 747.8
Tube Sample #1	748.3 to 750.3	744.4 to 746.4	738.8 to 741.8
Tube Sample #2	743.8 to 741.3	737.9 to 739.9	731.8 to 734.8
Tube Sample #3	738.8 to 741.3	731.9 to 734.9	-

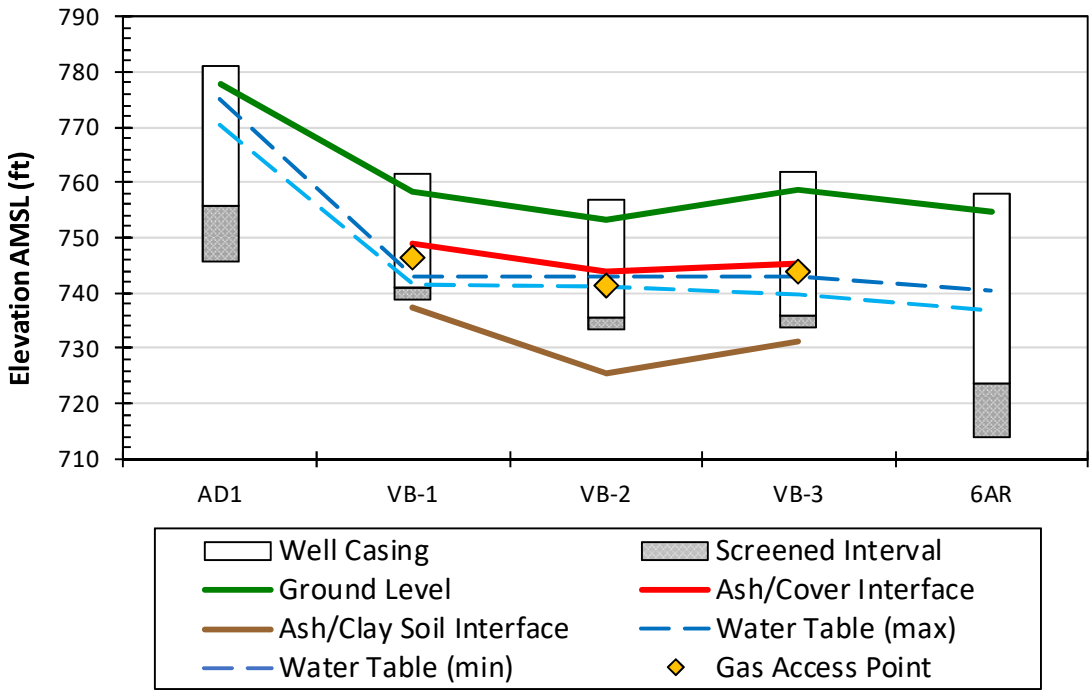

Figure 2-5
Summary of the groundwater well and PAP elevations including pond stratigraphy and location of GAPs

Monthly Field Monitoring

Porewater and subsurface gases were monitored monthly at each PAP location over a 13-month period from September 2018 through September 2019. In addition, groundwater samples were analyzed from one upgradient (AD1) and one downgradient (6AR) monitoring well.

Collection of Groundwater and Porewater

Figure 2-1 shows the relative locations for the three installed PAPs (VB-1, VB-2, and VB-3) and the two existing groundwater sampling wells. Although the location of the upgradient well (AD1) is out-of-frame relative to this figure, the general direction of the well is indicated. KSP field personnel accessed each well, stabilized the well using low-flow sampling techniques according to company standard operating procedures, and allowed the VU field team access to the effluent line for collection of groundwater and porewater samples. At no time did the site owners' personnel retain custody of any samples used for this analysis.

The sampling flowrates for groundwater wells averaged approximately 150 mL/min and 300 mL/min for AD1 and 6AR, respectively. Porewater was sampled at approximately 50 mL/min to minimize drawdown of the water level in each PAP. At 5-minute intervals, the pH, dissolved oxygen (DO), electrical conductivity (EC), oxidation-reduction potential (ORP), temperature, and turbidity of the sampled water were measured through a multi-parameter sonde and separate turbidity meter, while water level was measured with a portable electronic water level meter. All measured parameters were recorded by KSP field personnel. The criteria used to determine well stability were (i) turbidity less than 10 NTUs and (ii) pH stable within 0.1 standard unit over three consecutive 5-minute readings.

Groundwater and porewater samples were collected in 50-mL SCP Science Digitubes including duplicate samples collected for anion analysis via ion chromatograph (IC) and duplicate samples collected for metals and other cation analysis via inductively coupled plasma (ICP) techniques (see *Chemical Analysis of Eluates, Groundwater, and Porewater* for details). Samples for ICP analysis were preserved in the field by addition of 1.5 mL of Tracemetal® grade nitric acid (3% total acid addition) using a 100-1000 µL Oxford Benchmate manual pipette and disposable tips. A set of four samples was collected unfiltered followed by a set of samples passed through a Quickfilter, 609 cm^2, 0.45-mm inline filter. In total, eight 50-mL Digitubes were collected at each sampling location. All liquid samples were stored in a cooler of ice with an Elitech RC-5 USB temperature data logger to record the temperature within the cooler. Samples were transported by the field team to VU for immediate storage at 5 ºC prior to analysis.

Subsurface Gas Monitoring

A description of the monitoring process for subsurface gas and a picture of gas monitoring apparatus are provided in Section 3.

3
LABORATORY MATERIALS AND METHODS

The follow sections include brief descriptions of the laboratory test methods and analytical methods used in this study. Also included are the quality assurance/quality control (QA/QC) samples and criteria for each analytical method.

Collected Materials

Materials recovered during initial sample collection from the ash deposit included bulk samples from split spoons and intact cores contained in thin-wall tubes. Processing of bulk material for leaching tests included (i) homogenization within each split spoon sample and (ii) compositing samples near the screening level.

Subsampling and Homogenization of Bulk Samples

Homogenized split spoon samples were used to evaluate the vertical and horizontal variability of ash deposits and provide materials for developing a representative composite for characterization of leaching parameters to be compared to monthly porewater monitoring. Each recovered split spoon sample was removed from its vacuum-sealed bag and bisected along the longitudinal axis as shown in Figure 3-1a. If the structure of split spoon material was not intact, the preserved sample was bisected vertically along the axis of the plastic bag Figure 3-1b. One-half of the material was immediately vacuum-sealed into a plastic bag and stored in the environmentally controlled room at 5 ºC for future use.

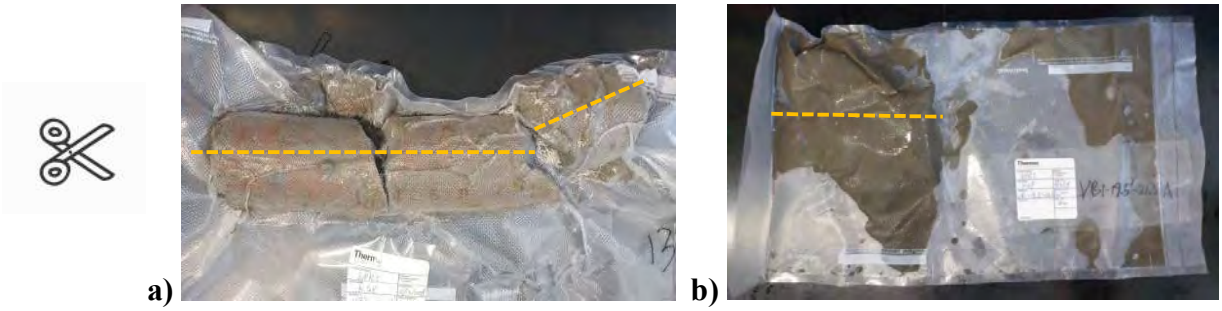

Figure 3-1
Schematic showing bisection of a) structurally sound split spoon material and b) bulk split spoon material

The remaining half of the split spoon material was placed in a plastic bag and sealed with lab tape to minimize exposure to air. This material was crushed with a rolling pin and homogenized by hand through the plastic bag until the contents were well mixed. This homogenized material was used as test material (i) in laboratory L/S=1 extractions for comparison to field L/S~1 extractions and (ii) for limited pH-dependence leaching methods to evaluate vertical heterogeneity within borehole samples.

Borehole Composite Materials

Homogenized split spoon material was used to develop a composite test material that would be representative of the bulk ash deposited near the screened interval of the PAP for each borehole. Table 3-1 shows the split spoon samples used to create each borehole composite sample. The selection of these intervals was based on the evaluation of laboratory L/S=1 extractions and considering the mass of composite that would be required to complete the testing program.

Table 3-1
Intervals (BGS) and Elevations (AMSL) of Split Spoon Samples Used in Borehole Composites

VB-1		VB-2		VB-3	
Interval (ft BGS)	**Elevation (ft AMSL)**	**Interval (ft BGS)**	**Elevation (ft AMSL)**	**Interval (ft BGS)**	**Elevation (ft AMSL)**
PAP Screen	740.8-738.8	PAP Screen	735.4-733.4	PAP Screen	735.8-733.8
13.5-15.5	744.8-742.8	16.5-18.5	736.9-734.9	21-23	737.8-735.8
15.5-17.5	742.8-740.8	18.5-20.5	734.9-732.9	23-25	735.8-733.8
17.5-19.5	740.8-738.8	20.5-22.5	732.9-730.9	25-27	733.8-731.8
19.5-21.5 (A)	738.8-737.3	-	-	-	-

The material was composited by mixing equal dry mass equivalents (i.e., the mass of "as received" material that equates to a prescribed mass of dry material) from each homogenized split spoon in a plastic bag. For VB-2 and VB-3 composites, each of three split spoons was used with 450 g-dry taken from each sample. However, for the VB-1 composite, there was not enough material in the three split spoons nearest the well screen, so a fourth split spoon was included with 250 g-dry taken from each homogenized split spoon sample. The plastic bag was sealed with lab tape to minimize air exposure and the composited material was homogenized by hand through the plastic bag until well mixed. This composited sample was used for total content analysis and characterization using LEAF leaching tests and traditional leaching tests (i.e., ASTM, TCLP, and SPLP).

Material Properties

Total Content by EPA Method 3052

The total elemental content of composite samples was determined by acid digestion following EPA Method 3052 with subsequent analysis of the digestate by Eurofins TestAmerica (Nashville, TN). According to the Method 3052, a solid sample of up to 0.5 g (wet) is digested in 9 mL of nitric acid and 3 mL of hydrofluoric acid for 15 minutes in a microwave to accelerate the digestion reactions. Addition acid and reagent combinations, including hydrochloric acid and hydrogen peroxide, are added to ensure that the solid is dissolved. The microwave temperature profile includes reaching 180 ± 5 ºC in approximately less than 5.5 minutes and remaining at 180 ± 5 ºC for 9.5 minutes for the completion of specific reactions. After cooling, the vessel contents were centrifuged and decanted. The small volume of remaining digestate was diluted to a volume of 100 mL and chemically analyzed. Inductively coupled plasma-optical emission

spectrometry (ICP-OES) following EPA Method 6010B was used to determine digestate concentrations for Ag, Al, As, Ba, Be, Ca, Cd, Cr, Co, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, Pb, Sb, Se, Sr, Ti, V, and Zn. Mercury in digestates was measured by using cold vapor atomic absorption following EPA Method 7470A. The total content (mg/kg) is calculated by multiplying the concentration measured in the digestate (mg/L) by the L/S of the extraction procedure (L/g). For this study, the resultant total content is effectively on a dry mass basis (mg/kg-dry) because the material submitted to the laboratory for testing was oven dried.

X-Ray Fluorescence Analysis

The elemental composition of coal ash samples was determined at UVA using x-ray fluorescence (XRF) quantitative analysis on an Epsilon 3X energy-dispersive XRF spectrometer (PANalytical, Malvern, UK) with a silver anode X-ray tube and 50-micron beryllium window. Five-gram subsamples of coal ash were taken from the undisturbed core samples, air-dried for 24 hours at room temperature, and ground by hand to less than 0.075 mm using an agate mortar and pestle. For analysis, ground samples were packed into an 18-mL sample cup (28 mm ID x 30 mm). Each subsample was analyzed in duplicate following ASTM 8064-16 for the XRF analytical method of silicate rocks.

Loss on Ignition

Loss on ignition (LOI) was measured at UVA for subsamples of undisturbed coal ash to quantify total organic matter content. LOI was conducted in accordance with ASTM D2974-14 by sintering a pre-weighed sample at 550 °C using a Lindberg/Blue M 1200 ºC box furnace (ThermoFisher Scientific, Waltham, MA). The mass lost during sintering was associated with the total organic matter.

Moisture Content

As part of the leaching test characterization using the LEAF methods, the moisture content of each study material was determined following ASTM D2216-19. Moisture content on a dry mass basis was calculated as the difference in the mass of a “wet” subsample compared to the sample after oven-drying to constant mass at 105 ± 5 ºC. The solids content is defined as the mass of solid material in an “as-tested” or “wet” subsample, measured on a “wet” basis. The determination of moisture content and solids content provides uniform bases for reporting of total content and leaching behavior results, allowing for comparison between moist and dry materials.

Porosity or Saturated Volumetric Water Content

Dry density (ρ_d) and porosity (n) of each material were determined at UVA using weight-volume computations, following the procedure in ASTM D7263-09. Under saturated conditions (i.e., when all voids are filled with water), the saturated volumetric water content (θ_s) equals the porosity.

Particle Size Distribution

Particle size distribution (PSD) of each coal ash sample was determined at UVA by a combination of mechanical analysis following ASTM D6913-17 and sedimentation analysis

following ASTM D7928-17. For mechanical analysis, a 100-g sample was oven-dried at 110±5 °C and passed through a series of US standard sieves: No. 10 (2 mm), No. 20 (0.85 mm), No. 60 (0.25 mm), No. 100 (0.15 mm), and No. 200 (0.075 mm). The fraction of the 100-g mass retained on each sieve was measured gravimetrically. Particle size distribution of the fraction coarser than the No. 200 sieve (0.075 mm) was calculated as the weight of solid retained on each sieve.

For sedimentation analysis, 50 g of dry solid that had passed the No. 200 (0.075 mm) sieve was soaked in 4% sodium metaphosphate, $(NaPO_3)_6$, solution for 12 hours and then transferred to a 1-L graduated cylinder. The graduated cylinder was capped, then agitated end-over-end for 60 seconds, and then settling of particles was monitored using a hydrometer. Stokes' law was used to compute the PSD from the hydrometer data for the fraction of particles finer than the No. 200 sieve.

Saturated Hydraulic Conductivity

Hydraulic conductivity tests were conducted in flexible-wall permeameters following the methods in ASTM D5084-16. Sections of undisturbed coal ash were extruded from the 73-mm ID, thin-wall sampling tubes (Figure 3-2) and cut into 76-mm long specimens. Non-woven geotextile disks and porous stones were placed on both ends of each coal ash specimen (Figure 3-3a) to ensure uniform flow distribution and to retain particles. Specimens were wrapped in a latex membrane and placed into a flexible-wall permeameter (Figure 3-3b).

In lieu of the more traditional tap water or 0.01 M $CaCl_2$ solution suggested in ASTM D5084, DIW was used as the permeant solution to ensure that the water entering the specimen had no ionic species that might alter the hydraulic conductivity or the leachable constituents in the coal ash. Effluent from the permeameter was collected following the procedure in ASTM D7100-11. Effluent samples were collected from the tests and stored in Teflon sample bottles with minimal headspace. Effluent samples were shipped under chain of custody to VU for chemical analysis.

The falling headwater-constant tailwater method was used with an average hydraulic gradient of 15. No backpressure was applied to simulate field conditions and to minimize alterations in geochemistry. All tests were conducted at an initial effective stress of 20 kPa and continued until the hydraulic conductivity reached hydraulic equilibrium as defined in ASTM D5084 (steady hydraulic conductivity, incremental outflow divided by inflow was constant within 1.0 ± 0.25). At the conclusion of the test, weight-volume calculations were used to determine that all specimens were fully saturated during testing.

After testing at 20 kPa was complete, three specimens, representing coarser, finer, and mid-range particle size distributions, were consolidated to 100 kPa and permeated again until hydraulic equilibrium was established (steady hydraulic conductivity, steady flow ratio 1.0 ± 0.25). The initial stress (20 kPa) was selected to replicate the stress condition of the coal ash with a burial depth of 1 m in the basin. The consolidation/permeation procedure was repeated at consolidation pressures of 250, 400, and 500 kPa to simulate stress at greater depths within the basin. The highest stress (500 kPa) corresponded to a depth of approximately 35 m. Effluent samples from these higher-stress experiments were not collected or chemically analyzed.

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Figure 3-2
Extrusion of undisturbed coal ash sample from a thin-wall sampling tube conducted at UVA

a) 

b) 

Figure 3-3
Hydraulic conductivity test specimen and permeameter setup: a) test specimen (brown, gray cylinder) between two geotextile filter disks (thin black disks) and two porous stones (blue-gray disk on each end); b) test specimen installed in flexible-wall permeameter

Traditional Extraction Tests

EPA Method 1311 – Toxicity Characteristic Leaching Procedure

EPA Method 1311, or TCLP, is a single-point batch leaching test used to determine the toxicity characteristic of a material and the disposal options for a material under the Resource Conservation and Recovery Act of 1986 (RCRA). At the time of test development, TCLP was designed to simulate eluate concentrations for a plausible mismanagement scenario where hazardous waste is disposed in a municipal solid waste landfill. Thus, a solution of acetic acid in DIW is the extraction fluid to represent the primary acidity in municipal solid waste landfill leachate. Selection of an extraction fluid is based on a pretest of the buffering capacity of a test sample for acetic acid. Extraction Fluid #1 is dilute acetic acid buffered at a pH of 4.93 ± 0.05 with sodium hydroxide, while Extraction Fluid #2 is dilute acetic acid at a pH of 2.88 ± 0.05 without added base. The test-specific L/S of 20 mL/g is based on a filtered sample after pressure filtration at 15 psi. Since the filtered solid may still contain moisture, the final dry-basis extraction L/S is typically greater than 20 mL/g-dry. The filtrate from pressure filtration was preserved and chemically analyzed in parallel to TCLP extracts.

For this study, 80 grams of filtered solid was mixed with 160 mL of Extraction Fluid #1 and tumbled at 28 ± 2 rpm for 18 ± 2 hours. Although not specified in the method, the pH of the final eluate was measured and recorded so that test results could be compared to other leaching methods. The eluate from the extraction was pressure-filtered through a 0.22-µm borosilicate glass fiber filter and preserved for analysis. Filtrate from pressure filtration and the extraction eluate were analyzed separately and an "effective" extraction concentration was calculated for each constituent as a volume-weighted average concentration of the two liquids. For QA/QC purposes, a method blank, with the filter paper and extraction fluid only, and a duplicate sample for VB-2 were conducted in parallel using the same reagents.

EPA Method 1312 – Synthetic Precipitation Leaching Procedure

EPA Method 1312, or SPLP, is a single-batch leaching test used to evaluate the leaching behavior of a waste material in contact with acidic rain. The test is performed in the same manner as in the TCLP, but with extraction fluids of 60/40 weight percent (wt%) sulfuric acid (H_2SO_4) and nitric acid (HNO_3) in DIW (Extraction Fluids #1 and #2) or DIW (Extraction Fluid #3). The selection of extraction fluid depends on the location of the site under investigation and the constituents being tested. Extraction Fluid #1 is used for sites east of the Mississippi River, Extraction Fluid #2 is used for sites west of the Mississippi River, and Extraction Fluid #3 is used only when cyanides or volatiles are to be analyzed.

For these tests, 100 grams of filtered solid was mixed with 160 mL of Extraction Fluid #1 and tumbled at 28±2 rpm for 18±2 hours. Although not specified in the method, the pH of the final eluate was measured and recorded so that test results could be compared to other leaching methods. The eluate from the extraction was pressure-filtered through a 0.22-µm borosilicate glass fiber filter and preserved for analysis. Filtrate from pressure filtration and the extraction eluate were analyzed separately and an "effective" extraction concentration for each constituent was calculated as a volume-weighted average of the two liquids. A method blank—extraction fluid with no solid carried through the test process—and a duplicate sample for VB-2 were analyzed.

ASTM D3987 – Shake Extraction of Solid Waste with Water

ASTM D3987-12, or ASTM, is a single-point extraction test that is used to estimate leaching concentrations when no acid or base is added to the extraction. Since the method is patterned after TCLP, the procedure is similar to the EPA method; however, DIW is used as the extraction fluid.

For these tests, a subsample of ash (70±0.1 g) was tumbled at 28±0.2 rpm with DIW at an L/S of 20 mL/g for 18±0.25 hours. After tumbling, the extract was separated from the solid by vacuum filtration through a 0.45-m polypropylene membrane and the pH of the final eluate was measured and recorded. Reagent and method blanks were analyzed, and a duplicate test was conducted on the VB-3 sample.

Leaching Environmental Assessment Framework (LEAF) Test Methods

EPA Method 1313 – Liquid-Solid Partitioning as a Function of Eluate pH Using a Batch Extraction Procedure

EPA Method 1313 is standardized, parallel batch extraction method used to evaluate the liquid-solid partitioning (LSP) of inorganic constituents as a function of eluate pH. The general procedure consists of nine batch extractions of a particle-size reduced subsample material that is contacted with leaching solution at an L/S of 10 mL/g-dry material and tumbled end-over-end over a specified contact interval. The leaching solution is DIW with additions of HNO_3 or potassium hydroxide (KOH) to adjust the final pH of the eluate to a target of nine specific pH values (i.e., pH values of 2, 4, 5.5, 7, 8, 9, 10.5, 12, and 13). An additional extraction without addition of acid or base was carried out to measure constituent leaching at the natural pH of the material.[1] After 24 hours of tumbling, the contact time associated with a sample particle size of 85 wt% less than 300 µm, the solid and liquid phases were separated by settling or centrifugation, and the pH, EC, and ORP of the clarified eluate were measured. The remaining slurry was vacuum-filtered through 0.45-µm pore size membranes prior to chemical analysis by ICP-OES, IC, and carbon analysis.

EPA Method 1313 provides (i) a titration curve of the pH response to additions of acid or base, (ii) the available content of constituents in the solid material, and (iii) the LSP curve for constituents over the tested pH range. Furthermore, the results of EPA Method 1313 are suitable for use in geochemical speciation modeling for the estimation of the solid phase mineralogy and surface chemistry that controls constituent release.

Variants of EPA 1313 Methods

In this program, the full EPA 1313 method and variants of EPA 1313 were carried out on ash materials for different purposes:

- An abbreviated, 3-point EPA 1313 (1313_3 pt) was conducted on two homogenized samples of individual split spoon samples from each borehole. Since the natural pH of the CCP

[1] The "natural pH," sometimes referred to as "own pH," is defined as the eluate pH in response to extraction in deionized water (i.e., no acid or base added) at an L/S of 10 mL/g-dry. To distinguish the natural pH at L/S=10 mL/g-dry (Method 1313 or 1313_3pt) from the pH response to DIW at L/S of 1 mL/g-dry measured using 1313_L/S=1, the former will continue to be called with "natural pH" while latter will be referred to as "own pH."

materials was expected to be near neutral, the pH targets selected included $1.5 \leq pH \leq 2$, the natural pH, and pH=9.0±0.5. The pH targets near pH 2.0 and 9.0 are useful for determining the available contents of cationic and oxyanionic constituents, respectively. The results of these 3-point pH-dependence tests on individual split spoon samples were compared to the full-range EPA 1313 of composite samples as an indicator of vertical heterogeneity within a borehole.

- EPA 1313 was carried out on composited ash samples from each borehole but using an L/S of 1 mL/g-dry and abbreviated to the natural pH and two pH targets on either side of the natural pH, for five pH values in total. This modified 1313 test, referred to as 1313_L/S=1, was used to evaluate how changes in L/S may influence LSP concentrations and to provide verification data for development of geochemical speciation models.

EPA Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio Using a Percolation Column Procedure

EPA Method 1314 is a standardized, up-flow column procedure used to evaluate release of inorganic constituents from percolating solid materials as a function of cumulative L/S (i.e., the volume of liquid that passes through the column relative to the dry mass of material in the column). In this study, EPA 1314 was used to characterize the L/S-dependent leaching of constituents in 250-400 g-dry composited ash samples (e.g., VB-1, VB-2, and VB-3). A 5-cm diameter by 30-cm glass column was packed with coal ash in a series of five lifts with moderate tamping between lifts. DIW was used as the eluent solution since CCPs in general have relatively low organic carbon and clay contents compared to soils. The eluent was pumped at a flow rate of 0.75±0.25 L/S per day through the column in an up-flow direction to minimize air entrapment and flow channeling. Eluates were collected at predetermined cumulative L/S values (i.e., 0.2, 0.5, 1, 1.5, 2, 2.5, 4.5, 5, 9.5 and 10 mL/g-dry). For each eluate fraction, the pH and conductivity were recorded prior to filtration and preservation for chemical analysis. To present the results, the concentrations of constituents in the eluates (mg/L) as well as the cumulative release through the end of each eluate fraction (mg/kg-dry) were plotted as functions of L/S in separate graphs.

Comparison of Leaching Test Parameters and Conditions

All leaching tests conducted for this program are designed to measure the LSP of constituent release from a material under the specified test conditions shown in Table 3-2. TCLP, SPLP, and ASTM are single-batch leaching tests. Similarly, the EPA 1313 test and its variants are batch procedures, but with parallel extractions to provide data over a range of test conditions. These batch tests, however, differ in the chemical makeup of extraction fluid as well as in the specified L/S. Moving from left to right in Table 3-2, the leaching test conditions are presented in order of decreasing L/S from left to right. In the last column are the test conditions for EPA 1314, designed to measure LSP as a function of cumulative L/S.

Table 3-2
Leaching Test Parameters and Test Conditions

Parameter	TCLP	SPLP	ASTM	1313	1313_3-pt	1313_L/S=1	1314
Method Type	Single-batch	Single-batch	Single-batch	Parallel batch	Parallel batch	Parallel batch	Column
Number of Eluates	1	1	1	9	3	5	9
Extraction Fluid	Acetic acid in DIW	H_2SO_4/HNO_3 in DIW	DIW	HNO_3 or KOH in DIW	HNO_3 or KOH in DIW	HNO_3 or KOH in DIW	DIW
Extraction Fluid pH	#1: 4.93 ± 0.05* #2: 2.88 ± 0.05	#1: 4.20 ± 0.05* #2: 5.00 ± 0.05 #3: DIW	-	-	-	-	-
L/S	20 mL/g-filtered	20 mL/g-filtered	20 mL/g-wet	10 mL/g-dry	10 mL/g-dry	1 mL/g-dry	0.2-10 mL/g-dry (cumulative)
Eluate pH	-	-	-	<2, 4, 5.5, 7, 8, 9, 10.5, 12, 13, natural pH	<2, 9, natural pH	5.5, 7, 8, 9, own pH	based on solid buffering capacity
Eluate Filtration	0.22-µm via pressure	0.22-µm via pressure	0.45-µm via vacuum	0.45-µm via vacuum	0.45-µm via vacuum	0.45-µm via vacuum	0.45-µm via vacuum
Eluate Measurements	pH, EC	pH, EC	pH, EC	pH, EC, ORP	pH, EC, ORP	pH, EC, ORP	pH, EC, ORP
Reagent Blank	No	No	Yes	No	No	No	Yes
Method Blank	Yes	Yes	Yes	Yes	Yes	Yes	No
Duplicate Test	VB-2	VB-2	VB-2	None	None	None	None
Chemical Analysis	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC	ICP-OES/MS	ICP-OES/MS DIC/DOC IC	ICP-OES/MS DIC/DOC IC
Samples Tested	VB-1, VB-2, VB-3 composites	VB-1, VB-2, VB-3 composites	VB-1, VB-2, VB-3 composites	VB-1, VB-2, VB-3 composites	2 individual split spoons per borehole	VB-1, VB-2, VB-3 composites	VB-1, VB-2, VB-3 composites

Note: * indicates the TCLP and SPLP extraction fluids used for these tests.

Chemical Analysis of Eluates, Groundwater, and Porewater

Eluate pH

Eluate pH was measured on all aqueous extracts following EPA Method 9040C using an Accumet XL20 meter and a combined pH electrode on approximately 5 mL of eluate. Prior to testing, the electrode was calibrated with two National Institute of Standards and Technology (NIST) traceable pH buffer solutions that bounded the anticipated range of pH to be measured. A third mid-range NIST buffer was used to verify the calibration.

Specific Conductance

Specific conductance, or EC, is a measure of the ability of an aqueous solution to carry an electrical current. The property is dependent on (i) the presence of ions; (ii) total concentration, mobility, and variance of ions in solutions; and (iii) the temperature of the measurement. Conductivity of all leaching test eluates was determined following EPA Method 9050A using a standard conductivity probe calibrated to an appropriate standard conductivity solution for the conductivity range of concern.

Oxidation-Reduction Potential

ORP is a voltage differential related to the redox state of a solid-liquid solution and its effect on chemical composition (e.g., reduced/oxidized iron, dissolved oxygen, biological activity). ORP voltage of all eluate solutions was measured with a probe, consisting of a platinum electrode and a reference electrode, placed in contact with the soil solution. In laboratory tests, the ORP voltage reading was converted to redox potential (Eh) by addition of a probe-specific correction factor of 228 mV at 25 °C. In field measurements, however, the probe correction factor was automatically compensated for by the instrument and are output as Eh values.

Since, redox reactions vary with pH and the mineral species present, redox is parameterized in geochemical modeling as the pH+pE, where pE is the negative logarithm of the free electron concentration, or –log([e^-]). The corrected Eh values of leachates and eluates were converted to a pE value using the following equation:

$$pE = \frac{F}{2.303RT}(Eh/1000)$$

where F is the Faraday constant (23,061 cal/(V mol)),

Eh is the redox potential of the solution (mV),
2.303 is a conversion (ln[e^-]/2.303 log[e^-]),
R is the gas constant (1.987 cal/(K mol)),

T is the temperature (K), and

1000 is a unit conversion (1,000 mV = 1 V).

Inductively Coupled Plasma Spectrometry

The eluate concentrations of trace elements and material major species (e.g., Al, Ca, Si) were determined using a combination of ICP-OES and inductively coupled plasma – mass

spectrometry (ICP-MS). The choice of instrumentation was determined based on detection limits, expected concentrations, and environmental threshold values. Table 3-3 provides the method detection limits (MDLs) and lower limits of quantitation (LLOQs) used in this project along with the working ranges for each constituent.

Major species and trace elements present at higher concentrations were determined using a Varian Model 720-ES ICP-OES (Agilent Technologies, Santa Clara, CA) following EPA Method 6010D. The ICP-OES was calibrated to a 5-point standard curve with an analytical range of 25 to 25,000 µg/L. For some high-concentration trace elements, the standard curve was extended up to 500,000 µg/L using a 7-point standard curve. For low-level trace analysis, concentrations were determined by ICP-MS using a Perkin Elmer Elan DRC II (Perkin Elmer, Waltham, MA) following EPA Method 6020A. The ICP-MS was calibrated to a 5-point standard curve with range between approximately 1 and 250 µg/L and extended with a 7-point curve to 1,000 µg/L for some constituents.

Analytical QA/QC included initial and continuing calibration checks and blanks, matrix spikes, and method blanks. Calibration check standards and matrix blanks were evaluated every 10 to 20 samples with the requirements that check standards were within 15% of the specified value and blanks were below LLOQs. Matrix spikes were required to have recoveries within 20% of the calculated concentration considering the spiked mass. Initial and continuing calibration check standards for ICP-OES and ICP-MS were 0.5 mg/L and 0.050 mg/L, respectively. Analyte concentrations measured at less than the MDL were reported as <MDL and graphed at one-half the MDL values to indicate that the measurement was conducted. Analytical results measured at less than the LLOQ but greater than the MDL are estimated values.

Table 3-3
Methods, MDLs, and LLOQs for Analysis of Eluates by ICP-OES and ICP-MS

Analyte	Symbol	Method	MDL (mg/L)	LLOQ (mg/L)
Aluminum	Al	ICP-OES	0.0034	0.025
Antimony	Sb	ICP-MS	0.00008	0.001
Arsenic	As	ICP-MS	0.00057	0.001
Barium	Ba	ICP-OES	0.0016	0.005
Beryllium	Be	ICP-MS	0.00042	0.001
Boron	B	ICP-OES	0.0023	0.025
Cadmium	Cd	ICP-MS	0.00019	0.001
Calcium	Ca	ICP-OES	0.0065	0.025
Chromium	Cr	ICP-MS	0.00047	0.001
Cobalt	Co	ICP-MS	0.00041	0.001
Copper	Cu	ICP-MS	0.00054	0.001
Iron	Fe	ICP-OES	0.0022	0.025
Lead	Pb	ICP-MS	0.00022	0.001
Lithium	Li	ICP-OES	0.0047	0.025
Magnesium	Mg	ICP-OES	0.0035	0.025
Manganese	Mn	ICP-OES	0.001	0.05
Molybdenum	Mo	ICP-MS	0.00059	0.001
Nickel	Ni	ICP-MS	0.00047	0.001
Phosphorus	P	ICP-OES	0.0068	0.025
Potassium	K	ICP-OES	0.0032	0.025
Selenium	Se	ICP-MS	0.00051	0.001
Silicon	Si	ICP-OES	0.0038	0.025
Sodium	Na	ICP-OES	0.0056	0.025
Strontium	Sr	ICP-OES	0.0037	0.025
Sulfur	S	ICP-OES	0.0058	0.025
Thallium	Tl	ICP-MS	0.00047	0.001
Titanium	Ti	ICP-OES	0.0023	0.025
Uranium	U	ICP-MS	0.00026	0.001
Vanadium	V	ICP-MS	0.00032	0.001
Zinc	Zn	ICP-MS	0.000647	0.001

Ion Chromatography

The concentrations of anions in leaching test eluates were determined by IC using a Metrohm 881 Compact IC Pro (Metrohm USA, Riverview, FL) with a Metrosep A Supp 5 column and a conductivity detector following EPA Method 9056A. A 7-anion calibration standard was diluted to form a 5-point calibration curve with the MDLs and LLOQs shown in Table 3-4. Since the calibration standards are diluted from a bulk multi-analyte standard, the calibration range differs for each analyte (e.g., 0.050-50 mg/L for Cl^- and 0.150-150 mg/L for SO_4^{-2}). Calibration check standards were required to be within 15% of the specified value, while acceptable analytical blanks were measured below the quantitation limits.

Table 3-4
MDLs and LLOQs for Analysis of Eluates by IC

Analyte	Symbol	MDL (mg/L)	LLOQ (mg/L)
Bromide	Br^-	0.0064	0.025
Chloride	Cl^-	0.0101	0.05
Fluoride	F^-	0.0063	0.02
Nitrate	NO_3^-	0.0112	0.1
Nitrite	NO_2^-	0.0108	0.05
Phosphate	PO_4^{-3}	0.0247	0.15
Sulfate	SO_4^{-2}	0.0254	0.15

Carbon Analysis

Carbon analysis for eluate samples included analyses for dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC). Carbon analysis was conducted using a Shimadzu TOC-V CPH/CPN (Shimadzu Scientific Instruments, Inc., Columbia, MD) by catalytic oxidation/non-dispersive infrared detection (NDIR) following EPA Method 9060A. Total carbon (TC) in the eluate is converted to carbon dioxide via oxidation or decomposition, carried by a zero-CO_2 air stream into the NDIR. For analysis of DIC, liquid samples are acidified with 2-molar hydrochloric acid to liberate carbonates and other forms of inorganic carbon from solution as carbon dioxide, which is sparged from the liquid sample into the NDIR by the zero-CO_2 carrier gas. DOC is determined by measuring the TC of a sample after purging of IC. The instrument was calibrated using sodium hydrogen carbonate and potassium hydrogen phthalate over a 5-point calibration curve for DIC and DOC, respectively. The resultant analytical range was between 0.1 and 100 mg/L, with MDL and LLOQ values shown in Table 3-5. Checks on QA/QC at a frequency of every 10 analytical samples included calibration checks with a required recovery within 15% of the specific value, and method blanks with a requirement that the concentration was less than quantifiable limits.

Table 3-5
MDLs and LLOQs for Eluate Analysis for Carbon

Analyte	Symbol	MDL (mg/L)	LLOQ (mg/L)
Inorganic carbon	DIC	0.15	0.50
Organic carbon	DOC	0.18	0.50

Subsurface Gas Analysis

The composition of subsurface gas was monitored monthly from September 2018 through September 2019. Subsurface gas was monitored for oxygen (O_2), carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S) using a hand-held field meter (Figure 3-4a). Table 3-6 shows the measurement units and calibration ranges for the five gases. To avoid any moisture from subsurface gas fouling the vacuum pump, the subsurface gas was drawn through a 250-mL syringe filled with desiccant (Figure 3-4b).

a)  b) 

Figure 3-4
Subsurface gas monitoring apparatus: a) field meter and b) connected tubing and desiccant syringe

Table 3-6
Calibration Ranges for Subsurface Gas Monitoring

Analyte	Symbol	Units	Calibration Range	
Ammonia	NH_3	ppm	0	500
Hydrogen sulfide	H_2S	ppm	0	500
Carbon dioxide	CO_2	%	0	5
Methane	CH_4	%	0	5
Oxygen	O_2	%	0	30

Data Management with LeachXS™

Information on how leaching tests were conducted was recorded by the laboratory technician in Microsoft Excel® spreadsheets specifically designed for each test for use as templates for data collection and archiving. Analytical data documenting concentrations of constituents from each leaching test were entered into the same spreadsheets. These data templates were used as the interface for loading laboratory and analytical data into LeachXS™ (VU, 2019), a database-driven data management and reporting software program. LeachXS was used to (i) archive the laboratory and analytical data from leaching tests; (ii) compare test results between composite materials (e.g., VB-1, VB-2, or VB-3) or test results (e.g., TCLP, SPLP, ASTM, and LEAF); and (iii) generate the Excel plots used for this report.

4
TEST RESULTS AND DISCUSSION

A large volume of data was generated during this research. The discussion that follows presents representative example figures that illustrate observations based on all data. Graphs and data tables reflecting all data are provided in the appendices. In addition, key observations within subsections are denoted by underscored text.

Physical and Hydraulic Properties

Physical properties of the fly ash samples used for measurement of hydraulic properties are summarized in Table 4-1, composition of the solids is summarized in Table 4-2, and the hydraulic conductivities are summarized in Table 4-3.

Particle size distributions of the coal ash samples are shown in Figure 4-1. All samples contained a broad range of particle sizes ranging from those associated with coarse-to-fine sand, silt, and clay-size (<2 μm) particles. Each has a broadly graded distribution with relatively comparable fractions of all sizes and no gaps. The fines content (i.e., silt and clay-size particles finer than 75 μm) ranges from 36.6 to 92.2%, and the clay-size (i.e., finer than 2 μm) ranges from 5.2 to 19.8%. No particles coarser than sand-size were observed.

Table 4-1
Physical Properties of Coal Ash Samples Used for Hydraulic Conductivity Assessment

Sample ID	Sample Elevation at Bottom (ft AMSL)	Sample Elevation at Top (ft AMSL)	Water Content (%)	Dry Unit Weight (mg/m^3)	Particle Size Fractions			
VB-1_OST_12-14.5	743.8	746.3	41.5	1.14	0.0	15.5	84.5	15.1
VB-1_OST_17-19.5	738.8	741.3	52.0	1.00	0.0	25.2	74.8	10.0
VB-2_OST_13.5-15.5	737.9	739.9	37.5	1.11	0.0	64.4	36.6	5.2
VB-2_OST_18.5-21.5	731.9	734.9	28.7	1.35	0.0	23.1	76.9	12.6
VB-3_OST_17-20	738.8	741.8	36.3	1.28	0.0	34.5	65.5	14.0
VB-3_OST_24-27	731.8	734.8	27.9	1.26	0.0	7.8	92.2	19.8

Sample VB-2_OST_13.5-15.5 was notably coarser than the other samples and was classified as silty sand (SM) in ASTM D2487. This classification is characteristic of bottom ash mixed with fly ash. All other samples were classified as fine-grained “elastic silt” (ML) as defined in ASTM D2487, which is characteristic of fly ash.

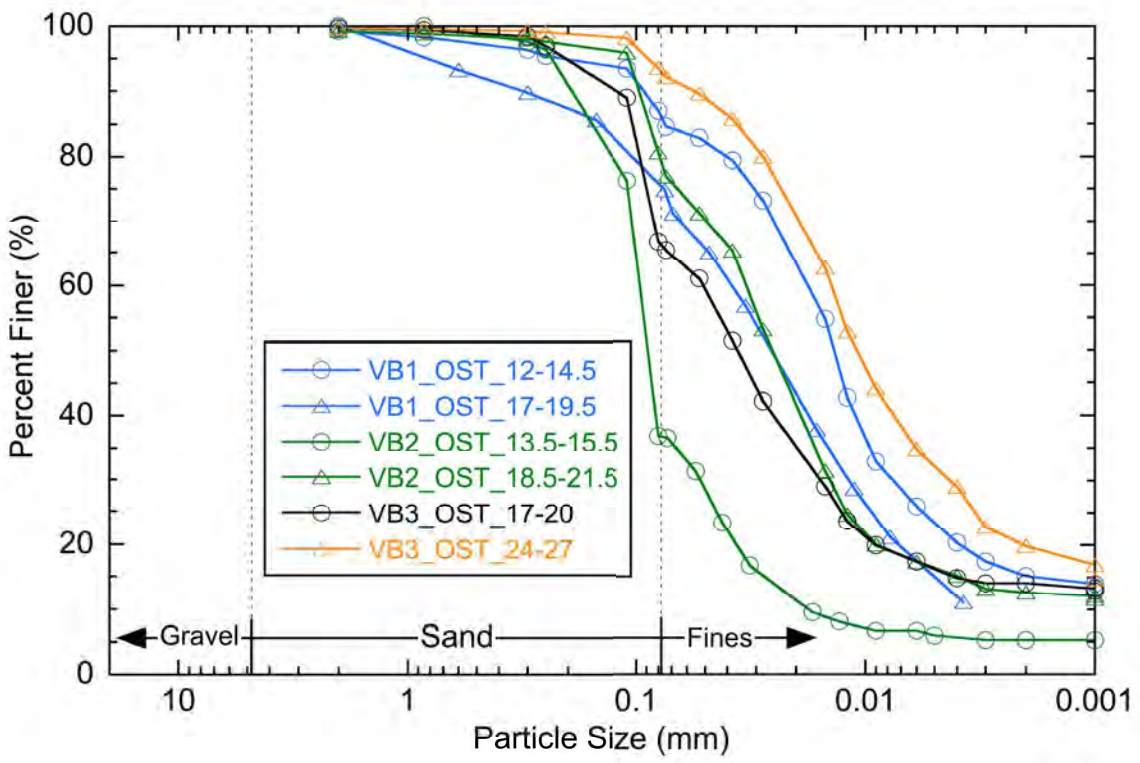

Figure 4-1
Particle size distribution of coal ash samples

Table 4-2 indicates that all of the ash samples are predominantly composed of Al and Si oxides, which reflects the predominant alumino-silicate mineral structure of the particulate. All samples contain modest amounts of Ca, K, Fe, and Ti. The VB-2 series samples are richer in iron than the other samples. The LOI varies considerably, from 0.50 to 11.83%.

Table 4-2
Composition of Solids (%) from LOI and XRF of Coal Ash Samples Used for Hydraulic Conductivity Assessment (elements exceeding 1.0%)

Composition	VB-1		VB-2		VB-3
	12-14.5	17-19.5	13.5-15.5	18.5-21.5	17-20
LOI	0.98	1.89	0.50	11.83	4.95
Al_2O_3	26.19	26.69	24.26	19.88	26.79
CaO	1.35	1.44	1.36	1.32	1.50
Fe_2O_3	16.14	11.34	22.99	19.45	12.61
K_2O	5.70	3.66	4.78	3.79	3.74
SiO_2	45.42	51.10	41.86	39.74	46.87
TiO_2	2.04	1.48	1.99	1.64	1.59

The hydraulic conductivities fall into two groups: the coarser, more permeable samples (VB-1_OST_17-19.5, VB-2_OST_13.5-15.5, and VB-3_OST_17-20) and the finer, less permeable samples (VB-1_OST_12-14.5, VB-2_OST_18.5-21.5, and VB-3_OST_24-27). The coarser samples have hydraulic conductivities in the range of 10^{-4} to 10^{-3} cm/s and fines content less than 75%, whereas the finer samples have hydraulic conductivities closer to 10^{-5} cm/s and fines content greater than 75%. There is a strong relationship between the hydraulic conductivity and fines content (Figure 4-2), with hydraulic conductivity diminishing as the fines content increases. The hydraulic conductivities also align well with hydraulic conductivities generally associated with the geotechnical classifications.

Table 4-3
Hydraulic Conductivity of Coal Ash Samples

Sample ID	Percent Fines (%)	Effective Stress (kPa)	Hydraulic Conductivity (cm/s)
VB-1_OST_12-14.5	84.5	20	2.0×10^{-5}
		100	2.0×10^{-5}
		250	1.4×10^{-5}
		400	1.3×10^{-5}
		500	1.3×10^{-5}
VB-1_OST_17-19.5	74.8	20	3.6×10^{-4}
VB-2_OST_13.5-15.5	36.6	20	1.3×10^{-3}
VB-2_OST_18.5-21.5	76.9	20	4.2×10^{-5}
		100	4.1×10^{-5}
		250	3.0×10^{-5}
		400	2.7×10^{-5}
		500	1.2×10^{-5}
VB-3_OST_17-20	65.5	20	6.3×10^{-4}
		100	6.9×10^{-4}
		250	2.5×10^{-4}
		400	2.3×10^{-4}
		500	9.7×10^{-5}
VB-3_OST_24-27	92.2	20	2.7×10^{-5}
		100	2.7×10^{-5}
		250	2.6×10^{-5}
		400	2.4×10^{-5}
		500	2.3×10^{-5}

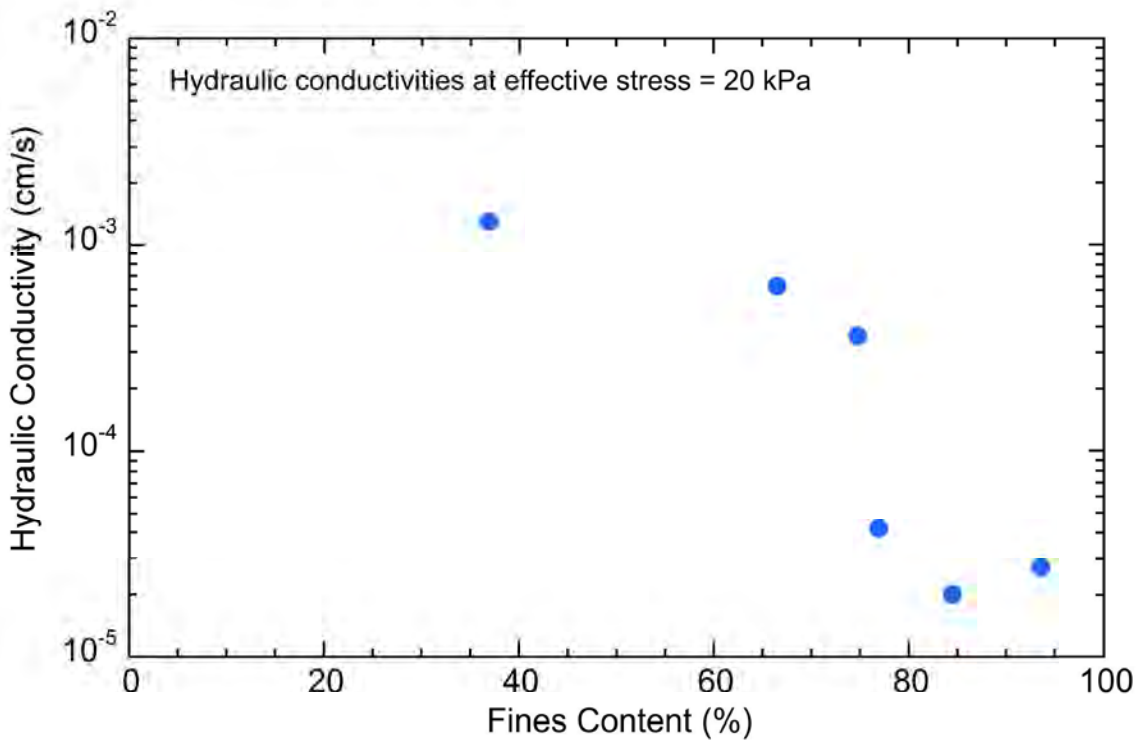

Figure 4-2
Hydraulic conductivity of coal ash at 20 kPa effective stress as a function of fines content

The hydraulic conductivity of the coal ash samples as a function of confining stress is shown in Figure 4-3. In general, the hydraulic conductivity decreases modestly with increasing effective stress. The hydraulic conductivity of the coarser, more permeable sample (VB-3_OST_17-20) is more sensitive to effective stress than the finer, less permeable samples. As the stress increased from 20 to 500 kPa, the hydraulic conductivity of the coarser sample decreased by a factor of 6.5. In contrast, the hydraulic conductivity of the finer, less permeable samples decreased by a factor of 2.1 on average over the same range of stresses. The greater sensitivity to stress for VB-3_OST_17-20 may reflect closure of larger pores between the sand-size particles, with the finer particles filling the remaining pores and resulting in lower hydraulic conductivity.

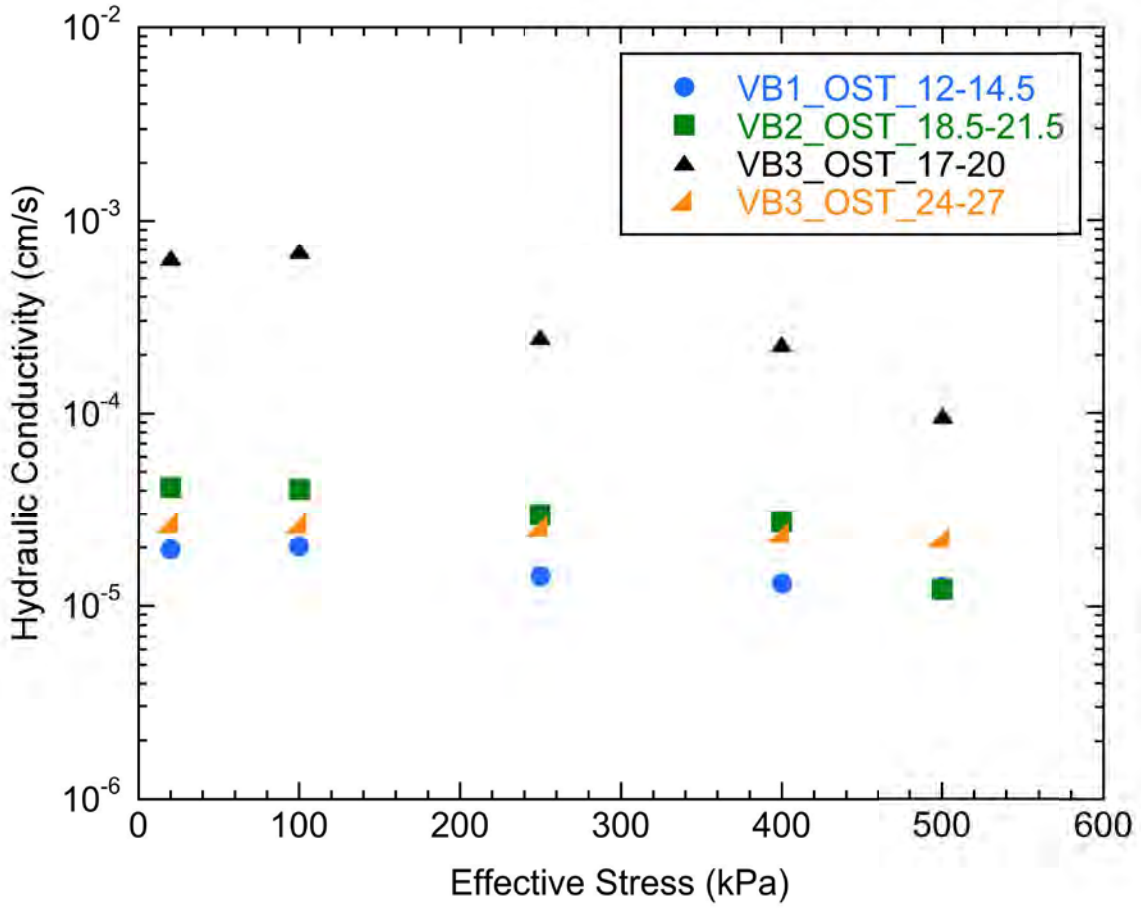

Figure 4-3
Hydraulic conductivity of coal ash samples as a function of effective stress

Individual Split Spoon Sample Testing

Evaluation of Field Extractions (L/S~1 vs. L/S=1)

During field sampling, extractions of split spoon materials were conducted using de-oxygenated water at an L/S~1. For each extract, approximately 150-g grab samples of recovered material from the center of the split spoon were contacted with approximately 150 mL of DI water that had been deoxygenated with nitrogen prior to field operations. If the split spoon indicated an interface between dissimilar materials (e.g., across the ash-cover or ash-liner interfaces or in layered ash), two extractions were conducted on grab samples of distinctive material types. Because the moisture content of the split spoon material varied with depth and texture, the resultant L/S of field extractions varied between 1.7 and 3.3 mL/g-dry.

The variation in L/S of field-extracted materials confounds the comparison of material within a borehole or between boreholes based on concentrations. Therefore, extractions at a constant L/S ratio were conducted in the laboratory. Collected bulk materials that had been vacuum-sealed to preserve the redox conditions of split spoon samples were homogenized within each split spoon. 100-g subsamples of homogenized material were extracted with DI water at an L/S=1 mL/g-dry. Figure 4-4 shows a comparison between field extractions (L/S~1) and laboratory extractions (L/S=1) as a function of pH and L/S. Comparisons of field and laboratory extraction data for all constituents are presented in Appendix C.1.

In these figures, the color of the data points indicates the borehole (e.g., VB-1 in blue, VB-2 in green, and VB-3 in orange), with lighter colors indicating field extractions and darker colors indicating laboratory extractions. The shape of the data point refers to the primary type of material used in the extraction (ash samples are shown as dots, cover material as squares, and liner material as diamonds). Solid data points are confirmed material types that fall within the material classification provided in the bore logs by the licensed geologist, while open data points indicate materials near interfaces that are likely to be a blend of two or more material types (e.g., open squares indicate blended samples of the ash and cover materials while open diamonds refer to blends of ash, layered ash, and liner material).

The data in Figure 4-4 show that the primary difference between laboratory tests is L/S ratio, which is most noticeable in the L/S-dependence plot. The pH range for the laboratory extractions is primarily the same as that of the field extractions.

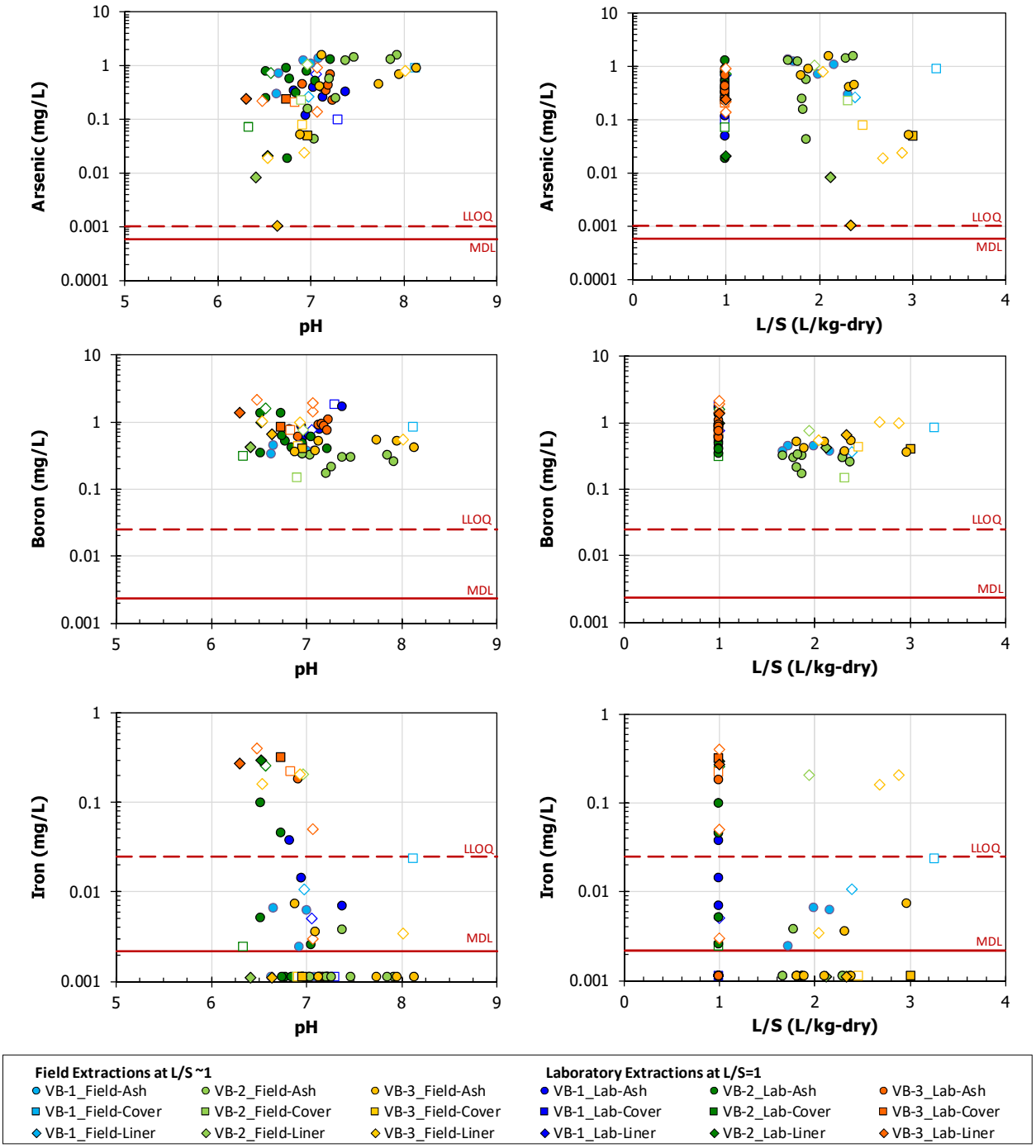

Figure 4-4
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right)

Vertical Heterogeneity Within and Between Boreholes

Profile Plots of Field and Laboratory Extraction Data

After surveying of the borehole and PAP locations and elevations, depths below grade that were monitored during sample recovery were converted to elevations ASML. The concentrations from field extractions (L/S~1) and laboratory extractions (L/S=1) of individual split spoon materials were plotted as a function of elevation to provide a visual metric of material heterogeneity with depth within a borehole. An example of these borehole profile plots is presented in Figure 4-5.

Each line of the figure represents the concentration profiles for a measured constituent in the laboratory extractions (L/S=1) for VB-1 in blue, VB-2 in green, and VB-3 in orange. The concentration is plotted along the x-axis, while the elevation for the center of the split spoon is plotted on the y-axis. The red horizontal line shows the elevation at the interface between cover material and the ash deposit, while the brown horizontal line indicates the elevation where the main ash deposit ended either at an interface with the underlying native clay liner material or in layers of different ash textures above the clay liner. The 2-foot wide shaded area indicates the screening interval for the PAP in each borehole. The 3 to 4 light-colored data points in each profile indicate the intervals from which material was taken to create the composite ash sample for each borehole used in detailed characterizations.

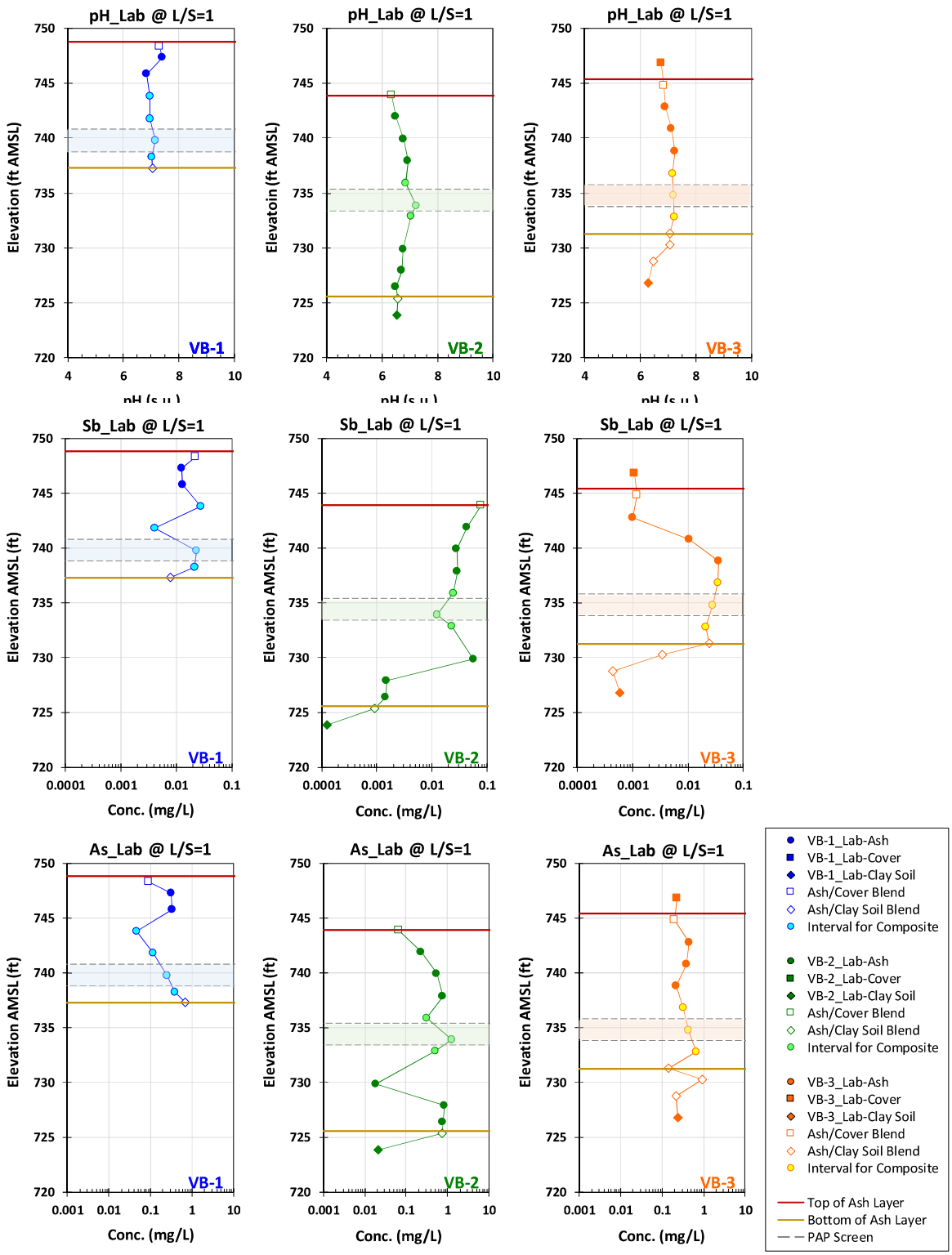

Figure 4-5
Laboratory extraction (L/S=1) concentration profiles within boreholes (VB-1, VB-2, VB-3) based on eluate concentration (SU or mg/L) for pH, antimony, and arsenic

Standardized Borehole Profiles of Laboratory Extraction (L/S=1) Concentrations

The concentration data for laboratory extractions of homogenized split spoon material were converted to standardized profile plots using the global mean and standard deviation for "known ash samples" in all boreholes based on geologist notes. The standardized concentration is calculated as:

$$\frac{x - \bar{x}}{s}$$

where x is the parameter (e.g., pH, concentration) from the extraction test,
$\bar{x}$ is the global mean of all "known ash samples" for all boreholes, and
s is the global standard deviation of all "known ash samples."

The standardized concentration provides a measure of the difference between the measured concentration and the mean as a number of standard deviations from the mean concentration. A homogenous material, for example, may have measurements within 2 standard deviations of the mean while measurements greater than 4 standard deviations may have more than random variations such as influence from cover or underlying material. Justification for use of ash sample global statistics, rather than within-borehole statistics, was based on the results of t-test results for pair-wise comparisons assuming unequal variances, which showed no statistical difference in means between boreholes. In addition, the use of global statistics in standardized concentration profiles allows for comparison between boreholes on the same basis.

Examples of the resulting standardized borehole profiles are shown in Figure 4-6 for major constituents and in Figure 4-7 for trace constituents. The standardized profiles for all constituents are presented Appendix C.2. The global mean and standard deviation for all constituents are tabulated in Table 4-4.

The process for collection of split spoon samples at boreholes VB-2 and VB-3 was designed to capture the interfaces at the cover and underlying materials, whereas the collection of split spoons at borehole VB-1 was centered on the ash material only. These sampling schemes are reflected in the results of the standardized profiles. Figure 4-6 shows that the concentration profiles for aluminum and iron from laboratory extractions (L/S=1) show very consistent response within the ash deposit, with clear influences from overlying and underlying materials. The profiles for antimony, arsenic, and boron in Figure 4-7 show more variation within the ash layers, with little to no influence from cover or underlying materials. Overall, the samples used in the composite materials for all boreholes were relatively consistent and are considered representative of the global mean of the stored ash.

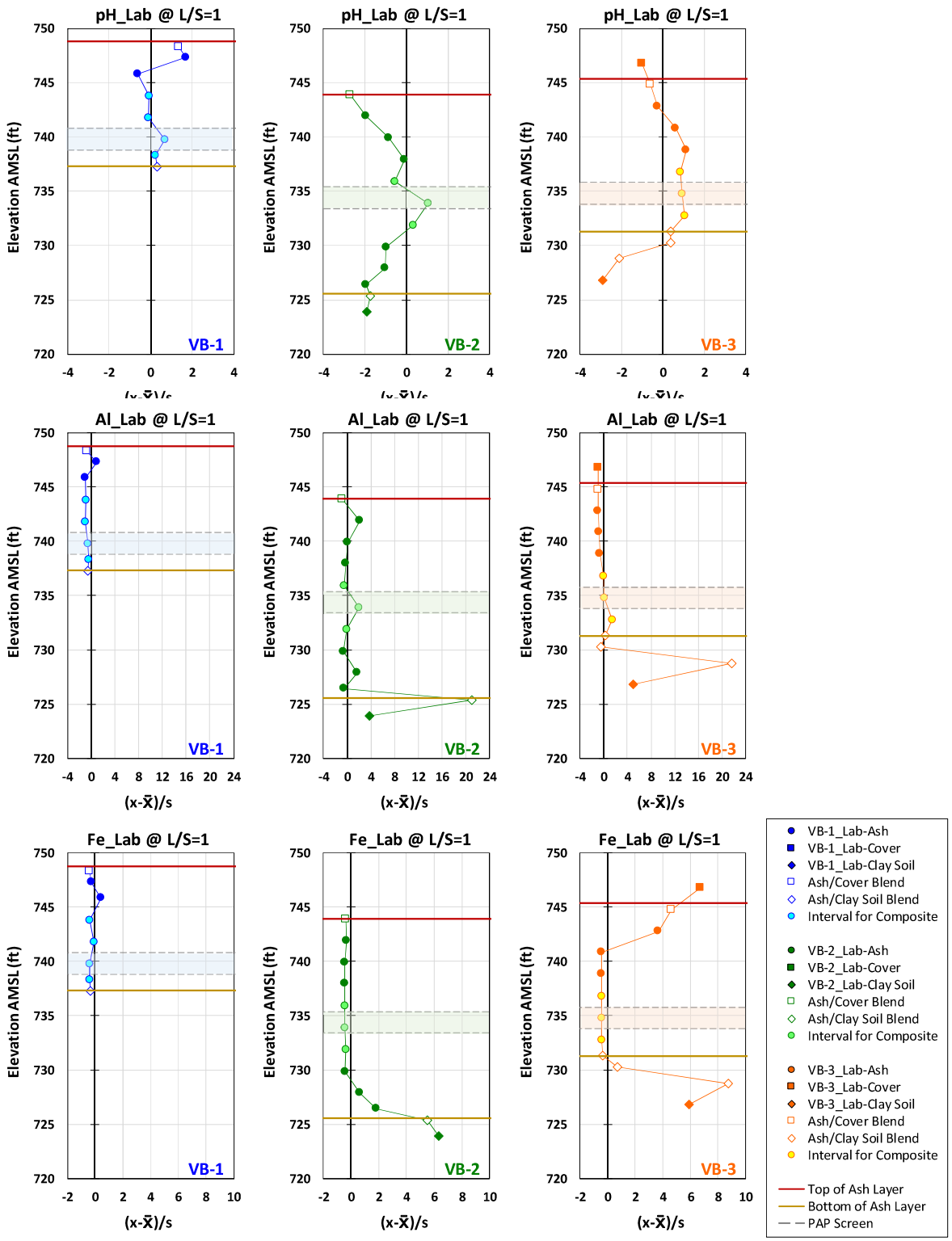

Figure 4-6
Laboratory extraction (L/S=1) concentration profiles within boreholes (VB-1, VB-2, and VB-3) standardized to the global mean (x̄) and standard deviation (s) of known ash samples for pH, aluminum, and iron

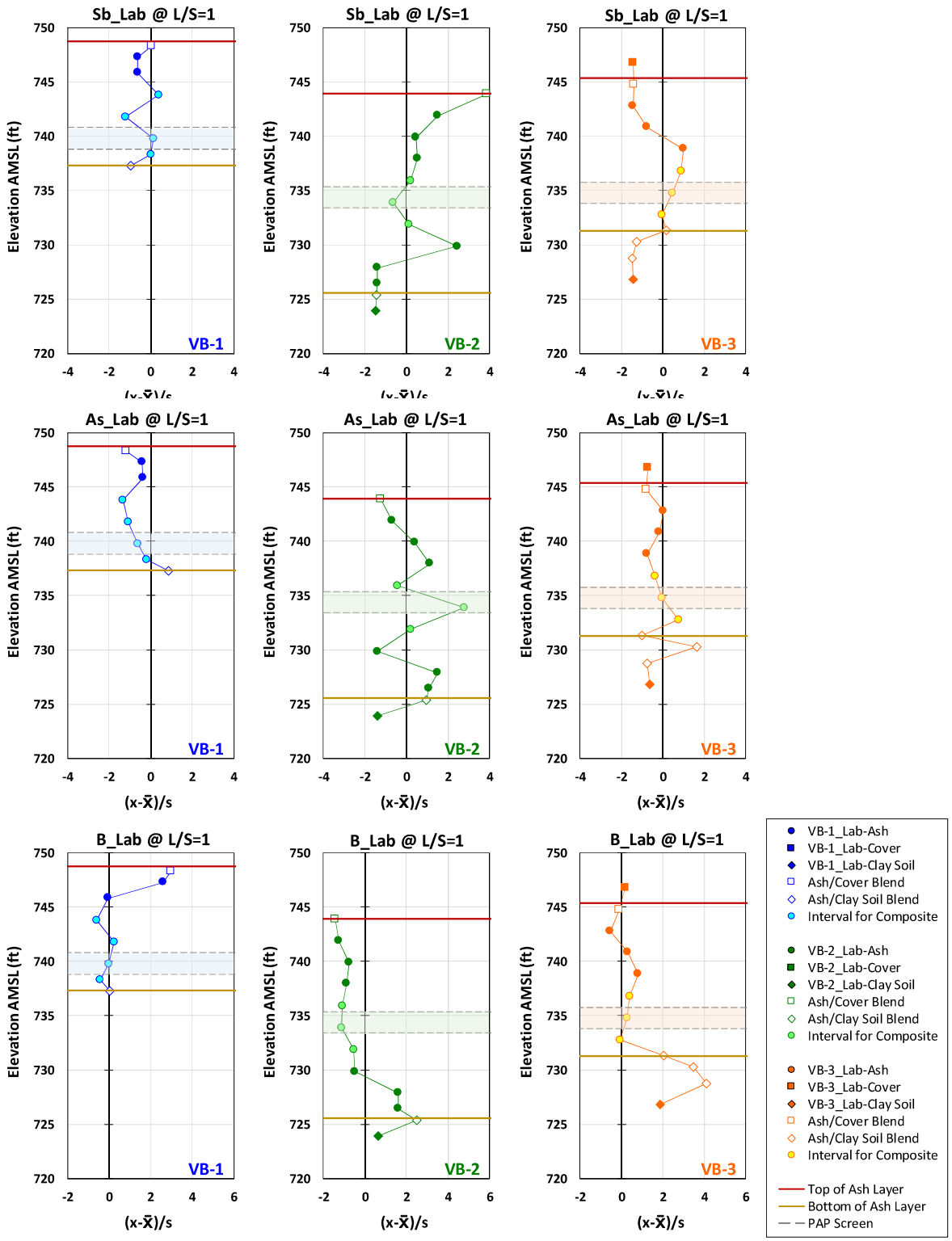

Figure 4-7
Laboratory extraction (L/S=1) concentration profiles within boreholes (VB-1, VB-2, and VB-3) standardized to the global mean (X̄) and standard deviation (s) of known ash samples for antimony, arsenic, and boron

Table 4-4
Global Mean and Standard Deviation of Laboratory Extractions (L/S=1) Concentrations

Analyte	Units	Global Statistics	
		Mean	Std. Dev.
EC	mS/cm	0.38	0.24
IS	Mol/L	0.0057	0.0036
pH	S.U.	6.98	0.23
ORP	mV	97.95	19.58
pE	-	5.51	0.33
pH+pE	-	12.49	0.42
Aluminum	mg/L	0.093	0.095
Antimony	mg/L	0.022	0.014
Arsenic	mg/L	0.44	0.30
Barium	mg/L	0.15	0.06
Beryllium	mg/L	<MDL	<MDL
Boron	mg/L	0.77	0.33
Cadmium	mg/L	<MDL	<MDL
Calcium	mg/L	73.69	57.83
Chromium	mg/L	0.0052	0.0022
Cobalt	mg/L	<MDL	<MDL
Copper	mg/L	0.0022	0.0015
DOC	mg/L	21.03	9.11
Iron	mg/L	0.02	0.04
Lead	mg/L	<MDL	<MDL
Lithium	mg/L	<MDL	<MDL
Magnesium	mg/L	14.37	12.89
Manganese	mg/L	0.41	1.03
Molybdenum	mg/L	0.79	1.46
Nickel	mg/L	<MDL	<MDL
Phosphorus	mg/L	0.19	0.11
Potassium	mg/L	7.79	3.80
Selenium	mg/L	0.21	0.23

Table 4-4 (continued)
Global Mean and Standard Deviation of Laboratory Extractions (L/S=1) Concentrations

Analyte	Units	Global Statistics	
		Mean	Std. Dev.
Silicon	mg/L	3.01	1.50
Sodium	mg/L	5.81	2.60
Strontium	mg/L	1.57	0.54
Sulfur	mg/L	38.81	57.03
Thallium	mg/L	<MDL	<MDL
Titanium	mg/L	<MDL	<MDL
Vanadium	mg/L	0.11	0.11
Zinc	mg/L	0.03	0.09

Notes: <MDL indicates all or most of the L/S=1 concentrations were less than the MDL

Comparison of Standardized Borehole Profiles for Field and Laboratory Extractions Based on Mass Release (mg/kg)

The standardized borehole variability graphs can be used to examine the differences between field extractions at L/S ~1 and laboratory extractions at L/S=1. Example comparisons for selected major and trace constituents are shown in Figure 4-8 and Figure 4-9, respectively, while the complete results for all measured constituents are presented in Appendix C.3.

In general, the variability of laboratory and field extraction are similar; however, the laboratory extractions are somewhat less variable than the field extractions. This observation is due to the homogenization within a split spoon sample that was conducted on the material used for laboratory extractions, especially for trace species where blending would matter most (see Figure 4-9). A secondary cause for lesser variability in the laboratory extraction data may be a result of redox changes between the laboratory and field extraction conditions.

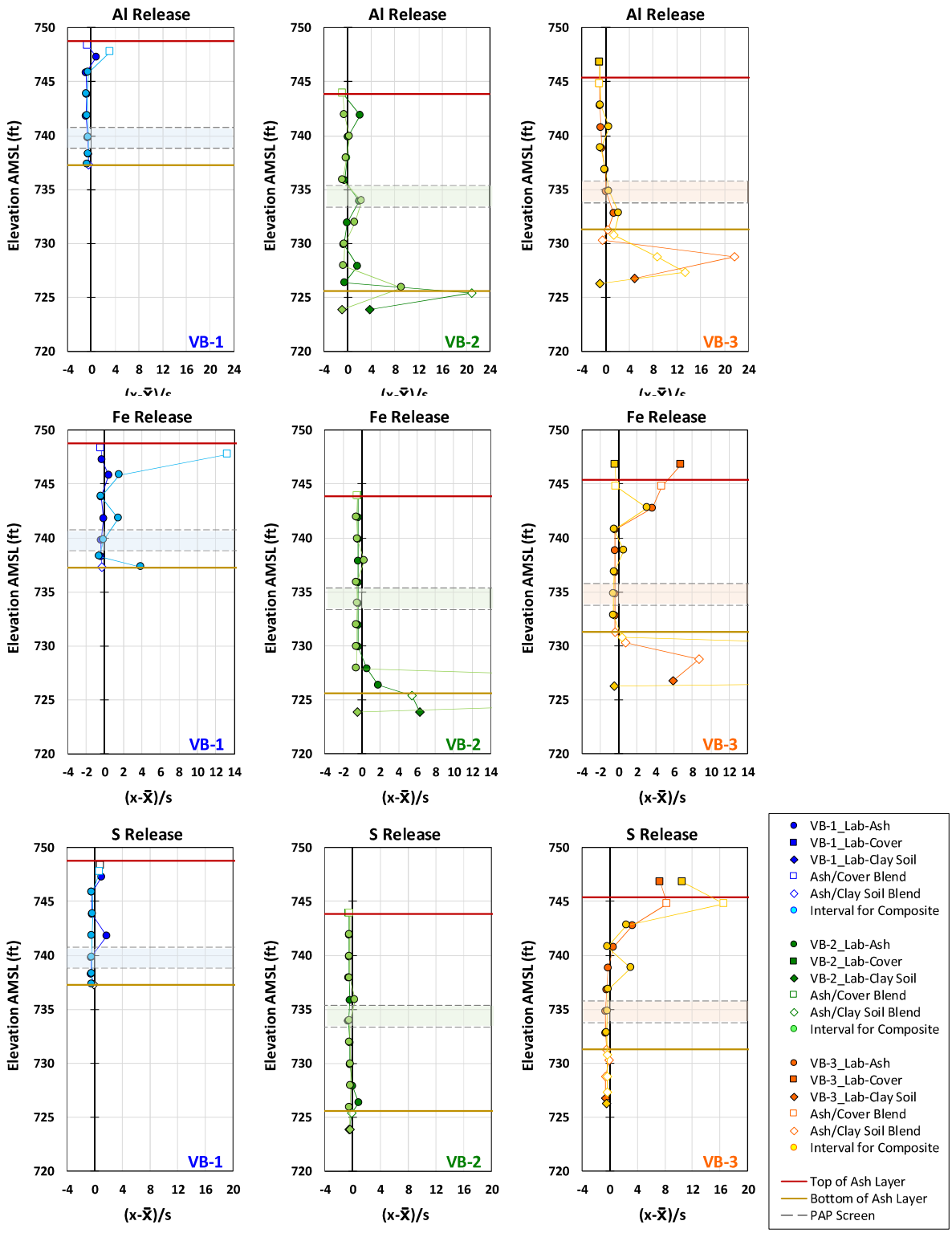

Figure 4-8
Comparison of standardized mass release profiles for field extractions (L/S~1) and laboratory extraction (L/S=1) of major constituents from VB-1, VB-2, and VB-3 for aluminum, iron, and sulfur

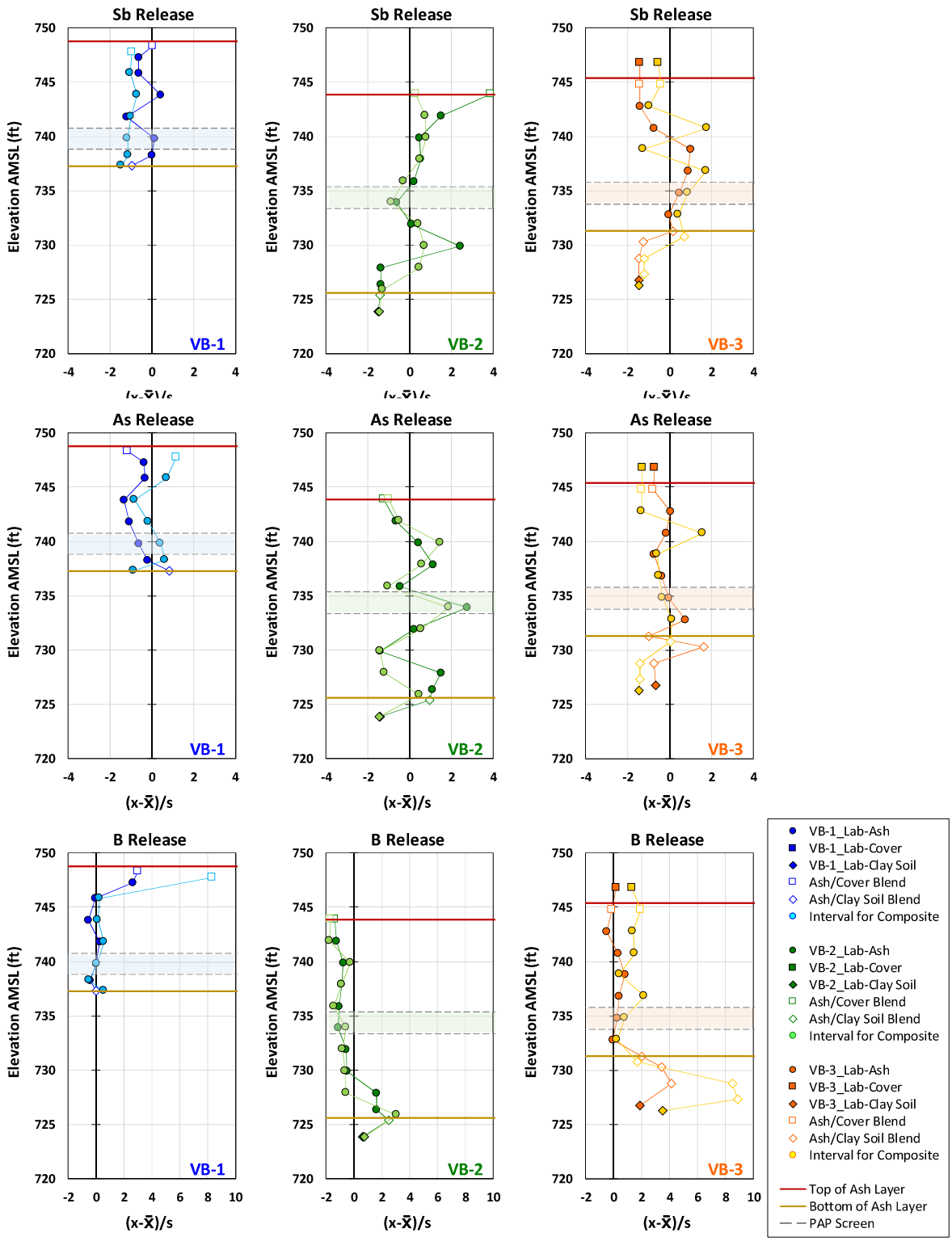

Figure 4-9
Comparison of standardized mass release profiles for field extractions (L/S~1) and laboratory extraction (L/S=1) of trace constituents from VB-1, VB-2, and VB-3 for antimony, arsenic, and boron

Composite Ash Sample Test Results

Subsamples of bulk material collected from split spoon sampling were homogenized within each bulk storage packet and then composited by equal mass over intervals around the PAP screening intervals. These composites were subject to detailed investigation of total and available content, leaching characteristics as a function of pH and L/S, and comparison between leaching tests and to porewater concentrations. The complete set of pH- and L/S-dependent results for all measured constituents is presented in Appendix D.1.

Total Content

In preparation for EPA Method 3052, ash samples were dried under nitrogen and ground to pass a No. 100 (150 μm) sieve. Therefore, although the EPA method is based on "as received" solid sample, which can include the inherent moisture within the material, the results presented on an "as received" mass (mg/kg) are, in this case, based on dry-mass (mg/kg-dry) like the LEAF tests. The total content reported for samples of the three composite materials is shown in Table 4-5. Of the 27 constituents analyzed, Sb, Mg, Hg, Se, Ag, and Tl were reported to have a total content less than the commercial laboratory's reporting limit shown in the table. Furthermore, the total content of thallium was not detected at a value greater than the shown MDL value. Based on the low total content and low eluate concentrations of initial leaching test results, Ag and Hg were not considered in the analysis of test leachates or the comparison to groundwater concentrations. The remaining constituents were retained because preliminary testing indicated that leaching concentrations were low, but quantifiable for most leaching tests.

Table 4-5
Total Content for Composite Samples VB-1, VB-2, and VB-3 Based on EPA Method 3052

Analyte	Symbol	MDL (mg/kg)	RL (mg/kg)	VB-1 (mg/kg)	VB-2 (mg/kg)	VB-3 (mg/kg)
Aluminum	Al	3.1	40	13,000	13,000	13,000
Antimony	Sb	2.0	6.0	3.5 J	3.3 J	4.5 J
Arsenic	As	1.4	10	92 B	110 B	110 B
Barium	Ba	0.24	1.0	370	360	400
Beryllium	Be	0.015	1.0	6.4	5.9	6.8
Cadmium	Cd	0.32	1.0	2.2	1.1	1.7
Calcium	Ca	11	500	930	980 F1	970
Chromium	Cr	0.14	1.5	140	140	150
Cobalt	Co	3.0	25	40	34	35
Copper	Cu	1.5	5.0	130	130	200
Iron	Fe	28	40	11,000	77,000	57,000
Lead	Pb	1.1	7.5	53	46	61
Lithium	Li	0.29	5.0	170	170	190

Table 4-5 (continued)
Total Content for Composite Samples VB-1, VB-2, and VB-3 Based on EPA Method 3052

Analyte	Symbol	MDL (mg/kg)	RL (mg/kg)	VB-1 (mg/kg)	VB-2 (mg/kg)	VB-3 (mg/kg)
Magnesium	Mg	3.7	500	110 J	110 J, F1	120 J
Manganese	Mn	0.11	1.5	250	210	170
Mercury	Hg	0.062	0.2	0.098 J	0.093 J	0.083 J
Molybdenum	Mo	0.16	4.0	8.2	4.5	5.0
Nickel	Ni	0.16	20	100	89	90
Potassium	K	100	1,000	12,000	15,000	15,000
Selenium	Se	1.7	7.5	6.1 J	4.4 J	5.3 J
Silver	Ag	0.11	3.0	1.8 J	1.7 J	1.9 J
Sodium	Na	260	500	1,400	1,700	1,800
Strontium	Sr	0.058	5.0	140	100 F1	120
Thallium	Tl	10	17	ND	ND	ND
Titanium	Ti	1.0	25	7,500	7,800	8,200
Vanadium	V	0.12	5.0	240	240	260
Zinc	Zn	2.0	12	120	110	120

Notes: B the compound was found in the blank and sample.

F1 the matrix spike recovery is outside of acceptance limits

J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.

ND the compound was not detected at a concentration above the MDL.

pH-Dependent Leaching Tests

Titration curves from EPA 1313 and 1313_L/S=1 conducted on the VB-1, VB-2, and VB-3 composite samples are presented in Figure 4-10. The titration curve indicates the amount of acid or base (shown as acid additions less than zero) required to provide a specific eluate pH. This is sometimes referred to as the acid/base neutralization capacity of the material. Also shown in Figure 4-10 is the natural pH response for each composite material when no acid or base is added.

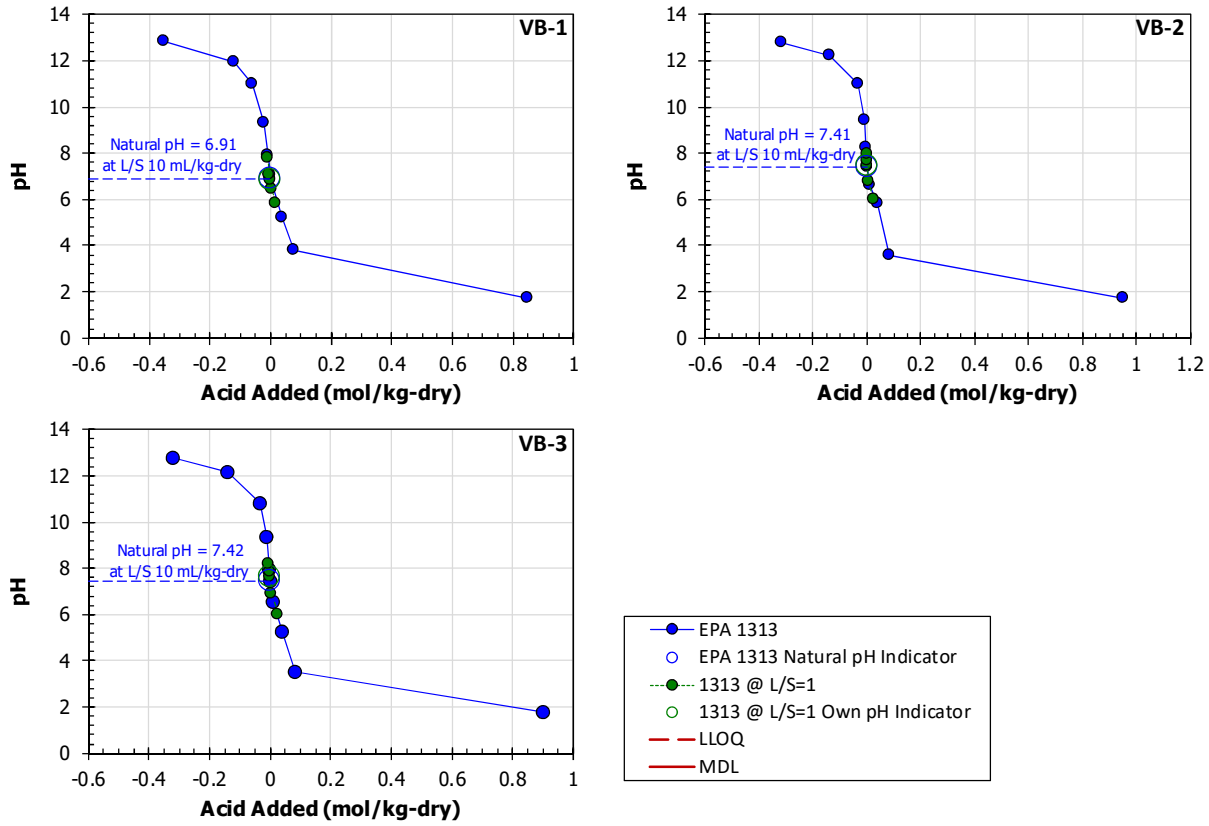

Figure 4-10
Titration curves from EPA 1313 test results from composite testing of VB-1, VB-2, and VB-3

The natural pH values for the three composites are presented in Table 4-6 along with the "own pH" values measured during 1313 testing at an L/S=1 mL/g-dry. Although the natural pH values for all composites are generally neutral, VB-1 is slightly more acidic (pH_{nat}=6.91) than the composites at VB-2 (pH_{nat}=7.41) or VB-3 (pH_{nat}=7.42). The different L/S ratios between natural pH and own pH had little effect on overall pH (less than 0.2 SU).

Table 4-6
Natural pH (EPA 1313) and Own pH (1313_L/S=1) of Composite Samples

	Method	L/S (mL/g-dry)	pH (SU) VB-1	pH (SU) VB-2	pH (SU) VB-3
Natural pH	EPA 1313	10	6.91	7.41	7.42
Own pH	1313_L/S=1	1	6.84	7.45	7.59

Constituent Concentrations

The concentration of a constituent in each eluate of a pH-dependent leaching test (i.e., EPA 1313 and 1313_L/S=1) is indicative of the LSP in equilibrium with the L/S, pH, EC, and ORP of the contacting fluid. Eluate concentrations are typically plotted as a function of eluate pH to indicate how LSP changes over a broad range of pH values. Example test results from EPA 1313 and

1313_L/S=1 are shown in Figure 4-11 through Figure 4-13 as pH-dependent eluate concentration (mg/L) and mass release (mg/kg-dry).

The pH-dependent leaching behavior of a constituent is useful when disposed materials may be contacted with water containing significant amounts of acid or base (e.g., pyrite-impacted groundwater or alkali process wastewaters). These data can be used to parameterize controlling mineral sets in geochemical speciation models, for example, LeachXS^{TM}/ORCHESTRA (Meeussen, 2015), to create a source term for fate and transport modeling.

Solubility-Controlled LSP vs. Available Content-Limited LSP

In addition, comparison of the effects of changing pH (e.g., within an EPA 1313 test) to the effects of changing L/S (e.g., between EPA 1313 and 1313_L/S=1 or EPA 1314) can be used to distinguish constituents with "solubility-controlled LSP" behavior from those with "available content-limited LSP." The following classifications are based on comparison of EPA 1313 test results to those of 1313_L/S=1 testing and, thus, the classifications are limited to a relatively narrow pH range about the natural pH. Outside of those bounds, constituents that were classified as available-content limited may show solubility-controlled LSP.

- Solubility-Controlled LSP – When the eluate concentrations are limited by mineral solubility and precipitation/dissolution, the LSP behavior is considered "solubility-controlled" and pH is a controlling factor for leaching. Eluate concentrations for these behaviors are often a strong function of pH. However, unless pH changes significantly when L/S is changed, eluate concentrations are a weak function of L/S. The pH-dependent results for Ba (Figure 4-11, top) as well as Cr, F^-, Sb, Se, V, and Zn (in Appendix D.1) are good examples of solubility-controlled LSP. For these constituents, eluate concentrations change by orders-of-magnitude as a function of pH but do not change when the L/S is reduced from L/S=10 mL/g-dry (EPA 1313) to L/S=1 mL/g-dry (1313_L/S=1).
- Similarly, adsorption/desorption processes can be highly pH-dependent and often can be classified along with solubility-controlled LSP. For example, the LSP behavior of arsenic (Figure 4-11, bottom) with regard to changes in pH and L/S has similar trends to the solubility-controlled LSP behavior of Ba; however, the primary mechanism for the pH-dependent LSP of arsenic is likely adsorption to hydrous ferric oxides (HFO) rather than solubility of arsenic species.

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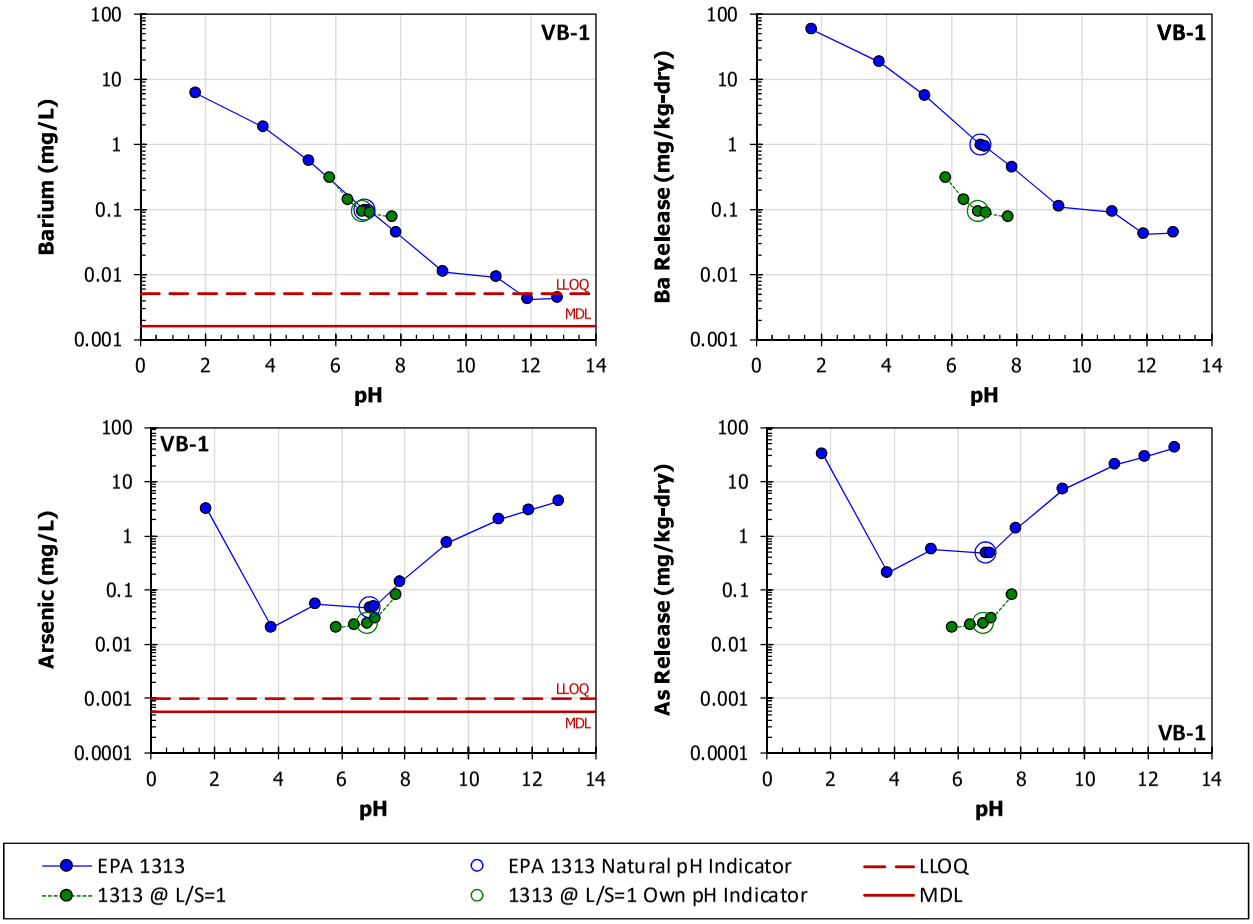

Figure 4-11
Example pH-dependent (EPA 1313) test results showing solubility-controlled LSP (barium) and adsorption-dominated LSP (arsenic)

- Available Content-Limited LSP – The concentration of some highly soluble constituents is not limited by the conditions of the eluate but by the amount of leachable mass in the solid. The characteristic pH-dependent behavior of these "available content-limited LSP" constituents is that eluate concentration curve is a weak function of pH but a strong function of L/S. Figure 4-12 presents examples of available content-limited LSP for B and SO_4^{-2} results from EPA 1313 and 1313_L/S=1. These figures show that pH-dependent concentrations within a test vary by approximately an order-of-magnitude across the entire pH range. However, when the L/S changes from L/S=10 mL/g-dry to L/S=1 mL/g-dry, the eluate concentration changes accordingly. Because the L/S effect is correlated to the magnitude of the L/S, the mass release (i.e., the eluate concentration multiplied by the L/S) is the same for both tests. Available content-limited LSP was observed for B, Ca, Cl^-, Mo, SO_4^{-2}, and Tl in VB-1, VB-2, and VB-3 composites (Appendix D.1).

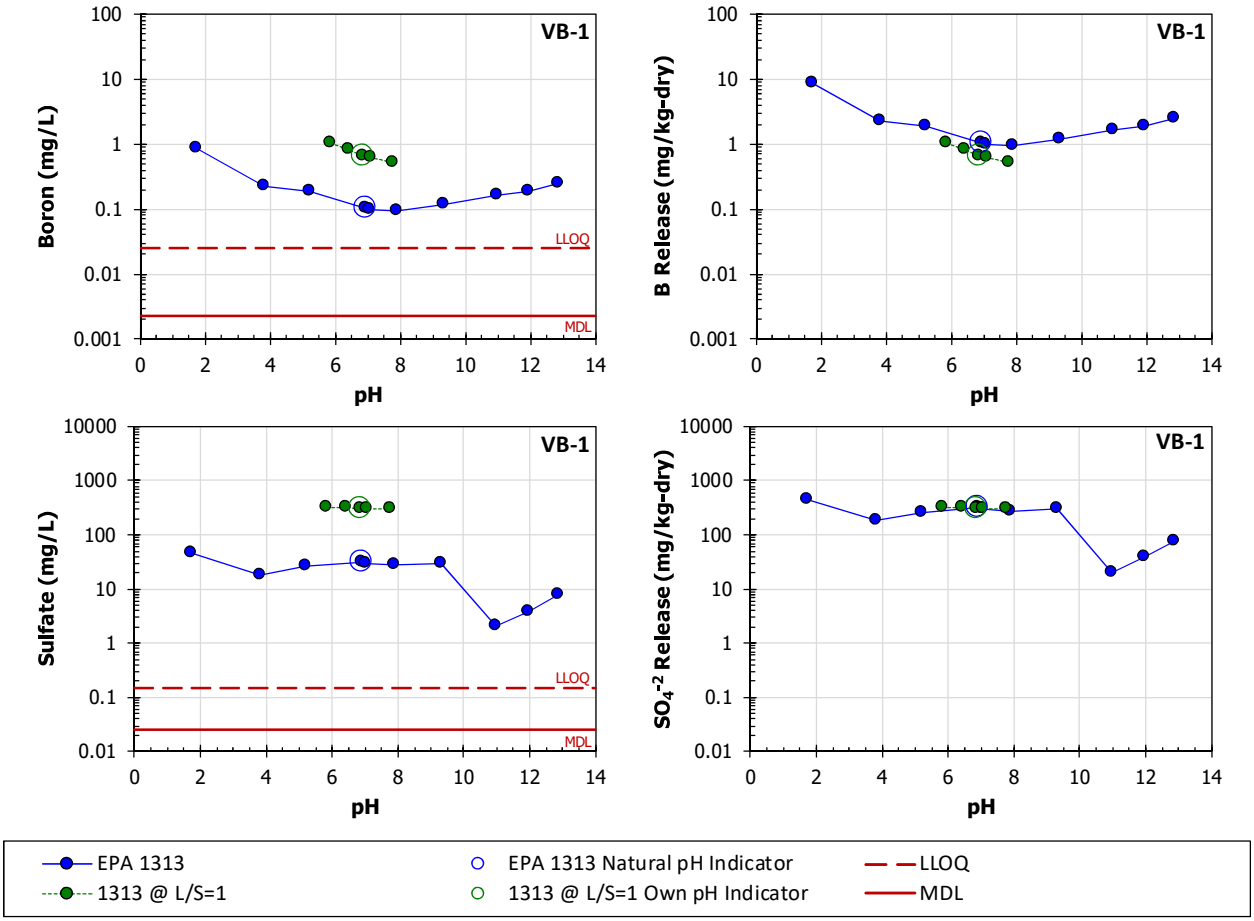

Figure 4-12
Example pH-dependent (EPA 1313) test results showing available content-limited LSP

For some constituents, the pH-dependent leaching data does not support the determination of LSP behavior, because eluate concentrations are less than the MDL for the analytical method. Figure 4-13 presents examples for Be and Li. Similar behavior was shown for Cd, Co, Cu, Fe, Ni, and Pb (Appendix D.1).

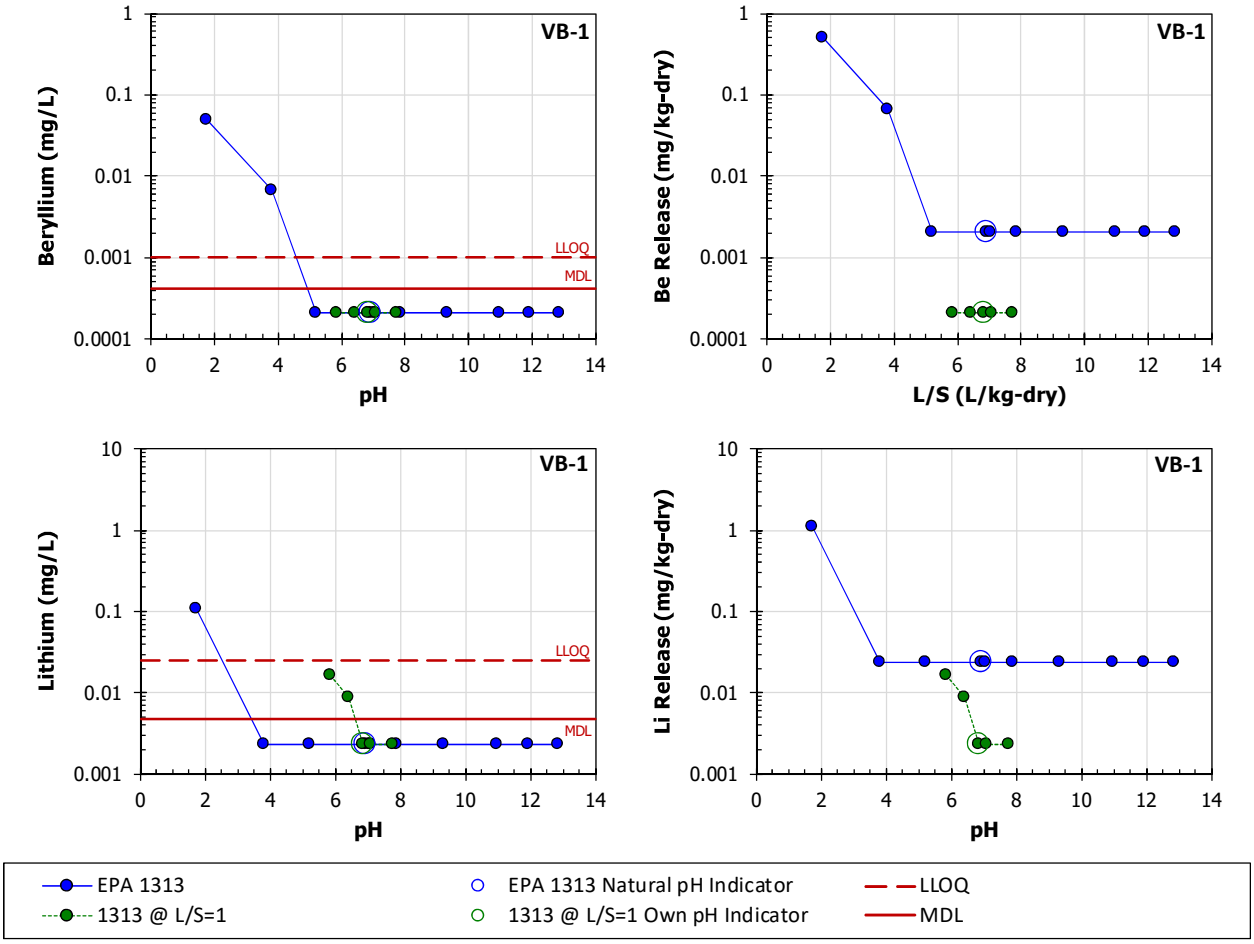

Figure 4-13
Example pH-dependent (EPA 1313) test results for constituents where LSP type could not be determined based on measured concentrations

Available Content Determination Using EPA 1313

The available content of the three borehole composites was determined from the maximum concentration over the pH range $2 \leq pH \leq 13$ from EPA 1313 testing. The available content values and pH locations for the maximum 1313 concentration are shown in Table 4-7. In Table 4-8, comparison of available content (mg/kg-dry) to the total content (mg/kg) shown in Table 4-5 indicates that only a small fraction of most constituents is leachable over a broad pH range. The high ratios of available Ca and Mg to their total content suggest either that digestion by EPA 3052 was not complete or that there is inherent error associated with multiplying a relatively small digestate concentration by a large effective L/S of 500 or more.

Table 4-7
Available Content for Composite Samples VB-1, VB-2, and VB-3 Based on the Maximum Concentration from EPA Method 1313

Analyte	Symbol	VB-1 (mg/kg-dry)	@ pH	VB-2 (mg/kg-dry)	@ pH	VB-3 (mg/kg-dry)	@ pH
Aluminum	Al	2,200	2	2,300	2	2,500	2
Antimony	Sb	0.22	13	0.15	13	0.20	13
Arsenic	As	43	13	46	13	51	13
Barium	Ba	59	2	75	2	74	2
Beryllium	Be	0.50	2	0.48	2	0.55	2
Boron	B	8.5	2	13	2	16	2
Bromide	Br^-	<0.064	NA	<0.064	NA	<0.064	NA
Cadmium	Cd	0.23	2	0.20	2	0.21	2
Calcium	Ca	1,500	2	1,800	2	1,700	2
Carbon, Inorganic	DIC	950	13	580	13	560	13
Carbon, Organic	DOC	160	13	93	13	130	13
Chloride	Cl^-	<0.064	4	<0.064	9	<0.064	7
Chromium	Cr	6.8	2	2.7	2	3.2	2
Cobalt	Co	2.2	2	0.36	2	0.35	2
Copper	Cu	12	2	11	2	52	2
Fluoride	F^-	19	2	20	2	28	2
Iron	Fe	110	2	110	2	110	2
Lead	Pb	3.6	2	0.82	2	0.99	2
Lithium	Li	1.1	2	1.3	2	1.6	2
Magnesium	Mg	290	2	280	2	320	2
Manganese	Mn	50	2	19	2	14	2
Molybdenum	Mo	3.6	13	0.48	13	0.55	13
Nickel	Ni	3.6	2	0.85	2	0.86	2
Nitrate	NO_3^-	11	12	8.3	9	3.3	9
Phosphate	PO_4^{-3}	470	2	140	2	130	2
Phosphorus	P	110	2	200	2	210	2
Potassium	K	140	2	200	2	220	2
Selenium	Se	1.4	13	0.87	13	1.5	13

Table 4-7 (continued)
Available Content for Composite Samples VB-1, VB-2, and VB-3 Based on the Maximum Concentration from EPA Method 1313

Analyte	Symbol	VB-1 (mg/kg-dry)	@ pH	VB-2 (mg/kg-dry)	@ pH	VB-3 (mg/kg-dry)	@ pH
Silicon	Si	1,400	2	1,500	2	1,400	2
Sodium	Na	31	2	36	2	35	2
Strontium	Sr	59	2	56	2	62	2
Sulfate	SO_4^{-2}	450	2	160	2	160	2
Sulfur	S	770	13	39	13	46	13
Thallium	Tl	0.74	2	0.21	2	0.27	2
Titanium	Ti	18	2	46	2	50	2
Uranium	U	1.3	2	0.38	2	0.41	2
Vanadium	V	24	2	17	2	19	2
Zinc	Zn	5.1	2	4.4	2	5.5	2

Notes: NA the target pH not available since all concentrations are less than MDL.

Table 4-8
Ratio of Available Content (EPA 1313) to Total Content (EPA 3052) for Composite Samples VB-1, VB-2, and VB-3

		Available Content / Total Content (-)		
Analyte	**Symbol**	**VB-1**	**VB-2**	**VB-3**
Aluminum	Al	0.17	0.18	0.19
Antimony	Sb	0.06 J*	0.05 J*	0.04 J*
Arsenic	As	0.47 B*	0.42 B*	0.46 B*
Barium	Ba	0.16	0.21	0.19
Beryllium	Be	0.08	0.08	0.08
Cadmium	Cd	0.10	0.18	0.12
Calcium	Ca	1.6	1.8 F1*	1.8
Chromium	Cr	0.049	0.019	0.021
Cobalt	Co	0.055	0.011	0.010
Copper	Cu	0.092	0.085	0.26
Iron	Fe	0.010	0.001	0.002
Lead	Pb	0.068	0.018	0.016
Lithium	Li	0.006	0.008	0.008
Magnesium	Mg	2.6 J*	2.5 J, F1*	2.7 J*
Manganese	Mn	0.20	0.090	0.082
Molybdenum	Mo	0.44	0.11	0.11
Nickel	Ni	0.036	0.010	0.01
Potassium	K	0.012	0.013	0.015
Selenium	Se	0.23 J*	0.20 J*	0.28 J*
Sodium	Na	0.022	0.021	0.019
Strontium	Sr	0.42	0.56 F1*	0.52
Titanium	Ti	0.002	0.006	0.006
Vanadium	V	0.10	0.071	0.073
Zinc	Zn	0.043	0.040	0.046

Notes:
- * total content data indicated an analytical anomaly (see error codes below).
- B the compound was found in the blank and sample of the total content analysis extract.
- F1 the matrix spike recovery for the total content analysis extract is outside of acceptance limits.
- J the total content result was less than the LLOQ but greater than or equal to the MDL; estimated value.

Comparison of pH-Dependent Leaching from Individual Split Spoon Samples to Composite Samples for Each Borehole

pH-dependent leaching data (EPA 1313) from composite samples was compared to laboratory extractions of individual split spoon materials to illustrate how the composite samples represented the strata of ash materials. Bulk materials collected by split spoon were homogenized within the vacuum-sealed bag prior to testing using a modified, 3-point version of EPA 1313. The 3-point version of EPA 1313 that was applied to individual split spoon samples included extractions at $1.5 \leq pH \leq 2$, the natural pH, and $pH = 9 \pm 0.5$, and the results were used as comparators to the full-range testing conducted on the composite samples. Example results are provided in Figure 4-14 and Figure 4-15 for major and trace constituents, respectively. The complete set of testing results are presented in Appendix D.2.

The data in these figures indicate the extent of agreement between individual split spoon data (individual points) and EPA 1313 testing of composites (continuous lines). The variability in leaching properties within a borehole (individual split spoons) is consistent with the laboratory and field extraction variability discussed above regarding variability of extraction tests within a borehole. The variability between composites and individual samples for trace constituents is dominated by the variability of composition for these constituents within the individual grab samples. When analyses approach quantitation limits (e.g., for trace constituents or LSP curves near the LLOQ), the variability is likely attributed to the measurement uncertainty.

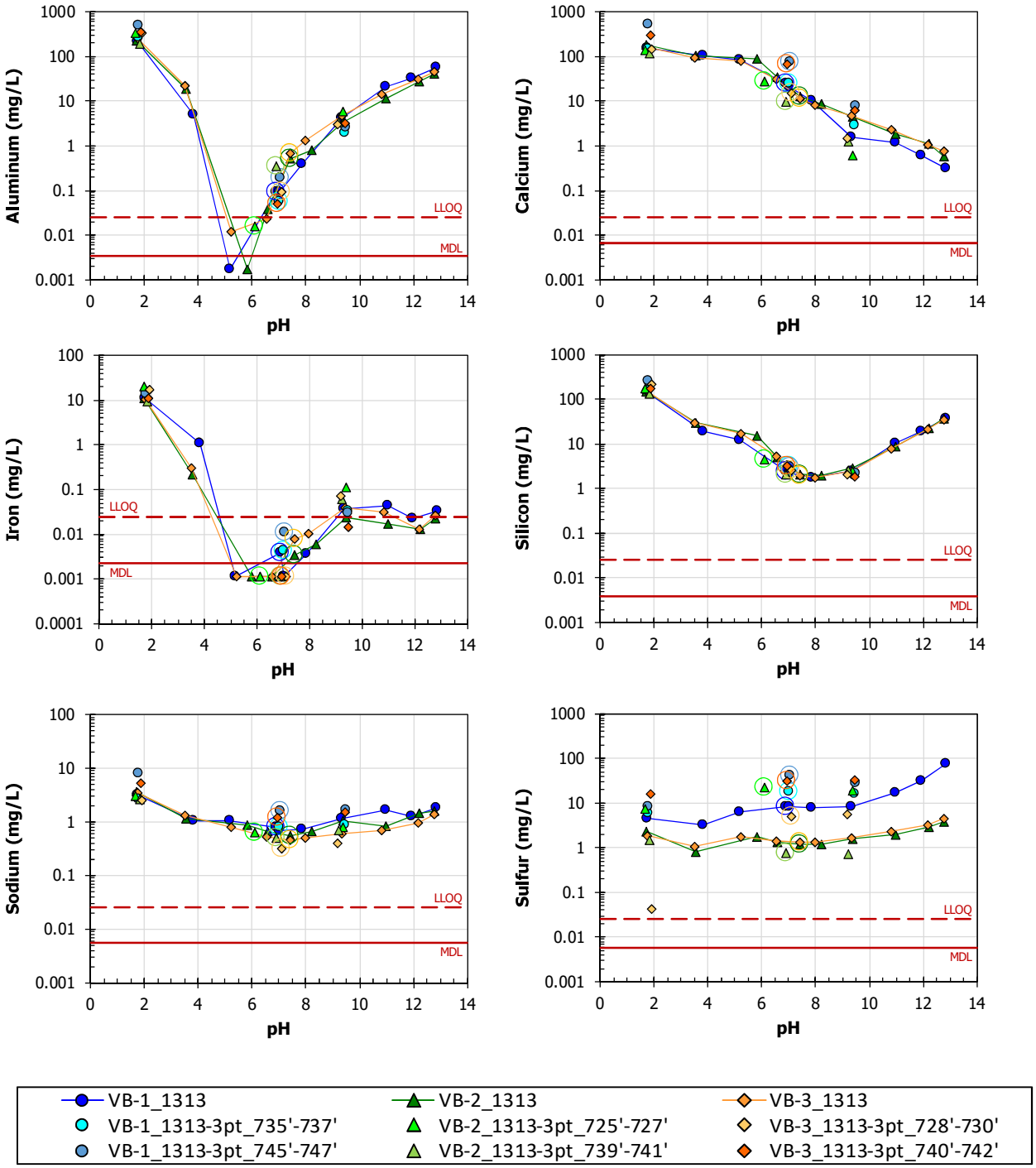

Figure 4-14
Comparison of pH-dependent leaching data for major constituents using individual split spoon samples (3-pt EPA 1313) and borehole composite materials (EPA 1313)

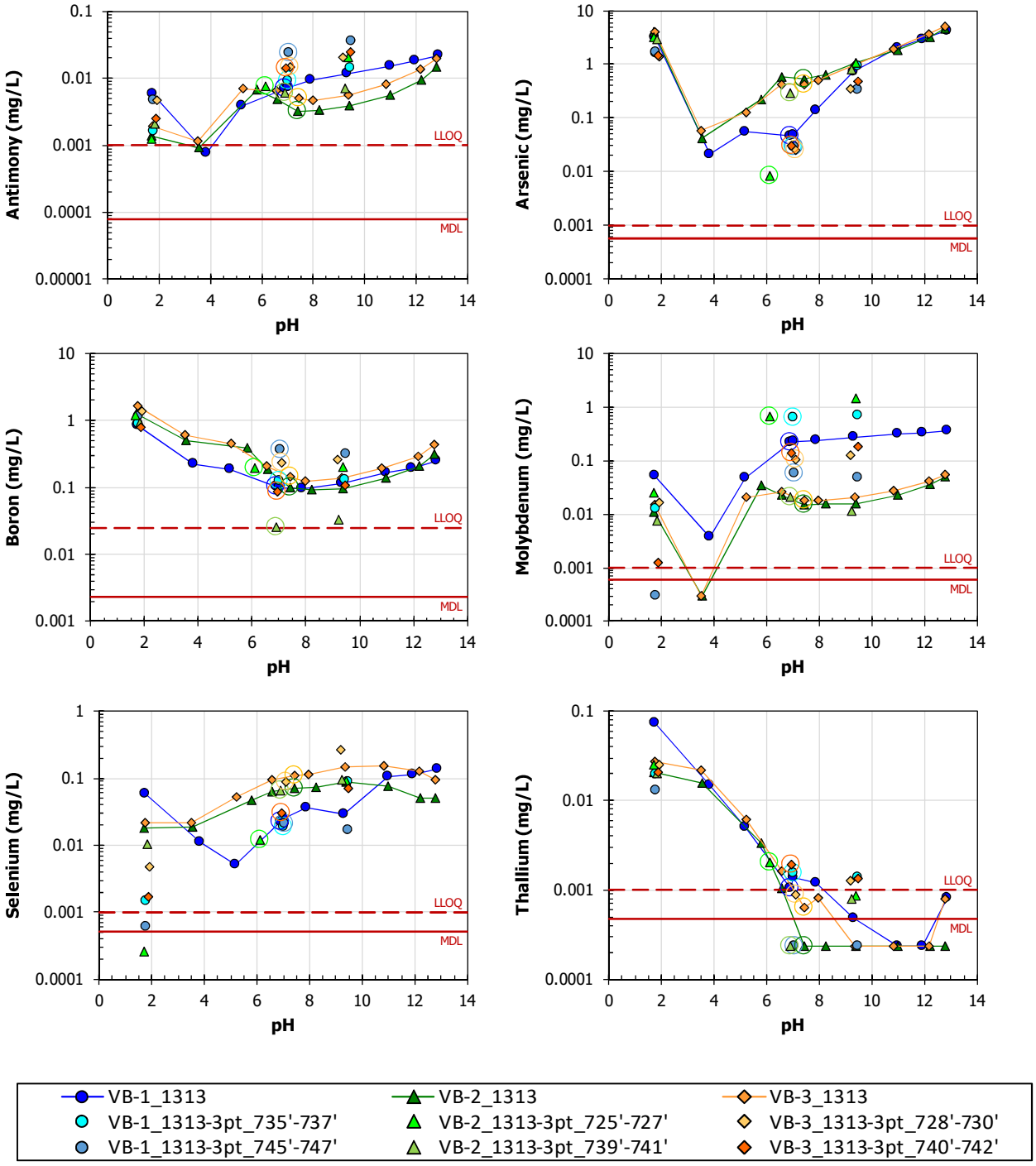

Figure 4-15
Comparison of pH-dependent leaching data for trace constituents using individual split spoon samples (3-pt EPA 1313) and borehole composite materials (EPA 1313)

L/S-Dependent Leaching Test Results

When conducted at low flow rate, the results of column tests (e.g., EPA 1314) indicate how the LSP of constituents changes as the cumulative L/S (i.e., the total amount of water passing through a column to the mass of solid in the column) increases. As soluble minerals dissolve and constituents are eluted from the material, different minerals control the release of constituents and the ionic strength of the eluate changes. In scenarios where L/S can be related to the rate of infiltration, column test data can provide an estimate of leaching concentration as a function of time (Garrabrants et al., 2019a; b).

Examples of typical L/S-dependent behavior from EPA 1314 conducted on the VB-1 composite are shown in Figure 4-16. In this figure, eluate concentration (mg/L) is presented in the left column while mass release (mg/kg-dry), determined by the accumulated interval mass released up through a cumulative L/S value, is shown in the right column. Interval mass release is calculated by multiplying the eluate concentration by the associated interval L/S value. In mass release graphs, the gray dashed line indicates the mass release proportional to the cumulative L/S expected if concentration is controlled by constant solubility.

- The eluate concentrations for Ba (Figure 4-16, top) are constant as a function of L/S and, thus, the mass release is proportional to the cumulative L/S and the mass release curve follows the solubility indicator line. This L/S-dependent behavior is consistent with a constituent that has solubility-controlled LSP. In the composites, As, F^-, Li, Sb, and V show the similar solubility-controlled LSP based on EPA 1314 data as Ba.
- For many constituents in the composite samples (Cd, Co, Cr, Ni, Se, Tl, and Zn), the L/S-dependent leaching data indicated that the constituent is quickly depleted from the matrix. For Tl (Figure 4-16, middle), the eluate concentration is a strong function of L/S but drops below the MDL when L/S increases beyond approximately L/S=3 L/kg-dry. This behavior is characteristic when the available content has been depleted.
- The L/S-dependent leaching of Cl^- (Figure 4-16, bottom) is an example of rapid release of a soluble fraction of the available content without depletion. This differs from the example behavior of Cd in that, after an initial "wash off" of a highly soluble fraction, leaching concentrations are detectable and relatively constant, suggesting a solubility-controlled fraction. Similar behavior was observed for B, Ca, Mo, and SO_4^{-2} in composite samples.
- Elements where EPA 1314 eluate concentrations were not detected include Be, Br^-, Cu, Fe, and Pb.

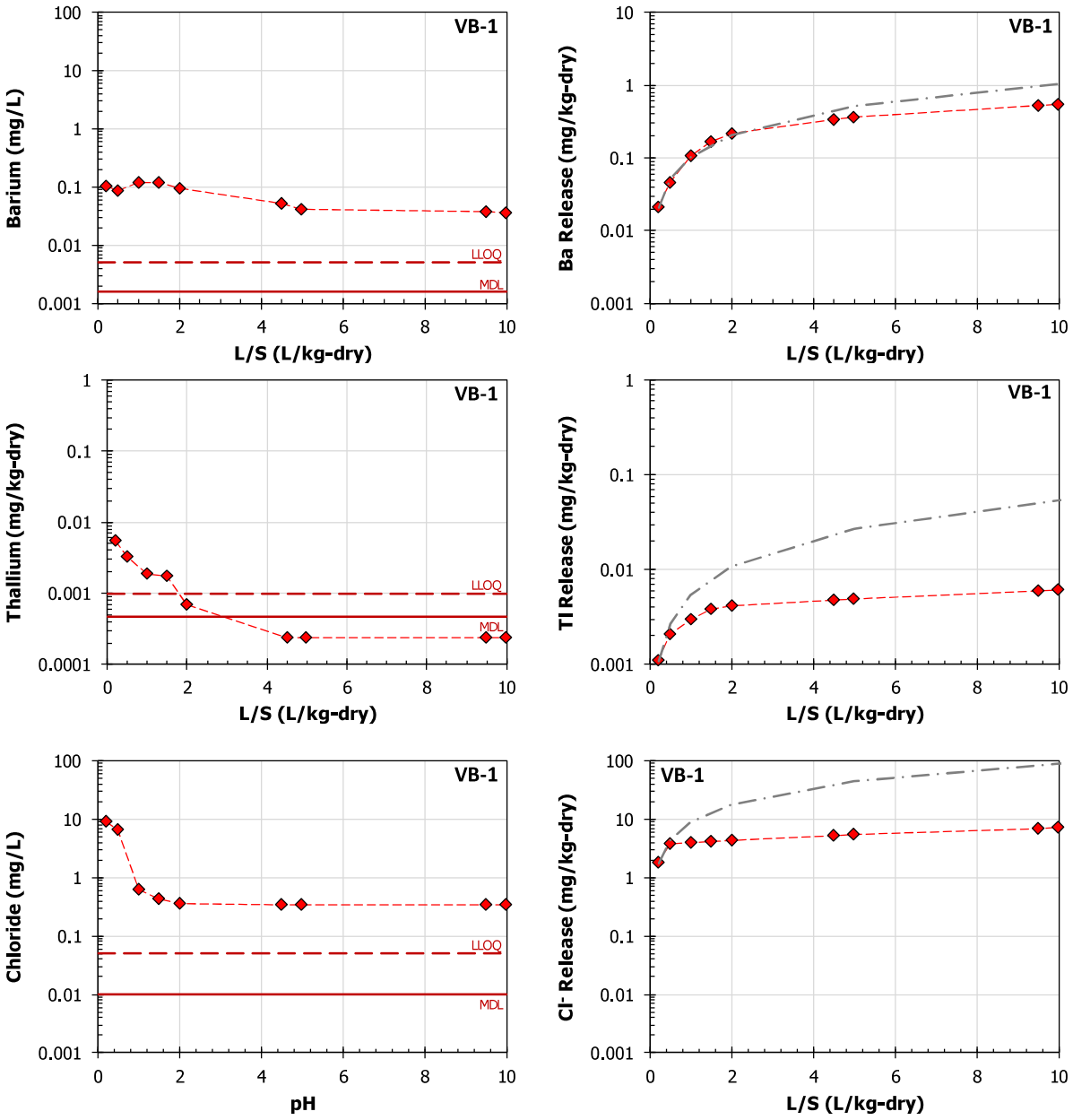

Figure 4-16
Example EPA 1314 test results from VB-1, showing a solubility-controlled constituent (barium), depletion of the available content (thallium), and wash-off of a soluble constituent fraction without depletion (chloride)

Traditional Extraction Test Results

The calculated L/S and measured pH from the extractions using the traditional leaching tests (TCLP, SPLP, and ASTM) are presented in Table 4-9.

Table 4-9
Liquid-to-Solid Ratio and Measured Extraction pH for Traditional Leaching Tests

Material	TCLP		SPLP		ASTM	
	L/S (mL/g-dry)	pH	L/S (mL/g-dry)	pH	L/S (mL/g-dry)	pH
VB-1	22.9	4.99	22.9	6.39	27.3	6.71
VB-2	22.1	5.00	22.1	6.89	28.1	7.27
VB-3	23.2	4.95	23.2	6.94	26.9	7.17

The amount of extraction fluid for ASTM is determined as the mass of the "as received" test material in grams divided by the test-specific L/S of 20 mL/g. The resultant L/S on a dry basis is greater than 20 because of the water inherent in the pores of the "as received" material. The procedures for TCLP and SPLP require a pressure filtration preconditioning of the test sample to remove excess liquid, which is analyzed separately. The extraction fluid is based on the mass of pressure-filtered solid material in grams divided by the same L/S of 20 mL/g. Therefore, the calculated L/S for TCLP and SPLP is lower than the L/S for the ASTM test that includes extra water.

The measured pH for ASTM, which uses DIW as an extraction fluid, is consistent with the natural pH (1313) and own pH (1313_L/S1) of the composites at VB-1, VB-2, and VB-3 reported in Table 4-6. The slight decrease in ASTM extraction pH compared to the natural pH (e.g., VB-1 pH_{ASTM}=6.71 versus pH_{Nat}= 6.91) may be attributed to the higher ASTM extraction L/S. For SPLP, the measured pH is slightly lower than the ASTM pH, consistent with the small amount of acid used in the extraction fluid. The stability of the measured pH for TCLP extracts across different composites reflects the buffering provided by the organic acetic acid.

The eluate constituent concentrations for TCLP, SPLP, and ASTM tests are presented in Table 4-10, Table 4-11, and Table 4-12, respectively. Since pH is an important factor for solubility-controlled LSP, these tables also include the final eluate pH. Recording of eluate pH allows for comparison of the results of these traditional tests to the pH- and L/S-dependent LEAF test results. In general, SPLP and ASTM concentrations were comparable to each other but were lower than TCLP concentrations due to the lower pH of TCLP eluates. Exceptions for this site (which may not be generalizable) include As, Mo, and SO_4^{-2}, where similar concentrations were measured in all three procedures, and PO_4^{-2}, Se, and V, where SPLP and ASTM eluates had higher concentration than TCLP eluates. All of these observations are consistent with the pH-dependent LSP curves discussed above.

Table 4-10
TCLP (EPA Method 1311) Eluate Concentrations

Analyte	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**4.99**	**5.00**	**4.95**
Aluminum	Al	0.90	0.78	0.89
Antimony	Sb	0.0038	0.0033	0.0047
Arsenic	As	0.055	0.18	0.17
Barium	Ba	2.0	2.1	2.0
Beryllium	Be	0.0015	0.00085 J	0.00084 J
Boron	B	0.37	0.47	0.48
Bromide	Br^-	ND	ND	ND
Cadmium	Cd	0.0039	0.0035	0.0040
Calcium	Ca	47	57	40
Carbon, Inorganic	DIC	0.19	0.24	0.22
Carbon, Organic	DOC	2,600	2,600	2,600
Chloride	Cl^-	640	640	630
Chromium	Cr	0.0026	0.0063	0.0085
Cobalt	Co	0.029	0.0066	0.0054
Copper	Cu	0.36	0.093	0.93
Fluoride	F^-	ND	ND	ND
Iron	Fe	0.028	0.0047 J	0.0028 J
Lead	Pb	ND	ND	ND
Lithium	Li	ND	ND	ND
Magnesium	Mg	7.6	5.0	3.2
Manganese	Mn	1.6	0.48	0.32
Molybdenum	Mo	0.024	0.0075	0.0084
Nickel	Ni	0.021	0.0042	0.0061
Nitrate	NO_3^-	1.9	2.0	1.8
Phosphate	PO_4^{-3}	ND	ND	ND
Phosphorus	P	0.030	0.15	0.13
Potassium	K	2.8	2.7	2.9
Selenium	Se	0.0033	0.011	0.019

Table 4-10 (continued)
TCLP (EPA Method 1311) Eluate Concentrations

Analyte	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**4.99**	**5.00**	**4.95**
Silicon	Si	7.0	11	10
Sodium	Na	590	580	590
Strontium	Sr	1.0	1.2	1.4
Sulfate	SO_4^{-2}	10	8.4	7.9
Sulfur	S	2.2	0.84	1.3
Thallium	Tl	0.0072	0.0059	0.0087
Titanium	Ti	ND	ND	0.015 J
Uranium	U	0.0061	0.0028	0.0054
Vanadium	V	0.010	0.012	0.020
Zinc	Zn	0.36	0.39	0.40

Notes: J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.

ND the compound was not detected at a concentration above the MDL.

Table 4-11
SPLP (EPA Method 1312) Eluate Concentrations

COPC	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**6.39**	**6.89**	**6.94**
Aluminum	Al	0.0080 J	0.23	0.20
Antimony	Sb	0.0020	0.0015	0.0025
Arsenic	As	0.027	0.21	0.16
Barium	Ba	0.19	0.12	0.13
Beryllium	Be	ND	ND	ND
Boron	B	0.084	0.097	0.11
Bromide	Br^-	ND	ND	ND
Cadmium	Cd	ND	ND	ND
Calcium	Ca	13	11	9.2
Carbon, Inorganic	DIC	2.2	3.9	3.4
Carbon, Organic	DOC	2.1	3.6	2.9
Chloride	Cl^-	1.9	1.8	2.2
Chromium	Cr	ND	ND	ND

Table 4-11 (continued)
SPLP (EPA Method 1312) Eluate Concentrations

COPC	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**6.39**	**6.89**	**6.94**
Cobalt	Co	ND	ND	ND
Copper	Cu	ND	ND	ND
Fluoride	F^-	ND	ND	ND
Iron	Fe	ND	ND	ND
Lead	Pb	ND	ND	ND
Lithium	Li	ND	ND	ND
Magnesium	Mg	0.65	0.54	0.57
Manganese	Mn	0.015 J	0.0044 J	0.0067 J
Molybdenum	Mo	0.038	0.0077	0.0091
Nickel	Ni	ND	ND	ND
Nitrate	NO_3^-	6.0	5.9	6.5
Phosphate	PO_4^{-3}	ND	0.32	0.18
Phosphorus	P	0.019 J	0.083	0.052
Potassium	K	0.32	0.33	0.34
Selenium	Se	0.20	0.042	0.056
Silicon	Si	1.5	1.2	1.2
Sodium	Na	0.64	0.58	0.34
Strontium	Sr	0.37	0.40	0.42
Sulfate	SO_4^{-2}	13	4.7	7.1
Sulfur	S	4.4	1.6	2.0
Thallium	Tl	ND	ND	ND
Titanium	Ti	ND	ND	ND
Uranium	U	ND	ND	ND
Vanadium	V	0.016	0.038	0.042
Zinc	Zn	ND	ND	ND

Notes: J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.
ND the compound was not detected at a concentration above the MDL.

Table 4-12
ASTM (ASTM D3987) Eluate Concentrations

COPC	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**6.71**	**7.27**	**7.17**
Aluminum	Al	ND	0.24	0.26
Antimony	Sb	0.0019	0.0011	0.0022
Arsenic	As	0.029	0.17	0.15
Barium	Ba	0.19	0.11	0.12
Beryllium	Be	ND	ND	ND
Boron	B	0.041	0.046	0.060
Bromide	Br^-	ND	ND	ND
Cadmium	Cd	ND	ND	ND
Calcium	Ca	11	8.3	7.2
Carbon, Inorganic	DIC	5.7	6.7	6.6
Carbon, Organic	DOC	2.5	3.9	3.5
Chloride	Cl^-	0.40	0.513	ND
Chromium	Cr	ND	ND	ND
Cobalt	Co	ND	ND	ND
Copper	Cu	ND	ND	ND
Fluoride	F^-	ND	ND	ND
Iron	Fe	ND	ND	ND
Lead	Pb	ND	ND	ND
Lithium	Li	ND	ND	ND
Magnesium	Mg	0.81	0.65	0.66
Manganese	Mn	0.014 J	0.0038 J	0.0061 J
Molybdenum	Mo	0.041	0.0058	0.0089
Nickel	Ni	ND	ND	ND
Nitrate	NO_3^-	0.12	0.15	0.17
Phosphate	PO_4^{-3}	0.082 J	0.26	0.16
Phosphorus	P	0.021 J	0.068	0.045
Potassium	K	0.37	0.34	0.36
Selenium	Se	0.024	0.029	0.050

Table 4-12 (continued)
ASTM (ASTM D3987) Eluate Concentrations

COPC	Symbol	VB-1 (mg/L)	VB-2 (mg/L)	VB-3 (mg/L)
	pH	**6.71**	**7.27**	**7.17**
Silicon	Si	1.5	1.0	1.2
Sodium	Na	0.67	0.50	0.46
Strontium	Sr	0.36	0.33	0.37
Sulfate	SO_4^{-2}	19	5.1	4.5
Sulfur	S	15	1.8	1.6
Thallium	Tl	ND	ND	ND
Titanium	Ti	ND	ND	ND
Uranium	U	ND	0.00056 J	0.00052 J
Vanadium	V	0.017	0.030	0.038
Zinc	Zn	ND	ND	ND

Notes: J the result is less than the LLOQ but greater than or equal to the MDL; estimated concentration.

ND the compound was not detected at a concentration above the MDL.

Comparison of Traditional and LEAF Test Results

When the pH and L/S of leaching tests are recorded, the test results from different leaching tests can be compared based on pH- or L/S-dependence. An example comparison is shown in Figure 4-17 for SO_4^{-2} leaching from the VB-1 composite. Similar comparisons for all constituents are presented in Appendix E.

Figure 4-17 presents data as a function of pH on the left and as a function of L/S on the right. For a constituent with available content-limited LSP, for example sulfate, the traditional leaching test data are consistent with LEAF test results considering the shift in pH (TCLP) and the higher L/S for the traditional tests.

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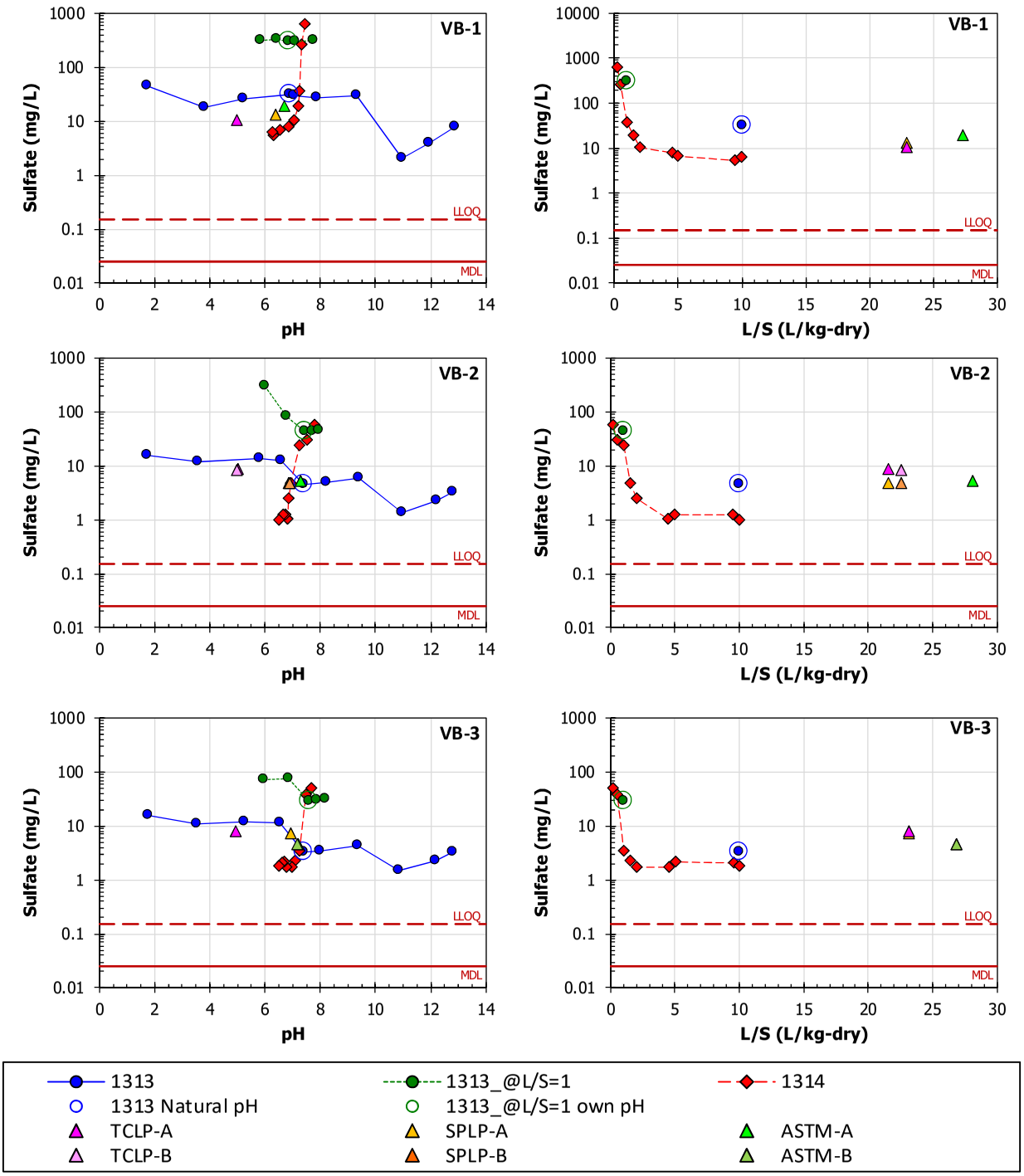

Figure 4-17
Comparison of sulfate concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

Groundwater, Porewater, and Subsurface Gas Monitoring

Measured field parameters for groundwater and porewater sampling as well as graphical presentation of groundwater and porewater concentrations are provided in Appendix F.1. These data represent the sampling period from September 2018 through September 2019.

Groundwater and Porewater Field Parameters

Plots of field measurements are shown in Figure 4-18 and Figure 4-19. Within each bar chart, data for groundwater sampled at the upgradient well (AD1) and downgradient well (6AR) are shown in light and dark gray, respectively, while data for porewater from the PAPs (VB-1, VB-2, and VB-3) are shown as blue, green, and gold bars, respectively.

The data in Figure 4-18 show that the water table elevation, pH, and electrical conductivity remain relatively constant over time at each sample point. No samples were collected in November due to a scheduling conflict. The mean water table at the upgradient well (773.4 ft AMSL) is approximately 30 feet higher in elevation than the mean water table of the three PAPs (741.6 ft AMSL) or the mean water table at the downgradient well (738.5 ft AMSL). The pH of the groundwater at the upgradient well is somewhat more alkaline ($pH_{ave\text{-}AD1}$=8.6±0.2) than the porewater in the PAPs ($pH_{ave\text{-}VB\text{-}1}$=8.1±0.1, $pH_{ave\text{-}VB\text{-}2}$=7.8±0.5, $pH_{ave\text{-}VB\text{-}3}$=7.7±0.4) and considerably more alkaline than in the downgradient well ($pH_{ave\text{-}6AR}$=4.8±0.1).

Figure 4-19 presents measured values of water temperature, ORP, and DO. Of these, water temperature and ORP show a seasonal trend. The decrease in ORP in the late summer and fall months may indicate an increase in biological activity. Although there is significant variability in the measured value, the mean dissolved oxygen in the downgradient well ($DO_{ave\text{-}6AR}$=1.0±0.5 mg/L) is somewhat lower than in the PAPs ($DO_{ave\text{-}VB\text{-}1}$=1.4±0.7 mg/L, $DO_{ave\text{-}VB\text{-}2}$=1.4±0.4 mg/L, $DO_{ave\text{-}VB\text{-}3}$=1.7±0.3 mg/L) and notably lower than in the upgradient well ($DO_{ave\text{-}AD1}$=2.6±0.5 mg/L). The expected value for dissolved oxygen at equilibrium with atmospheric oxygen at a temperature of 20 ºC is approximately 9.1 mg/L (USGS, 1998).

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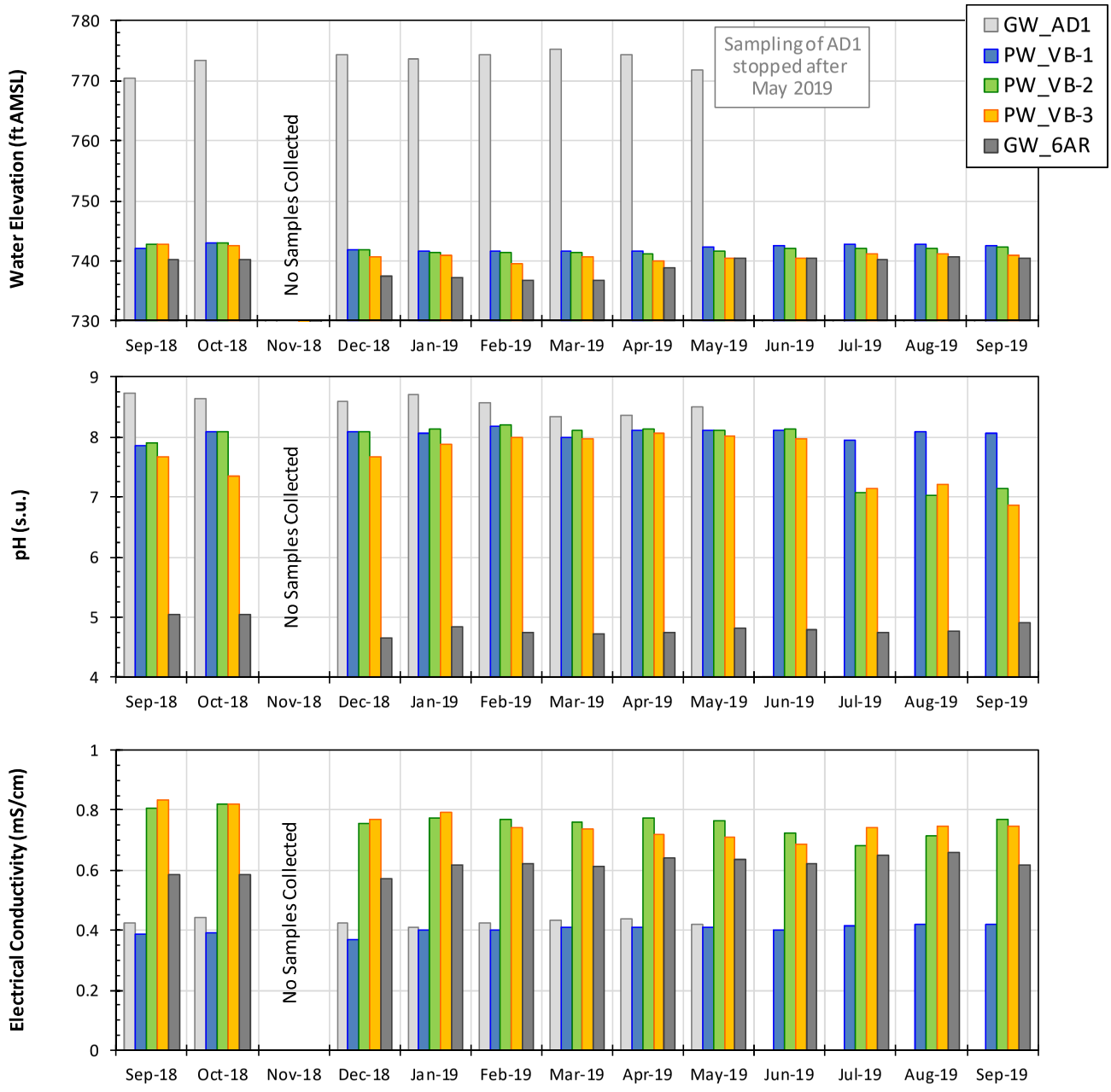

Figure 4-18
Groundwater and porewater field parameters from monthly sampling (elevation, pH, and EC)

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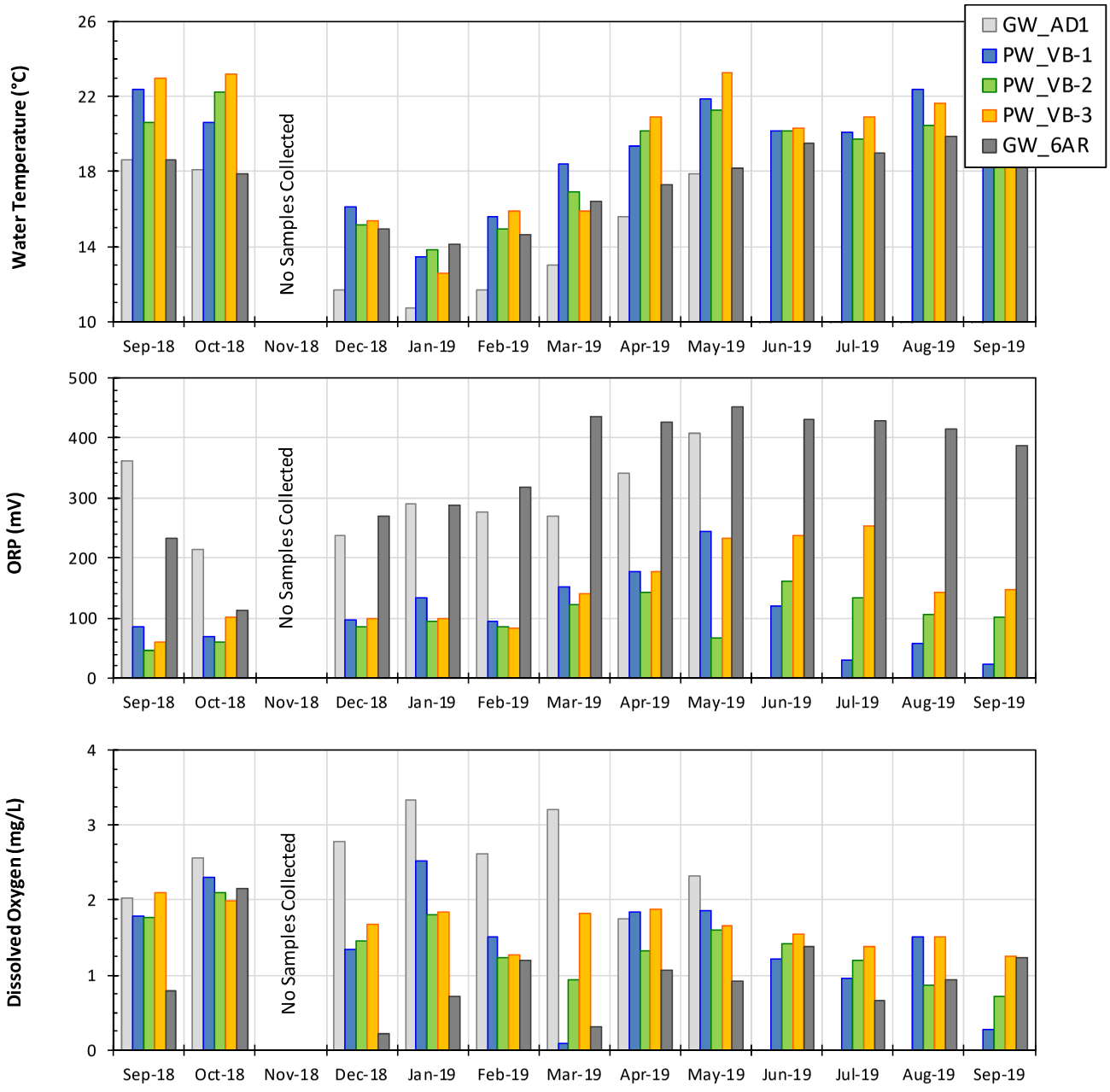

Figure 4-19
Groundwater and porewater field parameters from monthly sampling (temperature, ORP, and DO)

Concentrations in Groundwater and Porewater

Monthly analysis of groundwater wells and PAPs focused on 22 constituents, including 17 from 40 CFR 257 (As, B, Ba, Be, Ca, Cd, Cl^-, Co, Cr, F^-, Li, Mo, Pb, Sb, Se, SO_4^{-2} and Tl). Five additional constituents that were analyzed were Cu, Fe, Ni, V, and Zn. Examples of the results for selected constituents are presented in Figure 4-20 and Figure 4-21, while the graphical results for all 22 constituents are presented after the field parameter data tables in Appendix F.1.

Overall, concentrations in the downgradient groundwater well at 6AR are relatively low. A comprehensive review of impacts to groundwater based on one downgradient well (6AR) and one upgradient well (AD1) is not sufficiently robust to determine with confidence whether or not the groundwater quality at 6AR represents a release from the closed impoundment. Therefore, the discussion that follows allows for either possibility as the relationship between porewater and downgradient groundwater is explored. Table 4-13 groups the observed concentrations from monthly analysis to express the relationships between groundwater across the site (6AR vs. AD1) and porewater concentrations relative to downgradient groundwater (PAPs vs. 6AR). Of the 22 constituents analyzed, Pb, Sb, Tl, and V are not included in the table because the concentrations of these constituents were below the MDL in both porewater and groundwater.

Table 4-13
Relationships Between Upgradient Groundwater (AD1), Downgradient Groundwater (6AR), and Porewater at PAPs (VB-1, VB-2, and VB-3)

	Downgradient > Upgradient	**Downgradient ≤ Upgradient**
Porewater < Downgradient	Be**, Cd, Cr, Co, Fe,Ni, Se**, SO_4^{-2}, Zn	none
Porewater > Downgradient	B, Ca, Cl^-, Li	As*, Ba, Cu*, F^-, Mo*

Notes
* Indicates that groundwater concentrations mostly below the MDL
** Indicates that porewater concentrations all below the MDL

The following are observations from this review.

- Nine constituents (Be, Cd, Cr, Co, Fe, Ni, Se, SO_4^{-2}, and Zn) have higher concentrations in the downgradient monitoring well than in the upgradient background well, suggesting that there is a source for these constituents affecting the downgradient groundwater. However, these nine constituents also have higher concentrations in the downgradient well than in the porewater (e.g., Cd, Co, and Se in Figure 4-20), suggesting that porewater from the dewatered impoundment is not the primary source of the observed downgradient groundwater concentration. These observations suggest limited relationship between the recent porewater concentration and the downgradient groundwater concentrations at this site.
- Five constituents (As, Ba, Cu, F^-, and Mo) have higher concentration in porewater than in the downgradient monitoring well, suggesting that porewater has the potential to affect downgradient groundwater quality. However, the downgradient monitoring well has a concentration that is similar to or lower than concentrations in the upgradient monitoring well (e.g., As and F^- in Figure 4-21), indicating no change in groundwater quality for these constituents. Furthermore, porewater concentrations for As, F^-, and Mo are orders-of-magnitude higher than in the upgradient monitoring well, yet there is no increase in downgradient concentration relative to the upgradient well. These data suggest limited relationship between porewater and downgradient concentrations at this site.
- Four constituents (B, Ca, Cl^-, Li) have higher concentration in porewater than in downgradient groundwater, and higher concentrations in downgradient groundwater than in upgradient groundwater (e.g., B in Figure 4-21), suggesting a possible relationship between

the concentration in the ash deposit porewater and the concentration of groundwater in the downgradient well for these constituents. Furthermore, all four of these constituents may be considered indicators of coal ash leachate, but only B and Cl^- can be considered reasonably non-interacting with materials underlying the ash deposit.

The overall temporal means of porewater concentrations for B and Cl^- were calculated and compared to the difference in the temporal means of groundwater concentrations (i.e., temporal mean at 6AR minus temporal mean at AD1). If porewater concentrations can be used as an indicator of downgradient groundwater concentrations, this ratio should be similar between constituents. At VB-2, the closest PAP to the downgradient well at 6AR,[2] the ratios for B and Cl^- were both 2.8, indicating a potential relationship. In contrast, the same ratio for Ca was lower (1.4), while the ratio for Li was significantly higher (12). Increased Ca in the downgradient groundwater monitoring well relative to the upgradient well may be a consequence of the change in groundwater pH from ca. 8.5 to 4.5 and equilibrium with aquifer solids and/or influence from the ash porewater in conjunction with cation exchange and sorption within the aquifer. Similarly, increased Li concentrations may be a result of the change in groundwater pH or other influences, as well as uncertainty because the lithium concentrations in downgradient groundwater are near, and in some samples below, analytical method quantitation limits.

Overall, these observations indicate that porewater concentrations are unreliable as an indicator of whether or not a constituent will have an elevated downgradient concentration relative to upgradient groundwater. B and Cl^- are considered conservative ions, and the similar ratios suggest that these constituents can be tracers for evaluation of porewater migration into groundwater. However, porewater concentrations are not predictors of future groundwater concentrations because of the potential for rapid attenuation in proximity to the boundary of the disposal unit.

[2] These ratios do not vary significantly if all three PAPs are averaged.

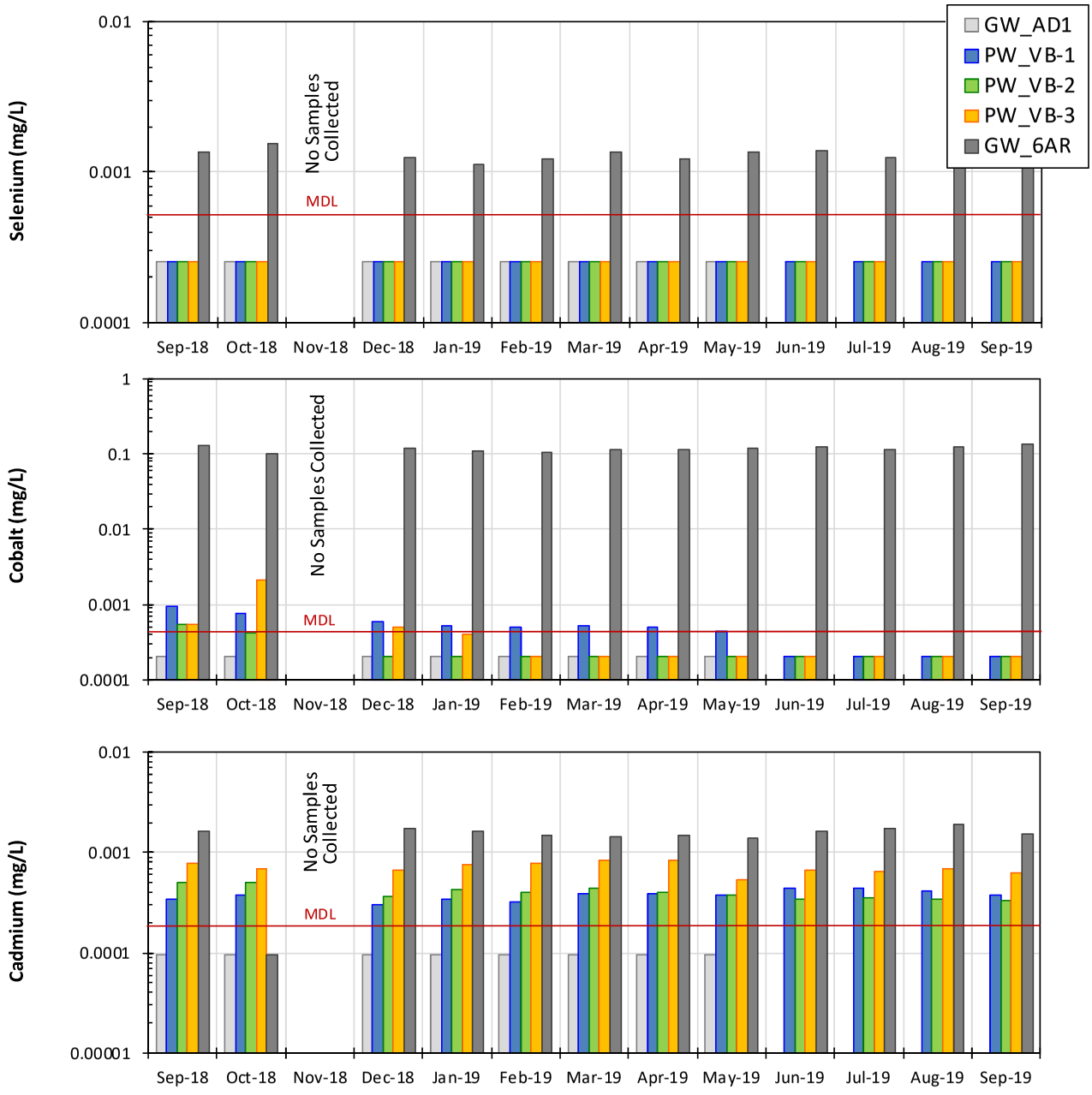

Figure 4-20
Groundwater and porewater monitoring from monthly sampling showing lower concentrations in ash deposit porewater (VB-1, VB-2, and VB-3) than in downgradient groundwater (6AR) (monitoring at AD1 was discontinued after May 2019)

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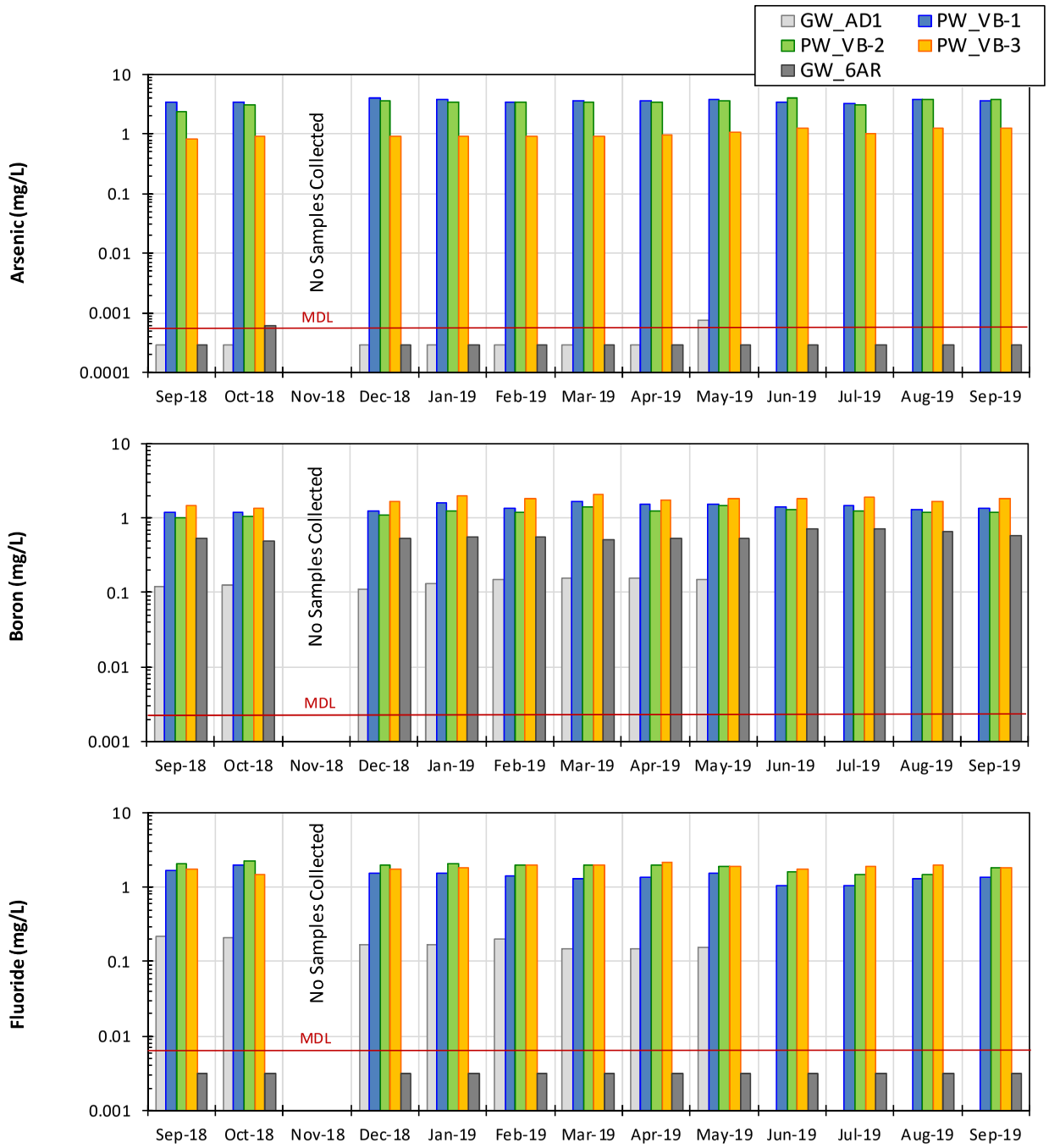

Figure 4-21
Groundwater and porewater monitoring from monthly sampling showing relatively higher concentrations in ash deposit porewater (VB-1, VB-2, and VB-3) than in groundwater (AD1 and 6AR) (monitoring at AD1 was discontinued after May 2019)

Variability in Porewater Concentrations

The temporal variability data for porewater parameters from monthly monitoring are presented as time-series plots as a function of date. The shapes of the time series show which porewater properties are relatively constant over the 13 months of sampling and which samples vary with

time. Time-series graphs for porewater parameters and constituents are presented in Appendix F.2. Examples of parameters showing temporal variability are presented in Figure 4-22 and Figure 4-23. In these figures, variability may be preliminarily attributed to one or more of several factors including (i) seasonal changes (e.g., temperature, redox conditions as seen by pH+pE; Figure 4-22), (ii) groundwater level changes due to infiltration and river intrusion (e.g., porewater level, decrease in pH of VB-2 and VB-3 during late summer 2019; Figure 4-22), and (iii) changing conditions shortly after closure of the impoundment (e.g., variability in cobalt, copper, iron, nickel, and zinc in VB-3 porewater during the summer of 2018; Appendix F.2). In comparison, many parameters remain relatively constant throughout this brief monitoring period (e.g., As, B, and Mo; Figure 4-23).

Concentrations from a PAP were deemed higher than other PAPs if consistently higher by a factor of 3 to 5 or more during all sample events. Overall, there was no pattern to spatial variability that applied to all monitored constituents, and concentrations between PAPs were usually within a factor of 10. However, there were patterns that were evident by element as listed below:

- No variability, all non-detect: Sb, Be, Pb, Se, Tl, V
- Little variability between PAPs: Ba, B, Ca, Cl, Cr, Co, Cu, F^-
- VB-1 and VB-2 consistently higher than VB-3: As, Li
- VB-3 consistently higher than VB-1 and VB-2: Cd, Fe, Mo, Ni, Zn
- VB-2 and VB-3 consistently higher than VB-1: SO_4

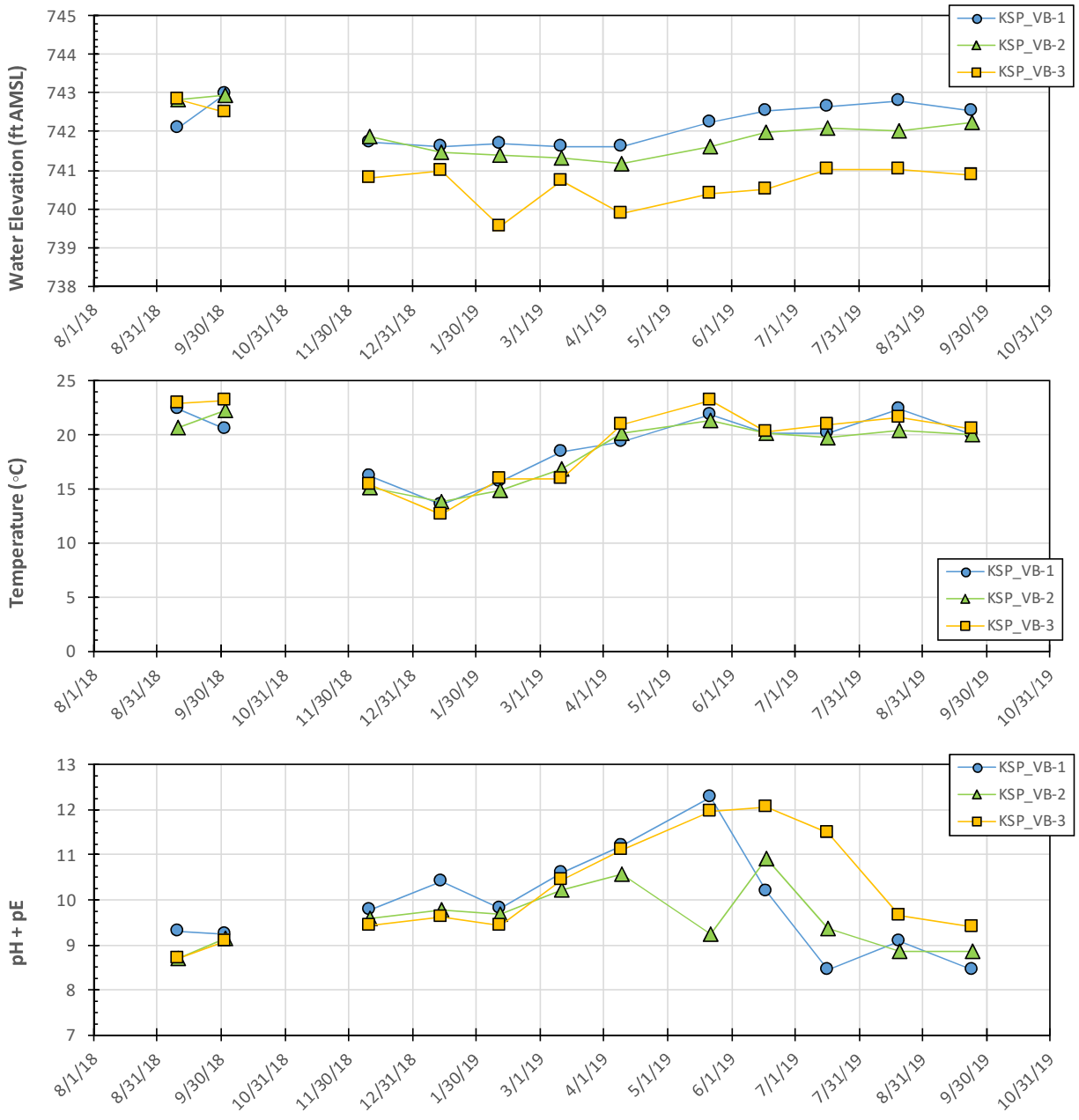

Figure 4-22
Example temporal porewater data showing seasonal or other variability: elevation, temperature, and pH+pE

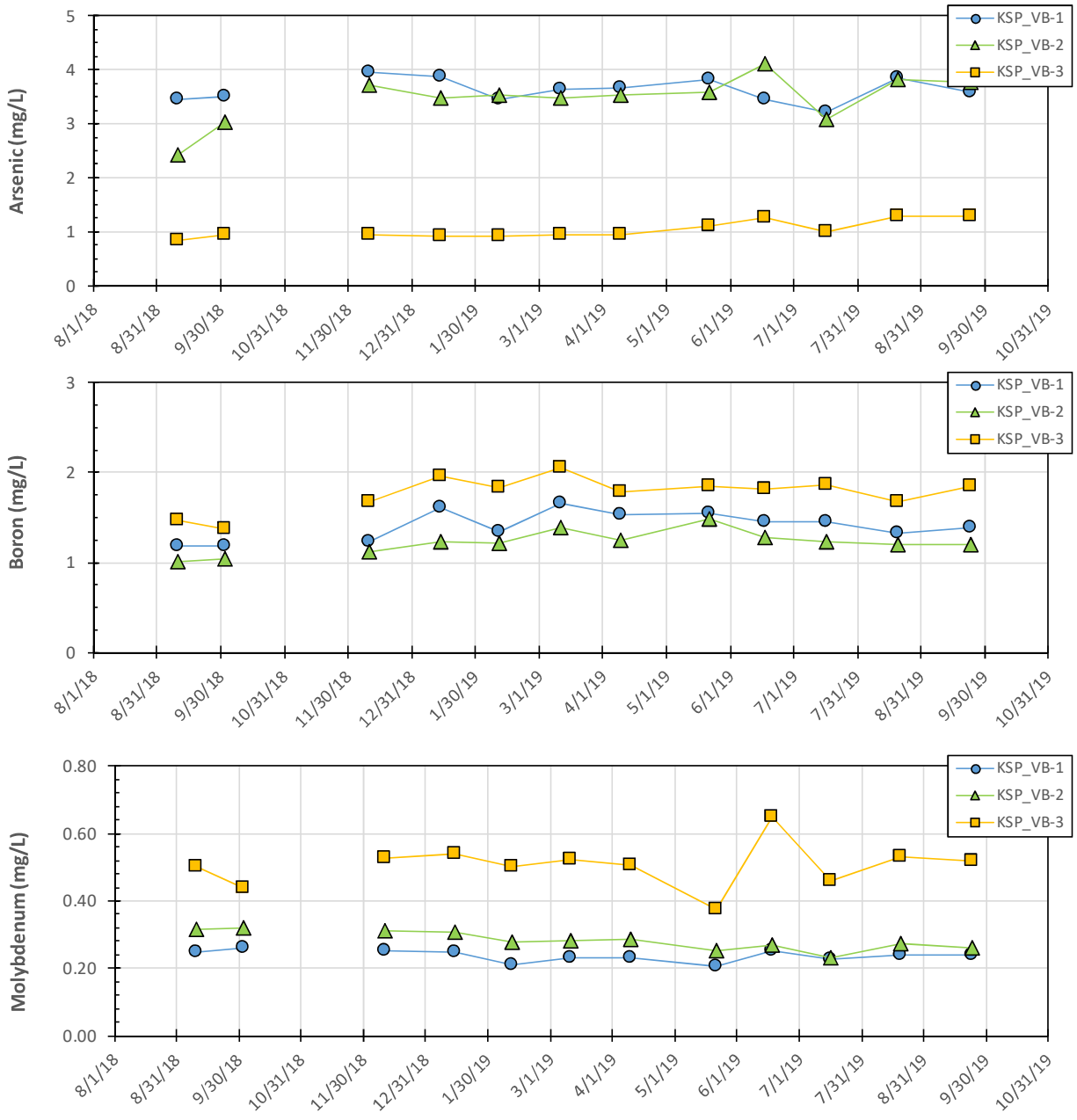

Figure 4-23
Example temporal porewater data showing relatively constant conditions: arsenic, boron, and molybdenum

Subsurface Gas Monitoring

The O_2, CO_2, CH_4, NH_4, and H_2S concentrations were measured in the three GAPs as presented in Figure 4-24 and Figure 4-25. Full tabular data for subsurface monitoring are presented along with graphical comparisons in Appendix F.3. Oxygen levels in the closed impoundment have been typically much less than in air, while CO_2 and CH_4 concentrations are often greater than the calibration limit of 5%. The concentrations of NH_4 and H_2S are sporadic but indicate elevated

concentrations up to 5 ppm for NH_4 and 30 ppm for H_2S. In general, these subsurface gas measurements imply a significant amount of biological activity that results in a stronger chemical reducing environment than indicated by the DO and ORP of the porewater samples.

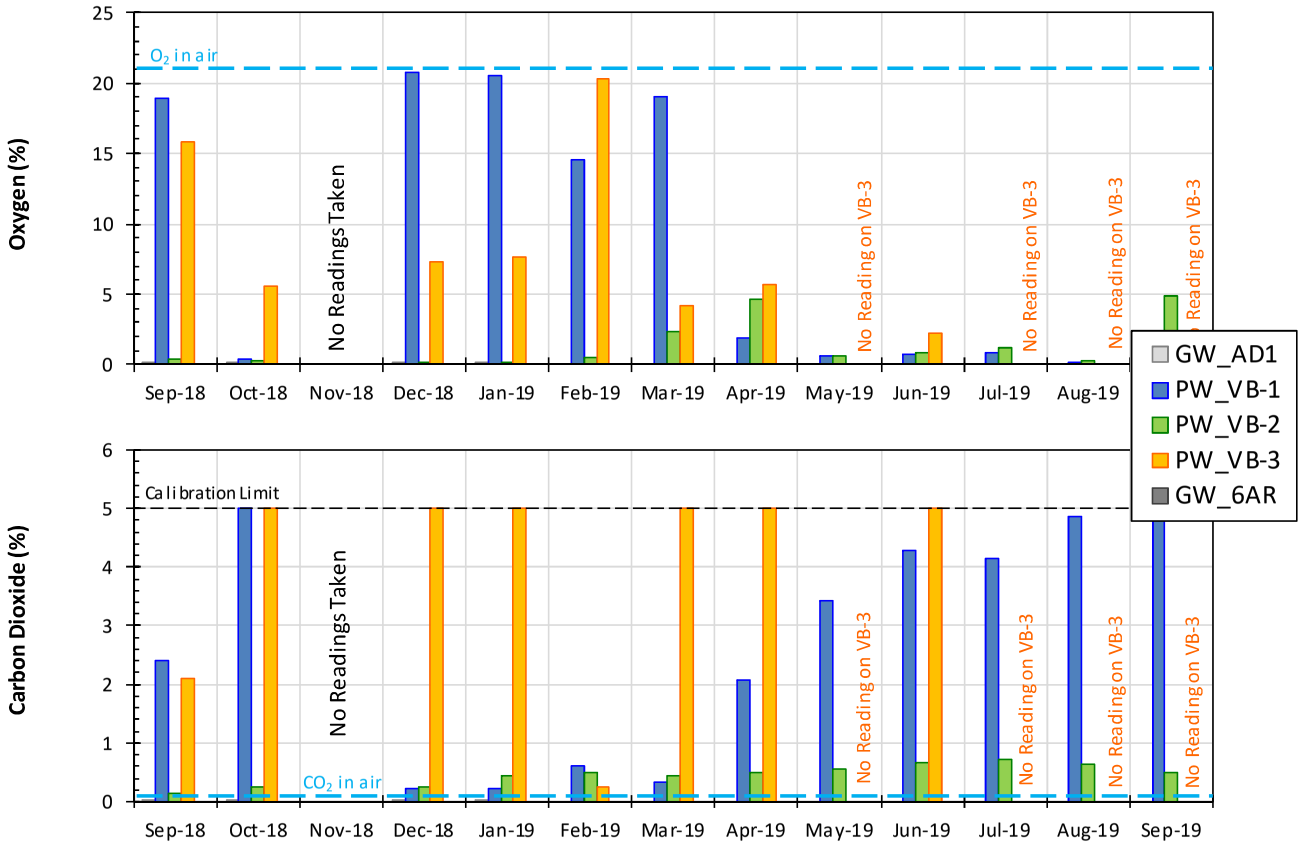

Figure 4-24
Concentration (%) of oxygen (O_2) and carbon dioxide (CO_2) from GAPs (VB-1, VB-2, and VB-3) in the subsurface of the closed ash impoundment

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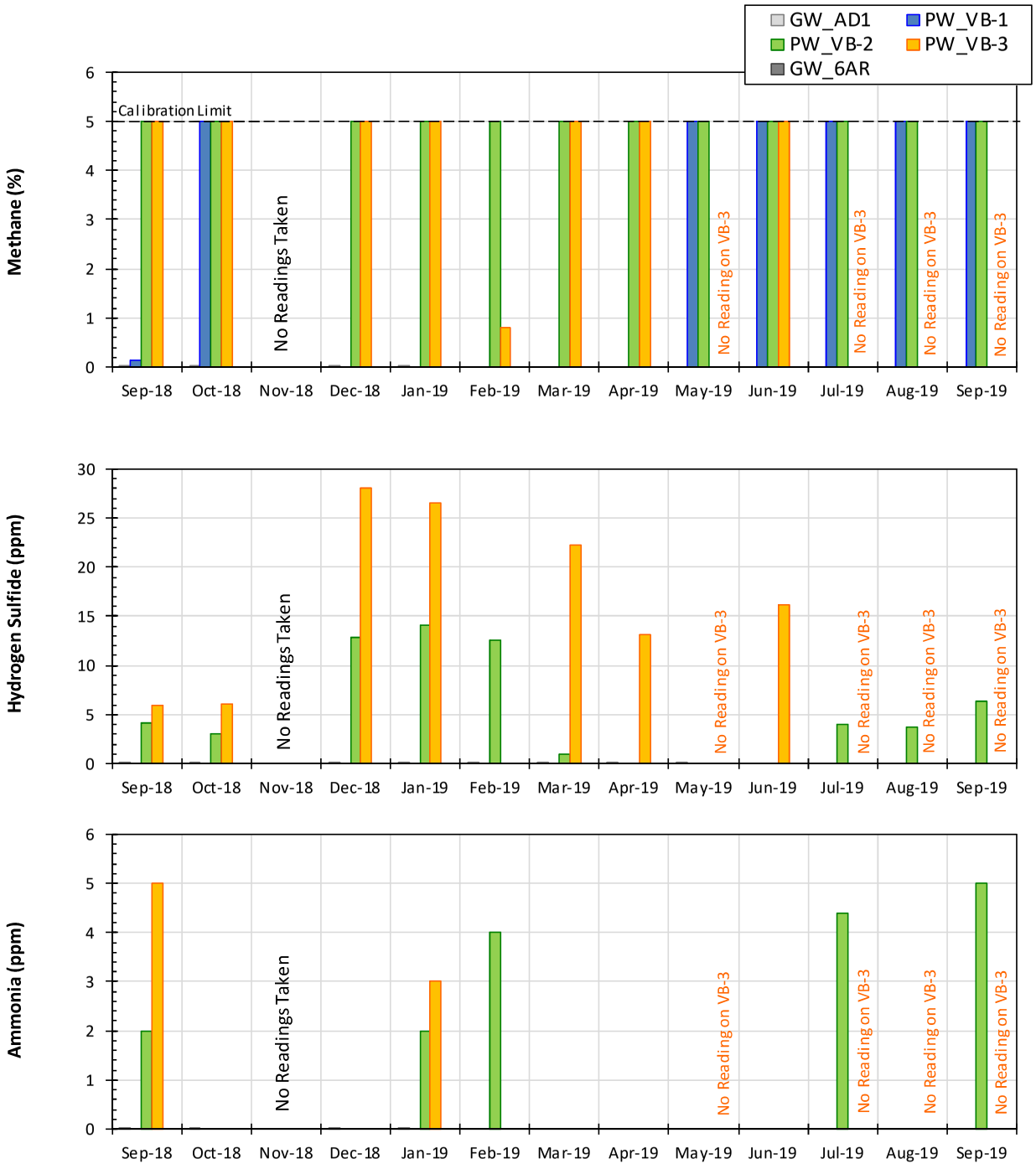

Figure 4-25
Concentrations of methane (CH_4), hydrogen sulfide (H_2S) and ammonia (NH_4) from GAPs (VB-1, VB-2, and VB-3) in the subsurface of the closed ash impoundment

Speciation of Arsenic, Iron, and Selenium Under Low Redox Conditions

At moderately low redox conditions, arsenic release can be associated with loss of HFO sorption sites as Fe(III) is reduced to Fe(II) at a pH+pE value of approximately 7 to 8. At these conditions, there would be a corresponding increase in the concentration of iron (Fe^{2+}) in solution. At lower values of pH+pE, sulfate is reduced to sulfide, and arsenic may be precipitated with sulfidic minerals. At these same redox conditions, biological activity would convert carbon dioxide to methane as observed for VB-2 and VB-3 (see top of Figure 4-25). These processes are consistent with the temporal dissolved arsenic and iron concentrations observed for VB-1, VB-2, and VB-3 (Figure 4-26), where increased dissolved iron in VB-3 was also accompanied with much lower dissolved arsenic concentration (ca. 3.5 vs. 1.0 mg/L) compared to VB-1 and VB-2. Considering the presence of methane, iron reduction appears to have been an intermediary step concurrent with sulfate reduction and methanogenesis, resulting in arsenic precipitation and lower solubility.

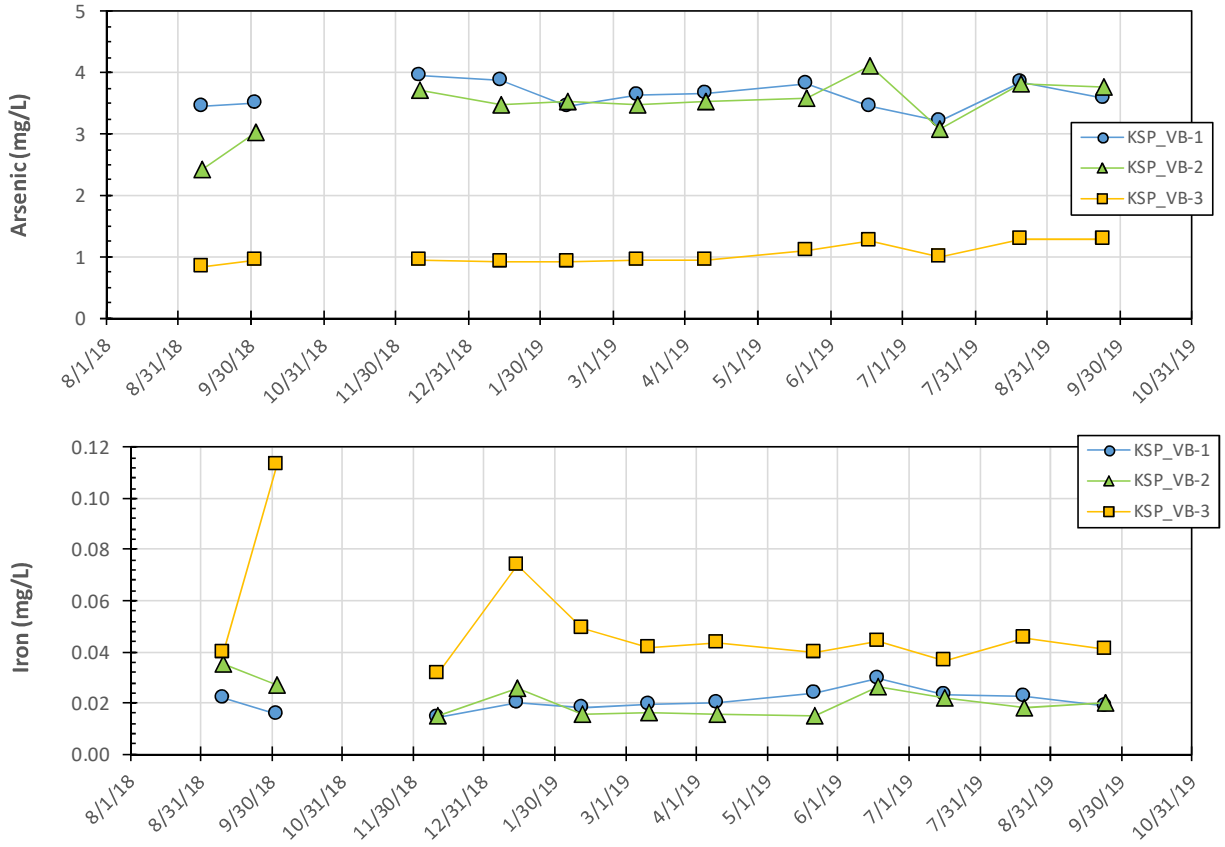

Figure 4-26
Temporal porewater data for arsenic and iron collected at boreholes VB-1, VB-2, and VB-3

Uncertainties in Redox Analysis and Impacts on Porewater Concentrations

Figure 4-27 presents a typical redox ladder for electron donors (e.g., O_2, $Fe(OH)_{3(am,\ s)}$, SO_4^{2-}, $CO_{2(g)}$) and products of biochemical reduction (e.g., CO_2, Fe^{2+}, HS^-, $CH_{4(g)}$).

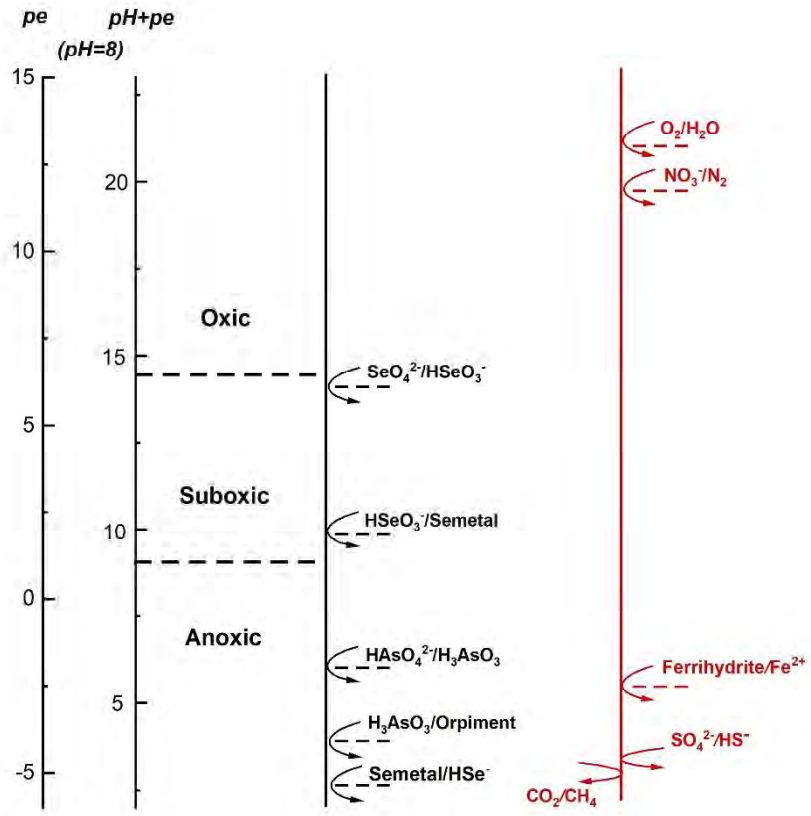

Figure 4-27
Redox ladder for relevant redox reactions (after Borch et al., 2010)

Porewater ORP measurements indicated suboxic to anoxic conditions, while subsurface gas measurements and porewater measurements of pH and dissolved constituents indicated mildly anoxic ($Fe(OH)_{3(am,\ s)}$ conversion to Fe^{2+}) to strongly anoxic and reducing (HS^- and robust CH_4 formation)[3] conditions in the ash deposit. Furthermore, porewater measured redox trended toward less reducing/more oxidizing conditions during warmer months, which is contrary to increased microbial activity, inducing more reducing conditions, at warmer temperatures. There is no clear explanation for the observed discrepancy between field-measured ORP and the redox state as deduced from gas measurements and porewater concentration data; however, the latter are generally considered more reliable indicators of redox conditions. There are several possible causes for the observed inconsistency:

- Integration Areas – Porewater reflects leaching in response to infiltration and possibly mixing with groundwater influx in response to changes in hydraulic heads (e.g., groundwater responses to changes in river elevation are evident in VB-3). In contrast, subsurface gas

[3] Hydrosulfide ion (HS^-) is a weak acid (pKa ≈6.9) resulting in a solution equilibrium with hydrogen sulfide (H_2S) gas, which was detected intermittently during subsurface gas analysis.

measurements integrate over a much larger area by diffusion and convection driven by barometric pressure changes. Gases released from the saturated zone in the coal ash can also be reflected in the gas monitoring. It is well established that the localized zones of microbially active/induced aerobic, suboxic, and highly reduced anoxic conditions can co-exist in close physical proximity (e.g., in biofilms).

- Sampling Effects – Porewater samples reflect integration over the zone of influence around the porewater access point during pumping for sampling.[4] Porewater sampling requires low-flow pumping of the porewater monitoring points, while the monitoring well remains uncapped and in exchange with the atmosphere. During initial monitoring point purging, porewater in the monitoring point can partially aerate and oxidize by oxygen exchange at the air-porewater interface within the monitoring point and the sand packing around the well screen if it is partially unsaturated.
- ORP Readings – Field monitoring instrumentation and the process of data documentation normally do not measure extremely low reducing conditions and, therefore, some negative instrument readings may have been misrepresented as positive readings. In order to examine this possibility, ORP based on sonde measurements (mV) at boreholes VB-1, VB-2, and VB-3 and resultant pH+pE values (Figure 4-28) are compared with the bounding case results if some sonde ORP measurements were actually negative values with the same absolute value (Figure 4-29). This figure indicates more reducing conditions during the warmer months and redox conditions (pH+pE) consistent with the subsurface gas measurements.

[4] For this project, porewater and groundwater sampling was conducted using low-flow sampling techniques that result in negligible drawdown.

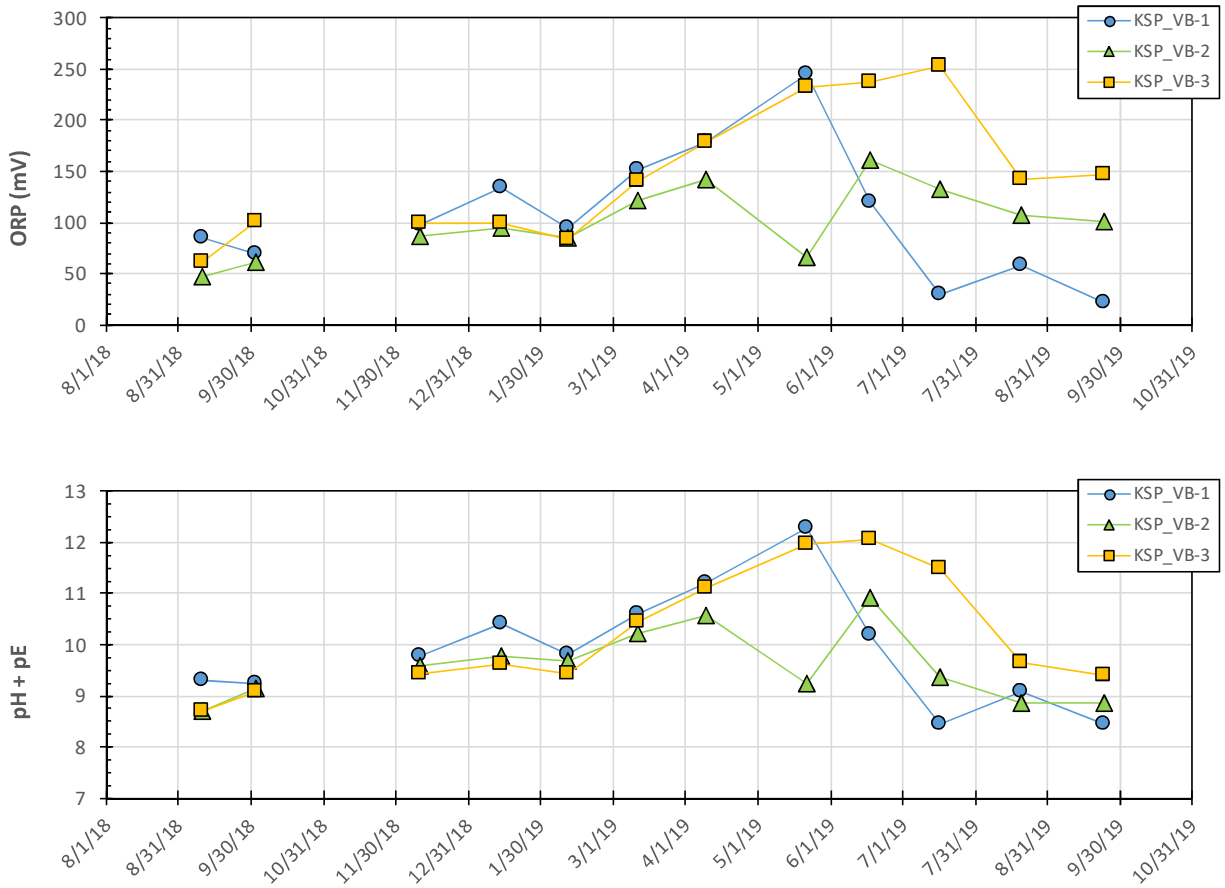

Figure 4-28
Oxidization reduction potential based on sonde measurements at boreholes VB-1, VB-2, and VB-3 and resultant pH+pE values

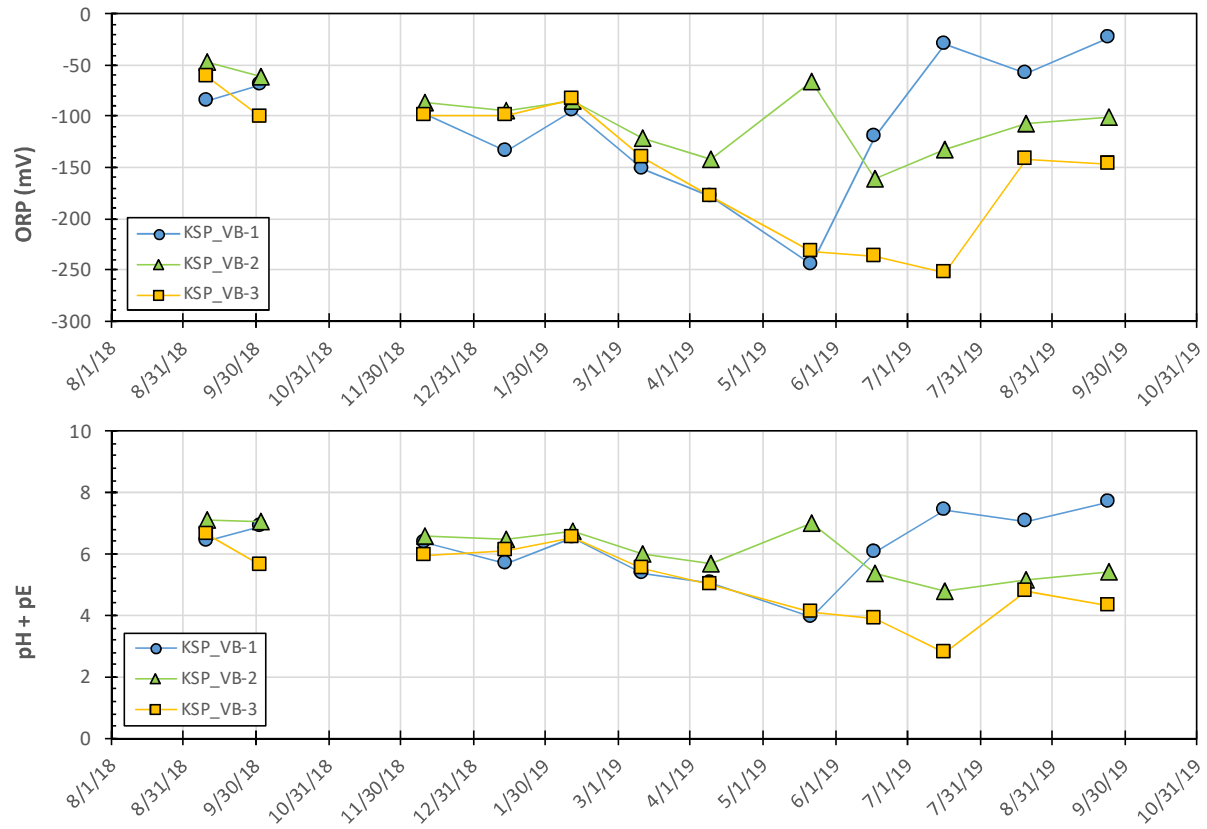

Figure 4-29
Oxidization reduction potential and resultant pH+pE values if recorded ORP measurements were negative for boreholes VB-1, VB-2, and VB-3

Comparison of Leaching Tests to Monthly Porewater Samples

The results of LEAF leaching tests and traditional tests (TCLP, SPLP, and ASTM) were plotted as a function of pH along with the porewater concentrations measured at the corresponding borehole (VB-1, VB-2, or VB-3). Examples of these comparisons are shown in Figure 4-30 through Figure 4-32, while a full set of results is presented in Appendix G. In the pH-dependence graphs, monitored porewater data are presented both as data points representing monthly measured porewater concentrations and as dashed lines representing the mean pH and mean concentration of all measured values.

To the right of each pH-dependence graph, bar charts show the ratio of the leaching test concentration to the mean porewater concentration. The seven ratios are shown in increasing order of L/S, including:

- The 1st eluate from EPA 1314 at L/S=0.2 mL/g-dry,
- The 2nd eluate from 1314 at L/S=0.3 mL/g-dry (cumulative L/S=0.5 mL/g-dry),
- The 1313_L/S=1 concentration at own pH at L/S=1 mL/g-dry,
- The 1313 concentration at natural pH at L/S=10 mL/g-dry,
- TCLP conducted at an average L/S of 23 mL/g-dry,
- SPLP conducted at an average L/S of 22 mL/g-dry, and
- ASTM at an average L/S of 27 mL/g-dry.

The eluate-to-porewater-concentration ratios indicate how closely leaching test concentrations can predict measured field concentrations. For example, Figure 4-30 shows that B porewater concentrations are reasonably predicted by low L/S leaching test data (EPA 1314 and 1313_L/S=1) while being under-predicted by at least an order-of-magnitude at higher L/S ratios. This is consistent with available content-limited LSP where eluate concentration is a strong function of L/S. However, arsenic is under-predicted in all leaching test approximations at VB-1 and VB-2 (Figure 4-31), most likely because of oxidation of solid materials with experiments conducted under laboratory conditions. This observation is consistent with the reducing conditions observed through subsurface gas monitoring and explains why arsenic concentrations are different in the field than in laboratory samples, possibly due to the loss of HFO as adsorption sites and precipitation as arsenic sulfides. Due to the effects of oxidation of laboratory samples, the leaching tests tend to over-predict the porewater concentrations of other oxyanions including Sb (Figure 4-32), Se, and V.

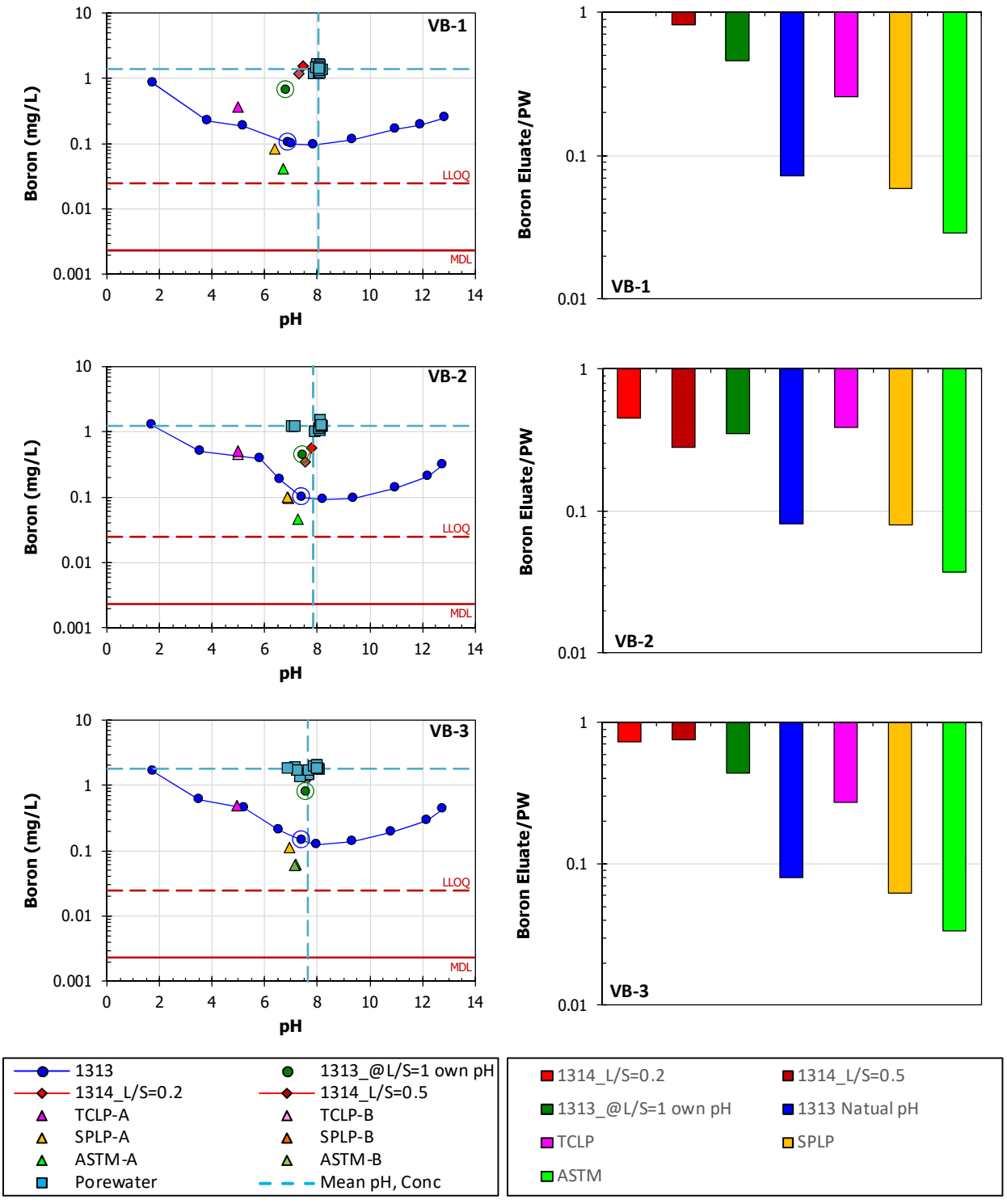

Figure 4-30
Boron concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

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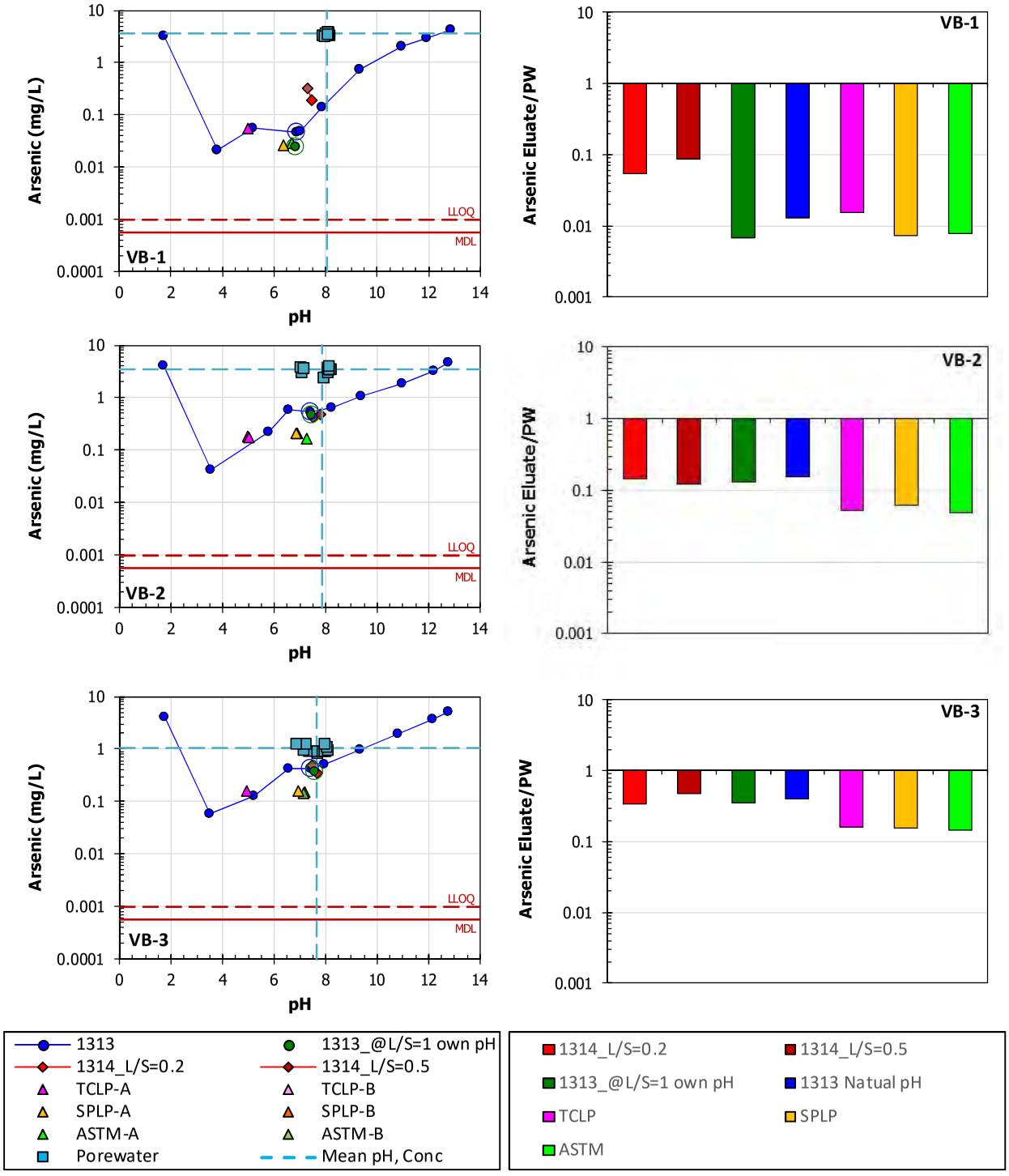

Figure 4-31
Arsenic concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

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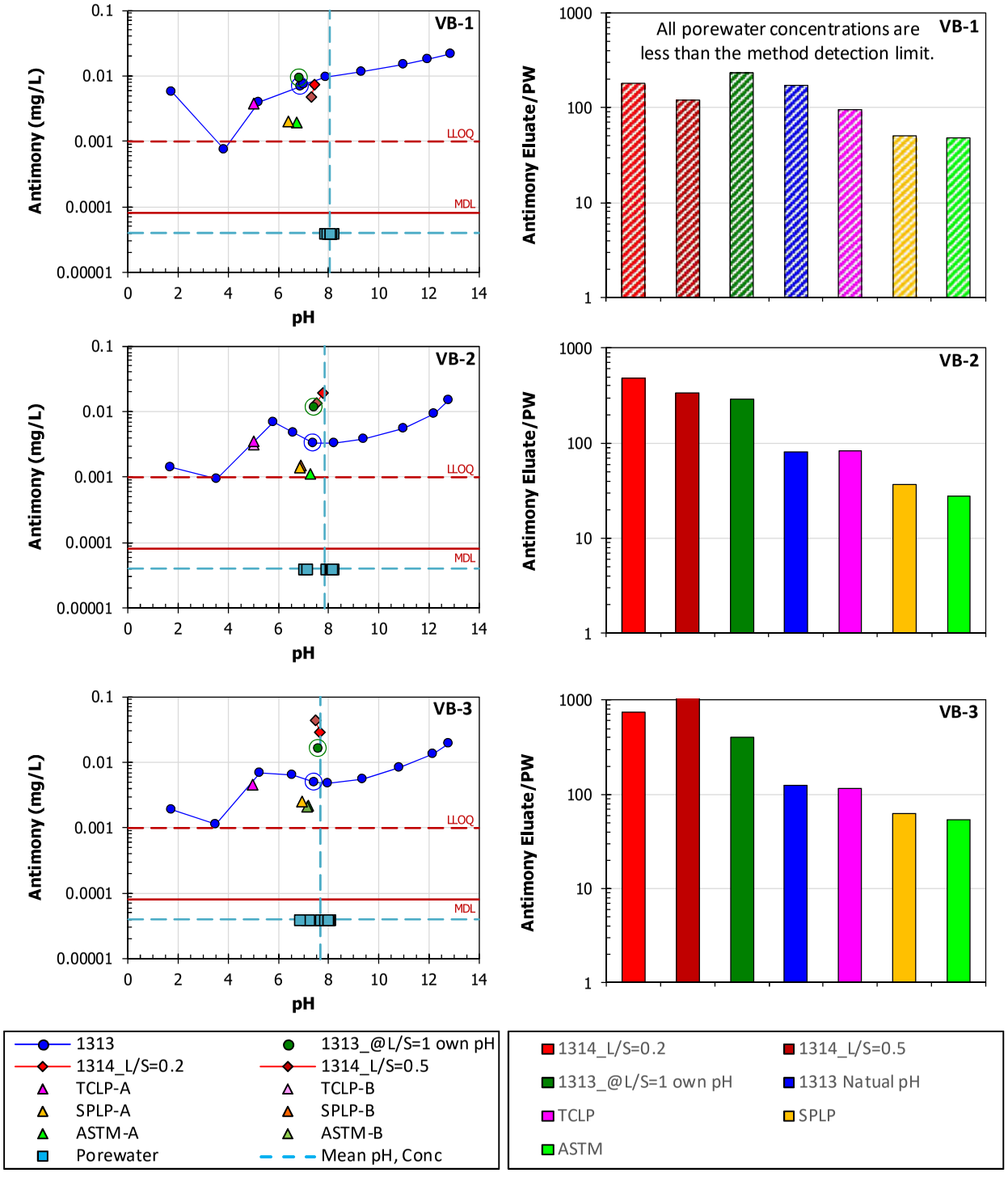

Figure 4-32
Antimony concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

A qualitative summary of the ability of different leaching tests to estimate the measured porewater concentrations at each of the PAPs is shown in Table 4-14 for constituents with solubility-controlled LSP, Table 4-15 for constituents with available content-limited LSP, and Table 4-16 for constituents where the LSP could not be determined. In those tables, shading is used to indicate if the leaching test estimate is within 25% of the mean groundwater concentration (green), within an order-of-magnitude of the mean porewater concentration (orange), or greater than an order-of-magnitude from the mean porewater concentration (red). When "GW <MDL" appears in the Notes column, the mean porewater concentration was less than the analytical MDL. Within the field of the table, an asterisk is used to indicate that the leaching test results were less than the MDL.

Table 4-14, Table 4-15, and Table 4-16 provide an overview of the ability of leaching tests, conducted on materials collected from a highly reducing environment and tests at mildly oxidizing conditions in a laboratory setting, to estimate porewater concentrations. The results of this qualitative summary should not be used without consideration of the redox conditions of the field and should always be shown along with the graphical data (e.g., Figure 4-30 through Figure 4-32) that preserve the pH result for the tests. For example, the table indicates that TCLP would provide a good estimate of porewater concentration for Ca; however, this is somewhat of a coincidence because the pH of TCLP is more than two pH units less than the natural pH of the ash.

Table 4-14
Summary of Leaching Tests to Predict Porewater Concentrations – Constituents with Solubility-Controlled LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP	SPLP	ASTM	Notes
Antimony	VB-1								GW <MDL
	VB-2								
	VB-3								
Arsenic[5]	VB-1								
	VB-2								
	VB-3								
Barium	VB-1								
	VB-2								
	VB-3								
Chromium	VB-1						*	*	
	VB-2						*	*	
	VB-3				*		*	*	
Fluoride	VB-1					*	*	*	
	VB-2					*	*	*	
	VB-3					*	*	*	
Selenium	VB-1								
	VB-2								GW <MDL
	VB-3								GW <MDL
Vanadium	VB-1								GW <MDL
	VB-2								GW <MDL
	VB-3								GW <MDL
Zinc	VB-1						*	*	GW <MDL
	VB-2						*	*	GW <MDL
	VB-3						*	*	

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

[5] Although the liquid-solid partitioning (LSP) for arsenic appears to be solubility-controlled, arsenic LSP is likely a result of adsorption onto hydrous ferric oxides (HFO) and not solubility of arsenic-bearing minerals.

Table 4-15
Summary of Leaching Tests to Predict Porewater Concentrations – Constituents with Available Content-Limited LSP

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20+	SPLP L/S=20+	ASTM L/S=20+	Notes
Boron	VB-1								
	VB-2								
	VB-3								
Calcium	VB-1								
	VB-2								
	VB-3								
Chloride	VB-1								
	VB-2								
	VB-3								
Molybdenum	VB-1								
	VB-2								
	VB-3								
Sulfate	VB-1								
	VB-2								
	VB-3								
Thallium	VB-1						*	*	GW <MDL
	VB-2				*		*	*	GW <MDL
	VB-3						*	*	GW <MDL

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

Table 4-16
Summary of Leaching Tests to Predict Porewater Concentrations – Constituents with no LSP Designation

Constituent		1314 L/S=0.2	1314 L/S=0.5	1313 L/S=1 Own pH	1313 L/S-10 Nat pH	TCLP L/S=20+	SPLP L/S=20+	ASTM L/S=20+	Notes
Beryllium	VB-1	*	*	*	*		*	*	GW <MDL
	VB-2	*	*	*	*		*	*	GW <MDL
	VB-3	*	*	*	*		*	*	GW <MDL
Cadmium	VB-1				*		*	*	
	VB-2			*	*		*	*	
	VB-3			*	*		*	*	GW <MDL
Cobalt	VB-1				*		*	*	
	VB-2	*	*	*	*		*	*	GW <MDL
	VB-3	*	*	*	*		*	*	
Copper	VB-1	*	*		*		*	*	GW <MDL
	VB-2	*	*	*	*		*	*	
	VB-3								GW <MDL
Iron	VB-1	*	*	*			*	*	
	VB-2	*	*				*	*	
	VB-3	*	*	*			*	*	
Lead	VB-1	*	*	*	*	*	*	*	GW <MDL
	VB-2	*	*	*	*	*	*	*	GW <MDL
	VB-3	*	*	*	*	*	*	*	GW <MDL
Lithium	VB-1			*	*	*	*	*	
	VB-2			*	*	*	*	*	
	VB-3			*	*	*	*	*	
Nickel	VB-1				*		*		
	VB-2			*	*		*	*	
	VB-3			*	*		*	*	

	Estimate within 25% of porewater (±25%)
	Estimate within order of magnitude (±10x)
	Estimate more than order of magnitude (>±10x)
GW <MDL	Mean porewater concentration < MDL
*	Test concentration <MDL

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5
SUMMARY OF OBSERVATIONS

The data presented in this report represent the results of geotechnical, hydrologic, and leaching characterization of samples of coal ash collected from the closed and capped impoundment at Plant 42201. The hydraulic conductivity of intact cores from the ash deposit was measured in context of the distribution of particles in the coal ash samples and the overburden pressure associated with disposal at depth within the pond. The leaching test results for LEAF tests (i.e., EPA Methods 1313 and 1314) were compared to those for traditional tests (i.e., ASTM, TCLP, and SPLP). In addition, leaching test results were compared to porewater concentrations determined from field samples, and field-sampled porewater concentrations were compared to groundwater concentrations, to evaluate similarities and dissimilarities between these results.

Based on the presented data and analysis, the following general observations can be made:

- The hydraulic conductivity of intact ash samples is dependent on the fraction of fines in the material. The measured hydraulic conductivity of finer, less permeable coal ash was lower (ranging from approximately $7x10^{-4}$ cm/s to $1x10^{-5}$ cm/s) than the hydraulic conductivity of coarser, more permeable coal ash (approximately $1x10^{-3}$ cm/s). In general, the hydraulic conductivity decreases modestly with increasing effective stress.
- The subsurface within the closed impoundment was more bio-chemically reducing than indicated by porewater analysis. Monitoring of subsurface gas concentrations shows the presence of hydrogen sulfide and methane, indicating strongly reducing conditions. Monthly data indicate that the extent of reducing conditions is spatially variable and may be seasonally dependent. In addition, arsenic concentrations in the porewater are at the high end of previously reported ranges for coal ash (EPRI, 2019) in some areas. At intermediate reducing conditions (e.g., at VB-1), elevated concentrations of arsenic (ca. 3 mg/L) are likely due to loss of HFO when ferric oxides are reduced and solubilized (conversion of insoluble Fe^{3+} to soluble Fe^{2+}). Under very low redox conditions, as observed by subsurface gas monitoring at VB-2 and VB-3 by the presence of methane, arsenic porewater concentrations decrease due to conversion of As(V) to As(III) and likely precipitation as sulfides. Conversely, the porewater concentrations of Sb and Se in the reduced pond environment are suppressed due to formation of reduced species with lower solubility.
- Some constituents in the porewater samples exhibited temporal variability due to factors such as (1) seasonal changes in pH and redox, (2) changes that appeared to be related to seasonal groundwater elevation changes, and (3) changing conditions shortly after closure of the impoundment. However, some constituents such as, B, and Mo remained relatively constant within each porewater access point throughout the 13-month monitoring period.
- The data collected suggest that porewater concentration is an unreliable indicator for which constituents will have elevated groundwater concentrations or for prediction of downgradient concentrations at this site.

- Traditional leaching tests (TCLP, SPLP, and ASTM) are poor indicators of measured porewater concentrations. Low liquid-to-solid ratio (L/S) eluates from EPA Method 1314 are better indicators than the traditional tests for concentrations for available content-limited constituents (B, Ca, Cl, Mo, Tl) because of the strong L/S-dependence. However, additional information (e.g., available content and porewater L/S) is needed to provide a reasonable approximation of porewater concentrations. For constituents with apparent solubility-controlled liquid-solid partitioning (Sb, As, Ba, Cr, F^-, Se, SO_4, V, Zn), pH-dependence tests (e.g., EPA Method 1313) may provide valuable information for geochemical modeling, but, for this site, the natural or own pH responses did not reliably estimate field porewater concentrations, in part due to differences in redox as noted in the next bullet.
- When the field environment is highly reducing, laboratory leaching results for redox sensitive elements (e.g., As, Cr, Sb, Se, and Fe) do not directly reflect the leaching anticipated in porewater. This is, in part, because reduced materials collected in the field are inevitably partially oxidized during sampling, handling, and testing.

6
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A
BORE LOGS AND WELL STRATIGRAPHY

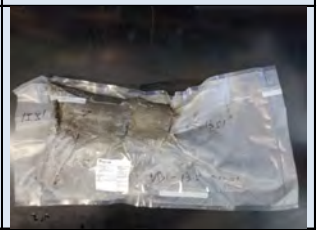
Borehole reports are maintained as electronic files available upon request to EPRI.

B
MATERIAL COLLECTION SAMPLE INDEX

Material Collection Sample Index

INVENTORY OF FIELD-COLLECTED ASH SAMPLES
KSP_VB-1
Collection Date June 19, 2018

Granular Ash Sampling

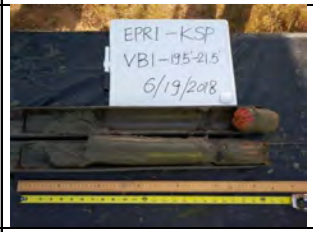
Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
9.5'-11.5'	EPRI_VB1_9.5'-11.5'	Fly Ash	L/S ~ 1	250-mL bottle	160.03	194.93	26.82		
	EPRI_VB1_9.5'-11.5'_A	Fly Ash (upper portion near interface)	Bulk	1-gal. vacuum-seal bag	865.8				
	EPRI_VB1_9.5'-11.5'_B	Fly Ash (lower portion)	Bulk	1-gal. vacuum-seal bag	1395				
11.5'-13.5'	EPRI_VB1_11.5'-13.5'	Fly Ash	L/S ~ 1	250-mL bottle	156.01	195.87	26.88		
	EPRI_VB1_11.5'-13.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1431.2				
Note: Starting with EPRI_VB1_13.5'-15.5', the driller add ed water to prevent back flow into auger.									
13.5'-15.5'	EPRI_VB1_13.5'-15.5'	Fly Ash	L/S ~ 1	250-mL bottle	157.52	204.29	26.86		
	EPRI_VB1_13.5'-15.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1145.4				

INVENTORY OF FIELD-COLLECTED ASH SAMPLES

KSP_VB-1

Collection Date June 19, 2018

Granular Ash Sampling

Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
15.5'-17.5'	EPRI_VB1_15.5'-17.5'	Fly Ash	L/S ~ 1	250-mL bottle	167.00	200.00	26.73		
	EPRI_VB1_15.5'-17.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	682.4				
17.5'-19.5'	EPRI_VB1_17.5'-19.5'	Fly Ash	L/S ~ 1	250-mL bottle	193.13	181.38	26.69		
	EPRI_VB1_17.5'-19.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	2038.0				
19.5'-21.5'	EPRI_VB1_19.5'-21.5'	Fly Ash	L/S ~ 1	250-mL bottle	195.47	181.19	26.83		
	EPRI_VB1_19.5'-21.5'(M)	Fly Ash	Moisture	250-mL bottle	33.95	-	26.82		
	EPRI_VB1_19.5'-21.5'_N	Native Clay	L/S ~ 1	250-mL bottle	152.48	220.16	26.85		
	EPRI_VB1_19.5'-21.5'_A	Fly Ash (upper portion)	Bulk	1-gal. vacuum-seal bag	957.5				
	EPRI_VB1_19.5'-21.5'_B	Fly Ash (lower portion near clay liner)	Bulk	1-gal. vacuum-seal bag	1408.9				

Material Collection Sample Index

INVENTORY OF FIELD-COLLECTED ASH SAMPLES
KSP_VB-1
Collection Date June 19, 2018

Minimally-Disturbed Core Sampling (Osterberg Sampler)

Depth Below Ground Level (ft)	Sample ID	Material Type	Tube Recovery	Container & Size	Saved Sample Picture
8'-10'	EPRI_VB1_OST_8'-10'	Upper Interface	17" recovered from 24" push	36"-long tube	
12'-14.5'	EPRI_VB1_OST_12'-14.5'	Fly Ash	24.5" recovered from 30" push	36"-long tube	
17'-19.5'	EPRI_VB1_OST_17'-19.5'	Fly Ash	24" recovered from 30" push	36"-long tube	
20'-22'	none	Lower Interface	0" recovered from 30" push (no recovery)		

INVENTORY OF FIELD-COLLECTED ASH SAMPLES

KSP_VB-2

Collection Date June 14, 2018

Granular Ash Sampling

Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
8.5'-10.5'	EPRI_VB2_8.5'-10.5'	Fly Ash	L/S ~ 1	250-mL bottle	153.1	96.58	26.73		
	EPRI_VB2_8.5'-10.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1294.8				
10.5'-12.5'	EPRI_VB2_10.5'-12.5'	Fly Ash	L/S ~ 1	250-mL bottle	170.64	78.75	26.97		
	EPRI_VB2_10.5'-12.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1592.2				
Note: Starting with EPRI_VB2_12.5'-14.5', the driller add ed water to prevent back flow into auger.									
12.5'-14.5'	EPRI_VB2_12.5'-14.5'	Fly Ash	L/S ~ 1	250-mL bottle	173.03	76.3	26.98		
	EPRI_VB2_12.5'-14.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	925.3				
14.5'-16.5'	EPRI_VB2_14.5'-16.5'	Fly Ash	L/S ~ 1	250-mL bottle	181.97	67.49	26.97		
	EPRI_VB2_14.5'-16.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	380.6				

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KSP_VB-2
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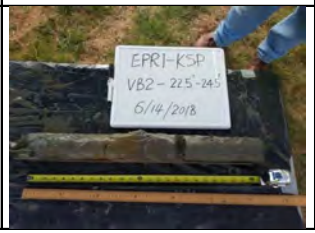
Granular Ash Sampling

16.5'-18.5'	EPRI_VB2_16.5'-18.5'	Fly Ash	L/S ~ 1	250-mL bottle	182.77	67.02	26.87		
	EPRI_VB2_16.5'-18.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1918.7				
18.5'-20.5'	EPRI_VB2_18.5'-20.5'	Fly Ash	L/S ~ 1	250-mL bottle	165.76	84.14	26.97		
	EPRI_VB2_18.5'-20.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1165.7				
20.5'-22.5'	EPRI_VB2_20.5'-22.5'	Fly Ash	L/S ~ 1	250-mL bottle	191.86	58.12	26.78		
	EPRI_VB2_20.5'-22.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1372.3				
22.5'-24.5'	EPRI_VB2_22.5'-24.5'	Fly Ash	L/S ~ 1	250-mL bottle	173.86	75.77	26.72		
	EPRI_VB2_22.5'-24.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1105.9				

INVENTORY OF FIELD-COLLECTED ASH SAMPLES

KSP_VB-2

Collection Date June 14, 2018

Granular Ash Sampling

24.5'-26.5'	EPRI_VB2_24.5'-26.5'	Fly Ash	L/S ~ 1	250-mL bottle	180.21	69.42	26.98		
	EPRI_VB2_24.5'-26.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	2908.6				
26.5'-28.5'	EPRI_VB2_26.5'-28.5'	Fly Ash	L/S ~ 1	250-mL bottle	180.69	69.13	26.97		
	EPRI_VB2_26.5'-28.5'_A	Fly Ash	Bulk	1-gal. vacuum-seal bag	1034.6				
	EPRI_VB2_26.5'-28.5'_B	Fly Ash	Bulk	1-gal. vacuum-seal bag	1243.6				
28.5'-30.5'	EPRI_VB2_28.5'-30.5'_N	Fly Ash	L/S ~ 1	250-mL bottle	149.41	100.63	26.98		
	EPRI_VB2_28.5'-30.5'(M)	Fly Ash	Moisture	250-mL bottle	51.59	-	26.72		
	EPRI_VB2_28.5'-30.5'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1076.8				

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INVENTORY OF FIELD-COLLECTED ASH SAMPLES
KSP_VB-2
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Minimally-Disturbed Core Sampling (Osterberg Sampler)

Depth Below Ground Level (ft)	Sample ID	Material Type	Tube Recovery	Container & Size	Saved Sample Picture
7'-9.5'	EPRI_VB2_OST_7'-9'	Upper Interface	28" recovered from 30" push	36"-long tube	
13.5'-15.5'	Osterberg-13.5'-15.5'	Fly Ash	23" recovered from 30" push	36"-long tube	
18.5'-21.5'	Osterberg-18.5'-21.5'	Fly Ash	30" recovered from 30" push	36"-long tube	
23.5'-26.5'	none	Fly Ash	0" recovered from 30" push (no recovery)	none	
27'-29'	none	Lower Interface	0" recovered from 30" push (no recovery)	none	

INVENTORY OF FIELD-COLLECTED ASH SAMPLES

KSP_VB-3

Collection Date June 12, 2018

Granular Ash Sampling

Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
11'-13'	EPRI_VB2_11'-13'	Fly Ash	L/S ~ 1	250-mL bottle	147.66	143.22	26.99		
	EPRI_VB3_11'-13'	Fly Ash (portion below clay cover)	Bulk	1-gal. vacuum-seal bag	1543.9				
13'-15'	EPRI_VB3_13'-15'	Fly Ash	L/S ~ 1	250-mL bottle	165.67	125.32	26.89		
	EPRI_VB3_13'-15'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1885				
15'-17'	EPRI_VB3_15'-17'	Fly Ash	L/S ~ 1	250-mL bottle	157.18	134	26.9		
	EPRI_VB3_15'-17'	Fly Ash	Bulk	1-gal. vacuum-seal bag	2025.5				
17'-19'	EPRI_VB3_17'-19'	Fly Ash	L/S ~ 1	250-mL bottle	173.83	117.37	26.88		
	EPRI_VB3_17'-19'	Fly Ash	Bulk	1-gal. vacuum-seal bag	2871				

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INVENTORY OF FIELD-COLLECTED ASH SAMPLES
KSP_VB-3
Collection Date June 12, 2018

Granular Ash Sampling

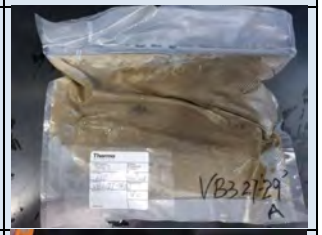
Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
19'-21'	EPRI_VB3_19'-21'	Fly Ash	L/S ~ 1	250-mL bottle	152.71	138.71	26.98		
	EPRI_VB3_19'-21'	Fly Ash	Bulk	1-gal. vacuum-seal bag	601.2				
Note: Starting with EPRI_VB2_21'-23', the driller add ed water to prevent back flow into auger.									
21'-23'	EPRI_VB3_21'-23'	Fly Ash	L/S ~ 1	250-mL bottle	183.03	108.44	26.77		
	EPRI_VB3_21'-23'	Fly Ash	Bulk	1-gal. vacuum-seal bag	966.5				
23'-25'	EPRI_VB3_23'-25'	Fly Ash	L/S ~ 1	250-mL bottle	189.81	101.78	26.98		
	EPRI_VB3_23'-25'	Fly Ash	Bulk	1-gal. vacuum-seal bag	1213.3				
25'-27'	EPRI_VB3_25'-27'	Fly Ash	L/S ~ 1	250-mL bottle	179.18	112.43	26.79		
	EPRI_VB3_25'-27'	Fly Ash	Bulk	1-gal. vacuum-seal bag	2365.5				

INVENTORY OF FIELD-COLLECTED ASH SAMPLES

KSP_VB-3

Collection Date June 12, 2018

Granular Ash Sampling

Depth Below Ground Level (ft)	Sample ID	Material Type	Sample Type	Container & Size	Mass of Ash (g)	Mass of Water Added (g)	Bottle Mass Without Lid (g)	Collected Sample Picture	Saved Sample Picture
27'-29'	EPRI_VB3_27'-29'	Fly Ash	L/S ~ 1	250-mL bottle	187.39	104.21	26.86		
	EPRI_VB3_27'-29'(M)	Fly Ash	Moisture	250-mL bottle	60.18				
	EPRI_VB3_27'-29'_A	Fly Ash (upper portion)	Bulk	1-gal. vacuum-seal bag	981.2				
	EPRI_VB3_27'-29'(B)	Fly Ash (portion below clay layers)	Bulk	1-gal. vacuum-seal bag	1435.5				
29'-31'	EPRI_VB3_29'-31'	Fly Ash	L/S ~ 1	250-mL bottle	164.03	127.98	26.79		
	EPRI_VB3_29'-31'	Fly Ash	Bulk	1-gal. vacuum-seal bag	3009.5				
31'-33'	EPRI_VB3_31'-33'ASH	Fly Ash	L/S ~ 1	250-mL bottle	153.89	138.28	26.89		
	EPRI_VB3_31'-33'_N	Native Clay	L/S ~ 1	250-mL bottle	168.19	123.83	26.9		
	EPRI_VB3_31'-33'	Fly Ash (portion above native clay liner)	Bulk	1-gal. vacuum-seal bag	2438.7				
33'	EPRI_VB3_33'	Native Clay	Moisture	250-mL bottle	60.29				

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INVENTORY OF FIELD-COLLECTED ASH SAMPLES
KSP_VB-3
Collection Date June 12, 2018

Minimally-Disturbed Core Sampling (Osterberg Sampler)

Depth Below Ground Level (ft)	Sample ID	Material Type	Tube Recovery	Container & Size	Saved Sample Picture
17'-20'	EPRI_VB3_OST_17'-20'	Fly Ash	23.5" recovered from 30" push	36"-long tube	
20'-23'	EPRI_VB3_OST_20'-23'	Fly Ash	0" recovered from 30" push (no recovery)	none	
24'-27'	EPRI_VB3_OST_24'-27'	Fly Ash	12" recovered from 30" push	36"-long tube	

Electronic Filing: Received, Clerk's Office 07/01/2024

C
INDIVIDUAL SPLIT SPOON SAMPLE ANALYSIS

Table of Appendices

C.1 Field Extractions (L/S~1) and Laboratory Extractions (L/S=1) as Functions of pH and L/S

C.2 Standardized Concentration Profiles from Laboratory Extractions (L/S=1) Using the Global Ash Mean and Standard Deviation

C.3 Comparison of Standardized Release Profiles

C.1 Field Extractions (L/S~1) and Laboratory Extractions (L/S=1) as Functions of pH and L/S

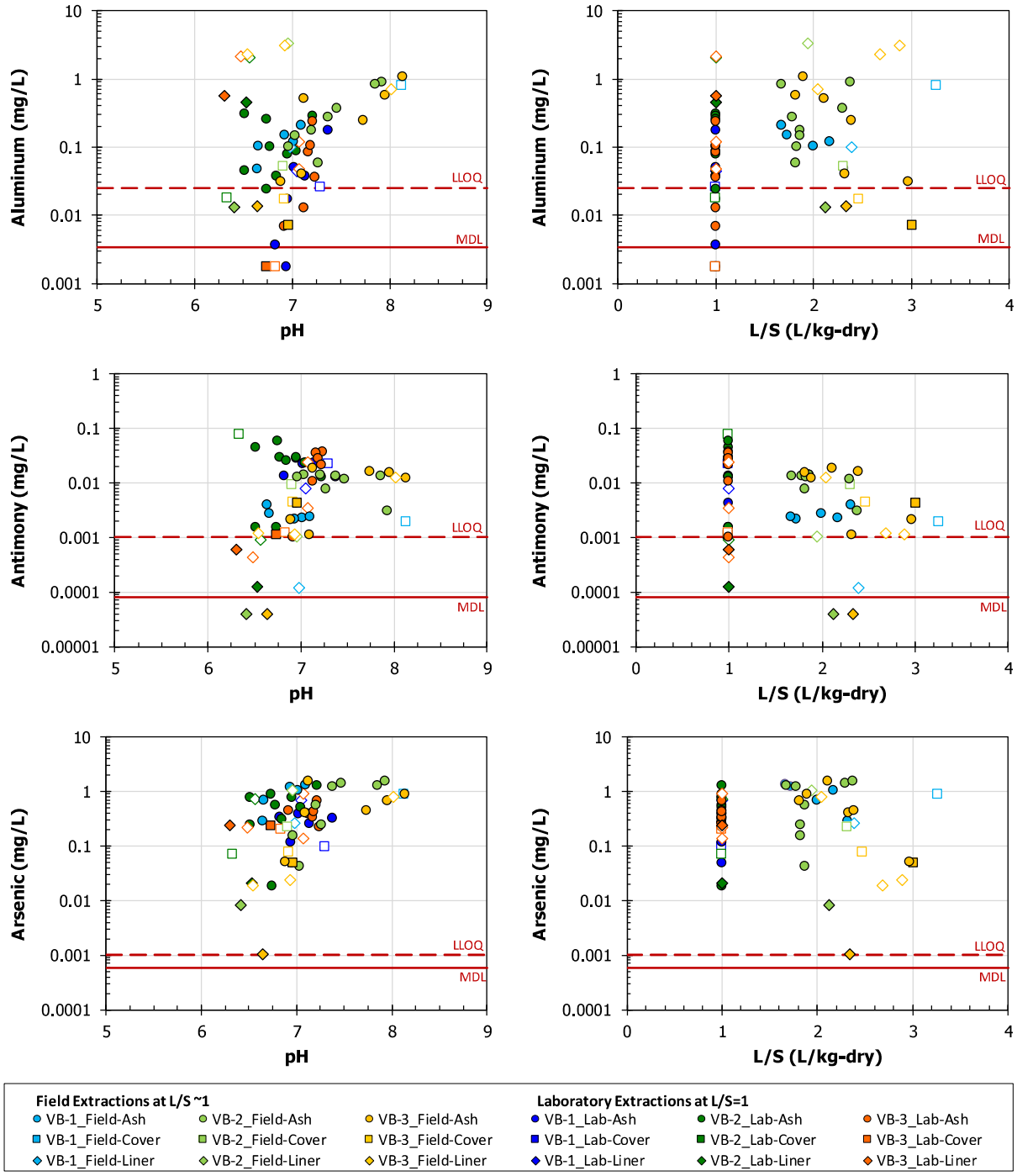

Figure C-1
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): aluminum, antimony, and arsenic.

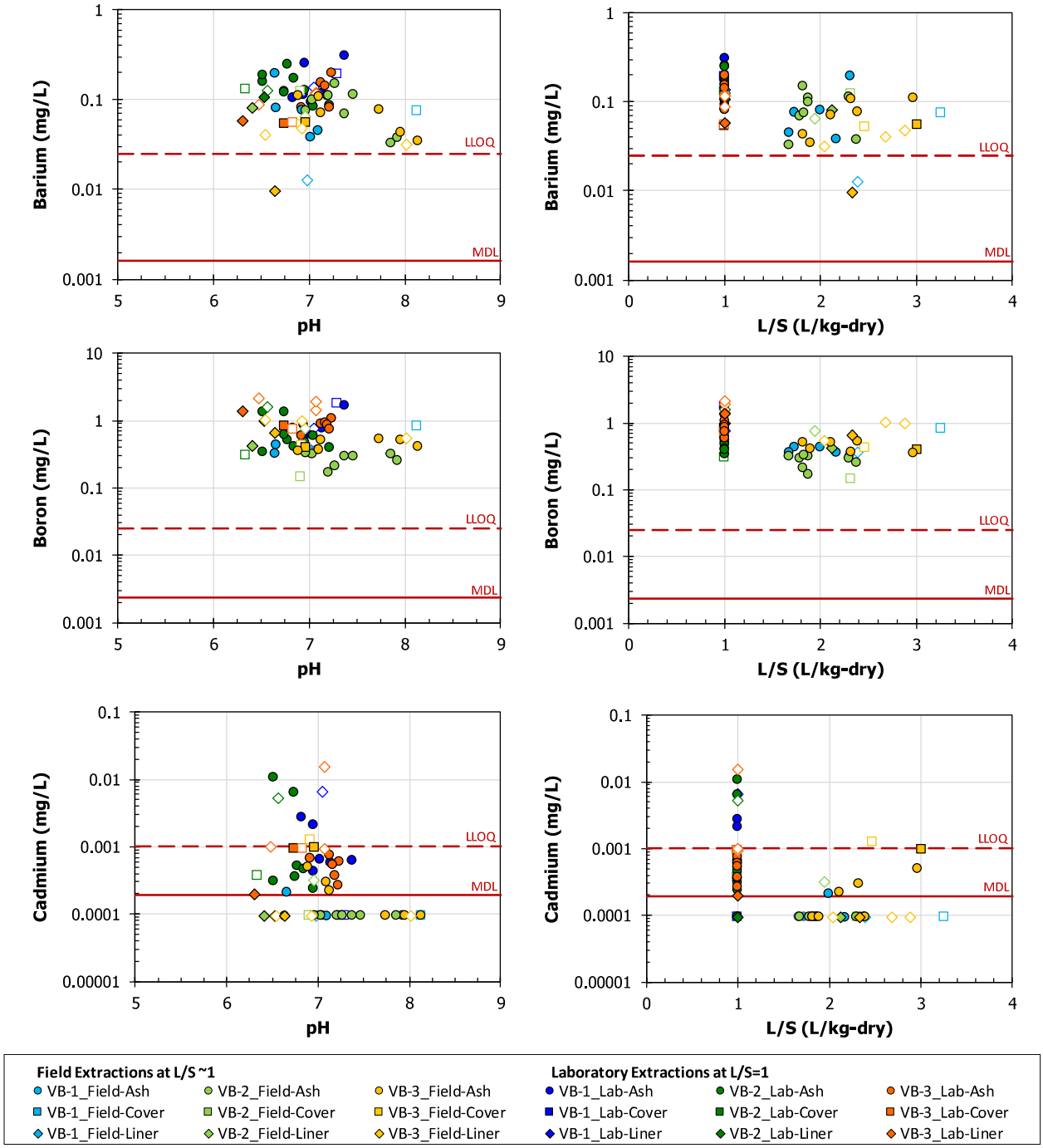

Figure C-2
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): barium, boron, and cadmium.

Individual Split Spoon Sample Analysis

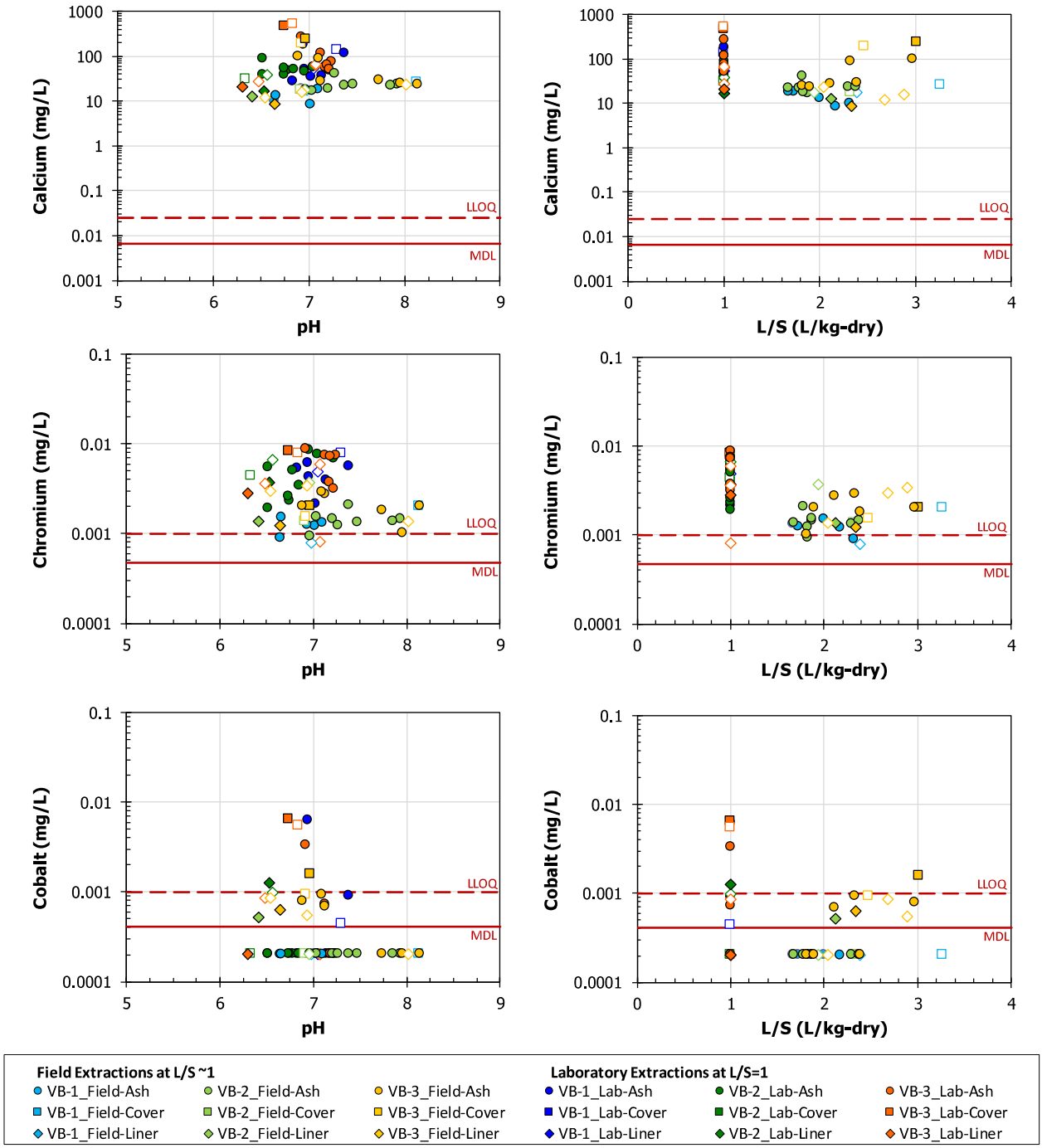

Figure C-3
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): calcium, chromium, cobalt.

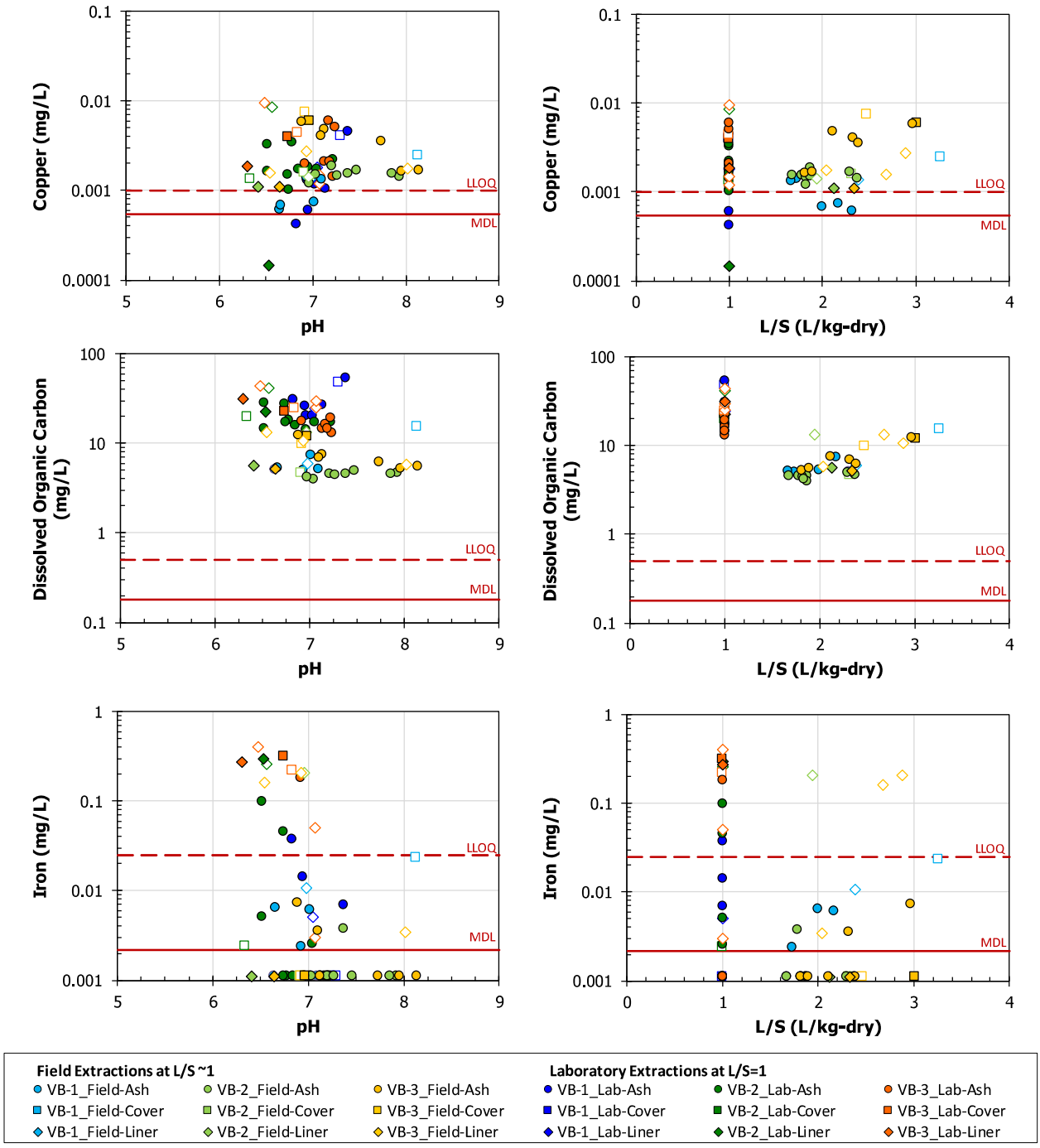

Figure C-4
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): copper, dissolved organic carbon, and iron.

Individual Split Spoon Sample Analysis

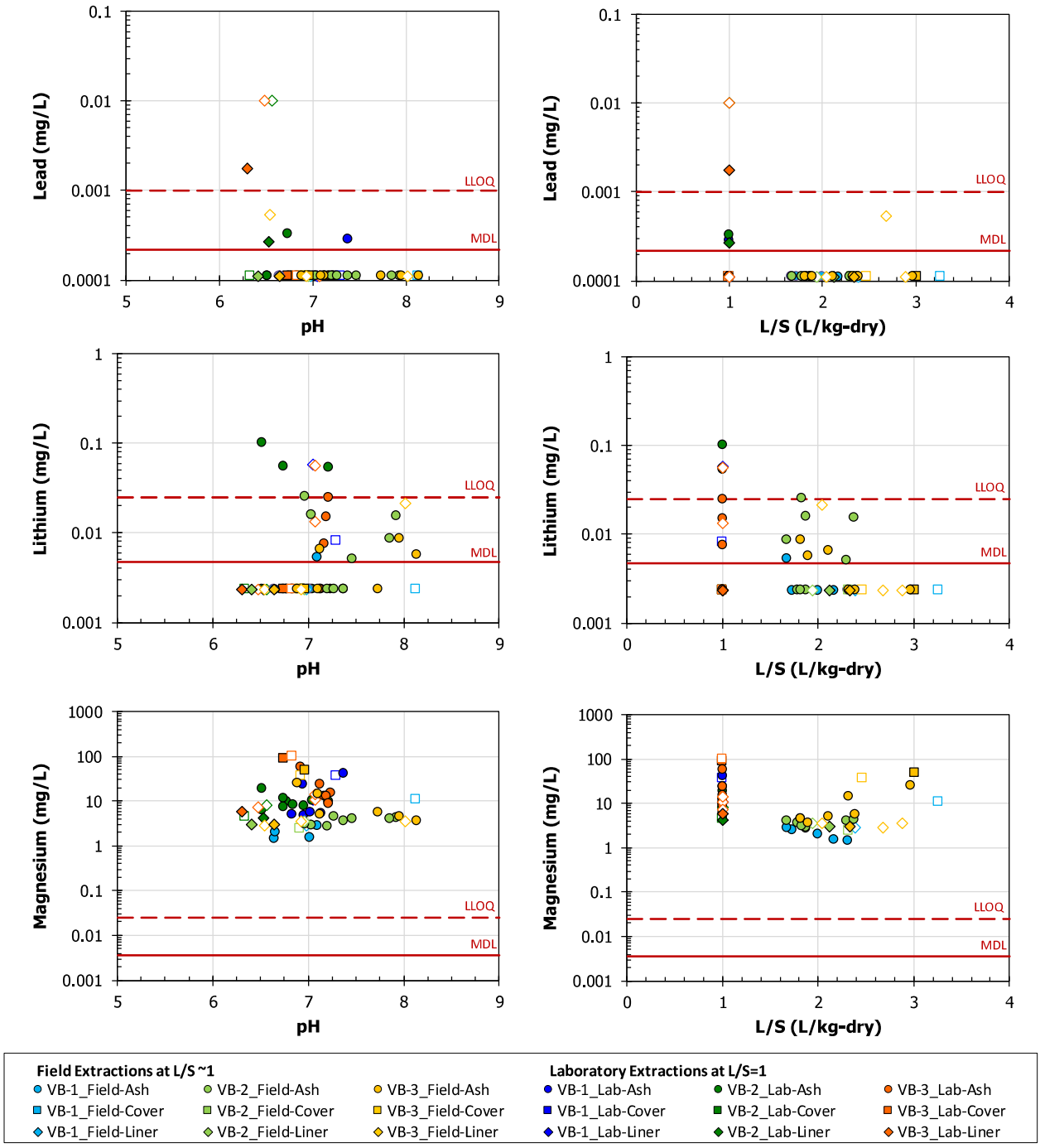

Figure C-5
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): lead, lithium and magnesium.

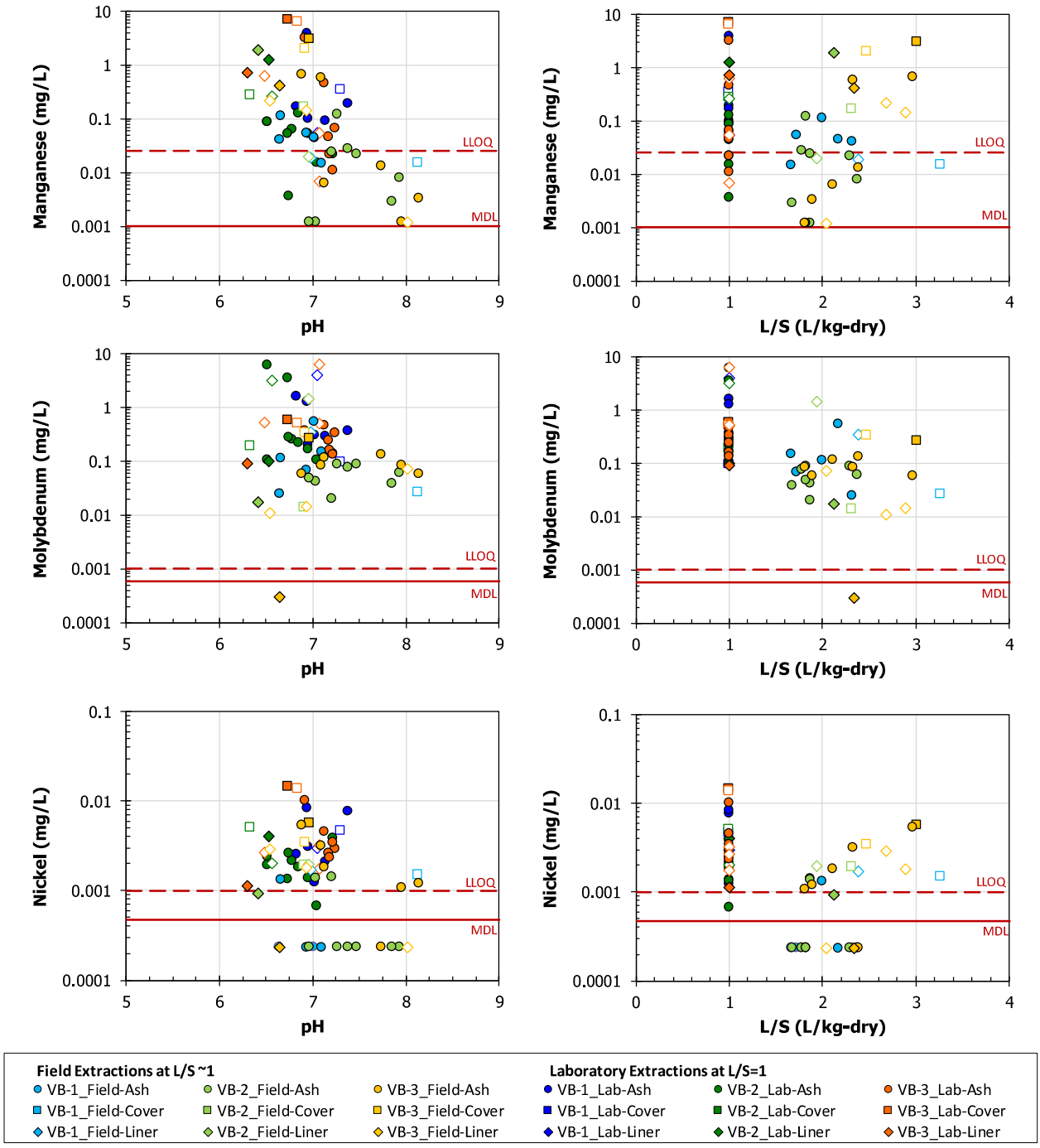

Figure C-6
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): manganese, molybdenum, and nickel.

Individual Split Spoon Sample Analysis

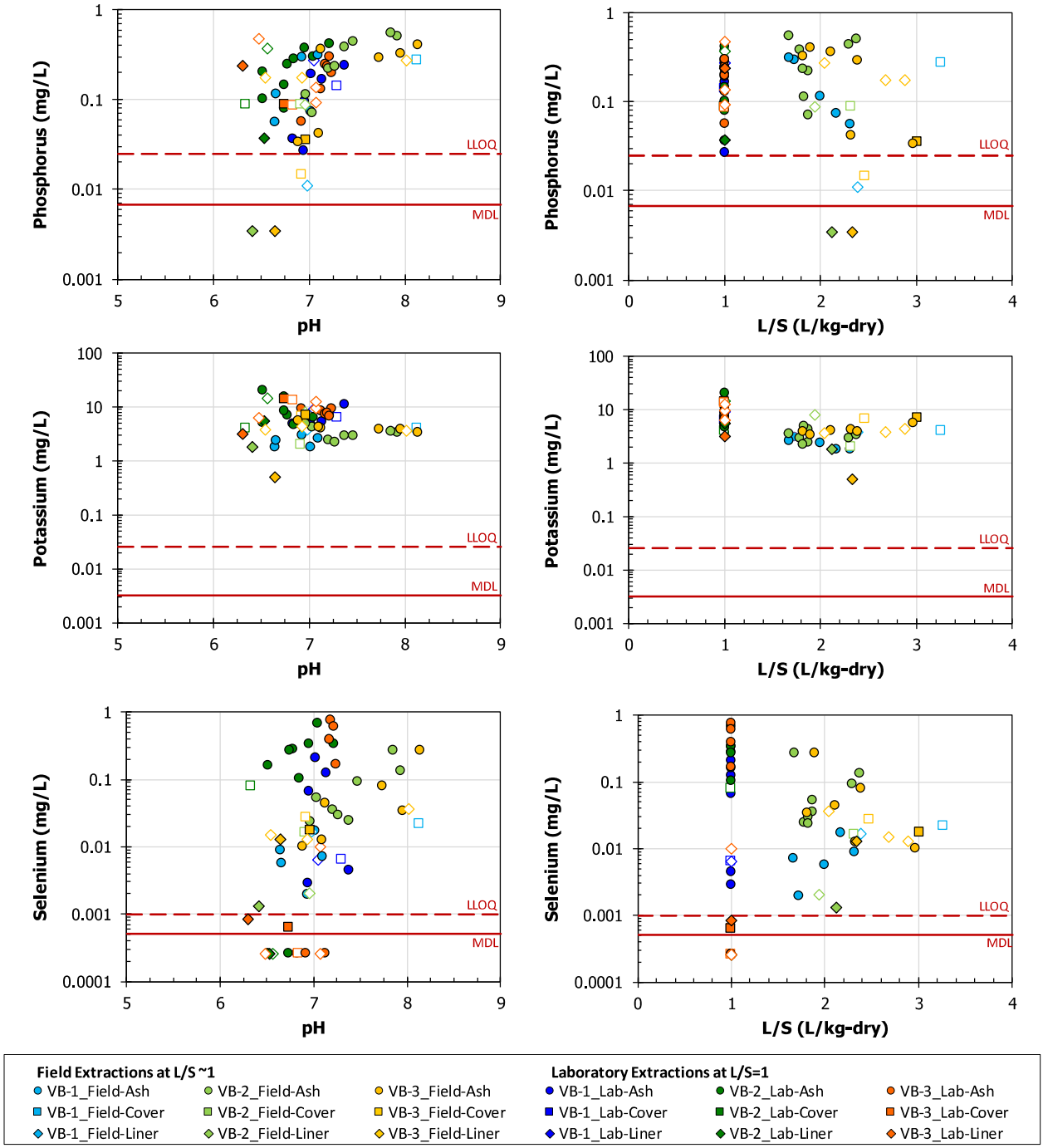

Figure C-7
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): phosphorus, potassium, and selenium.

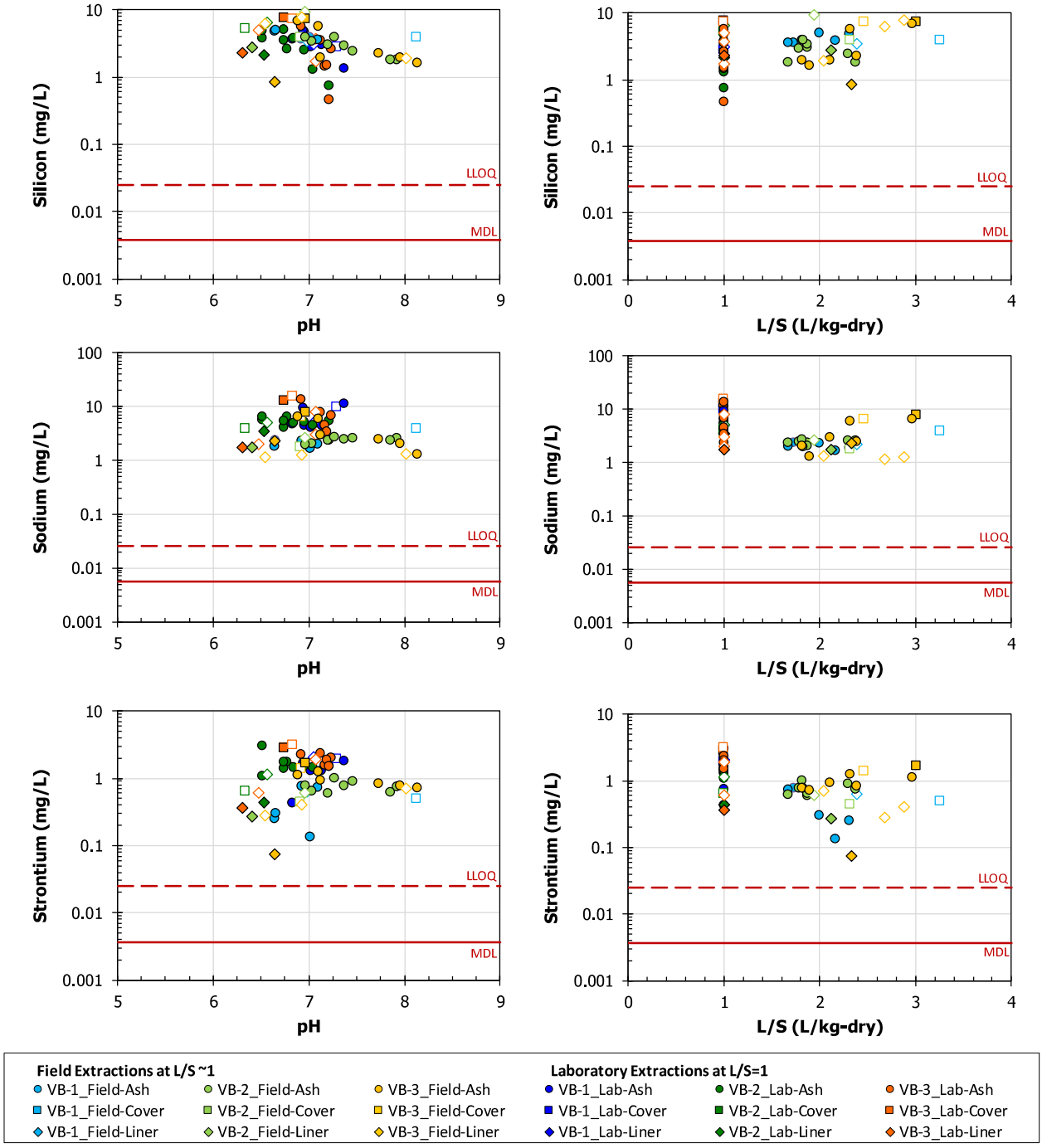

Figure C-8
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): silicon, sodium, and strontium.

Individual Split Spoon Sample Analysis

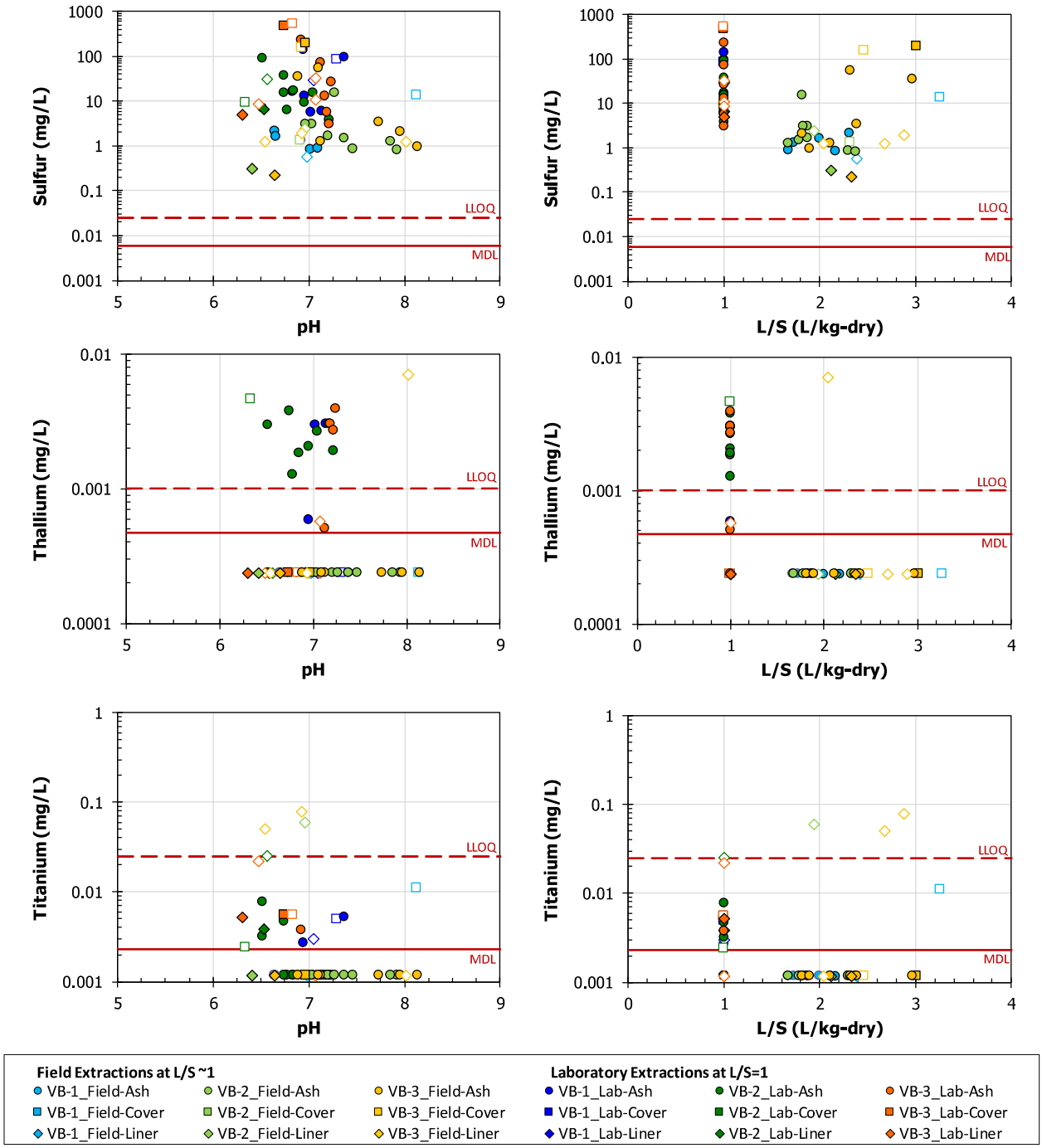

Figure C-9
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): sulfur, thallium, and titanium.

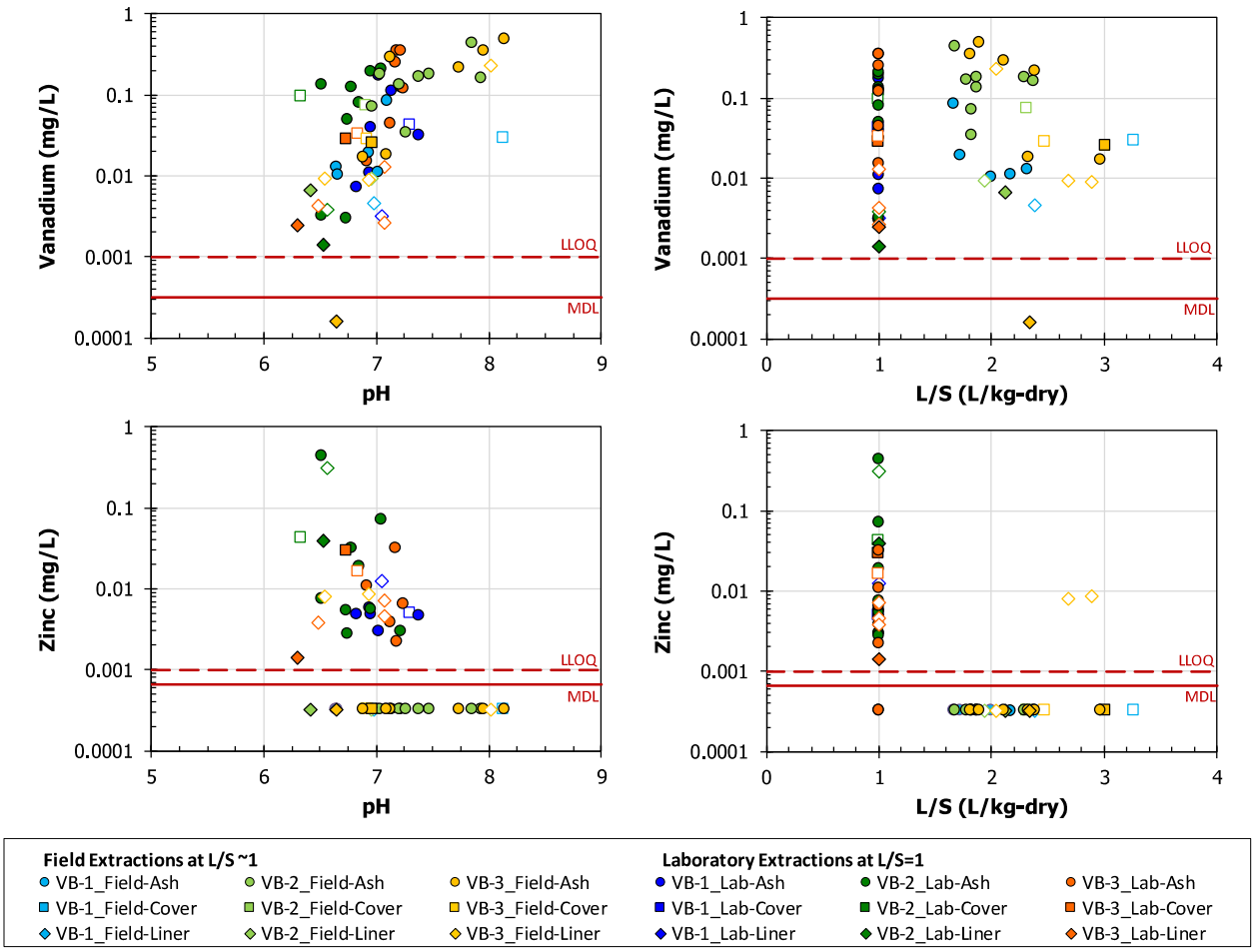

Figure C-10
Comparison of field extractions at L/S~1 (lighter colors) to laboratory extractions at L/S=1 (darker colors) for individual split spoon materials shown as a function of pH (left) and L/S (right): vanadium and zinc.

C.2 Standardized Concentration Profiles from Laboratory Extractions (L/S=1) Using the Global Ash Material Mean and Standard Deviation

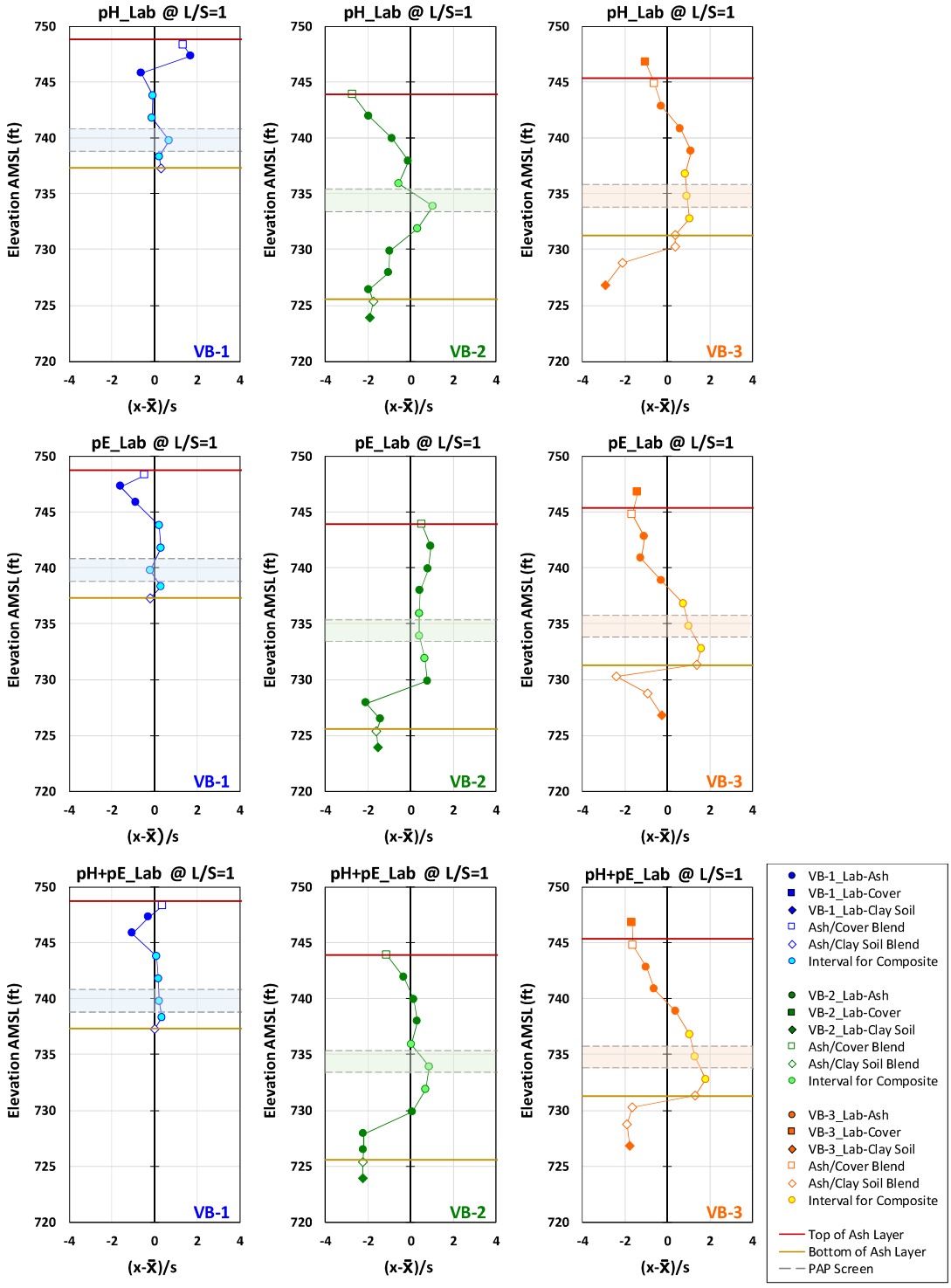

Figure C-11
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: pH, pE, and pH+pE.

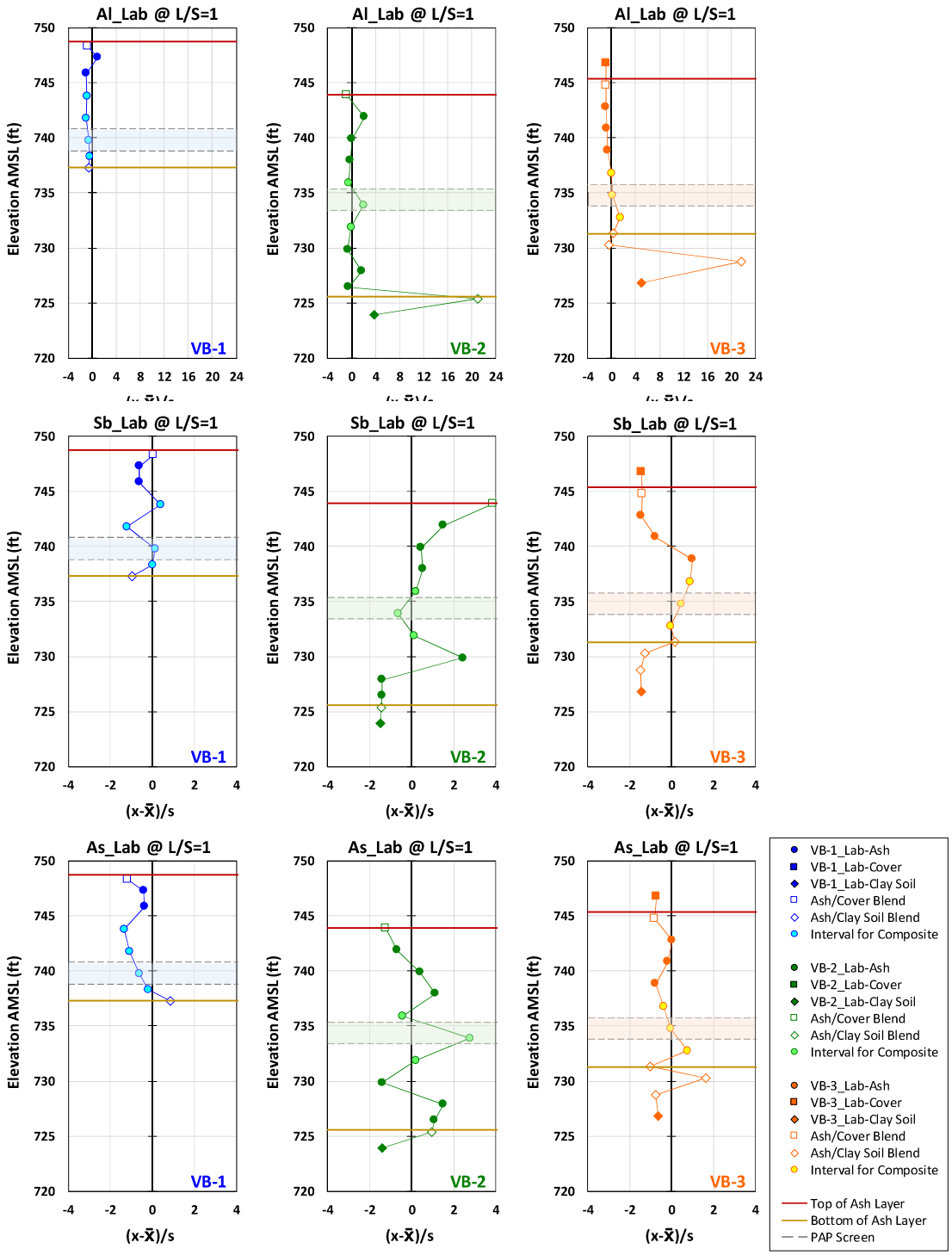

Figure C-12
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: aluminum, antimony, and arsenic.

Individual Split Spoon Sample Analysis

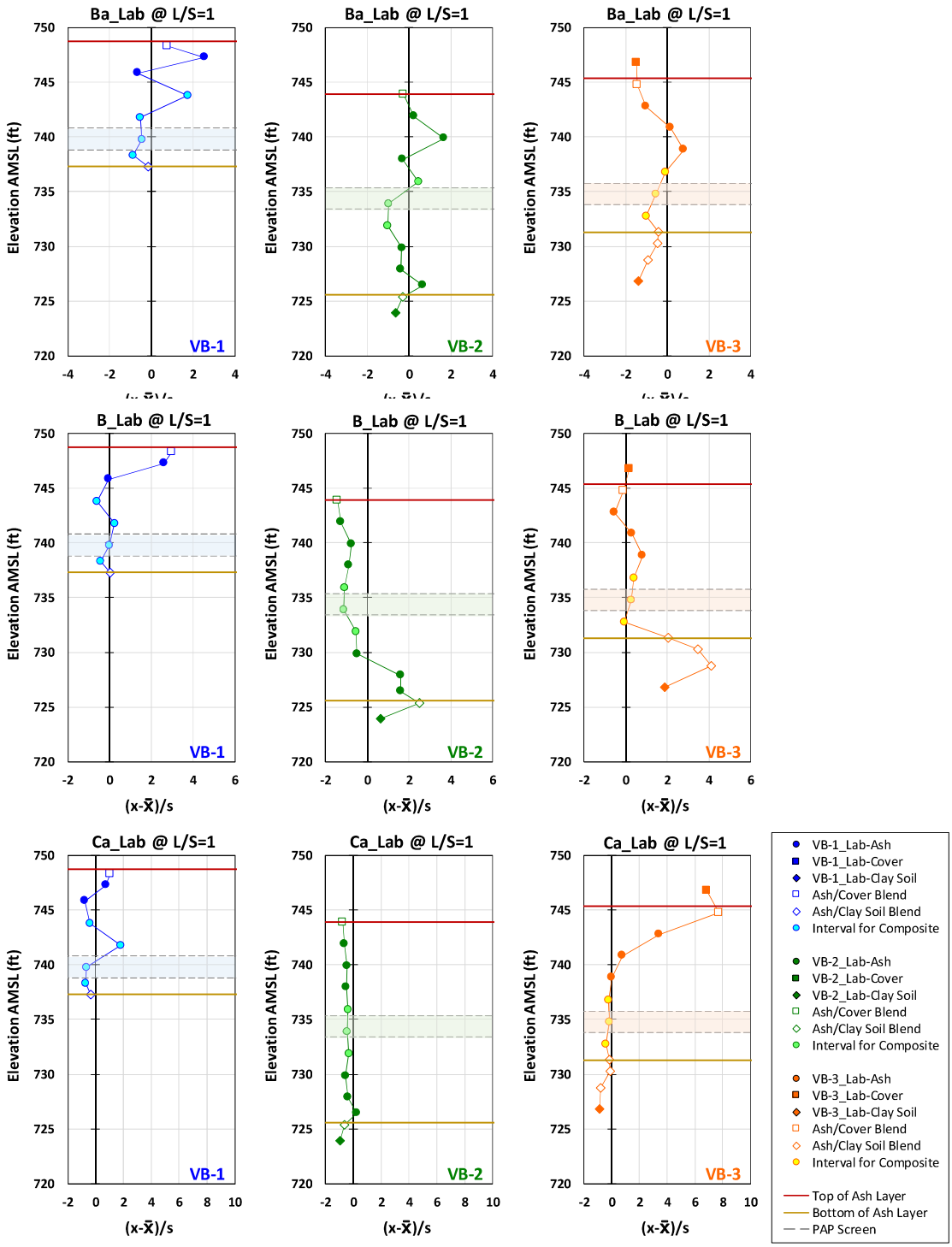

Figure C-13
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: barium, boron, and calcium.

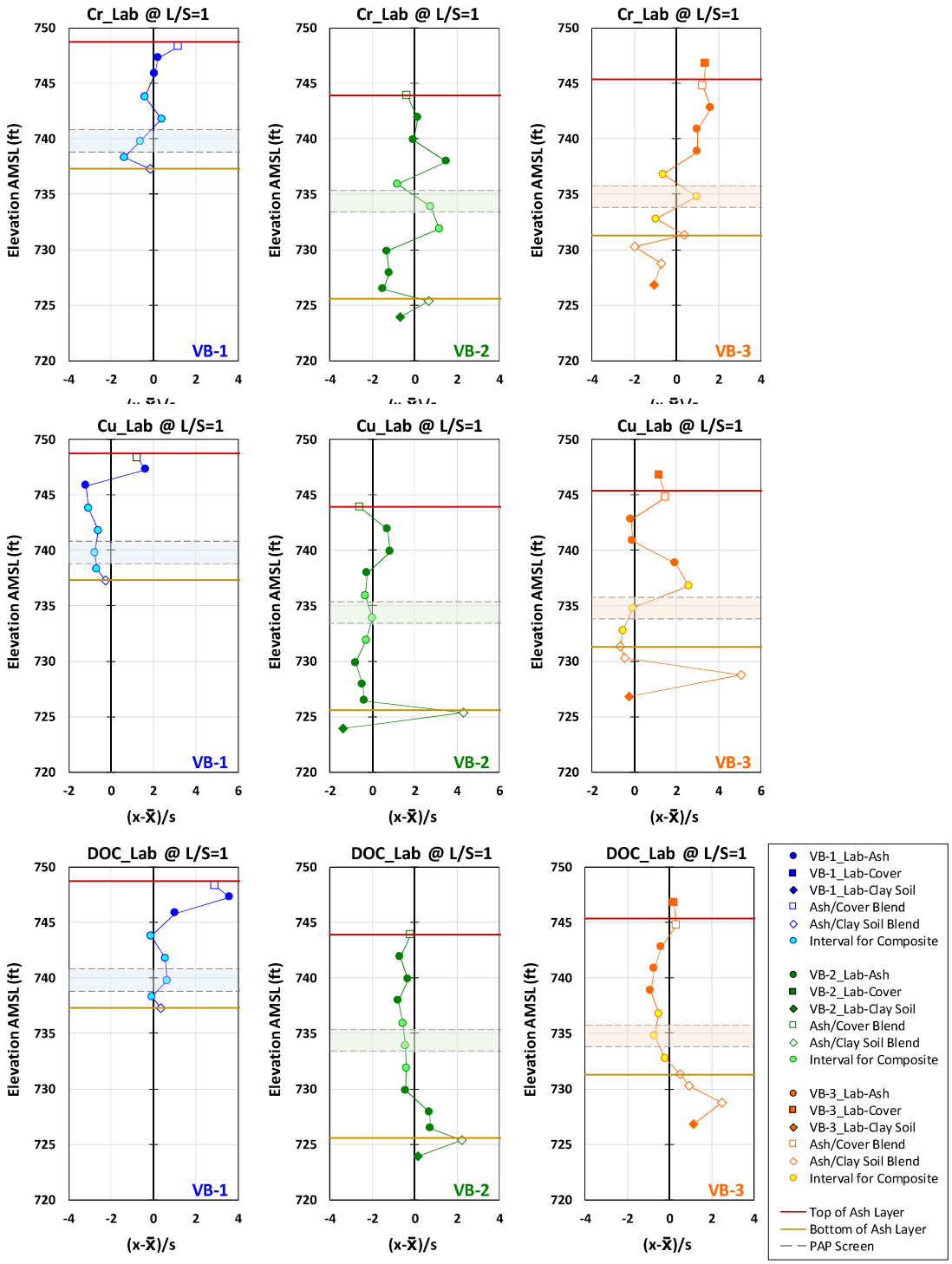

Figure C-14
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: chromium, copper, and dissolved organic carbon.

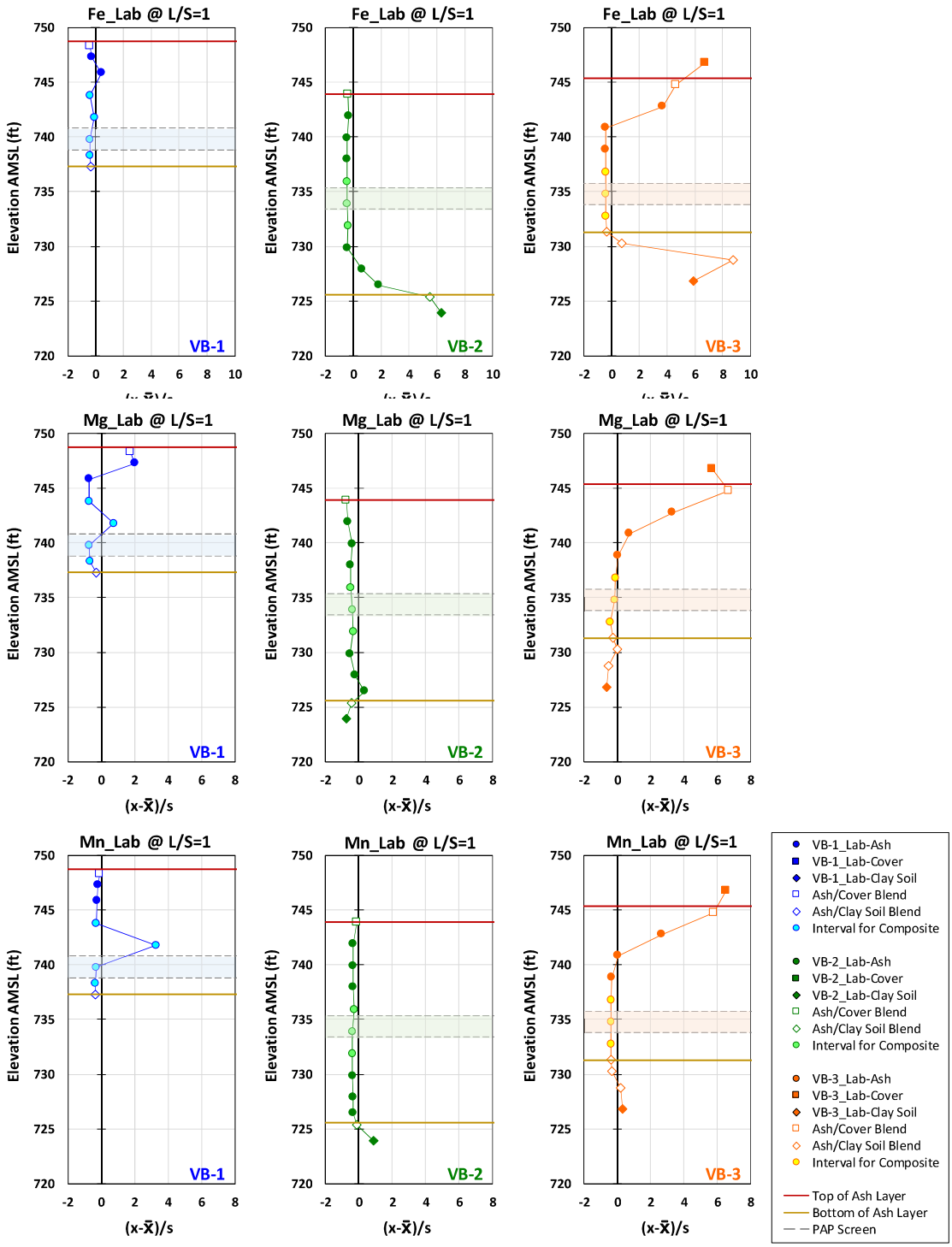

Figure C-15
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: iron, magnesium, and manganese.

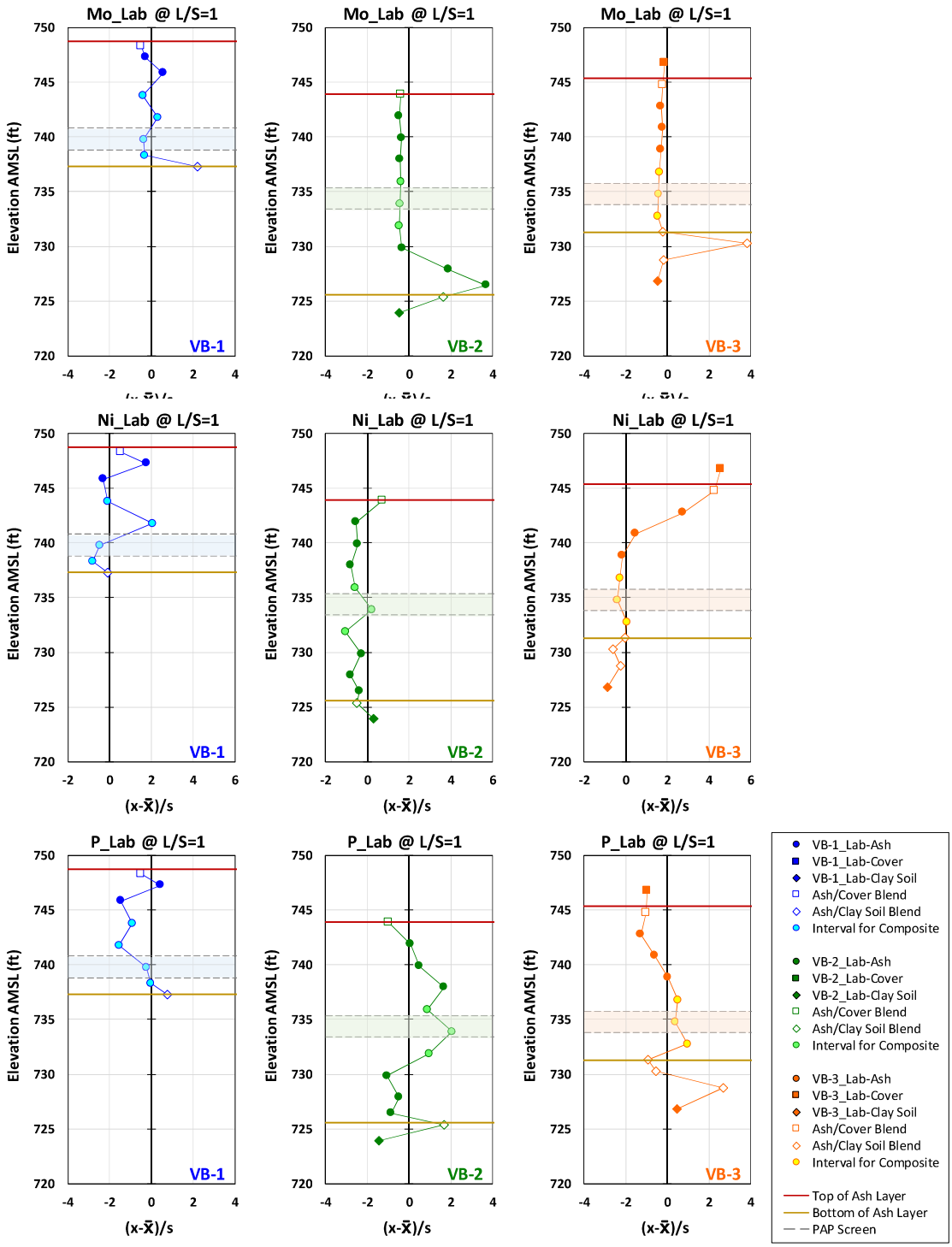

Figure C-16
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: molybdenum, nickel, and phosphorus.

Individual Split Spoon Sample Analysis

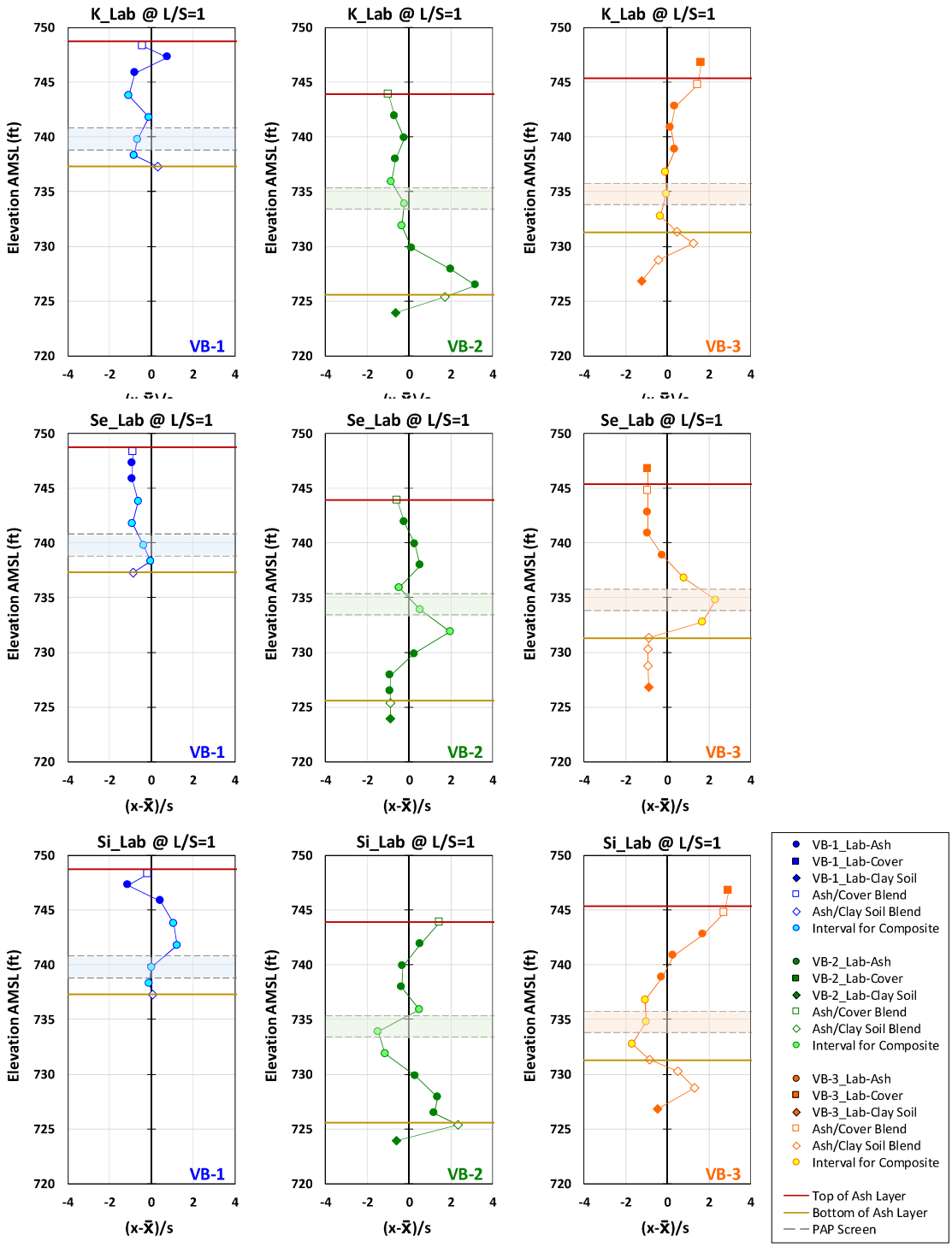

Figure C-17
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: potassium, selenium, and silicon.

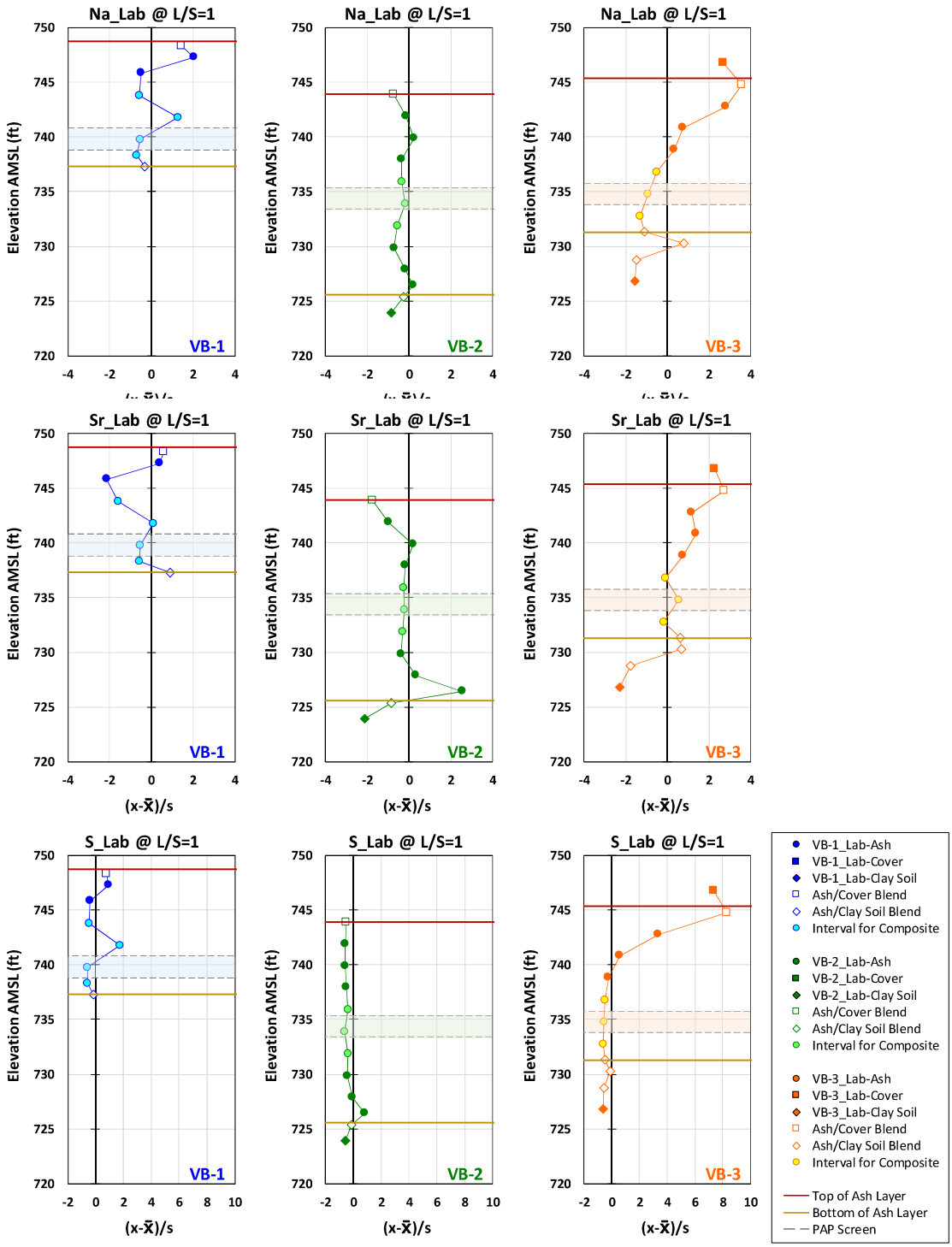

Figure C-18
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: sodium, strontium, and sulfur.

Individual Split Spoon Sample Analysis

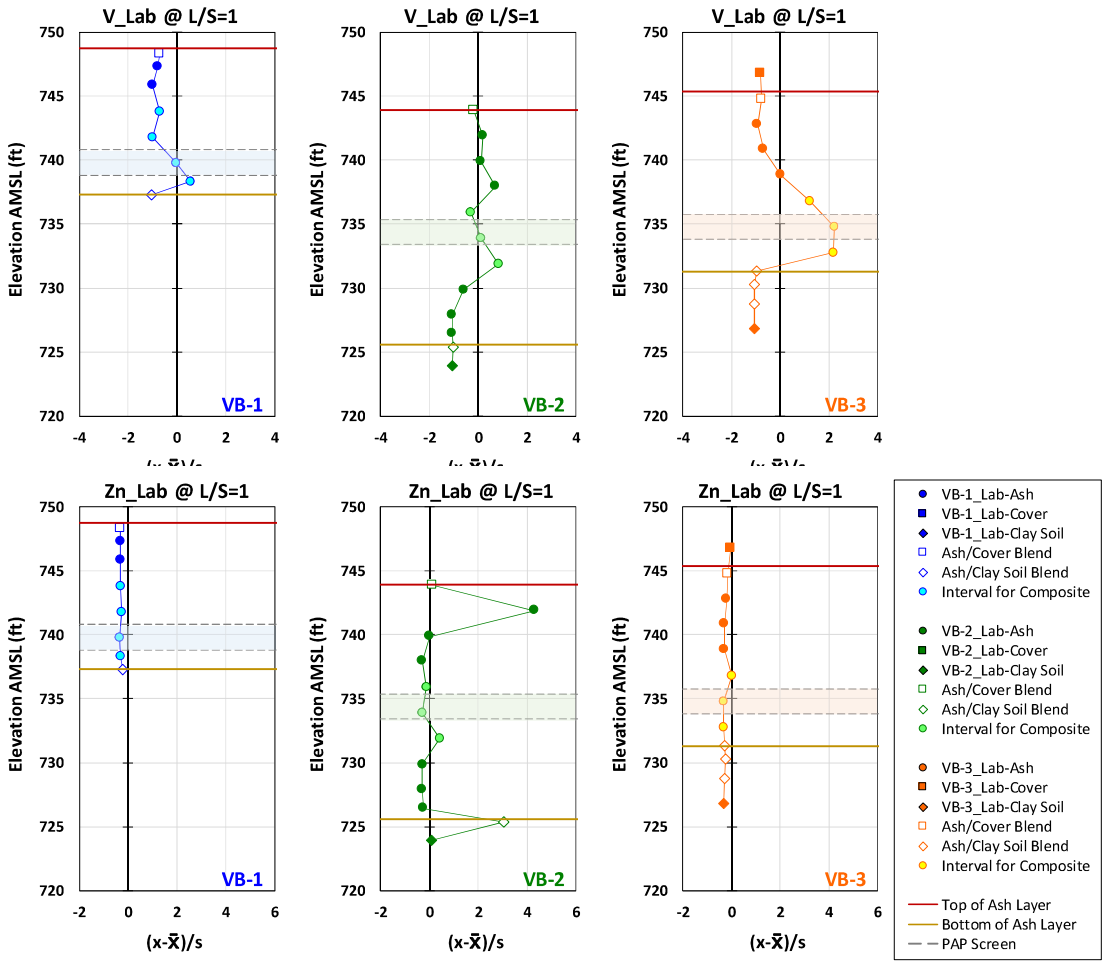

Figure C-19
Concentration profiles from laboratory extractions (L/S=1) standardized using the global ash material mean and standard deviation: vanadium and zinc.

C.3 Comparison of Standardized Release Profiles

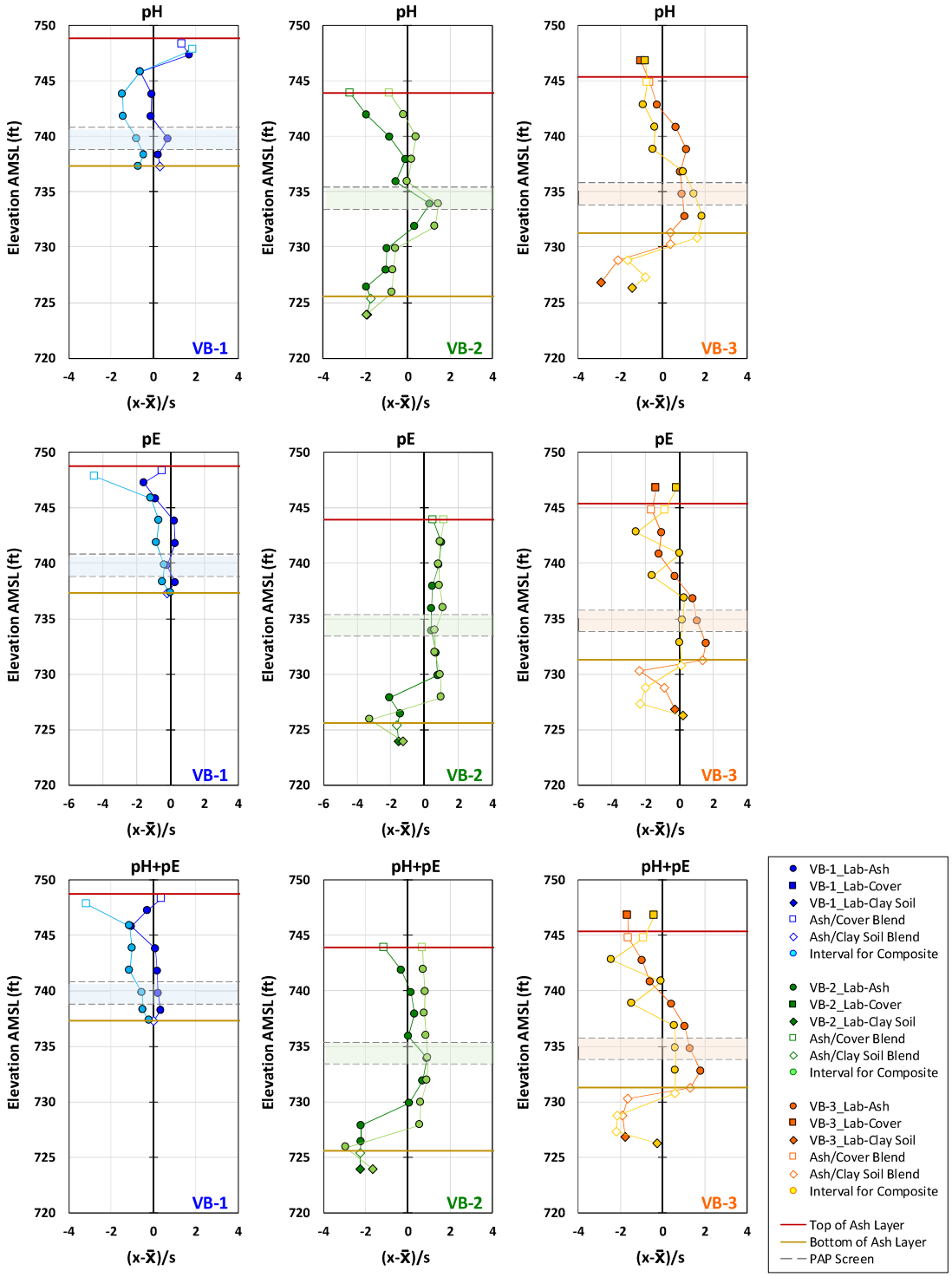

Figure C-20
Comparison of standardized profiles from field extractions (L/S~1) and laboratory extractions (L/S=1): pH, pE, and pH+pE.

Individual Split Spoon Sample Analysis

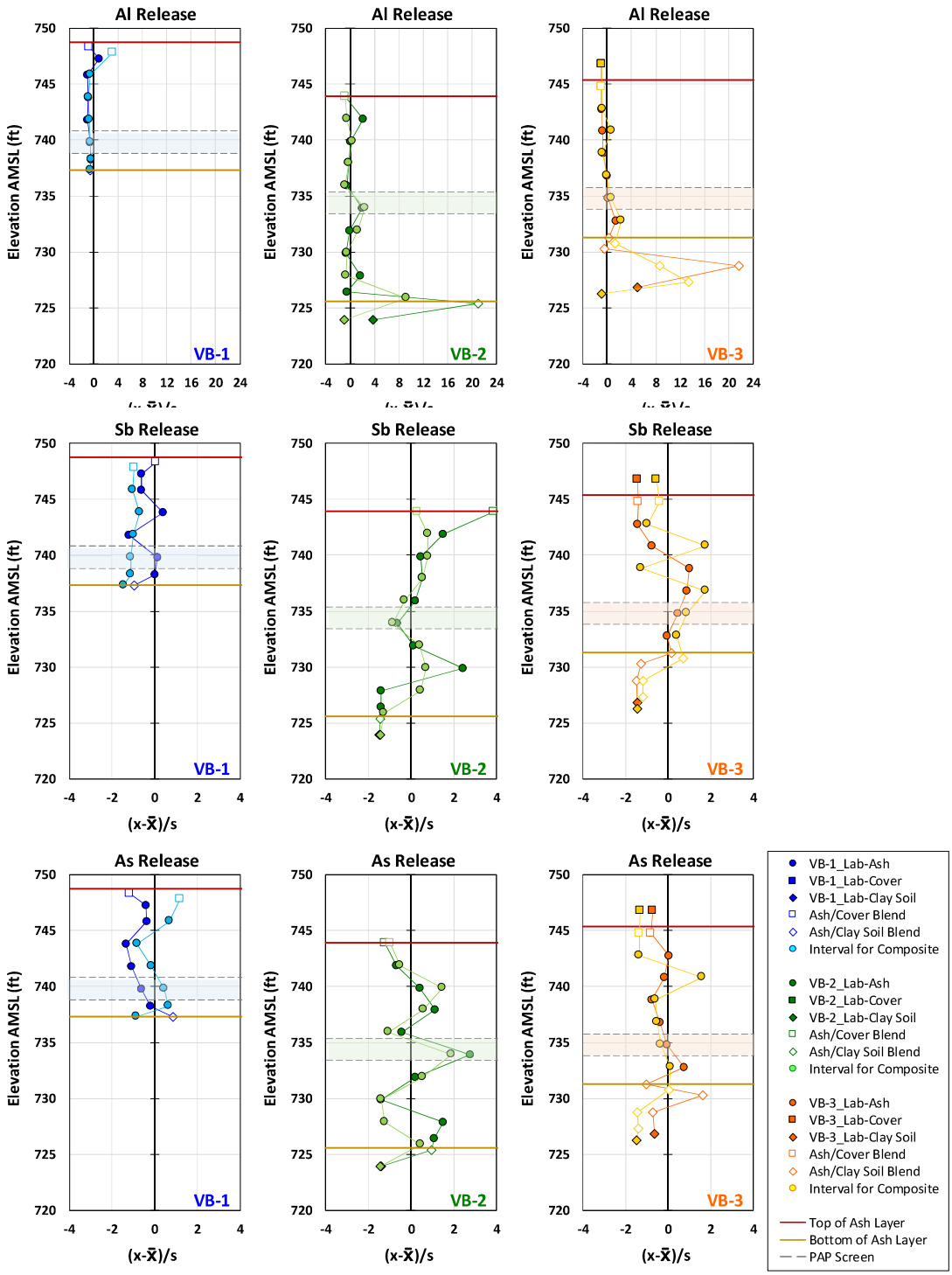

Figure C-21
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): aluminum, antimony, and arsenic.

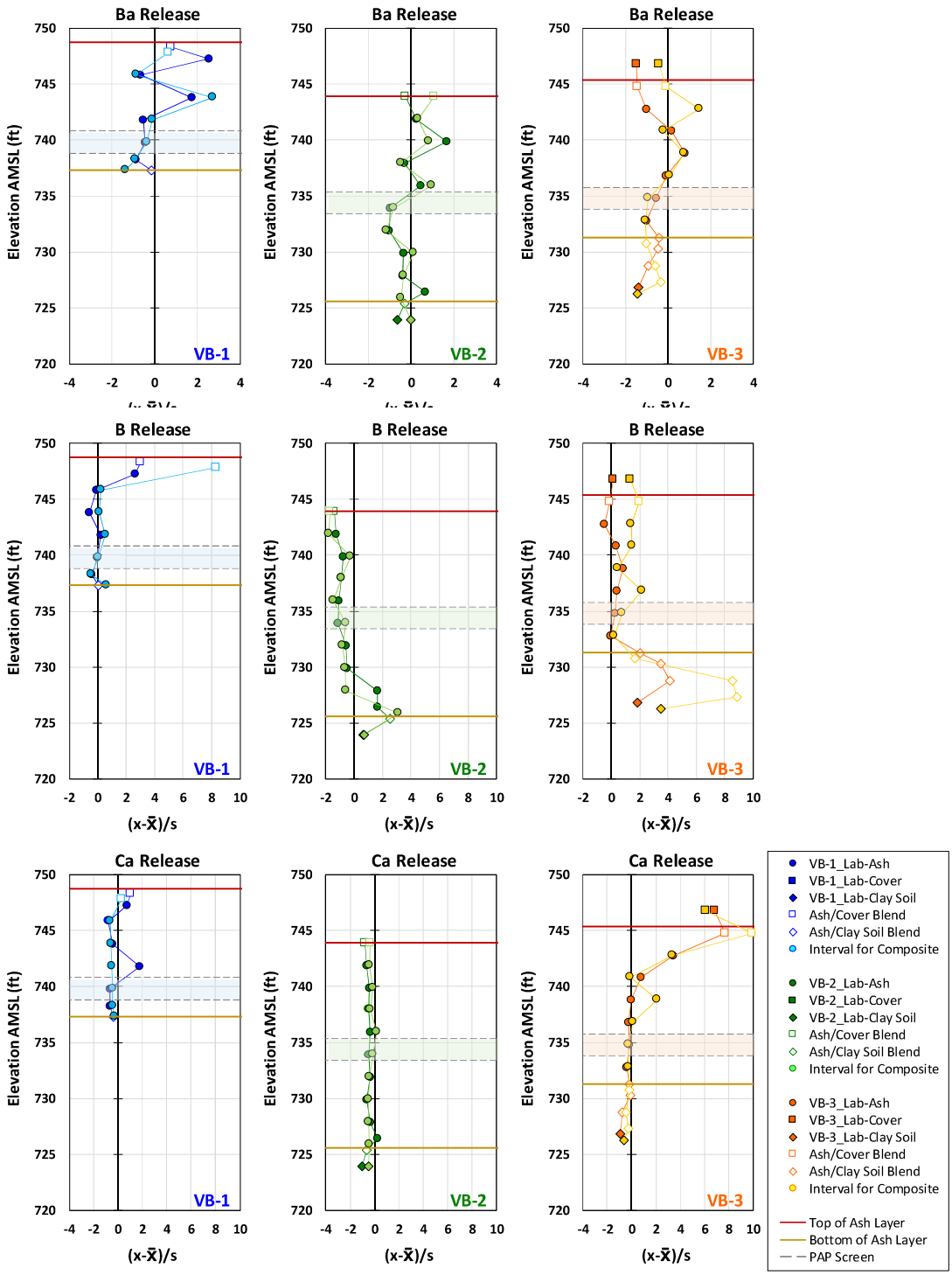

Figure C-22
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): barium, boron, and calcium.

Individual Split Spoon Sample Analysis

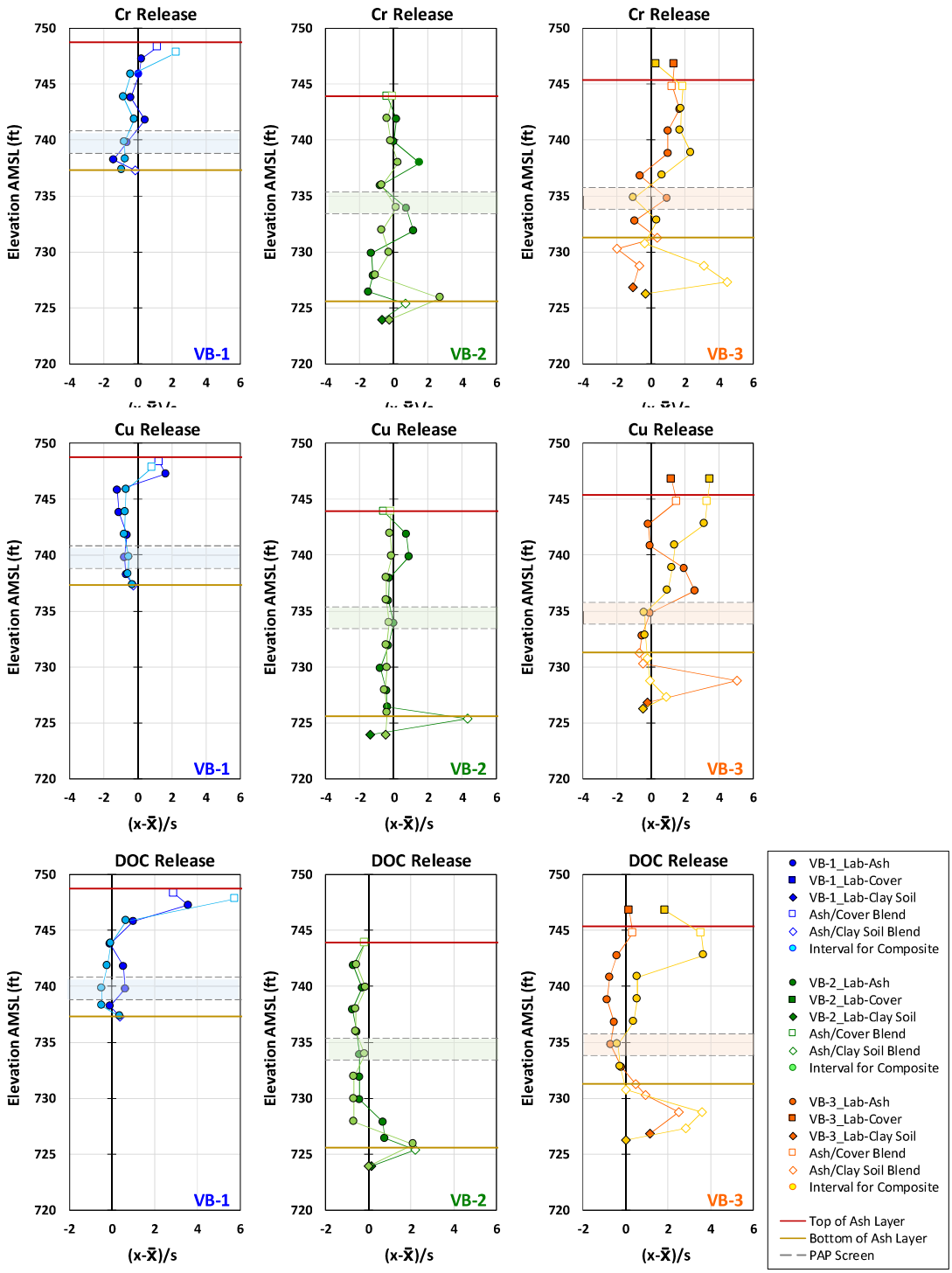

Figure C-23
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): chromium, copper, and dissolved organic carbon.

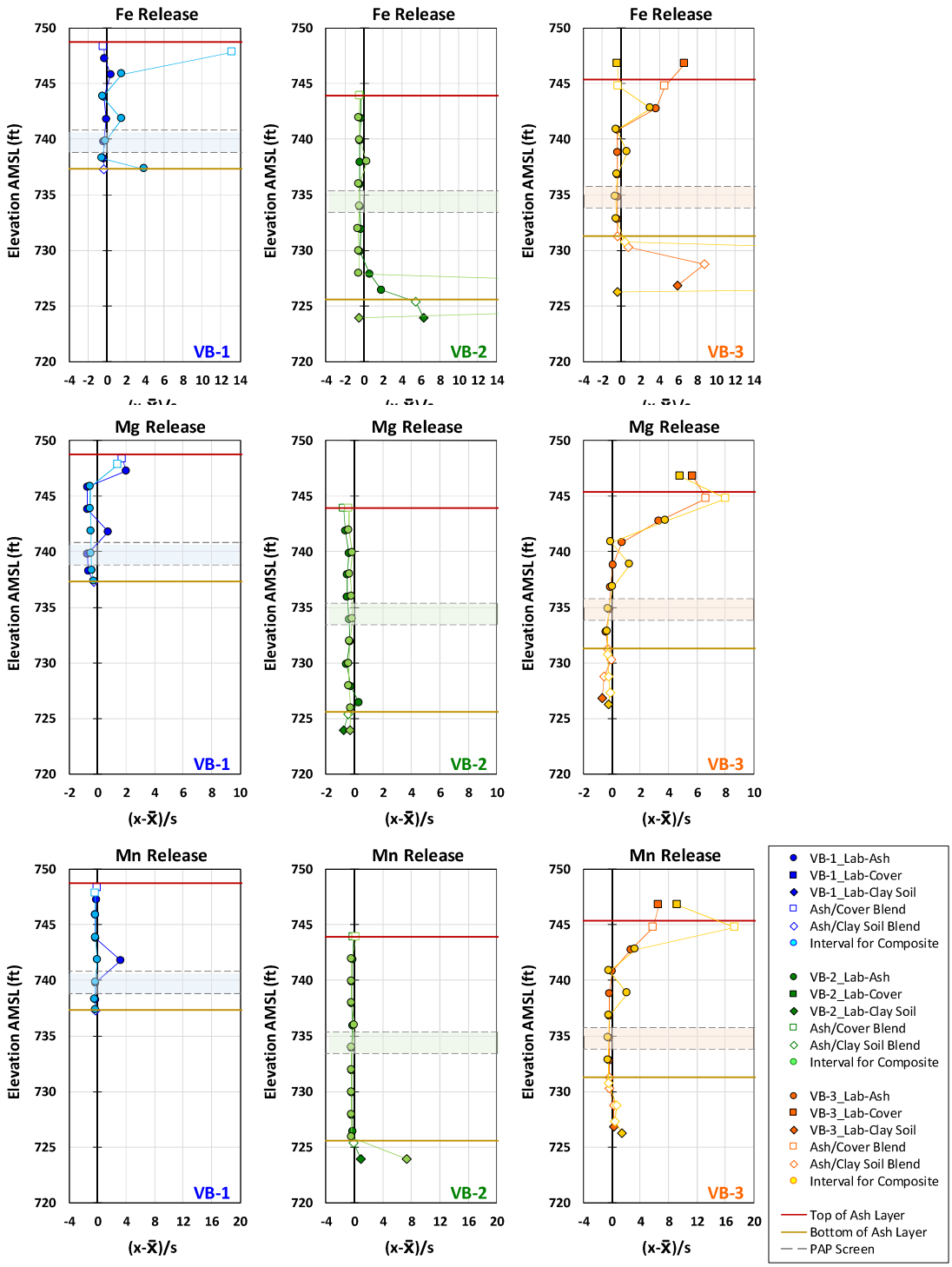

Figure C-24
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): iron, magnesium, and manganese.

Individual Split Spoon Sample Analysis

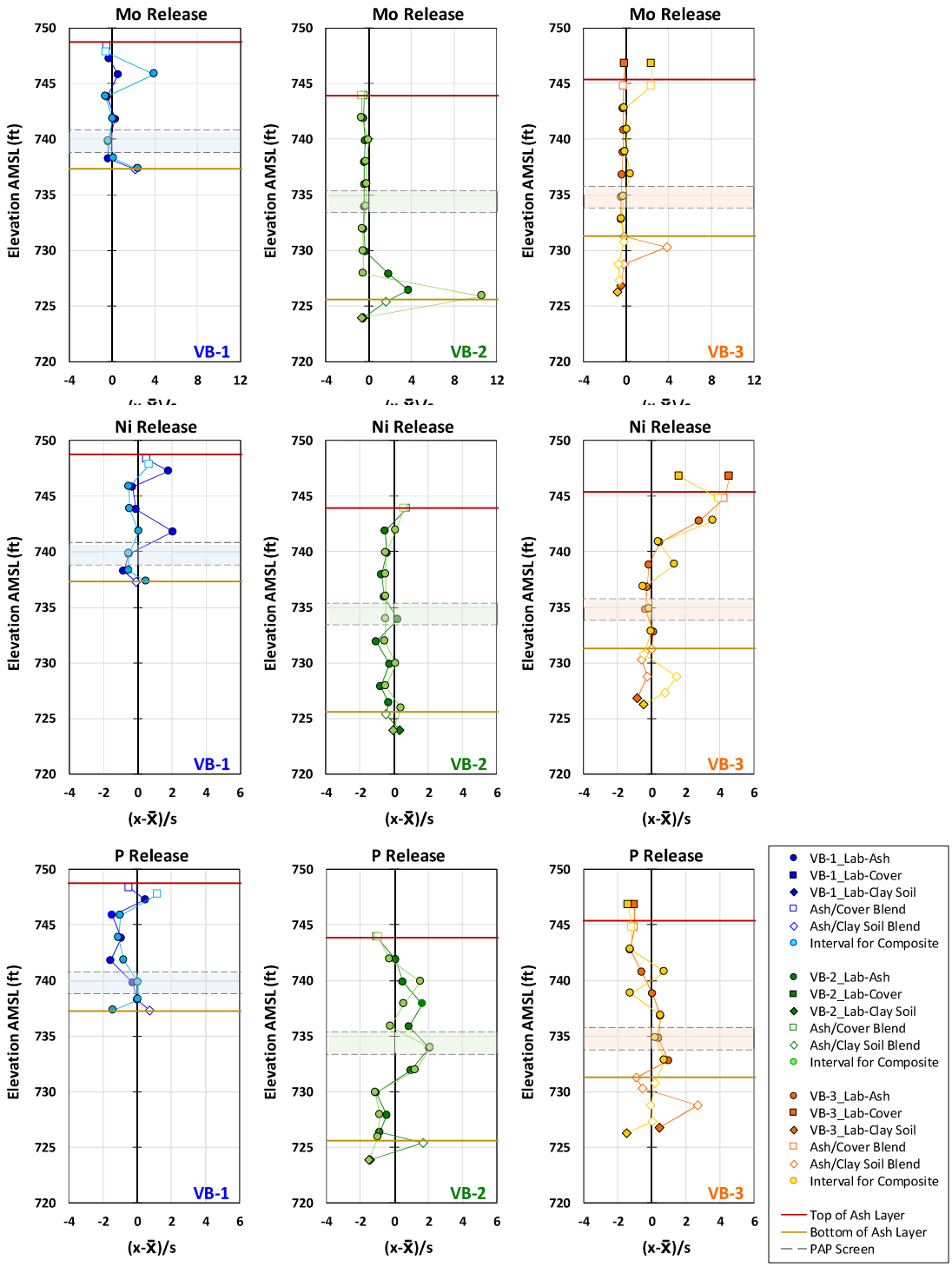

Figure C-25
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): molybdenum, nickel, and phosphorus.

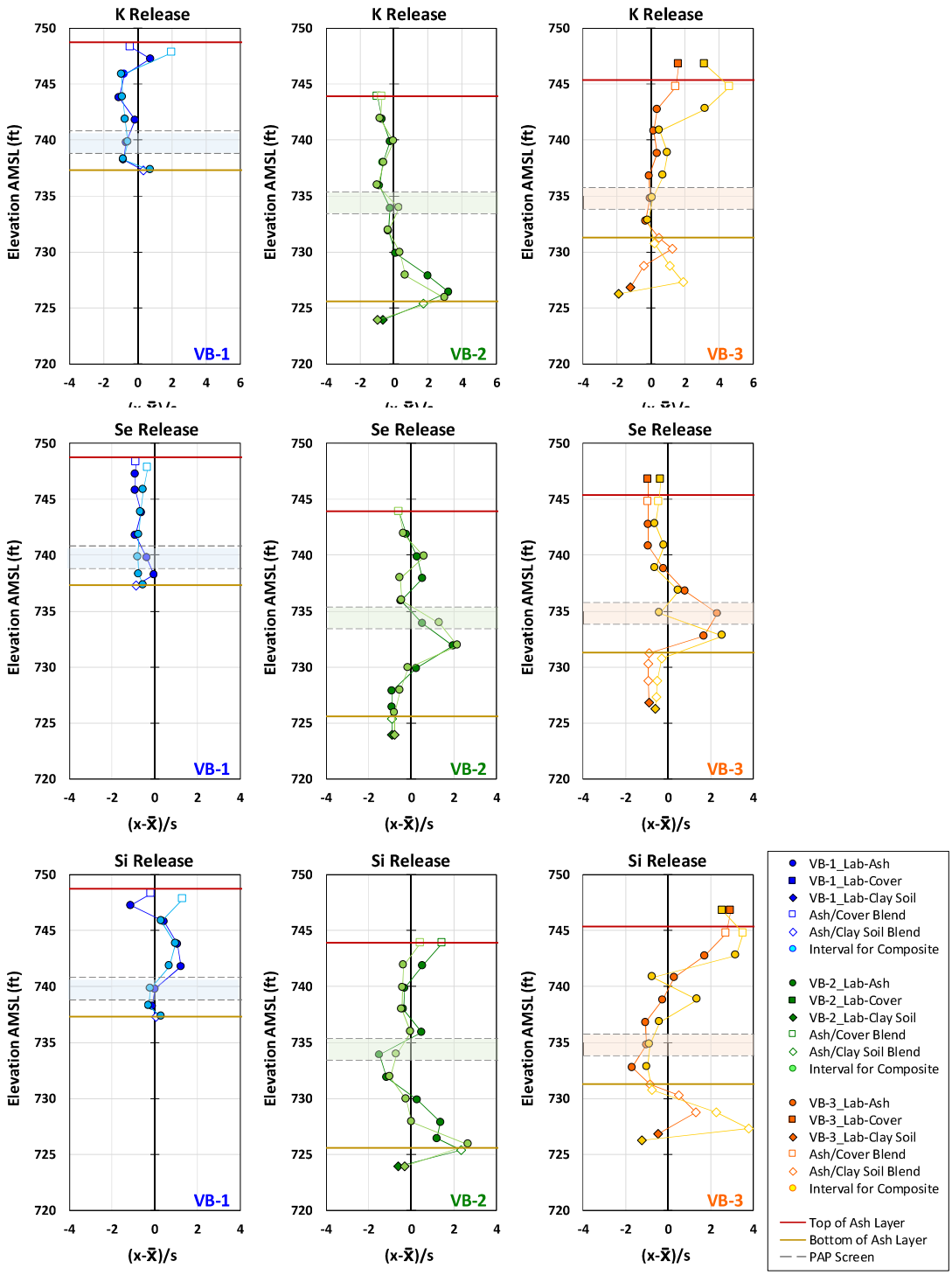

Figure C-26
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): potassium, selenium, and silicon.

Individual Split Spoon Sample Analysis

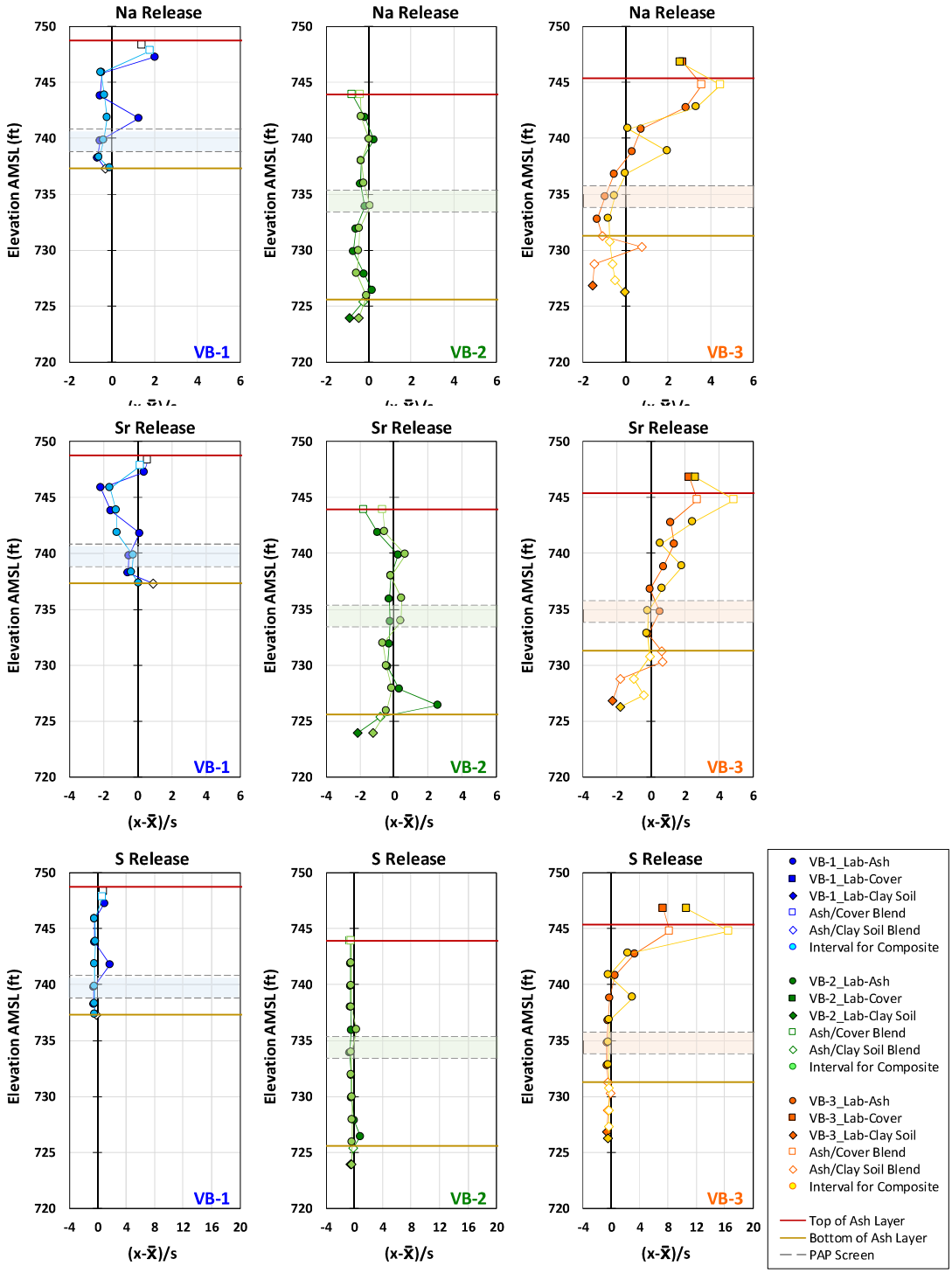

Figure C-27
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): sodium, strontium, and sulfur.

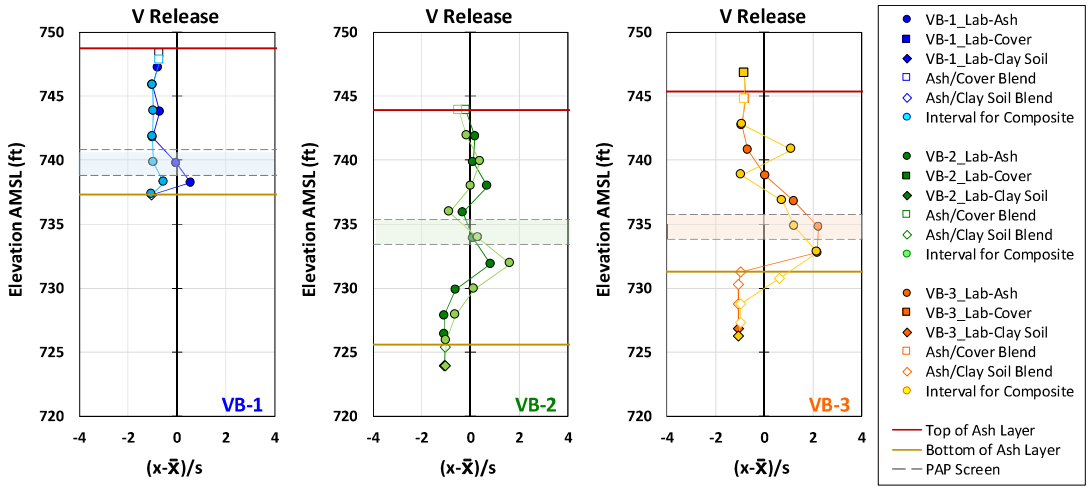

Figure C-28
Comparison of standardized mass release profiles (mg/kg) from field extractions (L/S~1) and laboratory extractions (L/S=1): vanadium.

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D
LEAF TEST RESULTS ON COMPOSITE SAMPLES

Table of Appendices

D.1 pH- and L/S-Dependent Test Results

The following graphs present the results of pH-dependent tests (i.e., EPA Method 1313 and the low L/S-modified 1313) and L/S-dependent test (i.e., EPA Method 1314) on composite samples from split spoon samples taken from three boreholes at the closed KSP impoundment. These figures show the following data for three composites of coal ash:

a) eluate concentration in mg/L as a function of pH (top, left),

b) eluate concentration in mg/L as a function of L/S (top, right),

c) mass release in mg/kg-dry as a function of pH (middle, left) including available content, derived from the maximum concentration in the 1313 LSP curve,

d) cumulative mass release in mg/kg-dry as a function of cumulative L/S (middle, right),

e) acid/base neutralization capacity (ANC/BNC) of the composite material as a function of pH, and

f) evolution of eluate pH from the percolation column test.

D.2 Comparison of Individual Split Spoon and Composite Sample Data

D.1 pH- and L/S-Dependent Test Results

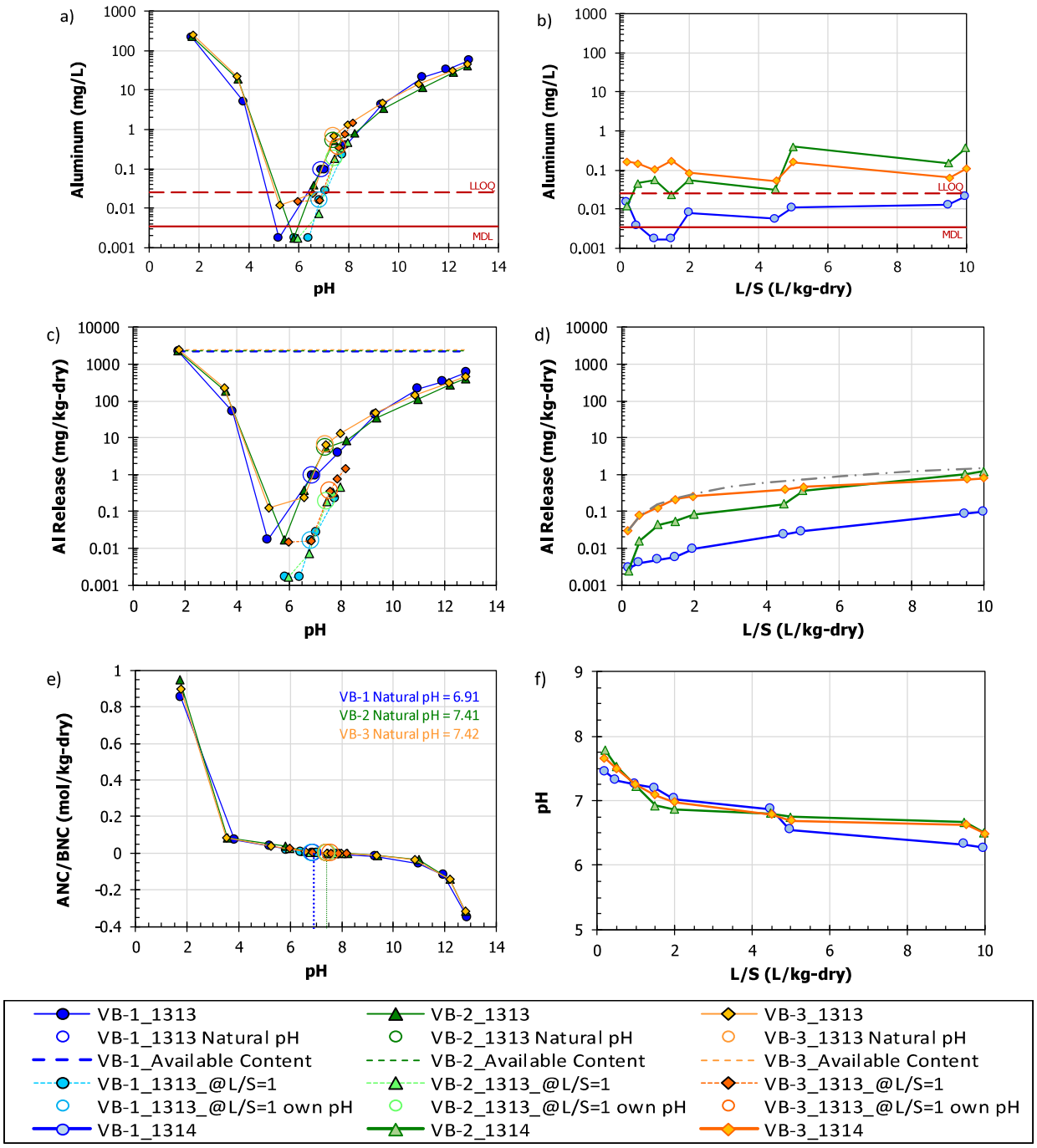

Figure D-1
Aluminum LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

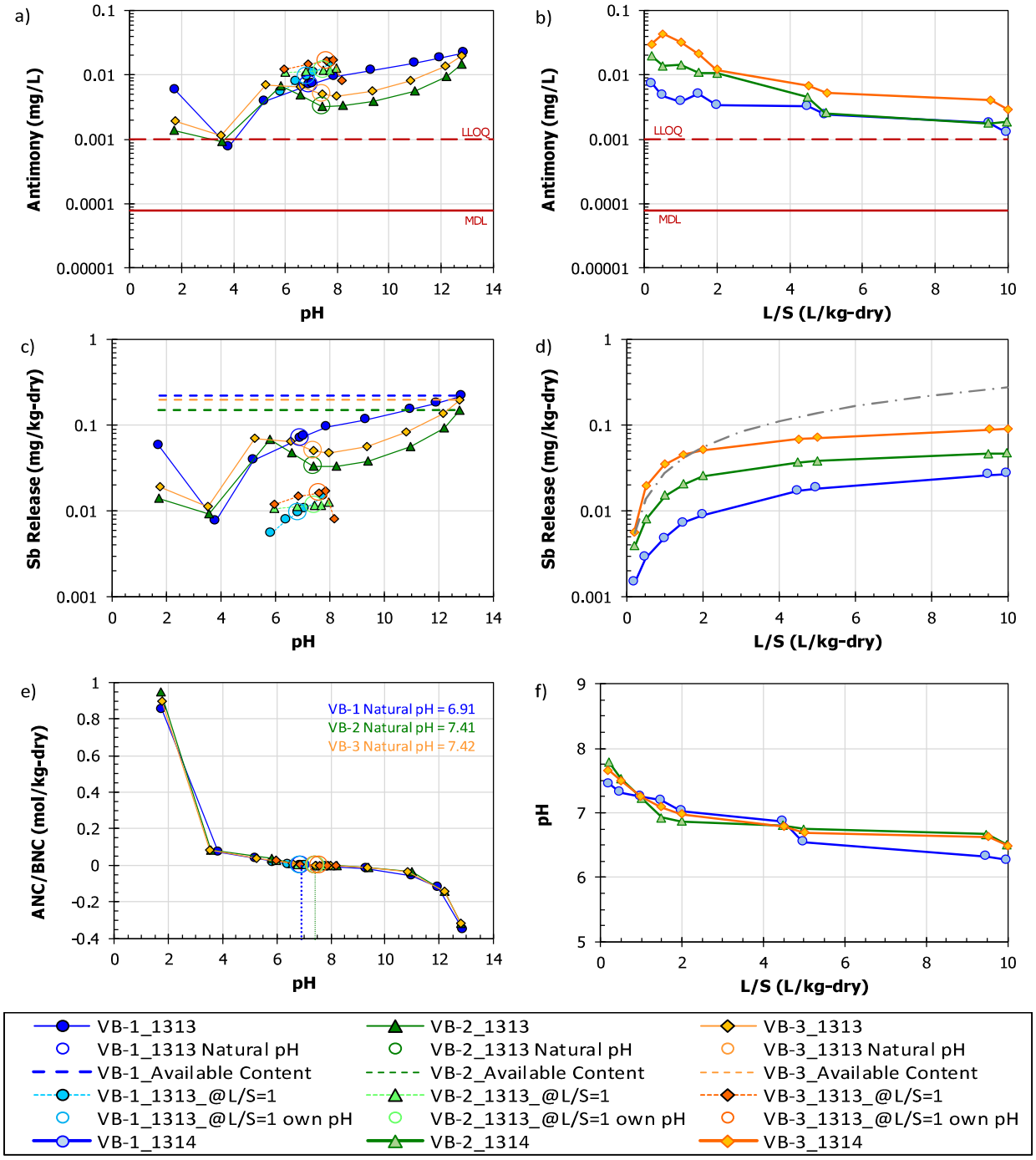

Figure D-2
Antimony LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

LEAF Test Results on Composite Samples

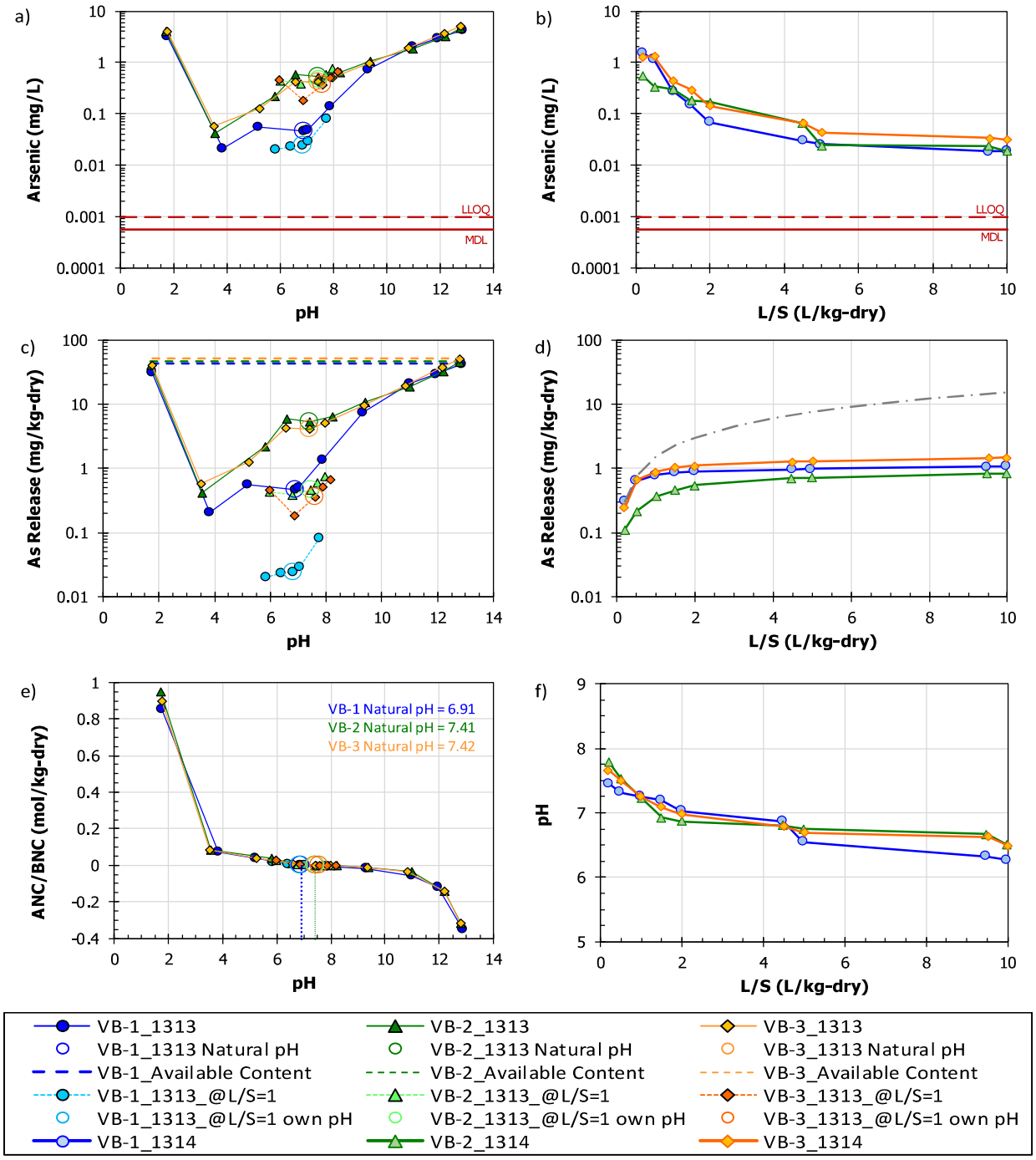

Figure D-3
Arsenic LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

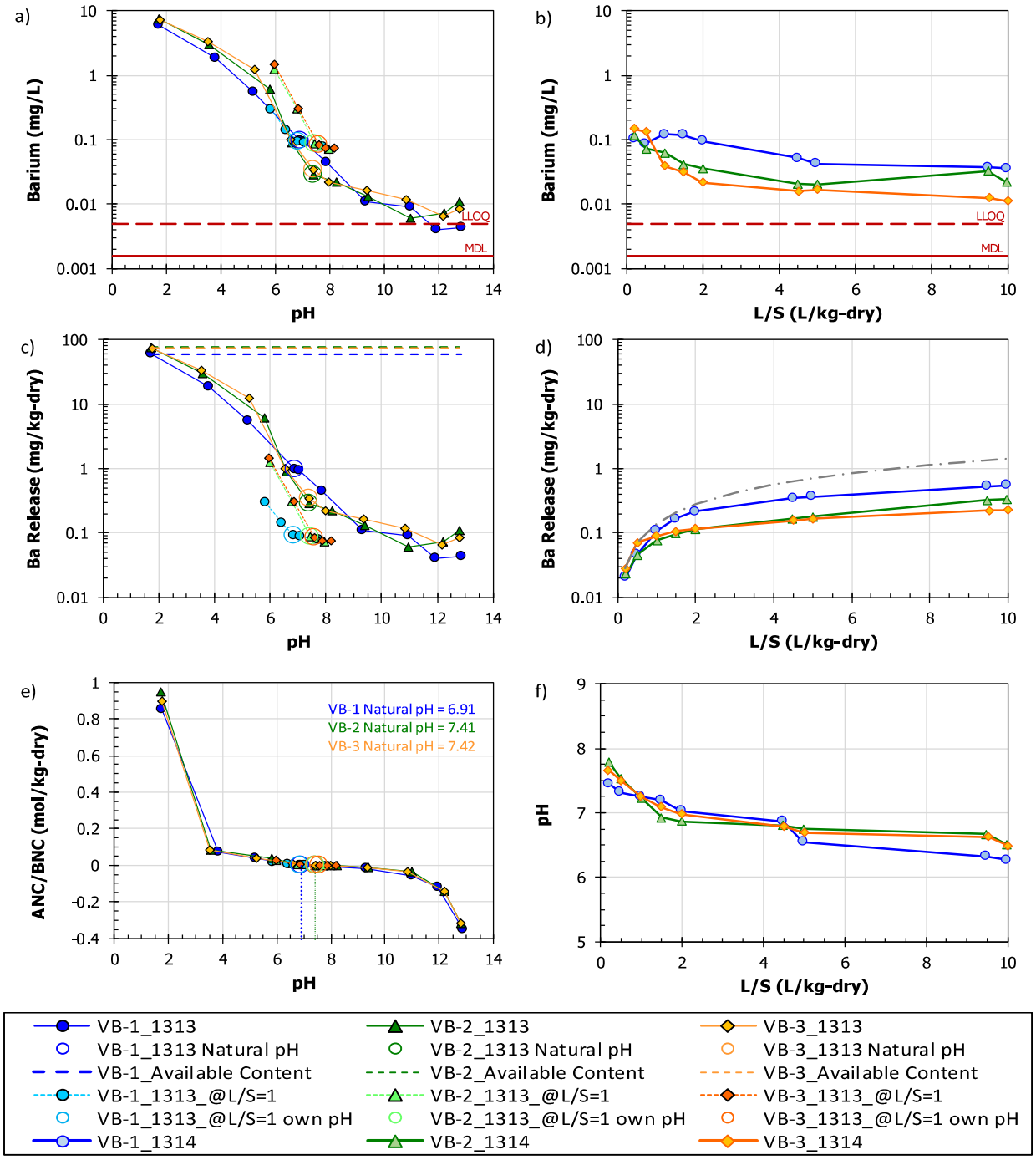

Figure D-4
Barium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

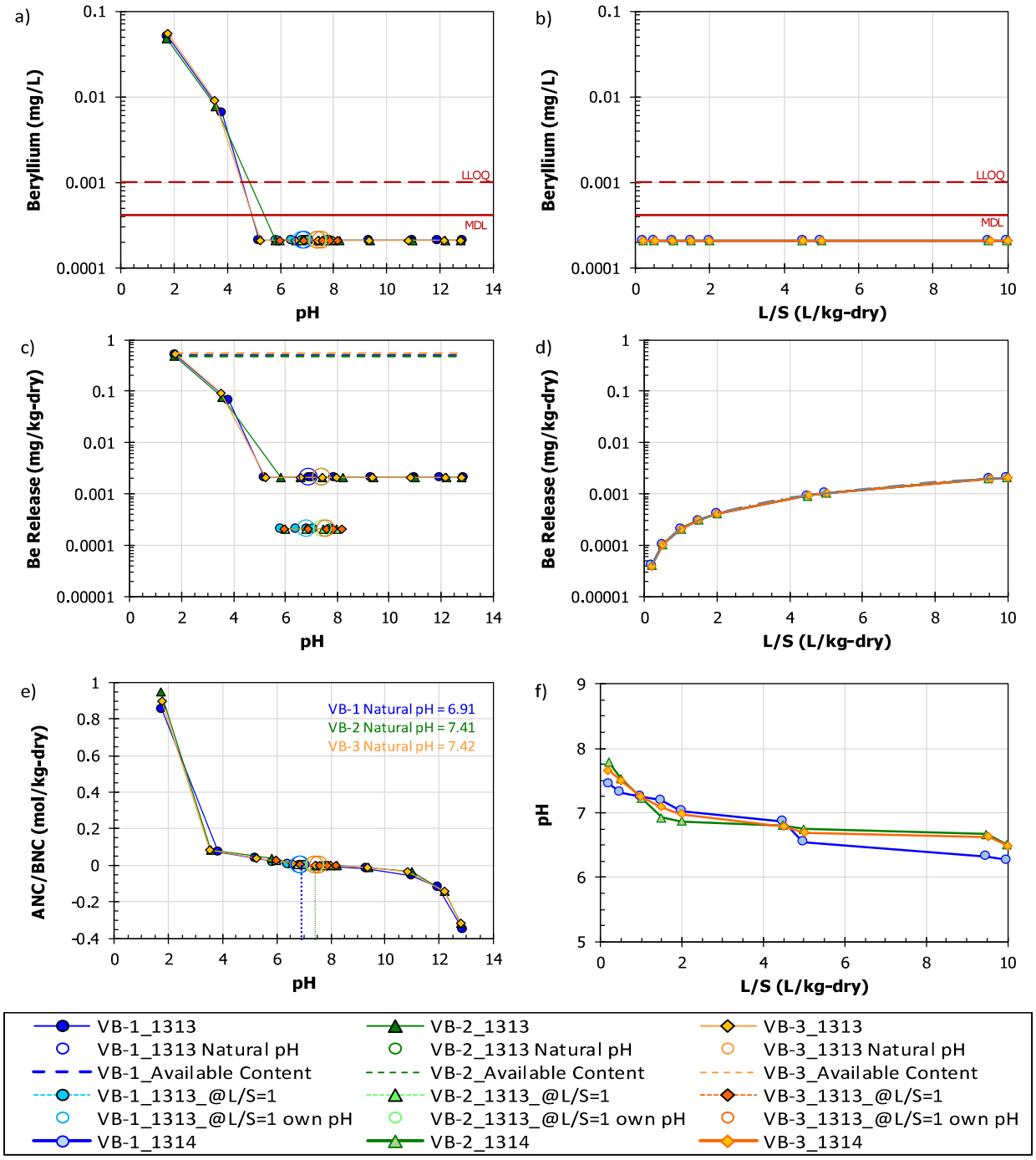

Figure D-5
Beryllium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

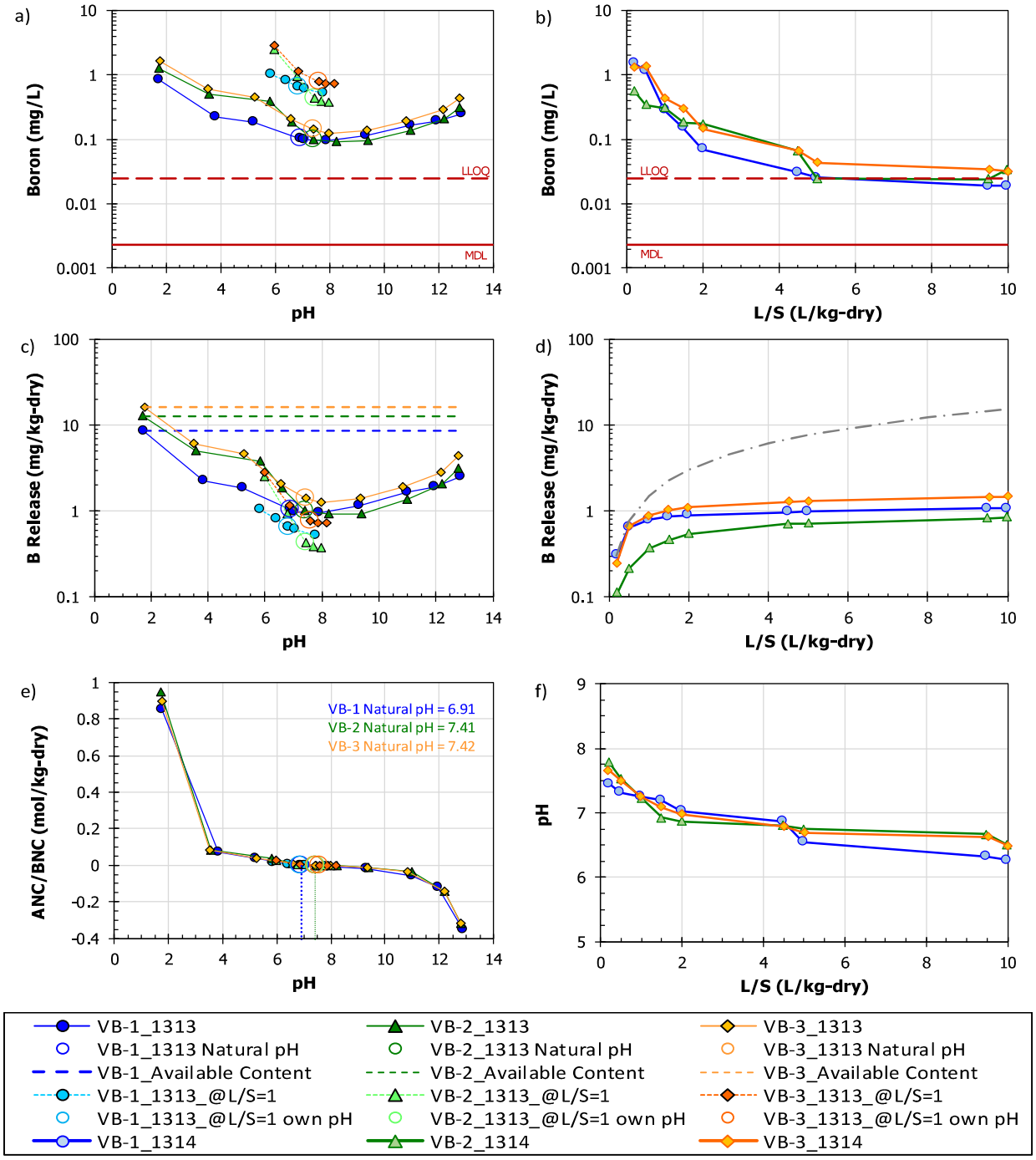

Figure D-6
Boron LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

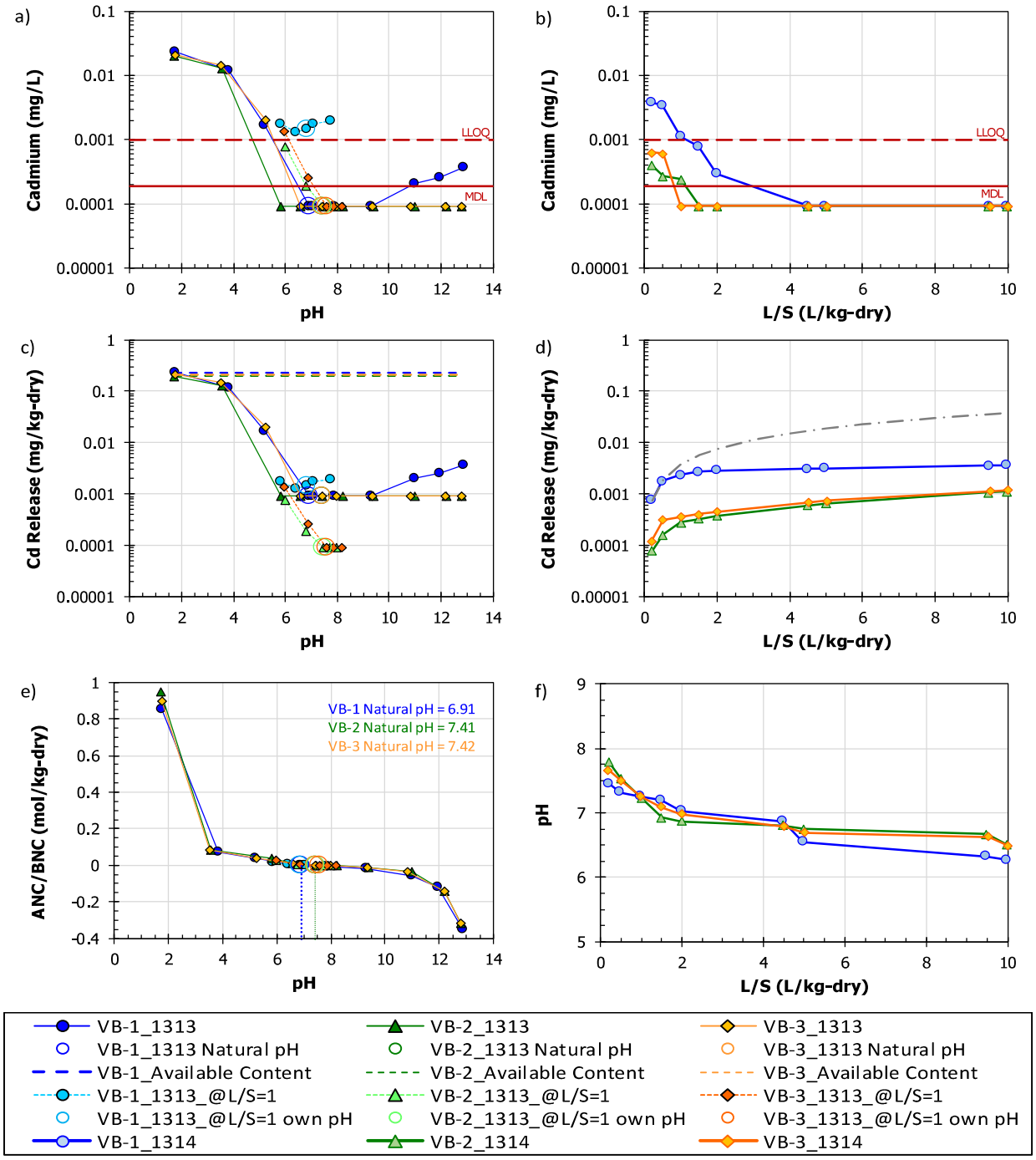

Figure D-7
Cadmium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

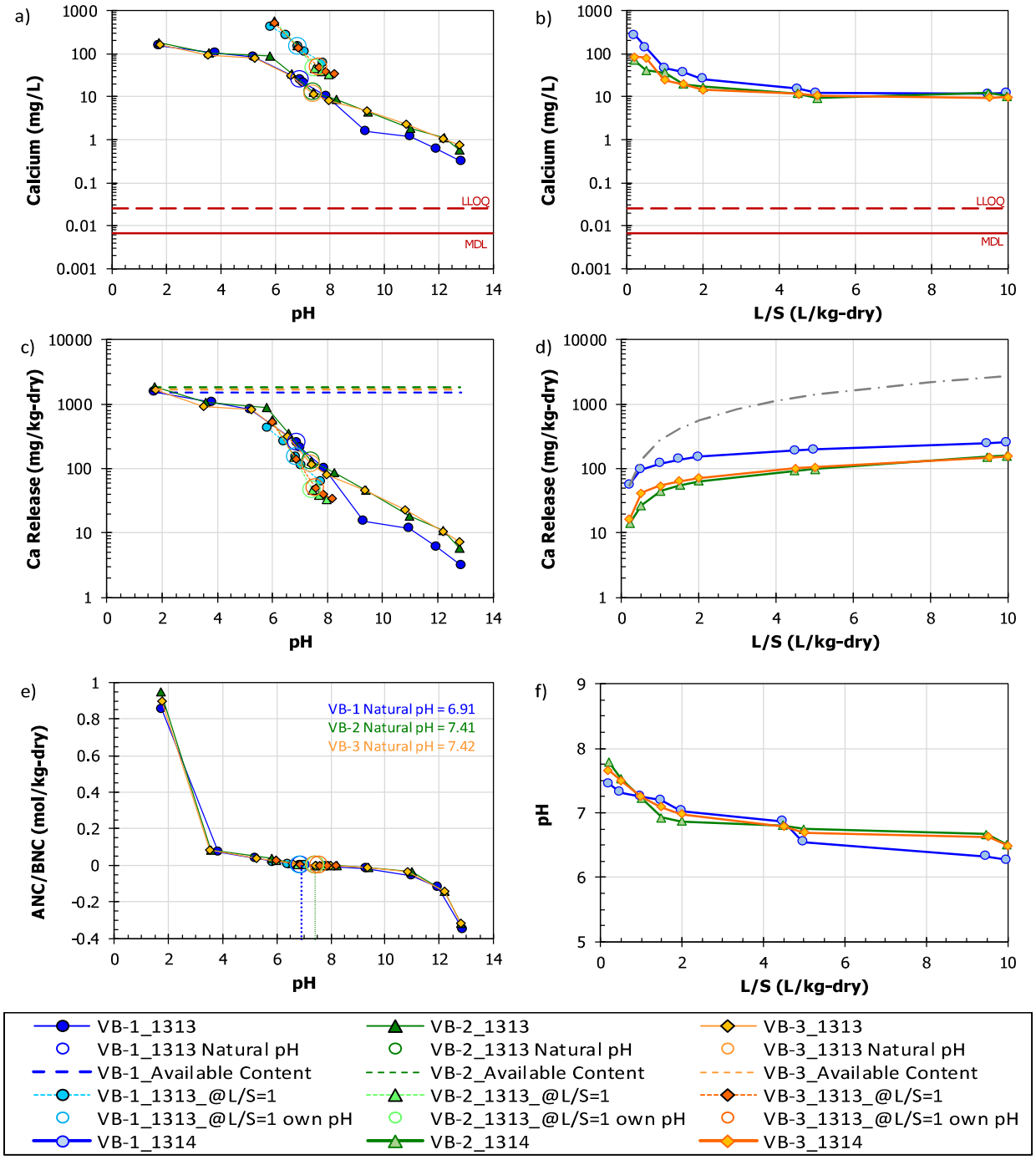

Figure D-8
Calcium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S.

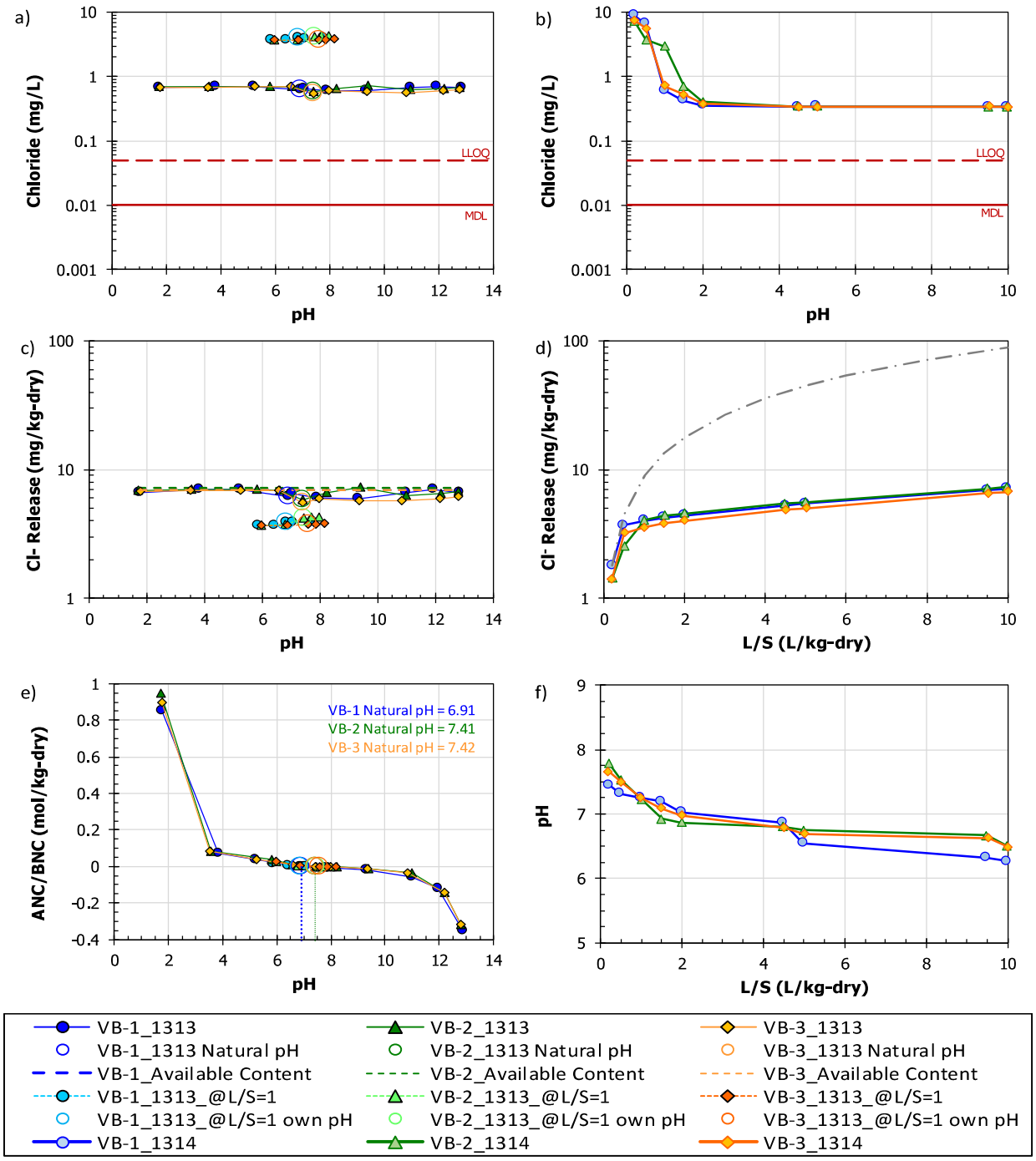

Figure D-9
Chloride LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S.

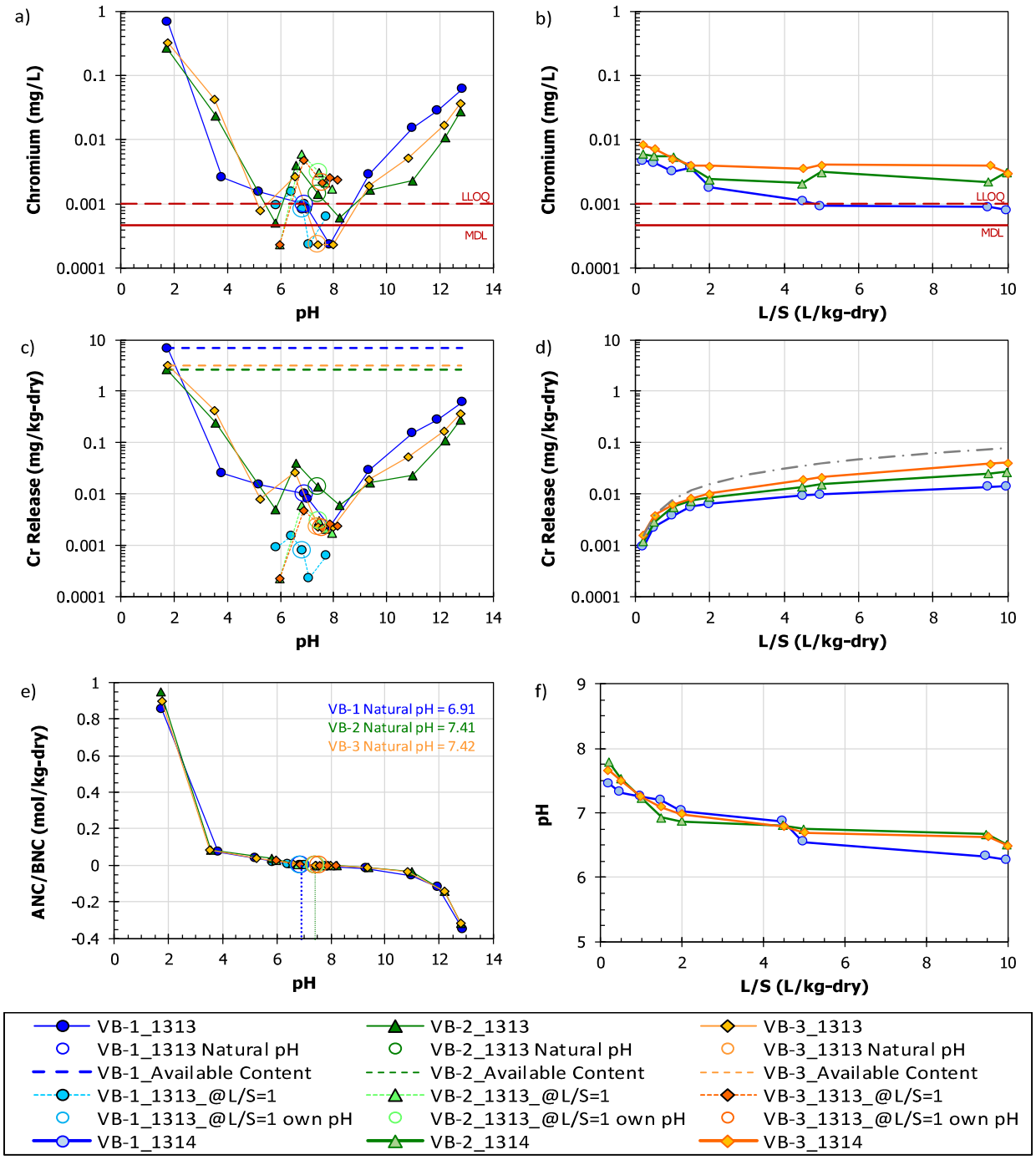

Figure D-10
Chromium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

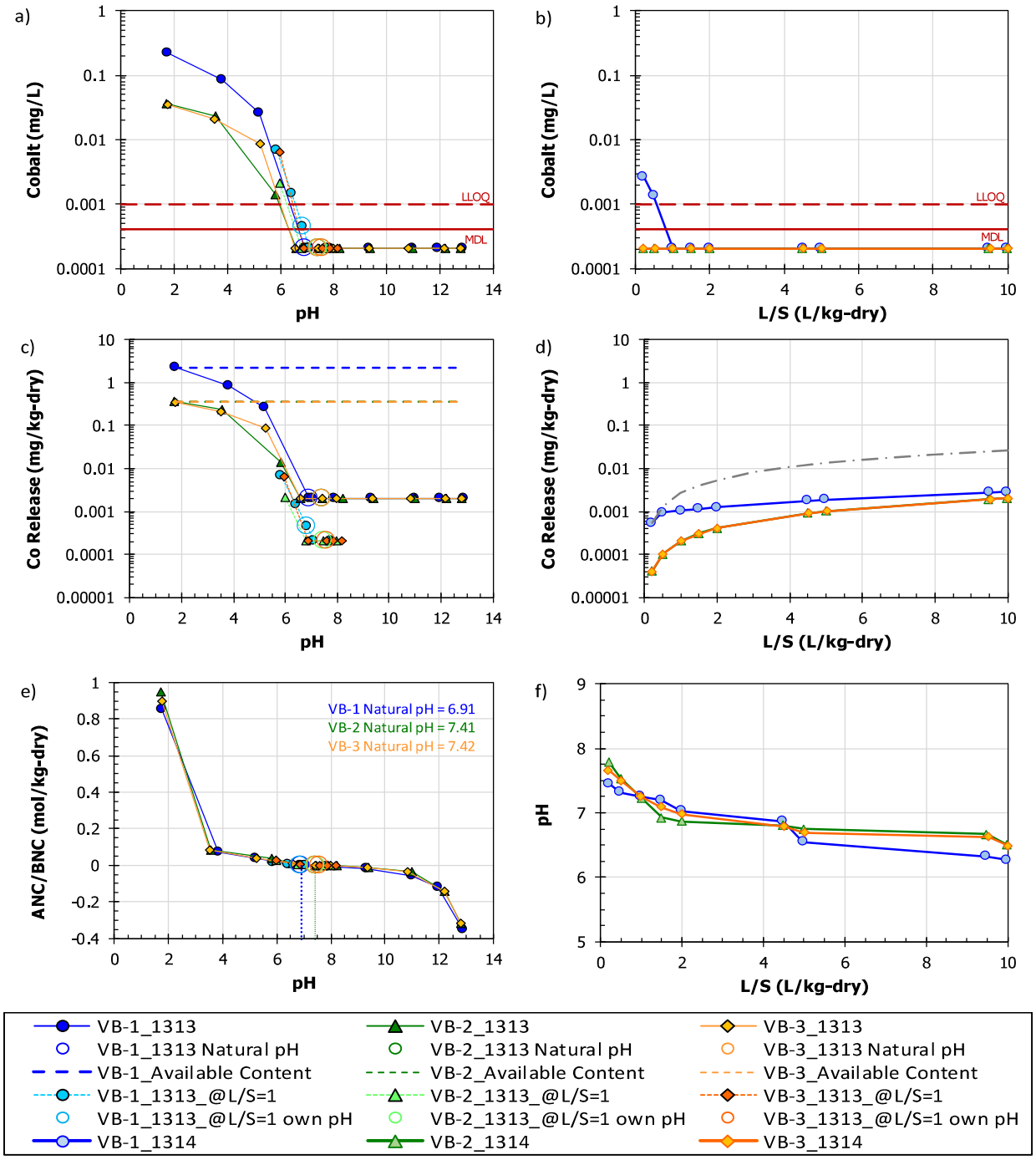

Figure D-11
Cobalt LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S.

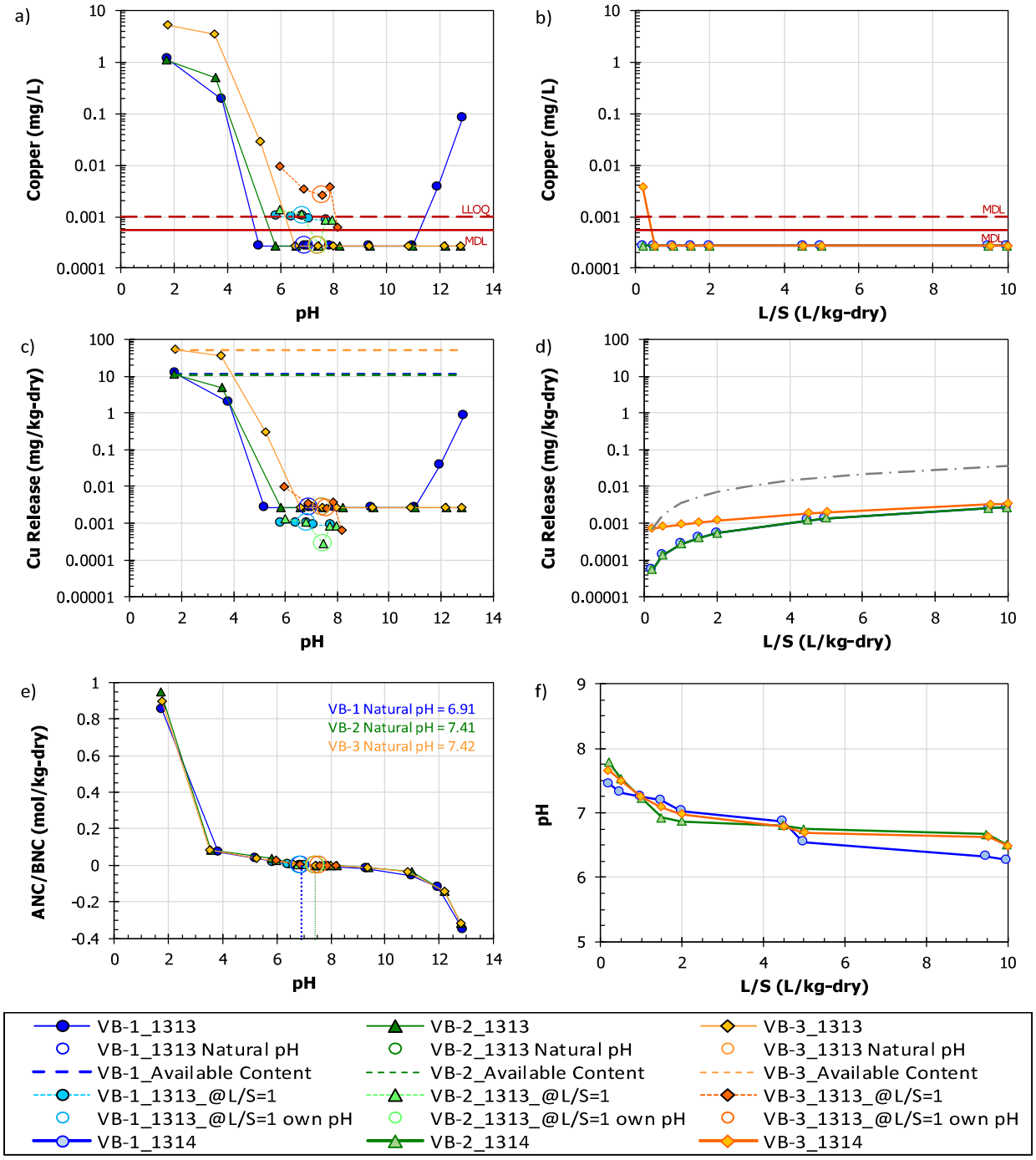

Figure D-12
Copper LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

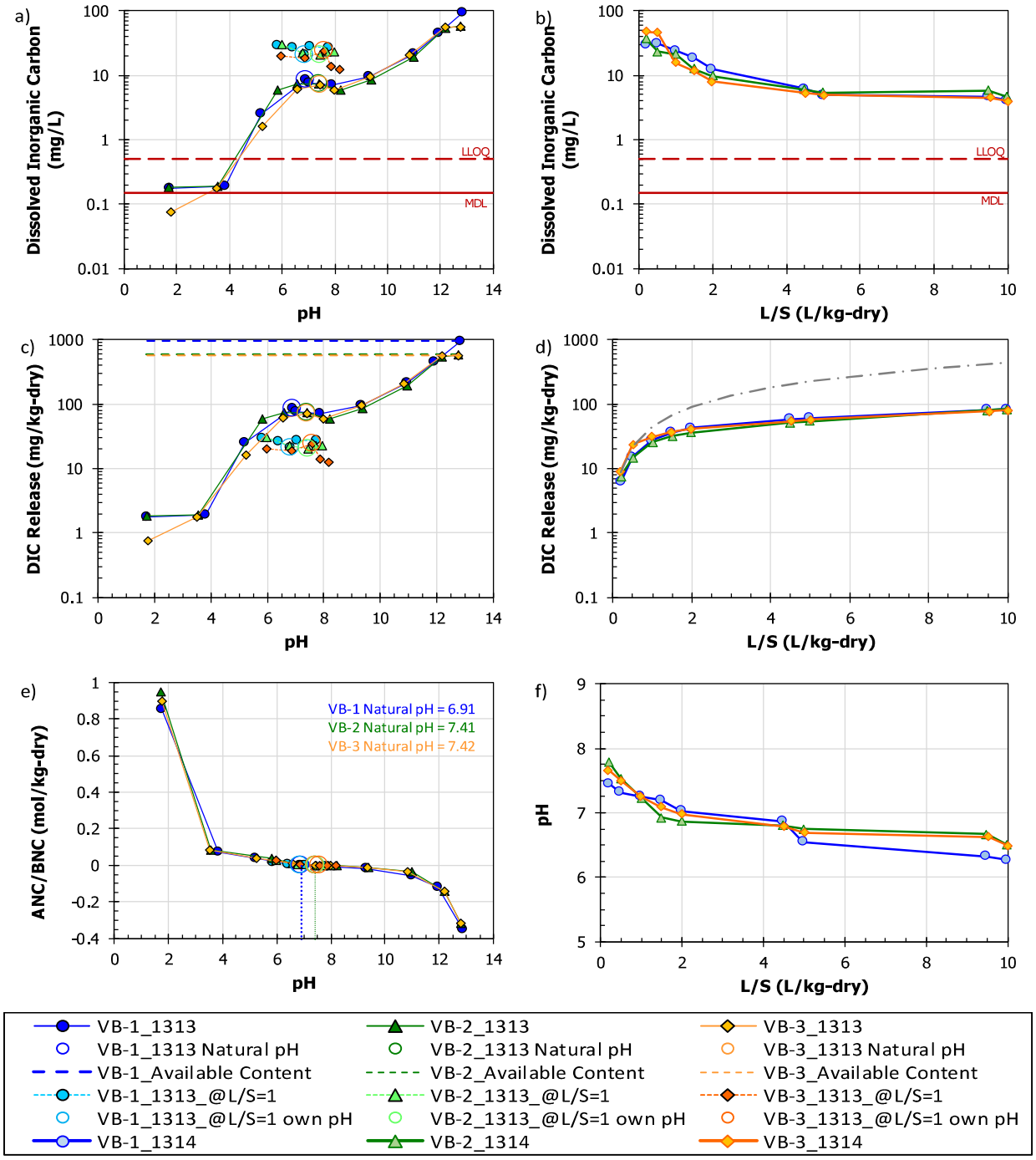

Figure D-13
Dissolved inorganic carbon LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

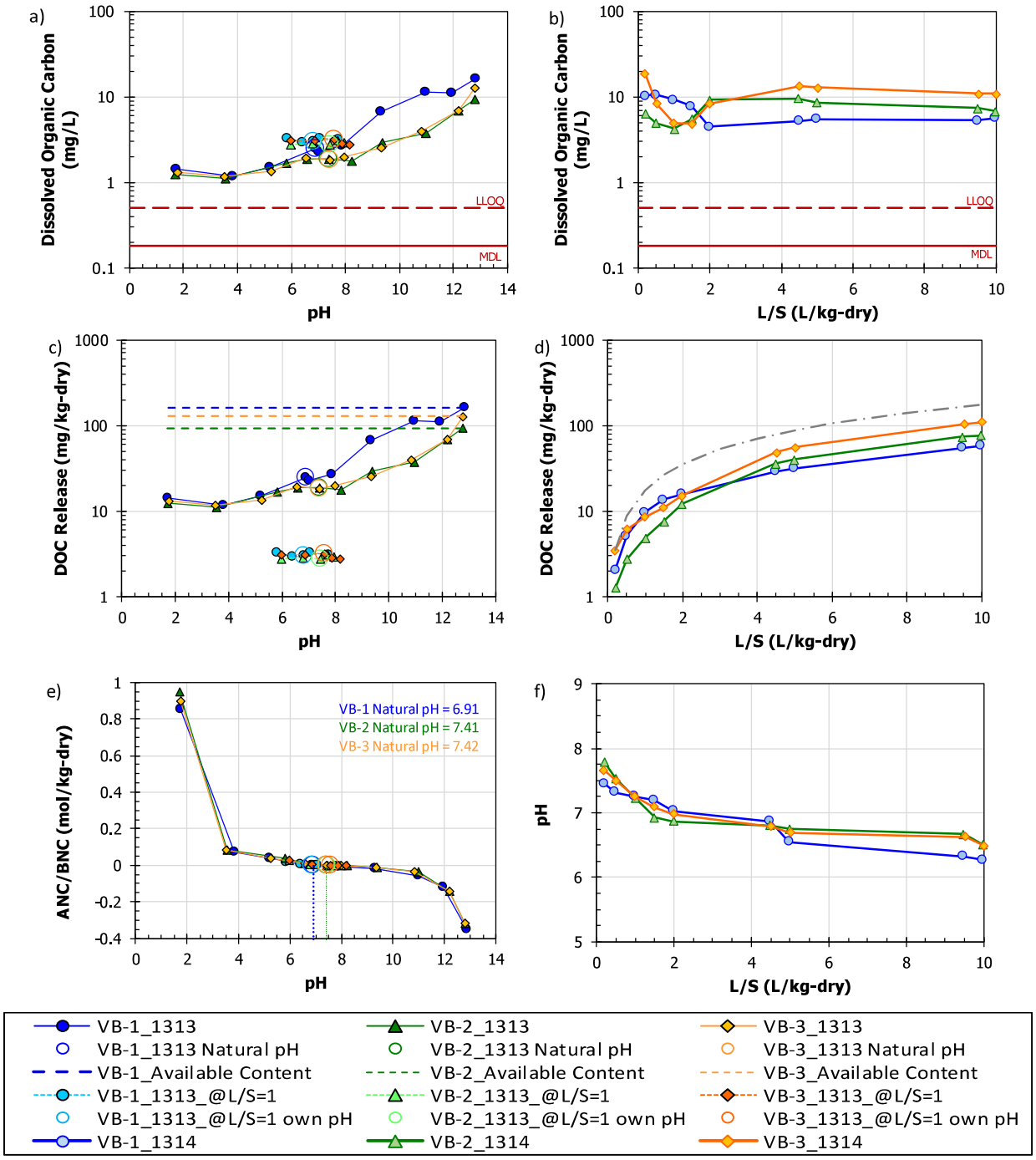

Figure D-14
Dissolved organic carbon LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

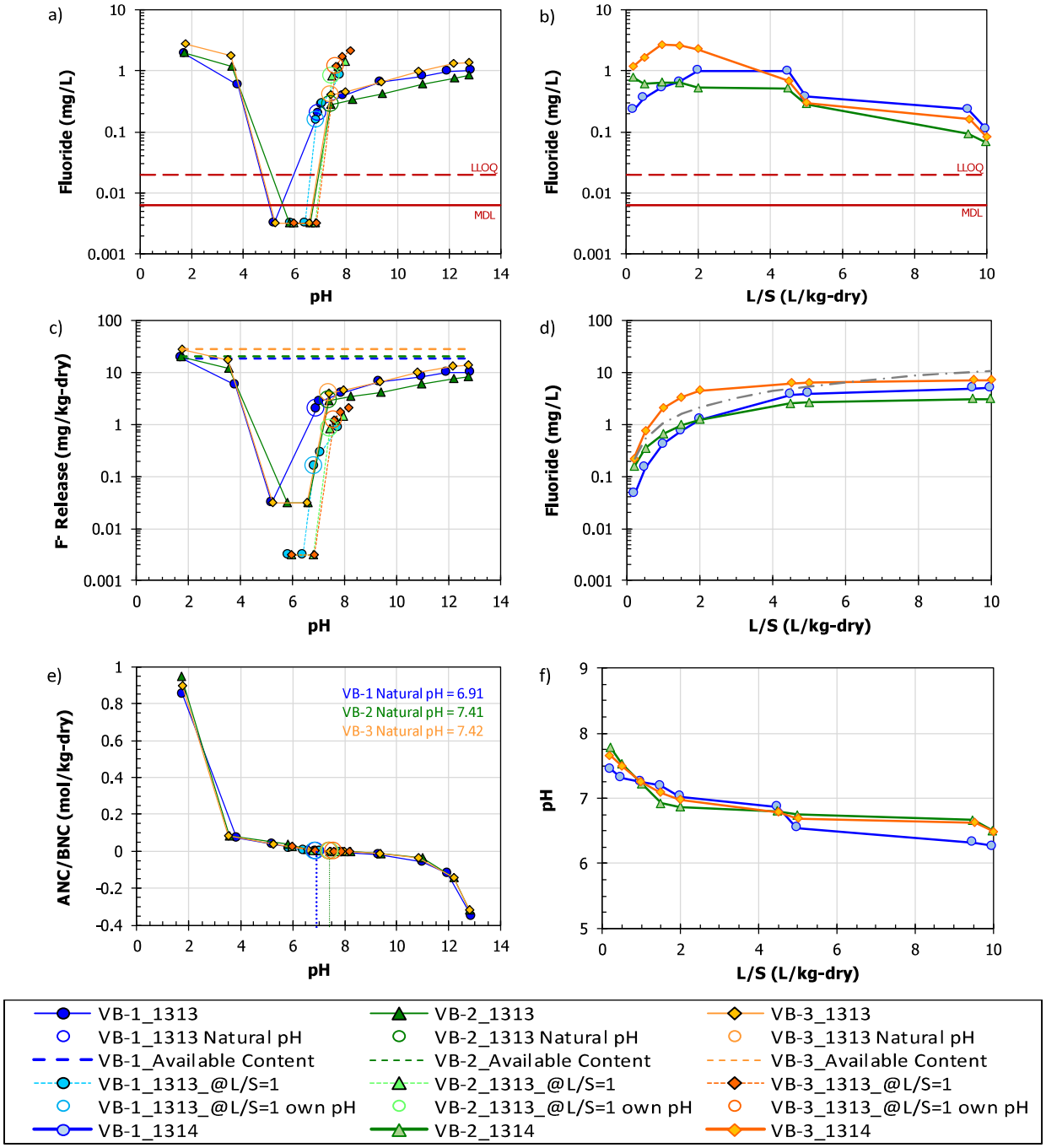

Figure D-15
Fluoride LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

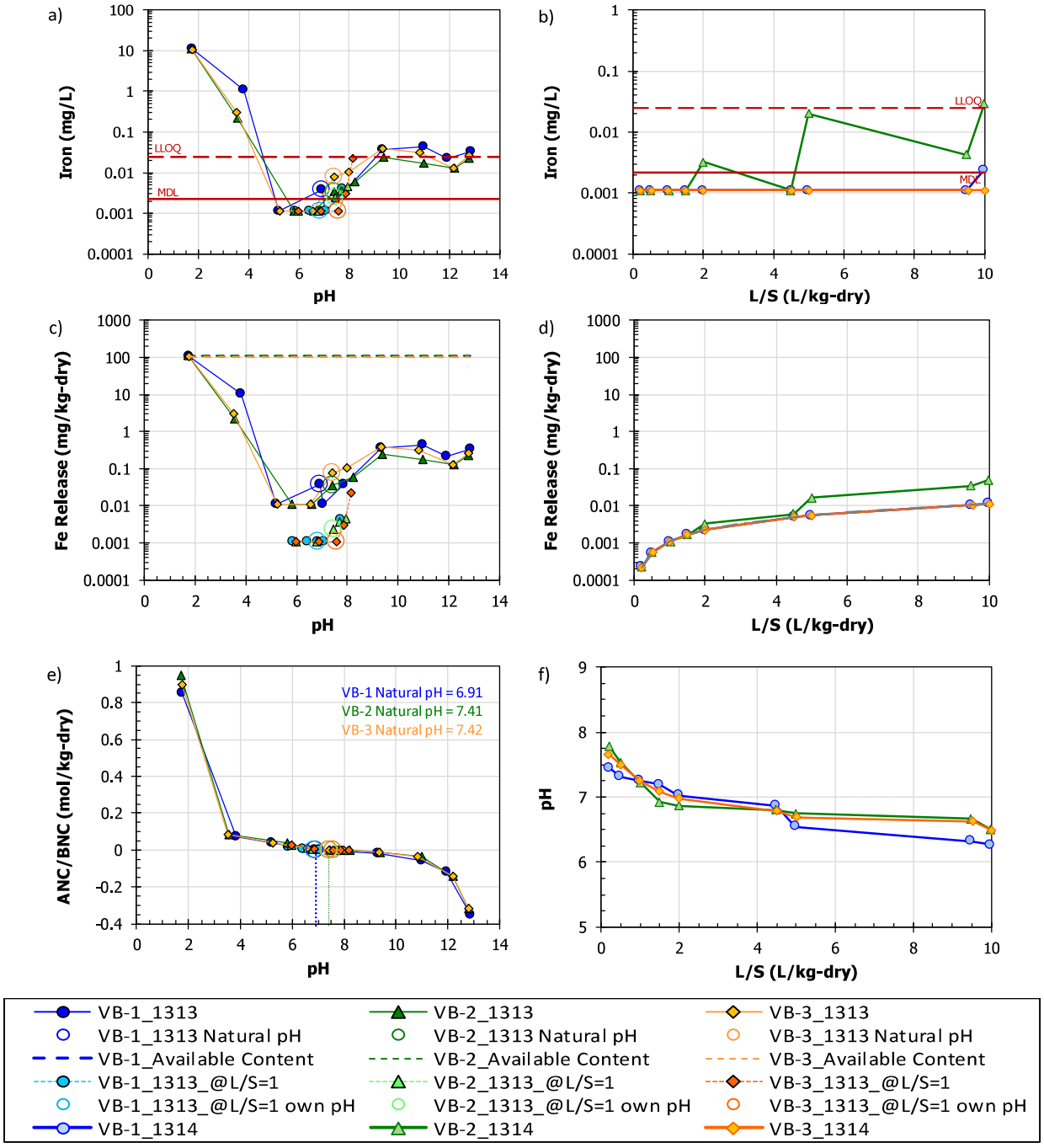

Figure D-16
Iron LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

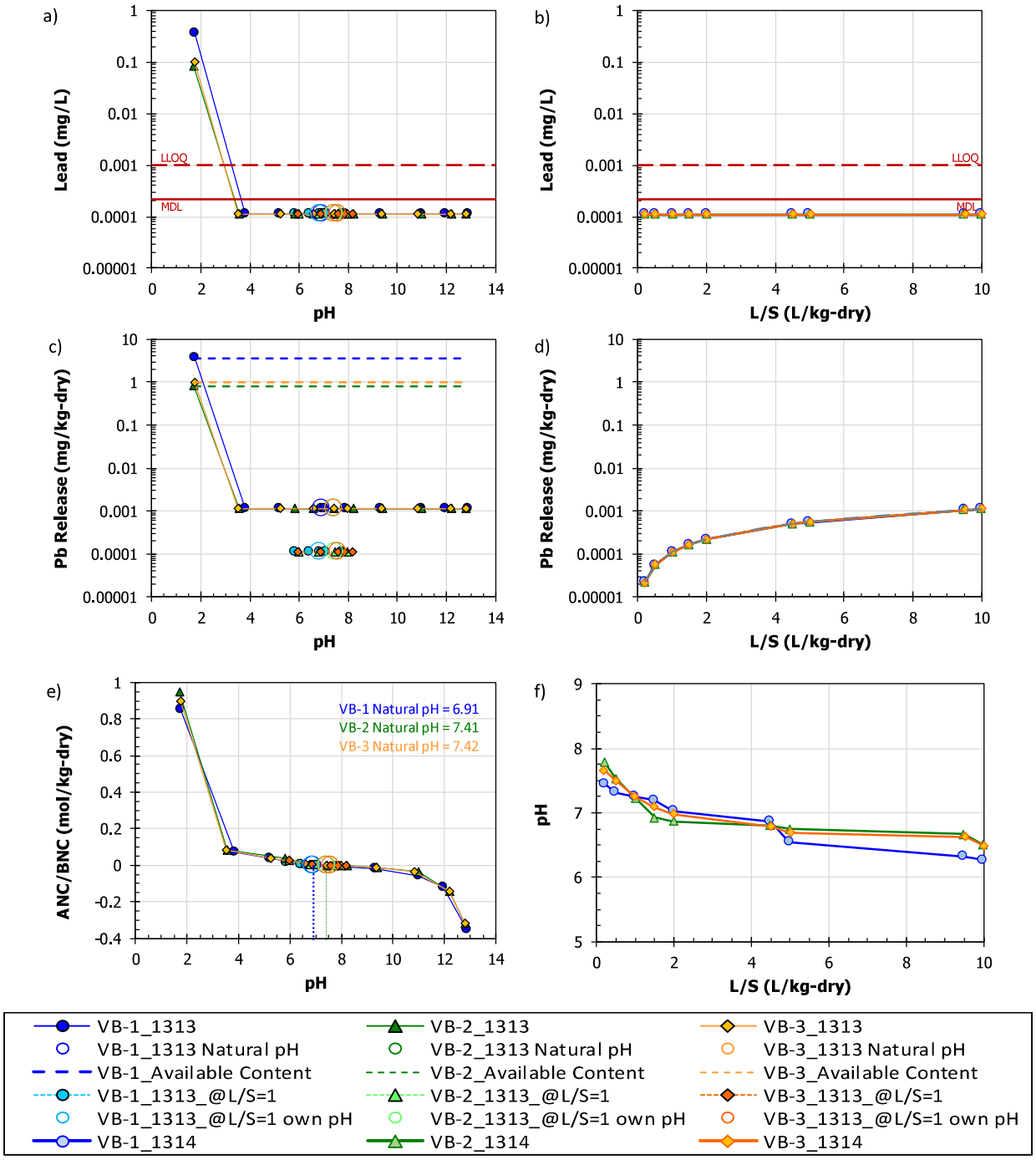

Figure D-17
Lead LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

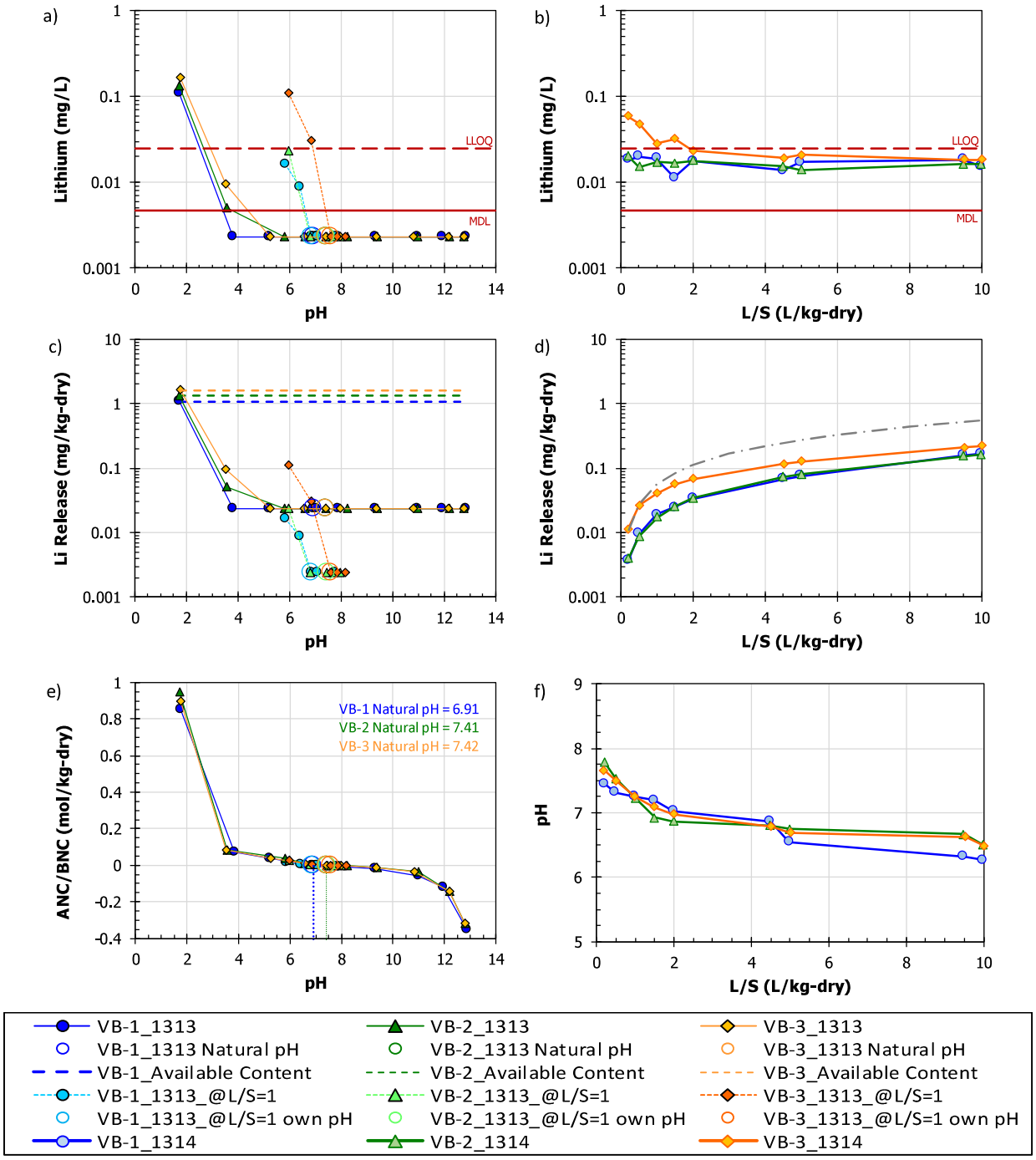

Figure D-18
Lithium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

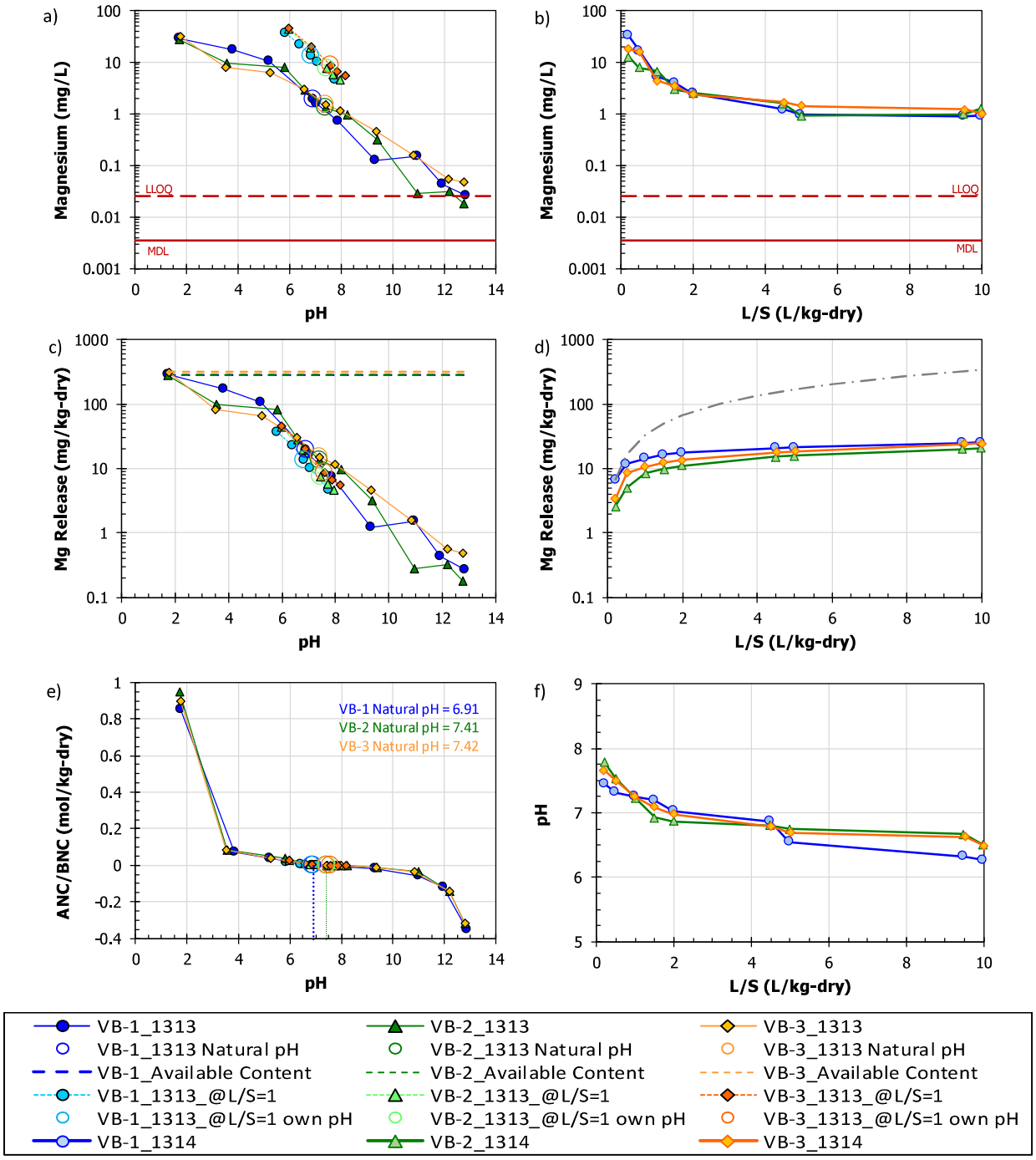

Figure D-19
Magnesium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

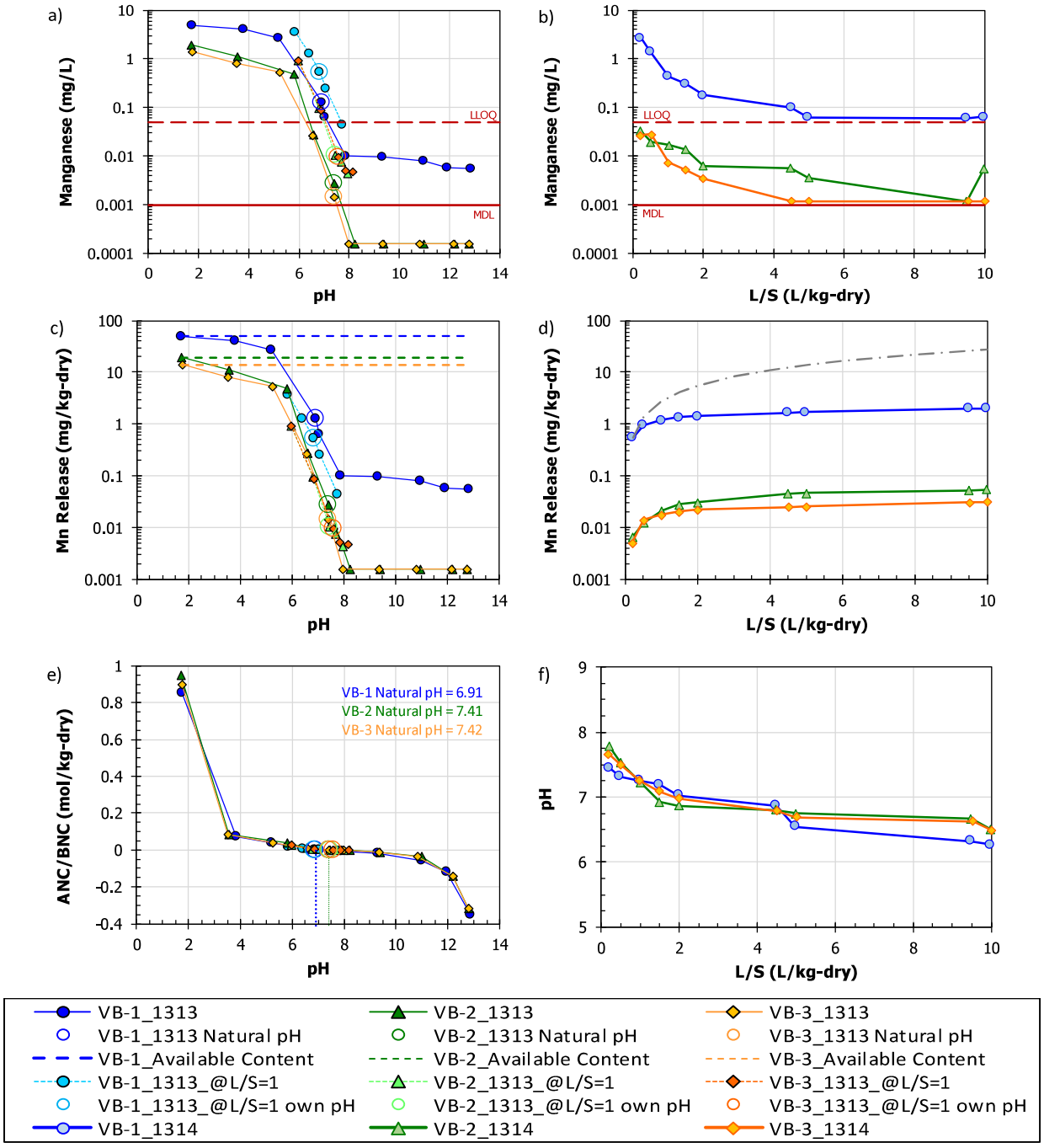

Figure D-20
Manganese LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

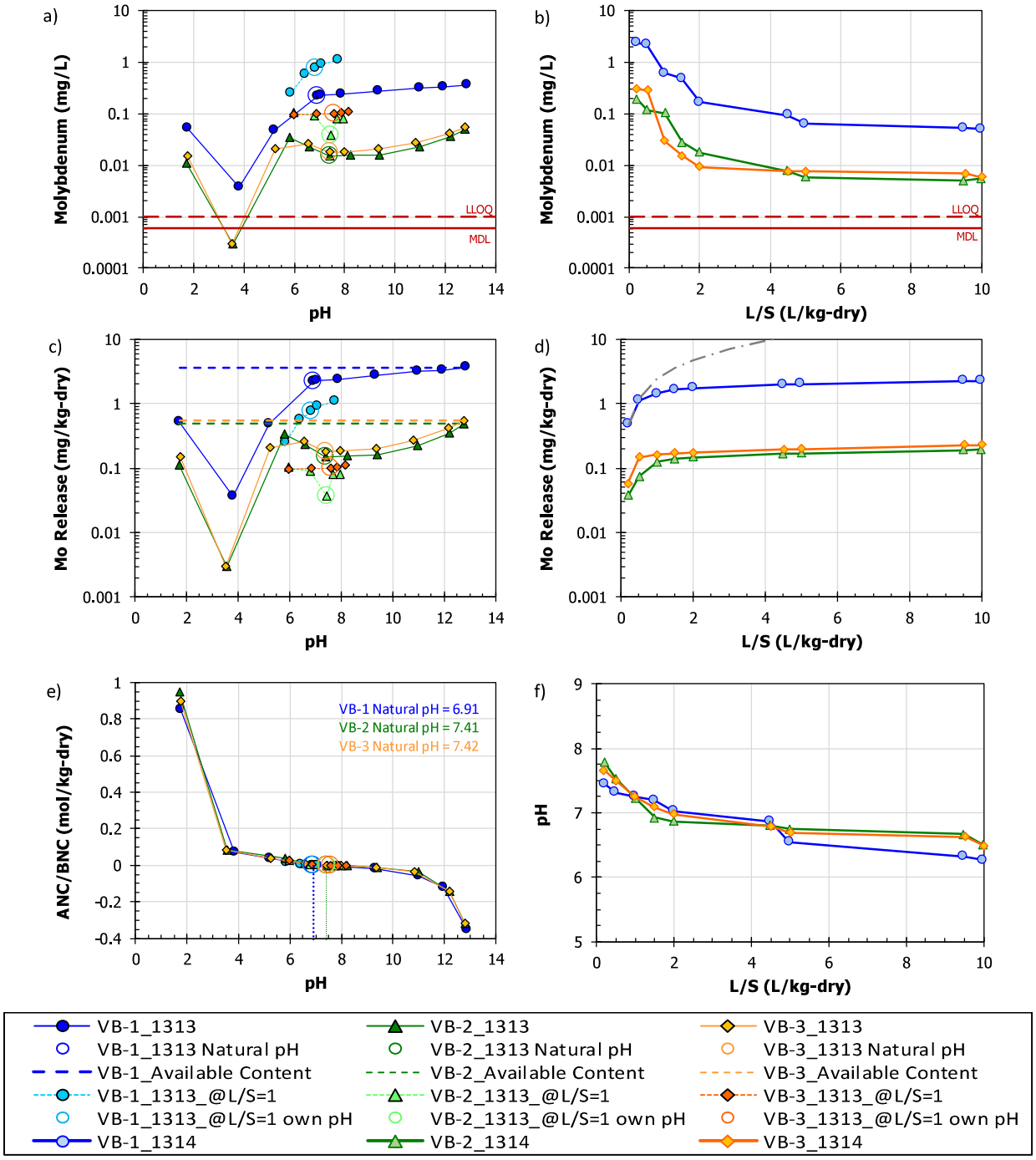

Figure D-21
Molybdenum LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

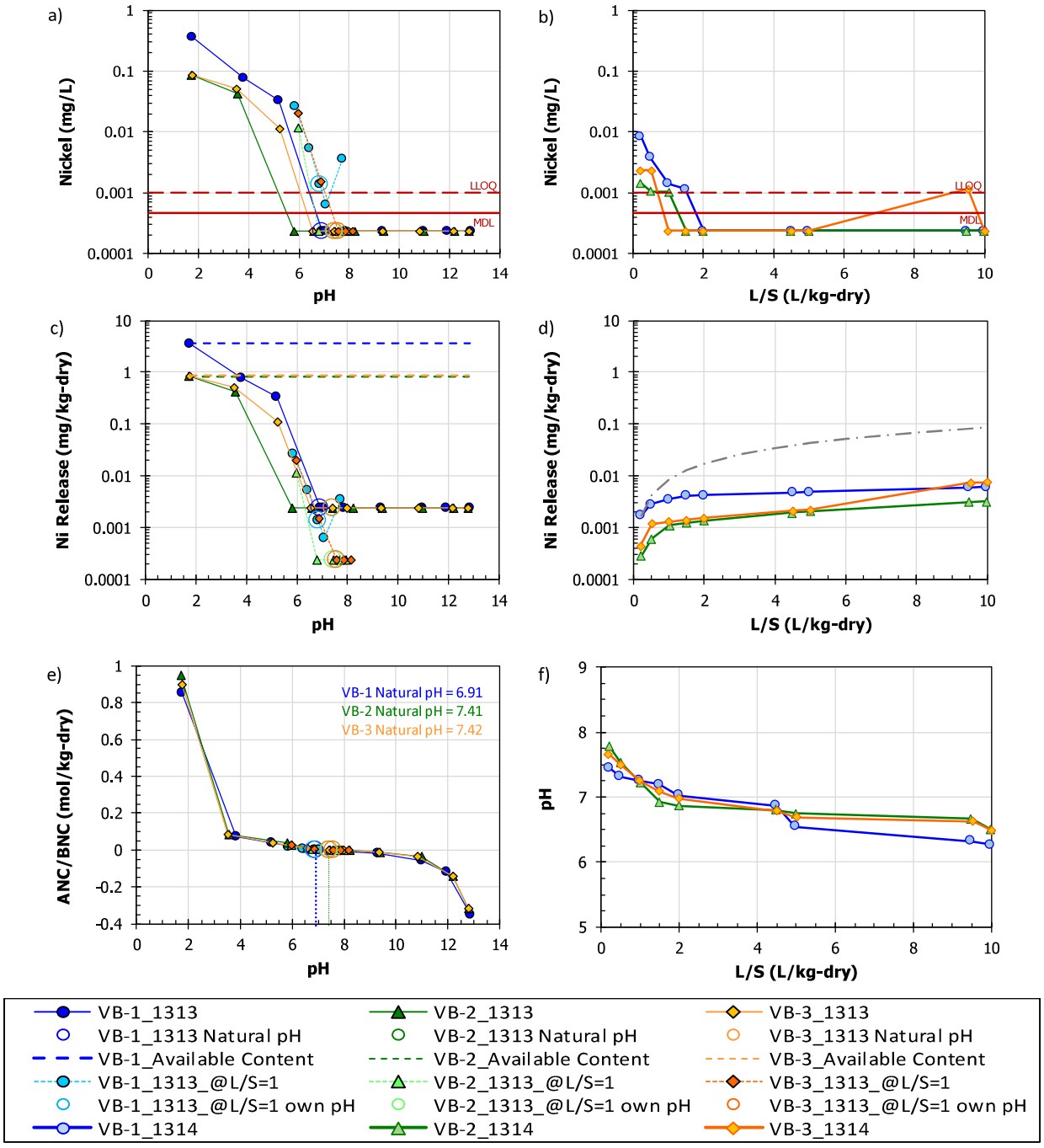

Figure D-22
Nickel LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

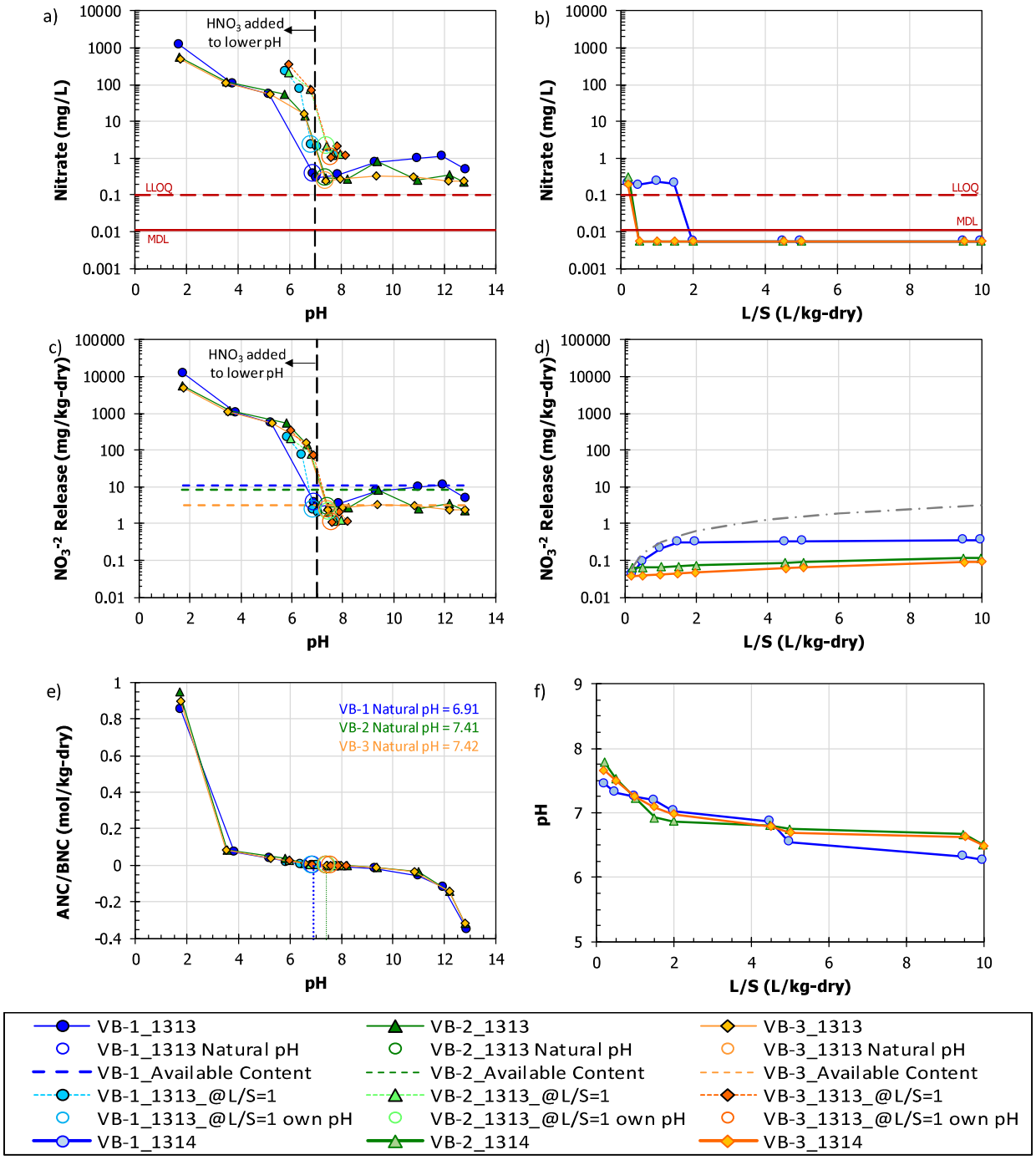

Figure D-23
Nitrate LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

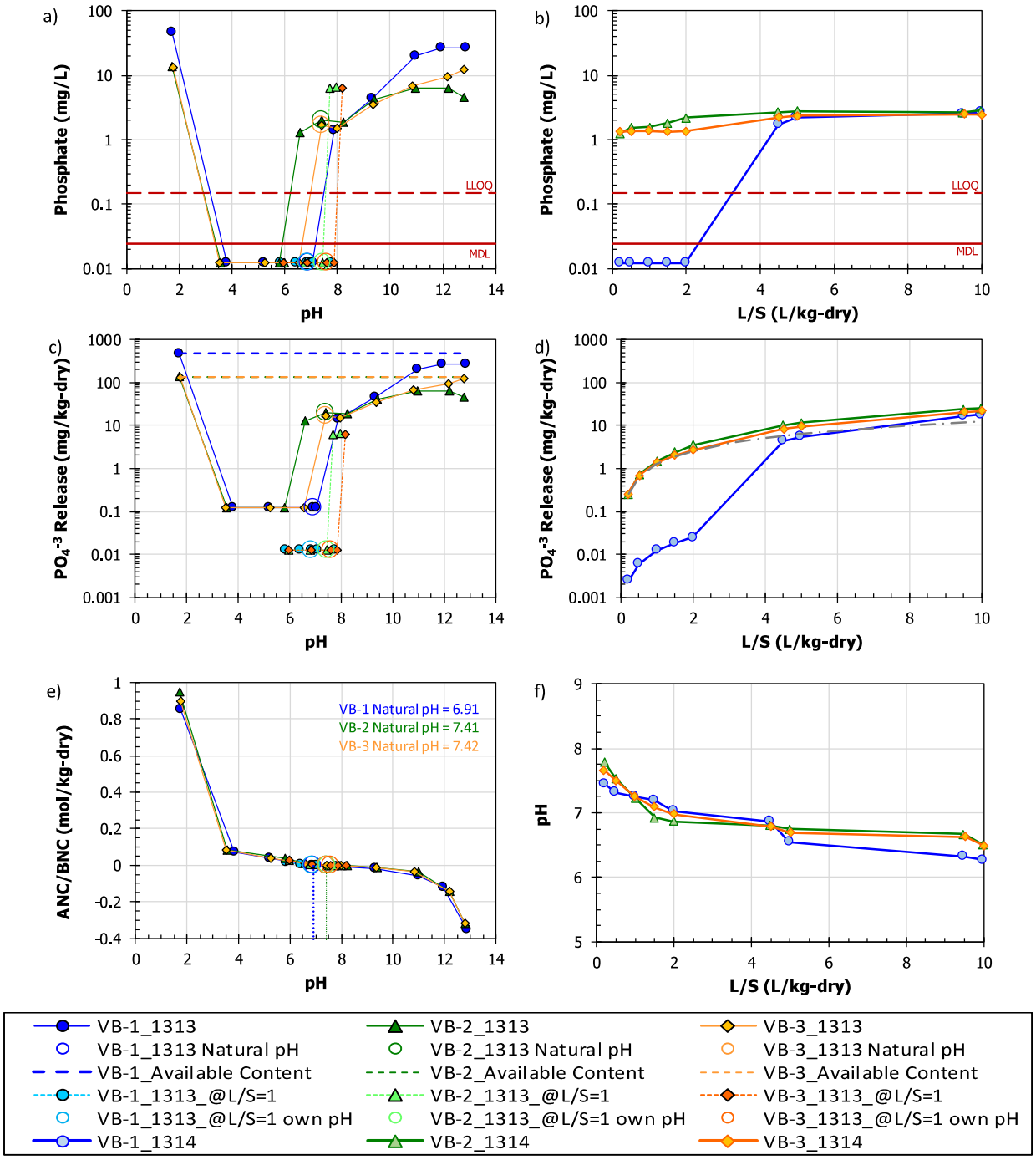

Figure D-24
Phosphate LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

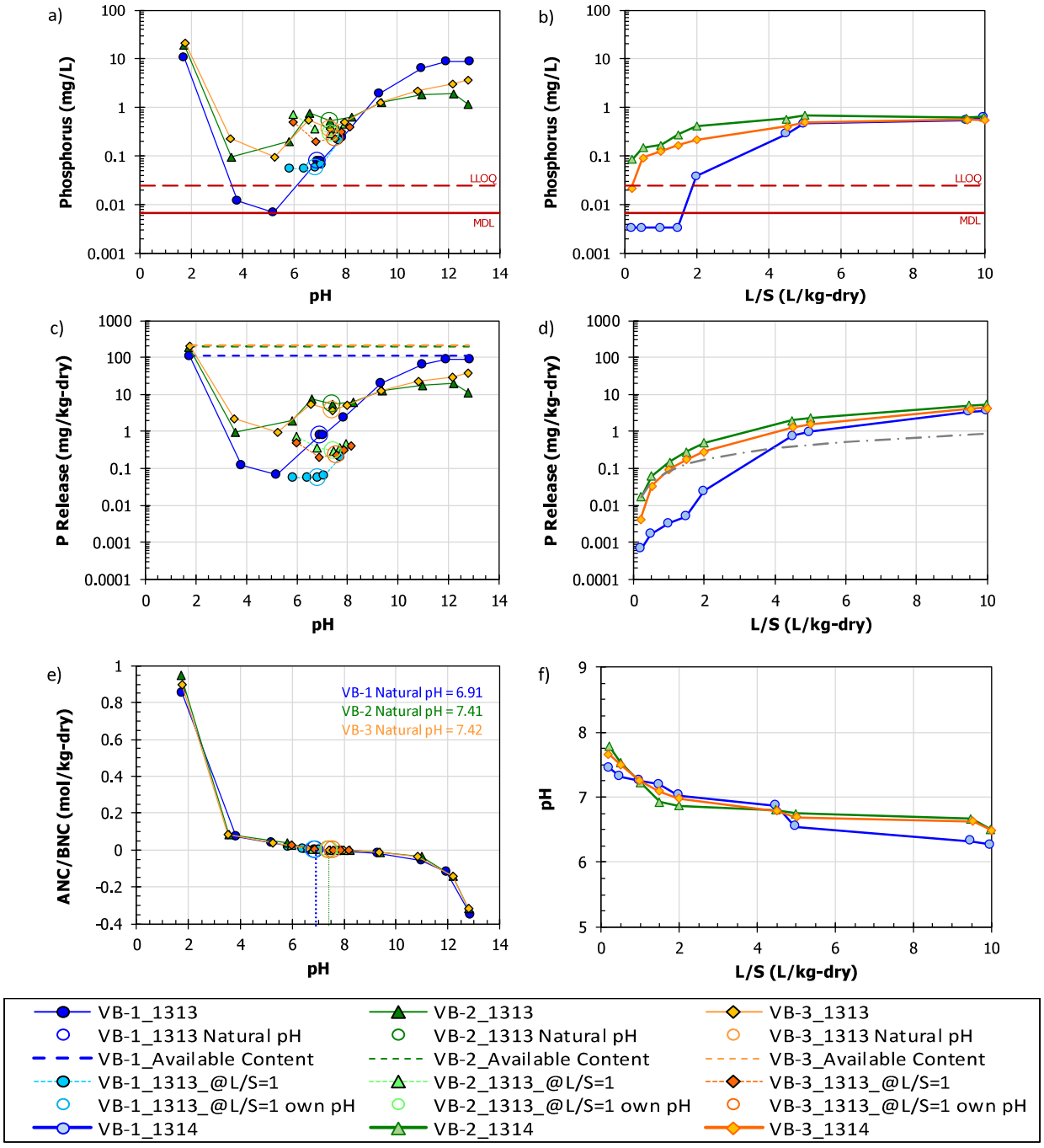

Figure D-25
Phosphorus LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

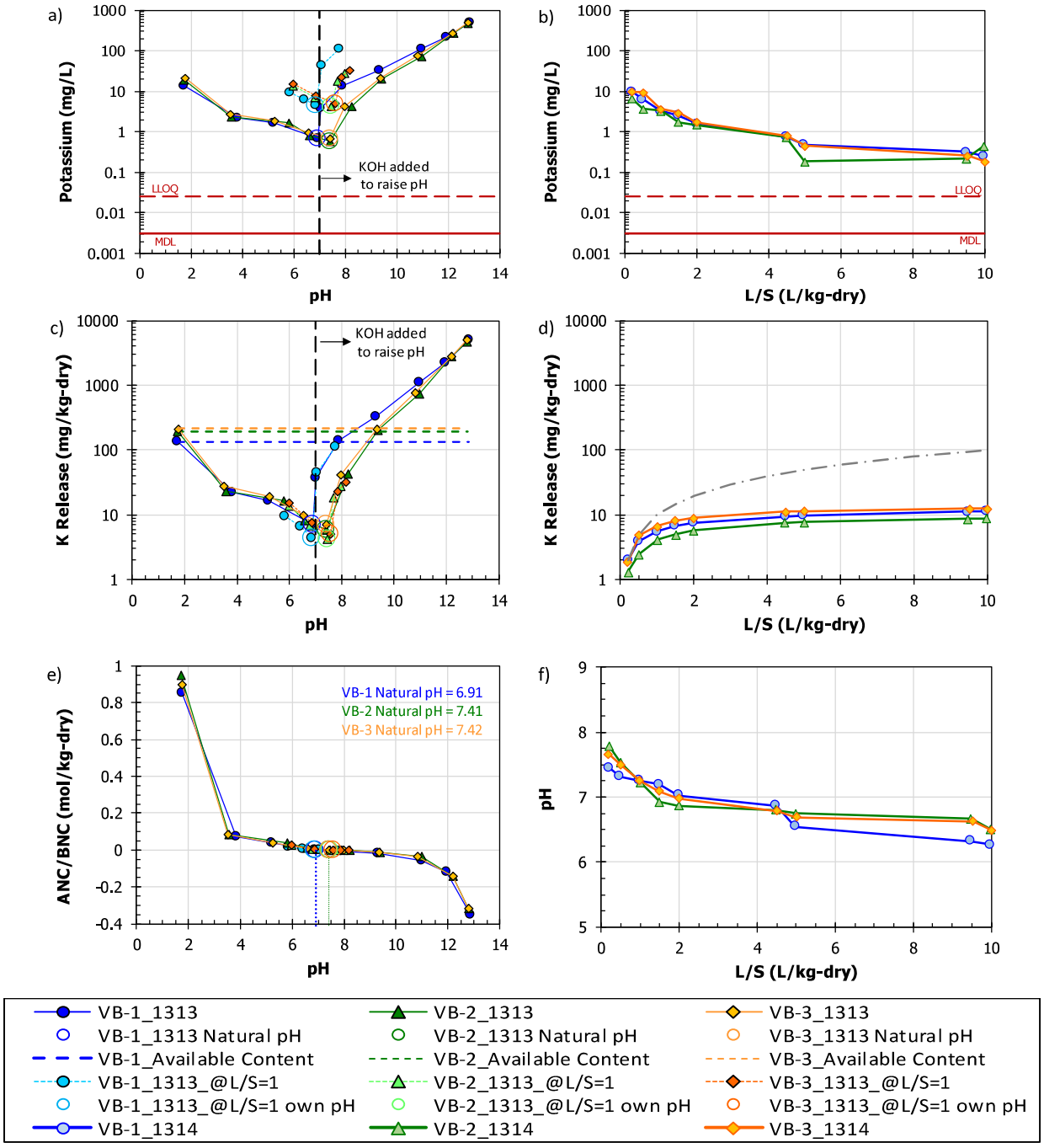

Figure D-26
Potassium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

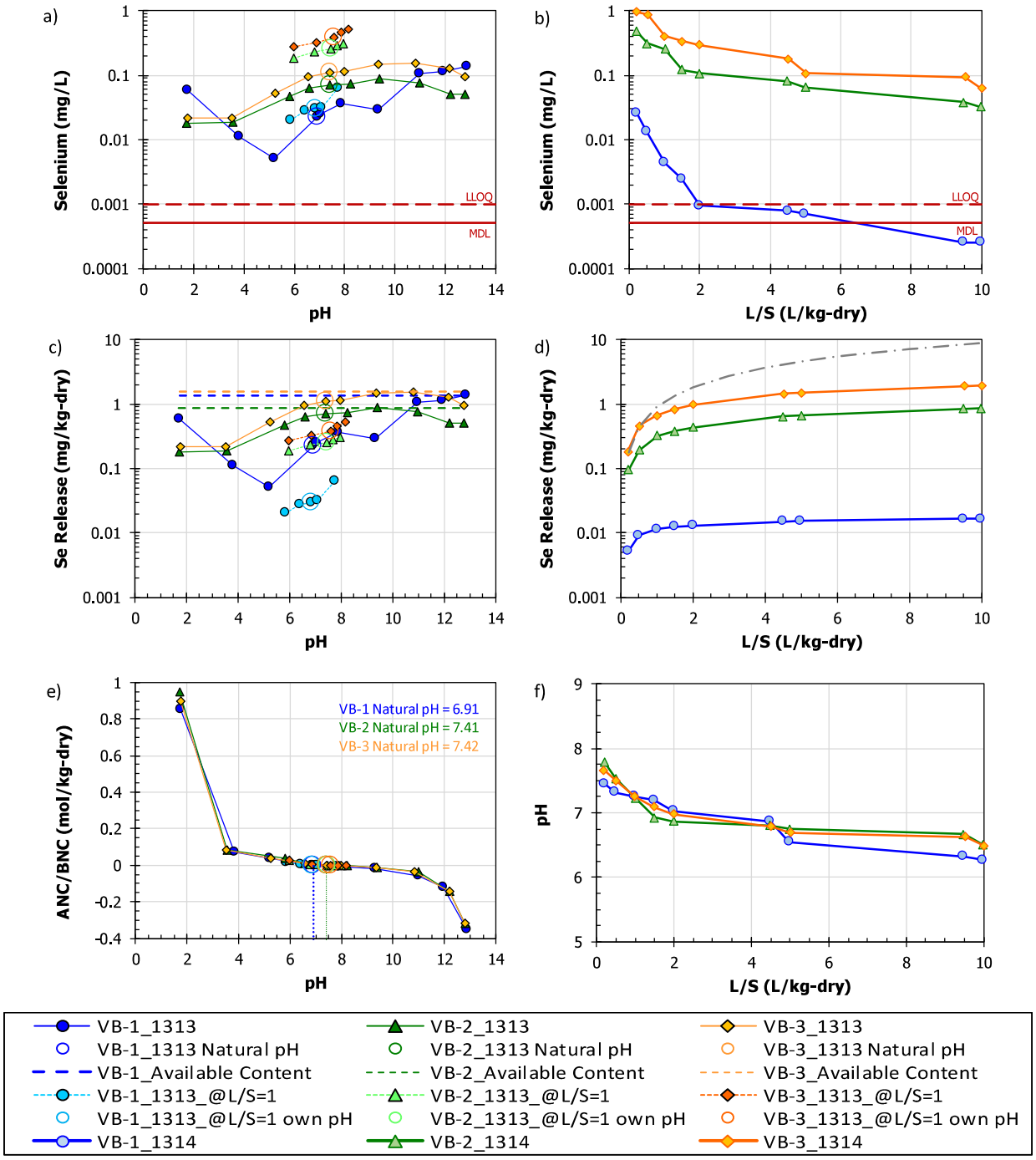

Figure D-27
Selenium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

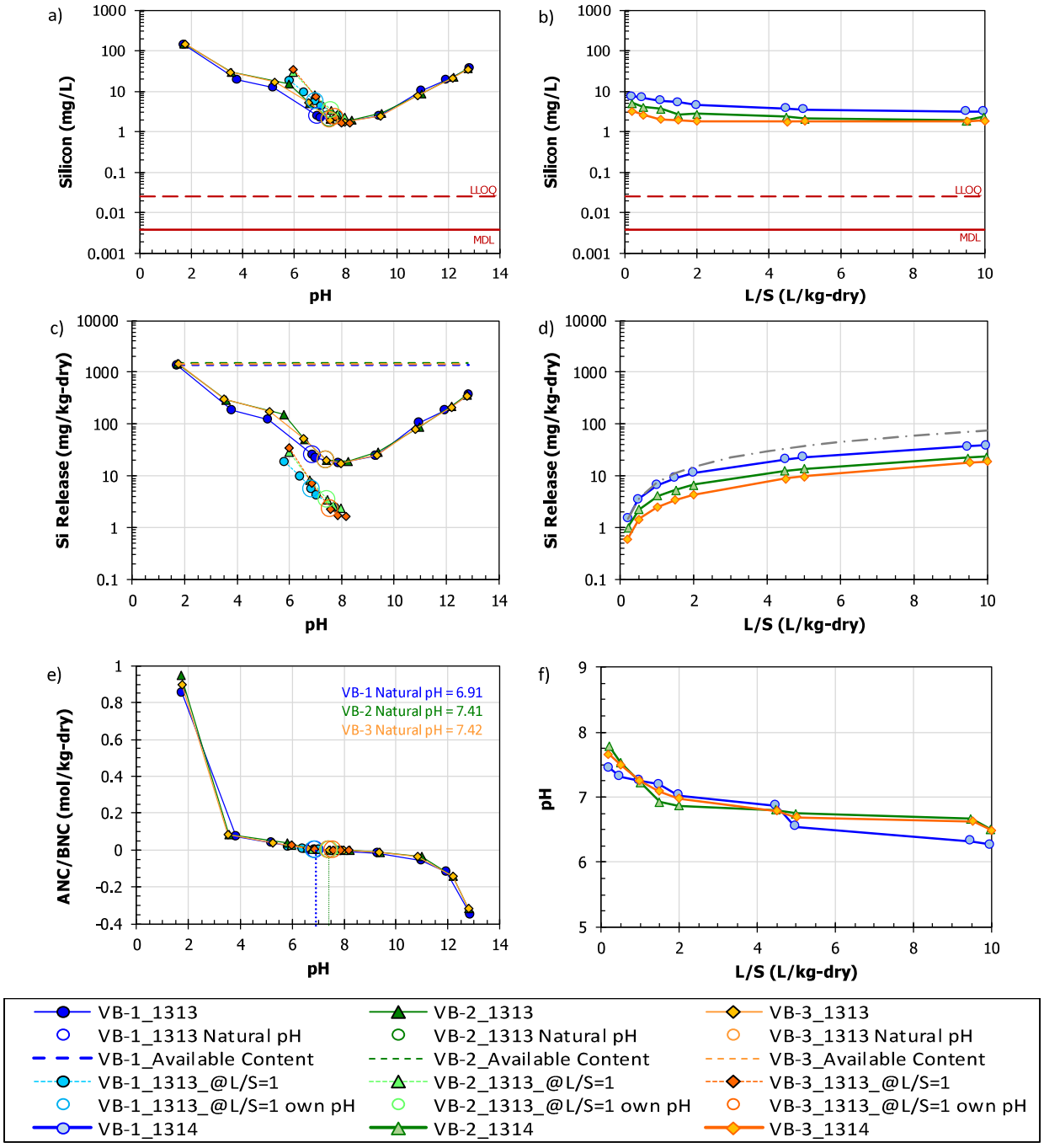

Figure D-28
Silicon LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

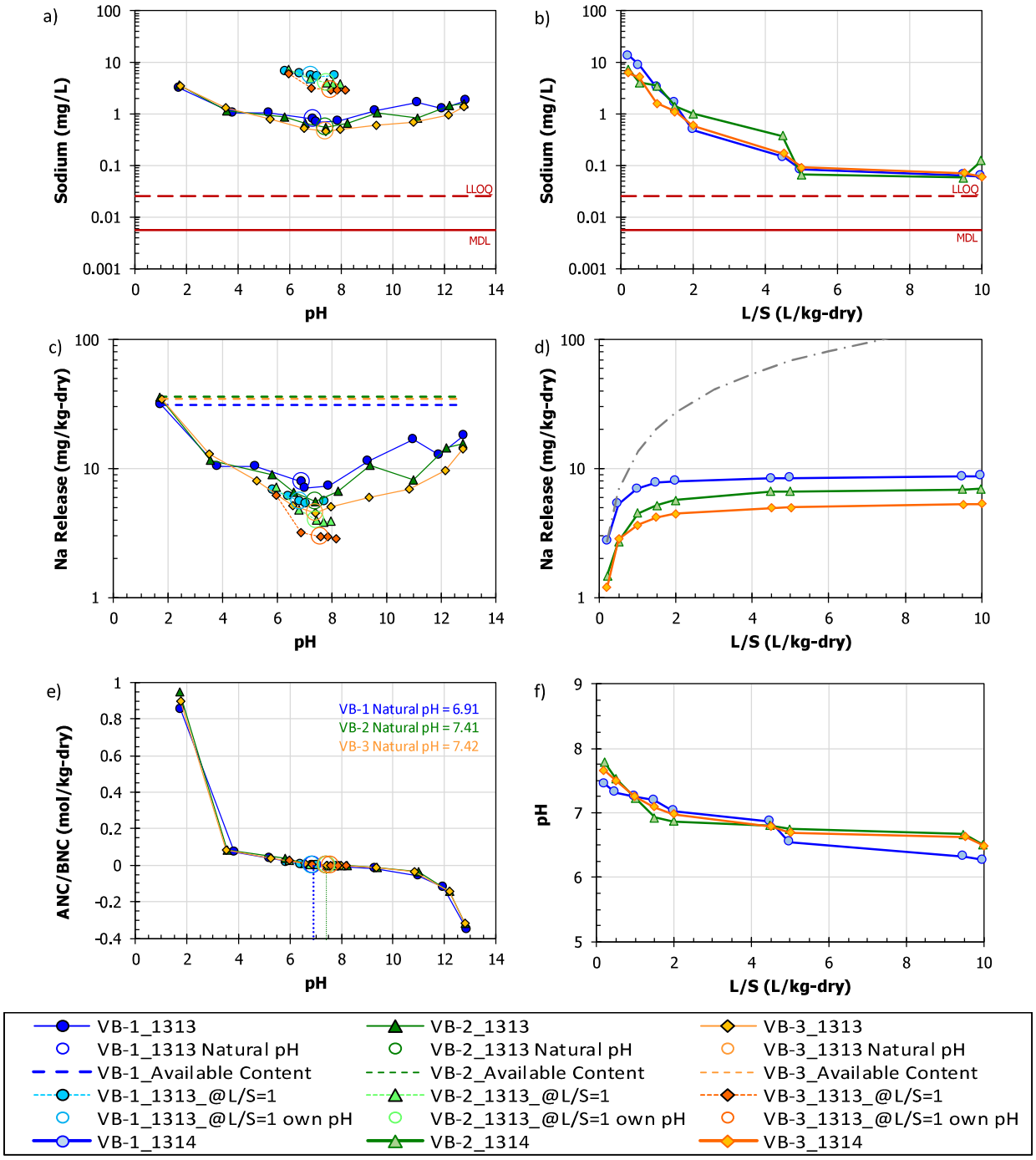

Figure D-29
Sodium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

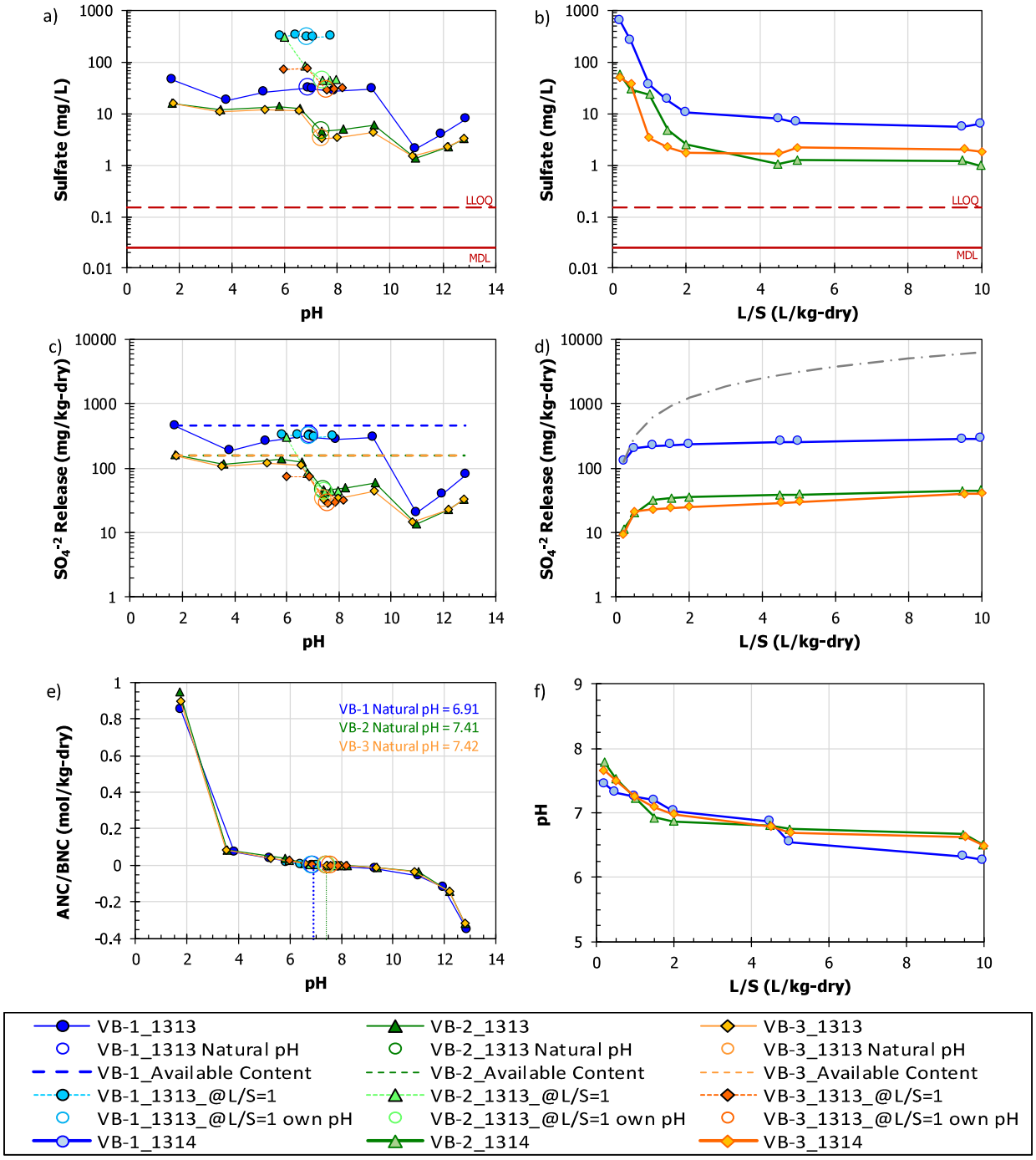

Figure D-30
Sulfate LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

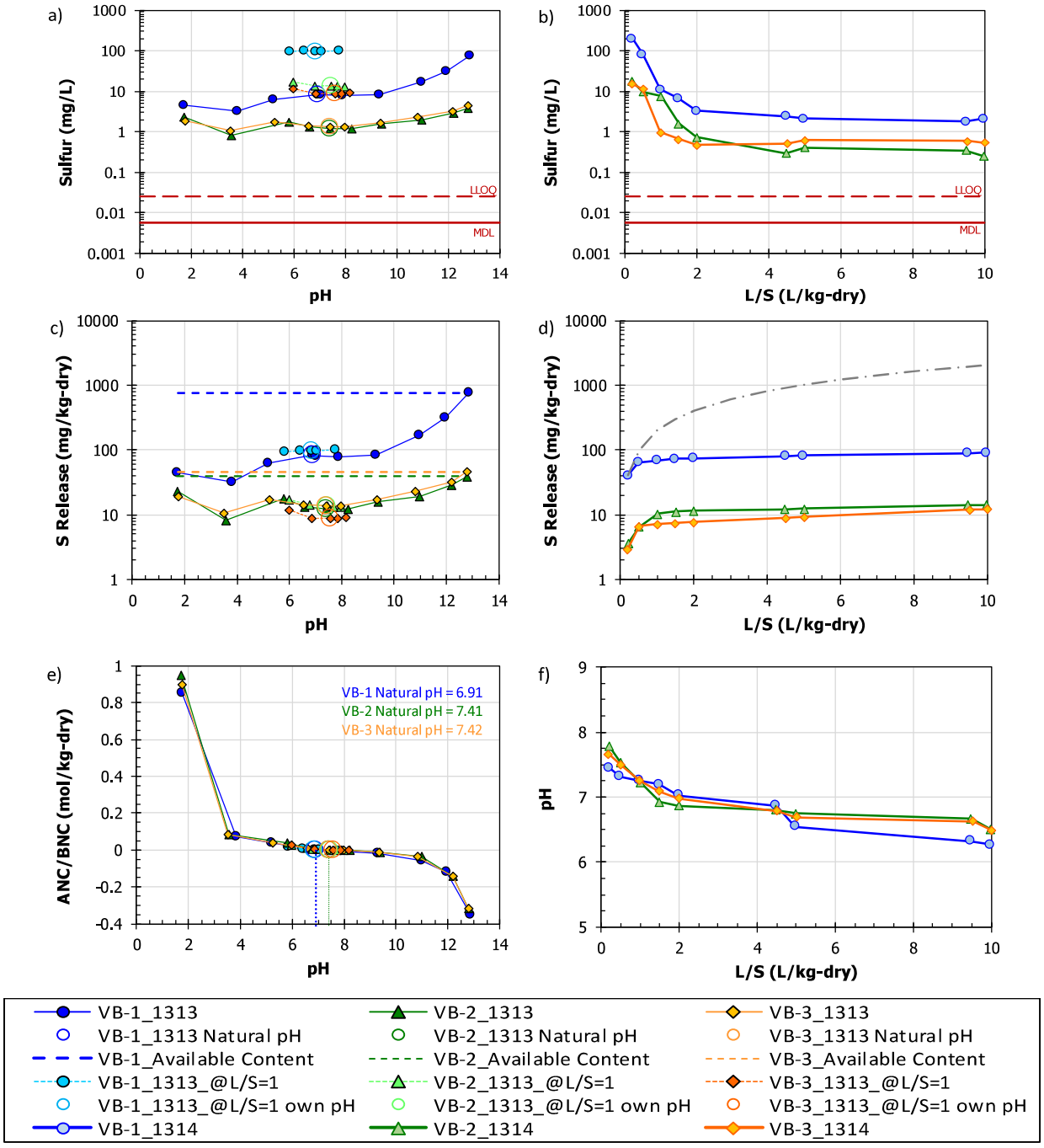

Figure D-31
Sulfur LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

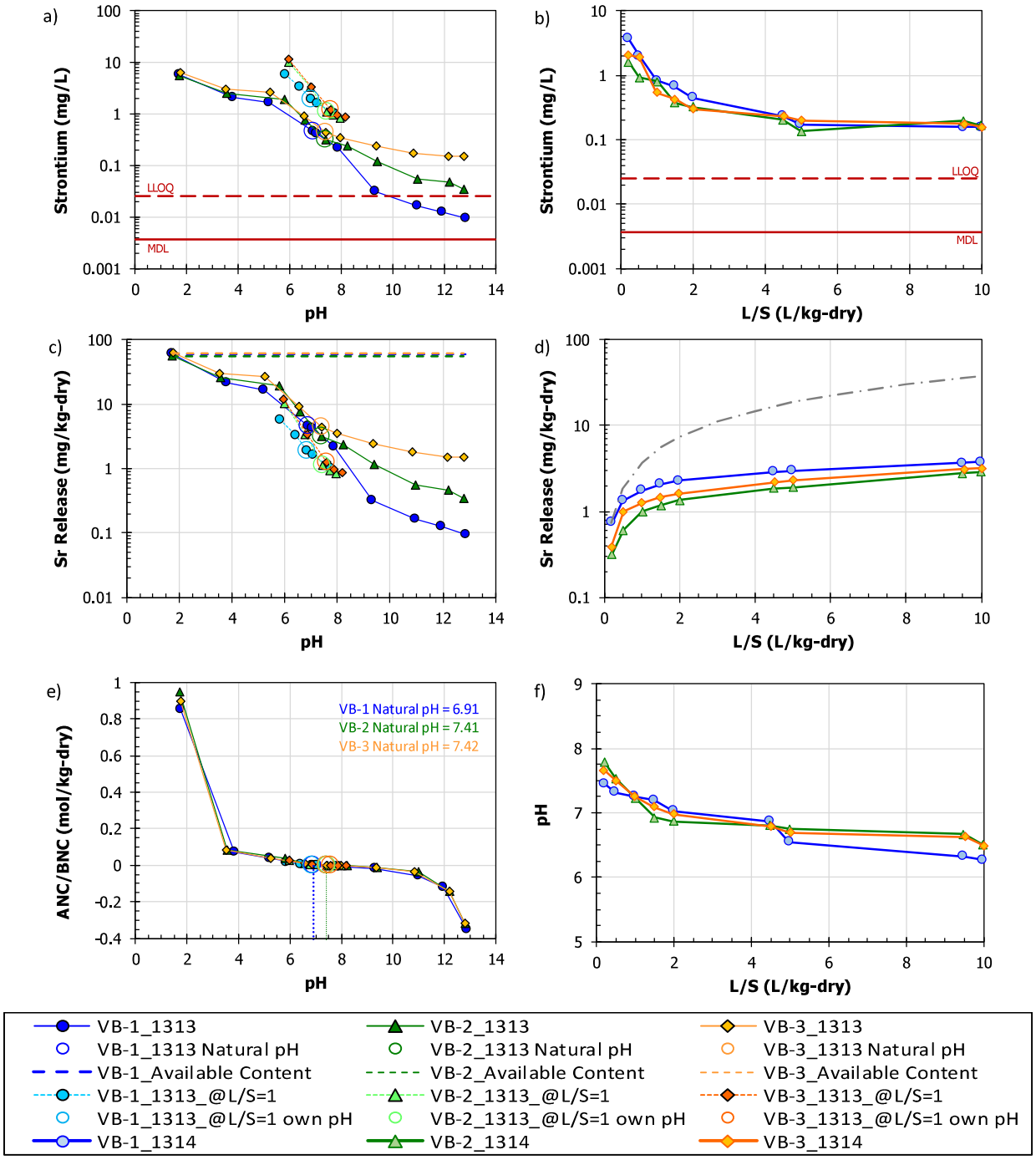

Figure D-32
Strontium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

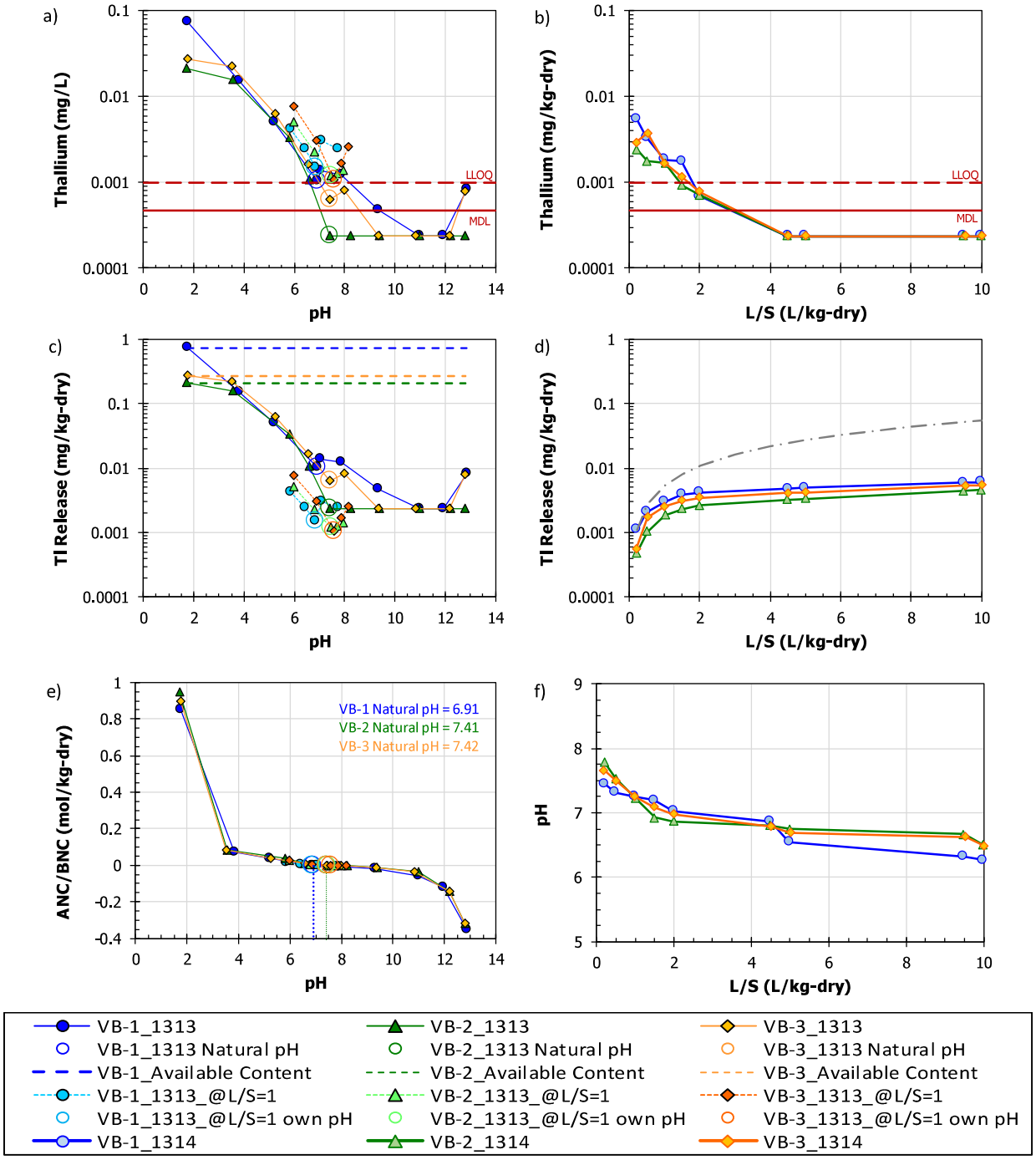

Figure D-33
Thallium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

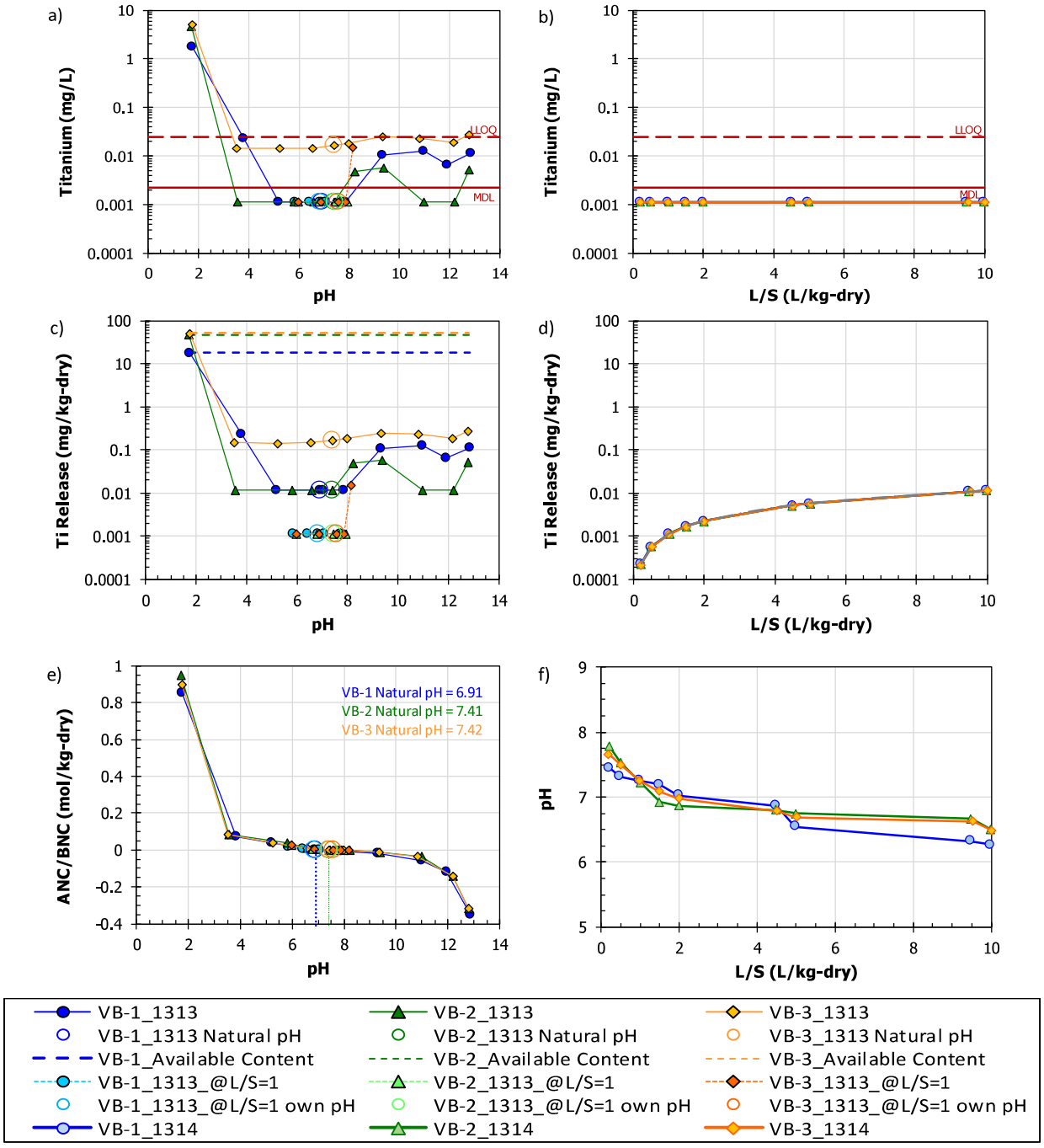

Figure D-34
Titanium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

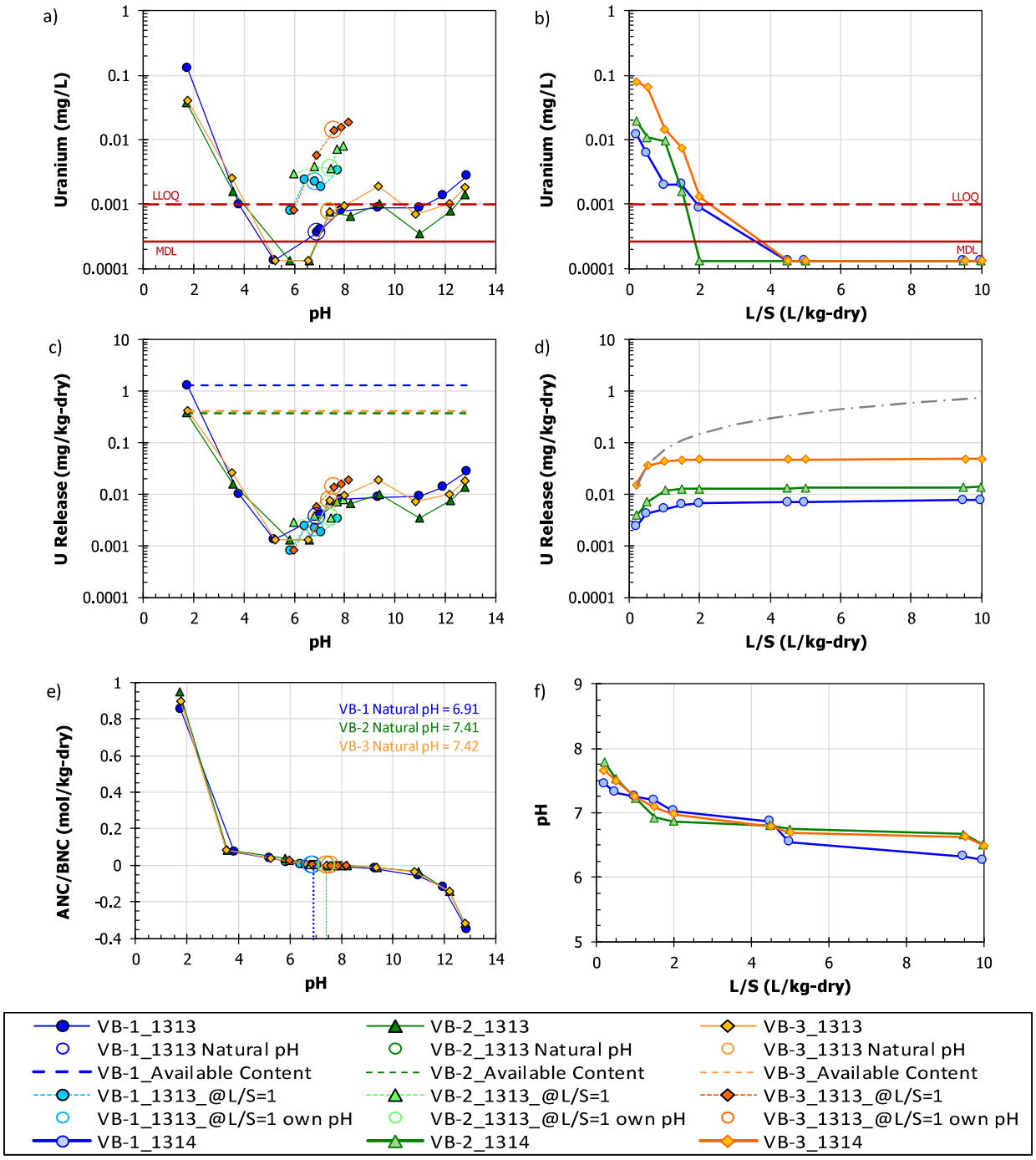

Figure D-35
Uranium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

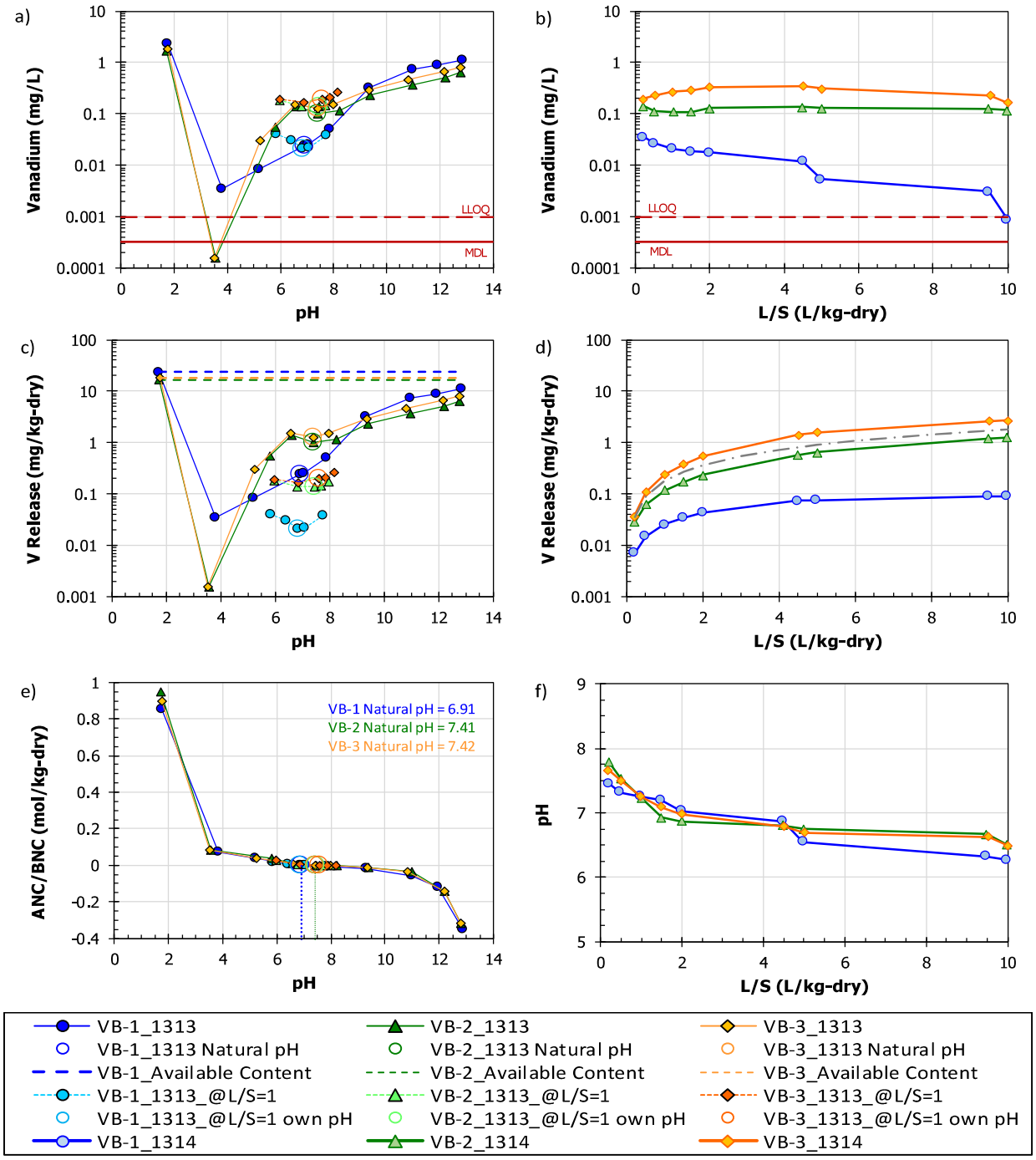

Figure D-36
Vanadium LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

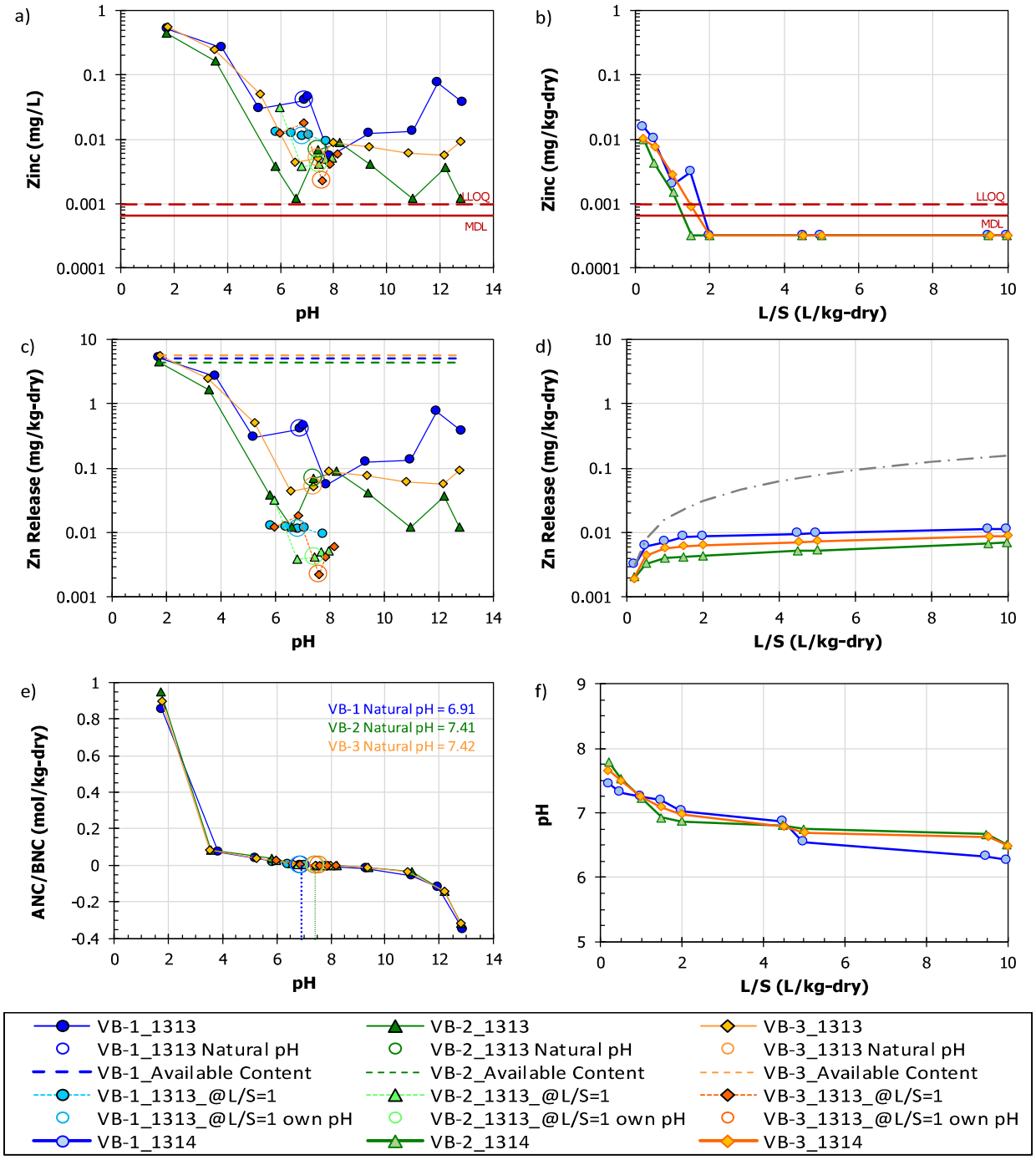

Figure D-37
Zinc LEAF test results from composite samples VB-1, VB-2, and VB-3: a) concentration as a function of pH, b) concentration as a function of L/S, c) mass release as a function of pH with available content, d) mass release as a function of L/S, e) acid/base neutralization capacity (ANC/BNC) as a function of pH, and f) column pH as a function of L/S

D.2 Comparison of Individual Split Spoon and Composite Sample Data

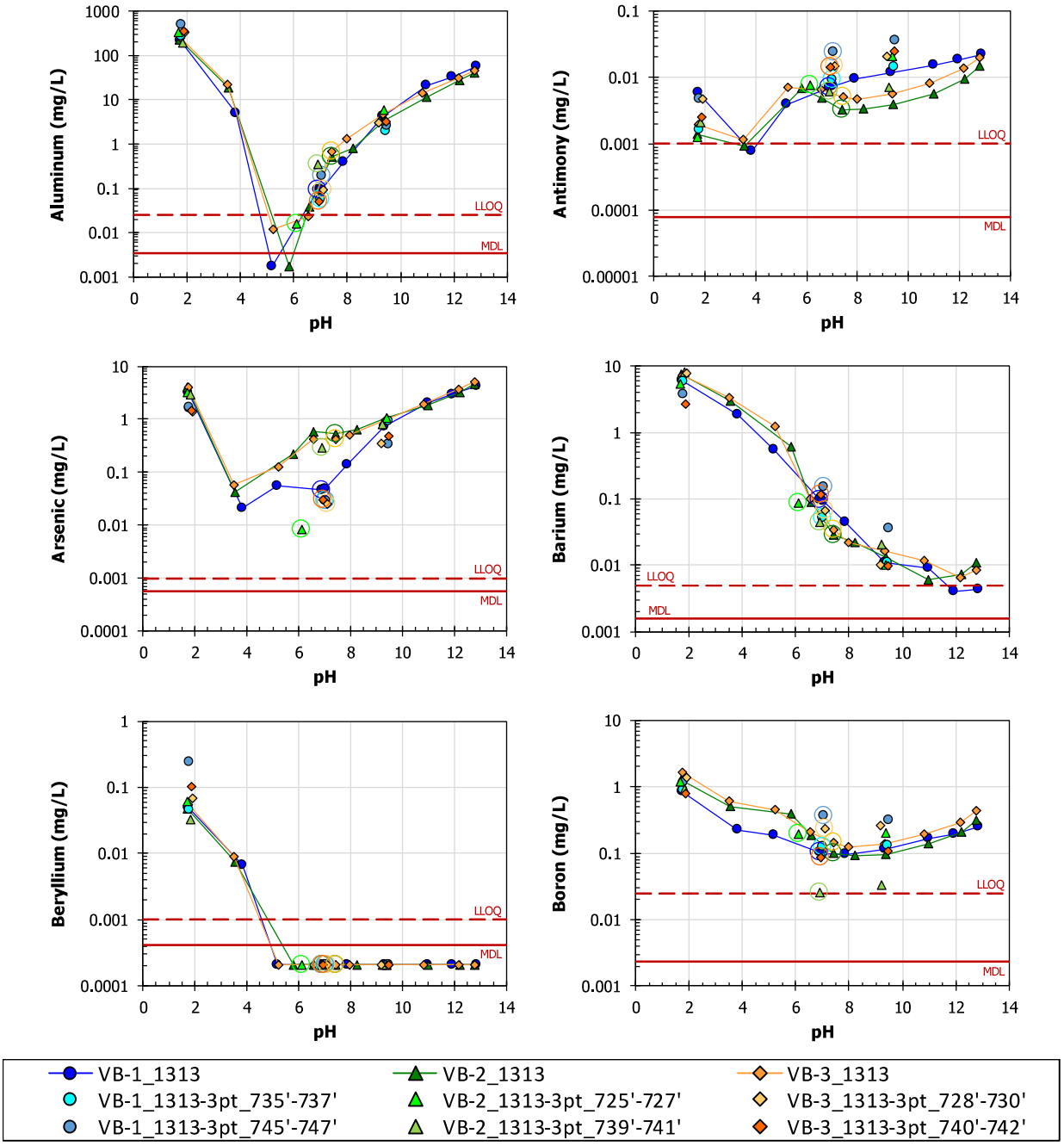

Figure D-38
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: aluminum, antimony, arsenic, barium, beryllium, and boron

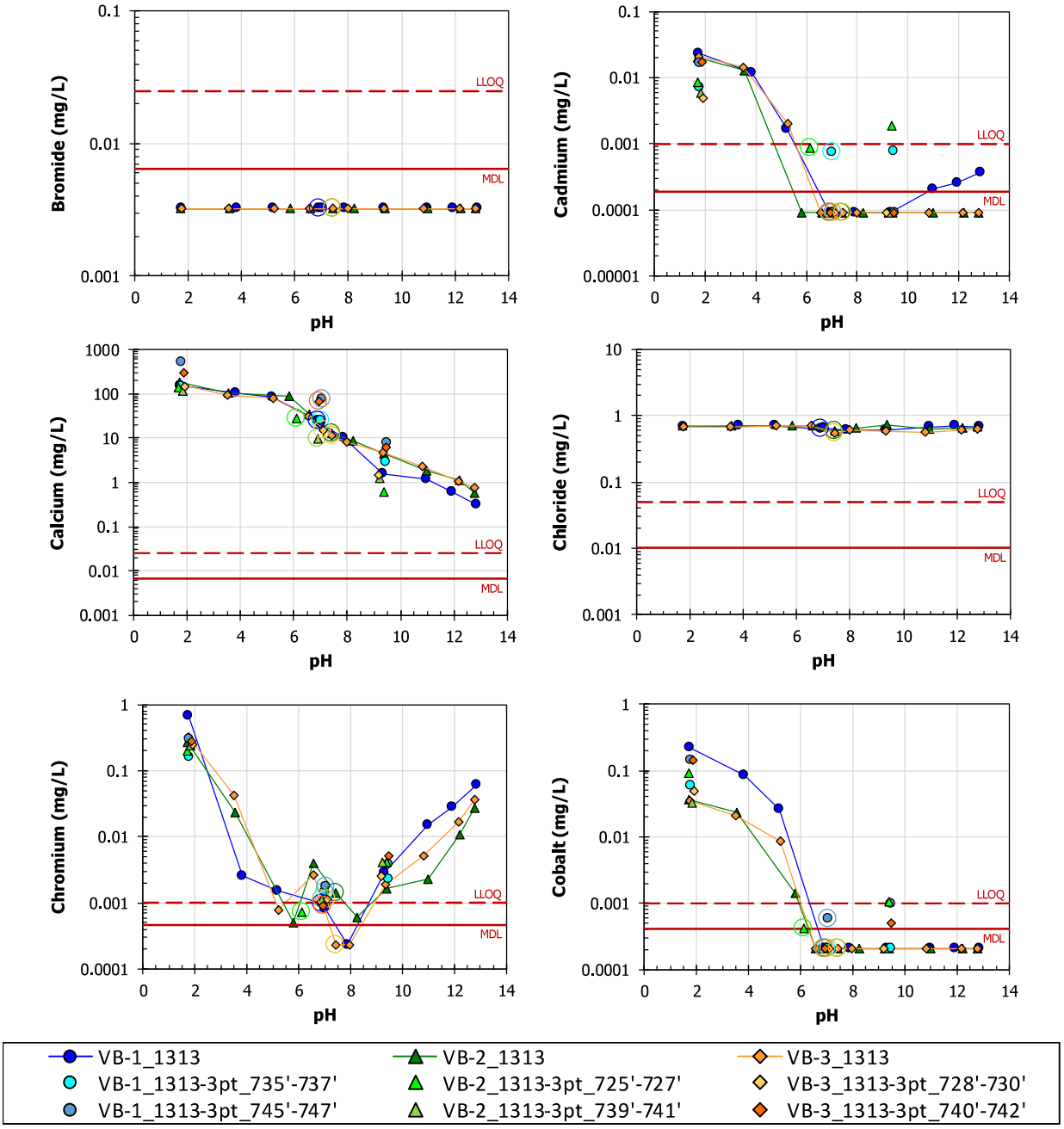

Figure D-39
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: bromide, cadmium, calcium, chloride, chromium, and cobalt

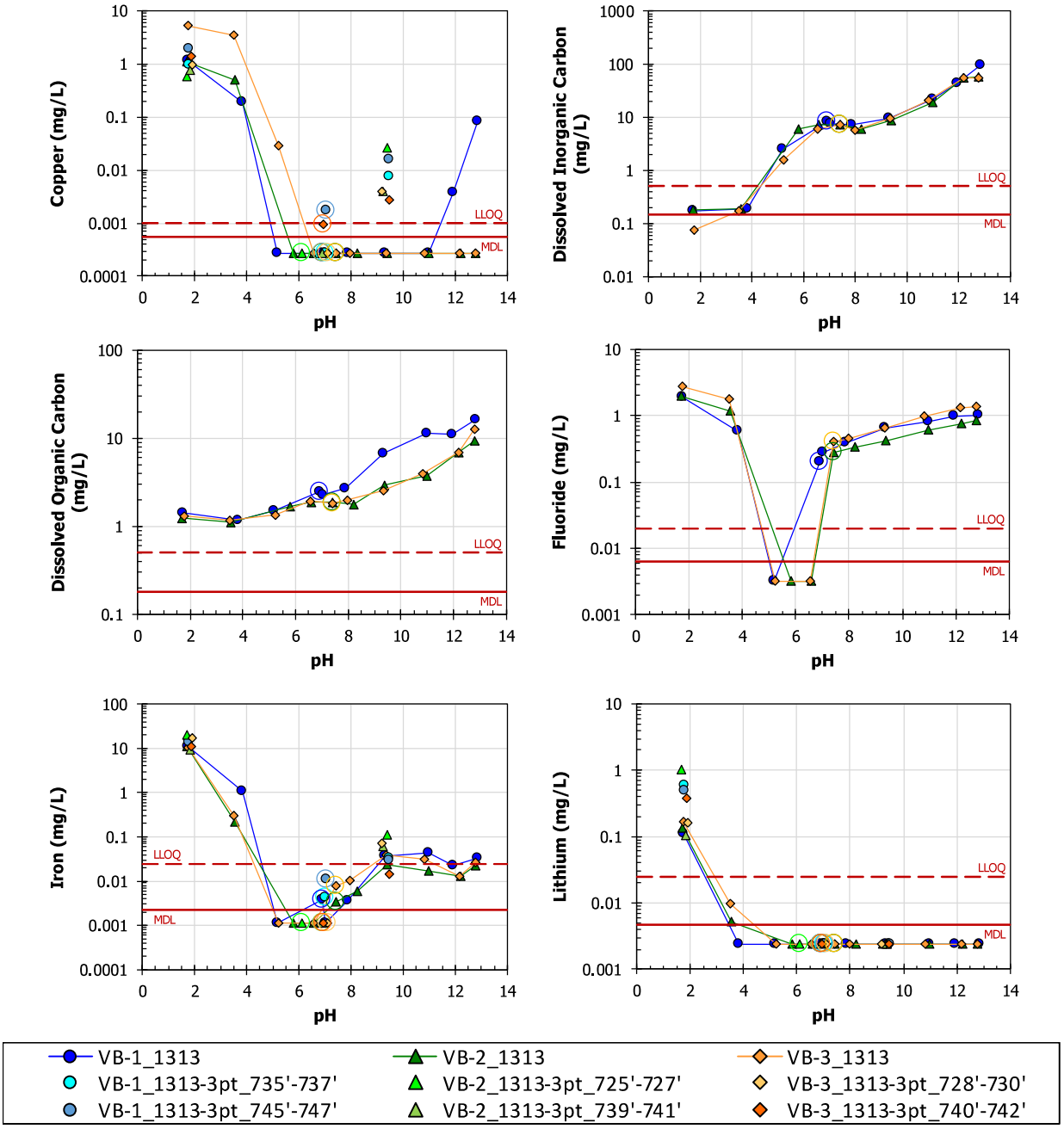

Figure D-40
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: copper, dissolved inorganic carbon, dissolved organic carbon, fluoride, iron, and lithium

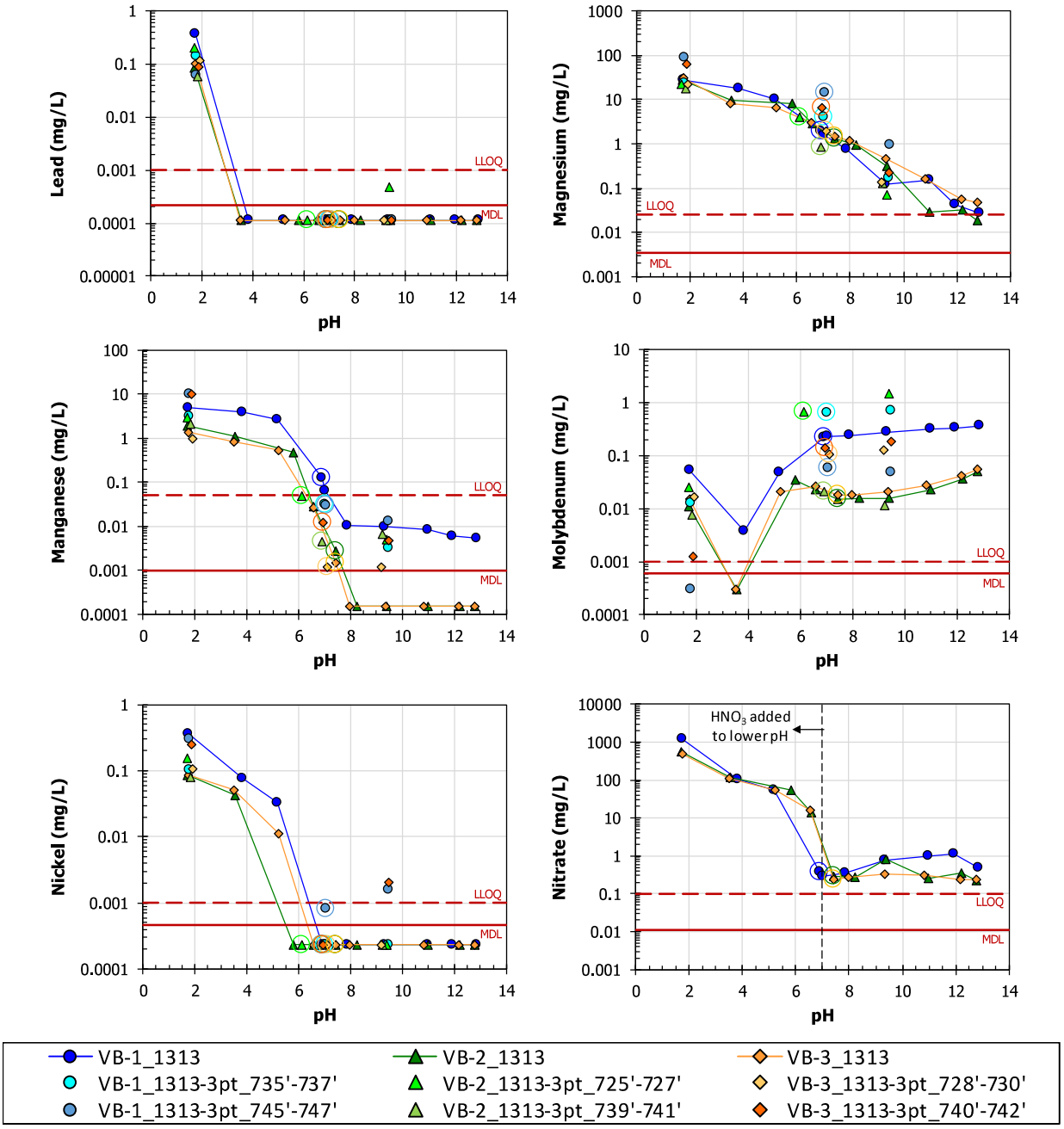

Figure D-41
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: lead, magnesium, manganese, molybdenum, nickel, and nitrate

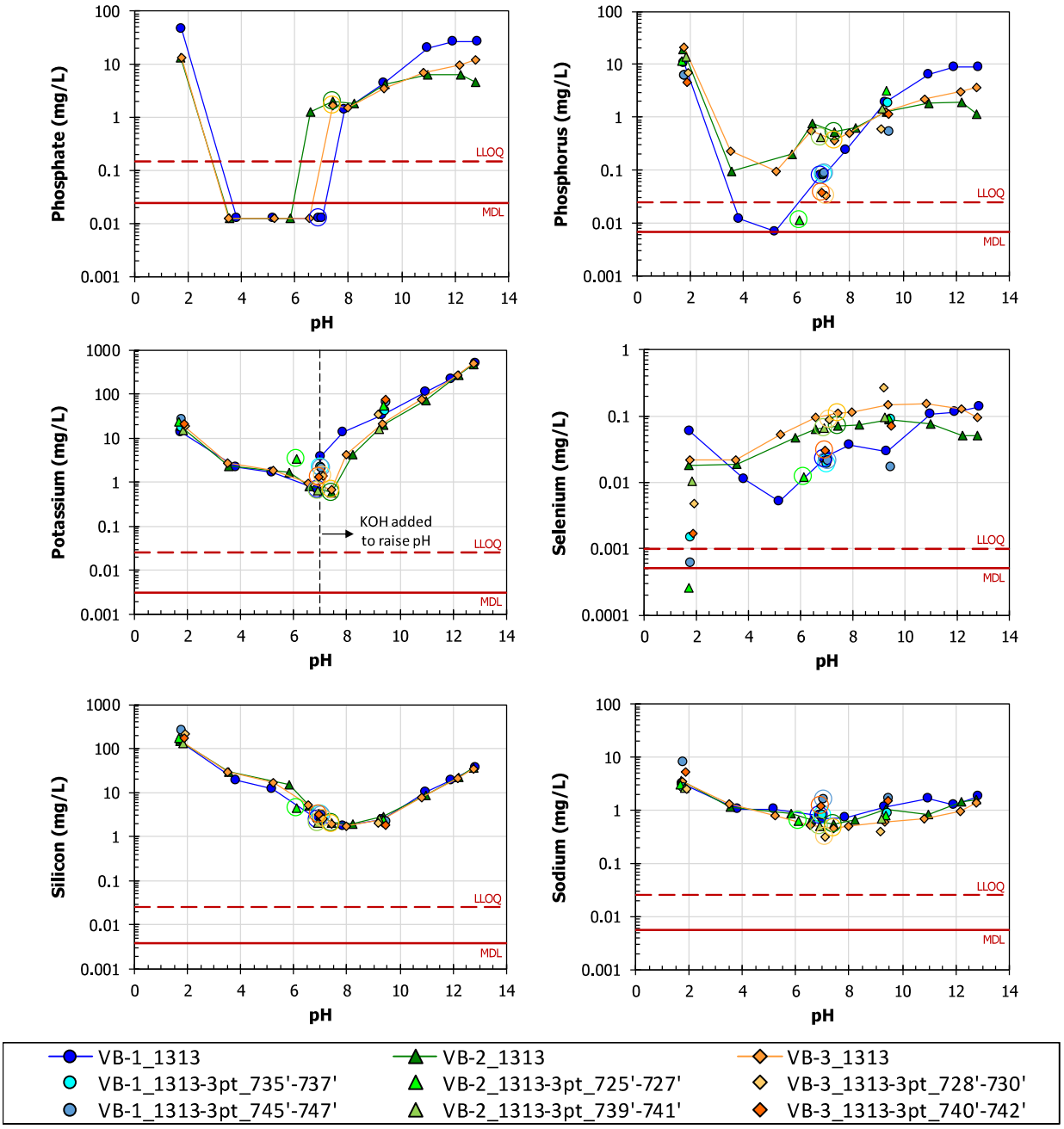

Figure D-42
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: phosphate, phosphorus, potassium, selenium, silicon, and sodium

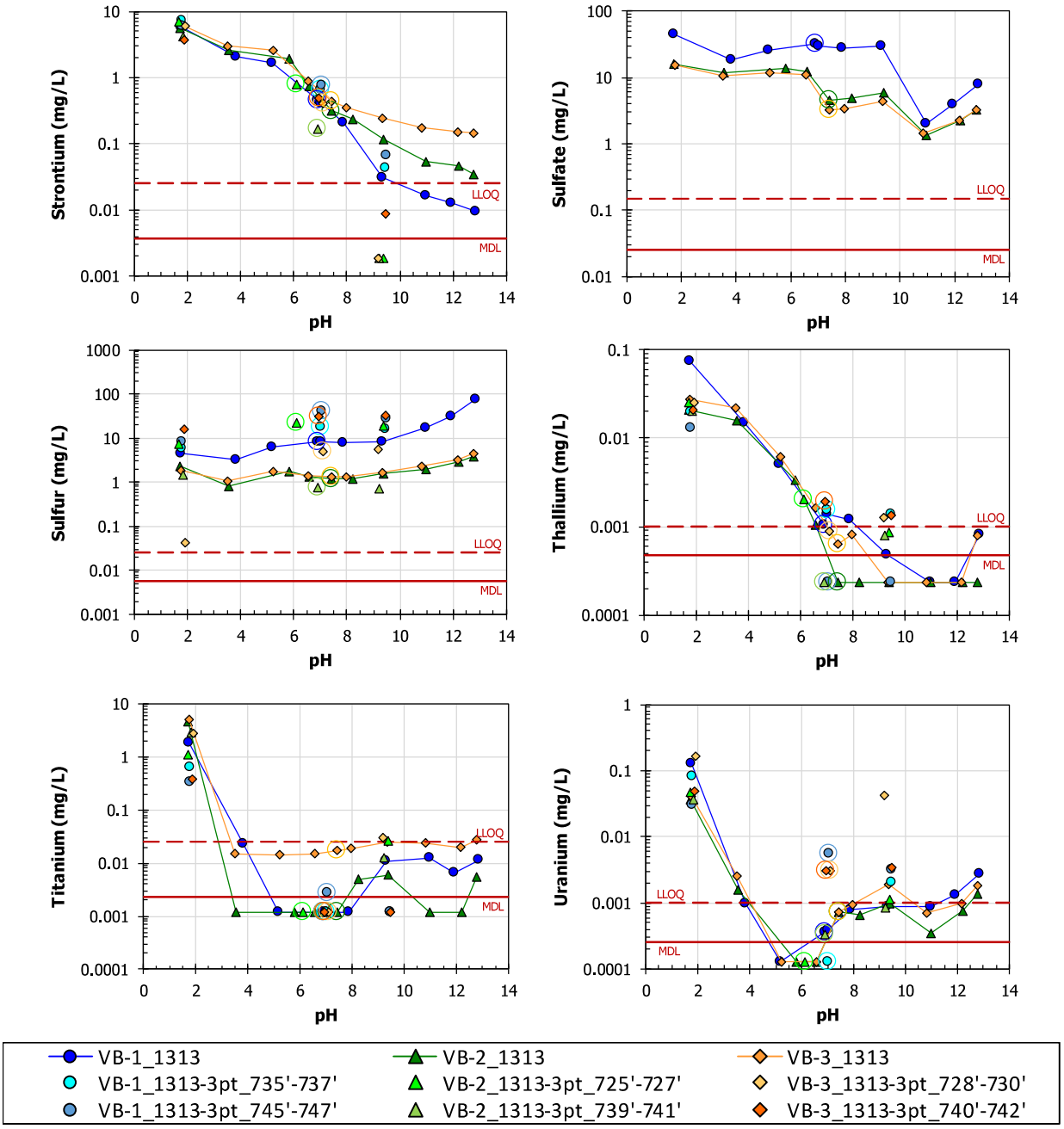

Figure D-43
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: strontium, sulfate, sulfur, thallium, titanium, and uranium

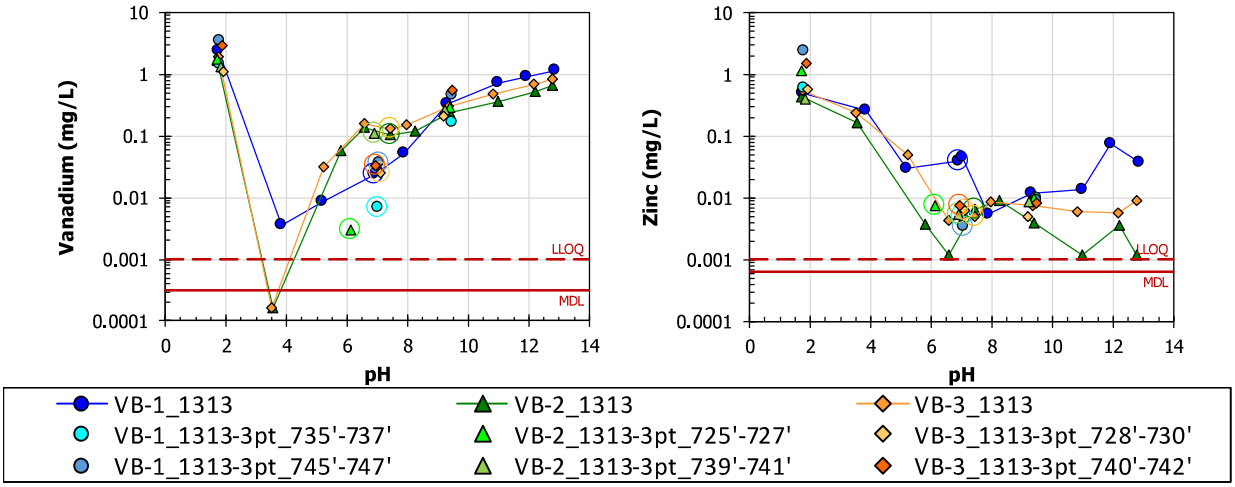

Figure D-44
pH-dependent concentration of composite samples (Method 1313) and discrete split spoon samples (Method 1313-3pt) from boreholes VB-1, VB-2 and VB-3: vanadium and zinc

E
COMPARISON OF TEST METHOD RESULTS

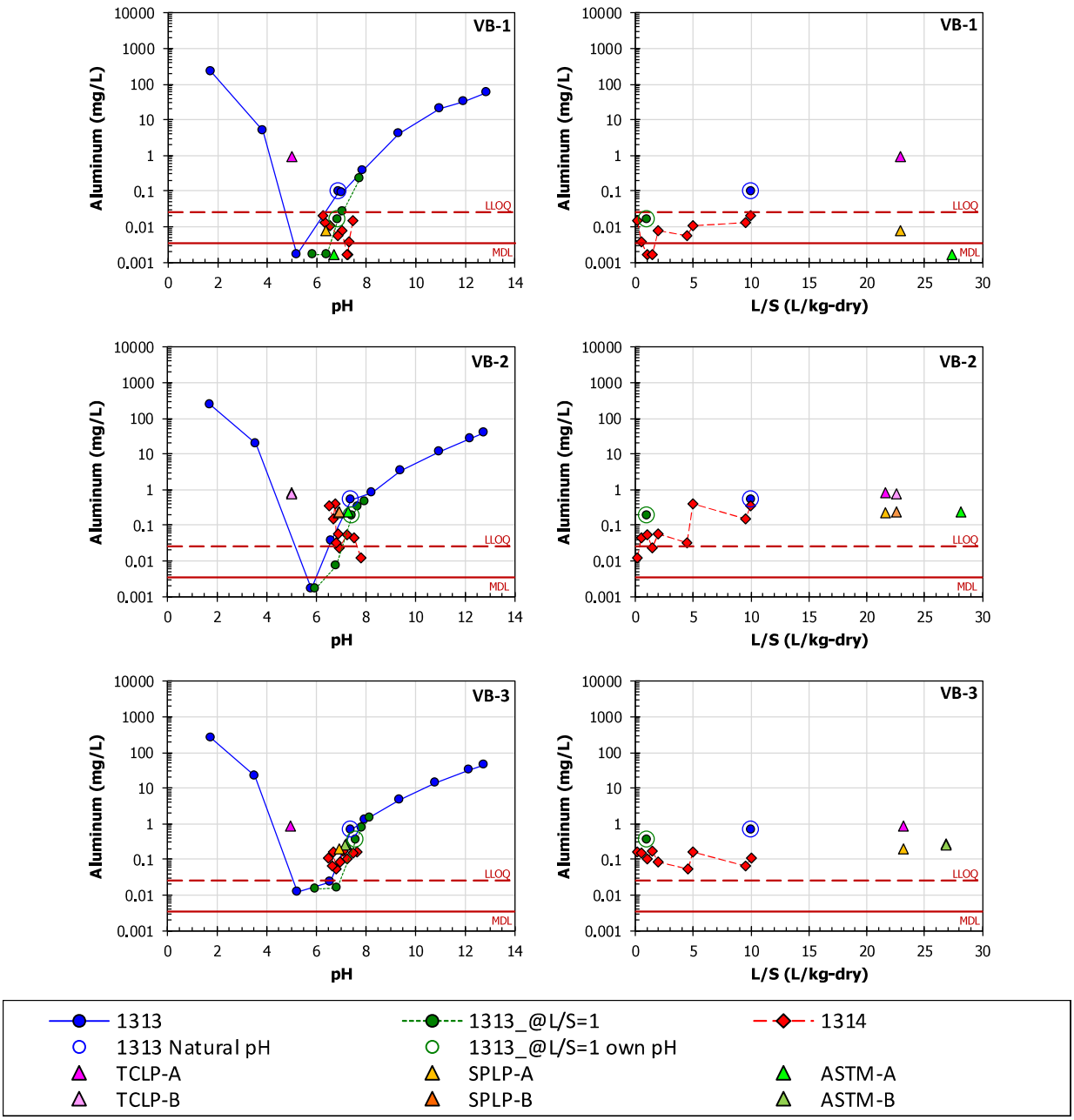

Figure E-1
Aluminum concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

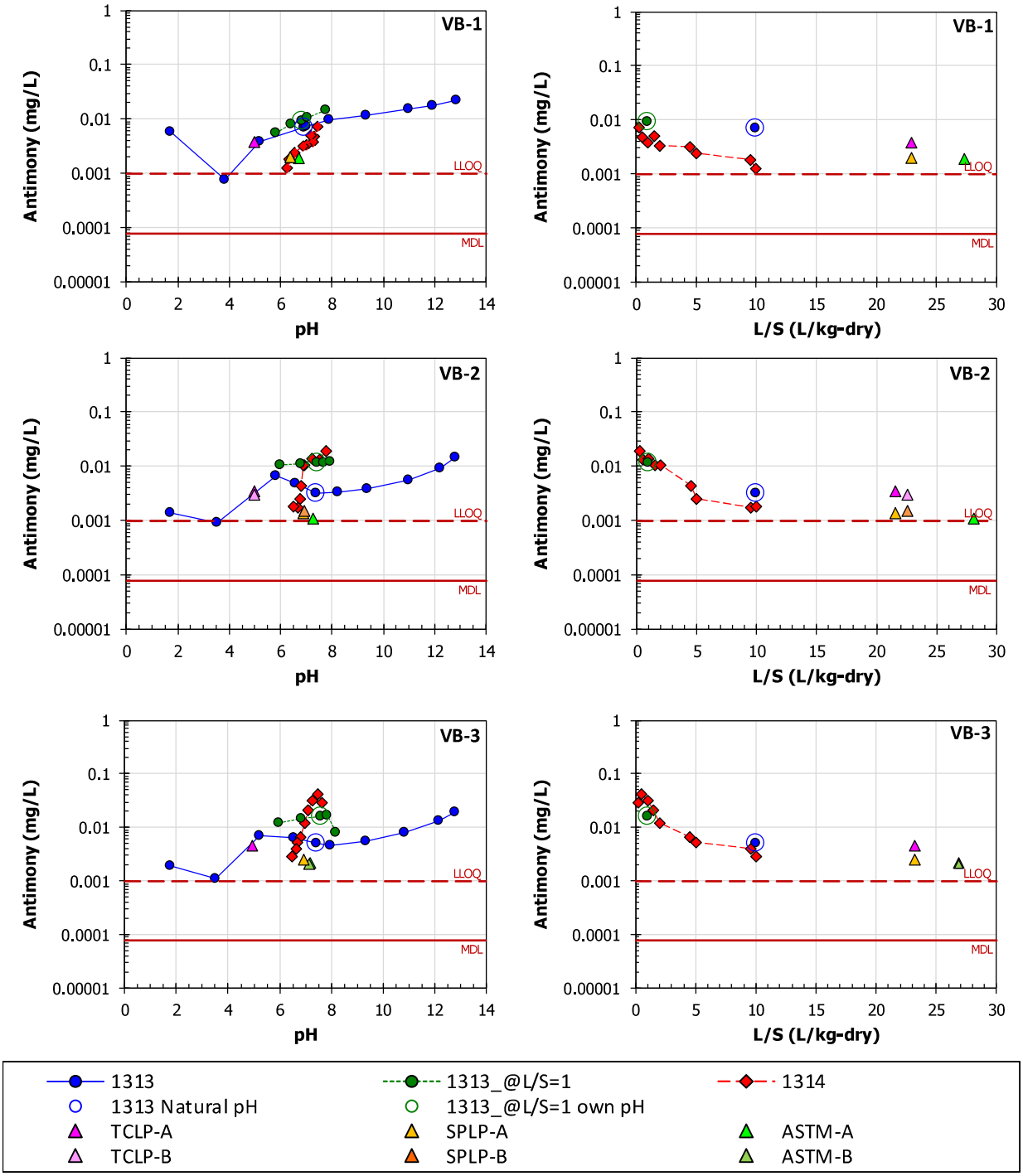

Figure E-2
Antimony concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

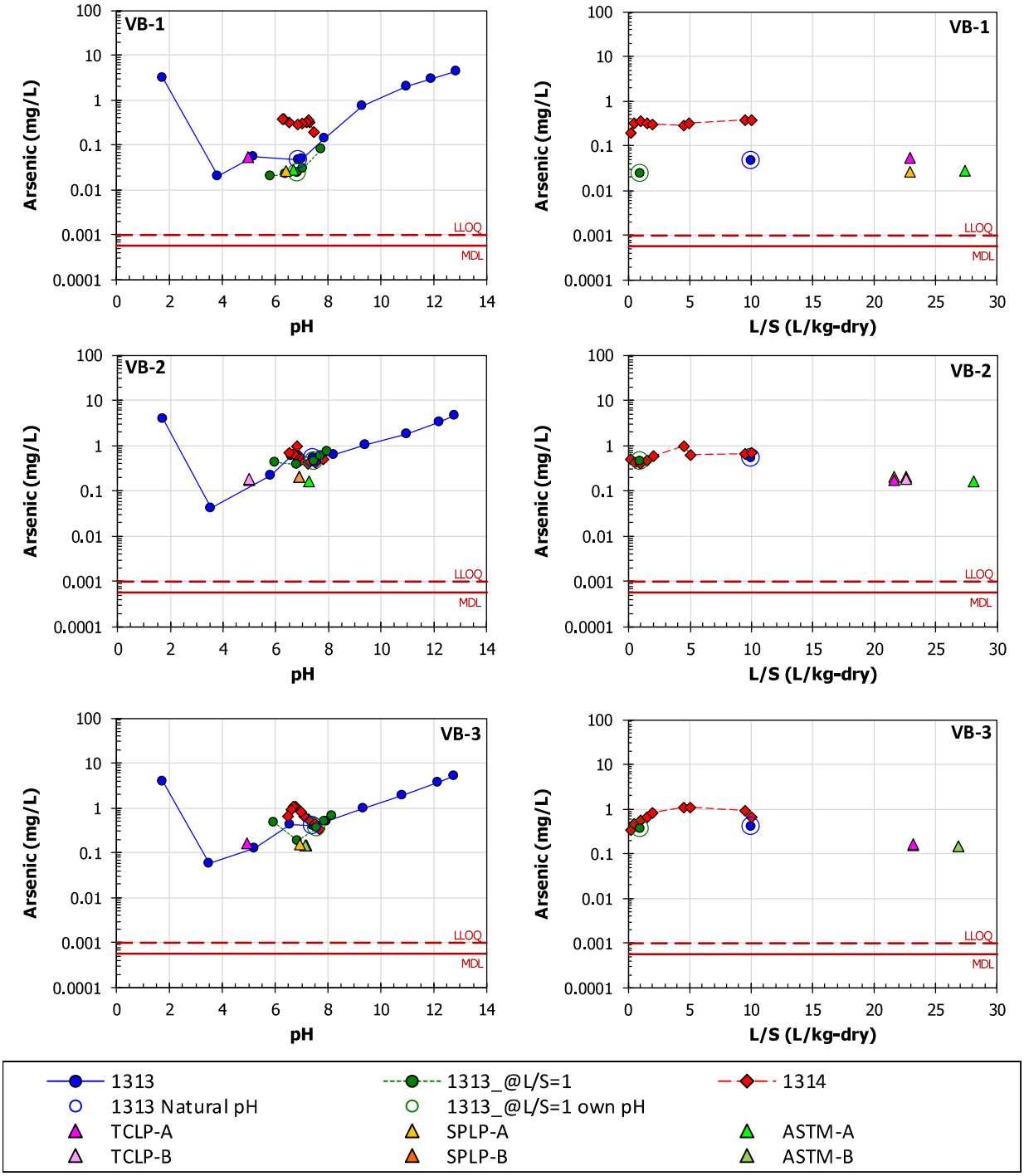

Figure E-3
Arsenic concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

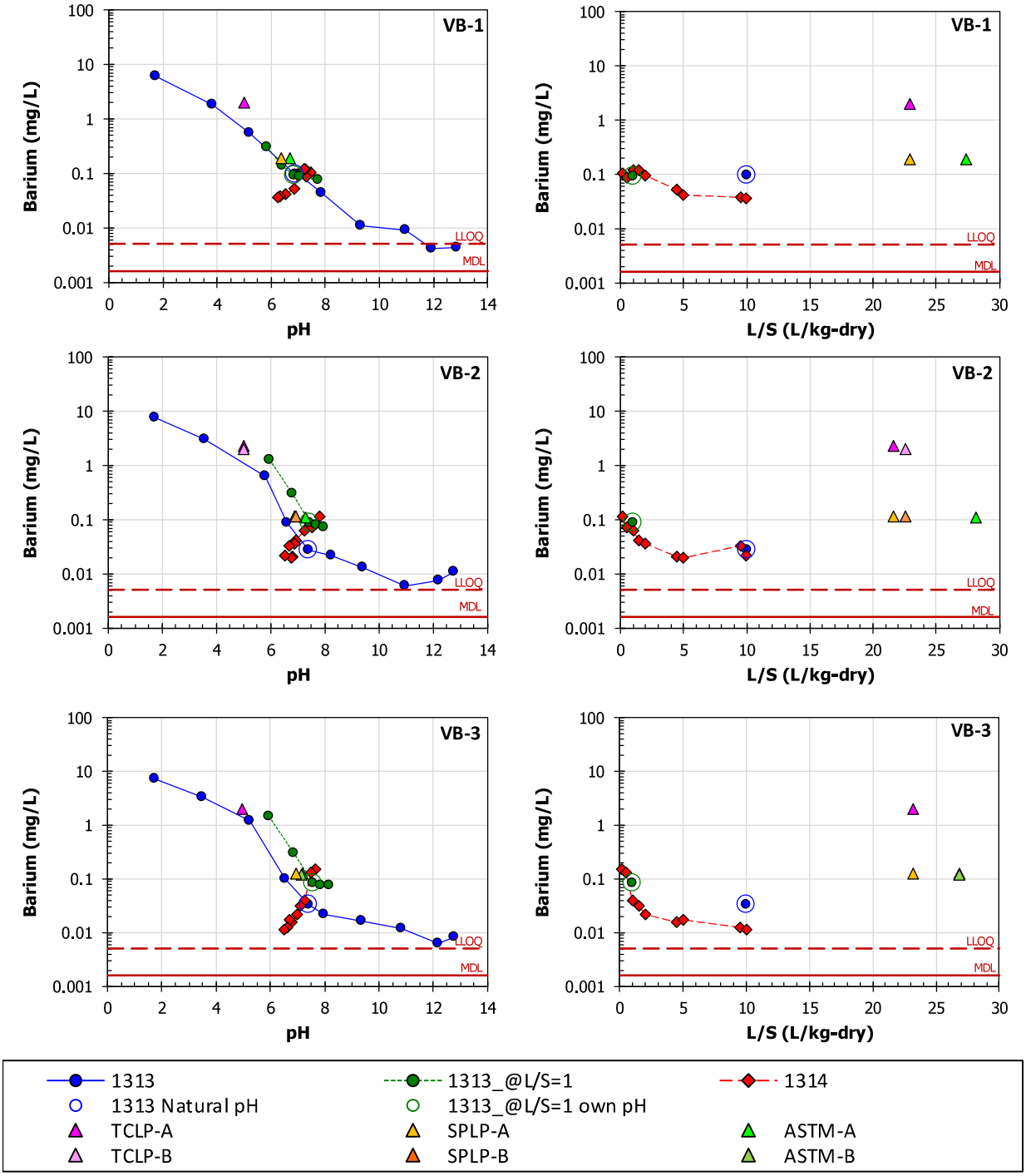

Figure E-4
Barium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

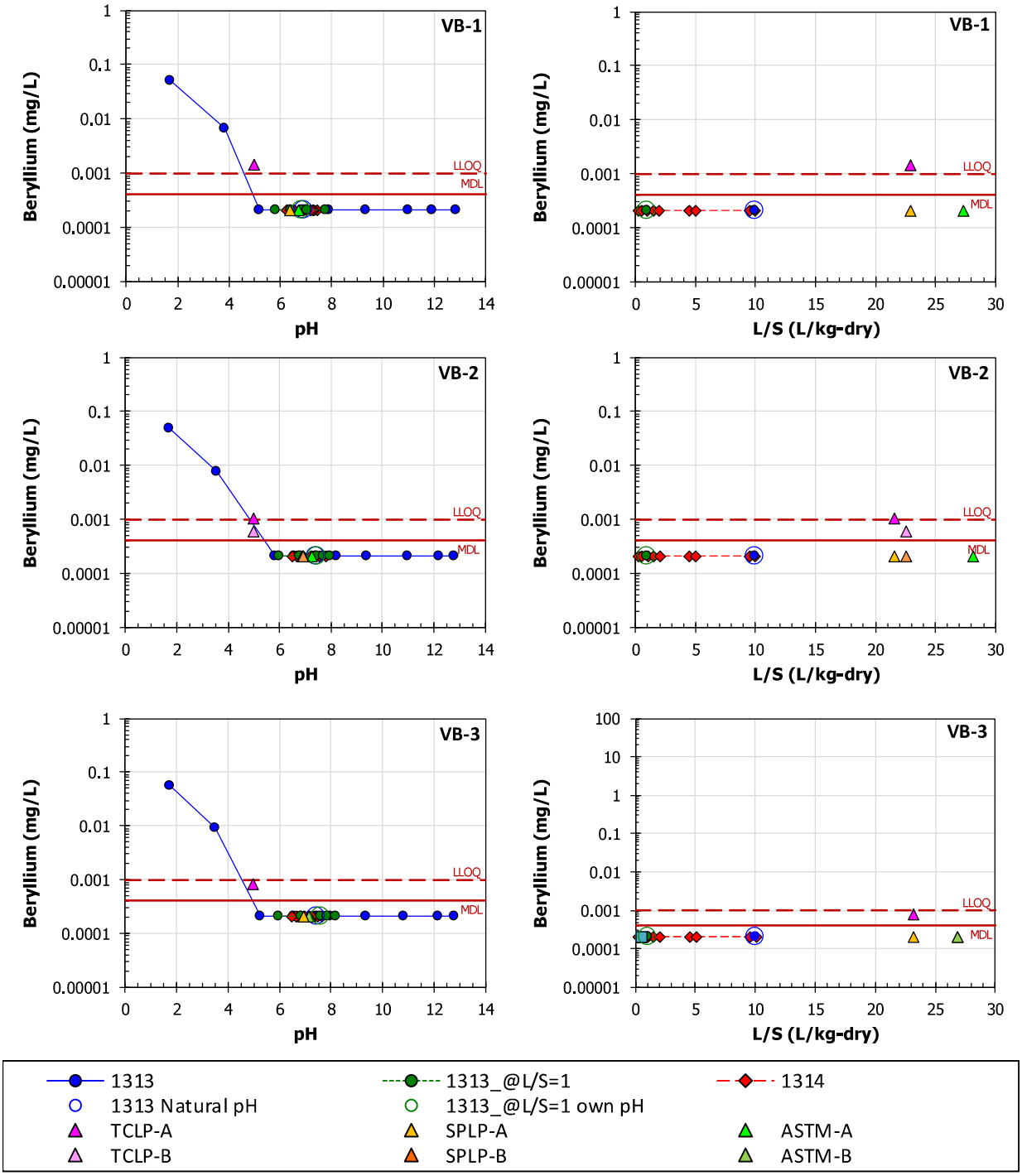

Figure E-5
Beryllium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

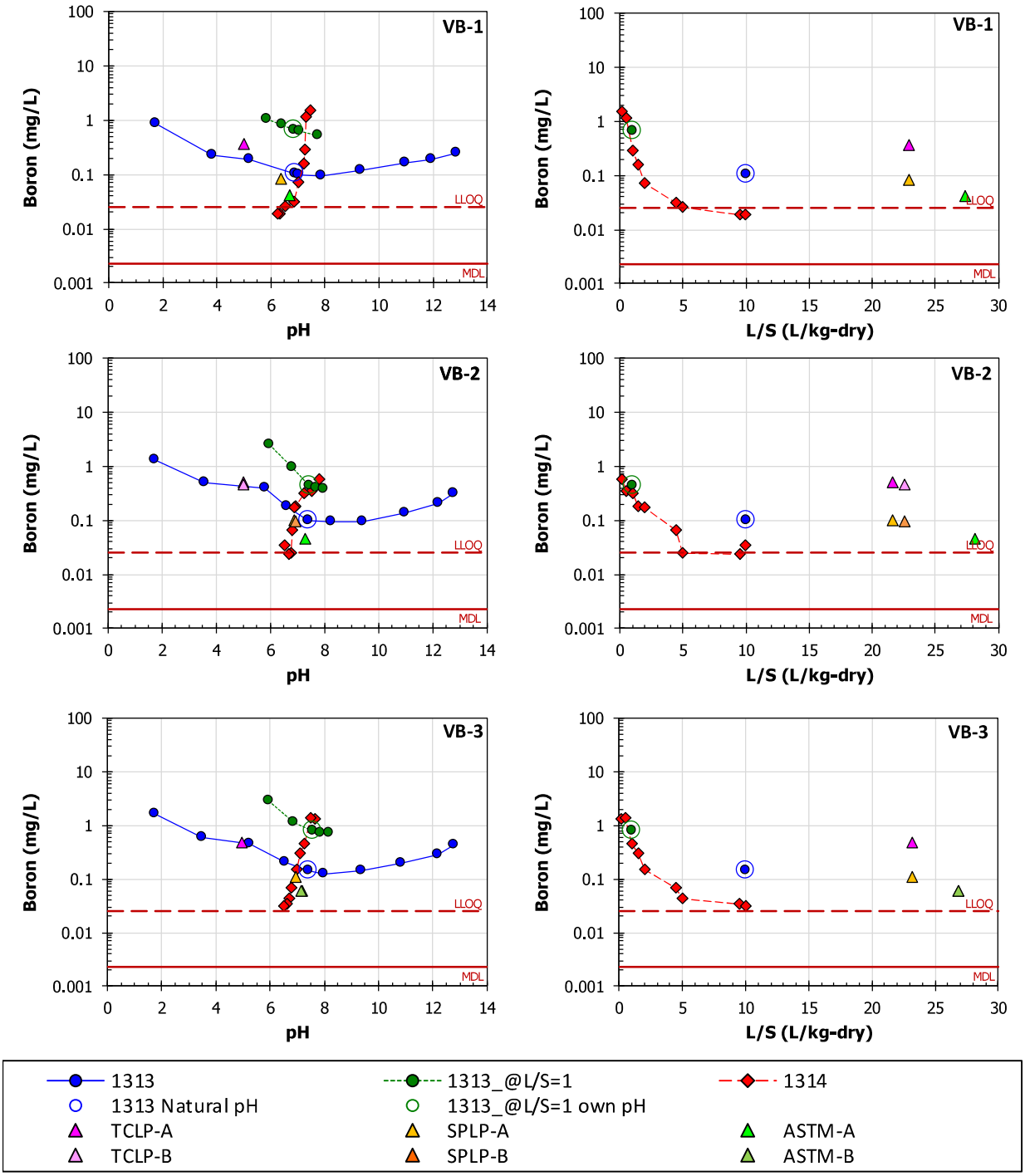

Figure E-6
Boron concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

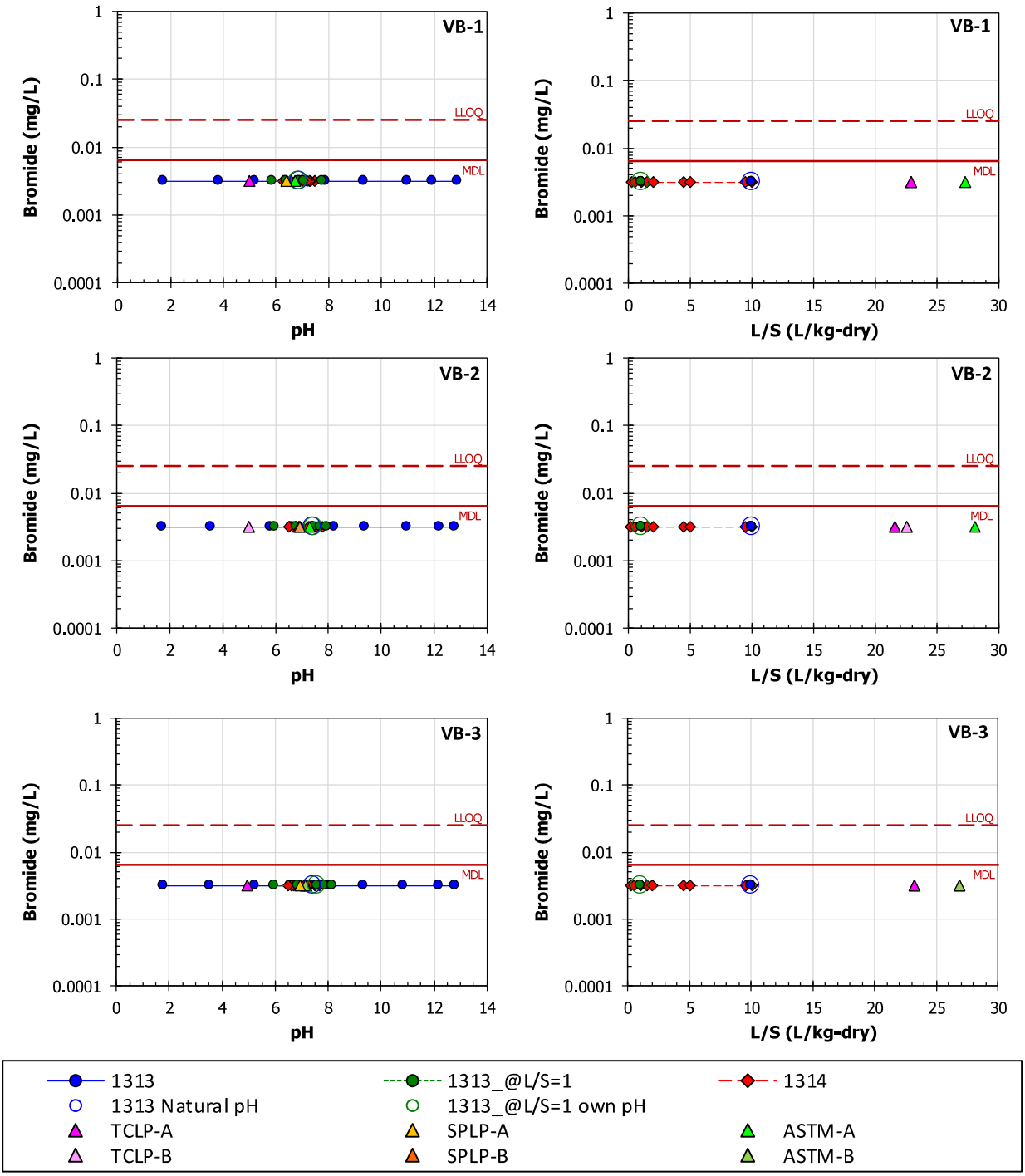

Figure E-7
Bromide concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

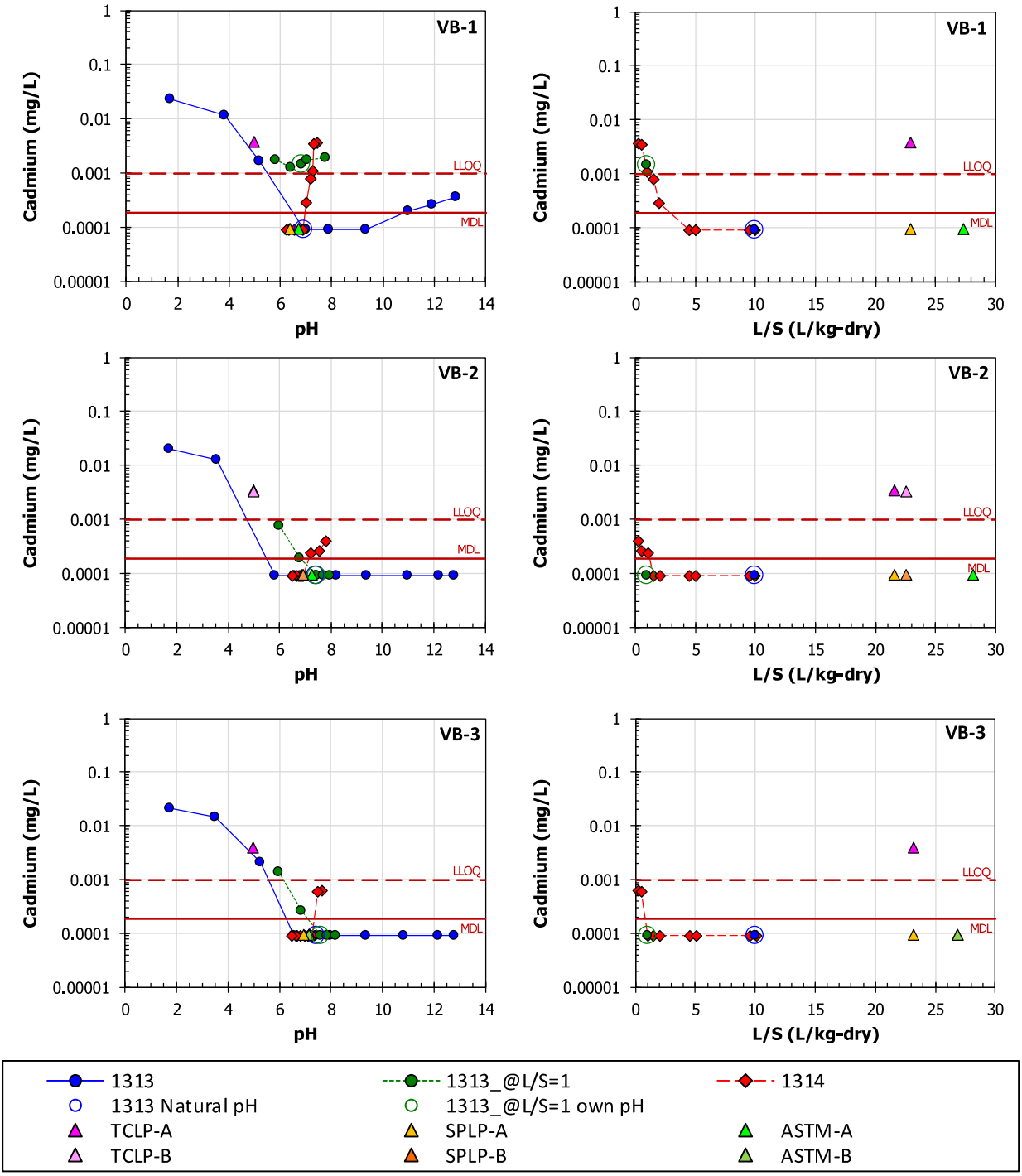

Figure E-8
Cadmium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

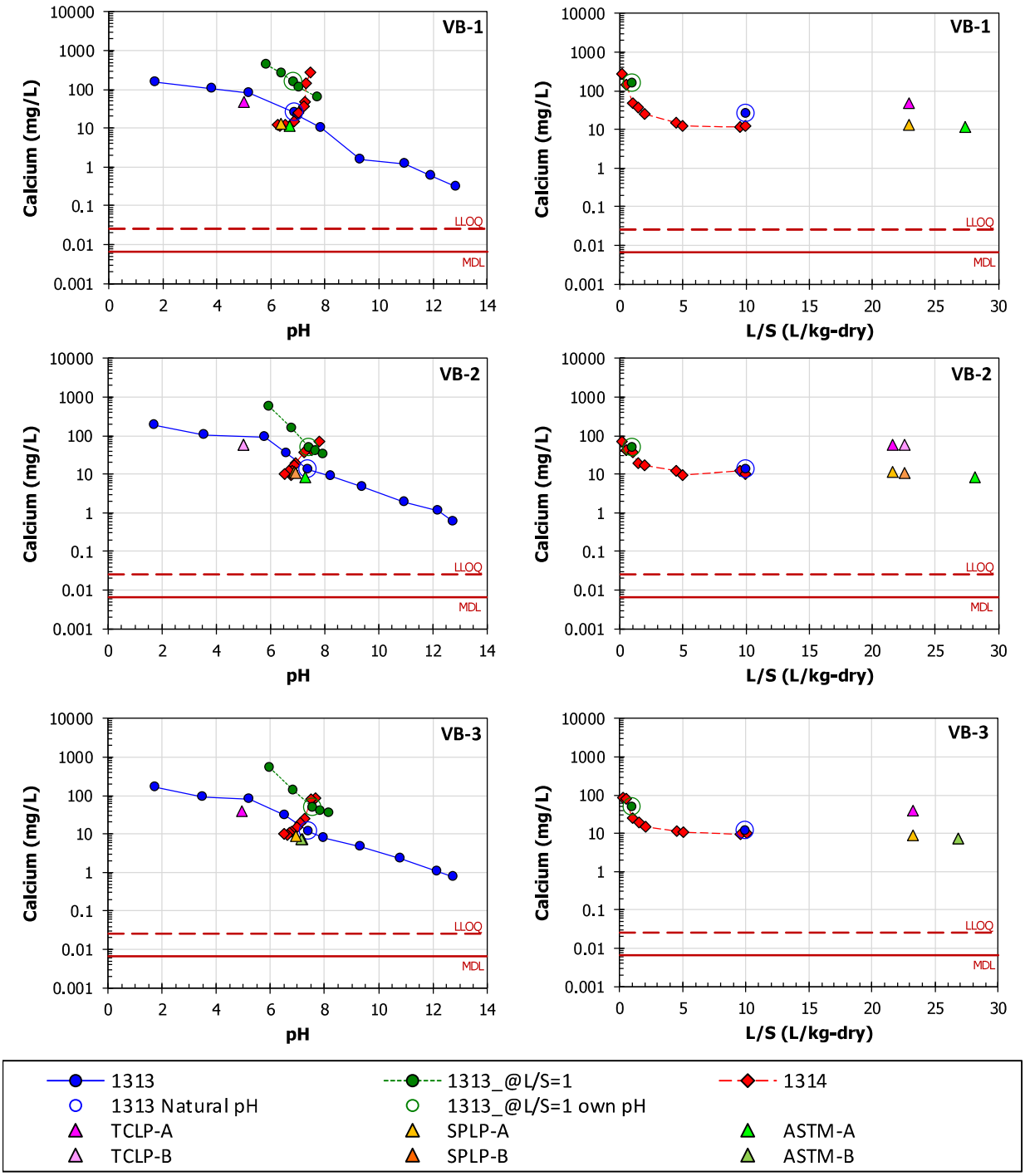

Figure E-9
Calcium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

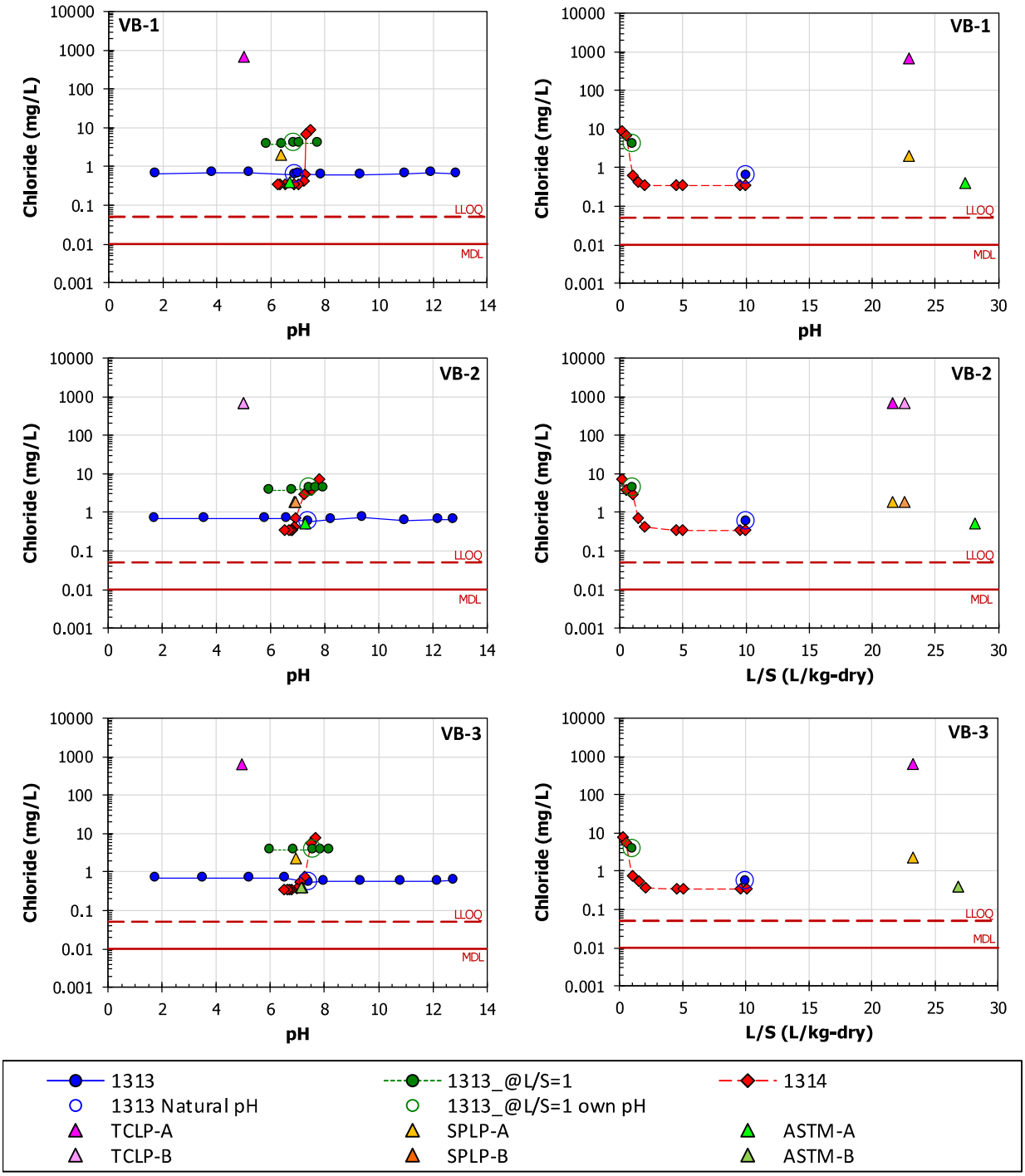

Figure E-10
Chloride concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

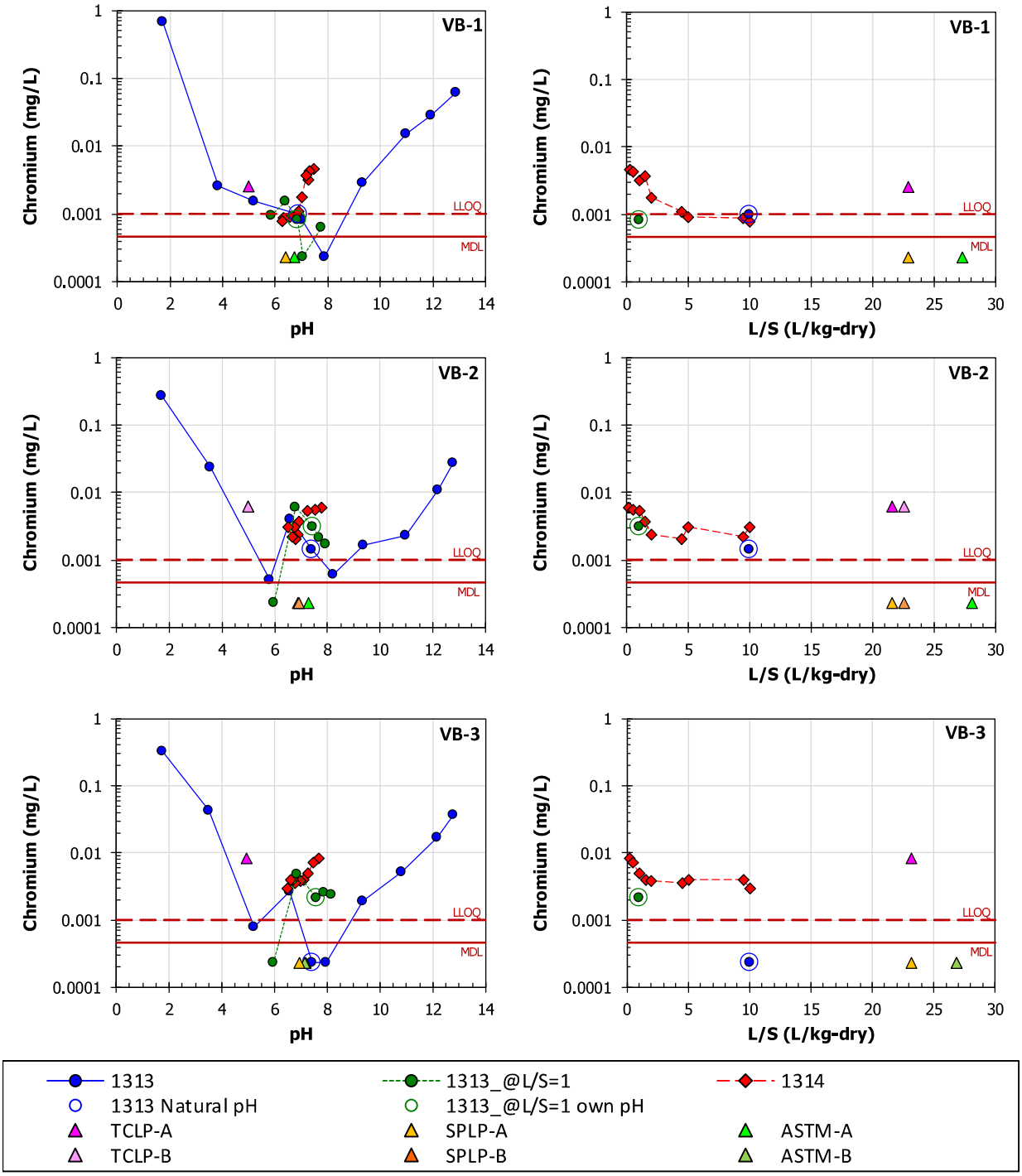

Figure E-11
Chromium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

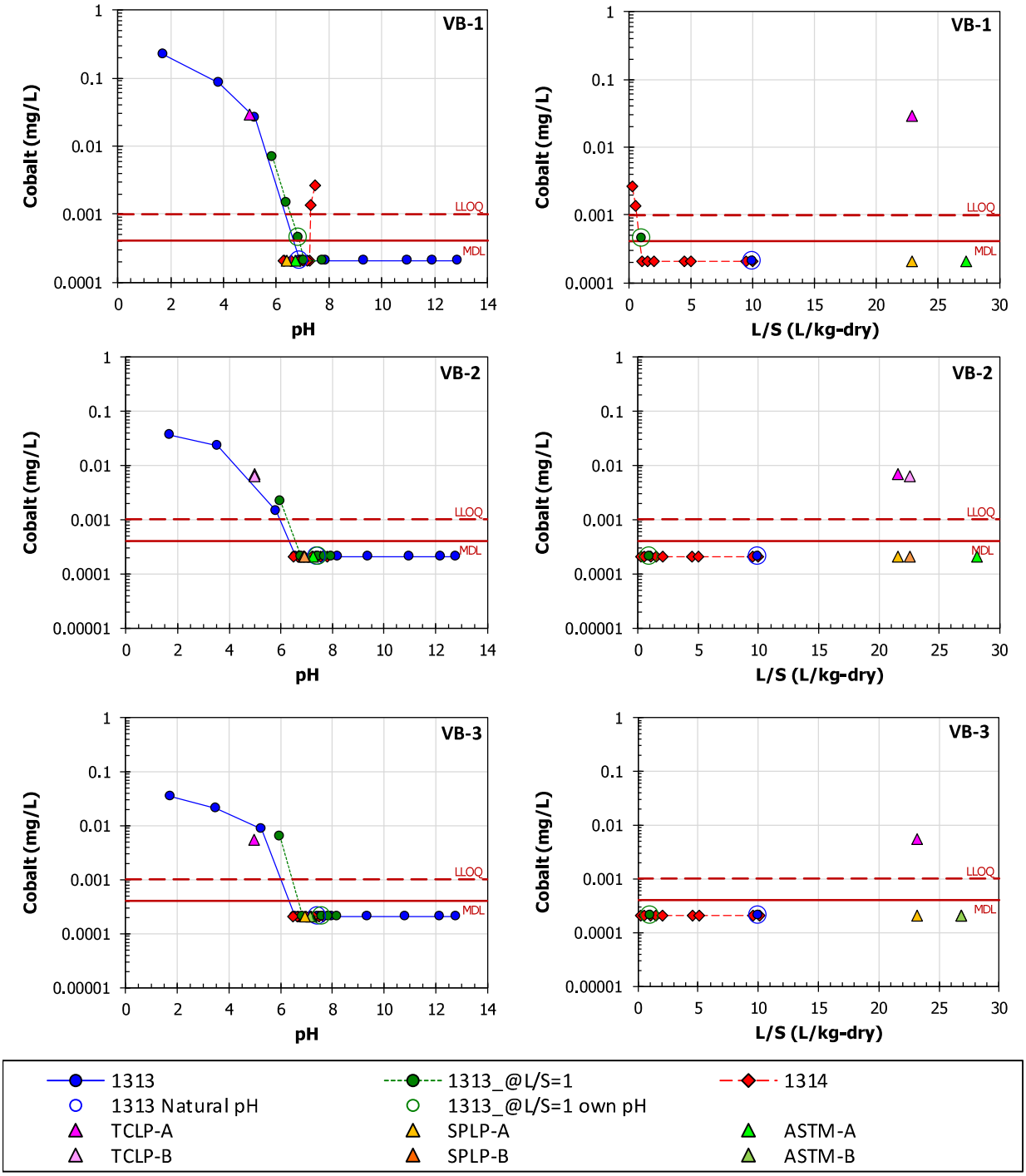

Figure E-12
Cobalt concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

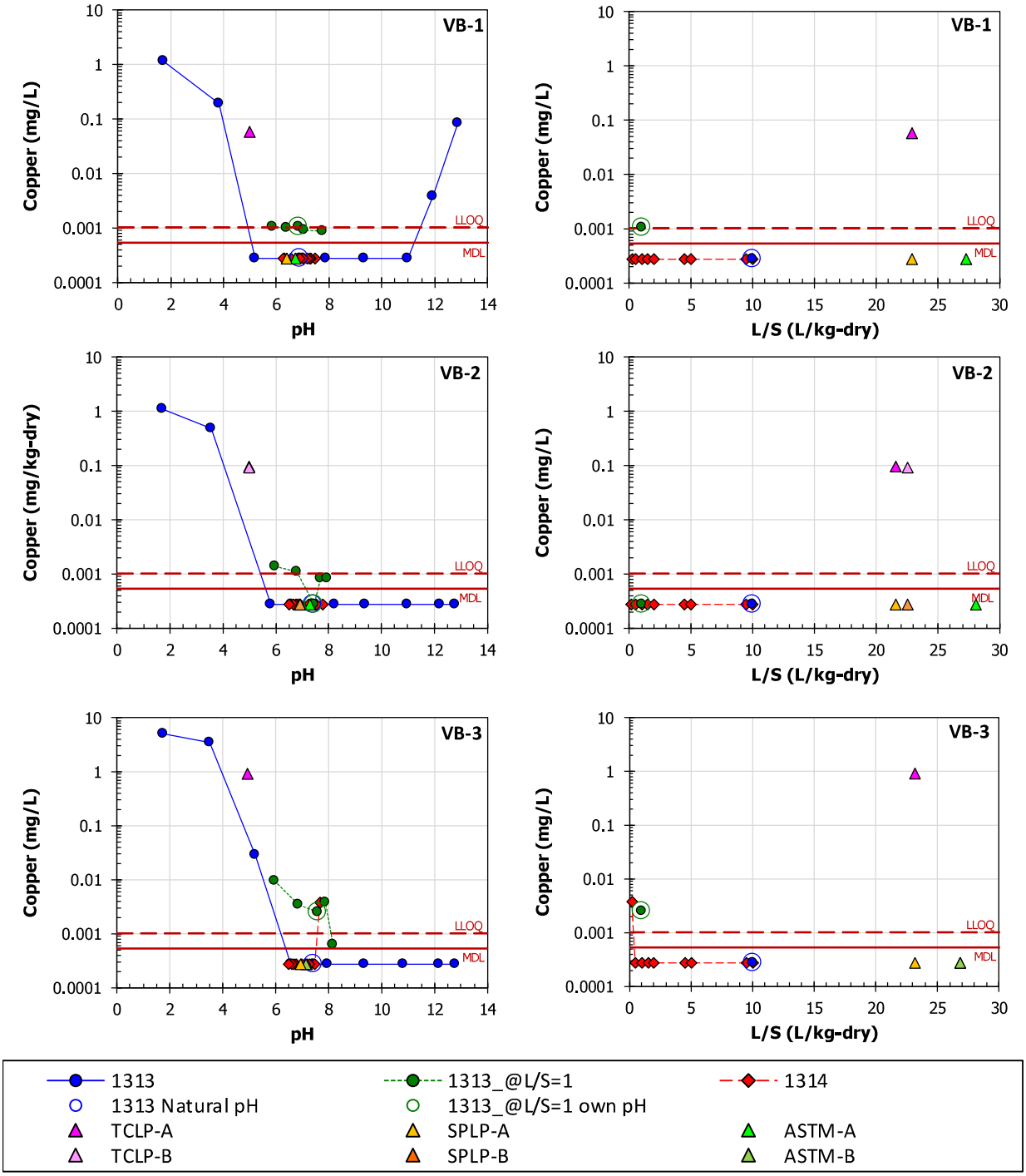

Figure E-13
Copper concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

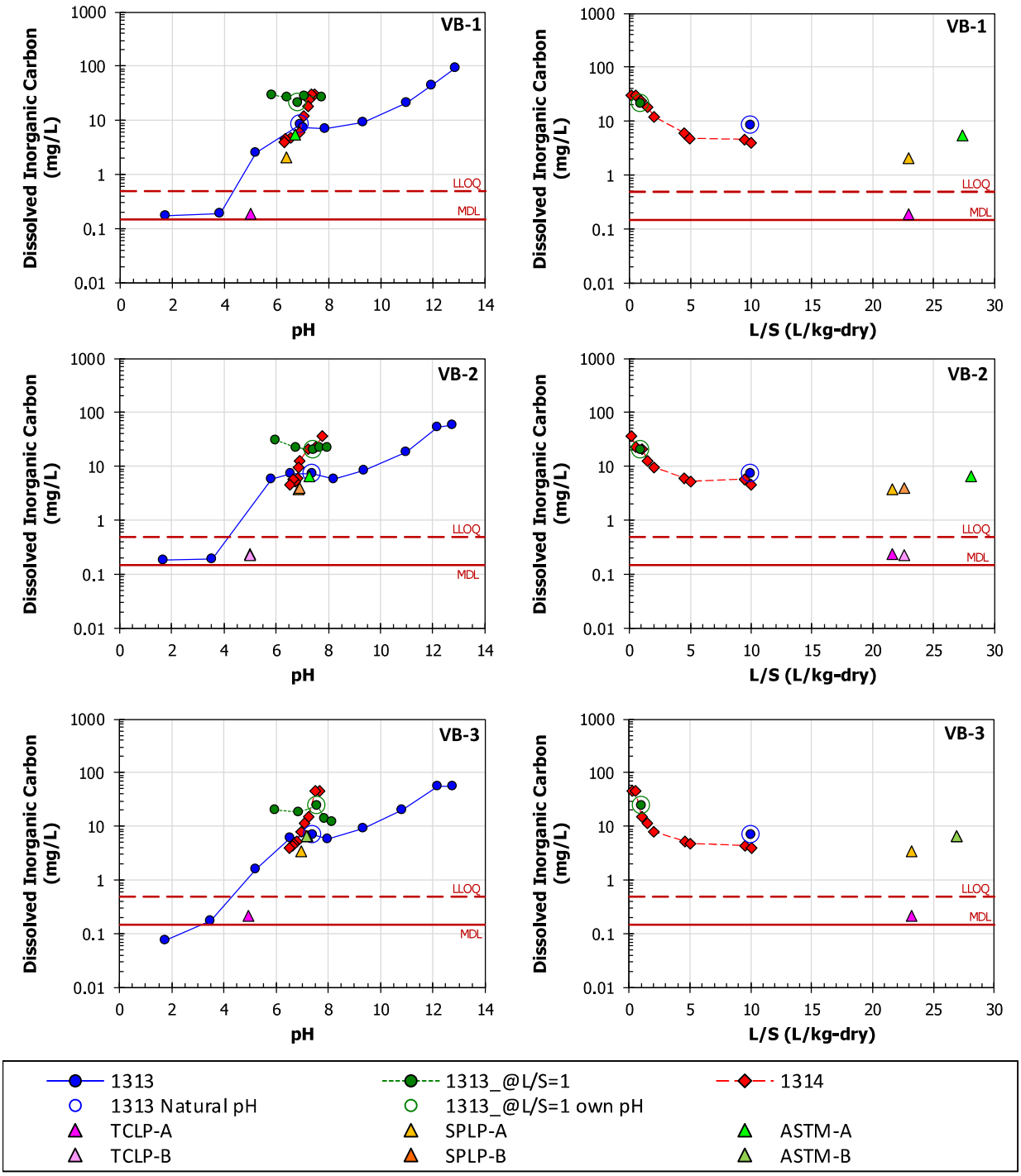

Figure E-14
Dissolved inorganic carbon concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

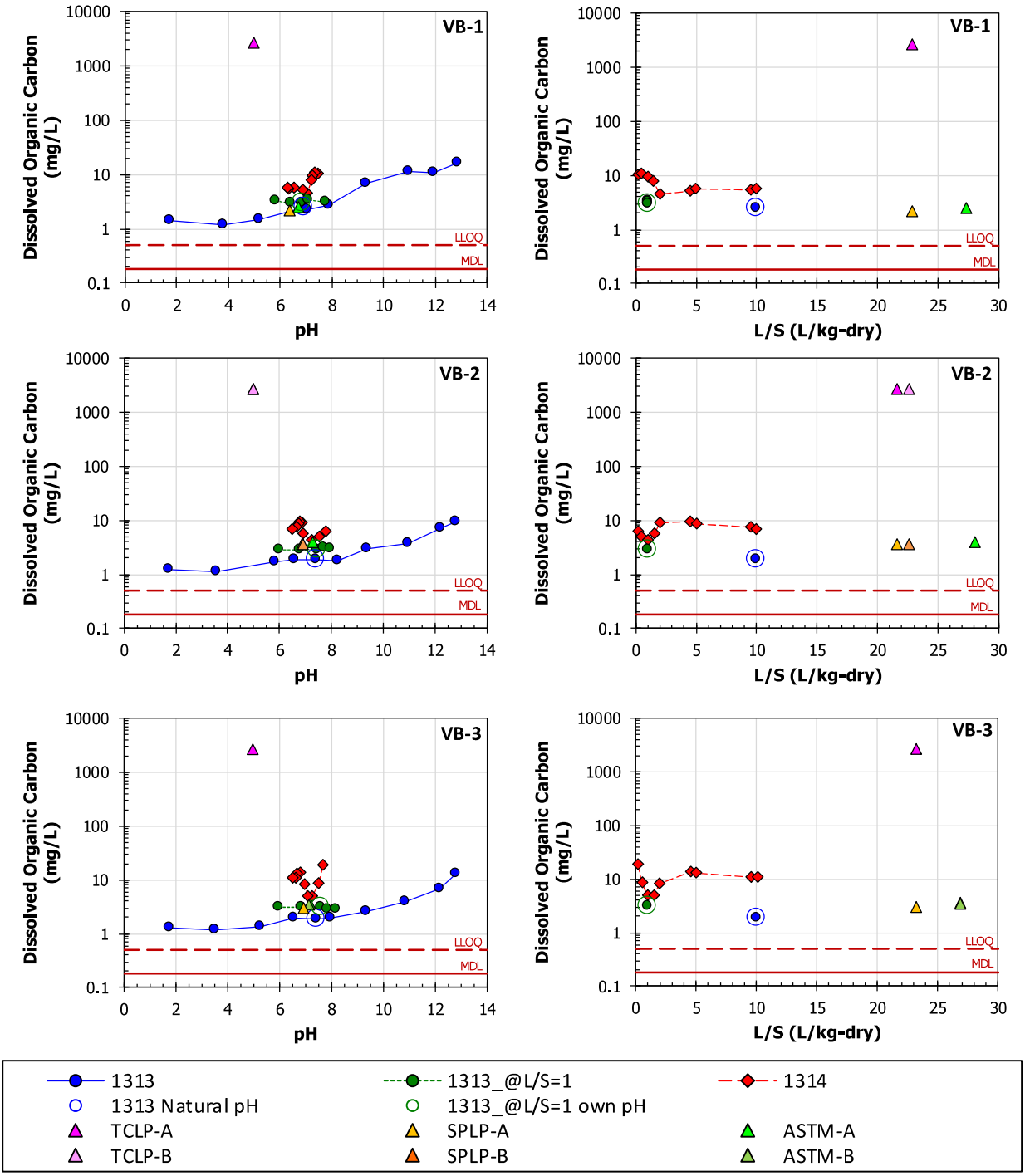

Figure E-15
Dissolved organic carbon concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

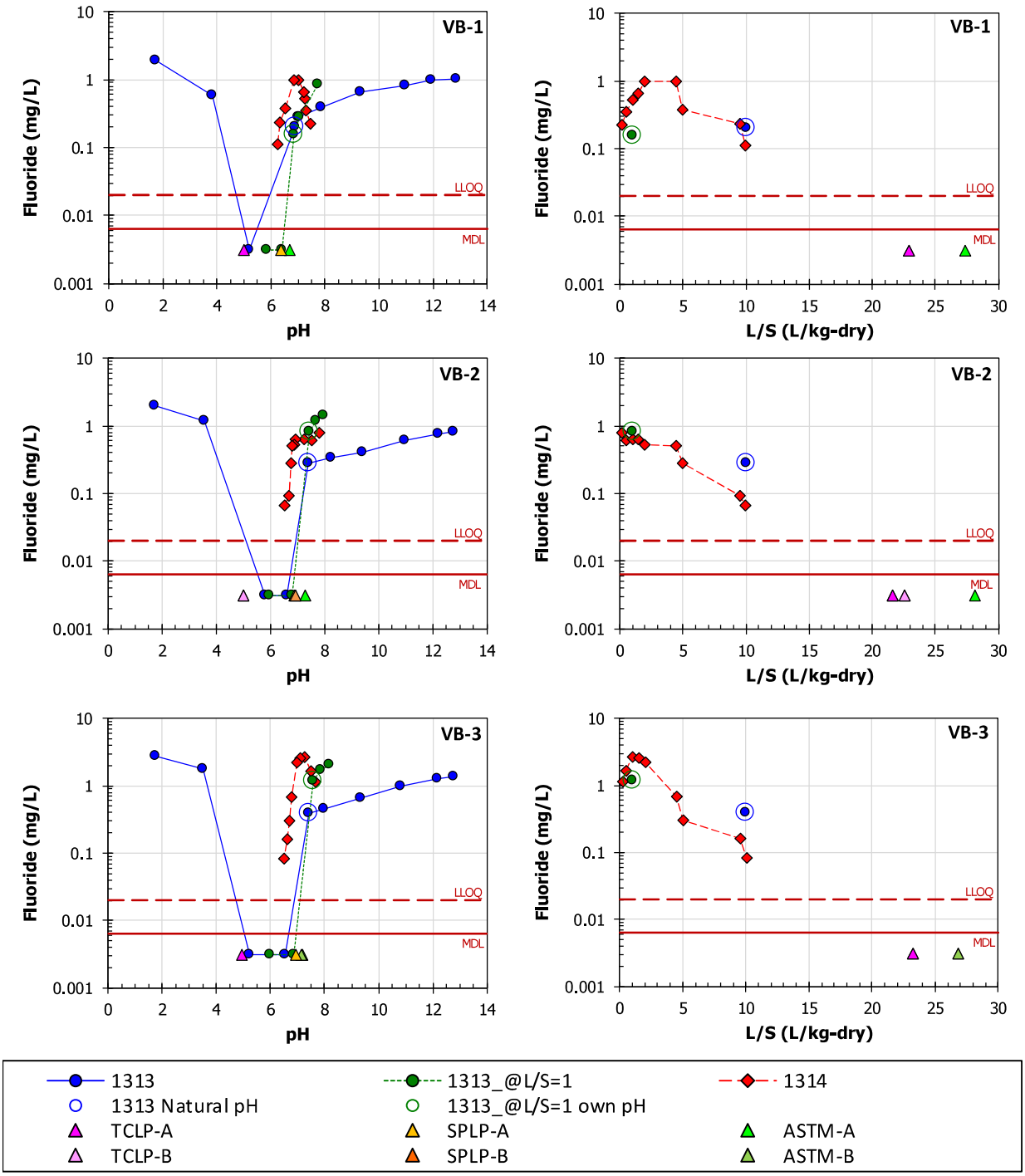

Figure E-16
Flouride concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

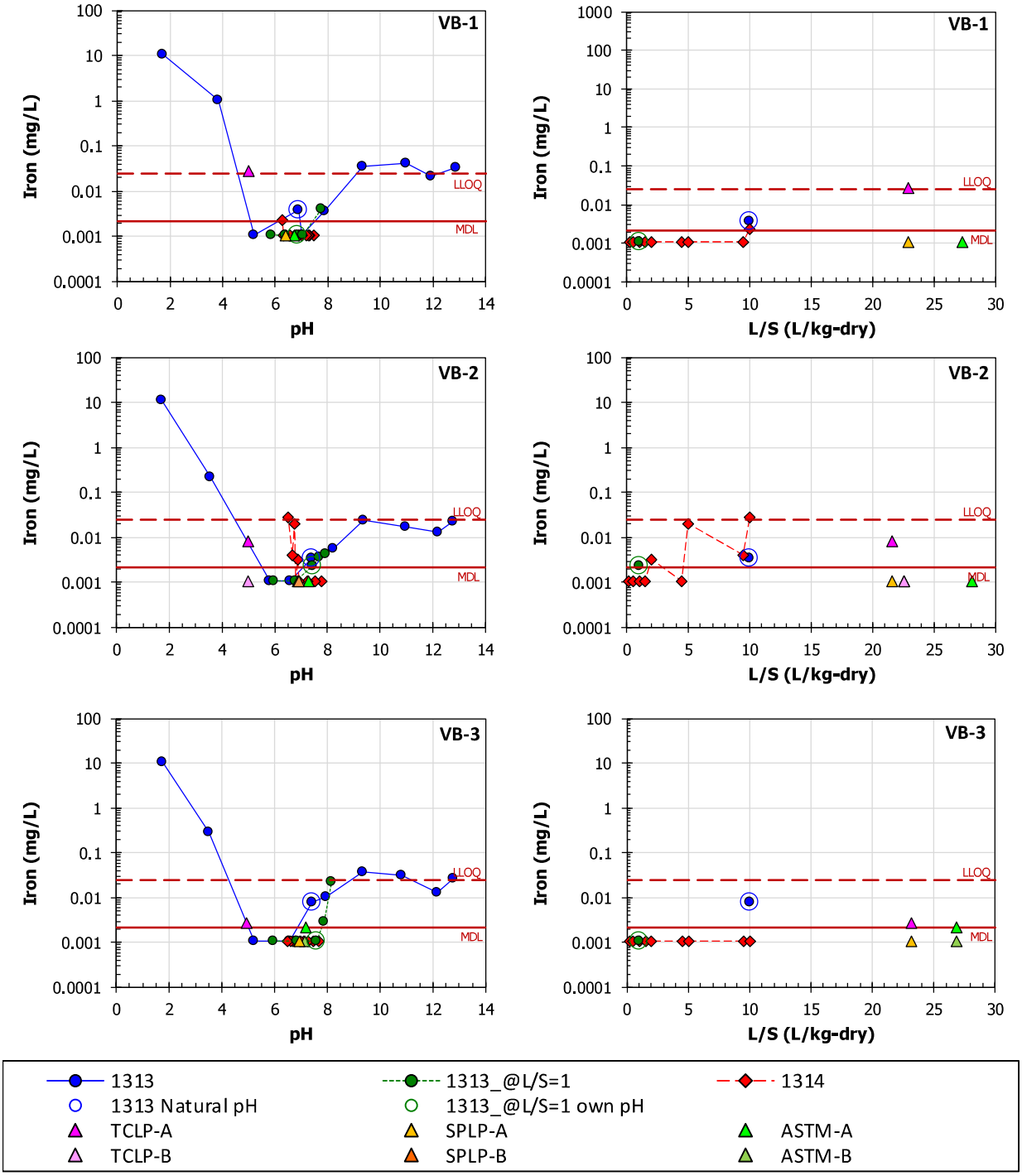

Figure E-17
Iron concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

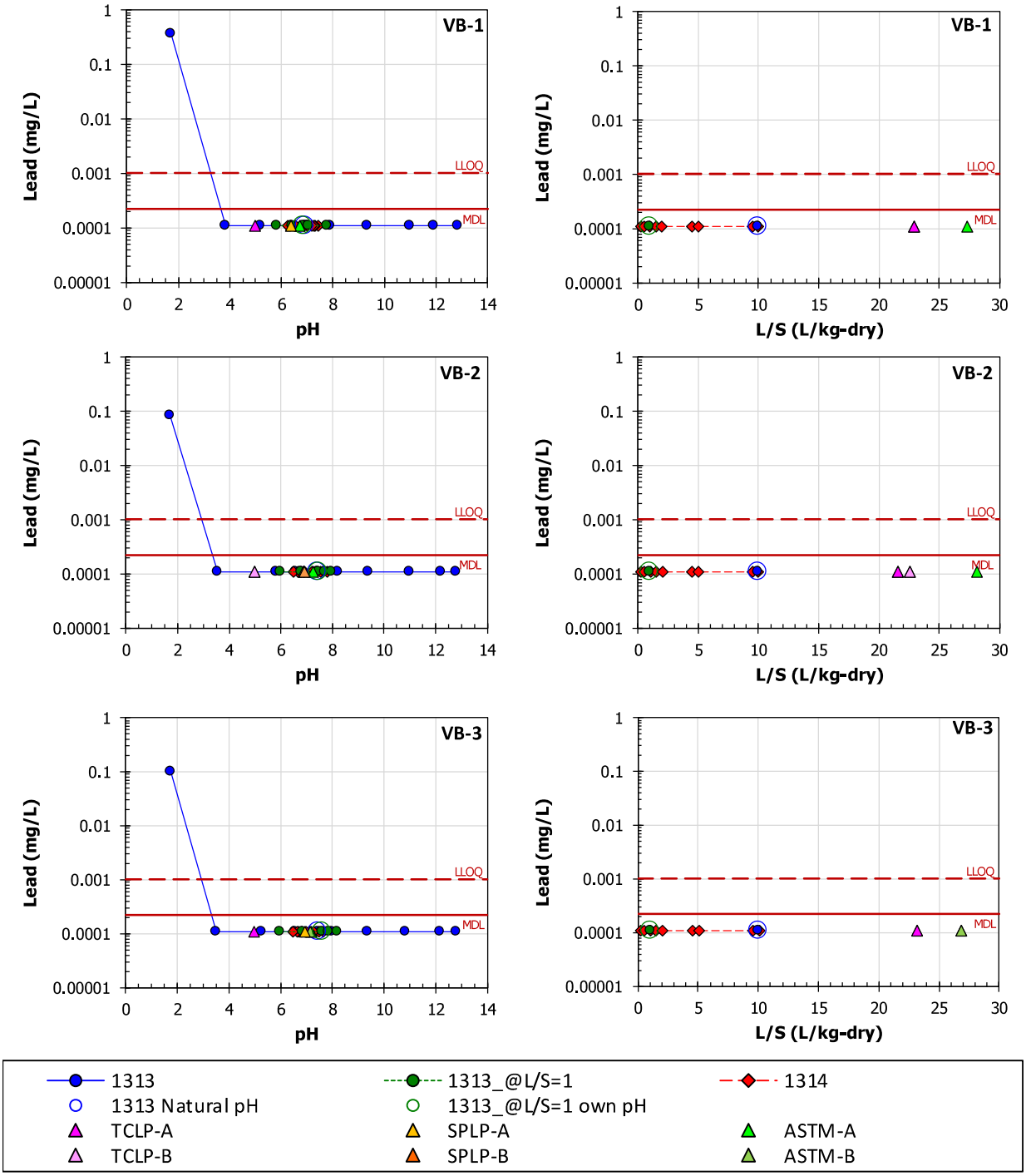

Figure E-18
Lead concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

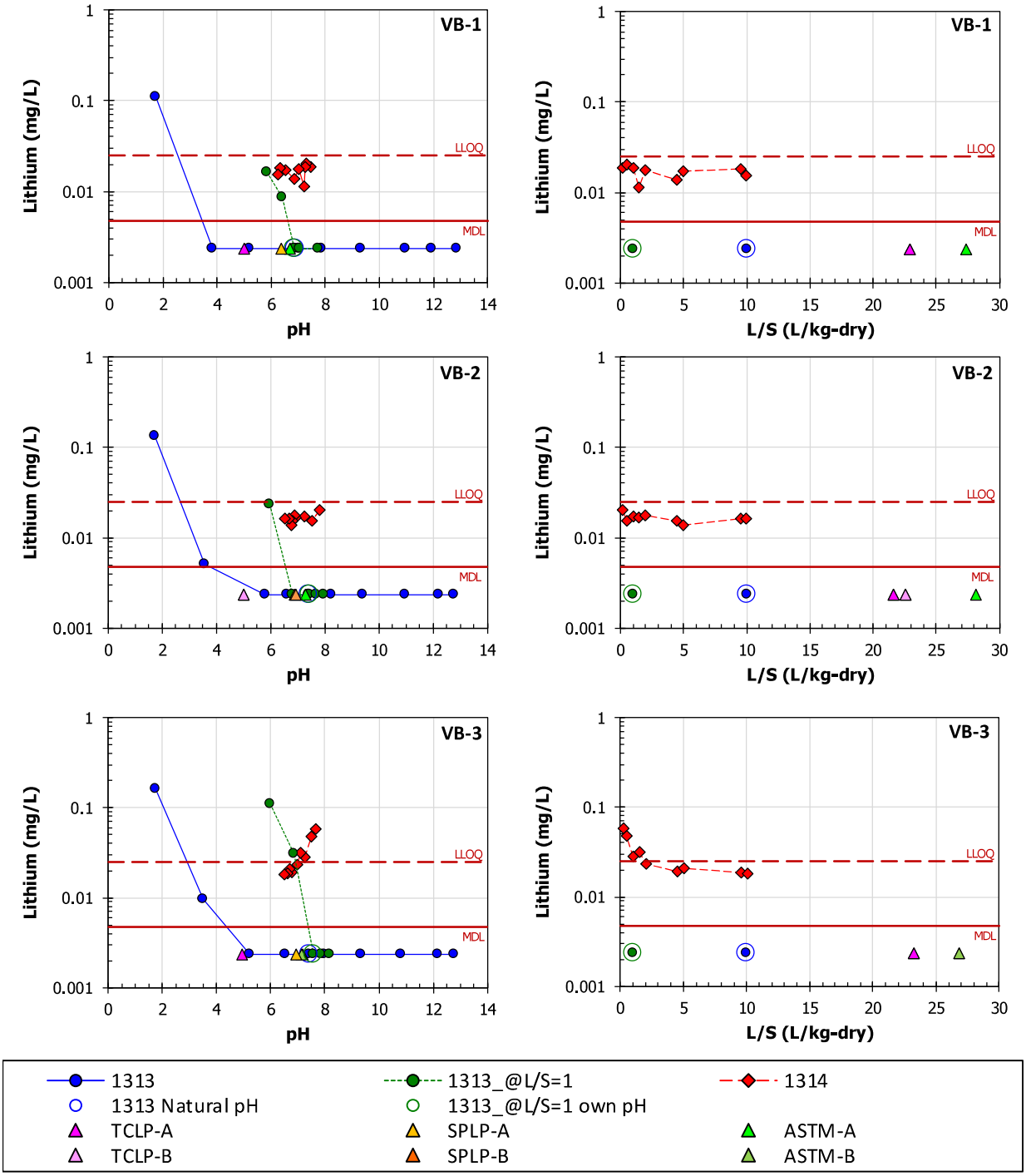

Figure E-19
Lithium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

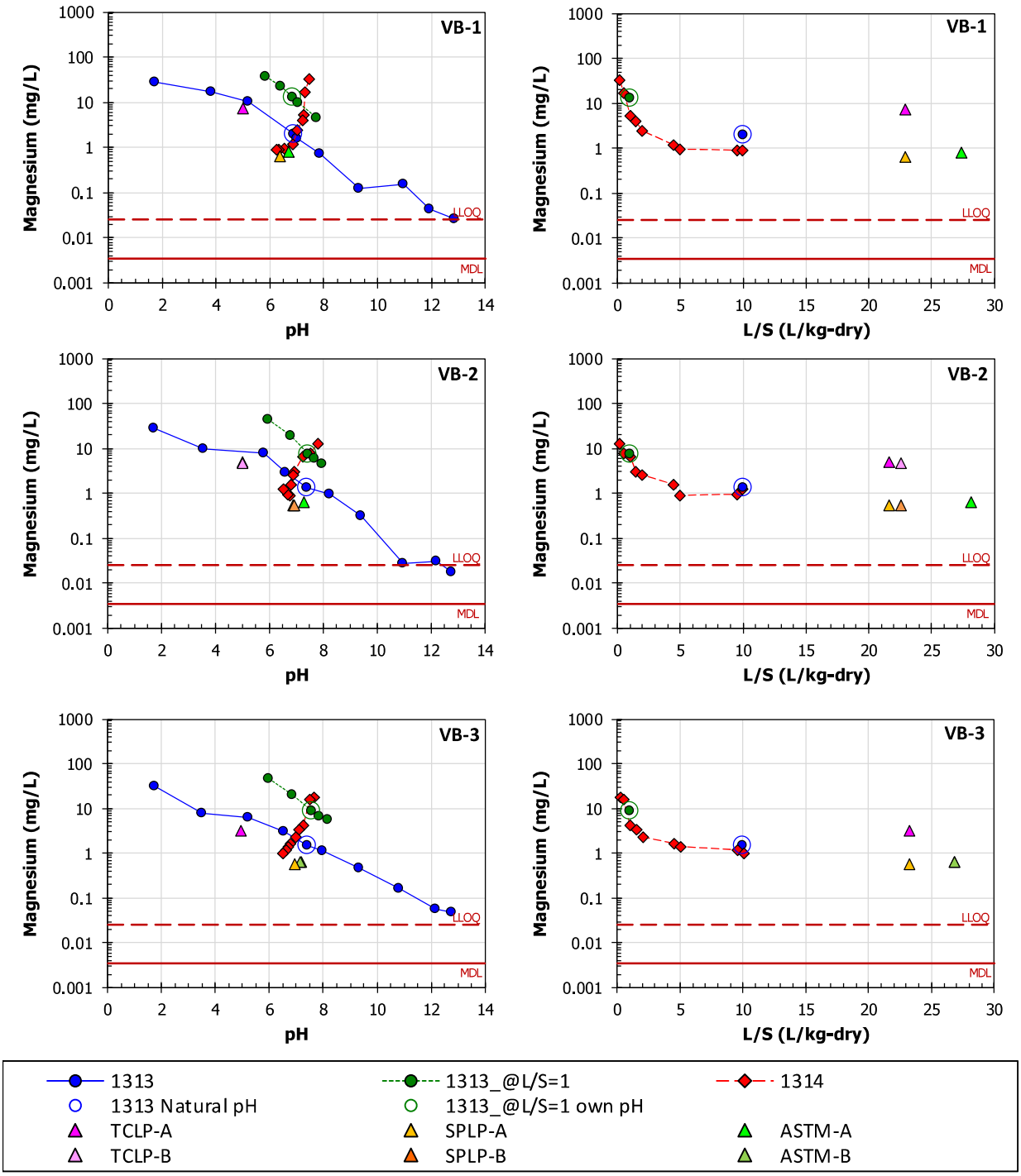

Figure E-20
Magnesium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

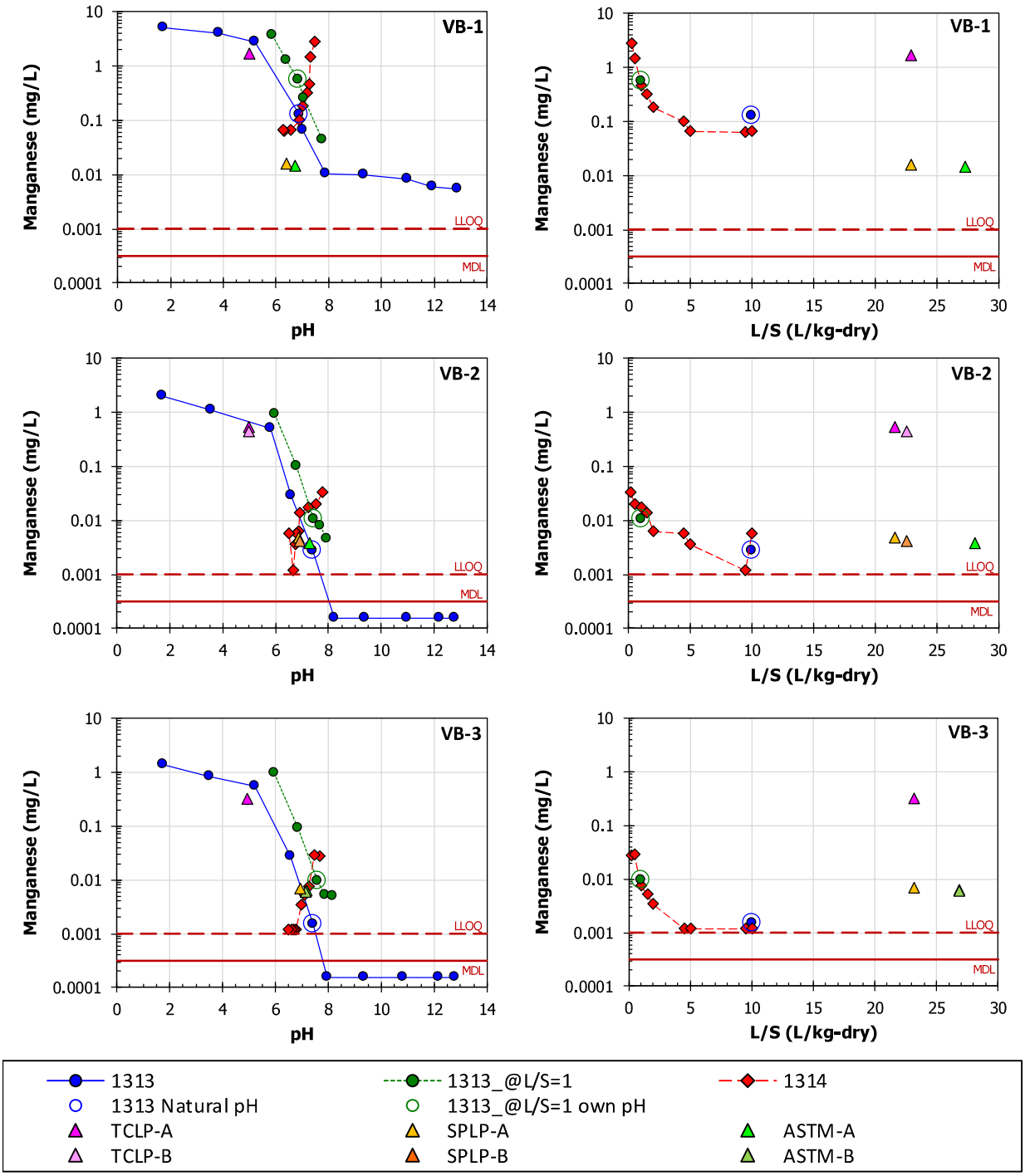

Figure E-21
Manganese concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

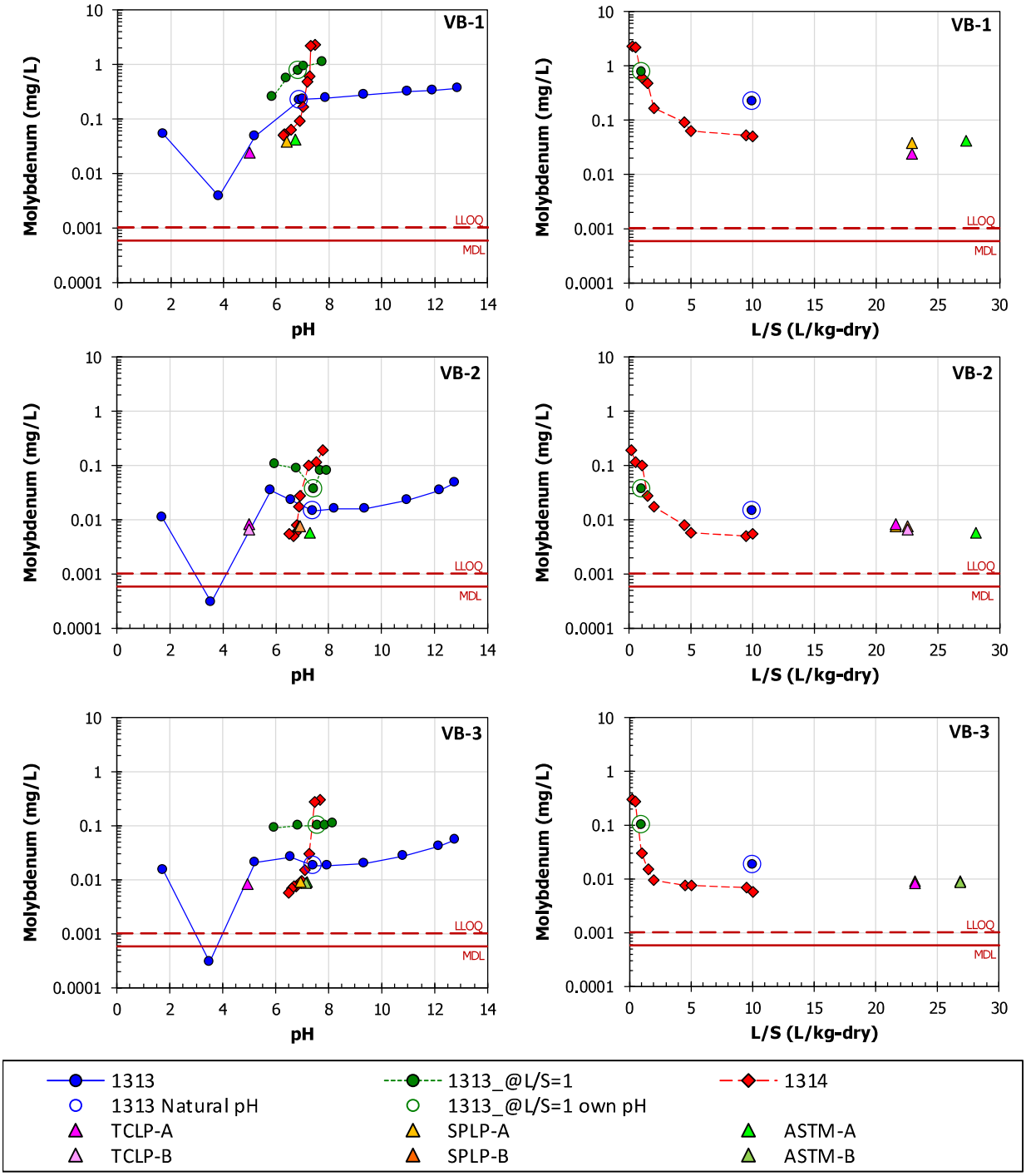

Figure E-22
Molybdenum concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

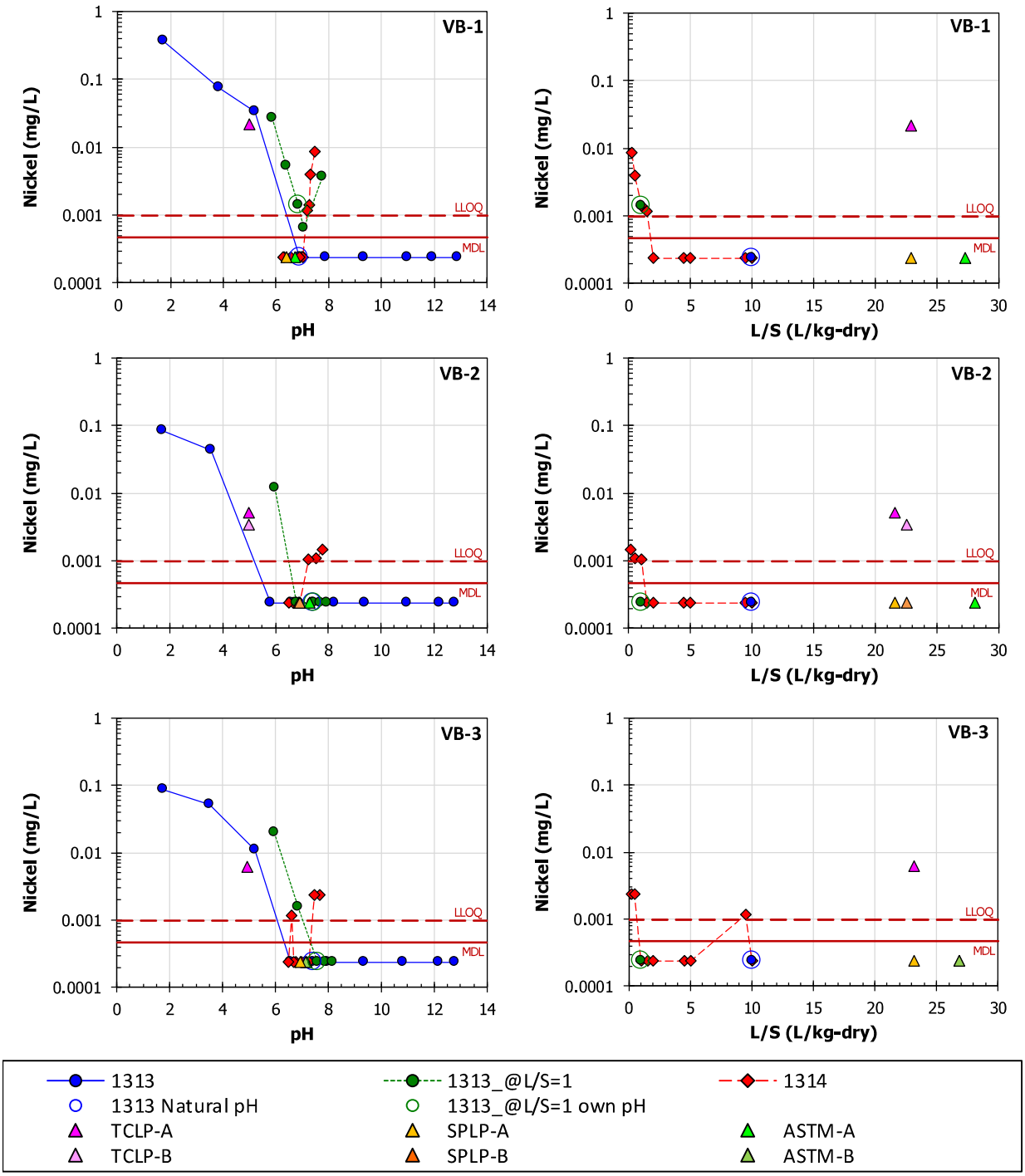

Figure E-23
Nickel concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

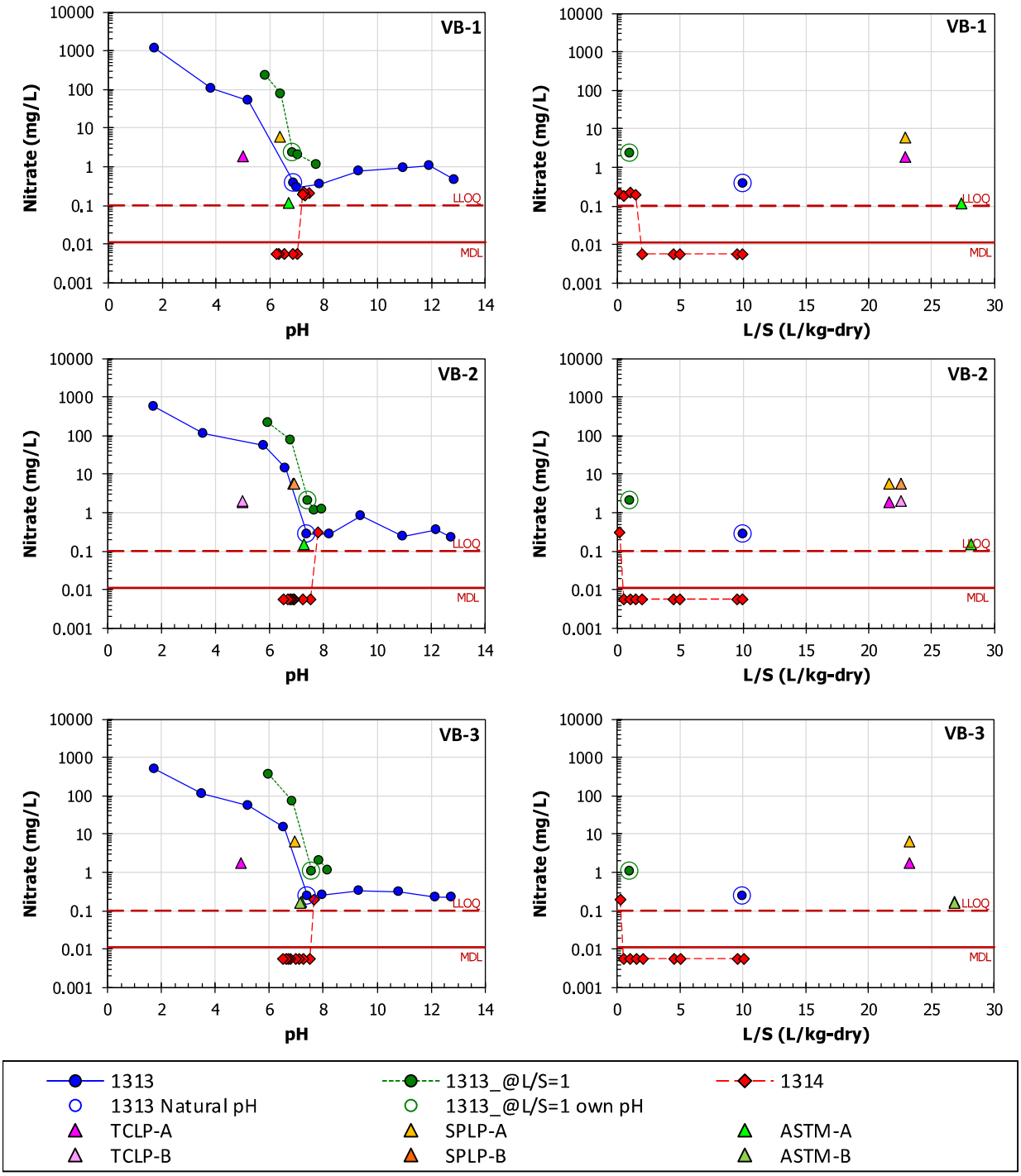

Figure E-24
Nitrate concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

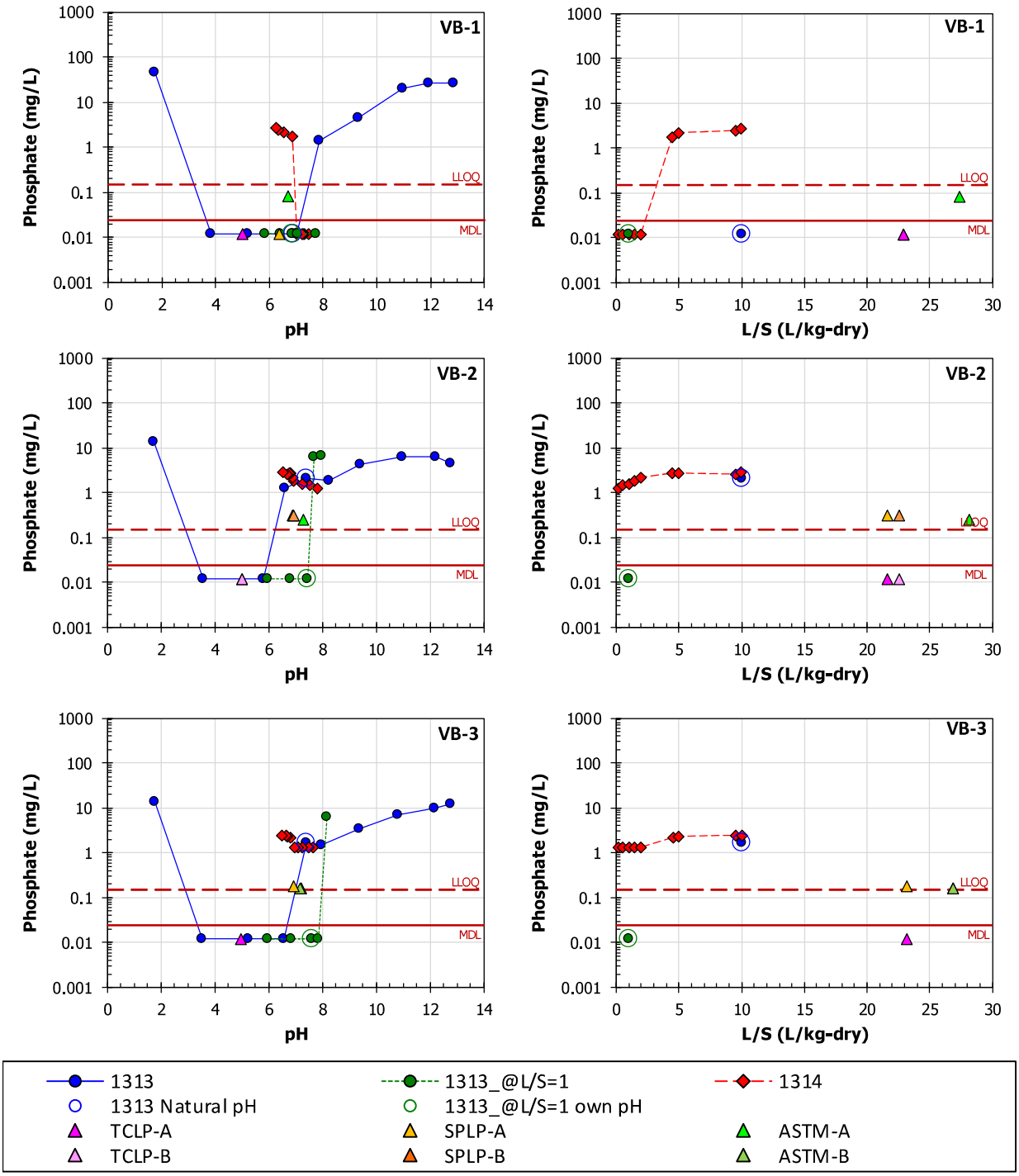

Figure E-25
Phosphate concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

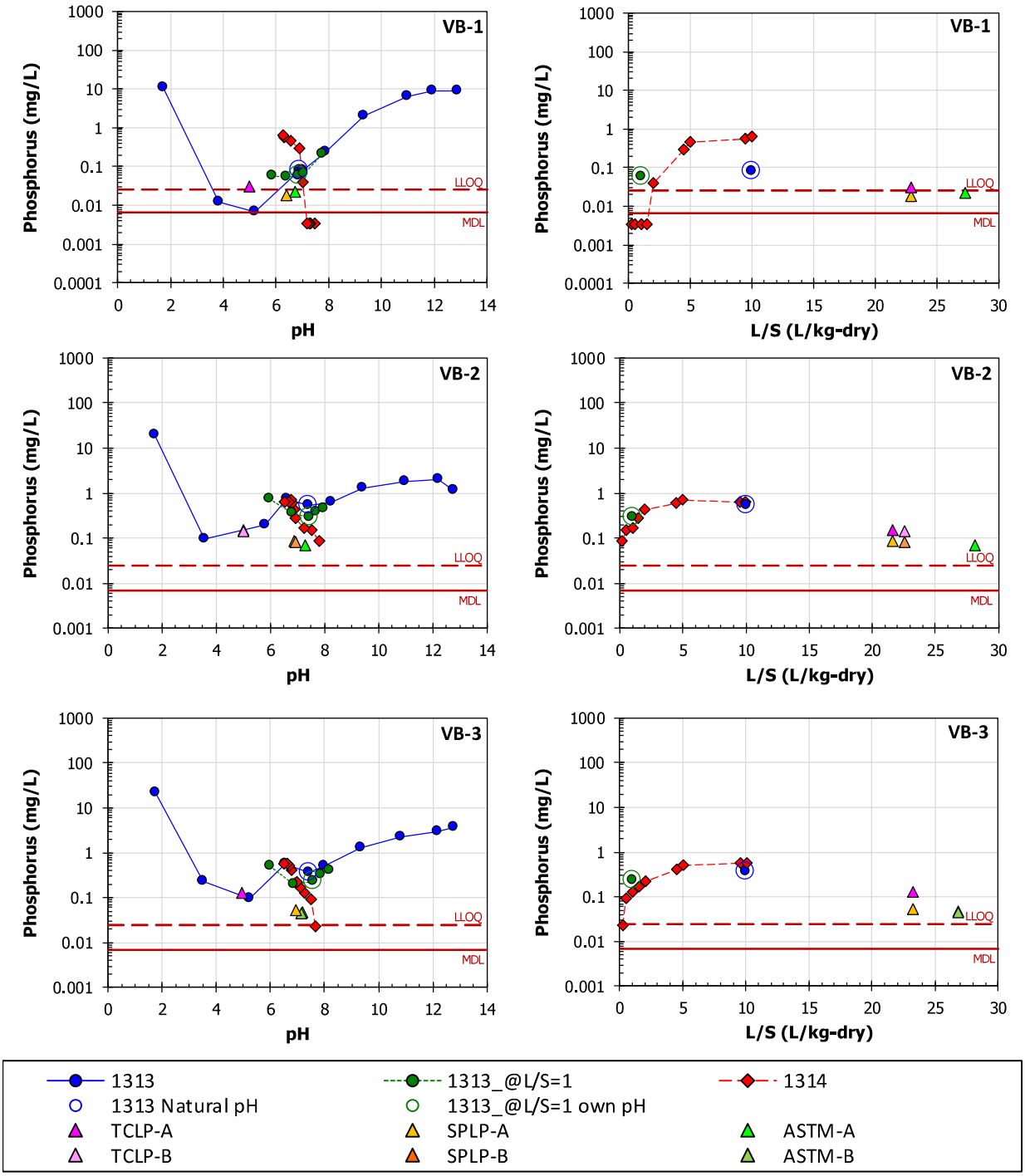

Figure E-26
Phosphorus concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

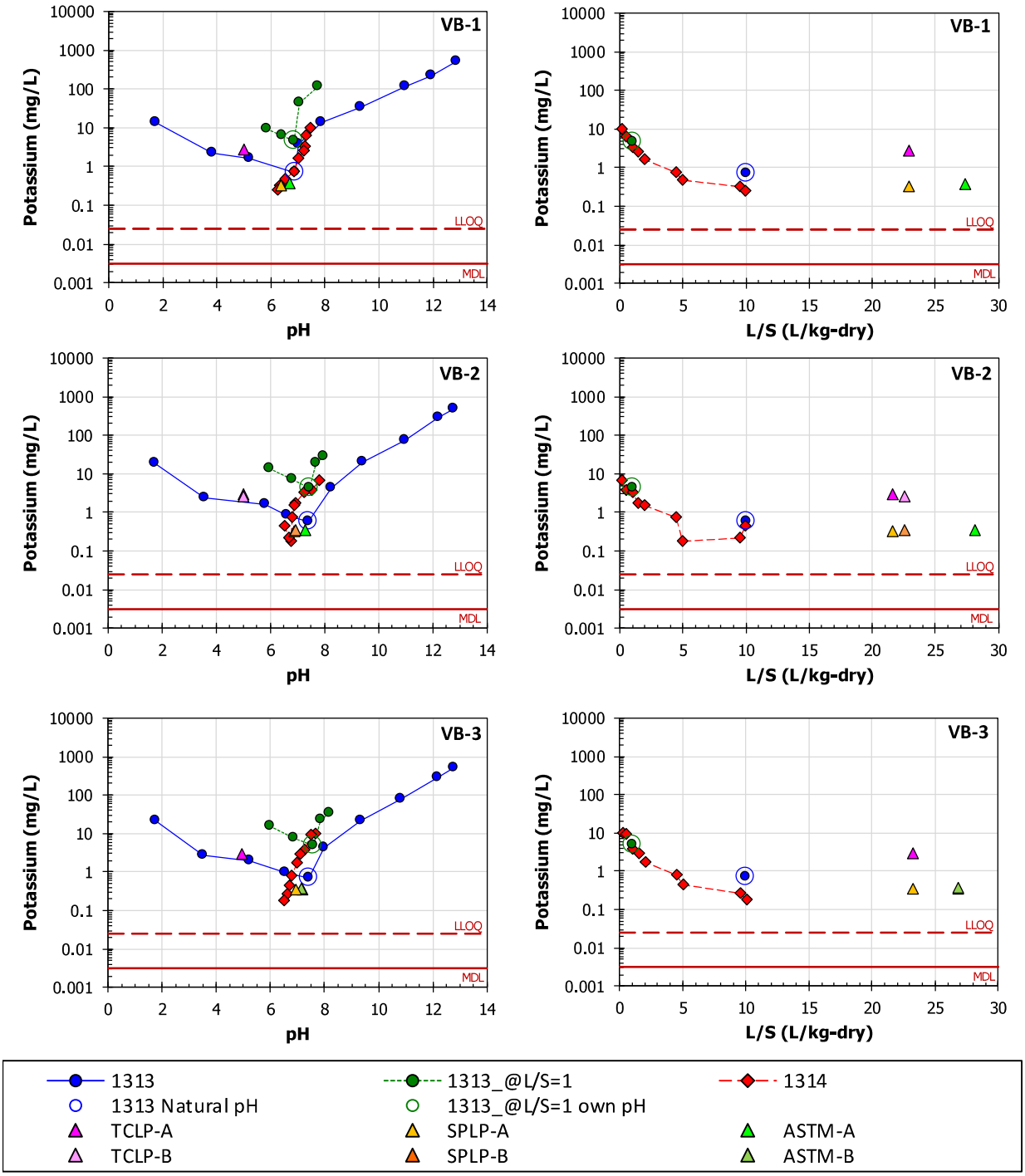

Figure E-27
Potassium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

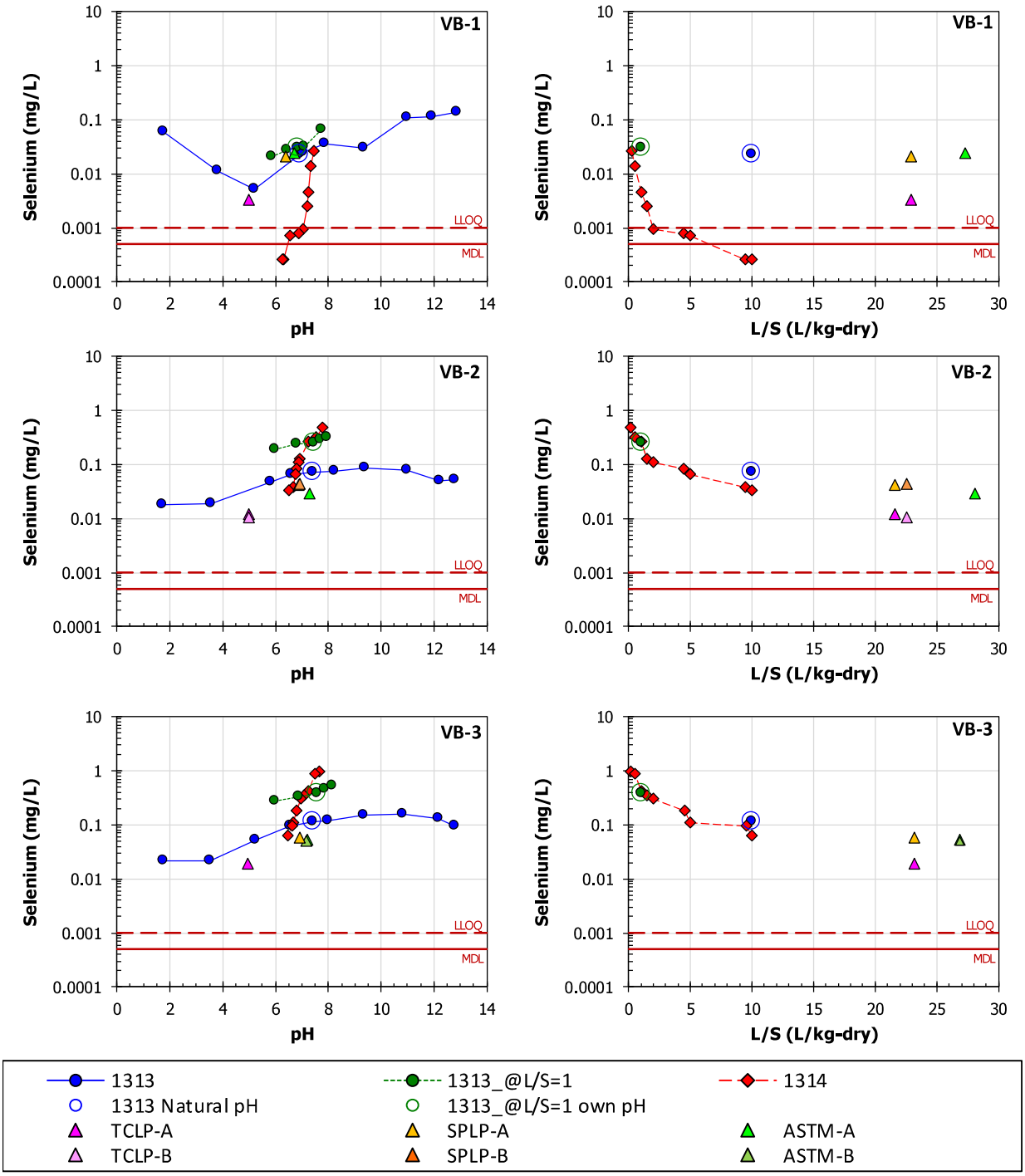

Figure E-28
Selenium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

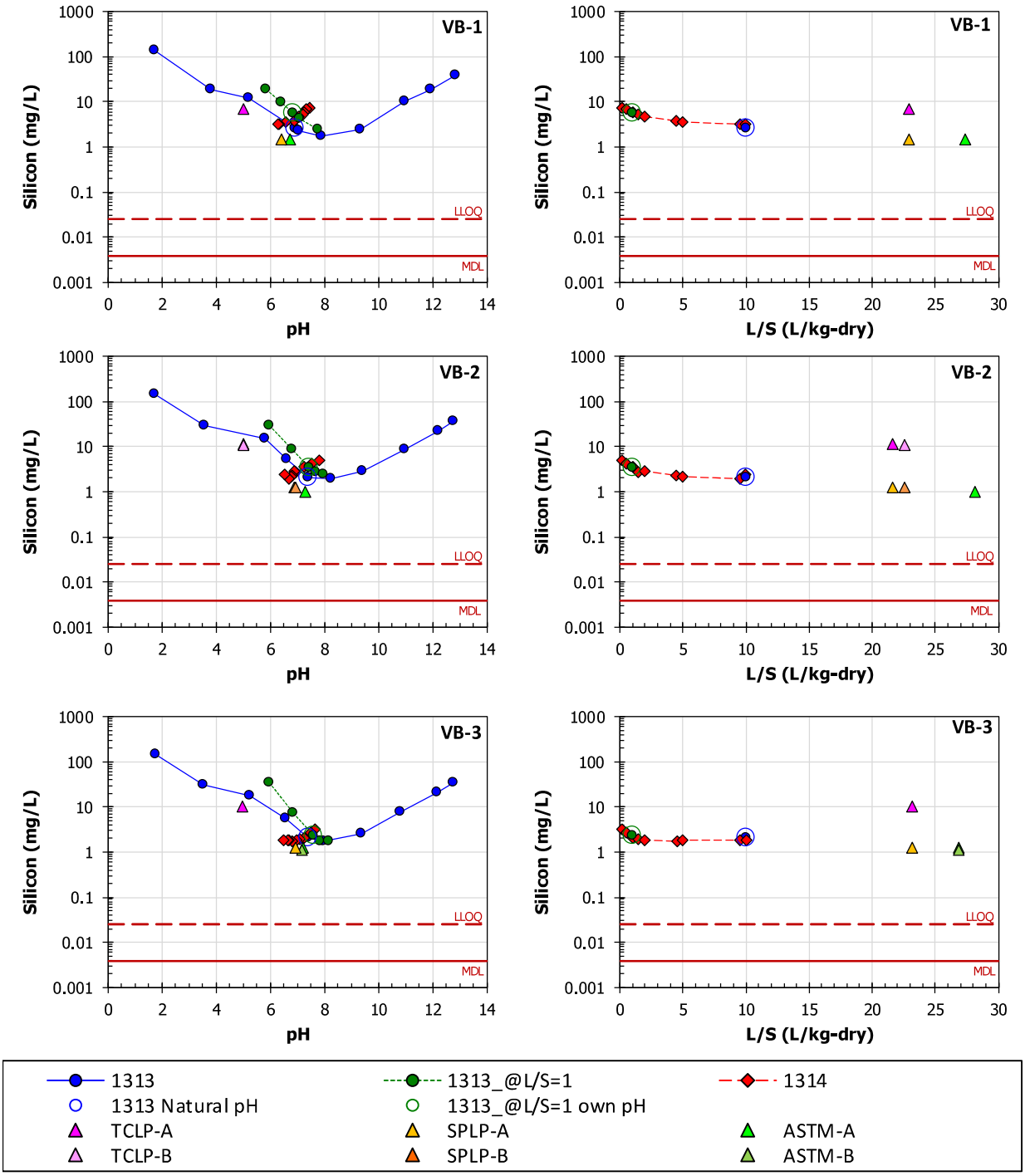

Figure E-29
Silicon concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

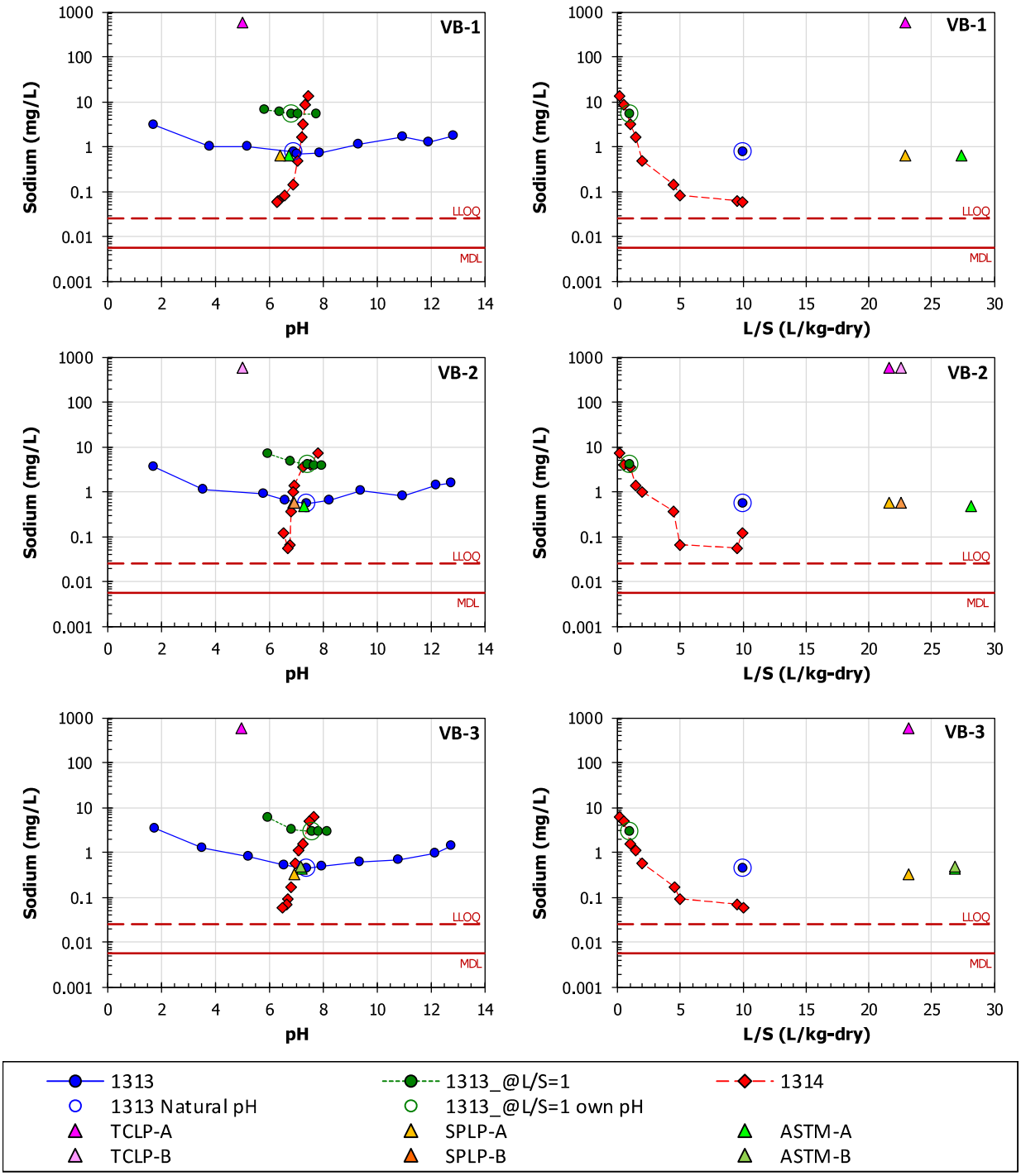

Figure E-30
Sodium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

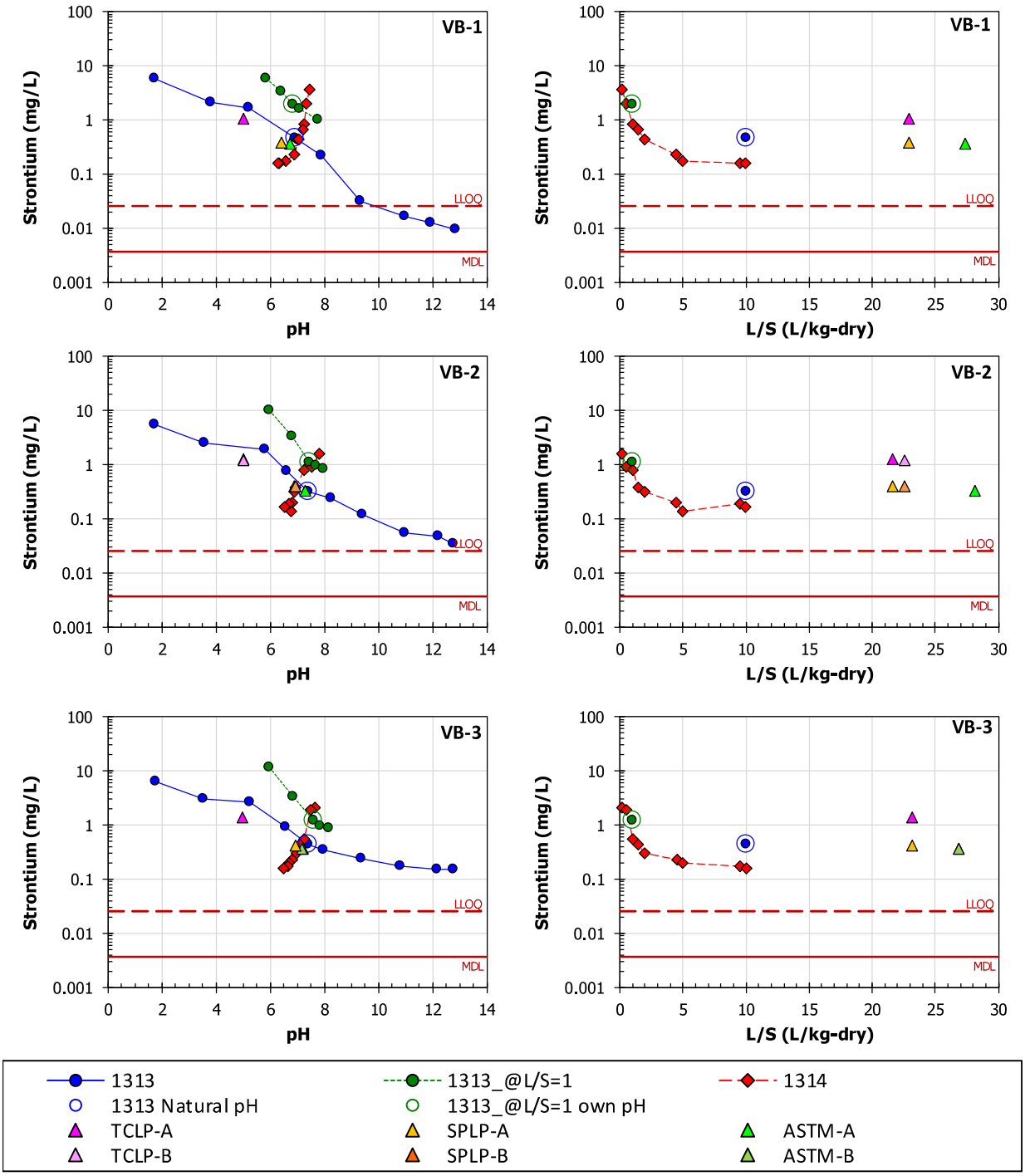

Figure E-31
Strontium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

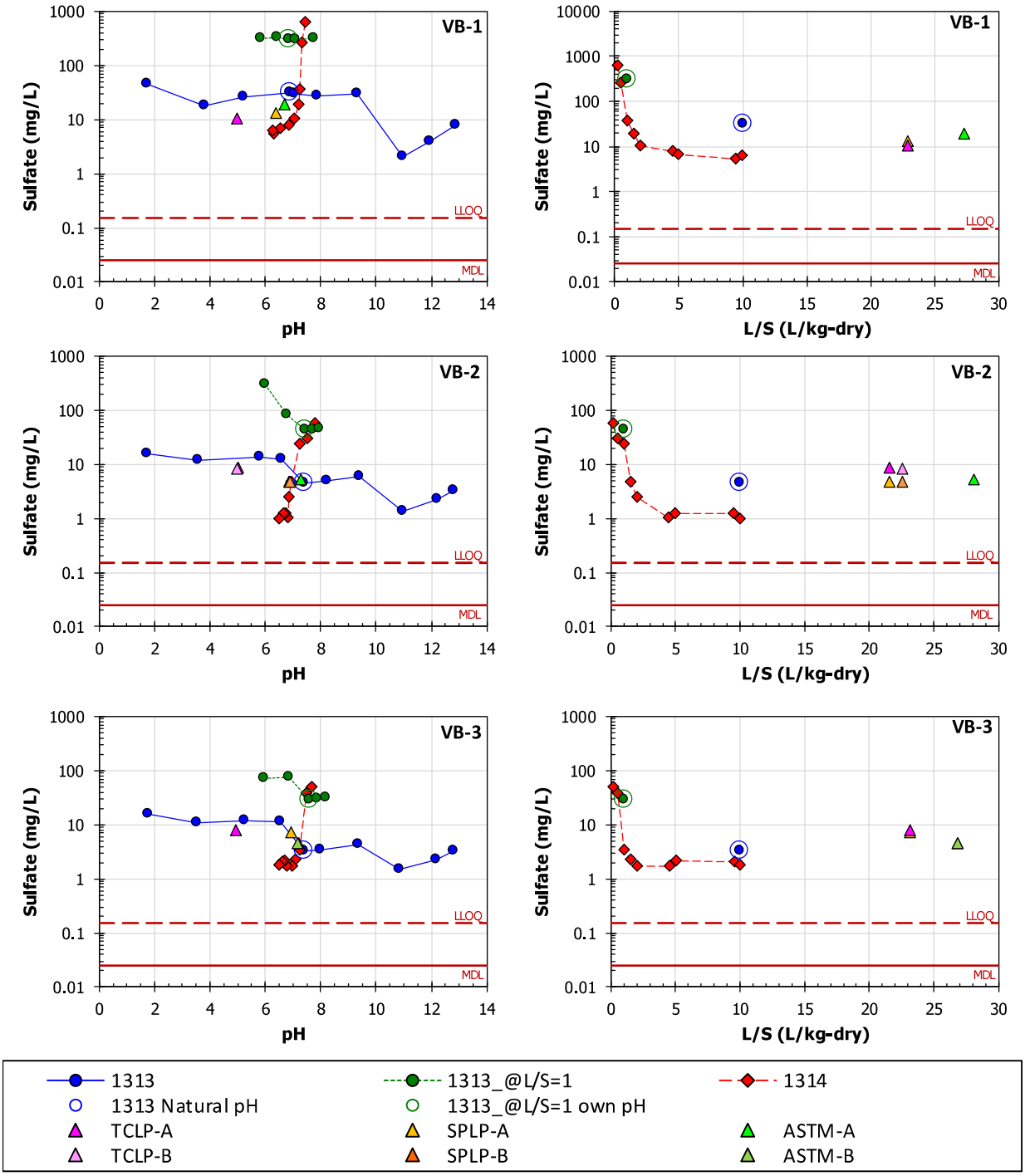

Figure E-32
Sulfate concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

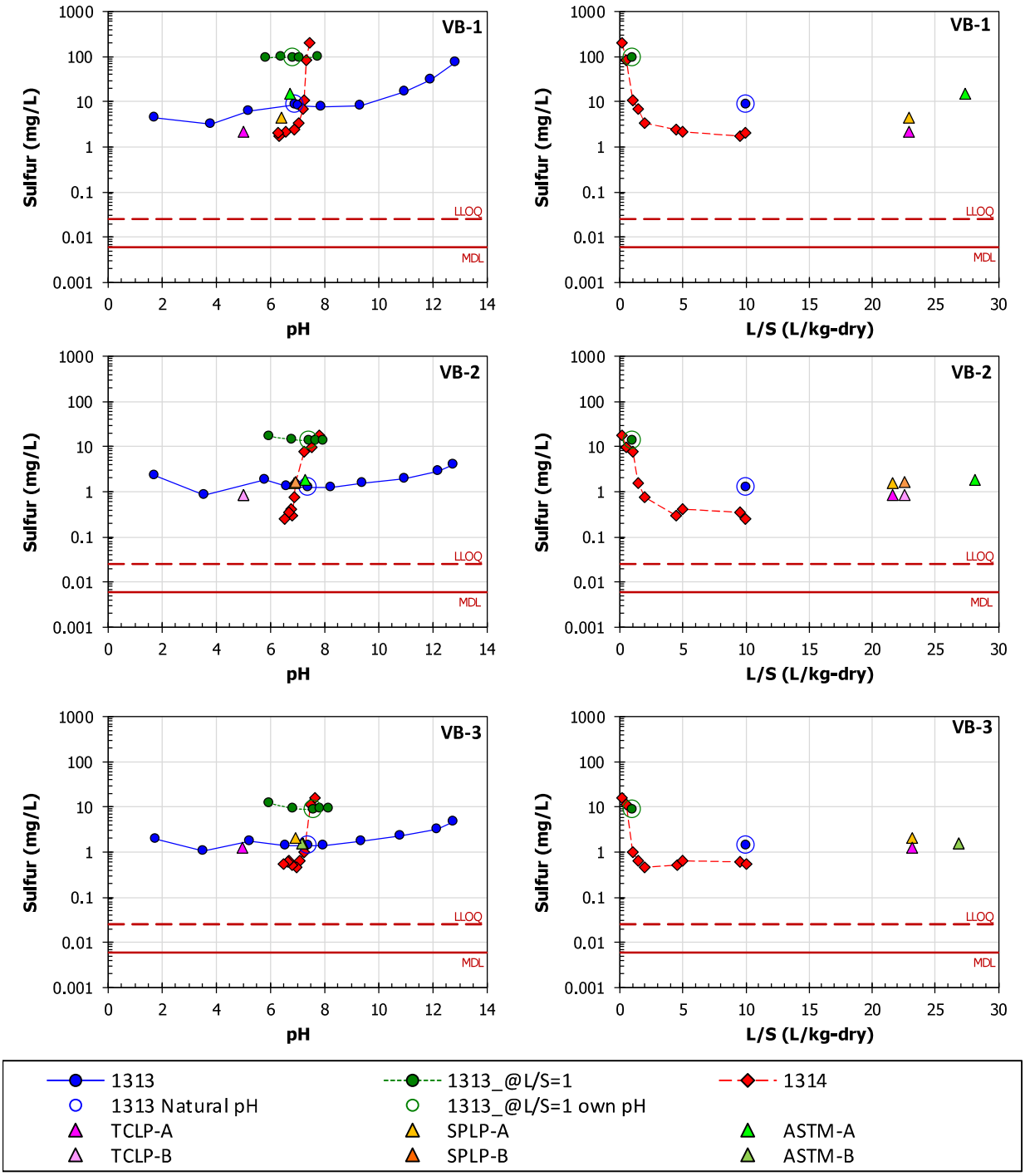

Figure E-33
Sulfur concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

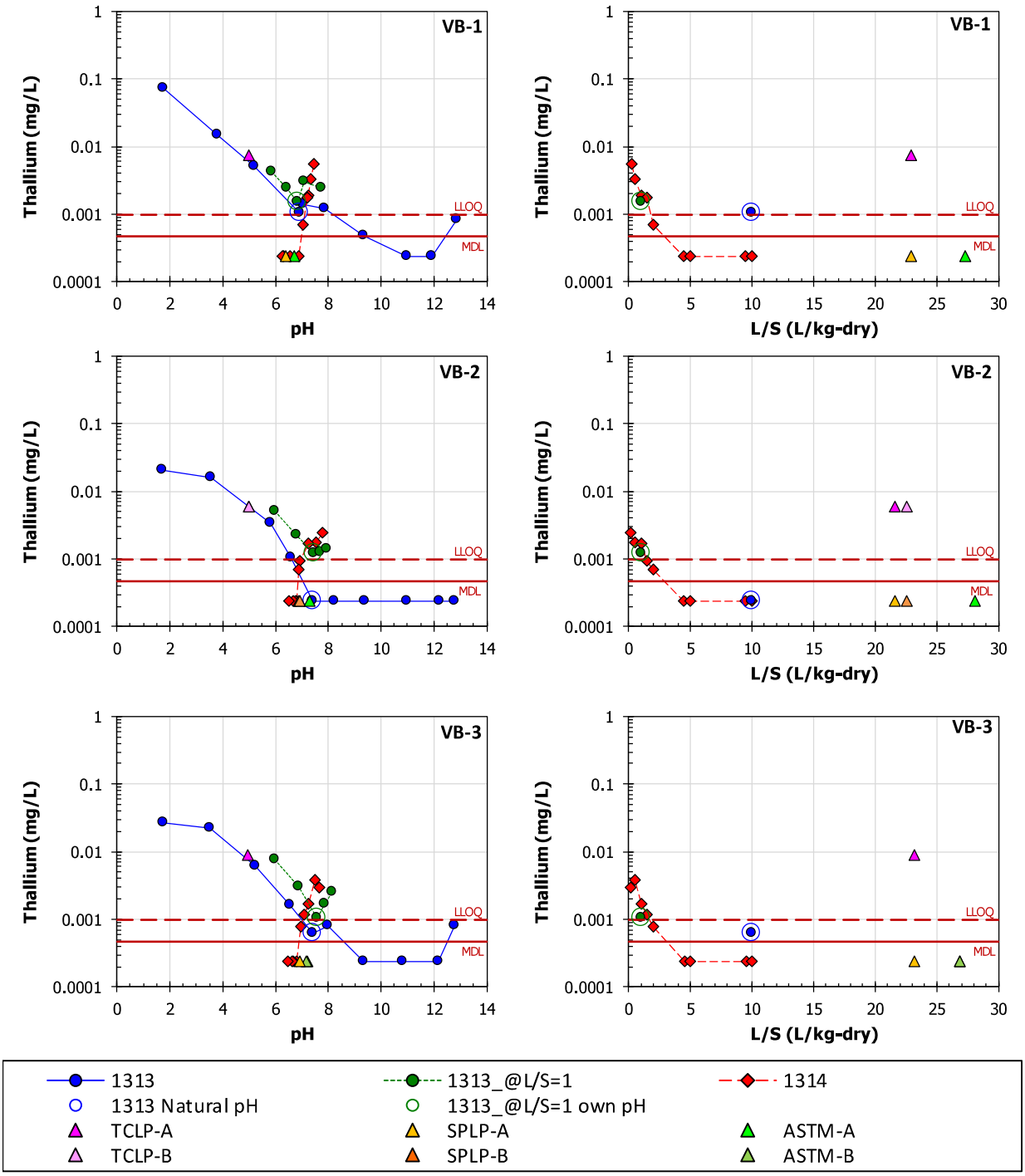

Figure E-34
Thallium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

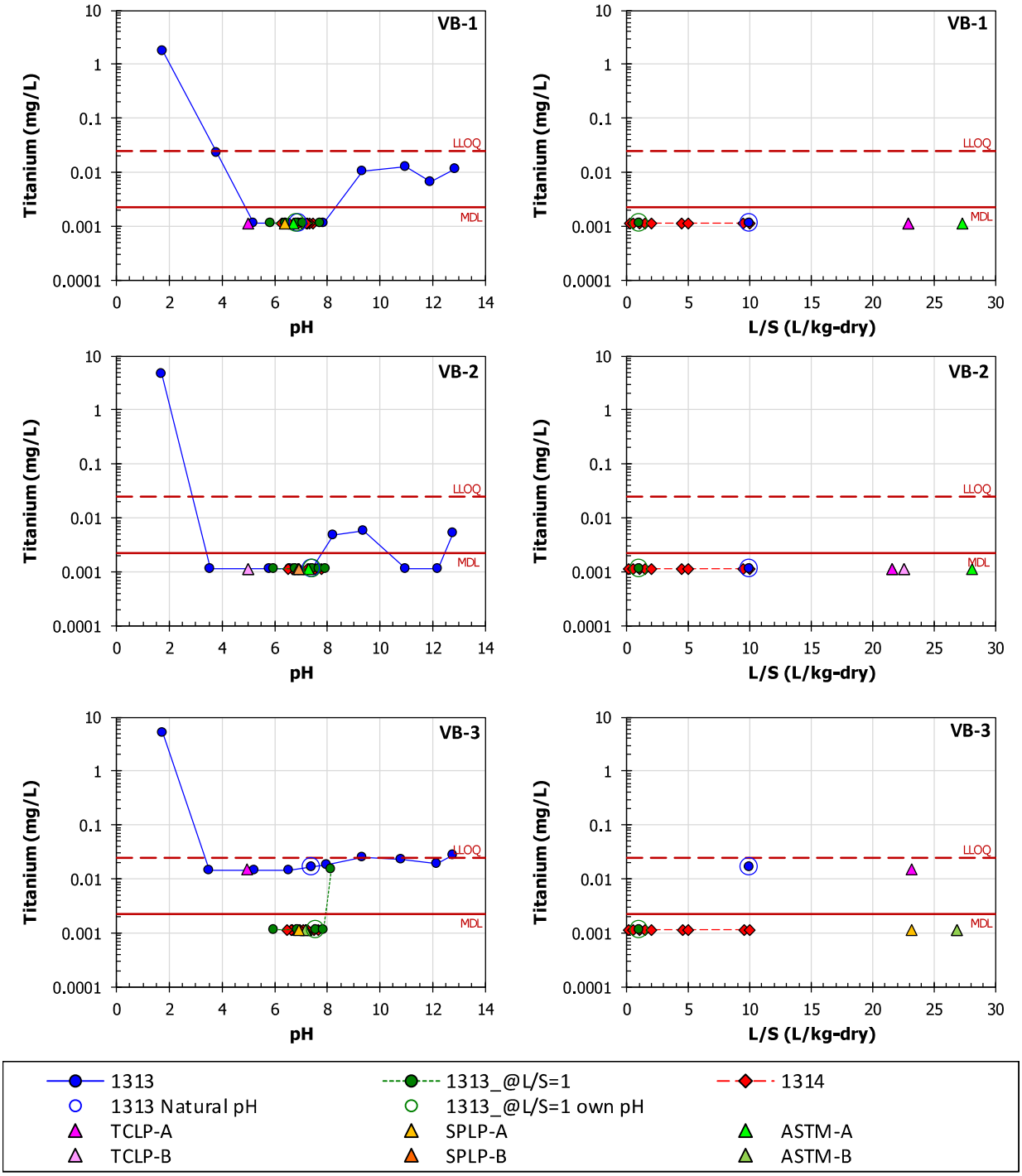

Figure E-35
Titanium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

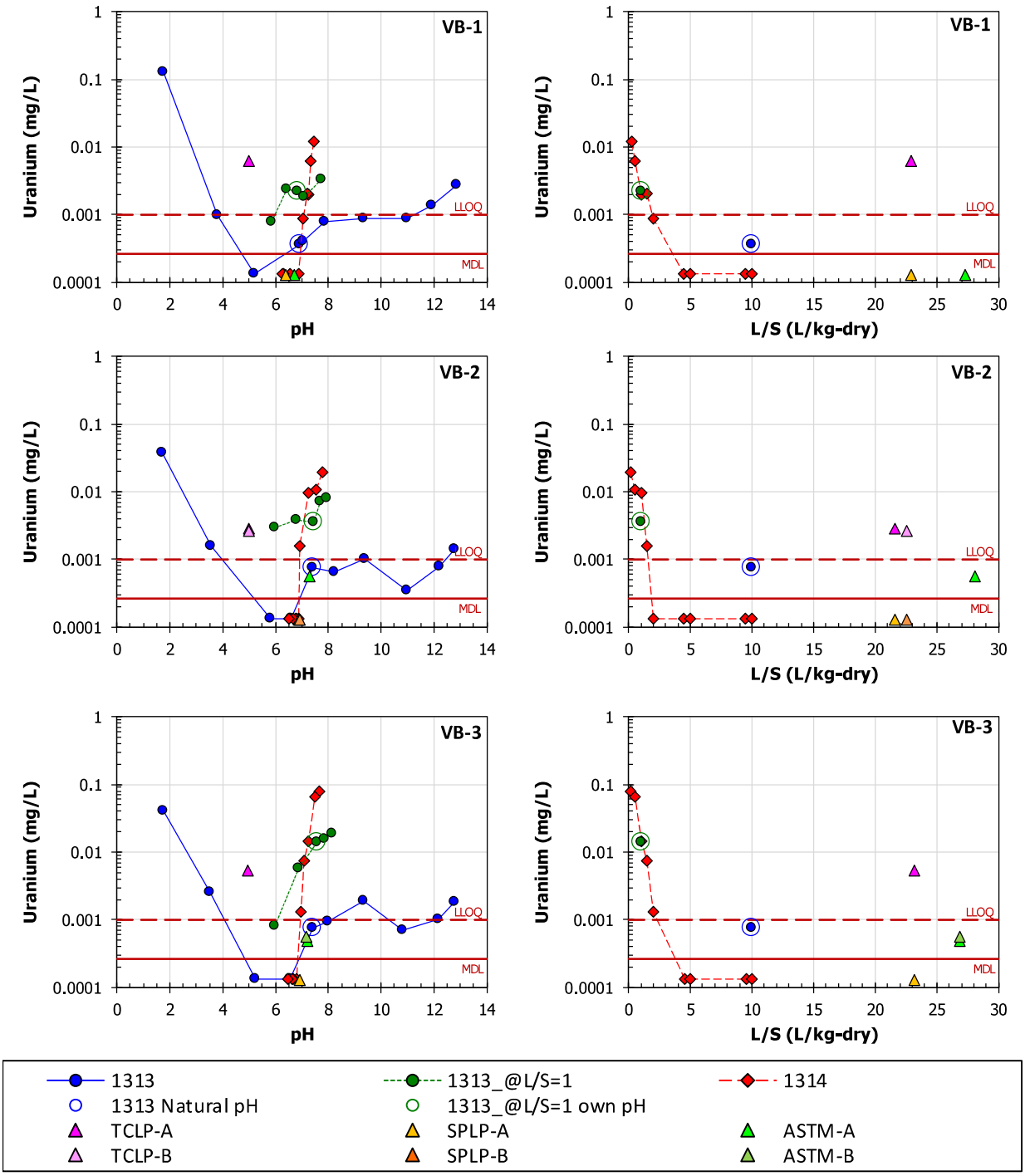

Figure E-36
Uranium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

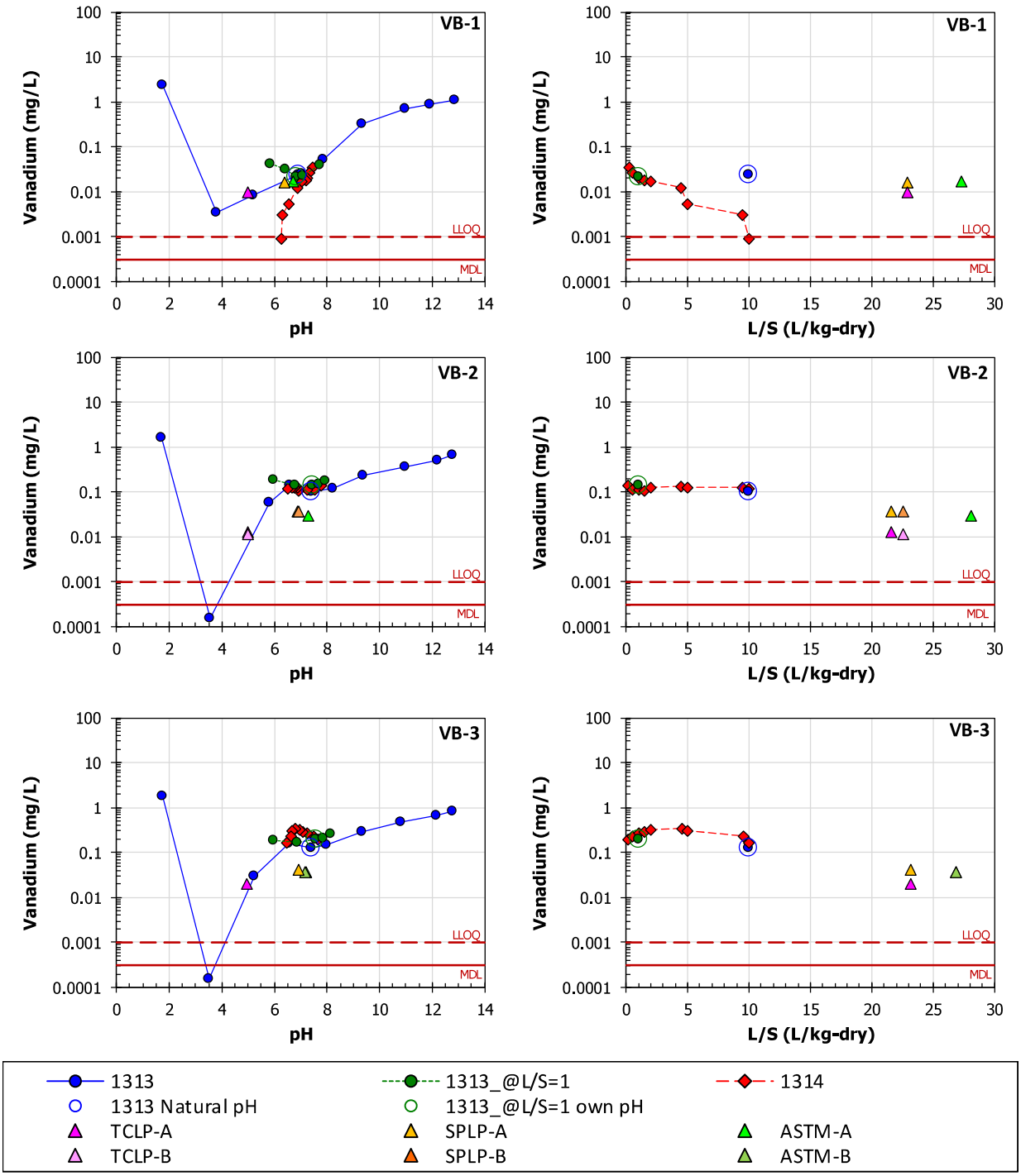

Figure E-37
Vanadium concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

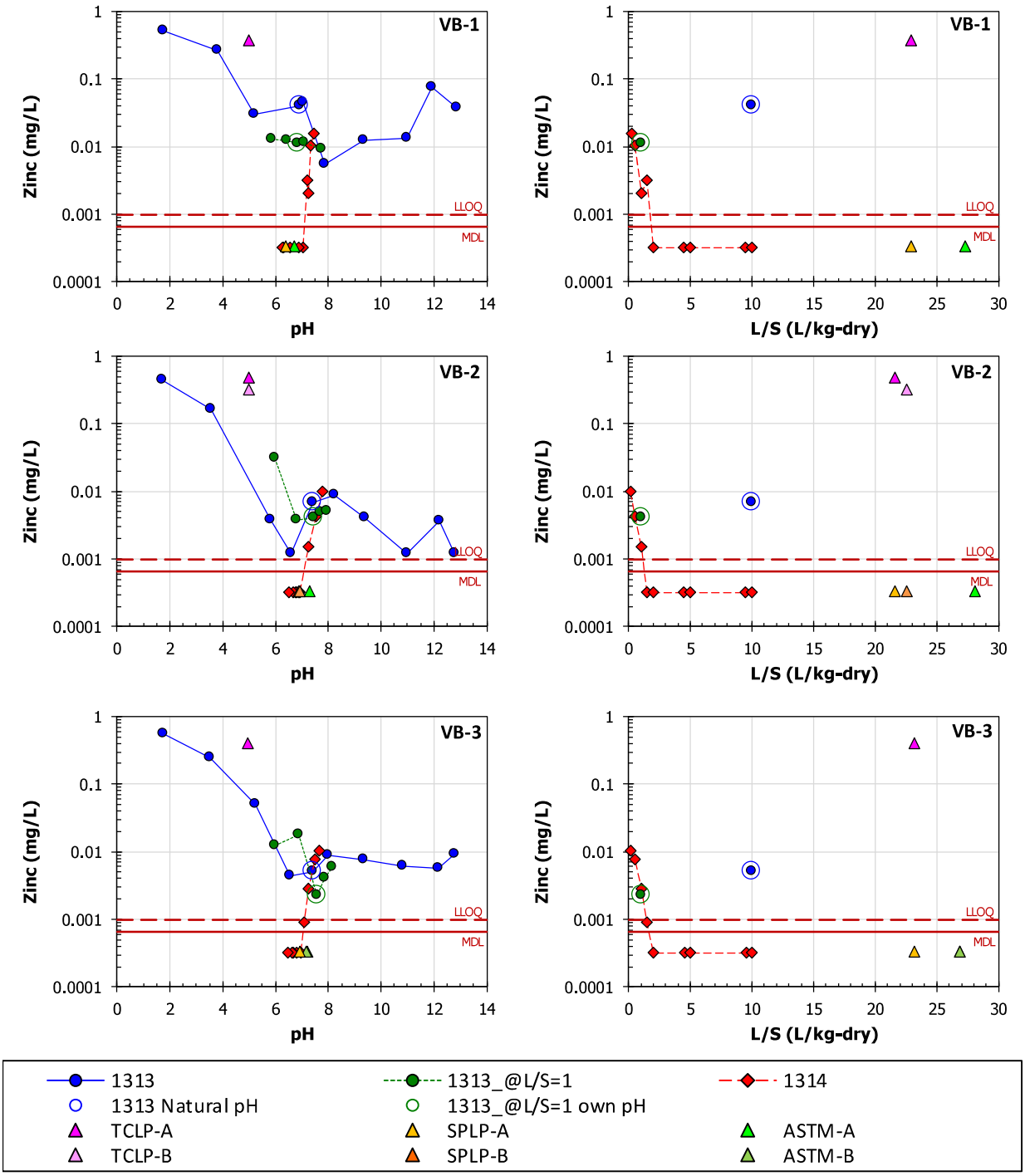

Figure E-38
Zinc concentrations from traditional leaching tests (TCLP, SPLP, and ASTM) compared to LEAF concentrations from composite samples VB-1, VB-2, and VB-3 shown as a function of pH (left) and L/S (right)

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F
GROUNDWATER AND POREWATER DATA

Table of Appendices

F.1 Groundwater and Porewater Field and Analytical Data

F.2 Time Series Graphs for Porewater Data

F.3 Subsurface Gas Parameter Tables and Graphs

F.1 Groundwater and Porewater Field Measurement Tables and Graphs

AD1 (upgradient background groundwater well)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/10	10/3	No Sample	12/12	1/14	2/11	3/12
Time at start	11:40	8:40	-	9:35	10:10	10:05	9:50
Water Table AMSL (ft)	770.4	773.3	-	774.3	773.5	774.2	775.2
Temperature (°C)	18.6	18.1	-	11.7	10.7	11.7	13.0
pH (s.u.)	8.72	8.63	-	8.60	8.71	8.57	8.33
DO (mg/L)	2.02	2.56	-	2.78	3.34	2.63	3.22
EC (mS/cm)	0.423	0.443	-	0.424	0.412	0.426	0.434
ORP (mV)	362	214	-	238	291	277	270
Turbidity (NTU)	3.39	1.73	-	2.68	1.46	1.55	1.44
Time at end	12:30	8:50	-	11:37	10:21	10:19	11:18

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22				
Time at start	10:05	10:05				
Water Table AMSL (ft)	774.3	771.9				
Temperature (°C)	15.6	17.86				
pH (s.u.)	8.36	8.50				
DO (mg/L)	1.76	2.33				
EC (mS/cm)	0.438	0.422				
ORP (mV)	342	408				
Turbidity (NTU)	2.44	1.43				
Time at end	10:18	10.:19				

Sampling at AD1 discontinued after May 2019.

VB-1 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/10	10/3	No Sample	12/11	1/14	2/11	3/12
Time at start	15:30	10:20	-	12:40	12:10	12:15	14:47
Water Table AMSL (ft)	742.1	743.0	-	741.7	741.6	741.7	741.6
Temperature (°C)	22.4	20.6	-	16.2	13.5	15.6	18.4
pH (s.u.)	7.86	8.08	-	8.09	8.06	8.17	8.00
DO (mg/L)	1.79	2.31	-	1.35	2.52	1.51	0.10
EC (mS/cm)	0.388	0.393	-	0.370	0.399	0.402	0.409
ORP (mV)	85	69	-	97	134	95	152
Turbidity (NTU)	3.13	0.80	-	1.02	0.99	0.35	0.25
Time at end	15:40	10:33	-	12:43	12:22	12:25	14:55

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
Time at start	12:40	12:40	13:10	14:05	13:25	11:55
Water Table AMSL (ft)	741.6	742.3	742.6	742.7	742.8	742.5
Temperature (°C)	19.4	21.9	20.2	20.1	22.4	20.0
pH (s.u.)	8.12	8.12	8.12	7.96	8.08	8.07
DO (mg/L)	1.84	1.87	1.22	0.96	1.52	0.27
EC (mS/cm)	0.408	0.412	0.400	0.416	0.422	0.418
ORP (mV)	179	245	121	30	59	23
Turbidity (NTU)	0.30	0.45	0.39	0.38	0.78	0.78
Time at end	12:49	12:54	13:19	14:17	13:38	12:02

VB-2 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/11	10/3	No Sample	12/11	1/14	2/11	3/13
Time at start	10:25	11:15	-	14:10	14:50	14:00	10:50
Water Table AMSL (ft)	742.8	743.0	-	741.9	741.5	741.4	741.3
Temperature (°C)	20.7	22.2	-	15.2	13.9	14.9	16.9
pH (s.u.)	7.91	8.10	-	8.08	8.13	8.20	8.11
DO (mg/L)	1.77	2.11	-	1.47	1.81	1.24	0.94
EC (mS/cm)	0.809	0.820	-	0.754	0.776	0.770	0.759
ORP (mV)	47	61	-	86	95	85	122
Turbidity (NTU)	2.47	1.35	-	1.13	1.16	0.57	0.51
Time at end	10:50	11:26	-	14:15	15:03	14:14	11:02

	Apr-18	May-18	Jun-18	Jul-18	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
Time at start	15:35	15:35	12:00	12:40	12:10	10:50
Water Table AMSL (ft)	741.2	741.6	742.0	742.1	742.0	742.2
Temperature (°C)	20.2	21.3	20.2	19.7	20.4	20.1
pH (s.u.)	8.13	8.12	8.13	7.08	7.02	7.14
DO (mg/L)	1.34	1.60	1.42	1.19	0.87	0.71
EC (mS/cm)	0.776	0.763	0.723	0.680	0.714	0.768
ORP (mV)	143	66	162	133	107	101
Turbidity (NTU)	0.47	0.39	0.40	0.36	0.65	0.66
Time at end	15:45	15:48	12:12	12:49	12:29	11:00

VB-3 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/11	10/3	No Sample	12/11	1/14	2/11	3/13
Time at start	12:20	13:05	-	15:30	13:55	15:30	12:10
Water Table AMSL (ft)	742.8	742.5	-	740.8	741.0	739.6	740.7
Temperature (°C)	22.97	23.21	-	15.36	12.61	15.93	15.91
pH (s.u.)	7.68	7.34	-	7.68	7.87	7.99	7.98
DO (mg/L)	2.11	1.99	-	1.68	1.84	1.28	1.82
EC (mS/cm)	0.832	0.822	-	0.768	0.792	0.742	0.738
ORP (mV)	61	102	-	100	100	84	141
Turbidity (NTU)	1.33	1.89	-	1.07	1.56	0.86	0.41
Time at end	12:40	13:16	-	15:33	14:10	15:41	12:18

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
Time at start	14:20	14:25	10:50	10:15	10:10	9:55
Water Table AMSL (ft)	739.9	740.4	740.5	741.0	741.0	740.9
Temperature (°C)	20.89	23.3	20.3	20.9	21.7	20.5
pH (s.u.)	8.07	8.03	7.98	7.14	7.22	6.87
DO (mg/L)	1.88	1.66	1.55	1.38	1.52	1.26
EC (mS/cm)	0.720	0.711	0.688	0.743	0.747	0.745
ORP (mV)	178	232	237	254	142	148
Turbidity (NTU)	0.41	0.30	0.19	0.39	0.71	0.74
Time at end	14:32	14:41	11:04	10:31	10:27	10:08

6AR (downgradient groundwater well)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/10	10/3	No Sample	12/11	1/14	2/11	3/12
Time at start	13:45	9:25	-	11:25	11:10	11:15	13:10
Water Table AMSL (ft)	740.3	740.2	-	737.4	737.2	736.8	736.8
Temperature (°C)	18.6	17.9	-	14.9	14.1	14.7	16.4
pH (s.u.)	5.05	5.05	-	4.66	4.84	4.75	4.73
DO (mg/L)	0.80	2.15	-	0.22	0.73	1.20	0.31
EC (mS/cm)	0.584	0.584	-	0.573	0.618	0.623	0.614
ORP (mV)	232	114	-	270	288	319	436
Turbidity (NTU)	0.92	0.65	-	0.58	0.80	0.50	0.63
Time at end	14:40	9:30	-	11:51	11:20	11:23	13:47

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
Time at start	11:25	11:20	14:20	15:15	14:50	13:30
Water Table AMSL (ft)	738.8	740.5	740.5	740.3	740.6	740.5
Temperature (°C)	17.3	17.5	19.5	19.0	19.9	20.2
pH (s.u.)	4.75	4.81	4.80	4.74	4.77	4.90
DO (mg/L)	1.08	0.92	1.39	0.67	0.95	1.24
EC (mS/cm)	0.641	0.638	0.624	0.651	0.658	0.617
ORP (mV)	427	451	431	428	416	388
Turbidity (NTU)	0.77	2.11	1.92	0.44	1.21	1.24
Time at end	11:32	11:34	14:50	15:21	15:01	13:38

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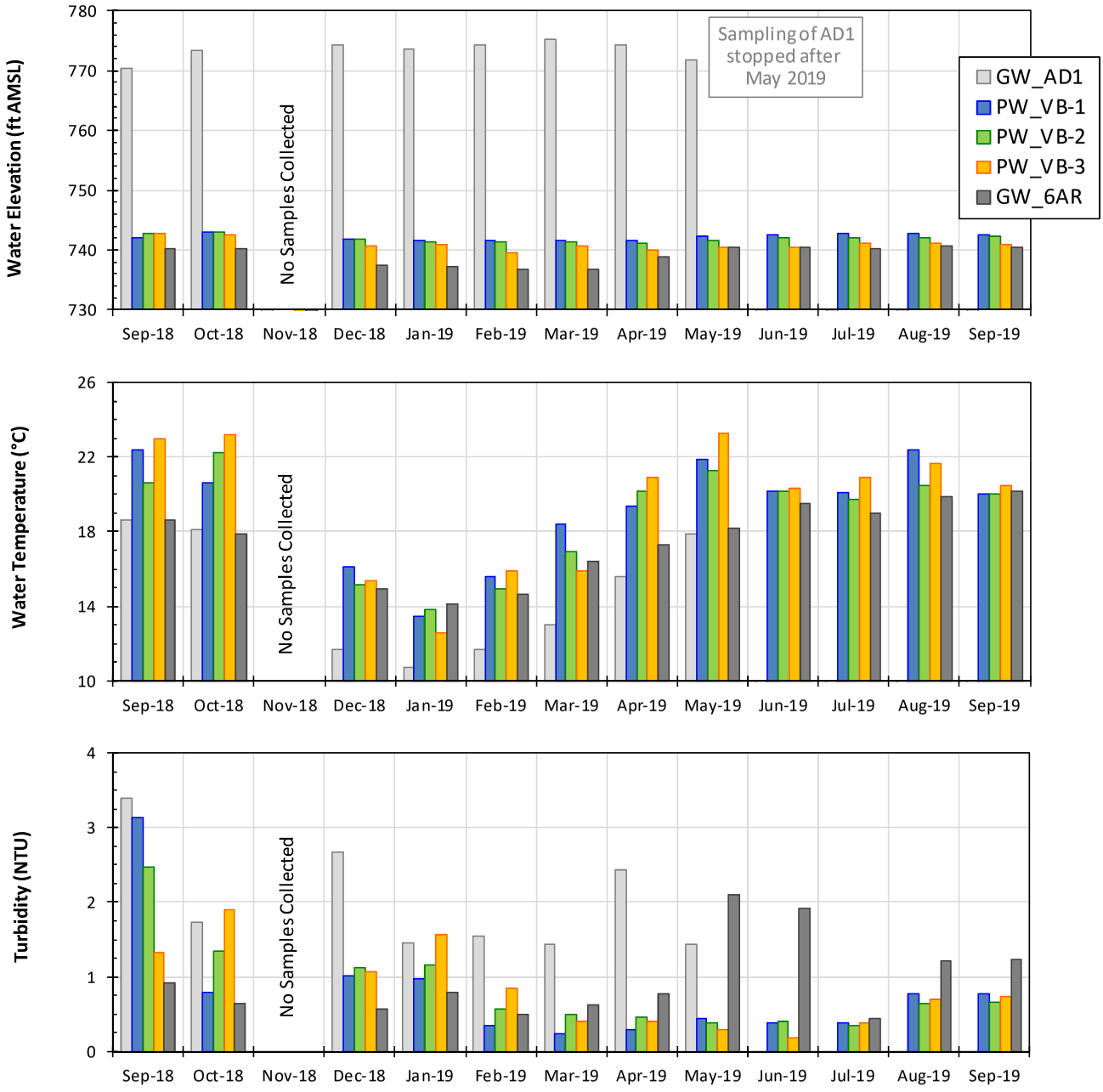

Figure F-1
Groundwater and porewater conditions during monthly sampling: water table elevation, water temperature, and turbidity

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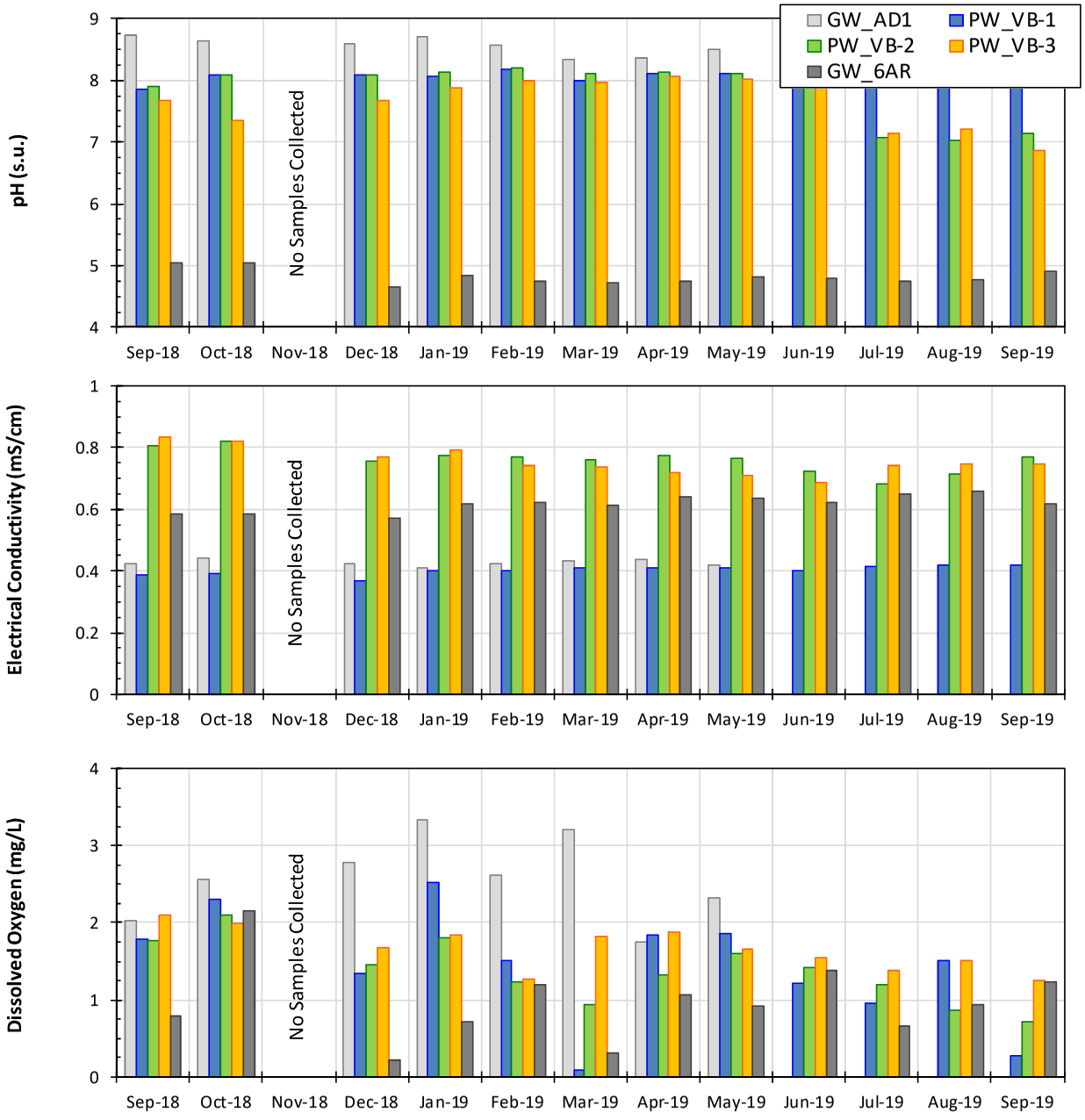

Figure F-2
Groundwater and porewater conditions during monthly sampling: pH, electrical conductivity, and dissolved oxygen

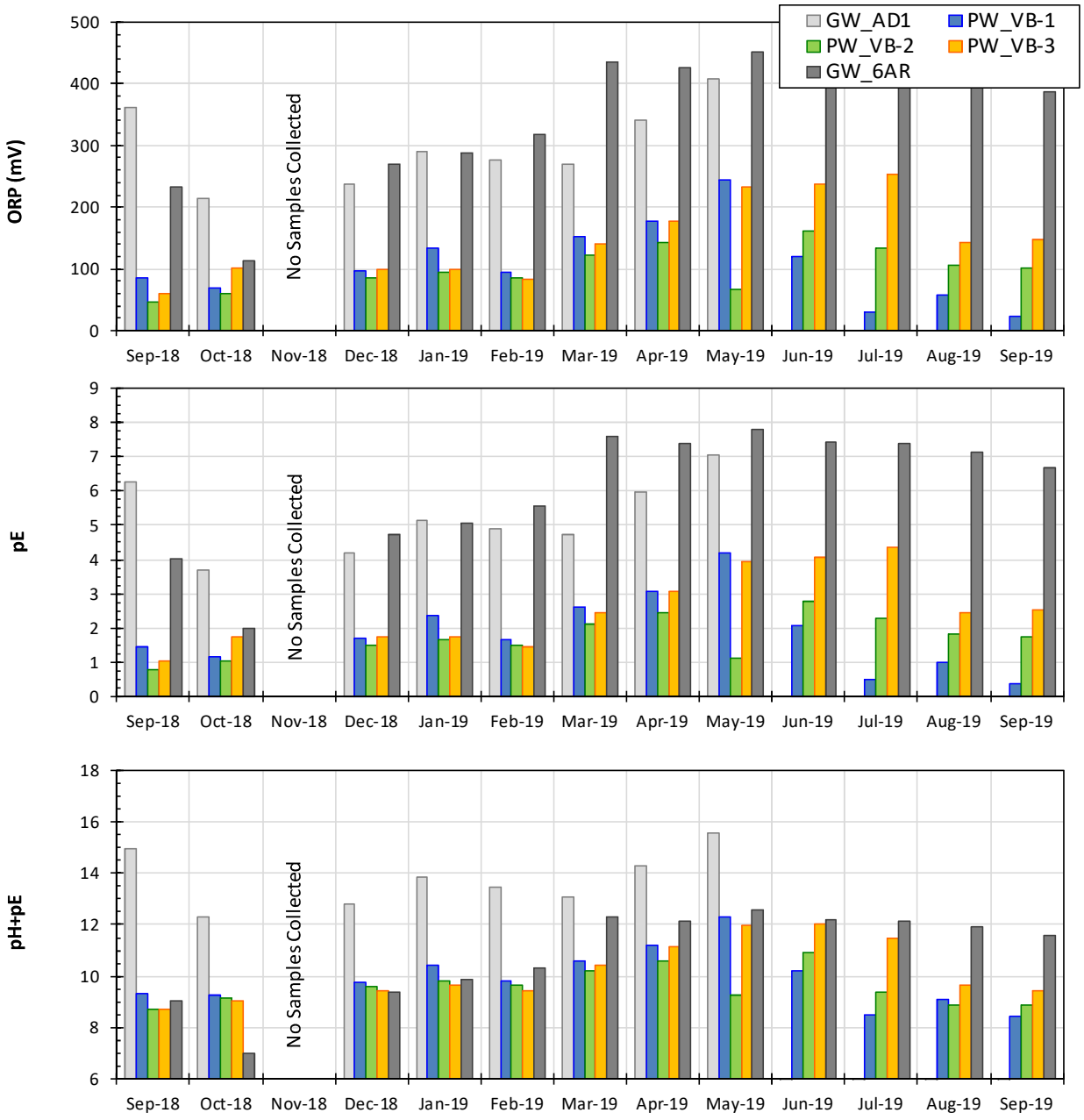

Figure F-3
Groundwater and porewater conditions during monthly sampling: ORP, pE (derived from ORP), and pH+pE (derived from ORP and pH)

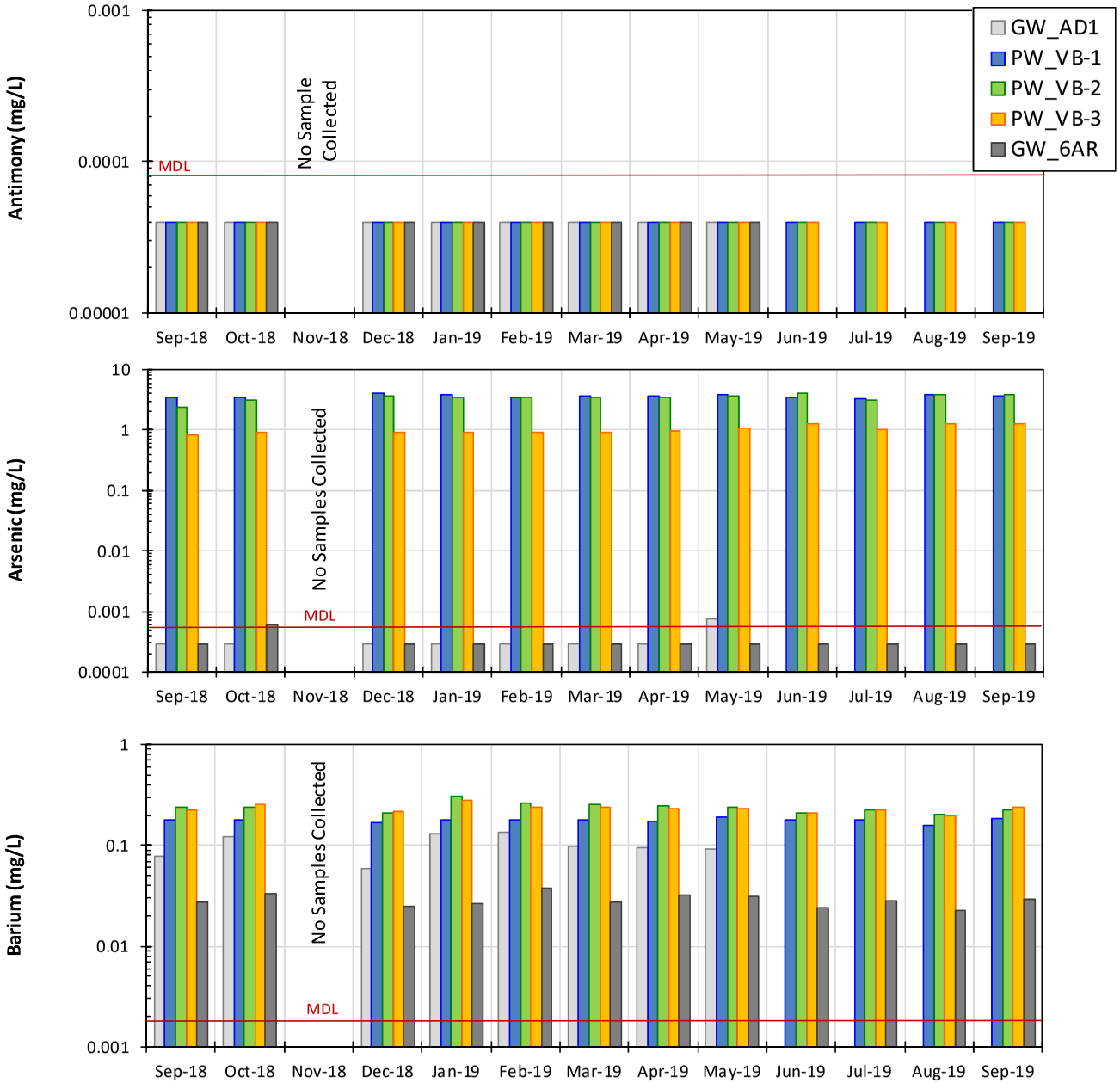

Figure F-4
Measured groundwater and porewater concentrations: antimony, arsenic, and barium; concentrations plotted on a logarithmic axis

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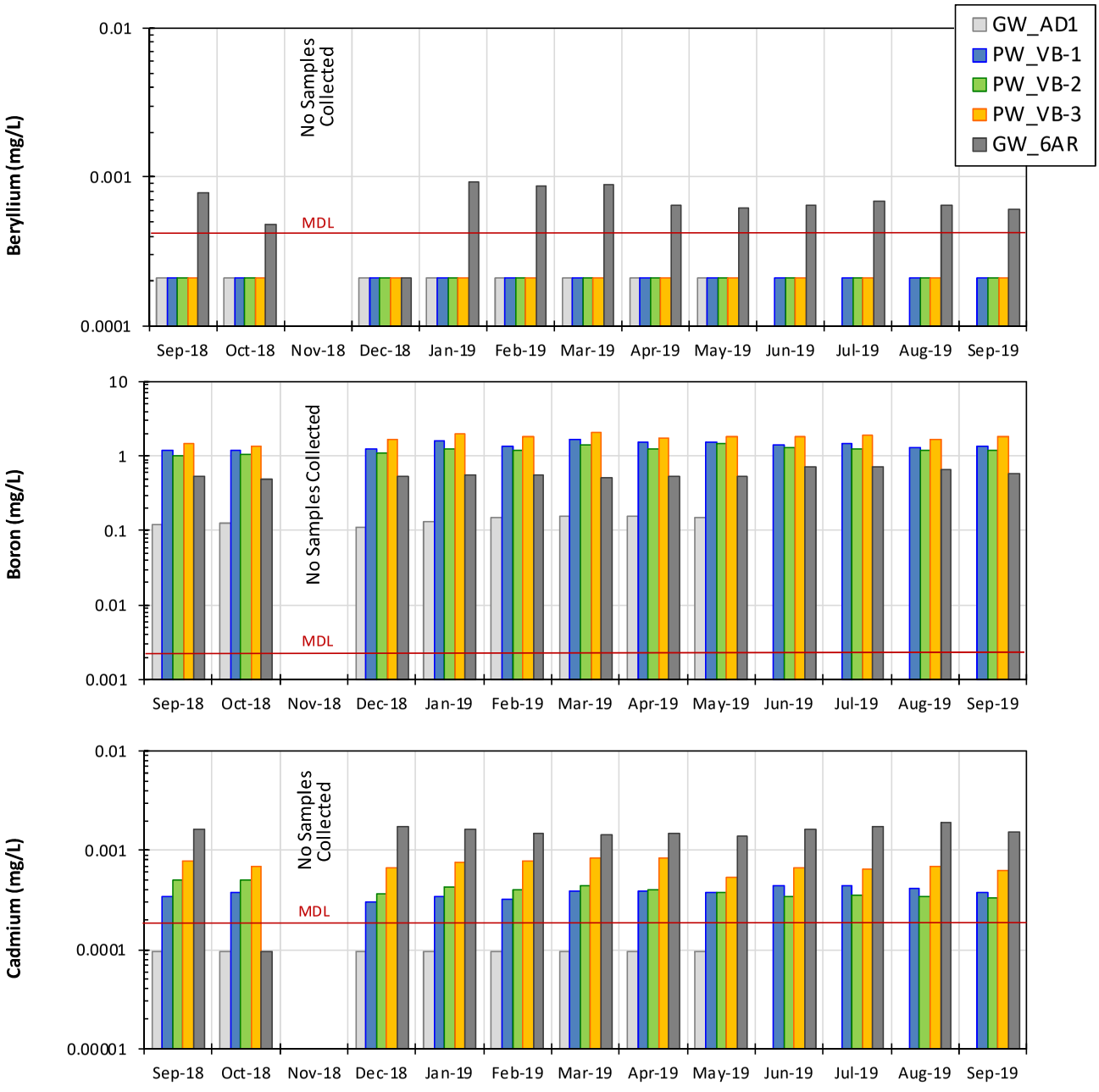

Figure F-5
Measured groundwater and porewater concentrations: beryllium, boron, and cadmium; concentrations plotted on a logarithmic axis

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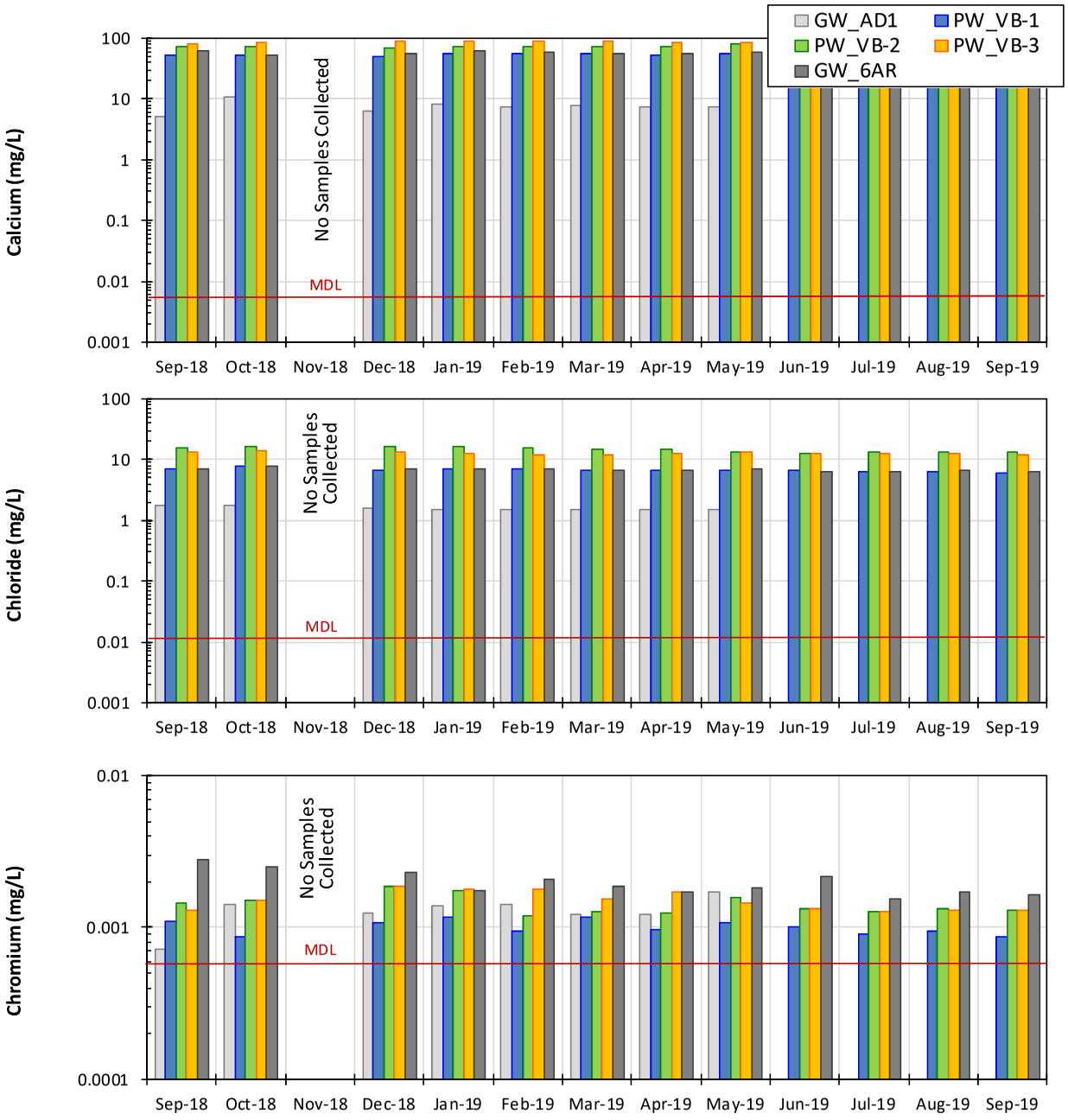

Figure F-6
Measured groundwater and porewater concentrations: calcium, chloride, and chromium; concentrations plotted on a logarithmic axis

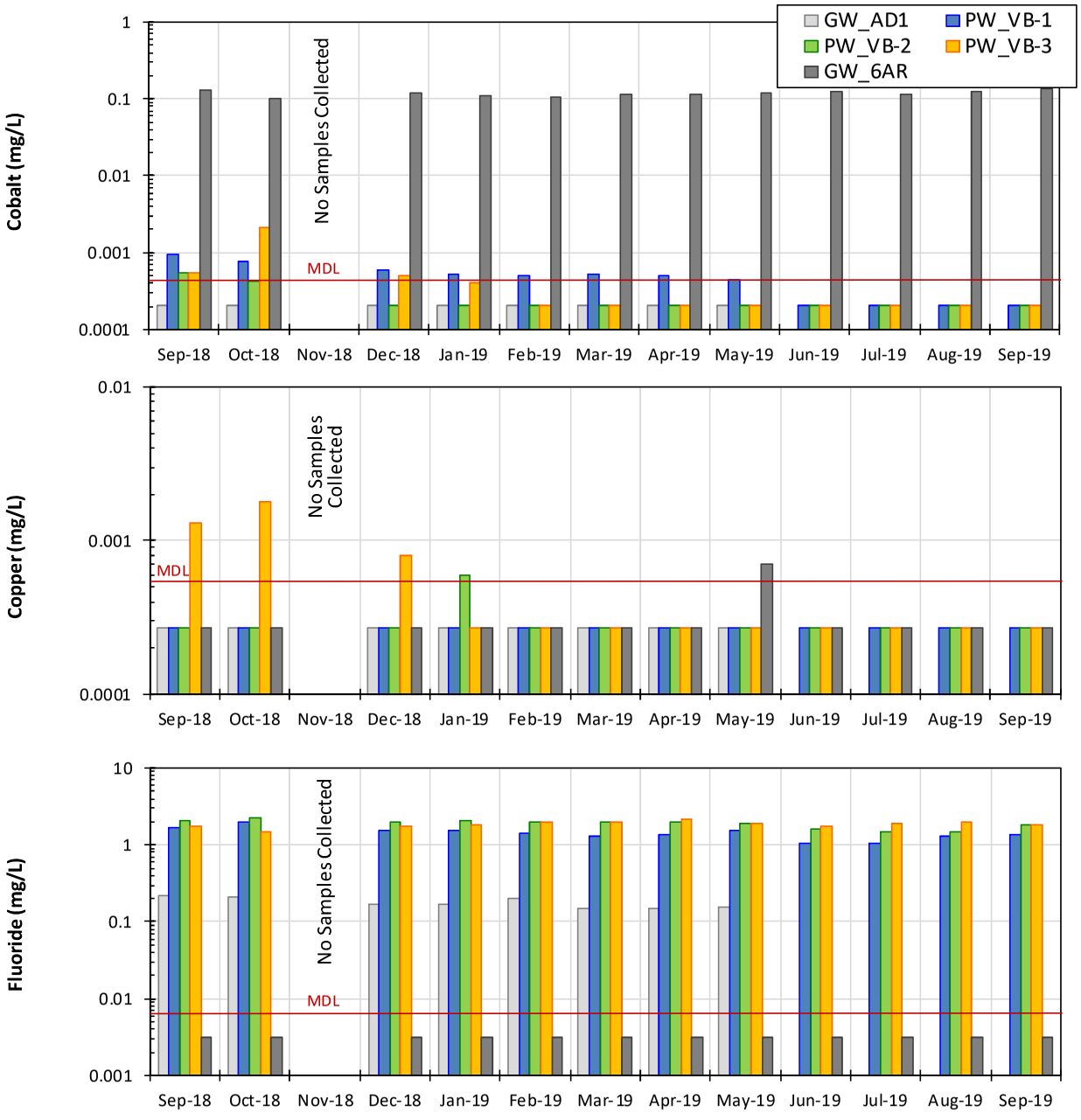

Figure F-7
Measured groundwater and porewater concentrations: cobalt, copper, and fluoride; concentrations plotted on a logarithmic axis

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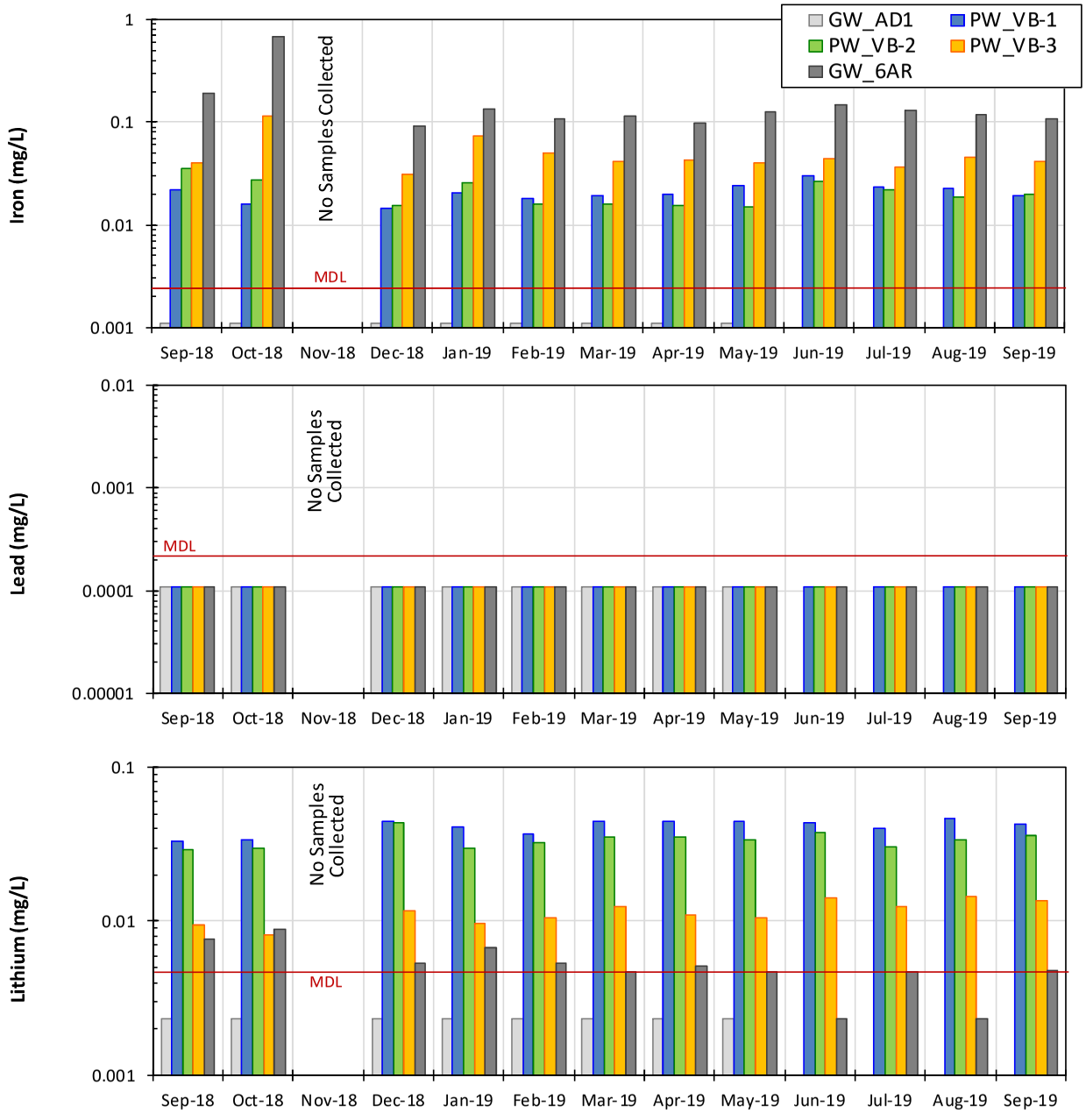

Figure F-8
Measured groundwater and porewater concentrations: iron, lead, and lithium; concentrations plotted on a logarithmic axis

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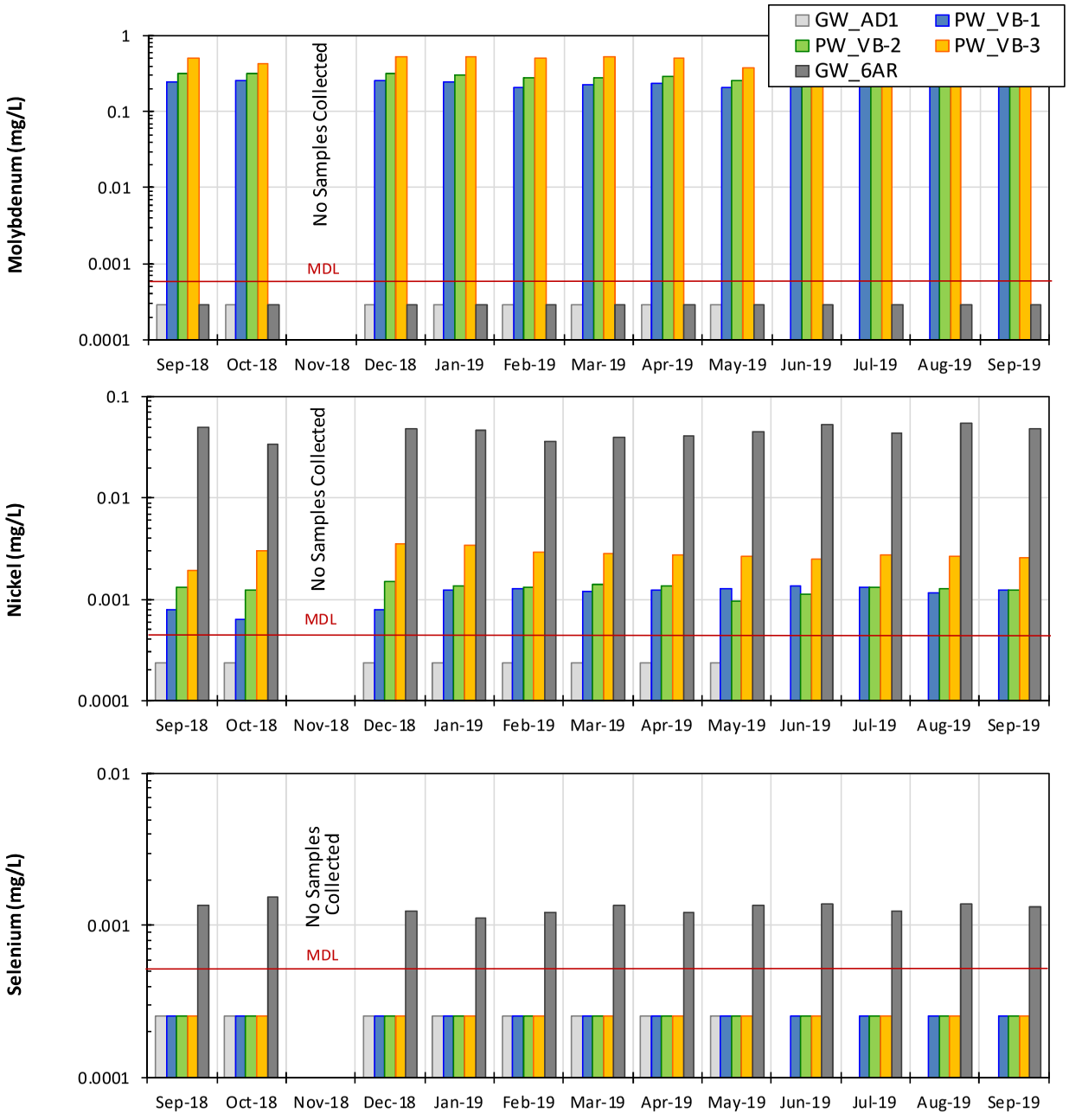

Figure F-9
Measured groundwater and porewater concentrations: molybdenum, nickel, and selenium; concentrations plotted on a logarithmic axis

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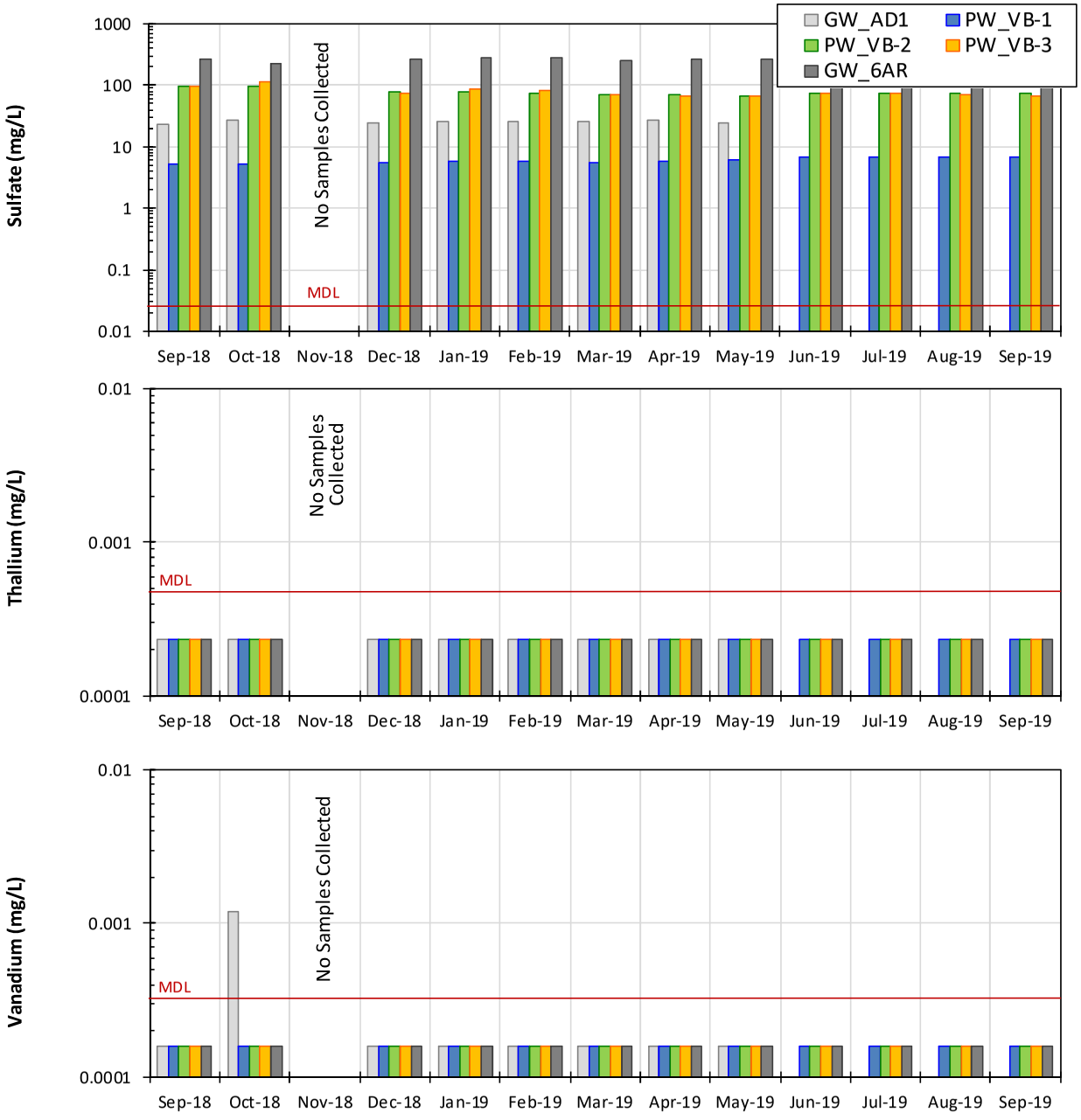

Figure F-10
Measured groundwater and porewater concentrations: sulfate, thallium, and vanadium; concentrations plotted on a logarithmic axis

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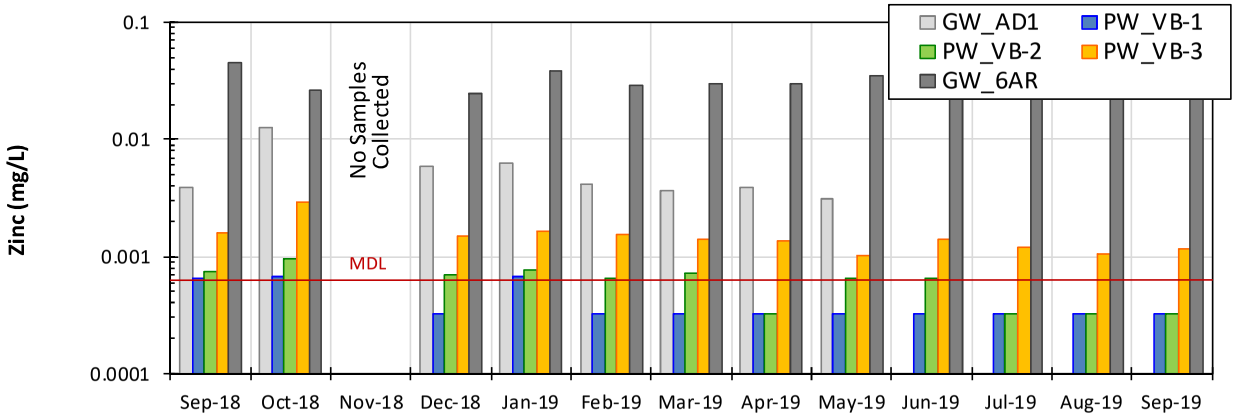

Figure F-11
Measured groundwater and porewater concentrations: zinc; concentrations plotted on a logarithmic axis

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F.2 Time Series Graphs for Porewater Data

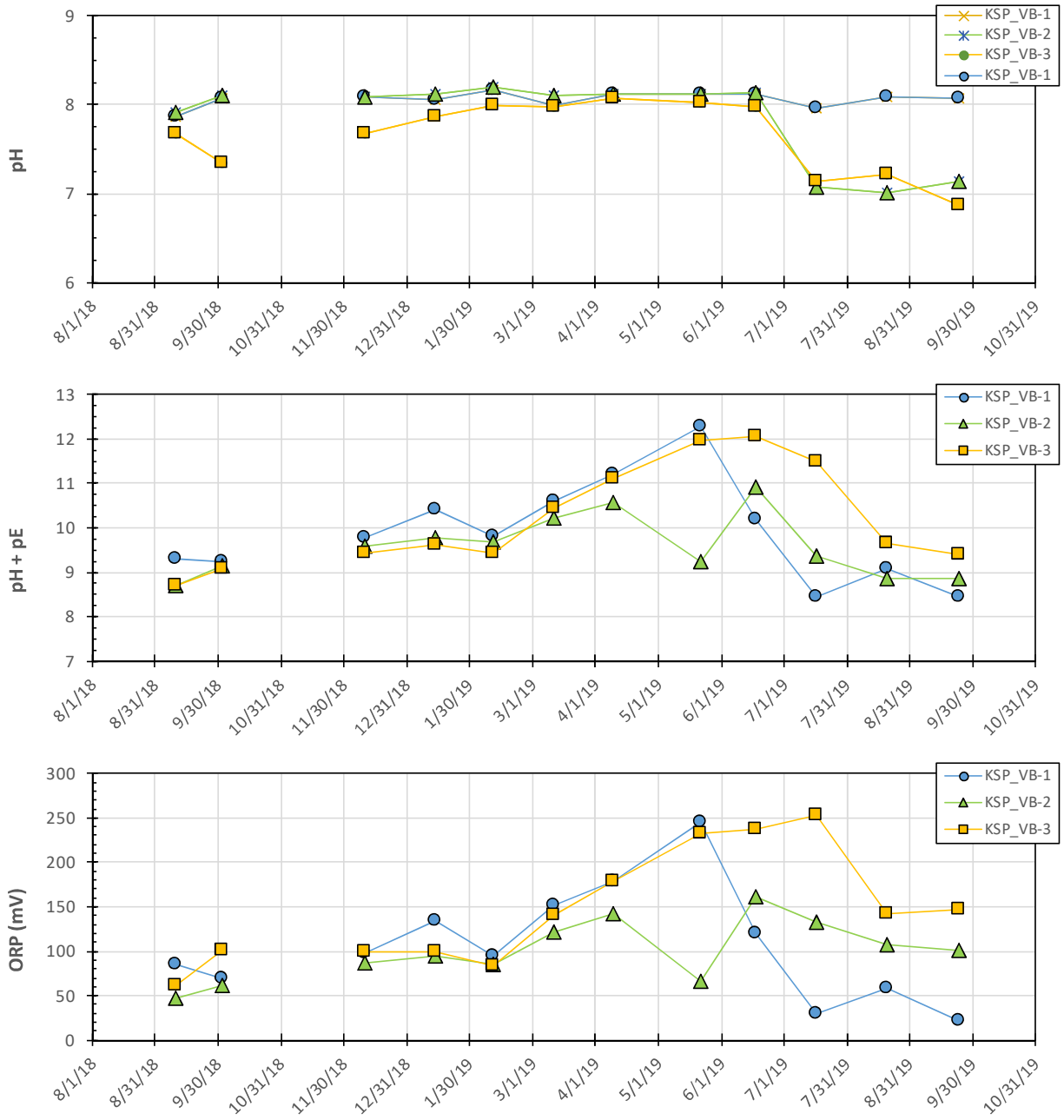

Figure F-12
Time-series plots of porewater conditions: pH, pH+pE, and ORP

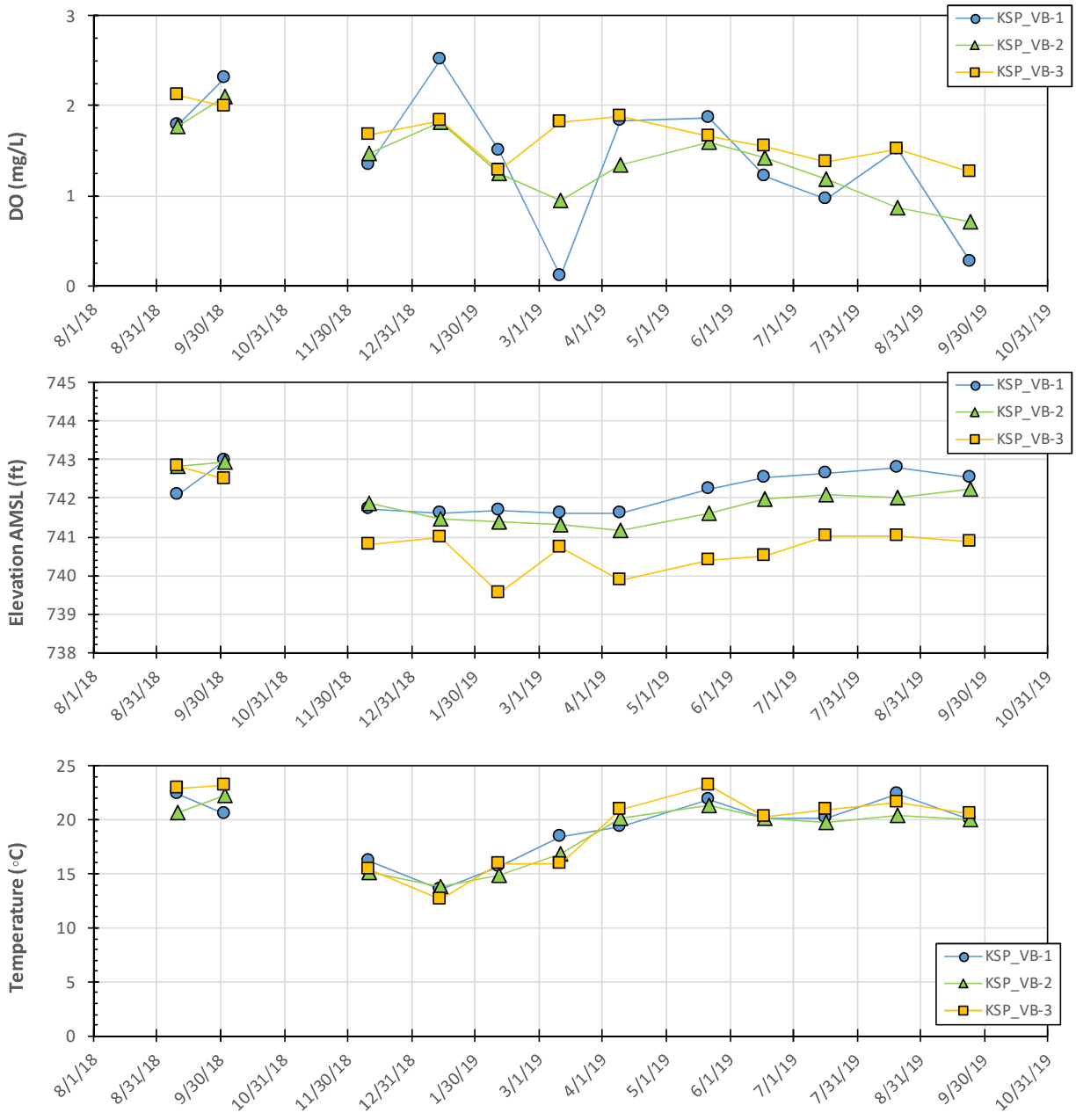

Figure F-13
Time-series plots of porewater conditions: dissolved oxygen (DO), water elevation, and temperature

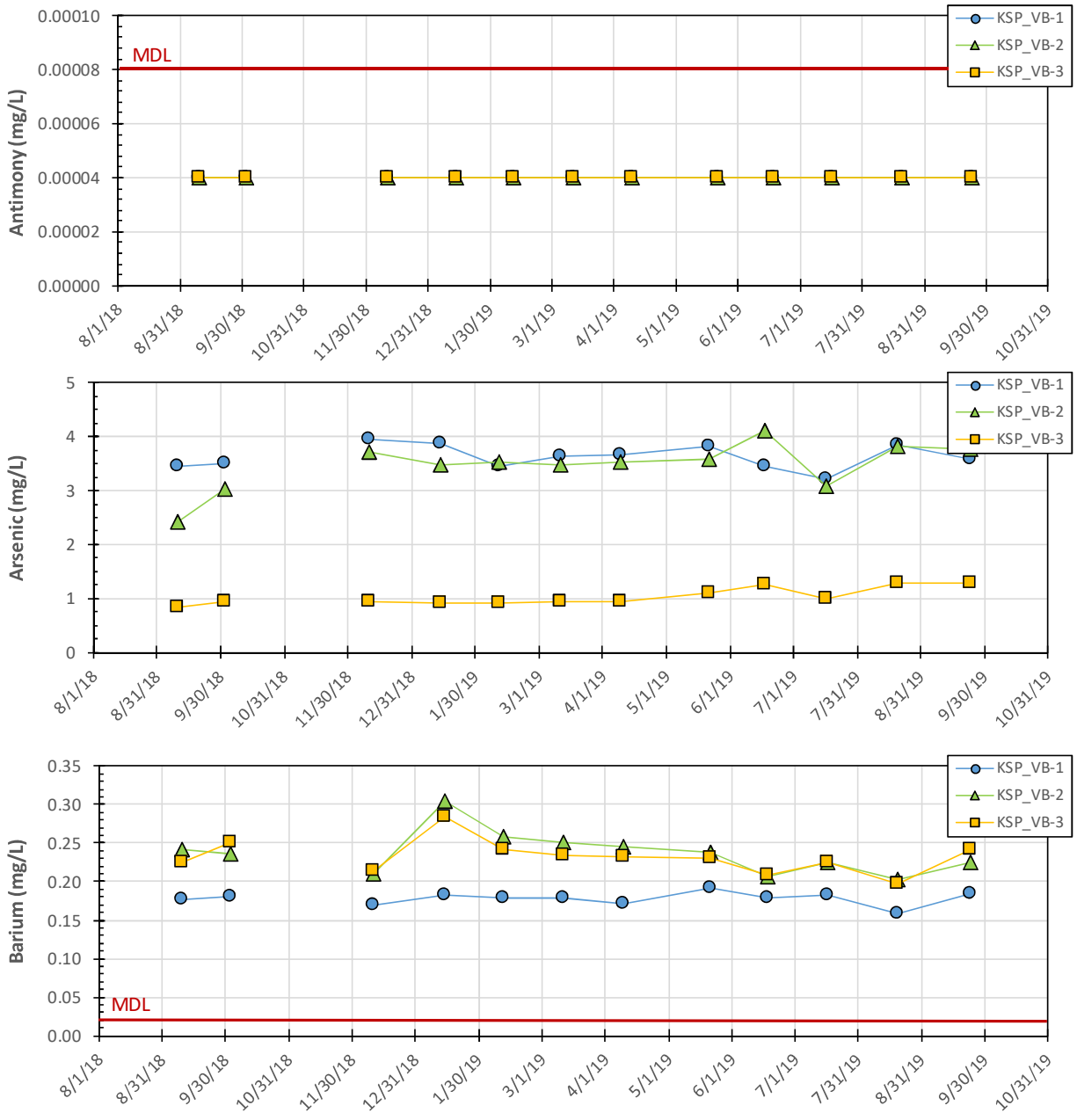

Figure F-14
Time-series plots of porewater concentrations: antimony, arsenic, and barium

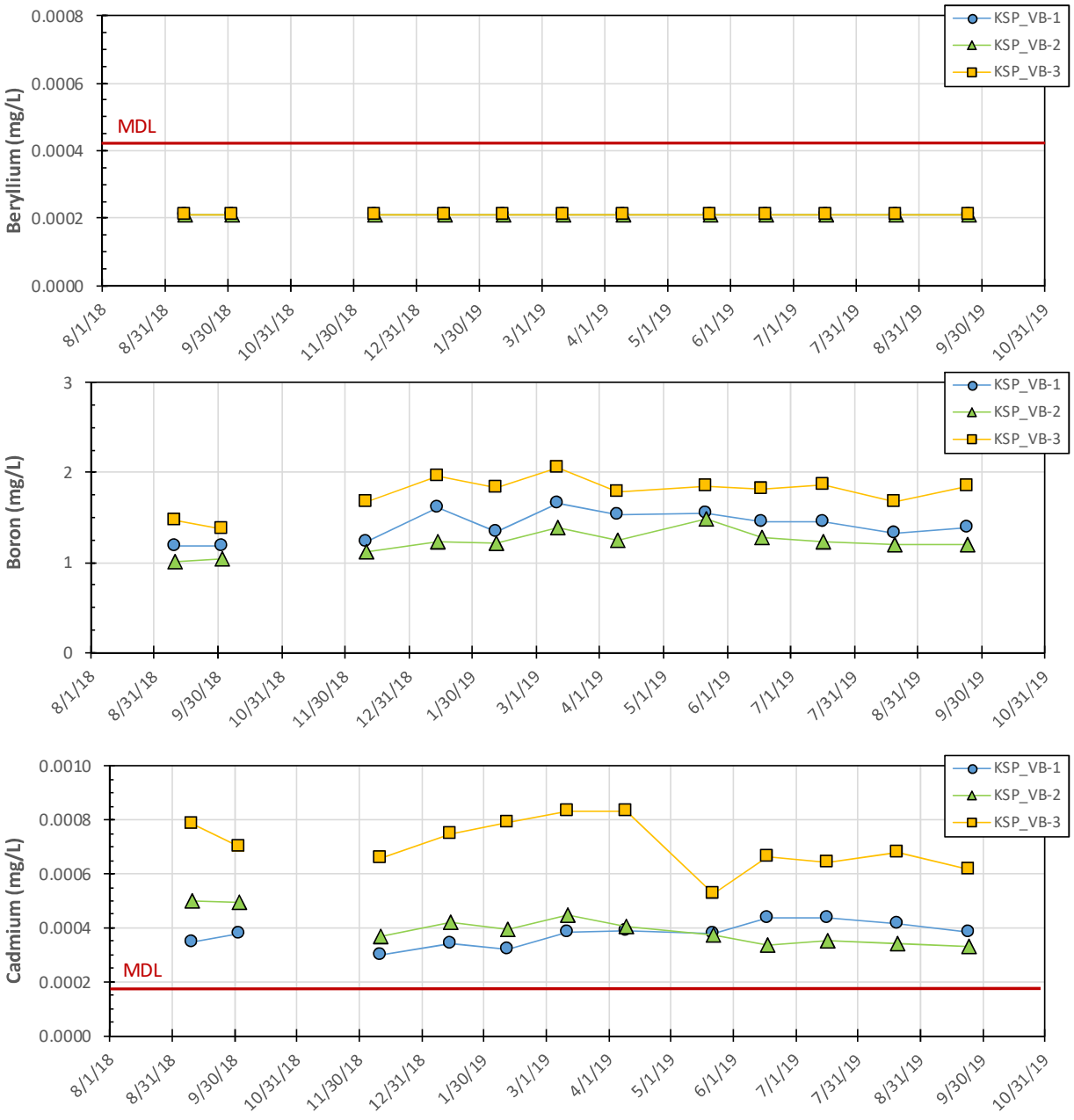

Figure F-15
Time-series plots of porewater concentrations: beryllium, boron, and cadmium

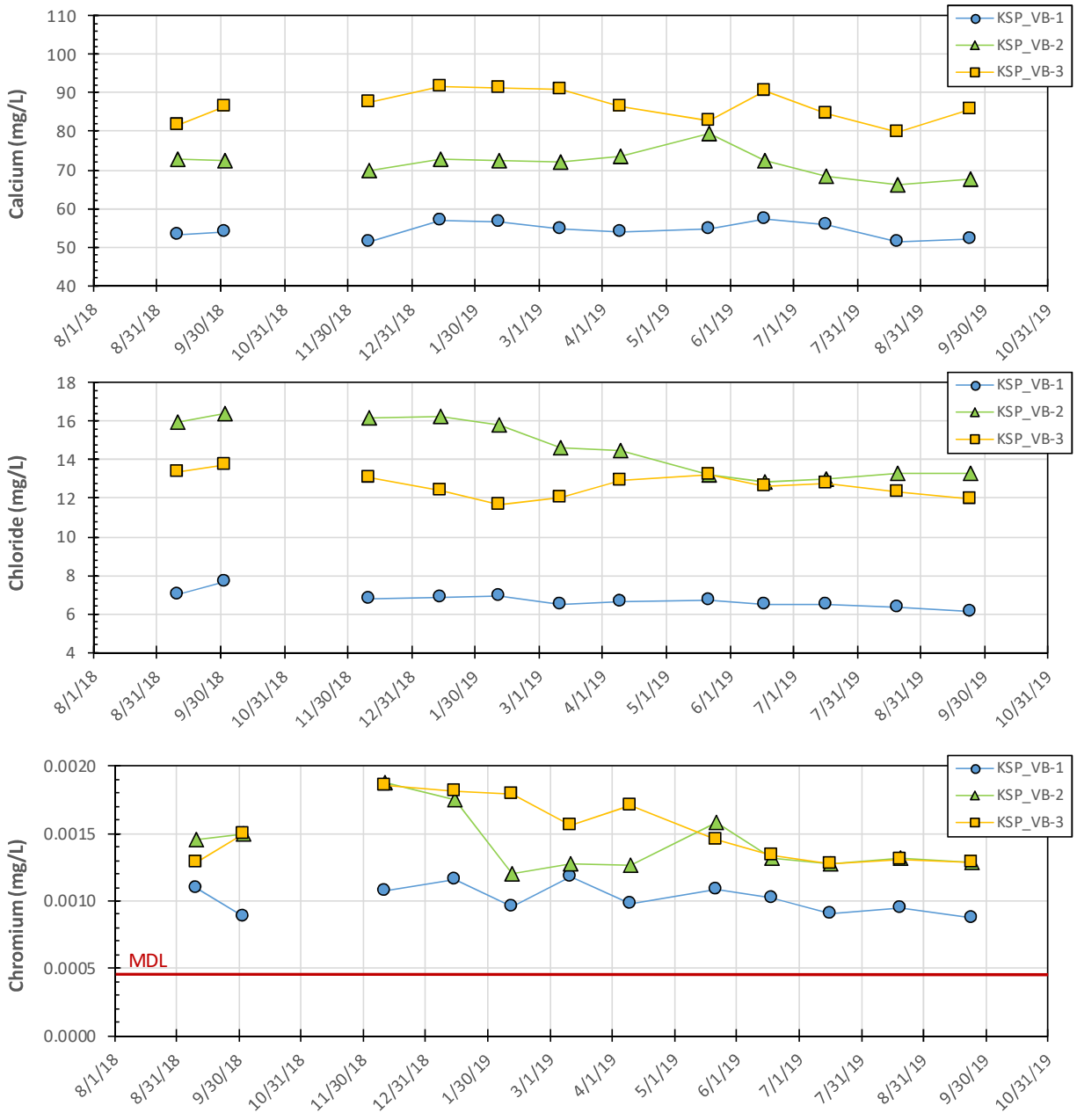

Figure F-16
Time-series plots of porewater concentrations: calcium, chloride, and chromium

Electronic Filing: Received, Clerk's Office 07/01/2024

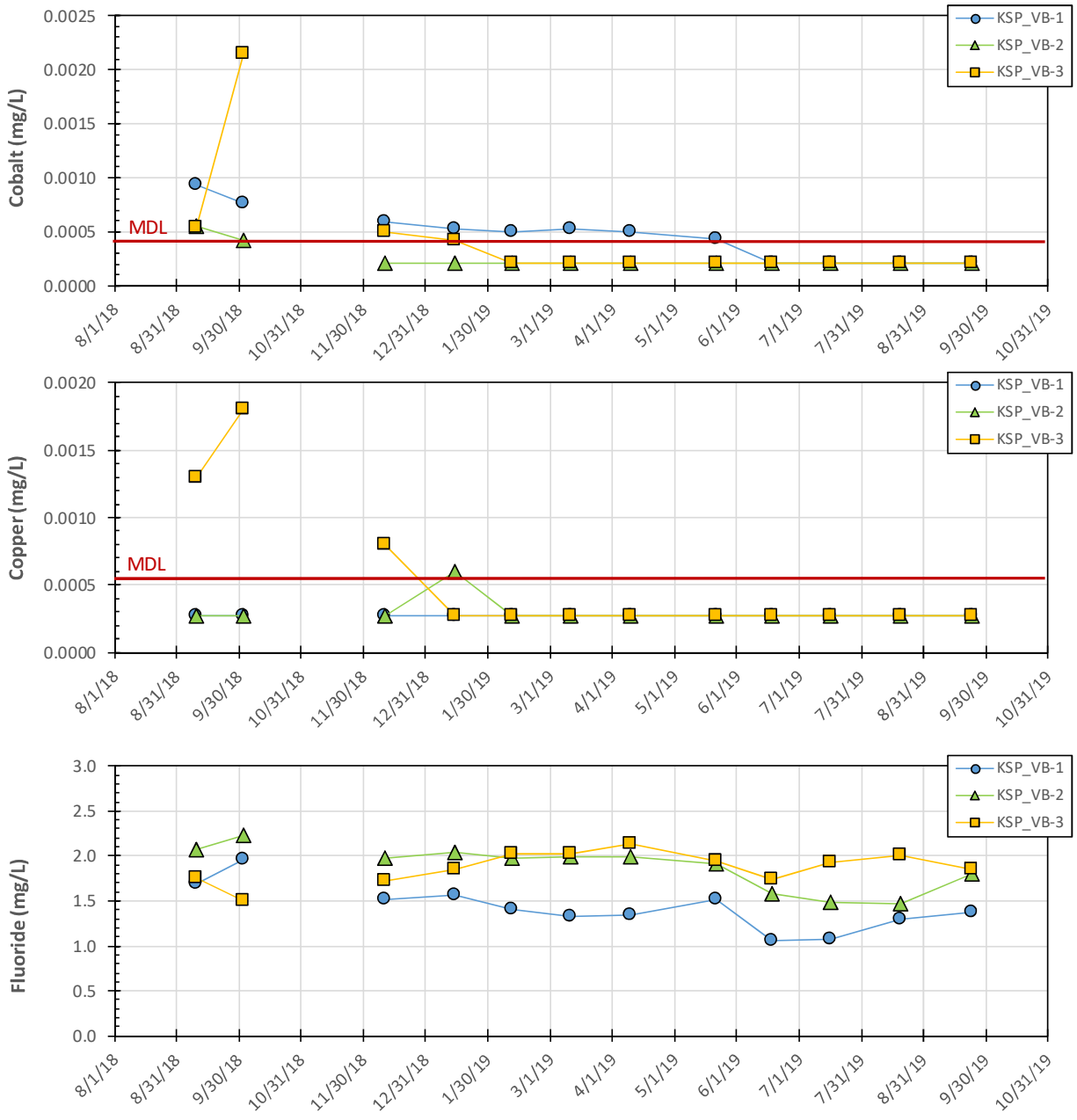

Figure F-17
Time-series plots of porewater concentrations: cobalt, copper, and fluoride

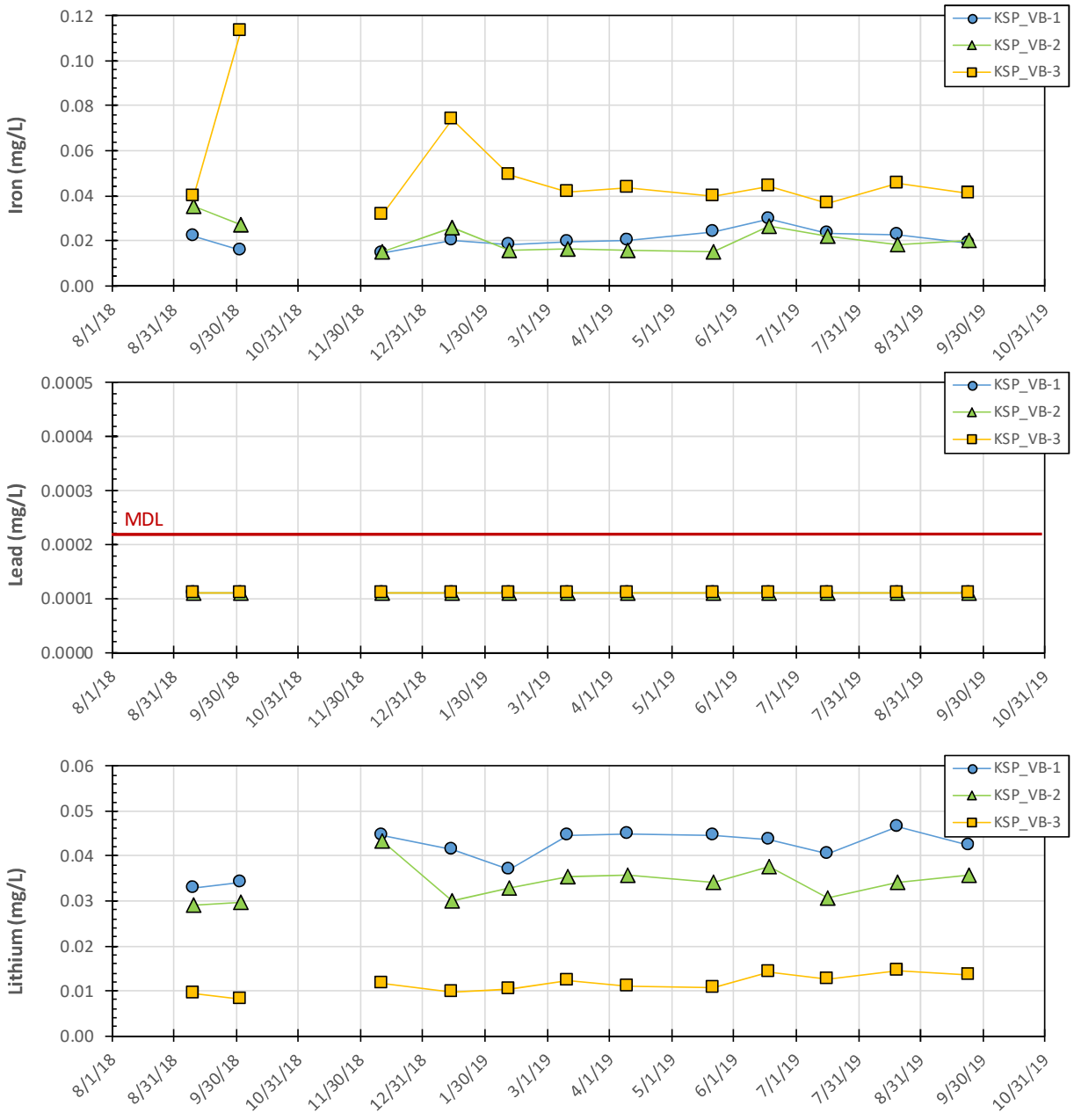

Figure F-18
Time-series plots of porewater concentrations: iron, lead, and lithium

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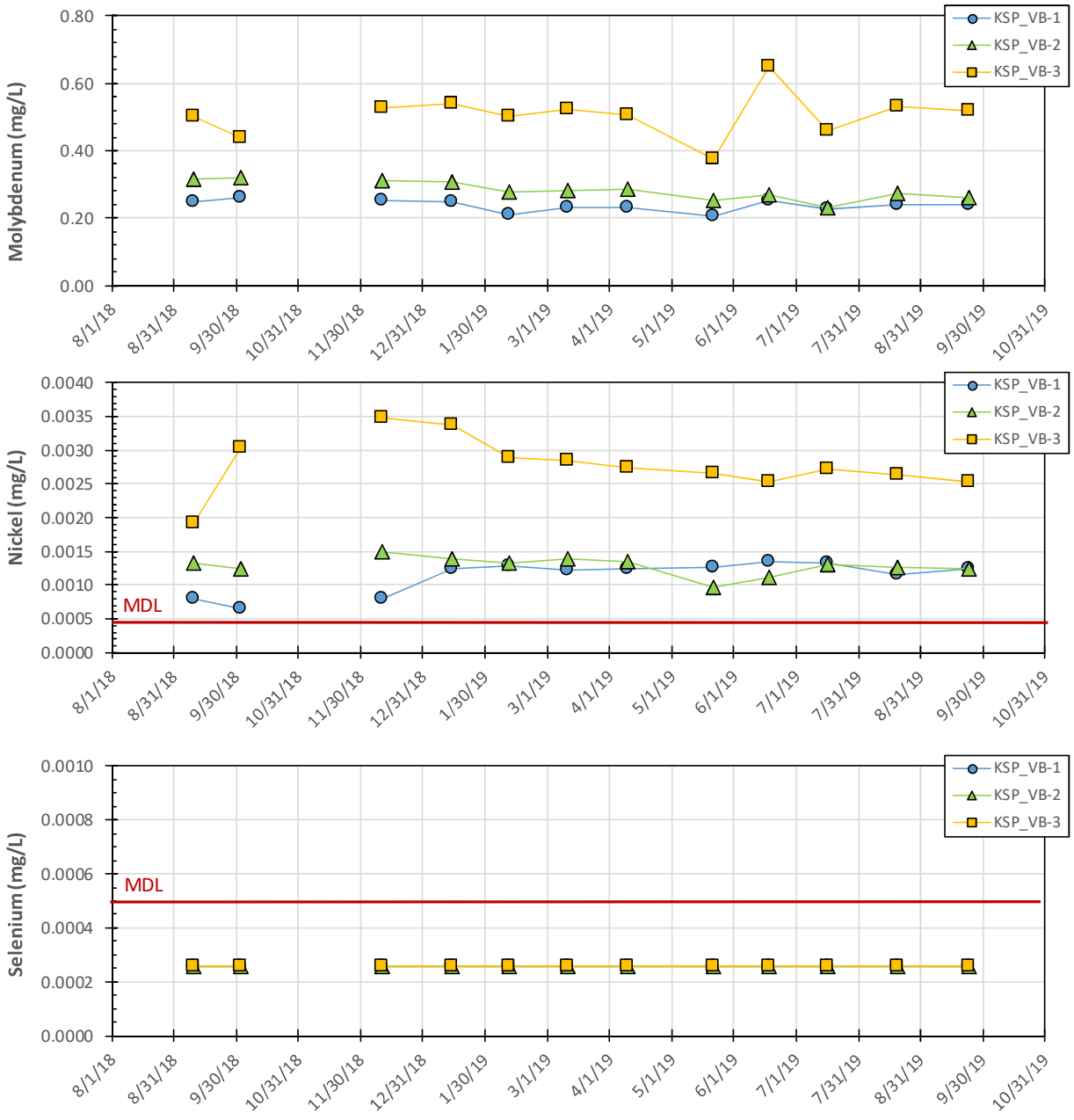

Figure F-19
Time-series plots of porewater concentrations: molybdenum, nickel, and selenium

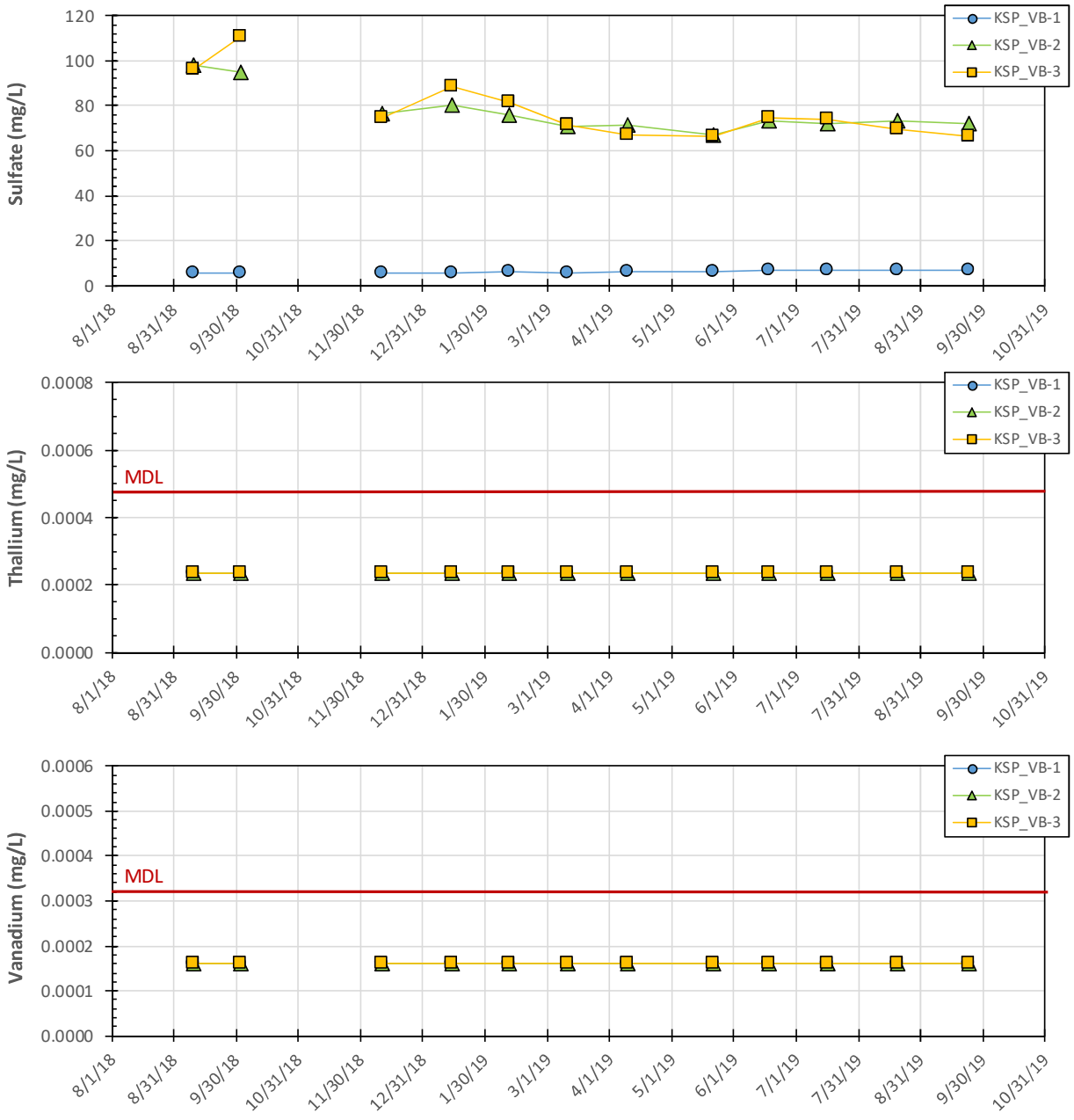

Figure F-20
Time-series plots of porewater concentrations: sulfate, thallium, and vanadium

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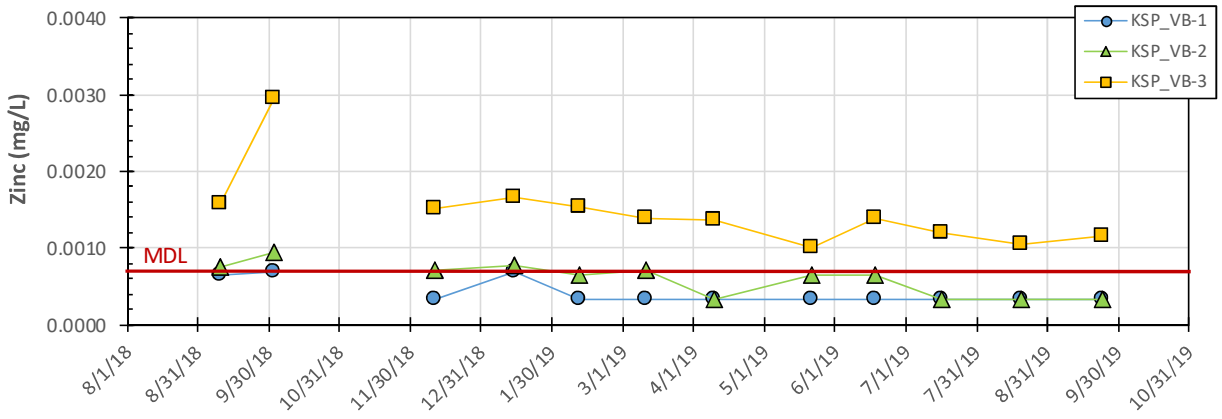

Figure F-21
Time-series plots of porewater concentrations: zinc

F.3 Subsurface Gas Parameter Tables and Graphs

VB-1 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/10	10/3	No Sample	12/11	1/14	2/11	3/12
O_2 (%)	18.9	0.4	-	20.8	20.6	14.6	19.0
CO_2 (%)	2.4	>5	-	0.22	0.22	0.61	0.32
CH_4 (%)	0.13	>5	-	0	0	0	0
NH_3 (mg/L)	0	0	-	0	0	0	-
H_2S (mg/L)	0	0	-	0	0	0	0
Note	-	-	-	-	-	-	-

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
O_2 (%)	1.9	0.6	0.7	0.8	0.2	0.3
CO_2 (%)	2.08	3.42	4.29	4.14	4.86	5.00
CH_4 (%)	0	>5	>5	>5	>5	>5
NH_3 (mg/L)	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0
Note	-	-	-	-	-	-

VB-2 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/11	10/3	No Sample	12/11	1/14	2/11	3/12
O_2 (%)	0.4	0.3	-	0.2	0.2	0.5	2.4
CO_2 (%)	0.14	0.26	-	0.24	0.45	0.51	0.45
CH_4 (%)	>5	>5	-	>5	>5	>5	>5
NH_3 (mg/L)	2.0	0	-	0	2.0	4.0	-
H_2S (mg/L)	4.1	3.0	-	12.8	14.1	12.6	0.9
Note	-	-	-	-	-	W @ 8 min	W @ 3 min

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	5/22	6/18	7/17	8/20	9/24
O_2 (%)	4.7	0.6	0.8	1.2	0.3	4.9
CO_2 (%)	0.51	0.55	0.65	0.71	0.63	0.50
CH_4 (%)	>5	>5	>5	>5	>5	>5
NH_3 (mg/L)	0	0	0	0	0	0
H_2S (mg/L)	0	0	0	0	0	0
Note	W @ 3 min	W @ 3 min				

Notes:

PF = pump fault (line blockage) occurred

W = water/ash mixture pumped from gas access line

Groundwater and Porewater Data

VB-3 (ash porewater borehole)

	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19
Sampling Date	9/11	10/3	No Sample	12/11	1/14	2/10	3/10
O_2 (%)	15.8	5.6	-	7.3	7.6	20.3	4.2
CO_2 (%)	2.1	>5	-	>5	>5	0.26	>5
CH_4 (%)	>5	>5	-	>5	>5	0.8	>5
NH_3 (mg/L)	>5	0	-	0	3.0	0	
H_2S (mg/L)	5.9	6.1	-	28.1	26.5	0	22.3
Note	-	PF @ 5 min	-	PF @ 6 min	-	W @ 5 min	PF @ 6 min

	Apr-19	May-19	Jun-19	Jul-19	Aug-19	Sep-19
Sampling Date	4/10	No Sample	6/18	7/17	8/20	9/24
O_2 (%)	5.7	-	2.2	-	-	-
CO_2 (%)	>5	-	>5	-	-	-
CH_4 (%)	>5	-	>5	-	-	-
NH_3 (mg/L)	0	-	0	-	-	-
H_2S (mg/L)	13.2	-	16.2	-	-	-
Note	PF @ 4 min	PF @ 0 min	PF @ 3 min	PF @ 0 min	PF @ 0 min	PF @ 0 min

Notes:

PF = pump fault (line blockage) occurred

W = water/ash mixture pumped from gas access line

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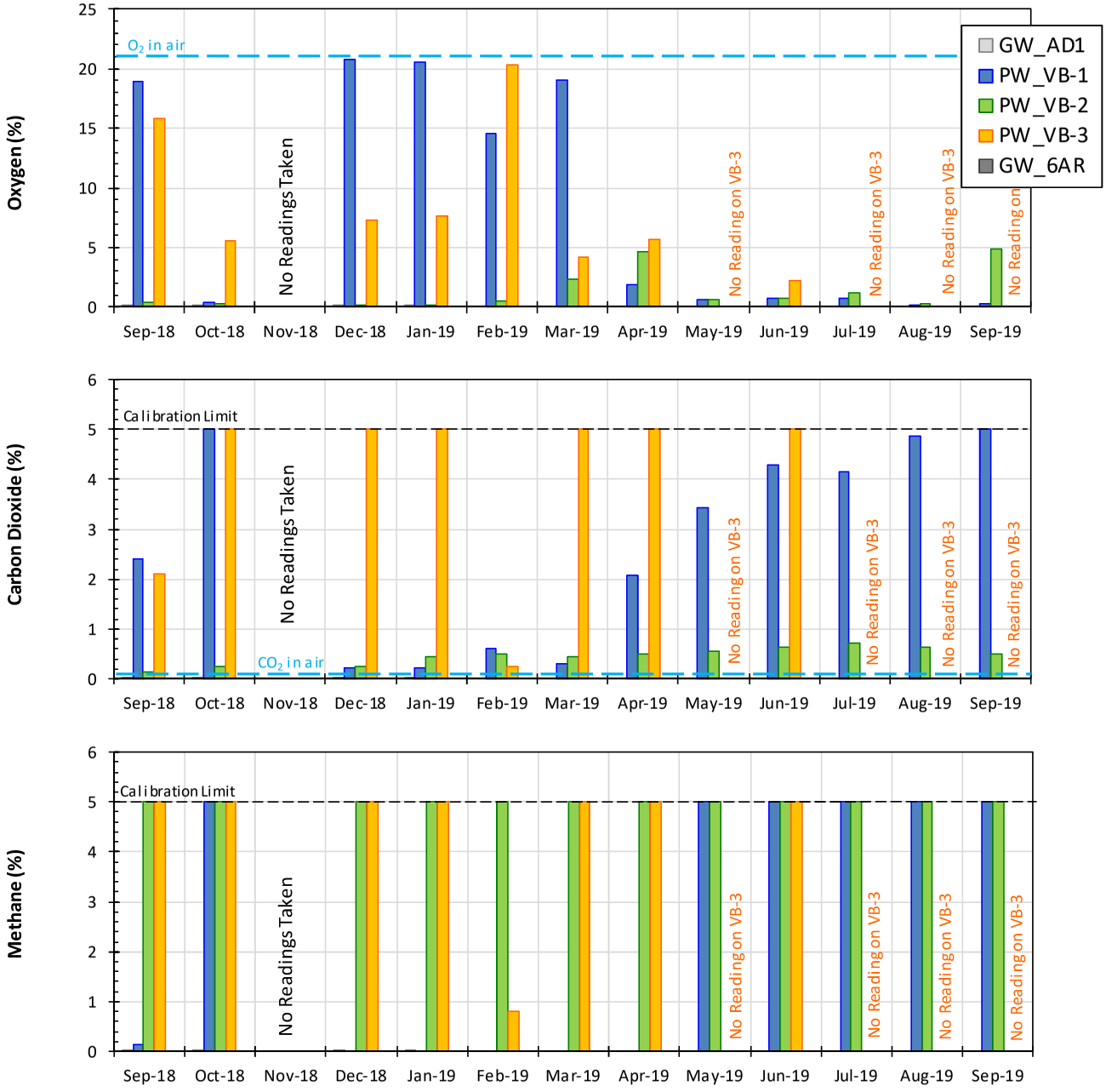

Figure F-22
Measured subsurface gas composition: oxygen, carbon dioxide, and methane

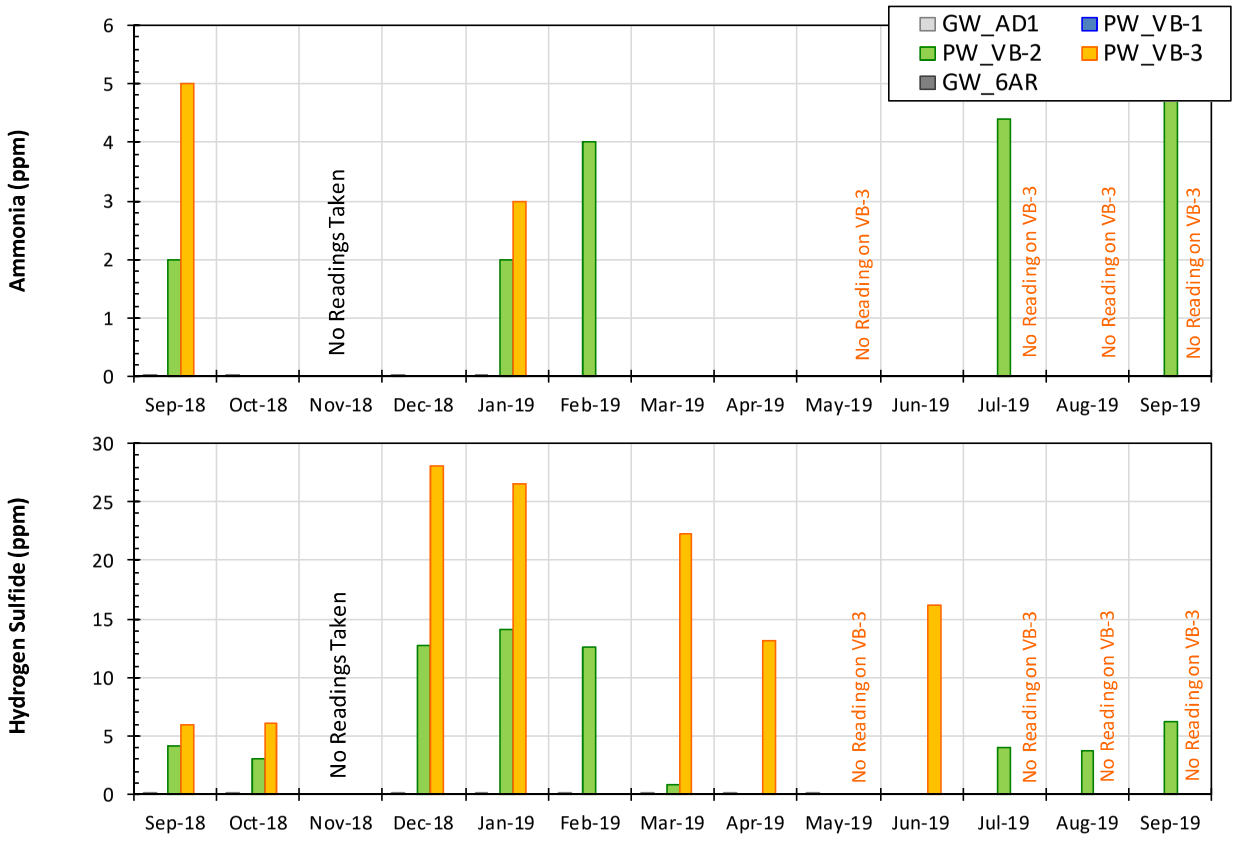

Figure F-23
Measured subsurface gas composition: ammonia and hydrogen sulfide

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G

COMPARISON OF POREWATER ESTIMATES FROM LEACHING TESTS WITH MEASURED VALUES

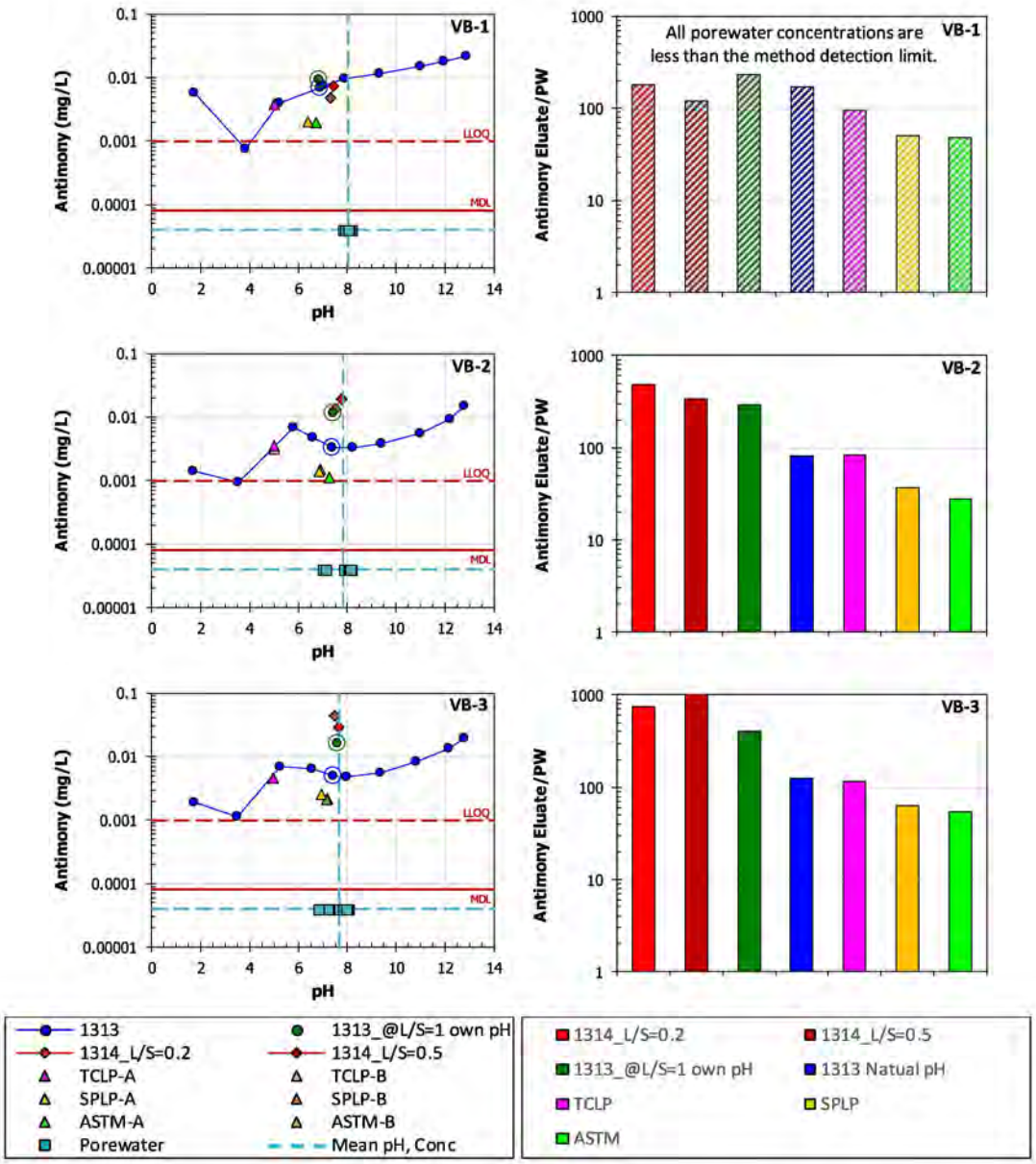


Figure G-1
Antimony concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate and porewater concentrations (right); crosshatched ratio results indicate estimates based on at least one MDL value

Comparison of Porewater Estimates from Leaching Tests with Measured Values

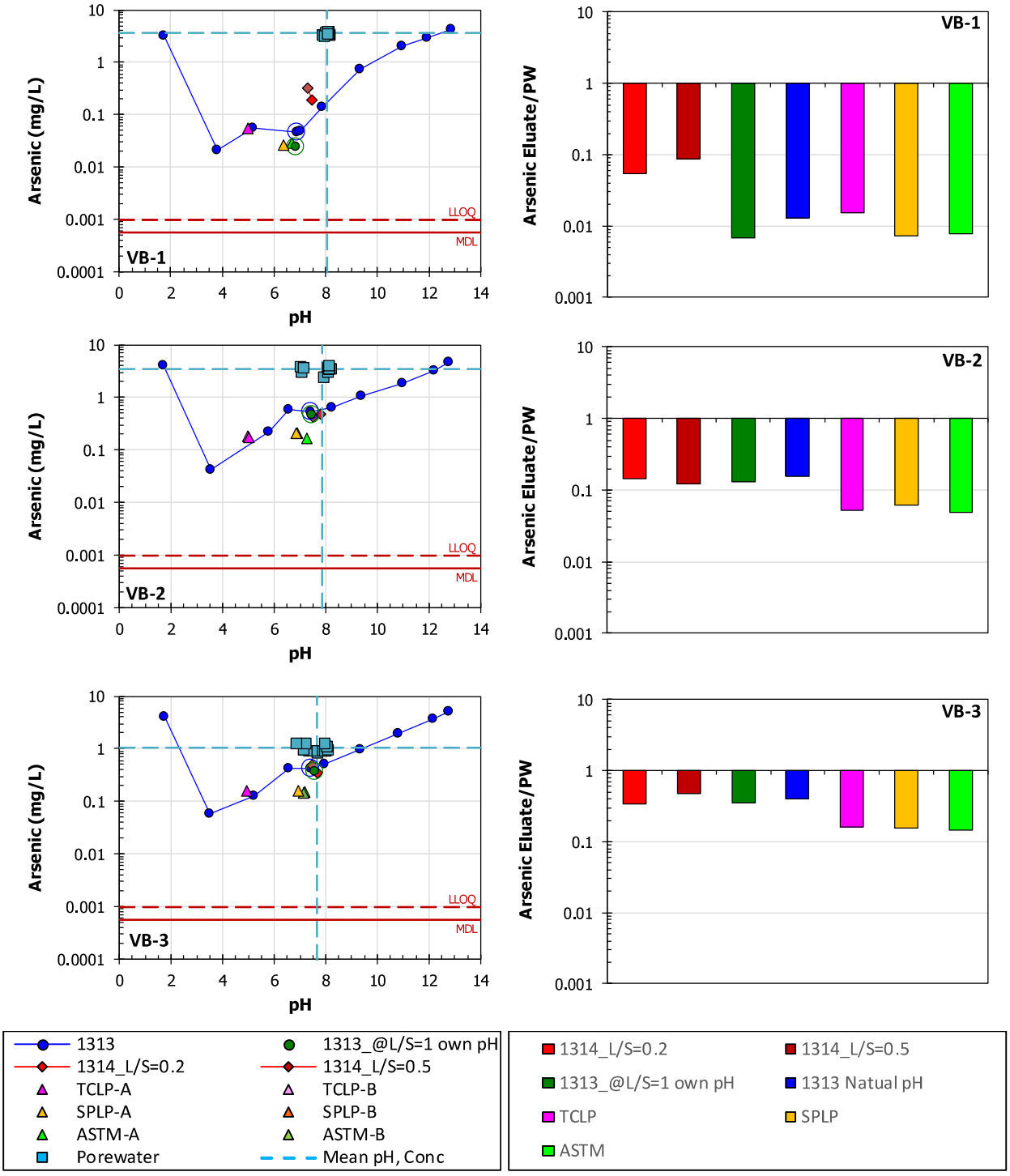


Figure G-2
Arsenic concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate and porewater concentrations (right)

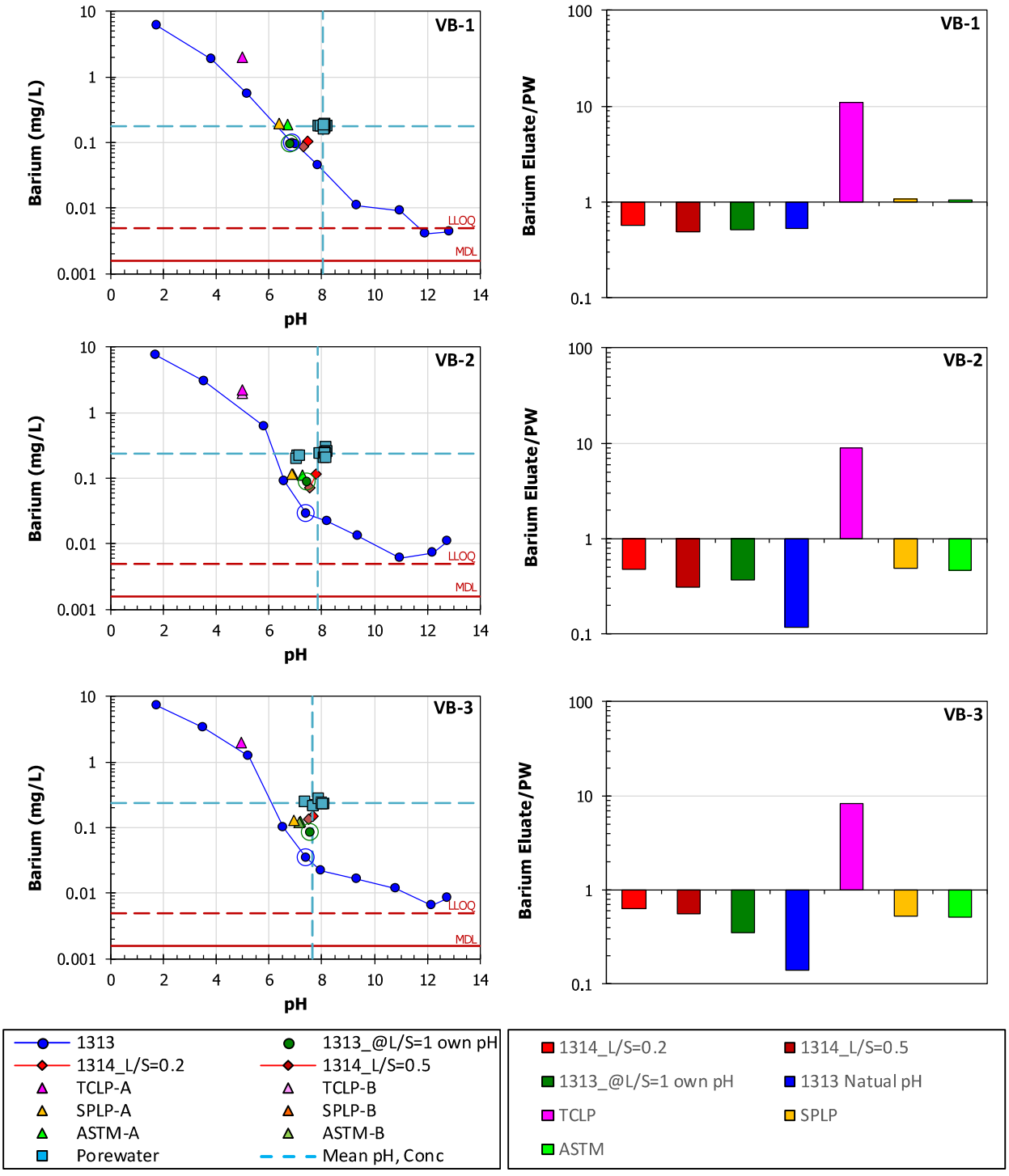


Figure G-3
Barium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate and porewater concentrations (right)

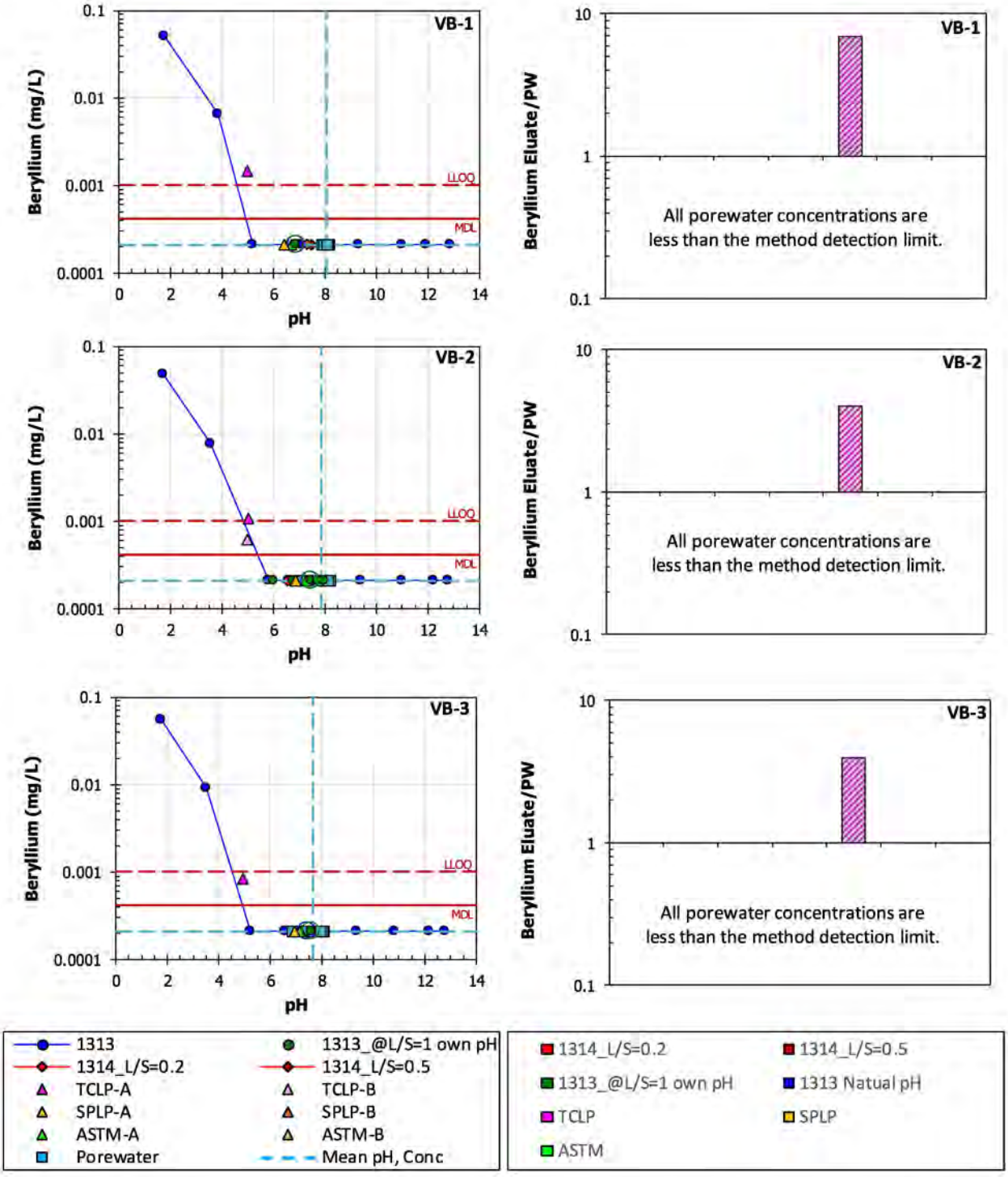


Figure G-4
Beryllium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

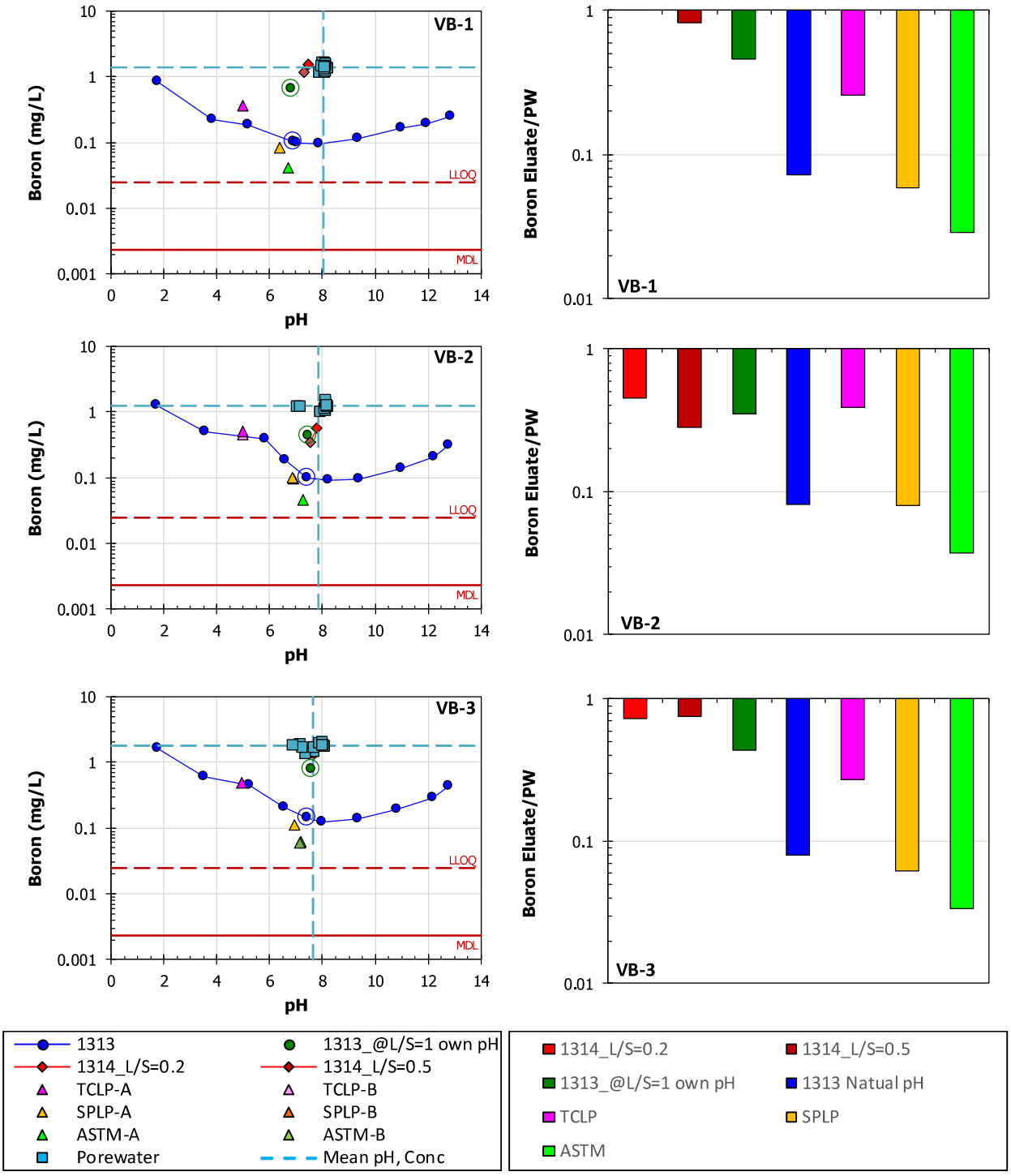


Figure G-5
Boron concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

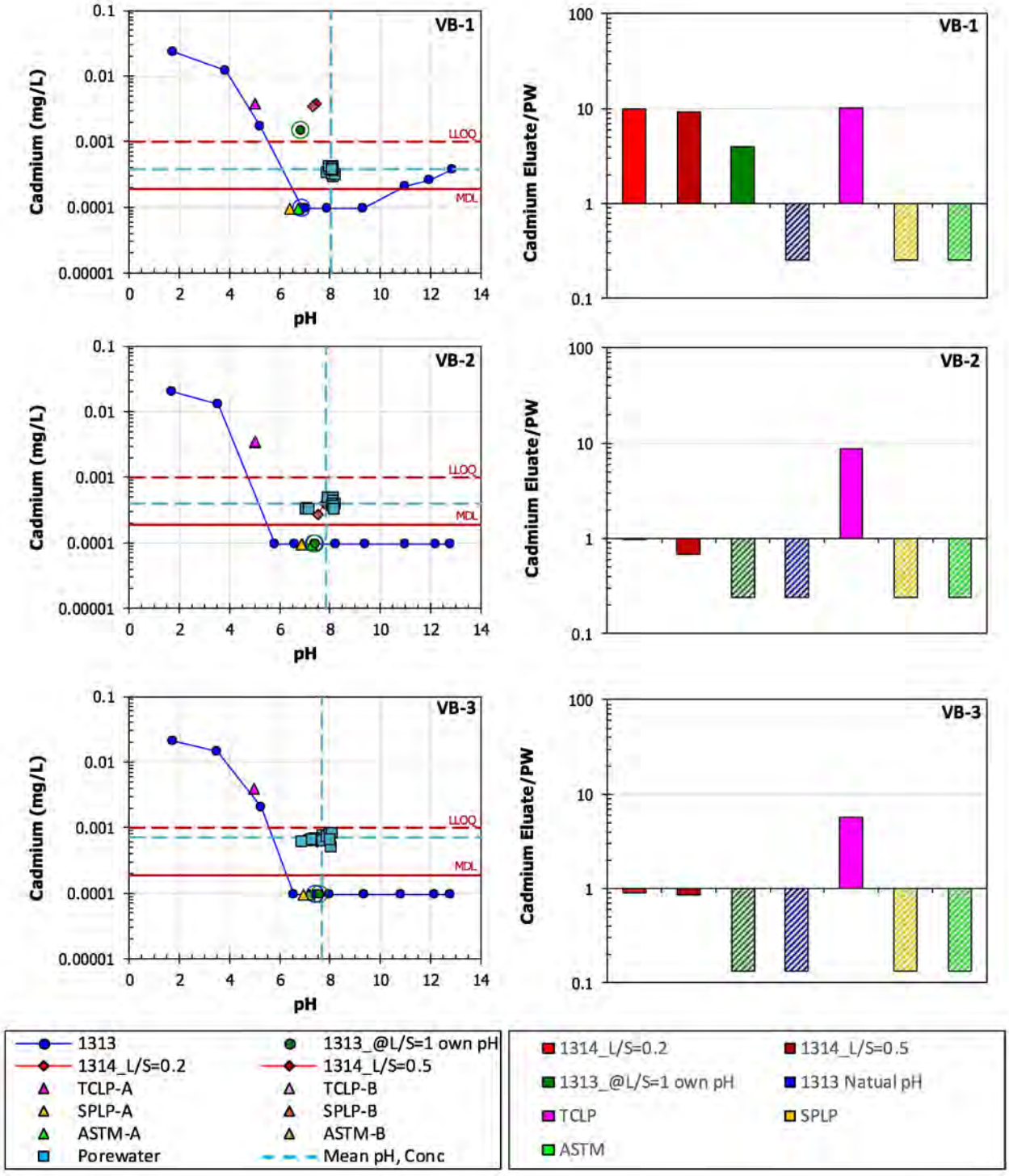


Figure G-6
Cadmium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

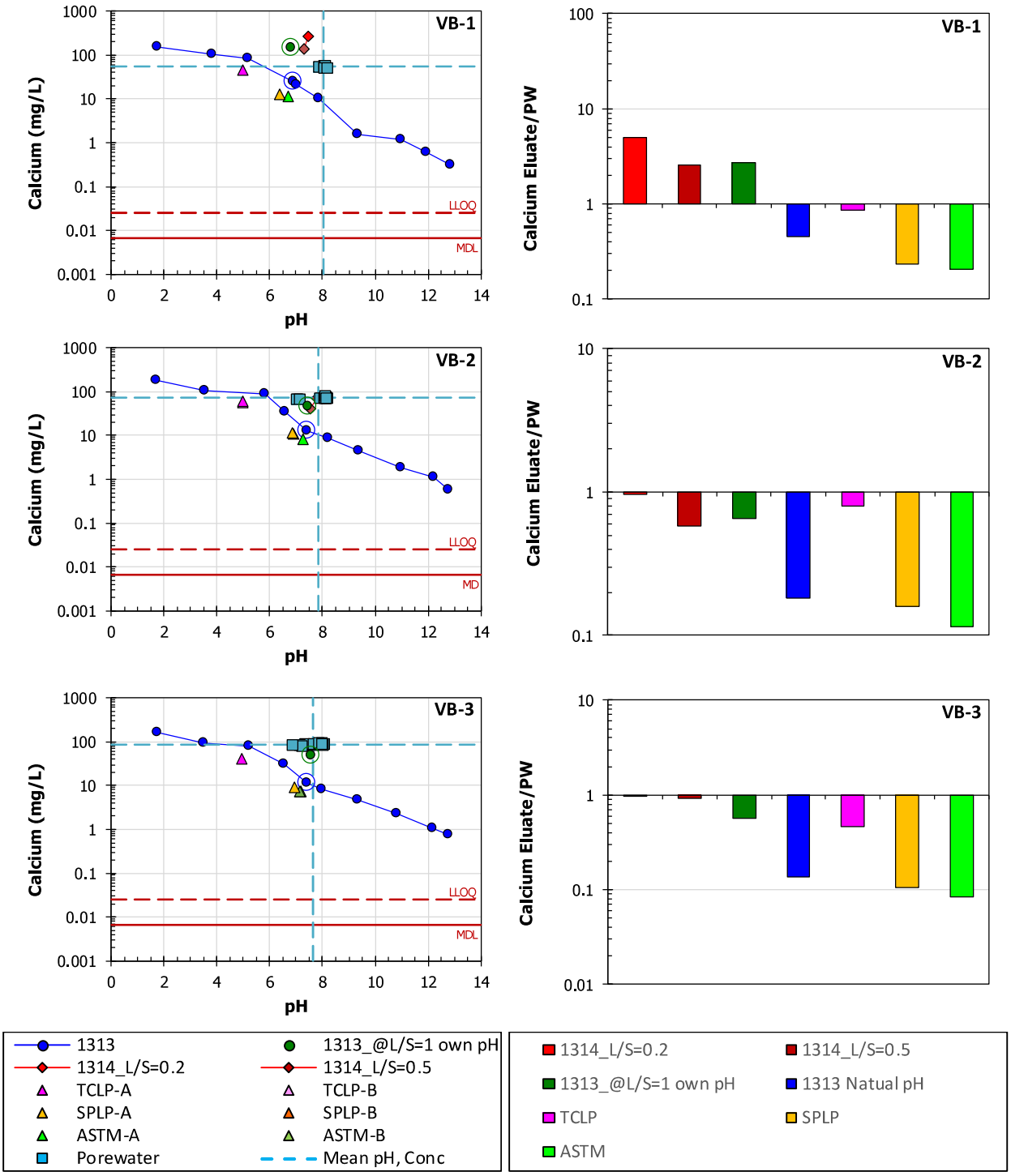


Figure G-7
Calcium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

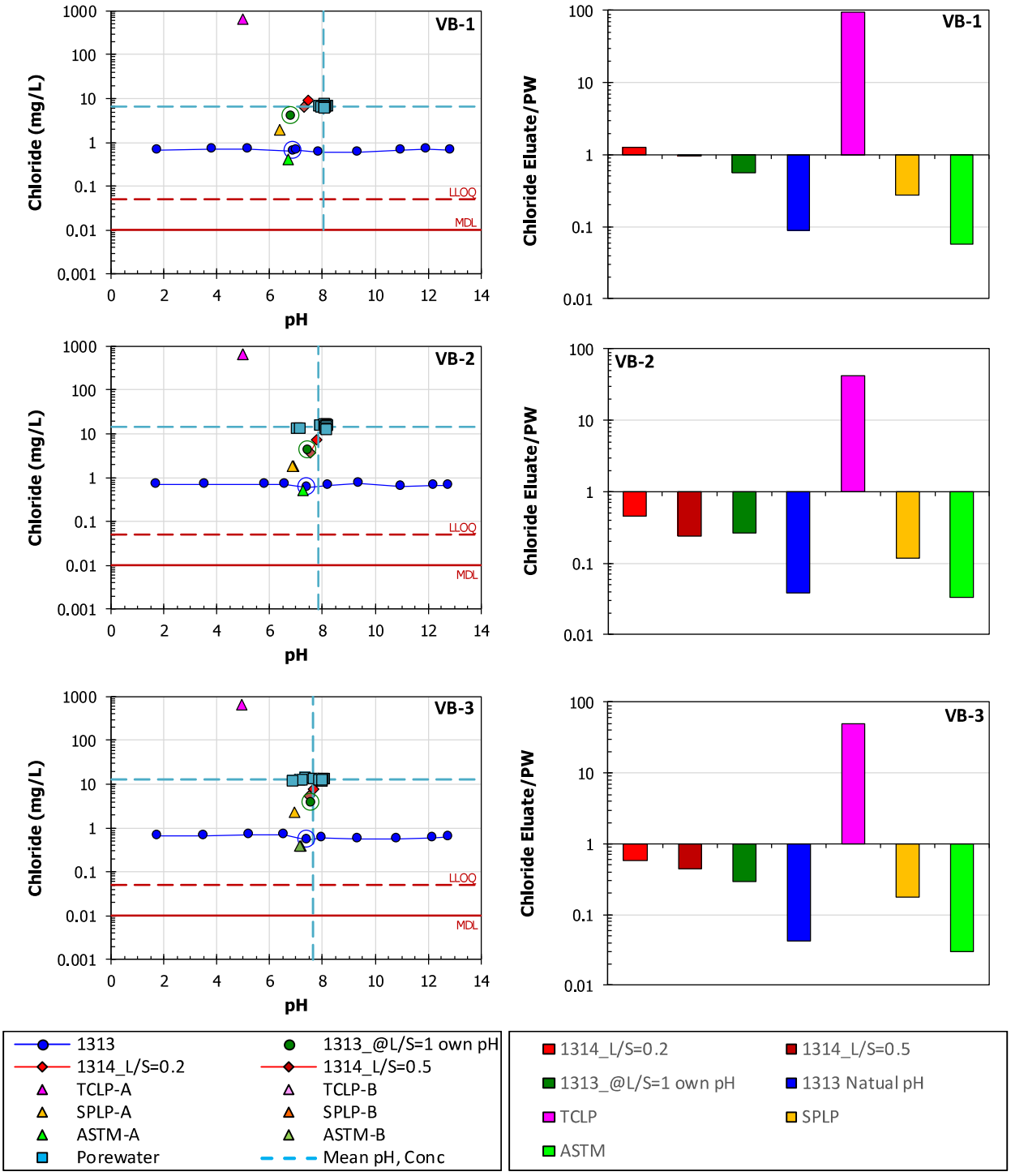


Figure G-8
Chloride concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

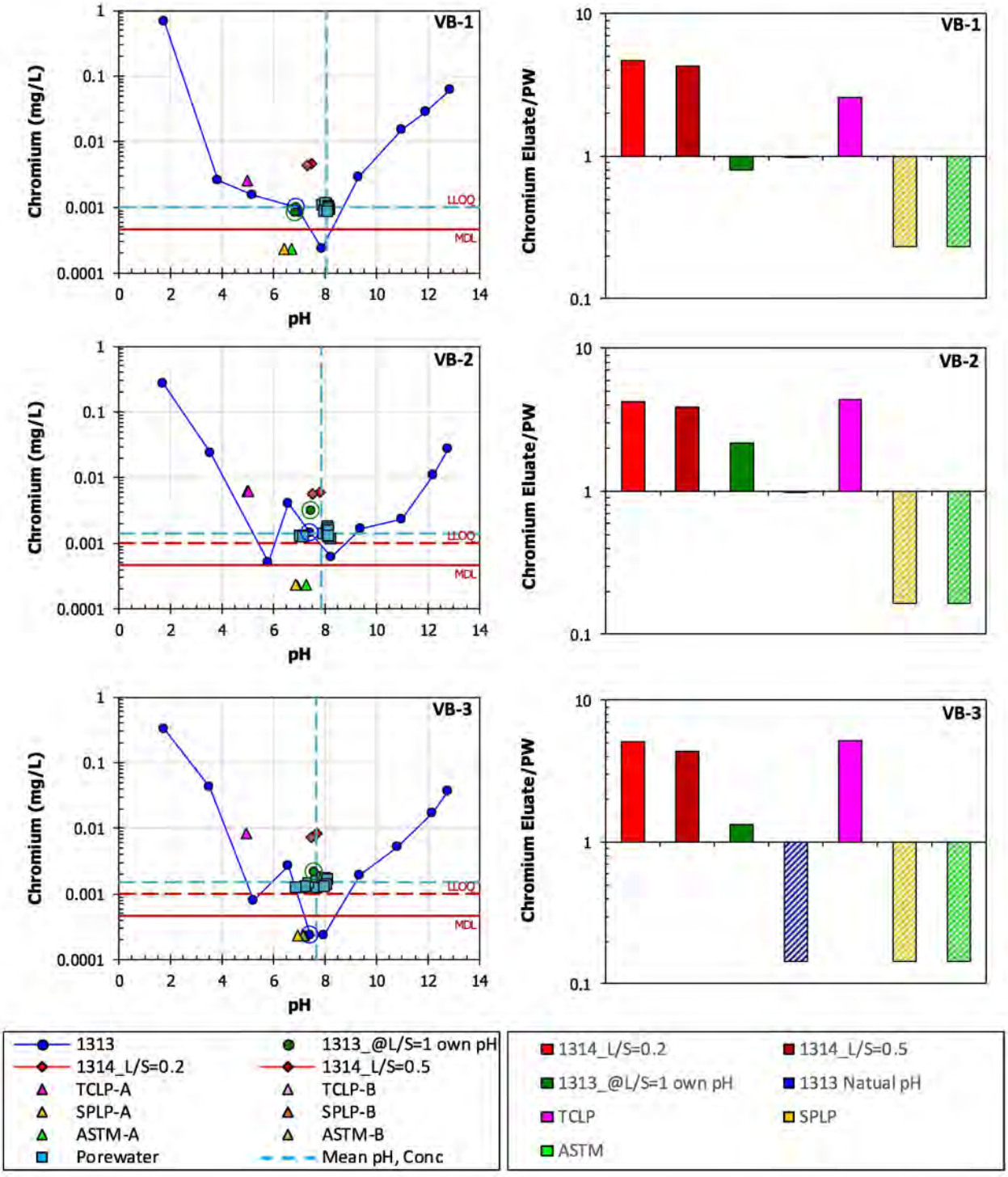


Figure G-9
Chromium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

Comparison of Porewater Estimates from Leaching Tests with Measured Values

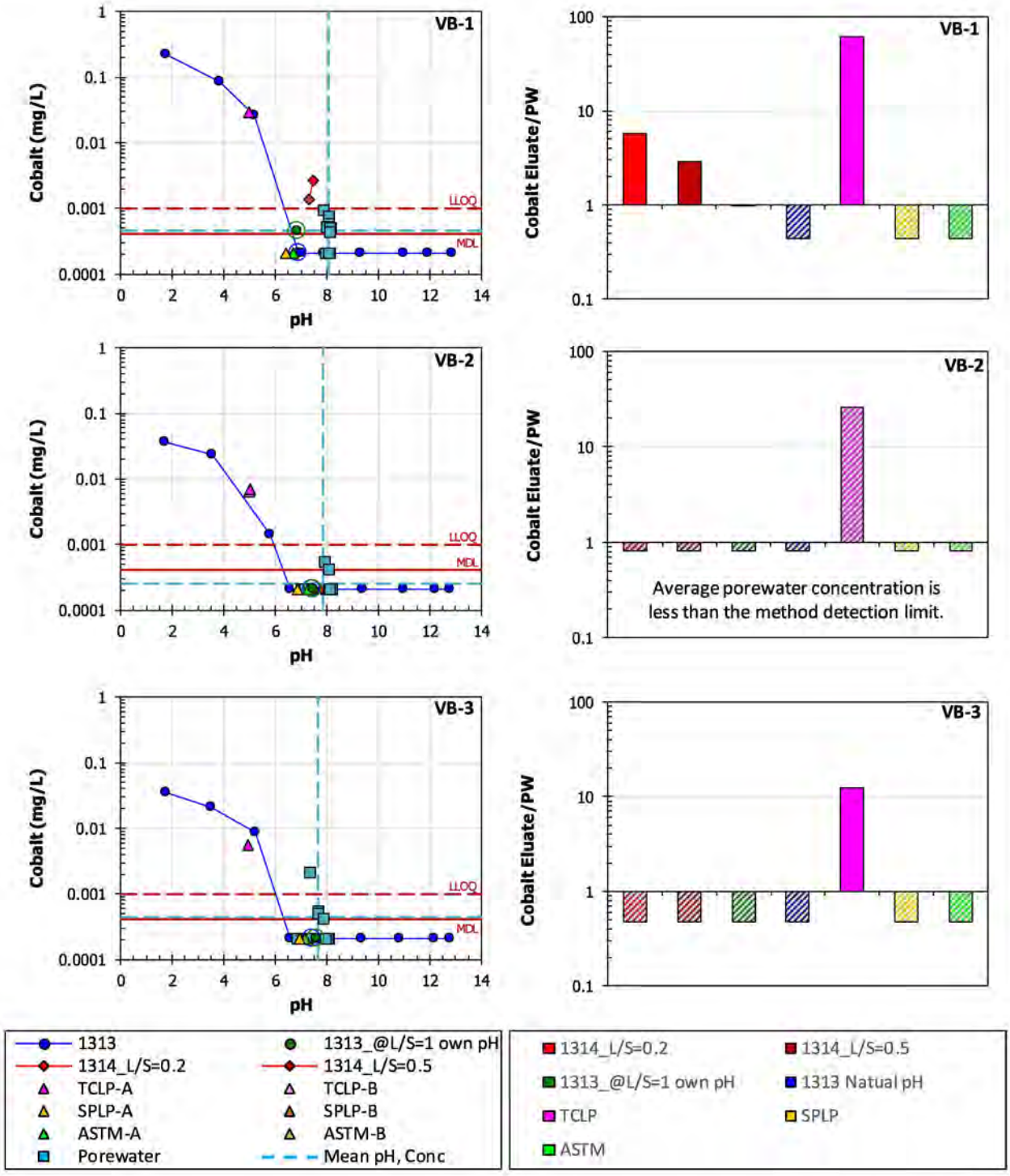


Figure G-10
Cobalt concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

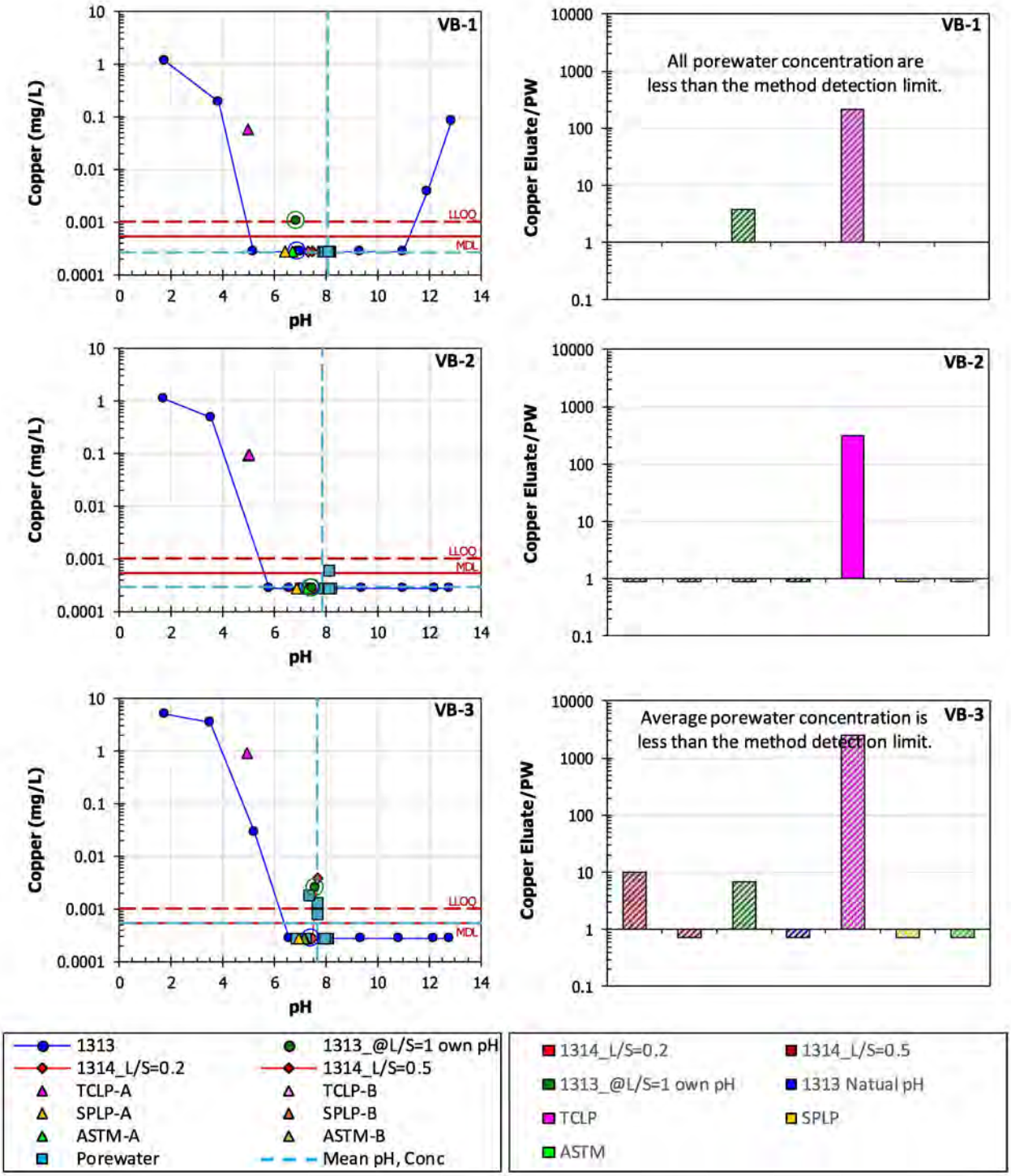


Figure G-11
Copper from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

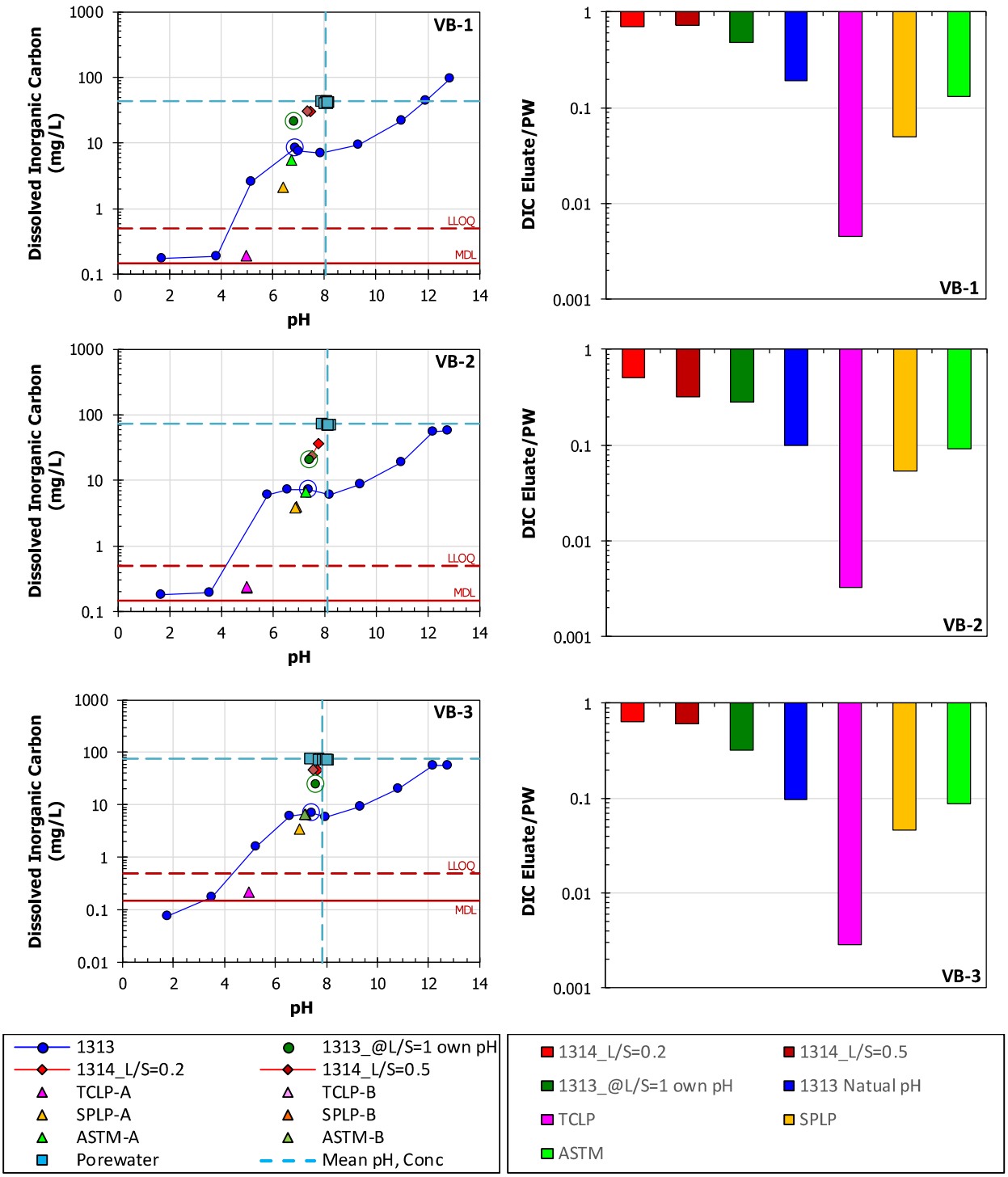


Figure G-12
Dissolved inorganic carbon concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

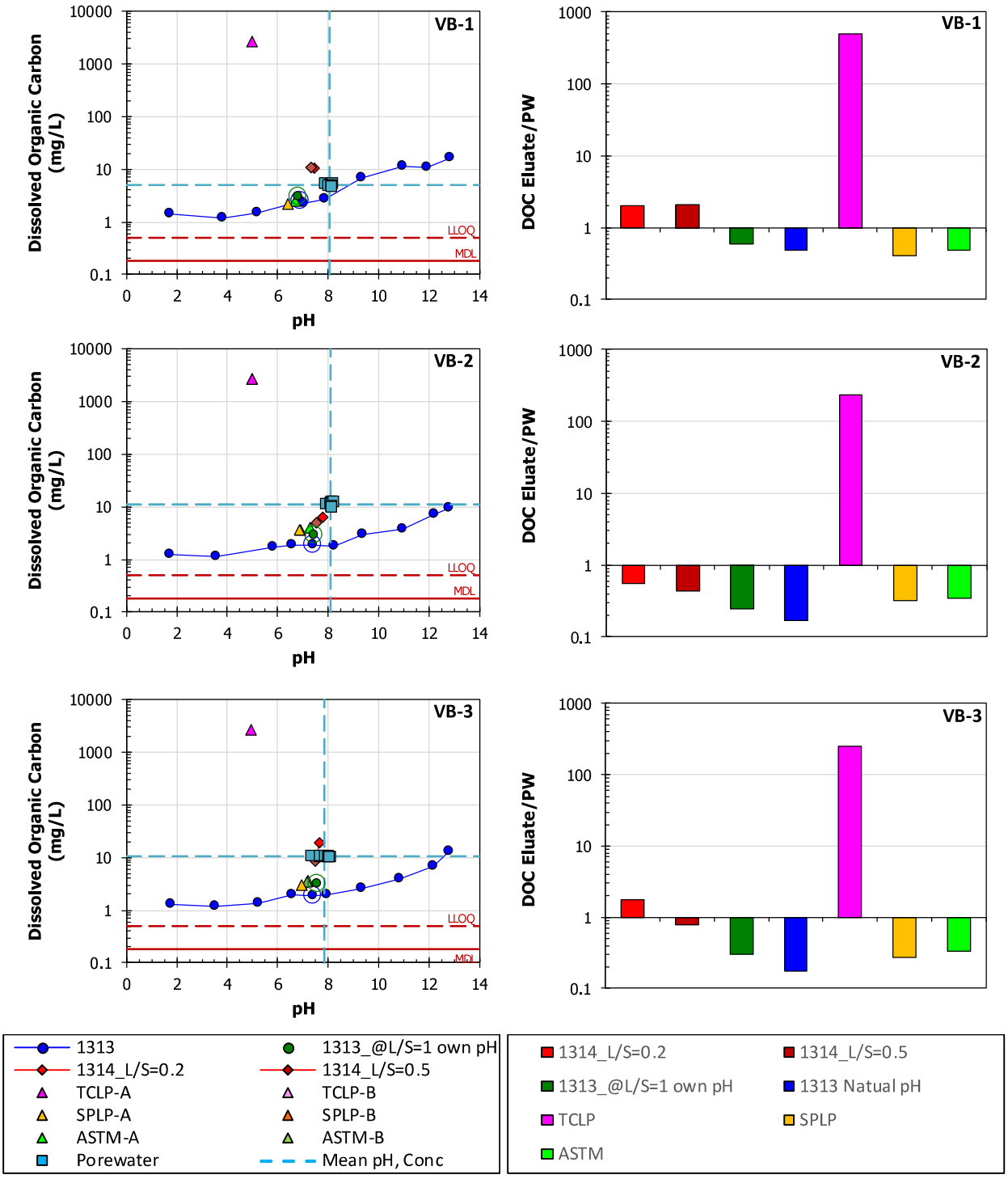


Figure G-13
Dissolved organic carbon concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

Comparison of Porewater Estimates from Leaching Tests with Measured Values

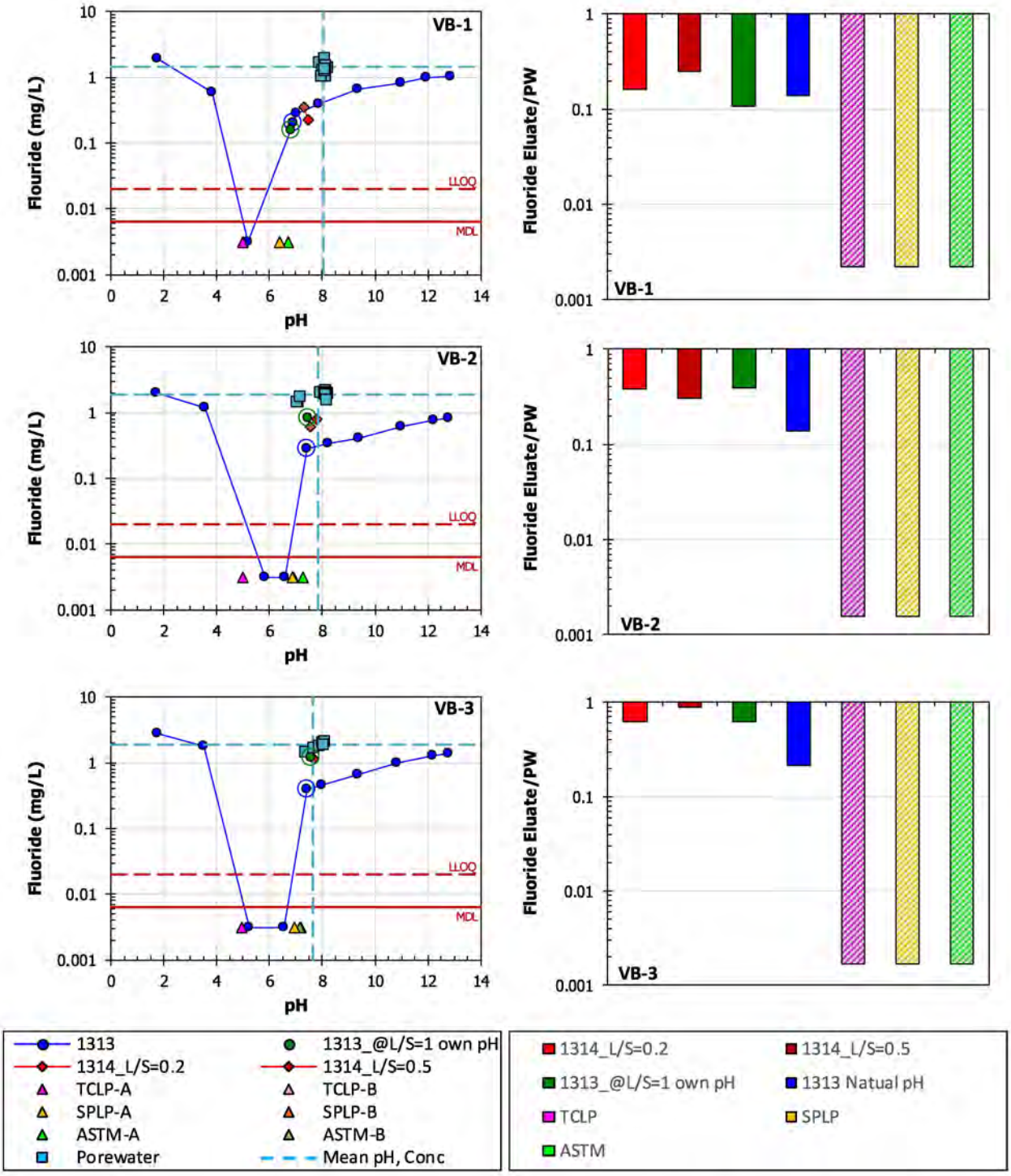


Figure G-14
Fluoride concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

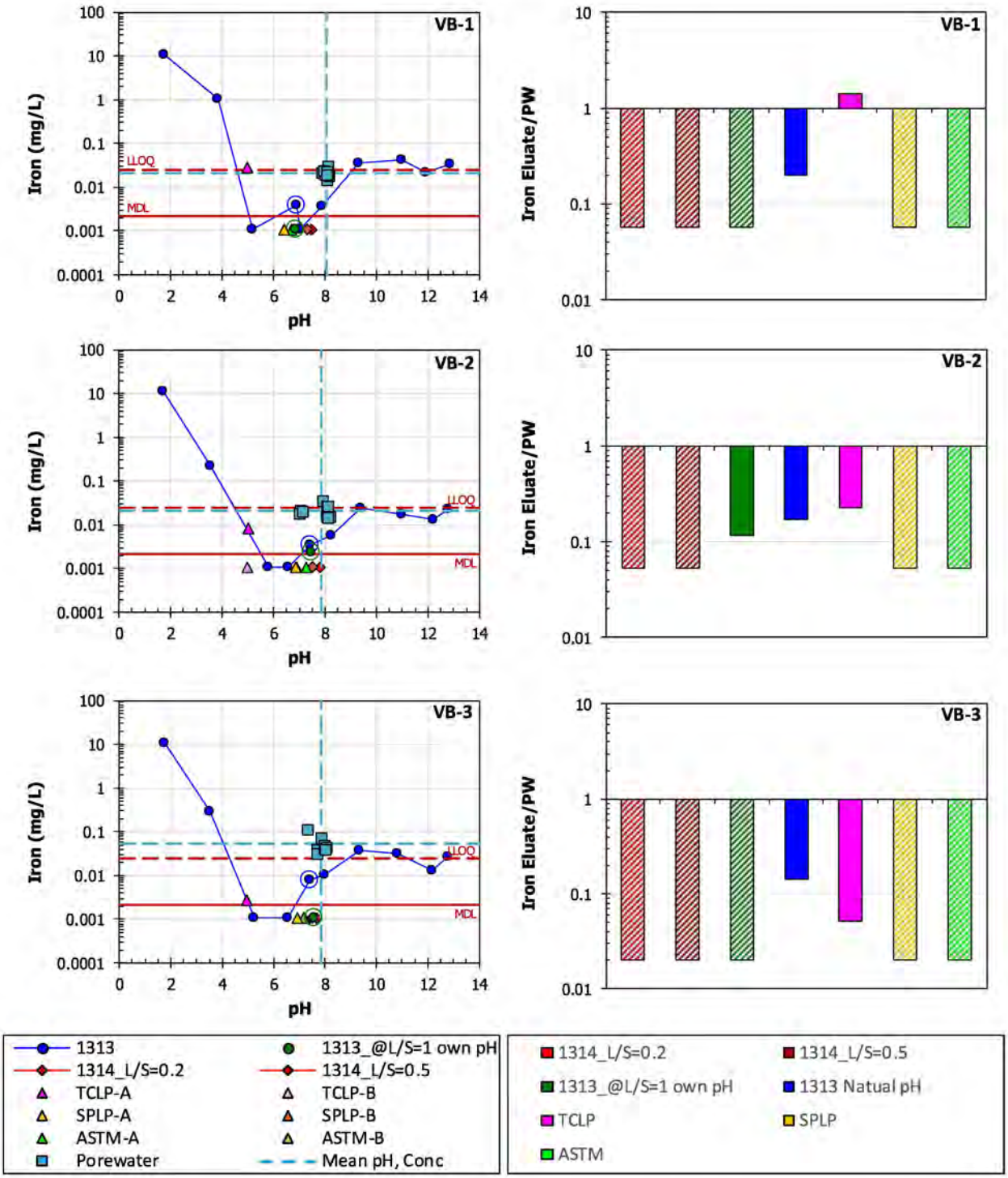


Figure G-15
Iron concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

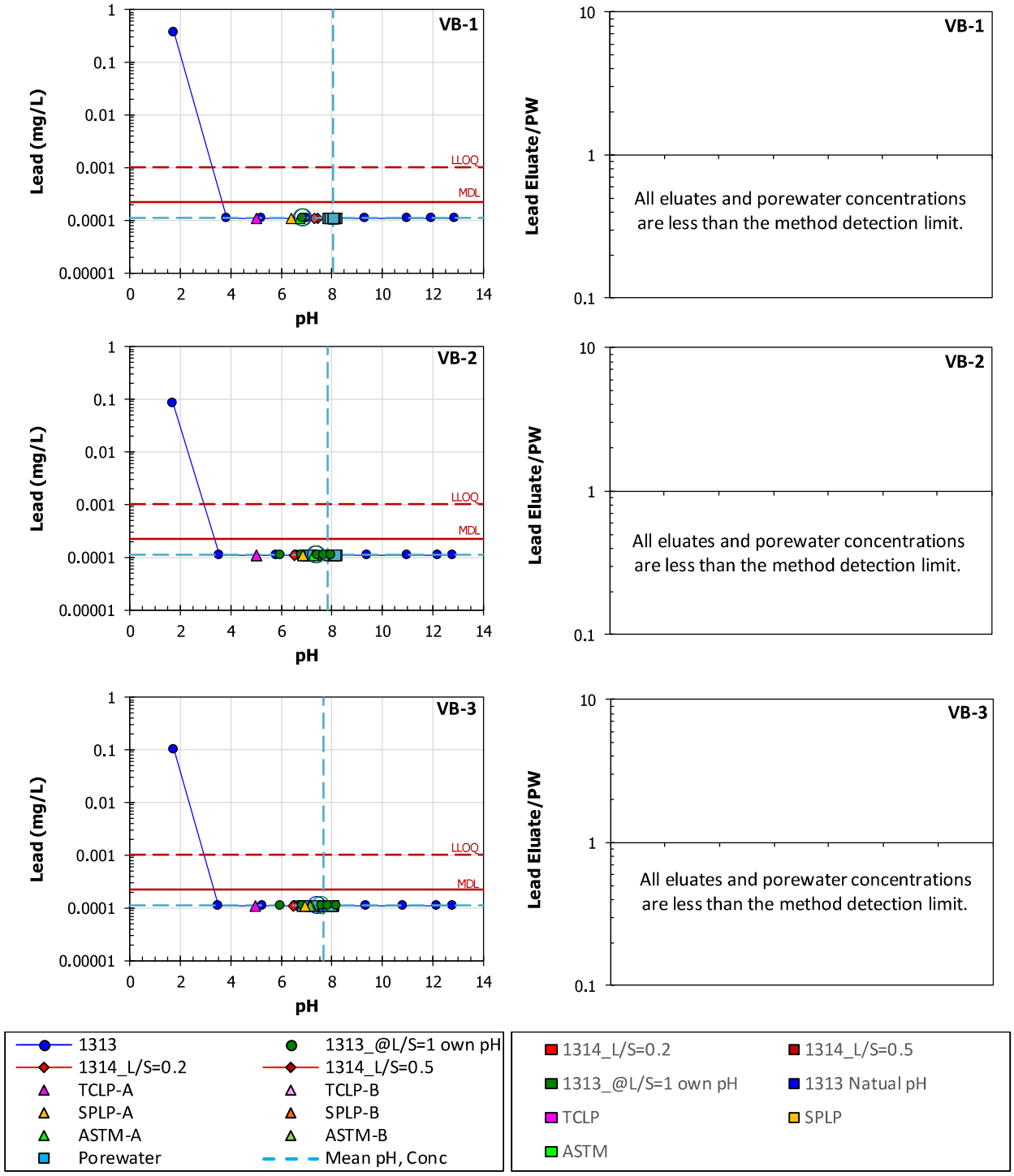


Figure G-16
Lead concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

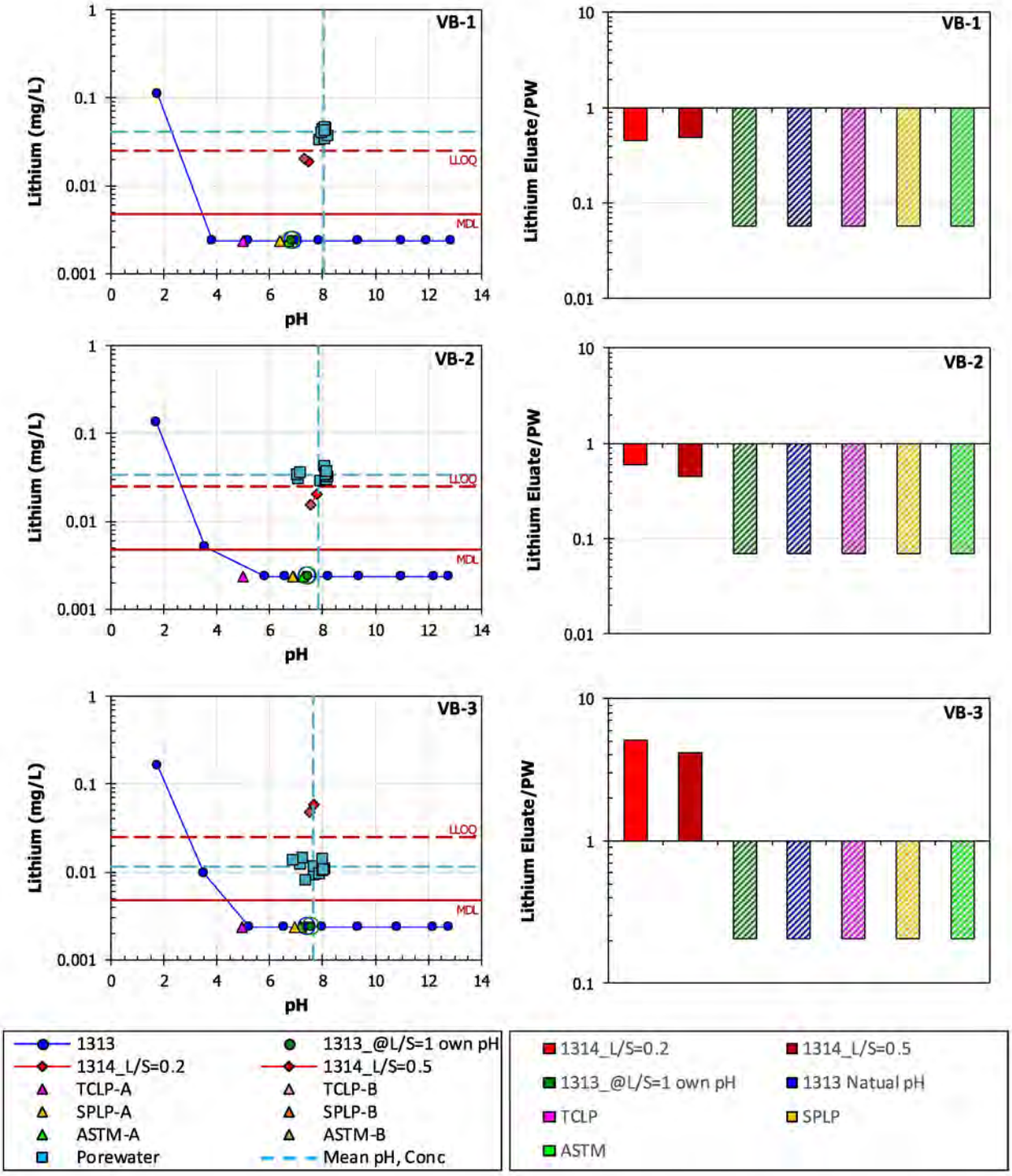


Figure G-17
Lithium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

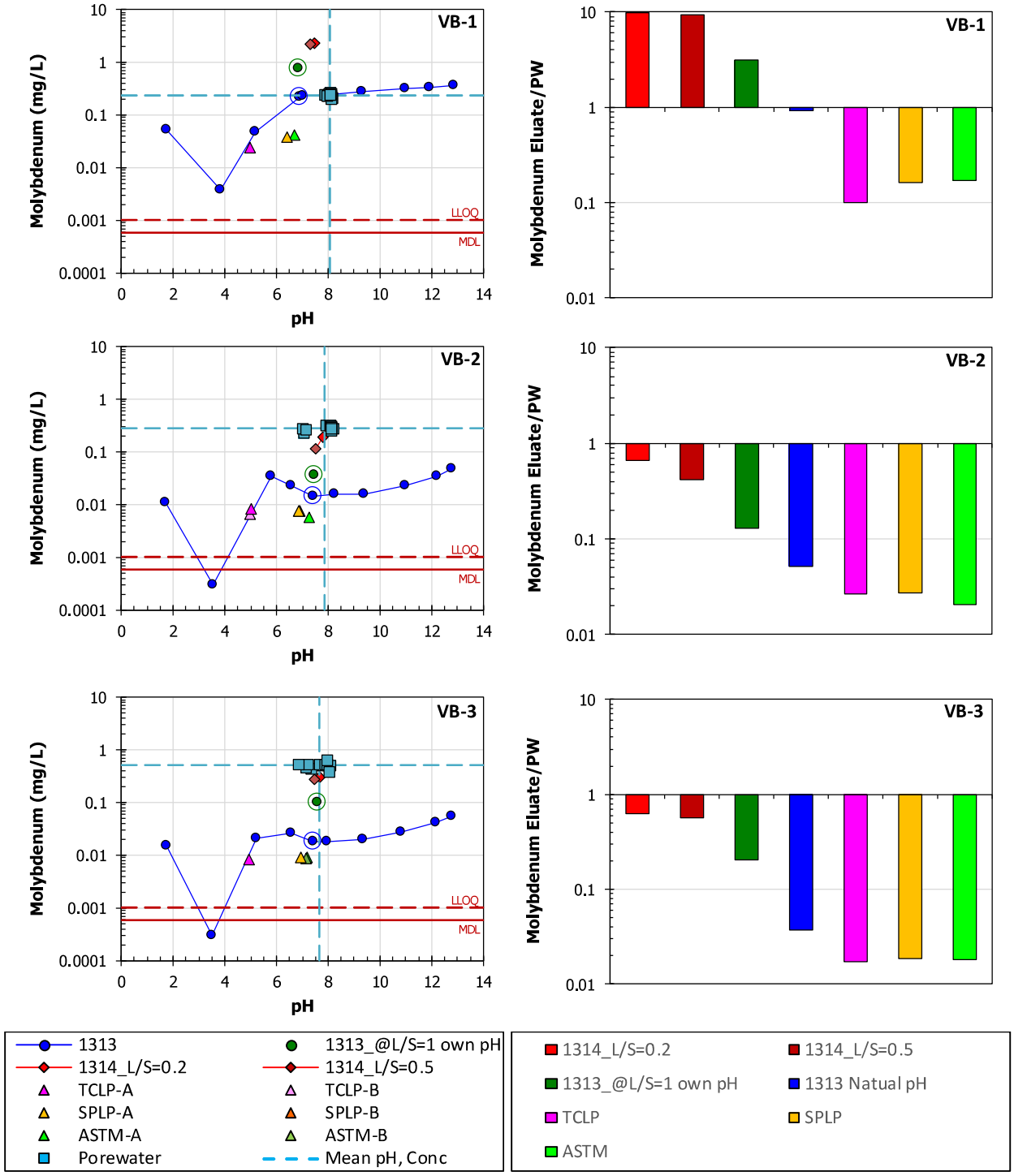


Figure G-18
Molybdenum concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)

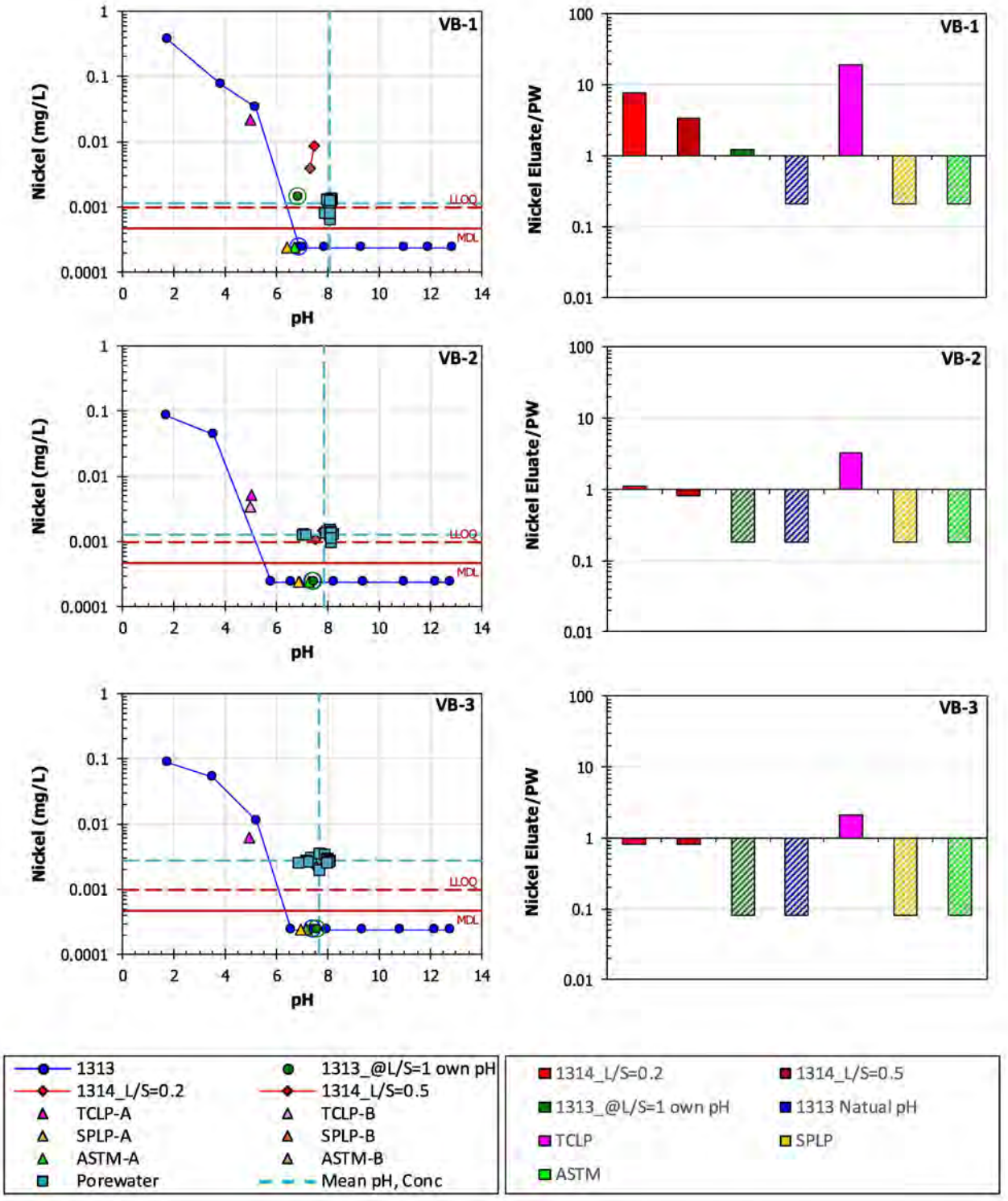


Figure G-19
Nickel concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

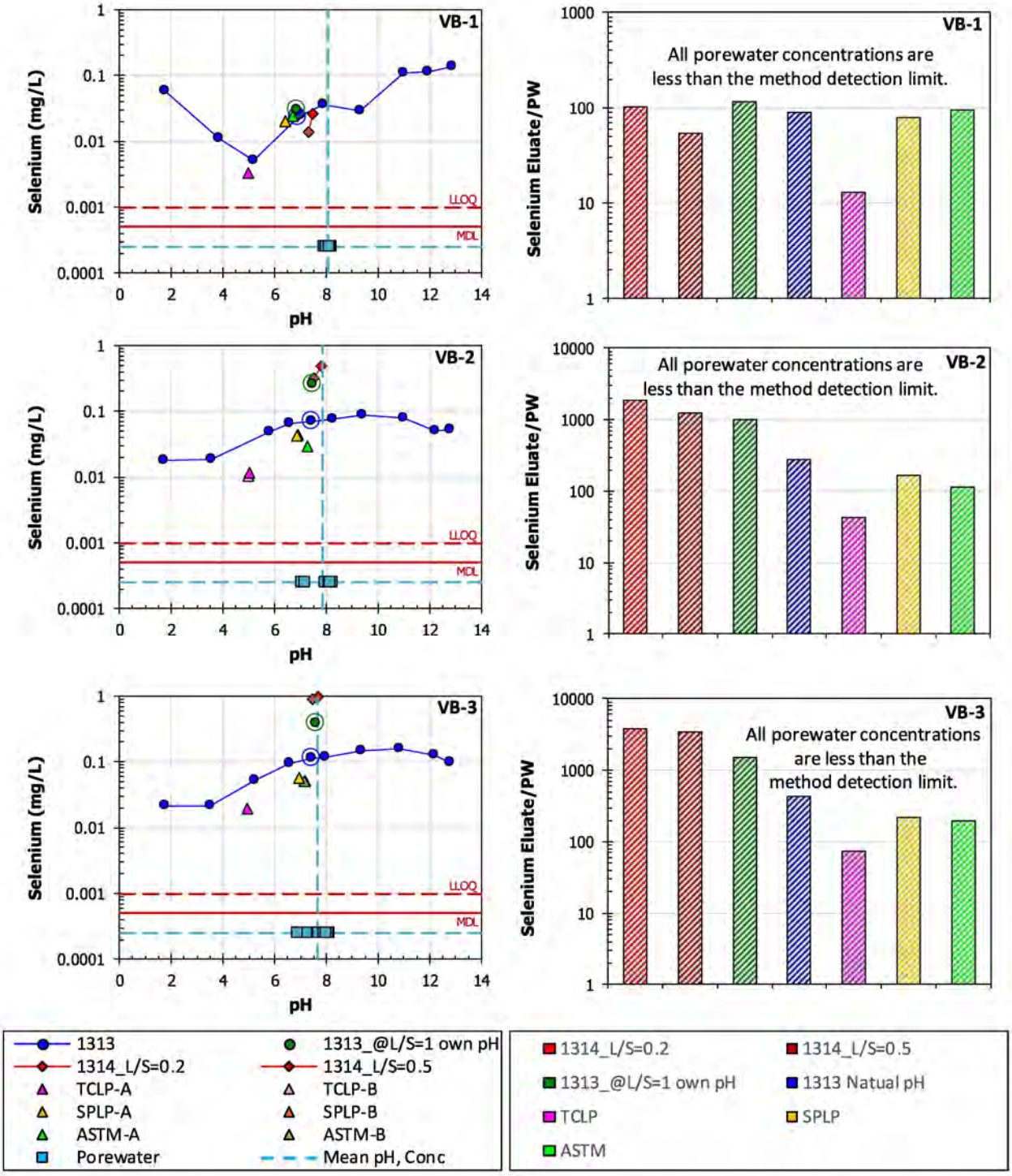


Figure G-20
Selenium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

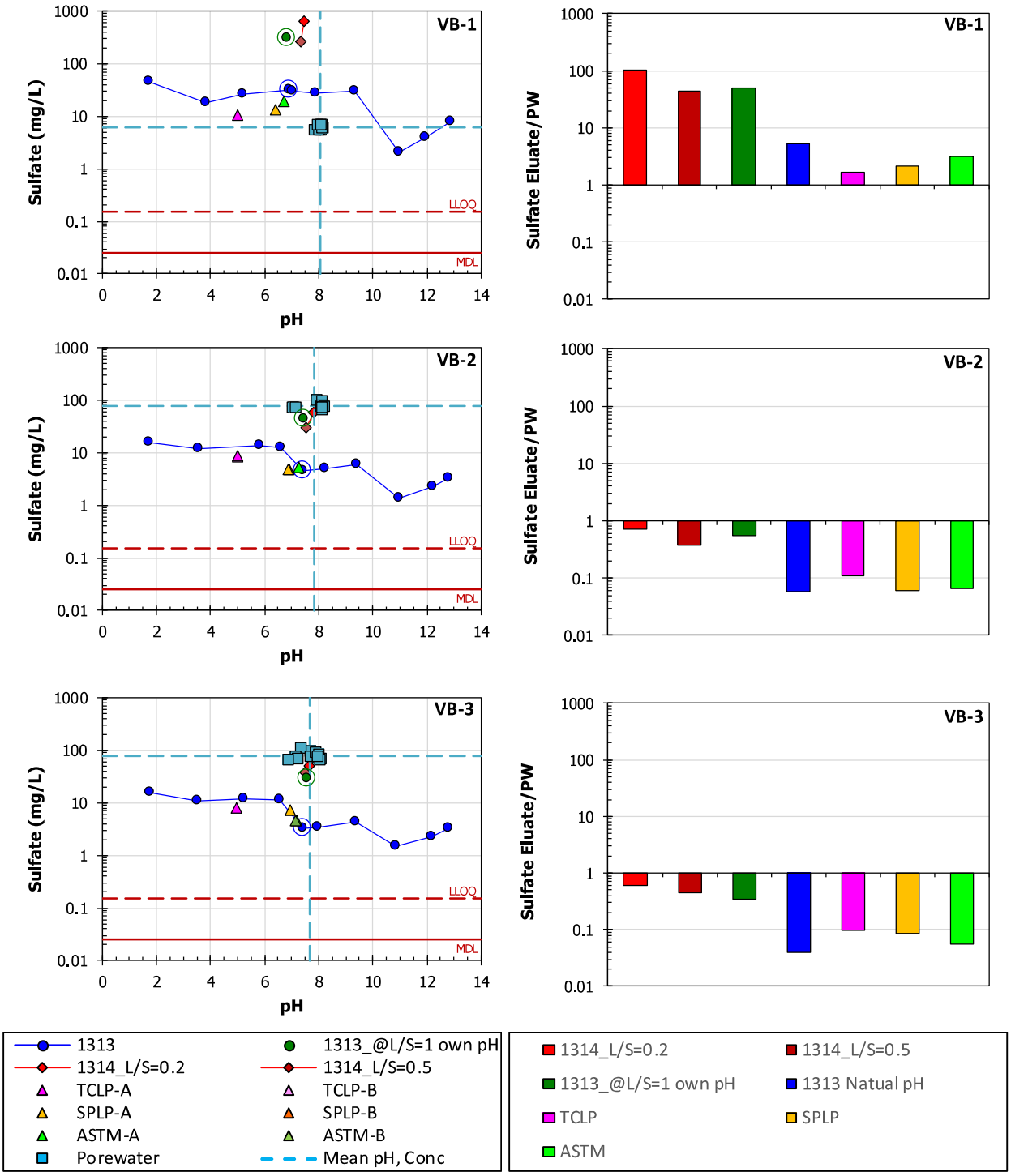
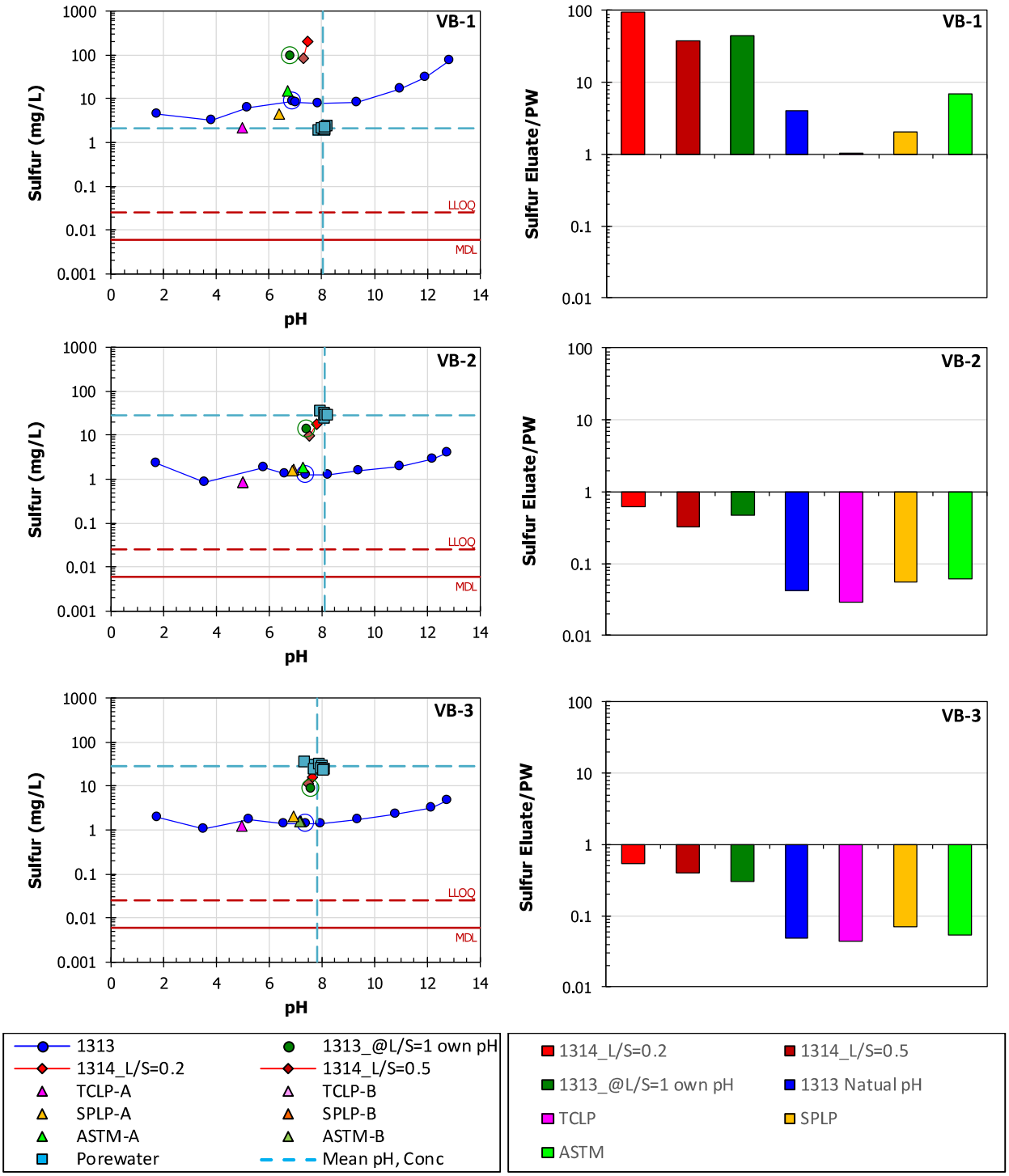


Figure G-21
Sulfate concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)



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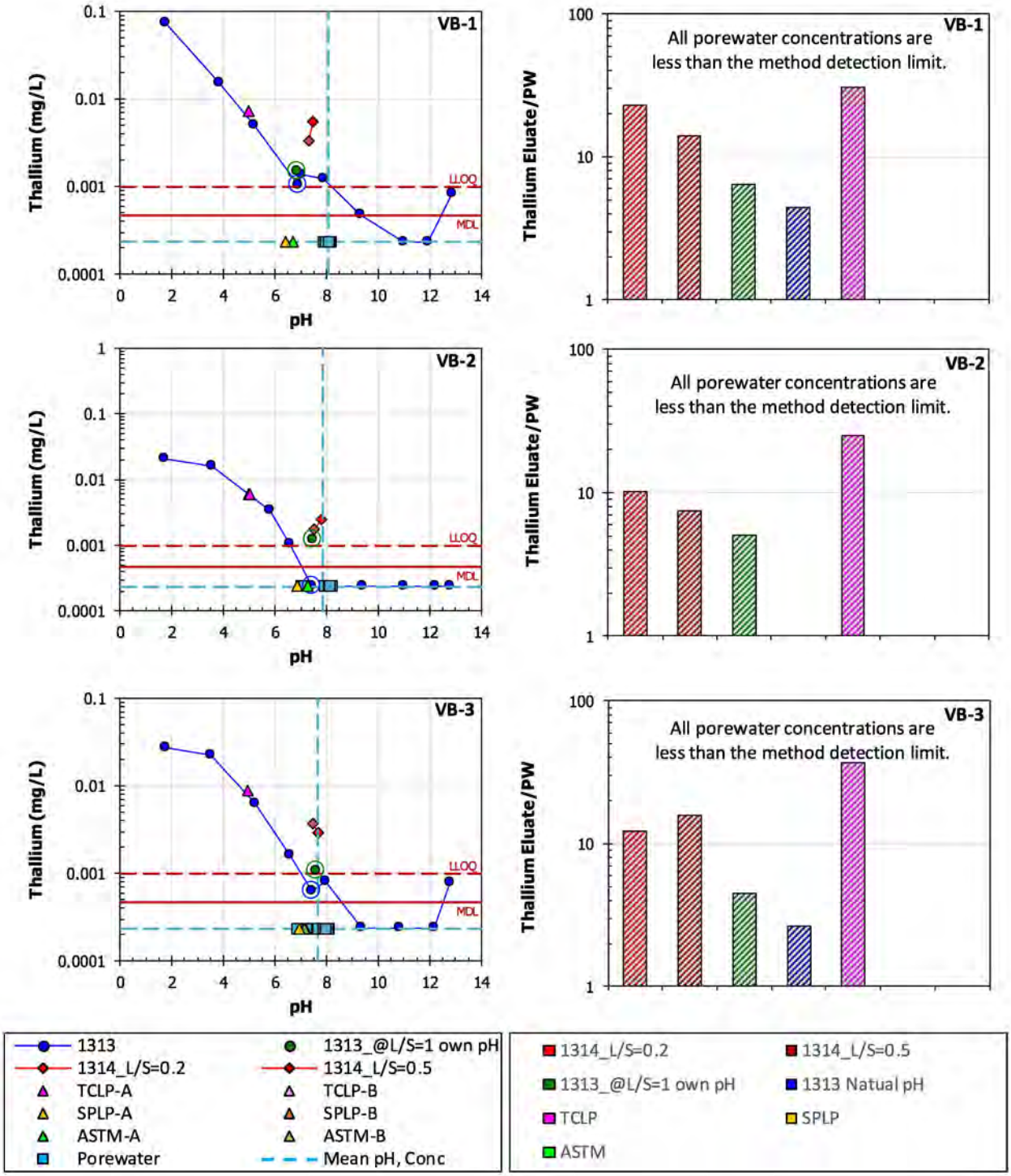
Sulfur concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right)



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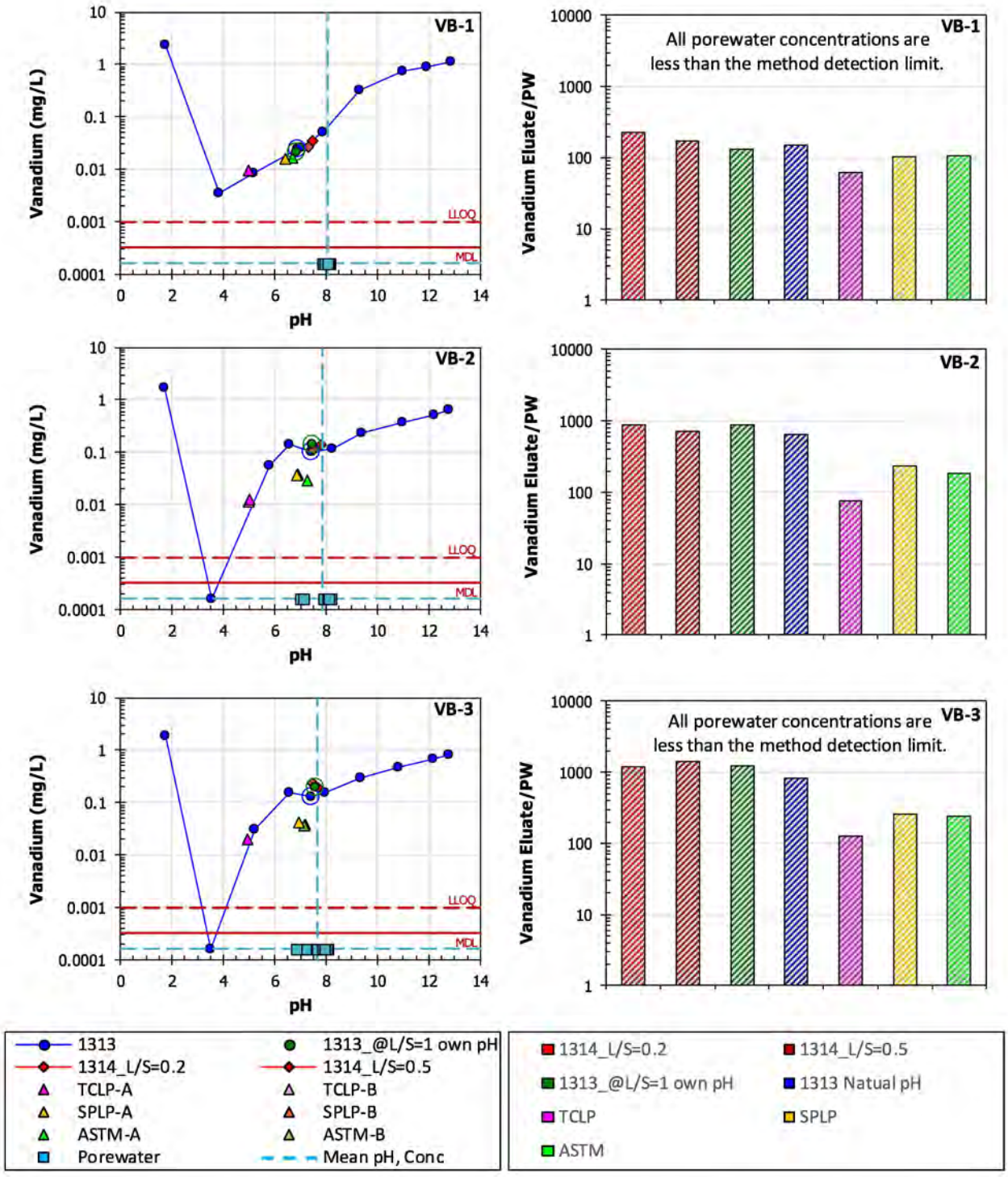
Thallium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value



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Vanadium concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

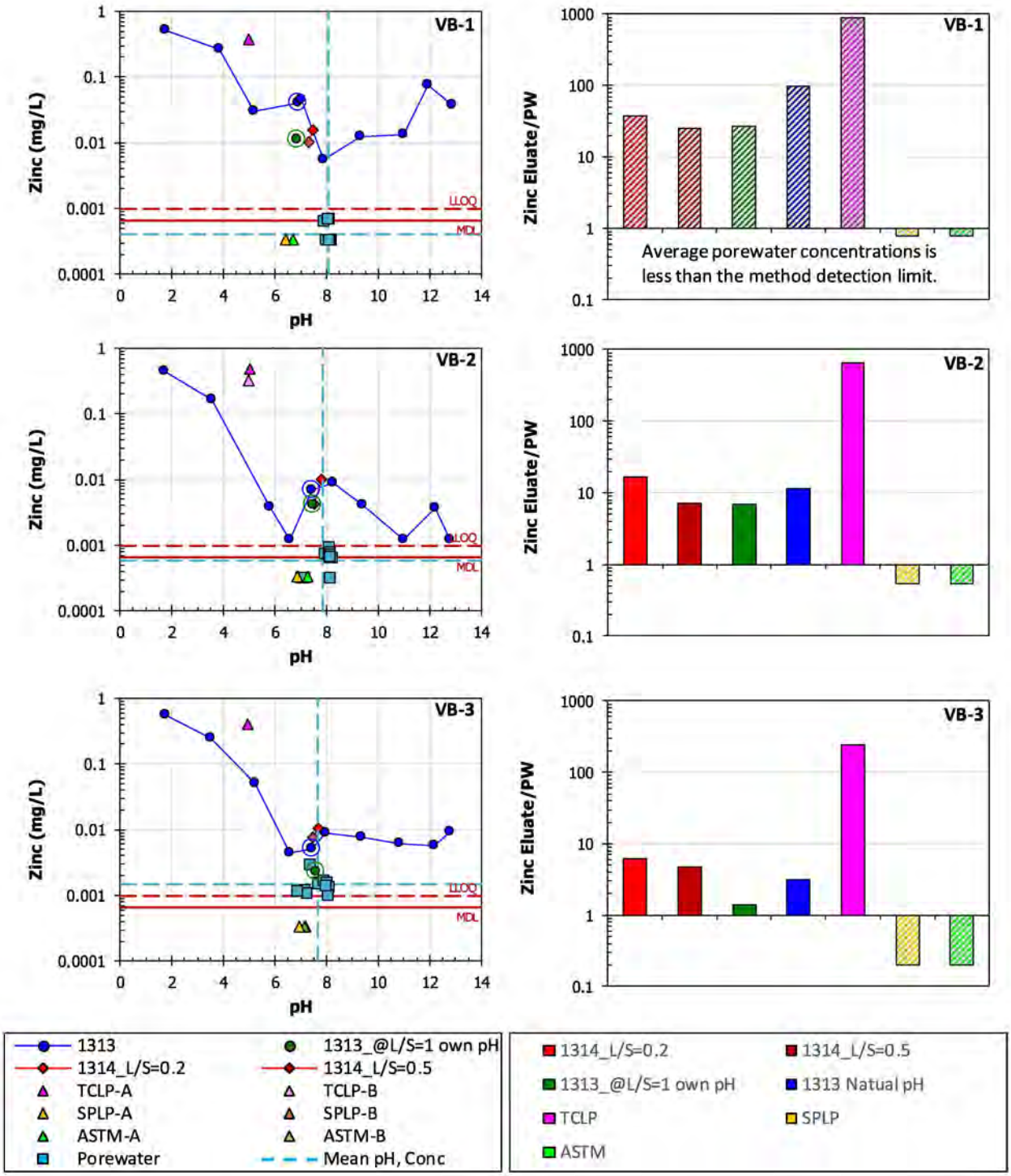

Figure G-25
Zinc concentration from leaching tests compared to measured and mean porewater concentrations shown as a function of pH (left) and as a ratio of eluate concentration to porewater concentration (right); crosshatched ratio results indicate estimates based on at least one MDL value

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Appendix 18

Electric Power Research Institute (EPRI), 2017. Guidelines for Development of Alternative Source Demonstrations at Coal Combustion Residual Sites. EPRI, Palo Alto, CA: 2017. 3002010920.

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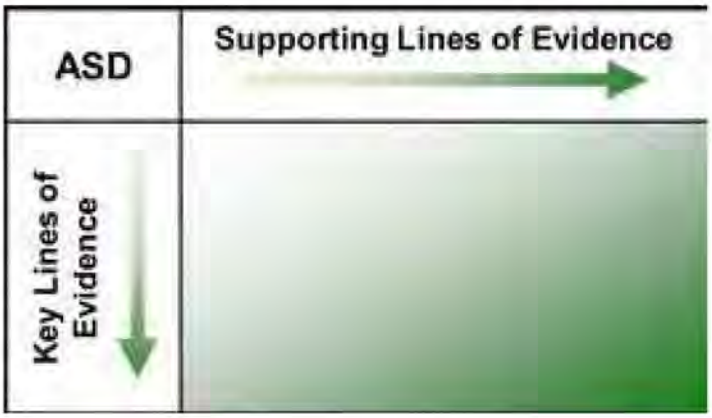
2017 TECHNICAL REPORT

Guidelines for Development of Alternative Source Demonstrations at Coal Combustion Residual Sites



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Guidelines for Development of Alternative Source Demonstrations at Coal Combustion Residual Sites

3002010920

Final Report, October 2017

EPRI Project Manager
B. Hensel

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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The following organizations prepared this report:

Natural Resource Technology, an OBG Company
234 W. Florida Street, Fifth Floor
Milwaukee, WI 53204

Principal Investigators
Y. Dedrickson
W. Roy
S. Cravens

Electric Power Research Institute
3420 Hillview Ave
Palo Alto, CA 94304

Principal Investigator
B. Hensel

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ABSTRACT

EPRI's guidance for alternative source demonstrations (ASDs) was developed to provide environmental managers at electric utilities with a list of alternative sources to check as well as a standardized, defensible approach for building and documenting an ASD when there are exceedances of one or more benchmarks established within a groundwater monitoring program. This guidance is designed for statistical benchmarks, in specific, statistically significant increases (SSIs) or statistically significant levels (SSLs) for groundwater monitoring under the federal Coal Combustion Residuals (CCR) rule and/or state regulations, but the guidance also applies to exceedances of other types of benchmarks such as groundwater quality standards.

The guidance provides information to help identify when a cause other than a release from the facility is the likely source of an SSI during detection monitoring or an SSL during assessment monitoring along with a checklist-based framework for developing a defensible ASD. The guidance covers ASDs developed in response to sampling causes, laboratory causes, statistical evaluation causes, natural variation, and alternative anthropogenic sources, with emphasis on development of an ASD when an SSI, SSL, or other exceedance is due to natural variation or an alternative anthropogenic source.

Keywords

Alternative source demonstration (ASD)
CCR Rule
Coal combustion residuals
Groundwater monitoring
Statistically significant increase (SSI)
Statistically significant level (SSL)

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Product Type: Technical Report

Product Title: Guidelines for Development of Alternative Source Demonstrations at Coal Combustion Residual Sites

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PRIMARY AUDIENCE: Electric utility environmental managers interpreting and responding to groundwater data collected under the Coal Combustion Residuals (CCR) rule and/or state rules

SECONDARY AUDIENCE: Consultants working for electric utilities with responsibility for responding to potential exceedances of benchmarks or criteria established for utility groundwater monitoring programs

KEY RESEARCH QUESTION

Groundwater monitoring programs developed for compliance with the federal CCR rule, and some state rules, use statistical analysis to determine whether or not individual results represent exceedances, which are often termed statistically significant increases (SSIs) over background in detection monitoring or statistically significant levels (SSLs) relative to a groundwater protection standard in assessment monitoring. However, the statistical methods are subject to false positive results, where a value that is not a true exceedance is flagged as such. Furthermore, there are literally dozens of causes related to sampling, laboratory analysis, natural variation, and other anthropogenic sources that can trigger an exceedance that is not due to a release from the monitored unit. When an exceedance is triggered due to a cause other than a release from the facility, federal and state regulations allow for an alternative source demonstration (ASD). At present, however, there are no criteria for how to develop and document an ASD.

RESEARCH OVERVIEW

This research provides guidance for identifying when an ASD is needed, evaluation techniques that can be used to support the demonstration, and a standardized checklist-driven approach for documenting a defensible ASD. The guidance is based on experience developing ASDs in states that have long used statistical analysis to determine compliance with groundwater quality benchmarks and is tailored for application in CCR monitoring programs.

KEY FINDINGS

- Potential sampling, laboratory, and statistical causes that can trigger an exceedance that is not due to a release from the CCR facility are described in Section 2. Checklist 1 outlines a methodology for demonstrating these causes.
- Natural variation can trigger an exceedance if there are changes in mineralogy along a groundwater flow path, changes in pH and/or redox over time or along a flow path, changes in groundwater elevation over time, and/or changes in groundwater flow direction over time (Section 4).
- Potential anthropogenic sources at a power plant that can trigger an exceedance at one or more monitoring locations include, but are not limited to, spills of petroleum or other materials, road salt, leakage of runoff from coal management areas, overspray of leachate used for dust control, accumulation of blowing dust near monitoring wells, leakage from leachate conveyance pipelines or tanks, and releases from other CCR units (Section 5).

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- Potential off-site anthropogenic sources include, but are not limited to, agricultural activities, road salt, coal mining, brines associated with oil and gas production, leaking underground pipes, pumping-induced brackish water, septic systems, and industrial or municipal waste management (Section 5).
- An ASD due to natural variation or an off-site or on-site anthropogenic source will be strongest if multiple lines of evidence are developed. Key lines of evidence include a lack of exceedances and a lack of increasing trends for primary indicators of the CCR, leachate concentrations for the affected constituent that are lower than concentrations observed in groundwater, major ion chemistry in the affected monitoring well that does not represent mixing of leachate with background groundwater, tritium age-dating showing that the groundwater is older than the CCR unit, and isotopic data showing that the groundwater at the affected monitoring well is not a mixture of background groundwater and leachate (Section 6).

WHY THIS MATTERS

False identification of an SSI can trigger assessment monitoring, and false identification of an SSL can trigger corrective action, either of which can increase the cost and manpower resources needed for groundwater compliance at CCR sites. An ASD can be used to demonstrate that these incremental increases in resource allotment are not necessary if the statistical exceedance is not due to a release from the facility. ASDs may be reviewed by state regulators and the public, and this guidance provides a standardized, checklist-driven approach for documenting a strong ASD.

HOW TO APPLY RESULTS

Users of this guidance can begin by reviewing Sections 2, 4, and 5 to determine whether or not an ASD is appropriate, and if so, the potential alternative causes that may explain the ASD. Section 3 describes evaluation techniques that can be used to support the ASD. The user can then use the checklists described in Section 6 and provided at the end of the document in Appendix B to build the ASD.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Statistical analysis used in CCR groundwater monitoring programs is described in *Groundwater Monitoring Guidance for the Coal Combustion Residuals Rule*. EPRI, Palo Alto, CA: November 2015. 3002006287.
- Techniques for evaluating groundwater quality data are described in *Groundwater Quality Signatures for Assessing Potential Impacts from Coal Combustion Product Leachate*. EPRI, Palo Alto, CA: October 2012. 1017923.
- Methodologies for application and evaluation of isotopic analysis are provided in *Application of Isotopic Methods to Coal Combustion Residual Groundwater Quality Investigations*. EPRI, Palo Alto, CA: December 2017. 3002010911.

EPRI CONTACT: Bruce Hensel, Principal Technical Leader, bhensel@epri.com

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
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ACRONYMS AND ABBREVIATIONS

ASD	Alternative Source Demonstration
CCR	Coal Combustion Residual
CCR Rule	Coal Combustion Residuals Rule (40 CFR 257 Subpart D)
CFR	Code of Federal Regulations
EPRI	Electric Power Research Institute
FR	Federal Register
GWPS	Groundwater Protection Standard
LCL	Lower Confidence Limit
MCL	Maximum Contaminant Level
MDL	Method Detection Limit
ORP	Oxidation Reduction Potential
PQL	Practical Quantitation Level
RL	Reporting Level
UCL	Upper Confidence Level
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SSI	Statistically Significant Increase
SSL	Statistically Significant Level
TDS	Total Dissolved Solids
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

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1
INTRODUCTION

Scope of Guidance

This guidance for alternative source demonstrations (ASDs) was developed to provide environmental managers at electric utilities with a list of alternative sources to check, and a standardized, defensible approach for building and documenting an ASD when there are exceedances of one or more benchmarks established within a groundwater monitoring program. The guidance is designed for statistical benchmarks, specifically statistically significant increases (SSIs) or statistically significant levels (SSLs) for groundwater monitoring under the Coal Combustion Residuals Rule (CCR Rule)[1] and/or state regulations, but the guidance is also applicable to exceedances of other types of benchmarks such as groundwater quality standards.[2]

The guidance provides information to help identify when a cause other than a release from the facility is the likely cause of an SSI during detection monitoring or an SSL during assessment monitoring, and a framework for developing a defensible ASD.

As provided for in the CCR Rule,[3] an alternative source demonstration can have a variety of causes:

- Sampling causes (ASD Type I)
- Laboratory causes (ASD Type II)
- Statistical evaluation causes (ASD Type III)
- Natural variation not accounted for in the basic detection monitoring or assessment monitoring statistics (ASD Type IV)
- Potential alternative sources (ASD Type V)
  - Anthropogenic impacts
  - Natural sources

Potential alternative sources, both anthropogenic and due to natural environmental influences, are the main focus of this report.

The scope of this document does not include guidance for performing a site investigation or establishing a groundwater monitoring system. Readers can refer to EPRI (2015) and a variety of other documents, many of which are listed in EPRI (2015), for such information.

[1] 40 CFR 257 Subpart D; published in 80 FR 21302-21501, April 17, 2015.

[2] The remainder of this document will primarily reference exceedances of SSIs or SSLs even though the methodology applies to exceedances of all types of benchmarks.

[3] 40 CFR 257.94(e)(2) for detection monitoring; 40 CFR 257.95(g)(3)(ii) for assessment monitoring.

2
TYPES OF ALTERNATIVE SOURCES

As stated in the CCR Rule at 40 CFR 257.94(e)(2), "The owner or operator may demonstrate that a source other than the CCR unit caused the statistically significant increase over background levels for a constituent or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. The owner or operator must complete the written demonstration within 90 days of detecting a statistically significant increase over background levels to include obtaining a certification from a qualified professional engineer verifying the accuracy of the information in the report." This section describes the five types of ASDs, provides example causes, and presents examples for how those causes might be identified.

Potential causes or investigation paths associated with each of the alternative source categories identified in the CCR Rule are listed in Table 2-1 and are discussed below. Anthropogenic sources are further discussed in Section 5, and natural variation is discussed in Section 4.

Table 2-1
ASD Types and Causes

Sampling Causes (ASD Type I)	Laboratory Causes (ASD Type II)	Statistical Evaluation Causes (ASD Type III)	Natural Variation (ASD Type IV)	Alternative Sources (ASD Type V - Natural and Anthropogenic)
• Sample mislabeling • Contamination • Change in technique • Excessive suspended solids or turbidity • Other sampling anomalies	• Analytical method • Calibration • Analytical technique • Contamination • Interference • Recording • Dilution errors • Digestion methods	• Lack of statistical independence • Outliers • Trends • Non-detect processing • False positives • New background data	• Geology • Precipitation • Seasonality • Water level • Changes in pH and/or ORP • Biological activity • Time of travel	• See Tables 2-2 and 2-3

Sampling Causes (ASD Type I)

- Sample mislabeling: One form of sample mislabeling is sample switching. Sample switching can be identified by sudden changes in concentration for the same constituent at two monitoring wells (Figure 2-1). Multiple constituents will be affected when this occurs, although it would only be evident for constituents with large differences in concentration

between the two monitoring wells. The multiple constituents will come from the same type of sample bottle (e.g., metals, IC analysis) if only one sample bottle is switched, and can come from multiple bottles if all bottles for two samples are switched. If analysis results suddenly differ from normal for a particular well, look for similar anomalies at other wells for patterns that could indicate swapped identification.

Another form of mislabeling can occur if the sample is taken from a different monitoring well than listed on the label (e.g., MW-01b instead of MW-01a), when the other monitoring well is not in the sampling program. In this case, only one monitoring well will show an anomaly for multiple constituents. This anomaly should affect all sampled constituents, although it will only be evident for constituents where concentration is different in the sampled well, relative to the well that should have been sampled. This case is more difficult to identify and demonstrate than the case of the switched sample. If all concentrations in a resample return to previous levels, then it is a possible explanation.

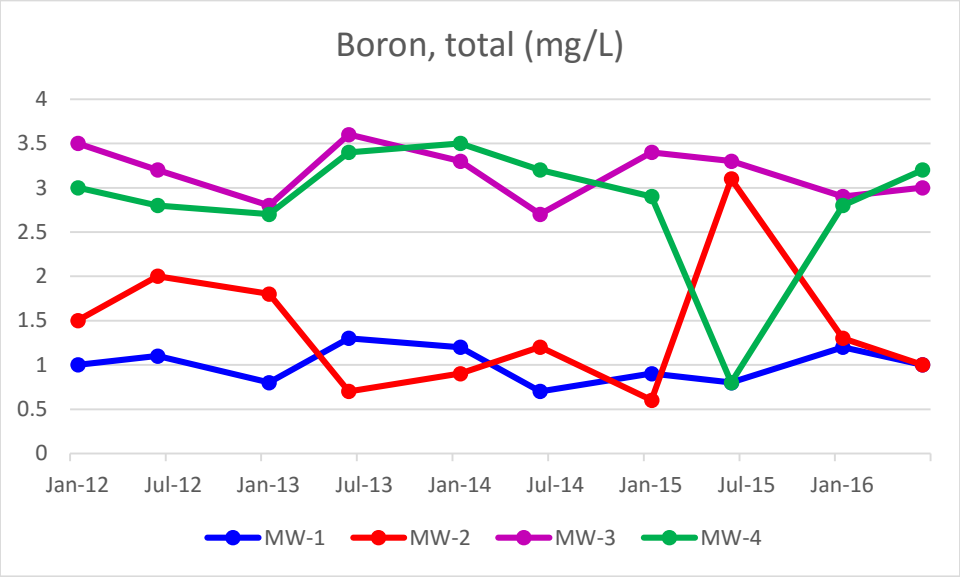

Figure 2-1
Time series plot showing potential sample mislabeling (switching)

- Contamination: If non-dedicated sampling devices are used to collect samples, contamination from the sampling equipment could potentially cause unrepresentative, elevated concentrations that could trigger an SSI/SSL. This type of sampling error is more likely to affect trace elements such as those found in Appendix IV of the CCR Rule than higher concentration elements such as those listed in Appendix III of the CCR Rule. An equipment blank (also called a rinsate blank) is a field quality control sample consisting of the rinsate from equipment used to collect the sample. Check the equipment blank analytical results to assess the potential for cross contamination, which will be evident by elevated concentration in the equipment blank. A field blank is a sample of deionized water from the laboratory that is opened in the field to assess the potential for field contamination. Field blanks are not always used for groundwater sampling at CCR sites. If field blank analytical results are available, check to assess the potential for field contamination unrelated to the sampling equipment.

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- Sampling technique: A change in sampling technique, whether planned or due to an error, can have an influence on resulting concentrations if it affects the amount of sediment, as measured by turbidity, in the sample. See the next bullet for turbidity effects.
- Turbidity: Sudden increases in total dissolved solids and/or trace element concentrations can sometimes be associated with an increase in suspended solids/turbidity in a sample, relative to previous samples. Because the CCR Rule requires collection and analysis of unfiltered samples, elements comprising or attached to the particulate matter that causes turbidity are digested and analyzed along with the dissolved elements in the sample. Therefore, a turbid sample can yield higher concentrations for the elements that make up or are attached to the particulate matter. Evaluate the sampling technique used and the field analytical results, particularly the turbidity value if available, to assure that low-flow sampling procedures were properly followed. If the field analytical results do not indicate that stabilization of the field parameters (pH, temperature, specific conductance, dissolved oxygen, redox potential, and turbidity) was achieved, then sampling technique may be a defensible cause for an SSI/SSL. Some facilities establish sampling protocols that include collection of replicate filtered samples whenever a sample location has a turbidity greater than 10 to 20 NTU to allow comparison of analytical results between filtered and unfiltered samples. If filtered results are available, and are considerably lower than the unfiltered results, then turbidity resulting from differences in sampling technique, a screen failure in the monitoring well, or a need for redevelopment may be defensible alternative causes.
- Sampling anomalies: Review field documents (chain of custody form, calibration logs for field equipment, field notes, and field data) to see if any issues were encountered during the sampling event that could potentially affect the sample integrity. Potential anomalies may include improper bottles or preservation, inadequate calibration of field instruments, failure to achieve stabilized field parameters prior to sampling, use of non-dedicated or improperly cleaned equipment, improper labeling, etc.

Laboratory Causes (ASD Type II)

There are opportunities for potential contamination or errors associated with laboratory procedures, equipment decontamination and calibration, and sample handling and analysis. In addition to the analytical results, laboratory reports include documentation of methods and data qualifier flags to indicate potential issues that may affect the accuracy of results. The following are common data qualifiers for inorganic constituents sanctioned by USEPA:

- U = Reading was less than the method detection limit (MDL).
- J = Reading was less than the contract required quantitation limit but greater than or equal to the MDL.
- B = Analyte was found in the method blank as well as in the sample. Indicates possible/probable blank contamination.
- E = Reported value is estimated due to the presence of an interference. Look for comments.
- N = Spiked sample recovery not within control limits.
- * = Duplicate analysis not within control limits.
- D = The reported value is from a dilution.

The B, E, N, *, and D flags all indicate potential for laboratory errors that may have triggered an SSI/SSL, and warrant a closer look at the results to determine if the reported results may be invalid and if resampling and/or an ASD should be considered.

Potential errors associated with laboratory handling and analysis include:

- Calibration: Use of poorly or inadequately calibrated instruments may cause elevated analytical results that are not representative of the water quality at the sampling location. If results for a particular analyte in multiple samples, particularly if all were analyzed on the same day (laboratories typically recalibrate their instrumentation daily), are higher than the norm, then poor calibration of analytical equipment may be a potential cause. Consider reviewing instrument calibration records to see if poor calibration is a defensible alternative source for the SSI or SSL.
- Contamination: One or more samples may be contaminated by improperly cleaned and/or prepared sample bottles, analytical equipment, calibration standards, reagents, or preservatives. This type of error is more likely to be evident for trace elements such as those found in Appendix IV of the CCR Rule than for higher concentration constituents such as those listed in Appendix III of the CCR Rule. If sample contamination is suspected, evaluate the analytical results for trip blanks (if available) and method blanks. Trip blanks are sample bottles filled with laboratory-prepared deionized water that accompany the samples to and from the field, without being opened. If trip blank results show detection of analytes, it is possible that the sample bottles may not have been properly cleaned or the deionized water may have been contaminated. Method blanks are analyte-free laboratory quality control samples subjected to the entire analytical process used to demonstrate that the analytical system did not introduce contamination. The method blank results should be below the method reporting limits. If they are not, then the analytical process may have introduced contamination. Look for "B" data qualifiers to determine if the analytes were detected in the method blank.
- Digestion Methods: Use of more aggressive digestion methods using hydrofluoric acid for total digestion rather than concentrated nitric and/or hydrochloric acids for "total recoverable metals" may result in higher trace element concentration results compared to results using "total recoverable metals" methods. USEPA requires digestion consistent with "total recoverable metals" methods under the CCR Rule. If more aggressive digestion methods were used, reanalysis (if there is any remaining undigested sample) or resampling is warranted to determine if the SSI/SSL result persists when total recoverable digestion methods are used.
- Dilution Corrections: If dilutions were necessary to overcome matrix interferences, then review analytical results to ensure that the analytical results were properly corrected and that the resulting detection levels are low enough to detect increases over background levels. Look for the "D" data qualifiers to determine if dilutions were used. If a sample result is suddenly higher (especially if it is close to an order of magnitude higher) than the norm at a sample location and dilution was used, it is possible that the sample results were not corrected for the dilution ratio (Figure 2-2). Use of dilution ratios typically increases the MDL. If the sample results are non-detect but the MDL is higher than the norm, erroneous statistical identification of increasing trends may occur, depending on how non-detects are handled in the statistical analysis.

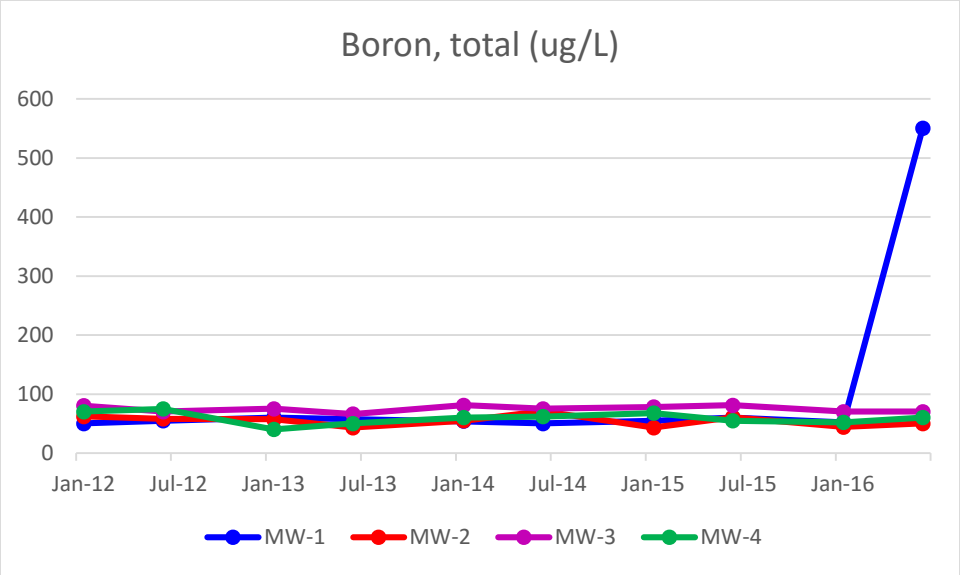

Figure 2-2
Time series plot showing potential dilution error

- Interference: Elevated analytical results may occur due to interference from other constituents present in the sample. If the laboratory identified interferences, the analytical report should include "E" data qualifiers. If interference was a problem, consider reanalyzing if there is sufficient remaining sample, and/or resampling and analyzing using methods that are less sensitive to interference from constituents of concern.
- Methods: Use of inappropriate methods or methods with reporting levels (RLs) or practical quantitation levels (PQLs) that are higher than background or maximum contaminant levels (MCLs) can result in erroneous analytical results or use of elevated non-detect values that can result in erroneous statistical determination of increasing trends. If use of inappropriate methods is suspected, verify that the methods used match those specified in the sampling and analysis plan, and are appropriate for the objectives of the groundwater monitoring program. Table 3-1 of EPRI (2015) shows methods, typical MDL and PQL capabilities, potential for interferences, and relative costs of test options for the CCR Rule Appendix III and Appendix IV constituents. This information can be very helpful in selecting and verifying that appropriate analytical methods were used.
- Technique: Poor analytical technique or use of poorly calibrated instruments (lack of quality control) can result in erroneous sample results. Check the laboratory report for data qualifiers ("B", "E", "N", "*") indicating that quality control may have been a problem.
- Transcription: Improper recording of results or mixing up results between samples can cause erroneous identification of SSI or SSL trends. If analytical results for two sampling locations are suddenly out of the norm, it's possible that the analytical results were transcribed to the wrong sampling locations. If a single location is suddenly out of the norm by an order of magnitude or more, it is possible that a transcription error such as inconsistency in units may have occurred.

Statistical Evaluation Causes (ASD Type III)

A primary challenge in statistical analysis is maintaining adequate statistical power while minimizing the false positive rate. While a detailed discussion of statistical methods and associated false positive rates is beyond the scope of this text, it is important to be aware that false positives can occur and are inherent in the statistical methods used for evaluation of groundwater quality data. See EPRI (2015) for guidance on statistical methods and recommendations for statistical approach under detection monitoring, assessment monitoring, and corrective action monitoring.

The following types of statistical errors could potentially falsely identify an SSI/SSL:

- Lack of statistical independence: The statistical comparison tests to determine if an SSI/SSL has occurred assume that the results are statistically independent. If samples are collected from the same well before the groundwater can flow through the well and be replaced with a fresh sample, then the samples are not physically independent and the comparison is not valid. As stated in the USEPA Unified Guidance (USEPA, 2009), the aquifer may "exhibit pockets or sub-zones of higher or lower concentration, perhaps due to location-specific differences in natural geochemistry or the dynamics of contaminant plume behavior over time." Generally, lack of statistical independence may be of concern if the groundwater velocity is less than 5-10 ft/yr. This type of statistical error is more likely to trigger an SSI during detection monitoring if a resampling protocol is included in the statistical plan, because the resample is collected more quickly after the original sample than the next regularly scheduled sample, and is therefore more likely to lack independence. This can be avoided by factoring groundwater flow rates into the timeframe calculation for resampling in a statistical analysis plan. Lack of independence is less likely to trigger an SSL during assessment monitoring due to the multiple sample design inherent with confidence intervals that are used in assessment monitoring statistics.
- Outliers: An outlier is a result that falls outside the typical range of values due to causes *other than* natural variability or a true change in concentration, and as such is not representative of groundwater quality. An analytical result that is suddenly much higher or lower than historical values represents a potential outlier, and there are graphical and statistical methods to identify such values. An SSI/SSL could be the result of an outlier due to transcription or typographical error, contamination, analytical interference, or other cause described under ASD Types I and II. Potential outliers need to be evaluated by reviewing sampling and laboratory documentation, and sometimes professional judgement needs to be applied to determine a) if the result is valid and should be included in the statistical analysis, b) if the result is due to an error and should be replaced with a corrected value, or c) if the value should be flagged and maintained in the database but not used in statistical calculations. If an outlier is confirmed, recalculation of the comparison to background or groundwater protection standard (GWPS) without the outlier can be performed to determine if the SSI or SSL determination was dependent on the outlier.
- False positives: A false positive is not an error per se; however, by statistical design, false positives can be expected to trigger a certain number of SSIs or SSLs under any statistical analysis plan. A false positive, also referred to as a Type I error, occurs when an SSI/SSL is falsely determined for a constituent at a compliance monitoring well relative to background groundwater quality (for SSIs) or a GWPS (for SSLs). The USEPA Unified Guidance

(USEPA, 2009) recommends that a statistical program be designed so that the site-wide false positive rate (SWFPR), which is the potential for one or more false positives on a site-wide scale, be 10% or less per year (5% per semi-annual sample event). See EPRI (2015) for a detailed discussion of statistical options and recommendations for balancing statistical power with false positive rates. Proving a false positive for an ASD may be challenging, and may require a weight of evidence approach as described in Section 6.

- Non-detect processing: Method detection limits change over time, although usually downward, or can suddenly increase by a factor of 10 or more when a laboratory dilution is used. If there is a dilution, or if MDLs increase (Figure 2-3), then an SSI could result if MDLs are used in statistical analyses. Potential for this type of statistical cause can be minimized by using set reporting limits for non-detect results and by using the double quantification rule when all background results are lower than the reporting limit.

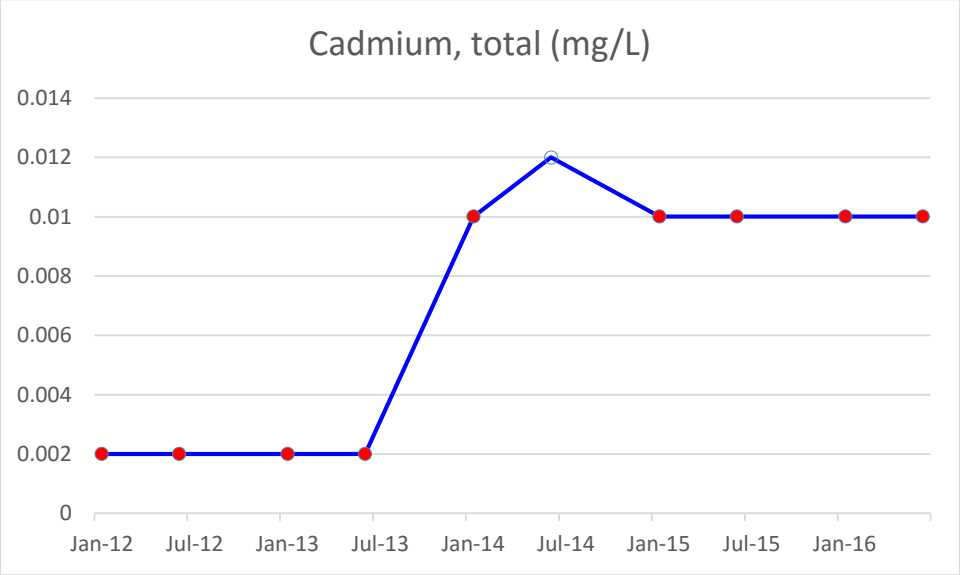

Figure 2-3
Time series plot of showing increasing trend associated with changing detection limits. Red markers indicate sample results below the minimum detection level associated with each respective sampling event.

Background Data: In the initial stages of detection monitoring, if there are numerous SSIs in the absence of a suspected release from the facility (e.g., a new lined landfill), then it is possible that background groundwater is not representative of downgradient groundwater due to spatial or temporal variability. The Unified Guidance (USEPA, 2009) states that a "high quality background dataset is the single most important key to a successful statistical groundwater monitoring program" and recommends a minimum of at least 8 to 10 independent samples for the initial background dataset before running most statistical tests.

Later on, apparent SSIs or SSLs can be triggered when new background data are added to an existing background dataset if that addition results in a change in statistical analysis method. This is particularly relevant if new data changes the distribution of the background dataset from parametric to non-parametric (Figure 2-4), because most non-parametric tests used in

groundwater analysis use the highest value as the upper limit (for detection monitoring) or GWPS (for assessment monitoring), and have a higher false-positive rate than their parametric counterparts.

Refer to Chapter 5 of the Unified Guidance (USEPA, 2009) for a thorough discussion of establishing background, reviewing and updating background, and effects of spatial and temporal variability on background.

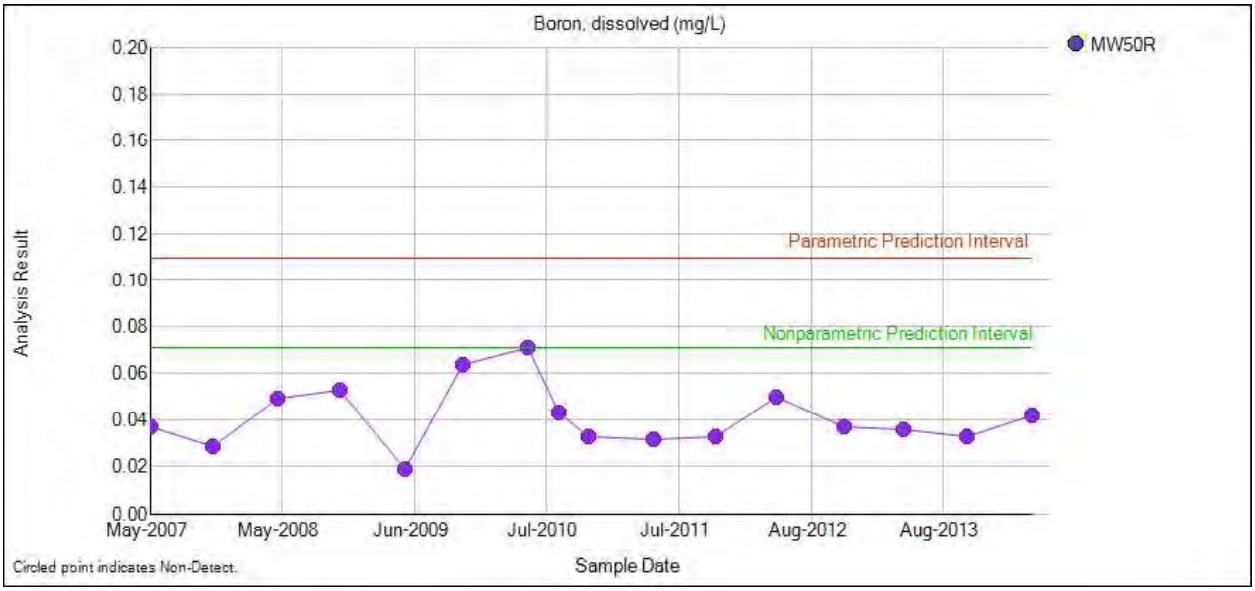

Figure 2-4
Background dataset illustrating the difference between a parametric and non-parametric upper prediction interval

Natural Variation (ASD Type IV)

Natural variation is recognized as a potential alternative cause of SSIs and SSLs under the CCR Rule. This category encompasses variability due to geologic influences such as dissolution of geomedia and natural ion exchange, changes in groundwater quality related to precipitation, seasonal changes in groundwater level or flow direction such as groundwater recharge and discharge fluctuations near surface water bodies, changing water levels in monitoring wells, time-of-travel for monitoring wells to detect upgradient changes, and influences related to changes in pH, oxidation reduction potential, and biological activity. These interactions and how they may affect groundwater quality are discussed in more detail in Section 4.

Alternative Sources (ASD Type V)

Sources for constituents dissolved in groundwater may come from both natural and anthropogenic sources. Natural sources include constituents present in groundwater from dissolution of minerals from the geomedia the groundwater has passed through. Anthropogenic sources can be complex and are too numerous to completely categorize, as many of them are likely to have source-specific signatures.

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Table 2-2 provides information on natural and anthropogenic occurrence and typical behavior in groundwater for Appendix III and IV constituents as well as other constituents that may be helpful for identification of potential alternative sources. This table also identifies the relevance of the constituent as a CCR indicator for coal ash and FGD gypsum leachate.[4]

Table 2-3 provides an overview of common constituents that may be present in groundwater from a variety of anthropogenic sources. This information is intended to stimulate thought regarding constituents that *may be* present in groundwater, absent a release from the CCR site, if one of these activities is upgradient and has experienced its own release. Table 2-3 is not definitive; the information may be incomplete or not representative of actual anthropogenic sources near a particular site under evaluation. Site-specific investigation of nearby activities and history can be performed to verify groundwater impacts if an anthropogenic alternative source is suspected.[4]

A more detailed discussion of common groundwater impacts and contaminants associated with some of the more likely alternative sources is provided in Section 5.

[4] Tables 2-2 and 2-3 are also provided in Appendix A for easy reference with the ASD checklists.

Table 2-2
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Boron	Key Indicator	Yes if unwashed	17 / 35 / 82 ug/L	No	Very mobile	Boron-containing rocks (especially marine shales and clays), seawater, volcanic and geothermal activities, mined in arid regions of the United States (and other countries)	Fly ash leachate, may also be present in FGD leachate; sewage sludge, boron-containing fertilizers or herbicides, manufacture of glass, fiberglass, ceramics, soaps, detergents, bleach, fire retardants, and lubricants; used in control rods of nuclear reactors, and to produce a green color in pyrotechnics and flames; also used in the aerospace industry	Micronutrient for plants but may be toxic to some plant species in high concentrations. Boron deficiencies are more common than toxicities. Mobile in most hydrogeological environments, particularly sandy materials. Sorption to clay reaches a maximum in the pH range of 8-10.
Calcium	No	Yes	21 / 43 / 70 mg/L	CEC	Slightly mobile	Calcium carbonate rocks, limestone, calcium clay; fifth most common element in Earth's crust	Water softening wastes, soil acidity neutralization (lime additions to soil), calcium road salt, deicing, agriculture, cement and concrete, drying agents	Calcium carbonate is one of the most common calcium minerals. The concentration in groundwater may be limited by the solubility of calcium carbonate or calcium sulfate (gypsum). May be sorbed by ion exchange in soil and sediments but tends to be a reversible reaction.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Chloride	No	Yes if unwashed	3.1 / 8.6 / 23 mg/L	No	Very mobile	Salt water and brackish water sources; chloride anion is the most abundant element (other than hydrogen and oxygen) in Earth's oceans	Road salt, deicing, water softening wastes, sewage, septic effluent, livestock waste, oil-field brines, salt water intrusion (oil and gas well production), industrial emissions, incinerator ash, landfill leachate, aerospace industry, automobile industry, soaps and detergents, drying agents, flame retardants, flocculants, pharmaceutical and medical waste	
Fluoride	Yes for some coal ash	Yes for some FGD gypsum	<0.1 / 0.2 / 0.4 mg/L	No	Mobile	Natural weathering of fluoride-containing minerals	Steel, brick, and aluminum manufacturing; waste incineration, municipal water treatment	Occurs as fluoride anion at pH > 3, hydrofluoric acid at pH < 3. Can be sorbed by amorphous aluminum and iron oxides under strongly acidic conditions.
pH	No	No	6.9 / 7.3 / 7.6 SU	- -	- -	Oxidation/weathering of naturally occurring pyritic soils due to well installation or other excavation may cause low pH	Low pH: Oxidation/weathering of pyrite in coal or coal ash, leaking batteries High pH: Certain coal ash leachates may have high pH; cement and concrete manufacturing and use, soaps and detergents	Fly ash leachate pH may be acidic or basic depending on coal type. Bituminous coals tend to produce more acidic leachate, especially if comanaged with pyritic mill rejects, and subbituminous coals tend to produce more basic leachate. Important due to impact of pH on leachability of many trace elements.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Sulfate	Yes for most coal ash	Key Indicator	4.7 / 14 / 36 mg/L	No	Very mobile	Sulfur is the 14th most abundant element in the Earth's crust; oxidation/ weathering of naturally occurring pyritic soils (such as iron sulfide)	Fly ash and FGD leachate, lead acid batteries, algaecides, gypsum mines, wood pulp production (paper mills), textile mills, tanneries, coal pyrite oxidation/weathering from mining or storage, industrial emissions and effluents, soaps and detergents, drying agents, flocculants, petroleum refining	Sulfate may precipitate with calcium, barium, and strontium. Not usually sorbed due to negative charge, but can be sorbed under acidic conditions by soils and sediments containing iron, aluminum, and manganese oxides with positive charges. May precipitate from solution as sulfides under strongly reducing conditions.
Total Dissolved Solids (TDS)	No	No	146 / 254 / 381 mg/L	- -	- -	TDS is largely based on concentration of major ions in groundwater (Ca, Mg, Na, K, carbonates, Cl, SO_4)		Refer to primary components.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Antimony	No	No	<1 ug/L	No	Very mobile		Flameproof retardants, batteries, lead shot; metal and glass manufacturing	Usually soluble but may be sorbed by iron, aluminum and manganese oxides under acidic conditions (EPRI, 1987).
Arsenic	No	No	0.23 / 0.79 / 3.0 ug/L	Yes, pH and redox	Variable	May be present in sulfide minerals and in organic forms; concentrations can be naturally higher than typical under reduced conditions or if sulfide minerals are oxidized	Wood preservatives (chromated copper arsenate), feed additives, pharmaceuticals, electronic devices, metallurgical applications, metal mining and smelting, cemeteries; pesticides/herbicides/ insecticides (prior to 1960)	Arsenic occurs in the 5+ oxidation state as arsenate (AsO_4^{3-}) under relatively neutral pH and oxidized conditions, and as 3+ arsenite (AsO_3^{3-}) under reduced conditions. Arsenic fate and transport is complex due to sensitivity to pH and redox. Sorption usually increases with decreasing pH.
Barium	No	No	24 / 54 / 120 ug/L	Yes	Mobile	Weathering of sedimentary rocks	Well drilling mud or fluid, mining; manufacture of glass, paint, and rubber	Usually present as relatively insoluble barium sulfate in fly ash. Most barium compounds have limited solubility. Sorbed by clay, soils, and sediment.
Beryllium	No	No	<1 ug/L	Yes, pH	Immobile	Relatively scarce in Earth's crust	Electronic and electrical components, telecommunications and computer components, defense applications	Strong tendency to sorb at neutral to alkaline pH. Sorption may be reduced in the presence of humic acids.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Cadmium	No	No	<1 ug/L	Yes, pH	Slightly mobile	Minor component in Earth's crust, occurs in zinc minerals	Batteries, waste incineration, sewage sludge disposal, paint pigments, phosphate fertilizers, automobiles, electroplating and metal fabricating	Can be sorbed by clay, soil, and sediment at pH less than 8, but sorption decreases at low pH.
Chromium	No	No	0.68 / 1.2 / 3.0 ug/L	Yes, pH and redox	Variable	Primarily occurs as Cr(III) in soils and rocks	Electroplating, leather tanning, wood pulp production (paper mills), metal ore refining, wood preservatives, steel manufacturing, automobiles, electroplating and metal fabricating, paint and coatings	The solubility of Cr(III) generally increases at pH levels <6.5 and >11. Cr(III) is the predominant dissolved species under reducing to mildly oxidizing conditions. Cr(IV) is more soluble than Cr(III) at neutral to alkaline pH. Cr(VI) is soluble at alkaline pH and mildly to strongly oxidizing conditions.
Cobalt	No	No	0.063 / 0.17 / 0.48 ug/L	Yes	Variable	Relatively scarce in Earth's crust; usually occurs in combination with arsenic and sulfur in nature	Rechargeable battery electrodes, radial tires, drying agents, catalysts, paint pigments, medical wastes, automobiles	May be sorbed by mineral oxides (e.g., Fe and Mn), crystalline materials such as aluminosilicate, and natural organic substances in soil.
Lead	No	No	0.018 / 0.070 / 0.27 ug/L	Yes pH	Variable	Rare in Earth's crust	Smelting and mining, batteries, waste incineration, leaded gasoline (before 1996), lead-containing paint, glass manufacturing, ammunition, firing ranges, plumbing, automobiles	Sorption usually increases with pH.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Lithium	Yes for some coal ash	No	2.0 / 6.0 / 18 ug/L	No	Mobile	Rare in Earth's crust, dissolution of lithium-containing minerals	Glass and ceramics production, lubricants, greases, batteries, salt water intrusion	Reacts with sulfate ions to form lithium sulfate anion.
Mercury	No	No	NR	No	Slightly mobile	Occurs as HgS in nature; can be converted to methylated forms by anaerobic microbes	Waste incineration, mercury mining, metal recycling, fungicides, fluorescent lamps, batteries, thermometers/ thermostats/switches (electronic equipment), automobiles	Can be sorbed by iron, magnesium, silicon oxides, and organic matter.
Molybdenum	Yes for some coal ash	No	0.32 / 1.0 / 3.3 ug/L	No	Very mobile	Usually combined with sulfur or oxygen in natural minerals	Steel production, catalysts, lubricants, pigments, fertilizers, animal feed	Micronutrient for plants and animals; may be in fertilizers or animal feed. Peak sorption at pH <5 and limited sorption above pH 8. Phosphate and other oxyanions will depress sorption.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Radium 226 + 228	No	No	NR / 0.28 / 1.2 pCi/L	Yes, CEC	No data	Natural decay product of uranium and thorium ores	Uranium mines, nuclear power, nuclear fuel and weapons manufacturing, uranium in coal	Radium decays to radon gas, so it is prevalent in locations where radon gas is a concern.
Selenium	No	No	0.12 / 0.34 / 1.0 ug/L	Yes, pH and redox	Variable	Usually occurs with silver, copper, lead, and nickel sulfide minerals; may exist in a variety of organic compounds	Metal mining and milling, industrial waste water, sewage effluent, waste incineration, saline agricultural waste waters	May exist as selenate (SeO_4^{2-}), selenite (SeO_3^{2-}), elemental selenium (Se^0), and selenide (Se^{2-}) in groundwater (shown in order from most to least oxic species). Since anionic selenium is the dominant form in groundwater, sorption typically is not significant. However, selenite can be sorbed by iron and aluminum oxides.
Thallium	No	No	<1 ug/L	Yes, redox	Mobile	Occurs in combinations with oxygen, sulfur, and halogens	Glass and electronic industries, iron and steel production, cement factories	May be immobilized under reducing conditions.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Aluminum	No	No	0.98 / 3.0 / 4.9 ug/L	Yes, pH	Slightly mobile	Most abundant metal in Earth's crust; weathering of aluminosilicate minerals	Mining and industrial emissions and effluents; most abundant metal in coal ash, cement and concrete, drying agents, well drilling, flocculants, abrasives, aluminum manufacturing	Most soluble in water under acidic and alkaline solutions, essentially insoluble in near neutral water. May be sorbed by soils, sediments, and organic matter.
Bromide	Possible for certain coal ash	Yes if unwashed	0.02 / 0.04 / 0.09 mg/L	No	Mobile	Brackish groundwater and sea water, relatively rare in Earth's crust	CCR fly ash and emission control wastes, particularly if bromide compounds were used to facilitate mercury capture; drinking water disinfection, flame retardants	
Copper	No	No	0.47 / 1.0 / 3.0 ug/L	Yes, pH and redox	Variable	Relatively common in Earth's crust	Manufacture of bronzes, brass, electrical conductors, and ammunition; sewage sludge wastes, municipal solid wastes, copper-containing fertilizers, cemeteries, electronics, plumbing, wood preservatives, automobiles, electroplating and metal fabricating	Solubility may be controlled by solubility of copper hydroxide. May sorb to organic matter, clay, aluminum, manganese, and iron oxides.
Iron	No	No	0.81 / 7.9 / 93 ug/L	Yes, pH and redox	Variable	Commonly has high concentration in groundwater under reduced conditions; Weathering of iron-containing minerals (dissolution of iron oxides under reducing conditions), 4th most common element in Earth's crust	Industrial emissions, pyrite oxidation/acid mine drainage from coal mining or storage, flocculants	Iron oxides my dissolve and become mobile under reducing conditions. Occurs as ferrous (+2) and ferric (+3) iron. Ferric iron can be sorbed by silica, clay, and iron and manganese oxides.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Magnesium	No	No	4.4 / 11 / 23 mg/L	CEC	Slightly mobile	Eighth most abundant element in the Earth's crust, abundant in sea water; dissolution of magnesium carbonates and clay minerals	Aluminum fabrication and welding (alloying agent), flares and pyrotechnics, fire retardants, heat-resistant bricks, animal feed, fertilizers, drying agents	Solubility may be limited under alkaline conditions. May be removed from solution by ion exchange in soils and sediments via reversible reactions.
Manganese	No	No	0.85 / 7.0 / 84 ug/L	Yes, pH and redox	Variable	Commonly has high concentration in groundwater under reduced conditions; 13th most abundant element in the Earth's crust	Production of steel and aluminum alloys, glass production, use as an additive in gasoline	
Nickel	No	No	0.35 / 1.1 / 2.5 ug/L	No	Variable	Commonly combined with iron or sulfur	Manufacture of steels, other metal alloys, and electronic applications; automobiles, electroplating and metal fabricating, petroleum	Sorbs to iron and manganese oxides, and clay to a lesser extent.
Nitrogen	No	No	0.07 / 0.55 / 2.4 (NO_3 as N) mg/L	Nitrification/ denitrifi-cation, redox	Very mobile as NO_3	In nature, nitrogen is converted from one redox state to another by abiotic reactions and microbial catalysis in oxic conditions: $NH_4OH \rightarrow NO_2 \rightarrow NO_3$; under reducing conditions: $NO_3 \rightarrow NO_2 \rightarrow N_2$	Fertilizers, livestock wastes, wastewater treatment plants, sewage and septic effluent, rubber manufacturing; ammonia sources include CCRs from sources using SNCR or SCR technology, coke production, flame retardants	NO_2 and NO_3 are not significantly sorbed by most soils, sediments, or clays, but NH_4OH is.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Phosphate	No	No	<0.01 / 0.02 / 0.04 mg/L	Yes, pH	Variable	Phosphorus is the 11th most abundant element in the Earth's crust	Fertilizers, wastewater treatment plants, sewage and septic effluents, industrial effluents, soaps and detergents, flame retardants	Can be sorbed by iron, aluminum, and manganese oxides, and by clay under acidic conditions.
Potassium	Yes for some coal ash	No	0.9 / 1.7 / 3.5 mg/L	CEC	Mobile	7th most abundant element in the Earth's crust; Weathering of potassium-containing minerals	Water treatment, fertilizers, sea water intrusion, soaps and detergents, drying agents	May be removed from groundwater by reversible ion exchange with soils and sediments.
Silicon	No	No	12 / 19 / 31 mg/L	Yes	Very mobile	2nd most abundant element in the Earth's crust; usually in the form of SiO_2	Glass, ceramics, abrasives, electronic devices, metal alloying, water filtration, insulation, cement, concrete, paper, rubber, lubricants, flocculants	Can be sorbed by iron and aluminum oxides, and by clay minerals.
Silver	No	No	<1 ug/L	Yes, pH	Variable		Textile plant wastewater, photographic materials, sewage sludge, medical wastes, electronics, electroplating and metal fabricating	Can be sorbed by soils but affected by pH, clay content, particle size, organic content, and free iron and manganese oxide content.
Sodium	Yes for some coal ash	No	5.2 / 11 / 29 mg/L	CEC	Mobile	6th most abundant element in Earth's crust; brackish groundwater and surface water, sea water, weathering of sodium-containing minerals	Road salt, deicing, septic effluent, sodium hydroxide water treatment wastes, water softening, salt water intrusion (gas and oil well production), sewage and septic effluent, soaps and detergents, drying agents	Most sodium compounds are soluble but may be sorbed by reversible ion exchange in soils or sediments.

Table 2-2 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Strontium	No	No	100 / 270 / 680 ug/L	Yes	Slightly mobile		Glass and ceramics production, pyrotechnics, phosphate fertilizers	Reacts with sulfate ions to form $SrSO_4^0$.
Vanadium	No	No	0.30 / 1.4 / 11 ug/L	Yes, pH and redox	Variable		Crude oil, oil shale, tar sands, phosphate fertilizers, wastes from steel production, petroleum	Can be sorbed by iron, aluminum, and manganese oxides; sorption decreases as pH increases.
Zinc	No	No	1.6 / 4.8 / 18 ug/L	Yes, pH	Variable		Fertilizers, protective coatings to reduce corrosion of metal surfaces, dry-cell batteries, castings, automobiles, lubricating oils and greases, plumbing/piping, electroplating and metal fabricating	Sorption increases with increasing pH but is also affected by clay content, particle size, organic content, and iron, aluminum, and manganese oxide content.

Notes:

1. Based on EPRI (2012). "No" indicates that the constituent it is not considered an indicator due to low concentration in CCR leachate relative to typical background, low mobility, and/or potential for reactivity.

2. Concentration ranges in ug/L from USGS (2011), Table 4; concentration ranges in mg/L or SU from USGS (2008), Tables 2 and 6; radium 226+228 from Szabo et. al (2012) supplemental table S-3; NR indicates that the concentration was not reported in any of these three documents.

3. Reactivity and mobility, while separate geochemical processes, are often interrelated. Reactivity descriptions in this table refer to chemical reactions, primarily precipitation and dissolution, that can change the concentration or mobility of the element in solution under typical aquifer conditions. Yes indicates that the constituent is subject to precipitation, coprecipitation, and/or dissolution reactions. In addition, pH and redox are indicated if they have a strong influence on the environments under which reactions occur and/or mobility. CEC is listed for constituents that are subject to cation exchange.

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4. The mobility classification is based on the classification system of van Loon and Duffy (2000). See Table 2-2 of EPRI (2012) for corresponding K_d values.

5. Refer to Appendix B in EPRI (2012) for brief summaries of geochemical factors affecting reactivity and sorption. Detailed information can be found for selected constituents in the following EPRI reports:

- Arsenic
  1015550 | Chemical Constituents in Coal Combustion Product Leachate: Arsenic | Profile | 2008
  1021212 | Arsenic in Coal Combustion Products | Tech Brief | 2010
- Beryllium
  1012583 | Chemical Constituents in Coal Combustion Product Leachate: Beryllium | Profile | 2006
- Boron
  1005258 | Chemical Constituents in Coal Combustion Product Leachate: Boron | Profile | 2005
  1023737 | Boron in Coal Combustion Products | Tech Brief | 2012
- Chromium
  1022143 | Chromium in Coal Combustion Products | Tech Brief | 2011
- Lithium
  In Prep | Chemical Constituents in Coal Combustion Products: Lithium | Profile | 2018
- Molybdenum
  1021815 | Chemical Constituents in Coal Combustion Products: Molybdenum | Profile | 2011
  In Prep | Molybdenum in Coal Combustion Products | Tech Brief | 2017
- Selenium
  3002001237 | Chemical Constituents in Coal Combustion Product Leachate: Selenium | Profile | 2013
  3002003761 | Selenium in Coal Combustion Products | Tech Brief | 2014
- Thallium
  1016801 | Chemical Constituents in Coal Combustion Product Leachate: Thallium | Profile | 2008
  3002001155 | Thallium in Coal Combustion Products | Tech Brief | 2013

Table 2-3
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Abrasives	**Silicon, aluminum**
Acid mine drainage	**Low pH, sulfate, iron**, dissolved solids, metals (aluminum, cadmium, calcium, chromium, cobalt, copper, magnesium, manganese, nickel, zinc, and others); can travel along mine shafts and tunnels and show up in unexpected locations (sometimes across aquifers) (notes 1, 26, 51, 54)
Aerospace industry	**Boron, perchlorate, chloride, cyanide, cadmium**, beryllium, solvents (trichloroethane, methylene chloride, trichloroethylene, toluene, methylethylketone), metals, oils (notes 2, 3, 4, 5, 51)
Aging infrastructure (leaking sewage, urban runoff)	Nitrate, phosphorus, sodium, chloride, organic substances, bacteria, pesticides, miscellaneous chemicals, cadmium, copper, iron, lead, selenium, zinc, and other elements (note 6)
Agriculture - animal feed lots	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate, chloride**, **arsenic**, **magnesium, molybdenum, selenium** and other elements, organic substances, bacteria/viruses (notes 7, 22, 51, 52, 54)
Agriculture - fertilization	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate**, **boron**, **cadmium, calcium**, chloride, cobalt, **copper**, cyanide, **magnesium**, **molybdenum, potassium, selenium, strontium, vanadium, zinc**, and other elements (notes 7, 22, 51, 52, 54)
Agriculture - irrigation	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate,** arsenic, boron, cadmium, calcium, chloride, cobalt, copper, cyanide, magnesium, mercury, molybdenum, potassium**, selenium**, sodium, sulfate, and other elements (notes 7, 8, 9, 22, 52)
Agriculture - lime addition	**Calcium** (note 22)
Agriculture - pesticides, herbicides, and insecticides	Aldicarb, Aldrin, alachlor, atrazine, carbofuran, chlordane, dacthal, DDT, dieldrin, bibromo-chloropropane, 1,2-dichloropropane, dinoseb, endrin, endosulfan, ethylene dibromide, heptachlor, hexachlorobenzene, lindane, mirex, PCBs, prometon, simazine, toxaphene, trifluralin; **arsenic** (prior to 1960), chloride, **mercury, boron**, **sulfate** (notes 10, 51, 52, 54)
Airport runways	**Sodium, potassium**, acetate, formate, urea (note 11)
Aluminum manufacturing	**Aluminum, fluoride, sodium**, magnesium, manganese, perfluorocarbons, polycyclic aromatic hydrocarbons (notes 12, 13)
Ammunition, firearms	**Lead, antimony, copper,** other heavy metals, nitrate, perchlorate, potassium, sulfur/sulfate, chloride (notes 14, 15, 22)
Asphalt plants	Oils, greases, PAHs, other hydrocarbons (note 16)
Automobile production	**Chloride, sulfate, phosphate,** oil and grease, solvents, ethylene glycol. Potential for heavy metals: aluminum (auto bodies), **cadmium** (tires and batteries), **cobalt** (radial tires), **chromium** (brakes, coolants, engine parts), **copper** (brake linings), iron (auto bodies), **lead** (batteries, lube oil and grease, bearings, brakes), **mercury** (batteries), **nickel** (lube oil, brakes), **zinc** (tires, fuel oil, lubricants) (notes 17, 18, 22)
Automobile repair shops	Gasoline, diesel fuel, oil, degreasing solvents (toluene, xylene, chlorinated solvents, MEK), ethylene glycol, lead, sulfate (notes 19, 44)

Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Batteries	**Sulfate, lead, antimony**, **cadmium, cobalt, lithium, mercury, zinc, low pH** (notes 22, 51)
Bleach manufacturing	**Boron** (bleaches containing sodium perborate) (notes 20, 31)
Brick manufacturing	**Aluminum, silicon, iron**, calcium, **fluoride**, **magnesium,** chromium (notes 21, 22, 52)
Catalysts	Aluminum, chromium, **cobalt**, copper, iron, **molybdenum**, titanium, tungsten, vanadium, zinc, and other metals (depends on catalyst manufactured or used) (note 22)
CCR - ash	**Boron, sulfate**, molybdenum, lithium, bromide, potassium, sodium, fluoride, selenium; may contain ammonia (nitrogen) if SCR or SNCR technology was used at the power plant (note 22)
CCR - FGD gypsum	**Sulfate**, fluoride, calcium, boron, bromide, chloride, selenium (note 22)
CCR - FGD fixated sludge	**Boron, sulfate**, calcium, chloride, molybdenum, lithium, bromide, potassium, sodium, fluoride, selenium (note 22)
Cemeteries	**Formaldehyde**, **copper, arsenic,** mercury, pesticides, fertilizers, weed killers (note 23)
Cement and concrete manufacturing and use	**High pH, aluminum, calcium, silicon, thallium,** chromium and other elements (notes 22, 24, 51)
Ceramics production	Oxides of carbon, **silicon, boron**, and nitrogen; may include aluminum, antimony, barium, copper, fluoride, iron, **lithium**, **strontium**, and other elements (notes 21, 22, 51)
Coal mining	**Sulfate, low pH, iron**, dissolved solids, trace elements (aluminum, beryllium, cadmium, chromium, cobalt, copper, lead, magnesium, manganese, mercury, nickel, selenium, **uranium (decays into radium 226+228)**, zinc and others); Oxidation of pyrite in coal can form sulfuric acid. The low pH increases solubility of many metals. (notes 1, 26, 51, 54)
Coatings	VOCs, solvents (halogenated solvents and non-halogenated solvents such as acetone, cresols, cresylic acid, nitrobenzene, benzene, toluene, xylene, methyl ethyl ketone, methylene chloride, etc.); trace elements may include barium, cadmium, **chromium**, cobalt, lead, mercury, molybdenum, nickel, titanium, and **zinc** (note 27)
Coke production (from coal)	**Phenols, ammonia (nitrogen), polycyclic aromatic hydrocarbons, cyanide**, benzene, naphthalene, anthracene, cresols, metals (see metals in "coal piles or coal waste piles") (note 28)
Computer and telecommunications components (electronics)	Trace elements may include aluminum, arsenic, barium, **beryllium**, cadmium, chromium, cobalt, **copper**, gallium, gold, iron, lead, manganese, mercury, palladium, platinum, selenium, **silver**, and zinc; solvents may include benzene, xylene (dimethylbenzene), trichloroethane, tetrachloroethane, ethylene glycol, methyl cellosolve; **silicon** (notes 29, 30, 32)

Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Defense applications	**Beryllium** (note 22)
Detergent or soap manufacturing	**Sodium, potassium, sulfates and sulfonates, high pH, phosphate**, **chloride, boron**, phenol, aluminosilicate, sodium citrate, nitrilotriacetate, alcohol ethoxylates, fats, oil and grease, lead, hexane, methyl alcohol, trichloroethane, perchloroethylene, benzene, toluene (notes 22, 34, 35)
Deicing	**Sodium, chloride**, **calcium**, magnesium, urea (notes 44, 51)
Drying agents	**Aluminum, calcium, sodium, potassium, magnesium, sulfate, chloride,** cobalt, lithium, phosphorus, silicon and/or other substances (notes 22, 36, 37)
Electronic equipment manufacturing and disposal	**Copper, silver, gold, palladium**, **arsenic, beryllium, copper, mercury, nickel,** selenium, **silicon, thallium** and other trace elements, chloride, fluoride, solvents (benzene, xylene, 1,1,1-trichloroethane, tetrachloroethane, methanol), ethylene glycol, hydrogen chloride, hydrogen fluoride (notes 22, 29, 30, 33, 51)
Electroplating and metal fabricating	**Cadmium, chromium, copper, nickel, silver**, sodium, tin, **zinc**, spent solvents, paints, spent acidic and alkaline solutions, cyanide, waste oils (notes 17, 22, 44, 51, 52, 56)
Explosives manufacturing and testing	**Nitroglycerin and nitro-aromatic compounds**, nitrate, perchlorate, ammonia, lithium, sodium, potassium, sulfur/sulfate, aluminum, chloride, **lead**, antimony, **copper**, nickel, silver (notes 38, 39, 40, 51)
Fertilizers	See Agriculture - fertilization
Fiberglass manufacturing	Aluminum, silicon, calcium, magnesium, **boron**, polyester or epoxy resin, styrene, solvents, volatile organic compounds, formaldehyde, urea, phenol, vinyl acetate (notes 31, 41)
Firearms, ammunition	See Ammunition, firearms
Firing ranges	**Lead**, antimony (notes 14, 22)
Fireworks manufacturing or use	Aluminum, antimony, arsenic, barium, **boron**, chloride, copper, lead, **magnesium**, nitrate, perchlorate, potassium, sulfur/sulfate, **strontium** (notes 31, 38, 39, 40, 51)
Flame retardant manufacturing or use	**Bromine, phosphate, nitrogen/nitrate, chloride**, **antimony, boron**, **magnesium**, polybrominated diphenyl ethers (PBDEs), PCBs (notes 22, 42, 43, 51)
Flocculants	**Sulfate, chloride, aluminum, iron**, ammonium, calcium, silica, polyamines (note 45)
Fluorescent lamps/bulbs	**Mercury**, PCBs in ballasts (note 47)
Fracking	See Oil and gas wells / production

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Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Fungicides	See Pesticides
Furniture (wood stripping and refinishing)	Methylene chloride, methanol, isopropyl alcohol, acetone, perchloroethylene, toluene, acidic and alkaline solutions, metals, other solvents, petroleum distillates, resins, halogenated hydrocarbons, glycol ether (note 44)
Gasoline stations	**Benzene, ethylbenzene, toluene, xylene, MTBE**, ethylene dichloride, naphthalene, other organic compounds, lead (prior to 1996), **manganese**; trichloroethylene, perchloroethylene, methylene chloride, carbon tetrachloride, oils, ethylene glycol, hydraulic fluid, detergents, and acids (notes 22, 49, 51, 52)
Glass manufacturing	**Silicon**, antimony, **barium, boron, lead**, iron, **lithium**, **manganese**, nickel, potassium, **strontium**, **thallium**, tin, zinc, fluoride (notes 22, 31, 50, 51)
Industrial emissions	**Chloride, sulfate, iron,** wide variety of other elements and chemical substances (notes 22, 51, 54)
Irrigation	See Agriculture – irrigation
Junk and scrap yards	Used oil, gasoline, antifreeze, lead, sulfuric acid, agricultural chemicals/pesticides/other chemicals, metals (note 44)
Lamp manufacturing and disposal	**Mercury**, bromide, chloride, fluoride, iodide, PCBs, sodium (notes 22, 47)
Landfills - industrial	Wide range of trace metals, acids, **chloride**, sulfate, organic substances and pesticides (notes 51, 53, 54)
Landfills - municipal	Salts (sodium, calcium, magnesium, **chloride**, etc.), metals (iron, copper, zinc, other heavy metals), nitrate, organic compounds, solvents, pesticides (notes 22, 51, 54)
Laundry - dry cleaning	**Perchloroethylene (tetrachloroethylene)**, camphor oil, turpentine spirits, benzene, kerosene, white gasoline, petroleum solvents (petroleum naphtha), chloroform, carbon tetrachloride, trichloroethylene, 1,1,2-trichlorotrifluoroethane, glycol ethers, 1,1,1-trichloroethane, decamethylcyclopentasiloxane, n-propyl bromide, liquid carbon dioxide, fluorocarbon-113, antimony, cadmium, copper, lead, sulfate, zinc (notes 20, 31, 44, 52)
Leather tanning	**Chromium**, **cyanide**, **tannins**, chlorinated phenols including PCB, azodyes, cadmium, cobalt, copper, antimony, barium, lead, selenium, mercury, zinc, arsenic, nickel, formaldehyde, pesticides, salts, lime, acids, sodium sulfide, hydrogen sulfide, sulfate (notes 22, 55, 56)
Lubricants and greases	**Zinc**, polyaromatic hydrocarbons, arsenic, **boron**, cadmium, lead, **lithium**, **molybdenum**, PCBs, **silicon**, and other elements (note 22)
Medical supplies or wastes	Chloride, formaldehyde, **arsenic**, cadmium, **cobalt**, lead, mercury**, silver**, other heavy metals, radioactive waste, infectious or pathological waste, dioxins and furans from incineration; Also see Pharmaceutical industry (notes 22, 51, 57, 58, 59, 62)

Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Metal manufacturing - smelting	**Aluminum**, **antimony**, **arsenic**, beryllium, cadmium, **chromium**, **copper**, cyanide, iron, **lead**, **magnesium** (aluminum manufacturing), **manganese** (steel and aluminum manufacturing), mercury, **molybdenum** (steel manufacturing), **nickel** (steel and other metal manufacturing), **selenium**, silver, **thallium** (iron and steel manufacturing), zinc and other elements, **fluoride** (steel and aluminum manufacturing), **silicon, vanadium** (steel manufacturing), **zinc** (notes 22, 44, 51, 52)
Metal mining	Aluminum, antimony, **arsenic**, beryllium, cadmium, **chromium**, **copper, cyanide**, iron, **lead, manganese**, **mercury, nickel, selenium**, silicon, silver, thallium, tungsten, zinc and other elements (notes 22, 51, 52, 54, 56)
Metal plating	Spent solvents, paints, spent acidic and alkaline solutions, waste oils, heavy metal sludges, metal dust, chromium, copper, nickel, selenium, **zinc** and other elements (notes 22, 44, 51, 52)
Metal recycling	Iron, copper, **mercury**, nickel, zinc, and other elements (note 22)
Mining - unspecified	Depends on contents of ore; may include aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, **sulfate** (gypsum mines), thallium, zinc, other minerals, hydraulic oils; **radium 226+228 (uranium mines)** (notes 22, 51)
Natural gas pipelines	**Methane, PCBs** (notes 60, 61)
Nuclear power	**Tritium**, **strontium 90, radium 226+228,** boron, beryllium (notes 31, 51, 54)
Oil and gas wells / production	Produced water may contain high **TDS, chloride, sodium**, sulfate, barium, boron, bromide, iodide, lithium, potassium, radionuclides, **vanadium** and other minerals, methane, volatile organic compounds (notes 52, 60, 63)
Ore refining / smelting	Aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, zinc and other elements (notes 22, 44, 51)
Paint and pigment manufacturing	VOCs, solvents (halogenated solvents, non-halogenated solvents such as acetone, cresols, cresylic acid, nitrobenzene, benzene, toluene, xylene, methyl ethyl ketone, methylene chloride, etc.); metals may include **barium**, **cadmium, cobalt**, **chromium**, **lead**, mercury, **molybdenum**, titanium, and zinc (notes 22, 44, 51, 52, 64)
Paper and pulp manufacturing	Organic and inorganic compounds including lignin, cellulose, phenols, mercaptans, **chromium**, nitrates, phosphates, **silicon, sulfides/sulfates**, chlorinated compounds including chloroform and dioxin (notes 22, 65)
Petroleum facilities and refining	Benzene, ethylene, toluene, xylene, methane, other organic compounds, hydrogen sulfide, **sulfate, nickel, vanadium** and other elements; some refineries use deep-injection wells to dispose of highly contaminated wastewater that could potentially contaminate groundwater (note 51)
Pharmaceutical industry	Wide variety of organic solvents; **arsenic, cobalt**, ammonia, chloride, cobalt, **silver** and other elements; Also see Medical supplies or wastes (notes 22, 51, 57, 62)
Photographic materials/photography	**Silver,** sodium, potassium (notes 22, 51)

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Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Pigments	See Paint and pigment manufacturing
Plastic manufacturing	Cadmium, cyanide, benzene, vinyl hydrochloride, phthalates, trichloroethane, acetone, methylene chloride, methyl ethyl ketone, styrene, toluene, trichloroethane, sulfate, methanol, ethylene oxide, volatile organic compounds, sodium, caustic, nickel, lead, cadmium, mercury (notes 51, 66)
Plumbing	**Copper, lead, zinc** (note 51)
Road salting	**Chloride, sodium**, **calcium**, other salts (notes 22, 44)
Rubber manufacturing	**Ammonia, amines**, acetic acid, **barium**, cobalt, formic acid, sodium, **silicon**, sulfite/sulfate, organics, nitrogen compounds (notes 22, 69)
Salt or brackish water intrusion (from well drilling)	**High TDS, chloride**, boron, bromide, calcium, **lithium**, magnesium, **potassium, sodium**, sulfate, and other minerals (notes 22, 51, 54)
Salvage and junk yards	Grease, oil, solvents, lead and acid from batteries, metals (notes 44, 54)
Semiconductor manufacturing	Copper, silver, gold, palladium, arsenic, beryllium, copper, mercury, nickel, selenium, silicon, thallium and other elements, chloride, fluoride, solvents (benzene, xylene, 1,1,1-trichloroethane, tetrachloroethane, methanol), ethylene glycol, hydrogen chloride, hydrogen fluoride (notes 22, 29, 30, 33, 51)
Septic effluent	**Nitrate, phosphorus, chloride, sodium**, organic substances, bacteria and viruses, detergents, oils, heavy metals including cadmium, copper, lead, **selenium**, salts, septic tank cleaners such as trichloroethane or methylene chloride, and a wide variety of other chemicals (notes 22, 51, 52, 53)
Sewage	**Nitrate, phosphorus, chloride, sodium**, organic substances, bacteria and viruses, detergents, oils, **boron**, **cadmium**, **copper**, lead, **selenium, silver**, salts, and a wide variety of other chemicals (notes 22, 51, 52)
Soap or detergent manufacturing or use	See Detergent and soap manufacturing
Soil acidity neutralization	**Calcium**
Steel (including stainless) and iron manufacturing	Iron, chromium, manganese, nickel, ammonia, cyanide, chloride, copper, fluoride, molybdenum, sulfate, tin, thallium, zinc, hydraulic oils
Textiles	Polyvinyl chloride, chlorine bleach, benzidine, toluidine, cyanide, formaldehyde, hydrocarbons, ammonia, nitrate, organic solvents, chloride, sodium, fluoride, silicon, **sulfate**, phosphate, boron, bromide, chromium, copper, aluminum, antimony, potassium, aluminum, **silver**, titanium, zinc, copper, insecticides (notes 22, 51, 56, 67, 68)
Thermometers, thermostats, switches	**Mercury** (note 51)

Table 2-3 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Underground storage tanks (USTs leaking petroleum products such as gasoline)	Benzene, toluene, xylene, other organic compounds (notes 49, 51, 53)
Urban runoff	Oils, heavy metals, salts, copper, zinc, and other chemicals (notes 6, 18, 54)
Waste incineration	**Chloride, cadmium**, chromium**, fluoride, lead, mercury**, selenium, dioxins and furans (note 22)
Water treatment - flocculants	See Flocculants (note 45)
Water treatment - industrial effluents	Wide variety of metals, aluminum, **chloride**, **phosphate**, **potassium, sulfate**, nitrate, **selenium, silicon**, **sodium**, organics depending on industry (notes 22, 46)
Water treatment - municipal supply	Bromide, **chlorine, fluoride** (notes 22, 51)
Water treatment - treated sewage effluent	May contain **nitrates and other nitrogen compounds, phosphates, sodium, chloride**, **selenium, silicon**, and a variety of other elements (notes 22, 51, 52)
Water treatment - water softening	**Sodium, chloride**, **calcium**, magnesium, iron, other salts and metals (note 22)
Water treatment - cooling water	Chromium, zinc (notes 51, 52)
Well drilling (mud or fluid)	Constituents of bentonite clay and the natural geomedia including **aluminum, barium**, calcium, potassium, sodium and other minerals (note 22)
Wood preservatives and treatments	**Pentachlorophenol (PCP), creosote**, **copper, chromium, arsenic** (chromated copper arsenic, ammoniacal copper arsenate) (notes 22, 44, 48, 51)

* Bold indicates likely key indicators; list will vary by site-specific source; list may be incomplete or may not accurately represent a particular source.

Sources of Information for Table 2-3:

1. USEPA (1980)
2. USEPA. 2014. Technical Fact Sheet – Perchlorate, January 2014. (Also available at https://www.epa.gov/sites/production/files/2014-03/documents/ffrrofactsheet_contaminant_perchlorate_january2014_final.pdf)
3. http://www.dmpcorp.com/industries/aerospace-defense-manufacture/
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3
ASD EVALUATION TECHNIQUES

Primary Indicators for Coal Combustion Residual Leachate

A key line of evidence in any ASD will be whether or not there is an SSI/SSL for one or more primary CCR leachate indicator constituents. For ASD purposes, a primary indicator is:

- a constituent that typically has high concentration in leachate, relative to background, such that it is expected to have elevated concentration in the event of a release, *and*
- is not reactive, and has high mobility in groundwater such that it is expected to be at the leading edge of the plume, meaning that it will have elevated concentrations relative to background across the entire area of the plume.

Boron (B) and sulfate (SO_4) are primary indicators for coal ash leachate (EPRI 2012). The association of both boron and sulfate with CCP leachate was established during the late 1970s (EPRI 1979, Cherkauer 1980). Based on the EPRI CPInfo database, boron concentrations in fly ash leachate range between 1.1 and 109 mg/L with an average concentration of 8.3 mg/L; sulfate concentrations range from 89 to 6,070 mg/L with an average concentration of 1,370 mg/L (EPRI 2012). For FGD gypsum, sulfate is a primary indicator constituent. Sulfate concentrations for FGD leachate range from 437 to 1,549 mg/L with average concentrations around 1,300 mg/L (EPRI 2012).

There may be other primary indicators for a given CCR site depending on a variety of factors (Table 3-1). For example, molybdenum may be a primary indicator for landfilled fly ash derived from bituminous coal, and boron, bromide, and chloride may be primary indicator constituents for unwashed FGD gypsum. When determining primary indicator constituents, the optimal approach is to start with field-measured leachate concentrations. If field data are not available, published sources provide an alternative source of data. EPRI (2016) provides landfill leachate data ranges for a variety of CCRs and source coals.

Table 3-1
Potential Indicator Constituents for Coal Ash and FGD Gypsum

Potential Indicators for Coal Ash		Potential Indicators for FGD Gypsum	
Constituent	**Advantages and Caveats**	**Constituent**	**Advantages and Caveats**
Boron	Typically present in leachate, non-reactive and mobile in common hydrogeologic environments, and not a common anthropogenic contaminant.	Sulfate	High concentrations expected in both washed and unwashed FGD gypsum (EPRI, 2011). Commonly analyzed. Very mobile in all hydrogeologic environments. Less useful in strongly reducing environments where sulfate can be reduced to hydrogen sulfide gas.
Molybdenum	Most useful for dry-managed coal ash. May be less mobile than boron in some hydrogeologic environments. Concentrations may be too low in impoundment leachate to be useful if background groundwater has detectable concentrations.	Fluoride	Assure that leachate concentration is higher than background, particularly for washed gypsum. Mobile in common hydrogeologic environments, although precipitation as CaF_2 is possible.
Lithium	Useful for coal ash management sites where the power plant burned bituminous coal. Leachate concentrations are typically low in coal ash derived from subbituminous and lignite coal (EPRI, 2006).	Calcium	High concentrations expected in both washed and unwashed FGD gypsum (EPRI, 2011). Understanding of carbonate chemistry necessary to assure that precipitation or dissolution does not affect downgradient concentrations.
Sulfate	Commonly analyzed and very mobile in all hydrogeologic environments. Concentration in impoundment leachate may in some cases be too low relative to background to be useful. Less useful in strongly reducing environments where sulfate can be reduced to hydrogen sulfide gas.	Boron	Mobile indicator constituent for unwashed FGD gypsum. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).
Bromide	May have high concentration in coal ash leachate at power plants where brominated powdered activated carbon (Br-PAC) or calcium bromide is used for mercury control. Leachate concentrations for coal ash generated absent use of these technologies may be too low to be useful. Mobile and non-reactive in typical groundwater environments.	Bromide	Mobile indicator constituent for unwashed FGD gypsum, especially if Br-PAC or CaBr used for mercury controls. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).

Table 3-1 (continued)
Potential Indicator Constituents for Coal Ash and FGD Gypsum

Potential Indicators for Coal Ash		Potential Indicators for FGD Gypsum	
Constituent	**Advantages and Caveats**	**Constituent**	**Advantages and Caveats**
Potassium	Commonly analyzed, although may be less mobile than boron and sulfate. Assure that leachate concentration is higher than background and that there are no anthropogenic sources such as agricultural fields where potassium may be applied in fertilizers.	Chloride	Mobile indicator constituent for unwashed FGD gypsum. Concentrations may be very high if transport water is recirculated. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).
Sodium	Useful for coal ash management sites where the power plant injects trona or sodium bicarbonate, or burned subbituminous coal. Absent dry sorbent injection, leachate concentrations are considerably lower in coal ash derived from bituminous coal, particularly at impoundments (EPRI, 2006). Assure that leachate concentration is higher than background and that there are no anthropogenic sources such as agricultural fields, or major highways in northern climates where sodium may be applied as road salts.		
Fluoride	Mobile and non-reactive in common hydrogeologic environments. Assure that leachate concentration is higher than background.		
Source: EPRI, 2012			

Site-Specific Leachate Analysis

Collection of site-specific field leachate data is useful for ASDs because it identifies 1) whether or not particular constituents that can cause an exceedance have higher concentration in leachate than in background groundwater, and 2) the leachate signature or fingerprint.

Where possible, leachate samples from landfills and impoundments can be collected using leachate wells, lysimeters, and/or leachate collection systems. These collection methods are preferred because the samples collected are representative of interstitial porewater. Because leachate characteristics will change with coal types and sources as well as changes in emission control technology, it is important to collect leachate samples representative of the spectrum of CCR materials placed into the CCR unit. Samples of pond water, sluice water, and runoff water are less useful than porewater samples for groundwater fingerprint analysis because their chemistry is affected by the composition of the source water used for sluicing as well as the leachate. Laboratory samples do not always represent actual leaching conditions (pH, redox, and liquid-to-solid ratio) and therefore, are less representative of actual field leachate composition than field samples. They are also more likely to provide only a snapshot of leachate chemistry based on the coal type and technologies used at the time of generation.

Water Quality Analyses for an ASD

The constituents included in a groundwater monitoring plan may not provide all data needed to evaluate certain lines of evidence for an ASD. The list below will typically provide the information needed for all except specialized lines of evidence.[5] Some of these constituents may already be part of the monitoring plan, while others may represent extra or special analyses.

- The constituents listed in Table 3-1, depending on the CCR managed in the site, in order to identify primary indicators for the leachate. All of these could be analyzed in leachate samples, and those with elevated concentration could be analyzed in groundwater samples.
- Major ion concentrations (alkalinity, chloride, sulfate, calcium, magnesium, potassium, and sodium) in leachate and groundwater. These concentrations can be used to evaluate whether downgradient groundwater chemistry remains representative of background groundwater chemistry. Major ion chemistry can also be used to evaluate natural variability due to seasonal changes or other causes.
- Field turbidity in groundwater is an indicator of the presence of suspended solids that may contribute to elevated concentrations of constituents monitored in unfiltered samples under the CCR Rule.
- pH in leachate and groundwater because it provides information on chemical reactions and mobility in groundwater.
- Dissolved oxygen (DO), oxidation reduction potential (ORP), and iron and manganese in groundwater are all indicators of redox conditions. Changes in redox can affect the chemical state and solubility of sulfate in addition to trace elements including arsenic and selenium. For example, under strongly reduced conditions, sulfate can be reduced to form hydrogen sulfide or it can precipitate as iron sulfide, arsenic reduces to the more mobile arsenite species, and selenium reduces to the low-mobility selenite species.

Water Quality Signatures

Natural surface water and groundwater may contain literally thousands of other substances (USGS, 2003). In fact, water is often referred to as the universal solvent because it dissolves more substances than any other solvent. Sources of these dissolved constituents or solutes include dust and gases collected as precipitation falls to the earth, dissolution of minerals in the soil and rocks, infiltration of contaminants from anthropogenic sources, etc. Groundwater monitored at a CCR unit for compliance with the CCR Rule is a compilation of the history of all sources of water comingling at that particular monitoring well. Different sources may contribute some of the same solutes, making source identification challenging. The identification and use of water quality "signatures" can be used as a tool for deciphering the similarity between potential sources and the water quality at a specific monitoring point.

EPRI (2012) describes three tiers of investigation for evaluation of water quality signatures to determine if elevated concentrations represent a release from a CCR facility. Conversely, these

[5] Specialized lines of evidence include geochemical modeling, isotopic signatures, and tritium age dating. Refer to EPRI (2017).

tools can also be used to evaluate whether or not sources other than CCR are contributing to groundwater quality degradation. The three tiers defined by EPRI (2012) are:

- Tier I: Trend Analysis and Statistics
- Tier II: Advanced Geochemical Evaluation Methods
- Tier III: Isotopic Analyses

This section provides guidance for interpretation of results using these evaluation techniques for an ASD.

Tier I Evaluation

By requiring determination of statistically significant increases/levels, the CCR Rule essentially requires Tier I statistical analysis under detection monitoring and under assessment monitoring. Many of the indicator constituents listed in Table 3-1 are included in constituent lists for these monitoring programs, including the primary constituents boron and sulfate. As discussed next, if there is an SSI/SSL without a corresponding increase in a primary indicator constituent (boron and usually sulfate[6] for coal ash), then this is a key line of evidence for an alternative source demonstration.

As previously introduced, an ideal primary indicator is a constituent that has concentrations in leachate greater than concentrations in background/upgradient groundwater, is mobile, and is relatively non-reactive in the hydrogeologic environment. Boron and sulfate are the most common primary indicators for coal ash leachate (EPRI, 2012). This is the first line of evidence to investigate for an ASD. If a constituent other than boron and/or sulfate is identified as an SSI/SSL but boron and/or sulfate are not also identified as elevated over background, it is unlikely that leakage from the CCR unit is the source of the SSI/SSL. This relationship holds for other potential indicators identified in Table 3-1, such as fluoride and sodium, if they have elevated concentration in site leachate relative to background.

If the site-specific leachate signature has not been determined, the potential indicators identified for fly ash and FGD gypsum in Table 3-1 can be considered. All of these potential indicators are naturally occurring and may be present in background groundwater. If any of these potential indicators are elevated over background but boron and/or sulfate are not, that provides a line of evidence for an ASD. Conversely, if any of these constituents have been identified as an SSI/SSL in addition to boron and sulfate, then temporal trends can be compared to determine if the constituents are trending together in the same direction. The more this "fingerprint" matches, the more strongly the monitoring results point to a release from the CCR unit. The trends in Figure 3-1 for boron, lithium, and sulfate indicate that lithium concentrations tend to rise and fall with boron and sulfate concentrations indicating that lithium may be an additional indicator parameter for a release from this site.

[6] Sulfate concentration increases may not be evident if groundwater is strongly reduced.

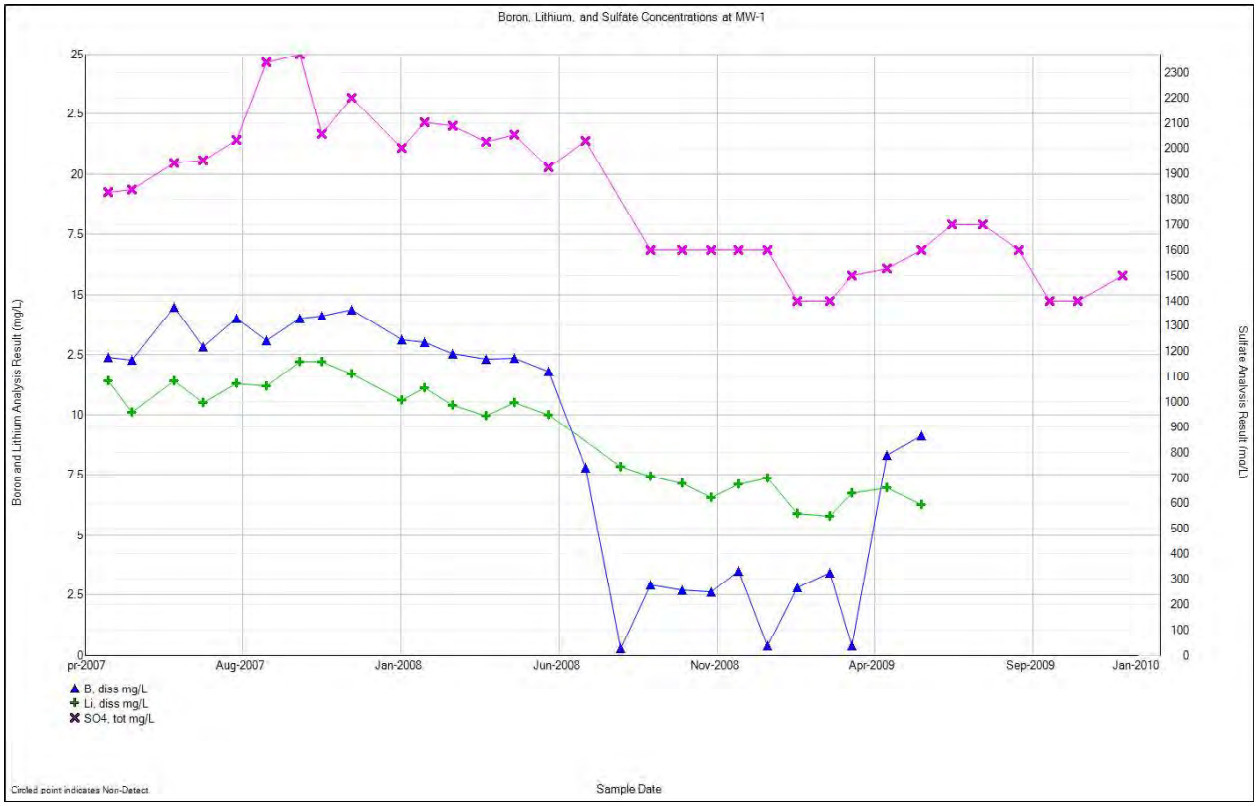


Figure 3-1
Time series plot showing potential correlation for lithium with boron and sulfate concentration changes indicating that lithium may be an indicator parameter for this site.

Scatter plots are another useful technique for identifying or refuting indicator parameters and identifying the presence of alternative sources. This technique plots one constituent on the X axis against another constituent on the Y axis. It can be used to show the relationship between two constituents. If the pattern of dots slopes from the lower left to the upper right portion of the graph, the two constituents are positively related (as one increases the other also increases). In this case, they are both likely related to the same source. If the pattern of dots slopes from the upper left to the lower right portion of the graph, the two constituents are negatively related and not from the same source. Figure 3-2 shows that arsenic and boron are not positively related. Therefore, even though the elevated boron concentrations suggest that a release has occurred, the lack of correlation suggests that the highest arsenic concentrations have a different source than the boron, which becomes a line of evidence in an ASD *specific to the arsenic*.

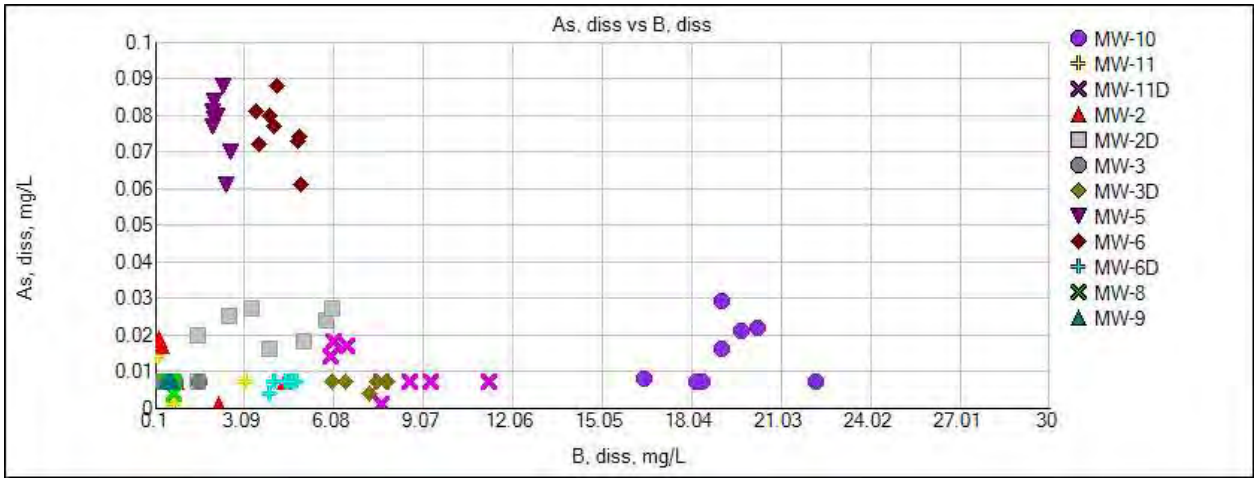


Figure 3-2
Scatter plot of arsenic versus boron, showing no correlation

Tier II Evaluation – Advanced Geochemical Evaluation Methods

Analysis of indicator constituents may not provide the lines of evidence needed for a strong ASD. More sophisticated methods may be needed at sites that have high concentrations of naturally occurring indicator constituents, multiple CCR sources, or upgradient sources of indicator constituents not related to the monitored unit, or where groundwater is brackish or saline. Furthermore, as groundwater travels through the environment, the composition may change due to geochemical interactions such as pH and ORP changes, influences from microbial activity, mixing with recharging surface water or other aquifers, or contamination from a variety of other anthropogenic or natural sources. The methods described below are useful for evaluating and visualizing the differences in water chemistry between upgradient and downgradient sampling locations.

Five Tier II methods were recommended in EPRI (2012) for multi-parameter comparison of water chemistry at multiple locations:

1. Ion ratios
2. Piper diagrams
3. Durov diagrams
4. Stiff diagrams
5. Fingerprint Analysis of Leachate Contaminants (FALCON)

This section adds a geochemical modeling and multivariate statistics to the EPRI (2012) list.

Ion Ratios and FALCON

The ion ratio method is the simplest approach from the list above and, unlike items 2 through 5, does not require analytical data for all major cations (calcium, magnesium, sodium, and potassium) and anions (chloride, sulfate, carbonate and bicarbonate or total alkalinity). Ion ratios are calculated by dividing the concentration of one constituent (usually the higher concentration constituent) by the concentration of another constituent from the same sample. Any units may be

used as long as the units are the same, because the ratio calculation is dimensionless. Ion ratios can be used to identify different source waters, or to determine that an additional source water is being added along a flow path. The method is based on the premise that if two constituents with similar mobility are released to groundwater, they will travel in groundwater at the same relative concentration or ratio unless they are mixed with water from other sources that have significantly different ratios of the same constituents. In other words, if leachate is released, then the relative concentration (ion ratio) in downgradient wells should be similar to the relative concentration in the leachate even if the concentration is diluted due to mixing with background groundwater. EPRI 2012 recommends that mobile, non-reactive constituents such as boron, chloride, lithium, molybdenum, and sulfate are the best candidates for this approach.

Table 3-2 illustrates the use of ion ratios as a line of evidence that downgradient well MW-3 is not impacted by ash leachate. In this example, MW-3 has higher sulfate concentrations than the two background wells, indicating that it may be impacted by CCR leachate. Boron concentrations at MW-3 are similar to upgradient well MW-1, whereas boron was not detected at upgradient well MW-2. Field leachate data indicate that chloride may be a CCR leachate indicator for this site in addition to boron and sulfate. Ion ratios for sulfate/chloride and boron/chloride were calculated and are provided in the chart (note that the boron/chloride ratios were multiplied by 1000 for enhanced visual representation). Since boron, sulfate, and chloride are all non-reactive in groundwater, ion ratios (boron/chloride and sulfate/chloride) representative of the leachate should remain consistent as leachate disperses and is diluted in groundwater unless there is another source of these constituents. In this case, the ion ratios at MW-3 are more representative of those at background wells MW-1 and MW-2, providing a line of evidence that CCR leachate is not the source of these constituents at MW-3.

Table 3-2
Use of Ion Ratios to Show that Groundwater Concentrations Are Not Caused by a CCR Release

		Background Wells		Downgradient Well	Field Leachate Concentration
Constituent	**Units**	**MW-1**	**MW-2**	**MW-3**	**LH-1**
B, tot	mg/L	0.02	<0.01	0.02	29
Cl, tot	mg/L	15	8	34	2,500
SO4, tot	mg/L	33	31	130	3,294
SO4/Cl Ratio		2.2	3.9	3.8	1.3
B/Cl Ratio	*1000	1.3	1.2	0.59	12

Ion ratios are also the basis of the Fingerprint Analysis of Leachate Contaminants (FALCON) method that was developed by the U.S. EPA. The FALCON method is more robust than simple ion ratios because it utilizes multiple constituents including all major cations and anions, as well as selected indicator constituents representative of the leachate signature. Regression analysis is used to mathematically represent the correlation between monitoring well, leachate, and background well signatures. EPRI (2012) provides a step-by-step procedure for the application of FALCON.

Piper, Durov, and Stiff Diagrams

Piper, Durov, and Stiff diagrams use graphical methods to group groundwater data to evaluate major ion chemistry. For an ASD, these methods are used to determine whether or not downgradient groundwater quality is a mixture of background groundwater and leachate. Interpretation of these plots can be subjective due to variation in the quality of various water groups. However, with Piper and Durov diagrams, a mixture is evident when downgradient groundwater quality plots at a point between leachate and background groundwater quality, and little or no mixing is determined if downgradient points plot with background, or at a point that is not between background and leachate. For a Stiff diagram, mixing is determined if the downgradient point evolves along a flow path to look less like background and more like leachate, where little or no mixing can be concluded if the shape of the downgradient point remains similar to background. These methods can also be used to evaluate whether or not an alternative source is affecting downgradient groundwater quality.

Common to each method is the necessity to conduct chemical analyses of the leachate and groundwater samples that include major cations and anions. Major cations present in natural water sources are calcium, magnesium, sodium, and potassium. Major anions are chloride, sulfate, bicarbonate, and carbonate. Bicarbonate and carbonate can be analyzed and reported together as total alkalinity. Prior to using graphical analysis for evaluation of major ion chemistry, it is good practice to calculate the charge balance in the sample. If the charge balance is not within an acceptable criterion (typically ±10%), it indicates that analytical results may be missing significant constituents, or there may be errors in the reported results. EPRI (2012) provides the equation and describes how to calculate and interpret the charge balance error for a water sample.

A Piper diagram is a graphical technique used to classify types of groundwater. It consists of two ternary plots (one for cations, and one for anions) linked to a diamond plot that is a combination of cations and anions. The Piper diagram below (Figure 3-3) shows an example where mixing is evident between leachate and groundwater, as denoted by the yellow-shaded area; however, the lysimeter chemistry does not indicate mixing of groundwater and leachate (primarily based on the cation triangle).

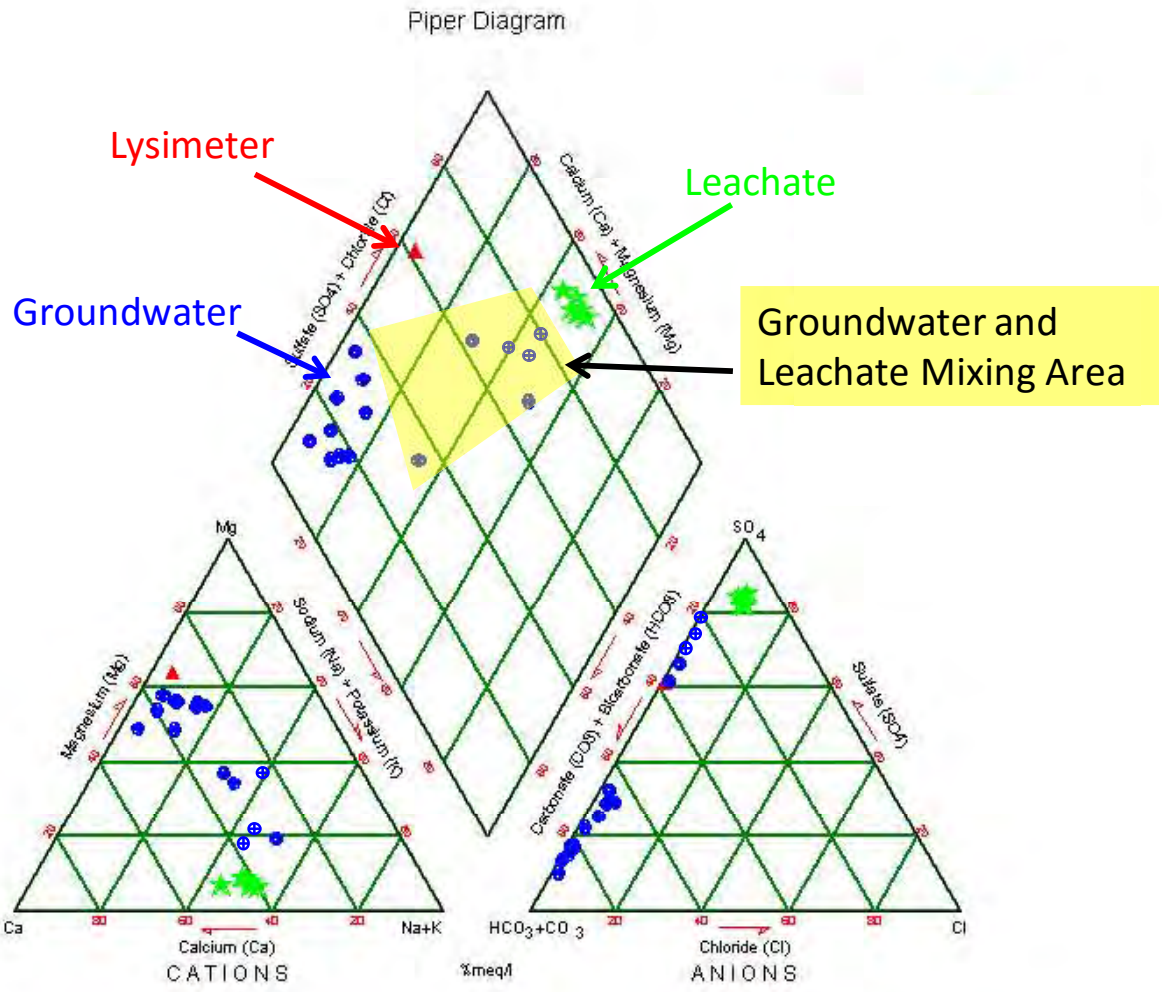


Figure 3-3
Example Piper diagram (from EPRI, 2012)

A Durov diagram is a combination of two ternary plots attached to a square-shaped plot. It displays data similar to a Piper diagram in different format. An example is provided in Figure 3-4. This diagram shows that bituminous coal ash leachate can be characterized as calcium-magnesium-sulfate water type, leachate from subbituminous coal ash can be characterized as sodium-calcium-sulfate water type, and background groundwater in this illustration can be characterized as calcium-magnesium-bicarbonate type.

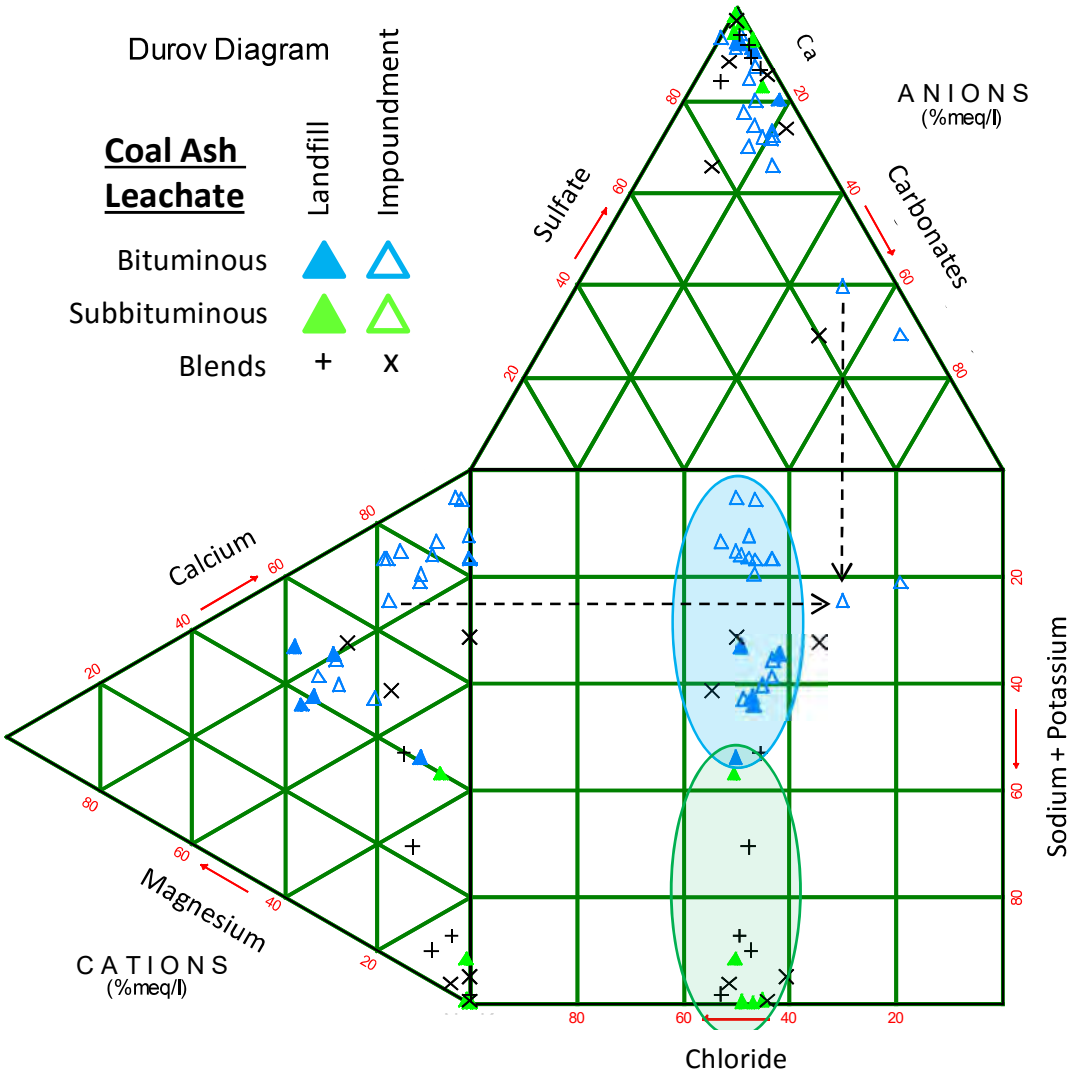


Figure 3-4
Durov diagram showing coal ash leachate derived from bituminous coal compared to subbituminous-lignite coal (From EPRI, 2012)

A Stiff diagram (Figure 3-5) is a multi-sided figure that compares the major cations in solution with the major anions. The resulting polygon can be placed in cross-sections or maps to show how the composition of the groundwater changes spatially.

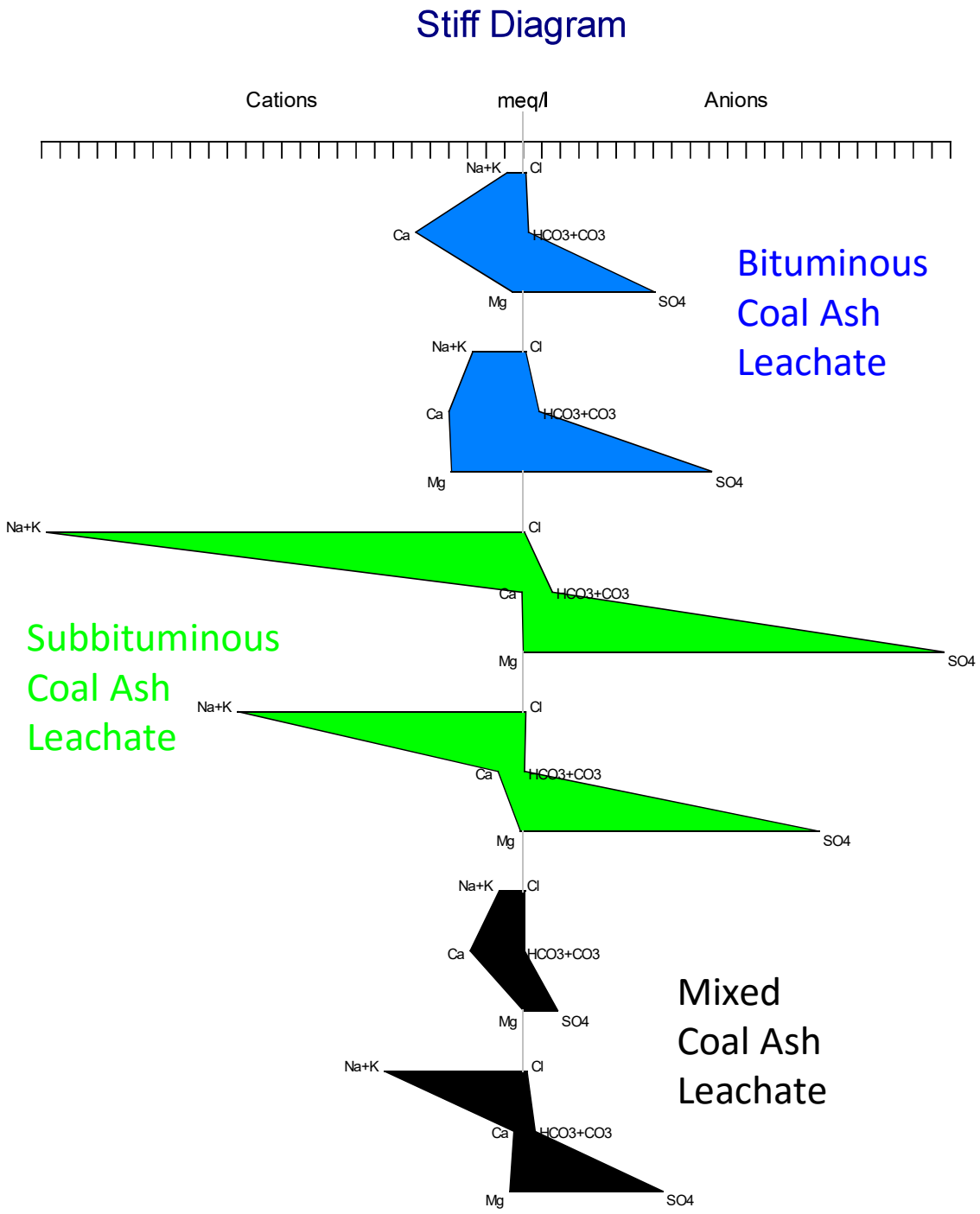


Figure 3-5
Stiff diagram showing six coal ash leachate samples (From EPRI, 2012)

Geochemical Modeling

Geochemical modeling is an additional Tier II geochemical method that can be used to evaluate the mobility of leachate or groundwater constituents based on chemical equilibrium and to potentially differentiate sources of groundwater contamination. Computer-assisted geochemical modeling has been used for many years to investigate the chemical equilibria of laboratory

extracts and field groundwater-leachate samples. EPRI (2017) discusses use of geochemical modeling to evaluate whether or not observed concentrations in a downgradient monitoring well can be a result of a groundwater flow path that includes mixing with CCR leachate.

Geochemical modeling can be used to identify the solid mineral phases that are controlling the solubility of dissolved cations and anions. Modeling can be used to identify whether dissolved constituents are thermodynamically favored to precipitate or remain in solution. Kinetic modeling attempts to identify the rate of chemical reactions. Such information is potentially useful for predicting the fate of dissolved constituents in a timeframe beyond the monitoring period. Kinetic modeling, however, may require additional information about the chemical and physical characteristics of the geomedia of the area under study.

Use of geochemical computer models requires entry of chemical characterization data for the groundwater sample(s) being evaluated. Analytical data, such as total sulfate or boron, are entered into the model, which will estimate the concentrations of several ionic forms (speciation) of each parameter. The model then calculates the degree of saturation of the liquid sample for hundreds of solid mineral phases. For example, if the liquid sample appears to be supersaturated with respect to a specific mineral, then that mineral is thermodynamically poised to precipitate from solution. Chemical precipitation may limit the movement of CCR constituents off-site.

The data required for chemical modeling are more extensive than those typically collected during a groundwater monitoring program. Most geochemical models require data for pH, ORP, alkalinity, and all the major anions and cations to ensure that the liquid sample is electrically balanced. In addition, solids data are often collected and used in the model to enhance confidence in results.

Multivariate Statistics

Multivariate statistics encompasses statistical analysis methods for evaluating more than two variables simultaneously and to determine how those variables relate to each other. Multivariate statistical techniques can be paired with geochemical modeling to determine the main sources of groundwater impacts in an aquifer, whether from a CCR leachate source, a naturally occurring source, or an anthropogenic source. Hydrogeological factors can also be co-evaluated with water quality data, including isotopic data from Tier III evaluations, using multivariate statistical methods. Although multivariate statistics is a powerful analysis tool for evaluating more complex datasets, it requires robust datasets, an experienced statistician, and a conceptual understanding of the input variables and their potential correlations. Computer software to perform multivariate statistical analysis relevant to environmental data is readily available.

Multivariate statistical methods utilized in the environmental field are typically correlation analysis, principal components analysis (PCA), and cluster analysis (CA). However, there are numerous other statistical methods available. Detailed explanations of the various multivariate methods available for statistical analysis are found in the following references:

- Anderson, T.W., 2003. An Introduction to Multivariate Statistical Analysis, Third Edition, John Wiley and Sons, Inc.
- Johnson, T.W. and D.W. Wichern, 2007. Applied Multivariate Statistical Analysis, Sixth Edition, Pearson Prentice Hall.

The scientific objectives identified by Johnson and Wichern (2007) for which multivariate statistics might be used include the following:

- **Data reduction or structural simplification**. To represent the information or conceptual model as simply as possible to aid in interpretation.
- **Sorting and grouping**. Groups of similar objects or variables are created based upon measured characteristics.
- **Investigation of dependence among variables**. Relationships between variables are evaluated to determine which variables might be independent and what two or more variables are dependent. From that information, the investigator might determine how the variables are related or what factor or feature they are related to.
- **Prediction**. Predicting the values of one or more variables based on observations of other variables. This is not a typical objective for an ASD evaluation.
- **Hypothesis construction and testing**. Testing of statistical hypotheses about multivariate populations to validate assumptions or reinforce other lines of evidence.

A brief description of a few of the more commonly used multivariate statistical methods pertinent to evaluation of groundwater and hydrogeologic data during an ASD is provided here, with the caveat that there are numerous other methods available.

Correlation Analysis can be performed on multiple variables, such as water quality constituents, to determine how much the variance of each constituent can be explained by the relationship with other constituents. Table 3-3 shows the Pearson product moment correlation matrix between pairs of variables measured in groundwater in background monitoring wells at a site. The correlation coefficients range between -1 and 1 and measure the strength of the linear relationship between the variables. The number of pairs of data values used to compute each coefficient was 60 (6 observations of each chemical parameter in groundwater per well for 10 wells). In the case of this dataset, correlations greater than 0.50 or less than -0.50 indicate statistically significant non-zero correlations at the 95 percent confidence level. Positive numbers indicate that the parameters are directly proportional, and negative numbers indicate that the parameters are inversely proportional. Bold-face numbers within highlighted boxes in the sample table indicate a high level of correlation between two parameters. Typically, correlation coefficients are rated as “high”, “medium”, and “low” (or “strong”, “moderate”, and “weak”) for values > 0.75, 0.75 to 0.50, and 0.50 to 0.30, respectively.

Table 3-3
Example Correlation Analysis Table

	Boron	Barium	Calcium	Chloride	Iron	Potassium	Lithium	Magnesium	Manganese	Sodium	Sulfate	TDS
Boron		0.13	-0.20	0.65	-0.02	0.25	0.47	-0.10	-0.04	0.63	-0.19	0.61
Barium			-0.11	0.77	**0.87**	0.38	0.28	-0.04	-0.16	0.73	-0.23	0.72
Calcium				-0.30	0.06	0.18	0.01	**0.98**	**0.81**	-0.34	**0.86**	0.00
Chloride					0.55	0.32	0.48	-0.17	-0.23	**0.94**	-0.37	**0.88**
Iron						0.40	0.31	0.11	0.10	0.58	0.06	0.62
Potassium							0.67	0.15	0.07	0.37	0.06	0.42
Lithium								0.05	0.08	0.45	-0.08	0.47
Magnesium									**0.86**	-0.21	**0.86**	0.14
Manganese										-0.18	**0.91**	0.15
Sodium											-0.29	**0.93**
Sulfate												0.01
TDS												

Principal Components Analysis (PCA) is used to reduce data to a small number of significant factors (i.e., components) for analyzing relationships among variables. PCA can be performed to evaluate the spatial variations of groundwater quality data and determine possible sources of specific contaminants. An analysis of principal components may reveal relationships between variables that were not readily apparent or suspected (Johnson and Wichern, 2007), or may assist in removing variables from an analysis that have no bearing on the objectives of an investigation. PCA analysis may serve as an intermediate step to determining what factors to focus on in an investigation and to assist in developing multiple lines of evidence in an ASD.

Cluster Analysis (CA) is a descriptive statistical analysis method used to identify groupings (i.e., clusters) of samples or other variables. CA is used to reveal the latent structure within a data set and is an exploratory tool only. For example, the data from a site can be analyzed using cluster analysis to demonstrate the following:

- Groupings of samples from wells into clusters based on water quality as defined by the major cations and anions
- Groupings of samples from wells into clusters based on water quality of minor and trace elements
- Groupings of wells into clusters based on selected water quality parameters and/or hydrogeologic variables

CA analysis results can be presented in several ways. To visually interpret how the data have been categorized, a graphical depiction of the clusters can be shown with a dendrogram. The dendrogram is a linkage tree that first links those samples or parameters that have the greatest similarity. Each subsequent linkage (or cluster) is less similar than earlier linkages. The greater the distance on the y-axis between linkages, the lower the significance between the linked samples or variables. In the example dendrogram displayed below (Figure 3-6), the first clusters of trace elements in groundwater upgradient from a CCR unit are between barium and iron, and the next cluster is aluminum and lithium. The correlation coefficient {R} calculated for barium and iron is strong at R = 0.87. The R value for aluminum and lithium is moderate at 0.63. Next, barium-iron is clustered with strontium (R = 0.54 and 0.56, respectively) and aluminum-lithium

is clustered with boron (R = -0.02 and 0.47, respectively). Manganese concentrations in groundwater at the study site are very poorly correlated with all the other minor/trace elements, and there is no cluster formed with any other parameters.

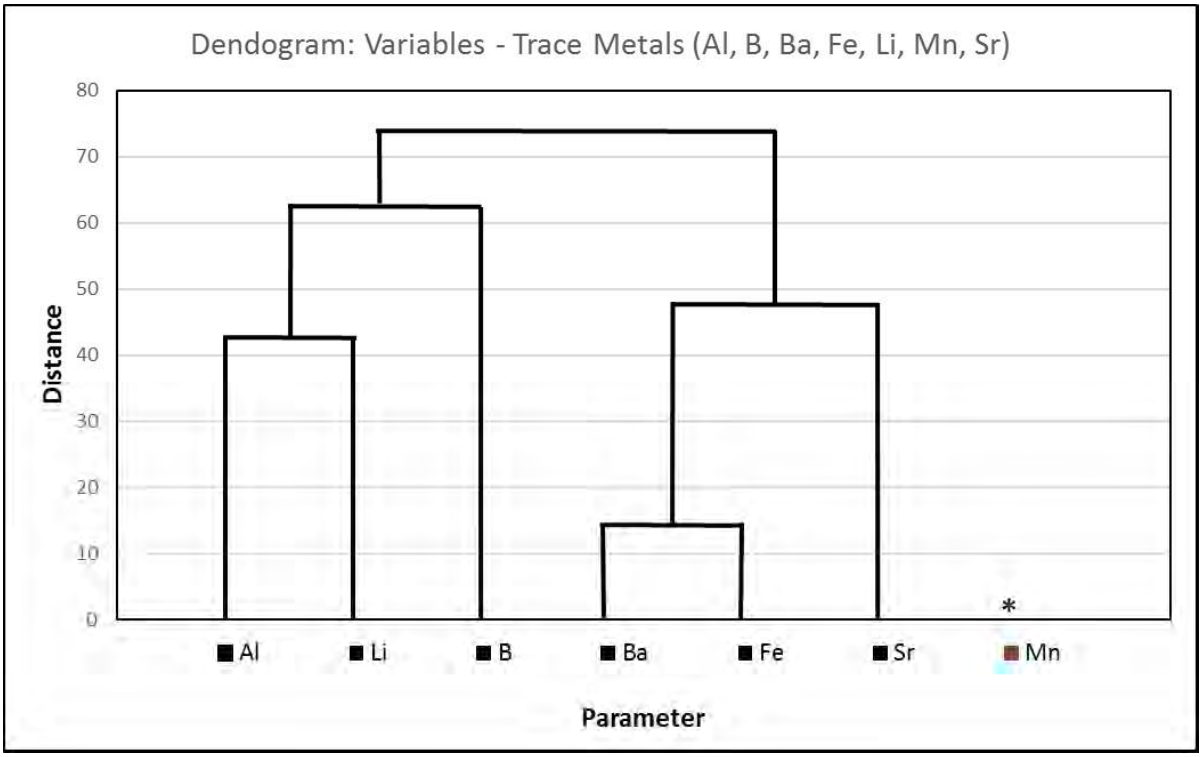


Figure 3-6
Example Cluster analysis dendrogram

Tier III Evaluation – Isotopic Analyses

Tier III uses isotopic analyses as a method to determine a groundwater signature. As described in EPRI (2017), isotopes have the same number of protons, but each form has a different number of neutrons. Because of this difference in atomic mass (neutrons plus protons), the isotopes will react differently with geomedia as they migrate in groundwater. These differences can be expressed as isotopic ratios, and can be used as diagnostic tools.

The application of isotopes as groundwater signatures is a relatively new technique, but boron isotopes are particularly relevant to CCR. Boron-11 is heavier than boron-10, and the heavier isotope is preferentially precipitated or sorbed from solution. Changes in the ratio of these two isotopes can yield information about the source of boron in the groundwater. Available data suggest that CCR leachate is often isotopically light, while groundwater may be isotopically heavy. Other isotopes that may be useful include strontium, oxygen, and hydrogen. EPRI (2012 and 2017) provides a comprehensive review on the use of boron and selected other isotopes as groundwater signatures.

Another form of isotopic analysis is tritium age dating. As discussed in EPRI (2017), tritium has a relatively short half-life of 12.3 years. Furthermore, there was an accumulation of tritium in the atmosphere in the early 1960s due to atmospheric atomic bomb testing. These two observations

enable use of tritium data to determine whether or not groundwater recharged prior to atmospheric testing of atomic bombs (i.e., prior to the 1960s) or since that time. If a CCR site was built during or after the 1960s, but the groundwater does not have detectable levels of tritium (meaning it recharged prior to the 1960s), that provides a line of evidence that an SSI/SSL is not due to a release from that site because the leachate from such a site would have detectable levels of tritium that should be evident in the downgradient groundwater.[7]

Hydrogeologic Scenario Evaluation

Hydrogeologic scenario evaluation is another line of evidence that can be used in an ASD. The premise is that if a mobile and non-reactive constituent is released to groundwater, it will travel in groundwater with a predictable concentration profile unless mixed with water from other sources that have significantly different concentrations of the same constituent. Following the ion ratio approach discussed above, the downgradient concentration of the mobile, non-reactive constituent of concern should be proportional to the mixing ratio of the relative volumes and concentrations of all sources combined and collected at the downgradient monitoring point.

Figure 3-7 presents a variety of hydrogeologic scenarios comparing leachate concentration of a mobile, non-reactive constituent to the concentrations observed in upgradient and downgradient wells. Groundwater flow directions are also considered to point out that some downgradient monitoring wells may be in a side-gradient or partial intercept path rather than in the direct path of the monitored upgradient groundwater. Each column in Figure 3-7 presents two to three hydrogeologic scenarios as follows:

- Column 1 – Scenarios providing a line of evidence that a CCR facility is the source of an SSI/SSL.
- Column 2 – Scenarios providing a line of evidence that both a CCR facility and a possible alternative source are the source of an SSI/SSL.
- Column 3 – Scenarios providing a line of evidence that an alternative source is causing an SSI/SSL.

The basis for these scenarios is fairly straightforward:[8]

- If leachate concentration is less than background, leachate cannot cause downgradient concentrations to be higher than background, and an alternative source is indicated.
- If downgradient concentrations are greater than leachate concentrations, an alternative source (natural or anthropogenic) must be present.

These scenarios, particularly those shown in columns 2 and 3 of Figure 3-7, demonstrate the benefit of multiple upgradient monitoring wells. This benefit is also realized for intrawell statistical programs if there is any potential for naturally occurring or anthropogenic changes in groundwater quality upgradient of the monitored unit.

[7] This line of evidence may not be valid in the case of a pond where "old" groundwater, for example from a deep aquifer, was used for sluice water.

[8] Assuming that leachate and background concentrations are well-characterized.

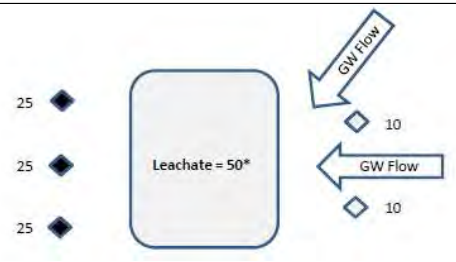
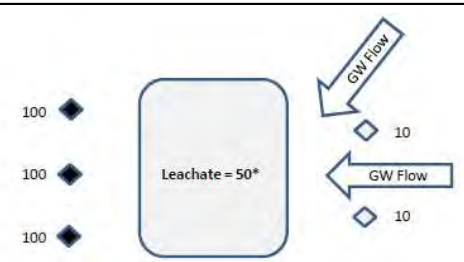
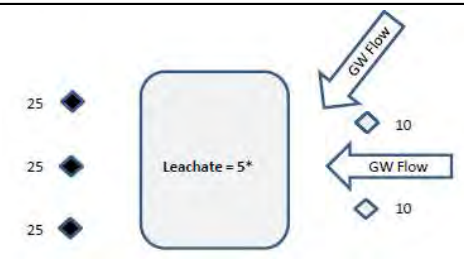
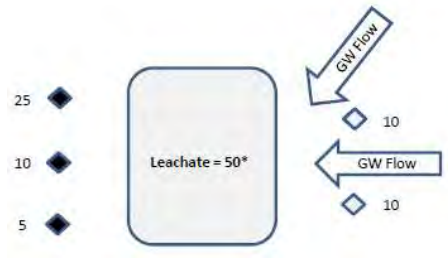
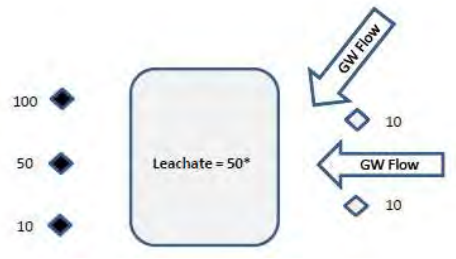
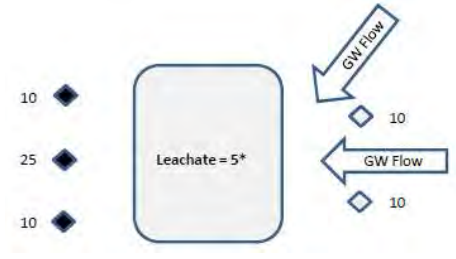
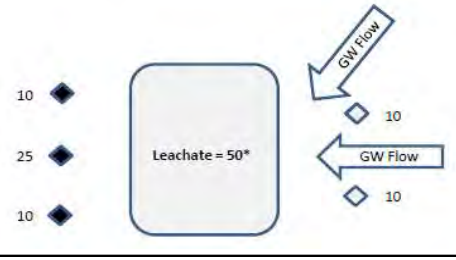
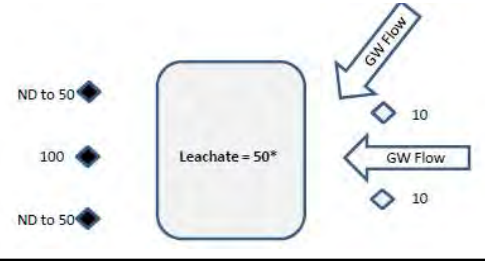
	Line of Evidence for:		
	CCR Leachate Release	**Possible CCR Leachate Release + Possible Alternative Source**	**Alternative Source Release**
	Column 1	**Column 2**	**Column 3**
Row a			
Row b			
Row c			
	1. Leachate concentration is higher than upgradient/background. 2. One or more downgradient concentrations are higher than upgradient/background but lower or equal to leachate concentration.	1. Leachate concentration is higher than upgradient/background. 2. One or more downgradient concentrations are higher than the leachate concentration.	1. Leachate concentration is less than upgradient/background.

Figure 3-7
Example hydrogeologic lines of evidence

Time-of-Travel Evaluation

Time-of-travel for a mobile and non-reactive source constituent to a downgradient monitoring well can also be considered as a potential line of evidence for connecting a source to an elevated result at a downgradient monitoring location. It takes time for a source constituent to travel downward to reach the aquifer and then travel within the aquifer to the downgradient monitoring location. For example, if groundwater velocity is 50 ft/year, assuming minimal dispersion, it would take about two years for a release to reach a monitoring well 100 feet from the waste boundary *if* the release occurred at the waste boundary, and *assuming* a relatively thin unsaturated zone. It would take more than two years if the release occurred toward the center of the facility as opposed to the waste boundary of a lined facility, or if there was a thick unsaturated zone. Since the permeability of different geological media such as sand, gravel, clay, silt, and fractured bedrock can vary considerably, time-of-travel evaluation requires knowledge of site and regional hydrogeology. If this information is available, it can be used to identify or discredit potential sources. Horizontal groundwater flow velocity through a uniform (homogeneous) water-bearing unit with no preferential flow direction (i.e., anisotropic), is calculated as follows:

$$V = K i / n_e$$

V = Groundwater Velocity
K = Hydraulic Conductivity
i = Hydraulic Gradient (unitless value)
n_e = Effective Porosity

Simple analytical models such as MYGRT (EPRI, 2005), or more advanced fate and transport models, can also be used for this evaluation. Models can account for dispersivity, which is not accounted for in the equation above.

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4
NATURAL VARIATION

Natural variation encompasses natural variation in background levels and variability due to geologic influences such as dissolution of geomedia and natural ion exchange, changes in groundwater quality and/or flow related to precipitation such as changing water levels in monitoring wells, groundwater recharge and discharge fluctuations near surface water bodies, and time-of-travel for monitoring wells to detect upgradient changes, as well as influences related to changes in pH, oxidation reduction potential, and biological activity. These interactions, and how they may affect groundwater quality, are discussed below.

Changes in Mineralogy Along a Groundwater Flow Path

The mineralogy of soils and rocks near the monitored CCR unit can affect the natural chemistry of groundwater. For example:

- Geomedia such as limestones and certain sand units that are rich in carbonates can add calcium to the groundwater.
- Geomedia with little carbonates lack buffering capability that can enable changes in chemistry if low-pH recharge from precipitation reduces the overall pH of the aquifer along the flow path.
- Geomedia that contain reactive clay minerals can alter the chemical composition of groundwater by dissolution-precipitation reactions, and by either removing (by sorption) or adding (by desorption) solutes along the flow path.

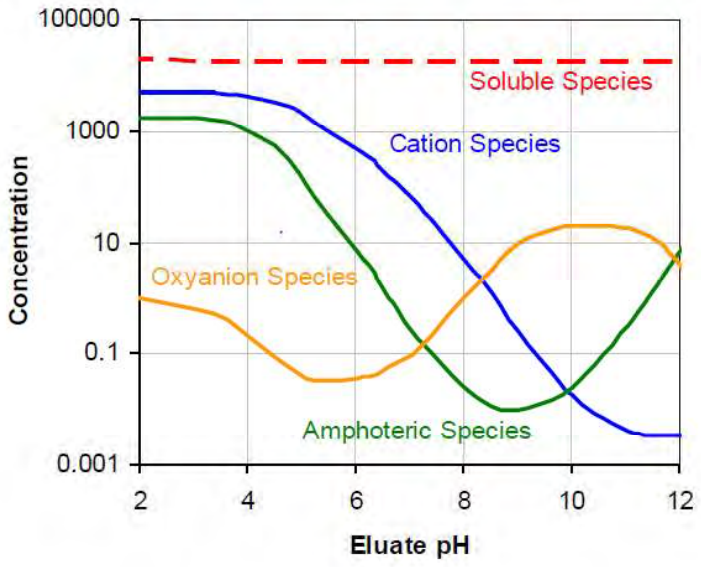
The extent of the reactions can be pH-dependent, which may depend on changes in mineralogy. These examples underscore the importance of placing background monitoring wells in the same geomedia as compliance monitoring wells. If background and compliance wells are in different geomedia,[9] then SSIs/SSLs due to this natural variation and unrelated to a release from the facility are possible, and even likely. An ASD in this case would highlight the mineralogical differences between the geomedia and constituents expected to be affected.

Changes in pH Along a Flow Path or over Time

If pH is different between background and compliance wells, and/or changes over time, it can cause chemical changes capable of triggering an SSI/SSL. Examples of concentration changes that can occur due to a change in pH are illustrated in Figure 4-1 and the text that follows. For the purposes of an ASD, if there is an SSI/SSL at a monitoring well where pH is different from

[9] It is not always possible to screen background wells in the same geomedia as compliance wells. In these cases, intrawell statistical analysis can avoid this form of natural variation; however, intrawell analysis may not be an option in certain detection monitoring plans if monitoring wells have already been affected by a release.

or has changed from background (SSI) or baseline (SSL), and the constituent with the SSI/SSL is sensitive to changes in pH, then the pH difference can be a line of evidence in an ASD.



Soluble Species: Sodium, potassium, chloride, boron, sulfate. Solubility is high and not dependent on pH.
Cation Species: Iron. Solubility is high at low pH and decreases with increasing pH.
Oxyanion Species: Arsenic, selenium, molybdenum. Solubility is characterized by pH dependent curves. Solubility is typically at a minimum at near neutral to slightly acidic pH range and at a maximum at near neutral to slightly alkaline pH.
Amphoteric Species: Aluminum, lead, copper. Solubility curve is similar to the cation species curve, but with a distinct low solubility range with higher solubility at lower and higher pH ranges.

Figure 4-1
Typical solubility behavior of various constituents as pH changes (EPRI, 2007)

Soluble species such as sodium, potassium, chloride, boron, and sulfate tend to have relatively high solubility that is not affected by changes in pH. Cation species such as iron usually have higher solubility at low pH and minimum solubility at high pH.

Oxyanion species include elements such as arsenic, selenium, and molybdenum that react with oxygen or hydroxide to form anions. The solubility of oxyanion species varies with pH and often ORP because their chemical form changes as these two variables change. For example, the specific form of arsenic in solution depends on both pH and ORP. Under highly alkaline conditions (pH > 11), the dominant form of arsenic is AsO_4^{3-}. In relatively acidic groundwater (pH < 7), the dominant form is $H_2AsO_4^-$ under oxidized conditions, and $As(OH)_3$ under reduced conditions. The solubility curves of oxyanions characteristically have minimum solubility at near neutral to slightly acidic pH and maximum solubility at slightly alkaline pH.

Amphoteric species such as aluminum, lead, and copper have solubility curves similar to the cation species; however, they typically exhibit a range of minimum solubility, with higher solubility at lower and higher pH ranges.

Changes in Redox

Similar to a change in pH, a change in the redox state of the groundwater can have a significant impact on the concentration of some constituents in groundwater. If there is an SSI/SSL at a monitoring well where there is indication that redox is different from or has changed from background (SSI) or baseline (SSL), and the constituent with the SSI/SSL is sensitive to changes in redox, then the redox change can be a line of evidence in an ASD (Figure 4-2).

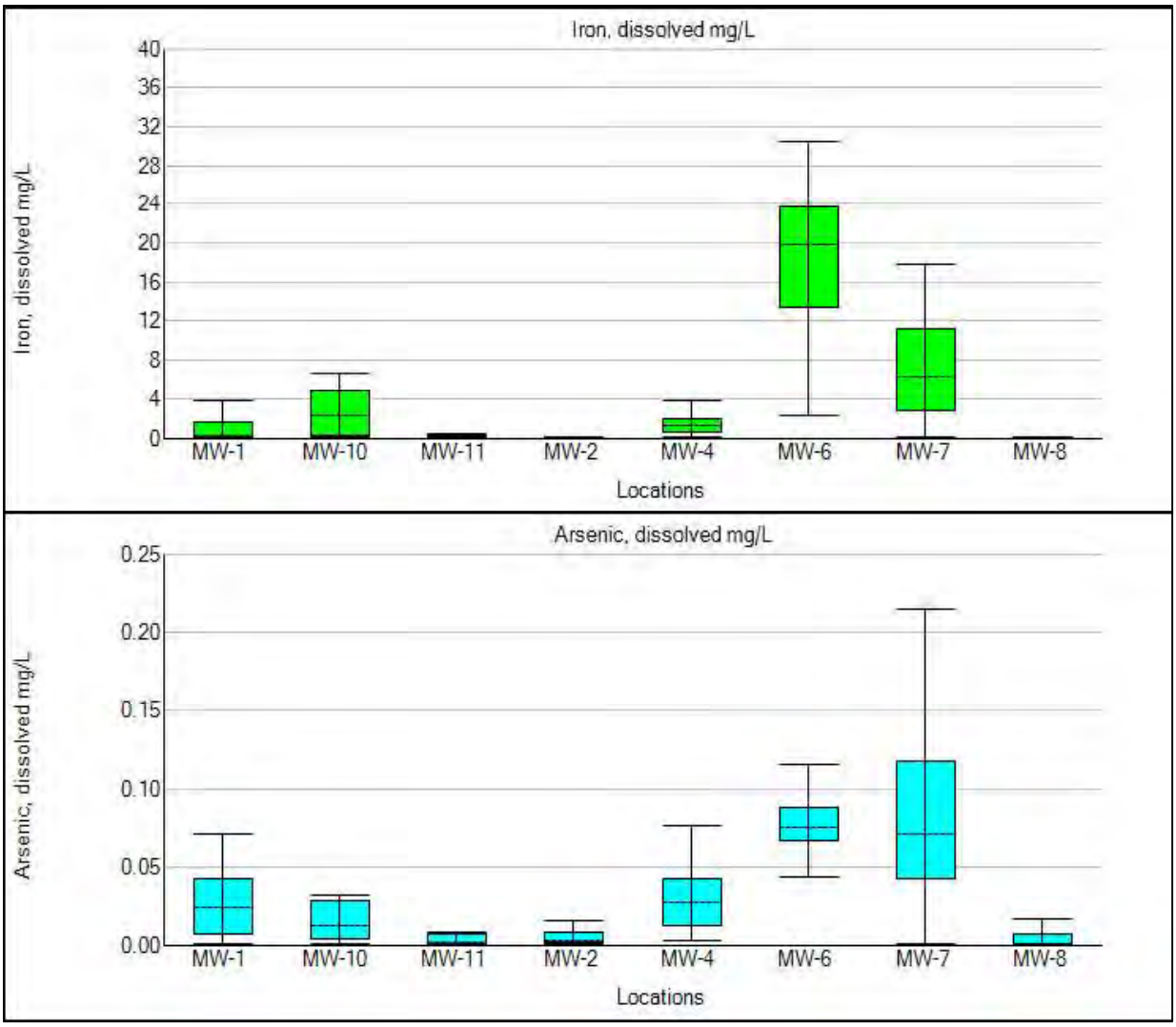


Figure 4-2
Example ASD line of evidence where elevated arsenic concentrations occur in monitoring wells with elevated iron, indicative of reduced conditions

The term redox refers to reduction-oxidation. Oxidation is the loss of electrons or an increase in the oxidation state of an ion or molecule. Reduction is the gain of electrons or a decrease in the oxidation state of an ion or molecule. In a more practical sense, the redox potential of groundwater reflects the dissolved oxygen content. Oxic water has higher levels of oxygen—if an element has multiple oxidation states in groundwater, then the species with a higher electrical charge will be prevalent in an oxic environment. Reduced groundwater typically has low dissolved oxygen content—the species with a lower electrical charge will be prevalent in a reduced environment. Redox potential, Eh, ORP, and pE are all measures of redox state. In addition, concentrations of iron and manganese can be used as indicators of redox state in groundwater because these constituents tend to have low concentration in oxic groundwater and high concentration in reduced groundwater.

Examples of redox-sensitive constituents include, but are not limited to the following:

- Naturally occurring sulfide minerals in reduced soils may form soluble sulfate if exposed to oxygen—which can occur when a monitoring well is installed, resulting in a naturally occurring increase in sulfate concentration in that monitoring well. Conversely, under strongly reducing conditions, sulfur in groundwater can convert from sulfate to hydrogen sulfide gas, with a corresponding reduction in sulfate concentration.
- Under oxidized conditions, arsenic in groundwater occurs in the 5+ oxidation state as arsenate (AsO_4^{3-}), but under reducing conditions it occurs in the 3+ oxidation state as arsenite (AsO_3^{3-}) and is more soluble and mobile. It is not uncommon to see naturally occurring arsenic in reduced groundwater. Conversely, if arsenic-containing sulfide minerals are present in an aquifer under reduced conditions, introduction of oxygen, for example by installing a monitoring well, can result in release of arsenic to groundwater in the vicinity of the monitoring well.
- The solubility and speciation of selenium in groundwater is dependent on the pH and ORP of the solution. In highly oxidized solutions, selenium exists as highly mobile selenate. Over a relatively large range in pH and ORP, selenium occurs in the selenite forms as $HSeO_3^-$ and SeO_3^{2-}. Under oxygen-poor conditions, the concentration of selenium in groundwater (as HSe^-) may be controlled by the solubility of ferroselite ($FeSe_2$). Because anionic selenium is the dominant form of the element in groundwater, sorption may not be significant by many types of geologic media.
- Boron, molybdenum, lithium, and cobalt concentrations are not significantly impacted by the range of redox commonly observed in groundwater.

Influence of Biological Activity

The potential for biologically mediated chemical reactions should not be overlooked. Some of the redox reactions described above, particularly release of naturally occurring arsenic, can be biologically mediated. For example, when pyrite (ferrous sulfide) deposits (commonly present in coal) are exposed to air by mining operations, oxidation and release of ferric iron, sulfate, and sulfuric acid can be accelerated by bacteria that thrive in a low-pH sulfuric acid environment, accelerating the reaction and increasing the release of sulfuric acid and other minerals present in the geomedia that are more soluble in low pH and/or oxidizing environments, such as arsenic. Another example of natural microbial redox activity in geomedia is oxidation of ammonia nitrogen to nitrate and/or nitrite compounds. As discussed in Section 5, the presence of ammonia, nitrate, or nitrite in CCR monitoring wells is typically related to agricultural activities; however, it may also be due to leaching of ammonia compounds deposited on fly ash or FGD solids due to the use of ammonia in selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR) emission control technology for reduction of nitrogen oxide emissions.

Changes in Groundwater Elevation at Compliance Wells

In some cases, groundwater can be naturally stratified, for example if shallow groundwater is oxic and deeper groundwater is reduced. Stratification may also occur near groundwater discharge points where upwelling of deep groundwater, which may have higher dissolved solids content than shallow groundwater, may be occurring. Stratification is also common near oceans

where saltwater wedges form beneath fresh water due to the higher density of seawater. When there is a natural stratification of groundwater quality, changes in groundwater elevation can trigger a naturally occurring SSI/SSL if the deeper water rises and intersects the monitoring well screen.

Such changes in groundwater elevation can be due to precipitation/recharge events, or changes in elevation at nearby groundwater discharge points such as rivers (which can also affect flow direction as described next). Changing groundwater elevation can be a line of evidence for an ASD if there is evidence that the groundwater is naturally stratified. A hydrograph showing a change in groundwater elevation (up or down) that corresponds with the SSI/SSL may be useful in supporting this cause.

Changes in Groundwater Flow Direction at Compliance Wells

Groundwater flow direction naturally exhibits variability. For many sites, this variability may not be significant; however for some sites, flow direction can vary by as much as 180 degrees. Inland locations may have relatively narrow ranges of variability, such that groundwater flow is usually in one broad direction. Sites along rivers can exhibit very large ranges of variability, including complete flow reversals, that are dependent on river stage. Much of this variability will be accounted for during the background monitoring period. However, if the background monitoring was performed during a period of little variation, or if there is an extreme hydrologic event such as a 100-year (or larger) flood, then groundwater flow can change in a way that was not accounted for during the background monitoring period, and if there is aerial variability in groundwater chemistry, then this change in flow direction can trigger an SSI/SSL due to natural variation in groundwater flow direction.

If groundwater flow direction at the time of, or prior to, sampling for an SSI/SSL is different than flow directions that occurred during the background monitoring period, then that is a line of evidence for a naturally occurring ASD. Groundwater flow direction is not typically monitored between sampling events, so a change in flow direction prior to a sampling event may need to be demonstrated based on indirect evidence such as river hydrographs showing that a particular river stage was not representative of the background monitoring period.

Another ASD consideration with changes in groundwater flow direction is detection of an alternative anthropogenic source that had not previously been detected. While the cause of the SSI/SSL in this case is not natural variation, the detection of the alternative source is due to natural variation.

Time-of-Travel Consideration for Natural Variation

As noted in Section 3, there will be a time lag between the time that a change in concentration affects background groundwater and when that same change is detected in downgradient groundwater. Just as it takes time for somebody to walk from point A to point B, it takes time for water to travel through geomedia. Methods for calculating that time lag are presented at the end of Section 3.

If a change in concentration is noted at an upgradient monitoring location, and a similar change at a downgradient well triggers an SSI/SSL at a later date, then a line of evidence for an ASD can be developed if it can be demonstrated that the detected constituents are the same as detected in

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the upgradient well, and the time lag is consistent with groundwater velocity between the upgradient and downgradient locations.

This line of evidence applies to both natural variability and upgradient anthropogenic sources. A natural variability example would be a case where pH changes in groundwater chemistry affect upgradient locations before downgradient locations.

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5
ANTHROPOGENIC IMPACTS TO GROUNDWATER

When considering alternative sources that may be contributing to an SSI/SSL, it is important to investigate the site and surrounding area for current and historical land uses. Mapping descriptions and locations of current and historical land uses near the CCR unit, along with groundwater flow direction and locations of surface water bodies, can narrow the list of likely alternative anthropogenic sources and identify constituents to look for that may point to an alternative source (Figure 5-1).

If the CCR unit is on or near a power plant, note the past and current locations of coal piles, impoundments, landfills, underground and aboveground oil storage tanks, known oil and chemical spill areas, CCR transport routes (i.e., haul roads and sluice lines) and processing areas, and areas where ash or other fill material has been used as structural fill. This information may help identify on-site activities that may be contributing to an SSI/SSL.

Understanding the area surrounding the CCR unit can guide the ASD investigation, because the groundwater signature often reflects the combined local land uses. Land uses and/or features that may be near coal-fired power plants are discussed below. Tables A-3 and A-4 in Appendix A list activities that can affect the groundwater concentrations of constituents monitored at CCR management facilities by constituent and by activity, respectively.[10]

[10] Tables A-3 and A-4 are also presented in Section 2 as Tables 2-2 and 2-3.



Figure 5-1
Examples of anthropogenic activities near a CCR unit with potential to affect groundwater quality in one or more monitoring wells, depending on the direction and variability of groundwater flow.

Power Plant Land Use and Operations

Power plant operations including other CCR impoundments and landfills, as well as historical land uses, can be reviewed as potential alternative sources, depending on their location relative to groundwater flow at the CCR unit with the SSI/SSL and the water quality signature. Areas to evaluate during the ASD include areas of coal or coal ash spillage, coal piles and coal pile runoff conveyance structures, underground storage tanks, underground piping, locations of past chemical spills, and other CCR management facilities.

Preparation of subgrades to achieve favorable power plant building conditions may have required low areas to be filled with structural fill. Historical requirements for fill material were not as strict as current standards for leachability and therefore, materials such as fly ash, bottom ash, construction debris, demolition debris, dredge spoils, and/or incinerator residue may have been used as fill material, particularly at older power plant sites. If these types of materials are present, they may contribute leachate to groundwater from random, non-point source locations. If historical fill practices are a potential concern, consider researching fill locations and material types and quality by reviewing historical fill maps and aerial photographs, reviewing historical fill records with sampling data and/or fill material descriptions, reviewing information available on neighboring properties, and interviewing knowledgeable persons and neighbors.

Historical ash management practices may have included on-site use of fly ash and/or bottom ash for fill, road base, berm construction, and other structural applications. Ash may also have been piled in various areas for dewatering or temporary storage or transfer to trucks. Former ash ponds and/or landfills may have been covered and closed on-site, or may have a residual contribution to groundwater contamination.

Current or past ash handling practices may also have allowed for dispersion of ash and subsequent accumulation in plant sumps, storm water swales and ponds, and other low-lying areas. In particular, wind-blown ash may accumulate in ditches, or leachate sprayed for dust control on an active landfill face may be blown off the lined area where it can infiltrate. Such conditions can contribute to localized, elevated groundwater concentrations with ash leachate signatures. It is important to be aware of these activities and their locations because their presence can result in SSIs/SSLs, but from sources other than a release from the liner/base of the monitored CCR unit.

Contaminants from underground storage tank (UST) leaks, aboveground tank and transformer leaks, underground oil piping leaks, or oil and/or chemical spills may also cause groundwater impacts, the extent of which depends on the severity and duration of the leak or spill. Oil-based contamination primarily involves organic constituents; however, trace elements may also be of concern. For example, biological activity associated with a petroleum plume may result in biologically mediated arsenic release from minerals in the aquifer. Therefore, it is important to be aware of site history as it relates to major oil and chemical spills, and UST and underground piping leaks in case these issues may potentially be impacting CCR monitoring.

If an on-site anthropogenic source is suspected, consider testing for additional analytes such as organics (to diagnose oil-related contamination), and/or all major ions to enable use of Tier II geochemical analysis to help determine similarity and source of groundwater collected at the monitoring wells. Other constituents such as aluminum, iron, and manganese may also be helpful in fingerprinting potential alternative power-plant-related groundwater impacts. Perhaps most

importantly, knowledge of site history can be very helpful in determining whether or not alternative plant-related sources are positioned upgradient of wells where an SSI/SSL was determined.

Agricultural Activities

If the CCR unit is located in an area with upgradient farmlands or livestock, then groundwater impacts associated with these agricultural activities can be evaluated for an ASD. Agricultural impacts to groundwater are possible due to its prevalence and the use of irrigation water, fertilizers, and pesticides to support optimal plant growth. The most common constituents of concern include nitrogen compounds (nitrate, nitrite, and ammonium) and phosphorus compounds associated with fertilizers, runoff from animal feedlots, and the use of manure for crop fertilization; however, other inorganic constituents may also come from agricultural sources (refer to Table A-4).

Relatively high levels of nitrate, nitrite, and/or ammonium ions in groundwater are indicators of agricultural impacts. Consider analyzing for these constituents, particularly in upgradient wells, if groundwater degradation from surrounding agriculture is possible.

If the power plant that produced the CCR utilizes SCR or SNCR technology, ammonia compounds may have adsorbed onto the ash (usually as ammonium bisulfate or ammonium sulfate) and may subsequently be released to groundwater as ammonium ions. Biological activity may convert the ammonium ions into nitrate and/or nitrite. Nitrogen compounds also may occur naturally in soil due to fixation by bacteria in the root nodules of legume plants, such as soybeans and alfalfa. Therefore, when considering a potential alternative source demonstration related to nitrogen compounds, consider agricultural activities surrounding the CCR management unit, the potential for natural occurrence associated with legumes, and the processes used to produce the CCR. It may be difficult to distinguish between naturally occurring nitrates/nitrites and those present due to leaching from fertilizers, animal wastes, or ammoniated CCR. However, phosphorus is not a common constituent of CCR, so the presence of elevated concentrations of phosphorus in groundwater typically points towards agricultural sources.

In addition to nitrogen and phosphorus, agricultural activities may also contribute trace elements, salts, herbicides, pesticides, and pathogens to the groundwater. Because herbicides, pesticides, and pathogens are not monitored under the CCR Rule, they are not discussed in more detail here, but if they are known to be present, their presence indicates a source other than CCR.

Salts and trace elements may leach into groundwater as a result of agriculture, particularly in arid western regions of the United States that rely heavily on irrigation to support agricultural activity (Carter, 1980). This is particularly a concern if the native soils originated from marine mud and sediments that may contain elevated concentrations of arsenic, boron, calcium, chloride, magnesium, mercury, molybdenum, nitrate, potassium, selenium, sodium, and sulfate, and/or if the irrigation water is salty.[11] Selenium is a common constituent of concern in these environments (Fio et al., 1991). Use of salty irrigation water can result in salt deposition and the

[11] http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/cwin/cwinappendix_a.pdf

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need for increased irrigation to flush salts from the root zone of the crops, resulting in increased leaching of these salts and trace elements to the receiving groundwater. Distinguishing between agricultural sources and CCR sources may be challenging in this situation. Evaluation of nitrogen and phosphorus compounds and/or use of Tier 2 geochemical methods can be used to try to distinguish between sources. Another evaluation option in this case is analysis for boron isotopes.

Road Salting

Use of salt or salt spray for road deicing can affect groundwater quality near roads in northern climates (Kelly et al., 2009). Common types of salt used for road deicing include sodium chloride, calcium chloride, magnesium chloride, and potassium chloride. High chloride concentrations in groundwater observed during detection monitoring may be due to road salting rather than a release from the monitored facility.

Leaking Underground Pipes

In large urban areas, liquid waste including household and commercial sewage, storm water runoff, and industrial wastewater, is transported to treatment facilities in underground pipes. Under certain conditions (i.e., leaks and outward flow) this underground infrastructure may serve as conduits to transport contaminants from their original source to other areas that may be difficult to connect with the source. If the groundwater quality signature indicates an anthropogenic source, but does not resemble CCR, and no other anthropogenic source is apparent, then it may be worthwhile to investigate whether or not leakage from underground pipes is a potential alternative source.

Gasoline (Gas) Stations

Leaking underground storage tanks (LUSTs) at gas stations containing gasoline, diesel, kerosene or oil are a common source of groundwater contamination. As of March 2012, over 504,000 leaks had been recorded from federally regulated LUSTs in the United States.[12] The associated groundwater contaminants include benzene, toluene, ethylbenzene, xylene, lead, MTBE (a gasoline additive), ethylene dichloride, and naphthalene. If the gas station included a service shop, other compounds that may be released include trichloroethylene, perchloroethylene, methylene chloride, carbon tetrachloride, oils, ethylene glycol, motor oil, hydraulic fluid, detergents, and acidic solutions. These compounds are not present in CCR leachate, so their presence in groundwater indicates a source other than CCR leachate.

Septic Systems

Septic systems are potential sources of nitrate, phosphorus, chloride, organic substances, bacteria and viruses, detergents, oils, salts, septic tank cleaners such as trichloroethane or methylene chloride, and a wide variety of other chemicals.[13] These systems rely on the capacity of the native soils to attenuate, and naturally occurring microbes to digest, elements and compounds

[12] http://earthrepair.ca/resources/scenarios/gas-stations/

[13] http://infohouse.p2ric.org/ref/01/00065.htm

contained in the sewage. If improperly located, designed, constructed, or maintained these systems may fail or inadequately treat the effluent. If spaced too closely due to residential population density, these systems may exceed the capacity of the local soil to assimilate the chemical loads. High concentrations of chloride, nitrate, phosphorus, and/or sodium provide a line of evidence for an ASD for monitoring wells downgradient of areas where septic systems are used.

Mineral and Oil Extraction

Mining (Non-Coal)

Leaching from slag piles and other mining-related activities can result in groundwater quality impacts. If the background monitoring does not fully characterize these impacts, then SSIs/SSLs are possible. The water quality signatures from mining sources are highly variable depending on the substance being mined and the composition of the local soils, but common constituents include phosphates, sulfates, fluorides, and trace elements. Furthermore, if pyrite (FeS_2) was exposed to oxygen and water from the mining process, the drainage may be acidic (low pH) and have high iron and sulfate concentrations, as discussed next.

Major ion chemistry may provide a line of evidence for an ASD in this case if groundwater at the monitoring well(s) with an SSI/SSL plots in a region of the Piper diagram that is not between leachate and background groundwater. Isotopic analysis may be also considered, although unless an isotopic signature is available for the suspected mining source, it would only demonstrate that the CCR is or is not the source of an SSI/SSL. As with all potential upgradient sources, a stronger line of evidence would be installation of an intermediate monitoring well if it is possible to install such a well downgradient of the suspected mining-related source *and* upgradient or side gradient of the CCR units.

Coal Mining

The coal mining process exposes underground coal, as well as stock piles of coal and coal refuse, to oxygen and moisture, which results in oxidation of the pyrite (iron and other sulfides). The resultant leachate has high concentrations of iron and is acidic due to high concentrations of sulfuric acid. As the acidic leachate moves through the natural environment, it breaks down clay, and silicate and carbonate minerals releasing silica, aluminum, calcium, magnesium, and manganese. Concentrations of trace elements including chromium, cobalt, copper, nickel, and zinc may also increase above background levels (USEPA, 1980). The solubility of most of these elements is higher under acidic conditions. If limestone is present near the mining site, the acidic water may be neutralized by the calcium carbonate alkalinity of the limestone, and the concentrations of these elements may decrease. If the soil does not have this inherent alkalinity, the acidic water, known as acid mine drainage, may migrate from the mine site as contaminated groundwater or surface water. Mine-impacted groundwater may travel to deeper or more distant aquifers along fractures, seams, mining tunnels, and other subsurface conduits, sometimes making it difficult to trace the source.

Building an ASD where coal mining impacts are the suspected source of an SSI/SSL may require multiple lines of evidence because the water quality signatures may be only slightly different from that of groundwater mixed with CCR leachate. An obvious line of evidence for an ASD

would be the presence of a coal mine in an upgradient position. Other lines of evidence may include pH differences if the CCR leachate is alkaline, since the coal mining leachate would be expected to be acidic; absolute concentrations if it can be demonstrated that groundwater has higher concentrations for some constituents than CCR leachate; and Tier II data comparison techniques such as geochemical modeling, multivariate statistics, and/or FALCON. Isotopic analysis would need to look at more than boron and strontium, since the coal may have similar isotopic ratios, and could also include hydrogen and oxygen isotopes to build an isotopic signature.

Oil and Gas Production

Hundreds of thousands of wells have been drilled in the United States for oil and gas exploration, production, and brine disposal. Brines with high concentrations of dissolved solids are extracted with oil and gas and separated from the oil and gas at the land surface. The brines, called produced water, are stored in tanks or surface impoundments until they are disposed, often by reinjecting back into the subsurface oil and gas formation. Mechanisms for brine release include leaks from tanks, impoundments (which are usually lined but were not always lined in the past) and piping. Oil field brines may also be released to groundwater if there is a leak in the casing of an injection well. In addition, abandoned oil and gas wells can act as direct conduits for vertical oil field brine migration if the seal is incomplete or has failed. Vertical migration via abandoned oil and gas wells can occur either up or down, depending on a variety of factors. Pressure-induced upwelling of brine from depth to shallow aquifers is most relevant for ASD purposes.

Multiple lines of evidence may be available for an ASD where impacts from oil field brines are suspected. Oil field brines can have elevated boron, chloride, and other constituent concentrations. The first line of evidence would be confirmation that oil and gas production occurred in the area of the CCR unit—such areas are commonly mapped by state geological surveys. Another line of evidence is major ion chemistry, because brines have high chloride concentrations while coal ash leachate has high sulfate concentration. Brines can have much higher total dissolved solids (TDS) than CCR leachate, and depending on the level of dilution in groundwater, absolute concentrations of constituents such as barium may be higher in the monitoring well than in the CCR leachate. Ion ratios may also yield a considerably different signature than CCR leachate (Figure 5-2).

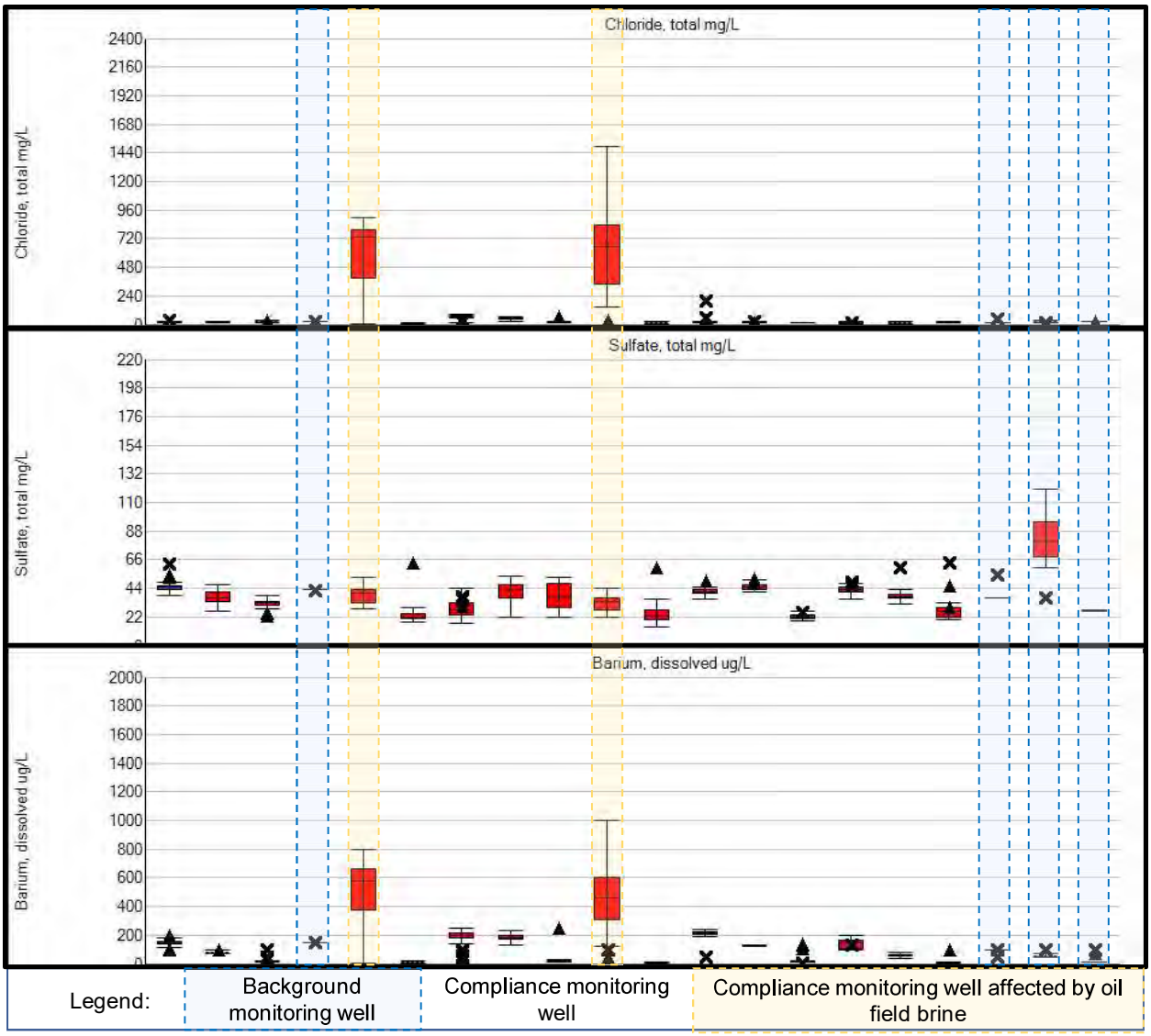

Figure 5-2
Box-whisker plots showing relatively high chloride and barium, and low sulfate concentrations, in brine-impacted groundwater monitored at a CCR management facility

Induced Salt Water Intrusion into Freshwater Aquifers

The water quality in shallow freshwater aquifers can be degraded by upwelling of deeper, naturally salty groundwater caused by heavy pumpage for anthropogenic activities such as mine dewatering, irrigation, or drinking water supplies if there is an underlying source of salt water. Salt water sources include seawater wedges and brackish groundwater that occurs naturally at depth in many areas of the United States.

Lines of evidence for an ASD based on induced pumping are similar to the lines of evidence when oil and gas brines are suspected as the cause of an SSI/SSL. First, there must be evidence for seawater or brackish water underlying the area where an SSI/SSL is observed. Additional lines of evidence can include major ion chemistry, because brackish groundwater and seawater have high chloride concentrations, while coal ash leachate has high sulfate concentration.

Brackish groundwater and seawater can also have higher TDS than CCR leachate, and depending on the level of dilution in groundwater, absolute concentrations of constituents such as barium may be higher in the monitoring well than in the CCR leachate. Ion ratios may also yield a considerably different signature than CCR leachate. Isotopic analysis could also be considered if other lines of evidence do not build a strong ASD, because boron in seawater and brines tends to be isotopically heavy ($\delta^{11}B > 0$), and boron in CCR leachate tends to be isotopically light ($\delta^{11}B < 0$) (Figure 5-3).

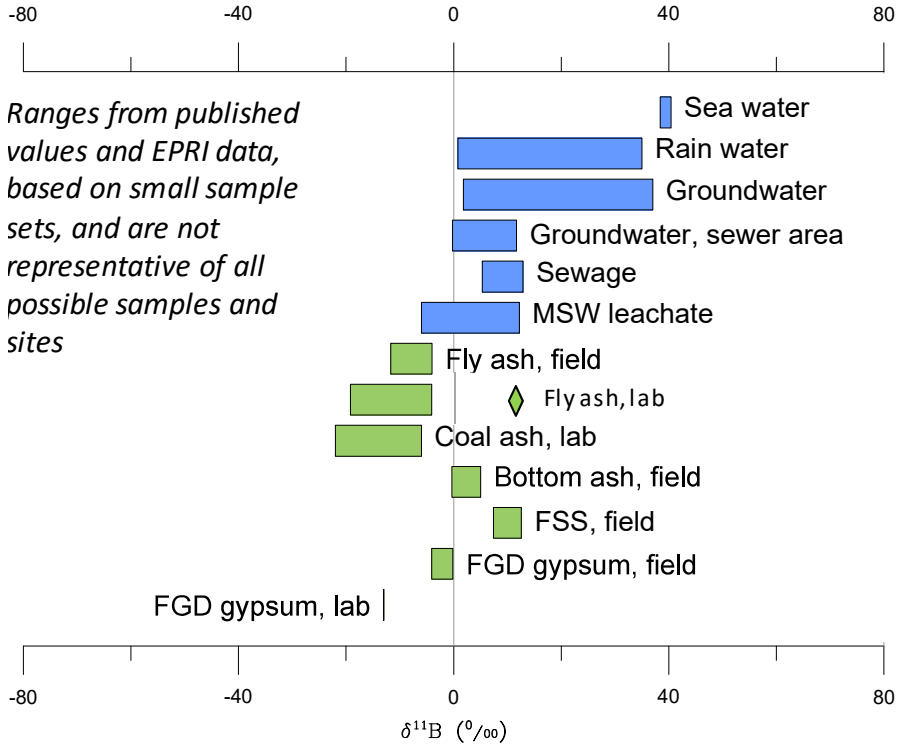

Figure 5-3
Boron isotope ranges, expressed as $\delta^{11}B$, based on EPRI (2012)

Industrial Land Use and Activities

Industrial activities produce liquid and solid waste containing a variety of inorganic constituents, organic compounds, acids, and chemicals that is too variable to cover in detail in this report. Environmental regulations now require treatment and proper disposal to prevent or minimize the risk of contamination to land and water resources, but this has not always been the case. Historical dumping, land application, seepage from unlined or poorly lined impoundments and landfills, and discharge of untreated or poorly treated waste may have contaminated the environment near areas with present or historical industrial activity.

If industrial impacts other than CCP leachate are suspected, the first line of evidence is to identify current and historical industrial activities and land use in the vicinity and upgradient of the monitored CCR unit. Identification of the types of industrial uses can help identify likely contaminants associated with these industrial activities. If these “industrial signatures” can be identified in the CCR program wells, they can be used as lines of evidence supporting an ASD.

Waste Disposal – Municipal and Industrial Landfills

State and federal regulations mandate liners and leachate collections for current landfills. However, prior to enactment and promulgation of implementing rules, waste disposal was often managed in open pits with minimal or no barriers to migration of leachate into groundwater. In the event of a release from a current or legacy solid waste landfill, potential constituents in the leachate include sodium and chloride, nitrate, organic compounds, and trace elements.

If a solid waste landfill is a suspected cause of an SSI/SSL, it may be possible to obtain leachate data from the agency that regulates the facility for use in a water quality signature evaluation. Groundwater monitoring data may also be available from the same agency, which could be used to document whether or not the solid waste landfill monitoring wells had elevated concentrations of the constituent(s) with an SSI/SSL. This assumes that the constituent is monitored at the solid waste landfill, because CCR indicators such as boron, lithium, and molybdenum are not always monitored at non-CCR sites. Otherwise, lines of evidence for an ASD can include major ion chemistry, ion ratio analysis, and perhaps isotopic analysis.

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6
PREPARATION OF AN ALTERNATIVE SOURCE DEMONSTRATON

Overview

A combination of tables and checklists have been developed to guide development of an ASD. The following assumptions are inherent with this process:

- There has been an SSI, an SSL, or an exceedance of a groundwater quality standard or benchmark.[14]
- The SSI/SSL is not due to a release from the CCR unit. Note that in some situations, ASDs may apply to all SSI/SSLs at a site, for example at a lined landfill where background groundwater monitoring does not fully characterize the variability possible in groundwater quality. In other situations, ASDs may apply to some, but not all, SSIs/SSLs at a CCR unit, as may be the case for an unlined impoundment where boron and sulfate concentrations in downgradient groundwater may be elevated due to a release, while other constituents in groundwater may be due to naturally occurring or anthropogenic sources.
- ASDs based on sampling (ASD I), laboratory (ASD II), or statistical (ASD III) causes do not require a weight of evidence approach, provided that the cause is documented, or otherwise verified and defensible.
- For natural variation (ASD IV) or alternative sources (ASD V), it is assumed that there are sufficient data to build a weight of evidence case that the SSI/SSL is not due to a release from the CCR unit. If such data are not available, then the ASD process may identify additional data collection that could be used to build a stronger ASD.

The first step in an ASD is to determine if ASD Types I, II, or III explain the SSI/SSL. If not, then a weight of evidence approach is used for ASD Types IV and V. The weight of evidence approach outlined here is dependent on two types of lines of evidence (Figure 6-1):

- Key lines of evidence are based on relationships that must be observed in order for an SSI/SSL to be due to a release from a CCR unit. If these relationships are not observed, then they are critical to establishing an ASD. It is difficult to build a strong ASD without any key lines of evidence. It may be possible to build an ASD with a single key line of evidence, but the ASD will be stronger with additional key or supporting lines of evidence.
- Supporting lines of evidence provide additional information that supports the ASD. Supporting lines of evidence are generally not sufficient to build an ASD unless there is at least one key line of evidence, although it may be possible if there are many supporting lines of evidence.

[14] Throughout this document, and continuing into this chapter, this is referred to as an SSI/SSL.

		Supporting Lines of Evidence		
		None	**Few**	**Many**
Key Lines of Evidence	**None**	No ASD	Weak ASD	ASD possible
	One	Weak ASD	ASD possible	**Strong ASD**
	Multiple	ASD possible	**Strong ASD**	**Strong ASD**

Figure 6-1
Use of key and supporting lines of evidence for ASD Types IV and V

Reference tables for the ASD process are included in the text of this report, and are also provided in Appendix A for simplified reference. The ASD checklists are provided in Appendix B. Table 6-1 summarizes potential causes to consider under each of the ASD types.

Table 6-1
Potential Causes for an SSI/SSL

Sampling Causes (ASD Type I)	Laboratory Causes (ASD Type II)	Statistical Evaluation Causes (ASD Type III)	Natural Variation (ASD Type IV)	Alternative Sources (ASD Type V - Natural and Anthropogenic)
• Sample mislabeling • Contamination • Change in technique • Excessive suspended solids or turbidity • Other sampling anomalies	• Analytical method • Calibration • Analytical technique • Contamination • Interference • Recording • Dilution errors • Digestion methods	• Lack of statistical independence • Outliers • Trends • Non-detect Processing • False positives • New background data	• Geology • Precipitation • Seasonality • Water level • Changes in pH and/or ORP • Biological activity • Time of travel	• See Appendix A, Tables A-3 and A-4

ASD Evaluation Checklists

Checklist 1: ASD Types I, II, and III

The evaluation process starts with ASD Checklist 1 (Appendix B). This checklist is based on the discussion in Section 2 and lists potential sampling, laboratory, and statistical causes for an SSI/SSL. In some cases, the data record may contain sufficient information to document an ASD, but in some cases resampling may be required. If there is documentation, or a resample to demonstrate one of these types of ASD, or if there is irrefutable evidence that one of these ASDs

caused the SSI/SSL, then a weight of evidence approach is not needed. Examples of documentation and evidence include, but are not limited to:

- Laboratory reports showing qualifier flags, uncorrected dilution calculations, contamination in blanks, poor spike recovery, or other anomalies
- Field sampling notes describing difficulties or anomalies encountered while sampling
- High turbidity values in the unfiltered sample, accompanied by filtered sample showing low concentration
- Resample results showing low concentrations
- Graphs clearly showing reversed results (see Figure 2-1), or concentration spikes by a factor of 10 or more (see Figure 2-2)
- Graphs and calculations showing that new background data have triggered a change in background normality, while downgradient concentrations have not increased

If the ASD is not documented, and other evidence is not irrefutable, or if there is insufficient time for resampling, then ASD Checklist 2 could be used to build a weight of evidence approach that the SSI/SSL is not due to a release from the site.

Checklist 2: ASD Types IV and V Lines of Evidence Associated with the CCR Unit

Checklist 2 can be used to guide the evaluation of lines of evidence associated with the CCR unit. The checklist provides a template for recording answers to questions related to primary indicator constituents, secondary indicator constituents, other chemical evaluation techniques, and hydrogeological evaluation. The answers to each question can be recorded in columns that organize the evidence pointing to a release from the CCR Unit (Column A), evidence pointing to a natural or anthropogenic alternative source (Column B), or unknown or indeterminate evidence (Column C). Note that all key lines of evidence are contained in Checklist 2.

If most answers fall into Column B, and particularly if the line of evidence is identified as "key," then weight of evidence is developed that an alternative cause explains the SSI/SSL. Checklist 3 can then be used to guide further evaluation of alternative causes.

Checklist 3: ASD Types IV and V Lines of Evidence Associated with Alternative Natural and Anthropogenic Sources

Checklist 3 is designed to develop lines of evidence to identify alternative source(s) for an SSI/SSL. There are no key lines of evidence on Checklist 3. Rather, it provides for a methodical approach to documenting alternative sources if evaluation using Checklist 2 indicates that an ASD is likely.

ASD Reporting

An ASD requires both defensible lines of evidence and a well-organized presentation of the lines of evidence that clearly lead to the conclusion that the SSI/SSL is not due to a release from the monitored CCR facility. The following format, modified from one developed by Southern Company (2016), provides a viable approach for ASD documentation. Other formats may be equally effective.

Introduction and summary of the SSI/SSL

An example of language that could be used for introducing the SSI/SSL is: "Review of the statistical analysis indicates that the concentrations of the parameters were within the [specify statistical test used] limits for each constituent at each monitoring well except for the following statistically significant increases/levels (SSIs/SSLs): [List each well with SSI/SSL constituents and identify all constituents at each well location that were identified to have SSI or SSL trends.]

Cite the ASD language included in the CCR Rule (or state rule is applicable) using explicit language

For example: "40 CFR 257.94(e)(2) allows the owner or operator 90 days from the date of determination to demonstrate that a source other than the CCR unit caused the SSI or that the apparent SSI was from a source other than the CCR unit or resulted from errors in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. Pursuant to 40 CFR 257.94(e)(2), the following text is provided as a demonstration that the listed SSIs are due to [identify the cause(s) applicable to the site-specific case]."

Present the ASD checklists

Identify all lines of evidence, and supporting data as needed, that the release is not from the CCR unit and is explained by alternative causes. Identify whether each line of evidence is key or supporting, and why. Also group and explain the evidence by well if multiple constituents have SSI trends at the same well(s). If the same constituent has SSI trends at multiple wells, explain how this is relevant to the ASD being presented. Include supporting data such as the checklists, maps, trend charts, geological factors, hydrogeological factors, and any geochemical data analysis tools used that support the conclusions.

Clearly state the conclusion and provide a closing statement

Example language for the closing statement if the ASD is for SSIs during detection monitoring: "The preceding information serves as the ASD prepared in accordance with 40 CFR 257.94(e)(2) and supports the position that the SSIs during [the monitoring period] are not due to a release from the CCR unit. Therefore, no further action (i.e., assessment monitoring) is warranted and [name the CCR unit] will remain in detection monitoring."

Certification by a PE (for ASDs developed under the CCR Rule)

An ASD developed under the CCR Rule requires certification by a Professional Engineer (PE). Including the PE early in the evaluation process can improve this individual's confidence in supporting the conclusions. Keep in mind that the PE may request time to review the data and the ASD report, and factor this time into schedules so that ASD compliance dates can be achieved (the demonstration must be completed and posted to the owner's CCR website within 90 days from the determination that an SSI or SSL has occurred under the CCR Rule). If the PE requires approval by a Professional Geologist (PG), ensure that a PG is also involved early in the evaluation. It may also be beneficial to develop a certification statement that passes management and legal approval.

7
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A
ASD REFERENCE TABLES

Table A-1
Potential Indicator Constituents for Coal Ash and FGD Gypsum

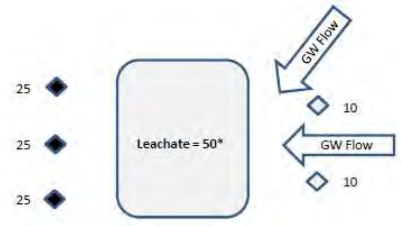
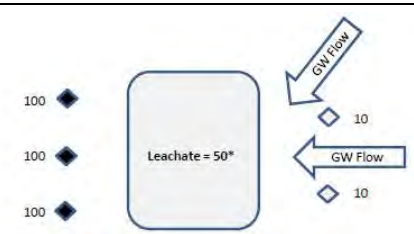
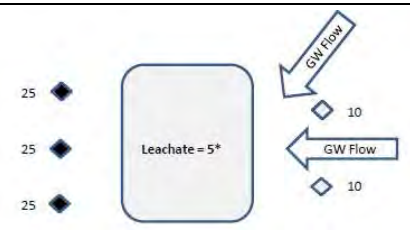
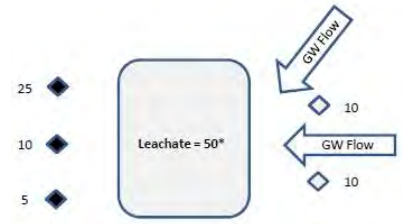
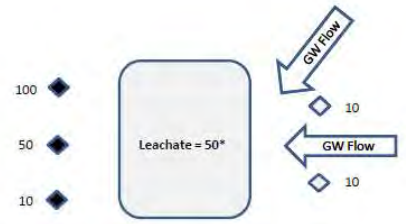
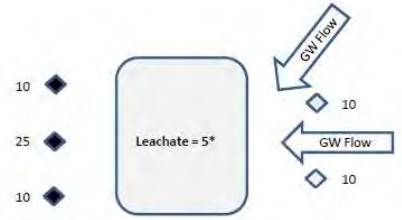
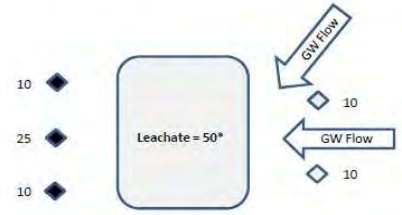
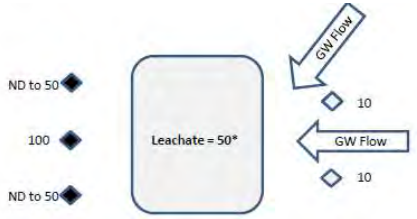
Potential Indicators for Coal Ash		Potential Indicators for FGD Gypsum	
Constituent	**Advantages and Caveats**	**Constituent**	**Advantages and Caveats**
Boron	Typically present in leachate, non-reactive and mobile in common hydrogeologic environments, and not a common anthropogenic contaminant.	Sulfate	High concentrations expected in both washed and unwashed FGD gypsum (EPRI, 2011). Commonly analyzed. Very mobile in all hydrogeologic environments. Less useful in strongly reducing environments where sulfate can be reduced to hydrogen sulfide gas.
Molybdenum	Most useful for dry-managed coal ash. May be less mobile than boron in some hydrogeologic environments. Concentrations may be too low in impoundment leachate to be useful if background groundwater has detectable concentrations.	Fluoride	Assure that leachate concentration is higher than background, particularly for washed gypsum. Mobile in common hydrogeologic environments, although precipitation as CaF_2 is possible.
Lithium	Useful for coal ash management sites where the power plant burned bituminous coal. Leachate concentrations are typically low in coal ash derived from subbituminous and lignite coal (EPRI, 2006).	Calcium	High concentrations expected in both washed and unwashed FGD gypsum (EPRI, 2011). Understanding of carbonate chemistry necessary to assure that precipitation or dissolution does not affect downgradient concentrations.
Sulfate	Commonly analyzed and very mobile in all hydrogeologic environments. Concentration in impoundment leachate may in some cases be too low relative to background to be useful. Less useful in strongly reducing environments where sulfate can be reduced to hydrogen sulfide gas.	Boron	Mobile indicator constituent for unwashed FGD gypsum. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).

Table A-1 (continued)
Potential Indicator Constituents for Coal Ash and FGD Gypsum

Potential Indicators for Coal Ash		Potential Indicators for FGD Gypsum	
Constituent	**Advantages and Caveats**	**Constituent**	**Advantages and Caveats**
Bromide	May have high concentration in coal ash leachate at power plants where brominated powdered activated carbon (Br-PAC) or calcium bromide is used for mercury control. Leachate concentrations for coal ash generated absent use of these technologies may be too low to be useful. Mobile and non-reactive in typical groundwater environments.	Bromide	Mobile indicator constituent for unwashed FGD gypsum, especially if Br-PAC or CaBr used for mercury controls. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).
Potassium	Commonly analyzed, although may be less mobile than boron and sulfate. Assure that leachate concentration is higher than background and that there are no anthropogenic sources such as agricultural fields where potassium may be applied in fertilizers.	Chloride	Mobile indicator constituent for unwashed FGD gypsum. Concentrations may be very high if transport water is recirculated. Concentrations for washed gypsum may be too low to be useful (EPRI, 2011).
Sodium	Useful for coal ash management sites where the power plant injects trona or sodium bicarbonate, or burned subbituminous coal. Absent dry sorbent injection, leachate concentrations are considerably lower in coal ash derived from bituminous coal, particularly at impoundments (EPRI, 2006). Assure that leachate concentration is higher than background and that there are no anthropogenic sources such as agricultural fields, or major highways in northern climates where sodium may be applied as road salts.		
Fluoride	Mobile and non-reactive in common hydrogeologic environments. Assure that leachate concentration is higher than background.		
Source: EPRI, 2012			

Note: This table is also presented in the body of the report as Table 3-1.

Table A-2
Hydrogeologic Scenarios

	Line of Evidence for:		
	CCR Leachate Release	**Possible CCR Leachate Release + Possible Alternative Source**	**Alternative Source Release**
	Column 1	**Column 2**	**Column 3**
Row a			
Row b			
Row c			
	1. Leachate concentration is higher than upgradient/background. 2. One or more downgradient concentrations are higher than upgradient/background but lower or equal to leachate concentration.	1. Leachate concentration is higher than upgradient/background. 2. One or more downgradient concentrations are higher than the leachate concentration.	1. Leachate concentration is less than upgradient/background.

This table is also presented in the body of the report as Figure 3-7.

Table A-3
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Boron	Key Indicator	Yes if unwashed	17 / 35 / 82 ug/L	No	Very mobile	Boron-containing rocks (especially marine shales and clays), seawater, volcanic and geothermal activities, mined in arid regions of the United States (and other countries)	Fly ash leachate, may also be present in FGD leachate; sewage sludge, boron-containing fertilizers or herbicides, manufacture of glass, fiberglass, ceramics, soaps, detergents, bleach, fire retardants, and lubricants; used in control rods of nuclear reactors, and to produce a green color in pyrotechnics and flames; also used in the aerospace industry	Micronutrient for plants but may be toxic to some plant species in high concentrations. Boron deficiencies are more common than toxicities. Mobile in most hydrogeological environments, particularly sandy materials. Sorption to clay reaches a maximum in the pH range of 8-10.
Calcium	No	Yes	21 / 43 / 70 mg/L	CEC	Slightly mobile	Calcium carbonate rocks, limestone, calcium clay; fifth most common element in Earth's crust	Water softening wastes, soil acidity neutralization (lime additions to soil), calcium road salt, deicing, agriculture, cement and concrete, drying agents	Calcium carbonate is one of the most common calcium minerals. The concentration in groundwater may be limited by the solubility of calcium carbonate or calcium sulfate (gypsum). May be sorbed by ion exchange in soil and sediments but tends to be a reversible reaction.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Chloride	No	Yes if unwashed	3.1 / 8.6 / 23 mg/L	No	Very mobile	Salt water and brackish water sources; chloride anion is the most abundant element (other than hydrogen and oxygen) in Earth's oceans	Road salt, deicing, water softening wastes, sewage, septic effluent, livestock waste, oil-field brines, salt water intrusion (oil and gas well production), industrial emissions, incinerator ash, landfill leachate, aerospace industry, automobile industry, soaps and detergents, drying agents, flame retardants, flocculants, pharmaceutical and medical waste	
Fluoride	Yes for some coal ash	Yes for some FGD gypsum	<0.1 / 0.2 / 0.4 mg/L	No	Mobile	Natural weathering of fluoride-containing minerals	Steel, brick, and aluminum manufacturing; waste incineration, municipal water treatment	Occurs as fluoride anion at pH > 3, hydrofluoric acid at pH < 3. Can be sorbed by amorphous aluminum and iron oxides under strongly acidic conditions.
pH	No	No	6.9 / 7.3 / 7.6 SU	- -	- -	Oxidation/weathering of naturally occurring pyritic soils due to well installation or other excavation may cause low pH	Low pH: Oxidation/weathering of pyrite in coal or coal ash, leaking batteries High pH: Certain coal ash leachates may have high pH; cement and concrete manufacturing and use, soaps and detergents	Fly ash leachate pH may be acidic or basic depending on coal type. Bituminous coals tend to produce more acidic leachate, especially if comanaged with pyritic mill rejects, and subbituminous coals tend to produce more basic leachate. Important due to impact of pH on leachability of many trace elements.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix III Detection Monitoring Constituents								
Sulfate	Yes for most coal ash	Key Indicator	4.7 / 14 / 36 mg/L	No	Very mobile	Sulfur is the 14th most abundant element in the Earth's crust; oxidation/weathering of naturally occurring pyritic soils (such as iron sulfide)	Fly ash and FGD leachate, lead acid batteries, algaecides, gypsum mines, wood pulp production (paper mills), textile mills, tanneries, coal pyrite oxidation/weathering from mining or storage, industrial emissions and effluents, soaps and detergents, drying agents, flocculants, petroleum refining	Sulfate may precipitate with calcium, barium, and strontium. Not usually sorbed due to negative charge, but can be sorbed under acidic conditions by soils and sediments containing iron, aluminum, and manganese oxides with positive charges. May precipitate from solution as sulfides under strongly reducing conditions.
Total Dissolved Solids (TDS)	No	No	146 / 254 / 381 mg/L	- -	- -	TDS is largely based on concentration of major ions in groundwater (Ca, Mg, Na, K, carbonates, Cl, SO_4)		Refer to primary components.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Antimony	No	No	<1 ug/L	No	Very mobile		Flameproof retardants, batteries, lead shot; metal and glass manufacturing	Usually soluble but may be sorbed by iron, aluminum and manganese oxides under acidic conditions (EPRI, 1987).
Arsenic	No	No	0.23 / 0.79 / 3.0 ug/L	Yes, pH and redox	Variable	May be present in sulfide minerals and in organic forms; concentrations can be naturally higher than typical under reduced conditions or if sulfide minerals are oxidized	Wood preservatives (chromated copper arsenate), feed additives, pharmaceuticals, electronic devices, metallurgical applications, metal mining and smelting, cemeteries; pesticides/herbicides/ insecticides (prior to 1960)	Arsenic occurs in the 5+ oxidation state as arsenate (AsO_4^{3-}) under relatively neutral pH and oxidized conditions, and as 3+ arsenite (AsO_3^{3-}) under reduced conditions. Arsenic fate and transport is complex due to sensitivity to pH and redox. Sorption usually increases with decreasing pH.
Barium	No	No	24 / 54 / 120 ug/L	Yes	Mobile	Weathering of sedimentary rocks	Well drilling mud or fluid, mining; manufacture of glass, paint, and rubber	Usually present as relatively insoluble barium sulfate in fly ash. Most barium compounds have limited solubility. Sorbed by clay, soils, and sediment.
Beryllium	No	No	<1 ug/L	Yes, pH	Immobile	Relatively scarce in Earth's crust	Electronic and electrical components, telecommunications and computer components, defense applications	Strong tendency to sorb at neutral to alkaline pH. Sorption may be reduced in the presence of humic acids.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Cadmium	No	No	<1 ug/L	Yes, pH	Slightly mobile	Minor component in Earth's crust, occurs in zinc minerals	Batteries, waste incineration, sewage sludge disposal, paint pigments, phosphate fertilizers, automobiles, electroplating and metal fabricating	Can be sorbed by clay, soil, and sediment at pH less than 8, but sorption decreases at low pH.
Chromium	No	No	0.68 / 1.2 / 3.0 ug/L	Yes, pH and redox	Variable	Primarily occurs as Cr(III) in soils and rocks	Electroplating, leather tanning, wood pulp production (paper mills), metal ore refining, wood preservatives, steel manufacturing, automobiles, electroplating and metal fabricating, paint and coatings	The solubility of Cr(III) generally increases at pH levels <6.5 and >11. Cr(III) is the predominant dissolved species under reducing to mildly oxidizing conditions. Cr(IV) is more soluble than Cr(III) at neutral to alkaline pH. Cr(VI) is soluble at alkaline pH and mildly to strongly oxidizing conditions.
Cobalt	No	No	0.063 / 0.17 / 0.48 ug/L	Yes	Variable	Relatively scarce in Earth's crust; usually occurs in combination with arsenic and sulfur in nature	Rechargeable battery electrodes, radial tires, drying agents, catalysts, paint pigments, medical wastes, automobiles	May be sorbed by mineral oxides (e.g., Fe and Mn), crystalline materials such as aluminosilicate, and natural organic substances in soil.
Lead	No	No	0.018 / 0.070 / 0.27 ug/L	Yes pH	Variable	Rare in Earth's crust	Smelting and mining, batteries, waste incineration, leaded gasoline (before 1996), lead-containing paint, glass manufacturing, ammunition, firing ranges, plumbing, automobiles	Sorption usually increases with pH.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Lithium	Yes for some coal ash	No	2.0 / 6.0 / 18 ug/L	No	Mobile	Rare in Earth's crust, dissolution of lithium-containing minerals	Glass and ceramics production, lubricants, greases, batteries, salt water intrusion	Reacts with sulfate ions to form lithium sulfate anion.
Mercury	No	No	NR	No	Slightly mobile	Occurs as HgS in nature; can be converted to methylated forms by anaerobic microbes	Waste incineration, mercury mining, metal recycling, fungicides, fluorescent lamps, batteries, thermometers/ thermostats/switches (electronic equipment), automobiles	Can be sorbed by iron, magnesium, silicon oxides, and organic matter.
Molybdenum	Yes for some coal ash	No	0.32 / 1.0 / 3.3 ug/L	No	Very mobile	Usually combined with sulfur or oxygen in natural minerals	Steel production, catalysts, lubricants, pigments, fertilizers, animal feed	Micronutrient for plants and animals; may be in fertilizers or animal feed. Peak sorption at pH <5 and limited sorption above pH 8. Phosphate and other oxyanions will depress sorption.

Table A-3 continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
CCR Rule Appendix IV Assessment Monitoring Constituents								
Radium 226 + 228	No	No	NR / 0.28 / 1.2 pCi/L	Yes, CEC	No data	Natural decay product of uranium and thorium ores	Uranium mines, nuclear power, nuclear fuel and weapons manufacturing, uranium in coal	Radium decays to radon gas, so it is prevalent in locations where radon gas is a concern.
Selenium	No	No	0.12 / 0.34 / 1.0 ug/L	Yes, pH and redox	Variable	Usually occurs with silver, copper, lead, and nickel sulfide minerals; may exist in a variety of organic compounds	Metal mining and milling, industrial waste water, sewage effluent, waste incineration, saline agricultural waste waters	May exist as selenate (SeO_4^{2-}), selenite (SeO_3^{2-}), elemental selenium (Se^0), and selenide (Se^{2-}) in groundwater (shown in order from most to least oxic species). Since anionic selenium is the dominant form in groundwater, sorption typically is not significant. However, selenite can be sorbed by iron and aluminum oxides.
Thallium	No	No	<1 ug/L	Yes, redox	Mobile	Occurs in combinations with oxygen, sulfur, and halogens	Glass and electronic industries, iron and steel production, cement factories	May be immobilized under reducing conditions.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Aluminum	No	No	0.98 / 3.0 / 4.9 ug/L	Yes, pH	Slightly mobile	Most abundant metal in Earth's crust; weathering of aluminosilicate minerals	Mining and industrial emissions and effluents; most abundant metal in coal ash, cement and concrete, drying agents, well drilling, flocculants, abrasives, aluminum manufacturing	Most soluble in water under acidic and alkaline solutions, essentially insoluble in near neutral water. May be sorbed by soils, sediments, and organic matter.
Bromide	Possible for certain coal ash	Yes if unwashed	0.02 / 0.04 / 0.09 mg/L	No	Mobile	Brackish groundwater and sea water, relatively rare in Earth's crust	CCR fly ash and emission control wastes, particularly if bromide compounds were used to facilitate mercury capture; drinking water disinfection, flame retardants	
Copper	No	No	0.47 / 1.0 / 3.0 ug/L	Yes, pH and redox	Variable	Relatively common in Earth's crust	Manufacture of bronzes, brass, electrical conductors, and ammunition; sewage sludge wastes, municipal solid wastes, copper-containing fertilizers, cemeteries, electronics, plumbing, wood preservatives, automobiles, electroplating and metal fabricating	Solubility may be controlled by solubility of copper hydroxide. May sorb to organic matter, clay, aluminum, manganese, and iron oxides.
Iron	No	No	0.81 / 7.9 / 93 ug/L	Yes, pH and redox	Variable	Commonly has high concentration in groundwater under reduced conditions; Weathering of iron-containing minerals (dissolution of iron oxides under reducing conditions), 4th most common element in Earth's crust	Industrial emissions, pyrite oxidation/acid mine drainage from coal mining or storage, flocculants	Iron oxides my dissolve and become mobile under reducing conditions. Occurs as ferrous (+2) and ferric (+3) iron. Ferric iron can be sorbed by silica, clay, and iron and manganese oxides.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Magnesium	No	No	4.4 / 11 / 23 mg/L	CEC	Slightly mobile	Eighth most abundant element in the Earth's crust, abundant in sea water; dissolution of magnesium carbonates and clay minerals	Aluminum fabrication and welding (alloying agent), flares and pyrotechnics, fire retardants, heat-resistant bricks, animal feed, fertilizers, drying agents	Solubility may be limited under alkaline conditions. May be removed from solution by ion exchange in soils and sediments via reversible reactions.
Manganese	No	No	0.85 / 7.0 / 84 ug/L	Yes, pH and redox	Variable	Commonly has high concentration in groundwater under reduced conditions; 13th most abundant element in the Earth's crust	Production of steel and aluminum alloys, glass production, use as an additive in gasoline	
Nickel	No	No	0.35 / 1.1 / 2.5 ug/L	No	Variable	Commonly combined with iron or sulfur	Manufacture of steels, other metal alloys, and electronic applications; automobiles, electroplating and metal fabricating, petroleum	Sorbs to iron and manganese oxides, and clay to a lesser extent.
Nitrogen	No	No	0.07 / 0.55 / 2.4 (NO_3 as N) mg/L	Nitrification/ denitrifi-cation, redox	Very mobile as NO_3	In nature, nitrogen is converted from one redox state to another by abiotic reactions and microbial catalysis in oxic conditions: $NH_4OH \rightarrow NO_2 \rightarrow NO_3$; under reducing conditions: $NO_3 \rightarrow NO_2 \rightarrow N_2$	Fertilizers, livestock wastes, wastewater treatment plants, sewage and septic effluent, rubber manufacturing; ammonia sources include CCRs from sources using SNCR or SCR technology, coke production, flame retardants	NO_2 and NO_3 are not significantly sorbed by most soils, sediments, or clays, but NH_4OH is.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Phosphate	No	No	<0.01 / 0.02 / 0.04 mg/L	Yes, pH	Variable	Phosphorus is the 11th most abundant element in the Earth's crust	Fertilizers, wastewater treatment plants, sewage and septic effluents, industrial effluents, soaps and detergents, flame retardants	Can be sorbed by iron, aluminum, and manganese oxides, and by clay under acidic conditions.
Potassium	Yes for some coal ash	No	0.9 / 1.7 / 3.5 mg/L	CEC	Mobile	7th most abundant element in the Earth's crust; Weathering of potassium-containing minerals	Water treatment, fertilizers, sea water intrusion, soaps and detergents, drying agents	May be removed from groundwater by reversible ion exchange with soils and sediments.
Silicon	No	No	12 / 19 / 31 mg/L	Yes	Very mobile	2nd most abundant element in the Earth's crust; usually in the form of SiO_2	Glass, ceramics, abrasives, electronic devices, metal alloying, water filtration, insulation, cement, concrete, paper, rubber, lubricants, flocculants	Can be sorbed by iron and aluminum oxides, and by clay minerals.
Silver	No	No	<1 ug/L	Yes, pH	Variable		Textile plant wastewater, photographic materials, sewage sludge, medical wastes, electronics, electroplating and metal fabricating	Can be sorbed by soils but affected by pH, clay content, particle size, organic content, and free iron and manganese oxide content.
Sodium	Yes for some coal ash	No	5.2 / 11 / 29 mg/L	CEC	Mobile	6th most abundant element in Earth's crust; brackish groundwater and surface water, sea water, weathering of sodium-containing minerals	Road salt, deicing, septic effluent, sodium hydroxide water treatment wastes, water softening, salt water intrusion (gas and oil well production), sewage and septic effluent, soaps and detergents, drying agents	Most sodium compounds are soluble but may be sorbed by reversible ion exchange in soils or sediments.

Table A-3 (continued)
Potential Alternative Sources by Constituent

Constituent Name	Coal Ash Indicator? (note 1)	FGD Gypsum Indicator? (note 1)	Typical U.S. Groundwater Concentration at 25th / 50th / 75th Percentile (note 2)	Reactivity (note 3)	Mobility (note 4)	Natural Prevalence and Naturally Occurring Causes for Presence in Groundwater	Potential Anthropogenic Sources	Comments (note 5)
Other Constituents								
Strontium	No	No	100 / 270 / 680 ug/L	Yes	Slightly mobile		Glass and ceramics production, pyrotechnics, phosphate fertilizers	Reacts with sulfate ions to form $SrSO_4^0$.
Vanadium	No	No	0.30 / 1.4 / 11 ug/L	Yes, pH and redox	Variable		Crude oil, oil shale, tar sands, phosphate fertilizers, wastes from steel production, petroleum	Can be sorbed by iron, aluminum, and manganese oxides; sorption decreases as pH increases.
Zinc	No	No	1.6 / 4.8 / 18 ug/L	Yes, pH	Variable		Fertilizers, protective coatings to reduce corrosion of metal surfaces, dry-cell batteries, castings, automobiles, lubricating oils and greases, plumbing/piping, electroplating and metal fabricating	Sorption increases with increasing pH but is also affected by clay content, particle size, organic content, and iron, aluminum, and manganese oxide content.

Notes:

1. Based on EPRI (2012). "No" indicates that the constituent it is not considered an indicator due to low concentration in CCR leachate relative to typical background, low mobility, and/or potential for reactivity.

2. Concentration ranges in ug/L from USGS (2011), Table 4; concentration ranges in mg/L or SU from USGS (2008), Tables 2 and 6; radium 226+228 from Szabo et. al (2012) supplemental table S-3; NR indicates that the concentration was not reported in any of these three documents.

3. Reactivity and mobility, while separate geochemical processes, are often interrelated. Reactivity descriptions in this table refer to chemical reactions, primarily precipitation and dissolution, that can change the concentration or mobility of the element in solution under typical aquifer conditions. Yes indicates that the constituent is subject to precipitation, coprecipitation, and/or dissolution reactions. In addition, pH and redox are indicated if they have a strong influence on the environments under which reactions occur and/or mobility. CEC is listed for constituents that are subject to cation exchange.

4. The mobility classification is based on the classification system of van Loon and Duffy (2000). See Table 2-2 of EPRI (2012) for corresponding K_d values.

5. Refer to Appendix B in EPRI (2012) for brief summaries of geochemical factors affecting reactivity and sorption. Detailed information can be found for selected constituents in the following EPRI reports:

- Arsenic
  1015550 | Chemical Constituents in Coal Combustion Product Leachate: Arsenic | Profile | 2008
  1021212 | Arsenic in Coal Combustion Products | Tech Brief | 2010
- Beryllium
  1012583 | Chemical Constituents in Coal Combustion Product Leachate: Beryllium | Profile | 2006
- Boron
  1005258 | Chemical Constituents in Coal Combustion Product Leachate: Boron | Profile | 2005
  1023737 | Boron in Coal Combustion Products | Tech Brief | 2012
- Chromium
  1022143 | Chromium in Coal Combustion Products | Tech Brief | 2011
- Lithium
  In Prep | Chemical Constituents in Coal Combustion Products: Lithium | Profile | 2018
- Molybdenum
  1021815 | Chemical Constituents in Coal Combustion Products: Molybdenum | Profile | 2011
  In Prep | Molybdenum in Coal Combustion Products | Tech Brief | 2017
- Selenium
  3002001237 | Chemical Constituents in Coal Combustion Product Leachate: Selenium | Profile | 2013
  3002003761 | Selenium in Coal Combustion Products | Tech Brief | 2014
- Thallium
  1016801 | Chemical Constituents in Coal Combustion Product Leachate: Thallium | Profile | 2008
  3002001155 | Thallium in Coal Combustion Products | Tech Brief | 2013

Table A-4
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Abrasives	**Silicon, aluminum**
Acid mine drainage	**Low pH, sulfate, iron**, dissolved solids, metals (aluminum, cadmium, calcium, chromium, cobalt, copper, magnesium, manganese, nickel, zinc, and others); can travel along mine shafts and tunnels and show up in unexpected locations (sometimes across aquifers) (notes 1, 26, 51, 54)
Aerospace industry	**Boron, perchlorate, chloride, cyanide, cadmium**, beryllium, solvents (trichloroethane, methylene chloride, trichloroethylene, toluene, methylethylketone), metals, oils (notes 2, 3, 4, 5, 51)
Aging infrastructure (leaking sewage, urban runoff)	Nitrate, phosphorus, sodium, chloride, organic substances, bacteria, pesticides, miscellaneous chemicals, cadmium, copper, iron, lead, selenium, zinc, and other elements (note 6)
Agriculture - animal feed lots	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate, chloride**, **arsenic**, **magnesium, molybdenum, selenium** and other elements, organic substances, bacteria/viruses (notes 7, 22, 51, 52, 54)
Agriculture - fertilization	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate**, **boron**, **cadmium, calcium**, chloride, cobalt, **copper**, cyanide, **magnesium**, **molybdenum, potassium, selenium, strontium, vanadium, zinc**, and other elements (notes 7, 22, 51, 52, 54)
Agriculture - irrigation	**Nitrates, ammonia, other nitrogen compounds, phosphorus/phosphate,** arsenic, boron, cadmium, calcium, chloride, cobalt, copper, cyanide, magnesium, mercury, molybdenum, potassium**, selenium**, sodium, sulfate, and other elements (notes 7, 8, 9, 22, 52)
Agriculture - lime addition	**Calcium** (note 22)
Agriculture - pesticides, herbicides, and insecticides	Aldicarb, Aldrin, alachlor, atrazine, carbofuran, chlordane, dacthal, DDT, dieldrin, bibromo-chloropropane, 1,2-dichloropropane, dinoseb, endrin, endosulfan, ethylene dibromide, heptachlor, hexachlorobenzene, lindane, mirex, PCBs, prometon, simazine, toxaphene, trifluralin; **arsenic** (prior to 1960), chloride, **mercury, boron**, **sulfate** (notes 10, 51, 52, 54)
Airport runways	**Sodium, potassium**, acetate, formate, urea (note 11)
Aluminum manufacturing	**Aluminum, fluoride, sodium**, magnesium, manganese, perfluorocarbons, polycyclic aromatic hydrocarbons (notes 12, 13)
Ammunition, firearms	**Lead, antimony, copper,** other heavy metals, nitrate, perchlorate, potassium, sulfur/sulfate, chloride (notes 14, 15, 22)
Asphalt plants	Oils, greases, PAHs, other hydrocarbons (note 16)
Automobile production	**Chloride, sulfate, phosphate,** oil and grease, solvents, ethylene glycol. Potential for heavy metals: aluminum (auto bodies), **cadmium** (tires and batteries), **cobalt** (radial tires), **chromium** (brakes, coolants, engine parts), **copper** (brake linings), iron (auto bodies), **lead** (batteries, lube oil and grease, bearings, brakes), **mercury** (batteries), **nickel** (lube oil, brakes), **zinc** (tires, fuel oil, lubricants) (notes 17, 18, 22)
Automobile repair shops	Gasoline, diesel fuel, oil, degreasing solvents (toluene, xylene, chlorinated solvents, MEK), ethylene glycol, lead, sulfate (notes 19, 44)

Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Batteries	**Sulfate, lead, antimony**, **cadmium, cobalt, lithium, mercury, zinc, low pH** (notes 22, 51)
Bleach manufacturing	**Boron** (bleaches containing sodium perborate) (notes 20, 31)
Brick manufacturing	**Aluminum, silicon, iron**, calcium, **fluoride**, **magnesium,** chromium (notes 21, 22, 52)
Catalysts	Aluminum, chromium, **cobalt**, copper, iron, **molybdenum**, titanium, tungsten, vanadium, zinc, and other metals (depends on catalyst manufactured or used) (note 22)
CCR - ash	**Boron, sulfate**, molybdenum, lithium, bromide, potassium, sodium, fluoride, selenium; may contain ammonia (nitrogen) if SCR or SNCR technology was used at the power plant (note 22)
CCR - FGD gypsum	**Sulfate**, fluoride, calcium, boron, bromide, chloride, selenium (note 22)
CCR - FGD fixated sludge	**Boron, sulfate**, calcium, chloride, molybdenum, lithium, bromide, potassium, sodium, fluoride, selenium (note 22)
Cemeteries	**Formaldehyde**, **copper, arsenic,** mercury, pesticides, fertilizers, weed killers (note 23)
Cement and concrete manufacturing and use	**High pH, aluminum, calcium, silicon, thallium,** chromium and other elements (notes 22, 24, 51)
Ceramics production	Oxides of carbon, **silicon, boron**, and nitrogen; may include aluminum, antimony, barium, copper, fluoride, iron, **lithium**, **strontium**, and other elements (notes 21, 22, 51)
Coal mining	**Sulfate, low pH, iron**, dissolved solids, trace elements (aluminum, beryllium, cadmium, chromium, cobalt, copper, lead, magnesium, manganese, mercury, nickel, selenium, **uranium (decays into radium 226+228)**, zinc and others); Oxidation of pyrite in coal can form sulfuric acid. The low pH increases solubility of many metals. (notes 1, 26, 51, 54)
Coatings	VOCs, solvents (halogenated solvents and non-halogenated solvents such as acetone, cresols, cresylic acid, nitrobenzene, benzene, toluene, xylene, methyl ethyl ketone, methylene chloride, etc.); trace elements may include barium, cadmium, **chromium**, cobalt, lead, mercury, molybdenum, nickel, titanium, and **zinc** (note 27)
Coke production (from coal)	**Phenols, ammonia (nitrogen), polycyclic aromatic hydrocarbons, cyanide**, benzene, naphthalene, anthracene, cresols, metals (see metals in "coal piles or coal waste piles") (note 28)
Computer and telecommunications components (electronics)	Trace elements may include aluminum, arsenic, barium, **beryllium**, cadmium, chromium, cobalt, **copper**, gallium, gold, iron, lead, manganese, mercury, palladium, platinum, selenium, **silver**, and zinc; solvents may include benzene, xylene (dimethylbenzene), trichloroethane, tetrachloroethane, ethylene glycol, methyl cellosolve; **silicon** (notes 29, 30, 32)

Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Defense applications	**Beryllium** (note 22)
Detergent or soap manufacturing	**Sodium, potassium, sulfates and sulfonates, high pH, phosphate**, **chloride, boron**, phenol, aluminosilicate, sodium citrate, nitrilotriacetate, alcohol ethoxylates, fats, oil and grease, lead, hexane, methyl alcohol, trichloroethane, perchloroethylene, benzene, toluene (notes 22, 34, 35)
Deicing	**Sodium, chloride**, **calcium**, magnesium, urea (notes 44, 51)
Drying agents	**Aluminum, calcium, sodium, potassium, magnesium, sulfate, chloride,** cobalt, lithium, phosphorus, silicon and/or other substances (notes 22, 36, 37)
Electronic equipment manufacturing and disposal	**Copper, silver, gold, palladium**, **arsenic, beryllium, copper, mercury, nickel,** selenium, **silicon, thallium** and other trace elements, chloride, fluoride, solvents (benzene, xylene, 1,1,1-trichloroethane, tetrachloroethane, methanol), ethylene glycol, hydrogen chloride, hydrogen fluoride (notes 22, 29, 30, 33, 51)
Electroplating and metal fabricating	**Cadmium, chromium, copper, nickel, silver**, sodium, tin, **zinc**, spent solvents, paints, spent acidic and alkaline solutions, cyanide, waste oils (notes 17, 22, 44, 51, 52, 56)
Explosives manufacturing and testing	**Nitroglycerin and nitro-aromatic compounds**, nitrate, perchlorate, ammonia, lithium, sodium, potassium, sulfur/sulfate, aluminum, chloride, **lead**, antimony, **copper**, nickel, silver (notes 38, 39, 40, 51)
Fertilizers	See Agriculture - fertilization
Fiberglass manufacturing	Aluminum, silicon, calcium, magnesium, **boron**, polyester or epoxy resin, styrene, solvents, volatile organic compounds, formaldehyde, urea, phenol, vinyl acetate (notes 31, 41)
Firearms, ammunition	See Ammunition, firearms
Firing ranges	**Lead**, antimony (notes 14, 22)
Fireworks manufacturing or use	Aluminum, antimony, arsenic, barium, **boron**, chloride, copper, lead, **magnesium**, nitrate, perchlorate, potassium, sulfur/sulfate, **strontium** (notes 31, 38, 39, 40, 51)
Flame retardant manufacturing or use	**Bromine, phosphate, nitrogen/nitrate, chloride**, **antimony, boron**, **magnesium**, polybrominated diphenyl ethers (PBDEs), PCBs (notes 22, 42, 43, 51)
Flocculants	**Sulfate, chloride, aluminum, iron**, ammonium, calcium, silica, polyamines (note 45)
Fluorescent lamps/bulbs	**Mercury**, PCBs in ballasts (note 47)
Fracking	See Oil and gas wells / production

Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Fungicides	See Pesticides
Furniture (wood stripping and refinishing)	Methylene chloride, methanol, isopropyl alcohol, acetone, perchloroethylene, toluene, acidic and alkaline solutions, metals, other solvents, petroleum distillates, resins, halogenated hydrocarbons, glycol ether (note 44)
Gasoline stations	**Benzene, ethylbenzene, toluene, xylene, MTBE**, ethylene dichloride, naphthalene, other organic compounds, lead (prior to 1996), **manganese**; trichloroethylene, perchloroethylene, methylene chloride, carbon tetrachloride, oils, ethylene glycol, hydraulic fluid, detergents, and acids (notes 22, 49, 51, 52)
Glass manufacturing	**Silicon**, antimony, **barium, boron, lead**, iron, **lithium**, **manganese**, nickel, potassium, **strontium**, **thallium**, tin, zinc, fluoride (notes 22, 31, 50, 51)
Industrial emissions	**Chloride, sulfate, iron,** wide variety of other elements and chemical substances (notes 22, 51, 54)
Irrigation	See Agriculture – irrigation
Junk and scrap yards	Used oil, gasoline, antifreeze, lead, sulfuric acid, agricultural chemicals/pesticides/other chemicals, metals (note 44)
Lamp manufacturing and disposal	**Mercury**, bromide, chloride, fluoride, iodide, PCBs, sodium (notes 22, 47)
Landfills - industrial	Wide range of trace metals, acids, **chloride**, sulfate, organic substances and pesticides (notes 51, 53, 54)
Landfills - municipal	Salts (sodium, calcium, magnesium, **chloride**, etc.), metals (iron, copper, zinc, other heavy metals), nitrate, organic compounds, solvents, pesticides (notes 22, 51, 54)
Laundry - dry cleaning	**Perchloroethylene (tetrachloroethylene)**, camphor oil, turpentine spirits, benzene, kerosene, white gasoline, petroleum solvents (petroleum naphtha), chloroform, carbon tetrachloride, trichloroethylene, 1,1,2-trichlorotrifluoroethane, glycol ethers, 1,1,1-trichloroethane, decamethylcyclopentasiloxane, n-propyl bromide, liquid carbon dioxide, fluorocarbon-113, antimony, cadmium, copper, lead, sulfate, zinc (notes 20, 31, 44, 52)
Leather tanning	**Chromium**, **cyanide**, **tannins**, chlorinated phenols including PCB, azodyes, cadmium, cobalt, copper, antimony, barium, lead, selenium, mercury, zinc, arsenic, nickel, formaldehyde, pesticides, salts, lime, acids, sodium sulfide, hydrogen sulfide, sulfate (notes 22, 55, 56)
Lubricants and greases	**Zinc**, polyaromatic hydrocarbons, arsenic, **boron**, cadmium, lead, **lithium**, **molybdenum**, PCBs, **silicon**, and other elements (note 22)
Medical supplies or wastes	Chloride, formaldehyde, **arsenic**, cadmium, **cobalt**, lead, mercury**, silver**, other heavy metals, radioactive waste, infectious or pathological waste, dioxins and furans from incineration; Also see Pharmaceutical industry (notes 22, 51, 57, 58, 59, 62)

Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Metal manufacturing - smelting	**Aluminum**, **antimony**, **arsenic**, beryllium, cadmium, **chromium**, **copper**, cyanide, iron, **lead**, **magnesium** (aluminum manufacturing), **manganese** (steel and aluminum manufacturing), mercury, **molybdenum** (steel manufacturing), **nickel** (steel and other metal manufacturing), **selenium**, silver, **thallium** (iron and steel manufacturing), zinc and other elements, **fluoride** (steel and aluminum manufacturing), **silicon, vanadium** (steel manufacturing), **zinc** (notes 22, 44, 51, 52)
Metal mining	Aluminum, antimony, **arsenic**, beryllium, cadmium, **chromium**, **copper, cyanide**, iron, **lead, manganese**, **mercury, nickel, selenium**, silicon, silver, thallium, tungsten, zinc and other elements (notes 22, 51, 52, 54, 56)
Metal plating	Spent solvents, paints, spent acidic and alkaline solutions, waste oils, heavy metal sludges, metal dust, chromium, copper, nickel, selenium, **zinc** and other elements (notes 22, 44, 51, 52)
Metal recycling	Iron, copper, **mercury**, nickel, zinc, and other elements (note 22)
Mining - unspecified	Depends on contents of ore; may include aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, **sulfate** (gypsum mines), thallium, zinc, other minerals, hydraulic oils; **radium 226+228 (uranium mines)** (notes 22, 51)
Natural gas pipelines	**Methane, PCBs** (notes 60, 61)
Nuclear power	**Tritium**, **strontium 90, radium 226+228,** boron, beryllium (notes 31, 51, 54)
Oil and gas wells / production	Produced water may contain high **TDS, chloride, sodium**, sulfate, barium, boron, bromide, iodide, lithium, potassium, radionuclides, **vanadium** and other minerals, methane, volatile organic compounds (notes 52, 60, 63)
Ore refining / smelting	Aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, cyanide, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, zinc and other elements (notes 22, 44, 51)
Paint and pigment manufacturing	VOCs, solvents (halogenated solvents, non-halogenated solvents such as acetone, cresols, cresylic acid, nitrobenzene, benzene, toluene, xylene, methyl ethyl ketone, methylene chloride, etc.); metals may include **barium**, **cadmium, cobalt**, **chromium**, **lead**, mercury, **molybdenum**, titanium, and zinc (notes 22, 44, 51, 52, 64)
Paper and pulp manufacturing	Organic and inorganic compounds including lignin, cellulose, phenols, mercaptans, **chromium**, nitrates, phosphates, **silicon, sulfides/sulfates**, chlorinated compounds including chloroform and dioxin (notes 22, 65)
Petroleum facilities and refining	Benzene, ethylene, toluene, xylene, methane, other organic compounds, hydrogen sulfide, **sulfate, nickel, vanadium** and other elements; some refineries use deep-injection wells to dispose of highly contaminated wastewater that could potentially contaminate groundwater (note 51)
Pharmaceutical industry	Wide variety of organic solvents; **arsenic, cobalt**, ammonia, chloride, cobalt, **silver** and other elements; Also see Medical supplies or wastes (notes 22, 51, 57, 62)
Photographic materials/photography	**Silver,** sodium, potassium (notes 22, 51)

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Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Pigments	See Paint and pigment manufacturing
Plastic manufacturing	Cadmium, cyanide, benzene, vinyl hydrochloride, phthalates, trichloroethane, acetone, methylene chloride, methyl ethyl ketone, styrene, toluene, trichloroethane, sulfate, methanol, ethylene oxide, volatile organic compounds, sodium, caustic, nickel, lead, cadmium, mercury (notes 51, 66)
Plumbing	**Copper, lead, zinc** (note 51)
Road salting	**Chloride, sodium**, **calcium**, other salts (notes 22, 44)
Rubber manufacturing	**Ammonia, amines**, acetic acid, **barium**, cobalt, formic acid, sodium, **silicon**, sulfite/sulfate, organics, nitrogen compounds (notes 22, 69)
Salt or brackish water intrusion (from well drilling)	**High TDS, chloride**, boron, bromide, calcium, **lithium**, magnesium, **potassium, sodium**, sulfate, and other minerals (notes 22, 51, 54)
Salvage and junk yards	Grease, oil, solvents, lead and acid from batteries, metals (notes 44, 54)
Semiconductor manufacturing	Copper, silver, gold, palladium, arsenic, beryllium, copper, mercury, nickel, selenium, silicon, thallium and other elements, chloride, fluoride, solvents (benzene, xylene, 1,1,1-trichloroethane, tetrachloroethane, methanol), ethylene glycol, hydrogen chloride, hydrogen fluoride (notes 22, 29, 30, 33, 51)
Septic effluent	**Nitrate, phosphorus, chloride, sodium**, organic substances, bacteria and viruses, detergents, oils, heavy metals including cadmium, copper, lead, **selenium**, salts, septic tank cleaners such as trichloroethane or methylene chloride, and a wide variety of other chemicals (notes 22, 51, 52, 53)
Sewage	**Nitrate, phosphorus, chloride, sodium**, organic substances, bacteria and viruses, detergents, oils, **boron**, **cadmium**, **copper**, lead, **selenium, silver**, salts, and a wide variety of other chemicals (notes 22, 51, 52)
Soap or detergent manufacturing or use	See Detergent and soap manufacturing
Soil acidity neutralization	**Calcium**
Steel (including stainless) and iron manufacturing	Iron, chromium, manganese, nickel, ammonia, cyanide, chloride, copper, fluoride, molybdenum, sulfate, tin, thallium, zinc, hydraulic oils
Textiles	Polyvinyl chloride, chlorine bleach, benzidine, toluidine, cyanide, formaldehyde, hydrocarbons, ammonia, nitrate, organic solvents, chloride, sodium, fluoride, silicon, **sulfate**, phosphate, boron, bromide, chromium, copper, aluminum, antimony, potassium, aluminum, **silver**, titanium, zinc, copper, insecticides (notes 22, 51, 56, 67, 68)
Thermometers, thermostats, switches	**Mercury** (note 51)

Table A-4 (continued)
Constituents Potentially Associated with Alternative Anthropogenic Sources

Potential Source	Constituents That May Be released to Groundwater*
Underground storage tanks (USTs leaking petroleum products such as gasoline)	Benzene, toluene, xylene, other organic compounds (notes 49, 51, 53)
Urban runoff	Oils, heavy metals, salts, copper, zinc, and other chemicals (notes 6, 18, 54)
Waste incineration	**Chloride, cadmium**, chromium**, fluoride, lead, mercury**, selenium, dioxins and furans (note 22)
Water treatment - flocculants	See Flocculants (note 45)
Water treatment - industrial effluents	Wide variety of metals, aluminum, **chloride**, **phosphate**, **potassium, sulfate**, nitrate, **selenium, silicon**, **sodium**, organics depending on industry (notes 22, 46)
Water treatment - municipal supply	Bromide, **chlorine, fluoride** (notes 22, 51)
Water treatment - treated sewage effluent	May contain **nitrates and other nitrogen compounds, phosphates, sodium, chloride**, **selenium, silicon**, and a variety of other elements (notes 22, 51, 52)
Water treatment - water softening	**Sodium, chloride**, **calcium**, magnesium, iron, other salts and metals (note 22)
Water treatment - cooling water	Chromium, zinc (notes 51, 52)
Well drilling (mud or fluid)	Constituents of bentonite clay and the natural geomedia including **aluminum, barium**, calcium, potassium, sodium and other minerals (note 22)
Wood preservatives and treatments	**Pentachlorophenol (PCP), creosote**, **copper, chromium, arsenic** (chromated copper arsenic, ammoniacal copper arsenate) (notes 22, 44, 48, 51)

* Bold indicates likely key indicators; list will vary by site-specific source; list may be incomplete or may not accurately represent a particular source.

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B
ASD CHECKLISTS

		Supporting Lines of Evidence		
		None	**Few**	**Many**
Key Lines of Evidence	**None**	No ASD	Weak ASD	ASD possible
	One	Weak ASD	ASD possible	**Strong ASD**
	Multiple	ASD possible	**Strong ASD**	**Strong ASD**

Figure B-1
Use of key and supporting lines of evidence for ASD Types IV and V

ASD Checklist 1: Sampling, Laboratory, or Statistical Causes

ASD Type	Potential Cause	Identify and Comment on Applicability of Potential Cause
Sampling Causes (ASD Type I)	Sample mislabeling	
	Contamination	
	Sampling technique	
	Turbidity	
	Sampling anomalies	
Laboratory Causes (ASD Type II)	Calibration	
	Contamination	
	Digestion methods	
	Dilution corrections	
	Interference	
	Analytical methods	
	Laboratory technique / qualifier flags	
	Transcription error(s)	
Statistical Evaluation Causes (ASD Type III)	Lack of statistical independence	
	Outliers	
	False positives	
	Non-detect processing	
	Background data / change in normality	

ASD Types I, II, and III do not require a weight of evidence approach. Refer to Section 2 for descriptions of potential causes.

ASD Checklist 2: Lines of Evidence Associated with the CCR Unit

		Column A	Column B	Column C				
	Line of Evidence (LOE)	**Points to release from the CCR unit if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
	Primary CCR Indicators							
1a	If the CCR unit contains fly ash, is there an SSI/SSL for boron and sulfate?	Yes	No	ND	Key	Monitoring Point	The primary indicators for CCR leachate typically have high concentration in the leachate, are mobile, and are not reactive in groundwater, such that any groundwater affected by a leachate release will have elevated concentration for the indicator constituent. Boron and sulfate are primary indicators for coal ash leachate. Sulfate is a primary indicator for FGD gypsum leachate. Other potential indicators are identified in Table A-1. Leachate analysis can confirm site-specific primary indicators by identifying constituents present in leachate in concentrations higher than background. An SSI/SSL is unlikely to be due to release from the facility if the leachate concentration is not higher than background.	Demonstrate using graphical and statistical analysis. Special leachate sampling may be needed if not already routinely sampled.
1b	If the CCR unit contains FGD gypsum (only) is there an SSI/SSL for sulfate?	Yes	No	ND	Key	Monitoring Point		
1c	Are there other constituents in the groundwater that represent primary indicators? List the applicable constituents.	Yes	No	ND	Supporting	Monitoring Point		
1d	Is there an SSI/SSL for any of the other primary indicators?	Yes	No	ND	Key if No	Monitoring Point		
1e	Is the *leachate* concentration for any of the primary indicators (including boron and sulfate) with an SSI/SSL statistically higher than background? List the applicable constituents.	Yes	No	ND	Key if No	Constituent		
1f	Are concentrations for the primary indicators increasing?	Yes	No	ND	Supporting	Monitoring Point		
	Secondary Indicators							
2a	Are there other SSI(s) or SSL(s) of Appendix III or IV parameters? (These are potential secondary indicators. List the applicable constituents.)	Yes	No	ND	Supporting	Monitoring Point	Secondary CCR indicators are defined by high concentration in the CCR leachate, but they may be less mobile or more reactive in the environment, or they may be relatively common in groundwater due to natural or anthropogenic causes. Leachate analysis is used to determine site-specific secondary indicators. An SSI/SSL is not likely to be due to release from the facility if the leachate concentration is not higher than background. This line of evidence is secondary to LOE 1. If LOE 1 points to an alternative source, then the alternative sources may also explain SSI/SSLs for secondary indicators.	Demonstrate using graphical and statistical analysis. Special leachate sampling may be needed if not already routinely sampled.
2b	Are the constituents identified in 2a present *in leachate* in concentrations statistically higher than background?	Yes	No	ND	Key if No	Constituent		
2c	Are concentrations for any of the secondary indicators increasing? List the applicable constituents.	Yes	No	ND	Supporting	Monitoring Point		

		Column A	Column B	Column C				
	Line of Evidence (LOE)	**Points to release from the CCR unit if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
	Other Chemistry							
3a	Are organic constituents present in concentrations statistically higher than background? If "yes," mark column B. (May not be relevant if the CCR unit is not a monofill.)	Not applicable	Yes	No	Supporting	Monitoring Point	Organic compounds are combusted in the power plant boiler. EPRI data [1987, 2016] has shown that organic compounds typically have non-detectable concentrations in CCR leachate. The presence of organic constituents in groundwater indicates that an alternative source has affected groundwater quality at that monitoring point, although it does not rule out the CCR unit as a source for inorganic constituents. Biologically mediated reactions within organic plumes can result in natural release from soil of redox-sensitive constituents such as arsenic.	Special analyses for organic compounds may be needed if there is reason to suspect that organic compounds are present in the groundwater. Demonstrate using graphical and statistical analysis.
3b	Is major ion chemistry similar to leachate?	Yes	No	ND	Key	Monitoring Point	If the SSI/SSL is due to a release from the facility, then the major ion chemistry of the groundwater sample should be a mixture of leachate and background groundwater.	Special sampling for all eight major ions may be necessary if not routinely analyzed as part of the groundwater monitoring program. This demonstration can be performed using Piper diagrams, Stiff charts, and ion ratios (see Section 3; Tier II analysis is also described in EPRI 2012).
3c	Does major ion chemistry suggest a mixture of leachate and background groundwater?	Yes	No	ND				
3d	Does tritium age dating indicate that the groundwater was recharged after the facility was first used?	Not applicable	No	Yes	Key if No	Monitoring Point	Tritium can be used to determine if groundwater recharged prior to atomic testing in the 1950s. The CCR unit is unlikely to be the cause of an SSI/SSL if groundwater is older than the unit.	Special analysis for tritium is required, refer to EPRI (2017) for more on this method.
3e	Does isotopic analysis show evidence of mixing with CCR leachate?	Yes	No	ND	Key	Monitoring Point	The CCR unit is unlikely to be the cause of an SSI/SSL if isotope ratios show no evidence of mixing between leachate and background groundwater.	Special analyses required for isotope testing, refer to EPRI (2017).

		Column A	Column B	Column C				
	Line of Evidence (LOE)	**Points to release from the CCR unit if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
	Hydrogeology							
4a	Is the monitoring well with an SSI/SSL downgradient from CCR unit at any point during year?	Yes	No	ND	Key if No	Monitoring Point	The monitoring well must be downgradient for the SSI/SSL to be attributed to the CCR unit.	Demonstrate using maps or calculated vectors for groundwater flow direction.
4b	Review the Hydrogeological vs Leachate Scenario Table (Table A-2) and identify the most representative scenario for each SSI or SSL case. List cases and scenario numbers.	(Check here for cases indicating a possible CCR release.) (Scenario types from Table A-2, column 1 or 2)	(Check here for cases indicating a possible alternative source.) (Scenario types from Table A-2, column 2 or 3)	ND	Key	Monitoring Point	CCR Leachate Release (Table A-2, column 1 scenarios) - If the CCR unit is the only source and the leachate concentration is higher than background, the downgradient well concentration should be equal to or less than the leachate concentration due to mixing with groundwater. CCR Leachate Release and/or Alternative Source (Table A-2, column 2 scenarios) - If the leachate concentration is higher than background and a downgradient concentration is higher than the leachate concentration, both leachate and an alternative source may be contributing to downgradient concentrations. Alternative Source Release (Table A-2, column 3 scenarios) - If the leachate concentration is less than background, the leachate cannot cause downgradient concentrations to be higher than background, and an alternative source is indicated.	This LOE requires site-specific knowledge of leachate concentrations. Demonstrate by comparing site-specific flow and concentration maps to Table A-2.
4c	Is the CCR unit immediately underlain by clay, shale, or other geologic media with low hydraulic conductivity?	No	Yes	ND	Supporting	Unit	Clay and shale can provide a physical barrier to migration from a CCR unit; however, CCR indicator concentrations, particularly boron, can be naturally elevated in these formations.	Cross-sections developed from boring logs
4d	Is the monitoring point distant from the facility AND does the constituent with an SSI/SSL have low mobility in groundwater given the hydrogeologic environment at the monitoring location (see Table A-3)?	No	Yes	ND	Supporting	Case	The CCR unit is less likely to be the source of the SSI/SSL if the constituent has low mobility and is monitored at a distant point.	Groundwater modeling, accounting for sorption, can be used to determine whether or not migration to the monitoring location is possible.
4e	Are the background monitoring wells screened in the same hydrostratigraphic unit, and along the same groundwater flow path, as the monitoring location with the SSI?	Yes	No	ND	Supporting	Monitoring Point	If the background and downgradient wells are not along the same flow path and/or are not screened in the same hydrostratigraphic unit, the SSI/SSL may indicate a natural difference between formations or flow paths, rather than an anthropogenic release.	The site conceptual model, based on groundwater flow and hydrogeology, provides data that can be used for this determination. Geochemical modeling can be used to evaluate the naturally occurring geochemistry expected for different hydrostratigraphic units, and whether or not the observed evolution in groundwater quality is consistent with what is known about the geochemistry of each hydrostratigraphic unit.

		Column A	Column B	Column C				
	Line of Evidence (LOE)	**Points to release from the CCR unit if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
	CCR Unit Design							
5a	Does the entire footprint of the monitored CCR unit have a liner?	No	Yes	ND	Supporting	Unit	The presence of a liner reduces the potential (relative to an unlined unit) for a release from the CCR unit, particularly if it is not underlain by a natural barrier material.	Review design documentation. The response to this question would be no if any portion of the monitored CCR unit is unlined.
5b	If the facility is lined, is it a composite liner?	No	Yes	ND	Supporting	Unit	A composite liner, consisting of a geosynthetic barrier material over clay, further reduces the potential for a release (relative to a clay liner) from a CCR unit.	Review design documentation. The response to this question would be no if any portion of the monitored CCR unit does not have a composite liner.
5c	Does the entire footprint of the CCR unit have a leachate collection system?	No	Yes	ND	Supporting	Unit	A leachate collection system further reduces the potential (relative to a unit with liner and no leachate collection) of a release from a CCR unit.	Review design documentation. The response to this question would be no if any portion of the monitored CCR unit does not have leachate collection.
5d	If the CCR unit is unlined, is it known to have or is it likely to have groundwater intersecting the CCR?	Yes	No	ND	Supporting	Unit	This LOE is indeterminate for active impoundments. This LOE is indeterminate for CCR units with engineered or natural liners. For cases that are not indeterminate, an intersecting water table increases the potential for a release to groundwater, relative to a facility where groundwater is below the CCR.	Water table elevation contours and engineering drawings can be compared to project whether or not the water table intersects the CCR. If engineering drawings are not available, and the facility is unlined, then borings can be performed to gauge CCR depth. Spring seepage into a CCR unit would be counted as intersecting groundwater.

Table Notes:

1. ND (not determined) indicates that this line of evidence was not tested or there are insufficient data to make a determination.
2. Line of Evidence (LOE) Types:
   Key lines of evidence are based on relationships that must be observed in order for an SSI/SSL to be due to a release from a CCR unit. If these relationships are not observed, then they are critical to establishing an ASD. It is difficult to build a strong ASD without any key lines of evidence. It may be possible to build an ASD with a single key line of evidence, but the ASD will be stronger with additional key or supporting lines of evidence.
   Supporting lines of evidence provide additional information that supports the ASD. Supporting lines of evidence are generally not sufficient to build an ASD unless there is at least one key line of evidence, although it may be possible if there are many supporting lines of evidence.
3. This LOE applies to:
   Constituent: An SSI/SSL for that constituent at any monitoring point
   Monitoring Point: All SSIs/SSLs at a specific monitoring point
   Case: An SSI/SSL for a specific constituent at a specific monitoring point
   Unit: All SSIs/SSLs at the monitored unit

ASD Checklist 3: Lines of Evidence Associated with Alternative Natural and Anthropogenic Sources

		Column A	Column B	Column C				
	Line of Evidence (LOE)	***Does not* point to alternative source if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
General								
6a	Are there any known alternative sources for any of the constituents of concern on-site or off-site?	No	Yes	ND	Supporting	Unit	Identification of an alternative source for one or more constituents with an SSI/SSL, in an upgradient location, establishes potential for an ASD.	Consider answering the questions below first to help identify possibilities, and then come back to this set of questions. Refer to Tables A-3 and A-4 for common anthropogenic sources for various constituents in groundwater. List and draw locations with reference to the CCR unit on a map.
6b	Are any current or former potential alternative sources upgradient of the monitoring location?	No	Yes	ND	Supporting	Monitoring Point		
6c	Do monitoring locations between a potential upgradient source and CCR unit have concentrations at SSI/SSL levels?	No	Yes	ND	Supporting	Constituent	If a constituent has high concentration in groundwater, relative to background, both upgradient and downgradient from a CCR unit, then an alternative source is possible, regardless of whether or not the responses to 6a and 6b are yes. If the upgradient concentration is similar to or higher than the downgradient concentration, then an alternative source is likely.	Demonstrate using statistical and graphical methods.
On-Site Alternative Source								
7a	Is the monitoring point downgradient of or near a coal pile, or coal pile runoff, or coal pile leachate management area?	No	Yes	ND	Supporting	Monitoring Point	If yes, the coal pile may be a potential alternative source if it is unlined.	Use Tier II analysis to test for differences in leachate and groundwater signatures. May require special sample from coal pile runoff ditch or collection pond.
7b	Are there former coal mines, mine spoil, or conveyers near the CCR unit or upgradient from the facility?	No	Yes	ND	Supporting	Unit	If yes, these may be alternative sources.	pH may be lower, and concentrations of iron, manganese, and trace elements may be higher in groundwater impacted by a coal mine relative to CCR leachate.
7c	Does the site have other CCR units that are upgradient or side gradient of the affected monitoring location?	No	Yes	ND	Supporting	Monitoring Point	If yes, the other CCR units may be alternative sources, particularly if they are unlined impoundments or landfills.	For this case CCR indicator constituents should have an SSI/SSL or increasing trend at the monitoring location. If water quality signatures are not different, then intermediate monitoring points may be needed.
7d	Is the CCR unit built on top of a former CCR disposal area (i.e., has a lined impoundment been built on top of a former unlined impoundment, or has a lined landfill been built on top of a portion of an unlined impoundment)?	No	Yes	ND	Supporting	Unit	If yes, groundwater quality may be affected by leachate from the underlying CCR.	For this case CCR indicator constituents should have an SSI/SSL or increasing trend at the monitoring location. If the overfill CCR unit is lined and concentrations of CCR leachate indicators are decreasing, an ASD may be possible showing that the groundwater impacts are due to the former CCR disposal activities. The water quality signature and isotope ratios for a legacy site may be different than those for the overfill unit if there has been a coal switch.

		Column A	Column B	Column C				
	Line of Evidence (LOE)	***Does not* point to alternative source if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
On-Site Alternative Source (continued)								
7e	Do the CCR unit or adjacent units have an active underdrain piping system or groundwater pumping system, or are there any groundwater pumping activities nearby, that could have localized influence on groundwater flow and quality?	No	Yes	ND	Supporting	Unit	If yes, consider potential effects on localized groundwater flow directions and quality.	Groundwater with CCR constituents can be pulled toward another CCR unit with an underdrain system or if CCR units are within the radius of influence of on-site production wells. For example, elevated CCR constituents from an unlined fly ash pond (e.g., boron) can occur in adjacent gypsum pond downgradient wells due to localized groundwater flow.
7f	Is there evidence that water used for dust suppression on uncovered CCR or coal piles flowed off the footprint of the liner or runoff containment system near the monitoring point?	No	Yes	ND	Supporting	Monitoring Point	Runoff water from dust control can contain many of the same constituents as CCR leachate. If wind or other issues cause a spray irrigation system to deposit leachate beyond the landfill boundary, then an SSI/SSL with a CCR leachate signature can result. These are examples of an ASD where management of the unit is responsible for the SSI/SSL, but the SSI/SSL is not due to a direct release of leachate to groundwater from the unit. A change in management can mitigate this SSI/SSL source.	Identify the source of dust suppression water (coal pile runoff water, leachate, reused water from other sources). Document, using photos or other evidence, potential pathways off the liner or beyond the runoff containment system. For these cases, CCR indicator constituents should have an SSI/SSL or increasing trend at the monitoring location. Concentrations should decrease after management improvements are implemented.
7g	Is leachate or sluice water used for dust control close to the monitoring location?	No	Yes	ND	Supporting	Monitoring Point		
7h	Is the monitoring point downgradient of or near a CCR handling area (silo, storage area, dewatering bin, sump, truck loading/unloading or washing area, etc.) or haul road?	No	Yes	ND	Supporting	Monitoring Point	These are examples of an ASD where CCR handling associated with the unit is responsible for the SSI/SSL, but the SSI/SSL is not due to a direct release of leachate to groundwater from the unit. Revisions to handling practices, or repairs to handling structures, can mitigate this SSI/SSL source.	Engineering investigation of CCR and leachate handling structures may be required to demonstrate these alternative sources. Documentation of spillage or leaks (by material type, source, and location) will support this ASD. For these cases, CCR indicator constituents should have an SSI/SSL or increasing trend at the monitoring location. This ASD is particularly effective if concentrations begin to decrease after the alternative source is mitigated (allowing for lag time due to slow-moving groundwater).
7i	Is the monitoring point downgradient of or near sluice water lines, handling equipment, or storage areas?	No	Yes	ND	Supporting	Monitoring Point		
7j	Is the monitoring point downgradient of or close to a leachate collection pipeline or leachate storage structure?	No	Yes	ND	Supporting	Monitoring Point		
7k	Have there been any documented spills of CCR or leachate or sluice water in upgradient or nearby locations?	No	Yes	ND	Supporting	Monitoring Point		
7l	Were CCRs ever drained or stockpiled in unlined areas and/or without run-off/leachate control in upgradient or nearby areas?	No	Yes	ND	Supporting	Monitoring Point		

		Column A	Column B	Column C				
	Line of Evidence (LOE)	***Does not* point to alternative source if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
On-Site Alternative Source (continued)								
7m	Is there any history of on-site or upgradient oil or chemical spills or leaking underground storage tanks?	No	Yes	ND	Supporting	Monitoring Point	If yes, groundwater may be impacted by oil or chemical spills.	Documentation of spillage or leaks (by material type, source, and location) will support this ASD. For this case, look for constituents that are higher than background that are not primary indicators of the site-specific CCR leachate signature.
7n	Does a significant amount of road salting occur on-site? (also see 9b)	No	Yes	ND	Supporting	Monitoring Point	If yes, concentrations for chloride and other major ions (depending on the type of salt; see Table A-4) may have an SSI/SSL.	If yes, look for notably elevated concentrations of the cations and anions comprising the salts used. If these are elevated, then an ASD related to road salting may be possible.
7o	Are fertilizers being used on-site for cap vegetation or other uses?	No	Yes	ND	Supporting	Monitoring Point	Consider if groundwater impacts include nitrates or phosphates, or if the fertilizers include calcium, sulfate, or other minerals that are monitored under the CCR program.	Documentation of on-site use of fertilizers will help support this ASD.
7p	Is there any history of on-site or upgradient ash utilization (structural fill, landfill, road base, berm construction, soil stabilization, etc.)?	No	Yes	ND	Supporting	Monitoring Point	If yes, these may be on-site alternative sources.	Documentation of historical site structural fill activities, source information, and analytical data will help support this ASD.
7q	Was the power plant site subgrade prepared with CCR, dredge spoils, incinerator residue, construction debris, industrial waste, or non-native soils?	No	Yes	ND	Supporting	Monitoring Point		
Natural Variation								
8a	Are background wells screened in the same geomedia as the monitoring point?	Yes	No	ND	Supporting	Monitoring Point	If no, then one or more SSI/SSL may be a result of naturally occurring differences in groundwater quality.	Geochemical modeling can be used to evaluate whether or not observed concentrations are consistent with the geomedia.
8b	Is the aquifer comprised of poorly buffered media such as sand and gravel?	No	Yes	ND	Supporting	Unit	If yes, then pH may be evolving if the pH or precipitation water is different than the groundwater, which can cause desorption or dissolution of pH-sensitive constituents.	Investigate long-term data records for evidence of pH changes. Refer to Table A-3 to determine if this case applies to the constituent with an SSI/SSL. Geochemical modeling may be considered to fully document this effect.
8c	Is the pH at the monitoring point similar to the background pH?	Yes	No	ND	Supporting	Monitoring Point	If no, then background is not fully representative of downgradient groundwater. Concentrations may evolve over the groundwater flow path.	Refer to Table A-3 to determine if this case applies to the constituent with an SSI/SSL. Geochemical modeling may be considered to fully document this effect.

		Column A	Column B	Column C				
	Line of Evidence (LOE)	***Does not* point to alternative source if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
Natural Variation (continued)								
8d	Is the monitoring point near a river?	No	Yes	ND	Supporting	Monitoring Point	If yes, then there may be changes in flow direction and/or groundwater elevations in response to changes in river stage that could result in monitoring different groundwater than during the background monitoring period. A yes response here also signifies potential for a redox change from oxic in upgradient areas where groundwater recharges, to reduced near the river where groundwater discharges.	Time-series plots can be used to see if there are correlations between river stage and concentration. Concentration distribution maps can be used to investigate effects of changes in flow direction. Check redox indicators to look for changes in redox.
8e	Is the constituent chemically reactive in groundwater, such that dissolution or desorption is possible (see Table A-3)?	No	Yes	ND	Supporting	Constituent	Reactive constituents can exhibit naturally occurring concentration changes if pH or redox conditions change along the flow path.	Refer to Table A-3 to determine if this case applies to the constituent with an SSI/SSL. Geochemical modeling can be used to test whether or not a change in geochemical conditions is causing a naturally occurring evolution of the groundwater.
8f	Is there a difference in redox indicators between background and compliance monitoring data?	No	Yes	ND	Supporting	Monitoring Point	This can affect redox-sensitive constituents, and can cause an SSI/SSL if the different redox environment only occurs at downgradient monitoring locations.	Compare background and compliance redox indicators to determine if this case applies. Refer to Table A-3 to determine if this case applies to the constituent with an SSI/SSL. Geochemical modeling may be considered to fully document this effect.
8g	Has there been a recent flood, recharge event, or dry period that caused groundwater elevation to rise or fall to elevations higher or lower than observed during the background monitoring period?	No	Yes	ND	Supporting	Unit	If yes, then there may be changes in groundwater elevation that could result in monitoring different groundwater than during the background monitoring period.	Time-series plots can be used to see if there are correlations between river stage and concentration.
8h	Does the aquifer contain saline water at depth?	No	Yes	ND	Supporting	Unit	If yes, monitoring wells close to the ocean, or that are deeper than background, may have higher concentrations of indicators for brine than background groundwater. Implementation of, or an increase in, groundwater withdrawals near the monitoring point could cause upwelling that would be a change over time.	The water quality signature for seawater and brines should be different than leachate, as described in Section 4.
8i	Was the direction of groundwater flow prior to or during the sample event different than observed during the background prior?	No	Yes	ND	Supporting	Monitoring Point	If yes, then the changes in flow direction could result in monitoring different groundwater than during the background monitoring period.	Concentration distribution maps can be used to investigate effects of changes in flow direction.

		Column A	Column B	Column C				
	Line of Evidence (LOE)	***Does not* point to alternative source if:**	**Points to alternative source if:**	**LOE is not applicable if:[1]**	**LOE Type[2]**	**Applies to[3]**	**Weight of Evidence Determination / Basis**	**Alternative Source Demonstration Approach**
Off-Site Anthropogenic								
9a	Are there former coal mines, mine spoil, or conveyers near the CCR unit or upgradient from the facility (also consider under "On-site")?	No	Yes	ND	Supporting	Unit	If yes, these may be alternative sources.	pH may be lower, and concentrations of iron, manganese, and trace elements may be higher, in groundwater impacted by a coal mine relative to CCR leachate.
9b	Does a significant amount of road salting occur off-site?	No	Yes	ND	Supporting	Unit	If yes, concentrations for chloride and other major ions (depending on the type of salt; see Table A-4) may have an SSI/SSL.	If yes, look for notably elevated concentrations of the cations and anions comprising the salts used. If these are elevated, then an ASD related to road salting may be possible.
9c	Does the surrounding land use include agriculture (crops)?	No	Yes	ND	Supporting	Unit	If yes, then concentrations of nitrates and other agricultural constituents (see Table A-4) may be elevated.	Use graphical or statistical analysis to demonstrate presence of agricultural indicators. This ASD is most effective if agricultural indicators are present in upgradient or intermediate monitoring points.
9d	Does the surrounding land use include agriculture (animal)?	No	Yes	ND	Supporting	Unit		
9e	Are there current or former underground or aboveground storage tanks that have had a release? (Consider gas stations and surrounding industrial activities.)	No	Yes	ND	Supporting	Unit	If yes, these may be alternative sources.	Identification of locations of underground and aboveground storage tanks, along with documented leak history (if known), will help support this ASD. Include locations of gas stations.
9f	Are there, or were there, oil and gas production wells in the vicinity of the site?	No	Yes	ND	Supporting	Unit	If yes, look for evidence of salt water intrusion, seepage of drilling fluid or additive chemicals, and organics.	Document locations of oil and gas wells.
9g	Are there existing or historical commercial and/or industrial sources of impacts, such as metal manufacturing, mining, landfills, Superfund or brownfield sites, wood treatment, etc.?	No	Yes	ND	Supporting	Unit	First determine if surrounding land use includes current or former industrial or commercial activity and identify types and locations. Then look for evidence of potential impacts to groundwater. Tables A-3 and A-4 provide information on potential impacts to groundwater related to common anthropogenic activities.	Review historical aerial photos, Sanborn maps, and available GIS data showing changing landscape and property use since the late 19th century. USGS topographic maps can be used to evaluate drainage patterns and topographic changes as well as locations of mines, quarries, and landfills. Review local, state, and federal information available through online databases or Freedom of Information Act requests related to brownfield sites and NPL listings. The local fire department and county health department may be good sources of information.
9h	Could any potential anthropogenic sources be causing changes to groundwater chemistry that would result in release of the constituent of concern through changes to pH, redox, etc.?	No	Yes	ND	Supporting	Unit	As noted, a change in pH or redox along a flow path or over time can cause concentrations for pH or redox-sensitive constituents to change.	Review field data to determine if a pH or redox change has occurred. Document the source of the pH or redox change. Refer to Table A-3 to verify that the SSI/SSL is for a constituent that is pH or redox-sensitive.
	Time-of-Travel Analysis							
10	Has groundwater flowing beneath potential sources had enough time to migrate to the affected monitoring well location?	No	Yes	ND	Supporting	Monitoring Point	Constituents must have time to travel downward to the aquifer and travel with the aquifer to the monitoring point. Sources must also be in upgradient or side gradient locations.	Use groundwater velocity calculation or simple analytical model to determine if there has been sufficient time for transport to the monitoring point.

Table Notes:

1. ND (not determined) indicates that this line of evidence was not tested or there are insufficient data to make a determination.
2. Line of Evidence (LOE) Types:
   Key lines of evidence are based on relationships that must be observed in order for an SSI/SSL to be due to a release from a CCR unit. If these relationships are not observed, then they are critical to establishing an ASD. It is difficult to build a strong ASD without any key lines of evidence. It may be possible to build an ASD with a single key line of evidence, but the ASD will be stronger with additional key or supporting lines of evidence.

Supporting lines of evidence provide additional information that supports the ASD. Supporting lines of evidence are generally not sufficient to build an ASD unless there is at least one key line of evidence, although it may be possible if there are many supporting lines of evidence.

3. This LOE applies to:
   Constituent: An SSI/SSL for that constituent at any monitoring point
   Monitoring Point: All SSIs/SSLs at a specific monitoring point
   Case: An SSI/SSL for a specific constituent at a specific monitoring point
   Unit: All SSIs/SSLs at the monitored unit

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com

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Appendix 19

United States Environmental Protection Agency (USEPA), 2019. Leaching Environmental Assessment Framework (LEAF) How-To Guide. SW-846 Update VII. Revision 1. May.

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Leaching Environmental Assessment Framework (LEAF) How-To Guide

Understanding the LEAF Approach and How and When to Use It

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Authors

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The authors of this guide are David S. Kosson (Vanderbilt University), Andrew Garrabrants (Vanderbilt University), Susan Thorneloe (EPA, Office of Research and Development), Daniel Fagnant (EPA, Office of Land and Emergency Management), Greg Helms (EPA, Office of Land and Emergency Management), Katie Connolly (ERG), and Molly Rodgers (ERG).

In addition to input we received from the peer review process, contributors and reviewers of this guide include Hans van der Sloot (Hans van der Sloot Consultancy, The Netherlands), Schatzi Fitz-James (EPA, Office of Land and Emergency Management), Paul Lemieux (EPA, Office of Research and Development), Ken Ladwig (Electric Power Research Institute), Connie Senior (ADA-ES), and Craig Benson (University of Virginia).

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Acronyms and Abbreviations

Acronym	Definition
ANC	acid neutralization capacity
CaFA	material specimen code for a coal combustion fly ash
CCR	coal combustion residue
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFS	material specimen code for a contaminated smelter site soil
COPC(s)	constituent(s) of potential concern
DAF(s)	dilution and attenuation factor(s)
DOC	dissolved organic carbon
EaFA	material specimen code for a coal combustion fly ash
EC	electrical conductivity [mV]
EDD	electronic data deliverable
EPACMTP	EPA Composite Model for Leachate Migration with Transformation Products
IWEM	Industrial Waste Management Evaluation Model
L/A	liquid-to-surface area ratio [mL/cm^3]
L/S	liquid-to-solid ratio [mL/g-dry]
LDR	Land Disposal Restrictions
LEAF	Leaching Environmental Assessment Framework
LLOQ	lower limit of quantification
LSP	liquid-solid partitioning
MCL	maximum contaminant level
MDL	method detection limit
MSWI	municipal solid waste incinerator
ORCHESTRA	Objects Representing Chemical Speciation and Transport
ORP	oxidation/reduction potential
QAPP	Quality Assurance Project Plan
QA/QC	quality assurance/quality control
POC	point of compliance
RCRA	Resource Conservation and Recovery Act
redox	reduction/oxidation
RSD_r	replicate standard deviation for repeatability
RSD_R	replicate standard deviation for reproducibility
RSL	Regional Screening Level
SAB	Science Advisory Board
SPLP	Synthetic Precipitation Leaching Procedure
SWA	material specimen code for a solidified waste form
TCLP	Toxicity Characteristic Leaching Procedure
U.S. EPA	United States Environmental Protection Agency

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Abstract

This document provides guidance on the use and application of the Leaching Environmental Assessment Framework (LEAF) published by the United States Environmental Protection Agency (U.S. EPA or the Agency). The purpose of this guide is to provide an understanding of LEAF to facilitate its broader use in environmental assessment. LEAF is a leaching evaluation framework, which consists of four leaching tests (i.e., U.S. EPA Methods 1313, 1314, 1315 and 1316), data management tools, and approaches for estimating constituent release from solid materials. The LEAF tests consider the effect on leaching of key environmental conditions and waste properties known to significantly affect constituent release. This document provides background on the LEAF tests as well as information on how to perform the tests and how to understand the test results. This document also provides guidance on the application of LEAF to assess leaching potential of COPCs from solid waste matrices for beneficial use, disposal, treatment, and remediation applications. In addition, this document addresses frequently asked questions about the four LEAF test methods, data management and reporting using freely-available software, and potential applications of the LEAF approach.

The approach to testing and evaluation presented in this guide is progressive in that each of the different methods provide information on the effect of different environmental parameters on leaching. Therefore, investment in each increment of additional testing and evaluation may reward the user with increasingly refined estimates of leaching. Traditionally, the potential for environmental impact through leaching of COPCs from a solid material disposed or otherwise in contact with the land into ground water or surface water can be estimated using one or more single-point leaching tests that represent a specific scenario or set of environmental conditions. Alternatively, LEAF testing may provide more reliable release estimates by assessing the impact on leaching of environmental factors and waste properties that are known to significantly affect constituent leaching and which vary in the environment and across waste forms. By testing over a range of values for release-controlling factors, the LEAF approach allows for flexibility in that a single data set can be used to evaluate multiple potential management scenarios for a material (e.g., disposal or beneficial use) under varied or site-specific environmental conditions.

The four LEAF test methods presented in this document have undergone interlaboratory validation for use with inorganic constituents of potential concern (COPCs), such as metals and radionuclides, and have been incorporated into the U.S. EPA compendium of laboratory methods, SW-846 (see *https://www.epa.gov/hw-sw846/sw-846-compendium*). The Agency recognizes that the leaching of organic constituents will follow the same principles (i.e., that key environmental conditions or waste properties that significantly affect leaching can be identified) but may require different testing methods to address controlling properties. Therefore, the next steps for the Agency are to adapt these methods or develop new methods applicable to evaluating the potential release of organic COPCs from waste or other materials.

Key Definitions

Term	Definition
Assessment Ratio	The estimated maximum leaching concentration for a COPC divided by the threshold value for a scenario.
Available Content	The fraction of the total concentration of a constituent in the solid phase (mg/kg-dry) that potentially may leach over a reasonably near-term timeframe (e.g., 100 y).
Available Content-Limited Leaching	A liquid-solid partitioning endpoint at which the available content of a constituent in the solid phase limits the amount leached into aqueous phase (i.e., the aqueous phase is less than the saturation concentration and the solid phase is depleted of the constituent's available content).
Chemical Species	Particular forms of a chemical element or compound (e.g., ions, molecules, molecule fragments, etc.) that contribute to the measured concentration of a constituent in a given liquid or solid phase.
Constituent	A chemical element or species in the liquid or solid phase, typically chemically analyzed based on total content of chemical species or compound.
Constituent of Potential Concern (COPC)	A constituent that may be present at concentrations of regulatory, environmental, or human health significance due to their toxicity or other properties.
Eluant	The water or aqueous solution used to contact or extract constituents from a material during a laboratory test.
Eluate	The aqueous solution, analyzed as part of a laboratory test, which results from contact of an eluant with the tested material.
Equilibrium Limited Leaching	A liquid-solid partitioning endpoint at which the leaching of constituents is limited by the amount of material leached at equilibrium conditions (e.g., available content limited leaching, solubility-limited leaching.)
Flow-through	The water contact scenario when precipitation, infiltrating water, or groundwater flows around the external surface area of a low-permeability material (e.g., cement-treated wastes, compacted materials) and release occurs at the interface between the flowing water and the material.
Leachant	The water or aqueous solution contacting a material under field conditions (e.g., infiltrating water, groundwater).
Leachate	The aqueous solution resulting from leachant contact with a material under field conditions.
Mass Transport (diffusion) - Limited Leaching	The release from solid material when leaching potential is less than equilibrium liquid-solid partitioning, typically constrained by the rate of diffusion through the material being leached.
Percolation	The water contact scenario in which precipitation, infiltrating water, or groundwater, moves through the contiguous voids of a porous material and leaching occurs at the solid-liquid interface between the percolating fluid and the solid material.
Solubility-Limited Leaching	A liquid-solid partitioning endpoint at which the solubility of a constituent in the aqueous phase or eluant limits the leaching process (i.e., the aqueous phase concentration is at saturation yet available constituent remains in the solid phase).
Sorption-Controlled Leaching	A liquid-solid partitioning endpoint at which neither the solid nor the aqueous phase limits leaching, but sorption to mineral or organic matter

	surfaces controls the concentration measured in the aqueous phase or eluant.
Source Term	A numerical or model-based estimate of constituent release used to represent leaching from material in a field application and which may also be used for subsequent fate and transport modeling.
Total Content	The concentration of a constituent in the solid material (mg/kg-dry) accounting for all species.
Washout	A rapid release of constituents resulting from highly soluble species rapidly dissolving in water percolating through a material; usually indicated during Method 1314 by a decrease in leaching concentration of approximately one order of magnitude or more from L/S = 0.2 mL/g-dry to 2.0 mL/g-dry.

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1. An Introduction to LEAF and this Guide

1.1 What is the Purpose of this Guide?

The purpose of this document is to provide information that improves understanding and supports application of the Leaching Environmental Assessment Framework (LEAF) published by the United States Environmental Protection Agency[1] (U.S. EPA, or the Agency) and, thereby, facilitate its broader use. LEAF is a leaching evaluation framework consisting of four leaching tests (i.e., U.S. EPA Methods 1313, 1314, 1315 and 1316; U.S. EPA, 2012f, 2013a, 2013b, 2013c) data management tools, and scenario assessment approaches that are designed to work together to provide an estimate of the release of constituents of potential concern (COPCs) from a wide range of solid materials. This document provides background and technical support for implementing LEAF to assess leaching potential of COPCs from solid waste matrices for beneficial use,[2] disposal, treatment and remediation applications. In addition, this document is designed to address frequently asked questions about the four EPA LEAF leaching test methods, data management and reporting using the freely available LeachXS™ Lite software,[3] and potential applications of the LEAF approach. For detailed information on EPA's SW-846 Methods, see *https://www.epa.gov/hw-sw846/sw-846-compendium*.

The LEAF test methods presented in this document have been validated for inorganic COPCs (U.S. EPA, 2012c, 2012d). The Agency believes the methodology in this guide is applicable to the leaching of heavy metals, and by extension, inorganic radionuclides.[4] Next steps for the Agency are to adapt these methods or develop new tests for estimating the leaching of organic COPCs. Although these leaching tests for organic COPCs will be based on the LEAF principles (i.e., testing protocols addressing identified environmental parameters having the greatest effect on COPC release), the specifics of organic COPC leaching may require development of different testing methods (i.e., different environmental factors may determine leaching behavior of organic COPC than for inorganic COPC). Every effort will be made to ensure the organic COPC test methods are compatible with the methods for inorganic COPC leaching, with the overall goal of creating an integrated set of tests that can be reliably used to evaluate the leaching potential of a broad range of wastes containing inorganic and/or organic COPCs.

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[1] EPA worked collaboratively with parallel efforts in the European Union to develop and harmonize test methods to support data comparisons. (Appendix A of this document identifies analogous leaching tests)

[2] EPA's *Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials* presents a voluntary approach for evaluating the potential adverse impacts to humans and the environment from a wide range of industrial non-hazardous secondary materials and their associated beneficial uses. Prior to beneficially using secondary materials in any projects, interested individuals or organizations should consult with the relevant state and federal environmental agencies to ensure proposed uses are consistent with state and federal requirements.

[3] LeachXS™ Lite is a free, limited capability version of the LeachXS™ decision support software. As a data management tool for use with LEAF data, LeachXS™ Lite is available for licensing at no cost at www.vanderbilt.edu/leaching.

[4] Chemically, inorganic radionuclides behave similarly to inorganic species that are not radionuclides. Therefore, the LEAF leaching test methods may be applicable to estimating radionuclide leaching release provided appropriate modifications are taken to ensure adequate worker protection and materials management and disposal during and after testing. LEAF can be applied to radionuclides for the purposes of evaluating leaching potential; however, LEAF does not address radiological risks associated with radionuclides.

1.2 Who Can Benefit from this Guide?

The intended audience for this guide includes waste generators; decision-makers for waste management, such as beneficial use of non-hazardous industrial secondary materials, waste treatment effectiveness, and site remediation; risk assessors; technical consultants; state environmental agency officials; analytical laboratories; and other interested stakeholders to the degree that their use is consistent with existing federal and state regulations and policies.

1.3 What is LEAF?

Leaching of COPCs from solid materials to surrounding soils, groundwater, or surface water can occur in the environment whenever a material is placed on or in the ground. A leaching assessment provides an estimate of the extent and rate of COPC release to the environment through waterborne pathways. In addition, leaching assessments can provide insights into material durability under environmental conditions based on the dissolution and transport of the primary constituents that comprise the solid matrix. Laboratory leaching tests provide the basis for estimating which constituents will leach, the rate at which they will leach, and the factors that control leaching. In addition, the data obtained from leaching tests can be used to develop a quantitative description of the leaching behavior of a material, referred to as a leaching source term, representing the release of COPCs from a material under defined management scenario conditions.

Leaching Key Terms

Chemical Species—Particular forms of a chemical element or compound (e.g., ions, molecules, molecule fragments, etc.) that contribute to the measured concentration of a constituent in a given liquid or solid phase.

Constituent—A chemical element, species, or compound in the liquid or solid phase, typically chemically analyzed based on total content of chemical species or compound.

Constituents of Potential Concern (COPCs) — Constituents that may be present at concentrations of regulatory, environmental, or human health significance due to their toxicity or other properties.

Source Term— A numerical or model based estimate of constituent release used to represent leaching from material in a field application and which may also be used for subsequent fate and transport modeling.

LEAF is an integrated framework that includes four laboratory methods for characterizing the leaching behavior of solid materials under specified release conditions. It also provides data management tools for collecting leaching data, comparing leaching behavior between materials, reporting graphical and tabular results, and suggesting approaches for using leaching data to support leaching assessments. LEAF provides a consistent approach to estimate leaching of COPCs from a wide range of solid materials including as-generated wastes, treated wastes (e.g., solidified/stabilized soils and sediments), secondary materials (e.g., blast furnace slags), energy residuals (e.g., coal fly ash, air pollution control residues), industrial processing residuals (e.g., mining, and mineral processing wastes) and contaminated soil or sediments. The LEAF test methods consider the effect on leaching of important leaching factors, such as pH, liquid-to-solid ratio (L/S) and physical form of the material, that represent a range of plausible field conditions (U.S. EPA, 2010). Thus, a single set of leaching data can be used to evaluate multiple management options or scenarios.

The LEAF framework provides the flexibility to generate evaluations ranging from screening assessments to detailed source characterization for site-specific or national assessments. Generally, as used in this

document, a screening level assessment means an evaluation based on the laboratory test results using the LEAF methods alone. A detailed source characterization uses the leach test results in a defined use scenario, including anticipated environmental conditions. Evaluating leach test results in the context of a particular scenario provides a more refined and detailed assessment of the likely impact of materials placement on land and COPC release under the conditions defined in the scenario. Therefore, testing can be tailored to address particular assessment objectives and the level of information needed to support decision-making. For some applications, leaching assessments using LEAF may be simple comparisons of leaching results to relevant benchmarks to evaluate performance of a material in a particular management scenario or identify COPCs with the potential for adverse impacts to the environment. In many cases, site-specific factors must be considered, and leaching test results may not directly reflect concentrations at the point of compliance. More complex assessments may require detailed characterization of leaching behavior sufficient to support groundwater (or surface runoff) fate and transport modeling between a source term and a point of compliance (POC), as determined by applicable state and federal regulations and policies. A number of models are available (U.S. EPA, 2015, 2017a) that can evaluate the fate and transport of COPCs in the environment using a source term derived from LEAF.

LEAF incorporates a consistent set of standardized testing methods and either generic or application-specific release models. Free publicly available data management and visualization software, LeachXS™ Lite including Microsoft Excel® templates, is provided to facilitate data management, evaluation, and reporting as part of LEAF assessments.

1.3.1 Why was LEAF Developed?

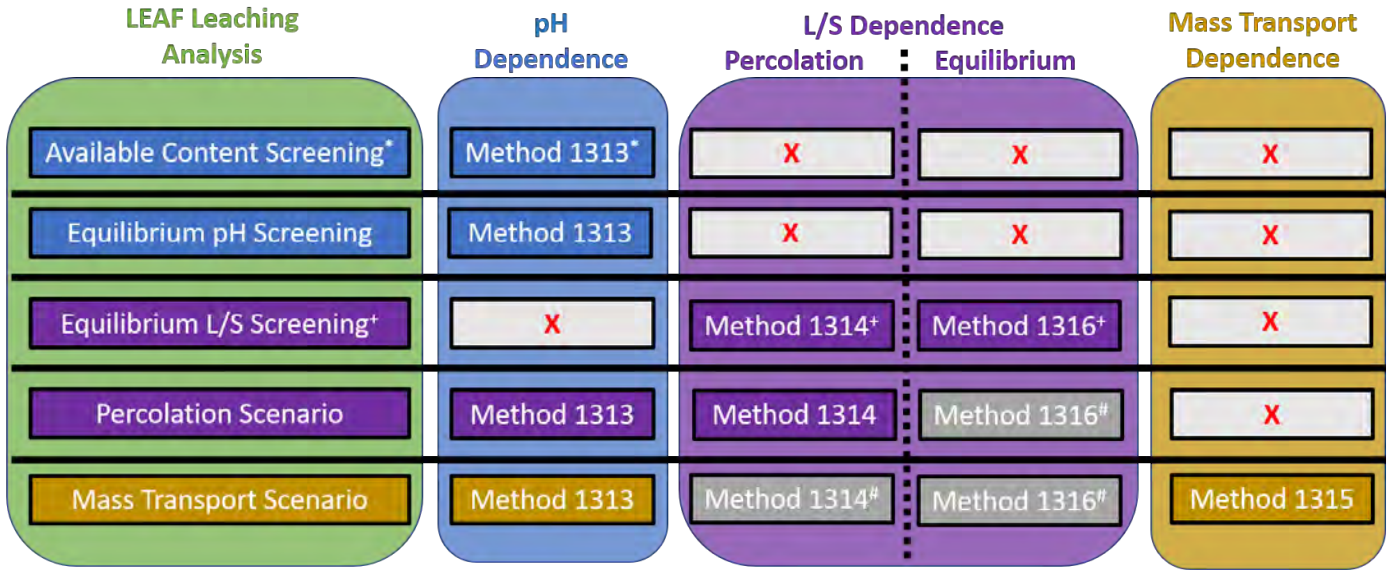
Traditionally, the potential for environmental impact through leaching of COPCs from a solid material disposed or otherwise in contact with the land into ground water or surface water has been estimated using one or more single-point leaching tests that represent a specific scenario or set of environmental conditions. For example, the Toxicity Characteristic Leaching Procedure, TCLP (U.S. EPA, 1992), simulates conditions that may be found within a municipal solid waste landfill while the Synthetic Precipitation Leaching Procedure, SPLP (U.S. EPA, 1994), mimics contact with a synthetic acidic infiltrate (U.S. EPA, 2010). Other single point test methods also simulate specific scenarios, e.g., ASTM D3987-12 (2012). Single-point test approaches can be appropriate for screening or classification purposes and TCLP remains required for specific regulatory applications such as hazardous waste classification under the toxicity characteristic regulation (40 CFR 261.24) and for many waste treatment regulatory standards. However, the U.S. EPA desired a flexible leaching characterization framework that can be tailored for use over a wide range of material types and release scenarios. Broad application of a uniform leaching characterization approach would enable comparison of leaching behavior between materials or between release scenarios.

Another approach that is sometimes used to assess constituent release in the environment involves defining liquid-solid partitioning as constants (K_d values) and modeling the movement of constituents through groundwater with constant partitioning values to soils and other media. This approach assumes that partitioning of COPCs from a solid material is proportional to the total COPC concentration (i.e., a linear partitioning relationship between the total content of the COPC in the material and contacting water). The K_d approach considers adsorption to mineral surfaces as a primary partitioning mechanism and may be a reasonable description for leaching or groundwater fate and transport of COPCs under dilute conditions. However, the partitioning of many constituents between a solid material and a contacting

liquid is not linear over varying values of pH or L/S and, therefore, has many of the same drawbacks as single point leach tests. Similar to single point leach tests, a linear partitioning coefficient does not provide the mechanistic understanding nor represent the important processes and factors that control leaching (e.g., solubility constraints, available content, or the physical form of the material). Thus, the K_d approach would not be a reasonable description of leaching when COPC solubility limits leaching, when only a fraction of the COPC is leachable, or when the available content limits the observed solution concentration (Thorneloe, Kosson, Sanchez, Garrabrants, & Helms, 2010; U.S. EPA, 2014c).

In 1991 and 1999, the Science Advisory Board (SAB) of the U.S. EPA reviewed the Agency's leaching evaluation methodology (U.S. EPA, 1991, 1999) and recommended that EPA develop new, flexible evaluation approaches that consider how environmental parameters may affect the release of COPCs. The SAB also expressed concern about the over-broad use of the TCLP protocol to assess leaching for scenarios in which the test conditions were very different from the actual or plausible conditions or in cases where there was no regulatory requirement to use the test. In addition, the SAB also identified a number of technical concerns about the design and use of the TCLP (U.S. EPA, 1991).

While not answering all of these SAB concerns, LEAF was developed to provide an approach that addressed what EPA considered the most critical issues raised. Each method directly addresses one of three release-controlling factors for inorganic COPCs that may vary under plausible use or disposal conditions: pH, the L/S of the test material relative to the leaching environment, and whether leaching is controlled by chemical equilibrium or by mass transport rates (e.g., diffusion). By testing over a range of values for these release-controlling factors, the LEAF approach allows for flexibility in that a single data set can be used to evaluate multiple potential management scenarios for a material (e.g., disposal or beneficial use) under different environmental conditions. The LEAF leaching tests include batch equilibrium tests, percolation column tests and semi-dynamic leaching tests intended to characterize the leaching behavior of a solid material under equilibrium or dynamic conditions. The results from these tests may be interpreted individually or integrated to identify a solid material's characteristic leaching behavior. Figure 1-1 illustrates the chemical factors influencing leaching estimated by LEAF testing and the combination of tests utilized by the screening or scenario leaching assessments presented in this document.



* Method 1313 only requires pH endpoint 2, 9, and 13 for Available Content Screening
+ Equilibrium L/S Screening can use either Method 1314 or Method 1316
# Optional method for leaching analysis

Figure 1-1. LEAF test methods in leaching evaluations and the chemical factors influencing leaching estimated by each test method. Leaching analyses presented in this guide(left column) utilize the test methods in the boxes to the right of the analysis. Methods in grey are optional depending on the specifics of a scenario. A red X indicates the leaching analysis does not use test for the environmental parameter.

1.3.2 Why Perform Leaching Tests?

Leaching tests are used to measure the amount of constituent mass that is released from a solid material into a set volume of water under specified laboratory conditions. The data collected from leaching tests is not directly representative of field leachates but is used to estimate how a material will leach when managed in the field. Laboratory testing results can be combined with knowledge of how a material is managed (or potentially mismanaged) to develop a description of how the COPCs will leach from material in a defined scenario, often referred to as a source term. The source term can be used to evaluate the potential for adverse impacts from placement of the material into or onto the land and forms the basis for a determination of the appropriateness of the material in the proposed management scenario. Further, the movement of leached COPCs away from the leaching source may be simulated using source terms in conjunction within several available groundwater fate and transport models.

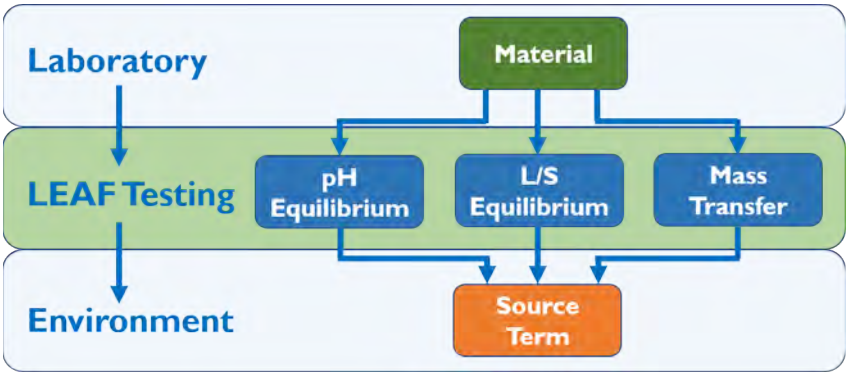


Figure 1-2. LEAF testing can estimate leaching from a material with varying environmental factors. A source term to represent leaching in the environment can be developed from LEAF testing.

1.3.3 When Can LEAF be Used?

The LEAF tests and approach is voluntary and not a requirement under the Resource Conservation and Recovery Act (RCRA). This guidance provides a general approach that needs to be tailoring to the specific application or regulation under which it is being used. For example, under RCRA, the TCLP test (EPA Method 1311) is used for classification of many wastes as hazardous (Subtitle C) or non-hazardous (Subtitle D) as part of the Toxicity Characteristic regulation (40 CFR 261.24). In addition, many RCRA land disposal restriction (LDR) treatment standards are based on the results from TCLP testing (40 CFR 268.40). LEAF is not a regulatory test but may be useful in support of evaluations not designed to meet requirements under the RCRA regulations. The use of LEAF on a site-specific basis needs to be tailored to the questions being asked. The usefulness of LEAF testing will depend on how well test results estimate environmental conditions for a specific application. Using data from ten case studies, comparisons have been made between LEAF testing and field leaching behavior over a range of materials and conditions (U.S. EPA, 2014c). Good agreement was found between field and laboratory results except for situations where redox or carbonation occurred. In these situations, geochemical speciation modeling was conducted in conjunction with the LEAF results, showing good agreement to what was found in field leaching behavior. (Garrabrants, Kirkland, Kosson, & van der Sloot, 2009; U.S. EPA, 2003, 2012b, 2014a, 2014b).

LEAF may also find application in support of cleanup decisions under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) that address specific contaminants on a site-specific basis. The performance values against which LEAF would be evaluated may differ depending on the specific regulatory program involved. For example, site-specific data is used to determine whether action is warranted at a site. Furthermore, under CERCLA as stated in the National Oil and Hazardous Substances Pollution Contingency Plan, "levels generally should be attained throughout the contaminated plume, or at and beyond the waste management area when waste is left in place" (55 FR 8753, March 8, 1990). Decision-makers should consult with the appropriate regulatory agency to ensure compliance when using LEAF testing in support of an evaluation.

Under CERCLA, cleanup decisions depend on site-specific factors. General guidance on use of LEAF data that would be applicable to all sites is impractical and beyond the scope of the How-to Guide. As such, EPA expects to provide additional guidance on the use of LEAF for CERCLA response actions as experience with LEAF evolves.

1.4 What Topics Are Covered in this Guide?

This document includes a range of topics, from background information on leaching to selecting a leaching test method and interpreting results. Some users of this guide may benefit from reading this material in a front to back manner while others may be better served by reviewing a selected section. The How-To Guide is modular in design but also builds upon previous sections. Specifically, the reader can learn about the following topics in each section.

Table 1-1. Overview of Topics in the How-To Guide

Section	Topics
Section 1: An Introduction to LEAF and this Guide	• The purpose of the How-To Guide • Who can benefit from the How-To Guide • Why LEAF was developed • The purpose of leaching tests
Section 2: Understanding the Leaching Process	• The definition of leaching • The definition of a source term • The definition of available content • An overview of fundamental leaching behavior including equilibrium control, mass transport control, and factors affecting leaching in the field
Section 3: An Overview of LEAF	• A description of analytical test methods and expected results for Methods 1313, 1314, 1315, and 1316 • The interlaboratory validation of LEAF methods • The field validation of LEAF methods • The suggested best practices for an analytical testing program • Best practices for quality assurance and quality control • Testing and analytical cost estimates for LEAF tests • Processing time estimates for LEAF tests

Table 1-1. Overview of Topics in the How-To Guide

Section	Topics
	• Laboratory data management discussion and tools
Section 4: Developing Leaching Evaluations using LEAF	• Some potential applications of LEAF • A general approach to developing an assessment framework • Assessment ratios and comparing test results to benchmark values • Developing a screening assessment • Developing a scenario assessment • Overview of environmental processes that can influence leaching • Determining available content • Interpolating data • Calculating water contact time • Identifying solubility and available content-limited leaching • Mass transport effects on leaching • Dilution and Attenuation in an Assessment Ratio • Using source terms from LEAF in environmental modeling
Section 5: Case Studies of Using LEAF for Assessments	• Screening Assessment Case Study: Evaluating Coal Combustion Fly Ash for Use as Structural Fill Material • Scenario Assessment Case Study: Evaluating Treatment Effectiveness of a Cement-Based Stabilization/Solidification (SS) Process
Section 6: Test Your Knowledge	• Exercises reviewing basic concepts using data from the screening assessment case study. • Calculating the available content of a material • Determining a plausible pH range for environmental conditions • Interpolating Method 1313 test results to environmental pH • Solubility versus available content limited leaching behavior
Section 7: Useful Resources	• A collection of related resources
Section 8: References	• References cited in this document

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2. Understanding the Leaching Process

2.1 What is Leaching?

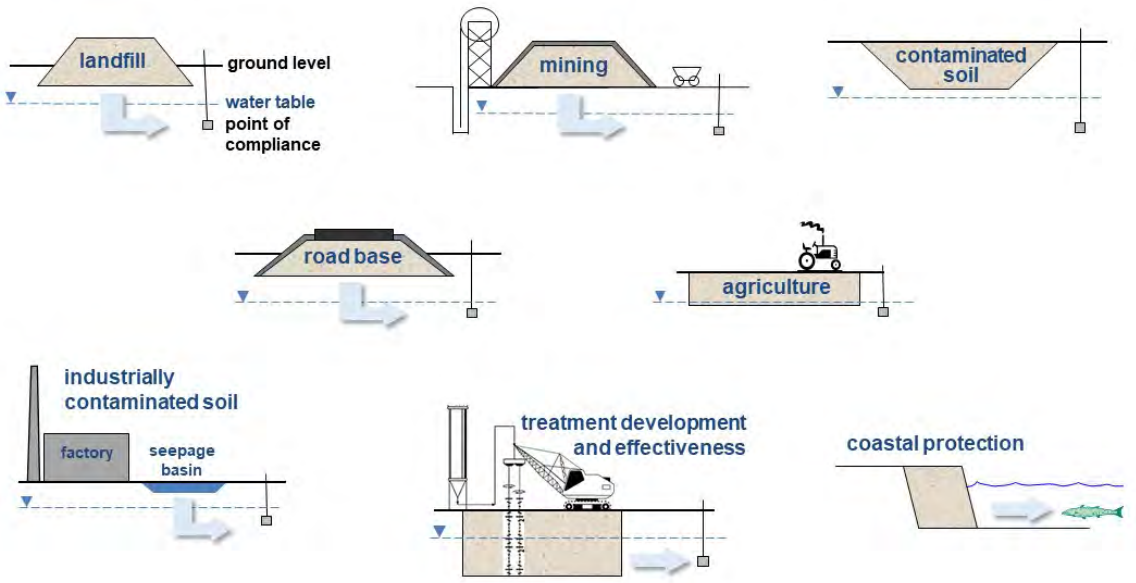
In an environmental context, leaching is the transfer of chemical species or compounds from a solid material into contacting water. In the environment, contacting water may result from infiltration of rainwater through overlying soils or through direct contact of the material with groundwater or surface water. Constituents that leach into the water have the potential to contaminate adjacent soils or disperse into groundwater or surface water bodies. The rate and extent of the release of inorganic constituents from a solid material are controlled by a combination of physical and chemical processes that depend on the properties of the solid material, the environmental exposure conditions or scenario, and the specific COPCs contained in the material.

2.2 What is a Source Term?

In leaching assessments, a leaching source term is a numerical description of constituent release from a material into contacting water under a defined set of environmental conditions. Figure 2-1 illustrates a variety of scenarios for which leaching from a solid material disposed or otherwise in contact with the land can be considered a primary source of environmental impact. In each of these scenarios, COPCs are released from material upon contact with water. This figure shows that these seemingly diverse applications often result in environmental release facilitated by water. For a chosen material, the leaching behavior at the source remains relatively constant based on environmental conditions in each of these scenarios, while the movement to groundwater or transport within groundwater can be significantly different between scenarios. For example, the POC may be considered at the boundary of the material or at some point down gradient of the source depending on applicable regulations.

The LEAF assessment approach provides a numerical estimate of COPC release (i.e., a source term) based on measured leaching data in the context of environmental conditions that a material might encounter in a chosen application. Leaching assessments typically include a description of the material in the field scenario, material geometry and placement relative to the groundwater, and ranges or changes to material properties or leaching conditions over time. While screening-level evaluation may utilize assumed or default values, detailed information will provide a more precise, and in some cases, more realistic estimate of release.

The selection of leaching test data to be used as a source term depends on the assessment objectives and the required level of detail, considering bounding cases and scenario uncertainties. Raw leaching test results may be used directly to formulate a generic source term that can be directly compared to relevant benchmarks or thresholds when the POC is at the material boundary. In some applications, LEAF test data may be compared between materials before and after treatment to evaluate the efficacy of treatment options (Kosson, van der Sloot, Sanchez, & Garrabrants, 2002). When detailed characterizations are required, the source term developed from LEAF may be used as an input to simple mass transport models, or with more-complex fate and transport models, to develop specific source terms for material- and site-specific applications. In addition, source terms may be developed considering variability as a basis for regional or national decisions (e.g., through Monte Carlo-based source terms used in fate and transport modeling for exposure assessment; U.S. EPA, 2014a, 2014b).



Adapted from van der Sloot, Kosson, and Hjelmar (2003).

Figure 2-1. Various environmental assessment scenarios showing a source term for leaching with transport to the water table and through the groundwater to a point of compliance. Note that the point of compliance may be at the unit boundary of the material for some applications.

2.3 What is the Available Content of a COPC?

All materials and wastes contain a number of chemical constituents, some of which may pose environmental hazards. The fraction of any COPC that is readily released into the environment is considered the "available content" for that COPC. The available content of a COPC is defined as the fraction of the total content that is not bound within decomposition-resistant (i.e., recalcitrant) phases, but that is "available" for release over the domain of leaching conditions. The sum of the recalcitrant and available fractions of a COPC is equal to the total content of the constituent in the material (U.S. EPA, 2014c). For inorganic constituents, available content is rarely the same as the total content because a fraction of the total mass may be tightly bound within the solid matrix and is not released under plausible field conditions. The available content can be determined from leaching tests as the mass release in milligram of constituent per kilogram of material calculated from the maximum leaching concentration tested at specific pH values (see Section 4.4.1). Determination of the available content provides a practical value of the potential release of constituents into the environment that may be used as a bounding estimate concentration for screening under assumed infinite source terms (see Section 4.2.4) or to place limits on the extent of leaching for finite source term approaches (see Section 4.2.5).

2.4 How Does Leaching Occur?

Leaching occurs when constituents within a material in the environment solubilize into contacting water. The leaching process is driven by the principles of mass transport, which defines the movement of constituents from a solid phase to contacting water to minimize gradients, or differences, in chemical activity within a phase or across the interface between phases (Bird, Stewart, & Lightfoot, 2001). In environmental conditions, which often have low ionic strength, gradients in chemical activities can often

be estimated as concentration gradients. Thus, leaching may be considered the result of gradients in constituent concentrations between the pore solution of the solid and the contacting water. As leaching progresses and concentration gradients are minimized, mass transport slows, and the system approaches a state of chemical equilibrium (i.e., concentrations in the liquid phase are constant).

If the leaching process continues until concentration gradients are minimized and mass transport ceases, the scenario is considered to have reached chemical equilibrium. Due to slow dissolution of some minerals and other time-dependent processes, chemical equilibrium may be achieved for some constituents, but not for all constituents, within a defined duration (such as a short assessment interval or the duration of some laboratory tests). When chemical equilibrium is achieved, however, the leaching process can have one of several endpoints with respect to a constituent:

- Available Content Limit: The solid phase becomes depleted of leachable constituent such that the transfer from solid to liquid stops. When this endpoint occurs, the extent of leaching is considered available content-limited because the fraction of the total constituent content that is available for leaching has been released.
- Solubility Limit: The water phase becomes saturated with respect to the constituent and leaching stops although there remains a fraction of constituent in the solid available for leaching. For this case, the extent of leaching is considered solubility-limited because the chemical parameters of the liquid phase that define the solubility of a constituent constrain the amount that can be released [5].

The identification of leaching behavior as solubility-limited or available content-limited plays an important role in the estimation of COPC release for environmental purposes. Leaching behavior is interpreted through evaluation and comparison of equilibrium-based leaching tests results as described in Section 4.4.5. Discussion of relevant adsorption processes associated with sorption-controlled leaching is provided in Section 4.4.4.

In practical terms, the time that it takes a solid-liquid system to reach an equilibrium endpoint depends on (i) the geometric size of the material (i.e., particle size for granular materials or the dimension perpendicular to mass transport for monolithic materials and compacted granular fills), (ii) the L/S (i.e., the amount of liquid relative to the amount of solid), (iii) the chemical characteristics of the COPC, and (iv) the chemical composition of the liquid phase (i.e., pH, oxidation-reduction potential, ionic strength, composition). For example, when the material is granular (i.e., consists of many particles with relatively small dimension) and is contacted by a relatively small amount of water, the leaching process reaches an apparent endpoint within the practical time of bench-scale leaching tests. For these systems, the extent of leaching (i.e. the COPC mass released) is the practical measure of COPC release because the system is likely to achieve equilibrium quickly in the environment. The liquid-solid partitioning (LSP) of COPCs

[5] While not constrained by the available content or aqueous solubility, a constituent may be distributed between the solid and water phase by adsorption to mineral or other phases under environmental conditions. Leaching at this endpoint is considered sorption-controlled because interfacial adsorption/desorption chemistry dictates the concentration of the constituent in the liquid phase. In basic leaching evaluations, sorption controlled processes are often not easily distinguishable from solubility-limited leaching and are thus treated similarly in this guide. LEAF data that indicate solubility-limited leaching, in fact, may reflect or consider the combined effect of solubility and adsorption as controlling processes. Depending on the surface charge of a granular material, adsorption can result in a constituent concentration in the leachate much lower than expected based on solubility alone. Chemical speciation modeling may be helpful in determining the chemical mechanisms that explain leaching concentrations when this level of information is needed.

between the contacting water and the solid material at equilibrium provides a measure of the extent of leaching with the available content representing the maximum extent of leaching. Conversely, larger particles, such as those within monoliths or compacted granular samples, require a longer time to reach an apparent endpoint to the leaching process. Thus, the rate of leaching becomes the dominant leaching characteristic that predicts the release of COPCs as measured by the rate of mass transport through the material to the interface between the material and the contacting water.

Therefore, over a wide range of environmental conditions, mass transport may be considered to control the rate of leaching while chemical equilibrium controls the extent of leaching. Ideally, comprehensive leaching assessment would address both the rate and the extent of constituent leaching as applicable based on the environmental conditions imposed by the combined influences of material and the management scenario.

2.4.1 The Extent of Leaching Through Liquid-Solid Partitioning (LSP)

LSP is the chemical equilibrium, or near-equilibrium, state that describes the distribution of a constituent between the solid phase and a contacting liquid. For many materials, LSP concentrations are the combined result of the available content, aqueous solubility of the various chemical species of the constituent, adsorption/desorption to (hydr)oxide surfaces and particulate carbon, and chemical reactions in the liquid phase. Thus, the LSP evaluated through leaching tests is intended to obtain one of the leaching process endpoints described above and to approximate chemical equilibrium between the aqueous and solid phases (U.S. EPA, 2010).

Important chemical factors influencing the measured constituent LSP include:

- **Eluant or leachate pH** that controls aqueous solubility of inorganic COPCs, dissolution of organic carbon, and sorption or desorption of COPCs to the surface of oxides, clays, minerals, and organic matter,[6]
- **Liquid-to-solid ratio (L/S)** defined as the volume of liquid in contact with a dry mass of solid,
- **Reduction/oxidation (redox) conditions** that may change the oxidation state of COPCs (e.g., Cr(III) to Cr(IV)) [7] and also the quantity of available surfaces for sorption; e.g. Fe(III) to Fe(II) results in a decrease in sorption to iron (hydr)oxide surfaces,
- **Dissolved organic matter** that can increase the measured concentration of COPCs through formation of soluble complexes with dissolved organic carbon (DOC),
- **Ionic strength and common ion effects** that suppress dissolution of some minerals, and
- **Biological activity** that result in pH changes or redox changes in the solid-liquid system.

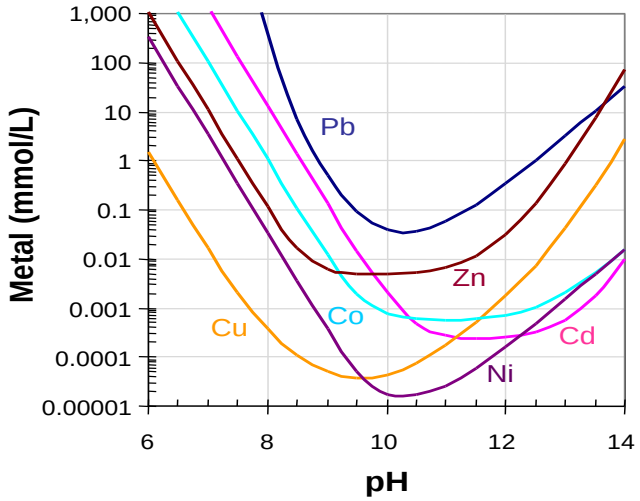
Of these chemical factors, pH and L/S are the two parameters that are most important for the majority of inorganic constituents with regard to constituent leaching and are the two parameters that can be best controlled in the laboratory. Information about the other factors can be collected during testing and used to refine release estimates based on geochemical models when needed, as described in Section 4.4.8.

[6] The pH of the eluate or leachate is the combined effect of the acidity or alkalinity of the contacting solution and the buffering, or acid/base neutralization, capacity of the contacting material.

[7] Since a change in the oxidation state of an ion changes solid and aqueous species it can form, oxidation-reduction conditions also can have an impact on leaching in some cases.

2.4.1.1 pH-dependence

Typically, the aqueous solubility of many inorganic species, including many COPCs, is a strong function of solution pH. Figure 2-2 presents a graph of the solubility of metal hydroxides over the pH range from 6 to 14 which may be applicable for some environmental scenarios (e.g., used of solidification/stabilization with cement as a soil or waste treatment). The figure shows that the solubility of these metals reaches a minimum value at approximately pH 10 but can vary by several orders-of-magnitude with relatively small shifts in pH. The pH-dependent behaviors shown in this figure are for simple, single hydroxide minerals in solution. In comparison, the mineralogy of soil and waste systems is relatively complex with each COPC potentially present in several different mineral species, each with its own solubility behavior. In the field, a number of potential mineral species may affect the solubility. Regardless, this figure is helpful as an illustration of the significant influence that pH can have on the measured LSP of waste and soil systems.



Adapted from Stumm and Morgan (1996).

Figure 2-2. Solubility of metal hydr(oxides) in water as a function of pH.

2.4.1.2 L/S-dependence

The L/S dependence of a constituent allows for estimations of leaching behavior over a range of water contact rates. A constituent may initially leach as a highly soluble species. However, once a significant amount of water has contacted the solution and transported the constituent away, the depleted constituent concentration in the solid material limits further leaching. This transition would be seen in laboratory experiments at increasing L/S. Alternatively, leaching may be initially limited by the constituent solubility and a constituent may leach at a relatively constant rate over longer periods.

Figure 2-3 presents an illustration of how changes in L/S can influence the LSP leaching behavior. In this figure, the five light colored dots represent units of a COPC that are available to leach or have leached while the five dark colored dots represent units of a COPC that are present in recalcitrant minerals and are not available to leach. Therefore, the available content of this constituent is 50% of the total content (i.e., 5 units available out of 10 units). The panels on the left show that, at low L/S (e.g., the L/S associated with the porewater of a material), constituents in the liquid phase reach a saturation point of 0.1 unit/mL (i.e., 2 units leached into 20 mL of water) and the leaching behavior is considered solubility-limited. As the amount of water is doubled from 20 to 40 mL, additional constituent is leached such that the liquid

concentration remains 0.1 unit/mL. Under solubility-limited release, the measured concentration for solubility-limited COPCs usually is a weak function of L/S as long as pH does not change significantly and complexing agents (e.g., DOC) are not present. As the volume of water increases to 60 mL, leaching continues and all of the available constituent mass is leached from the solid material; thus, the concentration in the liquid phase decreases to 0.08 unit/mL (5 units in 60 mL) and leaching has become limited by the available content. At this point, LSP becomes a strong function of L/S because the addition of water to 80 mL reduces the LSP concentration further to 0.06 units/mL because the same available mass of the constituent (5 units) is dissolved into a greater volume of water (80 mL).[8]

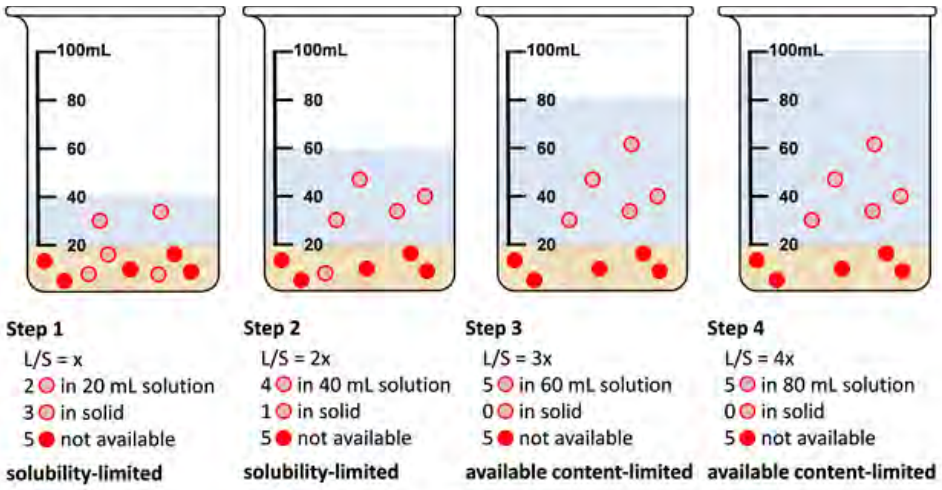


Figure 2-3. Illustration of the changes in LSP leaching behavior as the system L/S increases.

For many field scenarios, the L/S may be derived from the information on the rate of infiltration or groundwater contact and simple physical parameters of the material application. For example, the L/S of a landfill scenario can be determined by measuring the volume of leachate collected annually from the landfill and relative to the estimated volume of waste in the landfill or the landfill design capacity. When scenario-based information about the relative rate of water contact is known, laboratory data at varying L/S may be considered a surrogate for time that allows for the estimation of leaching as a function of time under field conditions or the prediction of the time required until constituents are depleted (see Section 4.4.3 for more on calculating L/S). The L/S may also be adjusted to account for the tendency of contacting water to preferentially flow on or around the material (See Section 4.4.4 for more on interpreting L/S from LEAF testing). In the laboratory, the L/S in a leaching test is varied by changing the relative proportions of test material and the leaching solution (i.e. leachant).

[8] In addition to the effect on L/S illustrated above, concurrent changes in pH, ionic strength and the presence of other dissolved species that can also influence solubility. For example, according to the Davies Equation for calculation of activity coefficients (Stumm & Morgan, 1996) a 0.1 M solution of barium carbonate would result in an ionic strength of 0.4 M and activity coefficients of 0.292, resulting in solution activity substantially lower than measured solution concentration. An example of a common ion effect is the lower observed concentration of barium in field leachate compared to laboratory test results because of lower L/S and presence of higher sulfate concentrations from dissolved calcium sulfate that reduces the solubility of barium sulfate by Le Chatelier's principle (U.S. EPA, 2014c)

2.4.2 The Rate of Leaching (Mass Transport)

Mass transport describes a set of mechanisms (e.g., diffusion, dissolution, adsorption, or complexation) that collectively control the transfer of constituents from areas of higher concentration to areas of lower concentration over time. Within a solid material, constituents move via diffusion from areas of higher concentration to lower concentration and may interact with the minerals and other solid phases comprising the material through various chemical reactions (e.g., dissolution/precipitation, adsorption/desorption). The specific rate of diffusion, or the molecular diffusivity, is the speed at which a constituent travels unhindered by physical or chemical constraints through water, proportional to the magnitude of the concentration gradient (i.e., diffusion is faster when incremental difference in concentrations is greater). The observed rate of diffusion for a constituent moving through a porous material, however, is slowed by the distance that the constituent has to travel, the effective porosity of the material, the connectivity and tortuosity of the porous network, and chemical reactions that occur along the diffusion pathway. Often, local chemical equilibrium between the solid material and porewater is assumed during mass transport, such that all of the chemical parameters that influence LSP also effect the rate of mass transport.

2.4.3 Leachability of a Material in the Field

The rate and extent that constituents can leach from a material are determined by a number of chemical and physical factors that can vary between sites and are not likely to remain constant in the field because the environmental media, including local conditions and the solid materials, change over time. Slight changes in key factors can have substantial effects on the magnitude of releases by changing either the rate at which a constituent can be released or the equilibrium water concentration. Some examples of key factors include:

- Changes to the L/S from increased precipitation that results in a shift between solubility-limited and available content-limited leaching behavior;
- Changes to the pH that alter the solubility of a constituent in the water (e.g., from acid precipitation, uptake of atmospheric carbon dioxide, oxidation of reduced minerals or biological activity);
- Changes to the redox conditions (e.g., reduction from biological activity that alter the oxidation state of a constituent [e.g., Cr(III) to Cr(IV)] or oxidation through contact with air);
- Changes to the physical structure of the material (e.g., degradation from internal stress through freeze/thaw cycles or mechanical erosion that increase the ratio of surface area/volume);
- The tendency for contacting water to preferentially flow over or around material;
- Introduction of DOC from organic material decay; and,
- Changes to the chemical composition of the material (e.g., from co-disposal with other materials).
- Changes to a material from weathering or self-cementation.

3. An Overview of LEAF

LEAF is an integrated framework that uses the results from up to four different laboratory tests to characterize the leaching behavior of solid materials. Coordinated development of LEAF has occurred between research laboratories in the U.S. and the European Union to develop and harmonize test methods to support data comparisons. Test methods analogous to LEAF test methods are available in the EU with minor differences intended to address the different testing standards (e.g., quality control requirements, method description requirements, etc., See Appendix A). The four test methods, U.S. EPA Methods 1313, 1314, 1315 and 1316, are designed to account for the effects of major factors known to affect leaching behavior of inorganic constituents for most wastes and management scenarios (Kosson et al., 2002). Because the test methods take into consideration a range of material properties and potential environmental conditions, the resulting data can provide estimates of constituent leaching behavior that reflect plausible field conditions and considers the impact of a wide range of material management scenarios (U.S. EPA, 2014c). The overarching framework provides direction on how to interpret and apply the data collected based on the complexity and specificity of the evaluation, ranging from a simple and generalized screening analysis to a complex and site or scenario-specific probabilistic analysis. This section provides general descriptions of the components of LEAF.

3.1 Analytical Leach Test Methods

For characterization of inorganic constituents, LEAF includes four distinct leaching test methods. These test methods directly address one of three most important factors affecting leaching of inorganics: the final leachate pH, the amount of water in contact with the material, and the physical form (i.e., granular vs. monolithic) of the material (U.S. EPA, 2014c). The test methods also measure important parameters of the liquid such as pH, electrical conductivity (EC) and DOC under the final leaching conditions. Together, these methods provide information on the available content, peak leaching concentration, time-dependent release (Kosson et al., 2002; U.S. EPA, 2010). These methods can be applied individually or in combination, based on information needed to characterize the leaching behavior of the material of interest.

LEAF Leaching Tests

Method 1313: Liquid-Solid Partitioning as a Function of Extract pH using a Parallel Batch Extraction Procedure (U.S. EPA, 2012f)

Method 1314: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio for Constituents in Solid Materials using an Up-flow Percolation Column Procedure (U.S. EPA, 2013a)

Method 1315: Mass Transfer Rates of Constituents in Monolithic and Compacted Granular Materials using a Semi-Dynamic Tank Leaching Procedure (U.S. EPA, 2013b)

Method 1316: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio using a Parallel Batch Extraction Procedure (U.S. EPA, 2013c)

The LEAF tests are conducted under a specified set of conditions, which provides a standardized basis for comparison among different samples, materials, leaching tests, and management scenarios. The data can be used to evaluate a range of environmental conditions that a given material may be exposed to in the field (U.S. EPA, 2014c). Even when a particular value of interest has not been explicitly measured (e.g., leaching at a particular pH or L/S value), it is possible to interpolate between measured concentrations to more accurately reflect anticipated field conditions. Each of the four test methods have undergone interlaboratory and field validation for inorganic COPCs (U.S. EPA, 2012c, 2012d, 2014c). A summary of the parameters for each method is presented in Table 3-1 with a description in the following subsections.

A full detailed description of the validated methods can be found on the SW-846 website under validated methods (U.S. EPA, 2017b).

Table 3-1. Comparison of Test Parameters for LEAF Leaching Methods

Test Variable	Method 1313	Method 1314	Method 1315	Method 1316
Test Type	Equilibrium; pH-dependent	Equilibrium; percolation	Mass transfer	Equilibrium; L/S-dependent
Test Description	Parallel batch extractions	Column test in up-flow mode	Tank test with periodic eluant renewal	Parallel batch extractions
Sample Type and Dimension	Granular particle size of 85% by mass less than 0.3, 2.0 or 5.0 mm	Granular particle size of 85% by mass less than 2 mm with 100% less than 5 mm	*Monolith:* cylinder or cube; 40-mm minimum dimension *Compacted granular:* cylinder with 40 mm minimum height	Granular particle size of 85% by mass less than 0.3, 2.0 or 5.0 mm
Test, Extraction or Interval Duration	Extractions for 24, 48 or 72 hours based on maximum particle size	Continuous elution to L/S 10 mL/g-dry Estimated test time of 13 days based on constant flowrate of 0.75 L/S per day	Intervals of 2, 23, 23 hours, 5, 7, 14, 14, 7 and 14 days Cumulative leaching time of 63 days	Extractions for 24, 48 or 72 hours based on maximum particle size
Eluant Composition	Reagent water with additions of HNO_3 or NaOH	Reagent water or 1 mM $CaCl_2$	Reagent water	Reagent water
pH Range	2 to 13 at specified targets	As controlled by material being tested	As controlled by material being tested	As controlled by material being tested
Amount of Solid	Minimum 20 g-dry per extract; Approx. 400 g-dry each for pre-test and test replicate (collect 1 kg for first test; 500 g for each replicate)	Minimum 300 g; 600–700 g per column (collect 1 kg per test run)	*Monolith:* as specified *Compacted granular:* 500–750 g per test run + 5 pre-test samples (collect 4 kg for first test, 1 kg for each replicate)	Minimum 20 g-dry per extract; 20 to 400 g-dry each extract (collect 1 kg per test run)
Eluant Volume	L/S of 10 mL/g-dry	Eluates collected through cumulative L/S 10 mL/g-dry	Liquid-surface area ratio of 9 mL/cm^2	L/S of 10, 5.0, 2.0, 1.0, and 0.5 mL/g-dry
Number of Analytical Solutions per Test	9 extractions (10 if natural pH is outside target range)	9 eluate fractions	9 interval solutions	5 extractions

3.1.1 U.S. EPA Method 1313: pH-Dependent LSP

Method 1313 is designed to evaluate the partitioning of constituents between liquid and solid phases at near equilibrium conditions over a wide range of pH values. The method consists of 9 to 10 parallel batch extractions of a solid material (Figure 3-1) at various endpoint target pH values and at an L/S of 10 mL/g-dry. The pH of each extraction is controlled by additions of a known volume of dilute acid or base, derived from prior knowledge of the acid neutralization capacity (ANC) of the material or from determination of the ANC based on a pre-test titration step. Parallel extractions provide aqueous extracts at up to nine target pH values between pH 2 and 13, plus the natural pH of the material (i.e., when leached with DI water, and no acid or base is added). To achieve equilibrium conditions faster and reduce testing time, particle size reduction of the sample material may be required (U.S. EPA, 2010). The measured constituent concentrations and acid/base neutralization capacity can be plotted as a function of leachate pH. The measured values can be plotted and graphically compared to relevant benchmarks to facilitate the presentation and interpretation of the data. Given that leachate concentrations can vary by multiple orders of magnitude over the full pH range, it is recommended that the graph be log transformed for ease of presentation.

Total Content—The concentration [mg/kg-dry] of a constituent in the solid material on a total dry mass basis.

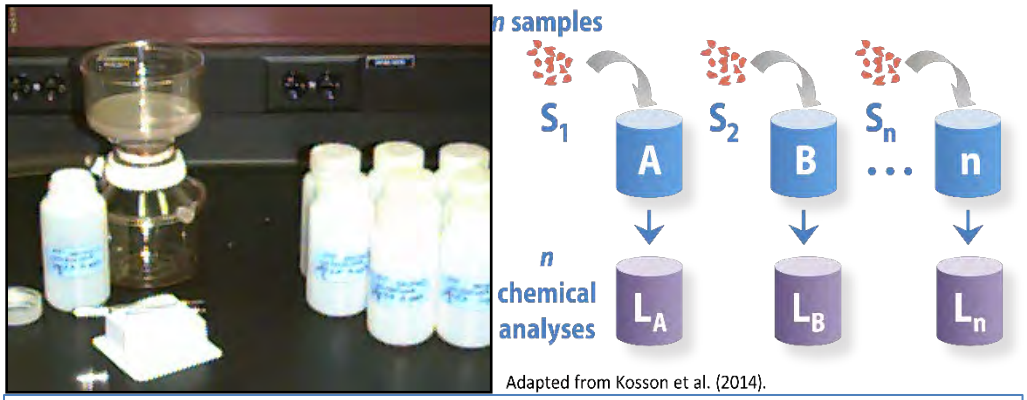
Available Content—The concentration [mg/kg-dry] of a constituent in a solid material on a total dry mass basis that potentially may leach over a reasonably near-term timeframe (e.g., 100 years). The available content is a fraction of the total content and, thus, less than or equal to the total content value.

Eluant—Water or aqueous solution used to contact or extract constituents from a material during a laboratory test.

Eluate—The aqueous solution, analyzed as part of a laboratory leaching test, that results from contact of an eluant with tested material.

Leachant—Water or aqueous solution contacting a material under field conditions (e.g., infiltrating water, groundwater).

Leachate—An aqueous solution resulting from leachant contact with a material under field conditions.



Method 1313 consists of 9-10 parallel batch extractions (*A* through *n*) of subsamples of a particulate solid (*S*) in deionized water with various additions of acid or base intended to result in specified endpoint target pH values, approximating LSP as a function of pH.

Figure 3-1. Experimental scheme of U.S. EPA Method 1313 as a parallel batch extraction test.

Figure 3-2 presents an example of pH-dependent results from Method 1313 for the acid-base titration curve of a coal combustion fly ash (EaFA) and the LSP curve for chromium presented as eluate concentration and mass release (Kosson, Garrabrants, DeLapp, & van der Sloot, 2014). For batch extractions, mass release [mg/kg-dry] is calculated by multiplying eluate concentrations [mg/L] by the eluate-specific L/S [L/kg-dry]. Typically, eluate concentrations are plotted as a function of pH along with the method detection limit (MDL) and lower limit of quantitation (LLOQ). In Figure 3-2, the data corresponding to the natural pH extraction (i.e., the extraction where the material dictates the eluate pH) is indicated by a large circle about the data point.

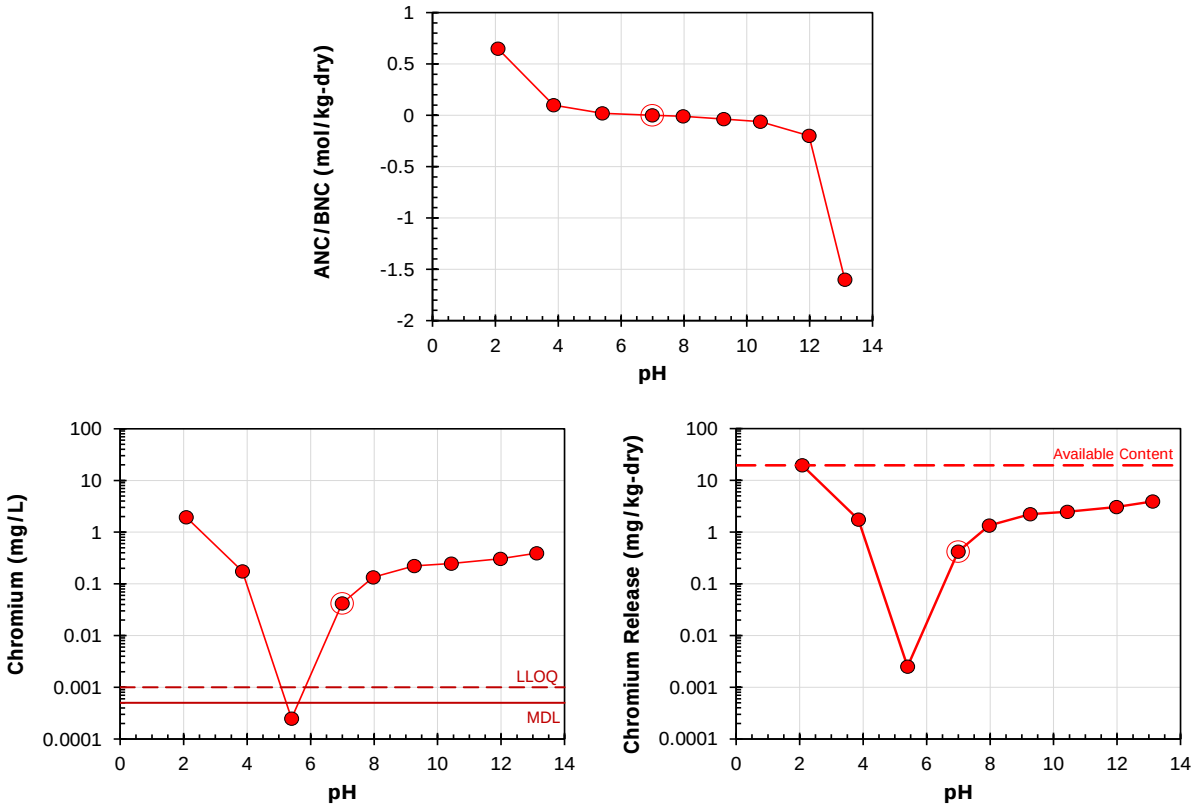


Figure 3-2. Example results from Method 1313 for leaching from a coal combustion fly ash (EaFA): Titration curve (top), chromium eluate concentration (lower, left) and chromium release with available content displayed (lower, right).

Many of the chemical processes that control liquid-solid partitioning are pH-dependent (e.g., solubility, mineral precipitation, adsorption reactions). Method 1313 provides an equilibrium partitioning curve as a function of pH that can be used to identify where leaching behavior is sensitive to changes in pH (i.e., where solubility may change significantly with a small change in pH). The method can also be used to estimate the leachable fraction, or available content, of constituents based on the maximum eluate concentration over the pH range (U.S. EPA, 2014c). LSP and available content information can be used as input into chemical speciation models to help understand the effects of physical and chemical factors that are difficult to control for in laboratory tests (e.g., material interactions, reducing conditions, reactions with atmospheric gases). Table 3-2 provides a summary of the potential applications of Method 1313 data.

Table 3-2. Potential Applications of Method 1313 Data

Data Collected	Potential Uses
Acid/base titration curve	• Impact on eluate pH from external sources of acidity or alkalinity (e.g., from mixing with other materials or from external sources such as acidic precipitation or ingress of carbon dioxide)
Equilibrium constituent concentrations at pH 2, 9, and 13	• Available content (i.e., the fraction of total content available for leaching based on maximum release at these 3 endpoint target pH values)
Equilibrium constituent concentrations at natural pH and at pH points within and bracketing scenario pH domain	• Determination of maximum potential leachate concentrations over scenario pH domain • Indication of solubility-limited or available content-limited leaching
Full suite of constituent concentrations for all test pH points	• Insights into chemistry controlling leaching • Comparison of characteristic constituent equilibrium partitioning as a function of pH between materials • Input for geochemical speciation modeling

3.1.2 U.S. EPA Method 1314: Percolation Column

Method 1314 is a percolation column test designed to evaluate constituent releases from solid materials as a function of cumulative L/S. The experimental scheme of Method 1314 is shown in Figure 3-3. The method consists of a column packed with granular material with moderate compaction to preserve the original porosity of the material. Particle size reduction of the sample material may be required to facilitate testing. Eluant is introduced through pumping of deionized water up through the column to minimize air entrainment and

Water Contact Key Terms

Percolation—The water contact scenario when precipitation, infiltrating water or groundwater, moves through the contiguous voids of a porous material and leaching occurs at the solid-liquid interface between the percolating fluid and the solid material.

Washout—A rapid release of constituents resulting from highly soluble species rapidly dissolving in water percolating through a material. Washout is usually indicated during Method 1314 by a decrease in leaching concentration of approximately one order of magnitude or more as the liquid to solid ratio increases from L/S = 0.2 mL/g-dry to 2.0 mL/g-dry.

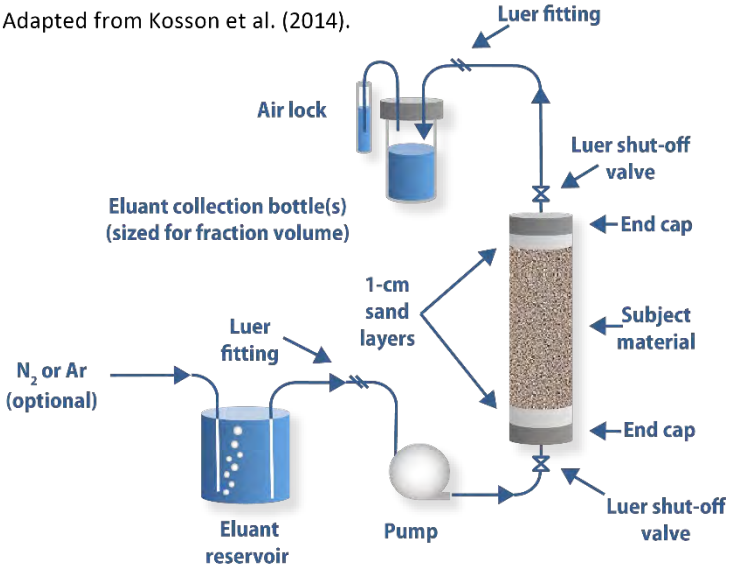
Flow-around—The water contact scenario when precipitation, infiltrating water, or groundwater flows around the external surface area of a low-permeability material (e.g., cement-treated wastes, compacted material) and release occurs at the interface between the flowing water and the material.

Mass transport/diffusion-limited leaching—The release from solid material when leaching is less than equilibrium liquid-solid partitioning, typically constrained by the rate of diffusion through the material being leached.

preferential flow.[9,10] The eluant flowrate is slow so that the resulting eluant concentrations approximate liquid-solid equilibrium within the column. Samples of column eluate are collected over nine specified cumulative L/S intervals. The eluate pH and specific conductance are measured. The eluate is filtered by pressure or vacuum in preparation for constituent analysis. Analytical aliquots of the extracts are collected and preserved accordingly based on the determinative methods to be performed (U.S. EPA, 2012c).



Adapted from Kosson et al. (2014).



Up-flow percolation column to collect eluates at specified L/S values, estimating liquid-solid partitioning at percolation release conditions that approximate chemical equilibrium.

Figure 3-3. Experimental scheme of U.S. EPA Method 1314 as a percolation column test.

Measured constituent concentrations can be plotted as a function of the cumulative L/S, either as measured [mg/L] or multiplied by the incremental L/S for that sample and summed into a cumulative mass release [mg/kg-dry]. Eluate concentration and cumulative mass release can be graphed as a function of cumulative L/S. The measured pH can be plotted against the L/S to determine if early washout of soluble ions has a substantial impact on leachate pH. Figure 3-4 provides example results from Method 1314 for a contaminated smelter site soil (CFS).

Data from Method 1314 provide an estimate of pore water concentrations at low L/S (e.g., L/S of 0.2 or 0.5 mL/g-dry) and illustrate how leaching behavior changes as the cumulative L/S ratio increases. As water percolates through the material, highly soluble salts such as sodium or potassium salts, DOC, and oxyanions may be washed out, typically with a tenfold reduction in leaching concentration by cumulative L/S of 2 mL/g-dry.

[9] Calcium chloride solution (1 mM) may be used instead of deionized water in cases where colloid formation is a concern to prevent deflocculation of clays and organic matter.

[10] The test method uses upflow through the column to minimize flow channeling. However, testing has demonstrated that use of upflow testing does not have significant impact of the results relative to field behavior (U.S. EPA, 2014c, Lopez et al, 2008)

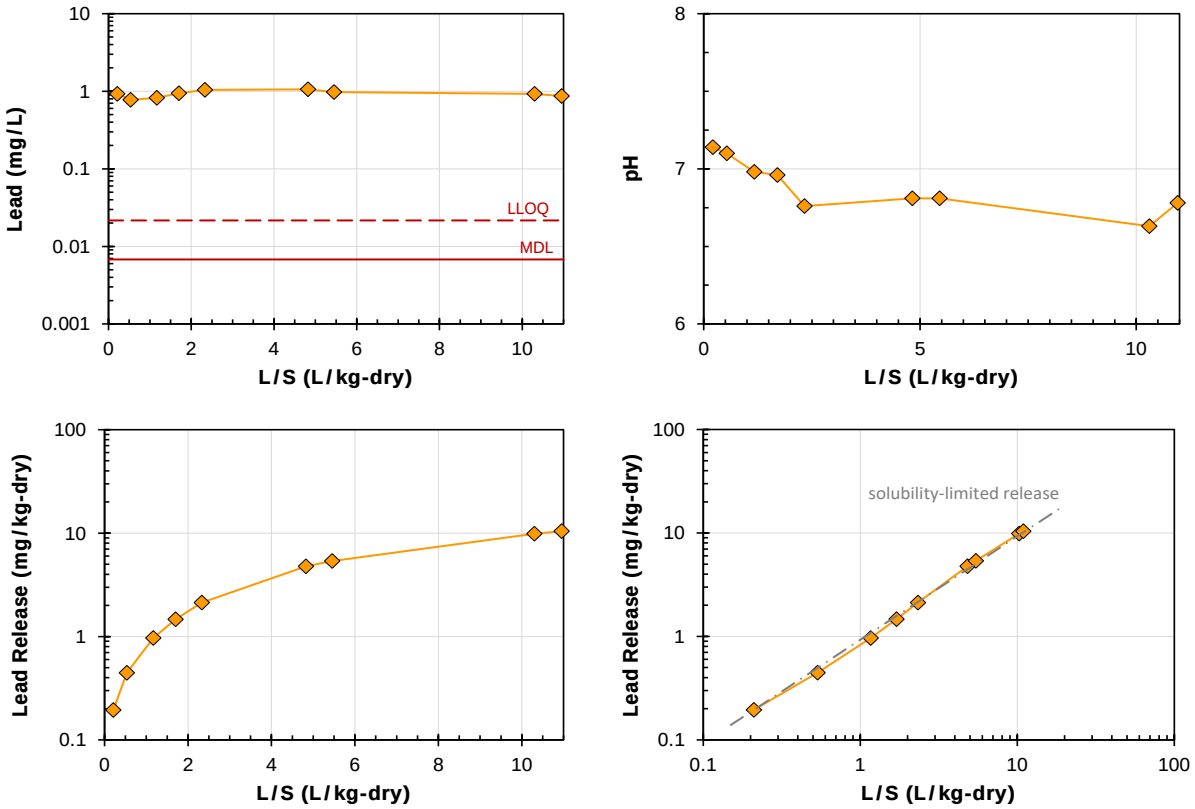


Figure 3-4. Example results from Method 1314 for lead as a function of L/S from a contaminated smelter site soil (CFS): Concentration (top, left), eluate pH (top, right) and cumulative release on Cartesian axis (lower, left) and logarithmic axis (lower, right).

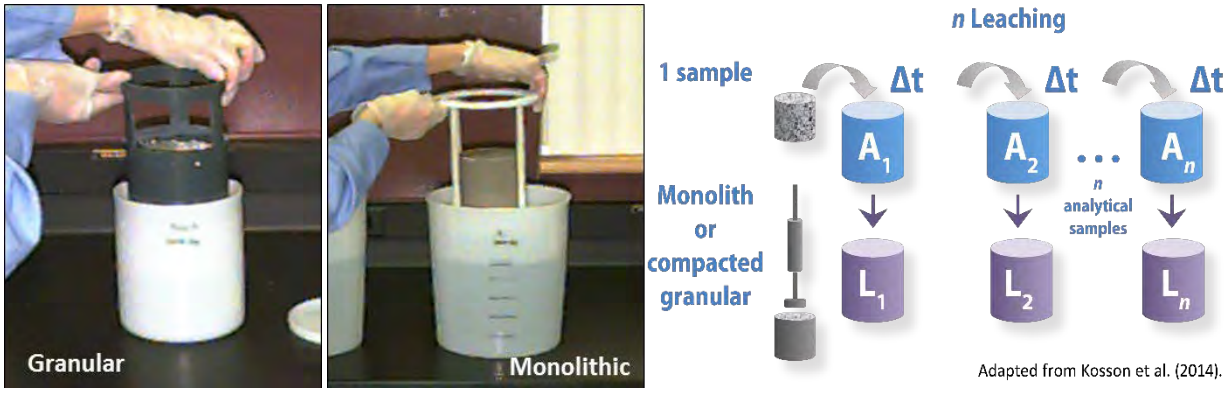
As infiltrating water percolates through a material, changes in the porewater chemistry can alter the dissolution of the more stable mineral phases, subsequent pore solutions and leaching of constituents. The data on concentrations as a function of cumulative L/S from this laboratory test can be used together with field infiltration rates to estimate leaching as a function of time. Table 3-3 presents a summary of the potential applications of Method 1314 data.

Table 3-3. Potential Applications of Method 1314 Data

Data Collected	Potential Uses
Constituent concentrations as a function of incremental and cumulative L/S	• Initial (i.e., porewater) and maximum leaching concentrations • Percolation leaching source term • Co-elution effects of COPC release (e.g., increased leaching of As after depletion of Ca; Ba and SO_4)
Eluate pH and conductivity as a function of incremental and cumulative L/S	• Estimate of porewater pH (at low L/S), ionic strength • pH relates Method 1314 results and Method 1313 results when plotted as a function of pH

3.1.3 U.S. EPA Method 1315: Rates of Mass Transfer

Method 1315 is a semi-dynamic tank leaching procedure used to determine the rate of mass transport from either monolithic materials (e.g., concrete materials, bricks, tiles) or compacted granular materials (e.g., soils, sediments, fly ash) as a function of time using deionized water as the leaching solution. The method consists of leaching of a test sample in a bath with periodic renewal of the leaching solution at specified cumulative leaching times (Figure 3-5). The volume of leachant used in the test is related to the surface area exposed to the liquid through a liquid-to-surface area ratio (L/A).



Sequential extraction of a monolith or compacted granular specimen to determine the maximum rate of release by diffusion and dissolution processes.

Figure 3-5. Experimental scheme of U.S. EPA Method 1315 as a tank leaching test.

Monolithic samples may be cylindrical or rectangular, while granular materials are compacted into cylindrical molds to a density that approximates the peak field density on a dry basis. At nine specified time-intervals, samples are transferred to fresh reagent water and the eluate from the previous interval is analyzed for eluate properties (e.g., pH, EC) and constituent concentrations. Measured constituent concentrations in mg/L are be plotted as a function of cumulative time and along with an analogous plot of eluate pH as a function of cumulative leaching time. Eluate concentrations are presented relative to MDLs and LLOQs to indicate quantitation of measured concentrations. The interval mass flux [mg/m^2-s], or the rate of mass released over an interval, is calculated by multiplying the eluate concentration [mg/L] by the ratio of the volume of leachate to the surface area of the sample [L/m^2] and dividing by the interval-specific time in seconds [s]. Similarly, the cumulative mass release [mg/m^2] is calculated by multiplying the interval mass flux by the interval specific time and summing across all previous leaching intervals. Both interval flux and cumulative mass release are plotted as a function of cumulative leaching time. Figure 3-6 presents example results from Method 1315 for a solidified waste form (U.S. EPA, 2012c, 2012d).

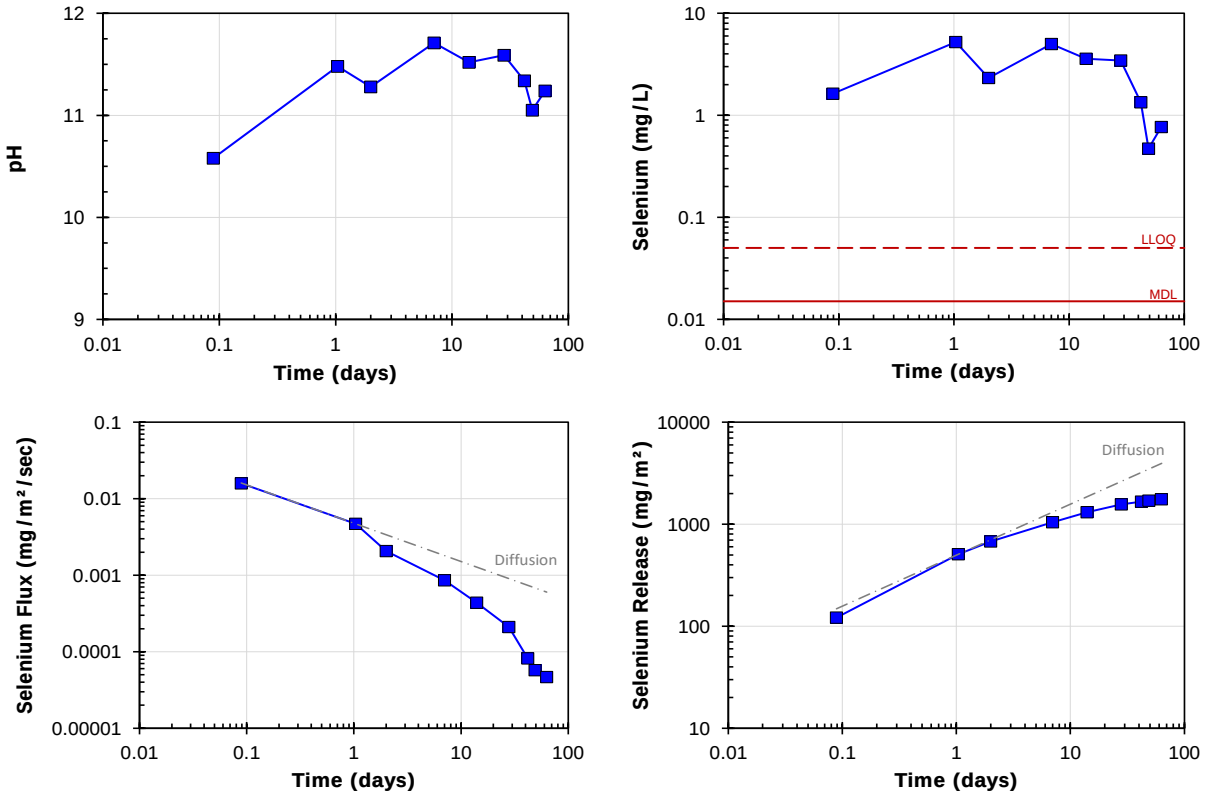


Figure 3-6. Example results from Method 1315 for selenium shown as a function of leaching time from a solidified waste form (SWA): Eluate pH (upper, left), eluate concentration (upper, right), mean interval flux (lower, left) and cumulative release (lower, right).

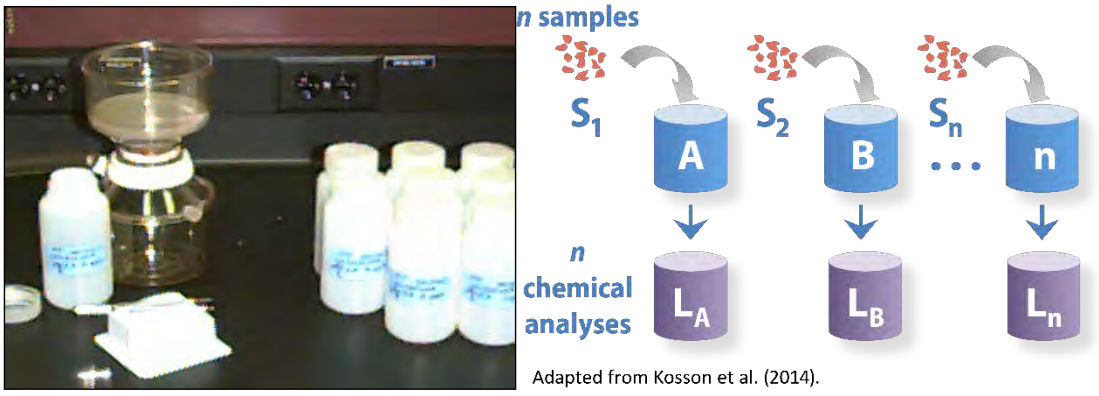
Data from Method 1315 indicate the rate of mass transport from the interior of the material to its external surface (i.e., the interface of the material with the surrounding environment). By maintaining a dilute eluate solution based on eluant refresh intervals, the boundary conditions for leaching result in a maximum release rate by diffusion for monolithic and compacted granular materials (U.S. EPA, 2010). Method 1315 is applicable for cases where water primarily flows around the material, rather than percolating through it. In the field, however, actual liquid to surface area ratios are often much less than the test conditions and leaching into the limited contacting liquid can reduce concentration gradients. Therefore, the rate of leaching in the field can be less than measured in the laboratory and Method 1315 data often are used to estimate the parameters (e.g., observed diffusivity) that control mass transfer for each constituent (Garrabants, Sanchez, Gervais, Moszkowicz, & Kosson, 2002). The data from Method 1315 may represent mass transport rates over short time durations with the mass transport parameters used to estimate rates of leaching in the field over longer time durations (U.S. EPA, 2012d). A summary of the potential applications of Method 1315 data is presented in Table 3-4.

Table 3-4. Potential Applications of Method 1315 Data

Data Collected	Potential Uses
Constituent release rates from monolithic and compacted granular materials	• Maximum leaching rates under diffusion conditions • Mass transport-based leaching source term • Tortuosity and observed diffusivity (diffusion-controlled release)
Compacted dry density (pre-test for granular materials)	• Bulk density of compacted granular materials under field compaction
Eluate pH and conductivity as a function of cumulative leaching time	• Concentrations graphed as function of pH with *Method 1313* results to verify *Method 1315* dilute boundary conditions • pH and total ionic strength domain of anticipated leaching

3.1.4 U.S. EPA Method 1316: L/S-Dependent LSP

Method 1316 is an equilibrium-based leaching test intended to provide eluate solutions over a range of L/S. This method consists of five parallel batch extractions of a particle-size-reduced solid material in reagent water over a range of L/S values from 0.5 to 10 mL/g-dry material (Figure 3-7).



Adapted from Kosson et al. (2014).

Parallel batch extractions with varying quantities of deionized water, approximating liquid-solid partitioning as a function of pH at chemical equilibrium.

Figure 3-7. Experimental scheme of U.S. EPA Method 1316 as a parallel batch extraction test.

At the end of the contact interval, the liquid and solid phases are separated by pressure or vacuum filtration in preparation for constituent analysis. Extract pH and specific conductance measurements are taken on an aliquot of the liquid phase. Analytical aliquots of the extracts are collected and preserved accordingly based on the determinative methods to be performed (U.S. EPA, 2012c). Measured eluate concentrations are plotted as a function of the L/S along with MDLs and LLOQs to indicate quantitation of measured concentrations. Method results are presented as eluate concentrations [mg/L] or as mass release [mg/kg] calculated by multiplying concentrations by the extraction-specific L/S [L/kg-dry]. Often, the measured eluate pH for each extraction is plotted against the L/S to provide content to pH-dependent

LSP concentration determined from Method 1313. Figure 3-8 provides example results from Method 1316 for a contaminated smelter site soil (U.S. EPA, 2012c, 2012d).

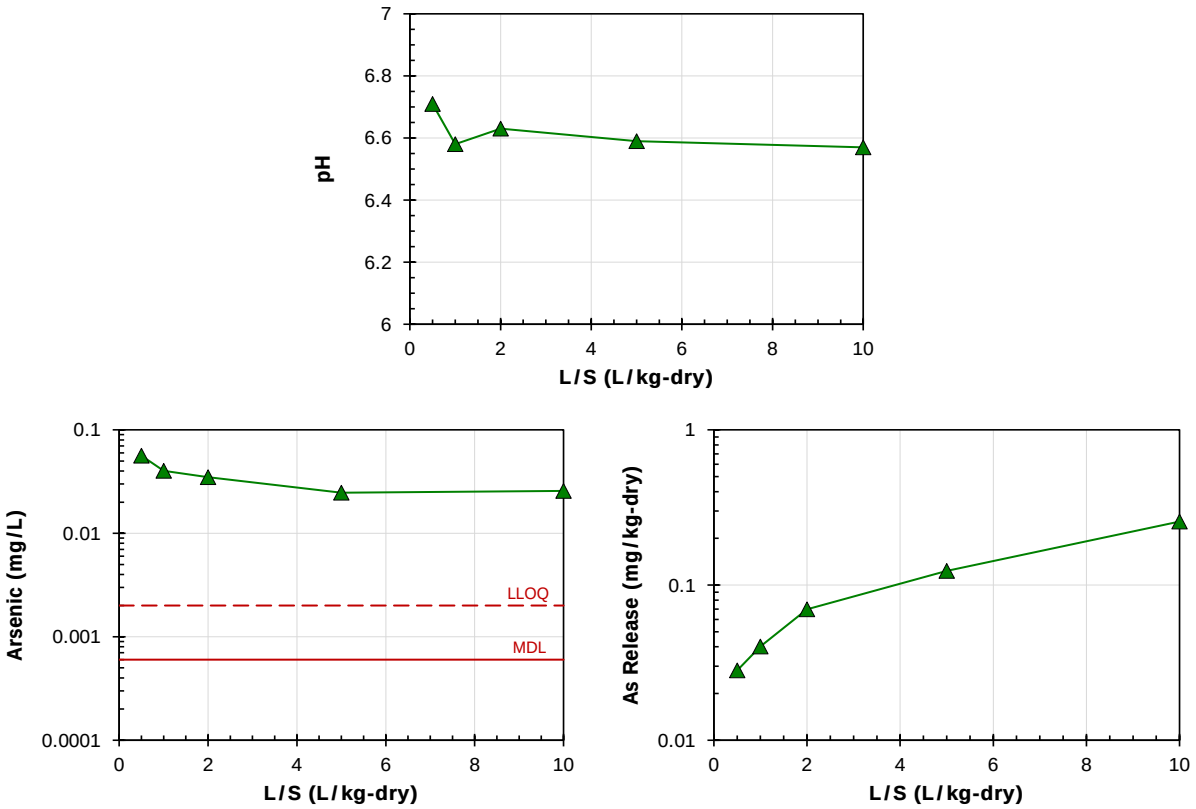


Figure 3-8. Example arsenic results for Method 1316 from a contaminated smelter site soil (CFS): Eluate pH (top), eluate concentration (lower, left) and release (lower, right).

Data from Method 1316 provides mass release information as a function of L/S similar to Method 1314 data. However, the Method 1316 eluate concentrations are often higher than Method 1314, reflecting the nature of the batch test where constituents are not sequentially removed from the system at each L/S as with a flow-through percolating column. The batch method may be useful when characterizing materials with physical properties that make flow through tests impractical (e.g., low-permeability clay soil, materials with cementitious properties). A summary of the applications of Method 1316 data is presented in Table 3-5.

Table 3-5. Potential Applications of Method 1316 Data

Data Collected	Potential Uses
COPC concentrations as a function of L/S	• Estimate porewater concentrations at low L/S
pH and conductivity as a function of L/S	• Porewater pH
COPC mass release as a function of L/S	• Constant mass release as a function of L/S is an indicator of available content limited leaching

3.1.5 Validation of LEAF Tests

Extensive method development and refinement occurred in the course of evaluating coal fly ash and other materials using the LEAF tests (U.S. EPA, 2009, 2010). LEAF has undergone multiple rounds of validation in the laboratory and in the field to ensure that the data generated is as precise, accurate, and realistic as possible (U.S. EPA, 2014c). The results of these studies indicate that the data generated by the test methods are repeatable and provide a good representation of what will occur in the field for inorganic constituents. The following text describes the results and conclusions of these different validation studies.

3.1.5.1 Interlaboratory Validation

EPA conducted interlaboratory validation studies to determine the repeatability and reproducibility of each LEAF method (U.S. EPA, 2012c, 2012d). For each method, between seven and ten laboratories participated in the study, each conducting testing in triplicate for a series of different materials types including coal fly ash, an analog of a solidified waste, a contaminated smelter site soil and a brass foundry sand. From eluate concentrations obtained from laboratory testing, method precision was calculated as the intra-laboratory repeatability relative standard deviation (RSD_r) and inter-laboratory reproducibility relative standard deviation (RSD_R). A summary of the interlaboratory validation results are presented in Table 3-6**.** For example, Method 1313 results indicate that mean lab precision was 10% of the measured value within a laboratory and 26% between laboratories. The results of interlaboratory validation provide the confidence that each method provides the characteristic leaching behavior that is intended by the LEAF leaching methods with a high degree of precision (U.S. EPA, 2012c, 2012d).

Table 3-6. Precision Data for LEAF Test Methods based on Interlaboratory Validation Studies

Method	Test Output	RSD_r	RSD_R
Method 1313	Eluate Concentration (average over pH range)	13%	28%
Method 1314	Eluate Concentration (mean at L/S 10 L/kg-dry)	12%	24%
	Mass Release (cumulative to L/S=0.5)	7%	18%
	Mass Release (cumulative to L/S=10)	5%	14%
Method 1315	Interval Flux (mean excluding wash-off)	12%	30%
	Mass Release (cumulative to 7 days)	9%	19%
	Mass Release (cumulative to 63 days)	6%	23%
Method 1316	Eluate Concentration (average over L/S range)	8%	19%

3.1.5.2 Field Validation

EPA evaluated the relationship between LEAF test results and leaching of inorganics from a broad range of materials under disposal and beneficial use scenarios. This evaluation was achieved by defining a framework for interpretation of laboratory testing results, comparison of laboratory testing on “as produced” material, laboratory testing of “field aged” material, and results from field leaching studies, and illustrating the use of chemical speciation modeling as a tool to facilitate evaluation of scenarios beyond the conditions of laboratory testing. LEAF has been shown to provide effective estimates of leaching behavior for inorganic constituents (e.g., Al, As, Sb, B, Ca, Cr, Cu, Fe, Pb, K, Mg, , Se, Si, Sr, V, Zn) for a wide range of materials (the same ones used in inter-laboratory validation) under both disposal and use conditions (U.S. EPA, 2014c).

Based on the results of this study, EPA concluded that the combined results from pH-dependent leaching tests (Method 1313) and percolation column tests (Method 1314) can provide accurate estimates of maximum field leachate concentrations, extent of leaching and expected leaching responses over time. In addition, this approach can predict or account for changes in environmental conditions under both disposal and use scenarios within reasonable bounds. Results from batch testing at low L/S (Method 1316) can be used in place of column test results when column testing is impractical. Method 1315 should be used in combination with Method 1313 for scenarios when mass transport from monolithic or compacted granular materials controls leaching. When field conditions exist that are beyond the domain of laboratory test conditions (e.g., reduction of oxidized material or introduction of DOC from external sources), consult with technical experts in geochemical speciation to develop an approach that is as technically robust as current scientific knowledge allows.

3.1.6 Relationship between LEAF and Single Point Tests (e.g., TCLP, SPLP)

Traditional single-point leaching tests use specified leaching solutions designed to simulate release under a specific set of environmental and management conditions. For example, the buffered, dilute acetic acid eluant at an L/S of 20 mL/g (wet basis) used in TCLP (Method 1311) is specified so the eluate concentrations represent leaching under a plausible mismanagement scenario of industrial waste co-disposal in a municipal solid waste landfill (U.S. EPA, 1992; U.S. Federal Register, 1986). Although procedurally analogous to TCLP, the SPLP (Method 1312) uses a blend of dilute inorganic acids to simulate near-surface exposure of solid material to acidic precipitation (U.S. EPA, 1994).

The LEAF leaching test methods are designed to measure intrinsic leaching properties over a range of environmentally relevant conditions. Eluate pH, L/S and physical form of the material (i.e., particle size) are controlled as independent variables to provide measurements of the rate and extent of constituent release into water contacting the material over a range of test conditions (Kosson et al., 2002)). For example, Method 1313 varies the final pH at targets between 2 and 14 while maintaining a constant L/S of 10 mL/g-dry, whereas Method 1316 allows the material to dictate eluate pH at five L/S levels between 0.5 and 10 mL/g-dry.

While typically not done in practice, when the endpoint pH of single point leach tests is recorded such as in TCLP test reports, the results can be compared to pH-dependent LSP results from LEAF leaching testing methods. The comparisons in Figure 3-9 illustrate that the results from single-point leaching tests typically reflect one data point on the LSP curve at equilibrium. However, due to the different L/S values used in these tests (e.g., TCLP and SPLP at L/S 20 mL/g; Method 1313 at L/S 10 mL/kg-dry), eluate concentrations from TCLP and SPLP may graph slightly below the LSP curve for Method 1313 data.

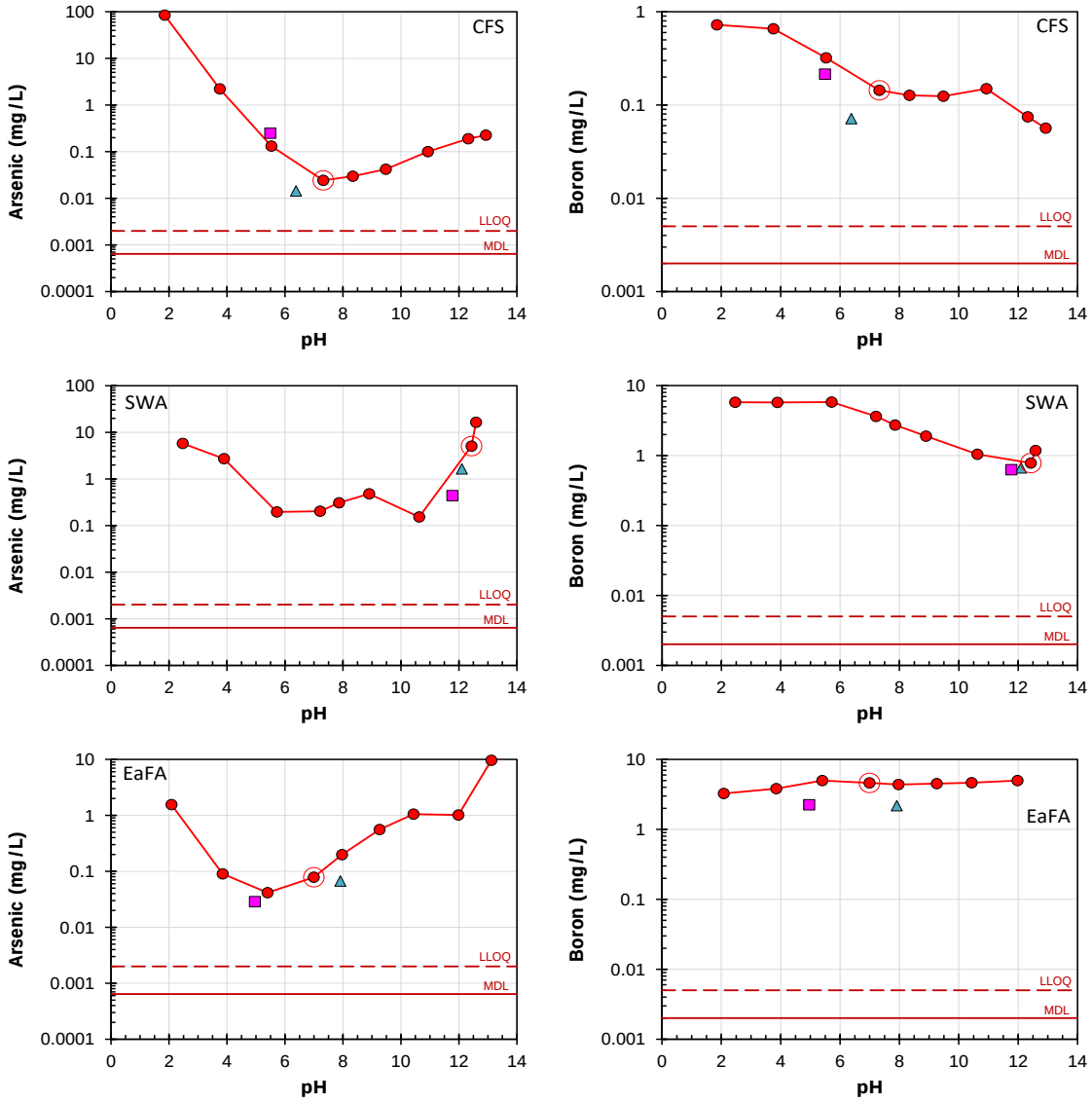


Figure 3-9. Comparison of TCLP (pink square) and SPLP (green triangle) results to pH-dependent leaching from Method 1313 for a contaminated smelter site soil (CFS; top), a solidified waste form (SWA; center) and a coal combustion fly ash (EaFA; bottom).

3.2 Building a Testing Program

Developing a testing program includes selection of appropriate leaching tests, target analytes for evaluation, and analytical methods to sufficiently detect and measure chosen analytes. The testing program should be specified in a quality assurance project plan (QAPP) that addresses the tests and conditions to be conducted as well as testing and analytical QA/QC criteria used to support the testing program. Additional information on development of analytical quality assurance can be found in chapter one of SW-846 (U.S. EPA, 2014d; available online at https://www.epa.gov/hw-sw846/quality-assurance-and-hazardous-waste-test-methods).

3.2.1 Material Collection for Leaching Tests

The goal of material sampling and subsequent material preparation should be to obtain representative samples and subsamples, or aliquots, of the materials being disposed or reused for use in the selected leaching tests. Guidance on sampling is available at *https://www.epa.gov/hw-sw846/sampling-guidance-documents-sw-846-compendium*. Initial sample collection should account for spatial and temporal variations in material characteristics through appropriate compositing of individual grab samples. For piles or accumulated quantities of (what is nominally) a single material, grab samples should be obtained from different locations and depths within the accumulated material. For a material produced over time, representative grab samples should be obtained at predefined intervals over the evaluation period. Individual grab samples should have enough mass to be spatially or temporally representative. The goal should be to have sufficient sample following preparation to meet the needs of the planned leaching testing and characterization needs of the project. The information in Table 3-1 (Section 3) includes recommended sample quantities for carrying out each LEAF leaching test. Depending upon variability in material composition, replicate testing may be needed. Often-convenient field sample sizes and containers are 2-liter wide-mouth jars, 1-gallon pails, and 5-gallon pails with tight-fitting re-sealable lids. The container materials (e.g., high-density polyethylene, glass) must be compatible with the COPCs.

Sample collection systems and subsequent handling should be designed to avoid changes in sample characteristics that may degrade the representativeness of the samples prior to analysis and can result in misleading results. For example, oxidation or carbonation of samples during collection and/or handling can result in changes in pH and constituent speciation and may significantly alter the leaching behavior of some constituents. Samples should be particle-size reduced and homogenized shortly before sub-sampling and testing to maximize the representativeness of results. Heterogeneity can result from variations in the solid material, aging of the cured materials, or by exposure of leaching solutions to the atmosphere.

3.2.2 Analytical Parameters

As specified in Methods 1313, 1314, 1315, and 1316, all eluates should be analyzed for pH and EC in the laboratory immediately after contact with the solid. For Method 1313, measurement of EC should be limited to only the natural pH eluate because of the addition of acid and base in other extractions provides an artifact in the interpretation of ionic strength. The measurement of oxidation/reduction potential (ORP) as an indicator of redox conditions is optional based on anticipated scenario conditions and material properties, but for similar reasons to EC measurements, should be limited to the natural pH test position for Method 1313 eluates (see 4.3.1 for more on interpreting ORP from LEAF testing).

The selection of COPCs and additional analytes for chemical analysis depends on the intended use of the results, with assessment-specific COPCs determined based on the requirements of the applicable regulatory agency, use of a screening list, and/or prior knowledge of the material being evaluated.

- **Screening for COPCs** – When the assessment objective to identify COPCs that have the potential to impact the environment, sufficient chemical analysis may include RCRA metals (i.e., Ag, As, Ba, Cd, Cr, Hg, Pb and Se) and/or inorganic species of the EPA Priority Pollutant List (i.e., Ag, As, Be, Cd, Cr, Cu, Hg, Pb, Ni, Sb, Se, Tl and Zn). However, additional analytes may need to be included based on consideration of the specific material being tested.

- **Understanding Basic Leaching Behavior** – In addition to the RCRA or EPA Priority Pollutant List, analyses should be conducted for constituents that can improve understanding of the LEAF test results based on the predominant chemistry of the final eluate. Because of their ability to increase eluate concentrations of COPCs, these additional constituents usually include dissolved carbon from both organic (DOC) and inorganic (e.g., dissolved inorganic carbon, carbonate) forms. Even minimal amounts of organic matter can dramatically influence the solution equilibrium chemistry of many important trace species such as copper and lead. Chloride ions can form soluble complexes with cadmium resulting in elevated measured concentrations of cadmium. In addition, analysis of dissolved iron is a useful indicator of redox state, where elevated Fe concentrations are indicative of reducing conditions.
- **Detailed Characterization** – For full characterization testing, chemical analysis is recommended to include the above analyses as well as a full suite of major and trace constituents in all leaching test eluates. Knowledge of the major constituents that control release of the trace constituents improves understanding of the factors that may affect leaching and allows for calibration of chemical speciation models. Prior knowledge from testing of analogous materials may reduce the need for, or extent of, characterization testing.

3.2.3 Suggested Best Practices for Conducting LEAF Tests

As commercial laboratories become more familiar with the LEAF leaching tests, valuable experience will be gained into the best practices for conducting these tests. Based on experience from developing, validating, and conducting the LEAF leaching methods, the following best practices are recommended:

3.2.3.1 Reagent Selection and Preparation

- For Method 1313, select a base solution (i.e., NaOH or KOH) compatible with leaching assessment objectives (i.e., potassium hydroxide should not be used if potassium is likely to be an assessment constituent). Interlaboratory validation of Method 1313 has shown that KOH may increase eluate concentrations of thallium and, therefore, NaOH should be used to raise eluate pH whenever thallium is a COPC (U.S. EPA, 2012c).
- To the extent possible, bulk reagent solutions (i.e., dilute solutions of acid or base used in Method 1313 or the deionized water used in all LEAF tests) should be prepared immediately prior to use. Storage of bulk solutions over prolonged periods between tests (e.g., > 1 week) should be avoided. Reagents should be stored in containers compatible with the reagent to avoid contamination of the solution (e.g., storing strong alkali solutions in borosilicate glass can result in contamination due to dissolution of boron; U.S. EPA, 2012c).

3.2.3.2 Measurement of Eluate pH

- Meters used for pH measurement should be calibrated with a minimum of two standard pH buffer solutions that span the range of anticipated pH values. Non-standard pH buffer solutions are available as special order for calibration of very low pH (pH < 2) and very high pH (pH > 12) as required for Method 1313. A third, mid-range standard solution (e.g., pH 7) should be used to verify the two-point calibration.
- When eluate solutions are physically separated from the solid material (e.g., after filtration), the weakly buffered liquid, especially highly alkaline solutions, may be highly susceptible to reactions

with air. Thus, eluate pH measurement should be conducted as soon as possible after collection of eluates to avoid carbonation of alkaline solutions and oxidation that could lead to precipitation of carbonate and iron species, respectively. However, care should be taken during pH measurement to ensure that a stable pH is obtained for each eluate.

3.2.3.3 Chemical Analysis

- Unlike single point extraction tests, the multipoint LEAF leaching test methods indicate "trends" in leaching behavior over a range of conditions. Therefore, eluates from a LEAF test should be considered a "set" of solutions that should be analyzed at a uniform analytical dilution whenever practical. However, the measured concentrations over the set of solutions may span several orders-of-magnitude, especially for Method 1313, and therefore analytical solutions may require various levels of dilution to complete analysis.
- Major constituents may require dilution that prevents determination of trace constituents, thus requiring analyses at more than one dilution factor to determine all specified constituents.
- Colloidal formation of DOC-bound analytes in leaching tests eluates can interfere with U.S. EPA SW-846 analytical methods (e.g., Method 6010 or 6010); however, the influence of colloids can be minimized by digestion of eluates following U.S. EPA SW-846 Method 3015A. Digestion may be necessary prior to analysis of Al, As, Be, Cd, Co, Cr, Cu, Fe, P, Pb, Sb, Ti, Tl, U, and Zn in all eluates with greater than 50 mg/L DOC.

3.2.3.4 Data Review

- Prior to the use of analytical data, the end user should review analytical QA/QC results to ensure accuracy and consistency in the evaluation of analytical blanks, spike recoveries, and analytical duplicates.
- Similarly, the results from leaching tests should be reviewed graphically for consistency in trends within and between test replicates. Abnormal jumps or discontinuities in interrelated data may indicate potential testing or analytical errors.

3.2.4 Quality Assurance/Quality Control

Preparing a detailed quality assurance project plan (QAPP) is an important first step in assuring high-quality information for subsequent decision-making. A QAPP should be tailored to the data quality needs of the project to ensure efficient use of resources. Minimum quality control for leaching tests should include use and analysis of method blanks (e.g., extractions conducted without solid material) as specified in each of the LEAF leaching test methods and appropriate quality control for the chemical analyses carried out on leaching test eluates (e.g., analytical spike recoveries, repeatability, calibration verification, etc.). Guidance on development of quality assurance project plans is provided by U.S. EPA (2002) and further information can be found at *https://www.epa.gov/quality*.

Quality assurance for leaching tests should consider the following steps:

- Obtaining representative material sample(s) for testing;
- Execution of leaching tests with test-level QA/QC evaluations;
- Chemical analysis of test eluates following accepted methods and QA/QC procedures; and

- Data management in a manner that minimizes human error and allows for validation relevant to data quality objectives.

3.2.4.1 QA/QC Samples in LEAF Leaching Tests

The procedure for each of the four LEAF leaching test methods includes steps for collecting QA/QC solutions (method blanks and eluant blanks) that are used to assess purity of the reagents and equipment surfaces used in the tests. These solutions include samples of bulk reagents or method blank eluates (i.e., extractions without solid material conducted in parallel with test extractions, using the same reagents and equipment) or samples of bulk reagents:

- **Method 1313** – method blanks conducted in deionized water (natural pH), the highest level of acid addition (pH 2.0 target), and the high level of base addition (pH 13 target);
- **Method 1314** – a sample of bulk eluant at the start of the test and when the eluant source is changed or refreshed;
- **Method 1315** – a series of method blanks conducted in parallel with test fractions; and
- **Method 1316** – a single method blank using deionized water conducted at the L/S 0.5 test fraction.

All QA/QC samples should be preserved and analyzed for COPCs in the same manner as test eluates and reviewed prior to utilization of leaching test results. Test method blanks should be less than the LLOQ or, if greater than the LLOQ, less than 20% of the minimum measured analyte concentration (U.S. EPA, 2012c, 2012d).

3.2.4.2 Analytical QA/QC

An analytical program, including identification of analytes, setting of quantitation limits and analytical quality assurance criteria, should be developed by consultation between the end user and the laboratory conducting the leaching test(s) and, if different, the laboratory conducting chemical analysis. Analytical data should be reviewed before applying LEAF assessment methodologies to ensure that quality assurance requirements have been met. Analytical QA/QC should include a selection of the solutions and evaluations shown in the sidebar to the right as appropriate to ensure adequate precision and accuracy of measurements. At a minimum, QA/QC should include establishing detection and quantitation limits for each analytical process and development of initial and continuing calibration.

Chemical analysis of leaching test eluates should include specification of reporting limits that are less than the applicable threshold values that will be used in subsequent decision-making. Management of values less than the reporting limits (e.g., less than the LLOQ or MDL) should be reported and used in calculations in a manner consistent with the relevant regulatory or other applicable evaluation program. Options for reporting and using values less than the reporting limits include using the reporting limit, one-half the reporting limit, or one-tenth the reporting limit.[11] Applicable U.S. EPA SW-846 analytical methods and example MDLs and LLOQs for a selection of COPCs are provided in Table 3-7.

[11] Further information on the determination and use of the LLOQ and MDL can be found at *https://www.epa.gov/measurements/detection-limitquantitation-limit-summary-table*

Analytical QA/QC Solutions

Although terminology may vary between laboratories, the following is a general list of typical analytical QA/QC terms that may be used in chemical analyses.

- **Method Detection Limit (MDL)**–a statistically derived concentration of an analyte indicating that the analyte concentration is greater than zero with 99% confidence. In practical terms, the MDL represents the minimum concentration of an analyte for a given analytical technique and sample matrix.
- **Quantitation Limit** – a minimum concentration of an analyte that can be measured within specified limits of precision and accuracy. Although various forms of quantitation limits are common, the lower limit of quantitation (LLOQ) should be reported for LEAF.
- **Reporting Limit** – the level at which method, permit, regulatory and client-specific objectives are met. The reporting limit should be greater than the statistically determined MDL but may be or may not be greater than quantitation limits.
- **Calibration Standard** – a certified standard solution containing known concentration of an analyte measured to establish an initial calibration curve or to verify the validity of the calibration curve during analysis.
- **Calibration Blank** – an analyte-free quality control sample prepared in the same manner as calibration standards and used to establish reagent and system contributions to the analytical result. Calibration blanks should be less than the quantitation limit.
- **Internal Standard** – a known amount of a non-interfering substance, different from the analyte, used to adjust sample concentrations for the substance amount introduced to the instrument. Internal standards are added to each analytical solution.
- **Matrix Spike** – an aliquot of sample with known quantities of specified analytes added (spike amount) and analyzed to estimate interferences.
- **Analytical Replicate** – an analytical sample that has been split into two equal portions used to measure precision associated with handling from preparation through analysis.

Commercial analytical laboratories have internal quality assurance/quality control procedures that comply with their accreditation programs (e.g., National Environmental Laboratory Accreditation Conference). When contracting with an analytical laboratory for LEAF testing, the user of this guide is encouraged to review the QA/QC procedures, measured QA/QC solutions and evaluation frequencies with the contracted analytical laboratory. These quality assurance and quality control procedures should be considered with respect to the leaching assessment project QAPP and data quality objectives.

Table 3-7. Example Analytical Method Detection Limit (MDL) and Lower Limit of Quantitation (LLOQ) Values Compared to U.S. Drinking Water Standards

	Symbol	Drinking Water Standard [µg/L]	Analytical Method	EPA SW-846 Method	MDL [µg/L]	LLOQ [µg/L]
Aluminum	Al	50-200[N1]	ICP-OES	Method 6010	1	50
Antimony	Sb	6	ICP-MS	Method 6020	0.08	1
Arsenic*	As	10	ICP-MS	Method 6020	0.36	1
Barium	Ba	2,000	ICP-OES	Method 6010	1	10
Beryllium	Be	4	ICP-MS	Method 6020	0.6	1
Boron	B	7,000[N2]	ICP-OES	Method 6010	4.3	10
Cadmium	Cd	5	ICP-MS	Method 6020	0.08	1
Calcium	Ca	—	ICP-OES	Method 6010	2.6	10
Carbon (Inorganic)	IC	—	TOC	Method 9060A	130	500
Carbon (Organic)	OC	—	TOC	Method 9060A	170	500
Chloride	Cl	250,000[N1]	IC	Method 9056A	6.5	20
Chromium*	Cr	100	ICP-MS	Method 6020	0.44	1
Cobalt	Co		ICP-OES	Method 6010	0.26	1
Copper	Cu	1,300[N3]	ICP-OES	Method 6010	2.5	10
Iron	Fe	300[N1]	ICP-OES	Method 6010	1.3	10
Lead	Pb	15[N3]	ICP-MS	Method 6020	0.062	1
Magnesium	Mg		ICP-OES	Method 6010	1.7	10
Manganese	Mn	1,600[N2]	ICP-OES	Method 6010	1	10
Mercury	Hg	2	CVAA	Method 7470A	NR	0.025
Molybdenum	Mo	200[N2]	ICP-OES	Method 6010	0.72	1
Nitrate	NO3	10,000	IC	Method 9056A	26	100
Nitrite	NO2	1,000	IC	Method 9056A	18	50
Phosphate	PO4		IC	Method 9056A	24	100
Phosphorus	P		ICP-OES	Method 6010	4.1	10
Potassium	K		ICP-OES	Method 6010	2.3	10
Selenium	Se	50	ICP-MS	Method 6020	0.54	1
Silicon	Si		ICP-OES	Method 6010	3.1	10
Sodium	Na		ICP-OES	Method 6010	3.7	10
Sulfate	SO4	250,000[N1]	IC	Method 9056A	21	100
Sulfur	S		ICP-OES	Method 6010	4.7	10
Thallium*	Tl	2	ICP-MS	Method 6020	0.53	1
Uranium	U	30	ICP-MS	Method 6020	0.18	1
Vanadium	V		ICP-OES	Method 6010	1.9	10
Zinc	Zn	10[N2]	ICP-OES	Method 6010	1	10

COPCs indicated in **bold red** are used in subsequent example cases.
* Method detection limit (MDL) greater than minimum indicator value.

Drinking water standards are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless noted:
[N1] National secondary drinking water regulations—non-enforceable guideline.
[N2] Drinking water equivalent level.
[N3] Treatment technique action level.

ICP-MS – Inductively coupled plasma mass spectrometry.
ICP-OES – Inductively coupled plasma optical emission spectrometry.
IC – Ion chromatography.
TOC – Total organic carbon.
CVAA – Cold vapor atomic absorption.

Typically, initial calibration is conducted at the beginning of the analytical process or as recommended by analytical process or the instrument manufacturer. Continuing calibration is recommended to be

conducted periodically (e.g., every 20 analytical samples) and assessed relative to the expected value (e.g., within 15% of the standard value). For chemical analysis of LEAF eluates, it is recommended that matrix spikes and analytical replicates be carried out on the following test fractions:

- **Method 1313:** Eluates corresponding to the natural pH condition, the maximum acid condition (lowest pH target), and the maximum base condition (highest pH target);
- **Method 1314:** Eluate collected at cumulative L/S 0.5 and 10 mL/g-dry;
- **Method 1315:** Eluate from the 1-day cumulative leaching fraction; and
- **Method 1316:** Eluate conducted at L/S 0.5 mL/g-dry.

Matrix spikes are measured periodically over a set of analyses (e.g., once for each test) and are evaluated as a percent recovery of a known spike amount (e.g., within 15% of expected value). Analytical replicates are recommended at regular intervals during an analysis (e.g., once for each test) and are evaluated as a replicate percent difference between replicate analyses.

3.2.5 Testing and Analytical Costs

Estimated total analytical costs for a single test are anticipated to range from $2,000 to $5,000, which includes an extensive suite of chemical analyses. Estimated costs for laboratory services are presented in Table 3-8 through Table 3-11. The method-specific costs in these tables are estimated for single testing runs on an unknown material with a more complete suite of chemical analytes (e.g. pH, EC, ORP, metals, anions) than may be applicable for other scenarios. Costs also include the preparation of an electronic data deliverable for uploading to LeachXS™ Lite for data interpretation. Additional cost information is available in EPA's *Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods* (US EPA, 2010). Reductions in costs to laboratories are anticipated as the methods become commercialized, equipment specific to the test methods is developed, and data interpretation becomes automated. LEAF may be more economical for significant amounts of material because the potential analytical costs may be fixed while the quantity of material is scalable. A stepwise approach to testing can be more economical for smaller material volumes and therefore more broadly feasible (Kosson, van der Sloot et al., 2002).

Table 3-8. Estimated Laboratory Costs for Method 1313

Parameters	Method	Matrix	Unit Price	Number of Analytical Samples [2]	Single Sample Cost
LEAF 1313 [1]	SW846 1313	Solid	$1,650	1	$1,650
pH	SW846 9040C	Water	$10	19	$190
Oxidation-reduction potential	SM 2580B	Water	$20	12	$240
Conductivity	SM 2510B	Water	$18	12	$216
DOC/DIC	SW846 9060A	Water	$30	12	$360
Metals (19-22)	SW846 6020A	Water	$80	12	$960
Mercury	SW846 7470A	Water	$25	12	$300
Anions (4-7)	SW846 9056A	Water	$75	12	$900
				Total:	$4,816

Source: A representative US commercial laboratory (2015)

[1] The cost for Method 1313 includes:
A) Sample air-drying to the prescribed >85% total solids.
B) Particle size reduction and sieving of the sample.
C) Nine parallel extractions at the prescribed method pH ranges.
D) Seven pretest extractions used to determine titration curve.
E) Three extraction blanks at low pH, neutral pH, and high pH.
F) A charge for an electronic data deliverable (EDD).

[2] Total number of analytical samples includes three method-prescribed blanks. Number of pH samples includes the seven pre-test samples.

Table 3-9. Estimated Laboratory Costs for Method 1314

Parameters	Method	Matrix	Unit Price	Number of Analytical Samples [2]	Single Sample Cost
LEAF 1314 [1]	SW846 1314	Solid	$1,870	1	$1,870
pH	SW846 9040C	Water	$10	10	$100
Oxidation-reduction potential	SM 2580B	Water	$20	10	$200
Conductivity	SM 2510B	Water	$18	10	$180
DOC/DIC	SW846 9060A	Water	$30	10	$300
Metals (19-22)	SW846 6020A	Water	$80	10	$800
Mercury	SW846 7470A	Water	$25	10	$250
Anions (4-7)	SW846 9056A	Water	$75	10	$750
				Total:	$4,450

Source: A representative US commercial laboratory (2015)

[1] Included in the cost for Method 1314 is the following:
A) Sample air-drying to the prescribed >85% total solids.
B) Particle size reduction and sieving of the sample.
C) One extraction blank collected at Time 1.
D) A charge for an EDD.

[2] Total number of analytical samples includes one method prescribed blank.

Table 3-10. Estimated Laboratory Costs for Method 1315

Parameters	Method	Matrix	Unit Price	Number of Analytical Samples [2]	Single Sample Cost
LEAF 1315 [1]	SW846 1315	Solid	$1,100	1	$1,100
pH	SW846 9040C	Water	$10	18	$180
Oxidation-reduction potential	SM 2580B	Water	$20	18	$360
Conductivity	SM 2510B	Water	$18	18	$324
DOC/DIC	SW846 9060A	Water	$30	18	$540
Metals (19-22)	SW846 6020A	Water	$80	18	$1,440
Mercury	SW846 7470A	Water	$25	18	$450
Anions (4-7)	SW846 9056A	Water	$75	18	$1,350
				Total:	$5,744

Source: A representative US commercial laboratory (2015)

Table 3-11. Estimated Laboratory Costs for Method 1316

Parameters	Method	Matrix	Unit Price	Number of Analytical Samples [2]	Single Sample Cost
LEAF 1316 [1]	SW846 1316	Solid	$730	1	$730
pH	SW846 9040C	Water	$10	6	$60
Conductivity	SM 2510B	Water	$18	6	$108
Oxidation-reduction potential	SM 2580B	Water	$20	6	$120
DOC/DIC	SW846 9060A	Water	$30	6	$180
Metals (19-22)	SW846 6020A	Water	$80	6	$480
Mercury	SW846 7470A	Water	$25	6	$150
Anions (4-7)	SW846 9056A	Water	$75	6	$450
				Total:	$2,278

Source: A representative US commercial laboratory (2015)

[1] Included in the cost for the Method 1316 is the following:
A) Sample air-drying to the prescribed >85% total solids.
B) Particle size reduction and sieving of the sample.
C) One extraction blank.
D) A charge for an EDD.

[2] Total number of analytical samples includes one method-prescribed blank.

3.2.6 Processing Time

Table 3-12 presents approximate processing times (in days) for conducting LEAF testing and chemical analysis of eluate after receipt of a material by the laboratory. Actual processing times would need to be negotiated with contracted laboratories. Accelerated testing may be available, though at least one week is needed for Method 1313 and 1316 and two weeks are needed for Method 1314. Method 1315 may be carried out more quickly if not all eluates are required. For a step-by-step breakdown of labor and processing time in a research laboratory, see the Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods (US EPA, 2010).

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Table 3-12. Processing Time

Method	Turnaround Time in Days from Receipt at Laboratory
Method 1313	35
Method 1314	35
Method 1315	84 (63 + 21 for analyses/reporting)
Method 1316	28

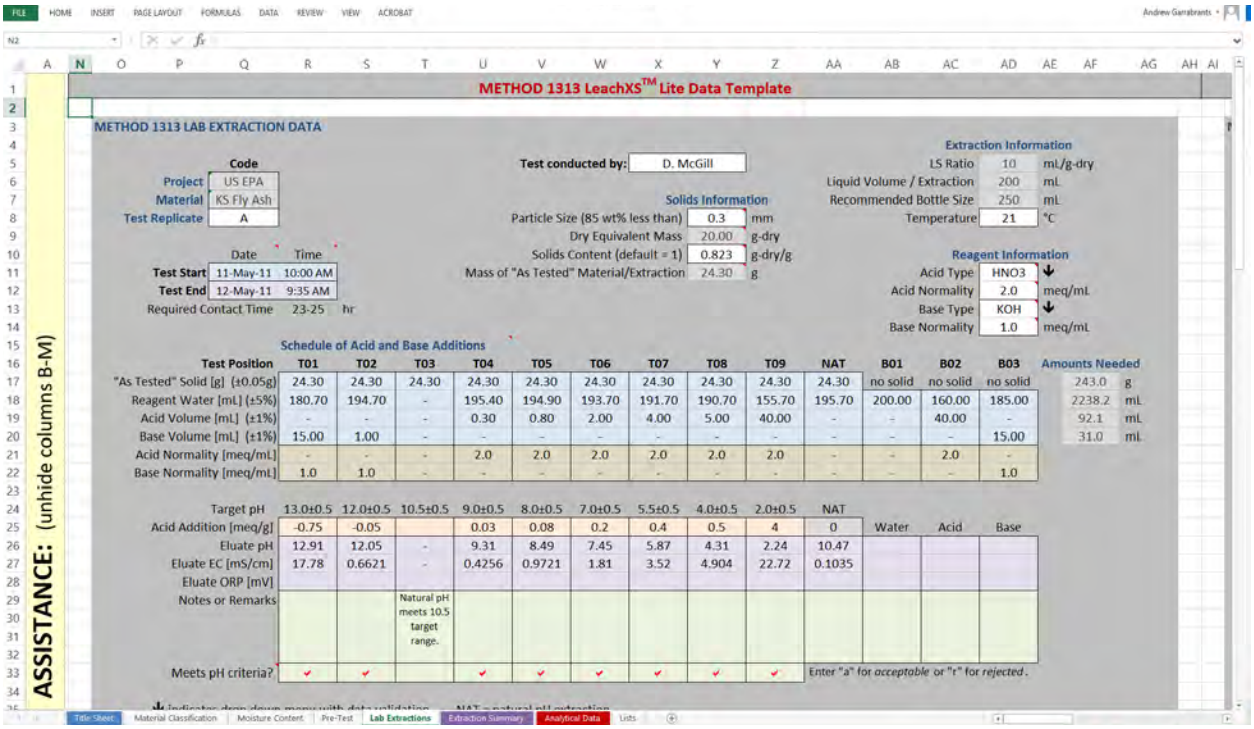
Source: US EPA (2010)

3.3 LEAF Data Management Tools

Because LEAF multi-point testing and comprehensive chemical analysis creates a considerably large data set of inter-related leaching measurements, LEAF includes tools for collecting, managing, and reporting data. Microsoft Excel® spreadsheets are provided as templates to assist laboratory personnel in preparation of tests and collection bench and analytical data. These templates import directly into LeachXS™ Lite, a desktop-based decision support software provided as a free download intended to be used as a data management tool for LEAF data (see Section 6, "Useful Resources").

3.3.1 Laboratory Data and Import Templates

LEAF and LeachXS™ Lite include a set of method-specific Excel® spreadsheet templates (available at *http://www.vanderbilt.edu/leaching/downloads/test-methods*) that laboratories can use to calculate test parameters, record and document laboratory observations, and archive analytical results. These data templates, illustrated in Figure 3-10, contain the verified calculations required to conduct each method at the bench scale. The embedded calculations and upload-ready format help assure data quality by minimizing errors in calculations and data transfer. Special care is recommended in ensuring that results are entered into the templates using the parameter units indicated (e.g., eluate concentrations in µg/L) and that the entered analytical data properly accounts for eluate dilutions for chemical analysis. These are the two most common errors in using the templates. Populated templates can be uploaded directly into all versions of the LeachXS™ data management program.



METHOD 1313 LeachXS™ Lite Data Template

METHOD 1313 LAB EXTRACTION DATA

Project	US EPA
Material	KS Fly Ash
Test Replicate	A

Test conducted by: D. McGill

	Date	Time
Test Start	11-May-11	10:00 AM
Test End	12-May-11	9:35 AM
Required Contact Time	23-25	hr

Solids Information

Particle Size (85 wt% less than)	0.3	mm
Dry Equivalent Mass	20.00	g-dry
Solids Content (default = 1)	0.823	g-dry/g
Mass of "As Tested" Material/Extraction	24.30	g

Extraction Information

LS Ratio	10	mL/g-dry
Liquid Volume / Extraction	200	mL
Recommended Bottle Size	250	mL
Temperature	21	°C

Reagent Information

Acid Type	HNO3	
Acid Normality	2.0	meq/mL
Base Type	KOH	
Base Normality	1.0	meq/mL

Schedule of Acid and Base Additions

Test Position	T01	T02	T03	T04	T05	T06	T07	T08	T09	NAT	B01	B02	B03	Amounts Needed
"As Tested" Solid [g] (±0.05g)	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	24.30	no solid	no solid	no solid	243.0 g
Reagent Water [mL] (±5%)	180.70	194.70	-	195.40	194.90	193.70	191.70	190.70	155.70	195.70	200.00	160.00	185.00	2238.2 mL
Acid Volume [mL] (±1%)	-	-	-	0.30	0.80	2.00	4.00	5.00	40.00	-	-	40.00	-	92.1 mL
Base Volume [mL] (±1%)	15.00	1.00	-	-	-	-	-	-	-	-	-	-	15.00	31.0 mL
Acid Normality [meq/mL]	-	-	-	2.0	2.0	2.0	2.0	2.0	2.0	-	-	2.0	-	
Base Normality [meq/mL]	1.0	1.0	-	-	-	-	-	-	-	-	-	-	1.0	

Target pH	13.0±0.5	12.0±0.5	10.5±0.5	9.0±0.5	8.0±0.5	7.0±0.5	5.5±0.5	4.0±0.5	2.0±0.5	NAT			
Acid Addition [meq/g]	-0.75	-0.05		0.03	0.08	0.2	0.4	0.5	4	0	Water	Acid	Base
Eluate pH	12.91	12.05	-	9.31	8.49	7.45	5.87	4.31	2.24	10.47			
Eluate EC [mS/cm]	17.78	0.6621	-	0.4256	0.9721	1.81	3.52	4.904	22.72	0.1035			
Eluate ORP [mV]													
Notes or Remarks			Natural pH meets 10.5 target range.										
Meets pH criteria?	✓	✓		✓	✓	✓	✓	✓	✓	Enter "a" for *acceptable* or "r" for *rejected*.			

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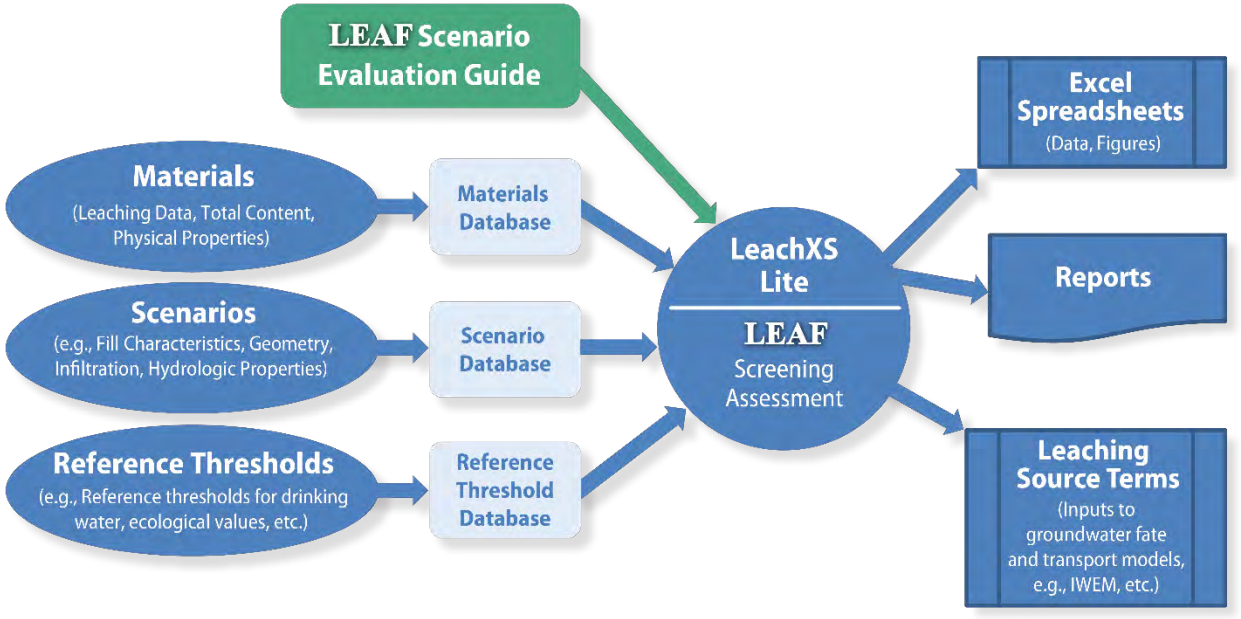
Figure 3-10. Example of a Microsoft Excel® data template for recording and archiving laboratory and analytical information from LEAF tests.

3.3.2 Data Management with LeachXS™ Lite

LeachXS™ Lite is a limited capacity version of LeachXS™[12] that provides users with a simplified tool for comparing leaching data between materials and test types and for exporting tabular and graphical leaching results. The Microsoft Excel® templates upload LEAF leaching test data directly from the LeachXS™ Lite interface and output results are exported as Microsoft Excel® workbooks for easy incorporation into reports and other documents. LeachXS™ Lite can be used to facilitate the process of compiling data from testing, compare leaching results within and between tests or material replicates and between different materials, and formulate standardized tables and graphics for data reporting. The flowchart in Figure 3-11 illustrates the general structure of the LeachXS™ program with the inputs to and outputs from LeachXS™ Lite.

[12] LeachXS™ is licensed software whereby on-going development is supported by annual user fees. The LeachXS™ program was developed in collaboration between Vanderbilt University, the Energy Research Centre of The Netherlands and Hans van der Sloot Consultancy. Development of early versions of LeachXS™ also included participation by DHI (Denmark).



IWEM = Industrial Waste Management Evaluation Model

Figure 3-11. LeachXS™ Lite program structure showing data inputs, databases and outputs.

LeachXS™ Lite was created as a collaboration between the LeachXS™ development team and U.S. EPA with the initial purpose of facilitating data analysis and presentation of leaching potential for CCRs in U.S. EPA research (U.S. EPA, 2006a, 2008, 2009). Thus, the default materials database included in LeachXS™ Lite contains leaching data on more than 40 constituents found in 70 CCR samples and several other materials. However, like the LEAF methods, the LeachXS™ Lite program is not specific to any particular material type and can be used to evaluate any material for which LEAF leaching data has been generated. A sample screen capture of the primary interface in LeachXS™ for comparison of leaching from granular materials is presented in Figure 3-12.

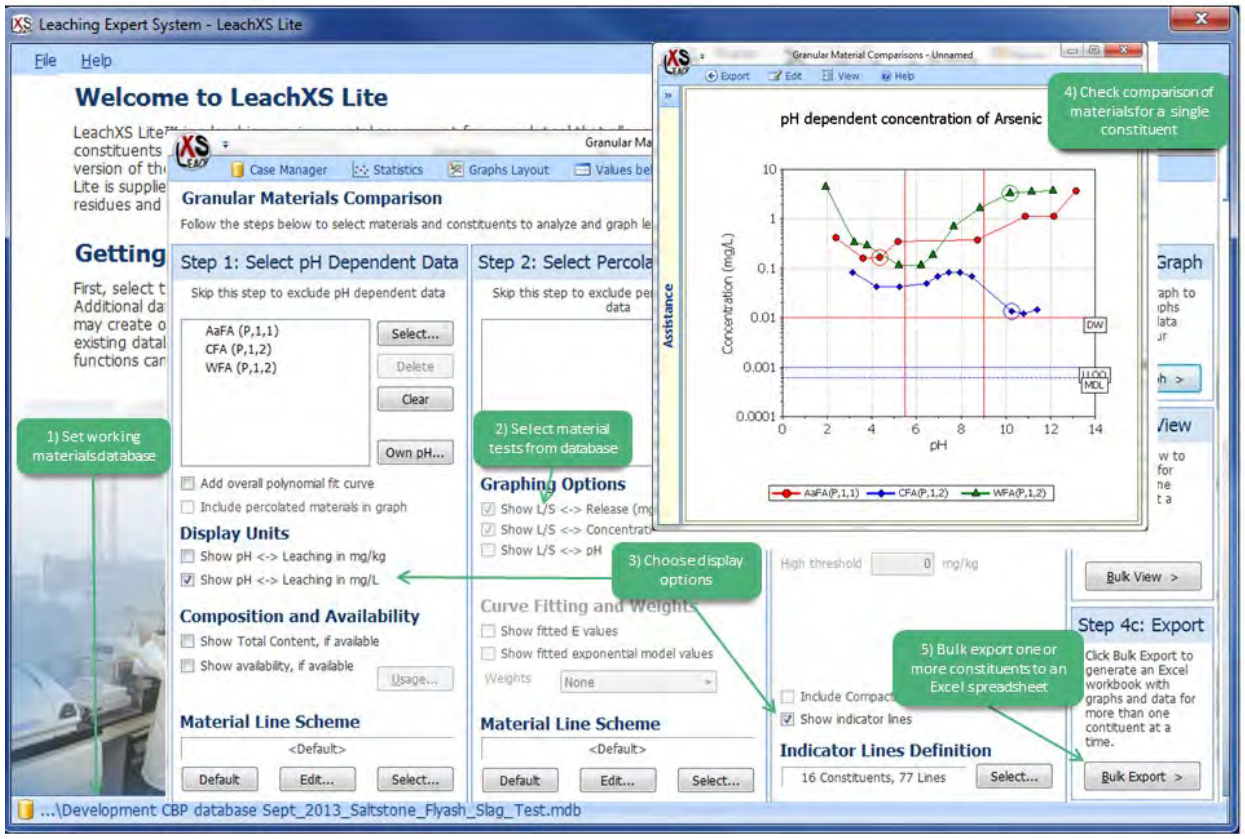


Figure 3-12. LeachXS™ Lite interface for comparison of granular materials showing the approach for comparing pH-dependent arsenic data for three CCR materials.

3.3.3 Pre-Existing Leaching Data

LeachXS™ Lite contains data on a limited number of samples analyzed through EPA support and other data that is publicly available. A wider spectrum of leach test results from data collected over several decades is available in the LeachXS™ database (available at *www.vanderbilt.edu/leaching*; accessed May 2, 2016). The comprehensive database includes LEAF test results from more than 250 waste types, secondary materials, contaminated soil, mineral processing slags, sludges, mine tailings, industrial waste streams (e.g., red mud), fertilizers, municipal solid waste and incineration residues, and construction products. In addition, users of LEAF and LeachXS™ Lite will generate additional data on materials of interest as testing continues. Such pre-existing LEAF data for a particular waste material or material type can be helpful in the understanding of a subject material and useful to inform testing schedules and possibly reduce testing costs.

For example, the material database contained within LeachXS™ Lite contains the leach test results that supported the EPA evaluations of CCRs from power plants employing different air pollution control technologies and burning different types of coal (U.S. EPA, 2006a, 2008, 2009). These materials include a number of samples of coal combustion fly ash, flue gas desulfurization (FGD) gypsum, and several combined CCR waste streams. CCR generators can compare LEAF leaching test method results for their materials to the existing LeachXS™ Lite data to put their materials into perspective of the wider range of

similar materials and to better understand CCR leaching potential from the interpretation of leaching data from these EPA evaluations.

For materials that are generated and evaluated on a regular or ongoing basis, pre-existing leaching data may be helpful for optimizing the assessment process. The scope of a testing program to characterize a waste can be potentially focused to obtain missing data or to evaluate consistency with previous material characterizations. Periodic testing of continuous or near-continuous waste streams can inform the industrial process as the long-term variability of leaching performance is established through time-dependent sampling and characterization.

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4. Developing Leaching Evaluations using LEAF

In general, a leaching assessment can be described as developing a leaching source term by estimating COPC release to the environment resulting from material contact with infiltrating rain or with groundwater. One or multiple LEAF tests can be used in an assessment depending on the parameters needed to represent the material when placed in the environment. The progressive nature of the LEAF framework tests allows assessment to occur in a stepwise progression with evaluation as to whether the results at each step are adequate to support a determination that the material is appropriate for the planned use or disposal. If the results at each step are not adequate, additional testing or more-detailed evaluations may be conducted to provide assessments that more fully reflect release in the anticipated placement. For example, a relatively simple screening assessment comparing the results of an individual LEAF test method directly with COPC target values (e.g., drinking water MCLs) may provide adequate support in some assessments when no COPC target values are exceeded at any pH value, or over the plausible range of pH values. However, when screening assessments cannot provide adequate supporting results, further testing (e.g., Method 1314 and/or Method 1315) and site-specific data may be required to develop a leaching source term that considers the effects of field conditions for a particular scenario and the time varying leaching behavior (referred to as a "scenario assessment"). Additionally, leaching assessments for some cases may utilize empirical or numerical modeling to describe the movement of COPCs from the source term derived from one or more LEAF test methods to a defined point-of-compliance.

Using a "source-to-compliance point" approach, the leaching test results are material specific in that they are only a function of the material leaching performance; the source term accounts for the release under the environmental conditions of the application scenario; and the source term may be used with dilution and attenuation factor(s) (DAFs) or as an input to fate and transport models to account for the location-specific point-of-compliance or source-to-receptor factors (in some cases, the POC may be treated waste prior to disposal, or the outer edge of contaminated soil that has been treated in-place, without use of groundwater transport modeling i.e., a DAF with the value 1). Results from this form of evaluation can be used to back-calculate from thresholds at the point of compliance or to develop threshold values directly comparable to leaching test results for specific scenarios. In addition, this approach allows for substantial decoupling of leaching test results, source term models, and location-specific factors to allow greater generalization of the approach and applicability of leaching test data. This approach allows users to generate "what if" model simulations to understand likely changes in release/risks for the material under hypothetical conditions.

This chapter explains how to develop a leaching evaluation utilizing the LEAF test methods. A leaching evaluation requires determining the appropriate tests and testing parameters and then understanding how laboratory scale results can be translated to field settings. The appropriate selection of leaching tests will depend upon both material properties and the anticipated environmental conditions, as well as on the environmental decision that testing is intended to support. In some cases, a simple evaluation with minimal testing will provide sufficient results that adequately support environmental decision-making. A more thorough and complex evaluation may be needed when there is large uncertainty in the leaching of a material due to possible changing environmental conditions, high waste heterogeneity, or waste generated in high volumes (where more certainty about release potential may be needed). Alternatively,

a more thorough leaching evaluation may be warranted when the estimated leaching is close to a regulatory threshold, where more certainty about the release potential would also be needed.

4.1 Applications of LEAF

LEAF has been used for leaching assessment of CCRs in both disposal and reuse situations, for evaluating waste treatment effectiveness and in other assessments. These uses illustrate that it can be used to estimate constituent leaching from a wide range of inorganic materials as-is, or under environmental scenarios relevant for the beneficial use, treatment, and disposal of waste:

- Materials types for which LEAF is applicable include wastes, treated wastes (e.g., materials treated by solidification/stabilization), secondary materials potentially being re-used (e.g., blast furnace slags, bauxite residues), energy residuals (e.g., coal combustion fly ash), contaminated soils and sediments, and mining and mineral processing wastes.
- Scenarios that can be evaluated using LEAF include, but are not limited to, coal combustion residue (CCR) disposal units, large or small scale use of secondary materials in concrete or road construction, management of mining and mineral processing wastes, evaluation of soil amendments, and evaluation of treatment effectiveness for contaminated soils, sediments, and wastes.
- LEAF leaching tests provide data that can be used to address a range of assessment objectives including simple screening assessments to evaluate material acceptability for a selected disposal or use application, consistency testing during and after treatment of waste or contaminated materials, and development of detailed leaching source terms for driving more complex fate and transport models.

The factors addressed by the LEAF leaching tests include the most significant determinants of leaching for most solid materials under most disposal or use conditions, including wastes and secondary materials (U.S. EPA, 2014c). The framework recognizes that some factors (e.g., reducing conditions), may be important for certain materials and field scenarios, but are difficult to evaluate reproducibly in a laboratory setting. However, their effects on the leaching process may be evaluated using LEAF test results in conjunction with geochemical speciation modeling. Section 4.3 provides examples of additional factors, typical COPC leaching behaviors and considerations when developing leaching assessments.

4.1.1 Material Characterization

LEAF was developed for the assessment of a broad range of materials; however, the need to assess CCR leaching proved to be an opportunity to refine and validate LEAF for inorganic constituents. As a result, the initial development of LEAF was directed at evaluating and comparing leaching potential of CCRs generated by facilities burning a range of coal types and utilizing various air pollution control technologies. LEAF was used to assess the potential leaching of mercury and other metals from CCRs over the range of field conditions to which CCRs are typically exposed during land disposal and in engineering and commercial re-use applications (Thorneloe et al., 2010; U.S. EPA, 2006a, 2008, 2009). The LEAF methods also provided leaching data in support of EPA's assessment of the potential hazards from using coal fly ash as partial replacement of cement in making concrete (Garrabrants, Kosson, DeLapp, & van der Sloot, 2014; Kosson et al., 2014; U.S. EPA, 2012b, 2012d, 2014a).

4.1.2 Beneficial Use Evaluation

LEAF has also been applied to leaching assessments estimating the environmental impacts from utilization of secondary materials, primarily as construction materials. The pH-dependent and L/S-dependent leaching behavior of contaminated dredged sediments for potential replacement of sand in the manufacture of controlled low-strength material, or flowable fill, has been characterized using LEAF tests (Gardner, Tsiatsios, Melton, & Seager, 2007). The LEAF approach has been used to evaluate the reuse of coal fly ash as road base material and construction of embankments; municipal solid waste incinerator (MSWI) bottom ash as road base; and secondary materials (e.g., coal fly ash, recycled concrete aggregate, furnace slags) used as partial substitutes for Portland cement or admixtures in cement and concrete construction products (U.S. EPA, 2014c). In Europe, leaching procedures analogous to the LEAF methods (see Appendix A) have been used to evaluate materials such as coal fly ash, recycled concrete aggregate or municipal solid waste incinerator bottom ash for reuse in road bases and embankments (Engelsen et al., 2010; Engelsen, Wibetoe, van der Sloot, Lund, & Petkovic, 2012), and use of a byproduct from the aluminum industry as soil amendment (Carter, van der Sloot, & Cooling, 2009). In China, LEAF methods have been used to evaluate the environmental safety of use of sewage sludge compost as an agricultural amendment (Fang, et al., 2017, 2018). Leaching data from LEAF or other relevant leaching tests can be used in EPA's *Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials,* which presents a voluntary approach for evaluating potential adverse impacts to human health and the environment from a wide range of industrial non-hazardous secondary materials and their associated beneficial uses. Prior to beneficially using secondary materials in any projects, interested individuals or organizations should consult with the relevant state and federal environmental agencies to ensure proposed uses are consistent with state and federal requirements.

4.1.3 Treatment Effectiveness

LEAF leaching test methods have also been applied to evaluate treatment effectiveness for remediation or disposal purposes for industrial wastes such as soil, sludge, and slag using stabilization/solidification technologies. In these cases, leachability is considered a primary performance parameter used to assess treatment effectiveness because it indicates the ability of a treatment material to retain or immobilize a specific set of site contaminants of concern (Pereira, Rodriguez-Pinero, & Vale, 2001). Additional examples of application of LEAF leaching test methods for treatment effectiveness include evaluation of treatment process effectiveness for contaminated soils (Sanchez et al., 2002; U.S. EPA, 2003).

4.1.4 Miscellaneous Uses

In Europe, leaching tests analogous to the LEAF methods have been used to develop regulatory criteria for construction products that may be used on the ground (BMD, 1995; SQD, 2007; Verschoor et al., 2008) and guidelines for assessment of sustainable landfill in the Netherlands (Brand et al., 2014). Additionally, leaching tests were used as the basis for evaluation of ecological toxicology (ecotox) testing of soils and wastes (Postma, van der Sloot, & van Zomeren, 2009). These applications are beyond the scope of this guide.

4.2 Developing an Assessment Framework

The goal of environmental leaching assessments is to provide an estimate of the leaching potential of constituents in a material for a plausible management scenario that is as accurate as practical or needed, but also represents an upper bound that does not underestimate the release of COPCs. LEAF leaching test

methods can be used effectively to estimate the field leaching behavior of a wide range of materials under both disposal and use conditions. However, it is important to interpret the leaching test results *in the context of the controlling physical and chemical mechanisms of the field scenario* (U.S. EPA, 2014c). The application of laboratory testing results to environmental decision-making requires comparability of the laboratory data with threshold or limit values at a defined point of compliance or location. This comparison may be achieved through (i) screening assessments (i.e., comparisons of bounding leaching concentrations based directly on test results with threshold values), (ii) scenario-based assessments for percolation and/or mass transport scenarios, or (iii) subsequent analyses such as the combining of LEAF source terms with fate and transport or geochemical speciation modeling representing environmental processes not accounted for by LEAF.

The first step in developing an assessment is to define the objectives of the assessment and the parameters of the potential material use or disposal scenario. These definitions will support the subsequent selection of appropriate leaching tests and will provide the basis for interpreting and applying the resultant leaching data. The assessment scenario is described by a conceptual model of constituent leaching that considers the physical and leaching characteristics of the material when doing a screening assessment. When conducting a scenario-based assessment, details about its anticipated placement (i.e., quantity, depth or height, footprint, porosity, etc.), the net amount and mode of water contact, the water quality, would be added to the waste characteristics data.

4.2.1 A Stepwise Assessment Approach

When developing an assessment approach using multiple tests to evaluate leaching in a scenario, the assessor can consider the information provided by each test in a stepwise fashion. Starting with the simplest tests and considering the expected results before moving on to more elaborate testing schemes allows for developing the appropriate leaching evaluation tailored to the environmental scenario. The LEAF assessment approach can be viewed as a set of progressive steps, whereby each successive step becomes more accurate by more fully reflecting site conditions present in the environment. However, each successive step requires an additional level of testing and interpretation. Screening assessments can provide increasingly refined estimates of the maximum leaching concentration (considered an “infinite source”) for each COPC, while scenario assessments provide estimates of the time varying leaching concentration and the amount of each COPC that may leach (i.e., a “finite source”). LEAF provides flexibility in developing an assessment approach because the amount of testing and effort can be tailored to the assessment, depending upon the objectives of the assessment and the relevant information regarding the material and the environment. An illustration of the hierarchy in this stepwise approach to leaching assessment is provided in Figure 4-1. LEAF provides user flexibility in that an evaluation may utilize one to four methods depending on the assessment objectives and project scope. A LEAF evaluation may vary from a simple screening estimate using the results of a single test method to a comprehensive evaluation of leaching behavior of multiple COPCs that encompass the results of all four LEAF methods. The selection of an evaluation approach will result in differing amounts of material required for testing and scenario specific information that required to conduct the assessment. Table 4-1 illustrates testing plans in screening based assessments (described in section 4.2.4). Table 4-2 illustrates testing plans for use in scenario-based assessments (described in section 4.2.5)

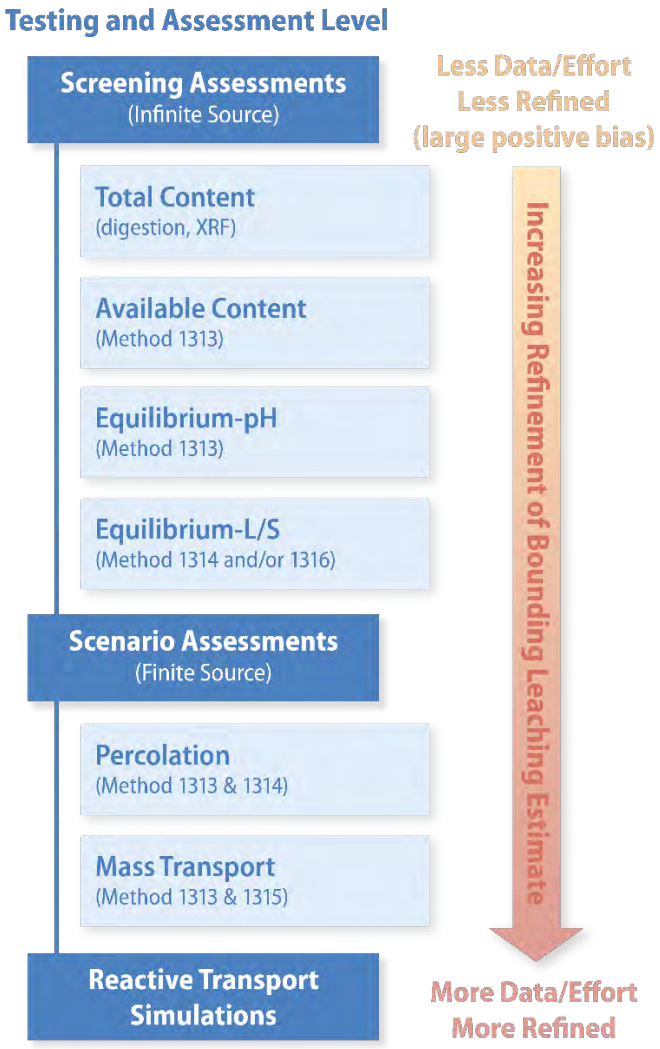


Figure adapted from Kosson and van der Sloot (2015).

Figure 4-1. Example assessment hierarchy presenting options for progressively working from more bounding assessments to less bounding assessments based on levels of leaching information.

4.2.2 Assessment Objectives

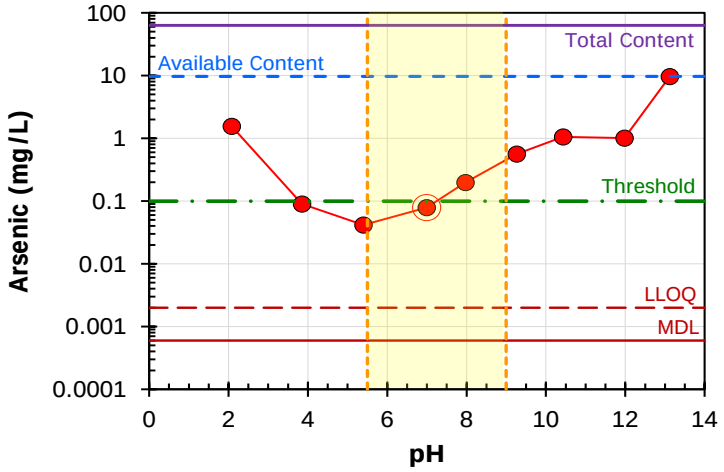
Since the LEAF approach is intended to be flexible and to follow a stepwise methodology, the objectives for conducting an assessment determine the amount of testing and data analysis required. For example, a relatively simple screening assessment typically requires less testing and interpretation than a more-complex "source-to-compliance point" assessment. The objectives of the assessment should address the decisions anticipated to be made, the nature and physical structure of materials to be tested, the potential scenarios that may be evaluated, and all applicable regulations or constraints. Definition of these objectives can follow the Agency's data quality objectives process (U.S. EPA, 2006b) whereby the data quality objectives or questions to be answered for a specific circumstance (e.g., beneficial use of a material, site characterization) may influence the decision to use LEAF and the selection of a testing program.

One outcome of defining the assessment objectives is the identification of the appropriate leaching assessment level (e.g., screening assessment vs. detailed characterization) required to meet the assessment objectives. The extent of information needed as part of the scenario definition increases as the evaluator seeks to achieve a more detailed and refined (and potentially, site-specific) estimate of constituent leaching. For example, screening level assessments, which seek to determine the acceptability of a material for a particular management scenario based on direct comparison of leaching test data to exposure limit values, such as MCLs, may only require a single test (e.g., Method 1313 or 1314) to provide an adequate basis for making a scientifically supported decision. Detailed characterization to support a complex fate and transport model between the leaching source term and a point of compliance will require integration of leaching data from several leaching tests and incorporation of knowledge of the environmental scenario. The assumptions used when defining assessment objectives and determining information needs should be fully described so that results between assessments can be meaningfully compared.

4.2.3 Comparing Test Results to Threshold Values

4.2.3.1 Direct Comparison of Eluates to Threshold Values

Depending on the defined assessment scenario and the regulatory program, relevant benchmarks may be derived from drinking water maximum contaminant levels (MCLs), national recommended water quality criteria, or EPA regional screening levels (RSLs); however, a set of specific benchmarks should be determined on a case-by-case basis based on assessment objectives and all associate constraints and limitations. Figure 4-2 illustrates a graphical comparison of leaching results over a range of pH values to the regulatory limit for a particular constituent, and to the total content of the constituent in the material that was evaluated. When used to evaluate materials, the LEAF leaching test method results can be used as the source term for risk assessment to generate estimated risk distributions that can form the basis for environmental decision-making. This example is for illustrative purposes; users should consult with the appropriate regulatory body to select appropriate acceptance criteria.



Adapted from Kosson et al. (2002).

Figure 4-2. Method 1313 LSP results over an applicable pH domain compared to total content, available content and a reference threshold.

When leaching under a plausible range of conditions is demonstrated to be below threshold values for all COPCs, it may be possible to conclude that the proposed application of the material is acceptable provided that all regulatory requirements have been met (U.S. EPA, 2012e). However, direct comparison of eluate concentration to benchmark concentrations (e.g., as illustrated in Figure 4-2) does not always complete an evaluation. Furthermore, the threshold values used in comparison should be relevant to the type of testing results being compared. For example, eluate concentrations from Method 1315 results are used for calculating fluxes and are not reflective of expected maximum leaching concentrations. Thus, Method 1315 eluate concentrations should not be applied to comparisons with threshold concentrations; whereas, the Method 1315 COPCs flux may be used after consideration of the relative amount of contacting water to exposed surface area in the assessment scenario. When comparing Method 1313 results to benchmark concentrations, the pH of Method 1313 and the pH of the benchmark may differ. One approach is to interpolate between two endpoint pH values from Method 1313 (see Section 4.4.2.)

The screening-level assessment of leaching in a particular application can follow the stepwise approach described in Section 4.2.1. Typically, the threshold criteria against which potential leaching of COPCs is evaluated (e.g., drinking water MCLs, surface water quality concentrations, etc.) are expressed as concentrations and, therefore, estimates of COPC leaching should be derived on a similar basis as concentrations. Screening assessments utilize estimates of maximum leaching concentration, C_{leach_max}, derived from a limited dataset of COPC leaching (e.g., from total content analysis or one or more LEAF tests) which are adjusted to an initial L/S value, $(L/S)_{initial}$. The initial L/S value can be a default value of 0.5 L/kg-dry, an estimate of porewater L/S based on materials properties,[13] or an L/S estimate that reflects the maximum expected leachate concentration for the specified scenario. For illustrative purposes, the default value of 0.5 L/kg-dry will be used in all examples of this guide.

For simple screening assessments, the maximum leaching concentration may assume that the total content of a COPC is leached into an initial L/S, while more-complex screening assessments may utilize the broader range of leaching behavior (e.g., Method 1313 and Method 1316) to estimate the maximum leaching concentration over a range of scenario conditions. All screening assessment assumed an infinite source of leaching based on results obtained from testing the material or treated material[14] as it would be used or disposed.

4.2.3.2 Assessment Ratios

The comparison between the estimated maximum leaching concentration (C_{leach_max}) and threshold limit concentrations (C_{thes}) can be illustrated by a simple ratio of the leaching concentration of a COPC divided by the target threshold value. For purposes of this document, this is referred to as an assessment ratio (AR), which considers the maximum leaching estimate and threshold concentrations.

$$AR = C_{leach\_max}/C_{thres} \qquad \textbf{Equation 4-1}$$

[13] The lower bound for the porewater L/S of a material can be estimated using the skeletal density, ρ_s [kg_{solid}/m^3_{solid}], and a bulk porosity, ε [m^3_{pore}/m^3] as ε /(1- ε)/ ρ_s *1,000 where 1,000 is a conversion factor for volume (1,000 L/m^3).

[14] Blending a material with soil or lime would be considered a treatment, and, therefore, the material should be tested "as used" considering the mixture. Separate testing and modeling can be used to predict the behavior of mixtures of materials; such testing and modeling is beyond the scope of this document.

where

AR	is the assessment ratio [-];
C_{leach_max}	is the estimated maximum concentration for the COPC [mg/L]; and
C_{thres}	is the threshold value for the COPC [mg/L].

When the assessment ratio for a COPC is less than or equal to 1 ($AR \leq 1$), the constituent is not likely to leach at concentrations greater than the threshold limit concentration under the anticipated scenario conditions and further evaluation may not be required. An assessment ratio greater than 1 ($AR > 1$) does not necessarily indicate that a COPC will leach at a level greater than the threshold limit concentration in the field but does indicate that further evaluation is required to refine the assessment. For example, a decision-maker may choose to perform additional leach testing using other LEAF methods to develop a more refined source term for COPC leaching or may modify the planned use in some way to reduce the release potential (e.g., a change in the environmental application).[15] Additionally, LEAF test results could be used as an input to groundwater fate and transport modeling to estimate the degree of offsite migration and potential for groundwater contamination. Additional LEAF leaching test results could result in a more refined modeling of the potential release. See Section 4.4.7 for consideration of dilution and attenuation within an Assessment Ratio.

[15] In research partially supported by U.S. EPA (e.g., use of 20 percent coal fly ash in making concrete could reduce fivefold the amount of COPC available to leach; Garrabrants et al., 2014; Kosson et al., 2014; U.S. EPA, 2012b), blending of fly ash into concrete as a replacement for Portland cement allowed for reuse of a secondary material without significant impact. The replacement ratio of 20% of the Portland cement fraction reduced the available content for some COPCs fivefold over the available content in fly ash alone; however, lowering the replacement ratio would further reduce the available content of fly ash COPCS in the concrete product.

Table 4-1. Summary of Suggested Test Methods and Analyses for Screening Assessments.

Test Methods	Eluate Analyses	Assessment Attributes
Step 1 – Total Content Screening (*if determined*)		
Total Content: digestion, XRF, etc.	COPCs	• Total content mass release [mg/kg-dry] converted to estimated maximum leaching concentration (C_{leach_max}) through division by a scenario L/S value [L/kg-dry]. • Conversion of total content [mg/kg] to dry mass basis [mg/kg-dry] is necessary using solids content or moisture content (wet basis).
Step 2 – Available Content Screening		
Method 1313: pH 2, 9, and 13	pH, EC,[1] COPCs, DOC	• Basis for infinite source term; assumes available content is maximum cumulative release under field conditions. • Available content mass release [mg/kg-dry] derived from maximum leachate concentration at Method 1313 endpoint target pH extractions at 2, 9, and 13. Target pH values in Method 1313 can be reduced to only those demonstrated to achieve maximum eluate concentration as used for available content determination. • Estimated maximum leaching concentration (C_{leach_max}); adjusted to initial L/S (default 0.5 L/kg-dry).
Step 3 – Equilibrium-pH Screening		
Method 1313: Applicable pH domain[2] and pH 2, 9, and 13	pH, EC,[1] COPCs, DOC	• Basis for infinite source term over applicable scenario pH domain; assumes equilibrium concentrations as an upper bound of leaching under field conditions. • Available content as indicated above; used to determine solubility-limited vs. available content-limited leaching. • Acid/base neutralization capacity to pH ≈ 7 relevant to evaluation of neutralization due to long-term aging processes (e.g., carbonation, acid attack). • Estimated maximum leachate concentration (C_{leach_max}) determined as the maximum eluate concentration over the applicable pH domain for solubility-limited constituents; adjusted to initial L/S (default at 0.5 L/kg-dry) for available content-limited COPCs.[3]
Step 4 – Equilibrium-L/S Screening		
Method 1313: Applicable pH domain[2] and pH 2, 9, and 13 and *Method 1314 or Method 1316:* Full set of L/S values	pH, EC,[1] COPCs, DOC	• Basis for infinite source term at low L/S; assumes eluate concentrations at low L/S are comparable to porewater. • Estimated maximum leachate concentration (C_{leach_max}) for solubility-limited and available content-limited leaching constituents determined as greater of maximum eluate concentration over the applicable pH domain or maximum eluate concentration over the L/S range.[4] • Supplemental basis for determination of solubility-limited vs. available content limited leaching when evaluated along with Method 1313 data.

[1] Electrical conductivity (EC) measurement in Method 1313 is recommended for natural pH eluate only due to interferences provided by acid/base additions.

[2] An applicable pH domain for an assessment scenario is determined by extending the default pH domain ($5.5 \le pH \le 9.0$) to include the natural pH of the material and adjustments required from consideration of the chemical composition of the contacting water, interfaces or commingling with other materials, and long-term changes in pH due to material aging processes.

[3] For many applications, available content-limited species include the Group IA cations (e.g., Na, K) and anions (e.g., Br^-, Cl^-, F^-, NO_3^-). In addition, oxyanions (e.g., As, B, Cr, Se, Mo, V) may display available content-limited leaching on a case-by-case basis.

[4] For some cases, the maximum concentration over the applicable pH domain from Method 1313 may be less than the maximum concentration over the L/S range from Method 1314 because of aqueous phase complexation by increased concentration of DOC or other constituents at low L/S values in Method 1314. Method 1314 results also can be used to provide a basis for narrowing the applicable pH domain for evaluation of Method 1313 results to the pH range observed during Method 1314, with 0.5 pH units added to the maximum pH observed and 0.5 pH units subtracted from the minimum pH observed during Method 1314, unless known aging processes would result in a broader pH domain (e.g., carbonation of alkali cement materials may result in observed pH values as low as pH 7).

Table 4-2. Summary of Suggested Test Methods and Analyses for Scenario-Based Assessments.

Test Methods	Eluate Analyses	Assessment Attributes
Percolation Through Permeable Material Scenario Assessment		
Method 1313: Full endpoint target pH values and *Method 1314:* Full set of L/S eluates or *Method 1316:* Full set of L/S eluates	pH, EC,[2] ORP,[3] COPCs, DOC, DIC, Major/minor constituents[4]	• Basis for infinite source term; assuming LSP with percolating water limited to available mass release. • Available content mass release [mg/kg-dry] at Method 1313 endpoint target pH values of 2, 9, and 13. • Acid/base neutralization capacity to pH ≈ 7 relevant to evaluation of neutralization due to long-term aging processes (e.g., carbonation, acid attack). • LSP as a function of pH providing a baseline understanding of leaching behavior and speciation assessment.[5] • Basis for determination of solubility-limited vs. available content-limited leaching through comparison between pH- and L/S-dependent leaching.[6] • Leachate concentration evolution as a function of L/S for source term development based on test elution curve. • Basis for verification of chemical speciation modeling at low L/S. • Supports fate and transport simulations considering sensitivity of field conditions (e.g., infiltration chemistry, preferential flow, material aging).
Mass Transport Limited Leaching Scenario (Impermeable Material) Assessment		
Method 1313: Full endpoint target pH values and *Method 1314:* Full set of L/S eluates and *Method 1315:* Full set of time intervals	pH, EC,[2] ORP,[3] COPCs, DOC, DIC, Major/minor constituents[4]	Attributes of Percolation Scenario Assessment plus: • Estimate of initial porewater concentration (Method 1314 through cumulative L/S 0.2 L/kg-dry). • Cumulative release and interval flux as a function of leaching time (Method 1315) for saturated and intermittent wetting conditions. • Basis for fate and transport model parameters (e.g., diffusivity, tortuosity) for simulation of evolving conditions (e.g., low liquid-to-surface area, external solution chemistry, carbonation, oxidation, intermittent wetting, etc.).

[1] Prior information, such as characterization information from similar materials, may reduce or supplant extent of equilibrium-based assessment for characterization.

[2] Electrical conductivity (EC) measurement in Method 1313 is recommended for natural pH eluate only due to interferences provided by acid/base additions.

[3] Oxidation reduction potential (ORP) measurement in Method 1313 is recommended for natural pH eluate only due to interferences provided by acid/base additions. ORP provides useful indications of material properties under abiotic and anoxic conditions, recognizing the sensitivity and uncertainty of ORP measurements.

[4] The list of major and minor constituents should include all constituents that are important to the mineralogy and chemical behavior of the material. At minimum, these constituents would include Al, Ba, Ca, Cl, Fe, Si, Mg, Na, P and S for many materials.

[5] Speciation assessment refers to evaluations and/or simulations that consider the effects of changes in pH, redox conditions, extent of carbonation, complexation with dissolved organic carbon, etc. on COPC release. Such assessments may be accomplished heuristically or in combination with geochemical speciation modeling.

[6] For many applications, available content-limited species include the Group IA cations (e.g., Na, K) and anions (e.g., Br^-, Cl^-, F^-, NO_3^-). In addition, oxyanions (e.g., As, B, Cr, Se, Mo, V) may display available content-limited leaching on a case-by-case basis.

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4.2.4 Screening Level Assessments

One approach to a leaching assessment that offsets the level of detail obtained from testing against the increased effort to provide more refined source terms is a series of screening approaches. These screening approaches are not required but may be used to determine whether more-detailed assessments (e.g., scenario-based assessments) are necessary or whether screening test results alone adequately support environmental decision-making. In some scenarios, the leaching behavior of COPCs may be screened against threshold values based on a source term that estimates leachate concentrations for the total content, available content, and equilibrium LSP (Figure 4-3). The levels of the screening approach allow for a trade-off between progressive refinement of a bounding estimate of potential leachate concentration against increased testing and analysis effort. The intent of a screening assessment is to determine which constituents are relevant to the scenario (i.e., which COPCs are likely to leach in concentrations presenting a threat to human health and the environment). Screening assessments utilize results from limited testing and default or minimal assessment scenario information to provide upper bound estimate of leaching (i.e., "not expected to exceed" concentrations). In the most conservative estimates, a screening may be based on an "infinite source" leaching assessment[16] that can be compared to threshold values (e.g., the total concentration of a COPC may be less than a threshold value). However, screening approaches should consider finite sources when possible.

An example of how these testing schemes may estimate environmental leaching is shown below in Figure 4-3. In an example screening application, an assessor may be already aware of or test for the total content of a COPC in a material. The total content value provides an upper limit on the amount of material that can be released. A screening use of Method 1313 with pH endpoints of 2, 9 and 13 will provide the assessor with an estimate of the available content of COPCs within the material. If a more specific pH domain of the environment is known, the assessor can choose to tailor Method 1313 to provide a better estimate of equilibrium-controlled leaching. If the assessor is aware that percolation effects will control leaching, Method 1314 provides additional information on the expected leaching behavior in the environment.

[16] An "infinite source" assumes that leaching will continue without change in COPC concentrations over infinite time (i.e., the COPC will never become depleted from the material). More advanced assessments typically assume a "finite source" whereby the COPC becomes depleted within the material once the available content has been leached.

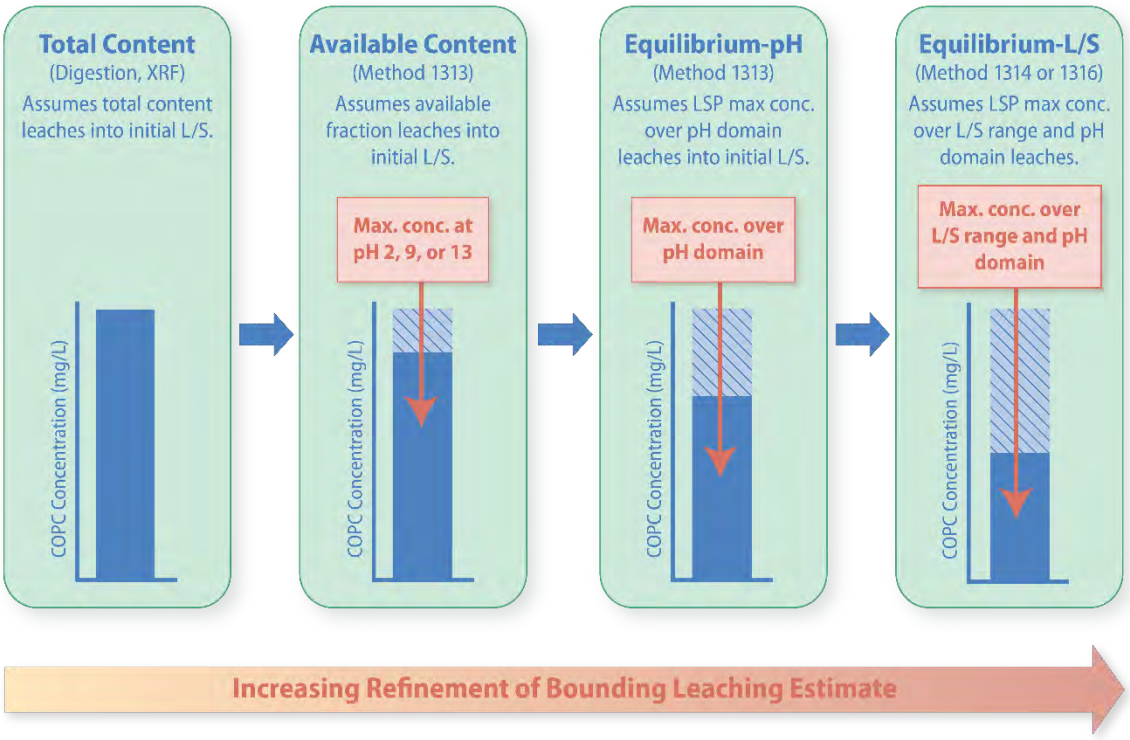

Figure 4-3. Screening level assessments, test methods and assumed leaching conditions[17].

Screening level assessments may recognize that not all COPCs are present in the material at sufficient concentration to be of concern and that not all COPCs present will leach under all scenario conditions. Therefore, the goal of the assessment is to identify and separate material constituents that may leach at less than or equal to the identified benchmark or threshold values from those COPCs that may be a concern. Constituents with upper bound leaching estimates less than benchmarks or thresholds would not require further analysis whereas an evaluation of COPCs with values that exceed benchmarks or thresholds may benefit from subsequent characterization and analysis.

A screening-based assessment generally assumes limited or partial information regarding the material and its placement into the environment when developing a leaching assessment. The more information that is available regarding the material and the environment, the more accurately a testing and analysis plan can reflect environmental conditions in the field. The flexibility provided by LEAF allows for the development of a range of assessments from a simple screening-based assessment with limited testing and limited environmental information to advanced scenario-based assessments with more elaborate testing and source term model development to evaluate anticipated environmental field conditions. A screening level assessment can be compared to relevant threshold values to identify and separate COPCs not likely to adversely impact the environment at threshold levels from COPCs for which further testing is required. Screening assessments often provide higher estimates of leaching than scenario assessments due to relying on estimates of maximum leachate concentrations or available content estimates.

[17] The max concentrations shown are illustrative and may differ by orders of magnitude depending on the testing and material.

4.2.4.1 Total Content Screening

Total content is the concentration of a COPC within the solid material [mg/kg$_{dry}$] that may be derived from destructive or non-destructive total analysis of the solid material. The total content of COPCs in a material (m_{total}) is obtained through analytical methods such as solid phase digestion (e.g., U.S. EPA Method 3052) or other total elemental analysis (e.g., X-ray fluorescence). Because this source term does not require any LEAF methods, it can serve as a useful first step when the bulk content is known from prior knowledge (e.g., available literature) or testing. This source term assumes that the entire bulk content of a material is released into the water immediately, resulting in the highest concentration that is physically possible, albeit unlikely.

The bulk content from digestion methods may be reported on a wet-mass basis [mg/kg], which will result in an incorrect estimation of releases if not converted into a dry-mass basis. Conversion between wet and dry bases requires knowledge of the moisture content of the material on a wet mass basis or, alternatively, the solids content. Equation 4-2 presents the conversion between wet and dry weight:

$$m_{total,dry} = (m_{total,wet})(SC) = (m_{total,wet})(1-MC_{dry}) \quad \textbf{Equation 4-2}$$

where

$m_{Total,dry}$	is	Bulk content adjusted to a dry mass [mg/kg-dry]
$m_{Total,wet}$	is	Bulk content reported on a wet mass [mg/kg]
MC_{dry}	is	Moisture content of the material [kg-H2O/kg]
SC	is	Solids content of the material [kg-dry/kg]

If total content of the COPCs in the material, m_{total}, is known from prior knowledge or obtained through a solid phase digestion method (e.g., U.S. EPA Method 3052) or other total elemental analysis (e.g., X-ray fluorescence), then the estimated maximum leaching concentration (C_{leach_max}) may be calculated by adjusting the total content on a mass basis for the initial L/S: [18]

$$C_{leach\_max} = m_{total}/(L/S)_{initial} \quad \textbf{Equation 4-3}$$

where

C_{leach_max}	is the maximum concentration based on total content
m_{total}	is the total content of a COPC [mg/kg-dry]; and
$(L/S)_{initial}$	is the initial L/S [L/kg-dry].

The calculated concentration is assumed to remain constant in all releases over the timeframe relevant to the assessment. Since it is likely that only a fraction of the total content is actually available to leach, use of total content to estimate the maximum leaching concentration should be considered the upper-

[18] Evaluation of field L/S values (i.e., Cases 5 and 8 in U.S. EPA, 2014c) demonstrated that an effective porewater L/S of 0.5 L/kg-dry is appropriate for coarse landfilled materials subject to percolation and preferential flow, resulting in a multiplier of 20 to adjust the eluate concentrations measured using Method 1313. L/S may be expressed in equivalent units of L/kg-dry that are typically used for the scenario scale or units of mL/g-dry that are typically used in laboratory testing (e.g., 10 L/kg-dry = 10 mL/g-dry).

most bound on possible concentrations. This maximum concentration is likely to overestimate the actual leaching of COPCs by a significant margin (i.e., one or more orders of magnitude). However, if total content data is obtained through either testing or prior knowledge, this initial step in the screening assessment sequence is easy to execute and may focus subsequent assessment effort on only those COPCs that have a potential to leach based on a significant presence in the material.

4.2.4.2 Available Content Screening

Following the stepwise approach, the screening assessment based on total content may be refined to consider only the fraction that is available to leach from the material. As discussed in detail in Section 4.4.1, the eluate concentration associated with available content of a COPC can be determined directly from Method 1313 extractions conducted at endpoint target pH values of 2, 9 and 13. The pH endpoint values of 2 and 13 provide a bounding estimate for the amount of leachable material over a broad pH range.

By test specifications, the available content concentration from Method 1313 data is determined at an L/S of 10 L/kg-dry. However, the concentration used in the screening assessment should be adjusted to the initial L/S by multiplying the maximum eluate concentration ($C_{1313(max\ pH\ 2,9,13)}$) by the ratio of the method-specific L/S for Method 1313 [$(L/S)_{1313}$ = 10 L/kg-dry] to the initial L/S, $(L/S)_{initial}$:

$$C_{leach\_max} = C_{1313(\max pH\ 2,9,13)} \times (L/S)_{1313}/(L/S)_{initial} \qquad \textbf{Equation 4-4}$$

Based on a default initial L/S value of 0.5 L/kg-dry, the resulting multiplier for the maximum Method 1313 eluate concentration over the pH domain in the equation is 20 (i.e., 10 L/kg-dry divided by 0.5 L/kg-dry):

$$C_{leach\_max} = C_{1313(\max pH\ 2,9,13)} \times \frac{10}{0.5} = 20 \times C_{1313(\max pH\ 2,9,13)}$$

For cases where available content is known or reported as a mass release [mg/kg-dry] but the underlying concentrations [mg/L] from Method 1313 are not known, the maximum leaching concentration may be estimated in the same manner as for the total content.

$$C_{leach\_max} = m_{avail}/(L/S)_{initial} \qquad \textbf{Equation 4-5}$$

where

m_{avail} is the available content of a COPC [mg/kg-dry]; and

$(L/S)_{initial}$ is the initial L/S [L/kg-dry].

One advantage of using the available content in a screening approach is that it requires only three Method 1313 extractions at endpoint target pH values of 2, 9, and 13; however, the estimate may be overly bounding because it assumes that the entire available content is leached. For COPCs with low solubility in the near-neutral pH range (e.g., lead, cadmium, chromium, etc.), the estimate of C_{leach_max} may be refined further by considering only that leaching that may occur over the applicable pH domain through equilibrium-based screening assessment.

4.2.4.3 Equilibrium-pH Screening

An equilibrium-based leaching evaluation considers the equilibrium-based partitioning of a constituent between a liquid and solid phase, LSP, over a range of applicable scenario conditions (i.e., pH domain and L/S range) as the basis for COPC release. The estimated maximum leaching concentration, C_{leach_max}, is based on the maximum concentration from interpolated values of Method 1313 over the applicable scenario pH domain, $C_{1313(max\ pH\ domain)}$, with consideration for that estimate for available content-limited COPCs to increase as the L/S decreases to the initial L/S value.

As discussed in Section 4.2.5.1, the applicable scenario pH domain is defined as part of the assessment scenario definition based on the default pH range of 5.5 ≤ pH ≤ 9. However, the applicable scenario pH domain may be adapted for specific materials or assessment scenarios. Typically, the definition of a scenario-specific pH domain considers the natural pH of the material, any established pH values imposed by scenario conditions, and any anticipated long-term neutralization effects.[19] Figure 4-4 presents examples of Method 1313 eluate concentrations, interpolated Method 1313 data, and the maximum concentration over the pH domain for cadmium (cation) and selenium (oxyanion) in three materials matrices – a coal combustion fly ash (CaFA), a contaminated field soil (CFS) and a solidified waste form (SWA). Note that the applicable pH domain for the assessment changes from the default 5.5 ≤ pH ≤ 9.0 used for the neutral pH soil to 7 ≤ pH ≤ 13 for the cement-based solidified waste form in order to capture the natural pH of the material and anticipated environmental process (e.g., carbonation) that may occur over time.

Whether a COPC is availability-content limited or solubility-limited can determine whether the LSP leaching concentration is a strong function of L/S (see Section 4.4.5 for determining solubility-limited leaching versus available content-limited leaching). When a COPC is demonstrated to be solubility-limited over the pH domain (e.g., cadmium for all material and selenium for CFS and CaFA in Figure 4-4,), the LSP concentration is a weak function of L/S. Therefore, C_{leach_max} can be assumed bounded by the maximum concentration in Method 1313 testing of the pH domain, $C_{1313\ (max\ pH\ domain}$:

$$C_{leach\_max} = C_{1313(\text{max pH domain})} \qquad \textbf{Equation 4-6}$$

If a COPC exhibits available content-limited leaching over the pH domain (e.g., SWA selenium in Figure 4-4), the maximum concentration measured over the applicable pH domain is likely to be a function of L/S. The estimated maximum leaching concentration, C_{leach_max}, is derived by adjusting the maximum Method 1313 concentration over the pH domain, $C_{1313(max\ pH\ domain)}$, to the initial L/S, $(L/S)_{initial}$, using Equation 4-7:

$$C_{leach\_max} = C_{1313(max\ pH\ domain)} \times (L/S)_{1313}/(L/S)_{initial} \qquad \textbf{Equation 4-7}$$

Using the default value of 0.5 L/kg-dry as the initial L/S, Equation 4-6 becomes:

$$C_{leach\_max} = C_{1313(max\ pH\ domain)} \times \frac{10}{0.5} = 20 \times C_{1313(\text{max } pH \text{ domain})}$$

[19] Although the applicable pH domain may be a fraction of the domain covered by Method 1313, it is useful to obtain data from the entire range of endpoint pH target values to provide definition of the available content (Section 4.4.1) and identification of available content-limited and solubility-limited leaching (Section 4.4.5).

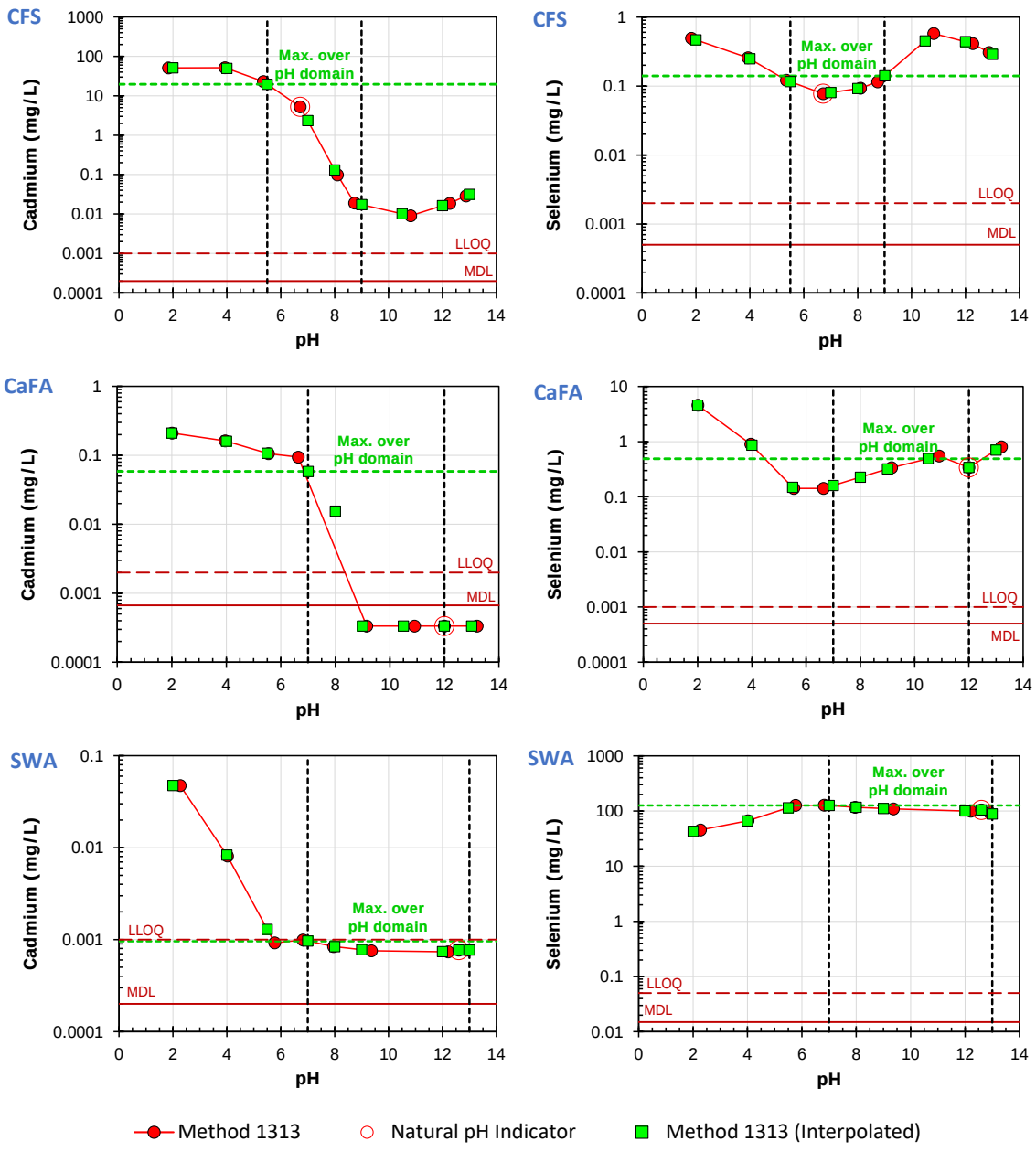

Figure 4-4. Maximum concentration over an applicable scenario pH domain for cadmium (left) and selenium (right) from Method 1313 testing of a coal combustion fly ash (CaFA), a contaminated soils (CFS) and a solidified waste form (SWA).

4.2.4.4 Full Liquid Solid Partitioning (LSP) Screening

In some evaluations, the material and environmental conditions may be uncertain or vary. LSP results from Methods 1313 and L/S results from Method 1314 or Method 1316 can be used to develop an upper estimate under the potential environmental conditions. The LSP screening level assessment builds from the equilibrium-pH assessment in that it assumes that COPCs leach at a maximum concentration associated with the greater of the pH effect over the applicable pH domain, or the L/S-dependent effect

on eluate concentration. Although data from Method 1314 or Method 1316 can be used in this evaluation, the data provided by Method 1314 should be considered over that from Method 1316 in low L/S screenings due to the ability of the column test to capture concentrations at very low L/S values (e.g., < 0.5 L/kg-dry) and the nature of the Method 1316 batch test to mask the evolution of competitive dissolution with L/S (see Section 4.4.4).

The estimated maximum leaching concentration in a full LSP screening, C_{leach_max}, is the greater value between the maximum concentration over the applicable pH domain, $C_{1313(max\,pH\,domain)}$, and the maximum concentration over the L/S range, $C_{(L/S)max}$:

$$C_{leach\_max} = MAX\left[C_{1313(max\,pH\,domain)}, C_{(L/S)max}\right] \qquad \textbf{Equation 4-8}$$

Figure 4-5 presents two examples of data leading to full LSP screening. Barium in solidified waste form (SWA) shows a solubility-limited leaching in Method 1313 and a relatively weak influence of L/S in both Method 1314 and Method 1316 data. Thus, the maximum concentration of barium over the applicable scenario pH domain is significantly greater than maximum eluate concentrations from Method 1314 or Method 1316. Conversely, the LSP data for boron in the coal combustion fly ash (EaFA) shows available content-limited leaching and strong influence of L/S. The estimated maximum leaching concentration for boron used in the full LSP screening assessment would be the greatest concentration at low L/S in Method 1314 (or, alternatively, the highest concentration in Method 1316 in the absence of Method 1314 data).

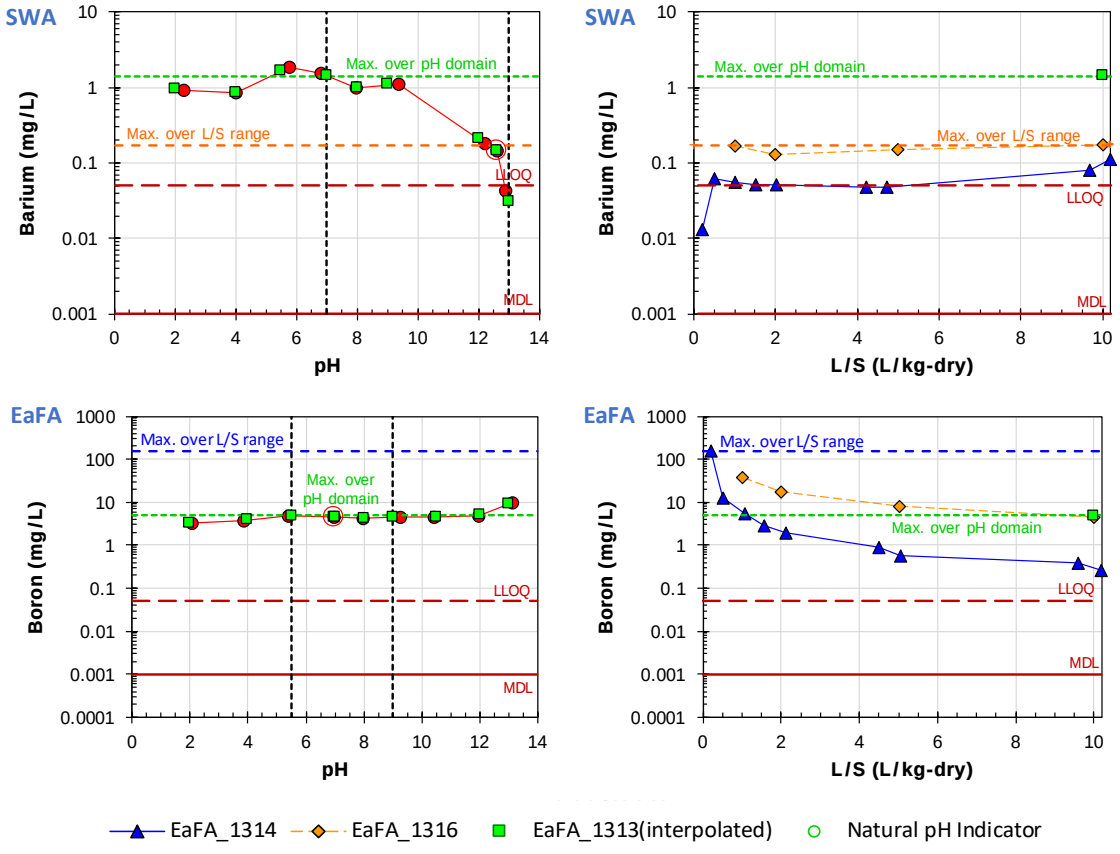

Figure 4-5. Full LSP screening data showing examples where pH effects dominate LSP (barium in solidified waste form, SWA) and where L/S-dependence influences maximum LSP concentration (boron in coal fly ash, EaFA).

4.2.5 Scenario Based Assessments

Screening assessments may provide bounding estimates of leaching in the environment. A scenario assessment may utilize information and testing that provides a more accurate estimate of leaching in the environment. Factors contributing to uncertainty in screening estimates can include use of an assumed "infinite source," reliance on only a limited amount of leaching data, or utilization of default or estimated scenario information. An assessor using LEAF may also have additional information regarding their site or material that can be used in conjunction with data from testing to refine their leaching assessment. These more-refined leaching estimates may be based on parameters derived from site-specific, generic scenario-specific[20] or national assessments of the leaching potential for a material. A site-specific assessment may include representative samples of a specific waste, with defined waste management unit designs, local environmental conditions including metrological and soil data and specific chemical interactions that may occur within the scenario. For a national assessment, LEAF results from numerous samples representative of a waste stream type are used in conjunction with the range of waste management unit designs, national meteorological data, soil types, and other information from numerous units to estimate a national probability distribution of release (U.S. EPA, 2014b). When such a probabilistic source term is used in conjunction with a groundwater fate and transport modeling, exposure pathways and toxicity estimates, a national distribution of risks from disposal or use of the material can be estimated. Similarly, regional assessments would take the same approach with inputs relevant to a region.

For the purposes of determining the applicability of a material for a scenario with respect to leaching performance, the flow chart presented in Figure 4-6 shows that the results from the appropriate LEAF leaching test methods integrate with site- or scenario-specific information to provide an estimated source term under the assumed release conditions. Scenario assessments rely on Method 1313 pH-dependent testing data used in conjunction with time or L/S-dependent data from Methods 1314, 1315 or 1316. The most appropriate method to incorporate with Method 1313 data will depend on the composition of the material, the mode of water contact, and the specifics of the assessment scenario. Method 1315 is best suited for flow-around scenarios where water is diverted around a material that is impermeable relative to the surrounding media. Method 1314 and 1316 are best suited for flow-through scenarios where the hydraulic conductivity of the material is relatively close to that of the surrounding media (within and order-of-magnitude) and water percolates through the material.

A source term developed to represent the estimated COPC release for each chemical of concern in an environmental application is based upon the testing results considered as whole. The development of the source term is dependent upon the testing and a description of the scenario chosen to represent the environmental scenario. Considered together, the results of the testing can be used to identify the bounding estimate of release as constrained by the anticipated effects of the range of pH, L/S, and mass transfer considerations.

[20] Where a range of materials may be considered for use under a single, bounding application scenario definition.

4.2.5.1 Determining the Applicable pH Domain

Evaluating the effects of pH plays an important role in almost all leaching assessments. In most scenarios, the natural pH of the material, the prevailing pH in the proposed application, and long-term pH shifts associated with material aging or degradation processes should be considered. Inorganic constituents generally exist in aqueous solution as ionic species, the solubility of which is often dependent upon pH. As a result, an evaluation of pH dependence on the available content of a material provides important understanding to almost all leaching evaluations for inorganic constituents (see Section 4.4.1 for details on calculating available content from Method 1313). The applicable pH domain for a management scenario may be based on knowledge of material or scenario characteristics, including those anticipated to evolve over time. Evolving scenario characteristics may include self-acidification (e.g., via oxidation of sulfide reactive phases or biodegradation of organic matter), commingling of the material with more alkaline or acidic materials, and external sources of acidity or alkalinity (e.g., from adjacent materials or the chemistry of contacting water). Examples of environmental conditions, including pH domains and special considerations, for several materials and scenarios are presented in Table 4-3.

Because pH-dependent leaching will be evaluated based on the results of Method 1313, which specifies endpoint target pH values, the applicable pH domain should be based on similar defined pH values. As a default range, the target pH domain[21,22] should include 5.5 ≤ pH ≤ 9.0, but should be expanded as appropriate to include the natural pH of the material. For example:

- For an alkaline coal fly ash with a natural pH of 10, the applicable pH domain would range from pH 5.5 (the lower end of the default domain) to pH 10.5 (the upper end extended to correspond with endpoint target pH values of Method 1313).[23]
- For an acidic coal fly ash with a natural pH of 4.2, the applicable pH domain would range from pH 4.0 (the lower end extended to correspond with the endpoint target pH values of Method 1313) to pH 9.0 (the upper end of the default domain).

The applicable pH range may be further refined (expanded or narrowed) based on material-specific or site-specific scenarios and knowledge of the material's behavior. Changes to the default pH domain should be supported based on anticipated changes in pH at boundary conditions, as a result of materials aging (e.g., carbonation), or potential for acid or alkali influx in context with the acid-base neutralization capacity information from Method 1313. Definition of scenario specific pH domains should be done in consultation with the appropriate regulatory authority.

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[21] Although LEAF is applicable to materials other than CCRs, the CCR risk analysis (U.S EPA 2014b) provides useful information regarding soil pH ranges across the U.S. These results indicate a soil pH distribution of 4.8 (5th percentile), 5.0 (10th percentile), 6.2 (median/50th percentile), 7.8 (90th percentile), and 8.2 (95th percentile). For ease of use with LEAF data at the screening level, a default pH domain should correspond with Method 1313 endpoint target pH values of 2, 4, 5.5, 7, 8, 9, 10.5, 12, and 13. Thus, the default pH domain is recommended as 5.5 ≤ pH ≤ 9.0 with the pH value of 9.0 roughly corresponding to the maximum solubility pH observed for many oxyanions of regulatory concern (e.g., As[V], Cr[VI], Se[VI]).

[22] The SSURGO database contains information about soil as collected by the National Cooperative Soil Survey over the course of a century. The information can be displayed in tables or as maps and is available for most areas in the United States and the Territories, Commonwealths, and Island Nations served by the USDA-NRCS. This database is available online at: https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey

[23] Interpolation of Method 1313 test results within LeachXS™ Lite is currently limited to the target pH values of the test method. Interpolation to user-defined pH values is a capability currently available within the full version of LeachXS™.

Table 4 3. Summary of Observed pH and Redox Conditions for Field Scenarios

Case Name (Country)	Leachates	pH Domain	Special Conditions
Coal fly ash landfill leachate (U.S.)	multiple, landfills	6-13	oxidizing to reducing
Coal fly ash in large-scale field lysimeters (Denmark)	lysimeters	11-13	oxidizing to reducing
Landfill of coal combustion fixated scrubber sludge with lime (U.S.)	landfill	6-12	oxidizing
Coal fly ash used as roadbase and in embankments (The Netherlands)	road base, embankment	8-12	oxidizing to reducing
Municipal solid waste incinerator (MSWI) incinerator bottom ash landfill (Denmark)	landfill	7-11	reducing
MSWI bottom ash used as roadbase (Sweden)	road base test section	7-10	oxidizing to reducing
Inorganic industrial waste landfill (The Netherlands)	lysimeters, landfill	6-9	oxidizing to reducing
Municipal solid waste landfill (The Netherlands)	landfill, multiple landfills	5-9	strongly reducing, high organic carbon
Stabilized MSWI fly ash disposal (The Netherlands)	pilot test cells, landfill	8-13	oxidizing
Portland cement mortars and concrete (Germany, Norway, and The Netherlands)		8-13	oxidizing, carbonation

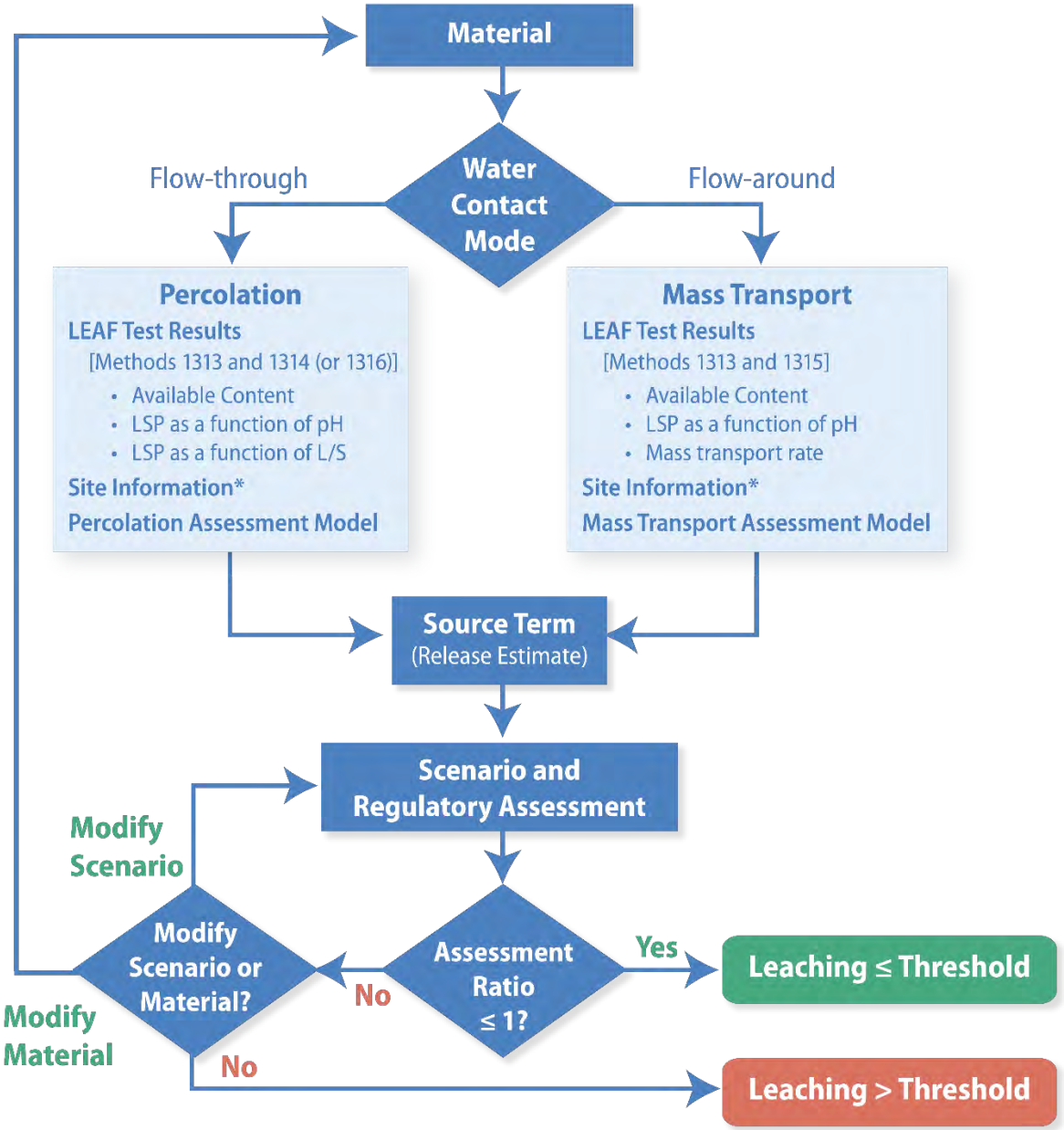
Source: U.S. EPA (2014c).

4.2.5.2 Water Contact and Material Placement in the Environment (Scenario Description)

The placement of material in the environment will have a significant influence on the amount of water that contacts the material and the mode through which water contacts the material. Direct contact with groundwater and intermittent rainfall can result in different leaching behavior for constituents. In addition, physical properties such as soil porosity can influence leaching of constituents. Important information that should be defined in a leaching scenario includes a description of how the material will be placed into the environment, the location of the placement relative to the water table (e.g., in the vadose or saturated zone), the physical dimensions of the placement, and the physical characteristics of the material.

Aside from the physical parameters of the placement, the most significant factor for the leaching assessment involves the mode of water contact between the material and infiltrating rainwater or groundwater. Material may be located: (i) above the ground surface where it is exposed directly to rainfall, (ii) in the vadose zone where contact is limited to that fraction of rainwater that infiltrates the subsurface, or (iii) in a saturated environment (e.g., below the water table in the groundwater or surface water sediments). The physical characteristics of a material and the environment (e.g., density, porosity, and hydraulic conductivity) may determine whether the contacting water flows through or flows around the material. When infiltration or groundwater flows through a permeable material at a relatively slow rate,

equilibrium controls the extent of leaching in what is termed a "percolation scenario." However, when the flow is fast or predominantly around a material with low hydraulic conductivity or through preferential flow pathways (Kosson et al., 2002), mass transport through the material to the water boundary controls the rate of leaching. The LEAF approach defines the applicable water contact mode as either percolation for materials that are as or more permeable than the surrounding materials or flow-around if the material performs as a monolith because of significantly lower permeability than the surrounding materials. A determination that the water contact mode is percolation based allows for evaluating leaching using Method 1314, while a flow-around scenario may be better represented by Method 1315 results.



* Default values or site-specific information
Figure adapted from Kosson, Garrabrants et al. (2012).

Figure 4-6. Flowchart for using LEAF for leaching assessments based on water contact.

4.2.5.3 Percolation Scenarios (Permeable Materials)

For management scenarios where water contact is primarily through percolation, Method 1314 results can be used directly as an estimate of field leaching as a function of the L/S for the management scenario. In some cases, Method 1316 results can also be used to understand time-dependent releases. In a percolation scenario, an evaluator may be using knowledge of water infiltration rates or management timescales to determine relevant L/S for the scenario. However, studies comparing laboratory results to field leachates indicate that actual field leachate may have significantly lower COPC concentrations because of preferential flow pathways. These studies suggest that leaching may be over-predicted by direct leaching test results by an order of magnitude for available content-limited COPCs for many assessment scenarios (U.S. EPA, 2014c). Solubility limited constituents may have less dependence on preferential flow and will be less often over-predicted due to preferential flow as a result. In some cases fate and transport models may be used to examine sensitivity to scenarios beyond laboratory testing conditions (Dijkstra, Meeussen, van der Sloot, & Comans, 2008; Meima & Comans, 1998).

Materials that could be encountered in percolation scenarios include granular material used as structural fill or landfilled. These types of materials have a larger surface area that is exposed to water that can result in equilibrium conditions being reached more quickly. Methods 1314 and 1316 provide data on leachate concentrations at or near equilibrium as a function of cumulative L/S. The lower L/S provide measurements of pore water concentrations. These empirical measurements can reflect instances where only a fraction of COPC mass is limited by available content and instances where solubility limits are reached before the lowest L/S, which may result in lower concentrations than predicted based on adjusting Method 1313 data. Conversely, these methods can capture shifts in the pH at low L/S due to the quick washout of highly soluble ions. This pH shift might result in higher early leachate concentrations than predicted based on the final fixed pH used in Method 1313. Thus, Methods 1314 and 1316 concentrations may provide a more realistic source term without additional adjustment.

4.2.5.4 Mass Transport Limited Leaching Scenarios (Impermeable Materials)

When the water contact is primarily from flow-around a relatively impermeable fill or monolithic material, the Fickian diffusion model (Crank, 1975) is commonly used to estimate mass transport of COPCs. Fickian diffusion assumes that a constituent is initially present throughout the material at a uniform concentration and that mass transfer takes place in response to concentration gradients in the pore water solution of the porous material. The Fickian diffusion model is most appropriate for release scenarios for which highly soluble species are a concern or for which external stresses do not induce sharp internal chemical gradients (e.g., pH gradients, carbonation, and redox changes) that significantly influence local LSP within the material (U.S. EPA, 2014c). The amount of water contacting the material also will impact the amount of a COPC released under a diffusion-controlled scenario.

The mass transport source term for the scenario-based assessment can be bounding because the amount of a COPC released can be several orders of magnitude less than would be estimated using an infinite bath assumption in field scenarios when (i) the material is subject to intermittent wetting due to periodic infiltration (Section 4.4.6), (ii) a portion of the material surface area is obscured from contacting water due engineering controls or placement in the environment, and (iii) where the amount of water contacting the material is limited and LSP at a limited L/S controls leaching.

See Section 4.4.6 for more information on understanding and evaluating mass transport parameters. Examples of use of empirical mass transport results from Method 1315 as part of scenario assessments are provided in Section 5.2 (See also U.S. EPA, 2014, Appendix C). Mass transport testing results also may be incorporated in more detailed reactive transport scenario modeling that integrates geochemical speciation with diffusion-controlled release.

4.3 Accounting for Environmental Processes That Can Influence Leaching

When defining assessment scenarios, both environmental conditions and the presence of important environmental processes should be considered. Environmental factors can alter leachability by changing the chemistry of the material, the concentration of COPCs at equilibrium or the rate of mass transport. The LEAF leaching tests are designed such that the data reflects the response to one or more of these factors under controlled laboratory conditions. However, it is important to acknowledge that these factors do not remain constant in the field as both the environmental media and the solid material under consideration will change over time. Within the normal range of values, some factors (e.g., temperature) are unlikely to have a significant effect on leachability whereas slight changes in other factors (e.g., pH) can have substantial effects on leaching.

Environmental processes may also need to be considered because of their capability to alter leaching under field conditions from those observed in laboratory testing. The effect of some processes may be observable from careful evaluation of testing results (e.g., As-Ca interactions) or by conditioning test materials prior to testing (e.g., carbonated vs non-carbonated materials). Other processes (e.g., evolving redox conditions) may be best evaluated through geochemical speciation modeling of leaching behavior.

Examples of key phenomena that can influence leaching include:

- Chemical, physical, and biological reactions that may occur on or within the material, including the change in redox, production of carbon dioxide, organic acids or other products of biodegradation that may change pH or liquid-solid partitioning of some constituents;
- External stresses (e.g., acids, carbon dioxide, dissolved organic matter) from the surrounding liquid or gas phases that can change the scenario pH or the sorption capacity of the material;
- Physical degradation of the solid matrix due to erosion or stress-related cracking (e.g., freeze/thaw or precipitation reactions);
- Preferential flow through a material that can “short-circuit” the percolation pathway resulting in leaching concentrations less than estimated by equilibrium-based leaching tests;
- Loss of primary matrix constituents due to the leaching process itself (e.g., calcium, sulfate, hydroxide, chloride); and
- Changes in the chemistry of the surrounding media (e.g., abiotic, or biotic oxidation/reduction reactions, and dissolution of atmospheric or biogenic carbon dioxide).

The factors that affect leachability do not act independently of each other and often multiple factors can result in releases that are synergistically different than would be predicted for each factor. However, validation of the LEAF approach to field-collected and monitored cases (U.S. EPA, 2014c) indicate that combined effects either are captured by the test data or can be considered through fate and transport modeling. In addition, the effects of varying a particular factor will differ for each inorganic constituent. As a result, understanding how the variability of the different chemical and physical factors (e.g., pH,

redox, dissolved organic carbon) can affect the leachability of each constituent of concern is key to understanding how the material will behave from a leaching perspective in an application scenario. Insights to these affects can be gained both through LEAF testing and geochemical speciation modeling (U.S EPA 2014c; van der Sloot et al, 2017).

4.3.1 Reducing and Oxidizing Conditions

An assessment scenario should consider the potential for the leaching behavior of COPCs to change due to anticipated changes in reducing or oxidizing conditions of the management scenario. These changes may be relevant if the assessment material contains redox-sensitive constituents that can leach more readily under reducing conditions and whether there is a possibility of oxidizing or reducing conditions under the planned management scenario. As a consequence of exposure during treatment or placement in a management scenario, changes in the redox state of a waste or secondary material can affect the speciation, solubility, and partitioning of multivalent constituents (e.g., Fe, As, Cr). For example, oxidizing conditions prevail widely in the near-surface environment due to contact with ambient oxygen; however, biological activity can deplete sources of oxygen over time, resulting in anoxic and reducing conditions. Biological activity is nearly ubiquitous at near neutral pH ($5.0 \leq pH \leq 8.5$), especially in the presence of microbial substrates such as organic carbon. Thus, a material initially managed under oxidized conditions may become reduced as is the case for some fill scenarios, municipal solid waste landfills or sediments (U.S. EPA, 2014c). The formation of reducing conditions during use or disposal may have adverse consequences with respect to leaching through the following mechanisms:

- Reduction of iron (hydr)oxides, Fe(III), which can result in increased dissolution of iron as Fe(II) and loss of sorption surfaces responsible for COPC retention (Ghosh, Mukiibi, & Ela, 2004);
- Direct reduction of multivalent species (e.g., arsenic, chromium, selenium, and molybdenum) that can change the solubility and sorption characteristics of COPCs; and
- Increased dissolution of organic matter that increase dissolved concentrations of some COPCs (e.g., lead and copper) through formation of soluble complexes with DOC.

For example, the effect of reducing conditions on arsenic is especially significant due to the conversion of As(V) to As(III) under moderately reducing conditions which may increase the total solubility of As and decrease As sorption (Dixit & Hering, 2003; Masscheleyn, Delaune, & Patrick Jr., 1991; Schwartz et al., 2016; Smedley & Kinniburgh, 2002; Vaca-Escobar, Villalobos, & Ceniceros-Gomez, 2012). However, strongly reducing conditions can result in the formation of sulfides, which can reduce the solubility of arsenic and other elements. Similarly, molybdenum and manganese exhibit increased partitioning to the aqueous phase under reducing conditions, while other COPCs exhibit decreased leaching under reducing conditions. For example, the partitioning of chromium to the aqueous phase typically is decreased under reducing conditions because of stronger adsorption and decreased solubility of Cr(III) compared to Cr(VI) at neutral pH conditions. Often, the presence of dissolved iron is an indicator of the formation or presence of reducing conditions.

Reducing conditions may be caused by commingling with other materials that are reducing such as slags or some mining wastes or the presence of significant amounts of biodegradable organic matter and barriers to exchange of atmospheric oxygen. In general, laboratory tests are always conducted under oxidizing conditions unless special precautions are taken (e.g., environmental chambers, anoxic gloveboxes). Examples of materials that are moderately oxidized include combustion residues and low-

organic-content soils.[24] Oxidizing conditions for initially reduced material can be caused by exposure to air and oxygenated water (i.e., infiltration). However, materials with high reducing capacities or high levels of degradable organic matter may remain or become reducing during testing (e.g., Method 1314) or under field conditions, even if initially oxidized or oxidized only at the surface. Materials that are initially reduced, or may generate reducing conditions, typically are slags (e.g., blast furnace slag), mining wastes, and high-organic-matter soils, compost, sewage sludge and sediments. The most common reducing constituents in waste are organic matter, reduced sulfur species (e.g., sulfides), and reduced Fe(II) species. In addition, reduced tin is also often used as a reducing agent in industrially produced materials (e.g., some cements).

Systems may become more oxidized resulting from reaction with atmospheric oxygen. These processes may result in the precipitation of reduced species (the reverse of reducing conditions) or increased solubility of some species (e.g., conversion of relatively insoluble Cr(III) to relatively soluble Cr(VI), i.e., formation of chromate (CrO_4^{2-}) and dichromate ($Cr_2O_7^{2-}$) anions. Oxidation of sulfides (e.g., pyrites [FeS_2]) may result in the release of sulfuric acid.

Within the LEAF testing methods, redox conditions are inferred by measurement of ORP in the test eluate. Depending on the natural pH of the material, ORP of Method 1313 eluates may be moderately oxidizing or reducing at mildly acidic to alkaline pH conditions. Unless the material has a high reducing capacity, oxidizing conditions tend to prevail at strongly acidic pH values because of the use of oxidizing nitric acid in the test method, along with oxygen exposure during sampling, handling, and testing. In addition, the presence of iron in solution at pH values above 5 is usually an indicator of reducing conditions because of the presence of Fe(II) which is more soluble than Fe(III) at those pH conditions. In Method 1314, oxidizing conditions usually prevail unless significant organic carbon and a near-neutral pH is present in the material being tested, in which case, reducing conditions can occur during the test. Again, the formation of reducing conditions is typically indicated by the increased leaching of iron. Establishment of reducing conditions during Method 1314 testing of some materials (e.g., compost-amended soils) has been observed at or after cumulative L/S of 5 mL/g-dry. For sensitive COPCs or environments, evaluation of material characteristics and potential changes in redox conditions is critical. Redox potential (Eh), sometimes referred to as “oxidation-reduction potential” (ORP), measured in solution using units of mV can be viewed as an electrical potential of the pool of the available free electrons (pE):

$$pE = -\log[e^-] = Eh \times F/(2.3 \times R \times T) \qquad \textbf{Equation 4-9}$$

where

- Eh is the redox potential (mV),
- F is Faraday’s Constant [96.42 kJ/(V eq)],
- R is the Universal Gas Constant (8.31 J/(K mol)], and
- T is temperature (K).

[24] The case studies (Section 5) are limited to oxic or oxidizing scenario conditions. Oxidizing conditions usually result in the highest extent of leaching for most COPCs. However, notable exceptions include mobilization of precipitated iron Fe(III) through reductive conversion to Fe(II), increased leaching of species (e.g., arsenic) adsorbed to dissolved hydrous iron oxides, soluble complexes for cations with dissolved organic carbon (e.g., humic, fulvic, or fatty acids), and methylation of mercury under reducing conditions that results in more toxic Hg speciation.

The equilibrium constant for redox-sensitive COPCs, K, may be expressed in terms of the concentrations of reduced species, oxidized species, H^+ and e^- in the system:

$$K = \frac{[reduced\ species]}{[oxidized\ species]\times[e^-]\times[H^+]} \qquad \textbf{Equation 4-10}$$

Or rearranging,

$$\log K = \log[red] - \log[ox] - \log[e^-] - \log[H^+] = pH + pE \qquad \textbf{Equation 4-11}$$

Thus, the relative value of (pH + pE) represents the tendency for oxidized species at higher values (oxidizing conditions) and reduced species at lesser values (reducing conditions). The reduction potentials of redox half reactions can be compared to the pE of the system to anticipate whether constituents may oxidize or reduce. Test results may also not reflect environmental conditions if the redox capability of the leachate does not reflect the redox capabilities of the environment. Additionally, redox reactions can occur over longer timeframes than bench testing allows for. When reduction or oxidation of COPCs to more mobile forms is anticipated, the estimated environmental impact may require geochemical speciation modeling or other considerations. In some cases, oxidizing atmospheres in the laboratory may underestimate reducing conditions encountered in the field, especially when field conditions do not allow for infiltration of the atmosphere. The translation of redox behavior from the lab to the field can be seen in the case studies EPA previously evaluated (U.S. EPA, 2014c).

The concentration of iron in solution as a function of pH is often a useful indicator of the redox state of a system. Typically, iron is present as Fe(III) under oxidizing conditions (pH + pE) > 15 and is insoluble at pH > 4, with solubility increasing with decreasing pH. With progressively more reducing conditions, indicated by progressively decreasing (pH + pE) and resulting in fractional conversion of Fe^{3+} to Fe^{2+}, the transition from insoluble iron to higher iron solubility occurs at greater pH values. The data in Figure 4-7 depicts iron leaching as a function of pH from municipal solid waste (MSW) as pH-dependent and column leaching test results. The various lines in the figures show the simulated LSP of iron under different redox conditions using geochemical speciation modeling (Figure 4.69, U.S. EPA, 2014c, van der Sloot, et al., 2017). Shown at L/S 10 mL/g-dry of the pH=dependent leaching test and L/S 0.3 mL/g-dry as the lowest L/S in the column test, the values of (pH + pE) range from (pH + pE) = 13 indicating oxidizing to mildly reducing conditions to (pH + pE) = 4 indicating strongly reducing conditions. In the pH region anticipated for field applications (pH ≥ 6), the test data from MSW leachate appear to correspond with (pH + pE) values between 4 and 6, indicating strongly reducing conditions (van der Sloot et al, 2017). .

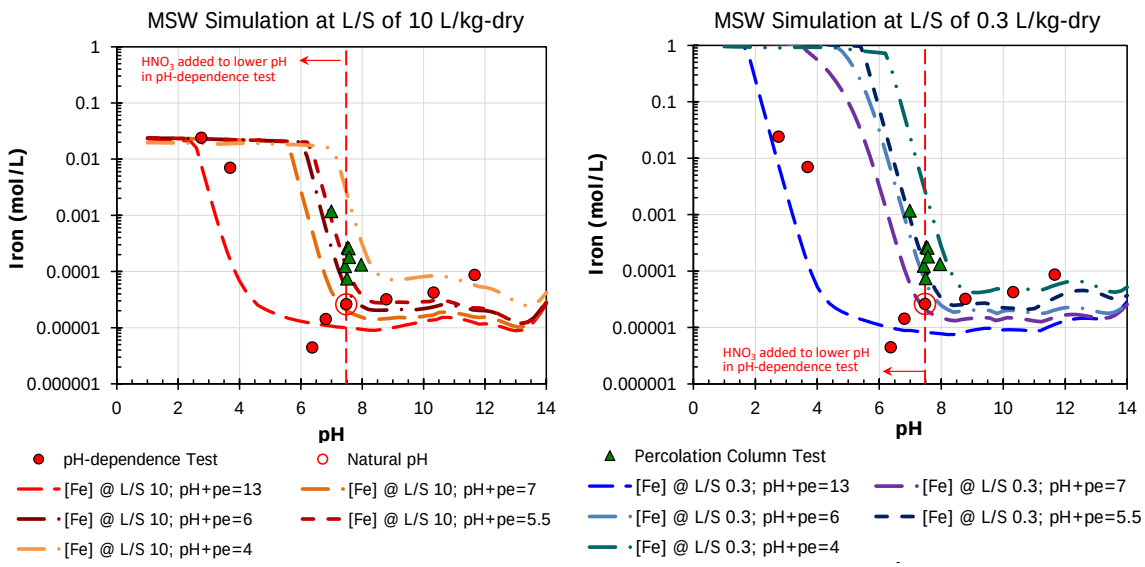


Figure 4-7. Comparison of geochemical simulation of iron leaching at various pH/redox conditions (pH + pE) to laboratory test results for mixed municipal solid waste (MSW) landfill material.

4.3.2 Carbonation of Alkaline Materials

Alkaline materials, especially those primarily composed of calcium hydroxide and calcium-aluminum-silicate minerals (e.g., lime and cement-based materials), are likely to react with carbon dioxide when placed in the environment. The results of the carbonation reaction include reduction of the alkalinity of the system (i.e., neutralization) and precipitation of relatively insoluble carbonate minerals within the pore structure of the material. Neutralization of the natural pH from pH > 10 to pH < 9 may concurrently alter the chemical speciation of COPCs [e.g., lead from soluble $Pb(OH)_4^{-2}$ may precipitate as insoluble $PbCO_3$ or result in Pb sorption to hydrated iron oxide], changes in the mineral distribution (e.g., dissolution of ettringite) or shifts in the COPC leaching concentration along the LSP curve. Exposure to carbon dioxide can result from near surface applications where the material is exposed to relatively moderate concentrations of atmospheric carbon dioxide or from exposure to elevated carbon dioxide in subsurface scenarios due to microbial respiration. Dissolved carbonates can also compete with other oxyanions for adsorption to reactive surfaces, e.g., iron (hydr)oxides, and, therefore, increase the leaching concentrations of oxyanions such as arsenates, chromates, molybdates and selenates.

4.3.3 Microbial Activity

When placed in the environment, the redox conditions of some systems may become more reducing due to microbial respiration processes that consume available oxygen, nitrate, metal oxides, sulfate, and carbonate (electron acceptors). These processes are most prevalent and important at pH between 5 and 9 and when significant concentrations of organic carbon are present as substrate (electron donors). As discussed above, reducing conditions can result in decreased leaching through formation of precipitates (e.g., sulfides) or can increase leaching through the formation of more soluble reduced species (e.g., copper, molybdenum, vanadium).

4.3.4 Complexation with Dissolved Organic Matter

Dissolved organic matter in the form of humic, fulvic or other analogous polar species as well as organic acids complex with many dissolved multivalent cations (e.g., Pb, Cu, Mn, Cr(III)), resulting in increased apparent solubility because of the presence of both uncomplexed and complexed ions in solution. The solubility of dissolved organic matter often is a strong function of pH because of protonation/deprotonation of ionic moieties and alkaline hydrolysis of more complex organic matter. In addition, organic acids are often formed because of microbial activity.

4.3.5 Co-precipitation of Arsenic with Calcium

Since a COPC may be incorporated into or sorbed onto solid mineral phases, the observed leaching behavior of a COPC in LEAF tests may be strongly influenced by the release of other constituents. In U.S. EPA (2014c), a significant increase in arsenic concentration was observed in the latter stages of the column test due to co-precipitation with calcium minerals. Figure 4-8 shows Method 1314 results for pH, calcium release and arsenic release from a low calcium fly ash (Sample ID: EaFA). Method 1313 results for each are shown on the right side of the figure. The graph in the top left shows that the eluate pH released from the column increases from an initial pH of 4.2 to a near-neutral pH by an L/S value of approximately 2 L/kg_{dry}. The titration curve to right indicates that only a small amount of acid needs be released to result in this pH increase. At an L/S of 2 L/kg_{dry}, the cumulative release of calcium has reached a plateau; however, since the LSP of calcium is not a strong function of pH between 4.2 and 7.1, the plateau in the calcium cumulative release curve must be a result of calcium depletion. The cumulative release of arsenic remains relatively low until calcium is depleted (i.e. the point at which cumulative calcium plateaus), beyond which arsenic increases significantly. Geochemical speciation modeling confirmed that arsenic is co-precipitated with calcium.

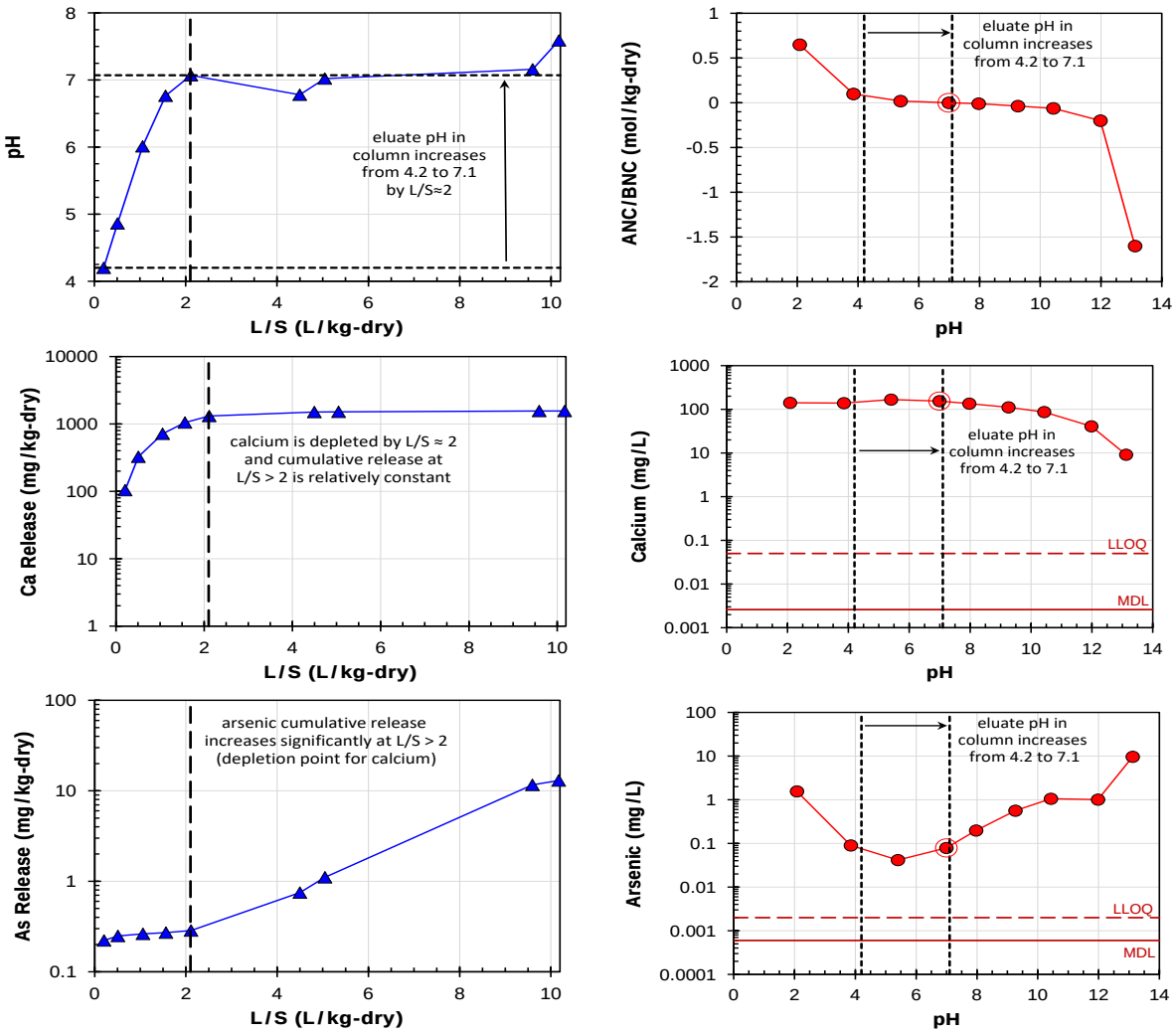


Figure 4-8. Method 1314 (left) and Method 1313 (right) for eluate pH, calcium, and arsenic.

4.3.6 Chemical Interactions

The observed leaching concentrations of specific COPCs can be a result of complex interactions, prompted, suppressed or enhanced by pH and the leaching of other constituents. For example, in the presence of calcium-bearing minerals, arsenic leaching may be minimal; however, leaching of arsenic may increase sharply when calcium concentrations decrease below approximately 100 mg/L because of the decrease in precipitation of calcium arsenate.

Figure 4-9 shows a comparison of LSP (interpolated from test data) and percolation column data for two coal combustion fly ash materials - a calcium-rich ash, CaFA, shown in red and a calcium-poor ash, EaFA, shown in gold. Panels A-H show the titration and pH behavior as well as the leaching data for calcium, arsenic and chromium. The column test data for calcium (Panel D) illustrates the depletion of calcium for EaFA prior to an L/S of 5 L/kg-dry (gold vertical line) that is not evident in the higher calcium CaFA ash. Panel F shows a corresponding increase in arsenic leaching from EaFA starting at approximately L/S 4.5 L/kg-dry, concurrent with the depletion of calcium. In CaFA, however, the leaching of arsenic remains unchanged consistent with calcium concentrations above 100 mg/L. The leaching of chromium (Panel H)

may appear at first to be similar to arsenic (i.e., the shape of the column eluate data for EaFA is similar for chromium and arsenic). However, comparison of chromium pH-dependent behavior (Panel G) with column concentrations (Panel H) shows that the increase in chromium between L/S 4.5 and 10 L/kg-dry are a consequence of the change in chromium leaching as a function of pH. Note that the initial eluate pH in the EaFA column is approximately pH 4 increasing rapidly to a pH of 7 by L/S 2 L/kg-dry (Panel B), while chromium LSP goes through a minimum leaching concentration at pH 5.5 (Panel G). The observed pH shift in the column data for EaFA is a consequence of an acidic coating on the fly ash due to sulfuric acid spray injection. This analysis illustrates the importance of evaluating pH-dependent leaching test results (Method 1313) in conjunction with percolation column leaching test results (Method 1314) to provide an improved understanding of complex leaching behavior.

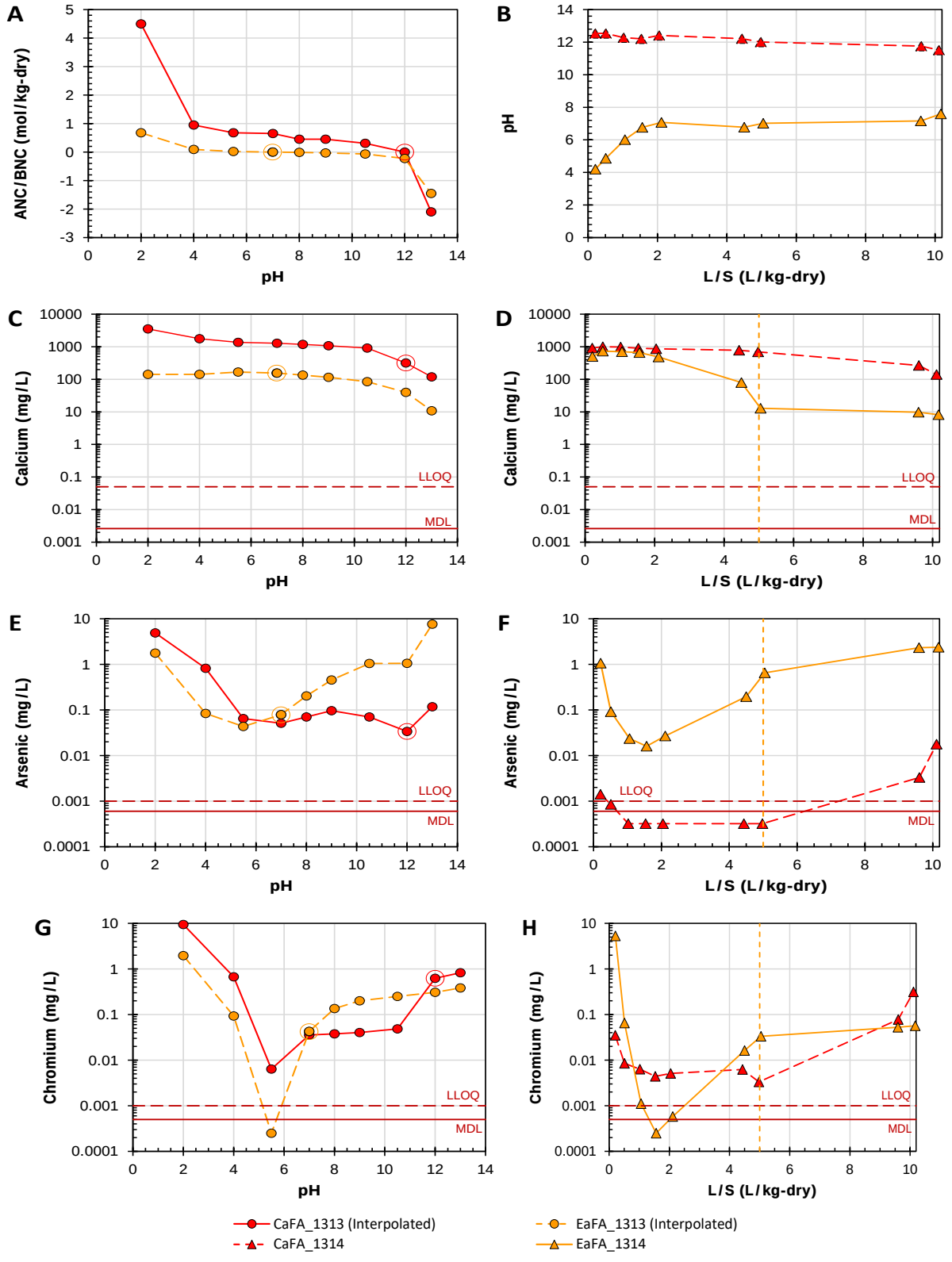


Figure 4-9. Comparison of Method 1313 and Method 1316 for calcium, arsenic and chromium leaching from low-calcium fly ash (EaFA) and high-calcium fly ash (CaFA).

4.4 Performing Common Analyses in Leaching Assessments

4.4.1 Determining the Available Content from Method 1313 Data

Within the LEAF approach, the available content is defined as the fraction of the total content that has the potential to leach under typical environmental conditions. The available content is determined as the mass release in mg/kg-dry associated with the maximum leaching concentration from Method 1313 conducted at endpoint target pH values of 2, 9, and 13:

$$m_{avail} = C_{max(pH\ 2,9,13)} \times (L/S)_{1313} \qquad \textbf{Equation 4-12}$$

where

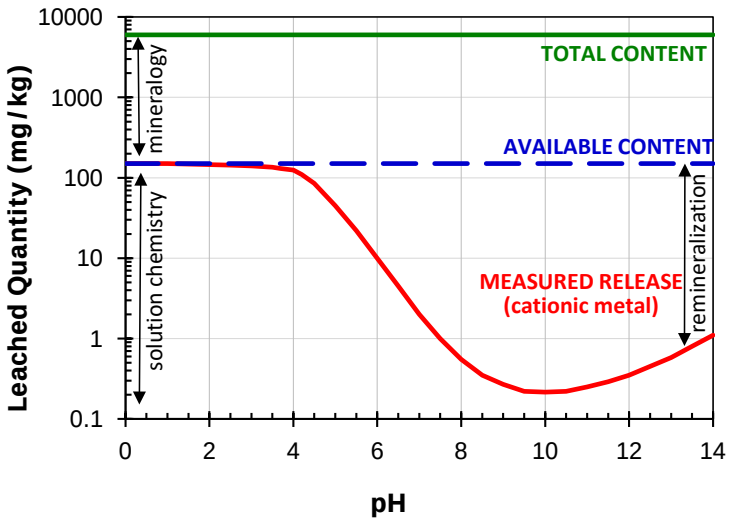
m_{avail} is the available content on a dry mass basis [mg/kg-dry];

$C_{max(pH\ 2,9,13)}$ is the maximum eluate concentration [mg/L] at the endpoint target pH values of 2, 9, and 13, and;

$(L/S)_{1313}$ is the liquid-to-solid ratio of the Method 1313 eluate (i.e., 10 L/kg-dry).

The relationship between total and available content relative to Method 1313 data is presented Figure 4-10. The figure presents the pH-dependent cumulative mass release of a cationic metal (red solid line) in comparison to total content (green solid line) and available content (blue dashed line). The total content is a single mass release value in mg/kg-dry derived from total analysis of the solid material (e.g., from digestion techniques or non-destructive methods). The total content is comprised of a fraction that is available for leaching and a fraction that is bound within the mineralogy of the solid material. The available fraction of the total content is both constituent-dependent (i.e., boron and lead will have different fractions that are available within a material) and material-dependent (i.e., lead may be primarily leachable in one material and recalcitrant to leaching in another). Retention is based on the specific structure of material solid phases (e.g., mineralogy, amorphous/glassy phases) and the potential substitutions of COPCs within those solid phases. For example, some mineral forms such as quartz are very stable so that COPCs bound within silicate are not likely to leach. Conversely, hydroxides tend to be more soluble under environmental pH conditions and COPCs that precipitate as hydroxides are released when the hydroxide minerals dissolve. As a practical matter, for the timeframes of interest for waste disposal/use, the fraction of COPCs bound in these stable mineral forms and amorphous phases is unlikely to be available for leaching (U.S. EPA, 2014c). As the pH changes (i.e., following the LSP curve), remineralization results in COPCs present in various solid phases being released or retained depending on the solubility values of individual minerals, sorption characteristics of the solid phases and solution chemistry.

Determination of available content based on the maximum concentration at end-point eluate pH values of 2, 9 and 13 is a practical approach because solubility of specific elements is at a maximum at one of these pH conditions over the Method 1313 test, and therefore release is available-content limited for most materials. The lowest pH value, pH=2, also results in dissolution of COPCs sorbed to iron (hydr)oxide surfaces and clays.



Adapted from Heasman et al. (1997).

Figure 4-10. Relationship between total content, available content and measured pH-dependent release for a cationic metal.

The reported values for available content using Method 1313 in some cases may be greater than the reported total content because of uncertainties in the testing methodologies. These uncertainties include: (i) inherent analytical uncertainty associated with both total content and leaching test chemical analysis, especially at low extract concentrations, (ii) reliance on very small material quantities used in total content analyses that may not be representative of the material as a whole, (iii) partial digestion techniques for total content analysis where recalcitrant minerals (e.g., silicates) are not fully dissolved, and (iv) analytical dilution of total content digestions from a concentrated but near-dry state to a volume sufficient for chemical analysis.

Figure 4-11 shows the Method 1313 data for cadmium, boron, molybdenum in each of three materials including a contaminated smelter site soil (CFS; left), a coal combustion fly ash (EaFA; middle) and a solidified waste form (SWA; right). Vertical lines in each graph indicate the endpoint target pH values of 2 (blue), 9 (red) and 13 (green) where the maximum concentration values would be expected for various pH-dependent behaviors. Numerical values for measured concentrations as well as the available content calculated at the endpoint target pH values are provided in Table 4-4, along with additional COPCs for comparison. Note that the actual measured concentration for the eluate is used for the calculation of available content, not the concentration interpolated to the target pH value. In all materials, the maximum concentration of cadmium occurs at a pH of approximately 2, which is consistent with cationic pH-dependence. For boron, the pH-dependent leaching is not a strong function of pH and the maximum concentration occurs at a pH near 2 for CFS and SWA, but at an alkaline pH for EaFA. The maximum concentration of molybdenum occurs at near pH 9 (SWA) or near 13 (CFS, EaFA). Note that the graphs in Figure 4-11 show essentially constant concentration at or near the available content for molybdenum (EaFA, SWA) and boron (EaFA) at pH ≥ 9.

Table 4-3. Comparison of Method 1313 Eluate Concentrations at pH 2, 9, 13 and Reported Available Content: Contaminated smelter site soil (CFS), coal combustion fly ash (EaFA) and solidified waste form (SWA).

COPC	Material	Conc. at pH 2 Target [mg/L]	Conc. at pH 9 Target [mg/L]	Conc. at pH 13 Target [mg/L]	Available Content [mg/kg-dry]	Max. Conc. at pH
Arsenic	CFS	**85**	0.042	0.23	850	1.9
	EaFA	1.6	0.56	**9.7**	970	13.1
	SWA	5.8	0.48	**16**	160	12.6
Boron	CFS	**0.72**	0.12	0.056	7.2	1.9
	EaFA	3.3	4.5	**5.0**	50	12.0*
	SWA	**5.8**	1.9	0.78	58	2.5
Cadmium	CFS	**47**	0.006	0.009	470	1.9
	EaFA	**0.066**	0.015	0.015	0.66	2.1
	SWA	**0.029**	< 0.002	< 0.002	0.29	2.5
Molybdenum	CFS	0.11	0.57	**1.3**	13	13.1
	EaFA	0.33	3.7	**3.9**	39	13.1
	SWA	0.0067	**0.15**	0.14	1.5	8.9
Selenium	CFS	**0.51**	0.20	0.29	5.1	1.9
	EaFA	0.55	4.0	**6.9**	69	13.1
	SWA	35	**130**	98	1,300	8.9
Zinc	CFS	**170**	0.009	5.6	1,700	1.9
	EaFA	**1.6**	< 0.001	0.057	16	2.1
	SWA	**1.9**	0.021	0.017	19	2.5

"<" indicates eluate concentration presented as less than reported MDL value.

"*" pH 13 extraction was not measured for boron due to base storage in dissolution of borosilicate glass (U.S. EPA, 2012c).

Eluate concentrations in **bold** indicate maximum concentration.

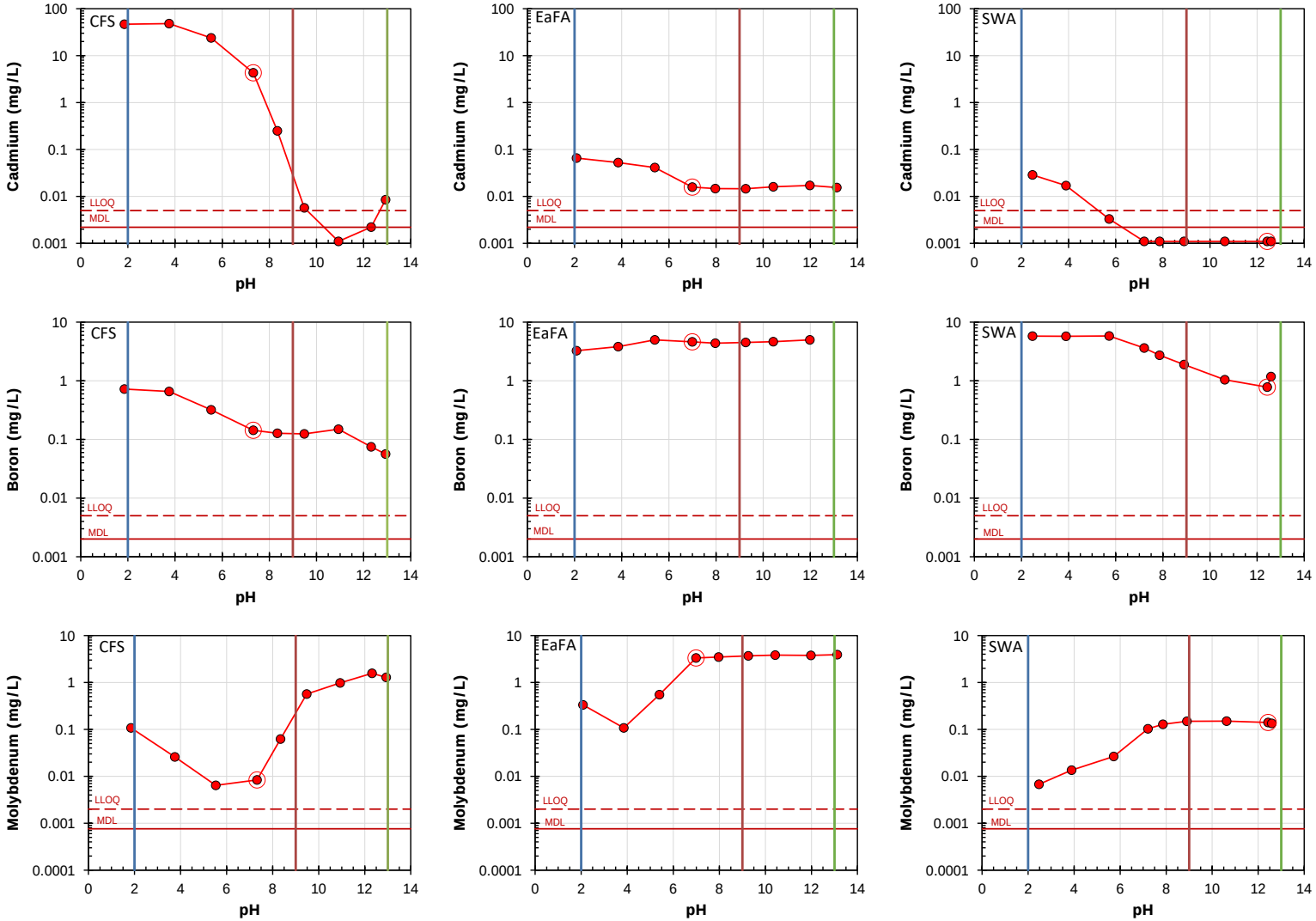


Figure 4-11. Comparison of eluate concentrations at specified pH values of 2, 9, and 13 used to determine the available content: Contaminated smelter site soil (CFS; left), coal combustion fly ash (EaFA; middle) and solidified waste form (SWA; right).

4.4.2 Interpolating Method 1313 Data to Endpoint Target pH

Since the pH-dependent leaching of many COPCs may be sensitive to minor fluctuations in eluate pH, it is necessary to interpolate Method 1313 test results to the specified endpoint target pH values to provide reproducible, comparative results to be used in conjunction with comparison the threshold or limit values. In practice, Method 1313 allows for a tolerance of ±0.5 pH unit for each target pH value recognizing the experimental error inherent to addition of acid and base and measurement of pH. However, the measured eluate concentration over the tolerance interval may result in a concentration difference as much as an order of magnitude. Thus, eluate concentration data to be used to evaluate leaching over a scenario pH domain should be interpolated to the endpoint target pH values to minimize the bias in eluate concentrations for highly pH-dependent COPCs. Interpolated eluate concentrations are obtained by standard linear interpolation of log-transformed data from two neighboring Method 1313 eluates (U.S. EPA, 2012c).[25]

$$\boldsymbol{logC = logC_a + (pH - pH_a) \times (logC_b - logC_a)/(pH_b - pH_a)} \qquad \textbf{Equation 4-13}$$

where

$logC$ is the log-transform of the eluate concentration interpolated to the endpoint target pH value of 2, 9, or 13 in log[mg/L];

pH_a is the measured pH value for eluate a;

pH_b is the measured pH value of eluate b;

$logC_a$ is the log-transform of the measured eluate concentration at pH_a in log[mg/L], and;

$logC_b$ is the log-transform of the measured eluate concentration at pH_b in log[mg/L].

Figure 4-12 shows that the overall result of interpolating measured concentration to Method 1313 endpoint target pH values is not significant except in pH regions where the LSP is highly sensitive (e.g., see iron near pH 4 or cadmium from pH 5-12).

Although interpolation should be considered carefully or may not be possible for data collected before the methods were standardized (e.g., Method SR002.1, the predecessor to Method 1313)[26] or from single-point leaching tests, older pH dependent data from the predecessor methods can provide a useful comparison basis (e.g., see U.S. EPA, 2012b) and be used for more detailed assessments (e.g., see U.S. EPA, 2014b). Interpolation can be carried out automatically in LeachXS™ Lite upon importing of Method 1313 test results.

[25] Interpolation of Method 1313 results to target pH values is achieved automatically using LeachXS™ Lite (see Section 3.3.2).

[26] Interpolation is recommended for Method 1313 results within ± 0.5 pH units of endpoint target pH values. However, if interpolation is conducted at greater intervals, consistency of interpolated values with the trend of the measured eluate concentration should be evaluated.

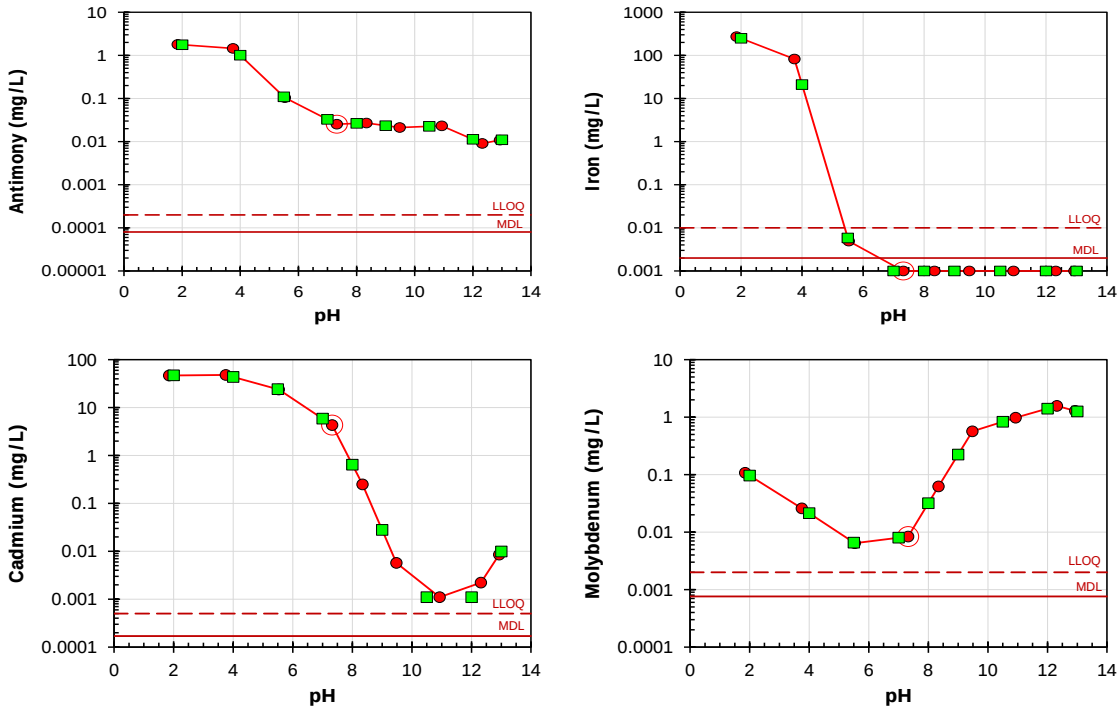


Figure 4-12. Comparison of measured Method 1313 eluate data (red dots) for a contaminated smelter site soil (CFS) with interpolated test results (green squares) using linear interpolation of log-transformed concentration data.

4.4.3 Calculating Water Contact and Assessment Time: Liquid-Solid Ratio (L/S, percolation mode) and Liquid-Area Ratio (L/A, flow around mode)

The amount of each COPC that leaches over time in a particular assessment scenario can be estimated based on the amount of contacting water. In order to evaluate a leaching assessment over time, a liquid to solid ratio (L/S) can be calculated based on the amount of material in the environment and the expected amount of water to contact that material over time. L/S is defined as the contacting water per unit mass of material (i.e., the L/S associated with the annual infiltration or groundwater flow rate) multiplied by the cumulative leaching time for the assessment. When the assessment is for a material that has a known geometry volume, per unit mass of the material in the application, LS can be calculated using Equation 4-14 (Hjelmar, 1990).

$$(L/S)_{scenario} = (Inf \times t_{yr})/(\rho \times H_{fill}) \times 1000 \qquad \textbf{Equation 4-14}$$

where

Inf is the annual rate of infiltration or groundwater flow [m/year];

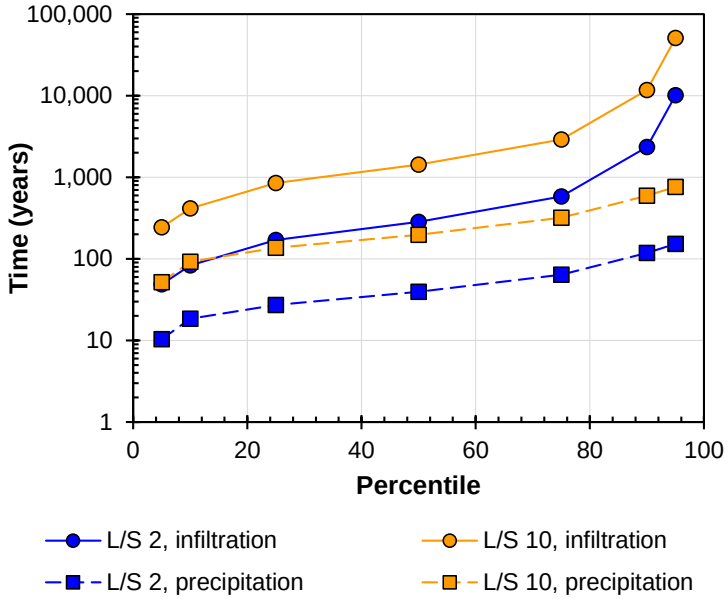
t_{yr} is the cumulative leaching time for the scenario [years];

ρ is the material bulk dry density [kg-dry/m^3];

H_{fill} is the dimension of the fill in the direction of water flow [m]; and

1000 is a units conversion factor (1,000 L = m^3).

Using the above approach, Figure 4-13 illustrates the distribution of time to achieve L/S 2 and 10 L/kg-dry for a selection of U.S. CCR landfills based on site geometries, material properties and the rates of annual precipitation or infiltration. These results indicate that only a small fraction of precipitation becomes infiltration and that achieving even a modest L/S of 2 L/kg-dry can take several decades to centuries depending on site-specific factors. The time to achieve a higher L/S value like 10 L/kg-dry can take from about 200 years and up to several millennia. Based on this evaluation at the 10th percentile (i.e., 90% of the cases in the distribution take longer than the 10th percentile), the cumulative time required to reach an L/S of 2 and 10 L/kg-dry in a U.S. CCR landfill is approximately 80 and 400 years, respectively.



Data adapted from U.S. EPA (2014b).

Figure 4-13. Statistical distribution of time to reach L/S=2 L/kg-dry or L/S=10 L/kg-dry based on national distributions of precipitation and infiltration for CCR landfills.

If the material of interest is present in a saturated zone (e.g., within groundwater or surface water sediments), the amount of water flowing through the material or contacting the external geometric surface area of a monolithic material can be estimated to determine the annual L/S for percolation cases or liquid to surface area (L/A) for mass transport cases. L/A is calculated based on the geometry and resulting surface area of your material that is in contact with water.

4.4.4 Interpreting Observed Liquid Solid Partitioning (LSP) Behavior

The observed leaching behavior of a material (e.g., waste, secondary material, contaminated soil, sediment, construction material), when exposed to water in the environment, can be viewed as the combined result of constituent mass transfer and chemical equilibrium between solid, liquid and gas phases. Chemical equilibrium, often described as liquid-solid partitioning (LSP), is considered the endpoint, or limit case, for mass transfer when concentration gradients have been minimized. LSP may be achieved over relatively short duration (e.g., minutes to hours) when water is directly and uniformly in contact with a representative volume of the solid phase (e.g., in the case of uniform percolation) or over

long durations (e.g., months to decades, or longer) when water contacts is limited to an external geometric surface in the case of monolithic or compacted granular materials. Additionally, the approach to chemical equilibrium is delayed when hydraulic conditions result in significant flow channeling which reduces the contact time between the liquid and the solid. In scenarios where LSP of a constituent cannot be assumed, the driving force for mass transport is the difference between the constituent concentration at equilibrium and the existing concentration in the leachate. Thus, an underlying knowledge of leaching behavior based on LSP and the rates of mass transport (due to diffusion or other processes) is crucial for the understanding of observed leaching behavior both in the laboratory and in the field.

The partitioning of constituents between solid and liquid phases at equilibrium is controlled primarily by the following factors:

- The content of the full set of constituents (COPCs and non-COPC constituents such as calcium, chloride, sulfate, phosphate and humic/fulvic substances) that can participate in partitioning,
- The system pH which acts as a master variable controlling the solubility and LSP of ionic species (e.g., most inorganic and many organic constituents),[27]
- The liquid-to-solid ratio (L/S) in the system defined as the amount of the water present relative to the equivalent dry mass of solid present in units of [mL/g-dry] at the laboratory scale and [L/kg-dry] at the field scale,
- The system redox potential which controls the oxidation state of constituents that have multiple potential valence states, such as Cr(III) versus Cr(VI), and
- The amount of reactive solid surfaces (e. g., iron (hydr)oxide, clay minerals, natural organic matter) available for constituent sorption.

Based on these factors, a COPC or other constituent may exist in the liquid phase as a combination of free and complexed chemical species either at aqueous saturation (maximum liquid concentration at the given pH, redox and system composition) or at a concentration less than aqueous saturation. The concentration at aqueous saturation also can be modified by the presence of complexing agents in the water such as dissolved humic or fulvic substances (often estimated from dissolved organic carbon) or chloride or other dissolved ionic substances.

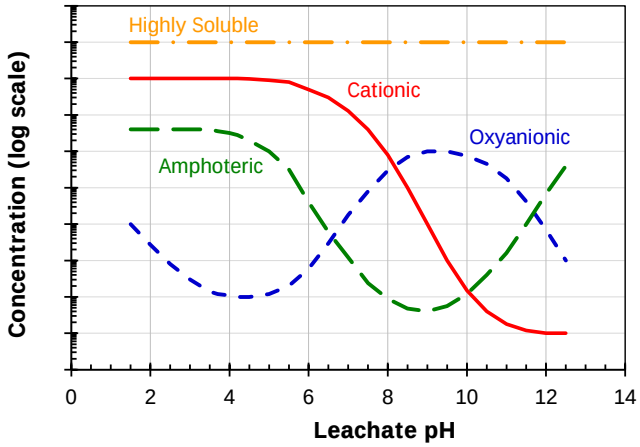
As discussed in Section 4.2.4.2 and 4.4.1, the available content is determined as the mass release associated with the maximum eluate concentration from pH-dependent LSP. In order to provide a uniform procedure for determining available content, the maximum LSP concentrations from Method 1313 testing are evaluated at pH values of 2, 9, and 13. The available content represents the fraction of the total content of a constituent that may leach under environmental conditions. In solution, the available content may represent an endpoint conditions for leaching (available content-limited leaching) if the available content in the solid material has been leached into solution at less than aqueous saturation. In addition, a constituent that is part of the available content (i.e., is leachable under the appropriate conditions) may exist as the solid in one or more chemical species:

[27] The system pH can also be viewed as the available concentration of H^+ or OH^- ions in the water (i.e., pH = -log[H^+] and pOH = 14 - pH).

- Precipitated in one or more mineral forms based on the dissolution/precipitation reactions that may take place based on the overall system composition,
- Co-precipitated within the mineral phase as by matrix substitution (i.e., a solid solution), or
- Sorbed to a reactive surface (e.g., iron (hydr)oxide, aluminum oxide, clay minerals, natural organic matter) based on adsorption/desorption or ion exchange reactions.

Many of the above reactions that define the observed LSP may not be well quantified or even well defined. Research in geochemistry seeks to define and quantify these reactions to the extent possible or practical. However, even without detailed geochemical knowledge, the leaching behavior is empirically observed through laboratory testing and field measurements.

In pH-dependent leaching tests, the shape of the observed LSP curve (i.e., relative locations of maxima and minima) typically has four classic shapes presented schematically in Figure 4-14.



Adapted from Kosson et al. (2002), as cited in U.S. EPA (2012f).

Figure 4-14. LSP patterns for classical pH-dependence leaching behaviors.

Although the shapes in the figure are idealized and seldom are seen as clearly as presented, these trends provide a basic evaluation of how COPCs may behavior in complex natural systems. Comparing measured LSP curves obtained through Method 1313 to these idealized shapes may be useful for interpreting broad-stroke speciation of a constituent. The four classic LSP behaviors as shown in the Figure 4-14 include:

- **Highly Soluble Species** – The LSP curves for highly soluble species (e.g., B, Cl, Na, K, etc.) are usually a weak function of pH where the measured concentration may vary by up to an order of magnitude across the entire pH domain. Often, highly soluble species are considered to leach to the point of depletion of the available content (i.e., no more leachable COC exists in the solid phase) and re-mineralization due to shifts in pH are minor. Because highly soluble species release a relatively constant available mass into solution, the concentration of highly soluble species in solution is typically a strong function of L/S (e.g., halving the amount of liquid doubles the concentration).

- **Cationic Species** – The LSP curves of cationic species (e.g., Ca, Cd, Fe, etc.) show a maximum concentration in the acidic pH range and a decreasing LSP trend in the alkaline range. Within the usual alkaline range of pH ≤ 14, the LSP concentration does not increase again. The maximum concentration value associated with determination of availability content is observed as an asymptote, typically, at pH < 4.
- **Amphoteric Species** – The LSP curve for amphoteric species [e.g., Al, As(III), Pb, Cr(III), Cu, Zn, etc.] tend toward a similar shape to that of cationic species; however, concentrations pass through a minimum in the alkaline pH range and increase in highly alkaline regimes. The increase at high pH is due to the increasing solubility of hydroxide complexes (e.g., $Zn(OH)_3^{-1}$, $Zn(OH)_4^{-2}$). The pH associated with the maximum LSP concentration used to determine the available content may be observed at low pH (pH = 2) or high pH (pH = 13).
- **Oxyanionic Species** – The LSP curves for oxyanions [e.g., As(V), Cr(VI), Se(VI), Mo(VI), etc.] often show maxima in the neutral to slightly alkaline range and a decrease in concentration as pH decreases. Since many metals which make up oxyanions (e.g., Cr in Cr_2O_7) may be sensitive to changes in oxidation-reduction potential, the LSP curve also may show a local maximum at low pH where more reducing conditions are present.

A more detailed evaluation of constituent speciation may be conducted through geochemical speciation models that infer the mineral phases, adsorption reactions, and soluble complexes that control the release of the constituent using Method 1313 data.

Figure 4-15 and Figure 4-16 provide results of Method 1313 testing, as a comparison of observed leaching behavior of several COPCs for four materials:

- CFS – a lead smelter field soil (U.S. EPA, 2012c, 2012d)
- SWA – a solidified waste analog (U.S. EPA, 2012c, 2012d)
- EaFA – a low calcium coal fly ash (U.S. EPA, 2012c, 2012d)
- CaFA – a high calcium coal fly ash (U.S. EPA, 2009)

Method 1313 results are also provided for several of the key elements that influence the leaching behavior as discussed above (e.g., calcium, iron, DOC, sulfate, phosphorous).

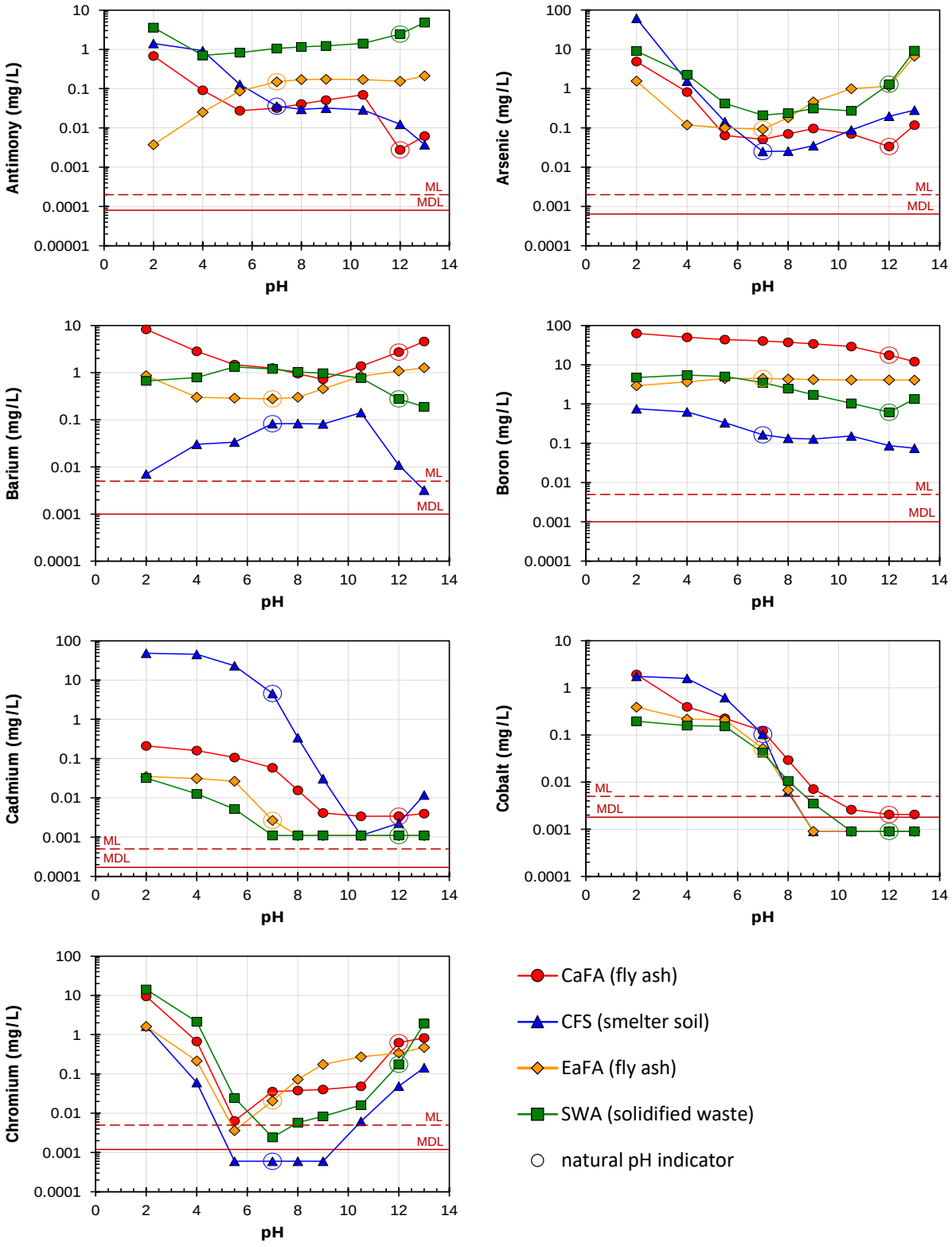


Figure 4-15. LSP behavior for different example waste forms: coal combustion fly ash (CaFA and EaFA), smelter site soil (CFS) and solidified waste (SWA).

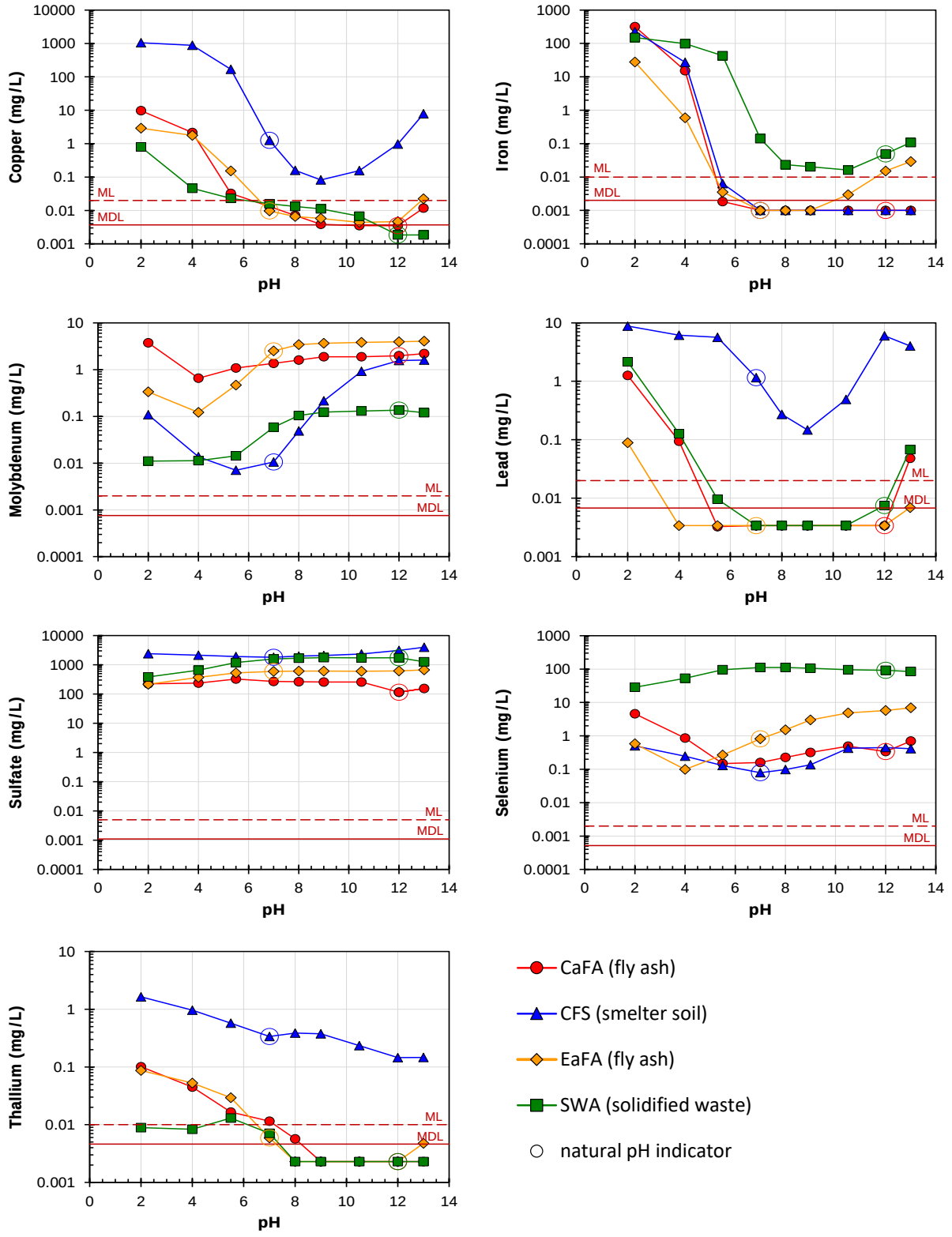


Figure 4-16. LSP behavior for different example waste forms: coal combustion fly ash (CaFA and EaFA), smelter site soil (CFS) and solidified waste (SWA).

4.4.5 Identifying Solubility- and Available Content-Limited Leaching

Screening-based assessments utilize an upper bounding estimate of the maximum expected leaching concentration of COPCs in comparisons with relevant thresholds (see Section 4.2.4). When using Method 1313 results to estimate the maximum leaching concentration, it is important to identify if the measured eluate concentration of each COPC over the scenario pH domain reflects available content-limited leaching in contrast to solubility-limited leaching.[28]

- When the LSP determined by Method 1313 reflects solubility limits or adsorption control, the eluate concentrations are a weak function of L/S and the maximum leaching concentration may be estimated at the Method 1313 test conditions.
- When LSP leaching reflects available content, however, higher leachate concentrations are expected a lower L/S values and lower leachate concentrations are expected at higher L/S values than laboratory test conditions. Thus, Method 1313 results must be adjusted from laboratory test conditions (i.e., 10 mL/g-dry) to the field scenario L/S to obtain the upper bound concentration estimate for COPCs.

The simplest way to determine if available content-limited leaching is occurring during Method 1313 is to compare the measured concentration at each targeted eluate pH to the maximum concentration used to determine the available content (Section 4.4.1). If leaching is limited by the available content, the measured concentration should be equal to the maximum concentration used to determine the available content within the uncertainty of the test method. Based on interlaboratory validation, the mean test uncertainty for Method 1313 has been determined to be 28% of the measured value shown in Table 3-6. Thus, leaching is considered available content-limited when evaluating each Method 1313 eluate if the following condition is met:

$$\frac{C_{\max(pH\ 2,9,13)} \times [1-0.28]}{C_{max(pH\ domain)} \times [1+0.28]} \leq 1 \qquad \textbf{Equation 4-15}$$

where

$C_{max(pH\ 2,9,13)}$ is the maximum eluate concentration used for determination of available content [mg/L];

$C_{max\ (pH\ domain)}$ is the maximum eluate concentration over the applicable scenario pH domain [mg/L], and;

0.28 is the reproducibility residual standard deviation (RSD_R) for concentrations from the Method 1313 interlaboratory validation study (Table 3-6).

If the fraction in Equation 4-15 is greater than 1, then the LSP behavior is dominated by solubility-limited or sorption-controlled leaching.

An alternate way to determine whether the environmental leaching is solubility (or sorption)-limited vs. available content-limited is based on evaluation of Method 1316 results. Graphical presentation of Method 1316 test results can provide insight into whether the leaching at the natural pH of a material is

[28] For some materials, some COPCs may reflect solubility-limited leaching over part of the applicable pH domain, and available content-limited leaching over another part of the applicable pH domain for the field scenario being evaluated. When this situation occurs, the maximum concentration estimate based on the available content-limited leaching is used.

available content-limited or solubility-limited. The Method 1313 and Method 1316 results for boron and chromium leaching from a coal combustion fly ash (EaFA) are shown in Figure 4-17**.** The maximum observed concentration of boron over the applicable pH domain of 5.5 ≤ pH ≤ 9 is 4.97 mg/L is statistically 100% of the maximum concentration of 4.99 mg/L measured at pH 12 for determination of the available content. In Method 1316, the mass release of boron is a weak function of L/S at values greater than 72% of the available content and the release at high L/S (where solubility constraints would normally be less) limited by the available content value. Therefore, boron displays available content-limited leaching behavior over the pH domain shown in Method 1313 results.

Solubility-limited leaching is indicated by Method 1313 concentrations over the applicable pH domain that are significantly less than the maximum concentration used to determine the available content and that vary strongly with pH values. For solubility-limited release, the mass release Method 1316 usually is a strong function of L/S (slope of approximately 1 of concentration as a function of L/S), increasing with L/S to a value that is only a fraction of the available content under laboratory conditions. In contrast, Method 1316 concentration data is a weak function of L/S for solubility-limited release. In Figure 4-17, the maximum concentration of chromium over the 5.5≤pH≤9 domain (0.22 mg/L) is significantly less than the maximum concentration at pH 2 (1.95 mg/L), indicating solubility-limited or sorption-controlled leaching. In addition, the mass release of chromium is a strong function of L/S increasing by a factor of approximately 20 between L/S value of 1 and 10 mL/g-dry. The mass release at L/S 10 (0.42 mg/kg-dry) is only 2% of the available content (19.6 mg/kg-dry).

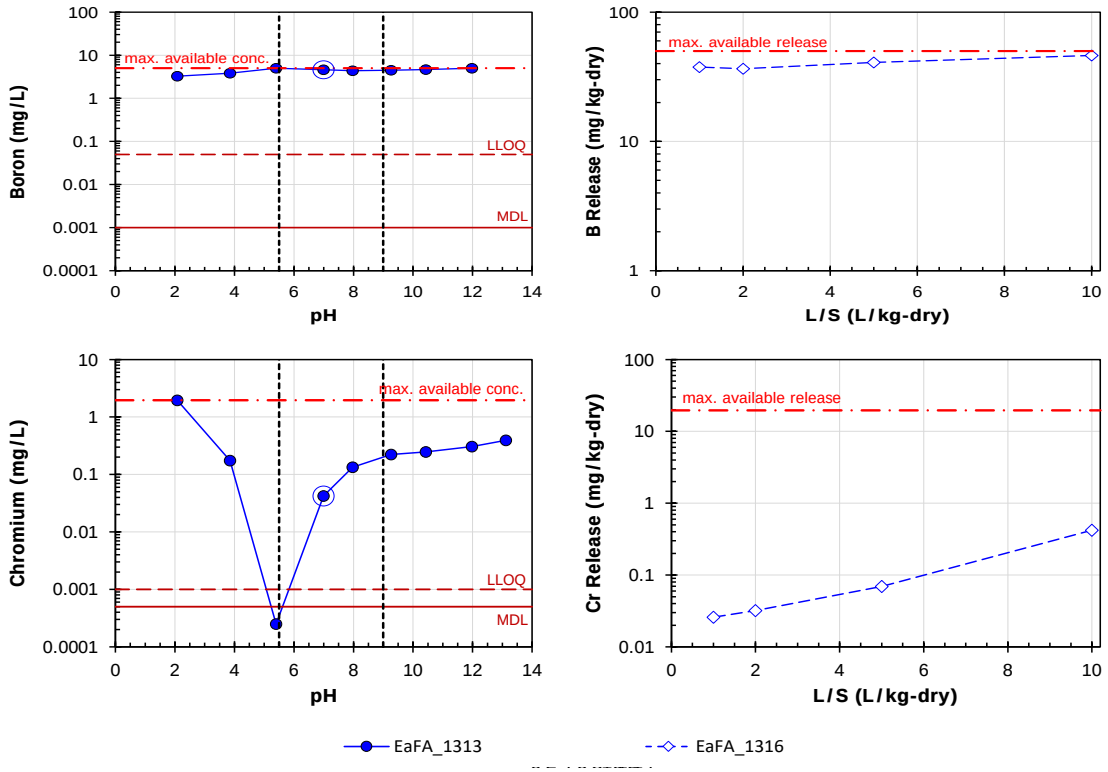


Figure 4-17. Available content-limited leaching of boron and solubility-limited leaching of chromium from a coal combustion fly ash (EaFA) based on the results of Method 1313 (left) and Method 1316 (right).

4.4.6 Understanding Mass Transport Parameters (Low Permeability Materials)

Method 1315 is most appropriate for understanding the rate of release under conditions where mass transport dominates the rate of constituent release (e.g., relatively impermeable materials). If the material will form, or be incorporated into, a solid monolithic or compacted granular form, it may be useful to perform Method 1315 to understand the degree to which the reduced surface area exposed to water contact reduces leaching. Example materials that benefit from mass transport testing include clay-like soils and sediments, or materials with low permeability due to cementitious or pozzolanic reactions. Method 1315 is applicable if water is expected to flow around the material, or if fractures in the material result in diffusion-limited release, based on exposed surface area.

Since the sample material in Method 1315 has contact with water only at the external geometric surface, COPCs must migrate from the interior of the material before partitioning into the leachate. The tortuous pathway for migration and chemical interactions with minerals and other constituents that occur along the pathway within the pore structure of the material reduce the observed rate of leaching. Field conditions associated with mass transport-controlled leaching are often different from Method 1315 laboratory test conditions:

- Method 1315 conditions are designed to maintain a dilute solution relative to aqueous solubility (e.g., an "infinite bath" boundary) through specification of a large L/A value and frequent eluant exchanges. These laboratory conditions ensure that the observed ratio of leaching is limited by transport through the material and by solubility-limited leaching in the Method 1315 leachate. The result is the Method 1315 measures a maximum rate of release for a given material. Field conditions often have a much smaller L/A that results in more cases where LSP at equilibrium limits leaching (especially for elements with low solubility). However, the range of these field conditions, which can be highly site-specific, cannot be universally represented in a standardized leaching test such as Method 1315.
- Method 1315 results represent a case of continuous mass transport over a cumulative leaching period of 63 days. The continuous liquid contact and eluant exchange intervals of Method 1315 are designed to maintain internal diffusion gradients within the material for the duration of the test. The peak interval flux measured at the beginning of Method 1315 declines rapidly because of the established concentration gradient within the material and, eventually, local depletion and low concentration gradients at the external surface of the material. However, field conditions often are variable such that a material present at the surface or in the vadose zone is likely to undergo intermittent water contact (e.g., due to a pattern of rainfall events leading to periodic infiltration). When a material is not in contact with water (i.e., during drying or storage periods), the internal concentration gradients established during the previous wetting period relax or "flatten out," replenishing the low porewater concentration at the material surface. In the porewater at the material surface, local equilibrium may be established during a drying or storage period. Thus, the initial release in the next wetting period is greater than would be anticipated by continuous leaching due to the elevated gradient across the material surface (Garrabants, Sanchez, & Kosson, 2003; Sanchez, Garrabants, & Kosson, 2003). The greater flux observed for wetting stages after drying or storage is referred to as a "first flush" phenomena. However, the cumulative mass release under intermittent wetting conditions typically is significantly less than

the mass release under continuous leaching conditions (i.e., those imposed by Method 1315) because material only leaches for a fraction of the total evaluation time.

- Natural aging of the material, leaching of the mineral structure, and exposure to external field conditions may result in the formation of a surface layer or "rind" that has a different composition and properties than the material that was tested in the laboratory. For example, exposure to atmospheric carbon dioxide leads to pore filling and neutralization of porewater pH that may reduce the observed leaching rate in cementitious materials. Similarly, pore filling may occur after chemical reaction with constituents present in contacting water (e.g., magnesium carbonate or sulfate precipitation). Leaching of constituents can result in an increase in porosity resulting from removal of highly soluble salts when initially present as a large fraction of the material.
- When the hydraulic conductivity of a monolithic or compact granular material is relatively close (within and order-of-magnitude) of the surround materials, field conditions may allow for a fraction of the contacting water to percolate through the material such that both percolation and diffusion processes are present. For these scenarios, the results of Method 1314 (or possibly Method 1316) at the estimated L/S ratio of the percolation provide a bounding estimate of the maximum leaching concentration.

Based on the above differences between Method 1315 test conditions and field conditions, the concentration results from Method 1315 cannot be considered representative of field leachates and should not be used in comparison to threshold values. However, Method 1315 results may be used in several different ways to estimate field leaching:

- The flux of COPCs measured during first intervals of Method 1315 testing may be used as a bounding estimate of initial leaching fluxes or fluxes after drying periods associated with intermittent wetting. This approach was used in assessing leaching from concrete containing coal fly ash (U.S. EPA, 2014a).
- The observed diffusivity of COPCs estimated from Method 1315 results applied to a simple Fickian diffusion model can provide a basis for comparison of relative leaching rates between different materials potentially used or managed under the same field conditions. For example, observed diffusivities can be used as a basis of comparison of the effectiveness of different treatment process for a waste (Sanchez, Kosson, Mattus, & Morris, 2001; Westsik Jr. et al., 2013).
- Method 1315 results may be used to parameterize diffusion processes in simple diffusion models in cases when physical-chemical conditions do not change (Garrabants et al., 2002) or more detailed fate and transport model to estimate long-term constituent leaching under a range of field exposure conditions or scenarios (SRR, 2013, 2014; U.S. EPA, 2014c).

Method 1315 is often conducted in conjunction with Method 1313 to provide information on both the *rate* and *extent* of leaching (Section 2.4). Release calculated from Method 1315 provides a "best estimate" of leaching rate under mass transport conditions that may be assumed as long as the material maintains its structural integrity. Method 1313 can provide an upper bounding estimate that may be useful for understanding leaching as the solid material breaks down over time and ensuring there is not excessive release. The combined effects of leaching rate and leaching extent were used to evaluate the impact of coal combustion fly ash substitution for Portland cement in commercial concrete considering under intermittent wetting conditions based on surface application of concrete exposed to precipitation (U.S.

EPA, 2014a). Empirical data from Method 1313 estimating available content and Method 1315 estimating effective diffusivity were used to evaluate applications of MSWI bottom ash scenarios (Kosson, van der Sloot, & Eighmy, 1996). These approaches can also be used in conjunction with chemical speciation-based mass transfer models to provide insights into potential changes in leaching that may occur in response to changing conditions within or on the external surface of the material being evaluated.

Method 1315 results should be accompanied by a careful review to understand controlling mechanisms during testing and apply appropriate assumptions in extrapolation 1315 results to field scenarios. LEAF users can determine which process dominates based on comparison of Method 1313 and 1315 results. As indicated earlier, the test conditions of Method 1315 (i.e., liquid-to-surface area ratio and eluant refresh schedules) are designed to maintain a dilute eluate with respect to LSP in order to maintain the driving force for constituent mass transport (e.g., diffusion and dissolution; U.S. EPA, 2010). Thus, Method 1315 concentrations should be significantly less than the corresponding Method 1313 LSP concentration at the same pH (e.g., arsenic and cadmium in the top of Figure 4-18) for the assumed boundary condition to be valid. If Method 1315 concentrations for a constituent approach or are equal to the LSP concentrations (e.g., boron and barium in Figure 4-18), the Method 1315 dilute boundary condition assumption may not have been maintained throughout the test and the LSP as defined by Method 1313 and 1314 should be used as the basis for assessment.

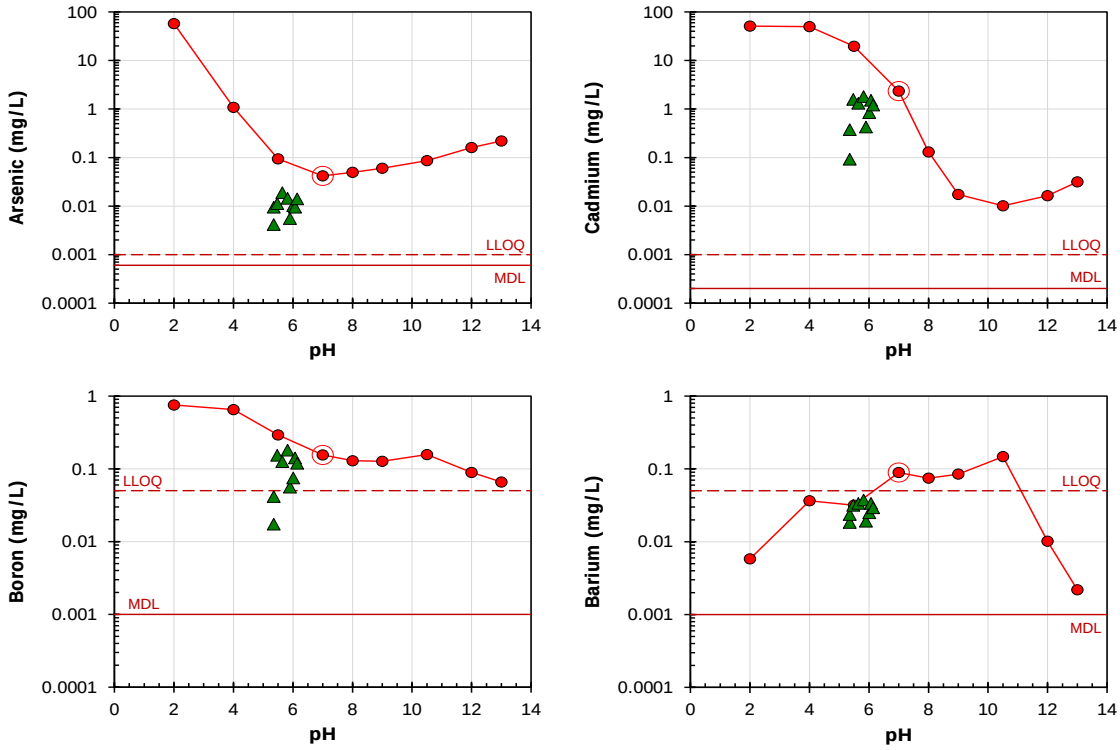


Figure 4-18. Comparison of mass transport data (green triangles, Method 1315) to equilibrium data shown as a function of pH (red circles, Method 1313) for a contaminated lead smelter soil (CFS).

In describing the leaching process (Section 2.4), mass transport was considered to continue as long as the concentration gradient was maintained which infers that when eluate concentrations approach

equilibrium concentrations, Method 1315 data represents equilibrium and not mass transport. As an internal quality control check, eluate concentrations may be plotted over the LSP data from Method 1313 to verify that the "dilute" boundary condition is met for each constituent.

- Barium eluate concentrations for Method 1315 are essentially the same as the results from Method 1313. Therefore, the resulting Method 1315 eluates were saturated solutions with respect to aluminum and did not meet the "dilute" boundary condition. Thus, these barium results were not mass transfer-controlled, and should not be interpreted as diffusion-controlled release.
- Arsenic eluate concentrations in Method 1315 are significantly less than the Method 1313 results at the corresponding eluate pH and greater than the LLOQ. Therefore, Method 1315 eluates were dilute solutions with respect to arsenic and the arsenic results can be further evaluated to determine if diffusion-controlled release is a reasonable assumption.

Inspection of the cumulative release and flux as functions of leaching time indicate that release of selenium initially followed the reference line for idealized Fickian diffusion (i.e., log-linear release with a slope of ½ with respect to time for cumulative release and -½ with respect to time for flux). After approximately 14 days, release declined somewhat which may be indicative of depletion of selenium from the material. In contrast, the cumulative release and flux of aluminum follow the slopes of ½ and -½, respectively; however, aluminum is not diffusion controlled because the Method 1315 data did not meet the criteria for maintaining dilute solutions. Furthermore, pH gradients internal to the monolith being tested result in varying pore solution concentrations of aluminum that cannot be effectively represented as a constant observed diffusivity in a simple Fickian diffusion-controlled release model.

4.4.7 Considering Dilution and Attenuation in an Assessment Ratio

In some evaluations, it may be appropriate to consider the effect of a relatively small volume of leachate interacting with a larger groundwater body through use of dilution and attenuation factors. The COPC concentrations from LEAF test results represent a source term for leaching directly into contacting water. Upon leaving the source and entering the environment, COPCs may become diluted or immobilized into the environment before reaching a receptor. A dilution and attenuation factor (DAF) can sometimes be used to estimate this reduction in concentration of a COPC in the environment. A DAF is COPC specific and based on existing knowledge of fate and transport for the site of interest. DAFs have a value greater than or equal to one (DAF ≥ 1), representing the reduction in COPC concentration due to dilution of leachate from the source into a larger waterbody or the attenuation of COPCs to surrounding materials and processes, such as sorption to soil.

Constituents can interact with different media in ways that are non-linear with respect to concentration, pH and other factors. In addition, interactions between different stressors have the potential to affect fate and transport. As a result, it is important to understand and discuss the basis for a DAF to demonstrate that the magnitude of reduction identified is applicable to a specific evaluation.

In situations where it is appropriate to apply existing DAF values, the source term from LEAF tests is divided by DAF values to estimate COPC concentrations at particular points downgradient which can be compared to threshold values. Alternatively, the Assessment Ratio (see Equation 4-1) can be modified to account for dilution and attenuation (Equation 4-16).

$$AR_{DAF} = \frac{AR}{DAF} = C_{leach\_max}/(DAF \times C_{thres}) \qquad \textbf{Equation 4-16}$$

Where

AR_{DAF} is the assessment ratio considering dilution and attenuation [-];

C_{leach_max} is the estimated maximum concentration for the COPC [mg/L] (within the applicable pH domain when using Method 1313 results or L/S range when using results from either Method 1314 or Method 1316);

C_{thres} is the threshold value for the COPC [mg/L]; and

DAF is a COPC-specific dilution and attenuation factor appropriate for a given site[-].

Unless otherwise specified, the Assessment Ratio used in this guide does not consider DAFs.

4.4.8 Integrating Source Terms into Models

Source terms developed using LEAF are dependent upon the level of testing and assessment applied. Simpler testing and assessments with less information regarding material placement in the environment result in less defined source terms. The infinite source term assumes that the material will continue to leach into the future. Infinite source terms developed from LEAF are often based on screening level assessments. Increased levels of testing and assessment can result in finite-release source terms. A finite source term representing time dependent leaching will often entail Method 1313 pH dependent data suited to the scenario pH domain, combined with data from Methods 1314, 1315 or 1316 to evaluate L/S dependence in the scenario.

The source terms developed from LEAF can be used directly, in conjunction with screening DAF values or with a bounding deterministic groundwater fate and transport model (e.g., the Industrial Waste Management Evaluation Model, or IWEM). The use of source terms from LEAF paired with modeling can provide a more complete understanding of likely releases and resulting risks in contrast to the results from a single-point leaching test. Sensitivity analysis can be carried out using estimates from LEAF testing of COPC release over the anticipated pH and other conditions of the landfill or use scenario. Numerical modeling can allow for consideration of vadose zone and groundwater transport of released constituents, exposure to humans or animals via drinking water, and the toxicity of the released COPCs. In these models, leaching data expressed on a concentration basis in mg/L or mass basis in mg/kg-dry represent the source term for estimating the release of potentially hazardous substances.

Leaching data from LEAF can be used as an input to a sophisticated mass transport model to develop a more-refined estimate of release for complex environmental conditions. For example, geochemical speciation modeling software allows for simulation of LSP as a function of pH, L/S, and leachate chemistry (e.g., redox changes, ionic strength) which can be used directly to inform decision-making or applied subsequently to several different mass transport models to simulate COPC release in a range of field leaching scenarios. Tools for geochemical speciation and reactive mass transport modeling include PHREEQC *wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc/*), MINTEQA2 *(www2.epa.gov/exposure-assessment-models/minteqa2*), LeachXS™ (van der Sloot & Kosson, 2012), and The Geochemist's Workbench *(www.gwb.com*).

Reactive mass transport models, including use of geochemical speciation, may be used to examine sensitivity to scenarios beyond laboratory testing conditions (Dijkstra et al., 2008; Meima & Comans,

1998). In addition, chemical speciation modeling of pH-dependent and L/S-dependent test data can be helpful to improve the understanding of the retention mechanisms that control the release of COPCs (e.g., mineral phase dissolution, sorption, and aqueous phase complexation phenomena) (van der Sloot, et al., 2017). Where data are adequate, modeling can be used to estimate the effects of factors that may modify leaching such as changes in the level of dissolved and particulate organic matter due to biological degradation, arsenic leaching in the presence of calcium, potential impacts of common ions, and the impact of constituents that can affect redox conditions (e.g., iron or sulfur), or changes in redox over time due to microbial processes (i.e., anaerobic biodegradation).

One approach to integrating field scenarios into understanding leaching behavior is to use numeric models designed to simulate specific release conditions. For example, when the water contact is primarily through flow-around a relatively impermeable fill, the Fickian diffusion model (Crank, 1975) is commonly used to estimate mass transport of COPCs. Fickian diffusion assumes that a constituent is initially present throughout the material at a uniform concentration and that mass transfer takes place in response to concentration gradients in the pore water solution of the porous material. The Fickian diffusion model is most appropriate for release scenarios for which highly soluble species are a concern or for which external stresses do not induce sharp internal chemical gradients (e.g., pH gradients, carbonation, and redox changes) that significantly influence local LSP within the material (U.S. EPA, 2014c).

The effects of physical parameters can be evaluated through coupling of the results from chemical speciation models with transport models, or reactive transport models. Chemical speciation and reactive transport models can be useful tools to evaluate: (i) conditions not practically achievable in the laboratory on material leaching behavior, (ii) the aging of materials under factors that historically control leaching in the field, and (iii) integration between laboratory and field leaching data (U.S. EPA, 2014c). ORCHESTRA can calculate chemical speciation in thermodynamic equilibrium systems using the same thermodynamic database format as other geochemical speciation programs (e.g., PHREEQC or MINTEQ) and contains state-of-the-art adsorption models for oxide and organic surfaces as well as solid solutions (U.S. EPA, 2014c).

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5. Case Studies of Using LEAF for Assessments

5.1 Screening Assessment: Evaluating Coal Combustion Fly Ash for Use as Structural Fill Material

The leaching data used in this illustrative example includes the measured and interpolated results of LEAF testing conducted on the subject materials and presented in U.S. EPA reports (U.S. EPA, 2009, 2012c, 2012d). The equations cited in the example are found in Section 4.2.4. Full graphical and tabular leaching data associated with the example are provided in Appendix B. This case study is for illustrative purposes only and is not intended to be directly applicable to any evaluation. The use of LEAF is voluntary but may provide information in support of a beneficial use determination.

In this example, a coal combustion fly ash is proposed for beneficial use as construction fill material. LEAF testing may provide useful information in support of meeting one of the four criteria defined by EPA for beneficial use of CCR, the environmental demonstration criteria.[29] Laboratory leaching test results for the coal combustion fly ash, EaFA, are used as reported by the U.S. EPA (U.S. EPA, 2012c, 2012d). The determination as to whether the fly ash material may be appropriate for use from a leaching perspective is conducted in stages as described by the stepwise screening assessment approach (Section 4.2.1 and Table 4-1). This evaluation provides an example of a leaching assessment that may be used as one of several factors within an overall evaluation determining the potential for adverse impacts to human health and the environmental associated with the proposed beneficial use of a material. EPA's *Methodology for Evaluating Beneficial Uses of Industrial Non-Hazardous Secondary Materials* presents a voluntary approach for evaluating a wide range of industrial non-hazardous secondary materials and their associated beneficial uses. Prior to beneficially using secondary materials in any projects, interested individuals or organizations should consult with the relevant state and federal environmental agencies to ensure proposed uses are consistent with state and federal requirements.

The simplest stage of the screening assessment is estimated maximum leaching concentration derived from total and available content of COPCs in the material. These estimated leaching concentrations are compared directly to relevant thresholds values based on requirements for beneficial use of a material, other applicable use criteria and the regulatory program. In this example, the criteria for beneficial use is assumed the compliance of estimated leaching concentrations for all COPCs with drinking water MCLs. If all COPC release estimate concentrations fall below the applicable regulatory threshold values, the beneficial use may be considered appropriate on this basis. The comparison between estimated leachate concentrations and threshold concentrations is made through calculation of an assessment ratio using Equation 4-1:

$$AR = C_{leach\_max} / C_{thres}$$

For the screening assessment in this case study, it is assumed that the assessment is conducted at the boundary of the fly ash fill.

[29] For coal combustion residuals (CCR), the Agency's April 2015 CCR Disposal Final Rule promulgated a definition for beneficial use (40 CFR 257.53). This definition identifies four criteria that distinguish beneficial use from disposal (21349 FR 80). Those considering beneficial use for CCR should consult both this definition and the relevant state authorities to identify all the requirements that would apply.

5.1.1 Definition of the Assessment Scenario

Following the workflow discussed in Section 4.2, the application scenario is defined as a 3-meter thick structural fill of fly ash material compacted in place to a dry density of 1,500 kg-dry/m^3 that is used as a permeable construction fill. The construction fill is covered by a layer of clean sandy loam with a natural pH of 6.0 and a permeability that allows infiltrating water to percolate through to the fill material at a rate of 25 cm per year.

The objective of this leaching assessment is to determine if the leaching of COPCs from the EaFA fly ash when used as construction fill is appropriate from a leaching perspective (i.e., to meet the environmental demonstration criteria within the definition of beneficial use of CCR material). Many of the scenario-based assumptions and parameters used in this hypothetical case study were chosen for purely illustrative purposes and were not intended to represent typical or default values to be used in similar assessments. For example, the U.S. national drinking water regulations were selected as thresholds in this hypothetical example to illustrate how LEAF leaching results may be evaluated relative to applicable benchmarks. The appropriate regulatory thresholds for actual scenarios will be dependent upon the rules and guidance of the applicable regulatory agency, but the methodology for evaluation will be essentially the same. Other potential thresholds could include site-specific performance values or surface or ambient water quality limits (e.g., U.S. EPA National Recommended Water Quality Criteria). Since this case study focuses on the leaching performance related to evaluation of coal combustion fly ash for construction applications, all other aspects of the application (e.g., geotechnical, etc.) are assumed not to preclude use of fly ash as construction fill.

Key Attributes of the Beneficial Use Case Study

Problem Statement – Will leaching concentrations of COPCs exceed or fall below the leaching thresholds designated at the point of compliance?

Assumed Field Conditions – A sandy loam soil with a natural pH of 6.0 is used as a cover over a 3-meter thick layer of construction fill. The soil offers negligible acidity to the infiltrating water that percolates through the soil at a net infiltration rate of 25 cm/year into the underlying construction fill material. The construction fill is compacted in place to a density of approximately 1,500 kg-dry/m^3.

Material Composition – The properties of a coal combustion fly ash material (EaFA) are as reported by U.S. EPA (2012c) and include total content analysis, Method 1313 and Method 1316 test results.

Assumed Threshold Values – For this hypothetical case study, it is assumed that the state environmental regulatory agency has determined the relevant COPCs to be antimony (Sb), arsenic (As), barium (Ba), boron (B), cadmium (Cd), lead (Pb), molybdenum (Mo), selenium (Se) and thallium (Tl) and that the applicable threshold values are the national drinking water regulations.

Assumed Point of Compliance – In consultation with the state environmental agency, the point of compliance is determined to be 100 m hydraulically downgradient from the proposed fill. Surface water quality threshold are not considered because the nearest surface water body is greater than 100 m from the source.

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5.1.2 Testing Program and Results

Since the overlying soil is a sandy loam with a natural pH of 6.0 and an insignificant amount of acidity, the natural pH of the fly ash fill will dominate the leachate pH. Therefore, Method 1313, Method 1316 and Method 1314 are the most appropriate LEAF tests to characterize leaching for this scenario and the leaching assessment should follow the screening approach in Figure 4-1 through the equilibrium-based and percolation-based leaching steps. Table 5-1 presents the total content by digestion and LEAF leaching data that were used to support the assessments in this case study. Because Method 1314 is preferred over Method 1316 data when both are available (see Section 4.2.4.4), Method 1314 data is used in the assessment presented here. Only the LEAF results that are relevant to the various assessment stage (i.e., leaching of the available content, maximum leaching over the application pH domain, maximum over the L/S range) are presented in Table 5-1; however, all leaching data, including data from Method 1316, are presented in graphical and tabular form in Appendix B.

Table 5-1. Total Content and LEAF Testing Results for EaFA Coal Combustion Fly Ash

EaFA		LEAF Leaching Test Results						
			Method 1313				Method 1314	
COPC	Total Content [mg/kg-dry]	Max Conc. pH 2, 9, 13 Used to Calculate Available Content [mg/L]	pH of Max Conc. used for Available Content	Max Conc. pH Domain 5.5 ≤ pH ≤ 9 [mg/L]	pH at Max Conc.	LSP Limit	Max Conc. Over L/S Range [mg/L]	L/S at Max Conc. [mL/g-dry]
Antimony (Sb)	1.5	0.18	13	0.15	7	Avail. Cont.	0.38	2
Arsenic (As)	63	9.7	13	0.46	9	Solubility	2.4	10
Barium (Ba)	830	0.88	2	0.48	9	Solubility	2.2	5
Boron (B)	1,400	9.8	13	5.0	5.5	Solubility	160	0.2
Cadmium (Cd)	3.5	0.056	2	0.028	5.5	Solubility	1.4	0.2
Chromium (Cr)	120	2.0	2	0.20	9	Solubility	5.3	0.2
Lead (Pb)	39	0.26	2	0.0015	5.5	Solubility	0.028	0.2
Molybdenum (Mo)	15	3.9	13	3.7	9	Avail. Cont.	22	0.5
Selenium (Se)	24	6.9	13	3.3	9	Solubility	6.9	2
Thallium (Tl)	0.91	0.26	2	0.03	5.5	Solubility	0.51	0.2

Source: U.S. EPA (2012c, 2012d).

Reported values of total content by digestion may be less than available content by Method 1313 because of uncertainty associated with testing (see Section 4.4.1)

5.1.3 Total and Available Content Screening

Screening based on total content is an assessment level that requires testing data outside of the scope of the LEAF test methods; therefore, it may not be practical for all assessments. Typically, total content data is provided through digestion of the solid material or through non-destructive testing. When total content data is available, estimates of maximum leaching concentration (C_{leach_max}) based on total content may be calculated for the default initial L/S value of 0.5 L/kg-dry using Equation 4-3.

$$C_{leach\_max} = m_{total}/(L/S)_{initial}$$

Using the testing and characterization data for the EaFA fly ash shown in Table 5-1, the total content for antimony is 1.5 mg/kg-dry and, therefore, Equation 4-3 becomes:

$$C_{leach\_max} = 1.5\left(\frac{mg}{kg-dry}\right)\Big|\frac{1}{0.5}\left(\frac{kg-dry}{L}\right) = 3.0\left(\frac{mg}{L}\right)$$

The C_{leach_max} value based on the total content assumes that the full amount of a COPC in a solid material leaches into a liquid at the default initial L/S.

The available content data in Table 5-1 is reported directly from Method 1313 as the maximum eluate concentration of the three available content pH extractions at endpoint target pH values of 2, 9 and 13. Therefore, the estimated maximum leaching concentration for available content is calculated using Equation 4-4:

$$C_{leach\_max} = C_{1313(\max pH\ 2,9,13)} \times \frac{(L/S)_{1313}}{(L/S)initial} = 20 \times C_{1313(max\ pH\ 2,9,13)}$$

Since, the L/S for Method 1313, $(L/S)_{1313}$, is defined as 10 L/kg-dry in the test method (U.S. EPA, 2012f), the multiplier for the maximum leaching concentration, $C_{1313(max\ pH\ 2,9,13)}$, is 20 (i.e., 10 L/kg-dry divided by 0.5 L/kg-dry). From Table 5-1, the available content of antimony was determined to be 0.17 mg/kg-dry measured at a pH of 13. Therefore, the estimated maximum leaching concentration for the available content assessment is:

$$C_{leach\_max} = 20\ \text{x}\ C_{1313(max\ pH\ 2,9,13)} = 20\ \text{x}\ 0.18\left(\frac{mg}{L}\right) = 3.6\left(\frac{mg}{L}\right)$$

Note that the estimated leachate concentration based on available content is greater than that estimated by total content**.** Section 4.4.1 discusses the uncertainties regarding total content analysis that may result in an available content greater than a total content.

Table 5-2 provides the threshold concentration for each COPC in EaFA, the estimated maximum leaching concentration and assessment ratio value for the total content and available content screening levels. Assessment ratio values less than or equal to one ($AR \leq 1$) indicate COPCs where the maximum leaching concentrations does not exceed threshold values and, therefore, are not likely to be a concern. For COPCs where the assessment ratio is greater than one ($AR > 1$), additional refinement of the assessment, either through further leaching evaluation or through alteration of the reuse scenario, is indicated. For all COPCs, the assessment ratios in Table 5-2 indicate that estimated leaching concentrations based on both total content and available content exceed threshold values by 1 to 4 orders of magnitude. However, this

screening level approach is highly bounding in that it assumes the complete release of the total or available content of all COPCs under field conditions. Thus, this assessment alone cannot support a conclusion that the proposed use of EaFA as a construction fill is acceptable and a more-refined assessment is required to account for environmental processes not considered in this initial screening.

Table 5-2. Initial Screening Values for EaFA Fly Ash Using LEAF Leaching Estimates

EaFA		Total Content		Available Content	
COPC	Threshold Value [mg/L]	C_{leach_max} [mg/L]	Assessment Ratio (AR)	C_{leach_max} [mg/L]	Assessment Ratio (AR)
Antimony (Sb)	0.006	3.0	**500**	3.6	**600**
Arsenic (As)	0.01	130	**13,000**	190	**19,000**
Barium (Ba)	2	1700	**830**	18	**8.8**
Boron (B)	7	2800	**400**	200	**28**
Cadmium (Cd)	0.005	7.0	**1,400**	1.1	**220**
Chromium (Cr)	0.1	240	**2,400**	40	**400**
Lead (Pb)	0.015	78	**5,200**	5.2	**350**
Molybdenum (Mo)	0.2	30	**150**	78	**390**
Selenium (Se)	0.05	48	**960**	140	**2,800**
Thallium (Tl)	0.002	1.8	**910**	5.2	**2,600**

Assessment ratios shown in **bold red** indicate COPCs where the maximum estimated leaching concentration for the assessment exceeds the indicated comparative threshold.

Threshold values are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless otherwise noted in Table 3-7.

5.1.4 Equilibrium-pH Screening (Method 1313)

In addition to available content, Method 1313 provides eluate concentration data across a broad pH range that may be focused to estimate the maximum leaching of COPCs over an applicable pH domain for the application scenario. The maximum concentration over an applicable pH domain provides a bounding estimate of potential leaching under field conditions that may be more accurate for COPCs with LSP behaviors that are a strong function of pH (e.g., heavy metals, radionuclides).

The selection and modification of an applicable scenario pH domain are discussed in Section 4.2.5.1 of the guide. For this case study, the default pH domain of 5.5 ≤ pH ≤ 9.0 was selected since the natural pH of EaFA (pH = 6.8) falls within this interval.[30] For COPCs where solubility-limited leaching dictates the concentration over the pH domain, the estimated maximum concentration is derived from the maximum concentration of the pH domain, $C_{1313(max\ pH\ domain)}$, using Equation 4-6:

$$C_{leach\_max} = C_{1313(\max pH\ domain)}$$

[30] As discussed in Section 4.2.5.1, the pH domain applicable to many scenarios should include the natural pH of the material and should consider the prevailing pH in proposed application and the pH effects associated with any aging or degradation processes to which the material might be exposed.

If a COPC has been demonstrated to be available content-limited over the entire applicable scenario pH domain, the estimated maximum leachate concentration will be a strong function of L/S and requires adjustment to the default initial L/S value of 0.5 L/kg-dry using Equation 4-4:

$$C_{leach\_max} = C_{1313(max\ pH\ domain)} \times \frac{(L/S)_{1313}}{(L/S)_{initial}}$$

Based on the Method 1313 testing data provided in Table 5-1, the maximum concentration of antimony over the default pH domain, 5.5 ≤ pH ≤ 9.0, is 0.15 mg/L measured at the natural pH of 6.8. Since antimony was determined to be available content limited over this pH domain, Equation 4-4 is used to estimate the maximum leachate concentration at the default L/S:

$$C_{leach\_max} = 20 \times C_{1313(max\ pH\ domain)}$$

$$C_{leach\_max} = 20 \times 0.15 \left(\frac{mg}{L}\right) = 3.0 \left(\frac{mg}{L}\right)$$

Table 5-3 provides a summary of the test results and estimated maximum leachate concentrations for the equilibrium-pH leaching assessment of EaFA fly ash. For each COPC, Method 1313 test data includes the maximum eluate concentration measured over the applicable pH domain and the identified LSP limit (i.e., available content- or solubility-limited leaching). The assessment columns show the corresponding C_{leach_max} value and the assessment ratio value based on the equilibrium-pH assessment. The assessment ratio results show that the maximum estimated field concentration for most COPCs in the EaFA fly ash exceed threshold values for the equilibrium-based assessment. Only the leaching of barium, boron and lead are acceptable based on this leaching assessment. Therefore, a more-detailed leaching source term, such as that provided by percolation leaching assessment using Method 1314, may be used to further refine the leaching assessment.

Table 5-3. Equilibrium-pH Assessment of Fly Ash

EaFA COPC	Threshold Value [mg/L]	Method 1313 Max Conc. Over pH Domain [mg/L]	LSP limit	Equil-pH Assessment C_{leach_max} [mg/L]	Equil-pH Assessment AR
Antimony (Sb)	0.006	0.15	Available Content	3.0	**500**
Arsenic (As)	0.01	0.46	Solubility	0.46	**46**
Barium (Ba)	2	0.48	Solubility	0.48	0.24
Boron (B)	7	5.0	Solubility	5.0	0.71
Cadmium (Cd)	0.005	0.028	Solubility	0.028	**5.6**
Chromium (Cr)	0.1	0.20	Solubility	0.2	**2.0**
Lead (Pb)	0.015	0.0015	Solubility	0.0015	0.10
Molybdenum (Mo)	0.2	3.7	Available Content	74	**370**
Selenium (Se)	0.05	3.3	Solubility	3.3	**66**
Thallium (Tl)	0.002	0.03	Solubility	0.03	**15**

Assessment ratios shown in **bold red** indicate COPCs where the maximum estimated leaching concentration for the assessment exceeds the indicated comparative threshold.

Threshold values are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless otherwise noted in Table 3-7.

5.1.5 Full LSP Screening (Method 1313 and Method 1314)

For the scenario presented in this illustrative example, a granular material is contacted with infiltration such that the mode of water contact may be considered percolation of infiltrating water through a relative permeable bed (Section 4.2.5.3). Therefore, the inclusion of L/S-dependent leaching data (e.g., from Method 1314 or Method 1316) in the screening assessment may provide increased refinement of the bounding estimate of leaching offered through equilibrium-pH screening.

The estimated maximum leachate concentration is the greater of the maximum eluate concentration over the applicable pH domain (i.e., $C_{1313(max\ pH\ domain)}$ from the equilibrium-pH screening) and the maximum eluate concentration as a function of L/S as shown in Equation 4-8:

$$C_{leach\_max} = MAX\left[C_{1313(max\ pH\ domain)}, C_{(L/S),max}\right]$$

An illustration of the improved understanding provided by Method 1314 is presented in Figure 5-1 by comparisons of EaFA eluate pH and COPC concentrations for Method 1314 (blue triangles), Method 1316 (orange diamonds) and the natural pH from Method 1313 (red dot with indicator circle). In the column test (Method 1314), the eluate pH data from the column indicates an initial eluate pH of 4.2 with increasing pH to near-neutral values an L/S of 2 L/kg-dry. Thereafter, the eluate pH in the column remained approximately pH 7, consistent with the pH in the batch style leaching tests (Method 1313 and Method 1316). The initially acidic pH that is obvious in the Method 1314 data is not indicated by the eluate pH in Method 1316 or the natural pH in Method 1313 due to the differences between batch tests and column elution tests. For this coal combustion ash, the cause of the initially low pH is a process operation where sulfuric acid is sprayed into the effluent stream to aid in electrostatic precipitator collection of fly ash resulting in an acidic surface coating on the EaFA sample.

The full results of Method 1314 testing of EaFA fly ash presented in Appendix B show the impact of the evolution in eluate pH in the column on the LSP behavior of each COPC as a function of pH (e.g., as characterized by Method 1313). As a result of the pH increase from pH 4.2 to pH 7, COPC concentrations in column eluates initially may be high when solubility is increased under acidic conditions only to decrease as pH becomes more neutral (e.g., cadmium). Alternatively, initial concentrations of a COPC in column eluates may be low because of lower solubility at acidic pH than at neutral pH (e.g., selenium). COPCs may rapidly wash out or are depleted after the pH reaches an available content-limited domain (e.g., boron). The arsenic and chromium represent special cases where increased eluate concentration reflect solubility-limited leaching at acidic and neutral pH but pass through a minimum solubility point at approximately pH 5.

Table 5-4 presents the maximum eluate concentrations for each COPC derived from Method 1314 testing of EaFA fly ash, along with the corresponding L/S at which the maximum occurred. The table also provides assessment ratio for the equilibrium-L/S assessment calculated as the maximum for each COPC in a percolation assessment step, calculated by dividing the maximum concentration over the L/S by the threshold value. The conclusions of the percolation assessment are consistent with those in previous steps indicating that most or all of the COPCs leach at concentrations above threshold value. Therefore, the only conclusion that can be reached based on this stepwise leaching assessment is that EaFA is not appropriate for the proposed permeable construction fill scenario.

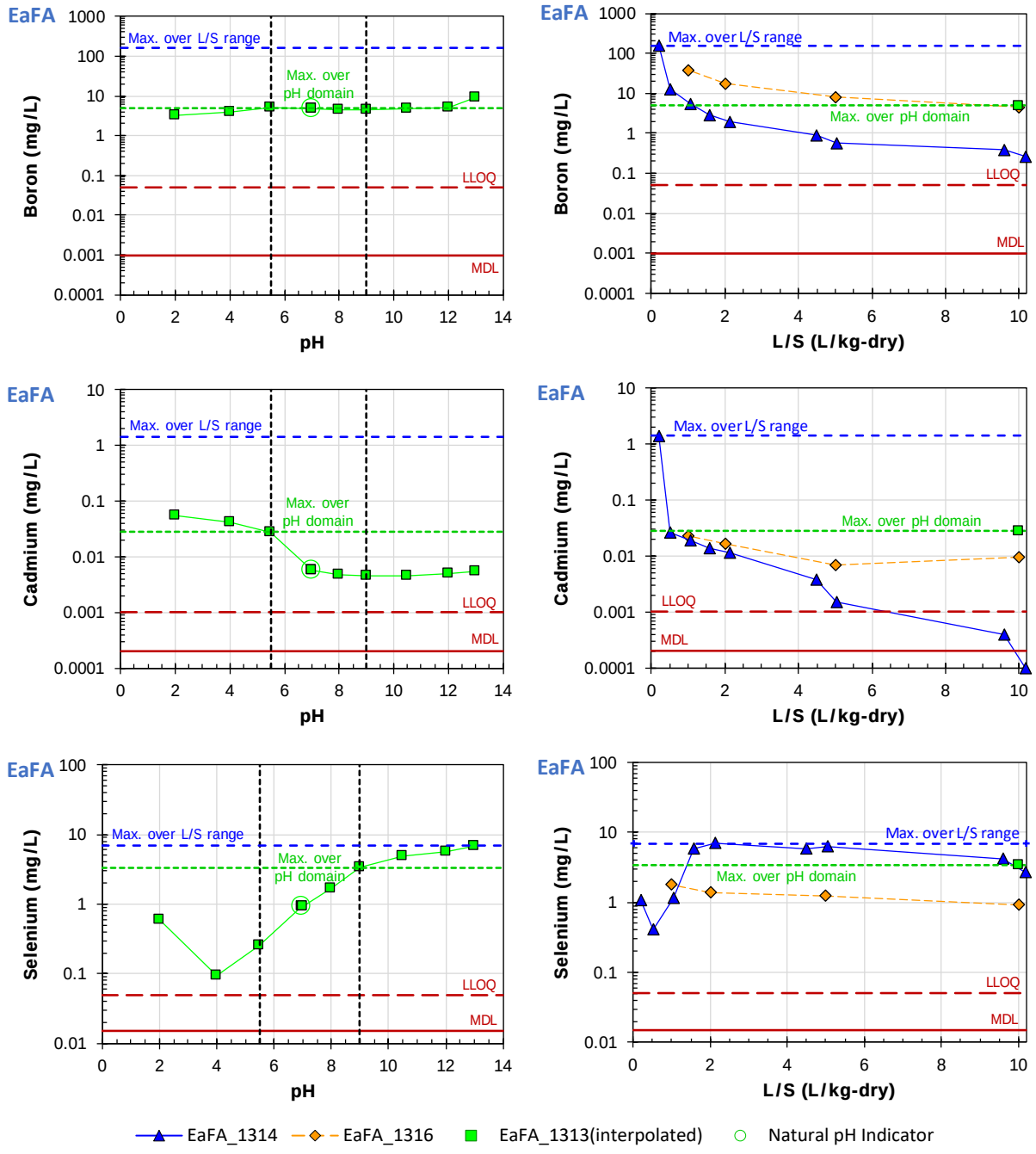

Figure 5-1. COPC concentrations as a function of pH (left) and L/S (right) for a coal combustion fly ash (EaFA) for full LSP screening assessment: Method 1313 interpolated), Method 1314, and Method 1316.

Table 5-4. Full LSP Screening Assessment of EaFA Fly Ash Fill Material

EaFA		Method 1313			Method 1314		Full LSP Assessment	
COPC	Threshold Value (mg/L)	Max Conc. pH Domain 5.5≤pH≤9 [mg/L]	pH at Max Conc.	LSP Limit	Max Conc. Over L/S [mg/L]	L/S at Max Conc. [mL/g-dry]	C_{leach_max} [mg/L]	Full LSP AR
Antimony (Sb)	0.006	0.15	7	Avail. Cont.	0.38	2	0.38	**64**
Arsenic (As)	0.01	0.46	9	Solubility	2.4	10	2.4	**240**
Barium (Ba)	2	0.48	9	Solubility	2.2	5	2.2	1.0
Boron (B)	7	5.0	5.5	Solubility	160	0.2	160	**22**
Cadmium (Cd)	0.005	0.028	5.5	Solubility	1.4	0.2	1.4	**280**
Chromium (Cr)	0.1	0.20	9	Solubility	5.3	0.2	5.3	**53**
Lead (Pb)	0.015	0.0015	5.5	Solubility	0.028	0.2	0.028	**1.8**
Molybdenum (Mo)	0.2	3.7	9	Avail. Cont.	22	0.5	22	**110**
Selenium (Se)	0.05	3.3	9	Solubility	6.9	2	6.9	**140**
Thallium (Tl)	0.002	0.03	5.5	Solubility	0.51	0.2	0.51	**260**

Assessment ratios shown in **bold red** indicate COPCs where the maximum estimated leaching concentration for the assessment exceeds the indicated comparative threshold.

Threshold values are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless otherwise noted in Table 3-7.

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5.1.6 Consideration of an Alternate Coal Combustion Fly Ash

In parallel to evaluation of EaFA, an alternate coal combustion fly ash, CaFA, was evaluated for use in the same scenario. The evaluation of this alternative material is one of many ways in which leaching assessments may vary. Results from LEAF testing of CaFA are provided in Table 5-7 while the associated assessment results are provided in Table 5-8.

The assessment for the alternative CaFA material was conducted in the same manner as described for EaFA fly ash with the exceptions that the upper bound of scenario pH domain was expanded from the default value 9.0 to a value of 12.0. Therefore, the applicable pH domain used in equilibrium-based assessment of Method 1313 data ($5.5 \leq pH \leq 12.0$) captured the natural pH of the CaFA material.

The results of the leaching assessment of CaFA provided in Table 5-8 indicate that the CaFA material is similarly not appropriate for use as a construction fill under the assumption of no dilution and attenuation. Although both CaFA and EaFa are coal combustion fly ash materials, the contrast between assessment results illustrates the importance of careful consideration of scenario parameters in accordance with existing regulatory requirements.

Table 5-5. LEAF Coal Fly Ash CaFA Total Content Analysis and LEAF Leaching Test Results

CaFA			LEAF Leaching Test Results						
				Method 1313			Method 1314		
COPC	Total Content [mg/kg-dry]	Available Content [mg/L]	pH for Available Content	Max Conc. pH Domain 7 ≤ pH ≤ 12 [mg/L]	pH at Max Conc.	Available content- or Solubility-limited	Max Conc. Over L/S Range [mg/L]	L/S at Max Conc. [mL/g-dry]
Antimony (Sb)	6.2	0.68	2	0.070	10.5	Solubility	0.039	10
Arsenic (As)	22	4.9	2	0.097	9	Solubility	0.018	10
Barium (Ba)	960	8.3	2	2.7	12	Solubility	400	0.2
Boron (B)	NA	63	2	41	7	Avail. Cont.	21	5
Cadmium (Cd)	1.7	0.21	2	0.058	7	Solubility	<0.00067	-
Chromium (Cr)	88	9.4	2	0.63	12	Solubility	0.31	10
Lead (Pb)	56	1.3	2	0.0026	7	Solubility	0.015	1
Molybdenum (Mo)	19	3.7	2	2.0	12	Solubility	4.7	9.5
Selenium (Se)	8.6	4.6	2	0.49	10.5	Solubility	0.83	2
Thallium (Tl)	1.5	0.10	2	0.0115	7	Solubility	<0.005	-

Reported values of total content by digestion may be less than available content by Method 1313 because of uncertainty associated with testing (see Section 4.4.1)

NA = boron total content not available because of metaborate addition.

"<" indicates all eluate values less than the reported MDL concentration.

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Table 5-6. Leaching Assessment Ratios for Alternative Coal Combustion Fly Ash CaFA

CaFA		Assessment Ratio (AR)			
COPC	Threshold Value [mg/L]	Total Content (total content leaches)	Available Content (available content leaches)	Equil-pH (max. conc. over pH domain)	Full LSP (max. conc. over pH domain and L/S range)
Antimony (Sb)	0.006	**2,100**	**2,300**	**12**	**12**
Arsenic (As)	0.01	**4,400**	**9,800**	**10**	**10**
Barium (Ba)	2	**960**	**83**	**1.4**	**200**
Boron (B)	7	NA	**180**	**120**	**5.8**
Cadmium (Cd)	0.005	**680**	**840**	**12**	**12**
Chromium (Cr)	0.1	**1,800**	**1,900**	**6.3**	**6.3**
Lead (Pb)	0.015	**7,500**	**1,700**	0.17	1.0
Molybdenum (Mo)	0.2	**190**	**370**	**10**	**24**
Selenium (Se)	0.05	**340**	**1,800**	**10**	**17**
Thallium (Tl)	0.002	**1,500**	**1,000**	**5.8**	**5.8**

NA indicates data or assessment ratios that are "not available."

Assessment ratios shown in **bold red** indicate COPCs where the maximum estimated leaching concentration for the assessment exceeds the indicated comparative threshold.

Assessment ratios shown as "<0.001" (see chromium and selenium) indicate values calculated at less than 0.001.

Threshold values are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless otherwise noted in Table 3-7.

5.2 Scenario Assessment: Evaluating Treatment Effectiveness of a Cement-Based Stabilization/Solidification (SS) Process

In this example, the potential effectiveness of onsite treatment using a cement-based Stabilization/Solidification (S/S) process is evaluated for contaminated soil at a copper and lead smelter. This evaluation provides an example of a leaching assessment for determining treatment effectiveness based on data from (Garrabrants et al. Pending Publication a, b). This case study is for illustrative purposes only and is not intended to be directly applicable to any evaluation. The use of LEAF is voluntary but may provide information in support of a treatment effectiveness study. A number of other tests or criteria may also be appropriate or required when determining treatment effectiveness.

The leaching of COPCs from contaminated foundry soil subject to Stabilization/Solidification (S/S-CFS) follows a mass transport leaching scenario. Infiltrating water flows around the exposed surface area of the monolith and COPCs must diffuse toward the exposed surface to leach. The rate of diffusion is driven by the internal concentration gradient between the concentration in the porewater at the core of the material and the concentration at the monolith surface. For permanently submerged materials in the water table, COPCs that diffuse to the material surface are leached into a continuous surrounding liquid phase; however, a continuous liquid phase does not exist in the vadose zone during the interval between infiltration events. Internal concentration gradients within the material relax by diffusion and the initial conditions within the monolith are restored for the beginning of the next infiltration event.

The methodology for estimating leaching concentrations under a mass transport scenario is based on the approach used to estimate COPC release from cement pavements containing coal combustion fly ash [US

EPA 2014a]. An effective leaching concentration is calculated for both 1-day and 2-day infiltration events as the estimated COPC mass released from the monolith dissolved in the volume of contacting water. The average leaching concentration over the assessment interval is determined as the weighted average of isolated and extended infiltration events (see 2.4.1.).

5.2.1 Definition of the Assessment Scenario

It has been determined that contaminated soil surrounding a copper and lead smelter is in need of remediation. The impact is localized to a 400 m^2 plan-view area (20 m by 20 m), starting at grade level to a depth of 5 m. The total volume of impacted material is 2,000 m^3. The soil is a loamy sand with an assumed bulk porosity of 0.4 cm^3_{pores}/cm^3, density of 1,700 kg/m^3, and field capacity of 0.24 cm^3_{water}/cm^3_{pore} based on the negligible drainage flux approach of Meyer and Gee (Meyer & Gee, 1999). The water table is sufficiently deep that it is not a concern for leaching of constituents at the unit boundary of the site.

The objective of this assessment is to determine if the release of COPCs from treated soil is acceptable from a leaching perspective. Many of the scenario-based assumptions and parameters used in this hypothetical case study were chosen for purely illustrative purposes and were not intended to represent typical or default values to be used in similar assessments. For example, the U.S. national drinking water regulations were selected as thresholds in this hypothetical example to illustrate how LEAF leaching results may be evaluated relative to applicable benchmarks. The appropriate regulatory thresholds for actual scenarios will be dependent upon the rules and guidance of the applicable regulatory agency, but the methodology for evaluation will be essentially the same. Other potential thresholds could include site-specific performance values or surface or ambient water quality limits (e.g., U.S. EPA National Recommended Water Quality Criteria). Since this case study focuses on the leaching performance related to evaluation of coal combustion fly ash for construction applications, all other aspects of the application (e.g., geotechnical, etc.) are assumed not to preclude use of fly ash as construction fill.

A portion of contaminated field soil (CFS) was treated for analysis of the treatment effectiveness at the laboratory bench scale. The proposed S/S remedy called for mixing the soil with Portland cement (12% dry mass basis) to create a monolithic material (S/S-CFS). The final water/binder ratio was 2:1 which is higher than typical cement blends; however, much of the added water was absorbed by the air-dried soil so that the effective water/binder ratio was estimated to be 0.65:1. The moisture content of the S/S-CFS was 26% (wet basis). The S/S-CFS material was cast into 5-cm diameter by 10-cm long cylindrical molds and cured in a humid environment (≥95% relative humidity) for a minimum cure time of 90 days. Prior to testing using Method 1313 and 1314 (both of which use granular or particle-size reduced material), the S/S-CFS material was crushed with a hammer and fed through a parallel plate grinder until >85% of the mass passed a No. 10 (2-mm) sieve. Cast materials used for Method 1315 were dry cut in half to create 5-cm diameter by 5-cm long monolithic samples.

Key Attributes of the Treatment Effectiveness Case Study

Problem Statement – Will leaching concentrations of COPCs exceed or fall below the thresholds designated at the point of compliance?

Assumed Field Conditions – The soil contamination is across a 400 m^2 plan-view area (20 m by 20 m), starting at grade level to a depth of 5 m. The total volume of impacted material is 2,000 m^3. The soil is a loamy sand with an assumed bulk porosity of 0.4 cm^3_{pores}/cm^3, density of 1,700 kg/m^3, and field capacity of 0.24 cm^3_{water}/cm^3_{pore} based on the negligible drainage flux approach of Meyer and Gee [Meyer and Gee, 1999]. The water table is sufficiently deep that it is not a concern for leaching of constituents at the unit boundary of the site.

Material Composition – Total content analysis of soil indicate concentrations of aluminum (Al), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) in excess of 1000 mg/kg. Other COPCs include arsenic (As), barium (Ba), beryllium (Be), chloride (Cl^-), fluoride (F^-), nitrate (NO_3), antimony (Sb), selenium (Se), sulfate (SO_4) and thallium (Tl).

Assumed Threshold Values – For this hypothetical case study, it is assumed that the state environmental regulatory agency has determined the relevant COPCs to be antimony (Sb), arsenic (As), barium (Ba), boron (B), cadmium (Cd), lead (Pb), molybdenum (Mo), selenium (Se) and thallium (Tl) and that the applicable threshold values are the national drinking water regulations.

Assumed Point of Compliance – The point of compliance is at the edge of the unit boundary of contaminated soil.

5.2.2 Testing Plan

The selection of appropriate leaching tests depends on the environmental factors that drive leaching in the field. In this scenario the use of Portland cement to solidify and stabilize the CFS material is expected to raise the pH and to limit leaching due to mass transfer. In order to estimate the effects of these two parameters, Methods 1313, 1314, and 1315 are chosen. Method 1315 is selected for this testing plan as it provides leaching data under mass transfer limited scenarios (e.g., leaching from a monolithic sample of S/S-CFS). Method 1313 is selected to serve two purposes in this testing plan. The first purpose of Method 1313 in this testing plan is to estimate the anticipated environmental pH (e.g., alkaline Portland cement will raise the pH of the material, See Figure 5-2). The second purpose of Method 1313 is to provide pH dependent equilibrium values for leaching of particle size reduced SS-CFS to compare against the mass transport limited results from Method 1315 (at L/S = 10). The use of Method 1313 is important because the test results from Method 1315 are a function of time and L/A ratio (comparable to L/S by considering sample geometry) while Method 1313 is a function of pH and fixed at an L/S of 10. The pH of the leachate in Method 1315 may change during testing and an understanding of the possible effects on equilibrium from Method 1313 data assists the evaluator in making the appropriate estimate on leachability in the field. Further characterization of potential leaching could rely on Methods 1314 or 1316. Both methods provide equilibrium leaching results for particle size reduced SS-CFR at L/S increments similar to the L/A increments used in Method 1315. In this case, Method 1314 is selected as the test method is an open system, potentially providing information on co-constituent dependent leaching behavior.

5.2.3 Material Characterization and Environmental Conditions

The total content analysis of a representative sample of contaminated soil indicated concentrations of aluminum (Al), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), and zinc (Zn) in excess of

1000 mg/kg. Other COPCs include arsenic (As), barium (Ba), beryllium (Be), chloride (Cl^-), fluoride (F^-), nitrate (NO_3), antimony (Sb), selenium (Se), sulfate (SO_4) and thallium (Tl) (See Table 5-9). This indicates the primary constituents of concern in the sample are inorganics, several of which are known to display pH dependent behavior (e.g., lead, and arsenic.)

Table 5-7. Total Content Analysis of Contaminated Field Soil (CFS) and Monolithic Material (S/S-CFS)

Material	Total Content (mg/kg)	
-	CFS	S/S-CFS
Aluminum	26,000	25,000
Antimony	460	440
Arsenic	360	250
Barium	530	520
Beryllium	0.34	0.38
Cadmium	14,000	13,000
Chloride	NA	NA
Chromium	1,200	550
Copper	15,000	16,000
Fluoride	NA	NA
Iron	17,000	49,000
Lead	3,400	3,100
Nitrate	NA	NA
Selenium	32	32
Sulfate	NA	NA
Thallium	35	24
Zinc	12,000	11,000

Note: "NA" indicates that contents Cl, F, NO_3 and SO_4 of $LiBO_2$ digests were not analyzed.

The change in pH of the CFS material due to stabilization/solidification was determined using HNO_3 and KOH additions in Method 1313 extract. Additions of KOH were used to raise the eluent pH above the natural pH of the material. Relative to the titration of CFS, the titration curve for S/S-CFS is shifted toward higher acid addition values, indicating more buffering capacity than the untreated soil (Figure 5-2). The differences in the natural pH of the materials (CFS pH_{nat} = 6.9 and S/S-CFS pH_{nat} = 12.8) and the shift in buffering capacity are a direct result of the addition of Portland cement during S/S treatment. The strong shift in pH of the material upon stabilization highlights the importance of leach testing for pH dependence as well as for testing for mass transfer limitations. The anticipated pH of the scenario needs to consider

the strong shift in pH to a highly alkaline environment and whether that alkalinity is sufficiently buffered to represent environmental conditions. An anticipated environmental pH for the untreated material (pH =6.9) would be 5.9 ≤ pH ≤ 7.9. For the treated material in this scenario, a more plausible range is 8 ≤ pH ≤ 13.3.

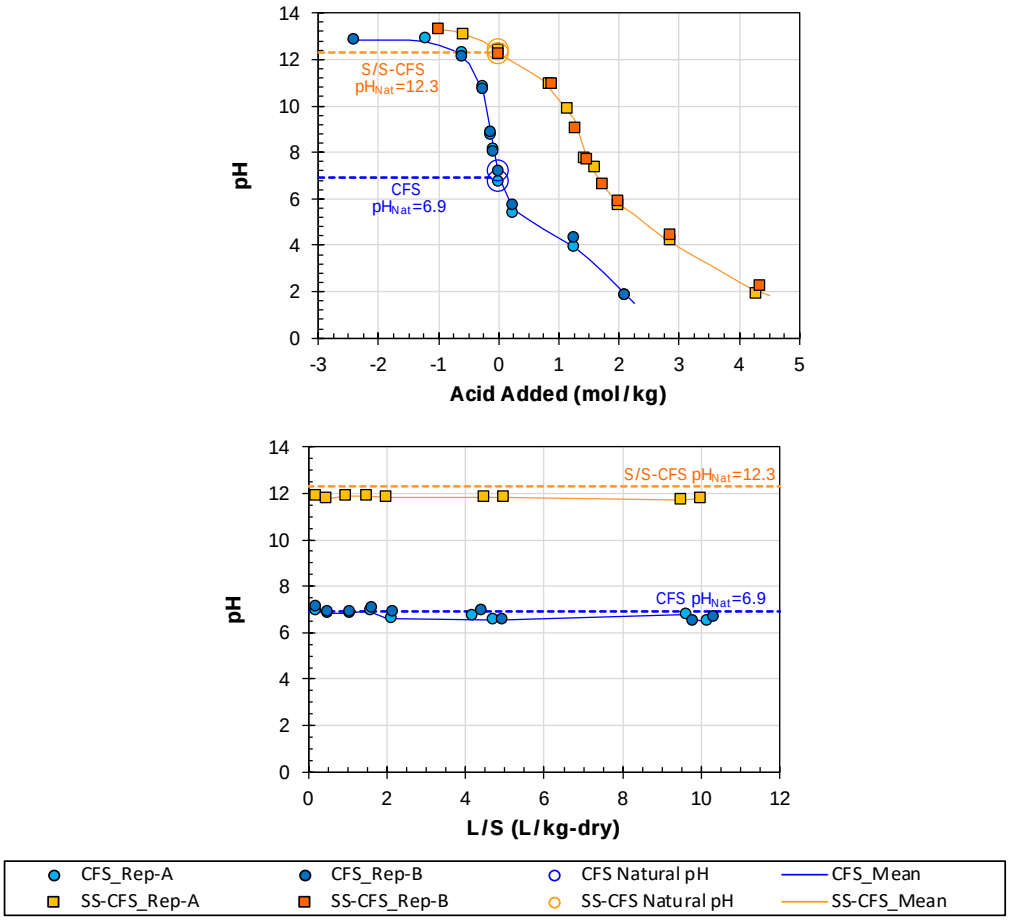

Figure 5-2. pH characterization of contaminated field soil (CFS) and monolithic material (S/S-CFS)

The volume of contacting water, or anticipated L/S, in the environment can be determined based on the infiltration rate of water. This illustrative scenario uses U.S. EPA meteorological data [14] for Nashville, TN (Table 5-8.) The EPA datasets included daily precipitation, evaporation, evapotranspiration, and other data collected over a 30-year period from 1961-1990. For days with recorded precipitation greater than zero, daily net infiltration was calculated as the balance of the daily precipitation (P), the pan evaporation (E_{PAN}), and the evapotranspiration (ET_0) data:

$$Inf = P - E_{pan} - ET_0$$

Summary statistics for the relevant precipitation data and infiltration data for this environmental setting are shown in Table 5-8.

Table 5-8. Precipitation data for Nashville, TN

	Units	Dry
City, State		Nashville, TN
Annual Precipitation	cm/y	120
Days with Precipitation	d/y	118
Annual Net Infiltration	cm/y	82
Infiltration Events ≤1-day (N1)	events/y	32
Infiltration Events >1-day (N2)	events/y	13
Net Infiltration of Events ≤1-day (P1)	cm/event	1.2
Net Infiltration of Events >1-day (P2)	cm/event	3.5
Infiltration Events >2-days	%	6.7%

After each infiltration event, soils in the subsurface drain to a relative pore saturation at field capacity [8]. The volume of water-filled pores at any saturation can be expressed in terms of L/S[31] as:

$$(L/S)_\theta = \frac{\varepsilon \cdot \theta \cdot v_{bed} \cdot 1{,}000}{m_d}$$

The capacity for water uptake (*i.e.*, volume of empty pores at the beginning of an infiltration event) is the difference between the L/S at water saturation (θ_{sat} = 1) and the L/S at field capacity (θ_f = 0.24). For the CFS bed, the L/S at water saturation and field capacity is 0.25 L/kg-dry and 0.15 L/kg-dry, respectively, indicating that the empty pore volume at the start of each infiltration event is 0.1 L/kg-dry. Converted to an L/S basis for the defined field scenarios, the annual net infiltration represents an L/S of 0.1 L/kg per year.

5.2.4 Mass Transport Assessment

In the mass transport scenario, L/S cannot be directly compared to lab results. Instead, daily infiltration events were separated into "isolated events" (≤one-day) and "extended events" (>one-day) based infiltration during consecutive days. The average duration of extended events was 2.5 days. Given that infiltration is not likely to occur over the entirety of an extended infiltration event, the mass release over a 2-day cumulative leaching interval, which can be provided directly by Method 1315, was a good approximation for release over extended infiltration events. The annual average number of infiltration events (N1 and N2) and water volumes per event (P1 and P2) over the 30-year dataset were determined and considered constant for each assessment interval. These data are used to estimate effective leaching concentrations for one- and two-day infiltration events. An average concentration for the assessment interval, I, can then be calculated based on the effective concentrations of the one- and two-day infiltration events.

[31] Where ε is the bulk porosity, [m^3_{pore}/m^3]; θ is water saturation, v_{bed} is the volume of material, and m_d is the dry mass.

The effective concentration for a one-day event is estimated using data points on the Method 1315 cumulative release curve (Figure 5-3). From the Method 1315 interval concentration data (c_j^{1315}), the cumulative mass release per area at the end of a test interval *J* (R_J) is calculated using the volume of eluate collected (v_j^{1315}) and the exposed surface area (A_{exp}^{1315}) of the test sample as:

$$\Sigma R_J = \frac{\Sigma_{j=1}^{J}\left(c_j^{1315} \cdot V_j^{1315}\right)}{A_{exp}^{1315}}$$

The mass released for the one-day interval is represented by the difference in cumulative release between the first leaching interval (ΣR_1, at cumulative leaching time of 0.08 days) and second leaching interval (ΣR_2, at cumulative leaching of 1.1 days).[32] The average volume of infiltration for a 1 day event (P1) is dependent upon the ratio of the infiltrated area (A_{inf}) to the exposed surface area (A_{exp}) of the SS-CFS material. The effective concentration of a COPC for a one-day event may be estimated as:

$$C1 = \frac{M1}{V1} = \frac{(\Sigma R_2 - \Sigma R_1) \cdot A_{exp}}{P1 \cdot A_{inf} \cdot 1{,}000}$$

An analogous equation for a two-day infiltration event uses ($\Sigma R_3 - \Sigma R_1$) to represent the mass release and *P2* to represent the average volume of infiltration over a 2-day interval:

$$C2 = \frac{M2}{V2} = \frac{(\Sigma R_3 - \Sigma R_1) \cdot A_{exp}}{P2 \cdot A_{inf} \cdot 1{,}000}$$

An average concentration for an assessment interval, *i*, may be calculated as a weighted average concentration over the series of one- and two-day infiltration events: This average leaching concentration is the effective leaching concentration over the assessment interval.

$$C_i^{av} = \left[\frac{N1 \cdot C1 + N2 \cdot C2}{N1 + N2}\right]$$

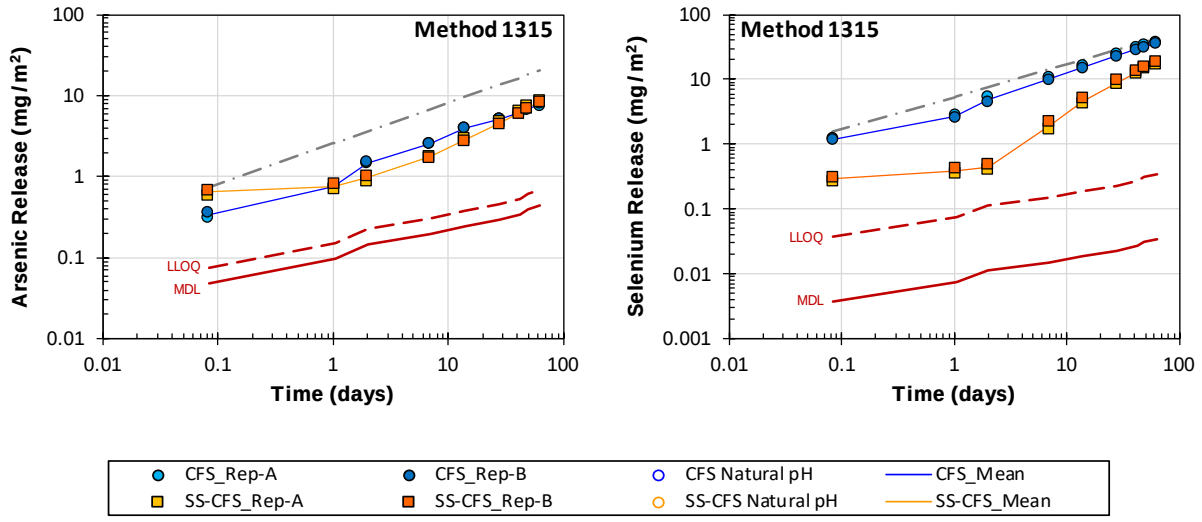

Figure 5-3. Method 1315 test results for arsenic and selenium release

[32] The concentration measured in the first interval of Method 1315 is often biased by surface dissolution and sample preparation (*e.g.*, washing off of cutting swarf). Therefore, the mass released this first interval at 0.08 days is not used in calculations as it is not representative of the mass transport leaching behavior of the bulk material.

5.2.5 LSP Considerations

The suggested effective leaching concentrations for one and two-day infiltration events are based on Method 1315 data where a relatively small sample is exposed to a large bath of water to maintain the interval concentration gradients that drive mass transport. However, these conditions are not indicative of the majority of field conditions where, typically, a small volume of water contacts a relatively large surface area. Thus, the effective concentration calculations can numerically exceed the thermodynamic bounds of chemical equilibrium represented by the Method 1313 data. If the effective leaching concentration for any one- or two-day event is greater than the measured Method 1313 solubility-controlled eluate concentration, the effective concentration should be set to the Method 1313 maximum concentration over the pH domain:

$$\text{if } C1(or\ C2) > C^{1313}_{max\ pH\ domain}\text{; then } C1\ (or\ C2) = C^{1313}_{max\ pH\ domain}$$

The results of Method 1313 and 1314 testing for arsenic and selenium before and after treatment can be seen in Figure 5-4. Method 1313 shows that both COPCs have pH dependent solubility behavior above the regulatory thresholds and that the stabilization process (i.e., increased alkalinity) effects the leachate concentrations.

The arsenic behavior seen in Methods 1313 and 1314 (Figure 5-4) suggests that arsenic is solubility controlled as Method 1313 results show a strong dependence of solubility on pH while Method 1314 results show weak dependence on L/S. The selenium behavior appears to be available content limited as there is a strong dependence of concentration on L/S and a weak dependence on pH. In comparison, the Method 1315 test results (Figure 5-3) show an initial concentration likely representative of pore water values and surface effects before a more gradual increase in leaching with time. The grey dashed line indicates the expected Fickian diffusion that would occur if no other mass transport limitations were in place. Both arsenic and selenium show less leaching than predicted by Fickian diffusion in Method 1315.

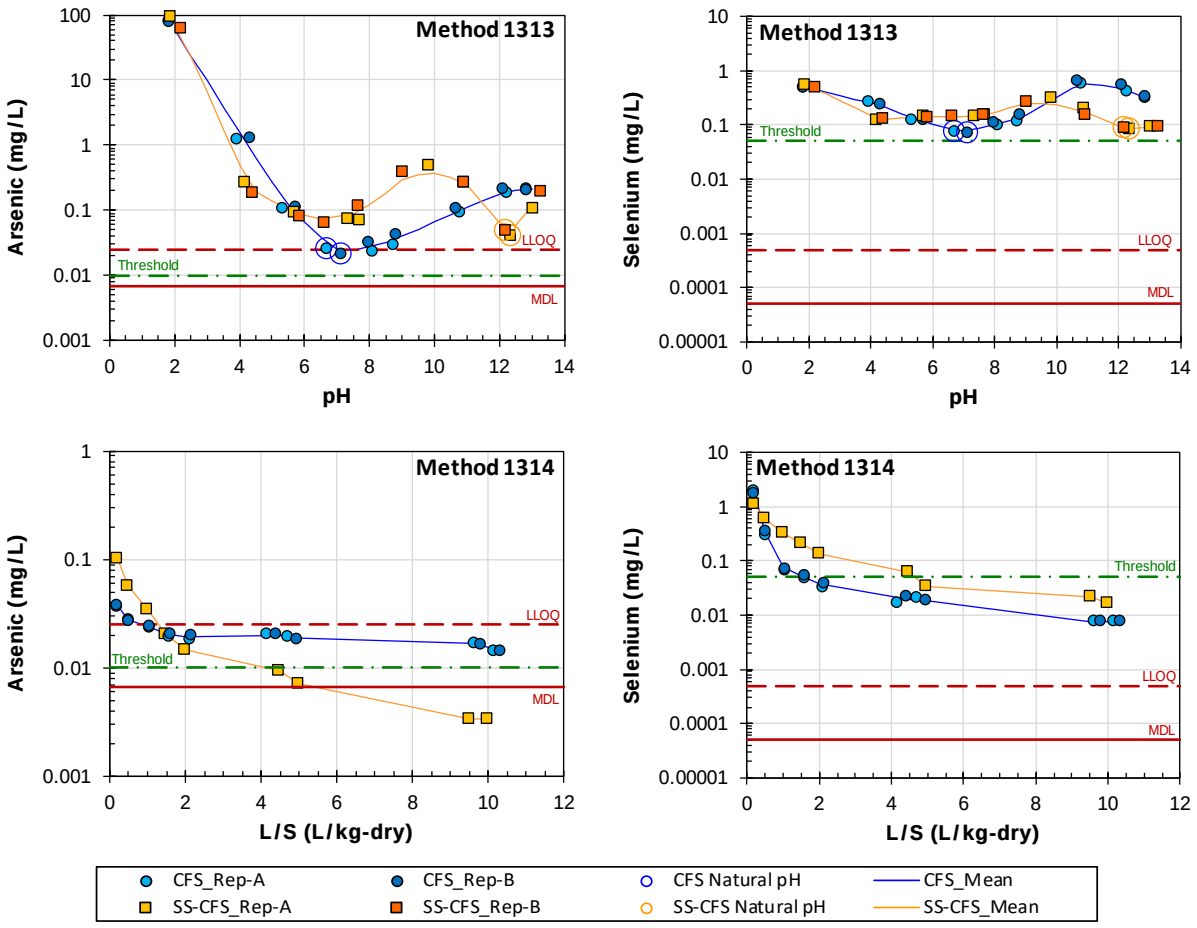

Figure 5-4. Method 1313 and 1314 test results for CFS and SS-CFS

The available content for arsenic and selenium can be determined from Method 1313 as the highest leachate concentration at a pH of 2, 9 and 13.

$$C_{leach\_max} = C_{1313(\max pH\ 2,9,13)}$$

Method 1313 also shows an increase in arsenic concentrations after treatment that directly overlaps with the scenario pH of 8 ≤ pH ≤ 13.3. The LSP limited concentration for arsenic is the maximum concentration within the pH range (including interpolation to endpoints of the pH range if necessary):

$$C_{leach\_max} = C_{1313(8 \le pH \le 13.3)}$$

The mass transport scenario has the restriction that the total mass released cannot exceed the available content for a COPC. The interval mass release for an assessment interval *i* is calculated as:

$$M_i = \mathrm{M1} + \mathrm{M2} = \frac{(\mathrm{N1 \cdot C1 \cdot P1 \cdot A}_{inf} \cdot 1000)}{m_d} + \frac{(\mathrm{N2 \cdot C2 \cdot P2 \cdot A}_{inf} \cdot 1000)}{m_d}$$

The available content at the end of an assessment interval is estimated as previous available content minus the mass released over the assessment interval. If the available content for any assessment interval

is less than zero, the COPC has depleted and the interval mass release is limited to the previous available content:

$$\text{if } (AC)_i < 0; \text{ then } (AC)_i = 0 \text{ and } M_i = (AC)_{i-1}$$

The average leaching concentration should be adjusted to match the mass released over the assessment interval. ARs may be calculated for the mass transport scenario based on the estimated leaching concentration for an assessment interval or an averaged value for an assessment period.

5.2.6 Treatment Effectiveness

The cumulative release of selected COPCs for untreated CFS and cement-treated S/S-CFS over a 30-year timescale is shown in Figure 5-5. In each figure, the available content is the upper limit of mass release and the CFS mass release was normalized to the exposed surface area of S/S-CFS monolith. The comparison between the original material and the treated material illustrates the effectiveness of treatment for different constituents. In this case, treatment of the S/S-CFS material would be expected to significantly reduce the rate of leaching for cadmium, selenium, and lead. Arsenic leaching was reduced to a lesser amount while chloride and nitrate releases were only significantly reduced by treatment over shorter timescales than 30 years.

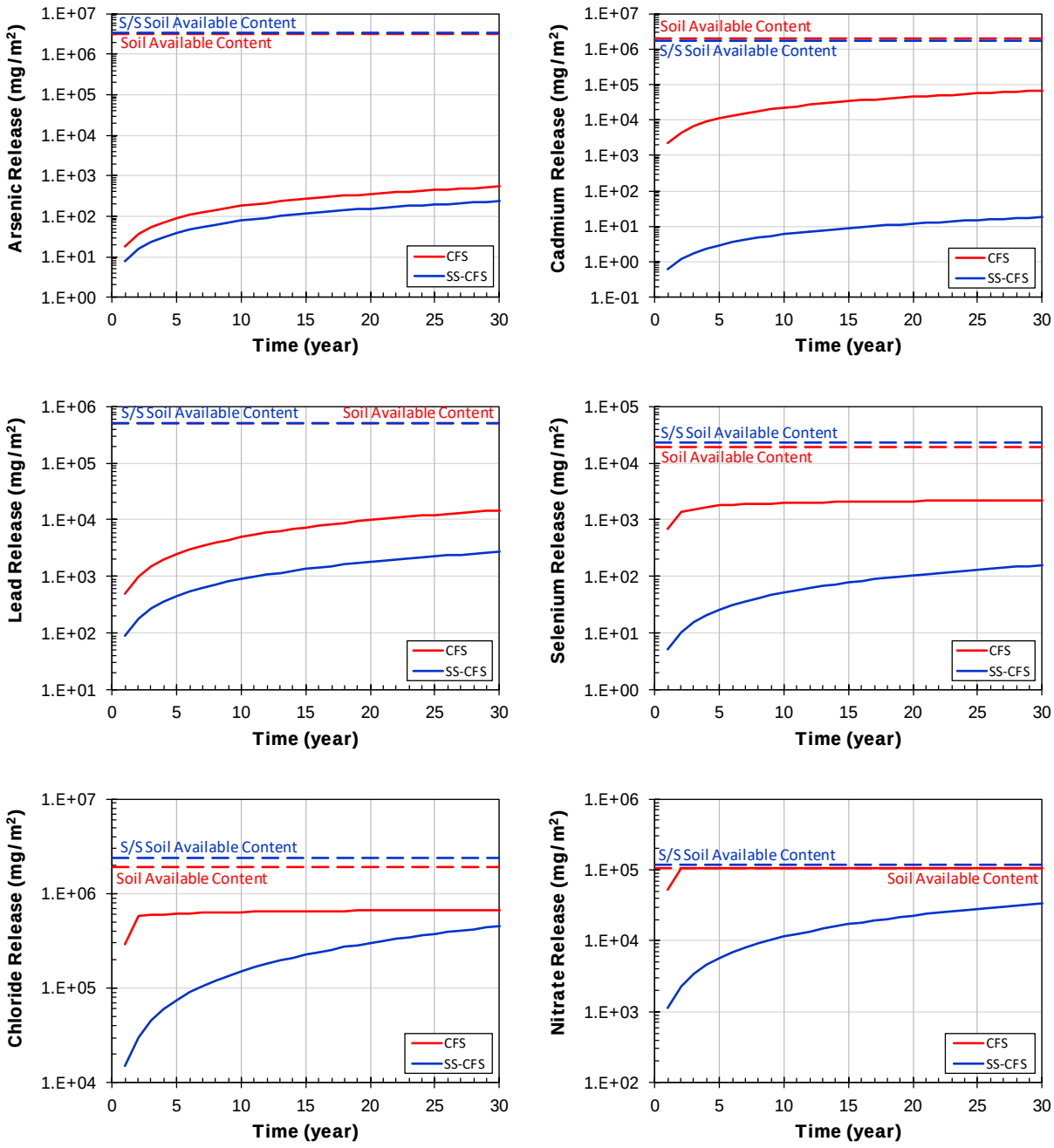

Figure 5-5. Mass transport limited leaching of arsenic, cadmium, lead, selenium, chloride, and nitrate.

5.2.7 Comparison to Reference Thresholds

The assessment ratio for COPCs can be calculated using the average concentrations for an assessment interval and the threshold values for this example, the U.S. EPA National Primary Drinking Water Regulations. In this scenario the point of compliance is at the unit boundary of the contaminated soil, meaning the leachate concentrations are directly compared to the threshold values with no consideration of dilution or attenuation. Table 5-9 below shows assessment ratios for 1, 5, and 30 year assessments. While the stabilization process was effective at reducing the mobility of the majority of the COPCs, Arsenic, lead and thallium remain above the threshold values. The proposed remedy for this site of in-situ stabilization with Portland cement is not appropriate based on LEAF testing results and the assumptions made in the assessment to estimate leaching in the field.

All leaching assessments make simplifying assumptions when developing estimates of leaching. This example provided estimates of leaching in the field assuming that LEAF test results from short timescales can represent long term behavior, and also relied on net infiltration parameters derived from 30 years of meteorological data to anticipate field conditions. In cases where leaching of COPCs exhibits time dependent behavior (e.g., one or more constituents becomes depleted), an average value for an assessment interval may not appropriately reflect the environmental conditions. Users of LEAF testing should work closely with the appropriate regulatory body when developing a leaching evaluation to meet regulatory requirements.

Table 5-9. Comparison of leaching assessment results to reference thresholds

COPC	Threshold (mg/L)	1-Year Assessment		5-Year Assessment		30-Year Assessment	
		C_{av} (mg/L)	AR (-)	C_{av} (mg/L)	AR (-)	C_{av} (mg/L)	AR (-)
Antimony	0.006	0.0022	*0.4*	0.0022	*0.4*	0.0022	*0.4*
Arsenic	0.01	0.018	1.8	0.018	1.8	0.018	1.8
Cadmium	0.005	0.0014	*0.3*	0.0014	*0.3*	0.0014	*0.3*
Chloride	250*	36	*0.1*	36	*0.1*	36	*0.1*
Chromium	0.1	0.014	*0.1*	0.014	*0.1*	0.014	*0.1*
Copper	1.3	0.070	*0.05*	0.070	*0.05*	0.070	*0.05*
Fluoride	4	0.019	*<0.01*	0.019	*<0.01*	0.019	*<0.01*
Lead	0.015	0.20	14	0.20	14	0.20	14
Nitrate	44	2.7	*0.06*	2.7	*0.06*	2.7	*0.06*
Selenium	0.05	0.014	*0.3*	0.014	*0.3*	0.014	*0.3*
Sulfate	250*	140	*0.6*	140	*0.6*	140	*0.6*
Thallium	0.002	0.17	87	0.17	87	0.17	87
Zinc	5*	0.018	*<0.01*	0.018	*<0.01*	0.018	*<0.01*

Notes: Orange italic text indicates ARs ≤1 (*i.e.*, no further assessment is required).

Threshold values based on U.S. EPA National Primary Drinking Water Regulations (U.S. EPA 2009) with * indicating secondary drinking water criteria.

6. Test Your Knowledge

The below exercises are based on the data used in the screening assessment case study above in Section 5.1. The calculations and concepts used below are explained in Section 4. This example is for illustrative purposes and is not intended to be directly applied to an evaluation. The actual use of LEAF testing must be tailored to a given purpose and site-specific conditions that may occur.

6.1 Paula's First Assignment

Paula the program manager is a new employee at a state environmental agency. Paula is working on a team to determine whether fly ash can be used as structural fill in a local project. The team assigns Paula to study the potential effects of the fly ash material on groundwater. The potential for leaching of constituents of concern to groundwater had been overlooked to this point by the team and Paula is starting from the beginning. Paula is eager to impress her new supervisor and coworkers, and she knows that she needs to start with a good testing plan to characterize the material. After talking to the analytical chemist in the Agency's testing lab, Paula realizes that she needs to understand her material and the environment to choose the right leaching tests.



Question 1: What does Paula need to know about her material and the environment before she can develop a leaching evaluation?

(See next page for answer)

Answer 1: What does Paula need to know about her material and the environment before she can develop a leaching evaluation?

- Paula needs to know the composition of her material and which constituents of concern are present.
- Paula also needs to know what the anticipated field conditions (now and over time) are in order to estimate leaching under the right conditions. For example, many inorganic constituents have pH dependent leaching behavior. Additionally, the amount, frequency, and mode of water contacting the material needs to be understood or estimated. Testing of soil at a site or consultation with databases for rainfall or soil data can provide valuable information.
- Paula will also need threshold values to compare her leaching estimates to. In some cases, the total content of constituents of concern may be so high or so low, testing will not provide value. For example, if leaching tests (or total content) show that leaching values will not exceed the relevant thresholds, then no further analysis may be needed. If there is uncertainty in the estimated leaching, further testing may determine a material is or is not appropriate for use.

6.2 Characterizing the Fly Ash

Paula checks back in with her analytical lab and learns that she is in luck. The total content analysis of a representative sample of fly ash has already been completed using acid digestion (EPA Method 3052) followed by ICP-OES (EPA Method 6010). The total content testing (shown below) indicates that the constituents of concern are primarily inorganic. The pH of the fly ash material is 6.8 and the pH of the soil the fly ash will be adjacent to is 6.0. Paula expects the fly ash material pH to control the pH of the leachate as the soil has no significant buffering capacity. Paula decides the default pH range suggested in the LEAF How-To Guide (Section 4.2.5.1) of $5.5 \leq pH \leq 9.0$ could be used here to estimate the anticipated pH of the fly ash and to estimate behavior if the pH were to change over time. Paula checks her notes from the team meeting to remind herself that the infiltration rate is expected to be 25 cm per year and the fly ash material will be compacted to 1,500 kg-dry/m^3. Before investing resources into testing, Paula compares the total content of her material against standards set by EPA drinking water regulations. She notes that the total concentrations of arsenic, chromium, and other inorganics appear high and warrant further testing before a decision is made on the appropriateness of the fly ash as structural fill.

COPC	Total Content [mg/kg-dry]	Drinking Water Standard [mg/L
Antimony (Sb)	1.5	0.006[N1]
Arsenic (As)	63	0.01
Barium (Ba)	830	2
Boron (B)	1,400	7[N2]
Cadmium (Cd)	3.5	0.005
Chromium (Cr)	120	0.1
Lead (Pb)	39	0.015[N3]
Molybdenum (Mo)	15	0.2[N2]
Selenium (Se)	24	0.05
Thallium (Tl)	0.91	0.002

Source: U.S. EPA (2012c, 2012d)
Drinking water standards are the National Primary Drinking Water Regulations (U.S. EPA, 2012a) unless noted:
[N1] National secondary drinking water regulations—non-enforceable guideline.
[N2] Drinking water equivalent level.
[N3] Treatment technique action level.

Question 2: Which constituents listed in the table above are of potential concern to Paula based on total content analysis?

(See next page for answer)

Answer 2: Which constituents are of potential concern to Paula based on total content analysis?

In this scenario Paula is comparing constituents against drinking water standards. All of the constituents listed in the table are above the drinking water standards and therefore are of concern to Paula.

In real applications, the standards against which a constituent is compared should be carefully considered. Consultation with the appropriate regulatory body may be needed.

Part 3: Paula's Proposed Testing Plan

Armed with knowledge of the material and the anticipated environmental conditions, Paula knows she needs to determine what tests are appropriate to estimate leaching from the fly ash. She knows that there are a variety of tests that may help her predict leaching in the environment, but she is specifically looking for testing that applies to inorganic constituents such as lead, arsenic, and chromium. This helps her narrow down the list, removing tests focused on organics or designed to simulate specific scenarios that do not adequately represent structural fill. She decides to then check with her coworkers, and the state's analytical laboratory to see what existing testing capabilities are available. Finally, before spending time and resources on testing, Paula checks in with technical consultant hired onto the project, who just happens to be you.



Question 3: What leaching tests should Paula employ in her evaluation?

(See next page for answer)

Answer 3: What leaching tests should Paula employ in her evaluation?

- Paula knows there are a variety of leaching tests available for inorganics, such as the EPA Methods; TCLP, SPLP, or LEAF Methods 1313, 1314, 1315, or 1316; ASTM Standards D-3897 or D-4874; and European methods such as EN 14429, NEN 7373, or EN 15863.
- The TCLP (EPA Method 1311) employs buffered solutions of acetic acid (either pH of 4.93 or 2.88) to simulate conditions in municipal solid waste landfills. TCLP is likely not the best choice for Paula as there is no acetic acid in her anticipated environment or in the waste and Paula is interested in evaluating pH dependent leaching closer to a pH of 6.
- The SPLP (EPA Method 1312) is designed to simulate leaching of organic or inorganic constituents in soils and employs a leachant consisting of a mixture of sulfuric and nitric acid with a pH of 4.2 or 5 depending on whether the soil is east or west of the Mississippi River. SPLP is not likely to be the most appropriate test for Paula's anticipated environmental conditions.
- EPA Method 1313 will allow Paula to estimate leaching in the field within a window of pH endpoints. Equilibrium data from this test alone will provide an estimate of the upper bound, or available content, that a constituent that may leach at a given pH. EPA Method 1313 is generally applicable to most scenarios with inorganics that have pH dependent solubility.
- EPA Method 1314 or EPA Method 1316 will allow Paula to estimate L/S dependent leaching behavior of the fly ash. The L/S dependent leaching results from either test will provide information on whether the material is solubility or availability controlled. EPA Method 1314 estimates percolation-based leaching in an open system, which may also provide insight into percolation-based effects or preferential flow. Method 1316 estimates equilibrium results from batch testing. In some cases, both tests may provide useful and complimentary results. However, testing from one of these two methods is often sufficient.
- EPA Method 1315 estimates mass transport limited leaching from densely compacted or stabilized material. The fly ash is not solidified into a bound matrix or otherwise densely compacted. As a result, this test method will provide minimal value to Paula's evaluation.

Note: This question does not have one right answer. A variety of other tests to estimate leaching are available that may or may not be suitable. LEAF testing is chosen for the purposes of this guide. See the Appendix for a comparison of LEAF testing to analogous European standards.

6.3 Preliminary Available Content Evaluation

Paula knows that she is interested in evaluating pH dependent behavior of her fly ash and selects EPA Method 1313 to do so. She also knows that L/S can be used as a surrogate for leaching over time and elects to choose EPA Method 1314 to evaluate this parameter (Note: Paula could have also chosen Method 1316 to evaluate L/S and it is not necessarily wrong to choose one or both methods for this purpose.) The analytical lab completes Method 1313 and 1314 testing and sends the test results to Paula. Paula is particularly worried about the high concentrations of arsenic in the leachate. Before proceeding to evaluate the solubility within the pH range of interest, Paula checks the available content for arsenic using Method 1313 results.



Question 4: Can you determine the available content for arsenic from the Method 1313 lab results (next page)? Hint: Paula recalls from reading the LEAF How-To Guide that available content is calculated from the highest concentrations in the leachate at pH 2, 9 or 13 (see Section 4.4.1).

EPA Method 1313

Sample: EaFA (P,1,1)

Concentration in mg/L

Fraction	*9*	*8*	*7*	*6*	*5*	*4*	*3*	*2*	*1*
pH	*2.08*	*3.85*	*5.40*	*6.99*	*7.97*	*9.26*	*10.4*	*12.0*	*13.1*
Al	128	32.0	0.335	0.202	1.21	17.7	27.1	33.8	37.0
As	1.55	0.0900	0.0417	0.0784	0.199	0.560	1.05	1.01	9.69
B	3.25	3.82	4.98	4.62	4.38	4.50	4.64	4.99	9.77
Ba	0.876	0.220	0.281	0.260	0.256	0.562	0.903	0.921	0.659
Be	0.441	0.142	0.00258	(0.000320)	(0.000320)	(0.000320)	(0.000320)	(0.000320)	(0.000320)
Br^-	(0.00871)	0.668	0.687	0.515	0.598	0.700	0.652	0.722	0.827
Ca	141	140	167	155	135	111	87.3	40.9	9.20
Cd	0.0555	0.0427	0.0311	0.00580	0.00470	0.00460	0.00461	0.00505	0.00540
Cl^-	1.64	1.57	1.25	1.30	1.28	1.30	1.26	1.30	4.19
Co	0.419	0.214	0.252	0.0261	0.00430	0.00140	0.00118	0.000726	(0.000207)
Cr	1.96	0.175	(0.000249)	0.0422	0.134	0.223	0.248	0.306	0.392
Cs	0.0642	0.0239	0.0172	0.0130	0.0148	0.0188	0.0218	0.0282	0.0336
Cu	3.16	1.91	0.0894	0.000900	(0.000351)	(0.000351)	0.000900	0.00192	0.0179
DIC	0.138	0.150	0.154	(0.0650)	(0.0650)	0.653	1.93	7.95	29.2
DOC	1.69	1.04	1.06	1.15	1.21	1.83	3.19	9.66	142
F^-	0.0945	3.34	0.409	1.70	2.05	3.13	3.62	3.91	9.38
Fe	33.9	0.419	(0.00100)	(0.00100)	(0.00100)	(0.00100)	(0.00100)	0.0202	0.0339
K	22.1	18.6	26.1	25.0	55.3	135	190	441	1719
Li	1.51	2.12	3.26	3.24	2.97	2.70	2.56	2.23	1.56
Mg	14.0	7.69	8.90	7.49	5.10	2.86	0.111	(0.000500)	(0.000500)
Mn	1.84	1.17	0.982	0.268	0.0324	(0.000171)	(0.000171)	(0.000171)	(0.000171)
Mo	0.334	0.108	0.552	3.32	3.49	3.70	3.83	3.77	3.92

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See next page for answer

Answer 4: Can you determine the available content for arsenic from the lab results?

Paula knows that the available content will be determined by the highest leaching concentration at a pH of 2, 9, or 13. For arsenic, the highest concentration in the leachate is 9.69 mg/L at a pH of 13.1. However, Paula needs to interpolate to estimate the concentration of arsenic at a pH of 13. In this case the pH endpoints of 13.1 and 12.0 are used to interpolate. Using Equation 4-13 from section 4.4.2, the concentration of arsenic in the leachate is found to be 7.9 mg/L at a pH of 13.

$$logC_{As} = logC_a + (pH - pH_a) \times (logC_b - logC_a)/(pH_b - pH_a)$$

$$logC_{As} = log(9.69) + (13 - 13.1) \times (log(1.01) - log(9.69))/(12 - 13.1)$$

$$\mathbf{C_{As} = 7.9\ \frac{mg}{L}}$$

Now that Paula has the concentration of arsenic in the leachate at a pH of 13, she needs to account for the liquid to solid ratio in Method 1313 using Equation 4-12 (See section 4.4.1)

$$m_{avail} = C_{max(pH\ 2,9,13)} \times (L/S)_{1313}$$

$$m_{avail} = 7.9\frac{mg}{L} \times 10\frac{L}{Kg - dry}$$

$$m_{avail} = 79\frac{mg}{kg - dry}$$

Available content can be reported as mg/kg-dry, however, Paula wants to be able to compare the available content to a leachate concentration that may represent her environmental scenario. Paula uses the initial L/S value of 0.5 to estimate the maximum potential for leaching when the material is initially placed as structural fill, based on available content.

$$C_{leach\_max} = m_{avail}/(L/S)_{initial}$$

$$\mathbf{m_{avail} = 79\frac{mg}{LKg - dry}/0.5\frac{L}{Kg - dry}}$$

$$\mathbf{m_{avail} = 158\frac{mg}{L}}$$

6.4 Paula's Plausible Range of pH Dependent Leaching

Paula is not relieved to see her available content estimate for arsenic is considerably higher than the regulatory thresholds for drinking water. However, Paula knows that her anticipated environment considers a pH between 5.5 and 9. Using the same data from Method 1313, Paula can calculate the maximum concentration of arsenic in the leachate within her anticipated conditions. What concentrations of arsenic can Paula expect to see in her leachate when she considers the applicable pH range?



Question 5: What is the maximum concentration of arsenic in the anticipated pH range? (Hint: Use the Method 1313 data from the table provided in Question 4.)

See next page for answer

Answer 5: What is the maximum concentration of arsenic in the anticipated pH range?

The maximum concentration of arsenic in the anticipated pH range is 0.46 mg/L. The Method 1313 data shows an arsenic concentration of 0.56 mg/L at a pH of 9.26 and 0.199mg/L at a pH of 7.97. The arsenic solubility is increasing with increasing pH and the highest pH in the anticipated pH range is 9. Paula therefore needs to interpolate an arsenic concentration value at pH 9 using the data at a pH of 9.26 and a pH of 7.97.

$$logC_{As} = logC_a + (pH - pH_a) \times (logC_b - logC_a)/(pH_b - pH_a)$$

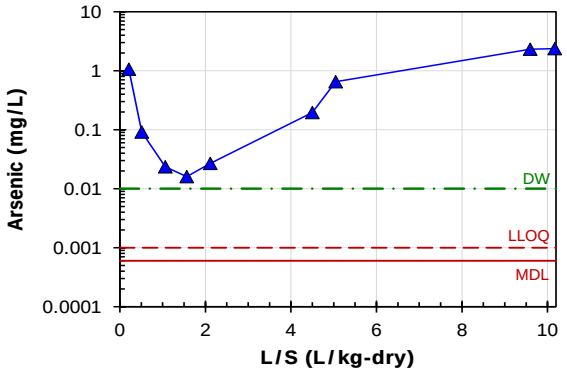
$$logC_{As} = log(0.56) + (9 - 9.26) \times (log(0.199) - log(0.56))/(7.97 - 9.26)$$

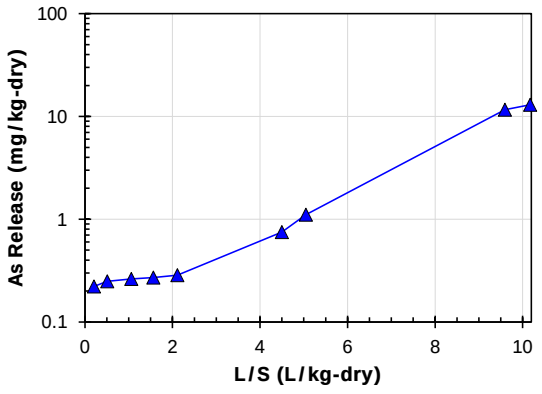
$$C_{As} = 0.46 \ \frac{mg}{L}$$

6.5 Confirming Solubility Limited Leaching

Paula reviewed the Method 1313 results and suspects that the leaching behavior of arsenic in her anticipated environment is solubility limited. She noticed that the leachate concentration controlling her available content, 7.9 mg/L at pH 12, is significantly higher than the maximum leaching concentrations within the anticipated environmental window, 5.5 ≤ pH ≤ 9.0, of 0.46 mg/L at pH 9. Paula would like to confirm the solubility limited behavior with the Method 1314 results.

Question 6: How can Paula confirm that arsenic is solubility limited using her Method 1314 data below? Hint: Paula realizes in reviewing her data that the L/S behavior of arsenic below an L/S ratio of 2 is controlled by interactions between calcium and arsenic. The calcium has washed out of the column at an L/S ratio greater than 2.





See next page for answer

Answer 6: How can Paula confirm that arsenic is solubility-limited using the 1314 data below?

- Paula can tell that the arsenic leaching is solubility controlled because the cumulative release of arsenic is a strong function of L/S (right figure).
- The method 1314 data in the left figure shows the concentration of arsenic is dependent on L/S below an L/S of 2 (L/Kg-dry). Solubility controlled leaching does not often show a strong dependence of concentration on L/S. However, Paula realized from looking at her other constituents that the solubility of arsenic at low L/S values was likely controlled by calcium, which washed out of the system at an L/S close to 2 (L/kg-dry).
- Paula can also compare the cumulative arsenic release at an L/S of 10 (mg/kg-dry) to the available content of 79 (mg/kg-dry). The release of only 14% of the available arsenic by an L/S ratio of 10 indicates the leaching is limited by solubility. Available-content limited leaching would have been expected to leach almost all of the available arsenic by or before L/S 10.
- A slope close to 1 on a logarithmic plot of cumulative constituent release versus L/S is often an indicator of solubility-limited leaching. Available-content limited leaching will often show a more rapid release of the constituent (e.g., an exponential curve).

6.6 Conclusions on Use for Structural Fill

While Paula has learned a great deal about the potential behavior of the arsenic in the fly ash, her analysis has not concluded that the fly ash is suitable for use as a structural fill. The estimated leaching concentration from Method 1313 results within the anticipated pH range of 0.46 mg/L is above Paula's threshold of the 0.01 mg/L drinking water standard. In addition, analysis of the 1314 data indicates that arsenic levels will reach 2.4 mg/L at an L/S of 10. The higher concentrations of arsenic at high L/S are a result of the initially acidic nature of the fly ash (likely from acid washing) changing over time to a more alkaline pH that better solubilizes (and therefore mobilizes) arsenic. At the same time, constituents such as calcium lower arsenic solubility while present but eventually wash out of the method 1314 column test. Paula returns to her supervisor with her results and to discuss considering alternative materials for structural fill in the project.



7. Useful Resources

Resource	Available Online[1]
LeachXS and LeachXS Lite	*www.vanderbilt.edu/leaching/leach-xs-lite/ www.leachxs.com/lxsdll.html*
LeachXS Lite data templates	*www.vanderbilt.edu/leaching/downloads/test-methods/*
LEAF leaching test methods	*https://www.epa.gov/hw-sw846/validated-test-methods-recommended-waste-testing*
TCLP leaching test method	*https://www.epa.gov/hw-sw846/sw-846-test-method-1311-toxicity-characteristic-leaching-procedure*
SPLP leaching test method	*https://www.epa.gov/hw-sw846/sw-846-test-method-1312-synthetic-precipitation-leaching-procedure*
EPA test methods: frequently asked questions	*https://www.epa.gov/hw-sw846/frequent-questions-about-sw-846-compendium-and-related-documents*
ORCHESTRA: geochemical speciation and reactive transport code	*http://orchestra.meeussen.nl/*
PHREEQC: computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations	*wwwbrr.cr.usgs.gov/projects/GWC_coupled/phreeqc*
MINTEQA2: geochemical equilibrium speciation model	*www2.epa.gov/exposure-assessment-models/minteqa2*
The Geochemist's Workbench: geochemical modeling software	*www.gwb.com*
IWEM: deterministic groundwater fate and transport model	*https://www.epa.gov/smm/industrial-waste-management-evaluation-model-version-31*
EPA's Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (EPA/600/R-14/061)	*www.vanderbilt.edu/leaching/wordpress/wp-content/uploads/600r14061-Lab-to-Field-LEAF1.pdf*
EPA's Background Information for the Leaching Environmental Assessment Framework (LEAF) Test Methods (EPA/600/R-10/170)	*https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryID=231332*
EPA's Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1313 and Method 1316 (EPA/600/R/12/623)	*https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryID=307273*
EPA's Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1314 and Method 1315 (EPA 600/R-12/624)	*nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100FAFC.TXT*
EPA's Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control (EPA/600/R-06/008)	*https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryID=147063*
EPA's Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control (EPA/600/R-08/077)	*nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EEGL.txt*
EPA's Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data (EPA/600/R-09/151)	*nepis.epa.gov/Adobe/PDF/P1007JBD.pdf*
EPA's Leaching Behavior of "AGREMAX" Collected from a Coal-Fired Power Plant in Puerto Rico (EPA/600/R-12/724)	*nepis.epa.gov/Adobe/PDF/P100G02B.pdf*
EPA's The Impact of Coal Combustion Fly Ash Used as a Supplemental Cementitious Material on the Leaching Constituents from Cements and Concretes (EPA/600/R-12/704)	*nepis.epa.gov/Adobe/PDF/P100FBS5.pdf*
EPA's Final Report for Sampling and Analysis Project—Beneficial Use of Red and Brown Mud and Phosphogypsum as Alternative Construction Materials	*nepis.epa.gov/Adobe/PDF/P100BMWU.pdf*
EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP)	*www.epa.gov/epawaste/nonhaz/industrial/tools/cmtp/index.htm*

[1] All websites accessed 2 May 2016.

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Appendix 20

United States Environmental Protection Agency (USEPA), 2016. Weight of Evidence in Ecological Assessment. EPA/100/R-16/001. December.

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Agency

EPA/100/R-16/001 December 2016
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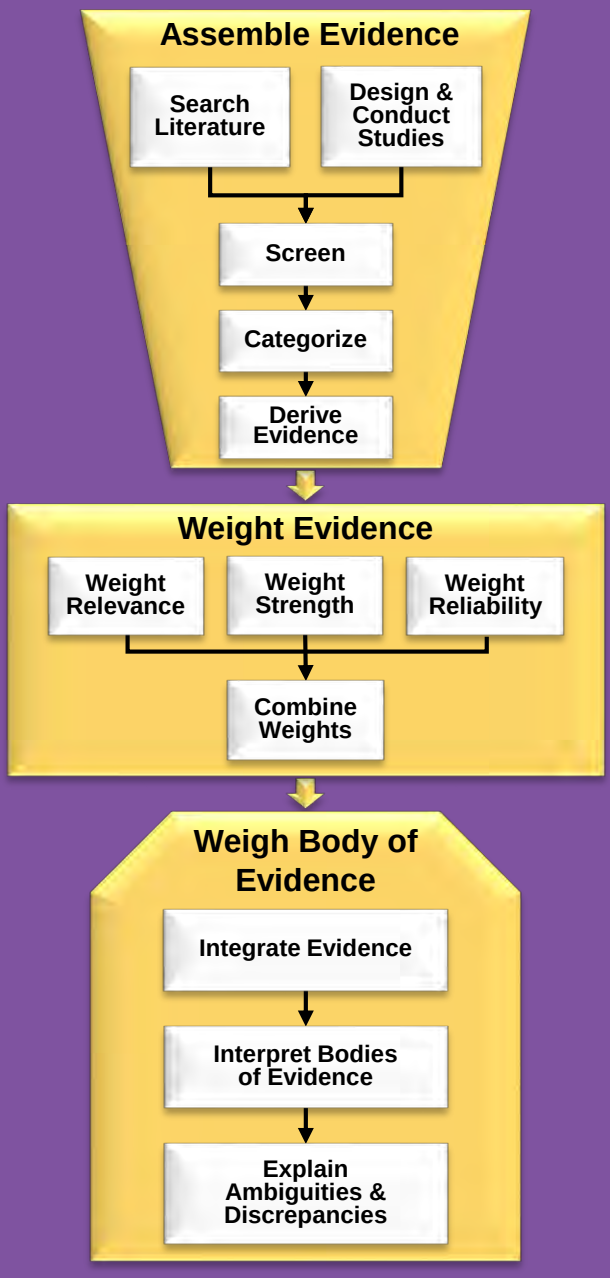
Weight of Evidence in Ecological Assessment



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WEIGHT OF EVIDENCE IN ECOLOGICAL ASSESSMENT

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AUTHORS, CONTRIBUTORS, AND REVIEWERS

AUTHOR

Glenn W. Suter II
National Center for Environmental Assessment
Office of Research and Development
Cincinnati, OH

TECHNICAL PANEL (Contributors)

Mace G. Barron
National Health and Environmental Effects Research Laboratory
Office of Research and Development
Gulf Breeze, FL

David Charters
Office of Superfund Remediation and Technology Innovation
Office of Land and Emergency Management
Edison, NJ

Susan M. Cormier
National Center for Environmental Assessment
Office of Research and Development
Cincinnati, OH

Karen Eisenreich
Office of Pollution Prevention and Toxics
Office of Chemical Safety and Pollution Prevention
Washington, DC

Kris Garber
Office of Pesticide Programs
Office of Chemical Safety and Pollution Prevention
Washington, DC

Wade Lehmann
Office of Science and Technology
Office of Water
Washington, DC

Scott Lynn
Office of Science Coordination and Policy
Office of Chemical Safety and Pollution Prevention
Washington, DC

Chris Sarsony
Office of Air Quality Planning and Standards
Office of Air and Radiation
Research Triangle Park, NC

Glenn W. Suter II (Panel Chairman)
National Center for Environmental Assessment
Office of Research and Development
Cincinnati, OH

Risk Assessment Forum Staff

Lawrence Martin
Office of the Science Advisor
Washington, DC

EPA Peer Reviewers

Daniel A. Axelrad
National Center for Environmental Economics
Office of Policy
Washington, DC

Bruce Duncan
Office of Environmental Assessment
Region 10
Seattle, WA

Wayne Munns
National Health and Environmental Effects Research Laboratory
Office of Research and Development
Narraganset, RI

Deirdre Murphy
Office of Air Quality Planning and Standards
Office of Air and Radiation
Research Triangle Park, NC

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Kathleen Raffaele
Policy Analysis and Regulatory Management Staff
Office of Land and Emergency Management
Washington, DC

Mary Reiley
Office of Science and Technology
Office of Water
Washington, DC

External Peer Reviewers

Brian W. Brooks
Center for Reservoir and Aquatic Systems Research
Baylor University
Waco, Texas

Peter M. Chapman
Chapman Environmental Strategies Ltd.
N. Vancouver, British Columbia, Canada

Valery E. Forbes
College of Biological Sciences
University of Minnesota
Saint Paul, Minnesota

Igor Linkov
Risk and Decision Science Focus Area
U.S. Army Engineer Research and Development Center
Concord, Massachusetts

PREFACE

The impetus for this document includes U.S. Environmental Protection Agency (EPA) policy, outside advice, and the expressed needs of EPA ecological assessors. Ensuring and maximizing the quality, objectivity, utility and integrity of information disseminated by the EPA "involves a 'weight-of-evidence' (WoE) approach that considers all relevant information and its quality, consistent with the level of effort and complexity of detail appropriate to a particular risk assessment" (U.S. EPA, 2002b). The EPA Science Advisory Board recommended that the Risk Assessment Forum's Ecological Oversight Committee consider the development of guidance for using the WoE approach a high priority (SAB, 2012). This document was prepared for EPA ecological assessors who expressed a desire for assistance in determining which WoE approaches are potentially appropriate for their assessments (U.S. EPA, 2010b).

This document has three goals. The first is to assist ecological assessors who plan to weigh multiple pieces of scientific evidence. We provide a standard framework consisting of three steps: assemble evidence, weight evidence, and weigh the body of evidence. We also present a broadly applicable system for assigning weights by evaluating and scoring the evidence and for combining the weighted evidence to determine the best-supported hypothesis. Additional material addresses how to deal with bodies of evidence that are discrepant or anomalous and how to express confidence in inferences based on the weight of evidence. Finally, we briefly address the weighing of evidence to derive quantities used in or generated by assessments.

The second goal is to make the weighing of evidence in ecological assessments more formal and defensible. Weighing evidence is best performed using pre-existing and well-described methods. The standard framework and default approach to weighing evidence presented in this document are expected to improve the practice and acceptance of weighing evidence.

The third goal is to make the logic of weighing evidence clearer and more consistent. For example, many of the EPA's weight-of-evidence analyses are based on Hill's considerations, a 50-year-old list that mixes characteristics of causal relationships, types of evidence, and properties of evidence. This document addresses those aspects of evidence separately and uses them systematically.

This document provides methods for weighing ecological evidence. Use of the methods will improve the consistency and reliability of WoE-based assessments and the defensibility of scientific input to decision making. This guidance is not meant to be prescriptive, nor does it dictate methods for specific programs and applications.

Tables, figures, and text boxes throughout the document provide examples of WoE practices. The specific methods in the examples were designed for particular statutory contexts and might need to be adapted before they are used in other contexts.

This document was prepared under the auspices of EPA's Risk Assessment Forum. The Risk Assessment Forum was established to promote scientific consensus on risk assessment issues and to incorporate this consensus into appropriate risk assessment guidance. To accomplish this purpose, the Forum assembles experts from throughout EPA in a formal process to study and report on these issues from an Agency-wide perspective.

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ACRONYMS AND ABBREVIATIONS

BBN	Bayesian belief network
EPA	U.S. Environmental Protection Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
IRIS	Integrated Risk Information System
ISA	Integrated Science Assessment
LC_{50}	median lethal concentration
LOAEL	lowest-observed-adverse-effect level
MCDA	multi-criteria decision analysis
NE	No Evidence
NOAEL	no-observed-adverse-effect level
OECD	Organization for Economic Cooperation and Development
PRG	preliminary remedial goal
QA	quality assurance
QAPP	Quality Assurance Project Plan
r	correlation coefficient
RQ	risk quotient
SMAV	species mean acute value
SSD	species sensitivity distribution
TMDL	total maximum daily load
WoE	weight of evidence

EXECUTIVE SUMMARY

This document presents an approach for using weight of evidence (WoE) in ecological assessments. WoE integrates multiple pieces of evidence to infer a quality such as causality, teratogenicity, impairment, protection, or recovery. WoE can also be used to derive quantities such as a benchmark value, a magnitude of effect or a bioaccumulation factor when multiple estimates are available. WoE is essential for ecological risk assessment, because diverse laboratory and field information must be assembled, evaluated and integrated. The EPA has often employed WoE in ecological assessments, but, in the absence of guidelines, the methods are inconsistent and often informal. Advisory bodies, professional societies and the assessment science literature all encourage more and better WoE. The proper use of an explicit WoE methodology can mean the difference between an ecological risk characterization with a murky rationale and one that is persuasive and consistent with best practices. The system presented here to improve the practice and acceptance of weighing evidence is broadly applicable for evaluating and scoring evidence and combining the weighted evidence to determine the best supported risk characterization. By helping to make the logic of weighing evidence clearer and more consistent, WoE will help make ecological assessments more informative and defensible.

Ecological assessments that employ WoE have made numerous important contributions to environmental protection. The following five examples of high profile ecological assessments demonstrate the value added through incorporating a WoE methodology. 1)The Bristol Bay, Alaska watershed assessment to protect the world's best remaining wild salmon populations, and the people and wildlife that depend on them, used formal WoE analyses to integrate evidence from laboratory tests, field studies, and effects of similar mines to estimate risks to salmon of various mining activities. 2) The restoration of thousands of biologically impaired waters uses a WoE method to determine the cause of impairment (https://www3.epa.gov/caddis). 3) The assessment to support the definition of waters of the United States used WoE to show how different types of aquatic systems are connected. 4) The protection of ambient water quality depends on the ecological assessments that derive aquatic life criteria. The recent benchmark and proposed criteria method for major ions measured as conductivity are based on effects observed in the field. They depend on WoE to determine that the relationships in the field are not confounded and that the same value applies to different areas. 5) The high profile assessment of risks to pollinators from the neonicotinoid pesticide imidicloprid relies on weighing evidence from laboratory tests, semi-field tests, crop applications, and reports from bee keepers. WoE has been increasingly important to ecological assessment and Agency decisions because of the use of eco-epidemiological approaches.

Although WoE has been used in various types of assessments for programs across the U.S. Environmental Protection Agency (EPA), approaches have varied. Many of the EPA's WoE applications use a narrative approach with some guidance provided by lists of considerations, but that approach has been deemed inadequate by the National Research Council (NRC, 2014). The approach in this document is more formal. It provides a framework, a set of properties of evidence, a scoring system, tables for presenting results of weighting, and weighing evidence, a system for organizing evidence in terms of types and the characteristics they address and a means of dealing with ambiguous or discrepant results.

The framework and methods in this document also provide an integrated approach to both infer a quality of interest and estimate an associated quantitative value. For example, WoE can be used to weigh the evidence that a chemical causes malformations in fish in ambient exposures (qualitative) and to derive the best estimate of a benchmark concentration for the chemical (quantitative). Unlike qualitative WoE, quantitative WoE is not an established practice in the EPA. Therefore, quantitative methods are only briefly discussed.

The frameworks for qualitative and quantitative WoE are presented in Figure S-1 and Figure S-2. Although the qualitative processes might appear complex, the basic framework is simple: assemble the evidence, weight the evidence, and weigh the body of evidence. The document explains how to perform each step (Sections 4−6) and explains when and how the process can be adapted or abbreviated (Section 7). Figure S-2 previews Section 8, which presents the process for using WoE to estimate quantities.

The sections preceding the explanation of the process include an introduction that defines and explains WoE (Section 1), a description of the uses of WoE in the EPA's ecological assessments (Section 2), and an explanation of how to perform planning and problem formulation for assessments that includes WoE (Section 3). Sections following the process sections describe the complementary relationship between WoE and uncertainty (Section 9) and the path forward for implementing WoE in the EPA (Section 10). Section 11 presents the literature cited in support of the document.

Appendix A presents a glossary of terms, as used in this document, related to WoE. Additional appendices briefly review WoE methods for estimating quantities (Appendix B), selecting models (Appendix C), and inferring qualities (Appendix D). They provide context for the methods in this document. Appendix E explains that qualities such as causation have characteristics such as co-occurrence that can be used to organize bodies of evidence and to provide a basis for determining the completeness of the body of evidence. Characteristics of causation are established, but characteristics of other inferred qualities such as protective or impaired are new and have not been tested.

The result of the qualitative WoE process (Figure S-1) is a qualitative conclusion (e.g., the metal mixture is the most likely cause) and an overall weight that expresses confidence in the conclusion (e.g., weight of evidence for the conclusion is moderate) or multiple weights (e.g., relevance of the evidence is low, but strength and reliability are both high).

The result of the quantitative WoE process (Figure S-2) is a weighted quantitative value. In a WoE analysis, those results could consist of the value and its units (the proposed remedial goal is 2 mg/kg dry sediment), one or more expressions of weight (the overall weight of evidence is high) and the estimated statistical scatter of the value (the 95% confidence interval [CI] = ± 0.5 mg/kg dry sediment).

This document provides methods for weighing ecological evidence. Use of the methods will improve the consistency and reliability of WoE-based assessments and the defensibility of scientific input to decision making. This guidance is not meant to be prescriptive, nor does it dictate methods for specific programs and applications.

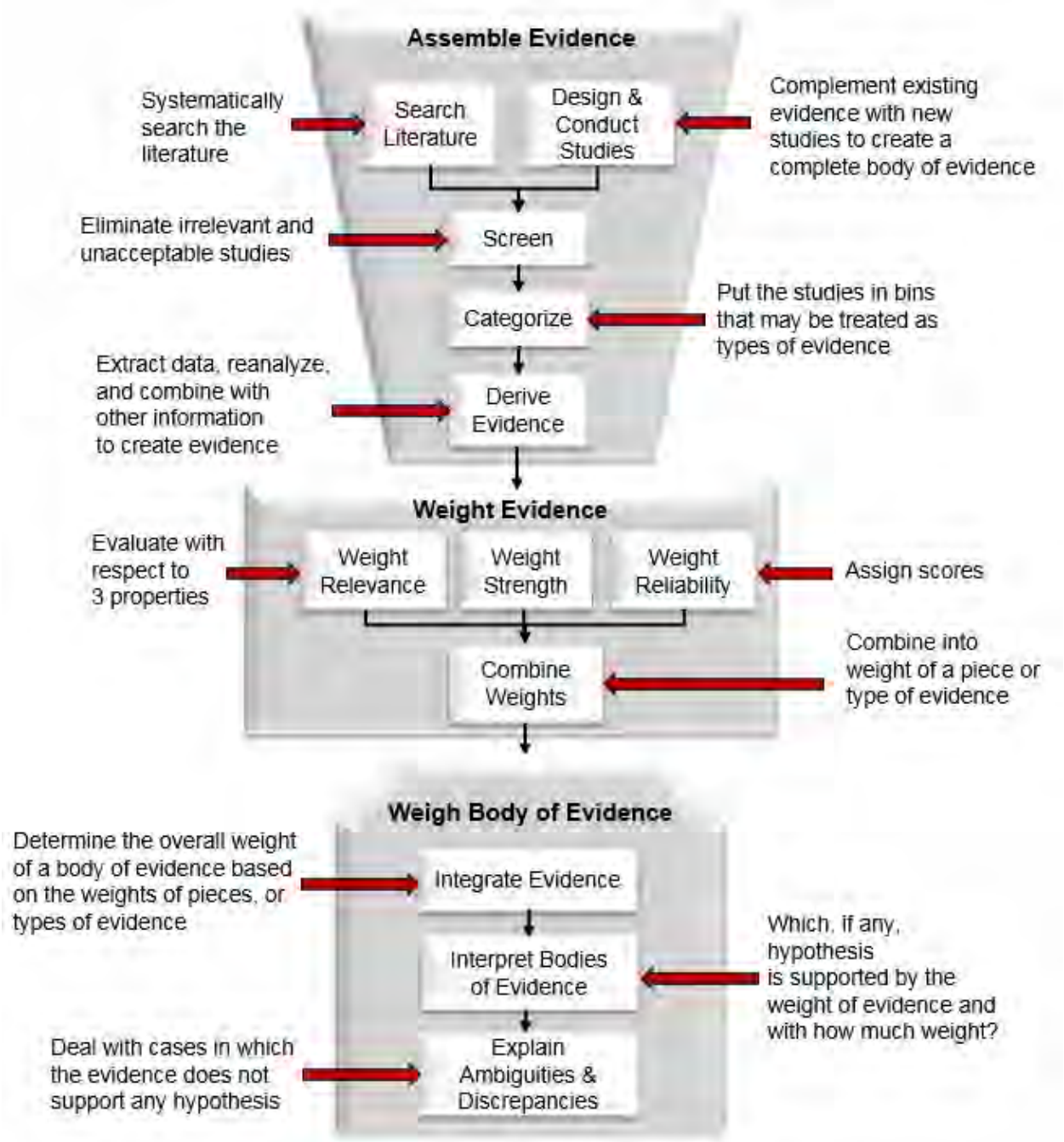

Figure S-1. An annotated diagram of the process for WoE to infer qualities by assembling evidence, weighting it, and weighing the resulting body of evidence, explained in Sections 4–7.

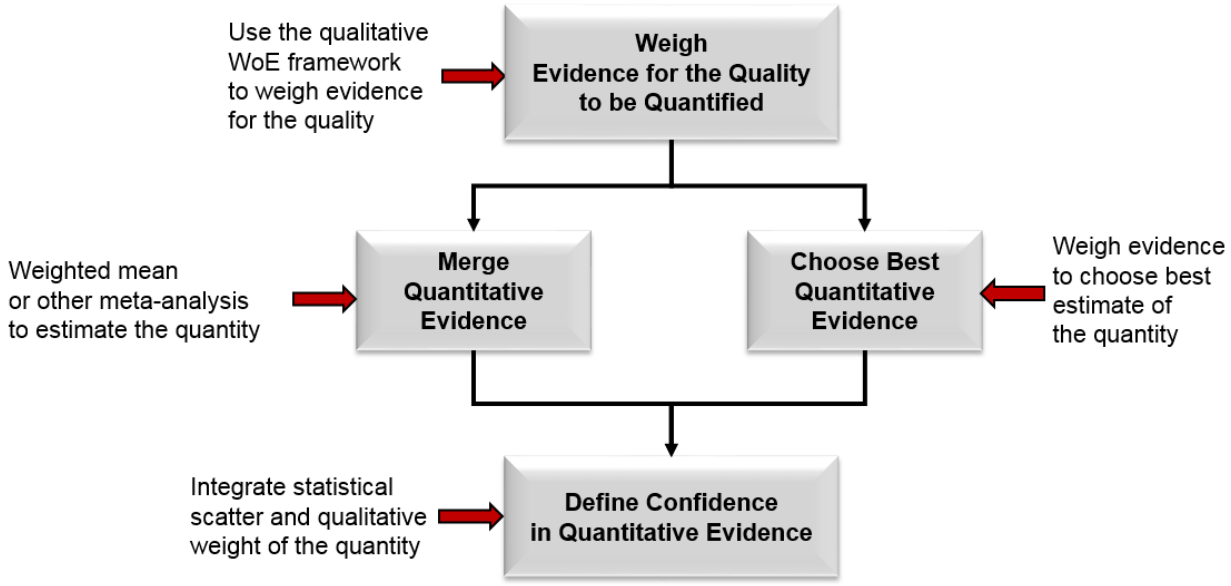

Figure S-2. An annotated diagram of the process for using WoE to estimate quantities, explained in Section 8. It begins by weighing evidence to determine the quality of interest (a qualitative WoE as depicted in Figure S-1), then uses one of two alternative methods to obtain results from multiple quantitative estimates, and finally defines the confidence in the result.

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1. INTRODUCTION

The process of weighing multiple pieces of evidence is useful for judging the truth of hypotheses, identifying the best explanation of phenomena, or deriving best models or best estimates. The weight-of-evidence (WoE) process involves (1) assembling evidence, (2) weighting evidence with respect to properties, and (3) weighing the integrated body of evidence. This WoE process is embedded in larger assessment processes, which include planning, problem formulation, analysis, synthesis, and communicating results.

Scientific investigations of a topic often generate multiple pieces of evidence of various types. For that reason, WoE is inherent in medicine, engineering, and other applied sciences, including environmental assessment. Because weighing evidence is so common, the importance of the process is often overlooked and as a result, it is generally performed informally and presented as a narrative. WoE, like other scientific activities, depends on transparency for its credibility. This document encourages more explicit WoE methods, but it also encourages fitting the WoE process to the assessment to avoid processes that complicate the assessment without enhancing the results.

The *Guidelines for Ecological Risk Assessment* did not include WoE (U.S. EPA, 1998). Instead, guidance was provided for a lines-of-evidence process that is equivalent to a narrative WoE guided by considerations (see Appendix D.2). Assessment practices now have advanced sufficiently to recommend WoE for ecological assessments.

1.1. Definitions

WoE is a metaphor adapted from jurisprudence, in which multiple pieces of evidence are metaphorically placed in the pans of the scales of justice and the side with the greatest weight prevails. The metaphor is appropriate for any situation in which multiple and diverse evidence are evaluated to reach a conclusion.

In this document, WoE is defined as an inferential process that assembles, evaluates, and integrates evidence to perform a technical inference in an assessment. WoE methods have been derived to estimate a quantity (Appendix B), inform model selection (Appendix C), or reach qualitative conclusions in an assessment (Appendix D).

As part of that inferential process, WoE characterizes properties of pieces of evidence and of bodies of evidence. First, WoE determines the degree of support for a hypothesis that a piece or type of evidence provides (i.e., the weight of a piece of evidence dropped into a pan of the scales). Hence, weights indicate which pieces and types of evidence make the greatest contribution to the inference. Second, WoE determines the degree of support for a hypothesis, relative to alternatives, that the available body of evidence provides (i.e., the accumulated weight in one pan relative to the other). These cumulative weights not only inform inferences, they also indicate how much confidence assessors have in the conclusion (Section 9).

For example, “WoE was used to determine the likely cause of a bird kill” (the process). “The occurrence of carbofuran granules in the crops of dead birds is convincing evidence of exposure” (a property of a piece of evidence). “The body of evidence consistently supports carbofuran as the cause” (a property of the body of evidence). Further discussion of these terms is presented in Box 1-1. Other terms are defined in the glossary in Appendix A.

1.2. After 50 Years, Advancing Beyond Hill's Considerations

The touchstone of WoE in health and environmental assessments is Hill's considerations (Hill, 1965). Hill recognized that causal inference requires qualitative WoE because no amount of quantitative analysis of associations can suffice (i.e., correlation is not causation). He listed nine considerations to guide the process. Hill's considerations include, but do not distinguish, characteristics of causal relationships (e.g., temporality), types of evidence (e.g., experiment), properties of evidence (e.g., strength), and properties of bodies of evidence [e.g., consistency; (Cormier et al., 2010)]. EPA has adopted Hill's considerations for hazard identification in Integrated Risk Information System (IRIS) assessments and Integrated Science Assessments (ISAs).[1] Hill's considerations were designed for determining the causes of observed epidemiological effects, however, and not for applications in which effects have not been observed. In particular, Hill presumed that co-occurrence of the putative causal agent and the effect of interest (smoking and lung cancer, in his case) was clearly documented, and his goal was to demonstrate that the relationship is causal. We, however, must also address cases for which a clear real-world association has not been demonstrated.

Box 1-1. Weight versus Weigh, Weighting versus Weighing

The terms weight, weigh, weighting, and weighing, which are used throughout this document, can be confusing. This ambiguity results in part from the fact that weight is both a noun and a verb.

To *weight* a piece of evidence is to assign importance to it (a process designated by a verb). As a result of that action, the evidence has weight (a result designated by a noun). The *weighting* process formalizes the evaluation of evidence, by assigning a descriptor or score.

To *weigh* a body of evidence is to combine the weights assigned to each of the pieces (a process designated by a verb). As a result of *weighing*, the body of evidence has weight (a result designated by a noun). The weighing process formalizes the integration of evidence by determining the weight of the body of evidence.

The WoE system presented here treats explanatory implication of evidence, types of evidence, properties of evidence, and properties of bodies of evidence as separate aspects of WoE (Box 1-2). Because each serves a different function in the WoE process, they are not treated as equivalent considerations. Distinguishing them makes clear that Hill's list lacks essential characteristics, types, and properties of evidence. These aspects are the basis for weighting and weighing evidence for causation and other qualities as presented in Sections 5–7.

[1] IRIS is a program that evaluates information on health effects of environmental contaminants to determine what hazards they pose to humans and to develop benchmark values (http://www.epa.gov/iris/). ISAs assess the scientific evidence for health and welfare effects of criteria air pollutants (http://www.epa.gov/ncea/isa/).

Box 1-2. Aspects of Evidence

This approach to weighing evidence distinguishes aspects of evidence in the WoE process that may not be clearly distinguished in prior approaches. They are introduced here and explained in more detail as they appear in the WoE process.

Piece of evidence: A piece is the evidence derived from a particular experiment or observational study. A piece of evidence is the minimum unit that might be weighted.

Type of evidence: A type is a category of evidence based on the nature of the study from which the evidence is derived. Examples include single-species, laboratory toxicity tests; microcosms; mesocosms; biomarker surveys; and community surveys. Types are used to organize and combine pieces of evidence to simplify weighting and weighing.

Explanatory implication of evidence: An explanation expresses the logical relationships between evidence and inference. For example, laboratory toxicity tests may provide evidence of the sufficiency of an exposure to cause the effect, and community surveys may provide evidence of co-occurrence of the effect and putative cause.

Body of evidence: A body of evidence is all of the evidence that applies to a particular hypothesis.

Property of evidence: Properties are the aspects of evidence that determine how much weight (influence) it should have. This approach uses three general properties: relevance, strength, and reliability.

Property of bodies of evidence: Bodies of evidence are weighted with respect to collective properties including number, coherence, diversity, and absence of bias.

1.3. SCOPE

This document is intended to inform ecological assessments. Human health assessments are mentioned and cited only as background and for purposes of comparison. Weighing multiple types of evidence has been performed more widely in ecological assessments than in human health assessments (Krimsky, 2005; Suter, 1993). Although ecological and human health assessments can be performed similarly, the types of ecological assessments that have driven the development of WoE tend to differ in important respects from human health assessments. In particular, types of ecological studies that contribute evidence to Superfund and Clean Water Act assessments include effluent and ambient media toxicity tests, toxicity identification evaluation, in situ tests, biotic community surveys, and demographic models. In addition, ecological assessments must weigh evidence related to multiple endpoint species and levels of organization, which increases the need for formal WoE methods.

This document presents a framework for application of WoE in various assessment contexts. WoE is an assessment tool, just as modeling and statistical analysis are assessment tools. Therefore, the framework for WoE is not a substitute for assessment frameworks (see Section 3).

WoE can be carried through the entire assessment process or be applied to an inference that is only a component of the assessment. WoE can be limited to hazard identification (e.g., Does ozone reduce plant growth at ambient levels?), the determination of an assumption (e.g., Should a bioaccumulation factor be used?), or the estimation of a parameter (e.g., weighing field and laboratory estimates of a chemical's half-life in water). In contrast, a WoE process can carry through an entire condition or causal assessment.

This document cites literature that is directly relevant to explaining this approach to WoE but does not attempt to cover the history of WoE in environmental assessments. Reviews of WoE approaches are available elsewhere (Rhomberg et al., 2013; Linkov et al., 2009; Pope et al., 2007; Krimsky, 2005; Weed, 2005).

This document focuses on WoE for qualities such as causality and impairment (Box 1-3). WoE methods to derive quantities and to choose models are discussed in Appendix B and Appendix C, and the use of qualitative WoE to enhance the derivation of quantitative results is discussed in Section 8. Qualitative WoE is emphasized because it is more common in ecological assessments than is quantitative WoE (Appendix D).

Box 1-3. Qualities and Qualitative Weight of Evidence

Qualitative WoE: A qualitative WoE is an assessment for which the endpoint is a quality such as a condition, mode of action, source, or type of effect. It typically includes both quantitative and qualitative evidence, but the result is not a numerical quantity.

Quality of Interest: The quality for which evidence is weighed is most often causality, but it can be any quality of interest. Examples of qualities that can be or have been inferred by WoE include:

- Coxie Creek is impaired.
- Acid mine drainage causes the impairment.
- Polychlorinated biphenyls are bioaccumulative.
- Selenium is teratogenic in fish.

Quality of Evidence: This document does not recommend weighting the quality of evidence. Instead, specific properties and sub-properties of evidence are weighted. This is because the term quality has been found to be too broad to be useful in the weighing of evidence (Higgins and Green, 2011). However, quality is used in a broad sense that is consistent with U.S. government data quality policy (U.S. EPA, 2002b).

1.4. Benefits and Challenges of Weight of Evidence

Although this document recommends the use of WoE, it recognizes that WoE can have limitations in practice. We assume that assessors will consider the potential benefits and challenges of WoE (Box 1-4) relative to the requirements of their assessment before proceeding to implement the approach recommended here.

WoE techniques inevitably involve subjective expert judgments. Such judgments can cause WoE to be criticized for being biased or arbitrary. However, the objections to subjectivity can be diminished by some good practices.

1. Prior to the assessment, specify the WoE method in as much detail as is practical to minimize the need for improvised judgments about methods or assumptions during the assessment.

2. Use the standard judgments of a program expressed as standard criteria for assigning or integrating weights. For example, tests performed using an Organization for Economic Cooperation and Development (OECD) protocol with good laboratory practices might be given a standard score of +++ for reliability.

3. Be objective, in the sense of being unbiased, by self-auditing (Box 1-5).

4. Work in groups and attempt to achieve consensus concerning judgments.

5. When making judgments, try to represent the opinions that knowledgeable and unbiased members of the scientific community would have, given the evidence and the inference to be made.

6. Find assessors with sufficient relevant knowledge and experience to qualify as experts.

Box 1-4 Potential Benefits and Challenges

Inference by weighing multiple pieces of evidence has advocates who recognize its potential benefits, but challenging aspects of its application have led some assessors to oppose its use.

Potential Benefits of WoE

The primary potential benefit of WoE is the greater confidence in results obtained by considering all relevant and reliable evidence. For example, it is not uncommon for causal assessments to consider only statistical evidence of co-occurrence of an effect and its potential causes. This approach provides much less confidence than one that also considers evidence of temporal sequence, interaction, and other characteristics of causal relationships. In many cases, no single type of evidence is sufficient to reach a conclusion. Ecological assessments of polluted ecosystems commonly benefit from considering evidence from laboratory toxicity tests of chemicals, tests of effluents, or ambient media and biological surveys. This benefit of WoE occurs because the body of relevant and scientifically credible evidence provides a more complete picture than does any piece of evidence alone.

A second potential benefit is an increase in the defensibility of an assessment. An explicit WoE method demonstrates that all relevant evidence has been considered and no credible evidence, either in support of or contrary to a hypothesis, has been arbitrarily dismissed. Without an explicit process planned in advance, reviewers might criticize or even dismiss an assessment for excluding data or evidence that they believe should have been given more consideration.

Defensibility of assessments also might be increased by the transparency of the processes it uses for inference. A formal WoE method enables reviewers and readers to understand and critique the processes of assembling, weighting, and weighing the evidence.

Potential Challenges to WoE

A formal WoE process can require considerable time and effort, which could lead to performance of fewer assessments or delayed decisions. Completing and documenting a formal systematic literature review or implementing an evidence scoring system might not be resource effective if the same conclusion can be obtained with a less resource-intensive assessment. The solution to this challenge is to tailor the WoE method to the assessment.

Box 1-5. Subjectivity and Objectivity

WoE-based assessments rely on subjective professional judgments because there is no other means of weighing a diverse body of evidence from models, laboratory tests, field tests, field surveys, and other information sources to identify the best-supported hypothesis. Although inevitable, subjectivity often is considered undesirable in assessments as in other scientific contexts.

Objective properties, such as the number of fish species in a stream, are properties external to the investigator that can be confirmed by any other investigator. Subjective properties such as the reliability of biological survey results are opinions of the investigator evaluating the survey, not inherent properties. The extent to which assessors agree in their judgment of reliability is due to shared preferences, not a measurable attribute of the surveyed community.

Subjective inferences can be objective in another sense, which is defined in federal policy (U.S. EPA, 2002b): Any inference can be considered objective if it is performed in a disinterested—and therefore impartial—manner. The guidance in this document aims to create circumstances for which an inference is minimally influenced by any personal or institutional biases and in which any systematic bias can be detected.

Performing laboratory or field studies to generate data for multiple types of evidence (e.g., chemistry, toxicity, and biology) for a WoE analysis—as opposed to simply summarizing data from available literature—is more resource intensive than generating a single type of evidence (e.g., only chemistry). The value of new information to the assessment should be considered during the planning stage to obtain sufficient, but not surplus, evidence (Keilser et al., 2014).

Complex WoE methods can obscure rather than clarify the derivation of results, particularly if the method is not clearly presented. A reader is likely to dismiss the results if the assessment is incomprehensible. Clear and consistent methods can reduce this problem.

Finally, a fundamental objection to WoE is that it might mix scientifically less robust evidence with highly reliable evidence. In some cases, the body of at least minimally relevant and reliable evidence might not contribute information beyond that supplied by a single best piece of evidence. This issue is addressed by including explicit steps for screening and weighting evidence rather than treating all evidence as equal.

These objections can be minimized by careful planning and by clearly presenting the WoE process. The WoE methods should be appropriate to the assessment. The amount of detail in evaluating and scoring evidence should be appropriate to the amount and diversity of the evidence, the time and resources available, and the degree to which decision makers and stakeholders wish to engage in a WoE process. The amount of detail can also be based on the degree to which the results of an assessment are potentially contentious. If, for example, an informal review of the evidence clearly shows a site is highly toxic and the obvious decision will be to remediate, a more detailed WoE process might waste resources, prolong the contamination, and confuse the issue. In situations for which the decision is obvious and could be urgent, a protracted WoE process is counterproductive.

2. APPLICATIONS OF WEIGHT OF EVIDENCE

The uses of WoE in ecological assessments are diverse, in part because ecological assessments are conducted in diverse regulatory contexts that require different assessment methods. In addition to asking assessors for predictions of potential adverse outcomes of proposed actions (i.e., to perform risk assessments), decision makers ask assessors to determine conditions (i.e., to perform condition assessments), determine the likely causes of adverse conditions (i.e., to perform causal assessments), and determine the actual outcomes of actions [i.e., to perform outcome assessments (U.S. EPA, 2010b; Cormier and Suter, 2008)]. Each type of assessment has its own logic and methods, and therefore, weighs evidence somewhat differently. Figure 2-1 illustrates a way to organize such assessments. Assessments can be initiated by the results of a prior assessment, and WoE results from prior assessments can inform subsequent assessments. For example, if a condition assessment identifies a biological impairment, a causal assessment should follow to identify the cause and source of the causal agent, a predictive risk assessment should follow to determine the remedy, and an outcome assessment should determine whether the remedy has sufficiently improved conditions. Assessments also can be initiated by external demands. For example, a predictive risk assessment might be prompted by an application to market a new pesticide.

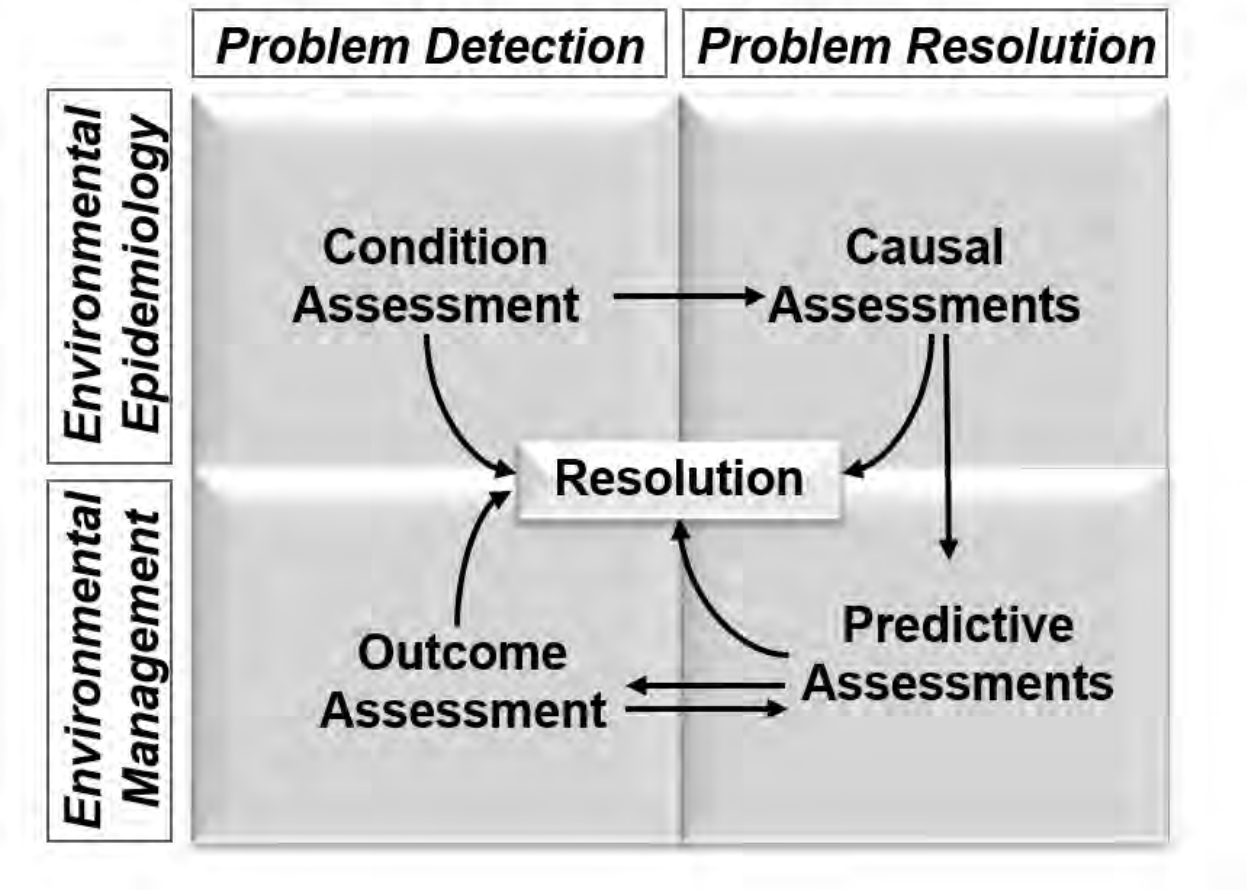

Figure 2-1. A framework depicting the relationships among types of environmental assessments. Modified from U.S. EPA (2010b); Cormier and Suter (2008).

All types of ecological assessments can weigh evidence quantitatively to combine multiple numerical values or to choose a model (see Appendix B and 11.Appendix C). This document, however, emphasizes using WoE for integrating evidence to derive a qualitative conclusion that supports a decision. Examples of qualitative conclusions are the biotic community of a stream is impaired, selenium causes cranial deformities, low pH caused the impairment, or coal ash is the source of the arsenic. To determine what qualities might require WoE, it can be helpful to consider what qualitative questions are answered by the various types of environmental assessments (Box 2-1).

Environmental problem solving often requires sequences of inferences to derive qualitative results and then quantitative results. For example, an ISA, that qualitatively weighs evidence to determine whether relevant concentrations of the pollutant cause particular effects, precedes the development of National Ambient Air Quality Standards. A qualitative weighing of evidence to determine whether the contaminated medium is causing significant adverse impacts precedes development of quantitative cleanup goals for a contaminated site. A qualitative weighing of evidence to determine whether a water pollutant is causing biological impairment might precede the development of quantitative total maximum daily load (TMDL) for the pollutant. These qualitative assessments could be treated as a separate product from the quantitative assessment (e.g., a qualitative ISA before a quantitative Welfare, Risk and Exposure Assessment). Alternatively, the qualitative assessment might be nested within the quantitative assessment as part of the problem formulation (e.g., as a hazard identification).

This section describes the various types of assessments, their application by EPA and the current and potential roles of WoE in performing the assessments.

2.1. Contaminated Sites

Contaminated sites provide a wide scope for applying WoE because the contaminated and potentially biologically impaired conditions allow for the generation of diverse evidence from observation, sampling, analysis, and testing. As a result, most of the relevant methods and literature on ecological WoE address contaminated sediments, soils, and waters (Appendix D). In the EPA, the primary venue for contaminated site assessments is Superfund sites.

The goal of contaminated site assessments is to determine whether contaminants pose an unacceptable ecological risk and, if so, what should be done to reduce it. When assessing a site, specific impaired areas can be identified without WoE by comparing contaminant concentrations to screening benchmarks. Those benchmark concentrations also could serve in some cases as the remedial goals, allowing for completion of the assessment without weighing evidence. For Superfund sites, however, multiple types of site-specific evidence are typically collected, including results of toxicity tests of contaminated media, biological surveys, or analysis of biological samples for biomarkers or body burdens of contaminants (Luftig, 1999). Such bodies of evidence can be weighed in a merged condition and causal assessment to answer the question: Is an unacceptable risk associated with the site contaminants? Such a qualitative assessment is the topic of the approaches for the sediment quality triad and the Massachusetts and Oak Ridge National Laboratory WoE methods described in Appendices D.3, 11.D.5, and D.7. Such assessments can also be performed using the approach presented in the following sections.

Box 2-1. Qualitative Questions for Which Evidence is Weighed in Different Types of Assessments

Causal Assessment

Causal assessments identify causes of observed effects and they take one of two general forms.

What causes general effect y? This is the general causal question. Examples: What causes colony collapse disorder in honeybees? What causes coral bleaching?

What causes specific effect y? This is the specific causal question. Examples: What caused low invertebrate species richness in the Coal River? What caused the 1980s decline in San Joaquin kit foxes in Elk Hills?

Risk (Predictive) Assessment

Most EPA predictive assessments are risk assessments. They begin with a problem formulation that includes a causal question regarding what hazard is associated with an agent and could be assessed.

Does agent x cause general effect y? This is a general hazard identification question for assessments like setting benchmarks or permitting use of a chemical. Examples: Does smoking cause lung cancer? Does atrazine cause deformities in frogs?

Might agent x cause effect y? This is a hazard identification question asked in risk assessments for specific actions. Examples: Might a tailings spill at the proposed mine cause a loss of salmon spawning? Might permitting a new use of atrazine result in an increase in frequency of frog deformities?

Is agent x causing effect y? This is a hazard identification question asked in risk assessments for an agent under existing conditions. Examples: Are the sediment contaminants reducing invertebrate species richness or abundance? Is acid deposition reducing forest production?

These causal questions can be answered by a separate causal assessment prior to the risk assessment or in the problem formulation for the risk assessment. Without hazard identification, defining the endpoint entity and attribute has no basis beyond using default endpoints such as fish mortality.

Other qualitative questions that might involve WoE also are answered in risk assessments. For example:

- Should dietary exposure be considered?
- Will the endangered species occur on the site in the future?
- Is the site large enough to support an assessment population of the species of concern?
- Is long-range transport a significant source?
- What are the contaminants of concern?
- Is the chemical a persistent organic pollutant?

Condition Assessment

Qualitative questions concerning conditions, such as the following, are relatively straightforward to assess when standard definitions of conditions are provided.

- Is the ecosystem impaired?
- Is the species endangered?
- Is the water contaminated?

However, framing the question could be conceptually difficult, particularly with respect to the standard of comparison: natural conditions, reference conditions, historical conditions, or defined standards.

Outcome Assessment

Qualitative questions of concerning outcome are like condition questions but include issues regarding the efficacy of remedial or regulatory actions.

- Is bioremediation sufficiently reducing exposure of endpoint species?
- Is the liner leaking?
- Is the site acceptable for recreational fishing?

Many Superfund assessments treat pieces of evidence as independent lines of evidence without weighing them (Integral Consulting Inc., 2013). Causal assessments performed by WoE for contaminated sites are illustrated by the Elk Hills and California Gulch cases (U.S. EPA, 2011c, 2009a). Such WoE assessments can be sufficient to complete the investigation, provided the decision logic is as follows: If the sediment or soil presents unacceptable risk due to waste contamination, remediate it (e.g., cap, remove, or biotreat it). For Superfund sites, however, a separate step defines chemical-specific preliminary remedial goals (PRGs). Either site-specific values or standard benchmark values might be used as PRGs for the areas identified as impaired by WoE. Site-specific PRGs can be derived from tests of site media or field exposure-response relationships used in the qualitative WoE to identify waste-impaired areas. However they are derived, PRGs represent acceptable risks, and are typically used in selecting a final remedy.

2.2. Environmental Condition

Although the condition of all ecosystems is of concern, the Clean Water Act is unique among U.S. antipollution laws in requiring that all sites (i.e., all state waters) be assessed to determine if they are impaired. The result is each state's 303(d) lists of impaired waters. Most listings are for exceedance of water quality standards, including concentrations of chemicals, levels of biological pollutants (e.g., fecal coliform counts), and physical properties (e.g., temperature). In addition, ecological properties can serve to identify impaired waters based on biological or narrative criteria. Commonly, multiple types of biological data, termed metrics, are combined into an index (Blocksom and Johnson, 2009; U.S. EPA, 1996). The regulations indicate that states should evaluate "all existing and readily available information" in developing their 303(d) lists (40 CFR §130.7(b)(5)), which suggests a WoE approach or other approaches (such as independent applicability) that consider all information (Appendix D, Box D-1).

If a water body is declared impaired based on biological effects, the cause should be identified. Guidance for using WoE to determine the cause of biological impairment was developed for the Office of Water (U.S. EPA, 2000), and a web-based support system was developed to aid in its application (http://www.epa.gov/caddis/). This system is the principal model for the WoE approach presented in this document.

Once the cause of water body impairment has been determined, the sources can be identified so that TMDLs can be developed (Clean Water Act §§ 130.2(f)-(i) and 130.7(c)). This is similar to the practice of determining sources at contaminated sites is known as environmental forensics because it often involves establishing legal liability (Murphy and Morrison, 2002). Its methods include environmental fingerprinting, isotope analyses, tracer studies, and transport modeling, and it often uses WoE. TMDLs are developed and implemented to eliminate the impairment by apportioning pollutant loading among the sources. This step typically does not involve WoE. The TMDL process often includes evaluation of the results, which can lead to removal of the stream reach from the 303(d) list. This outcome assessment can rely on biological endpoints and could involve WoE.

2.3. Existing Pesticides and Industrial Chemicals

The reregistration of pesticides provides an opportunity to collect multiple pieces and types of evidence related to pesticide use, as well as conventional laboratory data, that is generated from the registrant's data package and literature reviews by EPA. This body of evidence, which is weighed in a WoE narrative, can include results from laboratory studies of chemistry and toxicity, mesocosms, field experiments, surveys, and incident reports; pesticide monitoring and use data; and transport, fate, and exposure modeling.

Risks to animals and plants from pesticides are assessed using a tiered approach. In general, most assessments are focused on Tier 1, intended to estimate conservative environmental exposures. The risks associated with those exposures are assessed using risk quotients (RQs), which are predicted exposure levels divided by effect benchmark levels. RQs are based on the most sensitive endpoints available for survival, growth, or reproduction. When RQs exceed levels of concern, risks are characterized using a narrative WoE analysis. Although the process for deriving RQs is well established, the WoE analysis depends on the nature of the available data and the assessed chemical and its use patterns. Examples of evidence analyzed to evaluate risk conclusions include comparing estimates of exposure from models or monitoring data to available toxicity endpoints, evaluating whether laboratory fate studies are consistent with field dissipation studies, and using species sensitivity distributions to evaluate impacts of conservative assumptions on risk conclusions.

Assessments of existing chemicals under the Toxic Substances Control Act (TSCA) can weigh diverse bodies of evidence to determine whether a chemical substance presents or could present unreasonable risk of injury to health or the environment. WoE is used when conducting risk evaluations under TSCA Section 6(b) and making risk management decisions for existing chemical substances. Existing chemical assessments typically rely on a combination of predictive modeling and other computational approaches, empirical laboratory or field data specific for the chemical being assessed and empirical laboratory or field data from analogous chemicals. For example, the body of evidence can include empirical or modeled data on use and release and on transport and fate, physical/chemical properties of the chemical in question, exposure data that include field monitoring and modeled data and hazard data from laboratory toxicity tests or modeling. This information is used to assess risk and, much like the registration of pesticides, RQs are developed and the analysis depends on the available data. The assessments rely on a set of seven study quality and selection considerations (U.S. EPA, 2015b). Implementation of the new (signed June 22, 2016) Frank R. Lautenberg Chemical Safety for the 21st Century Act may change these practices. The act expressly uses the term "the weight of the scientific evidence."

2.4. New Pesticides and Industrial Chemicals

Registration of new pesticides is based on a large and diverse body of evidence (relative to other new chemicals) pursuant to the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) pesticide registration data requirements (http://www2.epa.gov/pesticide-registration/data-requirements). Similar to risk assessments for existing chemicals, a tiered approach is used. The major difference between risk assessments for new versus existing pesticides is generally the amount and types of available data. For new chemicals, the data required under FIFRA generally are available. Incident reports, monitoring data, and toxicity data for nonstandard test species, however, are rarely available for new chemicals.

The available evidence is also weighed when reviewing, assessing, and regulating new industrial chemicals under TSCA before they enter commerce. Assessments of new chemicals rely on a combination of predictive modeling and other computational approaches and empirical data from analogous substances and chemical categories and from empirical data the manufacturer submits. As with existing chemicals, the implementation of the Lautenberg act is likely to increase the importance of WoE for new chemicals.

Review of chemicals for potential endocrine-disruptive mechanisms of action is required for all pesticide active ingredients, all food-use pesticide inert ingredients, and some industrial chemicals. A WoE approach based on a set of considerations has been used for that purpose (U.S. EPA, 2012b).

2.5. Benchmark Derivation

The derivation of numerical criteria, standards, remedial goals, screening levels, and other benchmark concentrations or doses involves performing a type of risk assessment. Qualitative WoE can be applied during problem formulation to determine what hazards should be considered in the assessment. For example, ISAs—which identify hazards that may be assessed in Welfare Risk and Exposure Assessments for National Ambient Air Quality Standards—use WoE to determine what effects on welfare occur in the relevant range of air pollutant levels (U.S. EPA, 2014b, 2013). If different methods or data sets are used to derive benchmarks for different exposure routes or modes of action, WoE can be used to determine which approach to apply, as in the development of IRIS values (human health benchmarks) for carcinogens versus noncarcinogens (U.S. EPA, 2005b). Finally, if a benchmark is derived using field data, WoE can be used to determine whether the evidence suggests the relationship is causal or confounded (U.S. EPA, 2011b).

2.6. Proposed Discharges

WoE is seldom an option when assessing risks from proposed new discharges because evidence is limited to predicted release rates of constituent chemicals used in transport models, and the resulting estimated concentrations are related to benchmark concentrations. Tests of synthetic effluents or analogies to existing effluents that are expected to be similar to the proposed discharge, however, could create bodies of evidence that could be weighed.

2.7. Special Purpose Assessments

Some assessments are performed for particular nonroutine decisions. For example, the EPA performed a watershed risk assessment to inform potential decisions concerning the mining of metals in the Bristol Bay, Alaska, watershed (U.S. EPA, 2014a). The evidence used was diverse and included analogies to prior metal mines and pipelines. The evidence was therefore weighted and weighed using a method like the one in this document. Similarly, EPA borrowed from the WoE method developed for causal assessment of impaired waters to assess the connectivity of streams and wetlands to support the definition of waters of the United States (U.S. EPA, 2015a). These examples show how one-of-a-kind assessments can adapt the general approach presented in this document.

3. PROCESSES FOR WEIGHING EVIDENCE

3.1. An Introduction to the Weight of Evidence Process

The weighing of evidence is a tool that can be used for any type of assessment, at any point in an assessment process or throughout the entire assessment (Section 2; Figure 3-1). In a risk assessment, WoE is used in the problem formulation phase to identify the hazardous properties of the agent being assessed and the appropriate assessment endpoints. In particular, evidence can be weighed to determine whether it supports the hypothesis that a chemical causes some particular effect, such as failure to hatch, effects on a particular taxon, or effects by a particular route of exposure or mode of action (Meek et al., 2014). In the analysis phase, WoE can be used to select assumptions, estimate parameters, and develop models (Section 8, Appendix B, and Appendix C). In the synthesis phase, the models and parameter estimates are used to characterize risks, determine most likely causes, or determine whether an ecosystem is impaired. When multiple exposure-response relationships, spatial/temporal associations, or other relationships have been developed, WoE is used to combine them or to determine which relationship is the best (weightiest). Other types of assessments use WoE at different points in their frameworks (Section 2). In a causal assessment, WoE is carried through all analysis and synthesis phases (Norton et al., 2014).

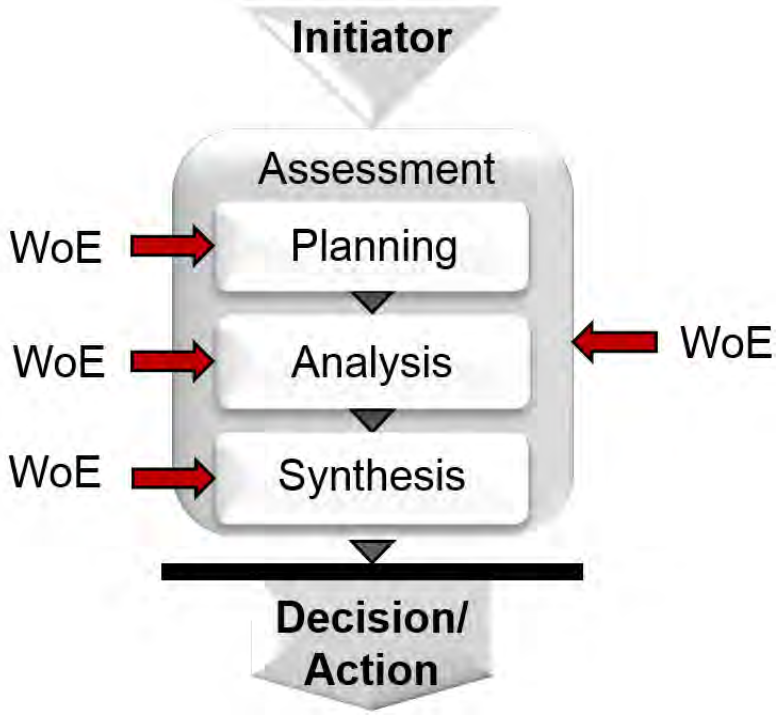

Figure 3-1. A basic framework for all types of environmental assessments (U.S. EPA, 2010b; Cormier and Suter, 2008). Weight of evidence can contribute to one or more individual steps (WoE on the left) or can be the basis for the entire assessment (WoE on the right).

However used, a formal WoE involves the same basic process (Figure 3-2). First, the evidence is assembled. This step involves finding published studies or performing new studies, determining whether their results are acceptably relevant and reliable, and extracting and analyzing data to generate useful evidence. Second, the pieces of evidence are weighted (i.e., evaluated and scored) to determine their influence on the results. Third, the body of evidence is weighed (i.e., weights are integrated and the body of evidence is interpreted) to arrive at a result.

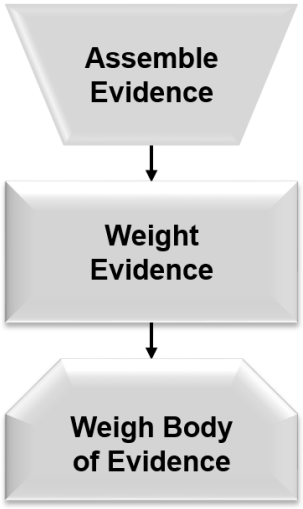

Figure 3-2. The basic WoE process (Suter and Cormier, 2011). The steps are elaborated in Sections 4–6, respectively, in this document.

WoE processes vary among applications, but these three steps are fundamental. First, you must have evidence. The final step, combining and interpreting (i.e., weighing) the evidence, is necessary to make the body of evidence inform the inference. The middle step, weighting, is also essential in that different pieces and types of evidence seldom have the same influence in an inference. However, the explicit assignment of weights is often skipped. This should be done only if the evidence is found to all be equally relevant and reliable (Section 7).

In many cases, multiple pieces of evidence are not explicitly weighed. Instead, evidence is informally weighed in a narrative (Box 3-1).

WoE can be applied to derive qualitative or quantitative results. It might be used to assess qualities such as causality, impairment, recovery, or occurrence of a specific effect or used to estimate quantitative results such as a benchmark value, a model parameter value, or the magnitude of effects. Inferences to quantities begin with quantitative evidence and apply quantitative methods (Section 8 and Appendix B). Inferences to qualities, however, use all relevant evidence (qualitative and quantitative) but apply qualitative inferential methods (Sections 5–7 and Appendix D). Even in WoE methods such as the Massachusetts system that use numerical scores, those scores are used to document qualitative judgments to reach a qualitative result (Menzie et al., 1996). The same qualitative methods can be used to make qualitative judgments about quantitative results (Section 8). For example, they might be used to judge the reliability of a quantitative effect estimate (e.g., 26 km of stream would be impaired and that result is highly reliable).

The general approach introduced in this section is intended to be flexible and broadly applicable. It is intended to provide more rigor and transparency than narrative WoE but less complexity and more flexibility than numerical systems and indices (Appendix D). The approach also is intended to merge inferences to qualitative and quantitative results in a useful manner. It can be applied to all types of environmental assessments and to both data-rich and data-poor cases.

Box 3-1. Best Practices for Narrative Weight of Evidence

Although this document explains how to use a formal method for WoE with explicit weighting and weighing, we recognize not everyone will follow this approach. Some assessors will continue to use a traditional narrative approach. In such cases, WoE narratives can benefit from some good practices.

1. When using evidence from the literature, design and carry out a literature search that will find the information needed in an unbiased manner (Section 4). Define not only the search terms but also the criteria for screening the results to obtain relevant and reliable evidence.
2. Even in a narrative approach, provide a table summarizing the selected evidence and indicate what was excluded and why.
3. Avoid narrative reviews that describes one piece of evidence after another and then present a conclusion. Instead, logically structure the narrative. At a minimum, present the evidence for a hypothesis and the evidence against it, and explain why one side has greater weight.
4. Make the narrative organization clear. Use lists and subsection headings to help the reader understand the logical structure.
5. Present the results clearly. Which hypothesis is best supported by the WoE, and how much confidence can be placed in the conclusion?
6. Express the degree of confidence in the conclusion.

3.2. Planning the Assessment to Use Weight of Evidence

All environmental assessments begin with a planning phase that defines how the assessment will be conducted. In risk assessments, this phase includes two steps termed planning and problem formulation (U.S. EPA, 1998). Assessment plans identify the evidence needs, methods that will be used to generate the evidence and methods for weighting and weighing multiple pieces and types of evidence. Specifying the WoE method in advance enhances transparency and defensibility. In particular, a previously defined system for evaluating evidence and assigning scores prevents the adjustment of weights to achieve a desired result. To the extent feasible and helpful, standard frameworks and methods should be used (Box 3-2).

In practice, there are levels of standardization. Sections 4–7 present a general WoE approach for EPA, which could reduce the burden of planning an assessment. Additional standardization can be achieved at the program level or in individual regions. The greatest specificity, however, occurs in the planning of individual assessments. Not specifying in advance how evidence will be

Box 3-2. Standardization of Weight of Evidence

Standardization of assessment practices is desirable in general. Standardization can increase efficiency by reducing the number of decisions to be made, improve assessments by setting standards of practice, and reduce bias by reducing the opportunities for assessors to make personal judgments. If the standard practices are too rigid and prescriptive given the variability in assessment problems and conditions, they can reduce efficiency, force less than optimal assessment practices, and create frustration. This conundrum is compounded when WoE approaches are used. Decisions are made concerning, among others, which inferences should be based on WoE, what evidence should be included, what properties of the evidence should be considered, and how the weights should be expressed. These decisions should be made on a program-specific basis.

weighed delays the decisions until the data are in hand and the evidence is being generated, weighted and weighed. At that point, the consequences of decisions might be apparent to the assessor. For example, if sediment toxicity tests for an area result in an average 33-percent mortality and no standard for scoring has been set, an assessor can score the evidence as 0, + or ++ (ambiguous, weak, or strong). That judgment could be biased if the assessor knows that the choice can tip the balance for or against dredging the sediment. Removing the temptation to choose a weight that gives a preferred answer by standardizing weights whenever appropriate is the better option.

Exceptions do exist. A detailed plan, on occasion, can result in nonsensical results when implemented, due to peculiarities of the case (Johnston et al., 2002). Therefore, allowing for deviations, and documenting the rationale, as Johnston et al. (2002) did, is essential.

Finally, when a decision is made to use WoE but the method was not prescribed in an analysis plan, assessors should document how they weighed the evidence and why they made their choices. Expert judgment, although essential, should be transparent.

Assessment planning should be adapted to include WoE considerations. Stakeholders and decision makers can be consulted for assurance that the weighing process is acceptable. WoE methods that are compatible with the potentially available data and evidence should be chosen. Alternatively, data needs should be specified with WoE in mind. In particular, literature reviews and new studies should be coordinated to generate complementary evidence. If a field survey will sample benthic invertebrates, literature reviews should seek toxicity studies of benthic invertebrates. Any new laboratory tests should address benthic invertebrates and preferably taxa that are sensitive or important at the site. Field sampling for different pieces of evidence (e.g., chemical concentrations, habitat characteristics, and occurrence of biological taxa) should be collocated in space and time so that the results can be used to derive relevant relationships or make comparisons.

When possible, the assessment problem to be addressed by WoE should be formulated in terms of alternative hypotheses. Identifying the hypothesis best supported by the WoE is conceptually simpler and more convincing than determining whether a single hypothesis has sufficient WoE. One hypothesis, considered alone, may appear to have sufficient evidence, but another hypothesis may have more and weightier evidence. Alternatively, a hypothesis may appear weak, but its status will be unclear until a stronger alternative is identified. For example, a study of a declining San Joaquin kit fox population began as an attempt to determine whether toxic chemicals were the cause. Its conclusion that they were not the cause became more convincing when a strongly supported alternative cause, predation, was identified (U.S. EPA, 2009a).

Because of the complexity of ecological systems and their responses to interventions, the development of conceptual models is essential to planning an ecological assessment (U.S. EPA, 1998). Conceptual models convey the processes and entities that link sources with effects on endpoints. The links can be used to guide the development of evidence for the WoE process. In risk assessments and other predictive assessments, questions can be asked such as, what sequence of events must occur following the proposed action before the endpoint effect can occur? For example, when assessing the risks from input of phosphorus to a lake, if an endpoint is fish kills due to low dissolved oxygen, the WoE should consider evidence for the occurrence of algal blooms, respiration and decomposition, and evidence against the occurrence of mixing because they all can influence dissolved oxygen (Figure 3-3). Similarly, when assessing the cause of an observed fish kill, if low dissolved oxygen is a hypothesized proximate cause, evidence of phosphorus input, algal production, decomposition, and the absence of mixing are supporting evidence that could be generated and evaluated. An approach for applying WoE to conceptual models is provided by the OECD (2013) guidance on adverse outcome pathways (Box 3-3).

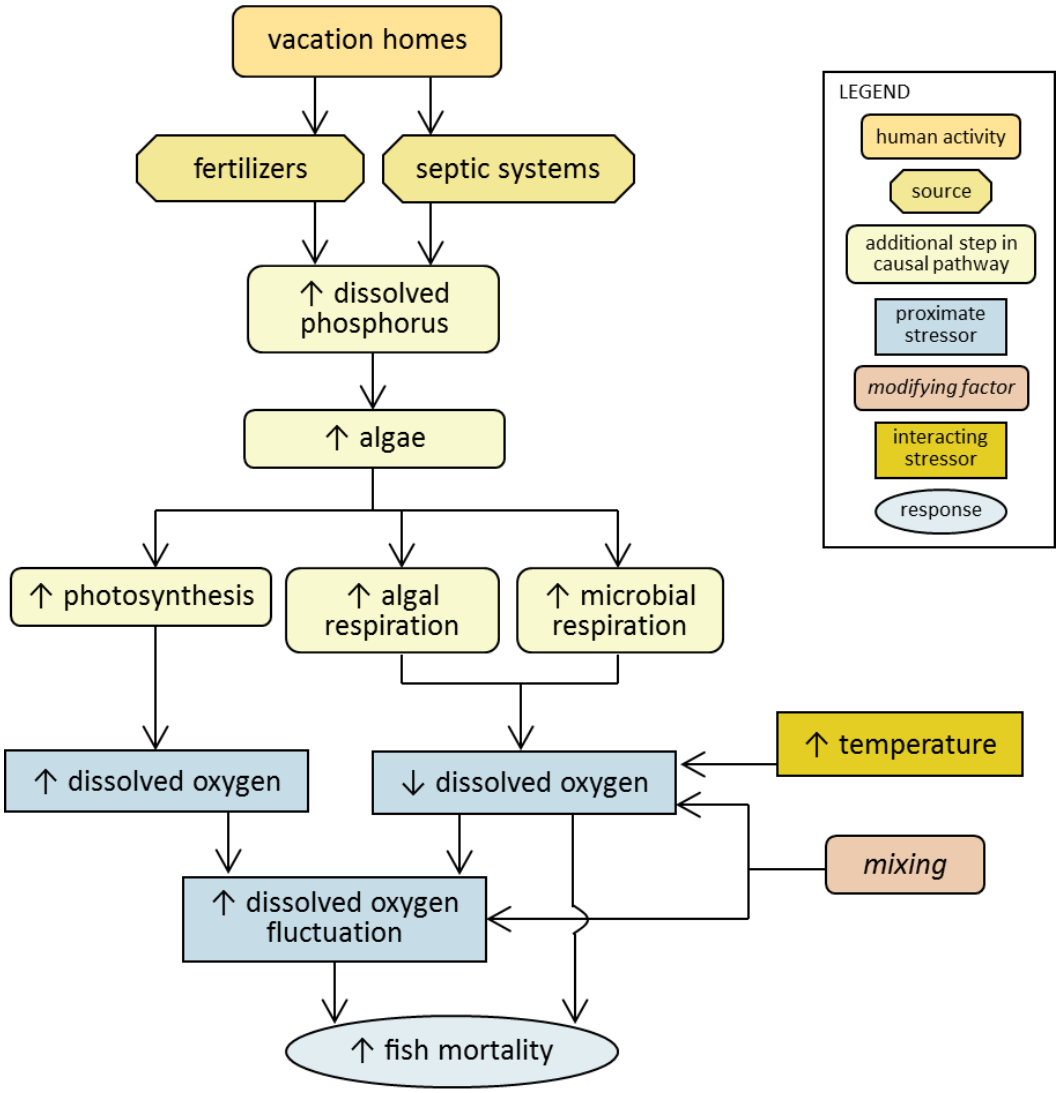

Figure 3-3. Conceptual model for a hypothetical ecological risk assessment of the relationship of phosphorous releases from a vacation home development to the risk of fish kills in a lake (graphic by Kate Schofield, using the conventions in CADDIS, at http://www3.epa.gov/caddis/).

Box 3-3. Weighing Evidence for Adverse Outcome Pathways

Adverse outcome pathways (AOPs) are representations of linkages between molecular initiating events and adverse outcomes measured at levels of biological organization considered relevant to risk assessments (Ankley et al., 2010). Although a goal of AOP development is to quantitatively implement them and predict relevant effects, currently they are primarily a form of hazard identification represented as conceptual models. For example, an AOP might link the binding of a chemical with a receptor in larval fish through a series of steps to failure of swim bladder inflation and then to reduced survival and perhaps to reduced population production (Villeneuve et al., 2014). As with other hazard identification exercises, WoE can be applied to determine the most likely hazards posed by a chemical and also to reveal gaps and weaknesses in the evidence. The OECD (2013) has recommended using Hill's considerations, tailored for AOPs, to evaluate key events, key event relationships, and overall AOPs. The tailored considerations are biological plausibility, essentiality, and empirical evidence. For each consideration, definitions of high, moderate and low confidence are provided. For example, moderate confidence in biological plausibility is defined as "the key event relationship is plausible based on analogy to accepted biological relationships but scientific understanding is not completely established." These OECD standard weights and definitions are equivalent to the standard findings and scores in Table 5-2, but types of evidence are not separately evaluated. Example cases of WoE are provided in the OECD (2013) guidance and derivative publications (Becker et al., 2015; Villeneuve et al., 2014). Subsequently, another WoE approach for AOPs was developed and demonstrated using numerical scores that were aggregated in a linear additive fashion into an overall WoE, a procedure analogous to multi-criteria decision analysis (Collier et al., 2016).

The planning of an assessment should include consideration of uncertainty. However, in the context of WoE analyses, uncertainty is one component of a set of complex issues related to confidence in the results (Section 9). As the OECD found when applying WoE to adverse outcome pathways, analysis of qualitative uncertainty is redundant with WoE (Becker et al., 2015). Conventional statistical measures such as distribution functions, standard deviations and confidence intervals are used to express the variability and uncertainty that appear as scatter in the data or scatter in modeling results. Many sources of uncertainty are unquantified or unquantifiable, however, and conventionally are simply listed. WoE can address this wider range of qualitative issues that determine confidence in the results—not just how closely the curve fits the points, but does the curve represent a causal relationship, and how relevant is the relationship to the case? A formal WoE method is a means to engage with these issues more clearly and consistently. Ideally, each quantitative result would have a conventional statistical estimate of uncertainty or variability and associated qualitative weights.

All assessments require professional judgments by assessors, but WoE makes the judgments more transparent. Clearly indicating where the assessors' judgments end and those of the decision maker begin is critical. It is clear that the decision maker, after conferring with assessors and potentially with stakeholders during the planning phase, specifies the topic and scope of the assessment and the decision to be made (U.S. EPA, 1998). It is also clear that, in the end, the decision maker determines what action will be taken. Judgments regarding the scientific evidence made between these management decisions are generally considered to be in the purview of science and are made by assessment scientists to avoid any potential political biases of decision makers (NRC, 1983). A point of potential ambiguity arrives at the conclusion of the assessment. A decision maker might request only a compilation and summary of the evidence and then decide, for example, whether the stream is impaired, which cause is the most likely or what concentration is the best benchmark value? The boundary between assessment and management, therefore, should be made clear in the planning phase because it determines the ultimate product of the assessment.

Because professional judgments play such a prominent role when weighing evidence, avoiding making the judgments in isolation is essential, particularly for less experienced assessors and for unconventional assessments. Support in professional judgment can be provided during the assessment by collaboration within the assessment team or afterwards by internal and external peer reviewers.

In the EPA, the planning of assessments includes the development and approval of a Quality Assurance Project Plan (QAPP). Although quality assurance (QA) and weighing evidence are not the same, WoE includes the screening of studies and the evaluation of evidence to weight it with respect to relevance and reliability, which encompasses evaluating the quality of input data. To avoid duplication of effort, an explicit WoE process can be used to meet the requirement for a QAPP (Box 3-4 and Section 9).

Box 3-4. Data Quality Assurance and Weight of Evidence

Quality assurance (QA) and WoE both consider the quality of scientific information and thus are related. The QA process determines whether the quality of environmental data and information supporting EPA decisions are appropriate for their intended uses (U.S. EPA, 2008). It includes documenting the process for ensuring information quality, including data generation, data analysis, and assessment methods. Thus, the development of a QAPP should encompass all aspects of the assessment planning process, including methods for WoE (U.S. EPA, 2002a). WoE contributes to QA because QA for assessments "involves a 'weight-of-evidence' approach that considers all relevant information and its quality" (U.S. EPA, 2002b). Therefore, during planning, QA should determine what WoE method is acceptable, and during the assessment, weighting determines whether the quality of information is acceptable. A formal WoE process should provide the rigor and transparency needed to meet QA requirements. Assessors should read the QA guidance and check with their organization's QA official to ensure that they properly merge QA and WoE.

3.3. Results and Transition

In this section we have dealt with determining the role of WoE in the assessment by integrating WoE considerations into the planning and problem formulation process. That is, we have identified one or more assessment problems with multiple pieces of evidence to be weighed, we have identified the WoE approach to be used, and we have determined how it relates to other aspects of the assessment. We are ready for the first step in the WoE framework, assembling the evidence.

4. ASSEMBLING EVIDENCE

4.1. The Process for Assembling Evidence

The success of WoE depends on identifying or generating useful evidence (Figure 4-1). Evidence is information that can be used to make an inference. For risk assessments and causal assessments, useful evidence principally includes information about causality (i.e., a relationship between the exposure and response and either an estimated exposure level or a response level). Exposure levels are used to solve the exposure-response relationship to estimate a future response to the potential exposure (e.g., to estimate the frequency of mortality in a conventional risk assessment) or plausible effects of the exposure (e.g., to determine whether the level of exposure was sufficient to cause the observed effect in a causal assessments; Figure 4-2). Response levels considered thresholds for unacceptability (e.g., 10-percent mortality) are used to solve the exposure-response relationship to estimate the exposure level that will protect against that unacceptable response (criteria assessments) or the exposure level that would be required to cause an observed effect (causal assessments; Figure 4-2). Exposure and response information can occur separately in a condition assessment. For example, evidence that the abundance of an endangered species is declining is sufficient for a condition assessment to prompt a causal assessment. Similarly, accumulation of a chemical in fish can be sufficient evidence of condition to prompt a risk assessment. In addition to information about exposure, response and the relationship between them, information about environmental conditions such as habitat structure or water chemistry also might be required to complete the information that constitutes a piece of evidence.

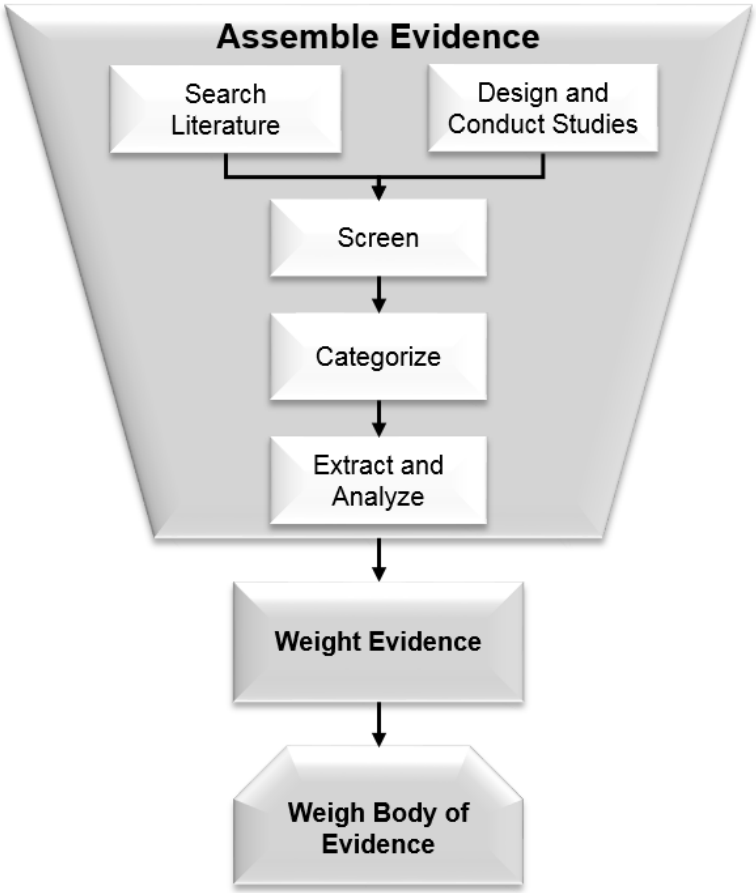

Figure 4-1. An elaboration of the process for assembling evidence, the first step in WoE.

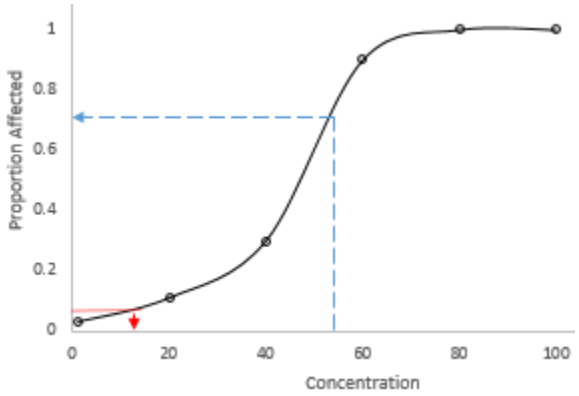

Figure 4-2. An exposure-response relationship (black curve) alone is evidence that the measured chemical can cause the effect. With a concentration, it can provide evidence of the level of effect that is expected (blue dashed arrow). With a level of effect, it can provide evidence of the concentration that would cause that level of effect or, in benchmark derivation, a concentration that would prevent greater effects (red dotted arrow).

Data alone are not evidence because evidence should indicate a hypothesized spatial, temporal, or causal relationship or the absence of a relationship. For example, contaminant concentrations are related to a particular place that has been, or potentially will be, exposed to some source and to reference concentrations from sites that are not exposed to the source. Concentrations without those relationships do not constitute evidence.

In sum, evidence usually requires more than one type of information. Recognizing this, Hope and Clarkson (2014) developed the term "evidence group" to describe the combination of an exposure-response relationship, information concerning environmental conditions that influence the relationship and either an exposure estimate or a response level. Thus, as this document discusses evidence, note that the discussion typically refers to a set of related bits of information that together constitute evidence.

4.2. Searching Literature and Assembling Evidence

A systematic literature review can provide more complete information than an informal review and can reduce the perception of bias in data selection (NRC, 2014). Recognition of the importance of performing reviews systematically has prompted development of several formal methods for systematic reviews (Box 4-1). Recent peer reviews of high-profile EPA assessments such as the stream and wetland connectivity report have called for better documented and systematic literature reviews (SAB, 2014). The method for literature review should be described in the analysis plan (U.S. EPA, 1998).

The EPA has developed the Health and Environmental Research Online (http://hero.epa.gov) database to document the literature searches and screening processes for ISAs and IRIS assessments. It provides transparency in literature searching, screening, and sorting processes and makes the results available to the public.

Box 4-1. Systematic Review

Systematic review is an approach for reviewing published scientific evidence based on a formal search protocol that provides a reasonably complete set of relevant studies that has been screened and reviewed in a consistent and replicable manner (Bilotta et al., 2014). The goal of systematic review methods is to ensure that the review is complete, unbiased, and transparent.

Systematic review was developed as a tool for integrating results of clinical trials in evidence-based medicine. The most prominent example is the Cochrane Collaboration, an organization that reviews evidence of the efficacy of medical treatments (Higgins and Green, 2011). The Campbell Collaboration (http://www.campbellcollaboration.org) extends systematic reviews to education, crime and justice, social welfare, and other issues. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) provides "an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses" (http://www.prisma-statement.org/). More recently, systematic review has been adapted to mammalian toxicology, epidemiology, and human health risk assessment. Examples include the industry-funded Evidence-Based Toxicology Collaboration (http://www.ebtox.com), the foundation-funded *Navigation Guide* (Woodruff and Sutton, 2014), and the U.S. National Toxicology Program's Office of Health Assessment and Translation method (Rooney et al., 2014). Another systematic review system has been developed for environmental management (CEE, 2013). None of the specific existing methods for systematic review are directly applicable to weighing evidence in the EPA's ecological assessments. In particular, systematic review does not integrate heterogeneous evidence, which is typically necessary in ecological assessments. However, they provide methods for the assembly of information from the literature.

4.2.1. Search the literature

The two major components of a literature search are defining the topic and designing the search. The first step identifies the topic with sufficient specificity to enable assessors or information specialists to design a search strategy. Examples include the chronic toxicity of arsenic to marine teleost fish and the biodegradation rate of benzene in fresh surface waters. If the assessments performed by an organization are sufficiently consistent, developing a standard format and content for defining the search topic might be desirable. The variants of Population, Exposure, Comparator, Outcomes, and Study Design (PECOS) systems, developed for reviews of epidemiological or clinical studies, could serve as models for defining ecological search topics (Woodruff and Sutton, 2014; CRD, 2009).

Comparisons of systematic reviews to conventional literature reviews have revealed that the latter are often incomplete or biased (Egger et al., 2003). One reason is the lack of professional assistance with searches. Some useful strategies such as the use of wild cards and truncation to obtain all forms of a search term as well as procedures for using different databases and search engines might not be familiar. Although guidance on literature searching is available (Gough et al., 2012; Higgins and Green, 2011; CRD, 2009), it is not specific to ecological assessment and could soon become outdated due to advances in information science such as text mining techniques.

Multiple search strategies and tools can be employed. Some examples include:

- Electronic databases such as ECOTOX;
- Literature search engines such as PUBMED, Web of Science, or Google Scholar;
- General search engines such as Google or Bing;

- Hand searches of key journals and books;
- Citation tracking of literature cited in key papers, books, or reports;
- Citation searching for publications citing key papers, books, or reports;
- Contacts with key authors and experts;
- Solicitation of information from stakeholders; and
- Internal databases (if they are not business confidential).

One should maintain a search log of sources searched, date, terms, and syntax (i.e., the combinations of the Boolean operators: and, or, not) used. Doing so can make the search explicit, transparent, and potentially replicable. Downloading search results to reference management software such as Endnote or Reference Manager, with a distinct name for the results of each search, also can be helpful.

The inclusion of difficult-to-locate studies (i.e., not published in a journal, not in English, or not indexed in MEDLINE) influenced the results of medical meta-analyses, but the influence varied among fields (Egger et al., 2003). Such studies tended to be less comprehensive and to have lower methodological quality. Identifying relevant studies in an unbiased fashion, however, is important. Issues of study relevance and reliability should be addressed during screening or weighting of the evidence rather than during the literature search.

4.2.2. Screen the studies

Screening the search results and studies performed for the assessment identifies irrelevant or clearly unreliable studies for elimination. Elimination criteria should be defined in advance, to the extent practicable, to avoid perceived or actual bias. Defining irrelevance is relatively straightforward. If the topic is chronic toxicity of arsenic to marine teleost fish, a freshwater invertebrate study would be eliminated. Some issues of relevance might not be apparent in advance. For example, assessors might realize during the screening process that not all arsenic species are relevant, so they should also screen out studies of irrelevant arsenic species. Screening for reliability is generally more difficult than screening for relevance and might not be performed at all. That is, assessors might choose to include all relevant studies and leave differences in reliability for the evidence-weighting phase. Eliminating studies with some obviously unacceptable attribute, such as lack of replication or lack of controls in a test, however, could be efficient. If the weighting phase is skipped (Section 7), performing a more thorough screening and considering the elimination of marginally reliable studies is important.

Some criteria commonly used to screen studies are not so clearly related to relevance or reliability. They include language (English only, unless translation services are available); peer review; and use of a standard protocol or good laboratory practices. Standard protocols ensure consistent and interpretable results, and good laboratory practices improve methodological reliability. Nonstandard studies, however, could provide relevant results and might also have good QA. Entire categories of sources could be eliminated, particularly secondary sources (if possible, primary literature should be used as sources of information), unpublished reports, or abstracts.

Some EPA programs have specific data-screening criteria. For example, the Office of Pesticide Programs screens open literature publications using 14 criteria (U.S. EPA, 2011a), and the ecological soil screening levels for plants and soil invertebrates have 11 acceptance criteria (U.S. EPA, 2005a). Other screening criteria are assessment specific, such as the assessment of connectivity of U.S. waters, which used a logic diagram for screening literature (U.S. EPA, 2015a).

When very large numbers of studies are screened, a tiered process can be used. For example, in the ISAs for criteria air pollutants, publications are screened based on their titles, then on abstracts, and finally on a full reading of the text (U.S. EPA, 2013). Duplicate screeners can minimize errors by identifying and resolving differences.

The EPA has published guidance on determining whether information quality is adequate (see Box 3-3). This procedure is conceptually equivalent to the screening process described here, but it is not followed by evidence weighting and weighing. The screening and weighting processes together should be sufficient to fulfill the EPA's mandate for information quality review.

4.2.3. Categorize the studies

Sorting studies is generally desirable so that distinct categories of evidence can be weighed before they are integrated to reach a conclusion (see Section 6.2). The categorization depends on the type of assessment, amount and diversity of evidence, circumstances of the assessment, and preferences of the assessors.

The most common approach to categorization is to assign evidence to types based on the sorts of studies from which the evidence is derived. For example, the Oak Ridge National Laboratory scheme for ecological assessment of contaminated sites divided evidence into single-chemical toxicity tests, body burdens, ambient media toxicity tests, biomarkers and pathologies, and biological surveys (Suter et al., 2000; Suter, 1996). Other types of assessments would use different types of evidence. In general, field studies are separated from laboratory studies, mechanistic studies are separated from studies of overt effects, and studies of effects at different levels of organization are separated. When only toxicity benchmark values are used as measures of effects, evidence might be categorized by mode of exposure [e.g., whole sediment, pore water, or tissue concentrations (Integral Consulting Inc., 2013)]. An assessment of a specific site might separate evidence from the site from evidence derived from other locations.

Evidence could also be categorized by the characteristic it illustrates. For example, evidence in causal assessments can be organized by characteristics of causal relationships such as interaction and co-occurrence (see Appendix E). Classification in terms of characteristics serves to explain the implication of the evidence for the inference.

4.2.4. Derive evidence from data and general knowledge

Data are raw materials for generating evidence. Data are generated by observation or experimentation and must be obtained from the investigators or extracted from the published studies that pass screening. Data can include:

- Numerical data such as the median lethal concentration (LC_{50}) values or raw exposure-response data;
- Categorical data such as whether benchmark levels are exceeded; or
- Narrative data such as the appearance of a water body, the behavior of animals, or a researcher's interpretations.

In addition to data, generally accepted knowledge such as physical laws and biological principles (e.g., receptor binding of certain chemicals or the role of species competition in structuring communities) contributes to evidence generation. Such knowledge can determine the information sought for generating evidence and the way to structure that evidence. Knowledge also might be the evidence itself. For

example, evidence that a biotic community was exposed to a release from an upstream source is provided by the general knowledge that flow would carry a persistent and soluble chemical downstream. General knowledge might appear as facts (water flows downhill) or as a mathematical model (e.g., a transport and fate model for streams).

If possible, numerical data sets should be obtained from the journal's supplementary material files or directly from the investigator. Transcribing numbers from data tables is prone to error.

If the data to be extracted are sufficiently consistent (e.g., all are from laboratory toxicity tests), development of a data form can facilitate extraction and increase completeness and consistency of the extracted data. Particularly if quantitative analysis is planned, an electronic form can efficiently combine data extraction and data entry. Any form should be piloted with a subset of the studies.

Ensuring data quality by checking the entered data for consistency with the source is desirable. One way to accomplish this is to have two individuals separately extract the data and then compare their results. Discrepancies can be due to errors or to ambiguities in the source that might be variously interpreted.

Some processing of the extracted data could be required before they can be used. In the simplest cases, a summary statistic such as an annual average is calculated. If evidence will be weighed, additional processing often is required. Evidence (as opposed to data) generally involves some sort of relationship such as the impaired stream reach was channelized, but the reference reach was not. Evidence of a condition could involve simple observation. For example, the absence of a taxon (e.g., no fish) is evidence of impairment. In addition, pieces of evidence that will be numerically combined must be converted into the same form and units (e.g., LC_{50}s converted to mg/L).

Processing data to obtain evidence also might require adjusting for the conditions to which the evidence will be applied. For example, laboratory test data might not be comparable to field data until they have been adjusted for water properties such as pH, hardness, or dissolved organic matter levels. Adjusting for the occurrence of mixtures involves applying an additivity model or other combined effects model to the individual chemical test data. Adjusting for biology might require considering seasonal occurrence of sensitive life stages.

Derivation of evidence involves the consideration of variance. Different data sets might appear to be inconsistent, until it is recognized that their distributions overlap.

4.3. Design and Conduct Studies and Assemble the Evidence

In some cases, studies can be performed to provide evidence for an assessment. In such cases, the inferential process should determine the evidence needs and drive the research planning. A simple example is provided by the sediment quality triad [(Chapman, 1996); see Appendix D, Table D-1]. That WoE method includes standard inference rules that require reliable data for the sediment's chemical composition, toxicity, and biological community composition. If any of these types of evidence are missing or unreliable, the inferential method fails. Some EPA offices and programs specify data to be generated for assessments. A prime example is the Office of Pesticide Programs' FIFRA data requirements. For other purposes, such as Superfund remedial investigations, the data needs are determined for individual cases. The Data Quality Objectives Process was developed for that purpose (Bilyard et al., 1997; U.S. EPA, 1994).

Like data from the literature, data produced for the assessment should be screened for acceptability. The Office of Solid Waste and Emergency Response provided detailed guidance to determine if contaminant data are useable (U.S. EPA, 1992a, b). If data quality objectives are developed, they should specify

standards for data acceptability. The description of data to be generated is a conventional component of the analysis plan (U.S. EPA, 1998).

As with data from literature reviews, data generated for the assessment must be input to the assessment's data management system and analyzed to derive the evidence. Unlike data from the literature, the raw data from studies performed for the assessment always should be available for analysis. Results of those studies should be categorized into the same types of evidence as the results of literature reviews.

4.4. Summary

The process of assembling evidence is more complex than the simple phrase implies. When weighing evidence, ensuring the process begins with a complete search of the literature is essential. QA procedures should be applied to the processes of obtaining or extracting data or other information from the literature. Information should be screened for relevance and reliability. Finally, information should be analyzed and organized in a way that facilitates its use as evidence.

4.5. Results and Transition

The results of assembling evidence are pieces of evidence that are at least minimally relevant and reliable, and are organized and presented in a useful form. The next step in WoE is to assign weights to the evidence that have been assembled.

5. WEIGHTING EVIDENCE

5.1. The Process of Weighting Evidence

In most assessments, some pieces of evidence will be more influential than others. The evaluation of the evidence can be implicit, as in a narrative WoE. When a formal WoE method is used, however, weighting the evidence determines the appropriate degree of influence (Figure 5-1). By not only evaluating the evidence but also expressing the weights explicitly as scores, assessors transparently determine the influence that particular pieces of evidence will have when the entire body of evidence is weighed (see Section 6). Weights are usually assigned to pieces of evidence. However, if the pieces of evidence in a category (Section 4.2.3) are similar, the category may be assigned a weight (see Section 6.2).

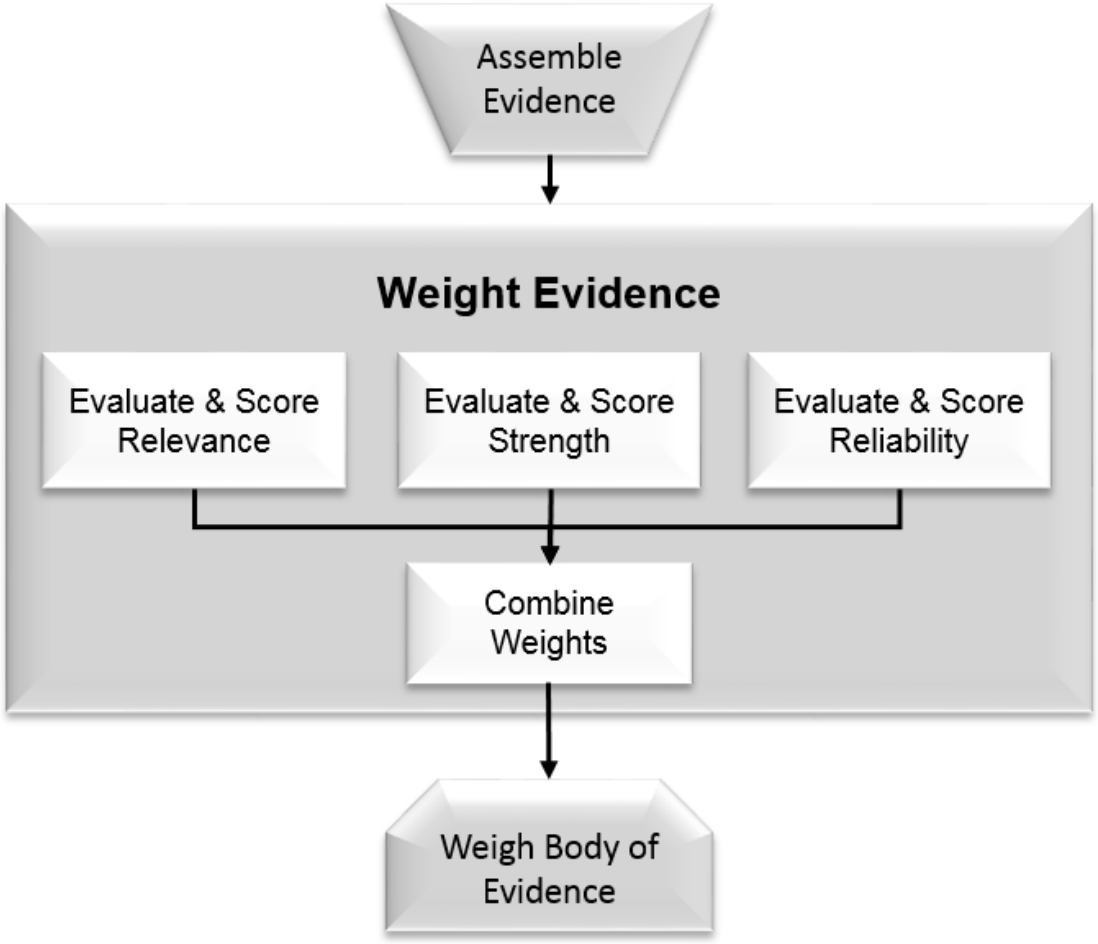

Figure 5-1. An elaboration of the process for weighting evidence, the second step in WoE.

The concept of weighting is familiar in statistics. For example, a weighted mean is the mean of study or sample values multiplied by weights, which are usually the numbers of observations. If one stream invertebrate survey of 10 sites reported a mean of 20 species and another survey of 40 sites reported a mean of 30 species, the true mean species richness across studies is found by multiplying each mean by the number of sites, adding the resulting products and dividing by 50. By weighting, the mean is shown

to be 28, not 25. Statistical weighting is an important tool of WoE for deriving quantities (see Section 8 and Appendix B) but is not considered further in this section.

The qualitative weighting of evidence has two components: evaluation and scoring. Evaluation of evidence determines the weight—how influential a piece of evidence should be, preferably based on defined properties. Scoring uses symbols to formalize the results of the evaluation. The weight is conceptual and the scores are symbolic. For example, a piece of evidence may be evaluated as moderately relevant, so the score for relevance is ++.

Many uses of WoE have not involved scoring. In these cases, either no results of evaluation are expressed or the results are expressed by descriptions. When assessors score the evidence, they are compelled to clarify the evaluation for the reader and themselves. In addition, scoring helps assessors provide clearly weighted evidence for the next step, the integration of evidence (see Section 6).

The approach presented here for qualitatively weighting evidence has been used in assessments of specific causation in the *Stressor Identification Guidance* (U.S. EPA, 2000) and in the Causal Analysis/Diagnosis Decision Information System (CADDIS, http://www3.epa.gov/caddis) and its applications. It has been used in an assessment of general causation for major ions as a cause of the impairment in stream communities (U.S. EPA, 2011b) and has been adapted to integrate evidence in a watershed risk assessment (U.S. EPA, 2014a). Below, the scoring system is presented first and then used to illustrate the evaluation of evidence.

5.2. Scoring Systems

A generally useful qualitative scoring system uses the symbols, +, − and 0, to represent evidence that, respectively, supports, weakens, or has no effect on the credibility of a hypothesis. More symbols represent greater weight. For example, the *Stressor Identification Guidance* and the CADDIS system for ecological causal assessment use the following scores.

+ + +, − − −	Convincingly supports or weakens
+ +, − −	Strongly supports or weakens
+, −	Somewhat supports or weakens
0	No effect (neutral or ambiguous)
NE	No evidence

The interpretation of plus or minus symbols is reasonably intuitive, and they have been used in other WoE systems (Rooney et al., 2014; Higgins and Green, 2011; Fox, 1991; Susser, 1986). These scoring symbols are quite general. They can be applied to a simple quantifiable property like strength of association or to a complex qualitative property like study design. Their regular use could result in clear and consist expression of WoE results. Nevertheless, other scoring systems might be more useful in particular applications.

Most other scoring systems used in environmental assessments only distinguish different degrees of support for a hypothesis. Some evidence, however, is clearly contrary to a hypothesis or has no effect. When a scoring system does not include those possibilities, a separate step must follow scoring to distinguish the logical implications of evidence [e.g., the evidence for the hypothesis is ++ for reliability and +++ for strength but it is contrary to the hypothesis (Johnston et al., 2002)]. The use of 0 and − symbols as well as + makes the logical implication of the evidence part of the weighting process rather than an afterthought.

Symbols are preferable to numerical scores because their use implies that they cannot be numerically combined. Two strongly supporting laboratory tests (++ and ++) are not equal to four somewhat supporting field tests (+, +, +, +). For a test result, a − score for study design and a + score for replication of the test do not sum to 0, because they are not commensurable. They simply signify different results for the different qualitative properties. Adding numerical scores generates a number with no units that signifies no quantity in particular.

These symbols also facilitate interpretation of bodies of evidence. When scanning a WoE table (see Section 6.2), seeing patterns in the frequencies of +, − and 0 symbols that indicate which hypotheses are supported by the weight of evidence is easier than if words or numbers are used to score evidence.

The system described above with three types of weight (positive, negative, and none) and three levels of weight (low, medium and high) has been found useful in environmental assessments, but more or less discrimination might be useful in some assessments. Binary (+/−) scores such as accept/reject and consistent/inconsistent have been recommended because more complex systems could be confusing or overwhelming (Hope and Clarkson, 2014). Alternatively, studies of survey responses have shown that people can distinguish five to seven possible response levels as in the Likert scale [e.g., very low, low, medium, high, very high (Dawes, 2008)]. Hence, the complexity of the scoring system can be adapted to the assessment and the desired degree of discrimination.

5.3. Properties to Be Weighted

Various properties of a piece or type of evidence can contribute to the degree of influence that it should exert. The specific properties fall within three general properties: relevance, strength, and reliability (defined in Box 5-1, Box 5-2, and Box 5-3).

Relevance (Box 5-1) includes biological, physical/chemical, and environmental aspects. It is at least minimally ensured when the assembled evidence is screened. Screening might be sufficient, and no further weighting of individual pieces of evidence for relevance may be necessary. For example, when assessing risk to black bears, if the only available mammalian toxicity tests are for laboratory rats and mice, the relevance of the tests cannot be distinguished because the relationships of rat and mouse sensitivities to bear sensitivity is unknown. In many cases, however, differences in study relevance are important to consider.

A strong signal is better differentiated from noise than is a weak signal, so a strong signal should be given more weight. Strong evidence shows (1) a large magnitude of difference between a treatment and control in an experiment or between exposed and reference conditions in an observational study, (2) a high degree of

Box 5-1. Relevance of a Piece or Type of Evidence

The relevance of a piece or type of evidence is the degree of correspondence between the evidence and the assessment endpoint to which it is applied.

Biological relevance—correspondence among the taxa, life stages, and processes measured or observed and the assessment endpoint (e.g., a *Daphnia* acute lethality test does not correspond well to insect life-cycle survival and fecundity, so relevance may be low).

Physical/chemical relevance—correspondence between the chemical or physical agent tested or measured at the studied site and the chemical or physical agent constituting the stressor of concern (e.g., pyrene may be used to represent a polycyclic aromatic hydrocarbon mixture, but relevance may be low).

Environmental relevance—correspondence between test conditions and conditions at the assessed site or the environmental conditions in a studied system and conditions in the region of concern (e.g., a pond mesocosm does not correspond well to a stream for many environmental parameters, so relevance may be low).

association between a putative cause and effect, or (3) a large number of elements in a set of evidence (see Box 5-2). Strength is a property of the study results, not the type of evidence or study method. The metrics for strength of evidence are familiar. Magnitude is typically represented by absolute and relative differences (e.g., body burdens were 20 times higher than at reference sites). Association is typically represented by correlation coefficients (e.g., Pearson's *r* for the correlation of emission rate and ambient concentrations was 0.8) or slopes (e.g., the regression of species richness on dissolved oxygen had a slope of 7). Number is commonly represented by the number of elements or frequency of occurrences (e.g., a fish kill has occurred at snowmelt every year for the past 6 years). Although strength occurs less frequently in WoE systems than relevance and reliability, some weight only strength (Chapman, 2007).

Box 5-2. Strength of a Piece or Type of Evidence

The strength of a piece or type of evidence is the degree of differentiation from control, reference, or randomness [modified from Norton et al. (2014)].

Magnitude—degree of difference between the amount of response at affected sites and at reference sites or in treatments and controls, between degrees of exposure or other relevant differences in the evidence, most commonly expressed as a difference between means or a ratio of means.

Association—degree to which variation in a variable representing a cause explains variation in a variable representing an effect, most commonly expressed as a correlation coefficient.

Number—the number of elements of a set of evidence (e.g., of symptoms or overt effects in a response or of steps in a causal pathway) that are reported to be observed or the number of occurrences.

Strength metrics lend themselves to standardization. For example, correlation coefficients were calculated for several associations in regional field data to determine the WoE for major ions as a cause of the extirpation of invertebrate genera and for potential confounding by other variables (U.S. EPA, 2011b). Standard scores were developed for the strength of correlations based on the authors' experience with correlations of parameters in surveys of physical, chemical, and biological properties of streams (Table 5-1). In this example, a correlation coefficient (r) between 0.25 and 0.75 is supportive but is not assigned an extra plus for strength. Because $r > 0.75$ is considered relatively strong for a correlation between a water quality measure and a biological response from a regional data set, it is given a second plus. No field correlations are believed to be convincing evidence, so none receive three + or − signs. Consistency and reasonableness of the scores are more important than the precise values chosen for the cutoffs, when they are used to compare alternative hypotheses. Documenting scoring criteria in advance also reduces the opportunities to bias the scoring relative to scoring performed without previously defined cutoff values.

Standard scores based on strength and logical implication are provided for evidence in causal assessments in the CADDIS system. The examples in Table 5-2 are based on standard alternative possible outcomes (findings) for each of 16 types of evidence and the interpretations of those outcomes in terms of the degree to which they support a potential cause. These scores show that different types of evidence have different outcomes with different implications for a hypothesis. The CADDIS table was developed for causal assessment in aquatic ecosystems. This approach to standard scoring is useful if the types of evidence and their findings are conventional. Other applications of this approach could have different types of evidence, possible outcomes, and interpretations.

Table 5-1. Weighting the strength of correlations (absolute value of *r*) and noting the logical **implication—an** example for evidence from stream biological surveys (Cormier and Suter, 2013; U.S. EPA, 2011b)

Assessment	Logical Implication and Strength	Score
The sign of the correlation coefficient depends on the relationship. For toxic relationships such as the correlation between conductivity and number of Ephemeroptera, the sign should be negative. Weak or positive correlations weaken the case for that candidate cause.	$\lvert r \rvert > 0.75$	+ +
	$0.75 \geq \lvert r \rvert \geq 0.25$	+
	$0.1 < \lvert r \rvert < 0.25$	0
	$\lvert r \rvert \leq 0.1$	−
	r has the wrong sign	− −

Table 5-2. Table of standard scores for 3 example types of evidence out of 15 types in CADDIS (http://www.epa.gov/caddis/si_step_scores.html). Each type of evidence is explained in its own CADDIS page.

Type of Evidence	Finding	Interpretation	Score
Spatial/temporal co-occurrence in site surveys	The effect occurs where or when the candidate cause occurs, OR the effect does not occur where or when the candidate cause does not occur.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because the association could be coincidental.	+
	Whether the candidate cause and the effect co-occur is uncertain.	This finding *neither supports nor weakens* the case for the candidate cause because the evidence is ambiguous.	0
	The effect does not occur where or when the candidate cause occurs, OR the effect occurs where or when the candidate cause does not occur.	This finding *convincingly weakens* the case for the candidate cause because causes must co-occur with their effects.	− − −
	The effect does not occur where and when the candidate cause occurs, OR the effect occurs where or when the candidate cause does not occur, and the evidence is indisputable.	This finding *refutes* the case for the candidate cause because causes must co-occur with their effects. Because the evidence is indisputable, other evidence need not be assessed.	R
Laboratory tests of site media	Laboratory tests with site media show clear biological effects that are closely related to the observed impairment.	This finding *convincingly supports* the case for the candidate cause.	+ + +
	Laboratory tests with site media show ambiguous effects, OR show clear effects that are not closely related to the observed impairment.	This finding *somewhat supports* the case for the candidate cause.	+
	Laboratory tests with site media show uncertain effects.	This finding *neither supports nor weakens* the case for the candidate cause.	0
	Laboratory tests with site media show no toxic effects that can be related to the observed impairment.	This finding *somewhat weakens* the case for the candidate cause but is not strongly weakening because test species, responses, or conditions might be inappropriate relative to field conditions.	−
Symptoms	Symptoms or species occurrences observed at the site are diagnostic of the candidate cause.	This finding is sufficient to *diagnose* the candidate cause as the cause of the impairment, even without the support of other types of evidence.	D
	Symptoms or species occurrences observed at the site include some but not all of a diagnostic set, OR symptoms or species occurrences observed at the site characterize the candidate cause and a few others.	This finding *somewhat supports* the case for the candidate cause, but is not strongly supportive because symptoms or species are indicative of multiple possible causes.	+

Type of Evidence	Finding	Interpretation	Score
	Symptoms or species occurrences observed at the site are ambiguous or occur with many causes.	This finding *neither supports nor weakens* the case for the candidate cause.	0
	Symptoms or species occurrences observed at the site are contrary to the candidate cause.	This finding *convincingly weakens* the case for the candidate cause.	−−−
	Symptoms or species occurrences observed at the site are indisputably contrary to the candidate cause.	This finding *refutes* the case for the candidate cause.	R

Properties of evidence that suggest the evidence is more reliable and should be given greater weight are listed in Box 5-3. Additional properties may be applicable in particular cases. Although scoring numerous properties for every piece of evidence could be burdensome, doing so would provide completeness and transparency for the weighting process. An alternative is to choose one or a few properties to be weighted that are judged most important or most likely to discriminate the various pieces of evidence. For example, if all evidence is consistent with prior knowledge (as is usually the case), consilience need not be scored. This approach—scoring the most important component properties of reliability—is generally useful. The least burdensome, but also least transparent, approach is to integrate the component properties of reliability implicitly for each piece of evidence and assign an overall reliability score.

Of these 11 component properties of reliability, the most attention has been devoted to study design. Developing a checklist of design features for each commonly used type of evidence is advisable. For example, Batley et al. (2002) developed a checklist of considerations for laboratory and field studies of sediment chemistry, toxicology, and community structure.

Box 5-3. Reliability of Evidence

Reliability consists of inherent properties that make evidence convincing [modified from Norton et al. (2014)].

Design and execution—evidence generated with a good study design that is well performed is more reliable.

Abundance—evidence from more numerous data is more reliable because it reflects greater replication or resolution.

Minimized confounding—evidence is more reliable when the sampling design or analysis controls extraneous correlates.

Specificity—evidence (e.g., a symptom or set of symptoms) specific to one cause or a few related causes is more reliable.

Potential for bias—evidence from a study that is not funded by an interested party, is not produced for advocacy, and is not produced by an investigator with conflicts of interest is more reliable.

Standardization—a standard method decreases the likelihood that the evidence is biased or analyses are inaccurate.

Corroboration—using models, indicators, or symptoms that have been verified by many studies and are accepted technical practice can greatly increase reliability.

Transparency—complete description of methods and inferential logic and availability of data for reanalysis provide the means to check the results and are presumed to increase reliability by reducing the likelihood of hidden faults.

Peer review—an independent peer review increases reliability of a source of information.

Consistency—the degree to which evidence does not vary in repeated instances within a study (e.g., across years, locations, sampling teams, or methods) is an indicator of reliability of a piece of evidence; when weighting types of evidence, consistency among studies of the same type is an indicator of reliability of the type.

Consilience—evidence shown to be consistent with scientific knowledge and theory, particularly with respect to underlying mechanisms, is more reliable.

Reliability is less if a study or a body of work appears biased. The potential for bias in scientific publications, although controversial, is well documented (Suter and Cormier, 2014; McGarity and Wagner, 2008). One clearly important source is publication bias, the disinclination of authors to submit and editors to accept studies with negative results (i.e., no effect is found). This bias can be detected by statistical analysis if the number of studies is sufficiently large (Ferguson and Brannick, 2012; Hunter and Schmidt, 2004). Other sources of bias can be detected only by comparing the results of studies from different sources. In particular, numerous reviews have identified different results from industry-funded studies and studies funded by neutral sources (Suter and Cormier, 2014; McGarity and Wagner, 2008). The most conspicuous example in ecological risk assessment is the difference between industry-funded and other studies and reviews concerning the teratogenicity of atrazine (Ralof, 2010). Such patterns of biases are not used to exclude data, but potential sources of bias should be identified, if possible, as they help interpret the body of evidence (NRC, 2014). For example, if results of industry-funded studies differ from government- or foundation-funded studies, they all must be carefully reviewed. If the cause of the difference cannot be determined, the reliability of the whole body of evidence may be down-weighted.

Biases may also result from personal ideologies, from a desire for publicity, or other reasons. These more personal sources are more difficult to detect but may show up in non-scientific writings.

In general, secondary sources should be screened out (Section 4.2.2), but if information from secondary sources is used, it cannot be considered highly reliable. The creation of secondary sources is an opportunity to introduce errors and biases in the extraction, analysis, and interpretation of data. Bad citing practices have been reported in the ecological literature, resulting in unsubstantiated conclusions (Sanz-Martin et al., 2016; Tood et al., 2010; Todd et al., 2007). Hence, if primary sources are unavailable, information may be taken from secondary sources but should be considered to have weak reliability. Cases in which a secondary source identifies and corrects an error in a primary source may be exceptions.

In addition to relevance, strength, and reliability, the type of evidence has sometimes been a weighting consideration. In particular, some assessors give more weight to field biological survey results than to other evidence (Chapman and Anderson, 2005). However, some field surveys have low relevance because they do not address the endpoint, do not address the sensitive taxa or other sensitive entities, or measure an irrelevant or insensitive response. In addition, field surveys might be so poorly designed or executed that the results are unreliable. For example, field data were given priority in a contaminated sediment study even though the field survey had "many limitations," including no appropriate reference sites (McPherson et al., 2008). Weighting the properties of the evidence is preferable to assuming that one type is always weightier.

Statistical analysis also has been a consideration in WoE. For example, a criterion for study evaluation in ISAs is "Are the statistical analyses appropriate, properly performed, and properly interpreted?" (U.S. EPA, 2013). However, the appropriateness of the analyses reported in a publication is immaterial if assessors perform their own analyses. Published studies should include original data or the authors should make data available for reanalysis. At least for influential evidence, assessors should consider reanalyzing the data so that results are relevant to the assessment, properly interpreted, and free of statistical errors or biases in assumptions. In such cases, evaluating the statistics the authors used is not pertinent. If original data are not available, the evidence could be given a negative score for transparency. To the extent possible, improper interpretations should be corrected (e.g., $p > 0.05$ does ***not*** mean no effect occurred), and assessors should consider down-weighting evidence that has inappropriate statistics if reanalysis is not feasible (e.g., time and resources are not available).

5.4. Tables of Weights

The primary inferential tool in weighting evidence is tabulations of pieces or categories of evidence and the weights assigned to them with respect to their properties. Because the assigned weights are expressed as scores, they are called scoring tables. Scoring tables may be aggregated to the extent that the weighting process is aggregated. Table 5-3 is a basic, generic scoring table in which both the evidence and properties are aggregated. The rows could have been individual pieces of evidence, but in this table, they are conventional types of evidence. Each of the three general properties is assigned a score based on the evaluation of the evidence each type provides. In the example, when assessing a contaminant as a potential cause of effects in the field, the results of laboratory tests of the contaminant can be positive but have low relevance to the field (+), the responses in the tests can be moderately strong (++), and the reliability of the tests can be high due to standard test designs, good laboratory practices, and regular audits (+++). In this example, the combined score (overall weight) might be + (weak supporting evidence) because the low relevance of the tests could make the strength of the results and the reliability of the method irrelevant to the inference. In other cases, a highly relevant test of the species of concern may not be sufficient to overcome very low reliability (e.g., due to absence of controls). In general, a property with very low weight will have greater influence than a moderate- or high-weight property. In

other words, a bad property of a piece of evidence tends to contaminate the whole thing. These examples illustrate why qualitative WoE is not arithmetic—you can't just add up the scores. It also illustrates why weights should be explained.

Table 5-3. Generic scoring table based on conventional types of evidence, with first line hypothetically completed. The overall weight is positive but low because the test relevance is low.

Types of Evidence	Relevance	Strength	Reliability	Overall Weight
Laboratory toxicity tests of a defined agent	+	++	+++	+
Effluent toxicity tests				
Ambient media toxicity tests				
Field biological surveys				
Field biomarkers and organ or whole-body concentrations				
Field symptoms				

Table 5-4 presents an example from a general causal assessment to determine whether dissolved major ions, measured as conductivity, cause extirpation of stream invertebrate genera. This scoring table presents three types of evidence for one characteristic of causation: the sufficiency of the observed conductivity levels to cause extirpation. Equivalent tables were presented for evidence related to each characteristic of causation. The properties of evidence were treated as binary (e.g., either the evidence is corroborated or not), so no more than one symbol was applied to a property. In this case, evidence is screened for sufficient relevance, and each relevant type of evidence is given one score designating its logical implication. Strength is scored using quantitative criteria as in Table 5-1. Corroboration is scored as the most important component of reliability in this case. Inclusion of a description of the evidence aids reader understanding.

After having assigned weights to each property of evidence (relevance, strength, and reliability), and possibly to multiple component properties of relevance, strength, or reliability, combining them into an overall weight for each piece or type of evidence might be desirable. If evidence is abundant, providing a single summary weight score can facilitate the integration step. Developing a system for combining the property weights can be relatively straightforward. The system used for the casual assessment, from which Table 5-4 was taken, is designed to provide a maximum cumulative score of three + or – units, for each of the three properties. However, as with other processes in WoE, the weights could be combined by expert judgment without defined procedures or criteria to maintain flexibility.

If evidence is scored for multiple component properties, the components should be combined before the three properties are combined. Seldom are multiple component properties of relevance or strength separately scored for a piece of evidence. Reliability has at least 11 component properties that are conceptually distinct, however, and more than one can be applied to a piece of evidence (Box 5-3). In Table 5-3, only corroboration is evaluated, but if multiple component properties of reliability were judged sufficiently important to be evaluated and scored, a separate reliability scoring table would be needed.

In any case, making the weighting convincing and transparent by explaining the reasons for the scores is desirable. This explanation could be presented in the text, but a simple statement, as in the last line of Table 5-4, might be sufficient.

Table 5-4. Example scoring table: scoring types of evidence for sufficiency (U.S. EPA, 2011b). The table is a direct copy and calls out a figure that does not appear in this document.

Type of Evidence	Description of Evidence	Log[a]	Str[b]	Cor[c]
Laboratory tests of ambient waters	A test showed acute lethality to an apparently resistant species, *Isonychia bicolor*, at conductivity levels similar to its XC_{95}.	+		
Field exposure-response relationships of biological metrics	Ephemeroptera were negatively correlated with conductivity in two data sets $r = -0.61$ and -0.72 (Figs. 2b and 4b) and $r = -0.90$ in Pond et al. (2008). This highly relevant evidence was obtained independently in two separate data sets, with moderate-to-strong correlations. Exposures were in the field with native species. Removal of sites with high levels of potential confounders had little effect on the correlation.	+		+
Field exposure-response relationships of composite indices	The field observations showed that, as conductivity increases, indices of stream condition (WVSCI and GLIMPSS) decrease [Fig. 5 and Pond et al. (2008)]. Correlations were strong [$r = -0.80$; $r = -0.90$ in Pond et al. (2008)]. Results were further corroborated by U.S. EPA (2010a). Exposures were in the field with native species.	+	+	+
Field exposure-response relationships of susceptible genera	At 500 µS/cm, the capture probabilities of more than 65% of genera began to decline. Similar results were obtained with West Virginia and Kentucky data sets.	+	+	+
Summary of sufficiency: Exposure to saline waters in Appalachia is sufficient to cause the declines of genera (+) with the salts found in the region's streams. The increases in effects of conductivity are strong even when other stressors are present (+). Different analytical approaches demonstrate that ionic strength is associated with different effect endpoints in different data sets in two states (+). The evidence is consistent. The total score is + + +.				

[a] Log = logical implication of relevant evidence, [b] Str = strength, [c] Cor = corroborated evidence.
GLIMPSS = Genus-Level Index of Most Probable Stream Status, WVSCI = West Virginia Stream Condition Index.

5.5. Not Combining Weights for Properties of Evidence

Assigning scores to each property of each piece or type of evidence might complete the weighting step. That is, separate scores for the properties, rather than a single combined weight, could be carried forward to the integration step. The advantage is that the weights assigned to each property are available to assessors while they are integrating across evidence within a hypothesis as shown in Table 6-2. In such cases, the WoE table shows which pieces of evidence are relevant, which are strong, and which are reliable. One might even score biological, physical/chemical, and environmental relevance separately if relevance is a particularly important issue in the case. The obvious disadvantage is that the integration becomes more complex because the assessor must consider weights for multiple properties while integrating multiple pieces of evidence. In addition, the relative influence of the properties might be evaluated less consistently and transparently if it is not determined in a separate step.

5.6. Summary

Once the evidence has been assembled, the WoE analysis begins in earnest with the assignment of weights to the evidence. Weights are represented by a generally useful scoring system that represents both the implication of the evidence (+, −, and 0) and the weightiness of the evidence (the number of

symbols). Three properties are scored: relevance, strength, and reliability. The evidence and associated weights are summarized in a scoring table. Weights for the three properties may be combined into an overall weight for each piece of evidence or all three may be carried forward into the next step, weighing the body of evidence.

5.7. Results and Transition

The result of the weighting step is a set of pieces or categories of evidence for each hypothesis, each of which has been assigned weights indicating how relevant, strong, and reliable it is. It is recommended that the weights be expressed as qualitative scores and organized in scoring tables. A narrative should also be provided describing the evidence and explaining the weights. This weighted set of pieces or categories of evidence are integrated and interpreted in the weighing step, which follows.

6. WEIGHING BODIES OF EVIDENCE

6.1. The Weighing Process

After weights have been assigned to pieces or categories of evidence, each resulting body of evidence is weighed to determine which, if any, hypothesis is supported. First, weighted evidence for each hypothesis is integrated to form weighed bodies of evidence for the hypotheses (Figure 6-1). Second, the bodies of evidence are interpreted to determine which hypothesis the evidence best supports. Finally, if the bodies of evidence are ambiguous or discrepant, the case should be reconsidered and additional evidence may be required.

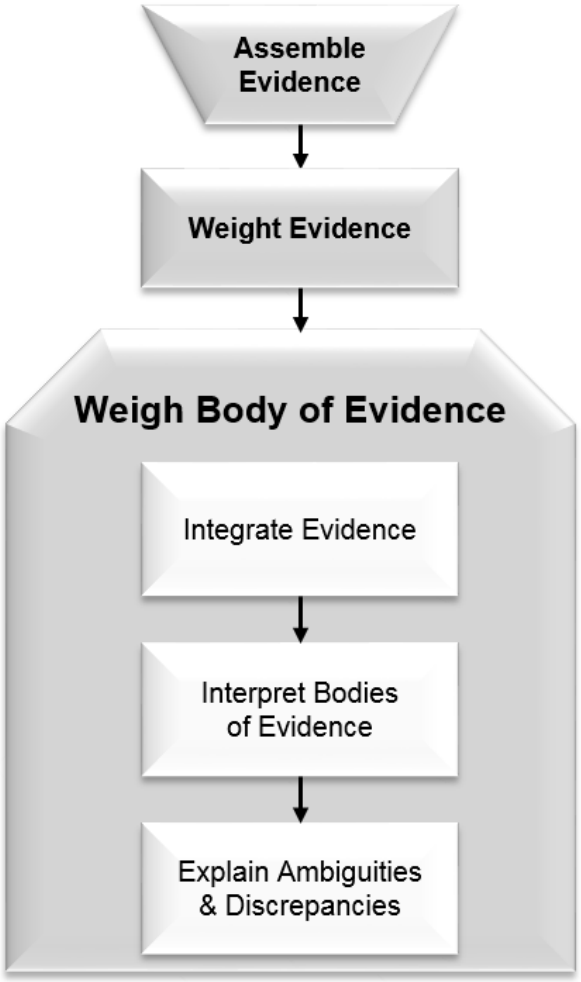

Figure 6-1. An elaboration of the process for weighing the body of evidence, the third step in weight of evidence.

6.2. Integrating Evidence

The input to the integration step is weighted pieces or categories of evidence, and the output is the weighed body of evidence for each hypothesis. The essential purpose of integration is to aggregate the evidence and associated weights into an overall weight. A secondary purpose of integration is to explain the role that the evidence serves in the inference.

1. Integration can aggregate numerous weighted pieces or categories of evidence (depending on the output of the weighting step) into a body of evidence. This purpose is typically served by deriving a combined weight for each type of evidence: evidence derived from laboratory acute tests, biomarkers, biological surveys, etc. Then, the weights are integrated across categories to weigh the body of evidence for each hypothesis.

2. Explanation can answer the question, what does the evidence do to support or weaken a hypothesis? For example, evidence from field surveys can support a hypothesized cause by showing that the cause and effect co-occur. Because WoE is often used to infer causation, the most broadly useful explanation is to associate the evidence with the characteristics of causation such as time order and interaction [Table 6-1, Table 6-4, and Table E-1 (Norton et al., 2014; Cormier et al., 2010)]. Characteristics, however, can be defined for any quality inferred by WoE such as impairment or remediation (see Appendix E). Even without defined characteristics, explanation can be performed by determining how each category of evidence relates to the hypotheses. For example, when weighing evidence for dietary bioaccumulation of a chemical in fish, concentrations in algae are evidence that the chemical occurs in the food web of the fish. If the evidence has been associated with characteristics, the sets of evidence for the characteristics can be used as categories of evidence in place of the conventional types of evidence (e.g., Table 6-4).

Evidence can be integrated in one or more steps, depending on the amount and its diversity and the circumstances of the assessment (Figure 6-2). The categories into which evidence is integrated can be types of evidence or characteristics of the quality of interest. If the pieces of evidence are few or all of one type, the body of evidence can simply be integrated after each piece of evidence is weighted (Figure 6-2a). If the differences among pieces of evidence within a category are small, weighting the pieces can be skipped and the category of evidence weighted as a whole (Figure 6-2b). When evidence is both abundant and diverse, the pieces of evidence can be weighted in each category, the categories weighed based on the weights of the pieces and the collective properties of the category (Box 6-1) and finally, the body of evidence weighed (Figure 6-2c). At the extreme, weighing a very large and diverse body of evidence can be very methodical and use multiple tiers of categories (Figure 6-2d). For example, evidence for fish acute toxicity, fish chronic toxicity, invertebrate acute toxicity, and invertebrate chronic toxicity might be separately weighted and the weights combined to weigh the evidence from all laboratory toxicity tests. Evidence from a laboratory toxicity test then could be weighed along with field tests, field surveys, and any other type of evidence to determine whether the weight of the body of evidence is sufficient to indicate that a chemical exposure is a cause of aquatic community impairment.

The degree to which the weighing of evidence is elaborated depends primarily on a tradeoff between rigor and disclosure on one hand and efficiency and simplicity on the other. The potential to confuse or overwhelm the reader with an elaborate weighing process, however, could also be a consideration. To address this problem, detailed weighting tables and text could be presented in an appendix for peer reviewers and others who need a deep understanding and a summary provided for decision makers and stakeholders.

As in the weighting step, the fundamental tool of evidence integration is a table, but this one is called a WoE table. A WoE table presents the evidence, organized in categories (types or characteristics), and the WoE scores for each evidence category and alternative hypothesis (Table 6-1). These scores come from the scoring tables created by weighting the evidence (Section 5). The same symbols are used in the weighing step as in weighting, because they express the same conceptual weights. In addition, collective properties of the body of evidence such as coherence are scored (Box 6-1). Finally, the overall weight for each hypothesis is presented. This generic table form is broadly useful, but the form of the table in any application depends on the amount of evidence, number of hypotheses, detail of the weighting, degree of

involvement of the decision maker, and other considerations. Examples of WoE tables for integrated evidence from actual assessments are presented in Table 6-2 through Table 6-4.

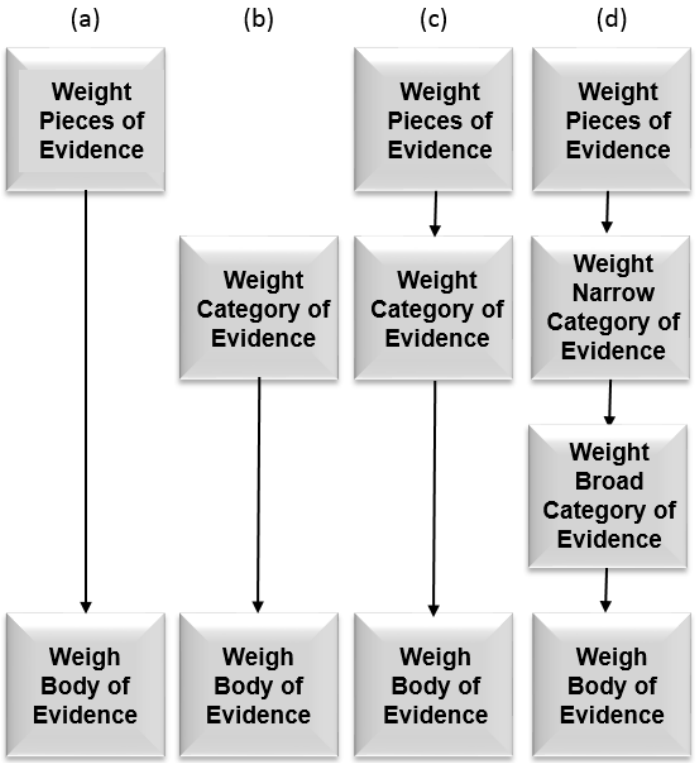

Figure 6-2. So**me alternative approaches (a−d) to weighting and weighing evidence based on different** approaches to aggregating evidence. Categories could be types of evidence or evidence for characteristics of the quality of interest. The choice depends on the amount and diversity of evidence, the circumstances of the assessment, and the judgments of the assessors. From Norton et al. (2014).

Box 6-1. Collective Properties of Bodies of Evidence. Modified from Norton et al. (2014).

The following collective properties of the body of evidence can be considered in addition to considering the relevance, strength, and reliability of the pieces or types of evidence. As with the properties of pieces or types of evidence, any of these could be used, depending on their relevance and utility for distinguishing among the hypotheses.

Number—more pieces or categories of evidence within a body of evidence increase the reliability, if they are consistent and are generated independently.

Coherence—logical consistency among types of evidence increases the reliability of a body of evidence, particularly when empirical and mechanistic evidence and evidence from a case and from elsewhere are coherent.

Absence of bias—consistent results from different funders and types of investigators (e.g., academic, industry, nongovernmental organization, government) are more reliable.

Diversity—evidence from more responses, taxa, life stages, or communities under more conditions is more likely to detect important exposures, responses, and relationships reliably.

Table 6-1. A generic weight-of-evidence table for *n* alternative causal hypotheses (H_1, H_2, ... H_n), based on causal characteristics and collective properties of the bodies of evidence

	Combined Weight		
	H_1	H_2	H_n
Characteristics of Causation			
Co-occurrence			
Sufficiency			
Time order			
Interaction			
Specific alteration			
Antecedents			
Body of Evidence, Collective Properties			
Number			
Coherence			
Absence of bias			
Diversity			
Integrated WoE			
WoE for the hypothesis			

Table 6-2 presents, for illustrative purposes, a subset of the types of evidence and causal hypotheses from a WoE table for determining the cause of a precipitous decline in the abundance of San Joaquin kit foxes on the Elk Hills Naval Petroleum Reserve, California (U.S. EPA, 2009a). The full table occupies multiple pages. The evidence was scored using the types and standard scores in CADDIS, which eliminates the need to weight the evidence for relevance, strength, and reliability. However, it requires accepting the relevance of the standard weights and scores. One collective property of the body of evidence (coherence) is the primary basis for weighing the body of evidence. The conclusion was that predation by coyotes was the dominant cause of the decline and the evidence was convincing. The

coyotes appear to have increased on the site (co-occurrence), the cause of death of radio-collared foxes was known (evidence of exposure or mechanism), population modeling showed that predation was sufficient alone to account for the decline (stressor-response relationship), and coyote control coincided with an end to the decline (manipulation of exposure). Toxic chemicals were present and exposure occurred and was documented by analysis, but far too few foxes were significantly exposed to account for the decline. Accidents contributed but the contribution was relatively small. Note that the + for coherence of disease indicates that the evidence consistently fails to support that hypothesis, so that cause can be eliminated.

Table 6-2. Partial WoE table for alternative possible causes of the decline of San Joaquin kit foxes. Only 4 of 6 potential causes and 7 of 16 types of evidence are included. Adapted from U.S. EPA (2009a).

Types of Evidence	Predation	Toxics	Accidents	Disease
Spatial/temporal co-occurrence	+	+	+	−
Temporal sequence	0	0	NE	NE
Evidence of exposure or biological mechanism	++	++	++	−−
Causal pathway	+	+	+	0
Manipulation of exposure	+	NE	NE	NE
Stressor-response relationships from simulation models	+++	−	+	−−
Coherence	+++	−	+	+

Table 6-3 provides an example of a WoE table from a risk assessment. One hazard in the Bristol Bay watershed assessment was the potential failure of a diesel fuel pipeline at a stream or river crossing, so evidence was weighed for the hypothesis that a spill at a crossing would reduce salmon production (U.S. EPA, 2014a). Unlike the generic types of evidence, Table 6-2 shows types of evidence that are specific to the hypothesis. Evidence concerning the exposure-response relationship was available from laboratory tests of dissolved or dispersed diesel fuel and from eight studies of diesel spills into streams. Exposure was estimated by modeling hypothetical spills to estimate dissolved concentrations, diesel/water ratios, and total volume spilled. The results of combining the weights across properties for each type are presented as brief narratives rather than as combined scores, but the scores for each property are combined across types of evidence. This WoE table shows the consistency of results (all are supportive). It also illustrates where the weakness in the evidence lies—studies of oil spills in streams have not characterized exposure well, as indicated by ambiguous reliability.

Table 6-4 presents a table with combined scores for assessing whether major ions in streams cause extirpation of benthic invertebrates (U.S. EPA, 2011b). The evidence is categorized in terms of characteristics of causation and is derived from the results of scoring tables for each characteristic like Table 5-4. That is, the summary score from weighting evidence for sufficiency in Table 5-4 (+++) is the sufficiency score in Table 6-4 (also +++).

Table 6-4 illustrates how explanation of the pieces or types of evidence in terms of characteristics of causation elucidates the meaning of the evidence for a hypothesis. For example, elevated concentrations of a chemical in numerous streams with impaired communities mean that the chemical and community *co-occur*, and therefore, exposure is likely. If the concentration is greater than concentrations that cause relevant toxic effects, that means that the exposure believed to be *sufficient* to cause the effect. Although such explanations of the evidence might appear self-evident to assessors, it can be an important part of the inference. Although organizing evidence in terms of characteristics serves primarily to help explain the

implications of the evidence, it can also show that a study can provide evidence of multiple characteristics. For example, a laboratory toxicity test can provide evidence of sufficiency (the level of exposure required to cause effects) and of alteration (symptomatic effects of the exposure that may be observed in the field).

Table 6-3. Summary of evidence concerning risks to fish from a diesel spill (U.S. EPA, 2014a). The risk characterization is based on weighing four pieces of evidence for different routes of exposure. All evidence is qualitatively weighted on three properties: logical implication, strength, and reliability of methods. Here, all pieces of evidence have the same logical implication: all suggest a diesel spill would have adverse effects.

Route of Exposure Source of Evidence (Exposure/E-R)	Logical Implication[a]	Strength	Reliability		Result
			Exposure	E-R[b]	
Dissolved hydrocarbons: Model/laboratory acute tests	+	+	0	+	Modeled dissolved diesel concentrations are clearly lethal to invertebrates and approximately lethal to trout.
Dissolved hydrocarbons: Model/laboratory-based standard	+	++	0	++	Modeled dissolved diesel concentrations greatly exceed the state standard.
Dispersed hydrocarbons: Diesel oil:water ratio/laboratory acute tests	+	++	0	+	Diesel oil:water ratios in the spills and in tests suggest lethality to invertebrates and trout.
All routes in actual spills: Amount spilled/observed effects	+	++	+	+	Diesel spills in other streams cause acute biological effects.
Integrated weight of evidence	+	++	0	+	The effects by four types of evidence are consistent, and the observed effects are strong. The greatest uncertainty is the relation of laboratory to field exposures.

Notes:
[a] Logical implication indicates relevance and a particular direction of the evidence (supports or weakens)
[b] E-R = exposure-response relationship

Table 6-4. Example of weighing evidence for a potential cause, major ions measured as conductivity, of the loss of macroinvertebrate genera (U.S. EPA, 2011b). The evidence is organized in terms of characteristics of causation.

Characteristic	Body of Evidence	Scores
Co–occurrence	Loss of genera occurs when conductivity is high but is rare when conductivity is low.	+++
Antecedence	Sources of the ionic mixture are present and are shown to increase stream conductivity in the region.	+++
Interaction	Aquatic organisms are directly exposed to dissolved ions. Based on first principles of physics, ionic gradients in high-conductivity streams would not favor the exchange of ions across gill epithelia. Physiological studies over the past 100 years have documented the many ways that physiological functions of organisms are affected by the relative amounts and concentrations of ions (i.e., combinations of ions that some genera do not have mechanisms or the capacity to regulate).	++
Alteration	Some genera and other response metrics and assemblages are affected at sites with higher conductivity, whereas others are not. These differences are characteristic of relative sensitivity to high conductivity.	+++
Sufficiency	Laboratory analyses report results of effects for a tolerant species, but test durations and most ionic compositions are not representative of exposure in streams. Based on field observations, however, regular increases in effects on invertebrates with increased ionic exposure indicate that exposures are sufficient.	+++
Time order	Conductivity is high and extirpation has occurred after mining permits are issued, but conductivity and biological data before and after mining began are not available.	NE
Summary of body of evidence	Five characteristics are supported and none weaken the body of evidence that increases in conductivity causes extirpation of freshwater benthic invertebrates.	Very likely

6.3. Interpreting Bodies of Evidence

Interpretation is the step in which the bodies of evidence for each hypothesis are used to determine which, if any, hypothesis is supported, and therefore, is likely to be true. Depending on the case, the interpretation of evidence could be performed by comparing alternative hypotheses or by judging whether the evidence sufficiently supports a particular hypothesis. Comparison of alternatives typically occurs in specific causal assessments (e.g., What is causing the low species richness in Jones Creek?). The hypothesis with the greatest weight of evidence is the most likely of the assessed possible causes. This is not just a matter of counting the scores. In particular, the coherence of each body of evidence with respect to the associated hypothesis is considered.

Multiple hypotheses might be likely or at least well supported. For example, both a water treatment plant effluent and stream channelization might be sufficient causes of low species richness in a stream, so both hypotheses could be accepted.

Judging a single hypothesis can be conceptualized as comparing the hypothesis against its negation (e.g., WoE for teratogen versus WoE for not a teratogen) or as a comparison of the weight of evidence for the hypothesis with a standard of sufficient evidence (e.g., a sufficient WoE for teratogenicity versus insufficient evidence). One particular hypothesis can be judged in some particular types of assessments:

(1) a general causal assessment (e.g., Does selenium cause terata in frogs?), (2) specific causal assessments for which only one potential cause is considered (e.g., Does the effluent cause the observed biological impairment?), (3) a condition assessment (e.g., Is the stream impaired?), or (4) an outcome assessment (e.g., Has the wetland recovered?).

These approaches to weighing evidence are consistent with that for the conventional standard of proof in civil legal proceedings and public policy, the "preponderance of the evidence." To meet a preponderance-of-evidence standard, a hypothesis must be shown to be more likely than its negation or than the alternative hypotheses. This standard is met by comparing the weights of the bodies of evidence for a hypothesis and its alternatives.

Hume (1748), Laplace (1812), and Sagan (1980) all made the point that extraordinary claims require extraordinary evidence. This inferential rule should be kept in mind when interpreting bodies of evidence. A hypothesis is extraordinary if there is no prior evidence for it (e.g., the agent has not previously been shown to cause the effect or has been shown to be effective only at much higher levels), or it is simply not plausible. Extraordinary evidence is very weighty evidence: highly relevant, strong, and reliable.

Interpreting the evidence for hypotheses usually involves applying a three-value logic (e.g., yes, no, maybe; true, false, uncertain; or high, low, intermediate). If the interpretation is comparative, as in determining which alternative cause is best supported by the evidence, examining a summary table of the scored evidence and identifying the likely causal hypothesis are possible. Even if the best hypothesis is not clear, proposed hypotheses that clearly are not supported and can be eliminated can nearly always be identified. For example, an assessment of the cause of a precipitous decline in smallmouth bass in the Susquehanna and Juniata Rivers, Pennsylvania, using the CADDIS WoE method and existing information was inconclusive (Shull and Pulket, 2015). It did, however, classify the 18 candidate causes into three bins: 2 likely, 8 unlikely, and 8 uncertain. These results are being used to prioritize and design subsequent research and monitoring. Similarly, when judging a single hypothesis (e.g., spilled tailings would pose a substantial risk to salmon production), the hope is for a body of evidence that clearly either supports or counters the hypothesis, but the evidence might be ambiguous (U.S. EPA, 2014a).

Some WoE systems have standard categorical outcomes defined in terms of properties of the body of evidence (U.S. EPA, 2013, 2005b). A description of the potential weights of evidence used for causal determinations (i.e., categorical outcomes for general causal assessments) of criteria air pollutants is shown in Table 6-5. In such cases, interpreting the evidence involves matching the properties of the body of evidence to one of the categories. The definitions of categories, however, could be based on the scored properties rather than narratives as in this example.

Ultimately, the interpretation of evidence is a matter of logic applied to evidence and background knowledge, preferably by multiple individuals with a range of expertise. It is not simply a matter of adding or counting scores. In particular, some pieces of evidence are conclusive alone. For example, if the effect precedes a potential cause or if an aqueous effect occurs upstream of the putative source, the cause can be eliminated even if other evidence is positive. More commonly, one piece or type of evidence will influence the interpretation of other evidence. Even WoE systems that use standard scoring criteria and arithmetic integration of numerical scores rely on logic to identify and correct results that are contrary to knowledge of the system (COA Sediment Task Group, 2008; Johnston et al., 2002). As a result, applying expert judgment in any WoE is necessary to achieve an adequate, explanatory account.

At this stage, it is desirable to limit the interpretation to the hypotheses and evidence that were defined in advance. Otherwise, "ad hoc machinations" to achieve an acceptable answer can occur (Douglas, 2012). If interpreting the evidence does not identify a clear preponderance of evidence for a hypothesis, techniques that go beyond the simple weighing of evidence can be applied, as explained in the following

section. However, it should be remembered that they violate the admonition against improvised reasoning so they are less convincing than results of weighing bodies of evidence and hypotheses defined in advance.

Table 6-5. Weight of evidence for causal determinations in the 2013 lead ISA (U.S. EPA, 2013).

Causal Determination	Evidence for Ecological and Welfare Effects
Causal relationship	Evidence is sufficient to conclude a causal relationship with relevant pollutant exposures (i.e., doses or exposures generally within one to two orders of magnitude of current levels). That is, the pollutant has been shown to result in effects in studies in which chance, bias, and confounding could be ruled out with reasonable confidence. Controlled exposure studies (laboratory or small- to medium-scale field studies) provide the strongest evidence for causality, but the scope of inference could be limited. Generally, determination is based on multiple studies conducted by multiple research groups, and evidence that is considered sufficient to infer a causal relationship is usually obtained from the joint consideration of many lines of evidence that reinforce each other.
Likely to be a causal relationship	Evidence is sufficient to conclude a likely causal association with relevant pollutant exposures. That is, an association has been observed between the pollutant and the outcome in studies in which chance, bias, and confounding are minimized, but uncertainties remain. For example, field studies show a relationship, but suspected interacting factors cannot be controlled, and other lines of evidence are limited or inconsistent. Generally, determination is based on multiple studies in multiple research groups.
Suggestive of a causal relationship	Evidence is suggestive of a causal relationship with relevant pollutant exposures, but chance, bias, and confounding cannot be ruled out. For example, at least one high-quality study shows an effect, but the results of other studies are inconsistent.
Inadequate to infer a causal relationship	The available studies are of insufficient quality, consistency, or statistical power to permit a conclusion regarding the presence or absence of an effect.
Not likely to be a causal relationship	Several adequate studies, examining relationships with relevant exposures, are consistent in failing to show an effect at any level of exposure.

6.4. Explaining Ambiguities and Discrepancies

The results of weighing bodies of evidence can be ambiguous and discrepancies among pieces or types of evidence can occur. Examples include WoE results for which:

1. The bodies of evidence for all assessed hypotheses are incoherent.

2. One hypothesis has sufficient, consistently positive evidence to support acceptance, but some other hypotheses also have some relevant and reliable positive evidence.

3. No hypothesis has predominantly positive evidence.

In ambiguous, discrepant, or nonsensical cases, one can stop the assessment process and call for more data or proceed to perform follow-on analyses to resolve problems with the existing evidence. The latter course could allow successful completion of the assessment by reconsidering the evidence or by reformulating the hypotheses. Having completed the WoE analysis, some hypotheses could have been

eliminated, but the grounds for elimination might need re-examination. Also, assessors should have become deeply familiar with the evidence. That familiarity and the assessors' background knowledge could make it possible to reinterpret the data or revise the hypotheses to explain and resolve the ambiguities. Reinterpretations, however, provide opportunities to fabricate false explanations of apparent patterns in the evidence. Formulating hypotheses to accommodate the evidence is discouraged in scientific inference because it can lead to bias or self-deception. It has come to be known as HARKing (hypothesizing after results are known). As in other judgments during the assessment process, clearly articulating arguments, avoiding over interpretation, involving multiple assessors with different perspectives, and using a clear and consistent method to build the case are essential. A generally useful approach is to (1) list the discrepancies, (2) ask whether each discrepancy could be explained by a misinterpretation of the evidence or by a misspecification of the hypothesis, (3) determine whether all discrepancies can be resolved by some combination of reinterpreting evidence and respecifying hypotheses, and (4) evaluate additional evidence relevant to the explanations.

Reinterpreting the evidence is facilitated by considering ambiguities in the data and the methods used to generate them. As presented in Appendix E, Table E-3, toxicity tests might not include sensitive species, life stages, or responses; the bioavailability or form of a toxicant might be inappropriate; the exposure durations might be too long or too short, etc. Biological surveys could be conducted in the wrong season, compared to an inappropriate reference, to measured responses or taxa that are insensitive to the causal agent, etc. Measures of exposure might miss episodic events, be taken under atypical conditions, not include the causal agents, be disjunct from the biological samples, etc. Any of the evidence could be derived from studies that are biased, poorly designed, or poorly conducted in ways that were not reported or not recognized in the weighting. Inventing explanations is not difficult—the difficulty is determining which are likely to be true.

In addition to reinterpreting the evidence, assessors might explain discrepancies by changing the hypotheses or adding hypotheses in light of the evidence. At least four strategies can be applied.

Redefine the endpoint effect. Causal relationships are often unclear because the effect is unclear. For example, determining the cause of decline in peregrine falcons depended on redefining the effect as reproductive failure associated with thin eggshells. That more specific definition steered assessors away from potential causes such as habitat loss, shooting, and egg collecting and toward toxic effects. In some cases, discrepancies might be explained by defining the spatial or temporal scope of the effect more specifically. For example, defining the effect as the occurrence of fish kills in a stream as a whole will lead to discrepancies in the evidence if kills occur only in a reach below an outfall and the dead fish drift downstream.

Reconsider sources and agents. Discrepancies in evidence could be due to sources, components of emissions, or actions that were not considered, because they were overlooked or of no concern to the decision maker or stakeholders.

Integrate causal agents or networks. Rather than being alternatives, the proposed causes of an effect could be acting jointly. Also, a proposed proximate cause might actually be an indirect cause that contributes to the true proximate cause. For example, habitat disturbance did not cause the decline in San Joaquin kit foxes on the Elk Hills Petroleum Reserve, but it apparently made the foxes more susceptible to the major cause, predation (U.S. EPA, 2009a). Such possibilities can be represented in practice by rearranging the components of a conceptual model or by combining alternative conceptual models. The conceptual model can be revised by removing the box-and-arrow combinations that are not supported by evidence and examining how the remaining boxes and arrows might link within the model or among models for different causes.

Look for patterns in the evidence. Looking for properties that the pieces or categories of evidence supporting a hypothesis share, which the contrary evidence does not share, might be helpful. This examination could be facilitated by creating a matrix of evidence versus relevant attributes of the evidence. Different results might be observed, for example, in field versus laboratory studies, lotic versus lentic studies, industry-funded versus foundation-funded studies, insect versus crustacean studies, etc.

Reinterpreted evidence or revised hypotheses could explain discrepancies in a manner that seems convincing to the assessors who developed them, but explanations improvised after the analysis to account for discrepancies might not convince others without independent evidence. Independent evidence might have been available but unused in prior weighing of evidence, because it had not been relevant. For example, if the proposed resolution of a discrepancy was low bioavailability of metals, measurements of dissolved organic matter might be used to confirm that explanation. Similarly, if low dissolved oxygen is a proposed cause of a fish kill, the survival of air-breathing organisms such as frogs and turtles is supportive (Cormier et al., 2010). Ideally, confirmatory evidence would be generated by identifying a previously unmeasured or unobserved property of the system that should occur under the revised hypothesis and then taking the measurements or observations that would establish its occurrence. If the amount of evidence and the number of possible explanations of the evidence are substantial, a formal reweighing of the evidence to address the revised hypotheses might be appropriate.

6.5. Presenting Results

The results of a qualitative WoE have two parts: the conclusion and the justification. The conclusion, in the best case, is a statement of the hypothesis that is clearly supported by the WoE (e.g., the cause is the thermal effluent, the stream is biologically impaired, or the population has recovered). Ambiguous results require more explanation (e.g., hypothetical causes 1, 3, and 5 can be eliminated, but 2 and 4 are somewhat supported). Graphical presentations can be useful, such as a revised conceptual model of the identified causal relationship or a map of the areas biologically impaired by the waste. When the assessments are sufficiently standardized, a standard reporting format could be implemented as in the International Uniform Chemical Information Database (IUCLID) dossier for assessing the toxic properties of chemicals in the European Union (ECHA, 2010).

The justification of a conclusion is a summary of the evidence and logic that support the conclusion. The justification, which will vary among assessments, typically includes:

1. Statements of overall weight of evidence for the conclusion (e.g., the evidence convincingly supports, strongly supports, or somewhat supports the cause) relative to the weights for alternatives or relative to a standard of evidence.

2. Statements of consistency or coherence (e.g., all the evidence was either convincingly or strongly supportive of the cause, except for laboratory acute tests, which had low relevance).

3. Statements of the extent to which characteristics of causation or other relevant characteristics are satisfied by the evidence (e.g., evidence was available to support all characteristics of causation except time order). Alternatively, state the extent to which standard types of evidence were available (e.g., all three components of the sediment quality triad were available). In any case, state how the body of evidence provides an explanation of the credibility of the accepted hypothesis.

4. Statements explaining why the conclusion is justified despite a low weight of the body of evidence, if necessary (e.g., even if other causes could be substantially contributing, collection and treatment of the effluent is likely to improve conditions and is mandated by regulations).

6.6. Summary

Having assigned weights to the pieces of evidence, the process of weighing evidence integrates and interprets the body of evidence to determine which, if any hypothesis has sufficient weight to be accepted. Depending on the amount and types of evidence, this may include a process of aggregating the evidence into categories and integrating the weights within categories. Once the weights have been integrated, the bodies of evidence for all hypotheses should be compared and the results interpreted. Interpretation may be obvious (e.g., only one hypothesis has positive evidence) but often it requires careful logic and judgment informed by the knowledge and experience of multiple assessors. If interpretation does not provide a conclusion, an analysis of the ambiguities and discrepancies that confounded the interpretation can suggest what additional evidence or alternative hypotheses should be considered. Finally, the results should be presented in a way that make clear the results and the process that generated them.

7. SPECIAL CASES AND ABBREVIATED PROCESSES

In some circumstances, the full three-step WoE process is not necessary or practical, but a two-step process is useful. The systematic assembly of evidence is always appropriate, but weighting might be unnecessary if all evidence is equivalent (Figure 7-1a), and weighing a body of evidence is unnecessary if only one piece of evidence is available (Figure 7-1b).

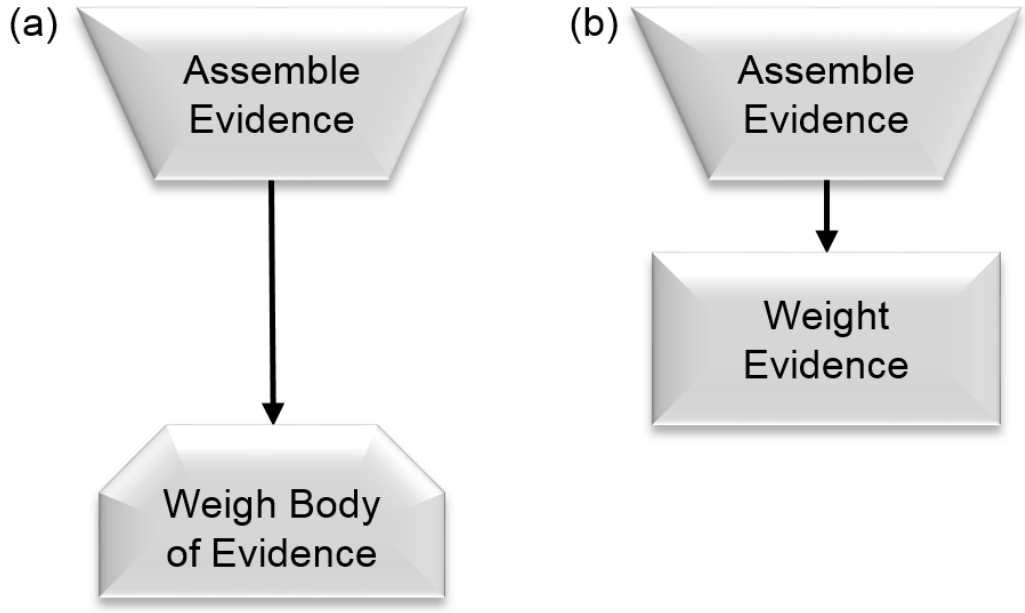

Figure 7-1. Steps in abbreviated weight-of-evidence processes: (a) skipping the weighting step when all evidence is equivalent or (b) weighting a single piece of evidence when multiple pieces are not available.

7.1. Weighing Without Weighting

Some WoE methods presume that all evidence is equal or at least that the differences are uninformative, so the weighting step (Section 5) can be skipped. For example, if all evidence is reliable and of the same type (e.g., multiple acute lethality tests performed by standard protocols), each piece of evidence will have equal influence in most cases. In practice, weighting is often skipped without determining that the relevance, strength, and reliability of the evidence are similar across pieces of evidence. Instead, if the pieces of evidence pass the screening step (see Section 3), the differences are assumed unimportant. An example of weighing evidence without weighting is the causal determination in an ISA regarding exposure to a specific air pollutant and specific effects (U.S. EPA, 2013).

A case for which distinguishing weights was unnecessary is provided by the studies used to determine that ingesting lead from lead mining and smelting caused the tundra swan kills in the Coeur d'Alene basin, Idaho (Table 7-1). The data used in the evidence were generated for the case, so they were all highly relevant; the studies were conducted by competent and reputable investigators following prescribed quality standards, so they were highly reliable; and the relationships were all strong. Because of that ideal situation, the presentation of evidence in WoE Table 7-1 is sufficient. Table 7-1 organizes the evidence in terms of characteristics of causation, rather than listing pieces or types, and briefly summarizes the evidence for each.

Table 7-1. Summary of evidence for lead as a cause of mass mortality of tundra swans in the **Coeur d'Alene** River Watershed (Norton et al., 2014). Based on evidence from URS Greiner Inc. and CH2M Hill (2011).

Causal Characteristic	Evidence
Co-occurrence	Swan kills occurred in Pb-contaminated lakes and wetlands and not elsewhere in the region.
Sufficiency	Mortality occurred in laboratory tests at Pb doses and body burdens observed in dead or moribund swans in the field. Consistent mortality in the field at blood Pb levels >0.5 µg/g.
Time order	No evidence—no pre-mining information on swan mortality.
Interaction	Dead and moribund swans had high blood and liver Pb levels. Pb-contaminated sediments were found in swan guts and excreta.
Specific alteration	Swans had pathologies characteristic of Pb toxicity, particularly, enlarged gall bladders containing viscous dark green bile.
Antecedents	Spills of Pb mine tailings and atmospheric deposition from smelters account for the high sediment Pb levels.

7.2. Weighting a Single Piece of Evidence

The concept of WoE was developed to combine multiple pieces of evidence in a way that gives each piece proper influence on the conclusion. When only one piece of evidence is available for an inference, the integration function of WoE does not apply. WoE, however, also leads assessors to consider the importance that should be assigned to a body of evidence and reveals the assessors' judgments to decision makers and stakeholders. This purpose of evaluating and interpreting a body of evidence can apply to a single piece. That is, explicitly evaluating the relevance, strength and reliability of a single piece of evidence can be informative.

Weighting a single piece of evidence also might provide consistent communication of the assessment process. That is, if many pieces of evidence are evaluated and scored for some hypotheses, the reader will expect to see scores for all hypotheses. If a hypothesis has only a single, stand-alone piece of evidence, scoring that one piece provides the expected consistency in weighing the evidence for all hypotheses.

In addition, weighting a single piece of evidence might reveal its inadequacy and lead to obtaining and weighing more evidence. For example, for the Patrick Bayou Superfund site, assessors intended to use modeling of toxicity to an amphipod as their primary approach to assessing risks to benthic invertebrates (Anchor, 2013). However, they found that the data were unreliable due to lack of reference data, confounding, poor correspondence to tests of other species, and unreliable polychlorinated biphenyl analyses. As a result, they adopted a WoE approach using the conventional triad of sediment quality evidence.

8. WEIGHT OF EVIDENCE FOR QUANTITATIVE RESULTS

Quantitative results of ecological assessments, such as benchmark concentrations, areas of habitat lost or rate constants, might be derived from multiple pieces of quantitative evidence. Commonly, these quantitative analyses follow the qualitative analyses that establish the hazard or other qualities to be quantified (Figure 8-1). Methods for deriving quantities by weighing evidence are discussed in Appendix B. They fall into two basic approaches: combine the quantitative evidence or choose the best quantitative evidence. Finally, weights can be assigned to the quantitative results to indicate how influential they should be.

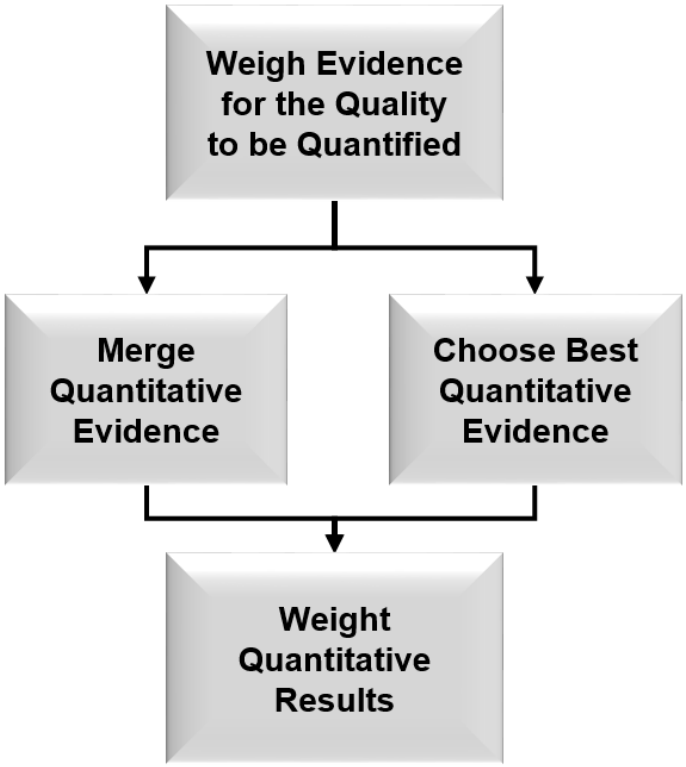

Figure 8-1. Potential steps in a process for using WoE to derive a quantitative result. Note that the top box of this process diagram encompasses the qualitative WoE process (Figure 3-2).

8.1. Weight of Evidence for the Quality to Be Quantified

Before deriving a quantity, determining what quality is to be quantified (Table 8-1) is necessary. This determination could require weighing evidence. For example, conventional risk assessments quantify, if possible, the magnitude and likelihood of a defined hazard. Environmental hazards are potential effects on an attribute of a biological entity (the assessment endpoint) resulting from exposure to an agent in particular conditions (described by the conceptual model). Similarly, criterion assessments quantify a threshold level of exposure corresponding to an unacceptable level of effect, and the effect itself is a quality that might be identified by WoE. Qualitative assessment could even precede the derivation of a model parameter. For example, a narrative WoE was used to determine whether a bioavailability adjustment factor should be used at a dioxin-contaminated site, and then the factor's value was chosen based on a prior quantitative WoE in a published review (Integral Consulting Inc., 2013). Quantitative condition assessments might determine the magnitude and spatial extent of impairment after a site has

been determined impaired by qualitative WoE applied to multiple metrics. In sum, this qualitative WoE determines whether the property to be quantified is real and significant in the context of the assessment.

Table 8-1. Qualities that could be identified by qualitative WoE and the associated quantities that could be derived by the quantitative WoE process (see Figure 3-2)

Example Quality	Example Corresponding Quantity
General cause: teratogen	Sufficient maternal body burden
General cause: carcinogen	Slope factor
Specific cause: chloride in effluent as cause of fish kills	Allowable maximum concentration
Specific cause: ammonia in stream as cause of biological impairment	Total maximum daily load
Bioaccumulative	Bioaccumulation factor
Exposure	Bioavailable concentration at point of contact
Susceptibility	Probability of responding
Alteration	Area of wetland

In some cases, assessments weigh evidence to derive a quantitative result without a prior WoE for a quality. For example, the derivation of ambient water quality criteria for aquatic life is nearly always based on a generic endpoint—protection of aquatic life from effects of direct aqueous exposures on survival, growth, or reproduction. However, for some criteria the generic endpoint is found to not be protective because an important specific effect or route of exposure is not adequately addressed. An example is the water quality criterion for selenium, which addressed a nonstandard effect (skeletal deformities in vertebrates) and route of exposure (exposure in ovo to selenium accumulated from a food web by the female parent). Such examples suggest that it may be desirable to weigh evidence for nonstandard qualities. Even if default qualities are assumed, the first step of WoE, the systematic assembly of evidence, should be performed to obtain all potentially useful quantitative estimates as well as associated information.

The place of these qualitative WoE processes in an overall assessment process depends on the type of assessment. For a conventional risk assessment, a WoE to choose the endpoints (i.e., What effects does the chemical or other agent cause in which potentially exposed organisms?) would be part of the problem formulation. The quantitative analysis and characterization phases follow to quantify the risks. In other cases, separate qualitative and quantitative assessments are performed. For example, a qualitative causal assessment to determine the cause of an observed effect may be followed by a quantitative risk assessment to derive a total maximum daily load, cleanup goal or other quantitative benchmark. In cases like the bioavailability adjustment factor example presented earlier, the qualitative and quantitative WoE processes might both be embedded in the analytical phase of an assessment.

8.2. Weight of Evidence for Deriving the Quantity

If more than one source of data with acceptable relevance and reliability is available to derive a quantitative result, the data sets should be weighed. Conventionally, the data sets would be integrated by combining the quantitative evidence or by choosing the best (i.e., weightiest) evidence. Another approach, the Rule of Five, has been useful in weighing evidence to determine a contaminated site cleanup goal (Box B-2).

8.2.1. Combining quantitative evidence

If the quantitative value can be derived from multiple data sets that are of sufficiently high relevance and reliability, the data sets can be numerically combined (Appendix B). In past EPA practices, this combining has involved taking the arithmetic or geometric mean. For example, multiple acceptable LC_{50} values are available for a species-chemical combination, their geometric mean is used when deriving national ambient water quality criteria (U.S. EPA, 1985). Geometric means of toxicity values are also used to derive soil screening levels (U.S. EPA, 2005a). Rather than treating all evidence equally, the values might be weighted before they are combined. Quantitative weighting could use a quantitative property of the study that influences its reliability such as the inverse variance.

Alternatively, quantities might be weighted based on some qualitative property. In this case, the qualitative weights are converted to numerical equivalents. For example, high, moderate, and low reliability of the study design might be converted to weights of 1, 0.7, and 0.5 or some other values, depending on how much influence study design should have and how great the variance in the study design might be.

Rather than using numerical weights to express the properties of the individual estimates, qualitative weights can be applied to the combined estimate. That is, after a combined value is derived, it might be assigned scores to express one or more qualitative aspects of its relevance or reliability. The weighted mean or other quantity derived from multiple sources should provide greater confidence than a quantity derived from any single source. Otherwise, the evidence should not have been combined.

8.2.2. Choosing the best quantitative evidence

If the range of relevance or reliability of alternative numerical values is large, choosing the best value rather than combining them is advisable. That is, the numerical values should be weighted for relevance and reliability, and the weightiest one used. (Note that in some contexts, established policy might require using the most protective acceptable value to ensure the degree of protection required by law.) Choosing the best value is particularly advisable when values can be derived from multiple types of evidence. For example, if a benchmark value of a contaminant could be derived from laboratory toxicity tests, a mesocosm test or a regional field survey, the results are likely to represent qualitatively different effects and might not be averaged, with or without weighting.

Using WoE to choose the best estimate is illustrated by Table 8-2. This table format presents the magnitude or probability of effects versus integrated weights of evidence for types or groups of evidence as recommended by Hope and Clarkson (2014). The table shows risk assessment results (probability of achieving the effect endpoint) estimated by analysis of each of four evidence groups (numbered circles) with integrated weights derived as in Section 6. In this hypothetical example, Evidence Group 3 might be chosen because it has the highest weight and is not an outlier in terms of the quantitative result (probability of effect). The result might be, Group 3 (evidence derived from stream mesocosm tests) is convincing and gives an estimate of 15% probability of reduced species richness.

Using WoE to choose the best value is not an established practice, but it is recommended for choosing among alternative test data for the same species, endpoint, duration, life stage, and testing conditions by the European Chemical Agency (ECHA, 2008). Although the European Chemical Agency does not specify a method of weighing, it indicates that various studies can provide supporting information to add weight to a particular test.

Table 8-2. WoE matrix to summarize quantitative risk estimates for four evidence types or groups (numbered circles) and their weights. Adapted from Hope and Clarkson (2014).

		Evidence Weight			
		0	+	++	+++
Probability of Achieving Effect Endpoint	>75%				
	51–75%				
	25–50%			①	
	5–24%			②	③
	<5%		④		

8.3. Weighting a Quantitative Result

Quantitative results are often accompanied by statistical expressions of variability or uncertainty, but determining how much weight the result should be given might also be useful. Weighting a quantitative result could inform decision makers and stakeholders about the result's relevance and reliability, irrespective of data scatter (Section 9). For example, an estimate of biological effects might have a small confidence interval, but it could have been generated from laboratory test data with low relevance to the case or might have been generated with poor controls or otherwise unreliable methods. As in weighting qualitative evidence, the specific properties of relevance and reliability listed in Box 5-1 and Box 5-3 and the collective properties listed in Box 6-1 could be included in the weighting of quantitative evidence if they are important.

Strength is generally not a relevant property for weighting quantitative results. For example, an exposure-response model with a high slope is strong, and therefore, lends weight to a causal hypothesis (i.e., a qualitative WoE). However, the result of a quantitative analysis to derive a benchmark exposure has whatever strength it has. An estimate of a benchmark value derived from an exposure-response relationship with a high slope is not given more weight than one derived from a relationship with a low slope.

Weighting might be used to determine the applicability of a number to particular uses. For example, at contaminated sites, weights might be used to distinguish soil benchmark values that are suitable only for screening values from those that might be suitable for cleanup goals. In any case, weights can be used along with statistical uncertainty measures to communicate confidence in results.

9. WEIGHT OF EVIDENCE AND UNCERTAINTY

The process of weighing evidence can be considered a means not only of deriving a conclusion, but also of documenting the assessors' confidence in the conclusion. That is, the weights assigned to pieces and categories of evidence are expressions of how confident the assessors are that the evidence should influence the conclusion in one direction or another. Additionally, the overall weight of the body of evidence is an expression of how much confidence the assessors have in that conclusion. If both laboratory tests and field surveys indicate that a chemical causes spinal deformities in fish, and both categories of evidence are evaluated and scored as highly relevant, strong, and reliable, we are confident that the chemical is a cause of deformities. Even if the WoE analysis is limited to a narrative, the narrative should describe the degree of confidence in the conclusion. For example, the categories of results in the ISAs and IRIS hazard assessments are explicit expressions of confidence in WoE narratives (e.g., "likely to be a causal relationship"—see Table 6-3). Such qualitative expressions of confidence are appropriate for a qualitative conclusion such as the observed relationship is likely causal, the chemical is likely a carcinogen, or the chemical is a contaminant of concern. If the standard scoring system was used to weight evidence, the resulting expression of overall confidence might be that the evidence is convincingly supportive, strongly supportive, or somewhat supportive of the conclusion. The appropriate expression of weight/confidence depends on the assessment and the decision to be supported.

The confidence concerning numerical values should include qualitative weights as well as conventional measures of scatter such as range or confidence limits[Figure 9-1 (Spiegelhalter and Riesch, 2011)].[2] For example, one would have low confidence in a benchmark value that is based on irrelevant evidence, even if it is statistically precise. Hence, presentations of quantitative results might have four parts:

1. The quality expressed—threshold for reproductive effects
2. The numerical result and units—*x* mg/L.
3. Scatter—95% CI of ±0.2*x* mg/L.
4. Weight—the body of evidence is highly relevant and moderately reliable, diverse, and coherent.

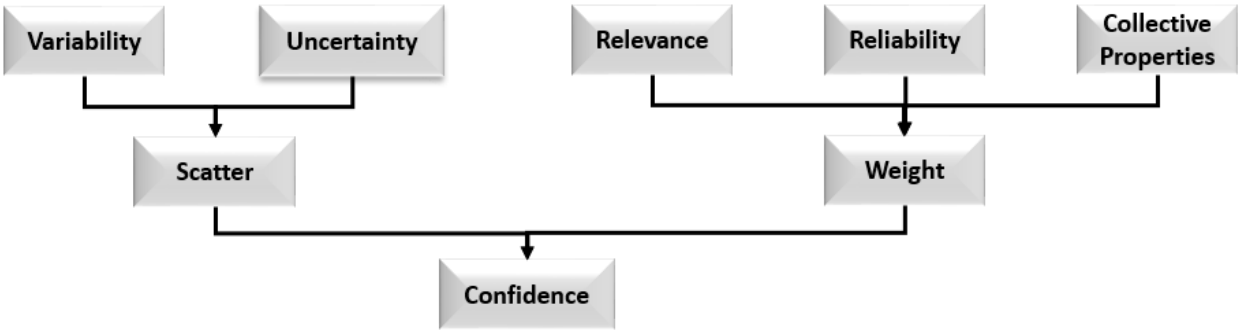

Figure 9-1. A diagram of the combination of statistical scatter and qualitative weight to define the confidence that should be afforded an assessment result.

[2] This discussion assumes an objectivist view that conceives uncertainty and variability as probabilities based on frequencies, which are distinct from qualitative judgments of weight. A subjectivist would consider all components of Figure 9-1 to be encompassed by degree of belief, and all components could be expressed as subjective probabilities.

The pieces and types of evidence that are not used to derive the numerical result could still provide information concerning the result. For example, another piece of evidence might place a limit on the possible range of effects and that information can be used to truncate the confidence limit on the estimated effect. Other evidence might inform the scope of a result. For example, a field-based benchmark value for a contaminant in streams might be based on benthic invertebrates because they provide the best data. Fish survey data that are not sufficient to derive a benchmark, however, might be sufficient to conclude that the invertebrate-based benchmark is likely also protective of the fish assemblage.

Conceivably, assessors could address the uncertainty concerning the confidence expressed by the WoE. No methods have been found for estimating or describing such meta-uncertainties. An estimate of WoE uncertainty, however, can be obtained by replicating the assessment. That is, multiple assessment teams could be engaged to assemble, weight, and weigh the evidence so that the variance among WoE results might be estimated. That implies an extraordinary effort for a routine assessment, but replication of a WoE for a condition assessment has been done experimentally (Bay et al., 2007). Six experts were provided conventional sediment quality triad data for 25 embayment sites in California. They were asked to rank the sites from best to worst and to categorize them into one of six standard categories. No instructions were provided, so the participants apparently used whatever WoE method they used in their professional practice. The rankings were highly correlated (mean Spearman rank correlation = 0.92). Differences in categorization of a site were common but mostly small and were primarily due to differences in relative weighting of the three types of evidence, so common weighting guidelines might have reduced discrepancies.

A sensitivity analysis would be more practical than replicating the assessment as a means of determining the variability in the weighting process. That is, assessors could determine the influence of changing the weights on WoE results. If the choice between alternative hypotheses could change when, for example, the reliability of a piece of evidence was scored as + rather than ++, that sensitivity would be noted. Such cases would tend to occur when few pieces of evidence are considered, when the overall weight for a body of evidence is marginal, or the bodies of evidence for alternative hypotheses have similar weights.

10. WEIGHT-OF-EVIDENCE SUMMARY AND THE PATH FORWARD

The basic framework of assembling evidence, weighting it, and weighing the body of evidence is fundamental to making inferences based on WoE (Figure 10-1). Even if a WoE is not explicitly performed using these steps, assessors should at least consider each of these processes. Adhering to an explicit framework can improve the WoE results, enhance transparency, and increase the confidence of reviewers, stakeholders, and decision makers.

The steps to implement the framework for qualitative WoE, with section numbers, include:

- Finding information (4.2.1),
- Design and conduct studies to fill information gaps (4.3)
- Screening studies (4.2.2),
- Categorizing studies (4.2.3),
- Deriving evidence from the data (4.2.4),
- Evaluating the evidence with respect to properties (5.3),
- Assigning weight scores based on the evaluation (5.3),
- Creating a scoring table to summarize the results of evidence weighting (5.4),
- Integrating the weighted evidence into bodies of evidence for each hypothesis (6.2),
- Creating a WoE table to summarize the results of evidence integration (6.2),
- Interpreting the bodies of evidence (6.3),
- Explaining ambiguities and discrepancies (6.4),
- Reiterating the process if necessary (6.4), and
- Presenting results (6.5).

In addition to the approach for applying WoE to qualities such as causality and impairment, this document briefly addresses WoE for quantities and how WoE for qualities and quantities are related (Section 8). Although WoE for quantities such as benchmark or parameter values is uncommon now, it seems likely that the use of meta-analysis and other techniques for weighting and combining quantities will gain increasing use. A combined approach to WoE for qualities and quantities is likely advantageous.

Similarly, this document briefly discusses the relationship between uncertainty and WoE (Section 9). By combining the somewhat narrow concept of uncertainty (i.e., measures of the scatter of data or of estimates) with the broader concept that some evidence and conclusions deserve more weight, it should be possible to improve the communication of confidence in assessment results.

The WoE approach in this document is based on experience in the EPA, particularly with determining the causes of impairment in ecosystems (http://www3.epa.gov/caddis/). Its application in practice will vary among programs due to differences in issues, policies, prior practices, and the amount and variety of evidence potentially available for weighing. As implementation of this approach progresses, context-specific guidance is expected to be developed in the form of exemplary applications of WoE or program-specific WoE guidance documents.

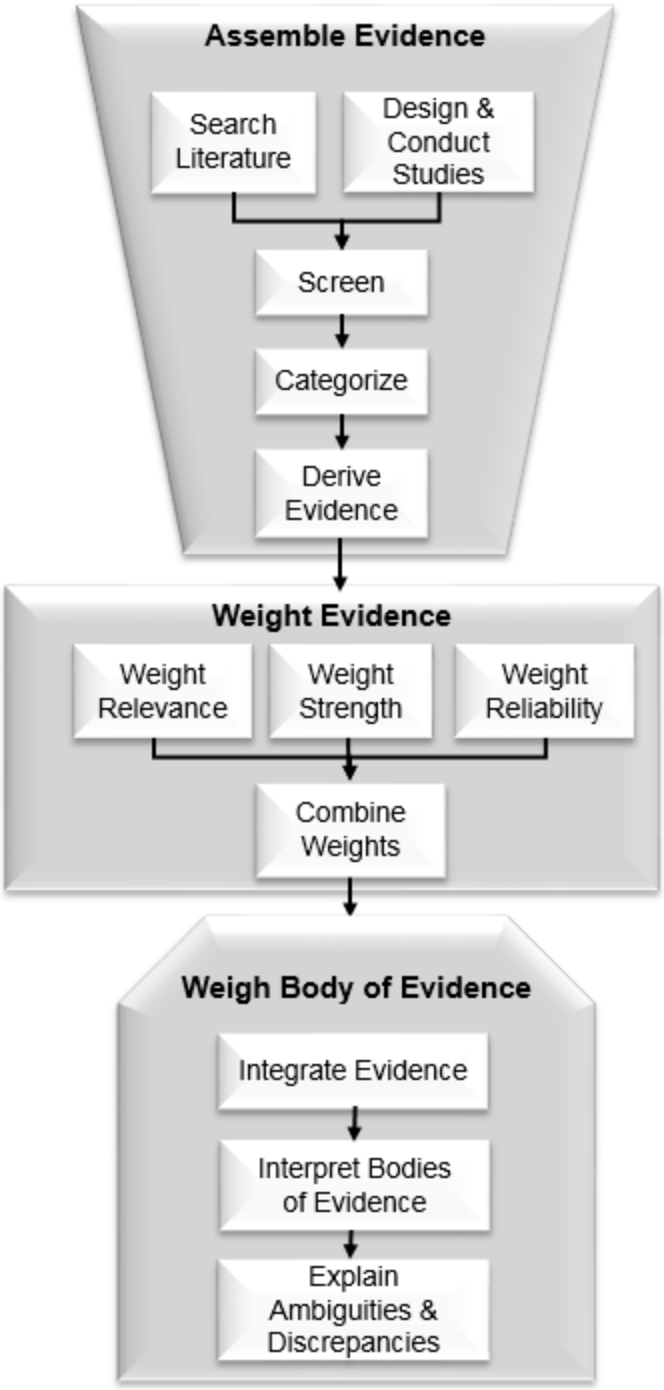

Figure 10-1. The detailed framework for qualitative WoE.

In summary, this document is intended to help ecological assessors improve the practice of WoE without imposing burdensome prescriptions. If read and applied in that spirit, this document should help advance the cause of well-informed environmental protection.

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APPENDIX A. GLOSSARY OF WEIGHT-OF-EVIDENCE TERMS

The following terms are defined as used in this document. The U.S. Environmental Protection Agency (EPA) might use these terms differently in other contexts.

Alteration: (1) A characteristic of causal relationships; it specifies that the affected entity is changed by physical, chemical, or other mechanisms leading to the defined effect. (2) A change in an entity that is consistent with interaction with a cause.

Ambiguous: Evidence that has no clear meaning or more than one possible meaning. Evidence may be ambiguous because it is weak (e.g., shows no clear relationships) or unreliable (e.g., reference sites may have important extraneous differences from exposed sites).

Antecedence: A characteristic of causal relationships; it specifies that the causal interaction is itself connected to processes that precede it, potentially leading back to a source.

Assessment, environmental: (1) A process of generating and presenting scientific information to inform an environmental regulatory or management decision. (2) The product of an environmental assessment process.

Benchmark: A criterion, standard, screening value, effect threshold, or other value used to differentiate potential exposure levels that are of concern from levels that are not of concern.

Case: (1) The situation that is the subject of an environmental assessment; for example, the case may be a water body experiencing an algal bloom, a hazardous waste site or a proposed pesticide use. (2) The weighted body of evidence for an assessment hypothesis; for example, "the lack of co-occurrence weakens the case for fine sediments as the cause."

Characteristics: Properties that define a quality of interest and that could be supported by evidence. For example, when weighing evidence for causation, evidence is sought to support six characteristics of causal relationships (Table E-1).

Coherence: The property of a body of evidence that its constituent pieces are logically linked together, thus, forming a reasonable explanation.

Confidence: The credence given a conclusion. For quantitative results, confidence is determined by the scatter of estimates as well as the weight of the evidence.

Considerations: Sets of heterogeneous aspects of causation or other qualitative hypotheses that are used to structure narrative weight of evidence (WoE). They are derived from or analogous to Hill's considerations (Hill, 1965).

Co-occurrence: (1) A characteristic of causal relationships; it specifies that the cause and effect are collocated in space and time at a scale appropriate to the cause and effect. (2) An instance of collocation in space and time.

Correspondence: The similarity of a piece or type of evidence to the entity or conditions to which the evidence will be applied. Evidence is relevant if it corresponds well to all aspects of the case (biological, physical/chemical, and environmental conditions).

Corroboration: Supporting evidence for an assessment proposition from one or more independent studies providing similar results.

Data: Unanalyzed results of measurements, counts, or observations used as a basis for reasoning or calculation.

Discrepant: Evidence that is inconsistent or contrary to established facts or theory.

Endpoint, assessment: An explicit expression of the environmental values to be protected, operationally defined as an ecological entity and its attributes.

Evaluation: The determination of how much influence a piece or category of evidence should be assigned. Evaluation plus the scoring of its results constitutes the weighting of evidence.

Evidence: Information that informs inferences regarding a condition, cause, prediction, or outcome.

Evidence, body of: All the applicable evidence used to make inferences concerning a proposition.

Evidence, category of: A grouping of evidence for consistency and to facilitate weighting. In WoE for environmental assessments, evidence is categorized in terms of conventional *types of evidence*, or in terms of characteristics that the evidence supports.

Evidence, line of: (1) A complex piece of evidence including multiple causal or logical steps that establishes a line of reasoning. (2) A general term used to refer to a piece or type of evidence—this use is discouraged to reduce ambiguous terminology.

Evidence, piece of: The basic unit of evidence; examples include the results of a toxicity test or a stream survey.

Evidence, type of: A category of evidence that is based on a distinct form of study. Conventional types include biological surveys, biomarkers, ambient media toxicity tests, single-substance toxicity tests, population and ecosystem models, and quantitative structure-activity relationships.

Explanation: The process of translating pieces or types of evidence into a characteristic of causation or some other attribute that is relevant to a hypothesis. It is part of evidence integration in the weighing of the body of evidence step.

Hazard: The potentially adverse properties of an agent that, with potential exposure of a receptor, imparts a risk. Hazards are identified by a general causal assessment, such as an Integrated Science Assessment, that typically employs a qualitative WoE.

Hypothesis: A proposition proposed to be a potential explanation of a phenomenon (the fish kill may be caused by high temperatures) or a potential outcome of a phenomenon (building more rooftops and parking areas will interfere with groundwater recharge).

Inference: (1) The act of reasoning from evidence. (2) A result of such reasoning.

Information: Data or other facts used to derive evidence.

Integration: The first step in the weighing of the body of evidence in which the pieces or categories of evidence are combined to characterize the body of evidence.

Interaction: (1) A characteristic of causal relationships; it specifies that a causal agent impinges upon, enters, binds to, or initiates a response in a susceptible entity in a way that can lead to the effect of concern. (2) An instance of interaction of a causal agent on a susceptible entity that can lead to an effect.

Interpretation: The second step in the weighing of the body of evidence in which the body of evidence for each hypothesis is compared to other hypotheses or judged against a standard to determine what conclusion is best supported by the weight of evidence.

Property: A feature of evidence that determines how much weight it should be assigned. In this document, the major properties are relevance, strength, and reliability.

Property, collective: A feature of bodies of evidence that, along with the properties of the constituent pieces of evidence, determines how much weight a body of evidence should be assigned. In this document, the collective properties are number, coherence, diversity, and absence of bias.

Proposition: A condition, cause, prediction, or outcome hypothesized as a possible outcome of an assessment.

Qualitative WoE: Weight of evidence to infer a quality such as causation or impairment.

Quality of interest: A distinctive attribute of an entity, relationship, or system that should be determined to exist or not for a hypothesis in an assessment.

Quantitative WoE: Weight of evidence to estimate a quantity such as a benchmark value or a biodegredation rate.

Reasonable explanation: (1) A statement or account that coherently explains a body of evidence. (2) Informed reasons for apparent inconsistencies in a body of evidence that provide coherence.

Refutation: The logical process of demonstrating the impossibility of a condition, cause, predicted effect, or outcome.

Relevance: A property of a piece or type of evidence that expresses the degree of correspondence between the evidence and the assessment endpoint to which it is applied.

Reliability: A property of evidence determined by the degree to which it has quality or other attributes that inspire confidence**.**

Risk: The likelihood of adverse effects associated with exposure to a stressor.

Scatter: The distribution of measured or estimated values due to uncertainty, variability, or both.

Scoring: The process of formalizing the evaluation of evidence by assigning a numeral, term, or symbol. Evaluation plus scoring constitutes weighting of evidence.

Strength: A property of evidence determined by the degree of differentiation from randomness or from control, background, or reference conditions.

Sufficiency: (1) A characteristic of a causal relationship; it specifies that the causal agent or event must be adequate to induce the effect in susceptible entities. (2) An occurrence of enough of an agent or process to affect a susceptible entity.

Table, scoring: A table created in the weighting step that presents the pieces or categories of evidence and their scores with respect to relevant properties.

Table, weight of evidence: A table created in the weighing step that summarizes the bodies of evidence and their weights for one or more hypotheses.

Time order: (1) A characteristic of a causal relationship; it specifies that the cause precedes the effect. (2) The sequence, in time, of the occurrence of a candidate cause and the effect of concern. It is sometimes called temporality or temporal sequence.

Uncertainty: Lack of knowledge concerning the state of an organism or system or concerning the true value of a quantity. Uncertainty is a property of the investigator and, unlike variability, may be reduced by measurement or observation.

Variability: Heterogeneity over time, space or members of a population. Variability is a property of nature and may not be reduced by measurement or observation.

Weigh: Consider the relevance, strength, and reliability of the body of evidence to assess the likelihood of a hypothesis.

Weight: (noun) The importance to an inference of a piece or category of evidence. (verb) To assign an importance descriptor or score to a piece or category of evidence.

Weight of evidence: (1) A process of making inferences from multiple pieces of evidence, adapted from the legal metaphor of the scales of justice. (2) The relative degree of support for a conclusion provided by evidence. The result of weighing the body of evidence.

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APPENDIX B. WEIGHT-OF-EVIDENCE METHODS FOR QUANTITATIVE RESULTS

Assessors are often confronted with multiple estimates of a quantitative value such as the median lethal concentration (LC_{50}) for a fish species, the half-life of a chemical in surface water, or the pH at which species richness is reduced in streams. A single estimate might be derived from multiple estimates, by weighing evidence to identify the best estimate or by using statistical techniques from meta-analysis to combine estimates (Borenstein et al., 2009; Hunter and Schmidt, 2004).

A simple method for combining values is selection of the single best (i.e., weightiest) estimate. This approach is commonly used because often one quantitative estimate is clearly superior to all others, so averaging would diminish accuracy. This approach also might be necessitated by statistical considerations, if the values cannot be combined because they do not represent independent samples from a common population of estimates (Borenstein et al., 2009). When this approach is used, a good practice is to identify in advance the properties of good estimates. Various procedures and criteria can be applied to various study properties when weighting to identify the best value (see Section 5). For example, LC_{50} values might be screened using reliability properties such as use of good laboratory practices and then the most relevant value could be chosen (e.g., the test performed in water most similar to water at the assessment site).

A common method in meta-analysis is averaging of multiple estimates. The geometric mean is often used because many environmental data sets are asymmetrical. Although weighting studies before averaging them is not common in environmental assessments, weighted averages are conventional in meta-analysis. The most common statistical model for weighting is the fixed-effects model, which weights by the inverse of the error variance (Borenstein et al., 2009). The term fixed effects is used because it implies that the estimates are all based on sampling a common variable from a common population with a set effects level (i.e., the only significant source of differences among the estimates being combined is sampling error). It has the advantage of giving more weight to larger studies and of normalizing the variance. If this assumption does not hold, a random effects model or the IVhet model can be employed (Borenstein et al., 2009).

Weighting also might be based on properties of the individual members of a higher-level entity that is being assessed. For example, in an assessment of ozone effects on forest production, estimates of reduction in timber production of individual tree species were weighted by the proportional basal trunk area before they were averaged to estimate loss of forest production (U.S. EPA, 2014b). Because of weighting, the average represented the loss of forest production and not just the averages of production losses for individuals of each species.

Although weighting in meta-analysis is usually based on statistical properties, weights based on qualitative properties also can be used (Turner et al., 2009). This approach is appropriate when studies vary significantly in terms of relevance or reliability relative to sampling variance or variance among the studied systems. For example, chronic toxicity test endpoints, even for the same species, often differ in the endpoint response, so statistical weighting would not capture the most critical differences among chronic test data. A statistical model has been developed that incorporates data quality or any other qualitative scale (Doi and Thalib, 2008). Statistical weighting models depend on variance estimates, which are not available for many environmental values such as conventional toxicity test endpoints. In those cases, weights can be assigned using improvised methods. Weighting for study quality has been common in meta-analysis, but it may introduce bias if not done appropriately (Turner et al., 2009; Greenland and O'Rourke, 2001).

Multiple quantitative estimates also can be used in regression analyses such as derivation of exposure-response relationships from multiple tests. As in averaging, the values are commonly weighted by the inverse of their error variance.

Quantitative results also can be combined into distributions. A common use is derivation of a value in environmental assessments from species sensitivity distributions (SSDs). SSDs are statistical distribution functions that, conventionally, are fit to the results of chemical toxicity tests and are generally interpreted as representing the distribution of sensitivity of species in communities. They are used to derive an exposure level that would be protective of a defined proportion of species or genera in communities or to estimate the proportion of species or genera that a defined exposure level would affect. The derivation of SSDs illustrates the issues involved in quantitative weighting of evidence (Box B-1).

Finally, rather than combining estimates, data sets from multiple studies have been combined to perform a statistical test or analysis. Some investigators combine data sets from multiple small studies with statistically insignificant results to obtain a data set large enough for the differences among treatments to be statistically significant. This practice is *not* recommended because it violates the premise of hypothesis testing that the likelihood of a data set given a null hypothesis is being determined. It is a form of *P*-hacking, which is the selection of data sets, tests, or hypotheses to achieve statistical significance. Alternatively, data sets can be combined to obtain a potentially better estimate of a mean and confidence interval than simply taking the mean of means. Also, multiple sets of exposure-response data might be combined to obtain a more accurate regression model of the relationship. As with averaging estimates, analyzing combined data sets requires attention to the statistical properties of the data.

Choosing the best estimate poses fewer technical issues than combining estimates. Combining estimates or data sets to generate an estimate introduces complications in computation and interpretation due to heterogeneity. In contrast, in a well-designed individual study, what the data and the summary statistics derived from the data represent is known. Different data sets representing the same relationship but generated at different times in different places or at different scales also might be so different due to ecological complexity and variability that they cannot or should not be combined. Further, if the studies to be combined have greatly different sample sizes and variance structures, statistically combining them might give counterintuitive results. At worst, studies that all indicate one relationship (e.g., declining species richness with increasing exposure) might give the opposite result when combined (i.e., increasing species richness with increasing exposure), a phenomenon known as Simpson's paradox (Blyth, 1972). Finally, the set of studies may be biased, particularly by the bias against publishing studies that show no effects. Thus, care should be taken when combining multiple estimates or data sets.

Despite these warnings, the benefits of combining estimates or data sets can be substantial. The combined estimate might be more accurate, particularly when sampling error is important. Inconsistencies among studies can be quantified and their sources can be analyzed. The influence on results of methodological or environmental differences among studies can be quantified. Further, some cases of combining estimates, such as averaging multiple toxicity test results for the same species following a standard protocol with moderate water chemistries, are unlikely to go astray.

Qualitative WoE may be used to derive quantitative results without combining or choosing among estimates. An example is the Rule of Five (Box B-2).

Box B-1. Combining and Weighting Data in Species Sensitivity Distributions

The combining and weighting of data in SSDs has two components. First, to derive the points in the distribution, the results of multiple tests of a species or of closely related species are combined. When deriving the species mean acute value (SMAV) for national ambient water quality criteria, multiple LC_{50}s are combined by taking the geometric mean and assigning that mean value to the species (U.S. EPA, 1985).

$$SMAV = \exp [(\sum \log LC_{50})/n]$$

The genus geometric mean value (i.e., the genus mean acute value or GMAV) is used when multiple congeneric species have been tested.

$$GMAV = \exp [(\sum \log SMAV)/n]$$

Weighting is not part of the currently accepted method for combining test results into either the species or genus means and its implications have not been investigated. However, one might weight the test results (e.g., LC_{50}s) before averaging, based on the variance, number of organisms tested, number of concentrations with partial response or some other property.

$$SMAV = \exp [(\sum(w_t \log LC_{50}))/\sum w_t]$$

Also, one might weight the species mean values before calculating the genus means based on the number of tests of each species or some other property.

$$GMAV = \exp [(\sum w_s \log SMAV)/\sum w_s]$$

(Note: Subscripts *t* and *s* indicate weights [w] for tests and species, respectively.)

Second, weighting might be involved in deriving the SSD from the species or genus mean values. If the SSD is intended to represent aquatic communities, a problem can occur with over- or under-representing particular taxa or functional groups, which might be resolved by weighting the data to achieve proportional representation (Duboudin et al., 2004; Forbes and Calow, 2002; Suter et al., 2002). This situation would require some difficult decisions. Should the weighting be based on the number of species in a higher taxon, a trophic group, or other grouping; on the relative abundance or biomass or on some measure of importance? Invertebrates would be weighted more than vertebrates for species richness, abundance, or biomass and perhaps much less for importance (depending on the measure of importance). Also, the assumption that the weighting should be based on particular categories [e.g., algae, invertebrates, and fish (Duboudin et al., 2004; Forbes and Calow, 2002)] presupposes low variance in sensitivities within those categories relative to between categories. That assumption is questionable given the large taxonomic differences within categories (e.g., cyanobacterial versus eukaryotic algae and arthropods versus mollusks, rotifers, and other invertebrates), which result in large differences in sensitivity. The communities represented by an SSD also would influence the weights. For example, stream invertebrates are predominantly benthic insects, but planktonic crustaceans and rotifers are important in lakes. Clearly, research would be required before introducing a weighting scheme for SSDs.

The derivation of weighted SSDs has been demonstrated by Semenzin et al. (2015); OECD (2013); U.S. EPA (2013). They weighted species and derived the SSD by weighted bootstrapping.

Box B-2. Cleanup Goals by Weight of Evidence Using the Rule of Five

Superfund cleanup goals for ecological risks are concentrations of contaminants that are higher than the no--observed-adverse-effect level (NOAEL) and lower than the lowest-observed-adverse-effect level (LOAEL). Because the interval between these values could be large (i.e., greater than a factor of 10) and because the measures of effect that define the bounds are not consistent, the common practice of interpolating by taking the geometric mean is often inadequate. Instead, a technique called the Rule of Five is used (Greenberg and Charters, 2007; Charters and Greenberg, 2004). The NOAEL-LOAEL interval is divided into six geometrically scaled intervals delimited by seven nodes. The node chosen as the cleanup goal depends on characteristics of the NOAEL and LOAEL, including their relevance to the assessment endpoint and their severity (e.g., Is the LOAEL defined by acute lethality or chronic reproductive effects?). The choice of node also can be influenced by measures of effects other than the LOAEL and NOAEL and by qualitative evidence concerning ecological exposure and effects on the site. The weighing of evidence to choose a node can be, at least in part, rule based. For example, a LOAEL based on mortality would move the choice one node below the middle node. The WoE also uses expert judgment. An example of applying the Rule of Five is in the Baseline Ecological Risk Assessment for the Estuary at the LCP Chemical Site in Brunswick, Georgia.

Another example of using qualitative methods to weigh evidence for quantities is the selection of surrogate values. When there are no data for a property of a chemical, the best estimate of the property may be derived from the best surrogate chemical for which the property is known. This approach, termed "read across," can be based on weighing multiple attributes of the chemicals including structure, physical/chemical properties (e.g., melting point, octanol/water partitioning coefficient) or biological properties [e.g., enzymes induced (ECHA, 2015; Wang et al., 2012)].

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APPENDIX C. WEIGHT-OF-EVIDENCE METHODS FOR DERIVING A MODEL

Weight of evidence (WoE) can play three roles in the derivation of mathematical models. First, the selection of a model from a set of alternatives can be based on WoE, where WoE refers to the relative weight provided to a model by the evidence (i.e., the available data). Good (1950) defined the WoE for members of a set of alternative models as their relative likelihoods, given a data set. Models can be compared using the sum of squares or other simple goodness-of-fit statistic, Bayes's factor or Akaike's information criterion (Anderson, 2008; Hilborn and Mangel, 1997). If the models represent alternative causal hypotheses, choice of the model that best explains the data can be said to have chosen the best causal explanation of the modeled effect (Newman and Clements, 2008). This use of the term WoE is distinct from the others in this document. Rather than weighting and weighing multiple pieces or types of evidence, Good's followers weigh the alternative models against each other with respect to a common data set. That approach is included here for completeness because it has appeared in the ecological assessment literature (Linkov et al., 2009; Smith et al., 2002). Rhomberg (2015) described using relative likelihoods for selecting among human toxicological hazards. He admits, however, that it is difficult to calculate likelihoods of models of toxicological hazards, and in practice, he uses qualitative WoE.

Bayesian model averaging extends this concept to provide a more recognizable example of weighing evidence to derive a model (U.S. EPA, 2009b). That is, rather than choosing a single best model, one might combine suitable models after weighting them based on their weights in Good's sense (i.e., their consistency with the data).

A more conventional use of the concept of WoE is the weighing of evidence concerning model assumptions. For example, to determine whether certain phenomena should be included in a model, one might assemble, weight, and weigh evidence concerning their occurrence. Such phenomena might include compensatory processes in a fish population, dietary toxicity in aquatic invertebrates exposed to an aqueous contaminant, nonlinearities in exposure-response relationships, or avoidance behavior at subtoxic exposures. The methods for weighing evidence for these model assumptions would be the same as for other qualitative conclusions. For example, Hertzberg and Teuschler (2002) developed a numerical index to weigh three properties of evidence for alternative models of mixtures toxicity.

Finally, model selection can be based on weighing a mixture of statistical and biological considerations. The benchmark dose guidance recommends choosing a dose-response model based on both biological plausibility and Akaike's information criterion (U.S. EPA, 2012a). A Science Advisory Board panel has recommended broadening the statistical and nonstatistical considerations to be weighed during model selection and using a more formal and transparent weighing process (SAB, 2015). For example, for dose-response modeling, they recommended prioritizing regression models that directly use exposure data for individuals.

Because any causal hypothesis, in theory, can be represented by a mathematical model, uses of WoE for model selection could be equivalent to the approaches for deriving qualitative conclusions presented in Sections 3−7.

APPENDIX D. WEIGHT-OF-EVIDENCE APPROACHES FOR QUALITATIVE CONCLUSIONS

This appendix summarizes the diversity of weight-of-evidence (WoE) approaches that have been used in assessments to answer questions concerning environmental qualities. Each approach has been useful in some cases, and they were carefully considered during the development of the approach presented in this document.

D.1. Narrative Weight of Evidence

Traditional narrative literature reviews and the assessments that adopt their approach describe a body of evidence and reach a conclusion by methods and criteria that are not explicit. The expertise of the reviewer is assumed sufficient to ensure a correct conclusion. The WoE is the conclusion that the author reaches through reading the literature and presents to the reader by logically structuring the review's narrative. This is a common approach for weighing evidence in environmental assessments. Narrative WoE is highly flexible, but the method by which results are obtained is not as transparent or reproducible as for other methods.

D.2. Consideration-Guided Narrative Weight of Evidence

WoE narratives can be given greater structure and logical consistency by organizing the narrative in terms of a set of considerations. For example, the U.S. Environmental Protection Agency's (EPA's) Integrated Risk Information System and Integrated Science Assessment documents use modifications of Hill's considerations when weighing evidence of general causation. Also, the WoE method for Tier 1 screening of potentially endocrine-disrupting chemicals provides five considerations (U.S. EPA, 2012b), and the chemical risk assessments conducted pursuant to the Toxic Substances Control Act use seven considerations (U.S. EPA, 2015b). However, these WoE methods depend on narratives and have not explicitly weighted or tabulated the evidence for the considerations. Also, the considerations are mixtures of various types of issues to consider, not consistent sets of criteria, properties, types of evidence, or characteristics. This method is an advance over unstructured narratives and is generally accepted.

D.3. Evidence Summary and Scoring Tables

Methodological rigor and transparency can be increased by creating summary tables for the evidence concerning an inference and assigning scores. For example, a set of summary and scoring tables was developed at ORNL for contaminated site assessments (Suter et al., 2000). The authors included tables for summarizing the methods and results for each type of evidence: biological surveys, bioindicators, ambient toxicity tests, tissue analyses, and single-chemical toxicity. Another table combined the results of the types of evidence (a score and associated explanation) and presented a score for the body of evidence for an endpoint.

D.4. Criteria-Guided Scoring

Criteria for weighting evidence have been combined with evidence scoring tables in the *Stressor Identification Guidance Document* and Causal Analysis/Diagnosis Decision Information System (CADDIS) to determine the causes of specific environmental impairments (http://www3.epa.gov/caddis/). Several examples of the application of this approach can be found in the CADDIS case studies. Pieces or types of evidence were scored based on Susser's method (U.S. EPA, 2000; Susser, 1986), but scoring types of evidence has been supplemented by scoring characteristics of causation to explain the relationship of the evidence to the hypotheses (Norton et al., 2014; Cormier et al., 2010). This approach

also has been applied to a risk assessment. The Bristol Bay watershed assessment used tables of evidence and scores to clarify the WoE for risks to salmon from spills of tailings, product concentrate and diesel fuel (U.S. EPA, 2014a). Pieces of evidence were described and scored for logical implication (relevance), strength, and quality (reliability), and summary scores were derived for the bodies of evidence. A version of criteria-guided scoring is presented in this document that generalizes the approach beyond causal assessment.

D.5. Standardized Scoring and Weighting

Consistency can be increased by specifying the evidence and criteria to be considered and the scores and weights to be assigned to the possible outcomes for each type of evidence. An example is provided by the Massachusetts weight-of-evidence method for assessing ecological risks at contaminated sites (Menzie et al., 1996). The method numerically scores evidence (termed measurement endpoints) on a scale of 1 to 5 for 10 properties, weights the scores by scaling values based on the importance of the properties, normalizes the scaled scores, and sums the result to give a "measurement endpoint weight." The body of evidence is then qualitatively weighed based on concurrence of the numerical weights. The standardization of scores and weights requires consistency of the cases to which the method is applied and is facilitated by consensus of all parties.

D.6. Indices

Standardized numerical scoring and weighting of evidence has been extended to the calculation of rather complex risk indices (Benedetti et al., 2012; Dagnino et al., 2008; Semenzin et al., 2008; Bombardier and Blaise, 2000). These indices are not quantitative risk estimates, but they often contain component calculations that are part of quantitative risk assessments such as sums of toxic units, so that the index values provide estimates "of relative hazard for the sites being investigated" (Bombardier and Bermingham, 1999). Because the indices often combine evidence across pieces, types, and endpoints, many of them are computationally complex and require support systems for data entry and computations (Semenzin et al., 2009).

Indices are also used to combine multiple metrics from biological survey data into a value that can be said to represent biological integrity (Karr et al., 1986) or deviation from reference condition (Hawkins, 2006). These indices are arithmetic combinations of metrics believed to discriminate impaired and unimpaired waters. Their derivation is not normally considered to constitute a weight-of-evidence process, but they do combine multiple pieces of evidence to determine a quality—the impairment of a biotic community.

Indices are specialized and their results are difficult to relate to the input data. For example, an index of biotic integrity serves its purpose of identifying impaired waters by numerically aggregating numerous incommensurable biological metrics. To assess the cause of the impairment or risks from remedial actions, however, the individual metrics should be extracted, weighted, and weighed appropriately, as described in Sections 4–6.

D.7. Rule Based

If the potential evidence results are few and all the results are reliable, specifying an interpretation of each potential body of evidence can be possible. The decision matrix for the sediment quality triad is a commonly used example of this approach to weighing evidence [Table D-1 (Chapman, 1990)]. The triad is used to determine whether toxic contaminants are impairing a sediment community. Its elements are chemical analyses of sediments that are compared to toxicological benchmark values, toxicity tests of the sediment and surveys of the sediment biotic community. If the scores for the triad elements are, for example, −, +, +, "unmeasured toxic chemicals are causing degradation," but if it is −, −, +, "alteration is

not due to toxic chemicals." The logic of Chapman's decision matrix is correct if the evidence is reliable, but the evidence might not be sufficiently reliable to support it for many reasons (Table D-2). As a result, weighting and interpreting the evidence often is required. Thus, the standard decision matrix is an idealization that serves primarily to clarify the potential relationships among types of evidence. More recently, ambiguities in results have been recognized and new decision matrices have been developed for sediment assessments that specify a decision for only a few of the possible outcomes; for the other outcomes that include conflicting results, they direct assessors to perform additional analyses (COA Sediment Task Group, 2008; Grapentine et al., 2002). Those additional analyses could use any of the other qualitative WoE methods.

Table D-1. Inference based on the sediment quality triad (Chapman, 1990)

Situation	Chemicals Present	Toxicity	Community Alteration	Possible Conclusions
1	+	+	+	Strong evidence for pollution-induced degradation
2	−	−	−	Strong evidence for no pollution-induced degradation
3	+	−	−	Contaminants are not bioavailable, or are present at nontoxic levels.
4	−	+	−	Unmeasured chemicals or conditions exist with the potential to cause degradation.
5	−	−	+	Alteration is not due to toxic chemicals.
6	+	+	−	Toxic chemicals are stressing the system but are not sufficient to significantly modify the community.
7	−	+	+	Unmeasured toxic chemicals are causing degradation.
8	+	−	+	Chemicals are not bioavailable or alteration is not due to toxic chemicals.

Responses are shown as either positive (+) or negative (−) indicating whether measurable and potentially significant differences from control/reference conditions are determined.

Table D-2. Some ways in which the triad decision table might fail (not including errors or poor technique)

Type of Evidence	False Positive (Exaggerated Effect)	False Negative (Minimized Effect)
Single-chemical analyses/ toxicity tests	Higher bioavailability in the laboratory Site background is high Overly sensitive test organisms (sensitive test species or life stages not present at the site)	Short duration Insensitive test species or life stages Critical response not included Multiple chemicals interact Incomplete routes of exposure
Whole-medium samples/ toxicity tests	Bioavailability increased by handling Sampling below bioactive zone Overly sensitive test organisms Inappropriate reference sites	Chemical lost or altered by handling Insensitive test organisms Inappropriate reference sites Insensitive test organisms Ambient conditions (e.g., UV light) are important to effects Critical response not included Contaminated locations or times missed
Sampling locations/ biological surveys	Confounding Inappropriate reference sites	Organisms too rare Response too infrequent Sensitive organisms not sampled Critical response not included Large sample scale Contaminated locations missed Inappropriate reference sites

Another rule for weighing evidence is independent applicability. The Office of Water classifies a water body as impaired if an adequate piece of evidence demonstrates an impairment, even if other evidence did not detect the impairment. This policy takes into consideration the possibility of false negatives and that different types of evidence detect different types of impairment (Box D-1).

A two-stage rule was developed by the European Center for Ecotoxicology and Toxicology of Chemicals for weighing human and animal data in chemical risk assessments (ECETOC, 2009). The category of evidence with the highest quality for a chemical is used, but if the quality of animal and human evidence is similar, an effect is assumed to be caused by the chemical if either category of evidence shows the effect. This logic could be applied to more than two categories of evidence if equivalent quality scales could be developed for all categories.

D.8. Quantitative Alternatives

Some authors have suggested that quantitative methods are inherently superior for making qualitative inferences from multiple pieces of evidence (Linkov et al., 2009). In particular, multi-criteria decision analysis (MCDA) and Bayesian belief networks (BBNs) have been suggested to be alternatives to conventional WoE (Linkov et al., 2015; Fenton and Neil, 2013).

Box D-1. Independent Applicability and Weight of Evidence

Independent applicability of evidence of impairment has been a policy of the EPA Office of Water. That is, if a water body fails to meet water quality criteria, is toxic, or is biologically impaired, it is an impaired water body. Independent applicability can result from two possible logics.

1. All types of evidence are fallible, so any evidence can generate false negative results. Rather than weigh evidence of impairment against evidence that failed to detect impairment, the evidence of impairment is accepted. Therefore, if any type of reliable evidence detects impairment, the water body is considered impaired. This logic is defensible if the consequences of not detecting an impaired ecosystem are more serious than the consequences of failing to detect. This justification is policy based. In addition, the logic can be defended by recognizing that poor methods or poor implementation are inherently more likely to fail to detect an effect than to detect a false effect. This justification is based on the fact that poor practices introduce extraneous variance are not spatially comprehensive and otherwise tend to obscure effects. Further, it is unlikely that a type of evidence will test or measure the most sensitive conditions, taxa, life stages, responses and interactions between species and stressors. Therefore, even good studies are likely to miss real effects. This does not imply that false positives never occur (see Table D-1), but rather, poor evidence is more likely to result in false negatives and unprotective decisions.

2. Each type of evidence addresses a distinct aspect of impairment. If any one aspect is found in a water body, the water body is impaired in that way. This assumption involves no synthesis. Each type of evidence is independently evaluated with respect to its aspect of impairment. This is explicitly the case with the European Union's Water Framework Directive that distinguishes good chemical status from good ecological and good hydrological statuses (van der Ohe et al., 2014; EC, 2013). European waters should achieve all three. Equivalently, the policy of independent applicability can be interpreted as a requirement to protect three types of integrity: chemical, toxicological, and ecological. This approach is supported by the inherent differences in the types of evidence. For example, a biocriterion based on the index of biotic integrity discriminates sites on a human disturbance gradient (Blocksom and Johnson, 2009). The index responds to the multiple stressors that occur commonly on such gradients and is most responsive to those stressors that are common components of human disturbance. Many of those stressors, such as flashy flow, have no numeric criteria. On the other hand, water quality criteria are based on responses to particular chemicals or other stressors and not necessarily to common human disturbances of aquatic systems. Water quality criteria and biocriteria are criteria for different impairments.

Note that this discussion applies to integrating evidence across types. When applying independent applicability, one might weigh evidence within types. For example, multiple toxicity tests of an ambient water could be combined to determine whether the water has unacceptable toxicity. Also, once a water body is declared impaired, WoE approaches can be applied when assessing the risks associated with alternative remedial or regulatory actions.

Although WoE integrates evidence concerning some environmental quality of interest, MCDA is intended to go farther and identify the best decision, given the problem framing, decision criteria, and preferences [e.g., Which is the best option for dredge spoil disposal given costs, risks, and stakeholder preferences? (Stahl et al., 2002)]. MCDA conventionally requires that probabilities be estimated for the outcomes of a decision and that a decision maker assign utilities to attributes of the outcomes (i.e., the decision criteria) to allow calculation of the expected utility of a decision (Linkov and Moberg, 2012). Weighting is involved in conventional MCDA when combining the multiple decision criteria (cost, aquatic toxicity, public acceptance, etc.). The computational methods of MCDA, however, have been adapted for a variety of uses beyond decision making, including combining numerically weighted evidence (Linkov and Moberg, 2012). One example is weighing the evidence for adverse outcome pathways [Box 3-3, (Collier et al., 2016)]. Linkov et al. (2015) described MCDA as a suitable proxy for Bayesian analysis.

BBNs are graphical models of the uncertainties and dependencies used to calculate the probability of an outcome in a causal network (Fenton and Neil, 2013). BBNs adapted for decision analysis are termed influence diagrams (Carriger and Barron, 2011). BBNs are computationally complex and not familiar to most environmental assessors and stakeholders, but available software makes their application relatively easy. When BBNs are involved in environmental inferences, they may not have data-derived probabilities; instead expert judgment is commonly used. These networks are WoE in the sense that the probability of a variable's state can be considered as its weight and branches of the network can considered chains of evidence (Small, 2008). For example, the probabilities of fishery closure could be one weighted piece of evidence and probabilities of levels of ecological impacts might be another; these can be combined by calculating the conditional probabilities to derive levels of offshore ecosystem services impacts (Carriger and Barron, 2011). Carriger and Barron (2016) have adapted BBNs to explicitly weigh multiple types of ecological evidence. They treated the three types of evidence in the sediment quality triad as branches of a BBN, calculated probabilities that each type was indicative of effects, weighted each in terms of its importance, and then calculated an overall probability of impairment. Because this method does not use a causal network, it is no longer a BBN in the conventional sense. However, it does provide a means of computationally combining evidence rather than using qualitative logic.

Although these methods have not been used for conventional qualitative WoE tasks such as identifying causes or hazards, nothing in this document precludes using them where appropriate. An example of a relevant potential regulatory application is the use of BBNs to optimize choices of toxicity tests in European chemical regulation in place of judgment-based WoE (Jaworska et al., 2010). This case is ideal for these quantitative methods because it is a relatively simple and consistent problem with a clear decision structure. Objectively estimating constituent probabilities of, for example, a positive rat carcinogenicity test given a positive Ames assay is possible. One simply needs a sufficient database of test results.

D.9. Summarize Only

Some assessors have argued that the weighing of evidence should not determine what conclusion is best supported by the evidence (Gray, 1994). Instead, they argue that assessors should assemble, clearly summarize, and simply present the evidence to the decision maker with enough background information for them to make a decision. Although this approach takes subjective judgments concerning the integration of evidence away from assessment scientists, it confers responsibility on decision makers to interpret scientific information, which they might not be trained to do, and requires time for inferential work that they might not have.

D.10. Conclusions

This summary of WoE approaches is intended to show the range of techniques that might be used for qualitative WoE. Methods proposed or used, however, do not necessarily fit into these categories. For example, McDonald et al. (2007) translated qualitative weights to numbers that are combined algebraically and then translated into a final qualitative conclusion. This method is typical of the WoE literature, which is replete with methods developed for the individual application. The inclination to develop a new WoE method for each application might be diminished by the availability in this document of a generic WoE approach that is flexible but provides some consistency across a variety of applications.

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APPENDIX E. CHARACTERISTICS OF INFERRED QUALITIES

Qualitative weight of evidence (WoE) addresses qualities, each of which is characterized by certain characteristics. For example, if the quality of interest is causation, the hypothesized relationship should have the characteristics of causation such as, the causal agent and the affected entity interact. Association of evidence with characteristics of causation, or characteristics of any other quality being addressed, can serve two purposes. First, characteristics explain what the evidence does for the hypothesis (Section 6.2). For example, aqueous concentrations of a chemical in streams can demonstrate co-occurrence but not interaction. Second, categorizing the evidence in terms of the characteristics can help to perform and justify the inference. For example, a WoE table organized in terms of causal characteristics may show that there is abundant evidence for co-occurrence but none for interaction, which would raise questions about bioavailability. Only characteristics of causation are established, but considering appropriate characteristics of other inferred qualities such as impairment or protectiveness also might be useful. Potential characteristics for five qualities are presented here.

E.1. Characteristics of Causation

In environmental assessments, WoE has been used primarily to assess causality. In fact, WoE has been equated with determining the degree of credence due a causal hypothesis (Rhomberg et al., 2013; Krimsky, 2005). WoE is particularly associated with causation because causality is a fundamental concept, and no one piece or type of evidence can prove causation (Norton et al., 2014). Rather, the relationships of evidence to characteristics of causal relationships should be considered. Six characteristics of causation, developed for ecological causal assessments, have proven useful for that purpose (Table E-1). By analogy to Hill's considerations, they have been called Cormier's causal characteristics (CCC).

Few bodies of evidence for causal assessments include evidence for all of these characteristics. Even in very well-studied cases, evidence of conditions prior to induction of the effect is seldom available to consider time order (Table 7-1). Even an incomplete WoE table based on characteristics, however, provides more insight into what is known about causation in a case than a table based only on types of evidence.

Although these characteristics were developed for causation in specific cases, they also can be relevant to general causation (i.e., Does agent *x* cause effect *y*?), if actual cases are available. The characteristics can be used to demonstrate that, at least in those actual cases, the agent could cause the effect. They can be particularly useful when the general question is framed in terms of real-world conditions. An example is the use of the characteristics to determine that, where aqueous conductivity is elevated due to major mineral ions in West Virginia and Kentucky, the ion mixture causes the extirpation of invertebrate genera (Cormier et al., 2013; Cormier and Suter, 2013; U.S. EPA, 2011b).

Although the characteristics apply to, and can be observed in actual cases, they are not observable in the same way when the general causal question is hypothetical. That is, hypothetically, can *x* cause *y* rather than, in fact, did *x* cause *y* or is *x* causing *y*? In particular, when the only evidence of effects is from toxicity tests, the co-occurrence and its antecedents are simply the design and setup of the test, and the time order is inevitable. Sufficiency in hypothetical causal assessments is not of interest because no particular effect level is identified, so no particular exposure is sufficient. Instead, we use the test data to establish an exposure-response relationship that can be applied generally. The real causal concerns are with the relevance of the co-occurrence, interaction, and alteration in the test to those in the field. Are the conditions, durations, species, and life stages in the tests relevant to the co-occurrence of interest in the

field? Are the interactions of the stressor and test organisms and the resulting alterations plausible in the field? Are others likely to be more sensitive or important?

Table E-1. Characteristics of causal relationships[a]

Causal Characteristics	Description	What Evidence of a Characteristic Shows
Time order	The cause precedes the effect.	Change in the entity after exposure to the cause and not before
Antecedence	The causal relationship is a result of a larger web of antecedent cause-and-effect relationships. Evidence includes sources and routes of transport.	Earlier events that led to the particular causal event. It demonstrates that a potential causal event is part of a network of prior causal events, which increases confidence that the potential causal event actually occurred (e.g., that it was not a result of a measurement error or hoax).
Co-occurrence	The cause co-occurs with the susceptible entity in space and time. Evidence includes contaminant concentrations in ambient media and habitat alterations.	The presence of both a causal agent and the affected entity in circumstances that create the potential for exposure
Interaction	The cause interacts with the entity in a way that can lead to the effect. Evidence includes injuries, body burdens, and biomarkers.	Signs that the entity has been exposed to the agent in such a way that changes can be initiated
Sufficiency	The intensity, frequency and duration of the cause are adequate, and the entity is sufficiently susceptible to produce the type and magnitude of the effect.	Enough of the cause and a sufficiently susceptible entity that can result in the level of the observed effect
Alteration	The entity is changed by physical, chemical, or other mechanisms leading to the defined effect. Evidence includes symptoms and related attributes of the affected entities.	Changes in the entity attributable to or at least appropriate to the cause, which can indicate that the mechanism is acting

[a] Modified from Norton et al. (2014); Cormier et al. (2010).

The characteristics of causation can be arranged in a logical sequence: *antecedent* causes lead to *co-occurrence* of the proximate cause with susceptible or affected organisms, which leads to *interaction* with the affected organisms and, if the interaction is *sufficient*, leads to *alteration* of the organisms. The characteristics also serve to prompt assessors to make full use of the evidence with respect to all characteristics of causation. For example, it is obvious that laboratory test data provide evidence concerning sufficiency, but the data also might provide evidence of alterations characteristic of organisms affected by the tested agent that might be observed in the field.

E.2. Characteristics of Protection

Criteria, standards, screening levels and other benchmarks are intended to define a limit on exposure that would be adequately protective. Protection, like causation, is a difficult concept with multiple characteristics (Table E-2). Benchmarks are usually derived using one piece or one type of evidence. WoE might be used, however, to assess the confidence provided by diverse evidence that a benchmark or a procedure for deriving benchmarks is appropriately protective. Although the U.S. Environmental Protection Agency has not explicitly used this potential application of WoE, characteristics like those Table E-2 might be useful.

Table E-2. Potential characteristics of a protective benchmark

Characteristics of Protective Benchmarks	Description
Causal relationship	The exposure-response relationship used in the derivation is likely to be causal.
Predictive model of the relationship	The model of the relationship predicts the effects of specified exposures.
Represent sensitive endpoints	Known sensitive endpoint species or other entities and responses can be represented by the relationship.
Exposure metric is relevant	The exposure metric represents the relevant exposure of the sensitive entities.
Set at an appropriately protective level	Independent data demonstrate, with sufficient confidence, a lack of effects of concern on the aquatic community and constituent taxa.
Discriminatory power	The benchmark discriminates between impaired and unimpaired communities with sufficient confidence.

E.3. Characteristics of Contaminants of Concern

Risk assessments of contaminated sites typically develop lists of contaminants of concern based on chemical analyses of site media. The contaminants of concern are then the subjects of the risk assessment. Concern may be determined by comparison to ecological benchmarks, but more often multiple characteristics of a contaminant are weighed to determine which make the list. The characteristics in Table E-3 are based on a text and a recent Superfund ecological risk assessment (Black & Veatch Special Projects Corps, 2011; Suter et al., 2000). The list may not be exhaustive.

Table E-3. Characteristics of a contaminant of concern at a contaminated site

Characteristics of Contaminants of Concern	Description
Associated with the waste or source	Chemicals that are not associated with the waste or effluent of interest could be from an extraneous local source, regional contamination, or natural background.
Frequently detected	Chemicals that are infrequently detected at the site are of lesser concern and might be artifacts.
Greater than local background	Chemicals at background levels are not of concern, unless the anthropogenic form is more bioavailable or toxic.
At potentially toxic levels	Concentrations above relevant ecotoxicological benchmarks are of concern.
Detection limits are inadequate	Chemicals that could not be detected at toxic levels are of concern, particularly if they are associated with the waste or source.
Belongs to the same class as an identified contaminant of concern	A chemical that is not of concern alone might belong to a class, such as polycyclic aromatic hydrocarbons, that could be assessed jointly.

E.4. Characteristics of Biological Impairment

Impairment of biotic populations or communities is determined under the Clean Water Act's Section 303(d) and in various other contexts. Although a population or community need be impaired in only one way to be categorized as impaired (Box D-1), multiple characteristics of impairment could increase confidence in the designation and increase support for a regulatory or remedial action. A few of

the possible characteristics of impairment include low taxonomic richness, proportion of dominant taxa, toxicity, contamination, poor physical habitat, and poor aesthetics, among others. These characteristics are familiar to ecological assessors and require no descriptions here.

E.5. Characteristics of Remediation

Assessments of the success of remedial actions are common and important examples of outcome assessments. Remediation is judged in terms of performance and effectiveness of the intervention (Table E-4). Obtaining sufficient evidence to determine whether ecological goals are attained because of the remedial action and not just natural recovery is valuable.

Table E-4. Potential characteristics of remediation

Characteristic of Remediation	Description
Performance of the Intervention	
Functions	The remedial technology functions as intended.
Reduces the agent	The technology substantially reduces the level and extent of the contaminant or other agent that causes the risk.
Achieves the physical/chemical goal	The levels of the causal agent are reduced sufficiently to achieve the goal.
Effectiveness of the Intervention	
Endpoint less exposed	The exposure of the environmental endpoint entity to the agent and their interaction are reduced as predicted.
Endpoint improved	The abundance, diversity, function, or other attributes of the endpoint entity improve within the expected time following the remediation.
Endpoint goal achieved	Reference conditions or other ecological endpoint goal are achieved in response to remediation.

E.6. Summary

Qualitative WoE is performed to support inferences concerning some qualitative property such as causality, protection, concern, or impairment. Causality has been the principal quality inferred by WoE in environmental assessments and is the only quality for which characteristics have been available. Tentative lists of characteristics are presented here as examples to demonstrate the potential use of characteristics as an organizing principle for WoE. Other qualitative properties such as recovery also might be addressed by weighing the evidence for defined characteristics. As in causal inference, weighing evidence for characteristics of these other properties could provide a better explanatory structure to WoE than simply weighing pieces or types of evidence.

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Appendix 21

United States Environmental Protection Agency (USEPA), 2014. Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework. EPA 600/R-14/061 September.

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Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework



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Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (LEAF)

D.S. Kosson[1], H.A. van der Sloot[2], A.C. Garrabrants[1] and P.F.A.B. Seignette[3]

[1] Vanderbilt University
Civil and Environmental Engineering
Nashville, TN 37215

[2] Hans van der Sloot Consultancy
Langedijk, The Netherlands

[3] Energy Research Centre of The Netherlands
Petten, The Netherlands

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Susan A. Thorneloe

U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
Air Pollution Prevention and Control Division
Research Triangle Park, NC 27711

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ABSTRACT

This report presents examples of the relationships between the results of laboratory leaching tests, as defined by the Leaching Environmental Assessment Framework (LEAF) or analogous international test methods, and leaching of constituents from a broad range of materials under disposal and beneficial use scenarios. A framework is defined for interpretation of laboratory testing results, including approaches for comparison of laboratory testing of fresh or field aged materials and leachate results from field applications. This report also illustrates the use of chemical speciation modeling for interpretation of leaching data and facilitated evaluation of scenarios beyond the conditions of laboratory testing. This report then provides recommendations for selection and use of the LEAF test methods, data interpretation, and chemical speciation-based models as tools for environmental leaching assessment.

Ten field cases were evaluated to illustrate how LEAF results can be used to compare to field leachate data for either the disposal or beneficial use of seven different materials. The field data presented in this report include leachate from field lysimeters, porewater from landfill or use applications, eluates from leaching tests conducted on sample cores taken from field sites, and leachate collected from landfills. The LEAF laboratory leaching tests in the comparisons are shown to be effective for estimating the field leaching behavior for a wide range of materials under both disposal and use conditions.

Interpretation of laboratory leaching test results to the field must be conducted within the context of the controlling physical and chemical mechanisms of the field scenario (e.g., pH, L/S, mode of water contact). The effects of field conditions that are beyond the physical-chemical domain of the laboratory test conditions can be evaluated through a combination of empirical calculations to extrapolate laboratory results and chemical speciation and reactive mass transport simulations that are calibrated based on LEAF testing results. Both direct laboratory testing results and outcomes from chemical speciation and reactive mass transport simulations can be used to provide a source term for subsequent fate and transport and risk assessment evaluations.

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EXECUTIVE SUMMARY

ES-1 Objectives and Background

The primary objective of this report is to provide an evaluation of the applicability and limitations of using laboratory leaching tests, as defined by the LEAF and LEAF-analogous methods, for estimating leaching of constituents of potential concern (COPCs) from a broad range of materials under field disposal and beneficial use scenarios. This evaluation compares results from laboratory testing of "as produced" material using LEAF methods, laboratory testing of "field aged" material, and field leaching studies of the material. Interpretation of LEAF leaching data is conducted within the context of a defined conceptual leaching model. Chemical speciation modeling is used as a tool to facilitate evaluation of scenarios beyond the conditions of common laboratory testing (i.e., normalize the laboratory data to the field conditions by estimating the impact of factors not practical to achieve in the laboratory, but which are known to occur and affect leaching). A second objective of this report is to provide recommendations on the selection and use of LEAF testing for different types of materials or wastes when evaluating disposal or use scenarios.

The Leaching Environmental Assessment Framework (LEAF) is fundamentally different than the simulation-based approach to testing, such as used for the toxicity characteristic leaching procedure (TCLP)[1], because it focuses on characterization of intrinsic material-specific leaching behaviors controlling the release of COPCs from solid materials over a broad range of test and environmental conditions, with application of the resulting leaching data to specific disposal or use conditions (Kosson et al., 2002). The framework consists of four laboratory leaching methods, data management tools, and leaching assessment approaches developed by Vanderbilt University in conjunction with U.S. EPA and international partners.

The four leach testing methods described in LEAF have been validated through interlaboratory studies (Garrabrants et al., 2012a, 2012b) and adopted into SW-846, the EPA compendium of laboratory tests (EPA, 2013a) as:

- Method 1313 – Liquid-Solid Partitioning as a Function of Extract pH using a Parallel Batch Extraction Procedure
- Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials using an Up-flow Percolation Column Procedure
- Method 1315 – Mass Transfer Rates in Monolithic and Compacted Granular Materials using a Semi-Dynamic Tank Leaching Procedure
- Method 1316 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio in Solid Materials using a Parallel Batch Extraction Procedure

These tests may be applied to solid materials to determine fundamental leaching parameters including liquid-solid partitioning (LSP) of constituents as a function of pH and

[1] TCLP was designed to simulate a plausible mismanagement scenario of co-disposal in a municipal solid waste landfill.

cumulative liquid-to-solid ratio (L/S) as well as the rate of constituent mass transfer from monolithic and compacted granular materials. Coordinated development of LEAF has occurred between research laboratories in the United States (U.S.) and the European Union (EU). The general approach and test methods described in this report also are applicable to assess release of organic substances, radionuclides and nano-particles. However, additional consideration is needed with respect to compatibility of the constituents of interest to the container materials used.

Leaching tests are tools used for estimating the environmental impact associated with disposal or utilization of materials and wastes on the land (e.g., soils, sediments, industrial wastes, demolition debris, etc.). Results of leaching assessments based on testing and interpretive models provide a source term as one part of an evaluation of environmental safety. In addition to test results, integral factors in applicability assessment or criteria development for use and disposal include (i) definition and application of appropriate fate and transport models from the source to the points of compliance and (ii) establishment of risk-informed constituent concentration thresholds at defined points of compliance.

Characterization of leaching behavior using the LEAF tests along with scenario-specific information can be used to assemble a leaching "source term" for many environmental scenarios or levels of environmental assessment including:

- screening level assessments at a site-specific, regional or national scale;
- detailed site-specific evaluations;
- performance comparisons between different materials or treatment processes under specific disposal or use scenarios;
- development of chemical speciation based models to evaluate potential material leaching behavior under field conditions that may be difficult or impossible to reproduce in the laboratory.

Assessing the applicability and accuracy of any predictive leaching assessment approach, however, requires evaluation through the use of pilot- and full-scale field studies in which leaching predictions for a particular material based on laboratory testing may be compared to measured leachate concentrations for that material collected under field conditions. Field studies also provide information regarding the relative importance of natural processes on leaching of COPCs including water flow patterns, extent of local chemical equilibrium, and chemical changes due to aging or exposure to the environment.

This report facilitates understanding application and accuracy of the LEAF test methods by addressing the following important relationships of LEAF test data:

- within datasets from the different LEAF test methods conducted on the same material;
- compared to the results of test methods currently in more widespread use, specifically the Toxicity Characteristic Leaching Procedure (TCLP; EPA Method 1311) and the Synthetic Precipitation Leaching Procedure (SPLP; EPA Method 1312);

- relative to field leaching and material behavior over a wider set of disposal and use scenarios;
- in conjunction with chemical speciation modeling and other knowledge to evaluate leaching under conditions beyond typical laboratory testing conditions.

Furthermore, this report provides recommendations for how environmental scientists, engineers and regulators may use LEAF as part of their evaluation programs.

ES-2 Evaluation Cases

In order to illustrate the relationship between laboratory data and field measurements, ten disposal and beneficial use cases for which both laboratory and field data exist have been identified and are presented in this report. These ten field evaluation cases consist of combinations of laboratory testing and field analysis for the following seven materials:

- coal fly ash (CFA; 3 cases);
- fixated scrubber sludge with lime (FSSL) produced at some coal-fired power plants by combining coal fly ash with flue gas desulfurization (FGD) scrubber residue and lime (1 case),
- municipal solid waste incinerator bottom ash (MSWI-BA; 2 cases);
- a predominantly inorganic waste mixture comprised of residues from soil cleanup residues, contaminated soil, sediments, construction and demolition (C&D) waste and small industry waste (IND; 1 case);
- municipal solid waste (MSW; 1 case);
- cement-stabilized municipal solid waste incinerator fly ash (S-MSWI-FA; 1 case);
- portland cement mortars and concrete (1 case).

Table 1-1ES-1 provides a summary of the cases and data sets evaluated in this report. In this table, the types of leaching test data (i.e., laboratory tests conducted on "as produced" site materials,[2] analog materials or field materials), field data (i.e., leachates collected from the field application) and case conditions are defined for each case. The symbols representing leaching test data for the cases in Table 1-1 include "pH" for pH dependent leaching data (e.g., from Method 1313 or equivalent), "L/S" for L/S-dependent leaching data (e.g., Method 1316 or equivalent), "Perc" for percolation column data (e.g., from Method 1314 or equivalent), and "MT" for mass transfer data (e.g., from Method 1315 or equivalent). For a few of the field case studies where laboratory test results were not available for the specific material present in the field, laboratory test results on closely analogous materials are used for comparison with field measurements. The field data presented in this report include (i) leachate from field lysimeters, (ii) porewater from landfill or use applications, (iii) eluate from leaching tests on sample cores taken from field sites, and (iv) leachate collected from landfills.

[2] In this report, "as produced" materials refer to newly processed materials that are ready for disposal or beneficial use in a field application. This distinction is made relative to aged field materials that have been retrieved from a field application for testing in the laboratory.

Table ES-1. Summary of Laboratory-To-Field Comparison Cases.

		Leaching Test Data			Field Data	
Report Section	Case Name (Country)	Site Materials [1]	Analog Materials [2]	Field Materials [3]	Leachates	Case Conditions
4.1	Coal Fly Ash Landfill Leachate (U.S.)	-	pH L/S Perc	-	Multiple landfills	Ox-Red, pH 6-13
4.2	Coal Fly Ash in Large-Scale Field Lysimeters (Denmark)	L/S	-	-	Lysimeters	Ox-Red, pH 11-13
4.3	Landfill of Coal Combustion Fixated Scrubber Sludge with Lime (U.S.)	pH L/S	-	pH L/S MT	Landfill	Ox, pH 6-12
4.4	Coal Fly Ash Used in Roadbase and Embankments (The Netherlands)	L/S	-	-	Roadbase, Embankment	pH 8-12
4.5	Municipal Solid Waste (MSW) Incinerator Bottom Ash Landfill (Denmark)	-	pH Perc	-	Landfill	Reducing, pH 7-11
4.6	MSW Incinerator Bottom Ash Used in Roadbase (Sweden)	-	pH Perc	pH L/S Perc	Roadbase test section	Ox-Red, pH 7-10
4.7	Inorganic Industrial Waste Landfill (The Netherlands)	pH Perc	-	pH L/S Perc	Lysimeters, Landfill	Ox-Red, pH 6-9
4.8	MSW Landfill (The Netherlands)	pH Perc	-	pH L/S Perc	Landfill, Multiple landfills	Strongly reducing, High DOC, pH 5-9
4.9	Stabilized MSW Incinerator Fly Ash Disposal (The Netherlands)	pH Perc MT	-	pH	Pilot test cells, Landfill	Oxidizing, pH 8-13
4.10	Portland Cement Mortars and Concrete (Germany, Norway, The Netherlands)	pH (recycled concrete)	pH	pH	-	Oxidizing, Carbonation, pH 8-13

Notes:

pH = pH-dependent leaching data (e.g., EPA Method 1313, PrEN 14429, PrEN 14997).

L/S = L/S-dependent data with deionized or demineralized water (e.g., EPA Method 1316, EN 12547).

Perc = Percolation column data, up-flow or down-flow (e.g., EPA Method 1314, CEN/TS 14405).

MT = Monolith or compacted granular mass transfer data (e.g., EPA Method 1315, PrEN 15863).

Ox-Red = oxidized to reducing conditions.

[1] Site Materials refers to "as produced" source materials placed into the field application.

[2] Analog Materials refers to comparative materials for cases where source material sample leaching characterization information was not available.

[3] Field Materials refers to materials retrieved from a field application for laboratory testing.

The field component and laboratory testing comparison for each case is as follows:

Case 1 (§ 4.1) examined the leaching behavior of coal fly ash under landfill disposal conditions as a class of materials by comparing the leaching concentration ranges and pH dependent relationships for field leachates and pore water in comparison to laboratory test results obtained from LEAF testing of a wide range of coal fly ash samples.

Case 2 (§ 4.2) compared the field leaching from large scale lysimeters over 7 years to results from laboratory percolation column tests.

Case 3 (§ 4.3) compared field leaching, field pore water samples, and laboratory leaching test results on landfill core samples, laboratory leaching test results on fresh "as disposed" material for mixed coal fly ash and FGD scrubber residues, referred to as fixated scrubber sludge.

Case 4 (§ 4.4) compared the results of field leaching over 2 years from a road base and embankment constructed with coal fly ash to percolation column results. Laboratory pH dependent leaching test results from an analogous material were also used for comparison.

Case 5 (§ 4.5) focused on landfill leaching from combined MSWI bottom ash and MSWI fly ash that was deposited in layers and monitored for 30 years. Field leaching results were compared to laboratory leaching of core samples obtained from the landfill and laboratory pH dependent test and percolation column test results from analogous materials.

Case 6 (§ 4.6) focused on MSWI bottom ash used as a subbase below an unbound base course and surface asphalt layers that was cored and evaluated 15 years after the road construction. Single point leaching was carried out on an extensive set of samples (n= 53) to evaluate the heterogeneity of material and exposure under field conditions.

Case 7 (§ 4.7) focused on comparison of laboratory and field lysimeter results to leaching from a 12,000 m^3 field pilot landfill for a mixture of predominantly inorganic wastes.

Case 8 (§ 4.8) focused on a 45,000 m^3 pilot-scale landfill for MSW in Landgraaf, The Netherlands, that was filled with a mixture of sewage sludge, construction and demolition (C&D) waste, MSW, industrial waste, car shredder waste, foundry sand, and soil cleanup residue. The pilot study was established to evaluate the biodegradation of organic matter-rich waste by leachate renewal and recycling.

Case 9 (§ 4.9) focused on a pilot-scale field demonstration of near surface disposal of MSWI fly ash stabilized with a mixture of pozzolonic binders (i.e., multiple ash types). Initial samples of the stabilized material were subjected to laboratory leaching tests. Leachate and runoff was collected during that evaluation period of approximately 4 years, after which cores were taken of the stabilized material for laboratory leaching testing. Comparative results were also available from a full-scale monofill receiving the

same stabilized waste. In addition, laboratory leaching was carried on cores obtained from field testing after 10 years from a corresponding full-scale facility.

Case 10 (§ 4.10) compared the leaching of cement and concrete samples with different aging periods, including 28 days (standard mortar), 4 years (recycled concrete aggregate), 40 years (field test site) and 2,000 years (Roman cement).

For each evaluation case, the following generalized approach was used to compare laboratory test results for a material to its field leaching:

(i) LSP Leaching – laboratory leaching results provide an understanding of the LSP for COPCs as a function of pH (e.g., from Method 1313) or L/S (e.g., from Method 1316 or Method 1314). [Field values for these parameters were also obtained]

(ii) Dynamic Leaching – percolation column leaching test results (e.g., from Method 1314) provide an understanding of percolation-controlled leaching of COPCs under idealized conditions, and/or mass transport leaching test results (e.g., Method 1315) provide intrinsic COPC release rates.

(iii) Laboratory-to-Field Comparison – laboratory LSP or dynamic leaching results (e.g., percolation or mass transport data) and conditions are compared with results and conditions measured in the field scenario to evaluate whether local equilibrium is controlling observed leaching under field conditions. If not, this comparison is used to determine the extent of preferential flow effects in percolation scenarios or limited water contact in mass transport scenarios.

(iv) Chemical Speciation and Reactive Transport Modeling – a chemical speciation fingerprint (CSF) for the material of interest and subsequent reactive transport modeling (i.e., combination of speciation and mass transport models) are used to explore the extent that non-ideal conditions (e.g., preferential flow) and aging conditions (e.g., redox changes, carbonation, etc.) influence observed field leaching behavior.

The broad range of potential uses of environmental leaching assessment implies that there is a need for a graded or tiered approach that provides for flexible, scenario-based assessments and allows tailoring of the needed testing and information based on the type of intended use of the assessment and available prior or related information. Furthermore, determination of constituent leaching estimates that are greater than or equal to the actual expected constituent leaching is necessary to maintain environmental protection in the face of uncertainty (often referred to as a "conservative" approach). The extent of the assessment bias toward over-estimation of COPC leaching should depend on the nature of the decision and the uncertainties regarding the available material and scenario information. However, even when used as a screening test, LEAF methods provide release estimates that are more accurate, reliable (because of test conditions defined based on fundamental principles of environmental chemistry and mass transport) and robust (able to consider multiple or evolving physical-chemical conditions) than are obtainable using any single-point leaching test. Testing using LEAF is considered to be more accurate because of the ability to consider the range of anticipated environmental conditions and intrinsic leaching characteristics of materials.

ES-3 Leaching Fundamentals and Use of Laboratory Leaching Data

LEAF is described in detail within the report and provides a conceptual framework for interpreting characteristic leaching behavior and comparing LEAF laboratory test results to field leaching. Detailed material characterization consists of laboratory measurement (i) LSP as a function of pH (pH-dependent leaching), (ii) LSP as a function of L/S either by percolation column or by parallel batch procedures, and (iii) rates of mass transport under diffusion-controlled conditions.

Equilibrium-based leaching test measure LSP under specified test conditions. For example, Methods 1313 and 1316 determine the effect of pH and L/S, respectively, on LSP under batch test conditions which are intended to approximate chemical equilibrium between the aqueous and solid phases (Garrabrants et al., 2010). Column percolation tests carried out at relatively slow flow conditions (e.g., residence time ~1 day or less) approximate local equilibrium between the pore solution and solid phase at any given point in the column. Column percolation tests also often are considered a surrogate for field leaching conditions for scenarios where infiltration or groundwater passes through a relatively permeable solid; however, field conditions are much more likely subject to preferential flow, and therefore infiltration bypassing the material in question results in lower observed concentrations in the field than the laboratory.

The following are characteristic responses of LSP observed from equilibrium-based leaching tests:

Response 1. Total Content vs. Availability. The fraction of the specific constituent that is not bound in recalcitrant phases and is released over the domain of leaching conditions (i.e., L/S=10 mL/g dry and pH between 2 and 13) is considered the available fraction of the total content in the material, often referred to as "availability." The sum of the constituent incorporated into recalcitrant phases and the available content of that constituent is equal to the total content of the constituent in the material.

Response 2. **LSP less than Aqueous Solubility.** A constituent, or fraction thereof, may be present in one or more readily soluble solid phases that dissolve fully into the aqueous phase under the leaching test conditions with the resultant constituent concentration in the aqueous phase less than the aqueous solubility (i.e., an under-saturated solution based on chemical thermodynamics). One example of this case is the dissolution of sodium chloride when the total amount of dissolvable sodium and chloride results in concentrations in the aqueous phase that are less than the respective solubility for each constituent. In this case, the available content of a constituent could be the limiting factor in the concentration seen in laboratory testing (referred to as "availability-limited" leaching).

Response 3. LSP at Aqueous Solubility. A constituent, or fraction thereof, may be present in one or more solid phases that will only partially dissolve into the aqueous phase under the leaching test conditions with the resulting constituent concentration in the aqueous phase at the aqueous solubility (i.e., a saturated solution). This phenomenon is referred to as "solubility-controlled" release.

Response 4. Surface Interaction. A constituent, or fraction thereof, may be present as a readily soluble species that is not initially present in the material as a distinct, precipitated solid phase. The constituent species may be present at a relatively low concentration and associated with a reactive solid surface where the LSP is controlled by adsorption/desorption or ion exchange phenomena. Such reactive surfaces include oxide minerals (e.g., iron, manganese, or alumina (hydr)oxides), (ii) clay-like minerals, (iii) particulate organic carbon (such as from decay of plant matter), and (iv) particulate carbon (such as char from combustion or activated carbon).

For many constituents, the initial speciation (i.e., chemical forms) and distribution in the solid material are often a combination of two or more of the four phenomena described as characteristic responses above. Primary factors that can modify the LSP of a particular constituent are pH, eluate ionic strength and aqueous phase complexation.[3] For constituents with multiple valence states under the range of oxidizing to reducing conditions observed in the field, the oxidation-reduction potential (ORP) of the porewater and bulk solutions in contact with solid materials can influence the resulting LSP and precipitated solid phases. The effect of redox conditions can also extend to constituents with only single valence state because of precipitation with reduced species (i.e., zinc precipitation with sulfides).

Laboratory leaching test results from pH dependent leaching (e.g., Method 1313) are used in this report in conjunction with other information known about a material (e.g., availability data, total carbon, etc.) to develop a "chemical speciation fingerprint" (CSF). This CSF includes the set of mineral phases, adsorbing surfaces, organic matter fractionation and the fraction of the total content of each constituent that is available for leaching. The resulting CSF may be used in conjunction with the results of L/S-dependence tests to assess the impact of low L/S ratios (such as those present under field conditions) on LSP or with results from percolation column tests (e.g., Method 1314) or results from mass transport (e.g., Method 1315) to calibrate needed mass transport parameters for simulations of dynamic leaching tests (i.e., mobile-immobile fractions for percolation column tests or tortuosity for monolith diffusion tests). The resulting combination of the CSF and mass transport parameters may then be used in conjunction with one or more field conceptual models (i.e., percolation with preferential flow or diffusion controlled release from a monolith) and a variety of initial and boundary conditions (e.g., system geometry, infiltration rate and chemistry, redox state, etc.) to estimate release under a range of field scenarios. Characterization of uncertainty at each step is needed to understand the accuracy and limitations of each simulation.

[3] The final conditions achieved during a leaching test or field conditions define the LSP, not the initial test conditions, because these are the conditions that define liquid-solid equilibrium. Thus, the pH of an eluate at the conclusion of a leaching test defines LSP, not the initial pH of the eluent.

ES-4 Case Summaries

Each of the cases included consideration of multiple constituents (from 5 up to 29 per individual case) that illustrated each of the characteristic leaching responses indicated above and provided the basis for understanding relationships between laboratory test results and field data as a function of constituent, material and field management scenario. The observed field pH domain, constituents considered and the primary conclusions for each of the case studies are presented in Table ES-2. The observed field pH domain indicated for a specific case may be narrower than what would be considered the applicable pH domain for the material and field scenario when applied prospectively because (i) the range of material characteristics may be broader than the specific materials tested in individual cases (for example, coal fly ash may range from very alkaline to acidic, as indicated by Case 1 but the specific coal fly ash evaluated in Case 2 was alkaline), and (ii) the relatively short duration of field testing (i.e., typically less than 10 years) may not fully reflect the long-term aging of the materials (for example, strongly alkaline materials are expected to react with atmospheric or biogenic carbon dioxide to result in slightly alkaline pH of ca. 8-9).

Table ES-2. The observed field pH domain, constituents considered and the primary conclusions for each of the case studies.

Report Section	Case Name (Country)	pH Domain	Constituents Considered	Primary Conclusions
4.1	Coal Fly Ash Landfill Leachate (U.S.)	6-13	Al, As, B, Ca, Cd, Co, Cr, Cu, F, Fe, K, Li, Mg, Mo, Mn, Na, Ni, Pb, S, Se, Si, Sr, Tl, V, Zn DOC	For a well-defined class of materials, the upper range of constituent concentrations from pH dependent testing over the relevant pH domain can be considered a conservative estimate of the upper limit of field concentrations constituents where solubility limits leaching. For highly soluble constituents, pH dependent test concentrations should be adjusted based on a correction factor between laboratory L/S and field pore water L/S. Field leachate concentrations lower than anticipated may be a consequence of either (i) reducing conditions (as seen for chromium and selenium) or (ii) common ion effects (as seen for barium in the presence of sulfate).
4.2	Coal Fly Ash in Large-Scale Field Lysimeters (Denmark)	11-13	Al, As, B, Ba, Br, Ca, Cd, Cl, Cr, Cu, Fe, Hg, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Sn, Sr, V, Zn; DOC	Laboratory percolation column testing provide a good estimate of initial leachate concentrations under field conditions. Laboratory percolation column testing also provides a good approximation of the evolution of leaching profiles as a function of L/S that would be expected under field conditions in the absence of preferential flow and establishment of reducing conditions.
4.3	Landfill of Coal Combustion Fixated Scrubber Sludge with Lime (U.S.)	6-12	Al, As, B, Ba, Ca, Cd, Cl, Co, Cr, Cu, F, K, Li, Mg, Mn, Mo, Na, S, Sb, Se, Si, Sr, Tl, Ti, V, Zn DOC	Carbonation of samples during field aging had a significant impact on the pH dependent leaching behavior of periodic table Group II elements (i.e., calcium, strontium) and some trace elements (i.e., arsenic). Higher concentrations of highly soluble species (i.e., potassium, sodium, chloride) observed in porewater compared laboratory testing can be readily estimated based on the ratio of laboratory L/S to field porewater L/S.
4.4	Coal Fly Ash Used in Roadbase and Embankments (The Netherlands)	8-12	Ca, Cr, Mo, S, Se,	The combined use of pH dependent leaching, percolation column leaching and chemical speciation simulations provided insights into the redox condition in the material (establishment of reducing conditions), impacts of carbonation, and the resultant consequences for leaching of oxyanions (e.g., chromium). Percolation column experiments provided a realistic estimate of the upper bound concentration for leaching of COPCs.

Report Section	Case Name (Country)	pH Domain	Constituents Considered	Primary Conclusions
4.5	Municipal Solid Waste (MSW) Incinerator Bottom Ash Landfill (Denmark)	7-11	Al, Cd, Ca, Cl, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, Pb, P, Zn	Concentrations obtained from laboratory batch extractions at L/S of 2 mL/g can be used as an estimate of peak concentrations in leachate from a heterogeneous fill material. The L/S of 2 L/kg is greater than the expected porewater L/S of ca. 0.2 to 0.5 L/kg but reflects the impacts of preferential flow through a heterogeneous material in a landfill. Testing at L/S of 2 mL/g in conjunction with pH dependent testing (at L/S of 10 mL/g) provides an estimate of increased concentrations relative to pH dependent testing that would be expected for highly soluble constituents and resulting from dissolved organic carbon (DOC) complexation effects at the low L/S values associated with early leachate from MSW landfills.
4.6	MSW Incinerator Bottom Ash Used in Roadbase (Sweden)	7-10	As, Al, B, Ba, Br, Ca, Cd, Cl, Cr, Co, Cu, Fe, K, Li, Mg, Mn, Mo, Na, Ni, P, Pb, S, Sb, Se, Si, Sr, V, Zn DOC	Laboratory testing of composite samples from field cores using pH dependent leaching and percolation column tests showed LSP and column elution consistent with leaching of MSW incinerator bottom ash from other sources with respect to both highly soluble constituents (e.g., Na, K, Cl) and constituents where solubility limits LSP as a function of pH (e.g., Ca, Cu, Pb, Zn). Combined leaching test results and chemical speciation modeling illustrated (i) the effects of DOC complexation to increase aqueous concentrations of copper, lead and zinc, and (ii) the effects of L/S on the expected concentrations of highly soluble and solubility limited constituents as a function of pH, with lower L/S conditions resulting in increased aqueous concentrations when the constituent solubility is not limiting leaching.
4.7	Inorganic Industrial Waste Landfill (The Netherlands)	6-9	Al, As, Ba, Ca, Cd, Cr, Cl, Cu, Fe, Hg, K, Mg, Mo, Na, Ni, P, Pb, S, Se, V, Zn DOC	Laboratory testing data obtained under oxidizing to mildly reducing conditions can be used in conjunction with chemical speciation modeling to estimate field leaching under mildly to strongly reducing conditions. The effects of reducing conditions include (i) chemical reduction of iron resulting in loss of HFO sorptive surfaces and increased dissolved iron, (ii) increased biogenic DOC concentrations, and (iii) increased leaching of some species resulting from chemical reduction to more soluble species, loss of iron oxide sorption sites, and/or increased partitioning into the leachate by complexation with DOC. For several constituents (i.e., arsenic, barium, chromium, copper, iron, phosphorous) the maximum concentrations observed in the field pilot-scale landfill were

Report Section	Case Name (Country)	pH Domain	Constituents Considered	Primary Conclusions
				significantly greater than maximum concentrations indicated by the laboratory column testing. However, leaching of many constituents was not impacted by the reducing conditions. These differing effects point to the need of *a priori* knowledge of the adsorption, solubilization and precipitation chemistry of different elements to interpret leaching results and the benefits of using chemical speciation modeling to facilitate interpretation.
4.8	MSW Landfill (The Netherlands)	5-9	Al, As, Ba, Ca, Cd, Cl, Cr, Cu, Fe, Hg, K, Mg, Mo, Na, Ni, P, Pb, Se, V, Zn DOC	Peak concentrations for highly soluble species from laboratory percolation column at L/S 0.5 mL/g agreed well with peak leachate concentrations from the landfill and were a factor of 20 times greater than observed using pH dependent leaching test at L/S 10 mL/g. Reducing conditions in the landfill resulted in higher concentrations in leachate than observed at corresponding pH values during pH dependent laboratory testing. Chemical speciation modeling based on laboratory testing under oxidized conditions facilitated understanding of leaching under expected reducing conditions in the field.
4.9	Stabilized MSW Incinerator Fly Ash Disposal (The Netherlands)	8-13	Al, As, Ba, Ca, Cl, Cr, Cu, Fe, Hg, K, Mg, Mn, Mo, Na, Ni, Pb, S, Se, Sr, V, Zn DOC	The observed peak field leachate concentrations of anionic species such as sulfate and oxyanions of arsenic, molybdenum, selenium, are indicative of pore-water (L/S ~0.2-0.5 mL/g, based on porosity of ca. 0.2-0.5) and are approximated as 20 times the concentration observed at corresponding pH in the pH-dependence test (L/S=10 mL/g). Peak monofill leachate concentrations of chloride and potassium were approximately a factor of 10 greater than measured using pH dependent testing on freshly prepared material and approximately half of peak values from percolation column tests, likely because of diffusion controlled release and preferential flow. Carbonation at the surface of the stabilized material from reaction with atmospheric carbon dioxide resulted in lower pH (6-9) for runoff and leachate samples and characteristic reductions in leaching of calcium, barium and strontium. Field leachate concentrations indicate solubility controlled (local equilibrium with the surface) for several constituents (e.g., copper, chromium, manganese) and were consistent with pH dependent leaching test results.

Report Section	Case Name (Country)	pH Domain	Constituents Considered	Primary Conclusions
4.10	Portland Cement Mortars and Concrete (Germany, Norway, The Netherlands)	7-13	Al, As, B, Ba, Ca, Cd, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Ni, P, Pb, S, Sb, Si, Sn, Sr, Zn DOC	Carbonation results in increased leaching of Ca, Ba, Sr and sulfate, consistent with loss of the ettringite mineral phase and pH dependent leaching test results. Increased leaching of oxyanions (e.g., molybdate, arsenate and chromate) also occurs with carbonation because of dissolution of the oxyanions substituted for sulfate in ettringite. pH dependent leaching test results on uncarbonated material can be used to estimate oxyanion leaching from carbonated materials at pH less than 10.

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ES-5 Recommendations for Use of the LEAF Test Methods for Beneficial Use and Disposal Decisions

LEAF test results can be used to provide a reasonably conservative (upper-bound) source-term for a wide range of materials in use and disposal scenarios. The resulting source term should be used in conjunction with additional assessment steps that include consideration of dilution and attenuation from the source to receptor, and relevant receptor thresholds. Information presented in this report supports grouping individual sources of similar materials based on process origin and leaching behavior into material grouping or classes (i.e., coal fly ash from combustion of bituminous coal, coal combustion flue gas desulfurization gypsum, blast furnace slags, MSWI bottom ash, etc.). Accumulation of LEAF testing data for a range of materials and over time can provide useful estimates of uncertainty and variability associated with leaching from specific materials and material classes. Creation of one or more databases containing leaching data used in regulatory decision making and monitoring can facilitate efficient use of leaching data in future assessments, including by reducing testing and evaluation costs for well-studied classes of materials.

Evaluating New Management Scenarios – Material Combinations and Pilot Studies

Leaching assessment can present two forms of challenges:

1. Evaluating a new use or disposal scenario for a previously evaluated material or material class; and,
2. Evaluating a new material class or specific material without prior characterization of materials within the same material class.

Careful consideration should be given to the extent of prior knowledge about both the material or class of material, and the anticipated use or disposal scenario before proceeding. Consideration should be given to the potential range and changes that may occur with respect to water contact, physical integrity of the material, blending or interfaces with other materials, chemistry within the material and of contacting solutions, and evolution of pH and redox (e.g., from atmospheric exchange, carbonation, sulfide oxidation, organic matter degradation, etc.). Insufficient prior leaching characterization data or experience with sufficiently similar materials under analogous management scenarios should trigger use of a field pilot demonstration project, when warranted based on a screening assessment that includes laboratory characterization, to insure that a priori unforeseen conditions do not result in a significant shift in the phenomena controlling leaching for the material and scenario under consideration.

The case studies presented in this report provide the basis for recommending specific components and considerations for initial material characterization and field demonstration projects.

Estimating Leaching Source Terms

In Kosson et al. (2002), leaching assessment using a performance or "impact-based approach" was proposed, that subsequently has been referred to as LEAF. The LEAF testing methodology allows for both empirical use of testing data for specific scenarios as part of a screening assessment, and use of the leaching test data in conjunction with chemical speciation and mass transport models to provide a more realistic and refined, scenario-specific estimate of constituent leaching that can be used as a source-term for risk assessment. While the screening assessment is a bounding estimate of leaching potential, consideration of waste and scenario-specific information allows many conservative assumptions to be replaced with further testing data and mass transport modeling results. A tiered-approach was proposed for developing the leaching source term, considering the type of evaluation being carried out, the level of information available, and the extent of conservatism embedded in the estimate. Subsequently, the EPA published its *Methodology for Evaluating Encapsulated Beneficial Uses of Coal Combustion Residuals* (2013b; also EPA, 2014) which describes a tiered approach that can be applied to a more limited set of uses of two secondary materials (i.e., coal fly ash use as a cement replacement in concrete and FGD gypsum use in gypsum board). The observations and information gathered in this report provides a basis for more detailed recommendations provided on the use of LEAF test methods, consistent with the initially proposed methodology (2002) and the EPA methodology (2013). It must be emphasized that these recommendations for use of leach test data only provide the approach for estimating the leaching source term (i.e., concentrations and amounts of a constituents leaching from the material under a specific scenario). Additional determinations are needed to define or account for (i) the location that serves as the basis for exposure assessment following constituent leaching release from a source scenario (e.g., point of compliance), (ii) dilution and attenuation in the vadose zone and groundwater or surface water from the point of release to the point of compliance, and (iii) appropriate exposure scenarios or reference thresholds (e.g., human health or ecological thresholds). These evaluations can be incorporated into a model of constituent fate and transport leading to possible receptor exposure (e.g., groundwater transport to a drinking water well, with water ingestion as the exposure pathway).

Scenario Definition

Defining the material use or disposal scenario is the first step to selecting the appropriate leaching tests and basis for interpreting the resulting data. The extent of information needed as part of the scenario definition increases as the evaluation seeks to achieve a more detailed and refined estimate of constituent leaching. The initial scenario definition should at a minimum include determination of the applicable pH domain, range of oxidation-reduction conditions, and the primary mode and amount of water contact.

Screening Assessment (Tier 1)

Recommendations for use of LEAF testing in screening assessment (Tier 1) and equilibrium-based assessment (Tier 2) are provided in Table ES-3. Note that Tier 1 and Tier 2 assessments are independent of the physical form (i.e., granular or monolithic) of the material. A leaching screening assessment is based on the estimated maximum leaching concentration anticipated for each COPC that would leach assuming an infinite source[4]. At this tier, maximum LSP is estimated based on the maximum concentration for each COPC measured over the applicable pH domain as defined by the scenario using the pH dependent leaching test (i.e., Method 1313) and then adjusted for the anticipated pore water L/S, unless it can be demonstrated that the specific COPC is solubility controlled throughout the applicable pH domain.

Equilibrium-based Assessment (Tier 2)

An equilibrium-based leaching evaluation would consider LSP over the applicable pH and redox domains and the maximum amount of each COPC available for leaching. Method 1313 results in conjunction with Method 1316 at L/S of 2 mL/g would be used to assess whether LSP for each COPC was constrained by aqueous solubility or availability. If the COPC exhibits significantly greater concentration at L/S of 2 mL/g (Method 1316) then measured from Method 1313 at the pH corresponding with the pH measured at L/S of 2 mL/g, then the Method 1313 results are considered to be availability constrained and the maximum concentration from Method 1313 over the applicable pH domain that is adjusted to the pore water L/S is used as the peak source concentration. If the COPC at L/S 2 mL/g is the same as (within uncertainty) the concentration measured at the corresponding pH from Method 1313, then the COPC is considered solubility constrained and the maximum concentration over the applicable pH domain from Method 1313 is used as the peak source concentration.

The maximum amount of a COPC that is available to leach per unit mass of material (i.e., “finite source”) is based on the maximum constituent release (i.e., mg/kg) over the entire pH domain of Method 1313 (typically pH 2 for cations and pH 9 for oxyanions). The amount of each COPC that leaches should be estimated based on the amount of contacting water per unit time (i.e., L/S per year) times the estimated peak concentration.

Initial characterization testing (Tier 2B) should include analysis of both major and trace constituents in all leaching test eluates because knowledge of the major constituents that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. However, prior knowledge from testing of analogous materials may reduce the need for or extent of characterization testing.

[4] For regulatory frameworks based on a source term concentration (typical in the United States), the maximum estimated leaching concentration is recommended for use in screening assessment. For regulatory frameworks based on the total mass of constituent potentially leached (as used in some international jurisdictions), availability is recommended for use in screening assessment.

Table ES-3. Tier 1 Screening Assessment and Tier 2 Equilibrium-Based Assessment - Summary of recommended test methods and analyses.

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 1 – Screening Assessment[1]	Method 1313 (applicable pH range only[2])	pH, Electrical conductivity (EC), COPCs, DOC	Maximum leachate conc.[3] estimated as 20x or 10x maximum eluate conc. for highly soluble constituents in granular materials[4, 5] and the measured maximum eluate conc. for monolithic materials and solubility controlled constituents (all materials).
Tier 2 – Equilibrium-based Assessment			
Tier 2A Compliance	Method 1313 (applicable pH range + pH=2, 7, 9 if not included) Method 1316 (L/S=2 mL/g or lowest L/S eluate)	pH, EC (natural pH only), COPCs, DOC	Availability estimated as maximum release at measured pH intervals including pH=2 and 9; provides basis for finite source by assuming that availability is maximum cumulative release under field conditions. EC used to estimate ionic strength. Acid/base neutralization capacity to pH=7. Maximum leachate conc. estimated as determined from Tier 2B based on Method 1313 results over applicable pH domain. Method 1316 allows identification of solubility controlled vs highly soluble constituents.
Tier 2B Characterization	Method 1313 (full set of eluates) Method 1316 (full set of eluates)	pH, EC & pE[6] (natural pH only)[7], COPCs, DOC, DIC, major and minor constituents (including P and S)	Availability as indicated in Tier 2A. Liquid-solid partitioning as a function of pH used for speciation assessment.[8] Provides baseline understanding of material leaching behavior. Supports chemical speciation simulations to understand effects of changes in L/S, pH, redox, and reactive constituents (e.g., DOC, carbon dioxide, etc.). Maximum leaching concentration as indicated for Tier 1 or based on simulation results at L/S of the material pore solution. Method 1316 provides basis for determination of solubility control and verification of chemical speciation modeling at low L/S.
Tier 2C Quality Control	Method 1313 at natural pH, and pH=2, 7 and/or 9	pH, EC, relevant COPCs[9] (natural pH and for availability) to meet environmental requirements and additional constituents to meet beneficial use requirements	Used to verify leaching over "applicable" pH range, acid/base neutralization capacity to pH=7, and availability of relevant COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Assumes definition after completion of Tier 2B and/or analogous prior information.[10] Chemical analysis only for determination of leaching at natural pH and availability (2 or 3 extracts). Further simplification may be possible based on additional available information.

Notes for Table ES-3:

[1]For regulatory frameworks based on a source term concentration, the maximum estimated leaching concentration is recommended for use in screening assessment. For regulatory frameworks based on the total mass of constituent potentially leached, availability is recommended for use in screening assessment.

[2]The applicable pH range is determined considering the material's natural pH, changes in pH due to material aging processes, infiltration conditions, and interfaces or comingling with other materials.

[3]"conc." is used as an abbreviation for concentration or concentrations.

[4]Twenty times the maximum eluate concentration is recommended for highly soluble species when the material is homogeneous (e.g., coal fly ash) and ten times the maximum eluate concentration is recommended for heterogeneous materials (e.g., MSW incinerator bottom ash) where significant preferential flow is anticipated. Both multipliers are to account for the increased concentrations expected when estimating pore water concentrations (L/S=0.2 to 0.5 L/kg) from test conditions of L/S=10 mL/g).

[5]Highly soluble species are Group IA elements (i.e., Na, K), anions (i.e., bromide, chloride, fluoride, nitrate), and oxyanions (i.e., As, B, Cr, Se, Mo, V.).

[6]Electron potential as a measure of oxidation reduction conditions (see § 2.2.3).

[7]Determination of EC and pe is recommended for natural pH eluate only. The sensitivity and uncertainty of pe measurements are recognized but pe measurement will provide a useful indication of whether or not the material is inherently reducing under abiotic and anoxic conditions.

[8]Speciation assessment refers to consideration of the effects of changes in pH, redox conditions, extent of carbonation, complexation with dissolved organic carbon, etc. which may be accomplished heuristically or in combination with geochemical speciation modeling.

[9]Relevant COPCs are those constituents that are present in the material and have been found through Tier 2B characterization and/or prior information to leach at concentrations or release values that approach or challenge regulatory or quality control thresholds.

[10]Prior information, such as characterization information from similar materials, may reduce or supplant the need for or extent of Tier 2B characterization.

Results from Method 1313 also can be used to indicate where increased leachate concentrations can be anticipated if there is a shift in field pH from the initial pH to other conditions over the range of pH defined for the specific scenario being evaluated. Chemical speciation modeling or other knowledge of the system should then be used to determine if changes in redox or other conditions (i.e., carbonation, infiltration chemistry) are likely to result in increased or decreased leaching.

For periodic demonstration of compliance with regulatory thresholds, the extent of Method 1313 testing can be reduced to the applicable pH domain and regulatory COPCs, pH and conductivity[5]. For quality control purposes, the extent of Method 1313 testing can be further reduced to only the natural pH value and along with the pH 2 and/or 9 as needed to measure availability for the relevant COPCs (those that are present and leach at concentrations that approach thresholds) and conductivity.

Knowledge of the chemical behavior of the COPCs and the scenario should be used to evaluate if higher leaching concentrations are anticipated because of changes in redox conditions. Anticipated changes in leaching because of changes in L/S, redox or chemical conditions can also be evaluated using chemical speciation modeling as demonstrated for the evaluation cases in this report.

Mass Transport-based Assessment (Tier 3)

Mass transport-based assessment can be divided into two distinct regimes: (i) percolation through the material as the predominant leaching mechanism, and (ii) mass transport from monolithic materials where diffusion to the exterior surface of the bulk material and surface dissolution control constituent leaching. Intermediate conditions between the percolation and monolith regimes, such as for large aggregates and cracked monolithic materials also exist, but are beyond the scope of this discussion. Summaries of recommended LEAF testing and evaluation are provided for percolation mass transport-based assessment and monolithic mass transport-based assessment in Table ES-4 and Table ES-5, respectively.

Percolation based regimes can be evaluated through use of the pH dependent test (i.e., Method 1313) in conjunction with the percolation column test (i.e., Method 1314 or Method 1316 for initial leachate concentrations). Considering the results of Cases 2, 5 and 8 (Sections 4.2, 4.5 and 4.8) initial eluates from Method 1314 or low L/S results from Method 1316 are good indicators of the anticipated COPC concentrations in initial field leachates and Method 1314 provides the evolution of the leachate concentrations over prolonged periods based on the progression of the L/S based on the field material geometry and annual infiltration rates.

[5] Measurement of conductivity is recommended as an indicator of total ionic strength and therefore can also provide an indication if there is a significant change in leaching of total salts over the monitoring interval.

Table ES-4. Tier 3 Percolation Mass Transport-Based Assessment – Summary of recommended test methods and analyses.

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 3 – Percolation Mass Transfer Rate-based Assessment			
Tier 3A Compliance	Method 1313 (pH=2, 9, applicable pH domain) Method 1314 (to L/S=2 mL/g)	pH, EC (natural pH only), COPCs, DOC	Allows verification of liquid-solid partitioning at natural pH and availability (from Method 1313). Maximum leachate conc. estimated as established by Tier 3B as greater of either i) maximum conc. from Method 1314 up to L/S =2 mL/g, or ii) maximum conc. from Method 1316, or iii) maximum conc. from Method 1313 over applicable pH domain.
Tier 3B Characterization	Method 1313 (full set of eluates) Method 1314 (full set of eluates) Method 1316 (L/S=2)	pH, EC (natural pH only), COPCs, DOC, DIC, major and minor constituents	Availability and leaching as a function of pH and evaluation of potential changes in conditions as indicated for Tier 2B. Method 1314 provides leachate evolution as a function of L/S for source term based on test elution curve. Supports reactive transport simulations to consider sensitivity to field conditions such as infiltration chemistry, preferential flow and material aging. Provides basis for verification of chemical speciation modeling at low L/S.
Tier 3C Quality Control	Method 1313 at pH=2, 7 and/or 9 and Method 1316 at L/S = 2	pH, EC, COPCs (1313 for availability and 1314 at L/S of peak release) to meet environmental requirements, additional constituents to meet beneficial use requirements	Method 1313 extractions used to verify acid/base neutralization capacity to pH=7, and availability of selected COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Method 1314 extract at L/S of prior peak concentration to verify maximum leaching conc. Assumes definition after completion of Tier 3B Characterization. Chemical analysis only for determination of leaching at peak release conc. and availability (2 or 3 extracts). Further simplification may be possible based on additional available information.

Table ES-5. Tier 3 Monolith Mass Transport-Based Assessment – Summary of recommended test methods and analyses[1].

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 3 – Monolith Mass Transport-based Assessment			
Tier 3A Compliance	Method 1313 (pH=2, 9, applicable pH domain) Method 1315 (to 7 days)	pH, EC (natural pH for Method 1313 and all Method 1315 eluates), COPCs, DOC	Allows verification of liquid-solid partitioning at natural pH and availability (from Method 1313). Maximum leachate conc. estimated as established by Tier 3B as greater of either i) maximum conc. from Method 1314 up to L/S =2 mL/g, or ii) maximum conc. from Method 1316, or iii) maximum conc. from Method 1313 over applicable pH domain.
Tier 3B Characterization	Method 1313 (full set of eluates) Method 1314 (full set of eluates) Method 1315 (to 64 days)	pH, EC (natural pH only for Method 1313 and all Method 1314, and 1315 eluates), COPCs, DOC, DIC, major and minor constituents	Availability and leaching as a function of pH as indicated for Tier 2B. Method 1314 (crushed material) up to L/S=2 provides estimate of initial pore water composition. Method 1315 provides cumulative release as a function of leaching time for saturated and intermittent wetting conditions. Also provides basis for estimating reactive transport parameters (e.g., tortuosity) for simulation of evolving conditions (e.g., low liquid to surface area, external solution chemistry, carbonation, oxidation, intermittent wetting, etc.). Provides basis for Tier 3C quality control.
Tier 3C Quality Control	Method 1313 at pH=2, 7 and/or 9 and Method 1315 (to 7 days)	pH, EC, COPCs (1313 for availability and 1314 at L/S of peak release) to meet environmental requirements, additional constituents to meet beneficial use requirements	Method 1313 extractions used to verify acid/base neutralization capacity to pH=7, and availability of selected COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Method 1315 cumulative release to 7 days to verify consistency with characterization results (Tier 2B). Assumes definition after completion of Tier 3B Characterization. Further simplification may be possible based on additional available information.

[1]The cure time prior to testing of monolithic materials is an important consideration because for many cementitious materials, hydration and microstructure development continues for more than a one year, with initial cure times of 90 days recommended prior to Method 1315 testing.

Initial percolation characterization testing (Tier 3B) should include analysis of both major and trace constituents in all leaching test eluates (Methods 1313 and 1314 or 1316) because knowledge of the major constituents (such as Ca, Fe, DOC or SO_4) that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. For compliance testing (Tier 3A), Method 1313 can be used as described above (Equilibrium Based Assessment) and Method 1314 analysis can be simplified to analysis of eluates as prescribed as Option E in Table 1 of the method (i.e. at L/S=0.2 and along with two composite samples) for COPCs, pH and conductivity, thus providing peak eluate concentrations and cumulative release.

Monolith regimes can be evaluated based on use of Method 1315 in conjunction with Method 1313 (Table ES-5). A detailed example of use of this information for evaluation of use of coal combustion fly ash as a substitute for Portland cement in concrete considering intermittent water contact via precipitation is available (EPA, 2013a). An example approach for use of empirical data from Method 1313 (i.e., for availability) and Method 1315 (i.e., for estimated effective diffusivity) is provided for MSWI bottom ash scenarios in Kosson et al (1996). These approaches can also be used in conjunction with chemical speciation based mass transfer models (see Section 3) to provide insights into potential changes in leaching that may occur in response to changing conditions within or on the external surface of the material being evaluated.

Initial monolith characterization testing should include analysis of both major and trace constituents in all leaching test eluates (Methods 1313 and 1315) because knowledge of the major constituents that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. For compliance testing, Method 1313 should be used to assess availability and solubility at the natural pH of the material (i.e., no acid or base addition) and Method 1315 analysis can be simplified to analysis of eluates at exchange up to 7 days for COPCs, pH and conductivity. For quality control purposes, Method 1315 reduced to only analysis of eluates up to 2 days for COPCs, pH and conductivity.

ES-6 Conclusions

This report evaluated the relationships between laboratory leaching tests as defined by the Leaching Environmental Assessment Framework (LEAF) or analogous EU/international test methods and leaching of COPCs from a broad range of materials under disposal and beneficial use scenarios. This evaluation was achieved by defining a framework for interpretation of laboratory testing results, comparison of laboratory testing on “as produced” material, laboratory testing of “field aged” material, and results from field leaching studies, and illustrating the use of chemical speciation modeling as a tool to facilitate evaluation of scenarios beyond the conditions of laboratory testing.

As identified in table ES-1, ten field cases were evaluated using a combination of laboratory testing and field analysis for seven different materials: (i) coal fly ash (CFA), (ii) fixated scrubber sludge typically produced by combining coal fly ash with acid gas scrubber residue

and lime at some coal fired power plants (FSSL), (iii) municipal solid waste incinerator bottom ash (MSWI-BA), (iv) a predominantly inorganic waste mixture comprised of residues from soil cleanup residues, contaminated soil, sediments, C&D waste and small industry waste(IND), (v) municipal solid waste (MSW), (vi) cement-stabilized municipal solid waste incinerator fly ash (S-MSWI-FA), and (vii) Portland cement mortars and concrete. The field data presented in this report include (i) leachate from field lysimeters, (ii) porewater from landfill or use applications, (iii) eluate from leaching tests on sample cores taken from field sites, and (iv)leachate collected from landfills. Principal uncertainties for field data include (i) the extent of preferential flow or dilution that may have occurred during water contact within the material and in sampling of landfill leachate, and (ii) the exposure and aging conditions that can occur and are reflected by the field data.

Primary aging processes and reactions that can impact leaching are (i) establishment of reducing conditions from biogenic processes (i.e., degradation of organic matter), (ii) oxidation from atmospheric exchange, and (iii) carbonation from either atmospheric exchange, dissolved carbon dioxide (or carbonates) in contacting water, or reaction with biogenic carbon dioxide. Other slow mineral formation processes, such as with stabilized waste after initial curing periods (e.g., 90 days), may result in relative small changes in leaching relative to freshly prepared material. Constituents in infiltrating or contacting water, either from natural processes (e.g., DOC in the form of humic substances from leaf decay) or from anthropogenic origin (e.g., leaching from up gradient disposed materials) may have a substantial effect on leaching.

Based on the above comparisons and observations along with results discussed in earlier sections, the following conclusions and recommendations are drawn:

1. The combination of results from pH-dependent leaching tests (i.e., EPA Method 1313 or CEN/TS 14429 or CEN/TS 14997) and percolation column tests (i.e., EPA Method 1314 or CEN/TS 14405) can be used to provide accurate estimates within defined uncertainty levels of maximum field leachate concentrations, extent of leaching and expected leaching responses over time and to changes in environmental conditions under both disposal and use scenarios. Leaching test results should be evaluated with consideration of the potential for changes in leaching conditions that are beyond the domain of laboratory test conditions, such as oxidation of reduced materials, reduction of oxidized material, carbonation and introduction of DOC from external sources. When field conditions beyond the domain of laboratory test conditions are plausable, chemical speciation modeling can be used to consider the magnitude of effects from the postulated changing conditions. Peak leaching concentrations and availability of COPCs estimated from laboratory testing can be used to provide a conservative estimate (i.e., reasonable upper bound) of anticipated field leaching. Results from batch testing at low L/S ratios (i.e., EPA Method 1316 or EN 12457) can also be used in place of column test results when column testing is impractical. Thus, the LEAF laboratory leaching tests can be used effectively to estimate the field leaching behavior of a wide range of materials under both disposal

and use conditions. Interpretation of the leaching test results should be in the context of the controlling physical and chemical mechanisms of the field scenario.

2. Field testing of new use or disposal scenarios or new classes of materials to be used or disposed in new ways is highly beneficial to understanding the factors that control leaching for the specific scenario. Thereafter, materials within a given class can be anticipated to behave similarly under the established use or disposal scenario and the LEAF testing approach can be used to distinguish "acceptable" versus "unacceptable" materials and use conditions within the general class of materials and scenario. The EPA guidance on beneficial use of coal fly ash in concrete (EPA, 2014) provides an example of the use of LEAF test results in such decisions.
3. Establishment of a national or international database of LEAF laboratory leaching test results for materials and leaching observed under field conditions would provide useful insights for evaluation of new cases and material use and disposal decisions. The database would allow effective comparison of leaching (i) from materials produced over time from the same facility, (ii) commonality from similar materials from a diverse set of facilities, and (iii) from different types of materials considered for similar beneficial use applications.
4. Field testing should include (i) sampling and leaching characterization of the initial material, including pH-dependent, column and monolithic mass transfer rate (where applicable) testing; (ii) field leachate collection and monitoring over extended time frames (i.e., several years); and (iii) collection and characterization of test materials after prolonged field exposure (i.e., core samples from field test sites). Sample collection systems and subsequent handling need to be designed to avoid sample changes prior to analysis that degrade the representativeness of the samples and can result in misleading results (e.g., sample oxidation or carbonation during collection or handling resulting in changes in pH and constituent speciation). Furthermore, sample analysis should include a full suite of major and trace constituents that influence and provide a context for understanding COPC leaching.
5. Chemical speciation modeling of liquid-solid partitioning can be used for understanding the mechanisms (e.g., mineral phases, sorption and aqueous phase complexation phenomena) controlling leaching of the full range of constituents in the laboratory and the field, and understanding material leaching under conditions that are not readily subject to testing. Although the general behavior of many of the major and trace constituents are reasonably represented in relevant scenarios, application of chemical speciation modeling to waste management currently is constrained by the availability of test data for identifying important solid phases and the range of available thermodynamic data available for model parameters. Application of chemical speciation modeling as a tool for understanding waste management should be expanded, along with underlying research to fill data gaps.
6. Single point leaching tests and other common leaching assessment approaches cannot provide needed insights into the expected leaching performance of materials

under the range of expected field conditions. The LEAF integrated evaluation of multiple types of leaching test data (i.e., pH dependent LSP along with percolation and/or monolithic mass transport behavior) and field data within the context of understanding fundamental leaching behavior (i.e., processes controlling liquid-solid partitioning and mass transport rates), along with use of chemical speciation based modeling provides insights into the expected leaching behavior over a range of field conditions that cannot be obtained otherwise. The resulting estimates of COPC release reduce the use of conservative assumptions in favor of more complete data and refined speciation models, and consequently expands alternatives and provides a sound scientific basis for making decisions about appropriate disposal or use of secondary materials under environmentally exposed conditions.

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ABBREVIATIONS AND ACRONYMS

BOD	biological oxygen demand
C&D	construction and demolition
CCR(s)	coal combustion residue(s)
CEN	Comité Européen de Normalisation, Brussels, Belgium
CFA	coal fly ash
COD	chemical oxygen demand
COPC(s)	constituent(s) of potential concern
CSF	chemical speciation fingerprint
DOC	dissolved organic carbon
DNV	Det Norske Veritas (a Norwegian classification society)
ECN	Energy Research Centre of The Netherlands, Petten, The Netherlands
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute, Palo Alto, CA
ESP(s)	electrostatic precipitator(s)
EU	European Union
FGD	flue gas desulfurization
FSSL	fixated scrubber sludge with lime
HFO	hydrous ferric oxide
IND	small industry waste
ISO	International Standards Organization, Geneva, Switzerland
LEAF	Leaching Environmental Assessment Framework
L/A	liquid-to-surface area ratio (mL/cm^2)
L/S	cumulative liquid-to-solid ratio (mL/g-dry or L/kg-dry; dry mass basis)
L/S_i	interval liquid-to-solid ration (mL/g-dry or L/kg-dry; dry mass basis)
LSP	liquid-solid partitioning
meq	milli-equivalents
MSW	municipal solid waste
MSWI	municipal solid waste incinerator
MSWI-BA	municipal solid waste incinerator bottom ash
MW	megawatt
NEN	Nederlands Normalisatie Instituut, Delft, The Netherlands
NOK	National Research Program Coal (The Netherlands)
ORD	Office of Research and Development (U.S. EPA)
ORP	oxidation-reduction potential
POM	particulate organic matter
RCA	recycled concrete aggregate
SHA	solid humic acid
S-MSWI-FA	stabilized municipal solid waste incinerator ash
SPLP	Synthetic Precipitation Leaching Procedure (EPA Method 1312)
TCLP	Toxicity Characteristic Leaching Procedure (EPA Method 1311)
U.S.	United States
VU	Vanderbilt University, Nashville, TN

1 INTRODUCTION

Leaching tests are tools typically used to estimate the environmental impact associated with disposal or utilization of materials and wastes on the land (e.g., soils, sediments, industrial wastes, demolition debris, etc.). However, the results of leaching tests are often used without sufficient consideration of the type of data available or the applicability of the available data for the chosen disposal or utilization scenario. Furthermore, results of leaching assessments based on testing and interpretive models only provide a source term as one part of an evaluation of environmental safety. In addition to test results, integral factors in applicability assessment or criteria development for use and disposal include (i) definition and application of appropriate fate and transport models and (ii) establishment of risk-informed constituent concentration thresholds at defined points of compliance.

The assumption that is often made, consciously or not, is that the leaching test "simulates" the release of constituents of potential concern (COPCs) as would happen in the application scenario and, therefore, the leaching test results represent the leachate that would occur in the field. Since many of the current leaching test methods are based on simulation of a particular pre-defined release scenario, the relevance of the leaching test results is restricted to the scenario being simulated. Furthermore, no single leaching test can encompass the *range of conditions* that a material or waste may be subjected to over the duration of use or disposal. Therefore, the applicability of the results of simulation-based leaching tests is often quite limited to the defined test conditions and relatively short assessment intervals. In order to address these limitations, a more robust science-based approach is needed for environmental leaching assessment that considers the impact on leaching of the chemical and physical characteristics of the tested materials and the range of environmental conditions likely to be encountered during disposal and utilization. These needs have been strongly articulated by the Science Advisory Board of the United States Environment Protection Agency (EPA) during reviews of regulatory leaching approaches (EPA, 1991, 1999).

1.1 The Leaching Environmental Framework

The Leaching Environmental Assessment Framework (LEAF) is fundamentally different than the defined simulation-based approach because it focuses on characterization of material-specific leaching behaviors controlling the release of COPCs from solid materials over a broad range of test and environmental conditions with application of the leaching data to specific disposal or use conditions (Kosson et al., 2002). The framework consists of four laboratory leaching methods, data management tools, and leaching assessment approaches developed by Vanderbilt University in conjunction with U.S. EPA and international partners.

1.1.1 LEAF Leaching Methods

The four leach testing methods described in LEAF have been validated through interlaboratory studies (Garrabrants et al., 2012a, 2012b) and adopted into SW-846, the EPA compendium of laboratory tests (EPA, 2013a) as:

- Method 1313 – Liquid-Solid Partitioning as a Function of Extract pH using a Parallel Batch Extraction Procedure
- Method 1314 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials using an Up-flow Percolation Column Procedure
- Method 1315 – Mass Transfer Rates in Monolithic and Compacted Granular Materials using a Semi-Dynamic Tank Leaching Procedure
- Method 1316 – Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio in Solid Materials using a Parallel Batch Extraction Procedure

These tests may be applied to solid materials to determine fundamental leaching parameters including liquid-solid partitioning (LSP) of constituents as a function of pH and cumulative liquid-to-solid ratio (L/S) as well as the rate of constituent mass transfer from monolithic and compacted granular materials. Coordinated development of LEAF has occurred between research laboratories in the United States (U.S.) and the European Union (EU). Thus, LEAF analogous test methods have been or are being developed within the EU with minor differences intended to address the different regulatory contexts (e.g., quality control requirements, method description requirements, etc.)

1.1.2 Data Management with LeachXS™

Typically, only those chemical species of environmental concern (e.g., heavy metals and select organic compounds) are measured under the current regulatory leaching structure, often for compliance purposes. However, the understanding of COPC leaching can be significantly increased if the release of major and minor species not typically studied are measured. For example, arsenic retention is often influenced by calcium and carbonate concentrations, while copper leaching concentrations are often influenced by dissolved organic carbon. Thus, examination of species that are not COPCs or other usual environmental analytes may provide insight into release mechanisms and the potential for changes in those release mechanisms for environmental COPCs. In addition, quantification of a broader range of constituents allows for chemical speciation modeling (see Section 3) and facilitates more fully descriptive leaching behavior modeling approaches. Therefore, the LEAF approach for environmental assessment is designed to provide a more complete evaluation of the leaching behavior which benefits from the analysis and evaluation of major and minor components of the solid matrix in addition to the typical species posing direct environmental concern.

However, the combination of multi-point leach testing and more comprehensive chemical analysis results in a considerable amount of data to be assessed, compared and reported. The leaching assessment and data management program, LeachXS™, has been developed to facilitate leaching data management. The database driven program is integrated with the LEAF methods through Microsoft Excel spreadsheets used to upload laboratory and analytical data into the LeachXS materials database. In addition, display tools allow for comparison of leaching results for multiple materials and facilitated reporting of the large amount of data required for full characterization. LeachXS also serves as an interface for statistical evaluations of leaching results, chemical speciation modeling using ORCHESTRA (Meeussen, 2003), and advanced reactive transport modeling for several pre-defined release scenarios. LeachXS Lite is a freely-licensed, limited capability version of the full LeachXS program (van der Sloot et al., 2003; van der Sloot et al., 2008b)

focused primarily on uploading, comparing, and display of leaching data between materials and test types.[6] The Lite version of LeachXS was developed, in part, to facilitate EPA characterization of coal combustion residues (CCRs) and associated reports (Sanchez et al., 2006, 2008; Kosson et al., 2009), but also is applicable to management and evaluation of LEAF data from a wide range of materials.

1.1.3 Leaching Assessment

Assessments based on the results of characterization-based leaching methods, such as LEAF and LEAF analogous methods, are more flexible than those from simulation-based tests because the data generated focus on relevant intrinsic leaching behavior independent of the disposal or utilization scenario. Characterization of leaching behavior using the LEAF tests along with scenario-specific information can be used to assemble a leaching "source term" for many environmental scenarios or levels of environmental assessment including:

- screening level assessments at a site-specific, regional or national scale;
- detailed site-specific evaluations;
- performance comparisons between different materials or treatment processes under specific disposal or use scenarios;
- development of chemical speciation based models to evaluate potential material leaching behavior under field conditions that may be difficult or impossible to reproduce in the laboratory.

However, it must be recognized that leaching assessment only provides that source-term as part of the overall evaluation process, which also must consider dilution and attenuation from the source to the point of exposure or compliance, and the relevant risk-informed decision or compliance human health and ecological thresholds.

1.1.4 Extension to Field Scenarios

The robustness of the LEAF approach comes from using laboratory data that includes a range of limiting conditions (i.e., LSP and maximum leaching mass transport rates) in conjunction with models for estimating release under a range of field conditions and scenarios. Assessing the applicability and accuracy of any predictive leaching assessment approach, however, requires evaluation through the use of pilot- and full-scale field studies in which leaching predictions for a particular material based on laboratory testing may be compared to measured leachate concentrations for that material collected under field conditions. Field studies also provide information regarding the relative importance of natural processes on leaching of COPCs including water flow patterns, extent of local chemical equilibrium, and chemical changes due to aging or exposure to the environment. For example, leaching of alkaline materials such as some cement-stabilized materials may be altered by reaction with atmospheric carbon dioxide, resulting in a less

[6] LeachXS Lite, which is a collaboration of Vanderbilt University (VU), Energy Research Centre of The Netherlands (ECN), EPA Office of Research and Development (ORD) and ARCADIS-U.S., Inc., does not include the advanced formatting, statistical calculations, or chemical speciation and reactive transport modeling capabilities native to the full LeachXS version. The LEAF methods, Excel data templates and LeachXS Lite are available free of charge at www.vanderbilt.edu/leaching.

alkaline pH for leaching and altered chemical speciation for some constituents (e.g., formation of lead carbonate from lead hydroxide).

This report facilitates understanding application and accuracy of the LEAF test methods by addressing the following important relationships of LEAF test data:

- within datasets from the different LEAF test methods conducted on the same material;
- compared to the results of test methods currently in more widespread use, specifically the Toxicity Characteristic Leaching Procedure (TCLP; EPA Method 1311) and the Synthetic Precipitation Leaching Procedure (SPLP; EPA Method 1312);
- relative to field leaching and material behavior over a wider set of disposal and use scenarios;
- in conjunction with chemical speciation modeling and other knowledge to evaluate leaching under conditions beyond typical laboratory testing conditions.

Furthermore, this report provides recommendations for how environmental scientists, engineers and regulators may use LEAF as part of their evaluation programs.

In this report, the liquid phase resulting from a laboratory leaching test is referred to as an "eluate" whereas liquid phase samples collect from field leachate samples are referred to as "leachate." The term "constituent" refers to a component of a substance in the liquid or solid phase and is the analytical summation of the various speciation forms of that constituent in that phase. In contrast, a "species" refers to the chemical unit or speciation of an element in the solid or liquid phases. Thus, the measured concentration of a constituent (e.g., lead or Pb) in an eluate or solid material may result from the presence of multiple species containing that element in the designated eluate, leachate, or solid (e.g., Pb^{+2}, $Pb(OH)_3^-$, $PbCl_2$ or organo-Pb species). The "release" of a constituent is defined as the mass of a constituent leached per mass of solid material (mg/kg) and is calculated by multiplying the measured COPC eluate concentration (mg/L) by the associated extract or leaching L/S (L/kg) represented by the volume of liquid in contact with a unit mass of solid. Release is therefore on a solid phase unit basis and is used to represent the amount of a constituent that has or potentially may leach, rather than the more familiar liquid phase unit basis that is used to describe leachate or eluate concentrations.

1.2 Report Objectives and Approach

The primary objective of this report is to provide results from an evaluation of the applicability and limitations of using laboratory leaching tests, as defined by the LEAF and LEAF-analogous methods, for estimating leaching of COPCs from a broad range of materials under field disposal and beneficial use scenarios. This evaluation is achieved by comparison of LEAF laboratory testing of "as produced" material using LEAF methods, laboratory testing of "field aged" material, and results from field leaching studies of the material. Interpretation of LEAF leaching data is conducted within the context of a defined conceptual leaching model and chemical speciation modeling is used as a tool to facilitate evaluation of scenarios beyond the conditions of common laboratory testing (i.e., normalize the laboratory data to the field conditions by estimating the impact of factors not practical to achieve in the laboratory, but which are known to occur and affect leaching). A second

objective of this report is to provide recommendations on the selection and use of LEAF testing for different types of materials or wastes when evaluating disposal or use scenarios.

1.2.1 Field Evaluation Cases

In order to illustrate the relationship between laboratory data and field measurements, ten disposal and beneficial use cases for which both laboratory and field data exist have been identified and are presented in this report. These ten field evaluation cases consist of combinations of laboratory testing and field analysis for the following seven materials:

- coal fly ash (CFA; 3 cases);
- fixated scrubber sludge with lime (FSSL) produced at some coal-fired power plants by combining coal fly ash with flue gas desulfurization (FGD) scrubber residue and lime (1 case),
- municipal solid waste incinerator bottom ash (MSWI-BA; 2 cases);
- a predominantly inorganic waste mixture comprised of residues from soil cleanup residues, contaminated soil, sediments, construction and demolition (C&D) waste and small industry waste (IND; 1 case);
- municipal solid waste (MSW; 1 case);
- cement-stabilized municipal solid waste incinerator fly ash (S-MSWI-FA; 1 case);
- portland cement mortars and concrete (1 case).

Table 1-1 provides a summary of the cases and data sets evaluated in this report. In this table, the types of leaching test data (i.e., laboratory tests conducted on "as produced" site materials,[7] analog materials or field materials), field data (i.e., leachates collected from the field application) and case conditions are defined for each case. The symbols representing leaching test data for the cases in Table 1-1 include "pH" for pH dependent leaching data (e.g., from Method 1313), "L/S" for L/S-dependent leaching data (e.g., Method 1316), "Perc" for percolation column data (e.g., from Method 1314), and "MT" for mass transfer data (e.g., from Method 1315). For a few of the field case studies where laboratory test results were not available for the specific material present in the field, laboratory test results on closely analogous materials are used for comparison with field measurements. The field data presented in this report include (i) leachate from field lysimeters, (ii) porewater from landfill or use applications, (iii) eluate from leaching tests on sample cores taken from field sites, and (iv) leachate collected from landfills.

[7] In this report, "as produced" materials refer to materials newly processed materials that are ready for disposal or beneficial use in a field application. This distinction is made relative to aged field materials that have been retrieved from a field application for testing in the laboratory.

Table 1-1. Summary of Laboratory-To-Field Comparison Cases

		Leaching Test Data			Field Data	
Report Section	Case Name (Country)	Site Materials [1]	Analog Materials [2]	Field Materials [3]	Leachates	Case Conditions
4.1	Coal Fly Ash Landfill Leachate (U.S.)	-	pH L/S Perc	-	Multiple landfills	Ox-Red, pH 6-13
4.2	Coal Fly Ash in Large-Scale Field Lysimeters (Denmark)	L/S	-	-	Lysimeters	Ox-Red, pH 11-13
4.3	Landfill of Coal Combustion Fixated Scrubber Sludge with Lime (U.S.)	pH L/S	-	pH L/S MT	Landfill	Ox, pH 6-12
4.4	Coal Fly Ash Used in Roadbase and Embankments (The Netherlands)	L/S	-	-	Roadbase, Embankment	pH 8-12
4.5	Municipal Solid Waste Incinerator Bottom Ash Landfill (Denmark)	-	pH Perc	-	Landfill	Reducing, pH 7-11
4.6	Municipal Solid Waste Incinerator Bottom Ash Used in Roadbase (Sweden)	-	pH Perc	pH L/S Perc	Roadbase test section	Ox-Red, pH 7-10
4.7	Inorganic Industrial Waste Landfill (The Netherlands)	pH Perc	-	pH L/S Perc	Lysimeters, Landfill	Ox-Red, pH 6-9
4.8	Municipal Solid Waste (The Netherlands)	pH Perc	-	pH L/S Perc	Landfill, Multiple landfills	Strongly Reducing, High DOC, pH 5-9
4.9	Stabilized Municipal Solid Waste Incinerator Fly Ash Disposal (The Netherlands)	pH Perc MT	-	pH	Pilot test cells, Landfill	Oxidizing, pH 8-13
4.10	Portland Cement Mortars and Concrete (Germany, Norway, The Netherlands)	pH (recycled concrete)	pH	pH	-	Oxidizing, Carbonation, pH 8-13

Notes:

pH = pH-dependent leaching data (e.g., EPA Method 1313, PrEN 14429, PrEN 14997).

L/S = L/S-dependent data with deionized or demineralized water (e.g., EPA Method 1316, EN 12547).

Perc = Percolation column data, up-flow or down-flow (e.g., EPA Method 1314, CEN/TS 14405).

MT = Monolith or compacted granular mass transfer data (e.g., EPA Method 1315, PrEN 15863).

Ox-Red = oxidized to reducing conditions.

[1] Site Materials refers to "as produced" source materials placed into the field application.

[2] Analog Materials refers to comparative materials for cases where source material sample leaching characterization information was not available.

[3] Field Materials refers to materials retrieved from a field application for laboratory testing.

1.2.2 Evaluation Approach

For each evaluation case, the following generalized approach is used to compare laboratory test results for a material to its field leaching:

(v) LSP Leaching – laboratory leaching results provide an understanding of the LSP for COPCs as a function of pH (e.g., from Method 1313) or L/S (e.g., from Method 1316 or Method 1314). [Field values for these parameters were also obtained]

(vi) Dynamic Leaching – percolation column leaching test results (e.g., from Method 1314) provide an understanding of percolation-controlled leaching of COPCs under idealized conditions, and/or mass transport leaching test results (e.g., Method 1315) provide intrinsic COPC release rates.

(vii) Laboratory-to-Field Comparison – laboratory LSP or dynamic leaching results (e.g., percolation or mass transport data) and conditions are compared with results and conditions measured in the field scenario to evaluate whether local equilibrium is controlling observed leaching under field conditions. If not, this comparison is used to determine the extent of preferential flow effects in percolation scenarios or limited water contact in mass transport scenarios.

(viii) Chemical Speciation and Reactive Transport Modeling – a chemical speciation fingerprint (CSF) for the material of interest and subsequent reactive transport modeling (i.e., combination of speciation and mass transport models) are used to explore the extent that non-ideal conditions (e.g., preferential flow) and aging conditions (e.g., redox changes, carbonation, etc.) influence observed field leaching behavior (see Section 3).

1.3 Data Quality and Quality Assurance

Two laboratories, Vanderbilt University (VU) and The Energy Research Centre of The Netherlands (ECN), were responsible for the laboratory leaching characterization of fly ash, cement mortars and concrete discussed in this report. VU carried out the leaching characterization of CBP fly ash, mortar and concrete samples, as well as the cement admixture paste sample (MBD2) as part of research on behalf of the Department of Energy, Office of Environmental Management. At VU, leaching procedures and chemical analyses were carried out under the same quality assurance and quality control procedures specified in the Quality Assurance Project Plan for characterization of CCRs for research carried out on behalf of USEPA (Kosson et al, 2009).

ECN carried out all leaching characterization of European cement and concrete samples included in this report. For more than two decades, ECN has been a national and international leader in developing and implementing leaching characterization methods. Since 1983, ECN has been actively involved in the development of leaching tests in support of national (The Netherlands) and European legislation (European Landfill Directive, 2002; Requirement 3 on Health and Environment in the Construction Products Directive, 1989; End of Waste Directive; in development) through chairmanship of working groups in the national standardisation body (Nederlands Normalisatie Instituut, NEN) and the European standardisation organisation CEN. ECN is a qualified laboratory for chemical analysis and for leaching tests under the Dutch quality assurance program RvA (Raad voor de Accreditatie) with annual external independent audits on the basis of NEN-EN-ISO 17025. ECN operates under ISO 9000 practice and has an ISO 9001 as well as an ISO 14001 certificate. ECN has participated in many

interlaboratory comparison (round-robin) studies for leaching characterization methods which has demonstrated its proficiency (van der Sloot et al., 1994, 1995, 2001b; Hohberg et al., 2000; de Groot et al., 1996). The interlaboratory validation studies for the LEAF test methods (Garrabrants et al., 2012a, 2012b), in which ECN participated and conducted LEAF-analogous European leaching methods in parallel demonstrated ECN's proficiency in leaching characterization as well as the comparability of results between USEPA Method 1313 and the European pH-dependence methods, CEN/TS 14429 and CEN/TS 14497.

DHI works in accordance with the quality management system standard: ISO 9001 as certified by Det Norske Veritas (DNV). The certificate is covering the following products or services: Consulting, software, research & development and laboratory testing, analysis & products within the area of water, environment & health

1.4 Report Limitations

This report focuses primarily on the leaching behavior of inorganic constituents, along with the influences of solid phase and dissolved organic carbon on inorganic constituent leaching. This report does not include evaluation of the leaching of organic substances (e.g., polycyclic aromatic hydrocarbons, pesticides, pharmaceuticals, etc.) or radionuclides. Future work is needed to include organics contaminants, radionuclides, and nanoparticles into LEAF although some work is already progressing in Europe and the U.S. through commercial labs to include organic contaminants and radionuclides.

The cases evaluated in this report are based on studies carried out over approximately the last two decades. All the data presented herein should be considered "secondary data." As such, the data were likely generated for purposes not specifically in support of this analysis. Nonetheless, these data are useful and broadly appropriate for use in this analysis with some limitations:

- Over the time period that is covered by these cases, the knowledge base for leaching assessment has grown considerably. Thus, if some of these studies were designed and carried out today, more extensive testing would be completed if necessary resources were available. However, many of the studies included complete characterization of the initial material, careful sampling and extensive laboratory leaching characterization in addition to carefully monitored field lysimeters and field, pilot-scale testing.
- Laboratory test methods have evolved since some of these studies were conducted with several of the most recent test methods standardized or in the process of being standardized in the U.S. and EU, respectively. In some cases, these studies were conducted using precursor methods that retain the objectives and general approaches of the standardized leaching tests. The results of analogous leaching tests (i.e., methods intended to determine the same leaching characteristic) have been shown to provide similar and directly comparable results despite minor variations in the procedure or test parameters (Garrabrants et al., 2012a; 2012b; Lopez-Meza et al., 2008; van der Sloot et al., 1995, 1997; van der Sloot 2010a; Hjelmar et al., 2012). Thus, the fundamental information and knowledge to be gained from past studies discussed in this report is still valid.

- In some cases, the collection and analysis of field data contain principal uncertainties including (i) the extent of preferential flow or dilution that may have occurred in sampling of landfill leachate, and (ii) the exact exposure and aging conditions that contribute to the field data. Therefore, for each case, the relevant attributes of each sample are summarized to the extent known or previously reported.
- The studies discussed in this report have been carried out by research groups in at least five countries, each with their own quality assurance and quality control requirements. These requirements are summarized in Section 4 and are discussed in more detail as part of the primary documents from which the cases are taken. However, all studies have been previously independently peer-reviewed as part of required publication processes.

2 LEACHING TESTS AND CONCEPTUAL INTERPRETATION FRAMEWORK

Leaching is defined as the release of constituents from a solid material to the aqueous phase when contacted with water. Release to the aqueous phase can be determined by constituent liquid-solid partitioning (including consideration of solubility, adsorption the solid phase, content available for leaching, aqueous complexation, etc.), the physical properties of the material that limit mass transport, the degree to which equilibrium is achieved, and the properties of the contacting liquid. The solid materials of interest may be soils or sediments (with or without known contamination), wastes (from municipal, industrial, construction, or nuclear material processing), treated wastes or waste forms (e.g., cement-stabilized wastes, vitrified wastes or products from a range of physical/chemical/thermal treatment processes), secondary materials under consideration for beneficial use (e.g., slags, flue gas desulfurization gypsum, coal fly ash), or construction materials. The contacting water may be from percolation through porous materials, flow around porous or nonporous (or fractured) monolithic materials, or from condensation processes. The material may be water-saturated or unsaturated. The source and fate of the water (and any leached constituents) may include precipitation, runoff, groundwater, surface water or collected leachate.

The goal of environmental leaching assessment is to provide an estimate of constituent leaching potential for materials under possible management scenarios that is as accurate as practical or needed, but also does not under-estimate release of COPCs. The intended use of assessments may be to evaluate the environmental safety of specific management options for a class of materials (e.g., beneficial use or disposal scenarios for coal combustion residues), evaluate a specific or set of use or disposal scenarios for a material (e.g., use of a particular coal fly ash in construction of a roadway, embankment or structural fill), establish classes or performance characteristics of materials that may be acceptable for use in defined use scenarios, compare the effectiveness of treatment processes for specific waste types (such as may be needed for regulatory determinations of equivalent treatment), delisting of materials categorized as hazardous wastes based on the material's origin, or to determine remediation goals for contaminated soils or sediments. The constituents identified as COPCs will be specific to the material being evaluated, with specific COPCs usually considered because of their inherent human or aquatic toxicity (e.g., arsenic, mercury, etc.). However, it is important to recognize that leaching of COPCs most often is strongly influenced by the leaching of other major and trace constituents in the material being evaluated and the constituents present initially in the contacting water, the general chemical state (e.g., pH, oxidation-reduction potential, and ionic strength) of the leachant in contact with the solid, and the physical characteristics of the material that impact water contact. All of the above factors influence the LSP of COPCs and the rate and extent to which equilibrium between the solid and liquid phase is approached.

The broad range of potential uses of environmental leaching assessment implies that there is a need for a graded or tiered approach that provides for flexible, scenario-based assessments and allows tailoring of the needed testing and information based on the type of intended use of the assessment and available prior or related information. Furthermore, determination of constituent leaching estimates that are greater than or equal to the actual expected constituent leaching is necessary to maintain environmental protection in the face of uncertainty (often referred to as a "conservative"

approach). The extent of the assessment bias toward over-estimation of COPC leaching should depend on the nature of the decision and the uncertainties regarding the available material and scenario information. However, even when used as a screening test, LEAF methods provide release estimates that are more accurate and reliable (i.e., less conservative, or less of an over-estimate) and robust (able to consider multiple or evolving physical-chemical conditions) than are obtainable using any single-point leaching test. Testing is considered to be more accurate because of the tailoring to the range of potential environmental conditions and intrinsic leaching characteristics of materials inherent in the design of LEAF.

Several physical-chemical factors such as preferential flow and reducing conditions are known to significantly impact leaching and observed leachate conditions under field conditions but are not readily reproduced through routine laboratory testing (i.e., using standardized commercial test methods). As a consequence, while the LEAF test methods directly incorporate many of the important factors that impact leaching, additional factors such as reducing conditions and preferential flow are considered through chemical speciation and reactive mass transport simulations as discussed in later sections of this report.

2.1 LEAF and LEAF-analogous Leaching Tests

The LEAF test methods are presented in Table 2-1 by EPA method number along with a listing of analogous EU leaching methods. The LEAF methods are designed to measure fundamental leaching parameters including:

- LSP as a function of eluate pH;
- LSP as a function of L/S under percolation (column flow) or batch extraction testing;
- mass transfer rates from COPC leaching from monolithic or compacted granular materials.

Method 1313 and Method 1316 are parallel batch procedures intended to characterize the LSP at conditions approaching equilibrium as a function of final extract pH and liquid-to-solid ratio (L/S), respectively. Method 1314 and Method 1315 are test methods intended to measure the rate of constituent release under percolation or diffusive/dissolution mass transfer conditions, respectively. The test parameters and values specified in these methods have been described in a background information document on the LEAF leaching methods with fully validated methods available (Garrabrants et al., 2010; Garrabrants et al., 2012a; 2012b).

LEAF-analogous methods, also shown in Table 2-1, include leaching methods from the EU which are similar in structure and intent to the LEAF methods. Many of these EU methods have only minor deviations in test structure (e.g., the number of test fractions taken) or in test parameters (e.g., specified targets or time durations) from their LEAF counterparts. Documentation supporting the development and use of the EU test methods is available in the public literature (van der Sloot et al., 2012; Hjelmar et al., 2012).

The following sections contain brief description of LEAF and LEAF-analogous methods, example outputs from LEAF testing, and comparison of the results of analogous EU and EPA method results using the same test material. More detailed comparison and information relevant to the precision of these methods also has been documented (Garrabrants et al., 2012a; 2012b).

Table 2-1. LEAF Test Methods and Analogous European/International Methods.

EPA Method	Method Name	Short Name	Analogous EU and International Methods
1313*	Liquid-Solid Partitioning as a Function of Extract pH using a Parallel Batch Extraction Procedure	pH-dependence Test	PrEN[a] 14429 PrEn 14997 ISO/TS 21268-4
1314	Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio for Constituents in Solid Materials using an Up-Flow Percolation Column Procedure	Column Test or Percolation Test	CEN/TS[b] 14405 CEN/TC 351-TS-3 ISO/TS 21268-3 NEN 7343 NEN 7373
1315*	Mass Transfer Rates of Constituents in Monolithic or Compacted Granular Materials using a Semi-dynamic Tank Leaching Procedure	Monolith Leach Test or Compacted Granular Leach Test (generally "Tank Leaching Test")	PrEN 15863 Compacted Granular Leach Test[c] CEN/TC 351-TS-2 NEN 7345 NEN 7375
1316*	Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio in Solid Materials using a Parallel Batch Extraction Procedure	Batch L/S-dependence Test	EN 12457-2

Notes:

*In Kosson et al. (2002) and other previous works, precursor methods with slightly different test conditions were used. These precursor methods include:

- SR002 as a precursor to Method 1313 without specific target pH values.
- MT01 (monolithic materials) and MT02 (compacted granular materials) as precursors to Method 1315 with minor interval duration changes.
- SR003 as a precursor to Method 1316 with no significant changes.

[a] The "PrEN" designation denotes a preliminary CEN standard method that has been approved by a CEN technical committee and has completed interlaboratory validation, but is in the final approval process for "EN" designation.

[b] The "TS" designation denotes a "technical specification" which is a test method resulting from multi-national consensus and approved by a CEN technical committee, but has not yet completed interlaboratory validation or the final approval process for "EN" designation.

[c] Specifications for the Compacted Granular Leach Test are under development.

2.1.1 pH-dependent Leaching Tests

The concentration of hydrogen ion in solution (i.e., pH) has a major influence on the dissolution of COPC-containing mineral phases as well as on the COPC speciation in aqueous solution and the extent of adsorption onto or ion exchange with reactive surfaces. Thus, pH is a master variable in leaching assessment and reporting of pH in the eluate or leachate (i.e., pH at the leaching test end point) is of critical importance because pH at the approximated chemical equilibrium conditions controls the observed liquid-solid partitioning behavior for many constituents. Tests that measure COPC leaching with respect to pH are an important class of equilibrium-based test methods where the pH of the final extract is controlled as an independent variable in order to characterize leaching over a broad range of pH values. The pH-dependent leaching tests tend to be parallel batch extraction tests (i.e., multiple batch extraction conducted at different test conditions) with specific target pH values intended for the final eluate pH. Control of pH typically is obtained either by initial acid addition or by automated acid/base addition. The resultant eluate COPC concentrations are

plotted as a function of final eluate pH and are interpreted as a continuum pH-dependent leaching curve.

Method 1313: Liquid-Solid Partitioning as a Function of pH using a Parallel Batch Extraction Procedure

Method 1313 consists of nine parallel batch extractions at targeted pH values and one extraction at the natural pH[8] of the material. The solid material may require particle size reduction by crushing in order to facilitate the approach to solid-liquid equilibrium within a reasonable extraction timeframe. Dilute acid or base in deionized water is added to each extraction according to a pre-test titration in order to achieve final extract pH values at specified target values ranging between 2 and 13 at an L/S of 10 mL/g-dry. The extraction contact time ranges from 24 to 72 hours based on the grain size of the "as tested" material (i.e., the material after any particle size reduction or air drying required to improve the handling of the "as received" material). The pH and conductivity of the final extract solution are recorded and vacuum- or pressure-assisted filtration is used to separate the liquid and solid phases prior to chemical analysis of the eluate. This method also provides a titration curve of the solid material defined as the eluate pH response to additions of acid or base expressed in milli-equivalents (meq) of acid per gram of material with base additions shown on the x-axis as acid additions less than zero.

Eluate concentrations for constituents of interest are plotted as a function of eluate pH allowing for comparison to quality control and assessment values (e.g., quantitation or detection limits and waste disposal or utilization criteria). Eluate concentrations may also be interpolated to the target pH values to provide a uniform basis for comparison of results as the recorded eluate pH is likely to differ slightly from target values within specified pH tolerances. Example results for Method 1313 are shown in Figure 2-1 for arsenic leaching from a coal combustion fly ash, both as measured arsenic concentrations plotted as at measured eluate pH values (left) as well as arsenic concentrations interpolated to Method 1313 target pH values (right). In the figure, concentrations for the different parallel batch extractions of the test are connected with a line; however, this line should not be used as a functional trendline showing pH-dependent leaching between data points. A large circle is used to denote the natural pH extraction data.

[8] The natural pH, also referred to as "own pH", is the final eluate pH response of a deionized water extraction of a solid material (i.e., no acid or base added) conducted at an L/S 10 mL/g-dry.

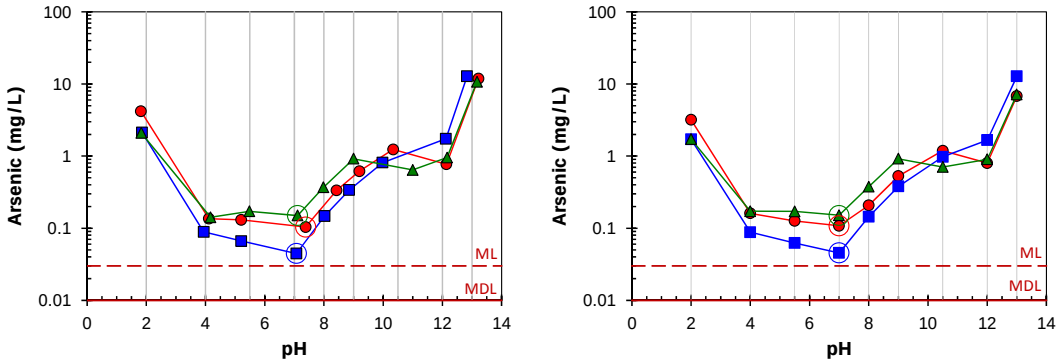

Figure 2-1. Example of Method 1313 data in triplicate for arsenic pH-dependent leaching from a coal combustion fly ash showing measured data (left) and interpolated data (right). The figures have been modified from those in Garrabrants et al., 2012a.

EU pH-dependent Methods PrEN 14429 and PrEN 14997

PrEN[9] 14429 and PrEN 14997 are European pH-dependent leaching tests developed by the Comité Européen de Normalisation (CEN) which are analogous to EPA Method 1313. Although initially designed to test waste materials, the approach of these methods has been adapted as ISO/TS 21268-4 under the International Standards Organization (ISO) program for soils and soil materials (ISO, 2007).

Separate sample portions are extracted in parallel at a fixed L/S ratio of 10 mL/g in dilute acid or base solutions in order to reach stationary pH values at the end of the extraction period. Sample portions of 15, 30, or 60 g (depending on sample heterogeneity and volumes of extractant required for chemical analysis) are prepared to have a grain size with 95% (m/m) less than 1 mm. Any particle size reduction is conducted by crushing. At least eight final pH values are required, covering at the minimum the range pH 4-12 (including the lowest value ≤4 and the highest value ≥12). The maximum pH differential between final pH points shall not exceed 1.5 pH units. The amounts of acid or base needed to cover the pH range can be derived from the results of a preliminary titration, from available experimental data on the material to be tested or from an arbitrary division of the predetermined maximum consumption of acid and base. The tests are carried out at a fixed contact time of 48 hours at which time equilibrium conditions are assumed for most constituents. The equilibrium condition is verified by a pH difference of less than 0.3 pH units between measurements taken after 44 hours and 48 hours. The results are expressed in mg/L of constituents for each final pH value. The quantity of acid or base that is added is recorded for each final pH value in mol H^+/kg of dry material with base additions expressed as negative values.

[9] The PrEN designation denotes that a draft method which is in the final process for approval as a European standard (EN). PrEN methods have been developed from a multi-national consensus process, approved by a CEN technical committee, and completed interlaboratory validation studies to assess method precision. The PrEN designation does not carry the status of an EN, but the method may be adopted as national standard. With regard to LEAF-analogous methods, the U.S. EPA interlaboratory validation study on EPA Method 1313 (Garrabrants et al., 2012a) has been accepted by CEN as the basis for validation for PrEN 14429 and PrEN 14997.

The primary difference between these two EU methods is how the extraction solution is introduced to the test portion:

- PrEN 14429 (2005) – Test portions are contacted with extraction solutions in a closed vessel with acid/base introduction through initial addition of extraction fluid. At the start of the test, the extraction solutions are prepared and divided evenly into three fractions. A fraction of extraction solution is added to the extraction bottle at the start of the test, after 30 minutes, and after 2 hours.
- PrEN 14997 (2005) – Test portions are placed into an open vessel with reagent water and acid/base is introduced via automated pH control. The method specifies that acid or base addition between cumulative extraction times of 44 and 48 hours shall not exceed 2% of maximum of the total acid/base addition at 48 hours.

Comparison of pH-dependent Leaching Test Results

The interlaboratory validation program for Method 1313 (Garrabrants et al., 2012a) allowed for a comparison of leaching test results between Method 1313 and the precursor "technical specifications" of PrEN 14429 and PrEN 14997 (denoted as CEN/TS 14429 and CEN/TS 14997, respectively). A sample of the results for testing of a coal combustion fly ash is shown in Figure 2-2 for selected COPCs.

In general, all pH-dependence leaching tests characterize the LSP behavior of fly ash; however, in Figure 2-2, minor differences were observed in the pH range $6 < pH < 12$. These differences are most likely attributed to kinetic effects where the approximate equilibrium in some tests may not be established over the test duration to the same degree.

2.1.2 L/S-dependent Leaching Tests

The amount of liquid in contact with a solid sample (i.e., L/S) is another critical parameter controlling the leaching of COPCs. At low L/S, liquid-solid partitioning and ionic effects in the aqueous solution control the release of COPCs while such solution chemistry effects are not significant at high L/S values where the mass of a COPC released into solution may be indicative of the total amount of COPC in the solid that is leachable. L/S-dependent leaching tests may be designed as batch extractions over a duration of time required to approach equilibrium or as percolation column tests at a flow rate low enough to approximate liquid-solid equilibrium. Eluate concentrations typically are expressed as a function of extraction L/S (for batch tests) or as cumulative L/S (for percolation tests).

Method 1314: Liquid-Solid Partitioning as a Function of Liquid-Solid Ratio using an Up-Flow Percolation Column Procedure

Method 1314 is an up-flow percolation column procedure used to evaluate the release of constituents from solid materials as a function of cumulative L/S.[10] Relative to field conditions, L/S

[10] Cumulative liquid-to-solid ratio will be denoted as L/S whereas the liquid-to-solid ratio for individual leaching intervals or test fractions will be denoted as L/S_i where the value *i* represents the endpoint cumulative L/S. For example, $L/S_{0.2}$ refers to first fraction of Method 1314 starting at L/S=0 mL/g-dry and ending at an L/S=0.2 mL/g-dry while L/S_{10} refers to the last fraction of the test starting at L/S=9.5 mL/g-dry ending at L/S=10 mL/g-dry.

can be a useful surrogate measure for time when infiltration rates are considered. In the context of the column test, L/S is defined as the volume of liquid passing through the column relative to the dry equivalent mass of test material in the column bed and is expressed in units of mL/g-dry. A sample of the solid material of approximately 300-600 grams is packed under moderate effort into a

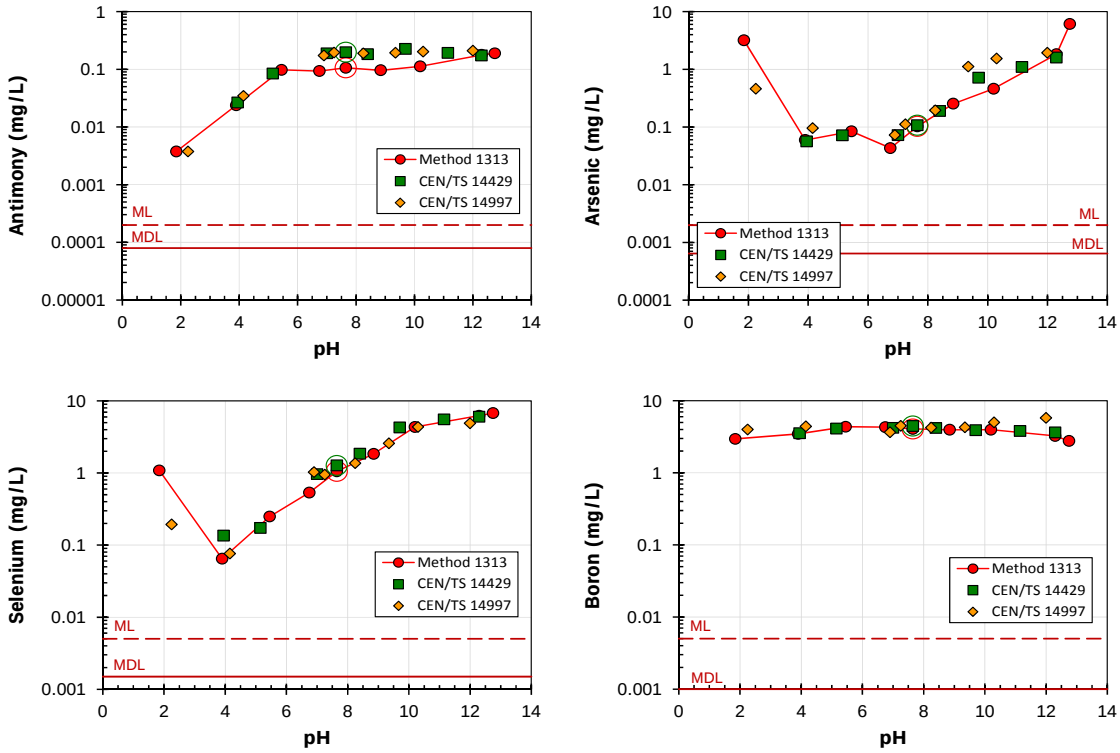

Figure 2-2. Comparison of pH-dependent leaching tests results for testing of a coal combustion fly ash using Method 1313, CEN/TS 14429 and CEN/TS 14997 (Garrabrants et al., 2012a).

5-cm diameter x 30-cm long column. Layers of clean silica sand are used at the top and bottom of the column to provide flow regulation on the inlet side and coarse filtration at the outlet. Leaching solution (eluent) is pumped upward through the material and eluate is collected as nine discrete volume fractions of the continuous elution volume. The up-flow percolation mode is intended to minimize air entrapment and flow channeling. The pump flow rate is adjusted to provide a volume of eluent equivalent to 0.75±0.25 L/S per day. For primarily inorganic materials, deionized water is used as the eluent for testing; however, a 1 mM solution of $CaCl_2$ may be used when testing certain materials (e.g., organic soils, clayey materials) where deflocculation of clay layers or dissolution of organic carbon may be a concern.

Method 1314 specifies nine eluate fractions collected at L/S values of 0.2, 0.5, 1.0, 1.5, 2.0, 4.5, 5.0, 9.5, and 10 mL/g-dry. The eluate pH, conductivity and optionally oxidation-reduction potential (ORP) are recorded for each fraction prior to filtration through a 0.45-µm membrane and preservation of an analytical sample. After chemical analysis of analytical samples, cumulative

release from the column at the specified L/S values is calculated from eluate concentrations and interval liquid-solid ratios (L/S_i). Thus, the measured eluate concentration for a given fraction represents the composite or integrated concentration over the designated cumulative L/S interval. Depending upon the intended use of the test results (e.g., when only cumulative release at specified L/S values is a concern), analytical samples may be composited to minimize analytical costs, but typically all eluate collections are analyzed for COPCs. For display purposes, eluate concentrations are typically graphed as a function of L/S, with the concentration of each individual fraction plotted at the cumulative L/S at the end of the fraction interval.[11] A second useful representation of percolation test data is the cumulative release for each constituent (i.e., the cumulative amount of a constituent leached per mass of material tested) as a function of cumulative L/S. Cumulative release is accurately plotted at the end-point cumulative L/S for each fraction interval. Example outputs from Method 1314 testing of a contaminated soil from a smelter site are presented in Figure 2-3 and include the pH of the collected eluate fractions, the graphs of eluate COPC concentration, and cumulative release of the COPC.

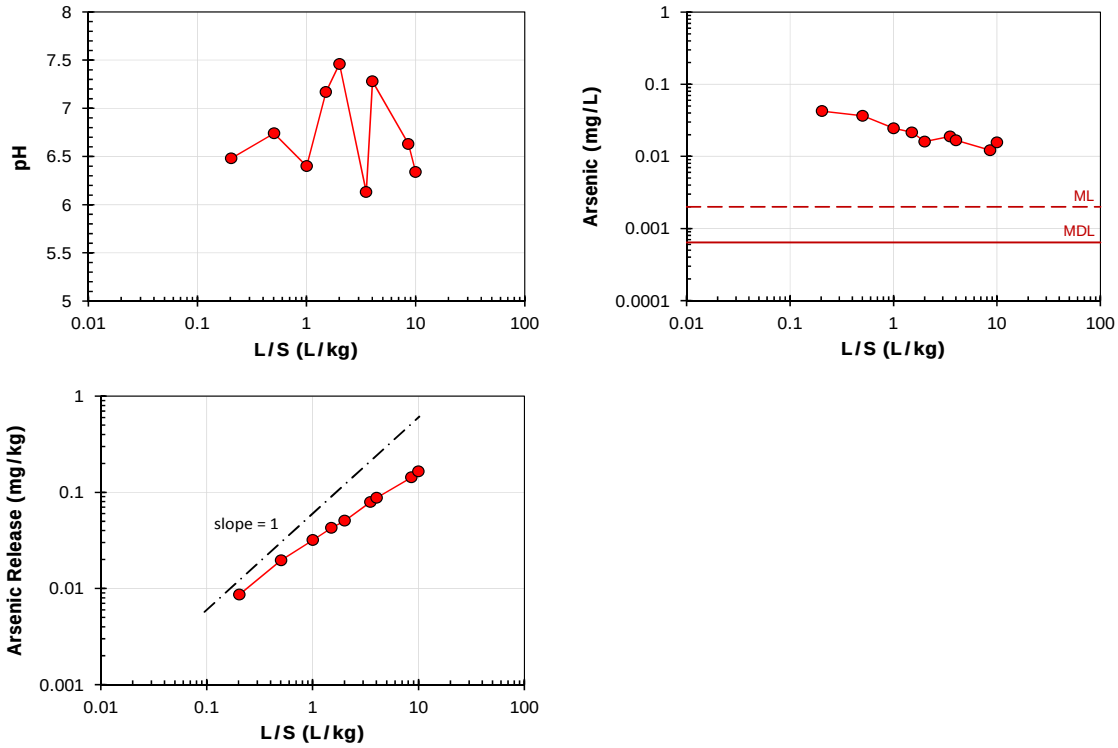

Figure 2-3. Example Method 1314 results for arsenic leaching from a contaminated smelter site soil showing eluate pH in collected fractions from the column, eluate arsenic concentrations, and cumulative release of arsenic with L/S (Garrabrants et al., 2012b).

[11] Since the eluate concentration represents a mean concentration, a more accurate representation would be obtained by plotting the COPC concentration at the geometric mean L/S over the fraction interval.

Method 1316: Liquid-Solid Partitioning as a Function of Liquid-Solid using a Parallel Batch Extraction Procedure

Method 1316 is an equilibrium-based leaching test intended to provide eluates over a range of L/S values from 10 to 0.5 mL/g-dry using five parallel batch extractions in DI water. No acid or base is added to the extractions so that the results can indicate changes in eluate pH with L/S. Particle size reduction of the solid material may be required in order to facilitate the approach to solid-liquid equilibrium. The contact time for the extractions ranges from 24 to 72 hours based on grain size in a similar manner. The pH and conductivity of the final extract solution are recorded. Solid and liquid phases are separated by vacuum- or pressure-assisted filtration and prepared for chemical analysis. This method provides data on the changes in equilibrium chemistry (i.e., ionic strength, constituent concentrations) as the L/S value approaches that are found within the solid phase pore solution. Method 1316 output (see example in Figure 2-4) is similar to the output of Method 1314 with eluate pH, eluate COPC concentration and COPC release plotted as functions of L/S. COPC release results are similar to the results of Method 1316; however, eluate concentrations are typically higher in Method 1316 due of the natural of batch extraction process.

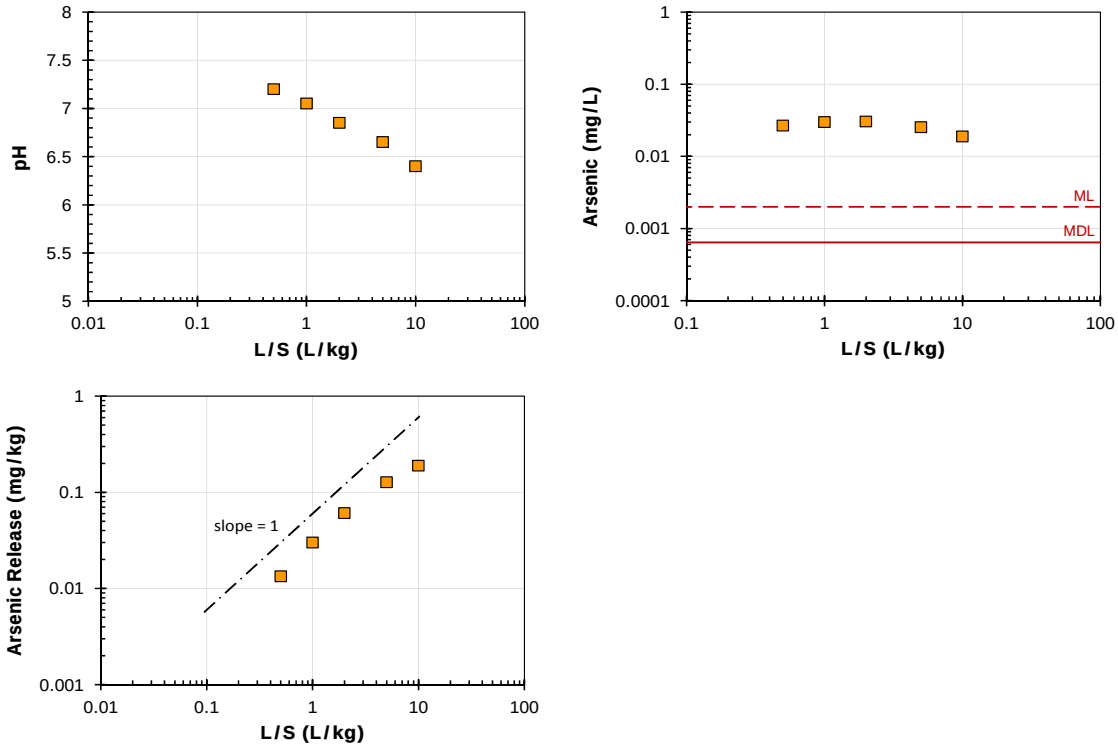

Figure 2-4. Example Method 1316 results for arsenic leaching from a contaminated smelter site soil showing eluate pH in collected fractions from the column, eluate arsenic concentrations, and cumulative release of arsenic with L/S (Garrabrants et al., 2012a).

EU Percolation Method CEN/TS 14405

CEN/TS 14405 (2004) is an up-flow percolation column test method designated as a "technical specification"[12] by CEN for characterization of waste and has been adopted by ISO under ISO/TS 21268-3 for soils and soil materials (ISO, 2007). A very similar column test, CEN/TC351-TS-3, sponsored through the CEN Technical Committee 351 is undergoing robustness testing (Hjelmar et al., 2012). The Dutch standards NEN 7343 (1995) and NEN 7373 (2004) from the Nederlands Normalisatie Instituut (NEN), are precursors of the CEN/TS 14405 method.

The procedure for CEN/TS 14405 is similar in intent and procedure to Method 1314 with minor differences in the number of eluates collected and, hence, the prescribed L/S values. CEN/TS 14405 allows for collection of an eluate at 0.1 mL/g-dry that is not specified in Method 1314 due to limitations of eluate volume at this low L/S. In addition, while Method 1314 specifies a flow rate based on L/S passing through the column which is dependent on the mass of solid in the column, CEN/TS 14405 specifies flow rate in terms of eluate volume per time, which is independent of the solid mass. The CEN/TS 14405 method determines the release of constituents from granular material packed into a column with a leachant percolating through the column packing. The test conditions, including the flow rate of the leachant, enable conclusions to be drawn from the results as to which components are rapidly washed out and which components are released under the influence of interaction with the matrix.

Test material, with or without particle size reduction, is packed into either a 5-cm or a 10-cm diameter plastic or glass column that is 30-cm long. Packing is achieved in a standardized manner with a plastic rammer. Demineralized water leachant is percolated in up-flow through the column at a specified flow rate of 12 mL/h for a 5-cm diameter column or 48 mL/h for 10-cm diameter column. The eluate is collected at seven fixed values of cumulative liquid-to-solid ratio or L/S (i.e., 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 and 10.0 mL/g-dry). Each eluate is characterized physically and chemically for pH, conductivity and concentrations of constituents of interest according to existing standard methods. In the test procedure, equilibrium conditions at the outlet of the column are verified after an equilibration period by measuring a pH deviation. The results of the test are expressed as a function of L/S, in terms of both eluate concentration (mg/L) and cumulative mass release (mg/kg-dry).

EU Batch L/S Method EN 12457

EN 12457 is a European Standard consisting of a four-part batch leaching procedure in which particle size-reduced material is extracted with deionized or demineralized water at room temperature. Parts 1, 2 and 4 of the standard are single-batch extractions at difference L/S ratios and particle size requirements. Part 3 consists of a two-step test with re-extraction of the recovered

[12] The "TS" designation denotes a CEN "technical specification" which is a method that has resulted from a multi-national consensus process and has been accepted by a CEN technical committee, but has not completed interlaboratory validation studies and final CEN approval. TS methods may be used as national standards. The U.S. EPA validation data for Method 1314 has been accepted as the basis for validation of CEN/TS 14405, but this method has not yet received the "PrEN" designation.

material from the first L/S 2.0 mL/g extraction in a second extraction step at L/S of 8.0 mL/g (cumulatively the L/S is equal to 10 mL/g). In comparison to the LEAF methods, EN 12457-2 is most similar to the L/S 10 target extractions in Method 1316 and the natural pH extraction of Method 1313.

Comparison of L/S-dependent Leaching Test Results

The results of Method 1314 and CEN/TS 14405 were compared during validation of the EPA percolation column test (Garrabrants et al., 2012b). In Figure 2-5, this comparison is shown for selected COPCs leached from a smelter site soil in terms of mass released from the column tests. Also include in this figure are the release values resulting from the batch L/S test, Method 1316, performed on the same material (Garrabrants, et al., 2012a). The three L/S-dependence tests result in very similar cumulative release data with all tests showing the same general behavior for each COPC. Differences in the cumulative release from these test methods were considered within the reproducibility values calculated for the individual LEAF tests (see Garrabrants et al., 2012a, 2012b for details on performance measurements).

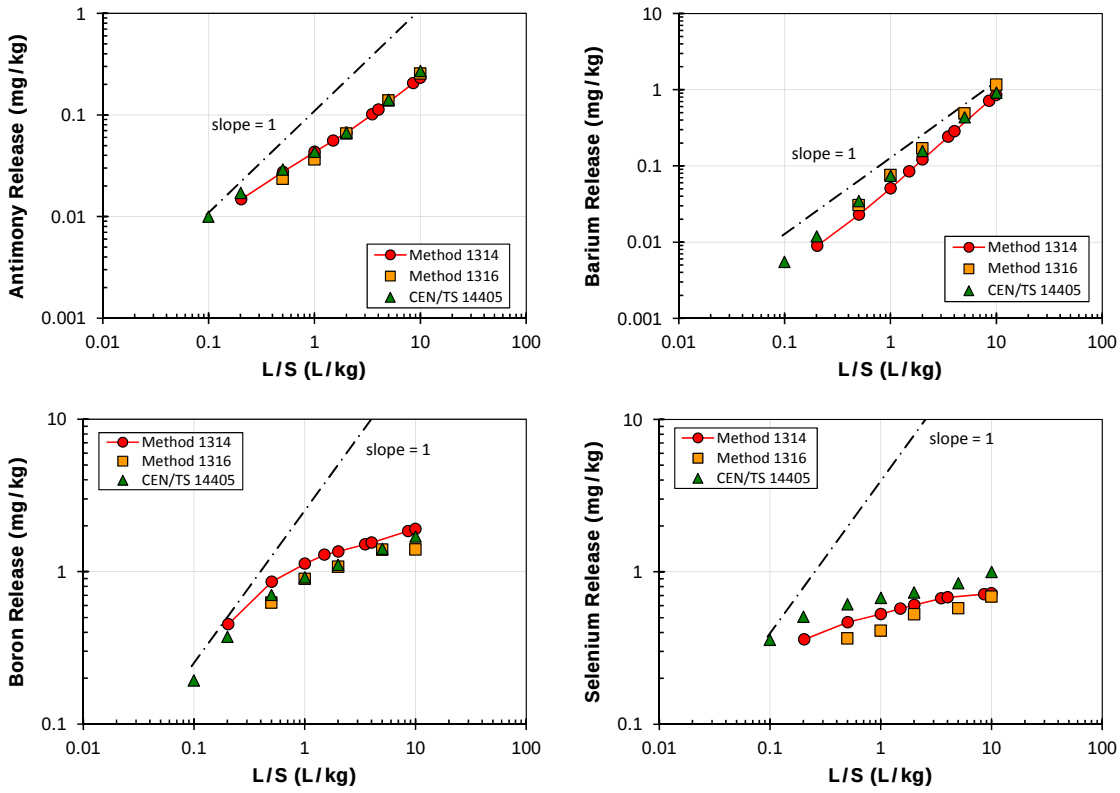

Figure 2-5. Comparison of L/S-dependent release for a contaminated smelter site soil using Method 1314 (percolation), Method 1316 (batch L/S) and CEN/TS 14405 (percolation). Data taken from Garrabrants et al., 2012a, 2012b.

2.1.3 Mass Transport-based Leaching Tests

For materials with low hydraulic conductivity relative to their surroundings, the majority of any infiltrating water will not percolate through the material but will be diverted to "flow around" the material. Examples, of such material would be clays and compacted granular materials and monolithic material derived from solidification/stabilization. When flow-around conditions exist, constituents must travel through the porous structure of the material to the bulk material surface in order to be release. Often, this mass transport through the material is the rate limiting factor in leaching assessments. The rate of mass transport may be characterized using tank leaching tests where a sample of monolithic or compacted granular material is suspended in a tank of leaching fluid over a specified leaching interval. The fluid is refreshed in order to maintain a concentration gradient between the material surface and the pore structure. This gradient is related the driving force for mass transport through the material. Refreshment of the leaching solution often is semi-dynamic, occurring in accordance with a specified refresh schedule, such that the leaching method appears as a large scale, sequential batch leaching procedure consisting of several leaching intervals that comprise a total or cumulative leaching time.

Method 1315: Mass Transfer Rates in Monolithic and Compacted Granular Materials using a Semi-dynamic Tank Leaching Procedure

Method 1315 is a semi-dynamic tank leaching procedure used to determine the rate of mass transport from either monolithic materials (e.g., concrete materials, bricks, tiles) or compacted granular materials (e.g., soils, sediments, fly ash) as a function of time. Monolithic test specimens may be cylinders or parallelepipeds, cast in molds or cut/cored to size from larger samples. Granular materials are compacted into cylindrical molds at optimum moisture content by Proctor-type compaction methods such as ASTM D698 (2007) or ASTM D1557 (2009). Test specimens are leached in intervals in a series of tanks containing deionized water with each leaching interval having a specified duration. The volume of deionized water in each tank is based on the surface area of the test specimen at a liquid-to-surface area ratio (L/A) of 9 mL/cm^2. At the end of each leaching interval, the test specimen is removed from the tank, the mass of the test specimen is recorded, and the specimen is submerged into another new tank containing fresh deionized water. The cumulative times corresponding to the end of the nine leaching intervals are 2, 25, 48 hours, 7, 14, 28, 42, 49, and 63 days. For each tank eluate, the pH, conductivity, and optionally ORP are recorded prior to filtration through a 0.45-µm membrane and preservation of an analytical sample.

After chemical analysis, the mean flux of constituents in each interval (i.e., mass released per surface area per unit time of the leaching interval) and the cumulative release of constituents (total mass released per unit surface area as a function of time) are calculated from the eluate concentration, the volume of eluate collected for each interval, the geometry and mass of the test specimen, and the duration of each interval. In addition, mass transfer characteristics (e.g., diffusivity, tortuosity) may be calculated using assumed mathematical models. An example of the outputs of Method 1315 conducted on sample of a solidified waste analog (i.e., cement, coal water matrix spike with metal oxide powders) is shown in Figure 2-6 and include (i) the evolution of pH in test fractions, (ii) eluate concentrations for a selected COPC, (iii) the mean interval mass flux

(mg/m² s) of the COPC as a function of cumulative leaching time, and (iv) the cumulative mass release (mg/m²) of the COPC as a function of cumulative leaching time. This test is used to assess the combined effects of pore water chemistry (e.g., dissolution, adsorption) and diffusion through a monolithic or compacted granular material.

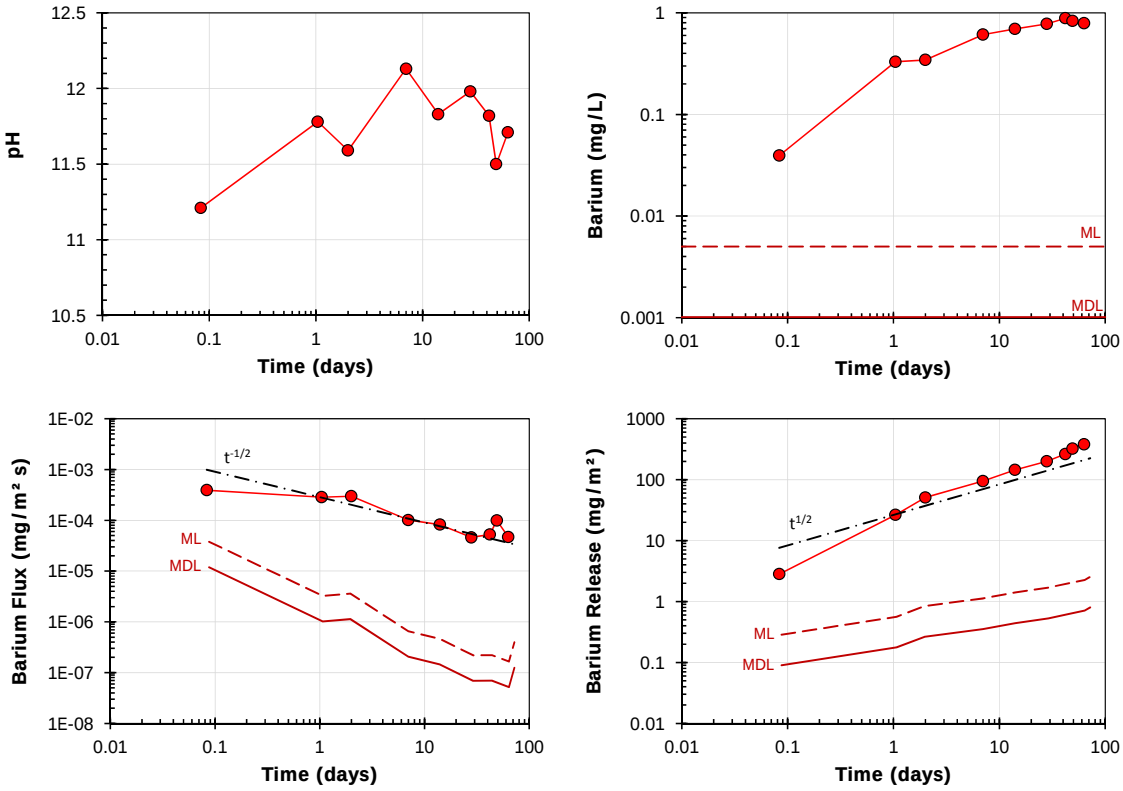

Figure 2-6. Example Method 1315 test results for barium leaching from a solidified waste analog material showing pH evolution, eluate concentration, mean interval flux and cumulative release (Garrabrants et al., 2012b).

EU Mass Transport Methods PrEN 15863 and NEN 7375

The EU mass transfer leaching test, PrEN 15863 (2009) and the Dutch standard mass transfer test, NEN 7375 (NEN, 2004), are similar in intent and procedure to Method 1315. Differences include the total testing duration, the number and duration of the testing intervals, and the basis for determination of the amount of liquid used in each leaching interval as shown in Table 2-2. Currently, a similar procedure, CEN/TC 351-TS-2, is undergoing robustness testing for use with construction products under CEN Technical Committee 351 (Hjelmar et al., 2012). Dutch standards NEN 7345 (1995) and NEN 7375 (2004) are precursors of the PrEN 15863 method while CEN/TS 15863 is the technical speciation designation for PrEN 15863.

NEN 7375 Procedure

NEN 7375 is a test intended to define leaching from molded or monolithic materials under mass transfer conditions as a function of time. The test determines the nature and properties of the material matrix by placing a complete sample in a leaching fluid of demineralized water and replenishing the eluate at eight specified cumulative times of 0.25, 1, 2.25, 4, 9, 16, 36, and 64 days. Test specimens should have a minimum dimension of 40 mm and a geometric surface area of at least 75 cm^2. The volume of eluent for each leaching interval is based on the test specimen volume with 2-5 mL of eluent for every cm^3 of test specimen. From analytical samples of each eluate collection, the composition of the eluate is determined using standard methods, and the leached quantity per unit area is calculated for each constituent. Parameters that can be deduced from the development of release of constituent over time include the extent of surface rinsing and the effective diffusion coefficient which can be used to estimate leaching over longer periods.

PrEN 15863 Procedure

PrEN 15863 is a procedure for leaching of a solid monolithic material in a similar manner as NEN 7375 or Method 1315. The test specifies that a regular shaped test specimen is prepared by cutting or coring in accordance with standard sampling methods. The test specimen is submerged in a tank of demineralized or deionized water for specified interval durations for a series of eight leaching intervals (see Table 2-2). Leachant is refreshed at cumulative times of 0.08, 1, 2.25, 8, 14, 15, 28, and 36 days. For each eluate, pH and conductivity are measured and recorded prior to preparation for chemical analysis using standard methods. The results of the test are the cumulative mass release (mg/m^2) expressed as a function of time.

Table 2-2. Comparison of Method 1315 and EU Mass Transfer Test Parameters.

Parameter	Method 1315	PrEN 15863	NEN 7375
Total Test Duration (d)	63	51	64
Eluate Volume Basis	specimen surface area	specimen surface area	specimen volume
Liquid Volume	9±1 mL/cm^2	8±1 mL/cm^3	2-5 cm^3/cm^3
Number of Intervals	9	8	8
Refresh Exchanges at Cumulative Times (d)	0.08 1.1 2.0 7 14 28 42 49 63	0.08 1.0 2.25 8 14 15 28 36	0.25 1.0 2.25 4 9 16 36 64

Comparison of Mass Transport Test Results

Figure 2-7 shows the comparison of interval mean flux for mass transport of selected COPCs in a solidified waste analog for EPA Method 1315, NEN 7375 and CEN/TS 15863 (the technical specification of PrEN 15863). This figure shows that the general trend of the interval flux is consistent despite the different interval durations of the tank leaching tests.

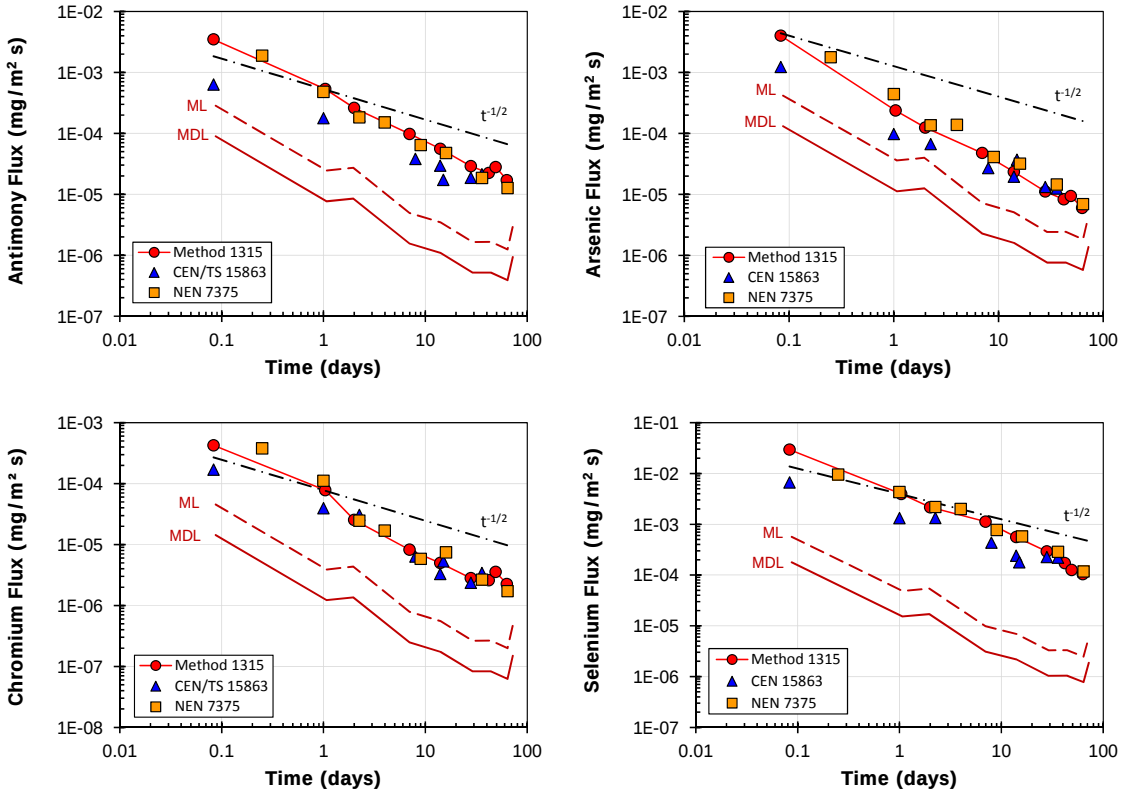

Figure 2-7. Comparison of mean interval flux release results for testing of a solidified waste analog using Method 1315, CEN/TS 15863 and NEN 7375. Data taken from Garrabrants et al., 2012b.

2.2 A Conceptual Framework for Interpreting Leaching Test Data

Detailed material characterization consists of laboratory measurement (i) LSP as a function of pH (pH-dependent leaching), (ii) LSP as a function of L/S either by percolation column or by parallel batch procedures, and (iii) rates of mass transport under diffusion-controlled conditions. Data sets from the currently-specified LEAF, EU and respective precursor test methods (Table 2-1) are the laboratory test results used in this report for comparison with field data. Laboratory leaching test results are used here primarily to illustrate a conceptual framework for the relationships between test method results and field data because more complete testing information is available for the

laboratory tests, including a wider range of test method results and constituents analyzed, than is available from reported field data and studies.

2.2.1 Liquid-Solid Partitioning at Equilibrium

Equilibrium-based leaching test measure LSP under specified test conditions. For example, Methods 1313 and 1316 determine the effect of pH and L/S, respectively, on LSP under batch test conditions which are intended to approximate chemical equilibrium between the aqueous and solid phases (Garrabrants et al., 2010). Similarly, column percolation tests carried out at relatively slow flow conditions (e.g., residence time ~1 day or less) approximate local equilibrium between the pore solution and solid phase at any given point in the column. Therefore, eluates collected between two L/S values indicate the average release over that L/S interval. The primary distinguishing feature of a percolation test over that of a batch L/S procedure is the column test captures the effects of different elution rates of COPCs into the pore solution at different L/S values with the result that the local composition of the system changes as the amount of liquid passes through the column. Under the assumption of a constant flow rate, the cumulative L/S (e.g., the volume eluted from the column divided by the dry mass of solid material in the column) is used as a surrogate for elution time.[13] Column percolation tests also often are considered a surrogate for field leaching conditions for scenarios where infiltration or groundwater passes through a relatively permeable solid; however, field conditions are much more likely subject to preferential flow, and therefore infiltration bypassing the material in question results in lower observed concentrations in the field than the laboratory.[14]

For all equilibrium-based leaching tests, the approximation of local equilibrium is the result of pragmatic choices in selection of appropriate contact times, because attaining true chemical thermodynamic equilibrium would, in most cases, require test durations far longer than practical for routine implementation in a decision-making framework.

Chemical Phenomena Affecting LSP

The resulting LSP of constituents in a material at chemical equilibrium can be the result of several chemical phenomena that occur either individually, with one phenomenon dominant in the observed behavior, or with multiple phenomena occurring simultaneously with different phenomena controlling the observed behavior under different pH or L/S conditions.

To illustrate this concept, the several response types are used to describe dominant leaching mechanisms under common partitioning behaviors. Most of these response types can be distinguished based on examination of the results from one or more of the LEAF test methods, however, for some situations, chemical speciation may be needed to clarify the contributing

[13] In many column test procedures, the number of pore-volumes eluting from the material is used as the comparison basis rather than cumulative L/S. Cumulative L/S was selected as the basis for comparison for Method 1314 because it is not dependent on system porosity and provides a convenient basis for comparing results of Method 1314 with Methods 1313 and 1316.

[14] The extent of preferential flow during percolation can be evaluated based on the observed concentrations and elution profiles for highly soluble constituents such as sodium, potassium, chloride and nitrate. Greater extents of preferential flow result in lower peak concentrations and longer tailing of elution curves.

mechanisms (i.e., distinguishing between precipitation and adsorption at low constituent concentrations).

Response 1. Total Content vs. Availability

A constituent, or fraction thereof, may be incorporated into one or more solid phases or mineral structures that do not readily dissolve in water, thereby rendering that fraction of the constituent not available for leaching under reasonable environmental conditions and relevant time frames (e.g., years to decades). Although the solid phase or mineral structure containing the constituent may be dissolved over geologic time frames due to weathering and aging which may allow for leaching of the constituent in the long term, these time frames typically are long enough that leaching may have little impact on groundwater when carried through a risk assessment. One example of this response is the incorporation of lead into stable alumina-silicate phases where the alumina silicate phases must be dissolved to release the lead and have been found to be stable over geologic time frames (i.e., amorphous glassy phases and other mineral phases). The fraction of lead not bound in these recalcitrant phases is considered the available fraction of the total content in the material, often referred to as "availability." The sum of the lead incorporated into recalcitrant phases and available content of lead is the total lead content in the material. Comparison of total content to maximum leaching concentration for a wide range of CCRs illustrated that total content and available content are not correlated (Thorneloe et al., 2010).

Response 2. LSP less than Aqueous Solubility

A constituent, or fraction thereof, may be present in one or more readily soluble solid phases that dissolve fully into the aqueous phase under the leaching test conditions with the resultant constituent concentration in the aqueous phase less than the aqueous solubility (i.e., an under-saturated solution). One example of this case is the dissolution of sodium chloride when the total amount of dissolvable sodium and chloride results in concentrations in the aqueous phase that are less than the respective solubility for each constituent. In this case, the available content of a constituent could be the limiting factor in the concentration seen in laboratory testing (referred to as "availability-limited" leaching).

For many of these highly soluble species, the LSP curve is not a strong function of pH, and eluate concentrations remain relatively constant across the pH range. When availability-limited release is dominant, eluate concentrations increase with decreasing L/S (i.e., the same mass of constituent is released into less liquid), but mass release is independent of L/S (i.e., when normalized to the mass of the solid material tested, mass of the constituent release is relatively constant with changes in L/S). An illustration of availability-limited leaching as a function of pH and L/S is shown in Figure 2-8 using chloride release from a sample of unwashed flue gas desulfurization (FGD) gypsum with material code SAU (Kosson et al., 2009).

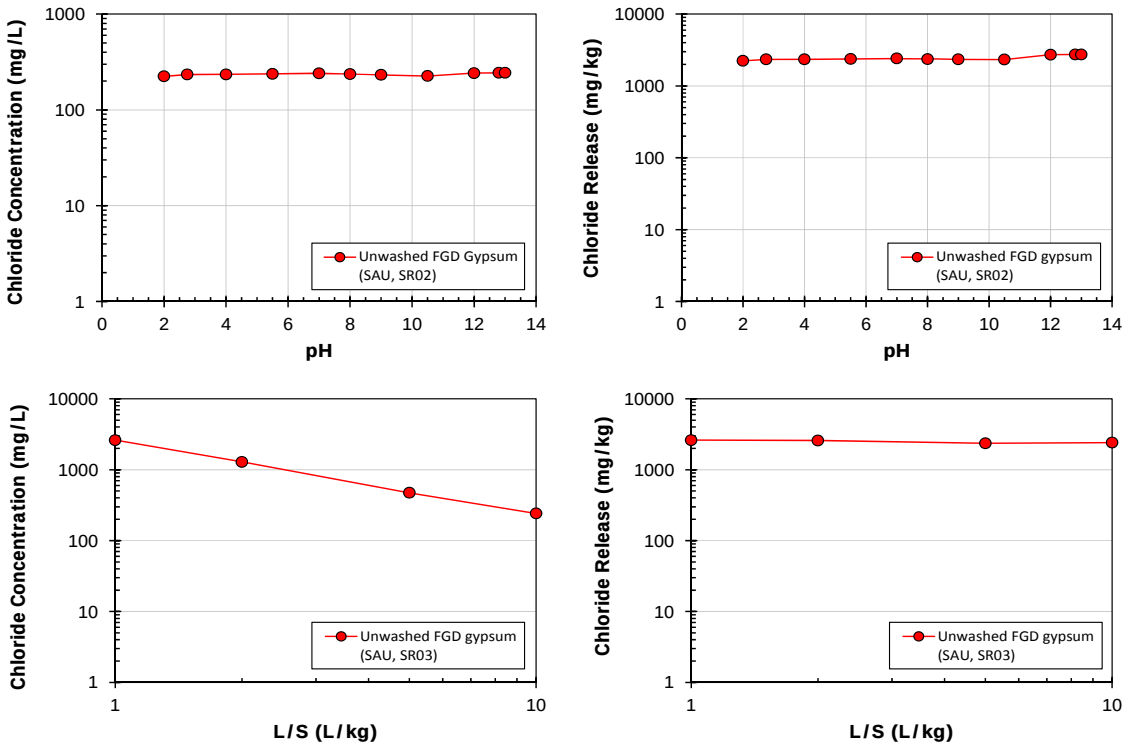

Figure 2-8. Chloride as an example of a highly soluble species where the observed leaching concentration is a function of L/S but not a function of pH for an unwashed gypsum material from coal combustion flue gas desulfurization (SAU, after Kosson et al., 2009).

Response 3. LSP at Aqueous Solubility

A constituent, or fraction thereof, may be present in one or more solid phases that will only partially dissolve into the aqueous phase under the leaching test conditions with the resulting constituent concentration in the aqueous phase at the aqueous solubility (i.e., a saturated solution). This phenomenon is referred to as "solubility-controlled" release. An example of this case is the dissolution of arsenic from a highly alkaline coal fly ash under neutral to alkaline pH (Figure 2-9).

When this phenomenon is dominant in leaching, eluate concentrations typically are strong functions of pH and are constant with decreasing L/S (i.e., the dissolution of the partial soluble solid phase controls the eluate concentration). As long as pH remains relatively constant with decreasing L/S, the constituent mass release will decrease with decreasing L/S at a rate approximately proportionate to the decrease in L/S (e.g., a reduction in L/S from 10 to 0.5 mL/g-dry will result in a 20x decrease in constituent). However, the greater ionic strength at lower L/S may also impact the amount leached. In addition, trace constituents may also co-precipitate with major element solid phases, resulting in solid solutions and more complex behavior where the observed liquid concentration for the trace species is proportional to the content of that species in the solid solution.

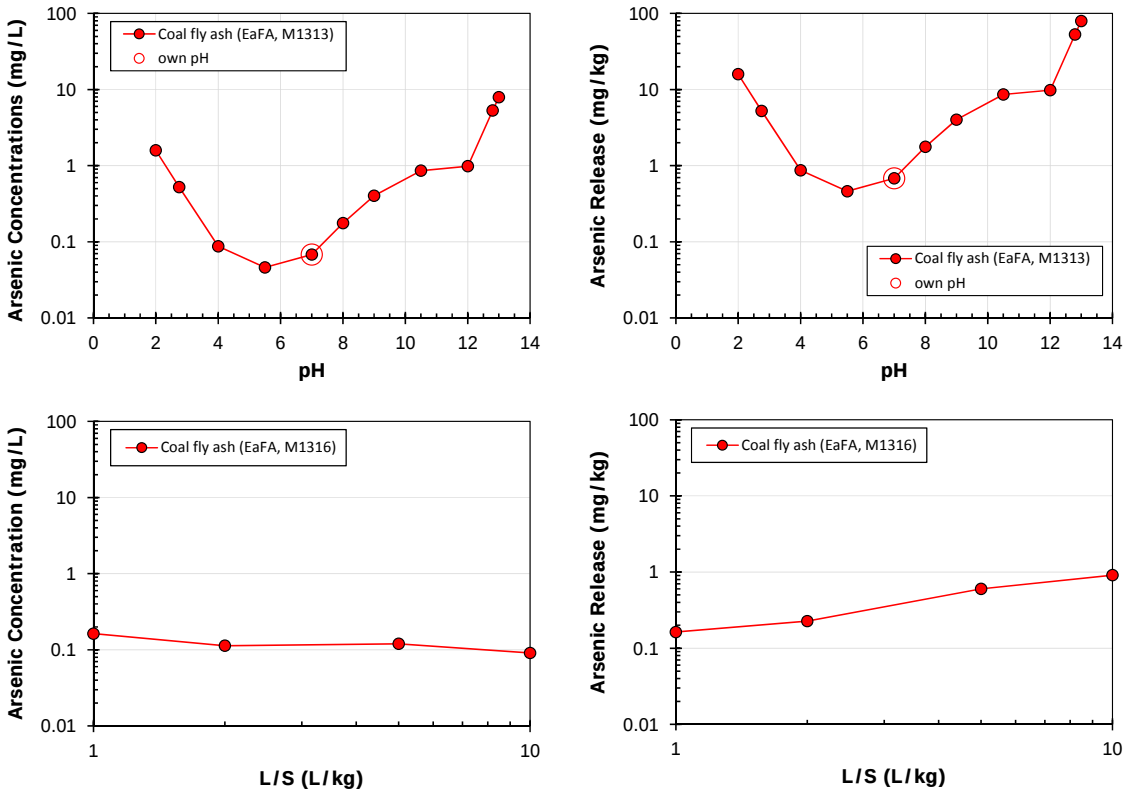

Figure 2-9. Arsenic as an example of solubility-controlled (saturated solution) leaching as a function of L/S and pH for a coal combustion fly ash (EaFA; after Garrabrants et al., 2012a).

Response 4. Surface Interaction

A constituent, or fraction thereof, may be present as a readily soluble species that is not initially present in the material as a distinct, precipitated solid phase. The constituent species may be present at a relatively low concentration associated with a reactive solid surface where the LSP is controlled by adsorption/desorption or ion exchange phenomena. Such reactive surfaces include oxide minerals (e.g., iron, manganese, or alumina (hydr)oxides), (ii) clay-like minerals, (iii) particulate organic carbon (such as from decay of plant matter), and (iv) particulate carbon (such as char from combustion or activated carbon). When adsorption/desorption or ion exchange phenomena control constituent leaching, the constituent species of interest is fractionally distributed between the aqueous and solid phases at equilibrium, with the fractional distribution influenced by (i) the total available amount of the constituent in the liquid-solid system, (ii) the nature and amount of reactive solid surface in the system, and (iii) the aqueous solubility of the species at the test conditions.

For many constituents, the initial speciation (i.e., chemical forms) and distribution in the solid material are often a combination of two or more of the four phenomena described above. Examples include (i) chloride present both in a relatively insoluble alumina-silicate phase and as sodium

chloride crystals (Responses 1 and 2, above; Figure 2-8), (ii) lead present both in a relatively insoluble alumina-silicate phase and as a lead molybdate phase (Responses 1 and 3, above), or (iii) arsenic present as several species with the resultant leaching behavior a combination of Responses 1, 2 and 4, as described above (Figure 2-9).

2.2.2 pH, Ionic Strength and Aqueous Phase Complexation as LSP Modifying Parameters

The above phenomena and resulting observed leaching behavior is further complicated by the following modifying factors:

Eluate pH

The solubility of some constituents, such as periodic table Group IA elements (e.g., sodium, potassium) and anions (e.g., chloride and nitrate), is not strongly affected by pH and, therefore, tends to have leaching characteristic behavior consistent with Response 2, above (Figure 2-8). In contrast, the solubility of some constituents is strongly dependent on pH and can exhibit behavior consistent with Response 2 over some pH domains and Response 3 over the remaining pH domains. For the example of a coal fly ash in Figure 2-10, magnesium is very soluble at pH < 8 (Response 2) while forming a saturated solution at pH > 9 (Response 3). Conversely, molybdenum is very soluble at pH > 8 while forming a saturated solution at pH < 6. This phenomenon allows the availability of many constituents to be estimated based on the maximum or asymptotic release over the domain of 2 < pH < 13.

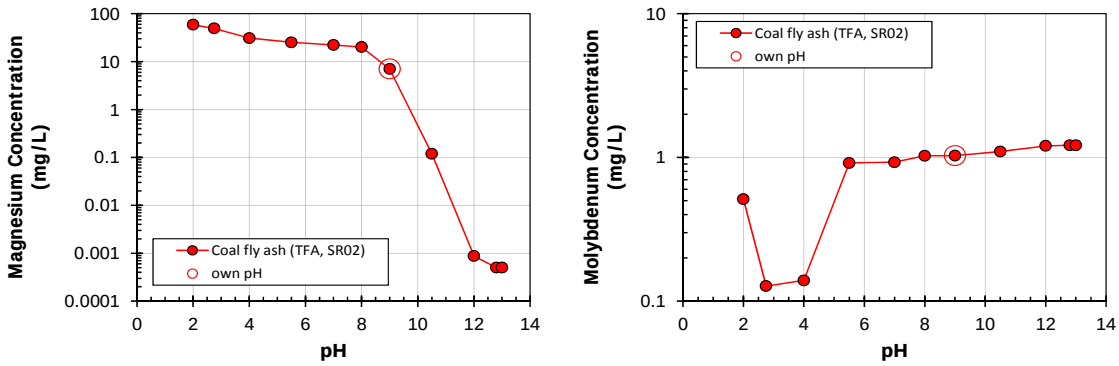

Figure 2-10. pH-dependent solubility of magnesium and molybdenum for coal fly ash sample TFA (after Kosson et al., 2009).

Ionic Strength

The presence of other constituents in the aqueous and solid phases often influences the solid phases present for the constituent of interest (speciation of precipitated solids) and resultant solid phase solubility in the aqueous phase. One effect of the presence of highly soluble constituents is reflected in changes in ionic strength, which impacts solubility through changes in chemical activity (i.e., activity coefficients). Another effect might be precipitation of a constituent phase due to dissolution of a related phase through the presence of a common ion.

An example of the common ion effect is that barium will precipitate as barium sulfate as calcium sulfate dissolves, leading to apparent chemical interactions between calcium and barium leaching in the presence of sulfate.

Complexation and Chelation

Some constituents in solution may complex or chelate with a constituent of interest, shifting equilibrium toward the aqueous phase and increasing the LSP eluate concentration over the aqueous solubility afforded only by mineral dissolution. Examples of this include (i) complexation of cadmium by chloride at neutral to moderately alkaline pH, and (ii) the chelation of copper with DOC (e.g., humic and fulvic substances, especially in MSW landfill leachate) at moderately acid to alkaline pH (Figure 2-11).

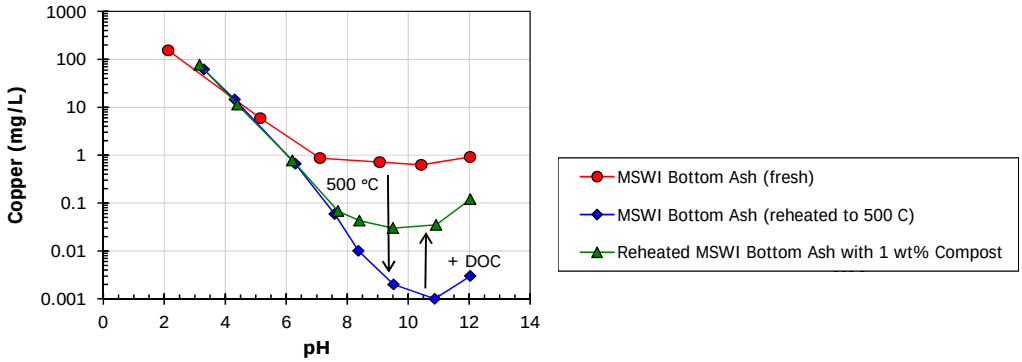

Figure 2-11. Illustration of the influence of organic matter and DOC on leaching of copper through three cases: (i) fresh municipal solid waste incinerator (MSWI) bottom ash, (ii) the same MSWI bottom ash heat treated at 500 °C to remove organic matter, and (iii) the heat-treated MSWI bottom ash from above with 1% compost added to provide organic matter (after van der Sloot et al., 2008c).

In most cases, only the total concentration of a constituent, rather than the chemical speciation of a constituent, is measured in a leaching test eluate or leachate and in the solid material being evaluated because of analytical method limitations or cost. Thus, chemical speciation of individual constituents is most often only inferred based on empirical observations (i.e., characteristic liquid-solid partitioning behavior) or assessed by chemical speciation modeling (see Section 3).

2.2.3 Oxidation-Reduction Considerations for Leaching Tests and Leaching Assessment

For constituents with multiple valence states under the range of oxidizing to reducing conditions observed in the field, the oxidation-reduction potential (ORP) of the porewater and bulk solutions in contact with solid materials can influence the resulting LSP and precipitated solid phases. In the context of the case studies evaluated in this report, the most relevant constituents for reduction/

oxidation (redox) are Fe and S as species that control the LSP of other constituents and As, Cr, Cu and V as redox sensitive species that frequently are considered COPCs in environmental systems.

In order to provide context for redox relationships with respect to leaching and geochemical speciation modeling (Manahan, 1991):

$$\text{pE} = \frac{F}{2.303RT}E_H = \frac{E_H}{0.0591}\ (at\ 25\ \text{C}),$$

where pE is the –log{electron activity} or redox of the aqueous system at the stated conditions,
F is Faraday's constant,
R is the ideal gas law constant,
T is the absolute temperature, and
E_H is the measured half-cell potential against a standard hydrogen electrode (in contrast to use of a saturated calomel reference electrode[15] as typically measured in the laboratory).

If the oxidized and reduced species (i.e., Fe^{3+} and Fe^{2+}) are both at unit activity[16], than $E=E^0$ and $pE=pE^0$ at the stated temperature (usually 25 C). Values for pE^0 are available in standard tabulations (Pourbaix, 1963; Sillen and Martell, 1964). For conditions where the oxidized and reduced species are not at unit activity (which is typically the situation for leachates and other real aqueous solutions), then the value for pE can be calculated as follows:

$$\text{pE} = pE^0 + \frac{1}{n}log\frac{\{oxidized\ species\}^a}{\{reduced\ species\}^b}$$

where a and b are the reaction stoichiometric coefficients for the redox half reaction and n is the number of electrons transferred.

The redox conditions for water are limited by the following oxidation and reduction reactions and resultant constraints:

Oxidation

$2H_2 \leftrightarrow O_2 + 4H^+ + 4e^-$

$\frac{1}{4}O_2 + H^+ + e^- \leftrightarrow \frac{1}{2}H_2O$ $\qquad pE^0 = 20.75$ (at 25 C)

$\text{pE} = pE^0 + \log\left(P_{O_2}^{\frac{1}{4}}[\text{H}^+]\right)$, assuming the partial pressure of oxygen, $P_{O_2} = 1$

$\text{pH} + \text{pE} = 20.75$

---

[15] In the laboratory, $E_H = E_{\text{measured}} + E_{\text{reference electrode}}$ where $E_{\text{reference electrode}}$ is dependent on the type of reference electrode used.

[16] Activity is the thermodynamic effective concentration in solution considering ion-ion interactions. In dilute solutions, activity is approximately equal to concentration, and unit activity is equal to a concentration of 1 mole/L.

However, in equilibrium with atmospheric oxygen, $P_{O_2} = 0.21$ and therefore

$$\mathrm{pH} + \mathrm{pE} = 20.59 \text{ (at 25 C)}$$

Reduction

$$2H_2O + 2e^- \leftrightarrow H_2 + 2OH^-$$

$$H^+ + e^- \leftrightarrow \tfrac{1}{2} H_2 \qquad pE^0 = 0.00 \text{ (at 25 C)}$$

$$\mathrm{pE} = pE^0 + \log([H^+])$$

$$\mathrm{pH} + \mathrm{pE} = 0 \text{ (at 25 C)}$$

The oxidation and reduction constraints imposed by the stability of water impose a plausible domain of pH + pE between 0 (fully reduced) and 20.75 (fully oxidized) as illustrated in Figure 2-12.

The actual redox of a system results from the combined effects of oxygen supply (i.e., atmospheric exchange, often limited by diffusion or barometric changes), oxygen consumption by microbial respiration and oxidation of organic matter (i.e., POM and DOC), anaerobic microbial respiration and fermentation (i.e., nitrate reduction (pE^0=21.05), iron reduction, sulfate reduction (pE^0=4.13) and carbonate reduction (pE^0=2.87), and/or the presence of reducing inorganic solid phases (i.e., sulfides, iron) which often result from high temperature processing (i.e., in slags from steel and iron production). Thus, reducing conditions in the field can result as a consequence of either the material being managed or imposed as a consequence of microbial processes and limited oxygen supply. Organic matter (i.e., POM and DOC) that provides the substrate (i.e., food source) for microbial processes can either originate from the material being managed (i.e., MSW, MSWI bottom ash, soils) or from external sources (i.e., decay of leaf litter or commingling of materials). During laboratory pH dependent testing (i.e., Method 1313), oxidizing to mildly reducing conditions (i.e., pH+pE ≥ 13) are most often present because of aerobic handling of materials and use of nitric acid to adjust pH, although more reduced conditions may result from highly reducing materials such as blast furnace slag. Percolation column testing (i.e., 1314) can result in an evolving redox condition as the test progresses for materials containing significant amounts of organic matter because initial conditions are oxic while microbial activity can deplete oxygen and produce reducing conditions as the test progresses over several days. The potential for redox changes should be considered when evaluating laboratory testing results and field scenarios. Consideration of potential effects of reducing conditions is most readily accomplished through sensitivity evaluation as part of chemical speciation modeling because accurate control of redox conditions in the laboratory presents many challenges that go beyond the capabilities of many commercial laboratories. Examples of using sensitivity analysis as part of chemical speciation modeling (i.e., varying the simulated conditions over a range of pH+pE values) is included in the discussion of many of the laboratory to field comparison cases in subsequent sections.

The relationship between pH and pE that results in the formation of a particular mineral phase depends on the stoichiometry of the reaction, and whether or not H^+ (or OH^-) is involved in the reaction as well as electron transfer (which is inherent in a redox reaction). For example, the reduction of iron according the reaction

$Fe(OH)_{3(s)} + 3H^+ + e^- \leftrightarrow Fe^{2+}_{(aq)} + 3H_2O$

includes the reduction reaction of $Fe^{3+} + e^- \rightarrow Fe^{2+}$, pE^0=13.2 (at 25 C).

This results in the relationship for the observed Fe activity in solution (where activity is approximately equal to concentration in dilute solutions),

$$3pH + pE = 17.16 - [Fe^{2+}].$$

Within the discussion included in this report, the following redox reactions are important:

1. Iron reduction from Fe^{3+} to Fe^{2+} because Fe^{3+} in the form of hydrous ferric oxide (HFO) provides adsorptive surfaces for many species, thus impacting LSP. Fe^{2+} is relatively soluble at neutral to mildly acidic pH, while Fe^{3+} is essentially insoluble over the same pH range, so reduction of Fe^{3+} to Fe^{2+} results in increased solution concentrations of Fe and loss of adsorption of other constituents from solution to HFO surfaces, increasing the solution concentrations of these constituents. A predominance diagram, which is a presentation of the predominant speciation of a constituent (solid phases or dissolved phases as indicated by charged species) as a function of pH (x-axis) and pE (y-axis), is provided for iron (0.1 M) in the presence of sulfate (0.1 M) in Figure 2-12. The precise speciation, precipitated phases and transitions reflected in a predominance diagram is dependent on the presence and overall content of multiple constituents in the simulated system (i.e., iron, sulfate, carbonate, calcium, etc. usually reflected as a molar concentration (M) in the unit solid plus liquid simulated volume) and therefore simple systems are used here to illustrate general phenomena. HFO predominates as the solid phase controlling iron solubility transitions to other phases between pH+pE between 5.5 and 4 at neutral to alkaline pH (orange region), becomes soluble Fe^{2+} between pH+pE between 5.5 and 13 and pH less than 7 (aqua region) and become completely solubilized at pH+pE greater than 4 and pH less than ca. 2.5. Iron precipitates with sulfide (produced from the concurrent reduction of sulfate) begins to form at pH+pE of 5.5 and predominates at pH+pE below approximately 4.
2. Sulfate reduction to sulfide (i.e., S_2^{2-} to S^{2-} or SO_4^{2-} to HS^-) results in the precipitation of other constituents (i.e., Fe, Cu) as sulfide minerals that are relatively insoluble. The relationship between the sulfur species can be written as (Stumm and Morgan, 1996)

   $SO_4^{2-} + 9H^+ + 8e^- \leftrightarrow HS^- + 4H_2O$

   which results in the relationship

   $$1.125pH + pE = 1/8 \log[SO_4^{2-}] - 1/8\log[HS^-]$$

   Figure 2-13 presents a Pourbaix diagram for sulfate (0.1 M) in the presence of iron (0.1 M). The aqua region (pH+pE greater than 5.5 and pH greater than ca. 3 indicates dissolved sulfate as the predominant speciation, while the red region that begins at pH less than 7 indicates a domain where reduced iron (Fe^{2+}) precipitates as iron sulfate ($FeSO_4$). At pH+pE less than 5.5 sulfate becomes reduced to sulfide and precipitates as iron sulfide species. In contrast, Figure 2-14, presents a predominance diagram for sulfate (0.1 M) in the presence of iron (0.1M) and now also with calcium (0.1 M). The addition of calcium to the system results in the formation of anhydrite ($CaSO_4$ or gypsum, indicated by a blue region) which

limits the availability of sulfate to precipitate with iron (iron sulfate now only forms in a very small region indicated in orange).

3. Figure 2-15 presents a predominance diagram for arsenic (0.1 M) in the presence of sulfate (0.1 M). Arsenic is present in aqueous solutions as As(v) in the form of $H_2AsO_4^-$, $HAsO_4^{2-}$ or AsO_4^{3-} (aqua, light green and light blue regions) and as As(III) in the form of H_2AsO^{3-} or $HAsO_3^{2-}$ (dark green regions), depending on the pH and pE of the system. At pH+pE less than 5.5, arsenic speciation transitions to As(III) precipitated with sulfide as the mineral orpiment (brown-gray region). Arsenic also precipitates with calcium and is adsorbed onto HFO surfaces when present (not included in Figure 2-15).

4. Figure 2-16 presents a predominance diagram for chromium (0.1 M). Reduction of Cr^{6+} (usually as CrO_4^{2-} in solution, light aqua region) to Cr^{3+} dramatically changes Cr solubility at slightly acid to slightly alkaline pH, where Cr^{3+} as $Cr(OH)_3$ is relatively insoluble near neutral pH (dark green region) while CrO_4^{2-} is very soluble. Cr^{3+} is soluble at both alkaline pH (as CrO^{2-}, light green region) and acidic pH (as $Cr(OH)^{2+}$, light olive region, or Cr^{3+}, light green region).

5. Figure 2-17 presents a predominance diagram for copper (0.1 M) in the presence of sulfate (0.1 M). Copper redox reactions result with complex set of potential solid phases with the primary Cu reduction being:

   $Cu^{2+} + e^- \rightarrow Cu^+ \quad pE^0 = 2.59$

6. At pH+pE greater than 13, copper precipitates as tenorite (CuO) from over a wide pH range (dark blue region) or at pH+pE between approximately 5.5 to 13 as cuprite (Cu_20). However, Figure 2-17 can be misleading because copper readily forms solution complexes with dissolved organic carbon (i.e., humic substances) and therefore much higher solution concentrations of copper are observed at near neutral pH in systems with significant amounts of organic carbon (i.e., soils and wastes) as discussed in later sections of this report. At pH+pE less than ca. 6, copper precipitates as sulfide mineral phases such covellite (CuS) and as Blaublei II (mix of CuS and Cu_2S).

7. For vanadium, multiple valence states and complex solution species are possible, with V(V) being the dominant valence state and present in solution as HVO_4^{2-}, HVO_7^{3-}, $H_3V_2O_7^-$ and VO^{2+} over alkaline to acidic pH, respectively (Figure 2-18). V(IV) as VO^{2+} (gray region) and V(III) as V^{3+} (light gray region) also can be present in solution at acidic reducing conditions.

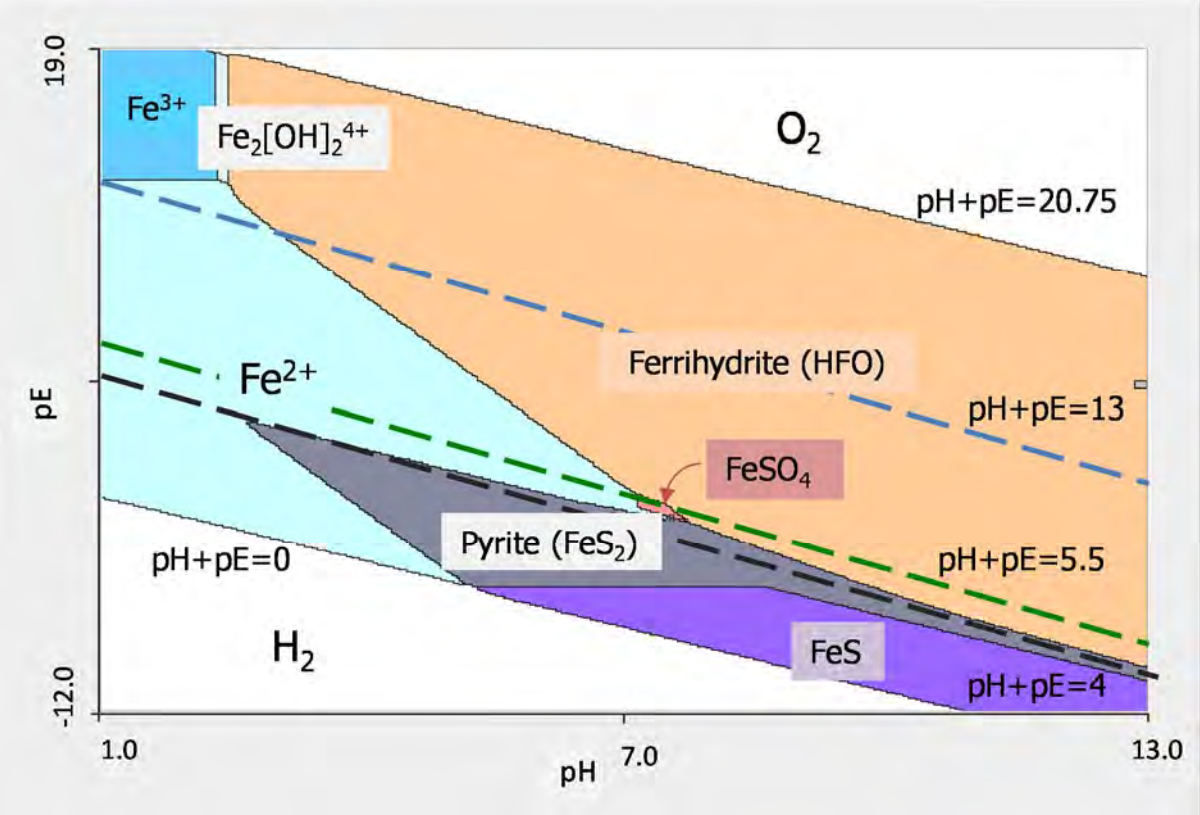

Figure 2-12. Predominance diagram for iron (0.1 M) in the presence of sulfate (0.1 M).

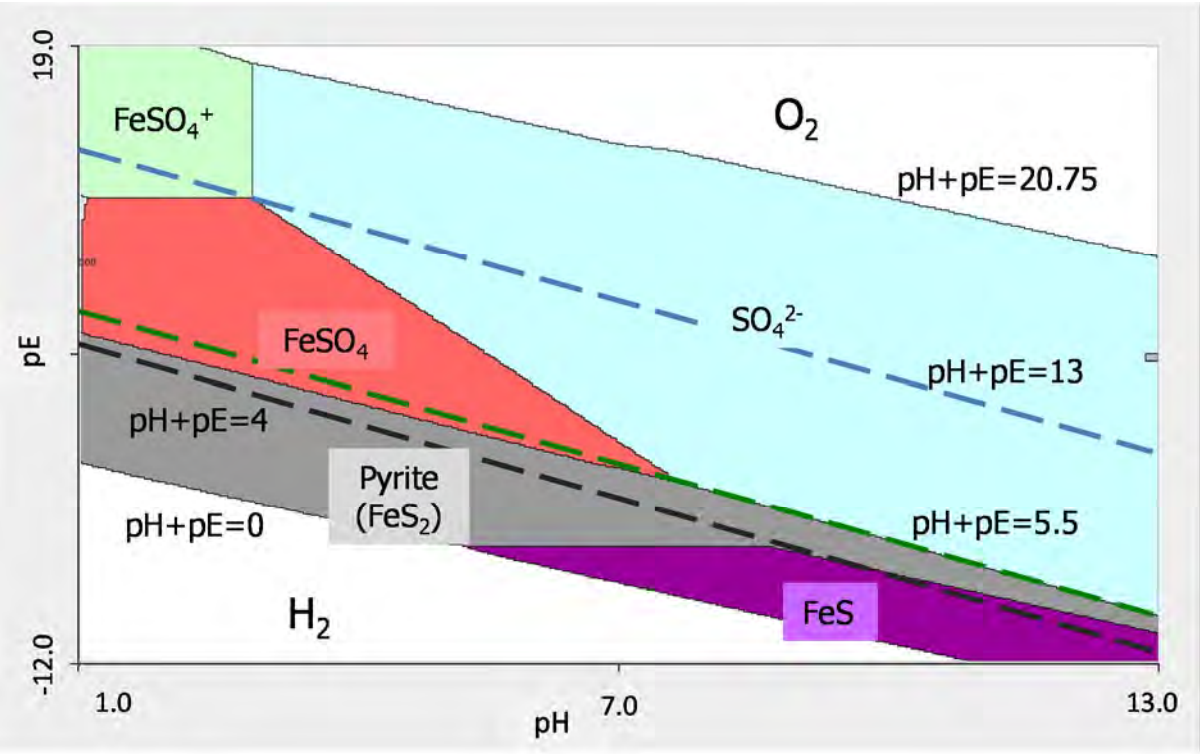

Figure 2-13. Predominance diagram for sulfate (0.1 M) in the presence of iron (0.1 M).

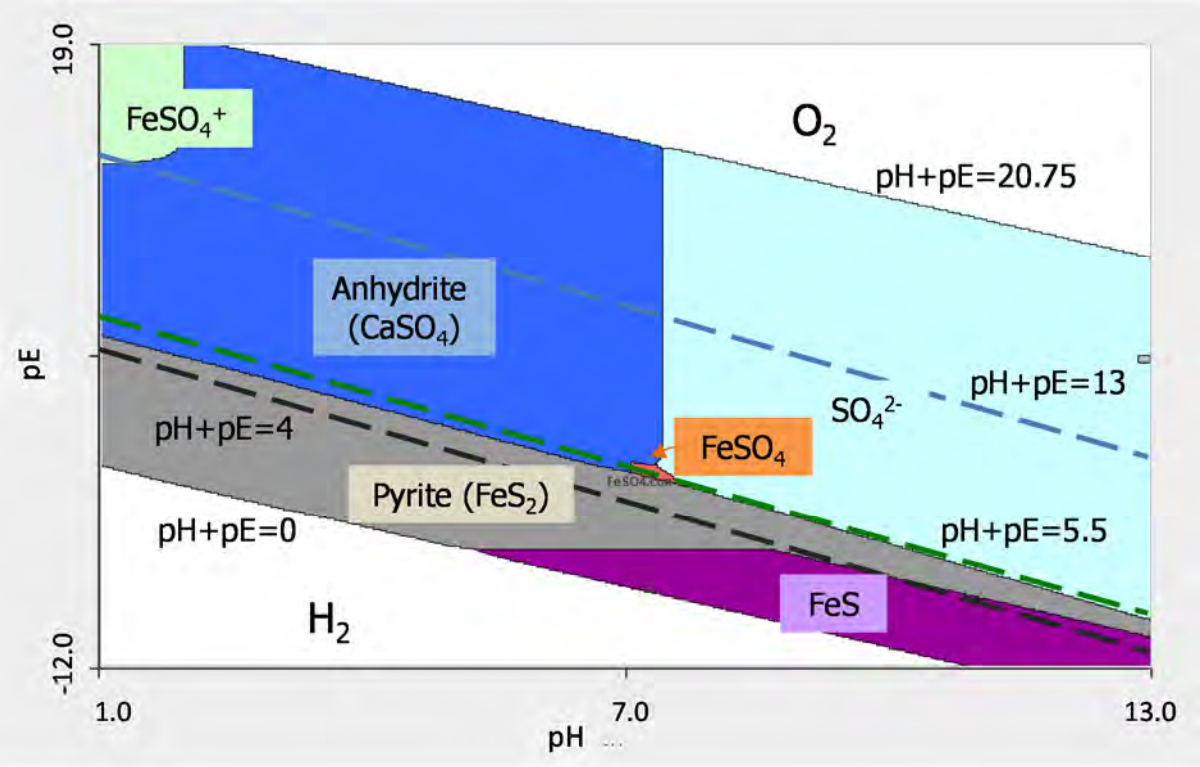

Figure 2-14. Predominance diagram for sulfate (0.1 M) in the presence of iron (0.1 M) and calcium 0.1 M).

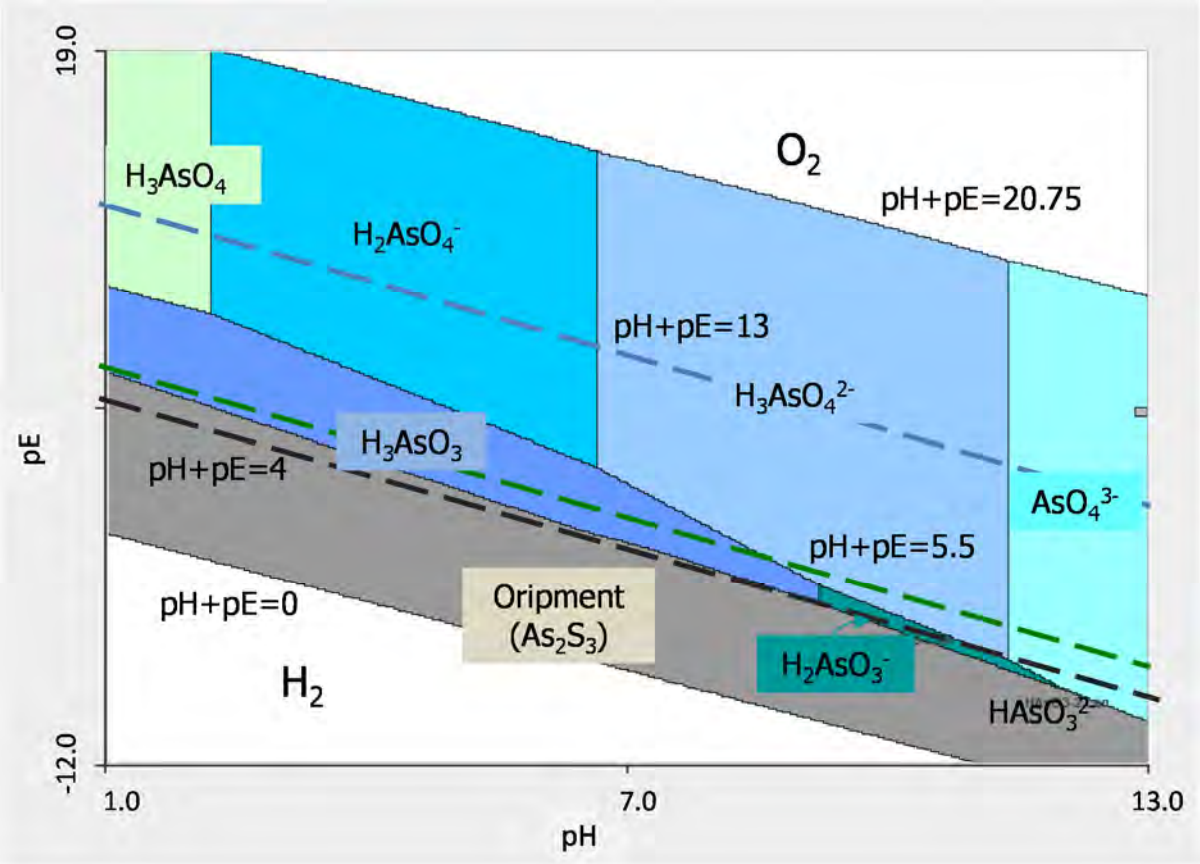

Figure 2-15. Predominance diagram for arsenic (0.1 M) in the presence of sulfate (0.1 M).

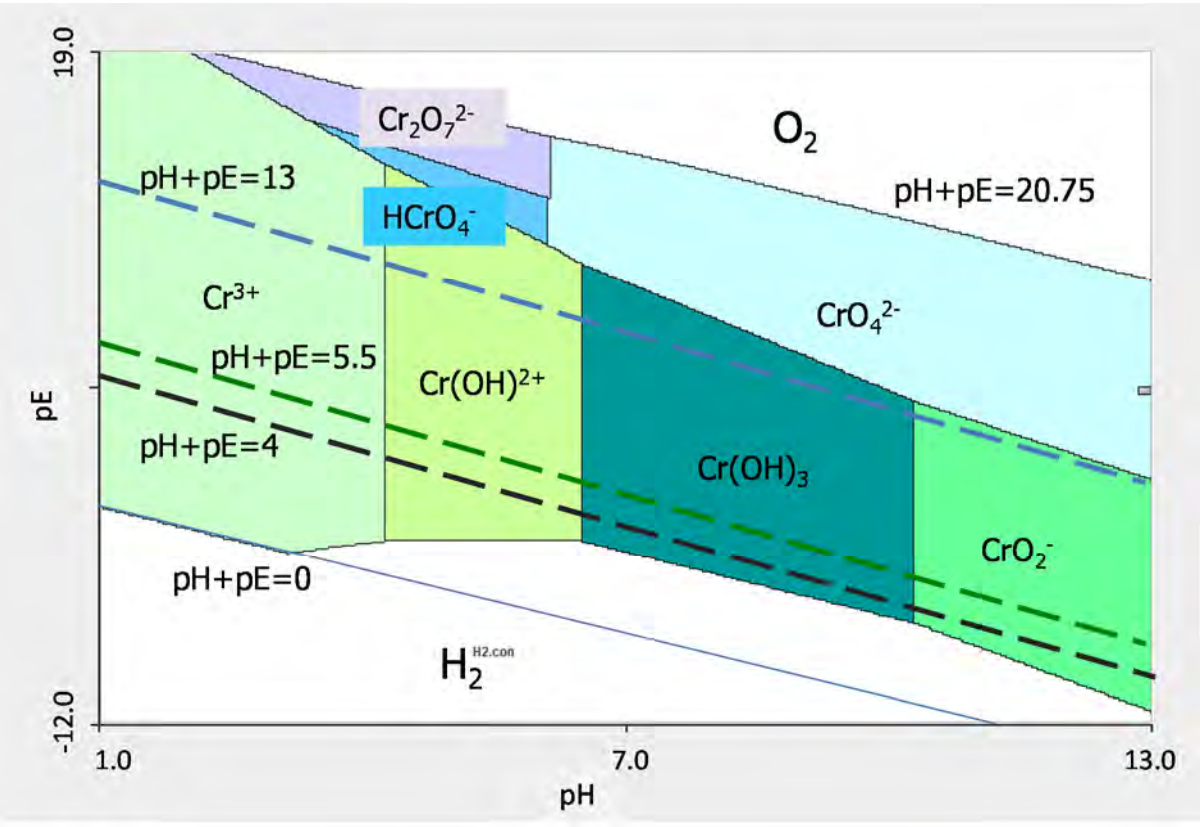

Figure 2-16. Predominance diagram for chromium (0.1 M).

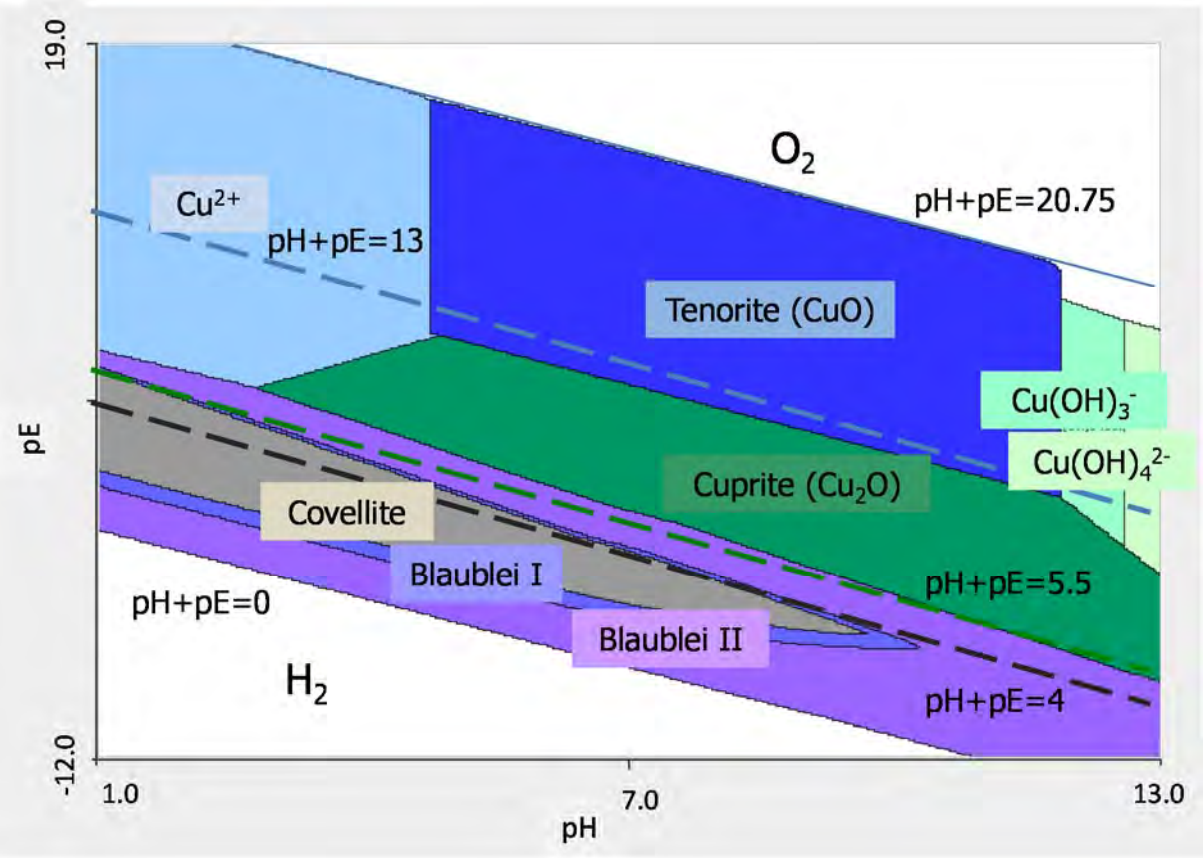

Figure 2-17. Predominance diagram for copper (0.1 M) in the presence of sulfate (0.1 M).

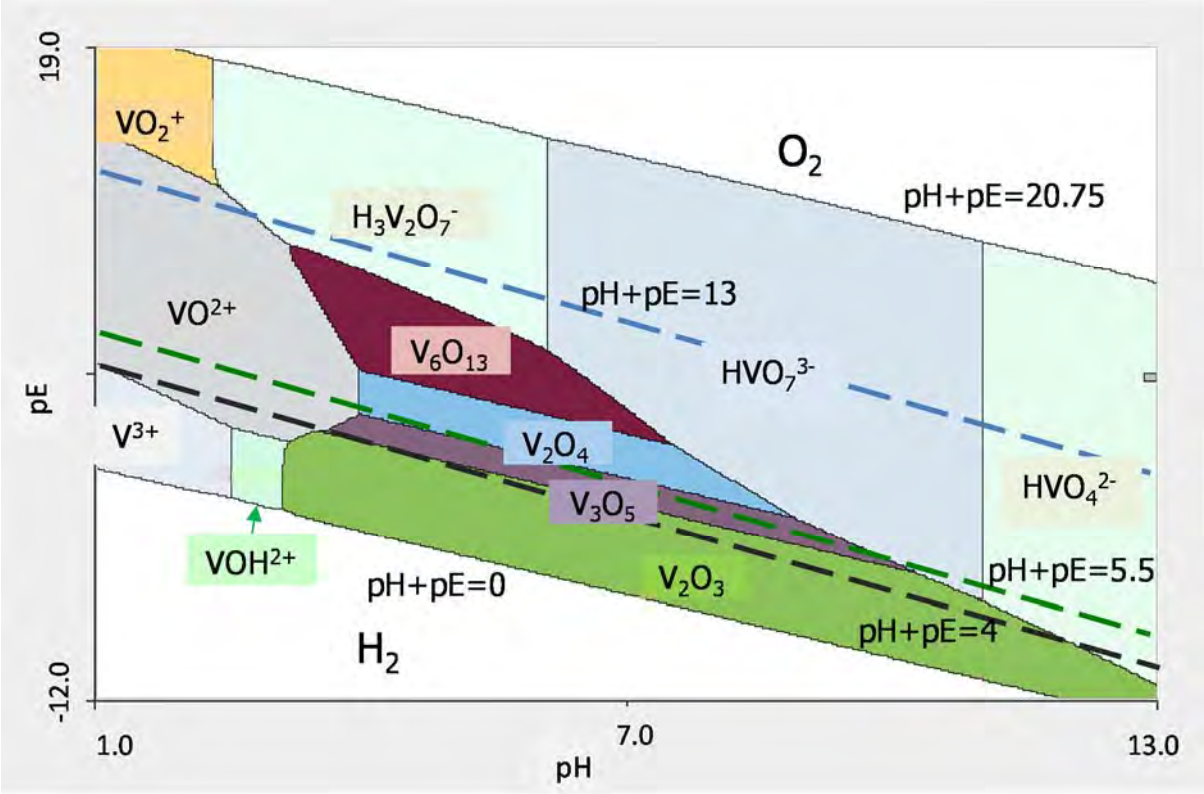

Figure 2-18 Predominance diagram for vanadium (0.001 M).

2.3 Relationships Between Results from the LEAF Leaching Tests

2.3.1 Equilibrium-based Leaching Tests

Eluate constituent concentrations from batch equilibrium-based leaching tests (e.g., Method 1313, Method 1316) should be consistent under the same test conditions within the range of documented inherent test variability (see Garrabrants et al., 2012a, 2012b). Therefore, COPC concentrations in the pH-dependent extraction at natural pH and L/S=10 mL/g are expected to be the same as COPC concentrations in an L/S-dependent extraction of the same material at L/S=10 mL/g. This can be demonstrated by plotting both pH- and L/S-dependent results as a function of eluate pH as shown in Figure 2-19 for leach testing of a contaminated smelter plant soil using Method 1313 and Method 1316.

The results of percolation tests may represent equilibrium between the solid and liquid phases or mass transfer of constituents from solid particles depending on test conditions (e.g., flow rate, column geometry, etc.). Initial interpretation of column percolation test results can be made based on the following:

- The two first eluate fractions collected as part of a percolation test, at cumulative L/S=0.2 and 0.5 mL/g-dry, provide a good estimate of constituent concentrations in the material porewater because of the pre-equilibration of the system prior to beginning eluent flow.

These two fractions also provide a useful estimate of the maximum expected initial leachate concentrations and porewater composition under field monofill conditions.[17] The constituent release measured in the first two eluate fractions collected as part of a percolation test (i.e., Method 1314) also are comparable to the L/S=0.5 mL/g-dry eluate collected as part of the L/S dependence test (i.e., Method 1316), while the integrated concentrations measured in the first two eluate fractions of Method 1314 are comparable to the L/S=0.5 mL/g-dry eluate collected as part of Method 1316. For both tests, the system composition is similar because little elution has occurred from the column at low L/S.

- For constituents that follow Response 2 LSP (i.e., highly soluble constituent), the cumulative release from the percolation test at cumulative L/S=10 mL/g-dry should be comparable to the release observed at the natural pH of the material from the pH-dependence test (i.e., Method 1313; see Lopez Meza, 2008) and at L/S=10 mL/g for the L/S dependence test (i.e., Method 1316) because the system is relatively dilute under the batch conditions of the pH-dependence test and the L/S dependence test at L/S=10 mL/g and, therefore, interactions with other ions (e.g., ionic strength effects) often are not significant[18]. Furthermore, the eluate concentration curve should follow "first flush" phenomena with a large decrease (i.e., one or more orders of magnitude) in eluate concentration by cumulative L/S=2 mL/g.
- For many Response 2 constituents, the release curve of the L/S-dependent leaching test appears to gradually approach a constant value. Often, the level of this asymptotic behavior roughly corresponds with the available content derived from the maximum of the pH-dependent leaching curve (see example boron release in Figure 2-19). Such behavior indicates a release-limiting case where the available content, or majority of the available content, has been released from the solid material.
- For constituents that follow Response 3 LSP (i.e., aqueous saturation), the percolation test eluate concentration is approximately constant as a function of cumulative L/S if the eluate pH is constant. The percolation test eluate concentration also should correspond with the pH-dependence test eluate concentrations at the corresponding eluate pH values. The resulting percolation test cumulative release curve has a slope of approximately 1.
- For constituents that follow Response 4 LSP (i.e., surface interaction), the percolation test eluate concentration profile will be variable between the profile observed for Response 2 and Response 3 LSP as described above because of adsorption-desorption partitioning which may result from either a linear or non-linear isotherm depending on the constituent, concentration and competing constituents. Similarly the slope for the cumulative release will be between that of Response 2 LSP and less than 1.

[17] Lower initial field leachate concentrations may be observed because of a greater extent of preferential flow or flow channeling under field conditions.

[18] According to the Davies equation for activity coefficients (Sawyer et al, 2003), the impact of ionic strength effects will be less than 20 percent of the measured concentration for an individual constituent if the ionic strength of the solution is less than 0.06 M for monovalent ions and less than 0.002 M for divalent ions.

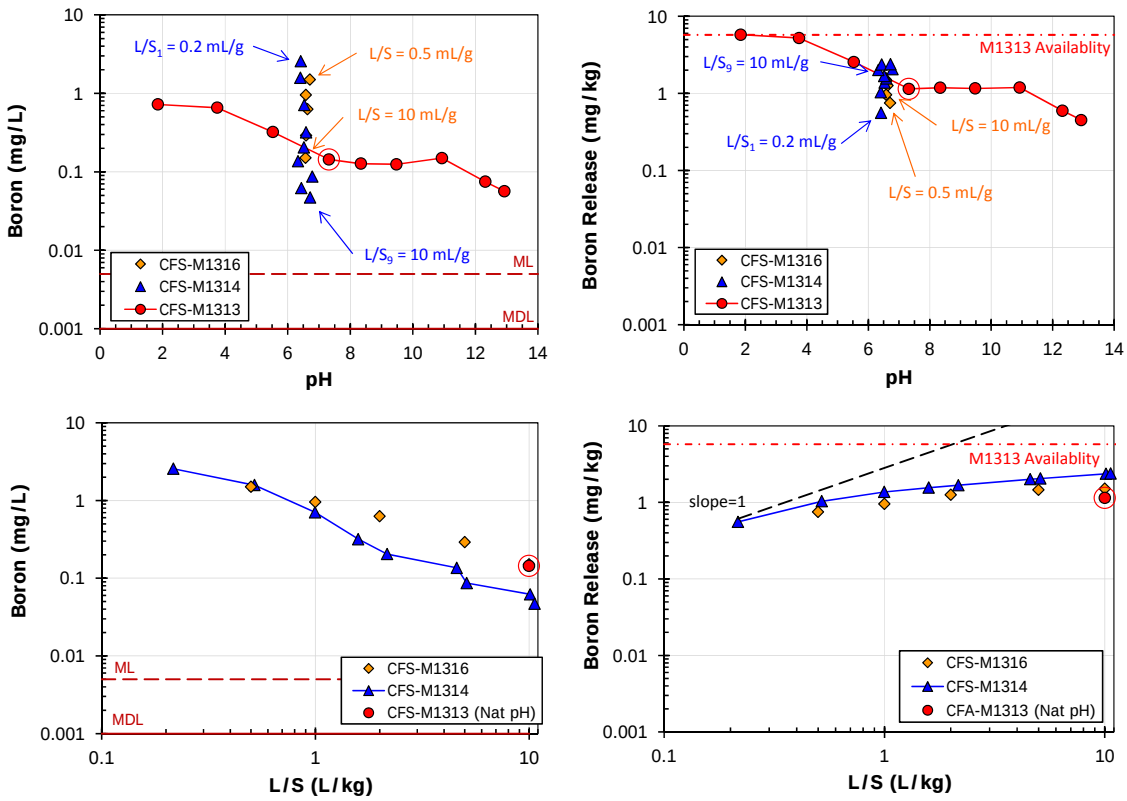

Figure 2-19. Comparison of eluate concentration (left) and release (right) for a Response 2 highly soluble species from pH-dependent (Method 1313) and L/S dependent (Method 1314 and Method 1316) leaching tests.

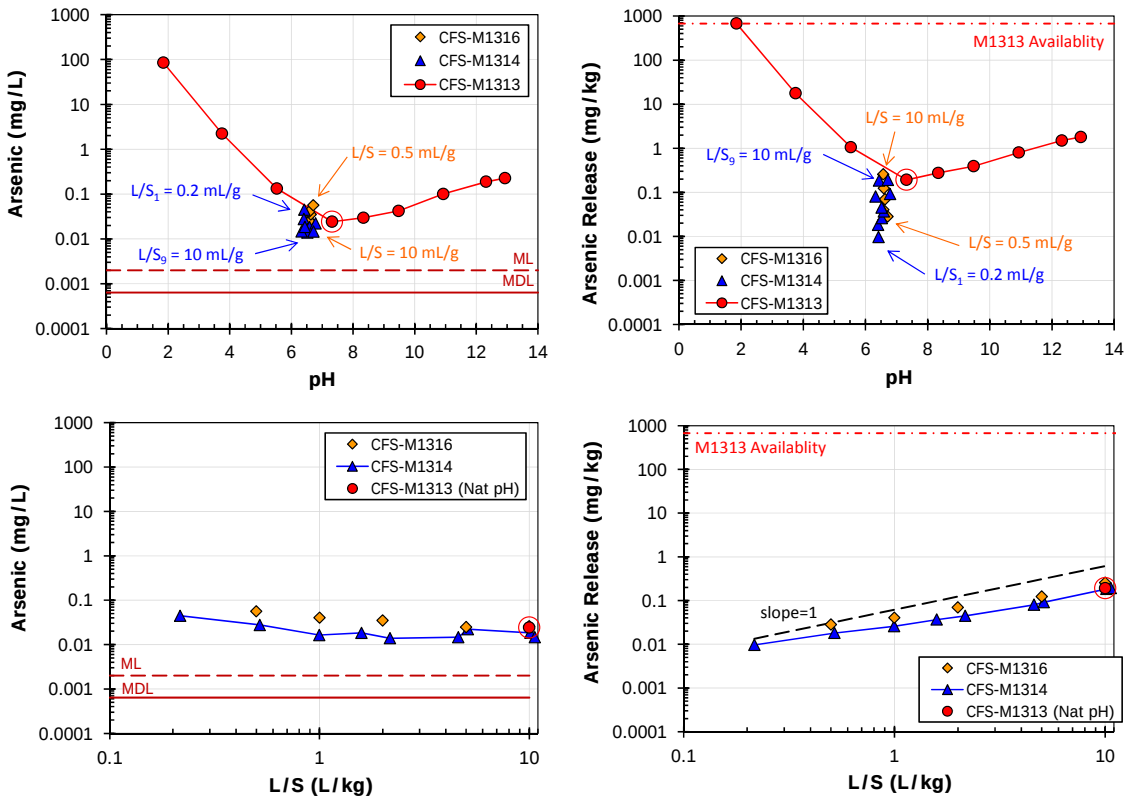

Figure 2-20. Comparison of eluate concentration (left) and release (right) for a Response 3 aqueous saturation species from pH-dependent (Method 1313) and L/S dependent (Method 1314 and Method 1316) leaching tests.

Further interpretation of percolation test results can be divided into understanding (i) the mass transfer behavior and (ii) the LSP behavior of constituents in the material during elution. The mass transfer behavior of a column is most easily determined based on the elution behavior of constituents that are highly soluble and have little pH-dependent leaching behavior (i.e., Response 2 from above). Thus, sodium, potassium or chloride often is the constituent selected to evaluate the mass transfer behavior observed based on results of a column test.

2.3.2 Mass Transfer-based Leaching and pH-dependent Leaching

Mass transfer-based leaching tests (e.g., Method 1315) are designed to measure the rate of mass transfer through the solid material to the bulk solid-liquid interface. Slow surface dissolution and/or internal resistance to constituent migration to the surface of the monolithic material reduces the leaching rate, which can be further reduced because of different chemical conditions within the matrix (i.e., pH, composition) than present at the surface-leaching fluid interface. Method 1315 is intended to assess the rate at which this occurs. A critical aspect of these tests is that the driving force for mass transfer (i.e., the concentration gradient between the solid and the bulk liquid phase) is maintained. Therefore, COPC concentrations in the bulk liquid phase should not approach equilibrium at the eluate pH value.

A first-order evaluation of whether or not the bulk liquid phase of a mass transfer-based leaching tests is at equilibrium is to compare eluate concentrations to the pH-dependent leaching data for the same material as a function of pH (Figure 2-21). Mass transfer data visually below the pH-dependent leaching curve indicates that equilibrium is not achieved during the leaching intervals of the mass transfer test. For most constituents of environmental concern, the example data shown for arsenic, cadmium, and boron in Figure 2-21 are typical when the leaching intervals specified in Method 1315 are followed. This comparison for constituents of the primary mineral phases of the material (e.g., calcium in the cement-based stabilized waste analog as shown in Figure 2-21) may appear to indicate that concentrations in the bulk liquid approach equilibrium; however, the results may reflect dissolution of minerals at the surface rather than mass transport through the material.

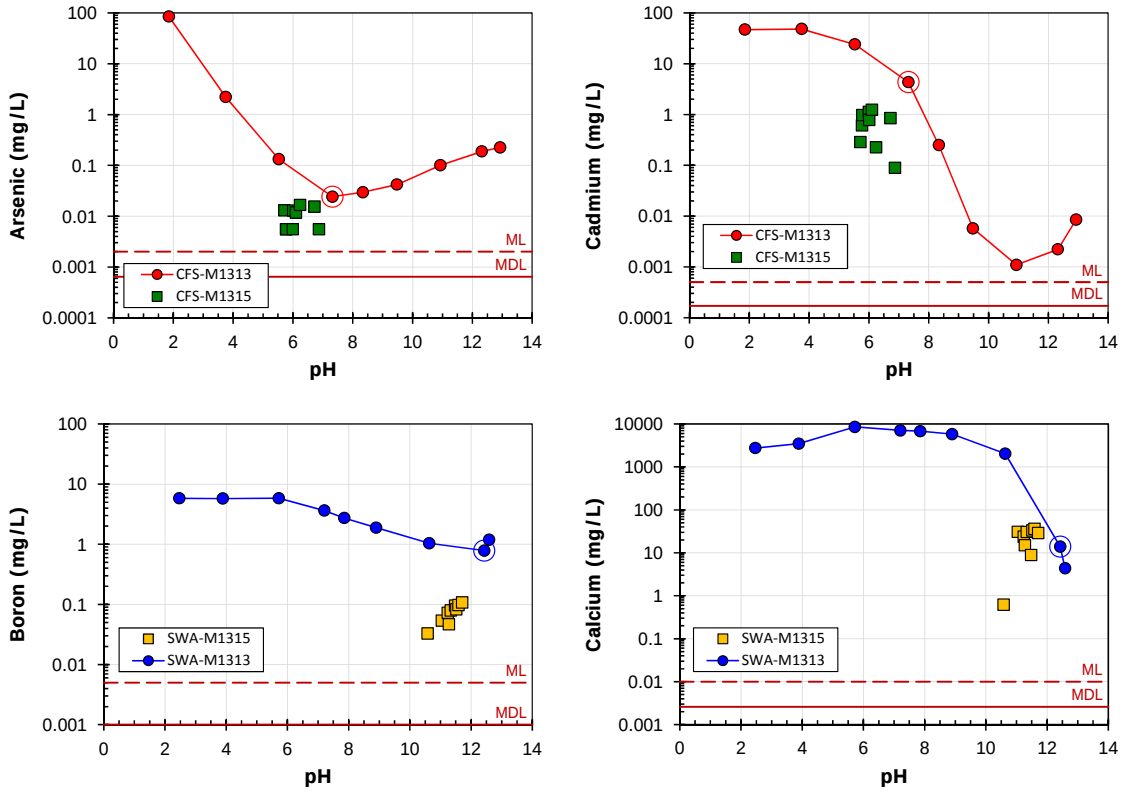

Figure 2-21. Comparison of mass transfer-based leaching data (single points) to pH-dependent leaching data (continuous series) as a check against equilibrium in the bulk liquid phase of the mass transfer test. Data is shown for a contaminated smelter site soil (CFS; top) and a solidified waste analog (SWA; bottom).

2.4 Relationships between LEAF Test Results and Single Batch Extractions

Many of the current leaching tests used to assess leaching from solid materials are single-batch extraction tests in structure. Thus, each test yields a single result for each COPC so that the result is limited to the test conditions under which the data point was derived.[19] However, under the assumption that the single batch extraction obtains equilibrium over the extraction interval and if the pH of the final eluate solution is recorded, the results of single-batch tests may be compared to LEAF test results by plotting the results as a function of pH. In Figure 2-22, the results of Method 1313 and Method 1316 testing for a contaminated smelter site soil (CFS) and a solidified waste analog (SWA) are compared to the results of EPA leaching tests that are currently used for leaching evaluation, TCLP and SPLP. In order to compare these data, the procedure for TCLP (EPA Method 1311) and SPLP (EPA Method 1312) had to be modified to include recording of the final eluate pH.

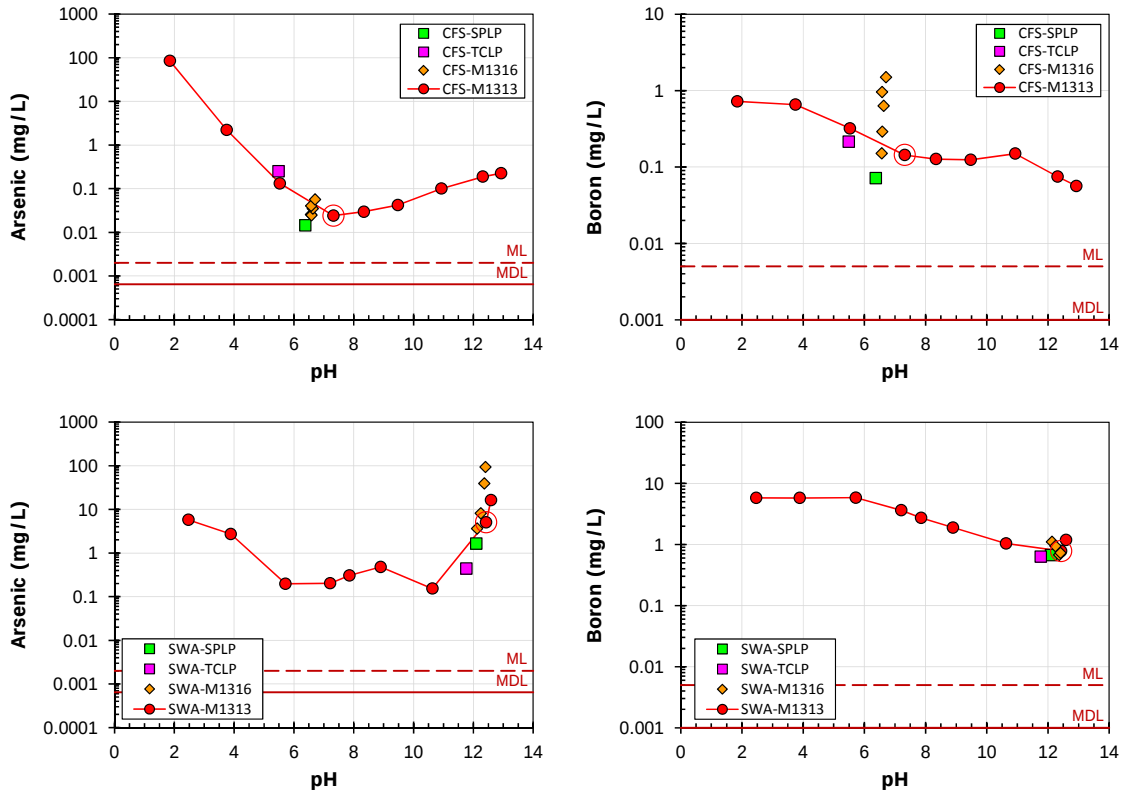

Figure 2-22. Comparison of single-batch extractions (i.e., TCLP and SPLP) to pH- and L/S-dependent leaching results for a contaminated smelter site soil (CFS; top) and a solidified waste analog (SWA; bottom).

[19] For example, TCLP specifies contacting particle size reduced material with a maximum particle size of 9.5 mm with either a NaOH buffered or unbuffered acetic acid leaching solution at an L/S of 20 mL/g-dry over an 18 hour period while SPLP specifies a similar particle size, L/S and duration conditions with a dilute nitric/sulfuric acid solution.

When compared to the LEAF test results, single-batch extraction results (e.g., TCLP and SPLP) often appear as another point along the pH-dependent trendline. For Response 2 species, TCLP and SPLP concentrations plot slightly below the pH-dependent trendline and are consistent with the increased L/S of the single batch tests. Species that follow solubility-controlled release (i.e., Response 3 species) have TCLP and SPLP data consistent with the pH-dependent trendline. Although the comparisons between single batch extractions and characteristic leaching tests are useful in interpreting COPC behavior, the single batch extraction data alone do not provide enough information to support such observations and therefore limit the ability to provide insight into leaching behavior for the broad set of disposal or utilization scenarios.

2.5 Determination of Constituent Availability

As discussed in Section 2.1.1, the amount of a constituent that partitions into the aqueous phase can be limited either by (i) the solubility of the constituent at the test conditions (resulting in a saturated solution at solid-liquid equilibrium), (ii) adsorption-desorption equilibrium partitioning between the aqueous solution and solid phases (i.e., sorption onto particulate organic matter or hydrous ferric oxide (HFO) surfaces), or (iii) the maximum leachable amount of the constituent. The maximum leachable amount may be either the total content, or often only a limited fraction of the total content because of constituent sequestration in relatively non-leachable phases such as durable glass phases or very poorly soluble alumina-silicate phases. Here, the maximum leachable quantity is referred to as the constituent availability. To measure or estimate constituent availability, test conditions must be established such that the aqueous phase solubility and adsorption processes do not limit leaching. Conditions to estimate availability can be established in test conditions either through (i) very large liquid-to-solid ratio, (ii) multiple extractions, (iii) use of chelating agents (e.g., EDTA) to increase aqueous solubility, or (iv) use of fundamental pH-solubility properties to select conditions of high solubility. Each of these approaches have been used with comparable results (NEN 7371, 2004; Garrabrants and Kosson, 2000; van der Sloot et al., 1997; Lopez Meza et al, 2008). From a practical perspective, it has been useful to integrate determination of constituent availability with pH dependence leaching (i.e., Method 1313). Constituent availability can be estimated from Method 1313 by selecting the maximum mass leached of each constituent over the pH domain from pH of 2 to 13. Most cationic elements will reach a plateau in leaching as pH decreases between pH 4 and 2. At pH 2, HFO phases are dissolved, resulting in leaching of adsorbed constituents. Most metal hydroxides (amphoteric constituents) will have a maximum solubility either at pH of 2 or approximately 13. Oxyanionic species (e.g., arsenate, molybdate, chromate) will have maximum solubility at mildly alkline pH (i.e., pH 9 – 10). Thus, the pH value at which availability is estimated will be constituent dependent.

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3 CHEMICAL SPECIATION AND MASS TRANSPORT MODELING AS INTERPRETATION TOOLS

Often, leaching tests are used to characterize samples of materials that are either to be placed into a field scenario or material samples that are obtained from a field test location. However, understanding of field leaching behavior frequently requires consideration of the changes in material leaching over time due to aging of the material and/or due to release conditions that are representative of the field scenario, but are not readily reproduced in the laboratory. Material aging phenomena may include reaction with species from the surrounding environment (e.g., oxygen, carbon dioxide, sulfate), depletion of primary species through leaching (e.g., loss of calcium hydroxide from cementitious materials), and changes in the physical nature of the material (e.g., cracking). Scenario conditions that cannot be easily reproduced in the laboratory but may affect leaching include low L/S ratios, changes in chemical oxidation-reduction state (e.g., from either biotic or abiotic processes), and the presence/extent of preferential flow pathways.

One approach toward integrating aging phenomena and scenario conditions into the understanding of material leaching behavior is through the use of numeric models designed to simulate chemical speciation or reactive transport of COPCs for defined release conditions. Chemical speciation models simultaneously solve the chemical thermodynamic and kinetic equations representing the material mineralogy/adsorption/aqueous interaction reactions that allow for evaluation of equilibrium liquid-solid partitioning as a function of material and fluid phase composition, pH and redox state. The effects of physical parameters (e.g., monolithic nature of materials that divert infiltration or preferential flow during percolation) may be evaluated through coupling of the results of chemical speciation models with mass transport models, often called reactive transport models. Thus, chemical speciation and reactive transport models can be useful tools to prospectively or retrospectively evaluate (i) conditions not practically achievable in the laboratory on material leaching behavior, (ii) the aging of materials under factors that historically control leaching in the field, and (iii) integration between laboratory and field leaching data.

Using these tools, useful simulations of LSP and mass transport leaching are achievable for a wide range of materials to evaluate the impacts of varying laboratory and field conditions using idealized conceptual models. Interpretation of leaching data using chemical speciation and reactive transport models has been advanced by the development of extended thermodynamic databases and the evolution of descriptions of chemical interactions with reactive surfaces. However, like all numeric models, the results of these models are limited by the state of current knowledge or the availability of accurate data for the materials being tested (e.g., see Sarkar et al, 2012). For leaching assessment purposes, areas where limits in current knowledge or available data may increase uncertainty in chemical speciation and reactive transport model results include:

- chemical speciation of solid phases in materials and wastes;
- aqueous solution characteristics (e.g., dissolved or colloidal organic matter);
- thermodynamic data for solid mineral phases;
- adsorption onto solid surfaces;
- solution conditions (e.g., very high ionic strength solutions);

- physical mass transport conditions.

3.1 Modeling and Simulation Approach

Laboratory leaching test results from pH dependent leaching (i.e., Method 1313 or PrEN 14429) is used in conjunction with other information known about a material (e.g., availability data, total carbon, etc.) to develop a "chemical speciation fingerprint" (CSF). This CSF includes the set of mineral phases, adsorbing surfaces, organic matter fractionation and the fraction of the total content of each constituent that is available for leaching (often referred to as "availability"). The resulting CSF may be used in conjunction with the results of L/S-dependence tests (e.g., Method 1316, EN 12457) to assess the impact of low L/S ratios on LSP or with percolation column tests (e.g., Method 1314, CEN/TS 14405, CEN/TS 16337-3) or mass transport (e.g., Method 1315, PrEN 15863, CEN/TS 16337-2) to calibrate needed mass transport parameters for simulations of dynamic leaching tests (i.e., mobile-immobile fractions for percolation column tests or tortuosity for monolith diffusion tests). The resulting combination of the CSF and mass transport parameters may be used in conjunction with one or more field conceptual models (i.e., percolation with preferential flow or diffusion controlled release from a monolith) and a variety of initial and boundary conditions (e.g., system geometry, infiltration rate and chemistry, redox state, etc.) to estimate release under a range of field scenarios. Characterization of uncertainty at each step is needed to understand the accuracy and limitations of each simulation.

3.2 Chemical Speciation and Reactive Transport Modeling in LeachXS

Recent developments in chemical speciation codes such as ORCHESTRA (Meeussen, 2003), MINTEQA2 (Allison et al., 1991), PHREEQC (Parkhurst, 1995), Geochemist's Workbench (Lee and Goldhaber, 2011) allow calculation of multi-element equilibrium concentrations based on available thermodynamic data and may include coupling with mass transport models.

The software package LeachXS™, used for data management and chemical speciation based simulations in this report, has the ORCHESTRA code embedded as the chemical speciation and reactive transport code for modeling experimental results and the chemical behavior of materials in specific application scenarios. ORCHESTRA can calculate chemical speciation in thermodynamic equilibrium systems using the same thermodynamic database format as PHREEQC or MINTEQA2, but also contains state-of-the-art adsorption models for oxide and organic surfaces as well as the ability to handle dissolution/precipitation of solid solutions.

Underlying chemical speciation models incorporate current knowledge about the chemical interactions between major, minor trace elements, such as mineral dissolution/precipitation, ion exchange, sorption and incorporation in solid solutions that result in the concentrations of elements in solution at liquid-solid equilibrium as a function of pH or L/S based on initial solid and liquid phase composition and redox state. A set of solid phases (i.e., minerals, solid solutions, adsorptive surfaces) and reactions (i.e., dissolution/precipitation, adsorption/desorption, reaction with carbon dioxide) in the form of reaction equations with corresponding thermodynamic equilibrium constants are solved simultaneously to calculate liquid-solid partitioning of major, minor and trace constituents including COPCs. Several books are available that describe the fundamentals of

chemical speciation and reactive mass transport modeling (Stumm and Morgan 1996; Appelo and Postma 2005).

In ORCHESTRA, ion adsorption onto organic matter is calculated with the NICA-Donnan model (Kinniburgh et al., 1999) using generic adsorption reactions (Milne et al., 2003). Adsorption of ions onto iron and aluminum oxides was modeled according to the generalized two layer model of Dzombak and Morel (1990). Aqueous speciation reactions and selected minerals were taken from the MINTEQA2 database (Allison et al., 1991). The MINTEQA2 database is internally consistent through use of a common set of primary entities and thermodynamic reference state; additional mineral reactions taken from literature were transformed into the same format by rewriting the reactions using primary entities in LeachXS-ORCHESTRA. For example, more recent thermodynamic data on solid phases relevant to cement, concrete and cement-stabilized waste forms has been obtained from Lothenbach, et al. (2008) and incorporated into the LeachXS-ORCHESTRA models used here. More detail on the use of the chemical speciation code can be found elsewhere (Dijkstra et al., 2006a, 2006b, 2008; Engelsen et al., 2009, 2010, 2012; Carter et al., 2008, 2009; van der Sloot et al., 2000, 2007, 2009, 2011; van der Sloot and van Zomeren, 2012; Sarkar et al., 2010; Sarkar et al., 2011; Sarkar et al., 2012).

3.2.1 Parameterization of ORCHESTRA

The input to the ORCHESTRA model to form a material-specific CSF consists of (i) element availability values, (ii) selected possible solubility-controlling minerals, (iii) definition of the reduction-oxidation state of the material, (iv) description of active Fe-and Al-oxide sites, and (v) a fractionation of organic matter between particular organic matter (POM) and reactive DOC concentration as a function of pH.

Availability

The maximum leached amount (mg of COPC/kg material) derived from pH-dependent leaching test concentrations between pH 2 and 13 is used as the concentration available for interaction under environmental conditions.

Possible Solubility-controlling Minerals

The chemical speciation model is used to generate saturation indices (SIs) for relevant mineral phases based on the eluate concentrations from pH-dependent leaching tests. From these SIs and prior knowledge of the material (e.g., previously identified mineral phases from speciation modeling or from published literature), solubility-controlling minerals are selected for possible inclusion in the definition of a CSF.

Reduction-oxidation State

The reduction-oxidation (redox) state of the material is specified as the sum of the electron activity (pE), which indicates the tendency for a solution to donate or accept a proton and pH. The numerical range for the sum pH+pE is based on the stability of water with values at between 0-20.75 for maximum reducing and oxidizing conditions (Stumm and Morgan, 1996). In pe vs. pH stability charts, this sum defines the upper and lower stability limits. For example, a pH+pE value of 10 represents slightly reducing conditions while a value of 15-16 represents

oxidizing conditions. The values for pH+pE selected for simulation may be either (i) based on measured laboratory or field values (with appropriate care taken to avoid sample changes during measurement and correction for the reference electrode used; see Section 2.2.3), (ii) based on observation of liquid-solid partitioning of iron , manganese and/or chromium as indicator species from field data and laboratory testing, or (iii) treated as a variable that is varied over a plausible range as part of a sensitivity study.

Reactive Surfaces Description

The surface area of reactive surfaces present in the solid is required in order to account for sorption of COPCs onto the solid surface. Reactive surface fractions are estimated from independent determinations of the test material or through selective chemical extractions on comparable materials. For example, the amount of amorphous and crystalline iron (hydr)oxide may be determined by a dithionite extraction (Kostka and Luther III, 1994), while amorphous aluminum (hydr)oxide may be determined by an oxalate extraction (Blakemore et al., 1987). In the CSF model, the extracted amounts of Fe and Al were summed and used as a surrogate for hydrous ferric oxides (HFO) as described by Meima and Comans (1998). Determination of HFO by ascorbic acid extraction has been standardized as ISO 12782-1 (2012).

Organic Matter and Inorganic Carbon Descriptions

POM and carbonate/bicarbonate content are either measured directly through total carbon analysis or estimated from the titration curve results of pH-dependent leaching tests. The total organic carbon in a solid can be divided into a solid fraction (POM) and a fraction that dissolves as a function of pH (DOC). DOC is available for interaction with COPCs in the eluate; however, the direct analysis of eluate DOC does not completely represent the reactive part of the dissolved organic matter. Based on experience with soil materials where the quantification between the hydrophilic fulvic, and humic acid fraction in DOC was estimated (van Zomeren and Comans, 2007), the reactive fraction of DOC is defined either as a constant value independent of pH or as a function of pH (i.e., with the lowest proportion of reactive forms at neutral pH and increasing towards both low and high pH). In the latter situation, a polynomial fit is created through eight data points to allow quantification of the reactive DOC at intermediate pH values in modeling (van Zomeren and Comans, 2007). Thus, the reactive component of the DOC used in chemical speciation modeling is parameterized as the solid humic acid (SHA) which represents the sum of the fulvic and humic fractions. In accordance with van Zomeren and Comans (2007), SHA is either (i) quantified by fractionation POM or (ii) assumed to be 20% of the total DOC, in case no data for the particular material were available.

Using the information specified above in conjunction with available prior knowledge of the material (such as previously identified mineral phases from speciation modeling or from published literature), the speciation of all elements is calculated in one problem definition in the Laboratory Simulation pH-Dependence Leaching Test model with the same parameter settings. This method of calculation limits the degrees of freedom in selecting parameter settings considerably, as improvement of the model description for one element may deteriorate the outcome for other elements.

3.3 Simulations in LeachXS

3.3.1 Laboratory Test Simulations

Laboratory testing results are used to calibrate and verify models (i.e., "laboratory simulations") that then can be used for estimating system responses under anticipated field conditions. The specific types of simulation models currently included in LeachXS are as follows:

Chemical Speciation and Solubility Indices

Solubility index for possible minerals are evaluated in comparison to LSP data obtained from pH-dependent tests or L/S-dependent test for initial identification of relevant mineral phases based on LSP data.

pH-dependence Test and LSP Simulation

Based on identified mineral phases and other parameters (e.g., availability values, carbon fractionation, etc.), a CSF is developed to simulate results obtained from pH dependence tests. The parameters of this model can be varied to assess changes to LSP due to L/S (e.g., low L/S ratios found in field conditions), solution chemistry (e.g., high ionic strength solutions in cementitious materials), redox conditions (e.g., oxidation of reductive materials), the amount of iron hydr(oxide) and clay surfaces available for sorption, and the amount/fractionation of particulate organic matter (POM) and DOC.

Monolith Leaching and Mass Transport Rate Test Simulation

The CSF may be combined with diffusion models to determine mass transport parameters (e.g., effective tortuosity values, diffusivity) based on results from mass transport tests. The mass transport model segments a monolithic solid (i.e., a true monolithic form or a compacted granular material compacted to act like a monolith) into a series of layers from the external boundary to the interior core (Figure 3-1). Within each layer, the monolith segment is divided into aqueous and solid phases defined by the CSF. Local equilibrium between phases in the segment is calculated at each time step to account for changes in pH and local composition based on dissolved constituent mass transport between the layers by diffusion through the liquid phase. The external surface of the monolith is simulated as being in contact with a well-mixed bath of finite volume which is refreshed at time intervals defined by the leaching test conditions (e.g., Method 1315). This laboratory simulation model also can be used to evaluate the impacts to release rates from changes in eluate volume, eluate chemistry (e.g., influx of acid or sulfate attack), and layering of material composition and properties within a monolith (e.g., a carbonated surface layer with an un-carbonated core).

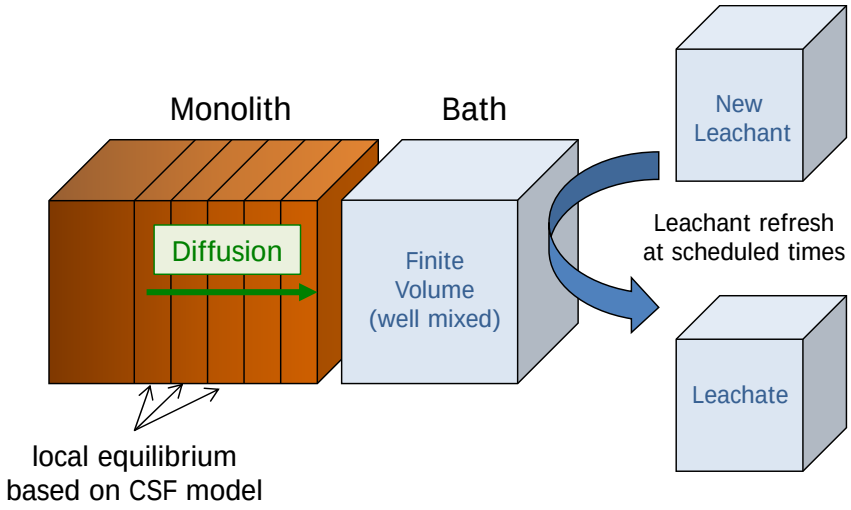


Figure 3-1. Mass transport model (laboratory simulation) scenario.

Percolation Test Simulation (mobile-immobile zones)

The CSF and percolation parameters may be used to evaluate the results of percolation column tests using the conceptual model of mobile and immobile zones. The conceptual model (Figure 3-2) consists of two zones segmented along the flow path, with one zone containing a mobile fluid phase in local equilibrium with the solid phase and the second zone containing an immobile fluid phase in local equilibrium with the solid phase. Within each column segment, each of the mobile and immobile zones are well mixed (i.e., uniform distribution of constituents within each of the solid phase and liquid phase orthogonal to the flow direction), and the mobile and immobile zones exchange dissolved constituents based on a mass transfer coefficient that can be considered an effective diffusion distance (van Genuchten and Dalton, 1986). This model is insensitive to percolation flow rate because homogeneity within the immobile zone is assumed. This model can be used for a first-order approximation of the effects of preferential flow in a percolation system, as well as the impacts of changes in redox and influent solution chemistry on the leaching of constituents.

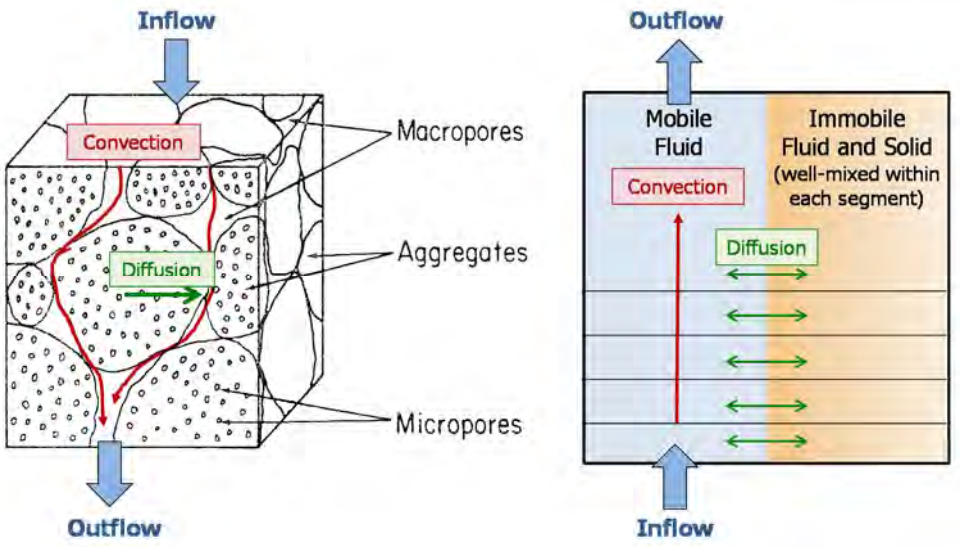


Figure 3-2. Conceptual model of percolation with mobile and immobile zones shown for soil aggregates (left; van Genuchten and Dalton, 1986) and as a 1-dimension approximation in ORCHESTRA (right).

Percolation Test Simulation (percolation-radial diffusion)

The CSF and percolation parameters also may be used for evaluation of percolation column test results using the conceptual model of percolation with radial diffusion from porous solid particles. The conceptual model (Figure 3-3) consists of two zones segmented along the flow path, with one zone containing a mobile fluid phase in local equilibrium with the solid phase and the second zone containing porous spheres with an immobile fluid phase (in contrast to the previous model using an immobile zone which was well mixed). Mass transport within the spheres occurs by diffusion through the fluid phase with the boundary condition of equal fluid composition at the interface between the sphere surface and the mobile zone, and no diffusion at the center of the spheres (van Beinum et al., 1999; Sarkar et al., 2013). Thus, fluid phase constituents can diffuse into and out of the spheres based on concentration gradients, and within the spheres local solid-liquid equilibrium is maintained at each radial layer within the sphere. Within each column segment, each of the phases in the mobile zone are well mixed (i.e., uniform distribution of constituents within each of the solid phase and liquid phase orthogonal to the flow direction) and in local equilibrium between the solid and liquid phases. This approach is more accurately reflective of systems where the diffusion gradients within the immobile zone control release to the mobile zone. Thus, this model is sensitive to overall percolation flow rate and can be used to reflect the impact of fast infiltration that does not reach complete equilibrium between mobile and immobile zones. This model can also be used to evaluate leaching under the effects of preferential flow, cracking in monoliths, varying flow conditions (e.g., intermittent flow, different flow rates), and solution chemistry.

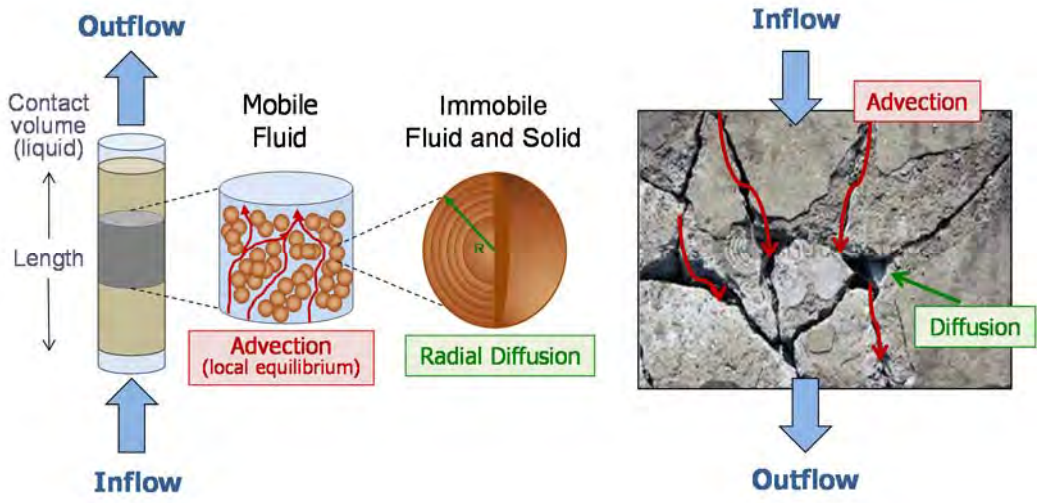


Figure 3-3. Conceptual model of percolation with radial diffusion in the immobile zone (Sarkar et al., 2013) shown as an up-flow column (left) and as flow through cracks in concrete (right).

3.3.2 LeachXS Field Test Simulations

In the different cases of laboratory to field evaluation data obtained from the field after a certain time of exposure to leaching under field conditions can be modeled just as was done for the laboratory test data. Results from laboratory testing and simulations described above can be used to parameterize the simulations for field scenarios and thus form a predictive estimate of field leaching under a range of conditions (i.e., "prediction scenarios"). Simulations of field scenarios illustrate the extent to which differences in field conditions compared to laboratory testing (i.e., contact water amounts and composition, and preferential flow) and changes in field conditions as a result of aging impact observed field leaching behavior. An illustration of this approach follows a description of prediction scenarios. For the illustration, the field data obtained in the pilot study on stabilized municipal solid waste incinerator (MSWI) scrubber residues (see Section 4.9) have been modelled using the same CSF as derived from the lab data. The main difference in this case is the higher carbonate level in the field exposed samples.

3.3.3 LeachXS Prediction Scenario Models

Monolithic Diffusion Prediction Scenarios

- Leaching – one dimensional diffusion from a monolith where system size, material layers, time frames, water contact and composition at the boundary can be varied to represent field scenarios. Unsaturated cases also can be simulated but without consideration of gas phase transport and reaction processes (e.g., oxygen or carbon dioxide gas phase transport and reaction).
- Leaching with Carbonation and Oxidation – analogous to the Leaching model above, but also allows for consideration of gas phase transport and reaction processes to consider impacts of carbonation and oxidation (Brown et al., 2013).

- Sulfate Attack with Leaching – this simulation allows coupling of physical degradation through sulfate attack on cementitious materials with leaching (Sarkar et al, 2010, 2012).

Percolation Prediction Scenarios

- Mobile-Immobile Zones Dual Regime Leaching – this simulation is analogous to the percolation column test (mobile-immobile zones) model but with adaptation appropriate for evaluating field scenarios (van Genuchten and Dalton, 1986).
- Percolation with Radial Diffusion Leaching – this simulation is analogous to the percolation column test (percolation with radial diffusion) model but with adaptation appropriate for evaluating field scenarios (Brown et al., 2013; Sarkar et al., 2013).

3.4 Example of Model Development for a Stabilized Waste Material

The chemical speciation and reactive transport models described earlier are illustrated through application to cement-stabilized MSWI bottom and fly ash as described in Section 4.9. The data used in laboratory simulation and field simulation modeling is shown in Table 3–1 through Table 3–3 and includes (i) the model parameters from the pH-dependence, percolation and monolith models (Table 3-1), (ii) the availability data used to parameterize the CSF (Table 3-2), and (iii) the CSF mineral phases derived from saturation indices in conjunction with pH-dependent leaching test data (Table 3-3). Extensive literature on cement-stabilized materials and cements is available (van der Sloot et al., 2007; van der Sloot et al., 2011) and provides initial indications of the solid mineral phases that are applicable to the major components of the stabilized waste. However, most often very limited, if any information, is available with respect to identification based on direct measurements of the mineral phases controlling release of the trace constituents because they are present below the detection limits of available analytical instruments. As a result, the controlling mineral phases for COPCs must be inferred from the LSP as a function of pH and L/S.

Table 3-1. Model Parameters for CSF Definition for Stabilized MSWI waste

Parameter	pH-dependent Model	Percolation Model	Monolith Model
L/S	10	varies	NA
Fraction DOC	0.2	0.2	0.2
pH+pE	15	15	15
Clay (kg/kg)	0	0	0
HFO (kg/kg)	$1x10^{-4}$	$1x10^{-4}$	$1x10^{-4}$
SHA (kg_{SHA}/kg_{TOC})	$2x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$
Porosity	NA	0.3	0.4
Density (kg/L)	NA	1.9	2.4
Initial pH of Solid	NA	12.1	12.4
Initial pH of Leachant	NA	7	7
Column Length (cm)	NA	25	NA
Relative Stagnant Volume (%)	NA	20	NA
Effective Diffusion Distance (cm)	NA	2	NA
Tortuosity	NA	NA	1.5
Specimen Length (cm)	NA	NA	10.9
Specimen Width (cm)	NA	NA	9.57
Specimen Height (cm)	NA	NA	9.57

Note: NA=data not applicable for the type of model.

Table 3-2 Chemical Availability Values for CSF Definition of Stabilized MSWI Waste

Species Name	Availability (mg/kg)	Species Name	Availability (mg/kg)
Al^{+3}	4,456	Mg^{+2}	3,900
H_3AsO_4	0.15	Mn^{+2}	170
H_3BO_3	59	MoO_4^{-2}	7.7
Ba^{+2}	19	Na^{+}	26,000
Br^{-}	830	Ni^{+2}	9.3
Ca^{+2}	84,000	PO_4^{-3}	4.7
Cd^{+2}	180	Pb^{+2}	960
Cl^{-}	54,000	SO_4^{-2}	11,000
CrO_4^{-2}	9.7	$Sb(OH)_6^{-}$	4.9
Cu^{+2}	360	SeO_4^{-2}	0.46
F^{-}	1,900	H_2SiO_4	3600
Fe^{+3}	74	Sr^{+2}	210
H_2CO_3	10,000	VO_2^{+}	0.58
K^{+}	34,000	Zn^{+2}	8000
Li^{+}	25		

Table 3-3. Mineral Phases in CSF Definition for Stabilized MSWI Waste

Chemical Formula*	Common Name	Chemical Formula*	Common Name
$2CaO\text{-}Al_2O_3\text{-}8H_2O$ [s]		$2CaO\text{-}2.4SiO_4\text{-}3.2H_2O$	Tobermorite-I
$2CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}8H_2O$ [s]		$0.83CaO\text{-}SiO_2\text{-}1.3H_2O$	Tobermorite-II
$2CaO\text{-}Fe_2O_3\text{-}8H_2O$ [s]			Tricarboaluminate
$2CaO\text{-}Fe_2O_3\text{-}SiO_2\text{-}8H_2O$ [s]		$Ca_3(PO_4)_2$	alpha-TCP
$3CaO\text{-}Al_2O_3[Ca(OH)_2]0.5\text{-}(CaCO_3)0.5\text{-}11.5H_2O$ [s]		$Ba[S,Cr]O_4$ [77% SO_4]	
$3CaO\text{-}Al_2O_3\text{-}6H_2O$ [s]		$Ba,SrSO_4$ [50% Ba]	
$3CaO\text{-}Al_2O_3\text{-}CaCO_3\text{-}11H_2O$ [s]		$Ca_3(AsO_4)_2\bullet 6H_2O$	
$3CaO\text{-}Al_2O_3\text{-}CaSO_4\text{-}12H_2O$ [s]		$CaMoO_4$ [c]	
$3CaO\text{-}Fe_2O_3[Ca(OH)_2]0.5(CaCO_3)0.5\text{-}11.5H_2O$ [s]		$Cd(OH)_2$ [C]	
$3CaO\text{-}Fe_2O_3\text{-}6H_2O$ [s]		$Cr(OH)_3$ [A]	
$3CaO\text{-}Fe_2O_3\text{-}CaCO_3\text{-}11H_2O$ [s]		$Cu(OH)_2$ [s]	
$3CaO\text{-}Fe_2O_3\text{-}CaSO_4\text{-}12H_2O$ [s]		$FeVO_4$	Iron Vanadate
$4CaO\text{-}Al_2O_3\text{-}13H_2O$ [s]		$Fe_2O_3\bullet 0.5H_2O$	Ferrihydrite
$4CaO\text{-}Fe_2O_3\text{-}13H_2O$ [s]		CaF_2	Fluorite
$Al(OH)_3$ [amorphous]	Gibbsite	$MgCO_3$	Magnesite
$CaSO_4$	Anhydrite	MnO(OH)	Manganite
$Mg(OH)_2$	Brucite	$Ni(OH)_2$ [s]	
$CaCO_3$	Calcite	Ni_2SiO_4	
$CaO\text{-}Al_2O_3\text{-}10H_2O$ [s]		$Pb(OH)_2$ [C]	
$Mg_6Al_2(CO_3)(OH)_{16}\bullet 4H_2O$	Hydrotalcite	$Pb_2V_2O_7$	
$Fe(OH)_3$ [microcrystalline]	Ferric hydroxide	$Pb_3(VO_4)_2$	
$Al(OH)_3$	Gibbsite	$PbCrO_4$	
$CaSO_4\bullet 2H_2O$	Gypsum	$PbMoO_4$ [c]	
$1.67CaO\text{-}SiO_2\text{-}2.1H_2O$	Jennite	$MnCO_3$	Rhodochrosite
$MgCO_3$	Magnesite	$SrCO_3$	Strontianite
$Ca(OH)_2$	Portlandite	CuO	Tenorite
SiO_2 [am]	Silica gel	Zn_2SiO_4	Willemite
$K_2Ca(SO_4)_2\bullet H_20$	Syngenite	ZnO	Zincite

Note: * - chemical formulae presented in cement-based notation or standard chemical format

For this illustration, the CSF that was developed from the pH-dependent model applied to pH-dependent test data subsequently was used in the percolation model (mobile-immobile zones) and the monolith model to simulate leaching under the conditions of respective percolation column and monolith diffusion tests. Results of the model simulations are provided in Figure 3-4 and Figure 3-5. The initial step toward assessing the simulation accuracy is the ability of the CSF to simulate the system response with respect to eluate pH, a master variable controlling leaching (see Section 2), for the pH dependent test, percolation column test and mass transport tests. In these figures, the pH titration curve is simulated to a high degree using the derived CSF and the eluate pH values for both percolation column and monolith leaching are well represented. For simulation of pH in the column test, peak pH response from the percolation model occurs at a lower L/S value than is indicated from the experimental data, most likely because of a greater amount of axial dispersion in the laboratory column which is not fully accounted for in the model. For the selected COPCs shown

in Figure 3-4 and Figure 3-5, the simulations provide a good representation of the experimental data for all three models, especially considering the uncertainties associated with both experimental data and simulations.

The effect of L/S on the pH-dependent model is shown in Figure 3-6. The results of the initial pH-dependent leaching test simulation at L/S of 10 mL/g-dry (solid, red line) are compared with results of the same CSF and model used to simulate LSP at 0.5 mL/g-dry (blue, dashed line). Also on the same graph, the simulation results are compared with experimental data from the pH-dependence test and percolation column test. Simulation results for Ca with an L/S of 10 mL/g-dry support the pH-dependent leaching data and indicate pH domains where Ca leaching is controlled by solubility (i.e., pH > 12) and by availability (i.e., pH < 12) as explained in Section 2. When the L/S decreases to 0.5 mL/g-dry, a similar pattern with a higher availability but the same solubility control is indicated. In Figure 3-6, this can be observed as the same Ca response for both simulations at pH greater than 12 while the simulation asymptotically approach different concentration values at pH less than 11. The difference in the concentration-based asymptote values is related to the L/S conditions under which the models were conducted (i.e., a similar mass released into less liquid at L/S 0.5 would result in a higher concentration). In contrast, potassium shows the behavior of a highly soluble species that exhibits LSP independent of pH and, therefore, a constant concentration as a function of pH. The pH-dependent model conducted at L/S 10 mL/g-dry is in good agreement with the pH-dependent test data and the simulation at the lower L/S of 0.5 mL/g-dry is in good agreement with the initial fraction observed from the percolation column test (i.e., the fraction collected at a cumulative L/S of 0.5 mL/g-dry). For selenium and molybdenum, the simulation and experimental results illustrate the more complex behaviors that can result as a function of pH and L/S.

For the four COPCs, experimental results for all eluates from the column test, ranging from L/S of 0.5 to 10 mL/g, are presented with the simulation results. When the eluate concentrations fall on the pH dependence curve for a range of L/S values this indicates that aqueous saturation of the constituent is controlling leaching within the column, as is the case for Ca. When initial percolation column test eluate concentrations correspond with the simulated values for the low L/S value (i.e., 0.5 mL/g) followed by continuous decrease in eluate concentration as is indicated for K and Se, this behavior is indicative of constituent release that is controlled by availability and depletion of the available fraction of the constituent as the percolation column test progresses.

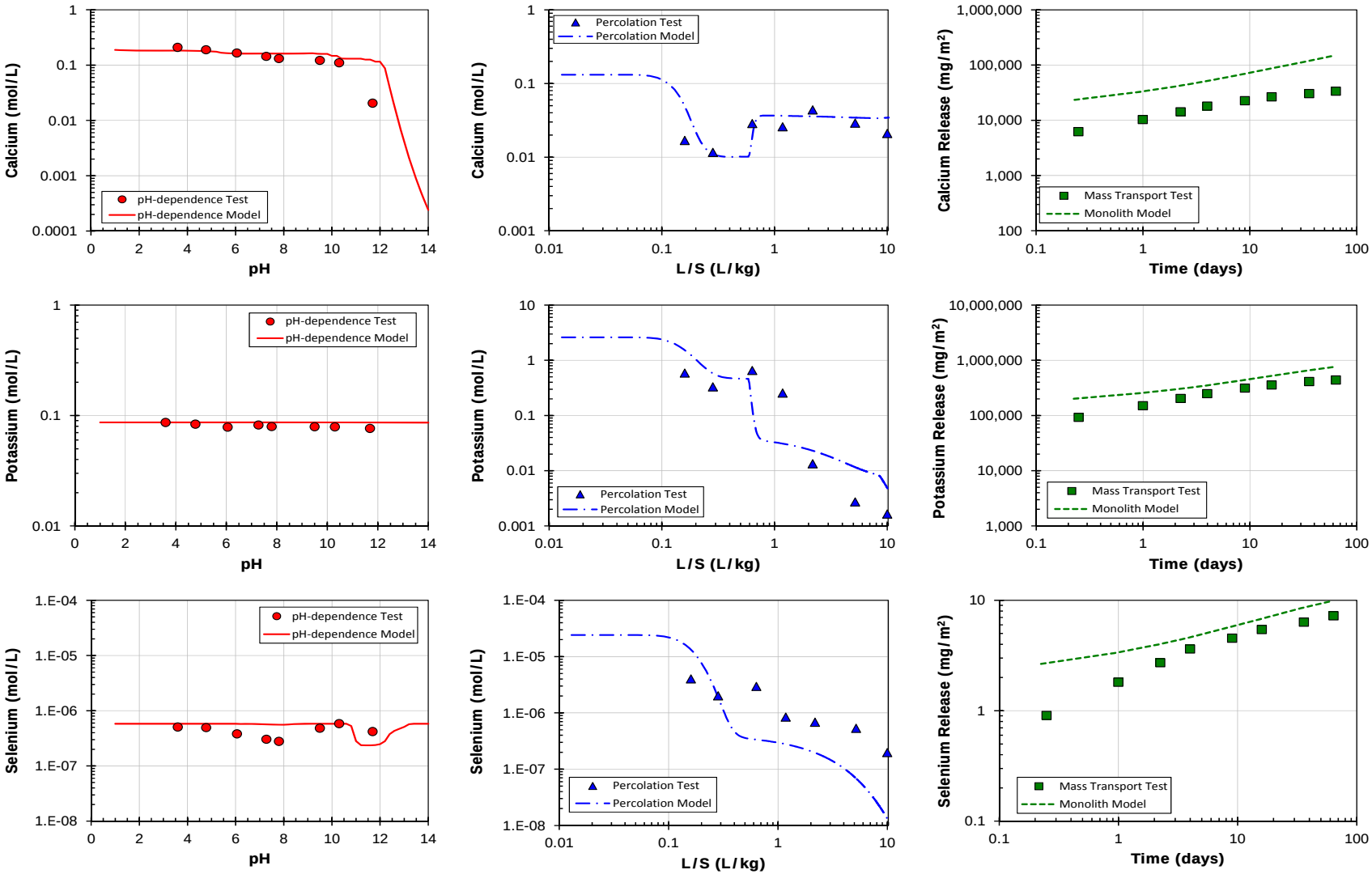


Figure 3-4. Comparison of laboratory simulation results for a stabilized MSWI residue (van der Sloot et al, 2007). Multi-element, multi-phase chemical speciation modeling is shown for pH-dependent leaching data (left), percolation test data (middle) and mass transport test data (right).

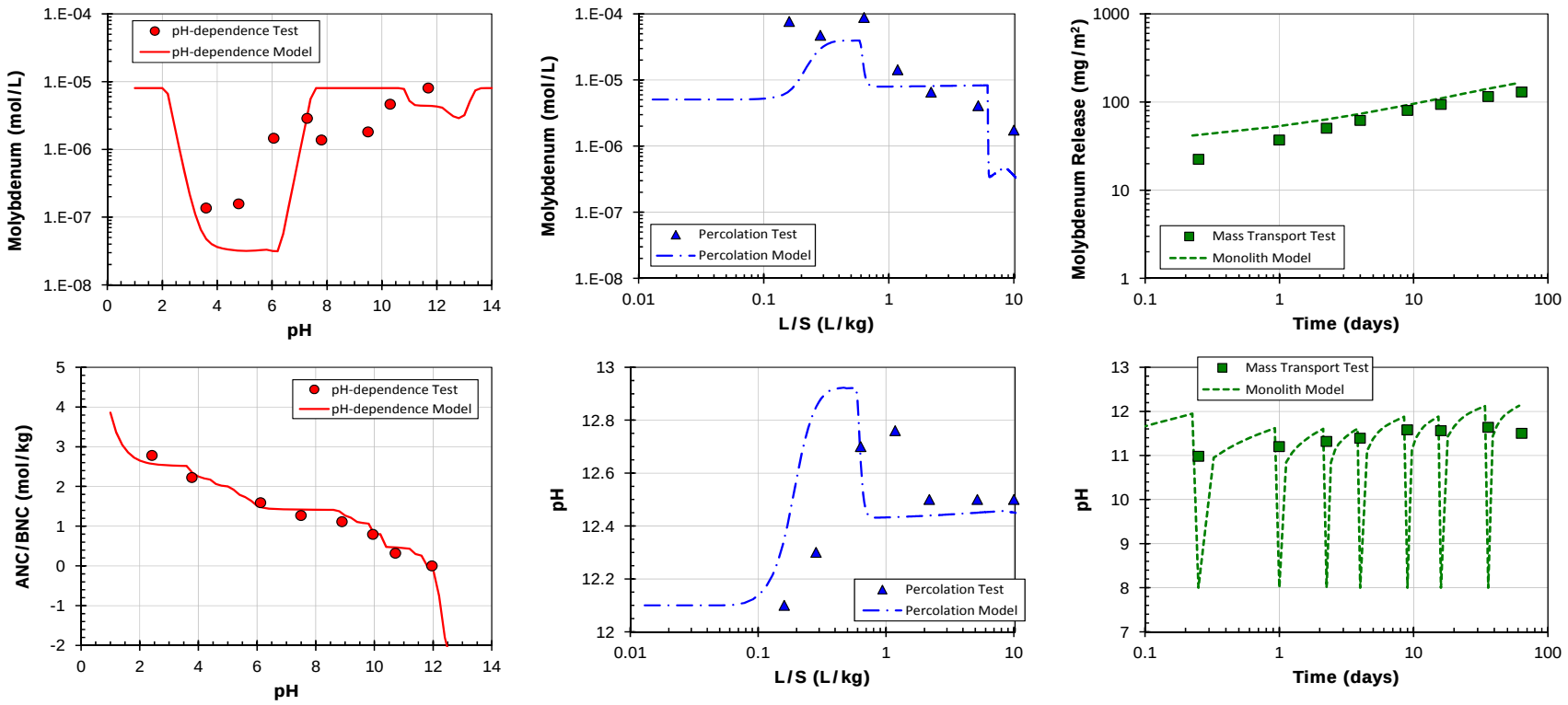


Figure 3-5. Comparison of laboratory simulation results for a stabilized MSWI residue (van der Sloot et al, 2007). Multi-element, multi-phase chemical speciation modeling is shown for pH-dependent leaching data (left), percolation test data (middle) and mass transport test data (right).

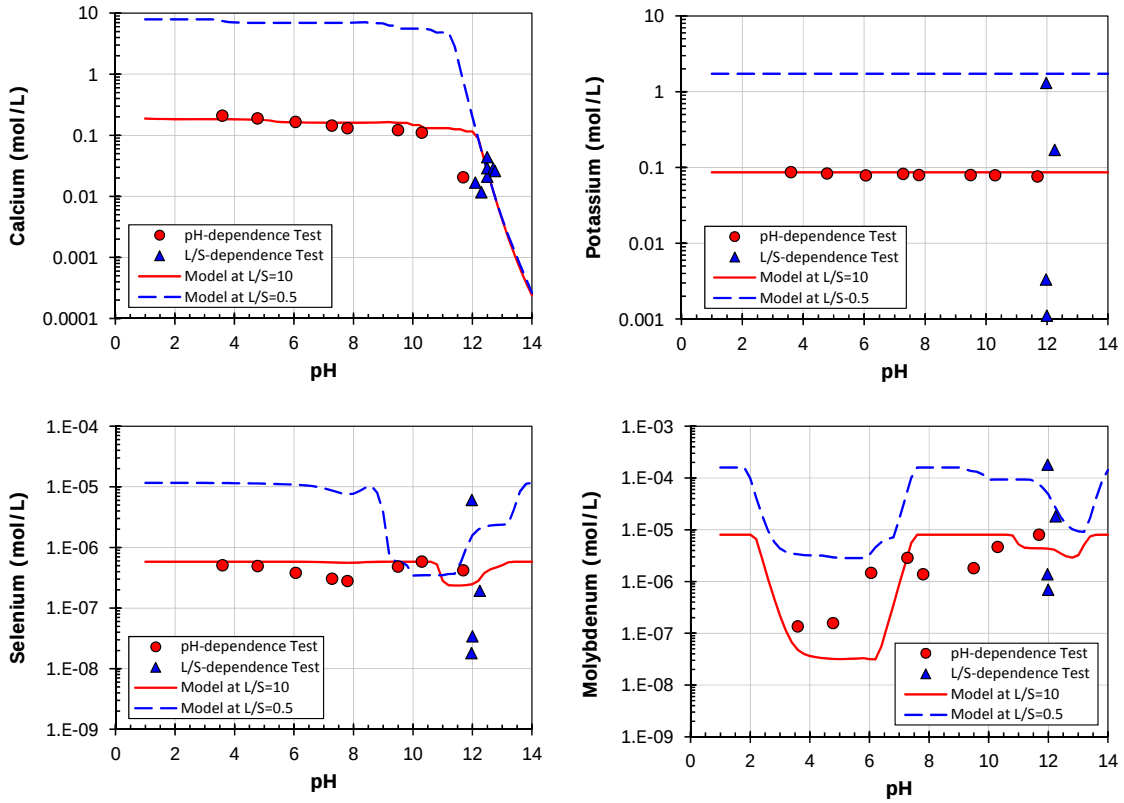


Figure 3-6. Laboratory leaching test simulation shown pH-dependent leaching (model at L/S=10 L/kg) and percolation leaching (model at L/S=0.5 L/kg) for select species in a solidified MSWI residue (van der Sloot et al, 2007).

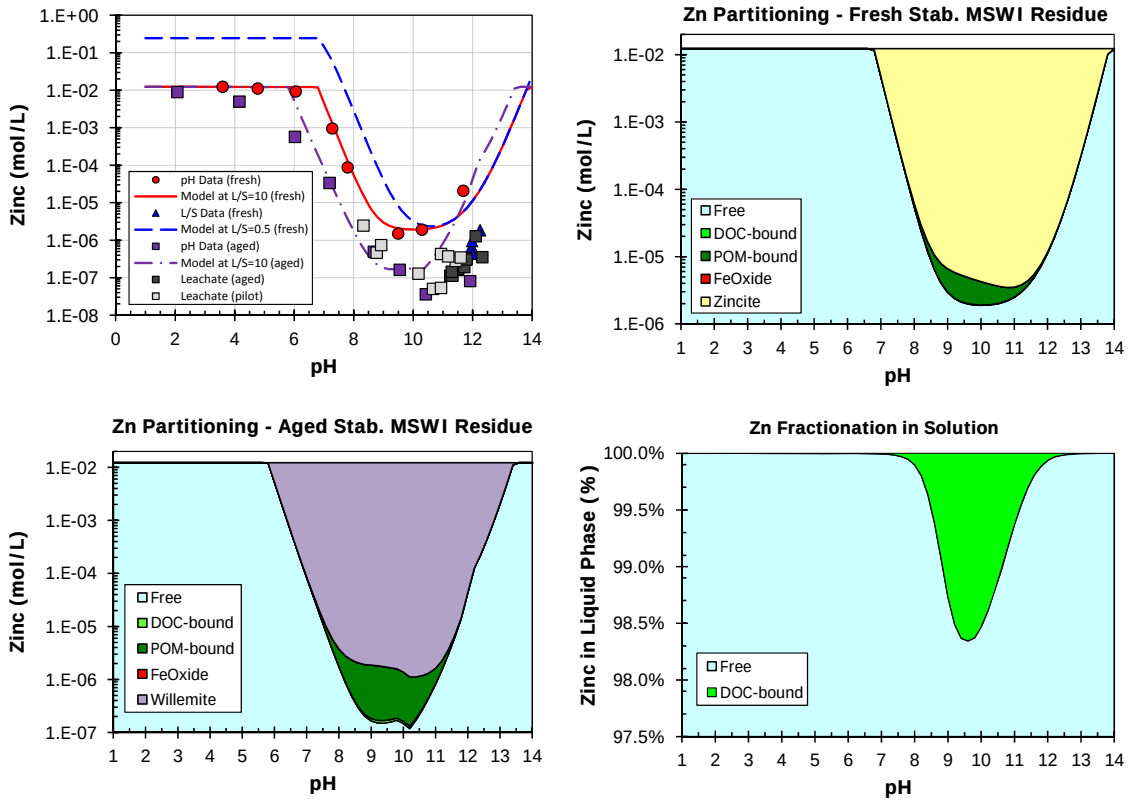


Figure 3-7. Chemical speciation and phase descriptions as a function of pH for a stabilized MSWI residue conducted on fresh material and aged (4 year) cores. Comparisons include pH-dependent model simulations (upper left), phase description for fresh material (upper right), phase descript for aged material (lower left) and liquid phase fraction for fresh material (lower right).

3.5 A Comparison of Copper and Lead Speciation in Several Materials

Figure 3-8 through Figure 3-11 present chemical speciation modeling compared to experimental results of pH dependent leaching for copper and lead from cement mortar, coal fly ash, stabilized waste, municipal solid waste, predominantly inorganic waste, and municipal solid waste incinerator bottom ash. For all cases, the left graph compares the experimental results from pH dependent leaching at L/S=10 mL/g (red dots) and percolation column results, with L/S ranging from 0.2 to 10 mL/g (blue dots), to the modeled aqueous phase concentration at L/S=10 and 0.3 mL/g (red line and blue dashed lines, respectively). The right graph for each case presents the distribution of the constituent concentration in the liquid phase between the amount complexed with dissolved organic matter (DOC-bound, bright green) and other dissolved species (i.e., the sum of free and other complexed species, "Free" indicated in light blue-green), while the remaining colored areas indicate speciation in the solid phase. For the graphs on the right side, the units (y-axis) are moles per liter of the total unit volume (i.e., total volume of solid and liquid phases). The sum of the DOC-bound and the "Free" species is equal to the total dissolved concentration (for either Cu or Pb) as

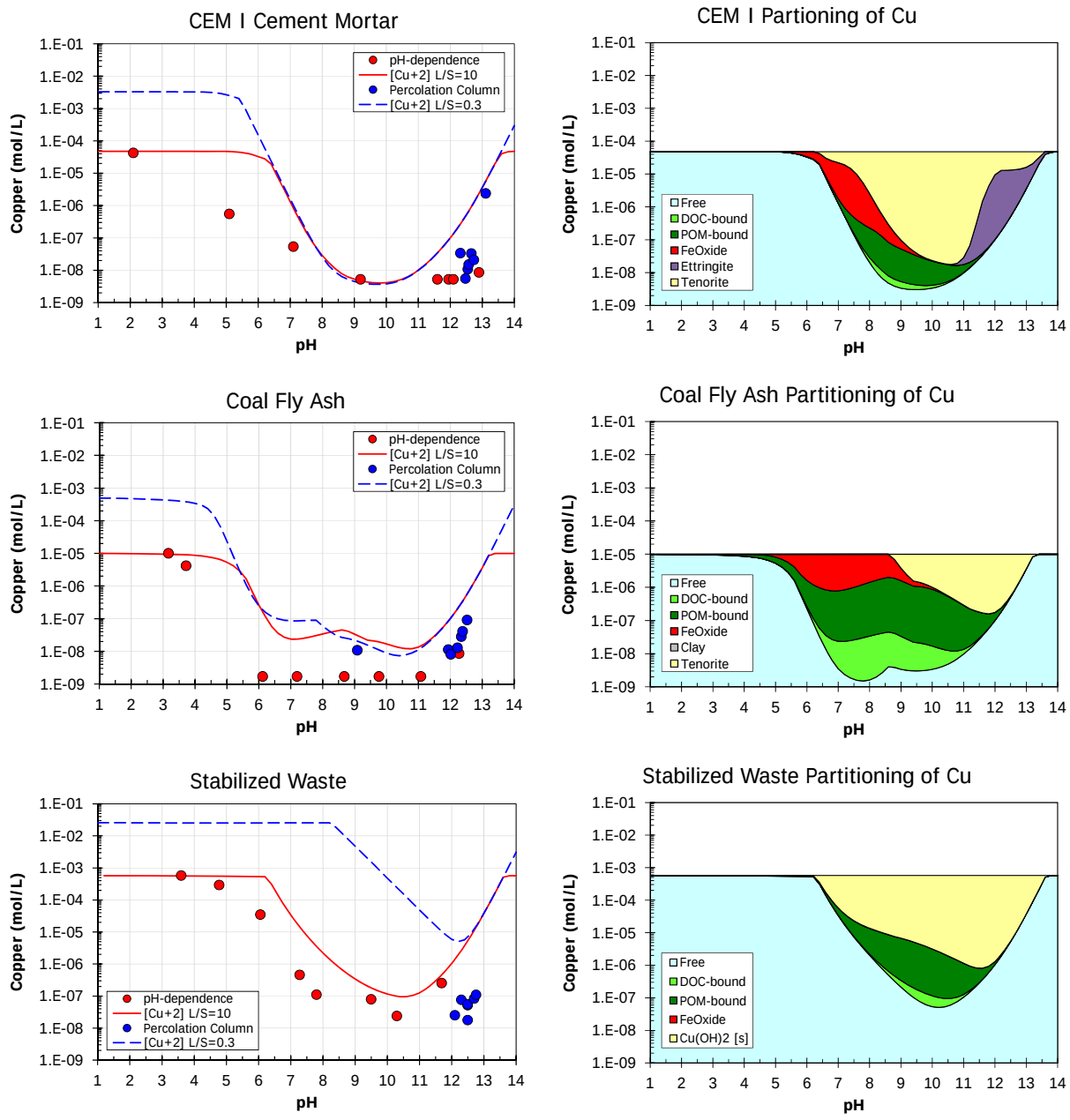


Figure 3-8. Geochemical model description of copper at L/S=10 with prediction to L/S=0.3 (left) and partitioning (L/S=10) based on multi-element geochemical speciation modelling (right). Data shown for cement mortar (top), coal fly ash (middle), and stabilized waste (bottom).

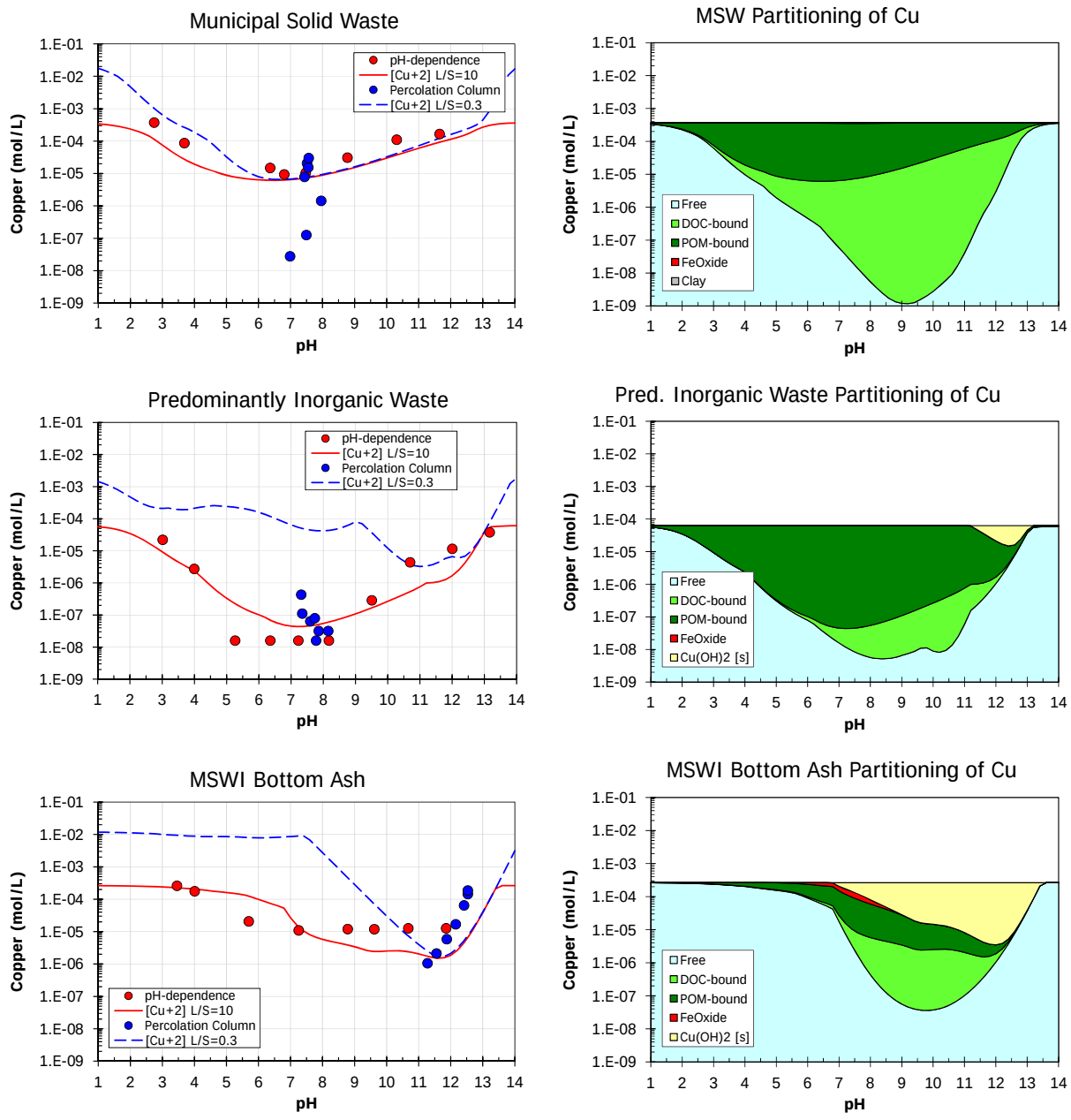


Figure 3-9. Geochemical model description of copper at L/S=10 with prediction to L/S=0.3 (left) and partitioning (L/S=10) based on multi-element geochemical speciation modelling (right). Data shown for municipal solid waste (top), predominantly inorganic waste (middle), and MSWI bottom ash (bottom).

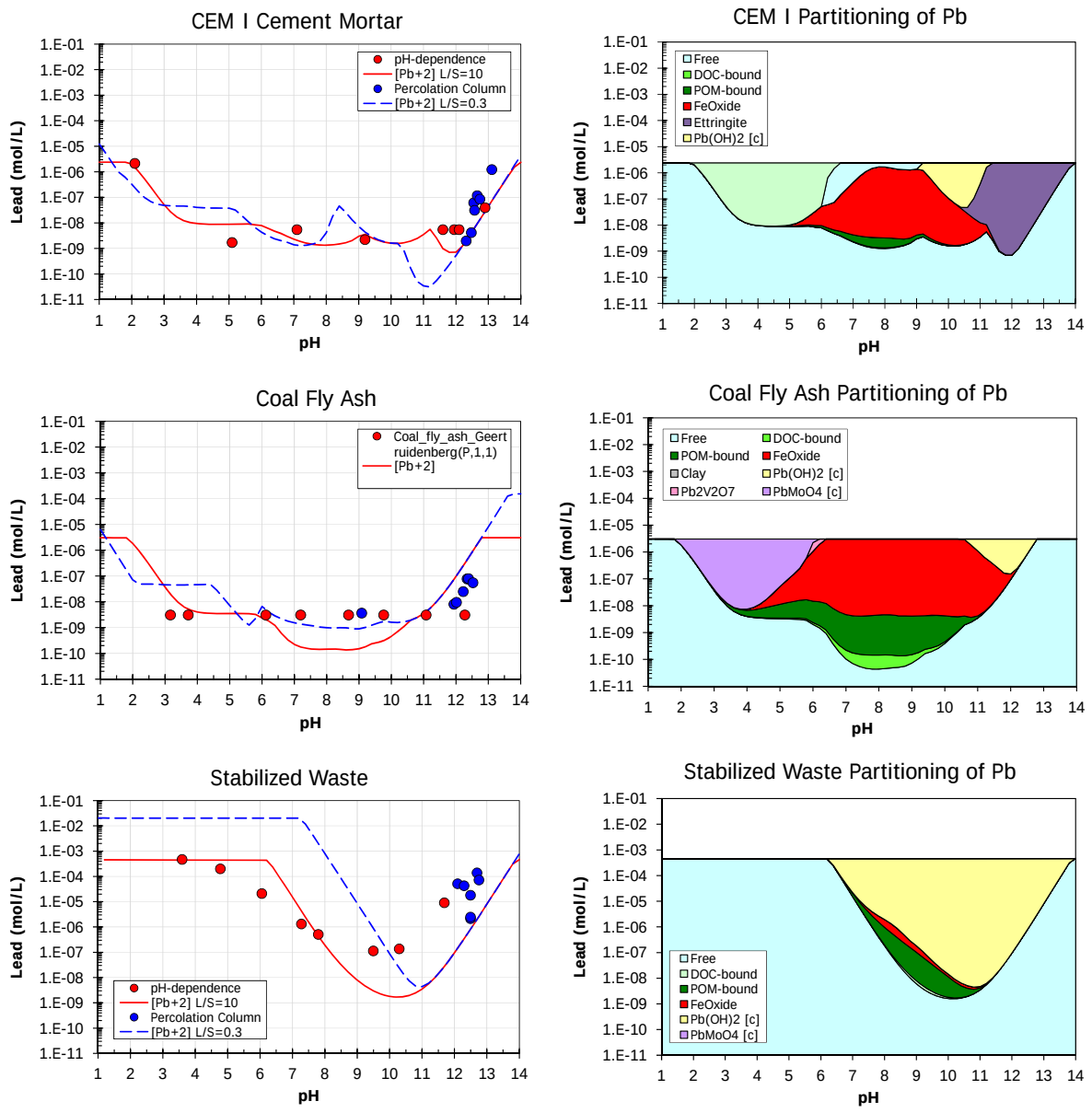


Figure 3-10. Geochemical model description of lead at L/S=10 with prediction to L/S=0.3 (left) and partitioning (L/S=10) based on multi-element geochemical speciation modelling (right). Data shown for cement mortar (top), coal fly ash (middle), and stabilized waste (bottom).

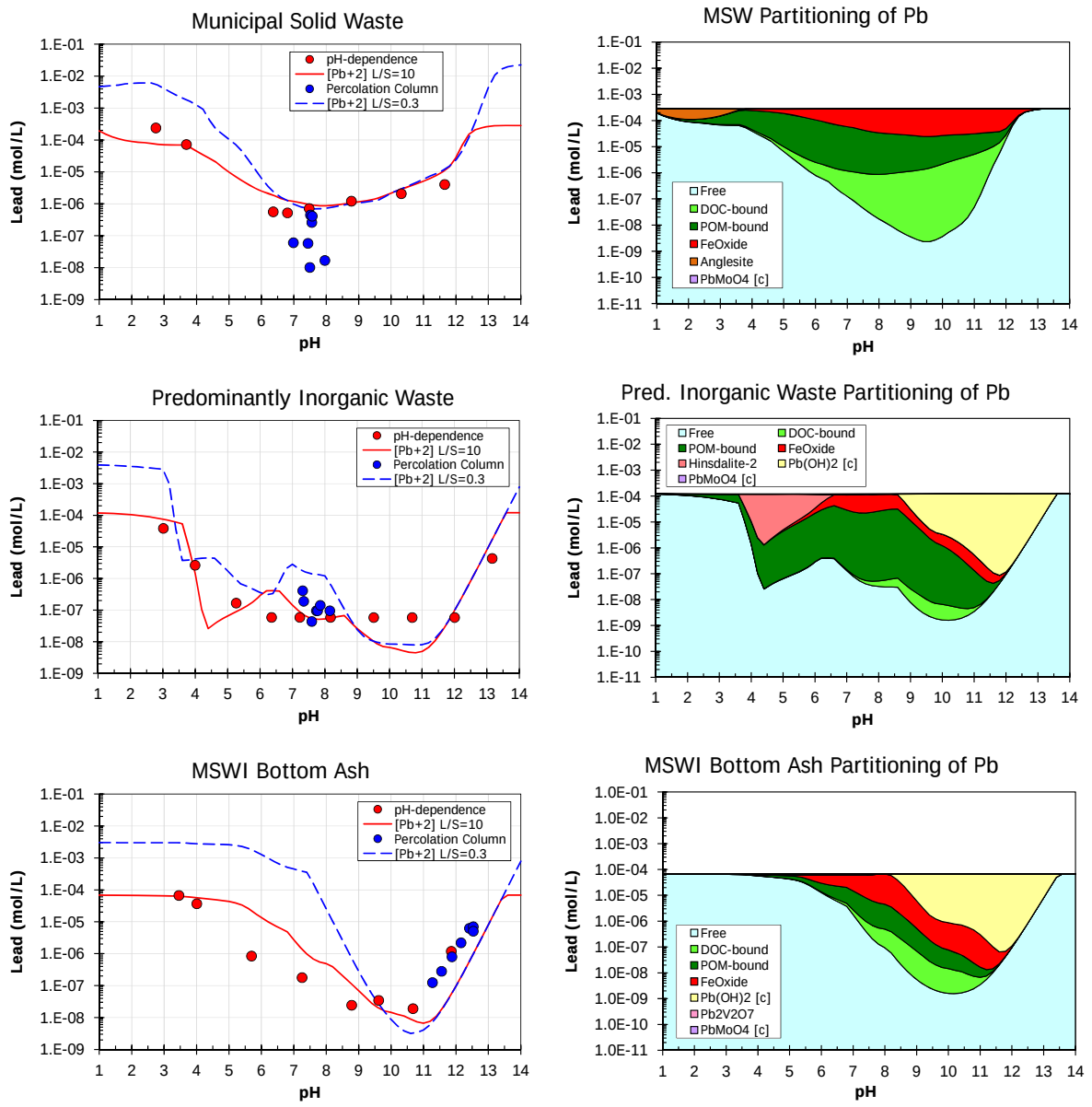


Figure 3-11. Geochemical model description of lead at L/S=10 with prediction to L/S=0.3 (left) and partitioning (L/S=10) based on multi-element geochemical speciation modelling (right). Data shown for municipal solid waste (top), predominantly inorganic waste (middle), and MSWI bottom ash (bottom).

modeled at L/S=10 mL/g and indicated on the red line on the respective left side graph. In each right side graph, the remaining colored areas indicate the relative amount of the Cu or Pb associated with specific solid phases over the indicated pH range. For example, dark green indicates adsorption with particulate organic matter and red indicates adsorption onto iron oxide surfaces. For the graphs of Cu partitioning, yellow indicates precipitation as tenorite or copper hydroxide [$Cu(OH)_2$] depending on the material, while for the lead graphs, yellow indicates precipitation as lead hydroxide [$Pb(OH)_2$]. Purple indicates co-precipitation with ettringite and red indicates adsorption onto iron (hydr)oxide surfaces.

Examination of Figure 3-8 through Figure 3-11 elucidates several important phenomena:

- The specific chemical species that control LSP varies as a function of pH (as well as pE, as discussed in Section 2.2.3) and material type.
- Comparison of LSP as a function of pH and at different L/S values (i.e., 10 and 0.3 mL/g, left side graphs) provides clear indication of when solubility in solution (i.e., a saturated solution) vs. the amount of a constituent that is available for leaching (i.e., availability) controls the observed aqueous phase concentration. For example the aqueous phase concentration of Cu in most of the materials is controlled by solubility at pH greater than 4, while a plateau in aqueous concentration is present at lower pH values. Saturated solutions are typically indicated when the simulated LSP at L/S=0.3 and 10 mL/g coincide. Materials leaching in the pH domain where the simulated LSP at L/S= 0.3 mL/g results in substantially higher aqueous concentrations than the simulated LSP at L/S=10 mL/g can be expected to higher leachate concentrations at low L/S values (i.e., initial percolates) than observed from the pH dependent leaching test carried out at L/S=10 mL/g.
- Complexation with dissolved organic matter and adsorption onto solid organic matter is more important for Cu than Pb LSP, and plays a critical role between pH 6 to 12. The presence of more DOC increases the amount of Cu in solution.
- The same set of phenomena and solid phases (i.e., organic matter complexation, precipitated solid phases, adsorption onto iron surfaces) are responsible for a significant fraction of the LSP behavior in multiple materials, albeit to different extents.

4 LABORATORY AND FIELD DATA FOR EVALUATION CASES

4.1 Coal Fly Ash Landfill Leachate (United States)

The burning of coal for energy production results in several forms of CCRs, including (i) fly ash, which is the fine material entrained in combustion gases and typically collected by an electro-static precipitator (ESP) in the first stage of air pollution control; (ii) scrubber residues, usually collected in the second stage of air pollution control, which may include processes for removal of gaseous sulfur oxides in the form of calcium, sodium or magnesium sulfides and sulfates (depending on facility configuration), and mercury removal by adsorption onto activated carbon; (iii) FGD gypsum, which is produced when the scrubber is designed and operated to force sulfidic gas oxidation to sulfates and precipitation with calcium; and (iv) bottom ash, which is the post-combustion residue removed from the combustion grates or chamber. In addition, preprocessing of coal prior to combustion can result in the production of a "coal milling reject" stream often including pyrite minerals that have high concentrations of reduced sulfur species and are difficult to size reduce. Specific CCR streams from a coal combustion power plant may be managed separately (e.g., for beneficial use of one or more streams, such as fly ash or FGD gypsum) or together for disposal. The specific leaching characteristics of individual CCRs are a function of the coal type combusted and the combustion system design and operating conditions. Extensive discussion is available on coal combustion facilities and the leaching characteristics of individual CCRs (Sanchez et al., 2006, 2008; Kosson et al., 2009).

4.1.1 Case Description

Landfill leachates, porewater and lysimeter samples[20] have been collected from multiple landfills and surface impoundments in the U.S. containing CCRs under an Electric Power Research Institute (EPRI) program (EPRI, 1988; 1998; 2006a; 2006b), and also by a U.S. EPA sampling program (EPA, 2000). The resulting set of field data was filtered to focus only on landfills receiving coal fly ash from coal combustion facilities without FGD scrubbers and not receiving coal milling rejects. In this way, the resulting set of data would reflect the range of landfill leachates produced from disposal environments where the fly ash predominated. It would not be possible to identify all disposal sites that receive only fly ash because most facilities co-dispose coal combustion bottom ash, although this waste stream is considered relatively inert. The resulting set of field data is compared to the range of pH-dependent leaching measured as part of a U.S. EPA study to characterize CCR leaching (Kosson et al., 2009) and a reference sample from an interlaboratory leaching test methods validation study (Garrabrants et al., 2012a; 2012b).

As part of the laboratory CCR characterization program, 35 fly ash samples were subjected to laboratory pH-dependent leaching by EPA Method 1313 and the corresponding precursor method SR002, as well as laboratory L/S dependent leaching by Method 1316 and the corresponding

[20] Leachate samples typically are taken from leachate collection systems, which may include sumps, collection wells and/or drainage above liner systems. Porewater samples typically are collected under suction from porous sampling devices embedded in the field material or by taking core samples and then using centrifugation, compression or suction to express pore water from the solid samples. Lysimeters typically are small-scale (e.g., on the order of 1 to 10 m^3) field test cells with liners and leachate collection intended to mimic larger field conditions.

precursor method SR003. Results of the laboratory testing program are summarized for each constituent as a function of pH or L/S based on the 5th, 50th, and 95th percentiles of the resulting data based on interpolation to common pH or L/S points (Garrabrants et al., 2012a) and graphed as either dashed (5th, 95th percentiles) or continuous lines (50th percentile). Field data are graphed as individual observations as a function of the measured sample pH along with the statistical (percentile) representation of the laboratory data.

4.1.2 Results and Discussion

A complete set of figures illustrating results from the field measurements in comparison to the statistical representation of the laboratory data is provided in Appendix A. The field sites and samples included can be summarized in Table 4-1. The field data includes core samples, pore water samples, leachates from lysimeter tests, leachates from well and leachate collection systems. The number of observations shown in Table 4-1 for calcium represents a high number of data points and full coverage of each site. The actual number of sites and data points for each COPC varies; thus, the ten total disposal sites are represented to various degrees.

Table 4-1. Summary of field sites and field data for calcium.

Sponsor	Site	Solid Core	Lysimeter Leachate	Well Leachate	Leachate Collection	Pore water
EPRI	38575	17	18		1	
EPRI	49003B				3	
EPRI	50207		21	104		
EPA	14093			3		
EPA	23214				1	
EPA	27413			3		
EPA	50211				1	
EPA	50212				1	
EPA	50213		2			
EPA	SX-BAG					5
Totals	**10**	**17**	**25**	**35**	**8**	**5**

The following are notable relationships between field leaching and leaching test results:

- Field leaching results for many constituents were well represented by the concentration as a function of pH domain of the laboratory leaching tests, considering the variability associated with the leaching behavior of fly ash from different facilities (Kosson et al., 2009). These constituents included aluminum, boron, calcium, copper, iron, potassium, magnesium, silicon, strontium, vanadium and zinc. Figure 4-1 illustrates this behavior for magnesium and vanadium. In most cases, there were a few data points that fell outside the laboratory distribution. For potassium, the laboratory distribution is skewed at alkaline pH because of the addition of potassium hydroxide during testing to achieve test pH values greater than the natural pH of the material.

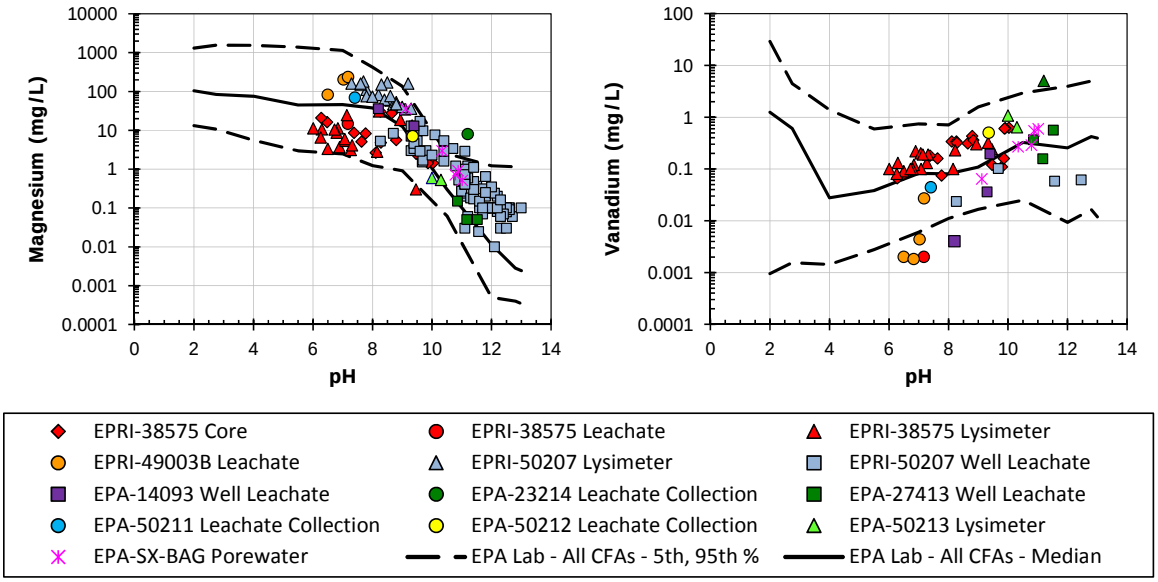


Figure 4-1. Comparison of field leachates to pH-dependent leaching for magnesium and vanadium release from CCRs.

- The range of pH observed for field leachate samples is in agreement with the range of natural pH observed during laboratory testing of fly ash from multiple sources. However, more acidic natural pHs were observed during laboratory testing (Kosson et al., 2009), but probably were not present in the field samples because of exclusion of sites containing pyrites (coal mill rejects) which also would correlate with high sulfur coals.
- For several constituents (e.g., arsenic, cadmium, chromium, manganese, nickel, and selenium), field leaching results exhibited bimodal behavior where one-third to one-half of the field results were well-represented by the domain of the laboratory concentrations as a function of pH domain, while the remaining data were significantly less than the laboratory testing results. Field concentrations that were less than the laboratory domain were also typically near detection limit values. Insufficient information was available to discern the cause of this response which may have been a result of relatively high detection limits, preferential flow or intrusion of dilution water. This bimodal behavior is illustrated in Figure 4-2 for arsenic, cadmium, chromium and selenium.

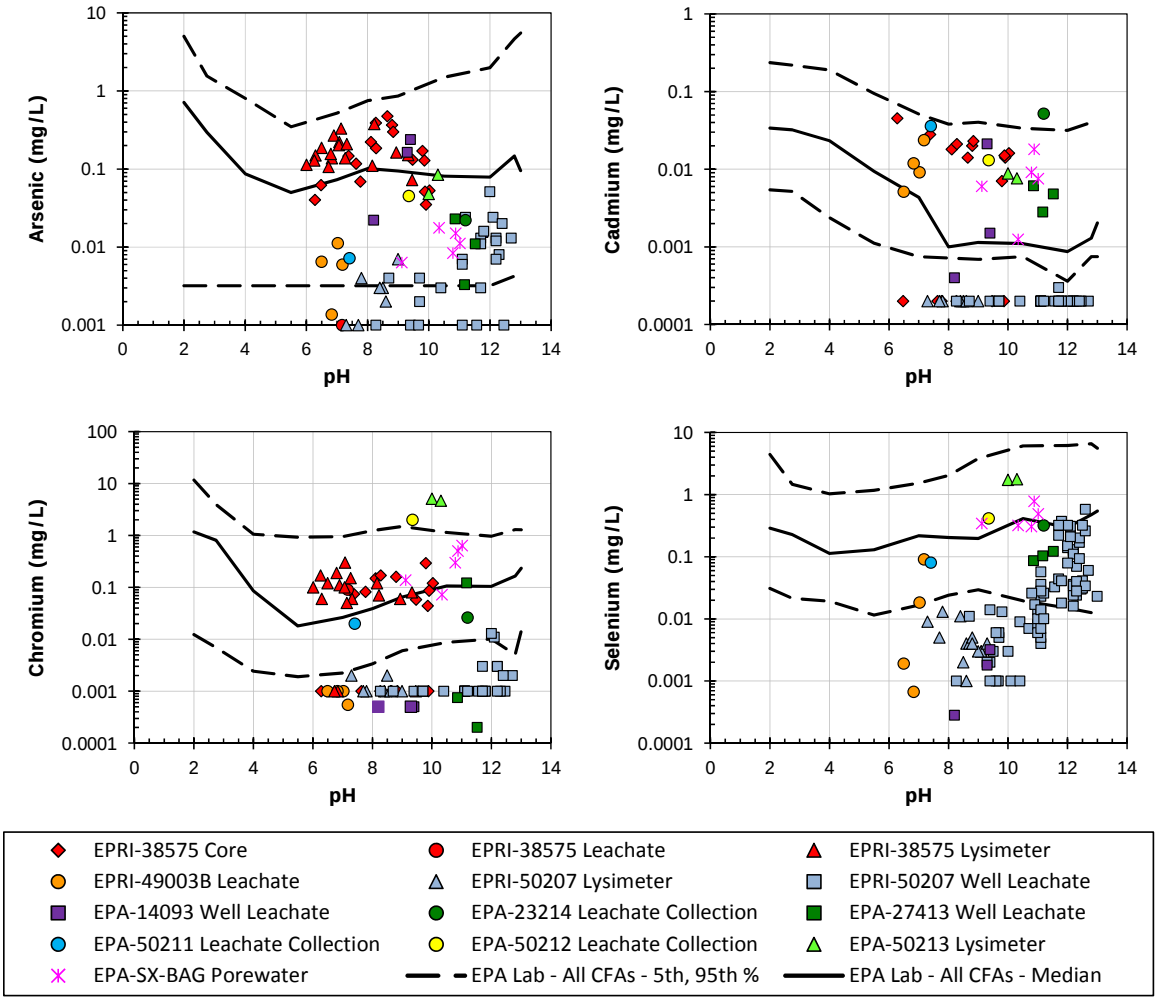


Figure 4-2. Bimodal behavior of field leaching results compared to pH-dependent leaching of arsenic, cadmium, chromium and selenium from CCRs.

- The upper range of field leaching concentrations for calcium and sulfate (Figure 4-3) reflects the solubility of calcium sulfate within the uncertainty of temperature and co-dissolved ions in solution (Marshall and Slusher, 1966). Note the 5th percentile dashed line for the laboratory extracts between pH 9 and 13 indicates a steep decrease in sulfate concentration with increasing pH. The decrease in sulfate at pH > 9 is consistent with the formation of ettringite, $Ca_6Al_2(SO_4)_3(OH)_{12}{\cdot}26H_2O$, in some high calcium fly ash samples (e.g., material codes XFA, ZFA in Figure 4-4 as compared to material codes EaFA or UFA). The formation of ettringite results in decreased sulfate solubility at alkaline pH as well as a similar decrease in chromium and molybdenum leaching resulting from anion inclusion and isomorphic substitution into ettringite.

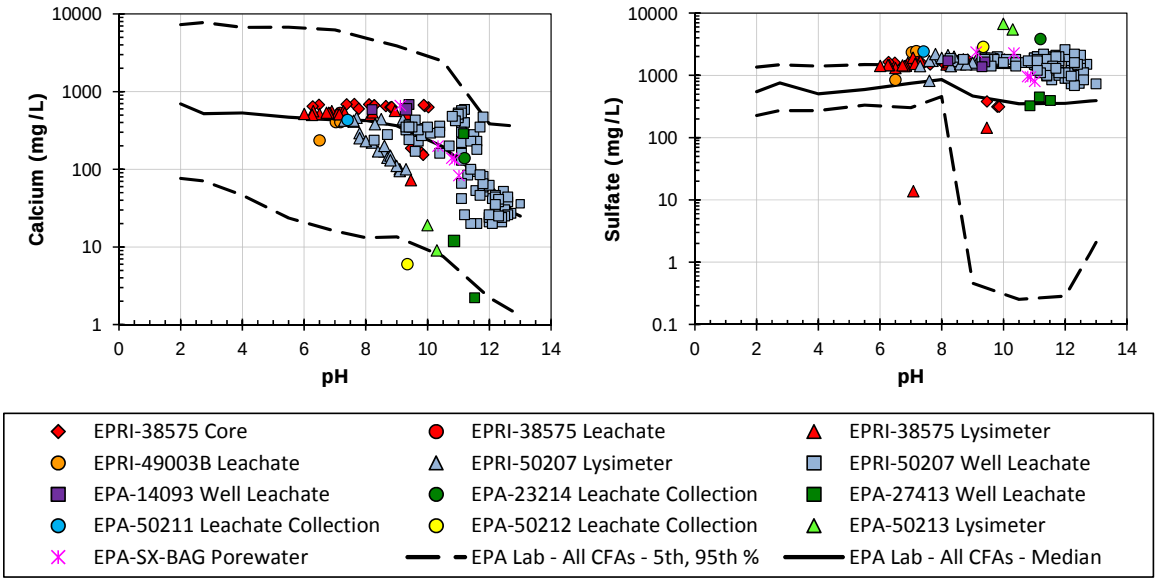


Figure 4-3. Comparison of field leachates to pH-dependent leaching for calcium and sulfate release from CCRs.

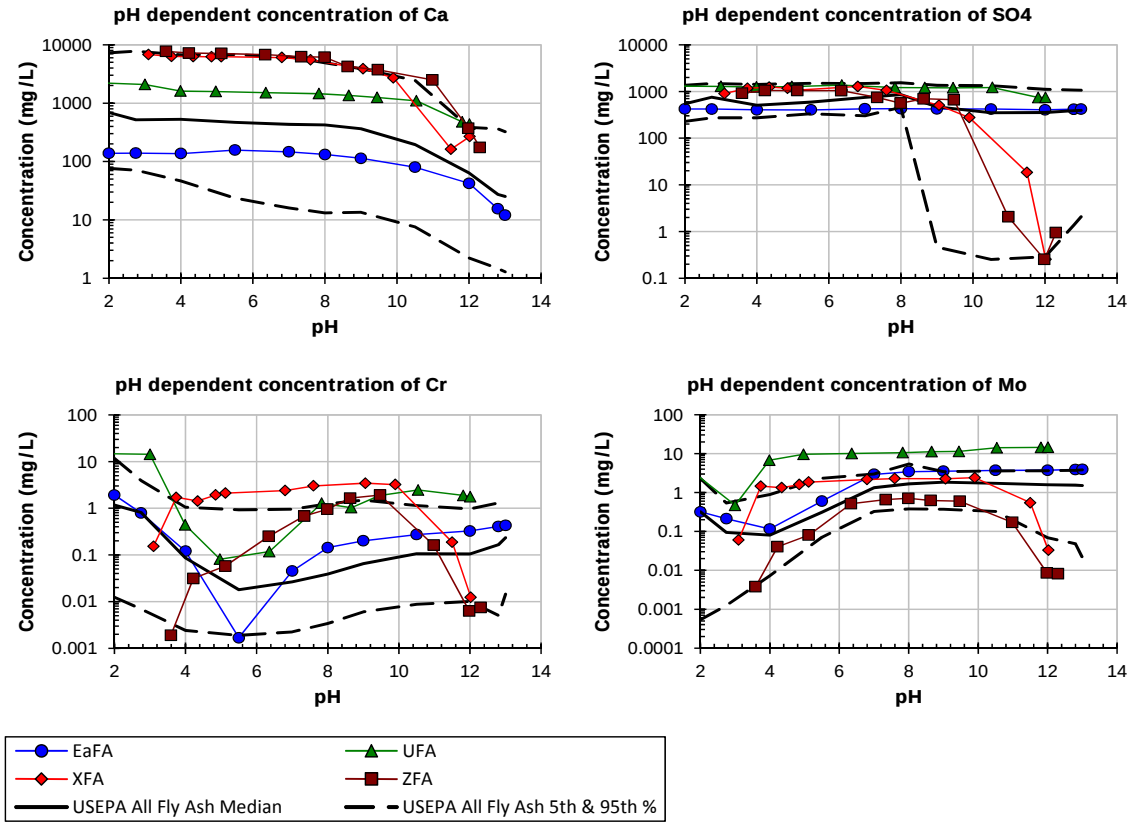


Figure 4-4. Effect of ettringite formation at alkaline pH on the leaching of chromium and molybdenum.

- The upper range of field leaching concentrations for chloride (ca. 290 mg/L) is approximately 15 times greater than the chloride concentrations at the 95th percentile for chloride based on laboratory testing at L/S 10 L/kg (Figure 4-5, left). For sodium, the upper range of field leaching concentrations (2,900 mg/L) is approximately 17 times the concentration at the 95th percentile for the laboratory testing at L/S 10 L/kg (Figure 4-5, right). These observed field values are reasonable given that the field porosity[21] is ca. 0.3 and a resulting multiplier of 33 is calculated if the assumption is made that all of the chloride or sulfate remains in solution (considering the porewater L/S would be approximately equal to the porosity, or 0.3 mL/g and the laboratory testing is at L/S = 10 mL/g, so the resulting correction factor would be 10/0.3=33. The results are also consistent with results of batch leaching as a function of L/S by Method 1316 and its precursor method SR003 (Kosson et al., 2002).

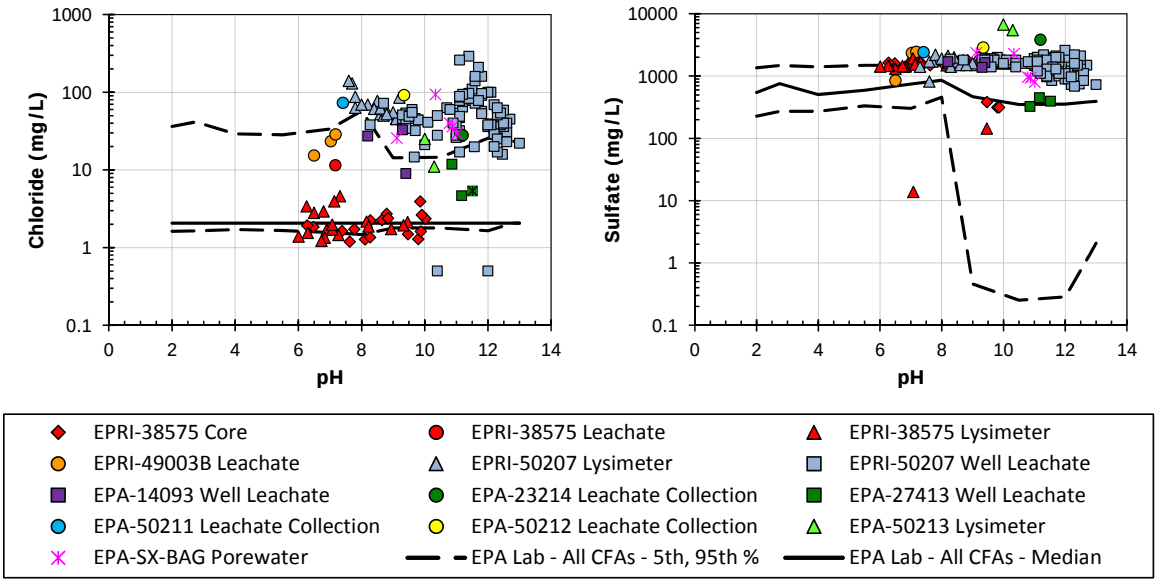


Figure 4-5. Comparison of field leachates to pH-dependent leaching for chloride and sulfate release from CCRs.

- Field leaching results for barium generally were between 0.02 and 0.2 mg/L, while laboratory test results were between 0.1 and 2 mg/L, and correlates with relatively high sulfate concentrations (Figure 4-6). This result is likely because of the higher sulfate concentrations and low liquid-solid ratio in the field that reduces barium solubility based on Le Chatelier's principle.

[21] "Field porosity" refers to the void fraction in the material under field conditions. Openshaw (1992) reported a compacted density of 1.3 g/cm3 for fly ash and a particle density of 1.9 g/cm3, indicating a compacted porosity of 0.32.

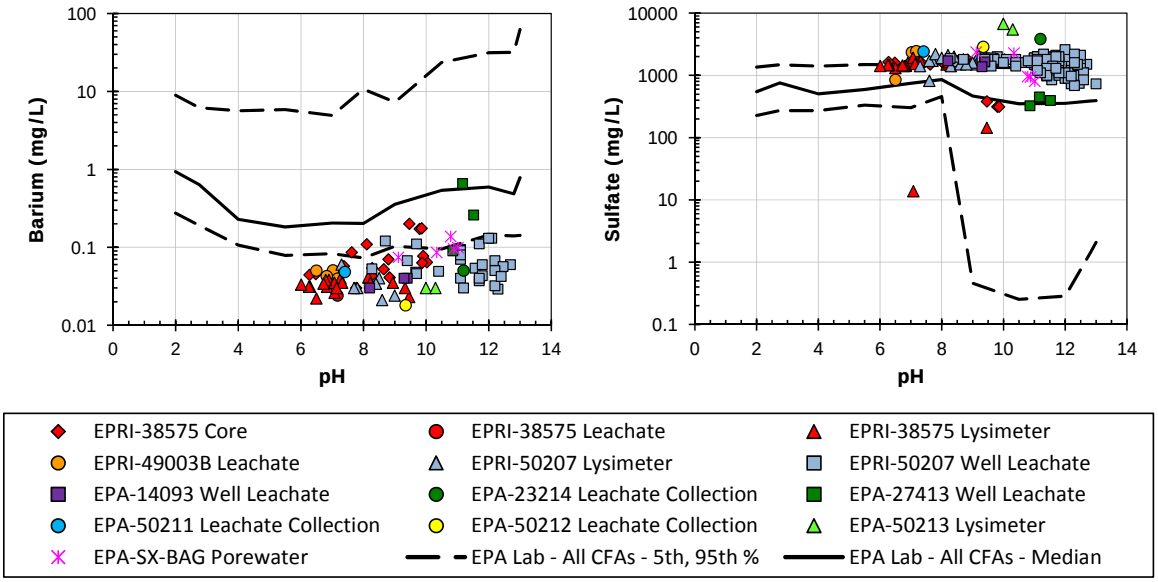


Figure 4-6. Comparison of field leachates to pH-dependent leaching for barium release from CCRs.

4.1.3 Case Summary

Case 1 examined the leaching behavior of coal fly ash under landfill disposal conditions as a class of materials. The study compares the leaching concentration ranges and pH dependent relationships for field leachates and pore water in comparison to laboratory test results obtained from LEAF testing of a wide range of coal fly ash samples. The applicable field leachate pH domain was from 6 to 13. Results of this case indicate that laboratory leaching characterization from a wide range of samples within a class of materials (i.e., coal fly ash) can be used to define the characteristic leaching behavior anticipated under field conditions (leachate concentration response as a function of pH and the anticipated ranges of concentrations, or bandwidth), associated with the response at specific pH values. The upper range of constituent concentrations from pH dependent testing (i.e., Method 1313) at a specific pH can be considered a conservative estimate of the upper limit of field concentrations, but laboratory concentrations of highly soluble constituents (i.e., availability limited) must be adjusted based on a correction factor between laboratory L/S and field pore water L/S. Field leachate concentrations lower than anticipated from laboratory pH dependent testing may be a consequence of either (i) reducing conditions (as seen for chromium and selenium) or (ii) common ion effects (as seen for barium in the presence of sulfate).

4.2 Leachate from Coal Fly Ash in Large-scale Field Lysimeters (Denmark)

4.2.1 Case Description

Large-scale lysimeter tests were carried out with coal fly ash in Denmark over the period of 1983 to 1990 (Hjelmar et al., 1991; Hjelmar, 1990). Individual lysimeters were 3m x 3m x 1.5 m deep (10 units) or 2.5 m deep (4 units) and used for a series of experiments, including those used for coal fly ash studies (Figure 4-7). Each lysimeter had a low density polyethylene liner and separate leachate collection. Filled lysimeters contained between 0.81 and 1.05 tonnes of fly ash and had 8-9 m^2 of surface area exposed to the atmosphere and natural precipitation. Two different fly ash materials, identified as HF1 and BF2, were obtained from different Danish power plants, each burning a different mixture of coal types. Results from BF2 as used in Lysimeters 4, 9 and 14 are the focus of the case comparison presented here. Similar results were obtained for HF1 and are available in Hjelmar (1990).

Fly ash samples HF1 and BF2 were also tested using laboratory percolation columns (Hjelmar et al., 1991). At the time of the testing, column test methods had not yet been standardized. For BF2, the column experimental conditions (identified as Column 4) were column diameter of 0.145 m, height of fly ash packing of 0.58 m for a total of 8.1 kg dry weight, and an influent velocity of 44-145 mm/day (up-flow). Similar column conditions were used for HF1. Column influent was a synthetic rainwater comprised of 0.5 mg/L NaCl, 0.19 mg/L $NaHCO_3$, 0.25 mg/L $CaCl_2 \cdot 2H_20$ and 0.27 mg/L Na_2SO_4. However, the report also concludes, "Therefore, it makes little difference whether artificial rainwater (with limited buffering capacity, as above), demineralized water or slightly acidified demineralized water is used in leaching experiments, except perhaps at very high L/S values" (Hjelmar et al., 1991, p. 26).

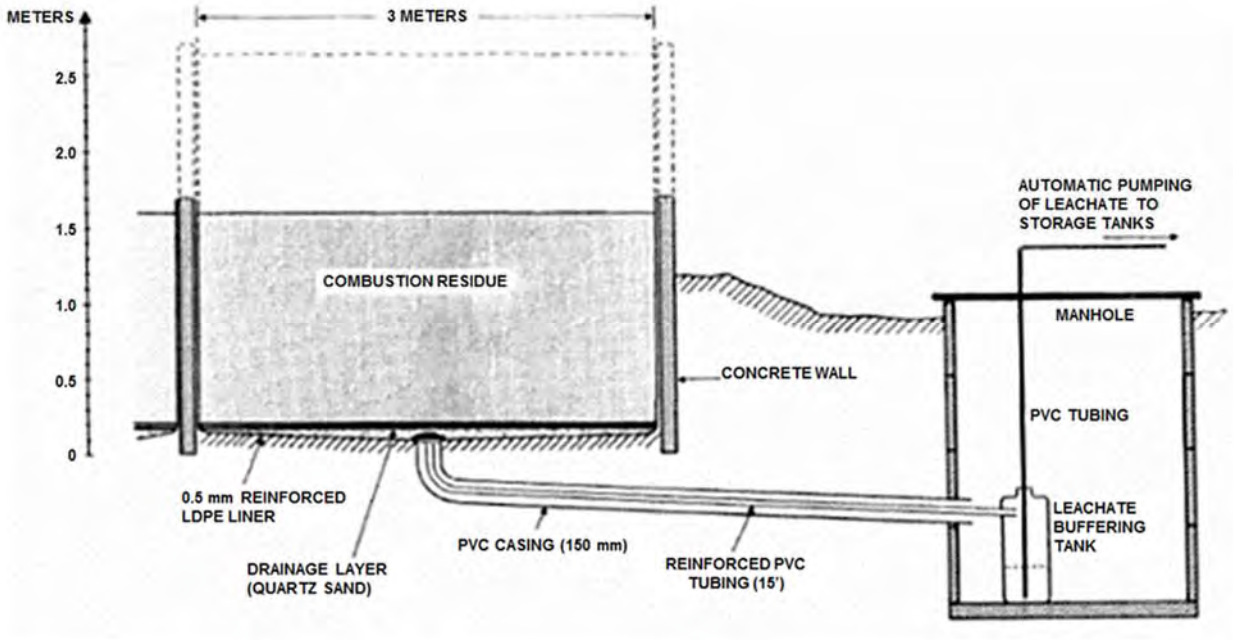


Figure 4-7. Cross-section of large-scale field lysimeter construction (Hjelmar et al., 1991).

4.2.2 Results and Discussion

Only a limited set of analytes was measured in field leachate and laboratory column eluates; only one data point (at L/S ~0.002) was available for Lysimeter 4. A comparison of leachate composition from field lysimeters and laboratory column testing (Column-4) is provided in Figure 4-8 for pH and major constituents and in Figure 4-9 for trace constituents.

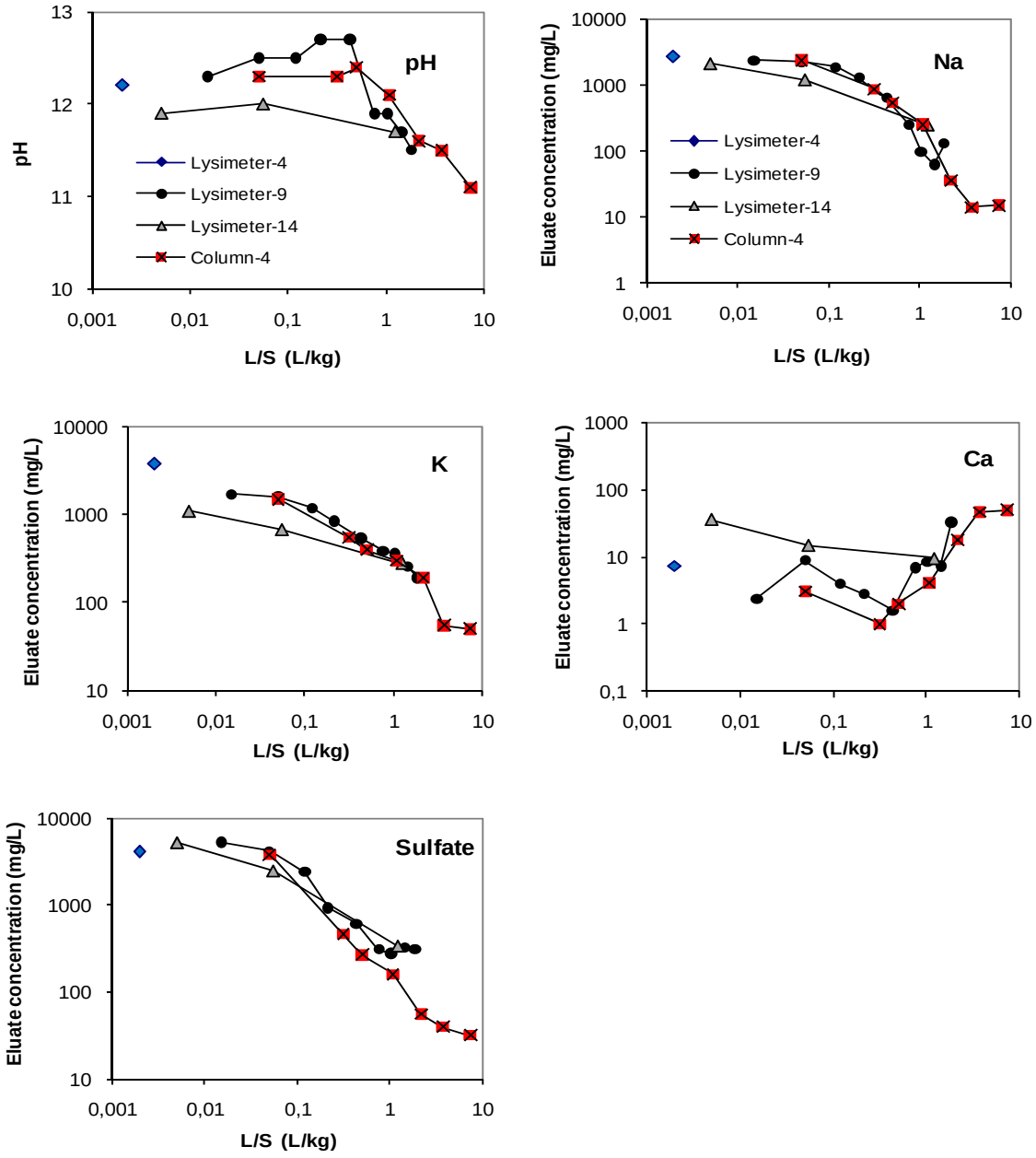


Figure 4-8. Comparison of leachate composition from field lysimeters and laboratory column testing (Column 4, red symbols) for pH, sodium, potassium, calcium and sulfate.

Leachate pH values were lower for Lysimeter 14 than for Lysimeter 9 and Column 4, along with somewhat higher calcium and somewhat lower arsenic concentrations in Lysimeter 14 than the other results. Leachate constituent concentrations from Lysimeter 9 and eluate concentrations from Column 4 were nearly identical for all constituents and consistent with the single observation reported for Lysimeter 4. This information indicates that preferential flow was not a major factor in the field lysimeter performance. In addition, the common behavior between laboratory and field conditions for oxyanions (i.e., chromium and selenium) suggests that establishment of strongly reducing conditions in the field was not a consideration for the material tested.

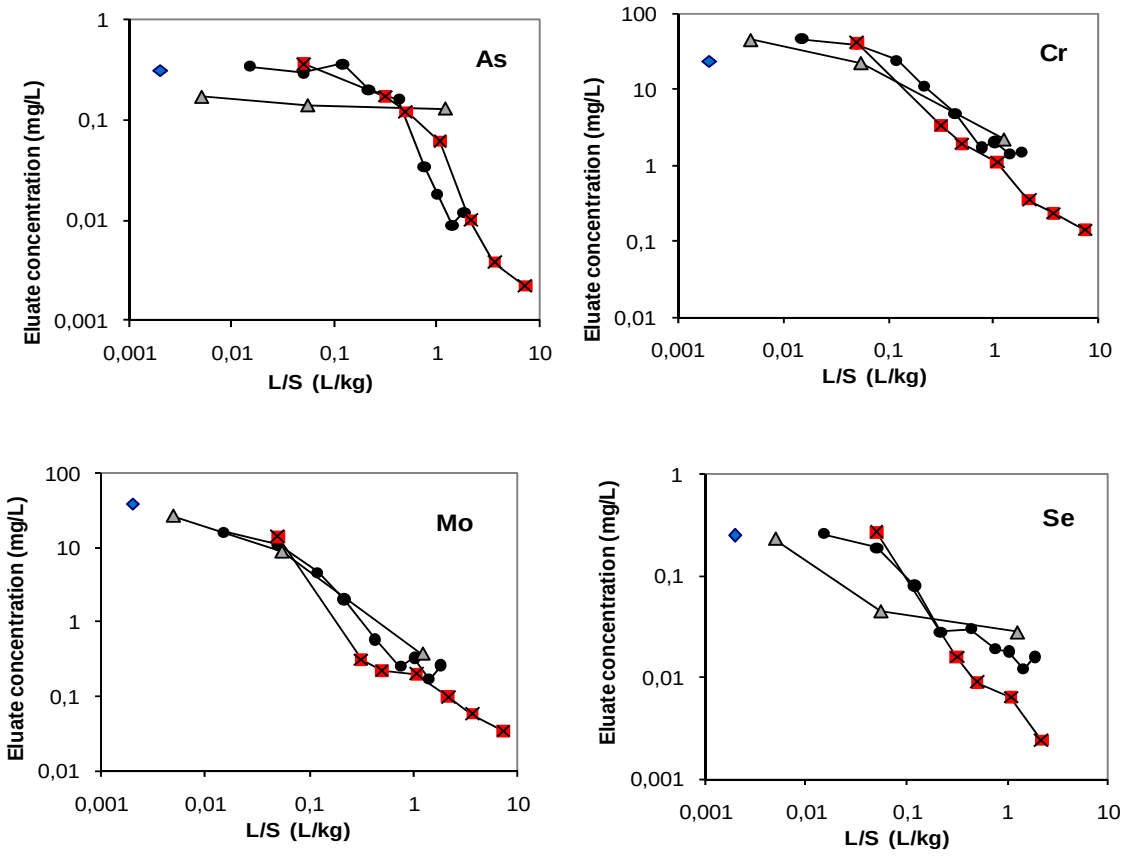


Figure 4-9. Comparison of leachate composition from field lysimeters and laboratory column testing (red symbols) for arsenic, chromium, molybdenum and selenium.

4.2.3 Case Summary

Case 2 compared the field leaching from large scale lysimeters over 7 years to results from laboratory percolation column tests. The observed field leachate pH was between 11 and 12.8. Results of this case indicate that laboratory percolation column testing (e.g., Method 1314) can provide a good estimate of initial leachate concentrations under field conditions established in lysimeters. Initial concentrations from field lysimeters at very low L/S (i.e., <0.01 L/kg) of some

species may be somewhat greater than observed from initial eluates of laboratory percolation column tests (i.e., molybdenum). Laboratory percolation column testing also provides a good approximation of the evolution of leaching profiles as a function of L/S that would be expected under field conditions in the absence of preferential flow and establishment of strong reducing conditions.

4.3 Landfill of Coal Combustion Fixated Scrubber Sludge with Lime (United States)

4.3.1 Case Description

FGD filter cake and fly ash are typical CCRs requiring environmental characterization in conjunction with material management. Plant 14090 served as a test case for comparison of laboratory leaching tests of produced blended CCRs, laboratory leaching of core samples from the disposal landfill site for the blended CCRs, and field leachate samples (EPRI, 2012).

Plant 14090 is a 1,000+ megawatt (MW) power plant. The plant burns pulverized eastern bituminous coal in a boiler. Cold-side electrostatic precipitators (ESPs) are used on all units for particulate control. Selective catalytic reduction is used at the plant but was not active during collection of the materials used in this study. The wet FGD systems on two units are used to reduce SO_2 emissions via limestone slurry sorbents and an inhibited oxidation process. The FGD solids, consisting primarily of calcium sulfite, are pumped from the absorber to a thickener. Liquid overflow from the thickener is recycled back into the FGD system, and the thickened sludge is pumped to a series of drum vacuum filters for further dewatering. Water removed by the drum vacuum filters is recycled back into the FGD system, and the filter cake (FC) is taken by conveyor belt to a pug mill, where it is mixed with dry fly ash and dry quicklime for stabilization. The resulting FSSLs are taken by conveyor to a temporary outdoor stockpile and then transported by truck either to a utilization site or to an on-site landfill. After setting, the stabilized solid forms a weak monolithic material that has some degree of compressive strength and moderately high alkalinity.

"As produced" FSSL was sampled from Plant 14090 and evaluated as part of an EPA program on leaching characterization of CCRs and identified by material code "MAD" (Sanchez et al., 2008) and testing for pH-dependent leaching following method SR002 and L/S dependent leaching using method SR003.[22] Core samples from the FSSL disposal landfill (designated "FCM") also were characterized for pH-dependent leaching using SR002 and L/S dependent leaching using SR003. Porewater was collected from two locations in the landfill (designated "SCS-1" and "SCS-2") between 2001 and 2007.

The concentrations of constituents in porewater samples collected from the FSSL landfill at Plant 14090 was compared as a function of pH to the equilibrium data from SR002 and SR003 tests.

[22] SR002 (abbreviated in figures as SR02) and SR003 (abbreviated in figures as SR03) are Vanderbilt University precursors of EPA Method 1313 and Method 1316, respectively. Although the general procedures and utilization of results are the same, these precursors differ from the current tests in the number of extracts and the exact target values (e.g., pH or L/S) required in each test.

Porewater was collected at two locations in the landfill (i.e., SCS-1 and SCS-2) from November 2001 through May 2007, providing 25 independent samples for analysis.

4.3.2 Results and Discussion

A complete set of figures illustrating results from the field porewater measurements in comparison to the laboratory leaching test results of "as produced" FSSL (i.e., MAD) and landfill core samples (i.e., FCM) is provided in Appendix B. The following are notable relationships among the testing results from the three types of samples:

- The average natural pH of the MAD material is approximately 11.9 and of the FCM material is 9.1 (based on replicate samples), whereas the average SCS sample pH is 7.4 with a span from pH 6-10. The high natural pH of the freshly mixed FSSL is due to addition of quicklime and the dissolution of $Ca(OH)_2$ at a pH of approximately 12.5. The decrease in natural pH from ca. 12.0 for MAD to 9.0 for FCM is consistent with the consumption of $Ca(OH)_2$ during carbonation of alkaline materials, including slower reactions with fly ash (natural pH 11.3) and scrubber solids (natural pH 8.9). Nominally, the natural pH of the field cored material should agree closely with the pH of landfill leachates. The discrepancy in pH readings may be caused by carbonation during handling and processing of landfill leachates. Based on the titration curve of FCM, approximately 0.5 milli-equivalents of acid per gram of material (meq/g) would be required to lower the pH of the FCM material to the mean leachate pH of 7.4. Considering the mass of FCM in the landfill, a significant amount of acid would be required to overcome the buffering capacity of the FCM material. However, considerably less acid (in the form of carbonation) would be needed to neutralize the porewater samples once they were no longer in contact (and therefore near equilibrium) with the solid phase. Therefore, porewater samples were likely neutralized through reaction with atmospheric carbon dioxide during collection and handling prior to analysis.
- The impact of aging and partial carbonation of field cores (FCM) in comparison to the "as produced" material (MAD) is apparent in the response of barium, calcium, magnesium and strontium between pH of 8 and 13, where FCM indicates decreased solubility relative to MAD (illustrated for barium, calcium and strontium in Figure 4-10). Porewater concentrations of these constituents are similar to or less than the concentrations measured for field core material. This is a typical response to carbonation and is consistent with other results for other materials presented in this report.
- Field porewater concentrations of barium are lower than measured in laboratory extracts of field cores and "as produced" material. This phenomena is similar to that observed for coal fly ash (see Section 4.1) and likely results from elevated concentrations of sulfate at the low L/S associated with porewater, thereby reducing barium sulfate solubility by common ion effects.

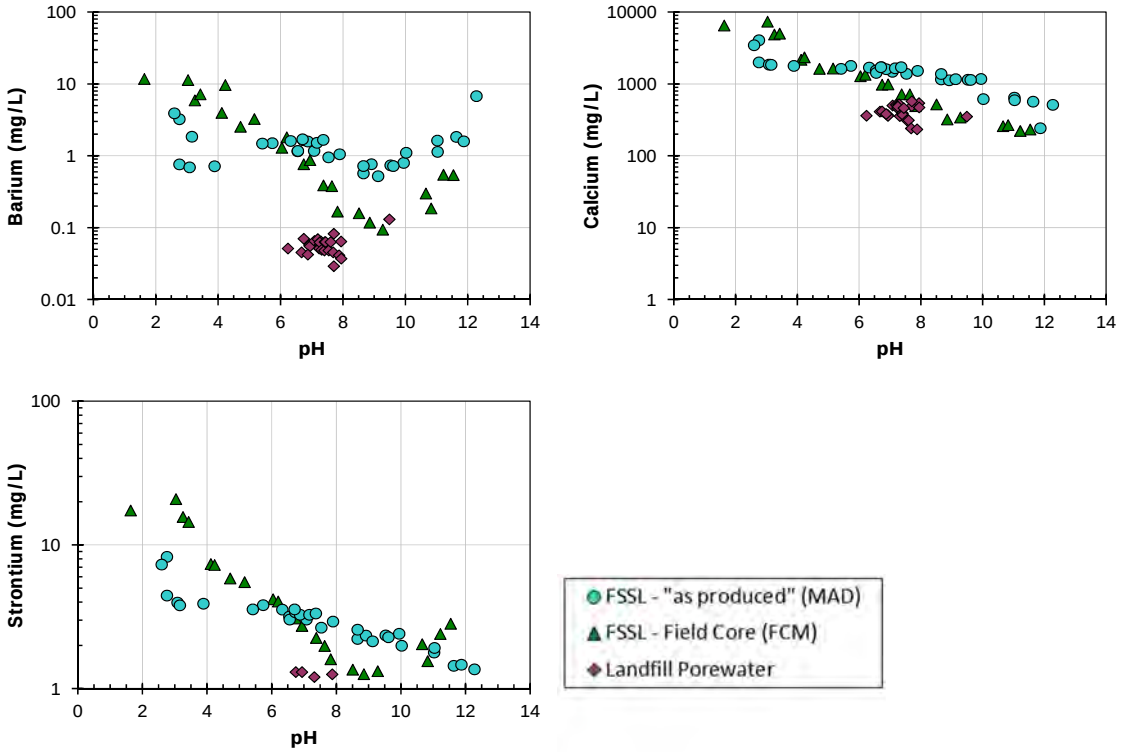


Figure 4-10. Comparison of pH-dependence testing of field-cored FSSL and "as produced" FSSL to field porewater samples showing the impact of aging and partial carbonation of field materials.

- When "as produced" and field core samples are compared, the coupling between chloride and cadmium leaching is evident (Figure 4-11). The higher chloride concentrations in the unaged "as produced" samples result in increased cadmium concentrations relative to the field cores. However, this effect of elevated chloride concentration increasing cadmium leaching is not evident when porewater samples are compared to laboratory results.

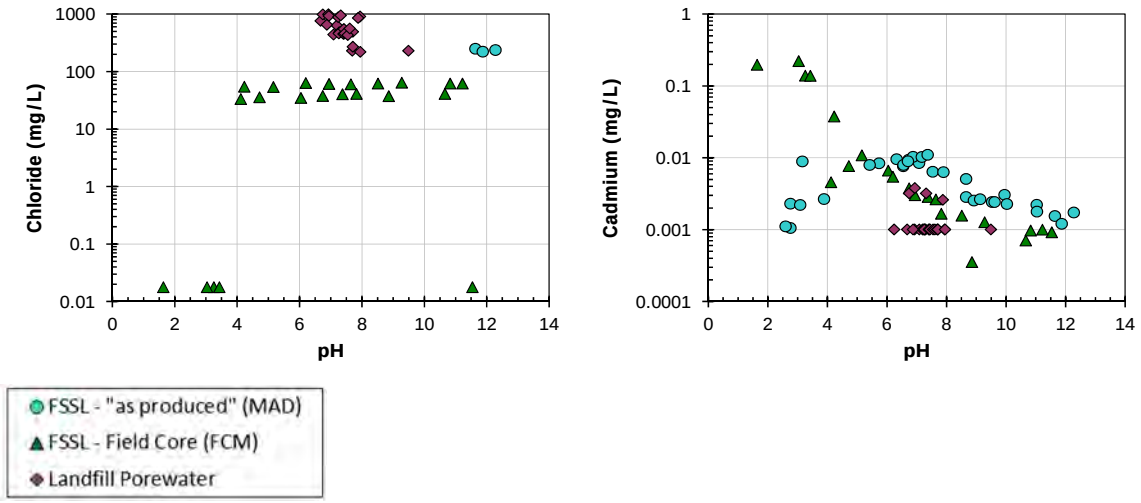


Figure 4-11. Comparison of chloride and cadmium leaching in field-cored FSSL and "as produced" FSSL to field porewater samples showing the impact of cadmium chloride chelation.

- The effect of dissolved organic carbon (DOC) concentrations resulting in increased copper concentrations is evident when comparing laboratory testing on the "as produced" material to field cores and porewater analysis at pH 6 to 8 (Figure 4-12).

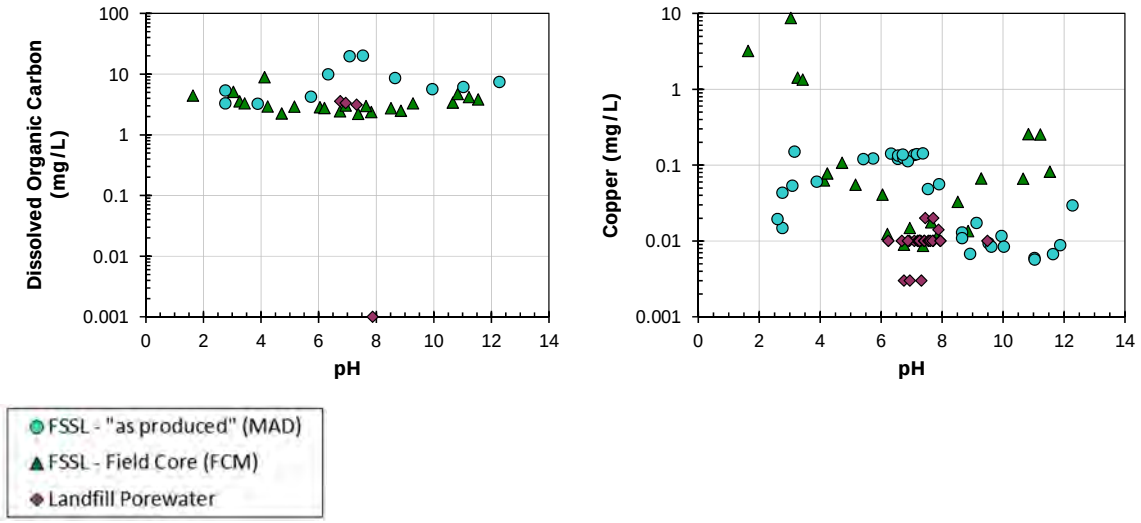


Figure 4-12. Comparison of dissolved organic carbon and copper leaching in field-cored FSSL and "as produced" FSSL to field porewater samples showing the impact of complexation of dissolved organic carbon with copper.

Concentrations of oxyanions are either similar to or less than the concentrations measured by the laboratory pH-dependent leaching test at the corresponding pH. These leachate concentrations are more closely related to the laboratory testing of the field cores (i.e., aged FCM material) than to the concentrations from laboratory testing of the unaged "as produced" material (MAD). This relationship is observed for several analytes including arsenic, boron, antimony, molybdenum, selenium and vanadium (illustrated for arsenic, boron, molybdenum and selenium in Figure 4-13). Molybdenum is the only oxyanion for which aging of the material resulted in increased concentrations relative to the "as produced" material (at pH less than 8.

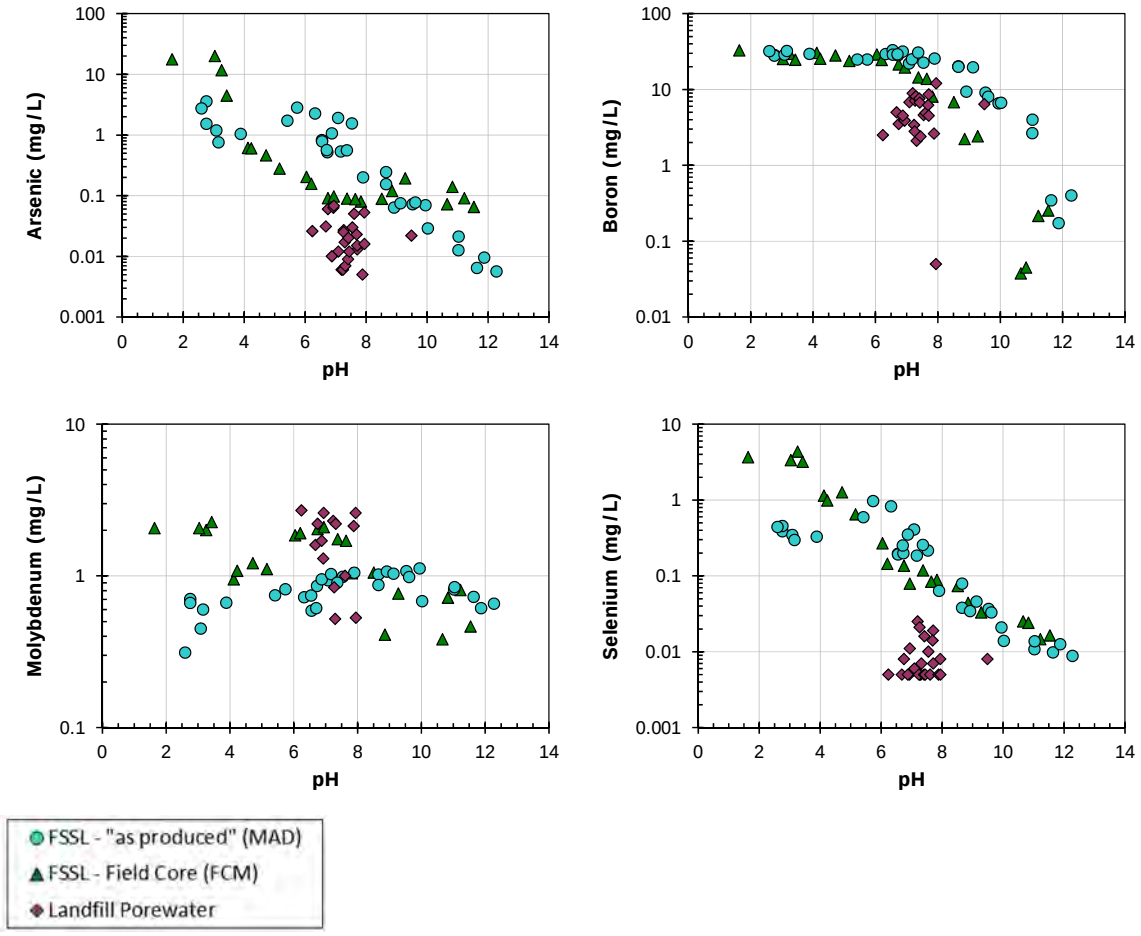
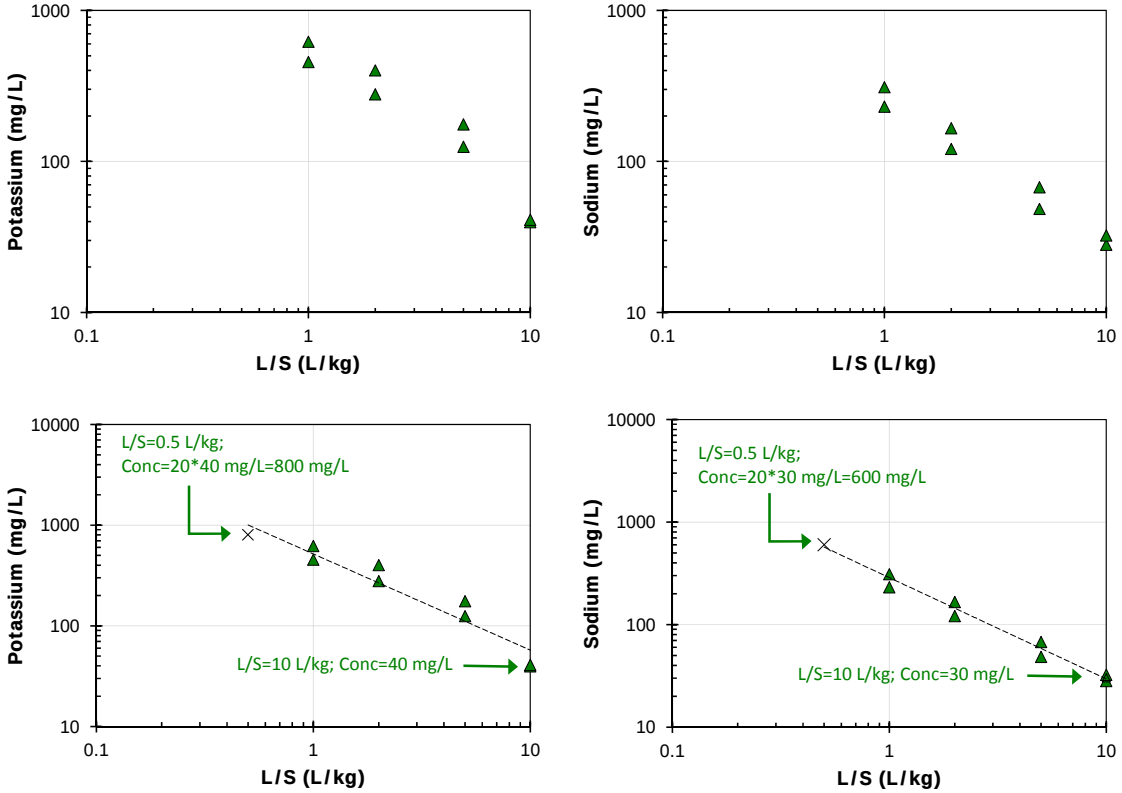


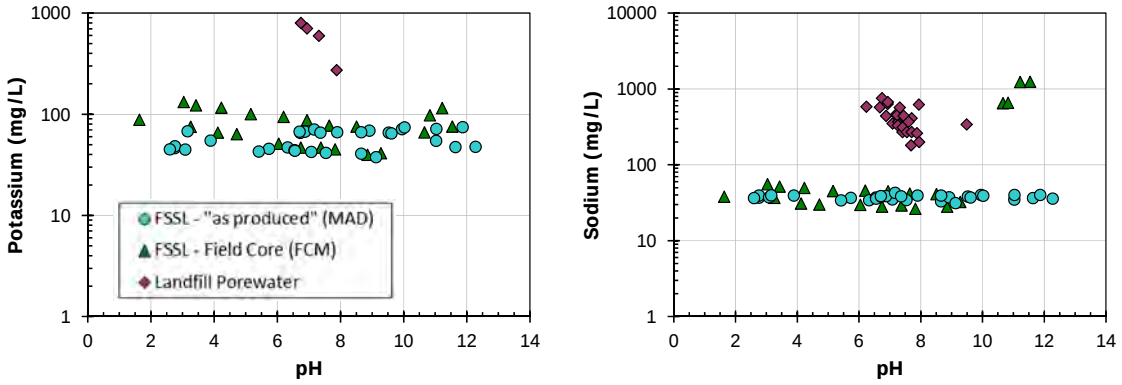
Figure 4-13. Comparison of arsenic, boron, molybdenum and selenium leaching in field-cored FSSL and "as produced" FSSL to field porewater samples.

Concentrations of highly soluble species, including chloride, potassium, lithium and sodium, are greater by up to a factor of 20 in the porewater (L/S less than 0.5 L/kg) than when measured by the pH-dependent leaching test at L/S of 10 L/kg. However, the porewater concentrations for these constituents are closely estimated by the laboratory batch L/S

dependent leaching test (i.e., SR03 or Method 1316; illustrated for potassium and sodium in



- Figure 4-14).



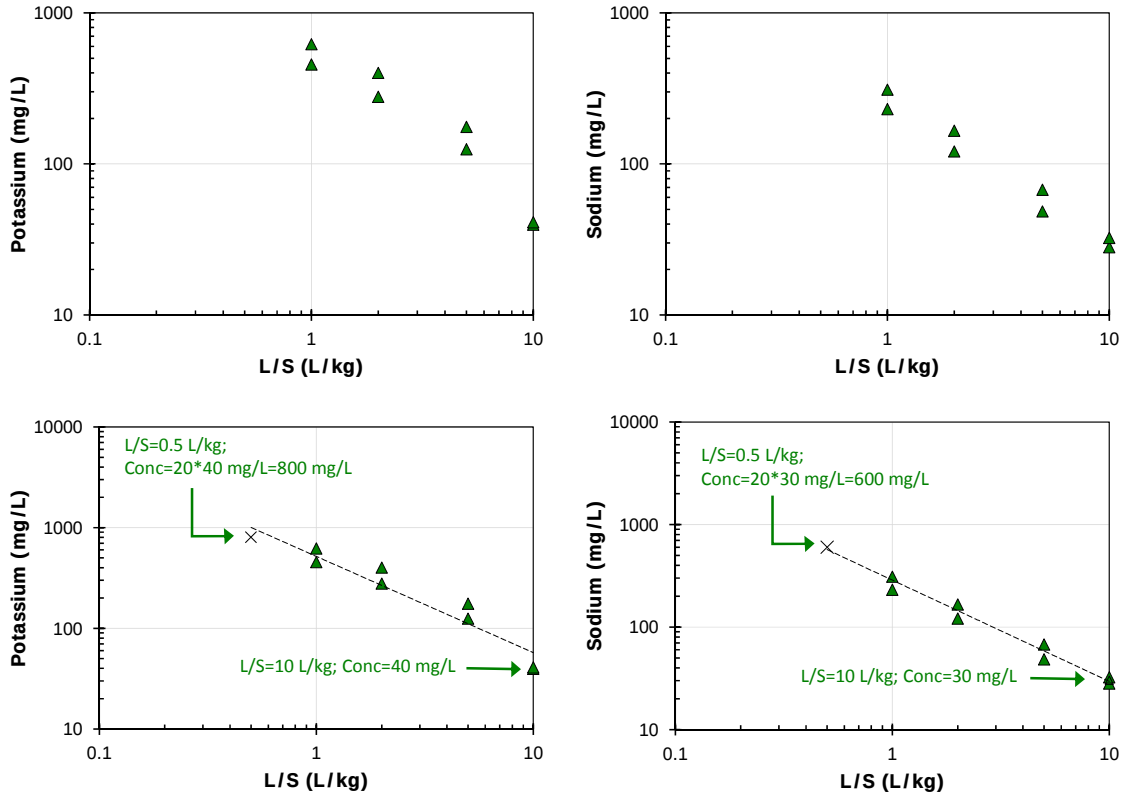


Figure 4-14. Comparison of potassium and sodium leaching in field-cored FSSL and "as produced" FSSL to field porewater samples (upper graphs). Lower four graphs present Method 1316 results applied to field core (FCM) and extrapolation to L/S=0.5 L/kg (dashed line) compared to result of 20x result from Method 1313 at natural pH.

4.3.3 Case Summary

Case 3 compared field leaching, field pore water samples, and laboratory leaching test results on landfill core samples, laboratory leaching test results on fresh "as disposed" material for mixed coal fly ash and FGD scrubber residues, referred to as fixated scrubber sludge. The applicable field pH domain was from pH 6 to 9.5. Results from this case indicate that carbonation of samples during field aging can have a significant impact on the pH dependent leaching behavior of periodic table Group II elements (i.e., calcium, strontium) and some trace elements (i.e., arsenic). Water samples (i.e., landfill porewater) are more susceptible to carbonation because of air contact and low buffering capacity, and therefore care should be taken in sampling and data interpretation. Higher concentrations of highly soluble species (i.e., potassium, sodium, chloride) can be anticipated in porewater in comparison with laboratory testing but the extent of elevated concentrations can be readily estimated based on the ratio of laboratory L/S to field porewater L/S.

4.4 Coal Fly Ash Used in Roadbase and Embankments (The Netherlands)

4.4.1 Case Description

In the framework of the National Research Program Coal (NOK), studies were done to evaluate beneficial coal fly ash uses (Spee and Reintjes, 1986). Two applications were studied in full scale - a roadbase made with bound fly ash covered by asphalt and sintered paving bricks (road sections of 100 m long and 8 m wide) with cement-stabilized fly ash used as a base for an embankment (100 m long). Cross-sections for the roadbase and the embankment applications are presented in Figure 4-16 and Figure 4-15, respectively. Measurements were carried out over a 2 year period, starting in 1984.

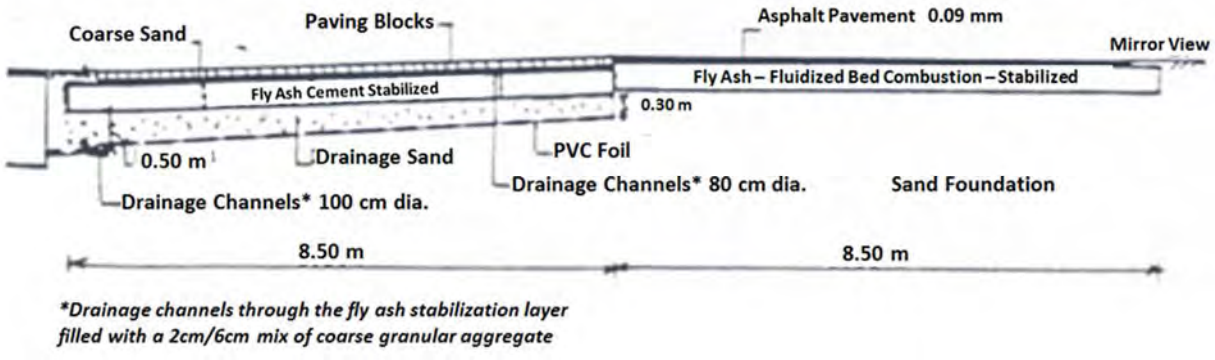


Figure 4-15. Cross section of roadbase constructed with cement stabilized coal fly ash (same as for the embankment). The stabilized fly ash (0.8 m thick) is overlain with an asphalt layer in the road surface area and by clinker material (coarse aggregate) on the sloped road shoulder area, and underlain with a sloped sand drainage layer (0.30 m thick). A polyvinyl chloride plastic sheet underlies the sand drainage layer to ensure leachate collection in a collection sump (at left).

Leachate obtained from collection wells at the side of the road and at the foot of the embankment was analyzed for a selection of substances. The coal fly ash used was stabilized with addition of 5% cement. This mixture was tested separately in a column experiment.

4.4.2 Results and Discussion

Results for calcium, chromium, molybdenum and selenium from leachate collected from the roadbase, embankment and laboratory percolation column studies are presented in Figure 4-17. The set of data (dots) with the lowest L/S values represents concentrations in the leachate collected from the embankment, while the continuous lines represent concentrations obtained from the laboratory percolation column experiments.

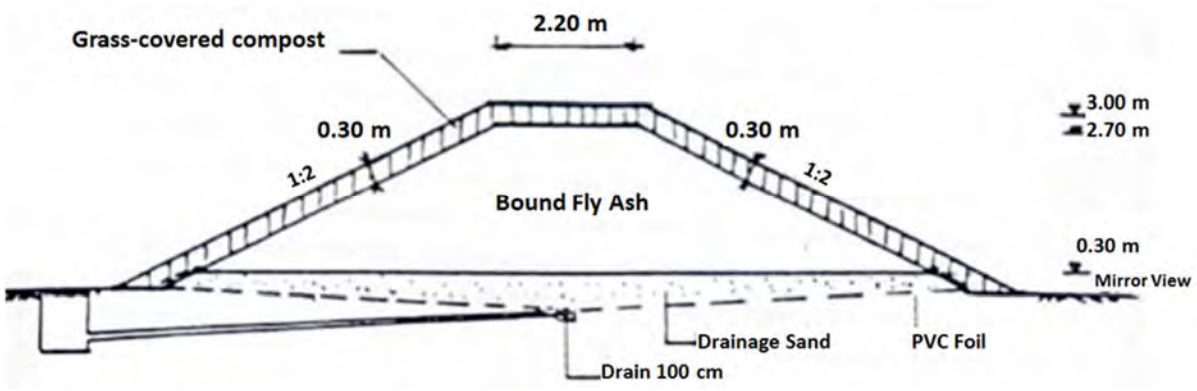


Figure 4-16. Cross-section of embankment constructed with cement stabilized coal fly ash as the core material and then covered with 0.3 m topsoil for growth of grass. A drainage sand layer underlies the stabilized coal fly ash, and a polyvinyl chloride plastic sheet underlies the sand drainage layer to ensure leachate collection through a drain (center bottom) and diversion to a collection sump (at left).

Leachate concentrations emanating from the embankment initially have relatively low concentrations that increase significantly at L/S of ca. 0.005 L/kg. This delayed release reflects displacement of initial porewater in the underlying sand drainage layer and retardation by partial adsorption by the sand drainage layer. Similarly, there is an offset as a function of L/S of ca. 0.5 L/kg for the concentrations of constituents in leachates emanating from the roadbase in comparison to the percolation column results. This offset is attributed to the collection of samples at much lower L/S for the field conditions and integration of sample volumes over the collection intervals for the laboratory columns. This effect has been further confirmed through independent tracer studies (van der Sloot et al, 1991). Although this data set is sparse, it does indicate that the laboratory column experiments conservatively approximate the peak leachate concentrations observed in the field.

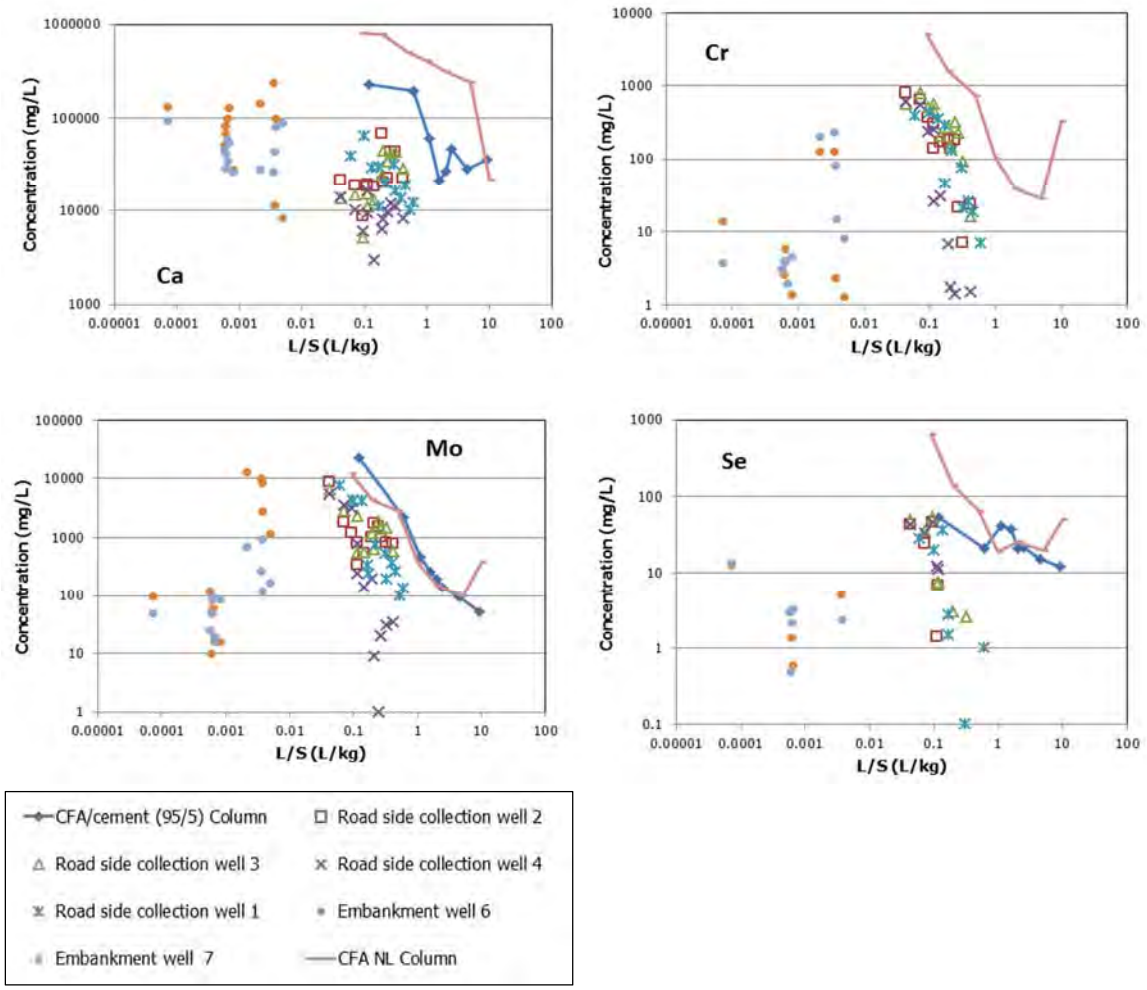


Figure 4-17. Field leachate concentrations from Dutch embankment and road base demonstration projects compared to laboratory percolation column experiments.

4.4.3 Insights Gained from Chemical Speciation of Coal Fly Ash Leaching

The following examples illustrate the impact of three common phenomena which strongly influence retention and leaching of COPCs – oxyanion substitution for sulfate in ettringite, carbonation due to uptake of CO_2, and oxidation/reduction. These phenomena are shown through comparison of leaching test data from a European coal combustion fly ash (pH-dependent and percolation column, material code CFA) to chemical speciation model results conducted at various L/S values. The presentation of chemical speciation results in these examples is similar to that used in comparison of materials.

In Figure 4-18 through Figure 4-20, leaching test results are presented along with chemical speciation modeling of LSP and associated phase partitioning of Cr, SO_4, and Mo. For each figure, the first panel compares pH-dependent leaching data (red dots) and percolation column data (blue triangles) to CSF model results at L/S 10 (red solid line) and L/S 0.3 (blue dashed line). The latter two panels of each figure show the relative contributions of mineral, carbon, and aqueous species

that are responsible for the shape and magnitude of the CFS model results at L/S 10 and L/S 0.3. In particular, these figures for Cr, SO_4, and Mo in CFA fly ash illustrate the importance of oxyanion substitution for sulfate in ettringite, $(CaO)_6(Al_2O_3)(SO_3)_3 \cdot 32H_2O$, as a retention mechanism for oxyanions such as molybdate and chromate in the pH range between 9 and 13.

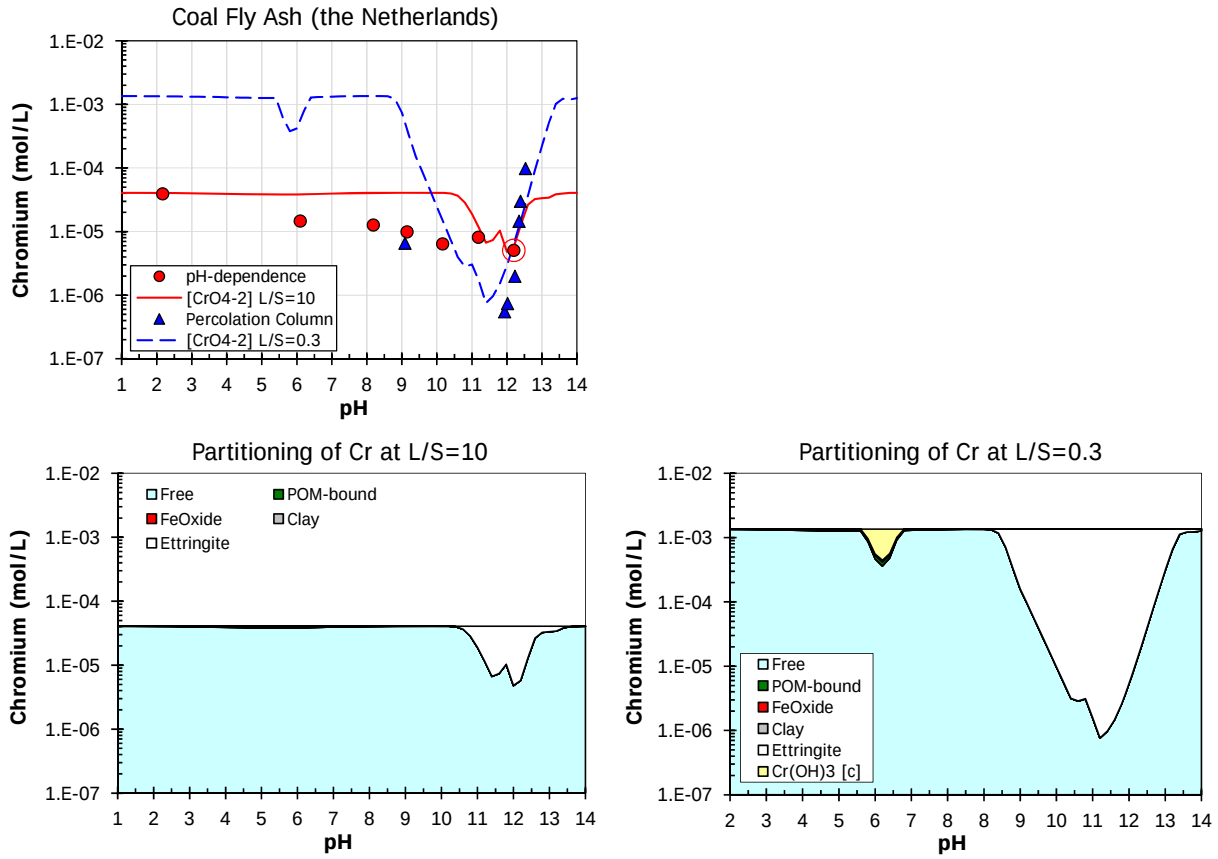


Figure 4-18. Chemical speciation model results for chromium at L/S=10 and L/S=0.3 compared to pH-dependent (CEN/TS 14429) and percolation column (CEN/TS 14405) leaching results for coal fly ash (the Netherlands).

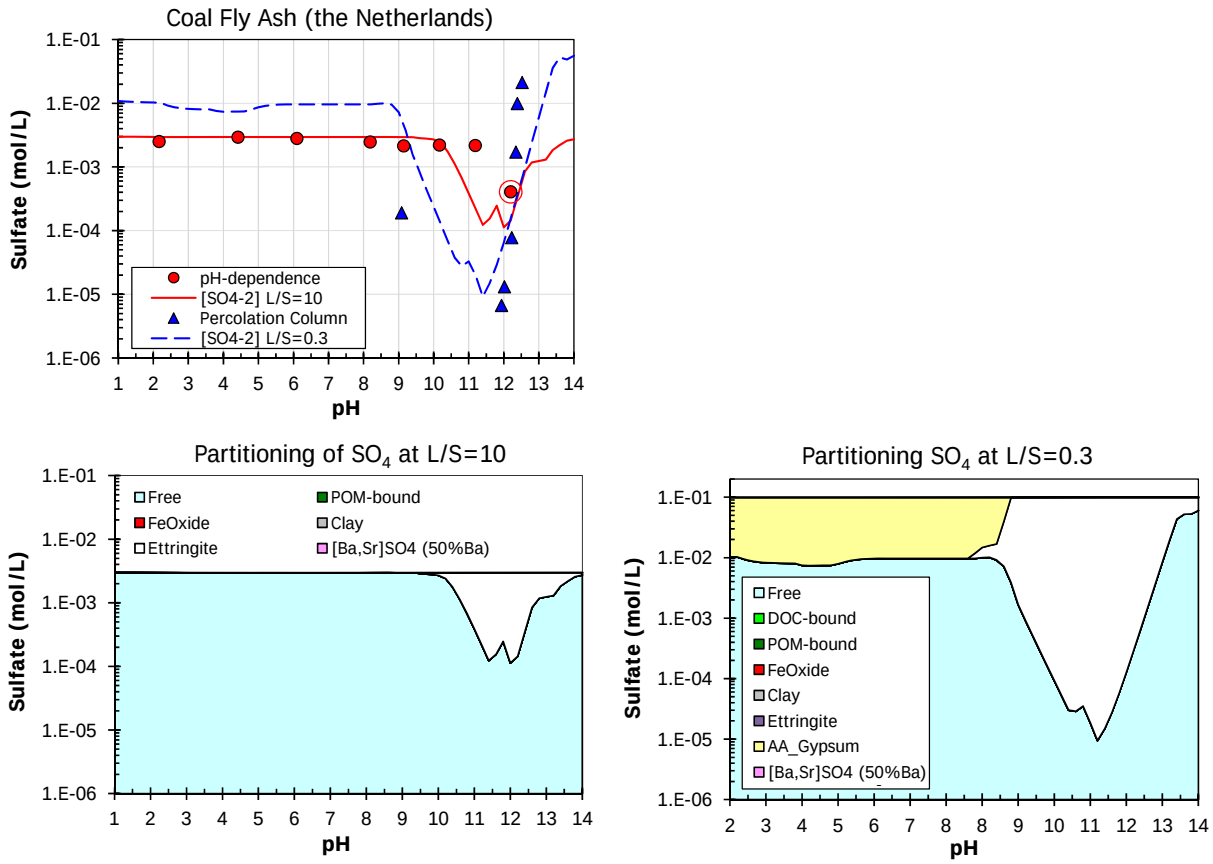


Figure 4-19. Chemical speciation model results for sulfate at L/S=10 and L/S=0.3 compared to pH-dependent (CEN/TS 14429) and percolation column (CEN/TS 14405) leaching results for coal fly ash (the Netherlands).

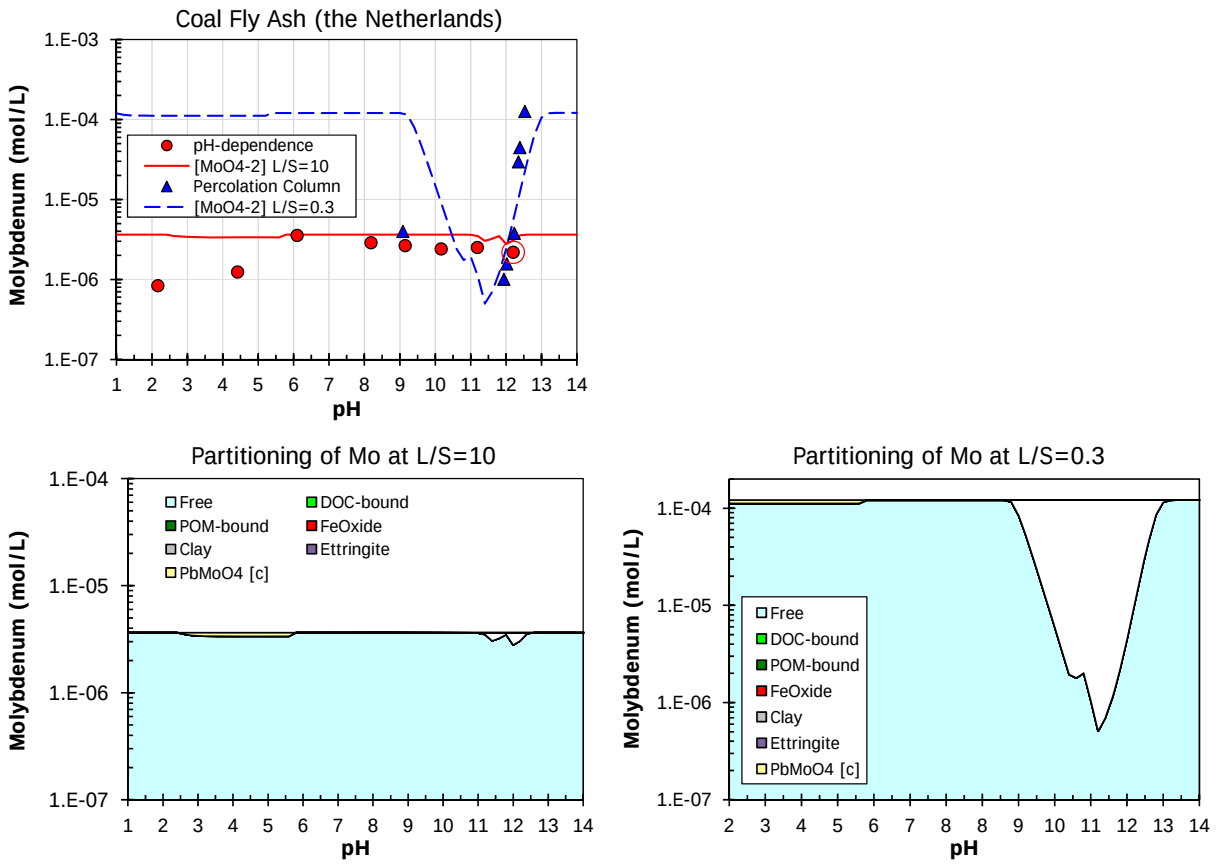


Figure 4-20. Chemical speciation model results for molybdenum at L/S=10 and L/S=0.3 compared to pH-dependent (CEN/TS 14429) and percolation column (CEN/TS 14405) leaching results for coal fly ash (the Netherlands).

Figure 4-21 and Figure 4-22 illustrate the impact of reaction with atmospheric carbon dioxide (i.e., carbonation) on the shift controlling mineral species. The two upper panels compare CSF model results at increasing degrees of carbonation (determined by CO_2 uptake between 1 and 7 wt %) to the leaching data for Ca and Ni. The lower figures show the phase partitioning that creates the CSF model LSP result. Figure 4-21 clearly demonstrates that increasing extent of carbonation yields a loss of ettringite and formation of calcite, $CaCO_3$, with a concurrent decrease in Ca solubility at pH greater than 7. In the case of Ni (Figure 4-22), increased carbonation increases the partitioning Ni into the aqueous phase due to the loss of oxyanion substituted ettringite and competition with carbonate adsorption onto HFO surfaces.

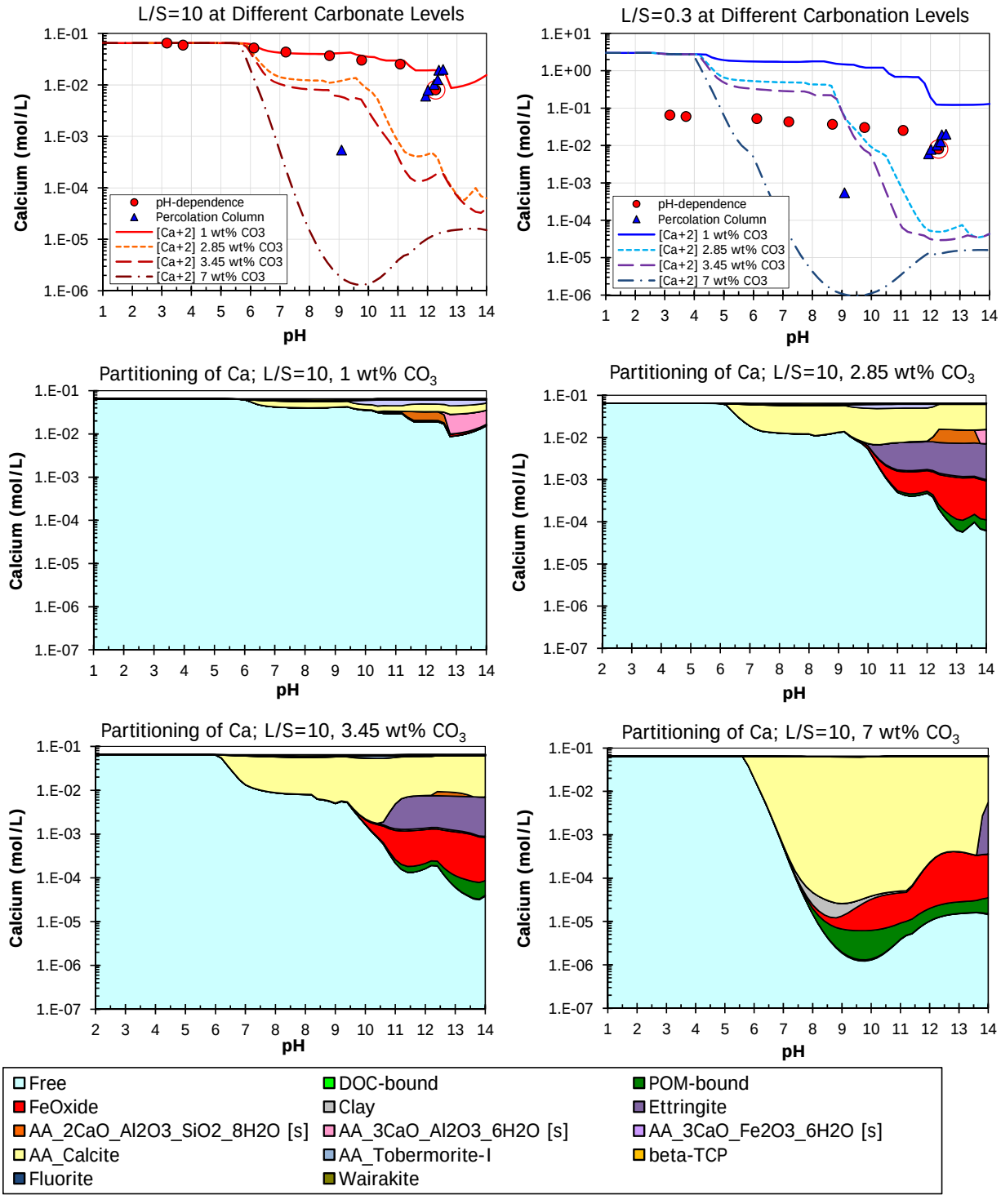


Figure 4-21. Effect of carbonation levels (wt% CO_3) on calcium model predictions and partitioning compared to pH-dependent (CEN/TS 14429) and percolation column (CEN/TS 14405) leaching test results.

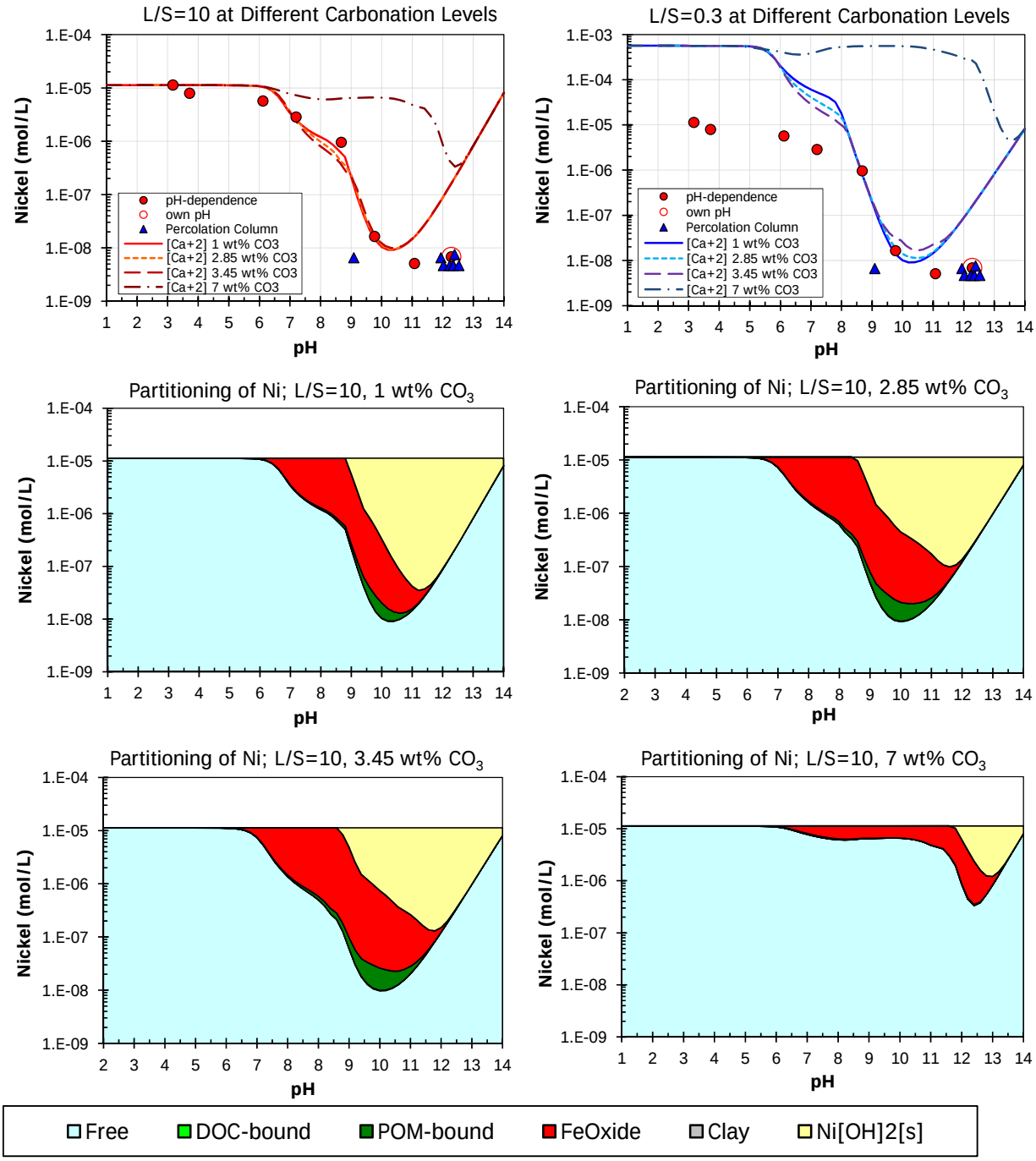


Figure 4-22. Effect of carbonation levels (wt% CO_3) on nickel model predictions and partitioning compared to pH-dependence (CEN/TS 14429) and percolation column (CEN/TS 14405) leaching test results.

Figure 4-23 illustrates the impact of reduction/oxidation on the percolation leaching of Cr. The panels on the left side of the figure show the results of percolation column leaching tests (blue symbols) and model results conducted at three levels of pH+pE. For the model results, the orange

symbols indicate data points at target L/S values while the orange dashed line indicates continuous elution as a function of L/S. The right hand panels present the phase partitioning at each level of pH+pE. Figure 4-23 illustrates that as the reducing conditions (i.e., higher values of pH+pE) results in a decrease in Cr leaching due is the reduction of Cr(VI) to Cr(III) and the low solubility of $Cr(OH)_3$ at mildly alkaline pH. Comparison of the field embankment samples with the simulations indicates pH+pE in the embankment between 12 and 12.8 with $Cr(OH)_3$ as the controlling solid phase.

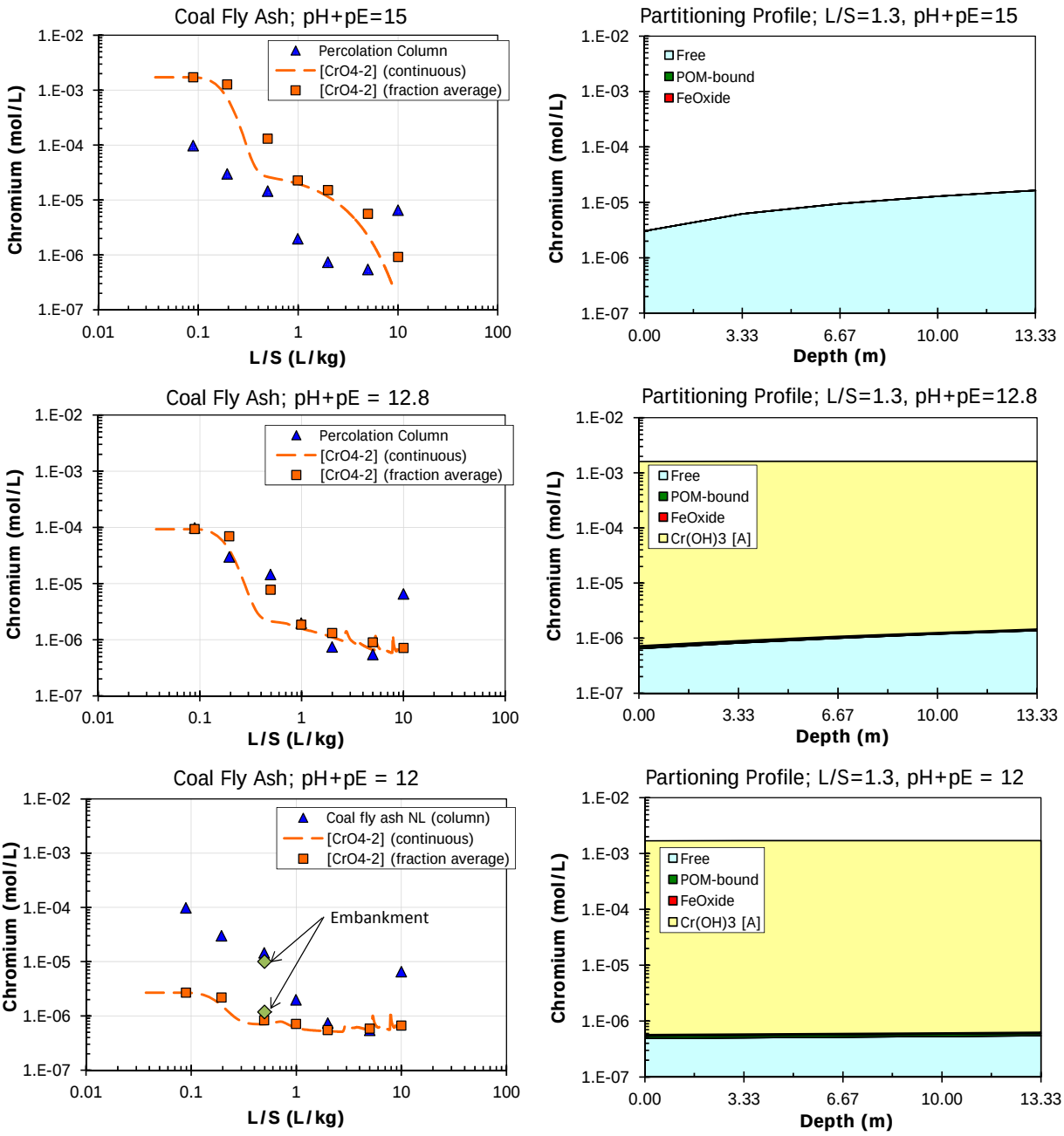


Figure 4-23. Effect of reducing and oxidizing (redox) conditions on chemical speciation results for chromium as a function of L/S (left) and chromium partitioning with depth (right) for coal fly ash (the Netherlands).

4.4.4 Case Summary

Case 4 compared the results of field leaching over 2 years from a road base and embankment constructed with coal fly ash to percolation column results. Laboratory pH dependent leaching test results from an analogous material were also used for comparison. Results of this case illustrate the

benefits of the combined use of pH dependent leaching and percolation column leaching in combination with chemical speciation simulations to understand field performance. Specifically, insights from the combined use of these tools provided insights into the redox condition in the material (establishment of reducing conditions), potential impacts of carbonation, and the resultant consequences for leaching of oxyanions (e.g., chromium). Percolation column experiments provided a realistic estimate of the upper bound concentration for leaching of COPCs, however, an initial delay was observed in the field before peak leaching concentrations were observed. The initial delay was attributed to the mass transport delay and attenuation associated with drainage materials (i.e., sand) underlying the primary fly ash fill. This highlights the need to carefully design and understand field monitoring strategies and their impact on field measurements.

4.5 Municipal Solid Waste Incinerator Bottom Ash Landfill (Denmark)

4.5.1 Case Description

A relatively small MSWI residue landfill, established between 1973 and 1976, has been monitored periodically for more than 30 years. The landfill is situated at Vestskoven in the western part of Greater Copenhagen in Denmark and contains approximately 10,000 m^3 of bottom ash and fly ash from a nearby MSW incinerator (Hjelmar and Hansen, 2005; Hjelmar et al., 1991). During the initial period of operation, the amount and quality of the leachate generated was monitored. In December 2003, two borings were made into the site and several samples of the landfilled material were collected from different depths of the site. In addition, leachate was collected from one of the two borings. Solid samples obtained from the borings were subjected to leach testing in accordance with technical specification EN 12457-1, a single batch extraction leaching test with deionized water at L/S of 2 L/kg. Field leachate samples and leaching test extracts were then analyzed for constituents of interest.

4.5.2 Landfill Construction

In June 1973, a circular site was dug a few meters into the ground with the excavated soil used to construct a dike at the perimeter of the hole. The site was lined with reinforced PVC on top of which a protective 0.3 m drainage layer of sand was placed. The bottom liner slopes towards the center where a leachate collection tank was installed. Access to the collection tank was afforded by a well shaft, allowing the removal of leachate by pumping. The well shaft was adjusted in height as landfilling progressed until the landfill reached its final height. During the period July 11 to August 29, 1973, the site was filled to the top of the dike with approximately 6000 m^3 of MSWI bottom ash and fly ash. The top of the site was then left open and exposed until 1976.

During the period January to June of 1976, an additional 4000 m^3 of bottom and fly ash was placed on top of the site, forming a circular mound. A 1 m layer of topsoil was placed directly on top of the MSWI residues. Self-sown grass and bushes soon covered the surface of the site. Figure 1 shows a cross-section of the closed site while Table 4-2 provides some physical details on the size and shape of the site.

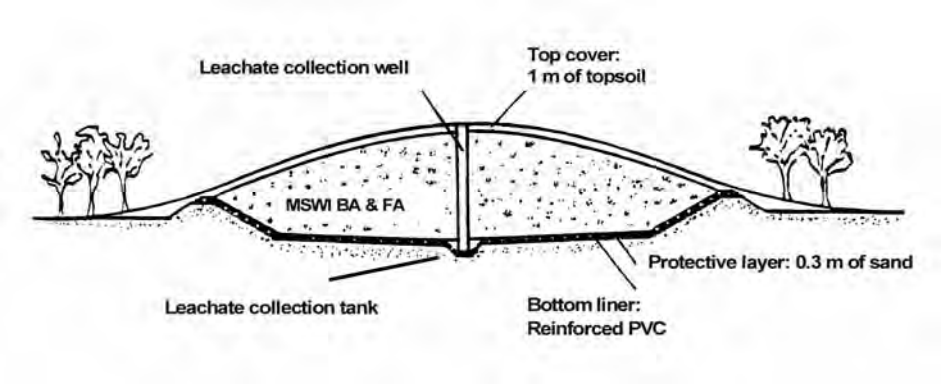


Figure 4-24. Cross-section of the MSWI residue monofill in Vestskoven, Denmark (Hjelmar and Hansen, 2005).

The landfilled material has been estimated to consist of approximately 85% of MSWI bottom ash and 15 % of MSWI fly ash. Observations made during the drilling of boreholes in 2003 revealed that a substantial amount of scrap metal was also present and that the fly ash was deposited in distinct layers. Although the exact bulk density is unknown, the dry bulk density of the landfilled material was estimated to be 1000 kg/m^3 in previously published information on the leachate development at the site (e.g. Hjelmar, 1989; Hjelmar, 1996; IAWG, 1997). Based on the information obtained in 2003, the estimate of the dry bulk density of the material in the monofill has been adjusted to 1,200 kg/m^3. The calculated values of the L/S used in this report are based on the revised value of the dry bulk density. The landfill is thus estimated to contain approximately 12,000 tonnes of MSWI residues (dry weight).

Table 4-2. Physical information about the Vestkoven MSWI monofill.

Parameter	Value
Amount of MSWO residues	10,000 m^3 (approximately)
Diameter of the site at the upper edges of the dike	52.4 m
Diameter of the site at the inner bottom of the dike	40 m
Surface area at the upper edge of the dike	2,157 m^2
Surface area at the inner bottom of the dike	1,257 m^2
Elevation of the bottom of the leachate collection tank	13.4 m above sea level
Elevation of the bottom liner	15.0 – 15.4 m above sea level
Elevation of the upper edge of the dike	18.4 m above sea level
Elevation at the top of the site	25.4 m above sea level
Maximum height of the MSWI at center	9.2 m (approximately)

4.5.3 Leachate Quantity and Quality

Since the landfill was established in 1973, the leachate produced has been pumped from the leachate tank at regular intervals. During the period from 1973 to 1977, the leachate was sprayed

onto the top of two adjacent MSWI residue landfills. From 1977 to 1980, the leachate was allowed to accumulate within the site. From 1980 to the present, the leachate has been pumped into tank trucks and removed from the site. The quantity of all leachate removed from site has been registered throughout its existence, and the leachate has been subjected to chemical analysis once a year (in the beginning more often). Water balances for the site have been calculated each year since 1980 and compared to precipitation data obtained from a nearby weather station (Hjelmar and Hansen, 2005). The results of the water balance calculations have shown that for the seven-year interval between 1998 and 2005, the leachate production has corresponded to 33% of the measured precipitation.

Leaching data were not available for the MSWI bottom ash and fly ash that was originally used in the MSWI landfill project. Therefore, a selection of leaching pH-dependent and percolation column test results from testing of MSWI bottom ash from Germany (Berger et al., 2005) and the Netherlands (van der Sloot et al., 2008c) are used as reference materials for this case.

4.5.4 Results and Discussion

A complete set of figures is provided in Appendix C for the comparison of Vestkoven monofill leachate concentrations (red circles) to laboratory results on Vestkoven core samples (grey diamonds) and off-site comparable materials from Germany, Italy, Austria, The Netherlands and the United Kingdom (solid symbols with lines). Laboratory data include (i) single batch extraction test results from EN 12457-1 testing of landfill cores and (ii) pH-dependent leaching test results for the reference materials, and (iii) percolation column testing for reference materials (Susset and Leuchs, 2008). Comparisons are shown as a function of pH (left) and L/S (right). Although the comparison materials represent the same class of materials placed into the Vestkoven landfill, the materials were not sampled from the monofill and, therefore, the results for comparison materials are provided only as an indication of expected leaching behavior.

The following are notable relationships between leaching test results for specific constituents:

- The batch extractions of cored samples at L/S 2 L/kg ranged from 7.6 to 11.6 which is consistent with the range of leachate pH values (Figure 2-5). Lower upper bound values of pH from field samples is expected because of reaction with carbon dioxide, either generated from decomposition of residual carbon in the fill material or from atmospheric exchange during leachate accumulation and sampling.

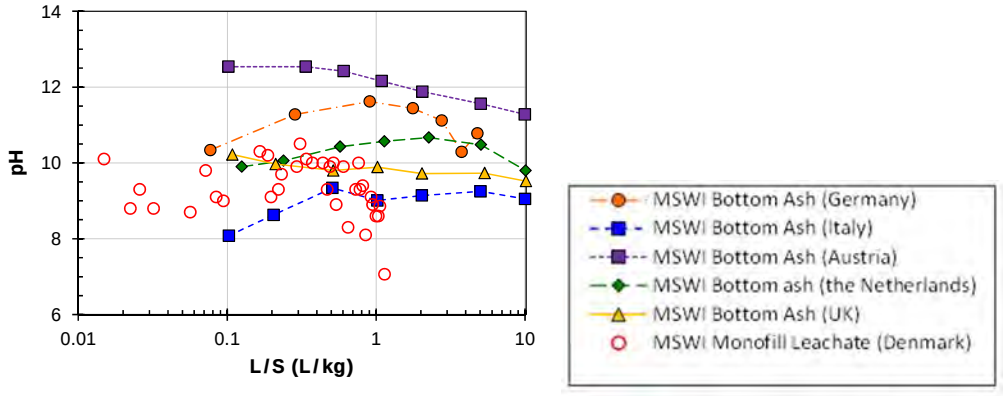


Figure 4-25. Eluate pH from leachates from the Vestkoven monofill (red circles) compared to the percolation column pH for comparable bottom ash samples (solid symbols).

- Analysis of batch extractions of core samples for arsenic was not available. Figure 4-26 presents the field leachate data in comparison to pH dependent test results and percolation column test results for the analogous reference materials. Maximum field leachate concentrations were approximately 10 times greater than anticipated based on pH dependent testing but consistent with column test results for the reference materials. Collectively, these results indicate that the fraction of arsenic not adsorbed to iron (the most likely retention mechanism for MSWI bottom ash) behaves as a highly soluble species, exhibiting higher concentrations at lower L/S.

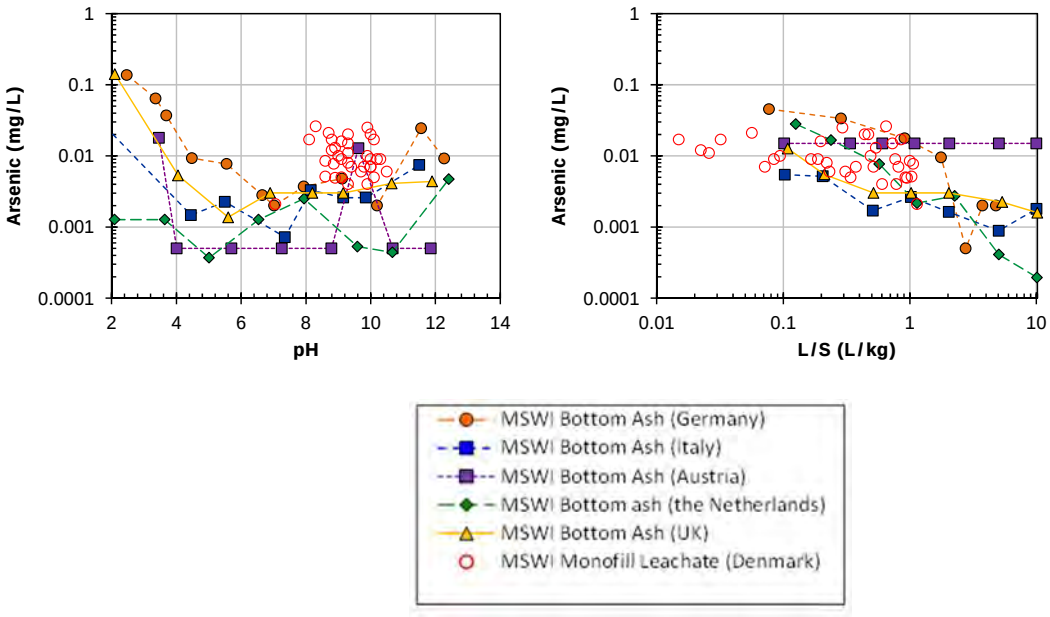


Figure 4-26. Arsenic concentration results from the Vestskoven MSWI monofill leachate samples (red circles). Data are shown for pH-dependent leaching (left) and percolation column testing (right). These results illustrate typical relationships between pH-dependent and column testing of cored samples and leachate measurements.

- The constituent concentration ranges from batch extractions of cored samples at L/S 2 L/kg also were consistent with the concentration ranges measured in the leachate samples obtained over several years of operation of the landfill (Figure 4-27). For many constituents (i.e., chromium, lead, potassium, sodium, chloride) the upper bound for extract concentrations from the core samples was greater than or similar to the upper bound for leachate concentrations, although both data sets exhibit considerable variability most likely resulting from heterogeneous water flow patterns through the landfill over the period of observation and the heterogeneity of the fill material. For zinc, the peak laboratory extractions at L/S 2 L/kg were up to an order of magnitude lower than the peak leachate concentrations at pH greater than 9; there is no clear explanation for this effect.

  Increasing zinc concentration in leachate as a function of L/S reflects the concurrent decrease in pH and increased zinc solubility with decreasing pH (Figure 4-27). Other constituents that exhibit similar behavior include aluminum, cadmium, calcium, chloride, chromium, copper, iron, potassium, magnesium, manganese, sodium, nickel, lead, phosphorus, sulfur, and sulfate. In many cases, comparisons for many constituents cannot be made since data from the batch extractions of the core samples did not include analytical results for arsenic, mercury and selenium while leachate sample results did not include analytical results for barium, bromide, cobalt, lithium, molybdenum, antimony, selenium, silicon, tin, strontium, or vanadium.

  Field leachate and core extract concentrations are consistent with pH dependent laboratory testing for chromium (apparently present predominantly as Cr(VI)) but were greater than pH dependent laboratory testing for lead and zinc because of DOC complexation at lower L/S but diluted at higher L/S (i.e., L/S of 10 mL/g used in pH dependent testing).

- The L/S of 2 L/kg used in the batch extractions provides an accurate estimate, within approximately 2x uncertainty, of peak initial leachate concentrations of highly soluble species such as sodium, potassium and chloride (Figure 4-28). This observation is consistent with the earlier explanation (see Sections 2.1.2 and 2.3.1) that concentrations of highly soluble constituents can be substantially greater than measured at L/S of 10 L/kg as used in the pH-dependent leaching tests. Higher concentrations of highly soluble constituents (i.e., concentrations consistent with approximate porewater L/S of 0.2-0.5 L/kg) were most likely not observed because of material heterogeneity and preferential flow. The leachate concentrations for highly soluble constituents also follow the expected elution curve as a function of L/S as typified by the comparison materials (e.g., high initial concentrations that decrease by more than one order of magnitude prior to L/S of 2 L/kg.

4.5.5 Case Summary

Case 5 focused on landfill leaching from combined MSWI bottom ash and MSWI fly ash that was deposited in layers and monitored for 30 years. Field leaching results were compared to laboratory leaching of core samples obtained from the landfill and laboratory pH dependent test

and percolation column test results from analogous materials. The resulting applicable pH domain based on laboratory testing and field leachate samples is approximately pH 7 to 11. Results of this case illustrate that concentrations obtained from laboratory batch extractions at L/S of 2 mL/g can be used as an estimate of peak concentrations in leachate from a heterogeneous fill material. The L/S of 2 L/kg is greater than the expected porewater L/S of ca. 0.2 to 0.5 L/kg but reflects the impacts of preferential flow through a heterogeneous material in a landfill. Testing at L/S of 2 mL/g in conjunction with pH dependent testing (at L/S of 10 mL/g) provides an estimate of increased concentrations relative to pH dependent testing that would be expected for highly soluble constituents and resulting from DOC complexation effects at the low L/S values associated with early leachate from landfills.

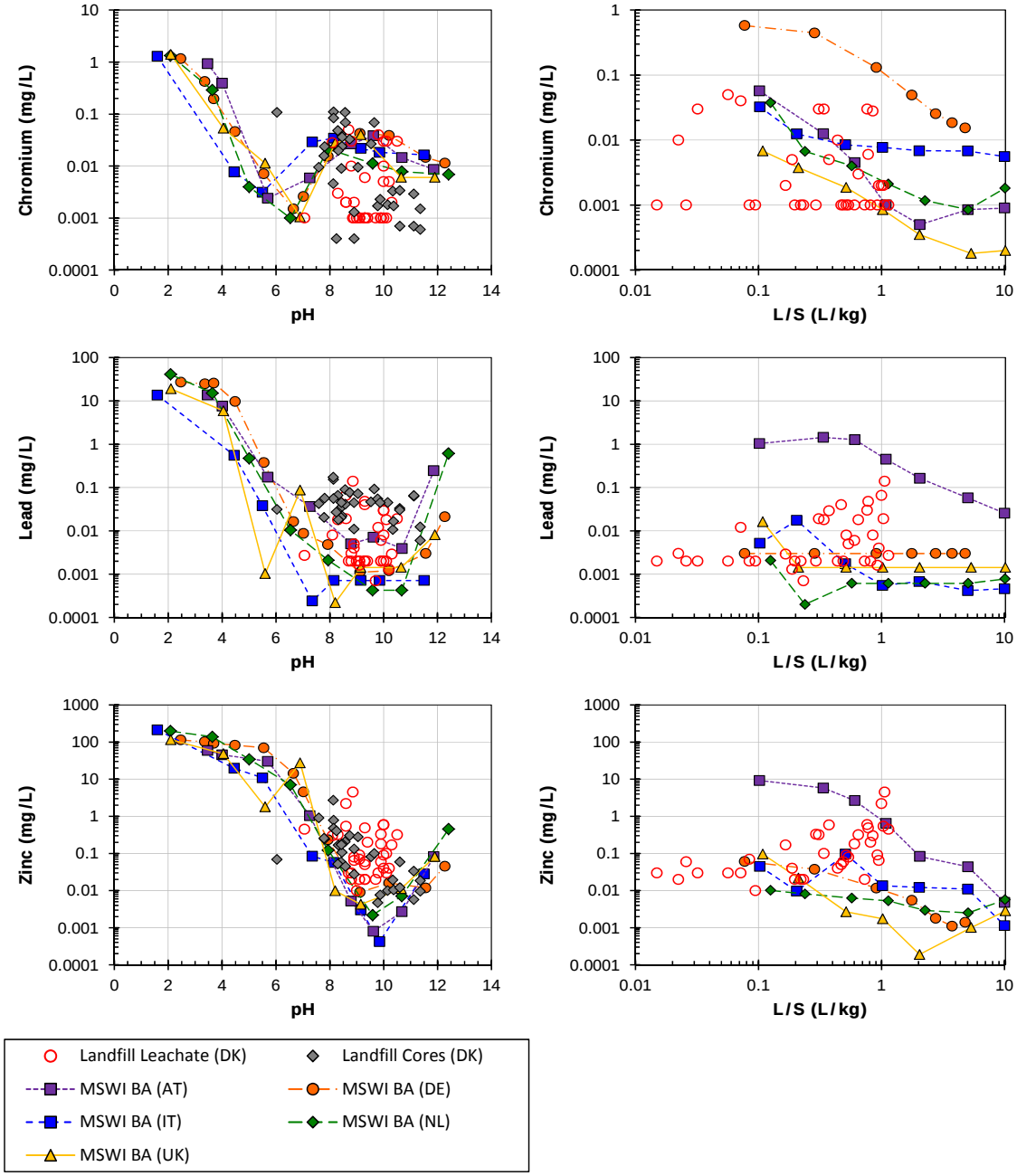


Figure 4-27. Chromium, lead and zinc concentration results from testing of cored materials from the Vestskoven MSWI monofill (grey diamonds) compared to leachate samples (red circles). Data are shown for pH-dependent leaching (left) and percolation column testing (right). These results illustrate typical relationships between pH-dependent and column testing of cored samples and leachate measurements.

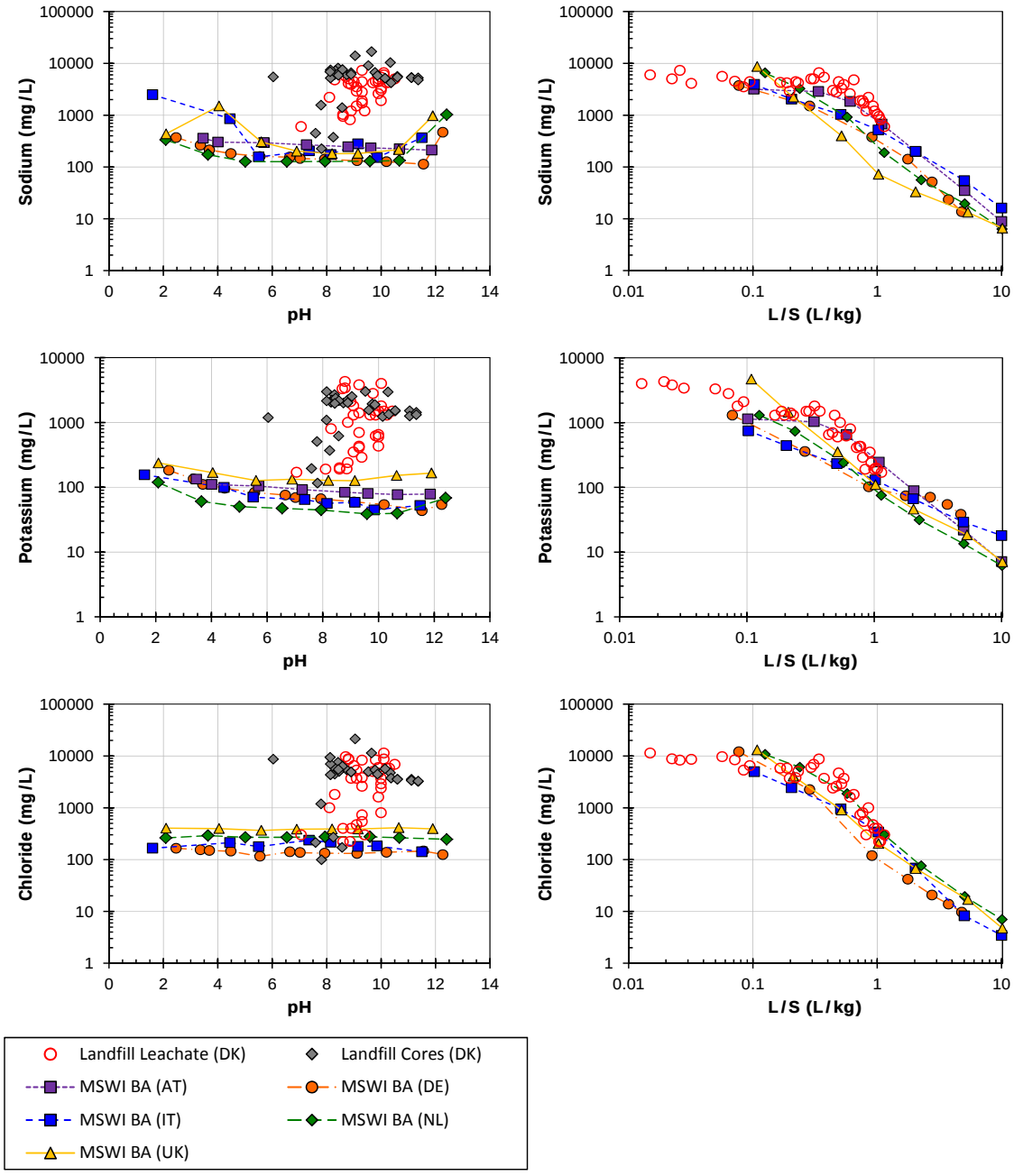


Figure 4-28. Sodium, potassium and chloride concentration results from testing of cored materials from the Vestskoven MSWI monofill (grey diamonds) compared to leachate samples (red circles). Data are shown for pH-dependent leaching (left) and percolation column testing (right). These results illustrate leaching behavior of highly soluble species.

4.6 Municipal Solid Waste Incinerator Bottom Ash Used in Roadbase (Sweden)

4.6.1 Case Description

MSWI bottom ash has been evaluated extensively and demonstrated to have consistent, systematic leaching of individual constituents as a function of pH (IAWG, 1997; Sabbas et al., 2003; Dijkstra et al., 2006a; 2006b). The extensive use of MSWI in Europe has provided considerable focus on the potential for beneficial use of bottom ash, which is the heterogeneous material that is discharged from the incinerator grate and is the largest residue stream from MSWIs (the other large residue stream being air pollution control residues). Thus, the evaluation case described here is the result of evaluation of the use of MSWI bottom ash as a roadbase material in Sweden, referred to as Vändöra (Bendz et al., 2009).

The test road was constructed in 1987 in Linköping, Sweden (Lundgren and Hartlén, 1991) and was 15 years old at the time when the samples were taken (Bendz et al., 2009). Other studies were performed on this road in 1998 (Andersson et al., 1999) and in 2002 (Flyhammar and Bendz, 2006). In two of the test sections, MSWI bottom ash was used as a subbase below an unbound base course and surface asphalt layers. The bottom ash was poorly separated and contained large pieces of incineration residues (e.g., larger than a few decimeters). The test road has been in a rather bad condition during periods of time in its lifetime, with longitudinal cracks along the centerline of the road. Therefore, infiltration through the pavement is likely to have taken place.

This field study, Vändöra Q4-241, was carried out in September 2003 (Bendz et al., 2006). The unbound base course and asphalt layers were removed and three sample collection trenches were excavated into the road construction in different sections. In this report, results are discussed from the characterization of the subbase layer (bottom ash) as presented in Lundgren and Hartlén (1991) while the complete set of field data is presented in Bendz et al. (2006).

Fifty-three solid samples of approximately 250 mL each were collected from the subbase layer in a checker board pattern. One-step batch tests in deionized water at L/S 10 L/kg were conducted on all 53 samples according to the standard EN 12457-2. The minimum pH-value of the samples in deionized water at L/S 10 L/kg was 7.4 and the maximum pH value was 10.0 (Figure 4-29).

The collected samples were formed into four groups based on the range of pH values measured in single batch extractions. These four groups were 7.4-8.0 (n=16), 8.0-8.5 (n=21), 8.5-9.0 (n=12), and 9.0-10.0 (n=4). Samples within each group were mixed together to form composite samples for pH-dependent leaching and percolation column leaching (material codes Vändöra 1, 2, 3 and 4, respectively). Samples in the pH range 7.4 to 8.5 are indicative of a significant amount of natural carbonation during the road use. Leaching tests as a function of pH were carried out at L/S 10 L/kg on the four grouped samples according to technical specification CEN/TS 14997. For Vändöra composites from the first three pH intervals, extraction pH values of 2, 4, 5, 6, 7, 8, 10, 11 and 12 were tested. For the composite from the fourth pH interval, due to the smaller sample size, extraction pH values of pH 2, 4, 6, 8, 10 and 12 only were measured. Percolation tests were conducted on the grouped samples Vändöra 1, 2 and 3 according to technical specification CEN/TS 14405. The sample amount for Vändöra 4 did not allow for a percolation test. Sampling for Vändöra 1 and 2 was at L/S 0.1, 0.5, 1.0 and 2.0 L/kg (cumulative), and for Vändöra 3 at L/S 0.2, 1.0 and 2.0 L/kg (cumulative).

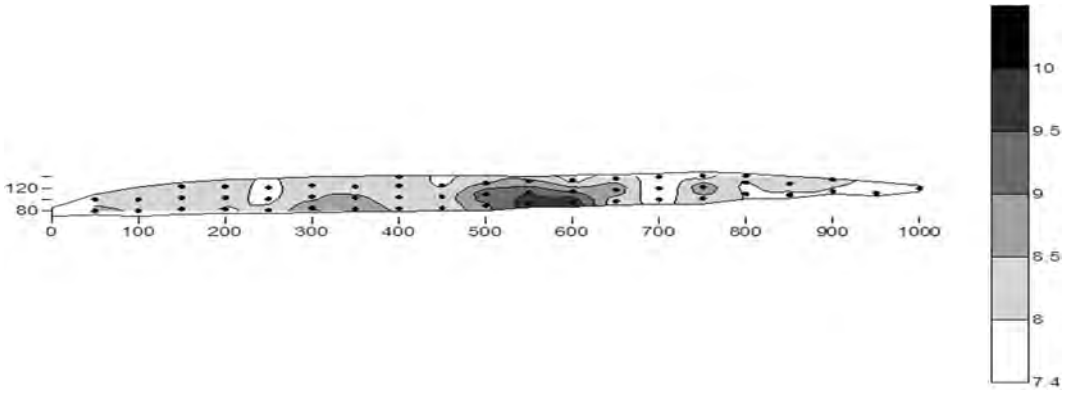


Figure 4-29. Spatial distribution of pH (EN 12457-2) in a section of subbase layer of MSWI bottom ash. The sampling points are marked as black dots (*n*=53) while the x- and y-axes are scaled in centimeters (Bendz et al., 2009).

Leaching data were not available for the MSWI bottom ash that was originally used in the Vändöra project. Therefore, a selection of pH-dependent leaching and percolation column test results from testing of MSWI bottom ash from Germany (Berger et al., 2005) and the Netherlands (van der Sloot et al., 2008c) are used as reference materials for this case.

4.6.2 Results and Discussion

A complete set of figures illustrating results from the single extraction batch tests (deionized water at L/S of 10 L/kg), pH-dependent leaching tests and column tests for the comparison materials is provided in Appendix D.

Measured pH values from laboratory testing of reference bottom ash materials from Germany and The Netherlands are compared to pH measured in core samples from the Vändöra Roadbase in Figure 4-30. The lower field material pH shows the effect of carbonation in the field with pH values between 8 and 8.5, approximately equal to the saturation pH for calcium carbonate.

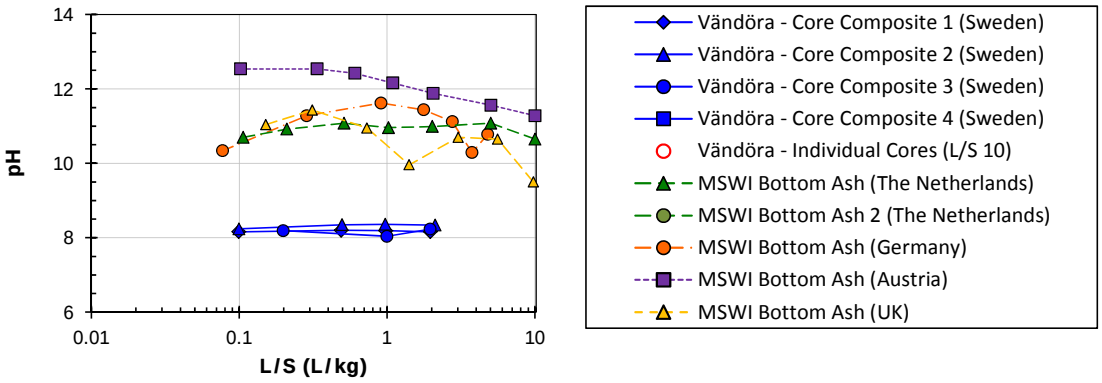


Figure 4-30. Measured pH in reference bottom ash and core samples from Vändöra roadbase.

For the comparison of leaching test eluates to field leachates, measured concentrations are displayed as functions of pH (left) and L/S (right). Single batch extraction test results (n=53, black circles) are plotted along with pH-dependent leaching test results for the four composite samples from the road subbase (red data sets) and the three reference materials (blue data sets); a sample key is provided Figure 4-30. In general, LSP was consistent between the single point extraction tests and the pH-dependent tests for the individual subbase samples, the composite subbase samples and the reference MSWI samples (Figure 4-31).

As expected, the individual subbase samples exhibit greater variability in pH and extract concentration because of differences in the extent of air exposure (i.e., carbonation, oxidation) and for more soluble species (i.e., chloride, potassium) different amounts of water contact because of preferential flow paths.

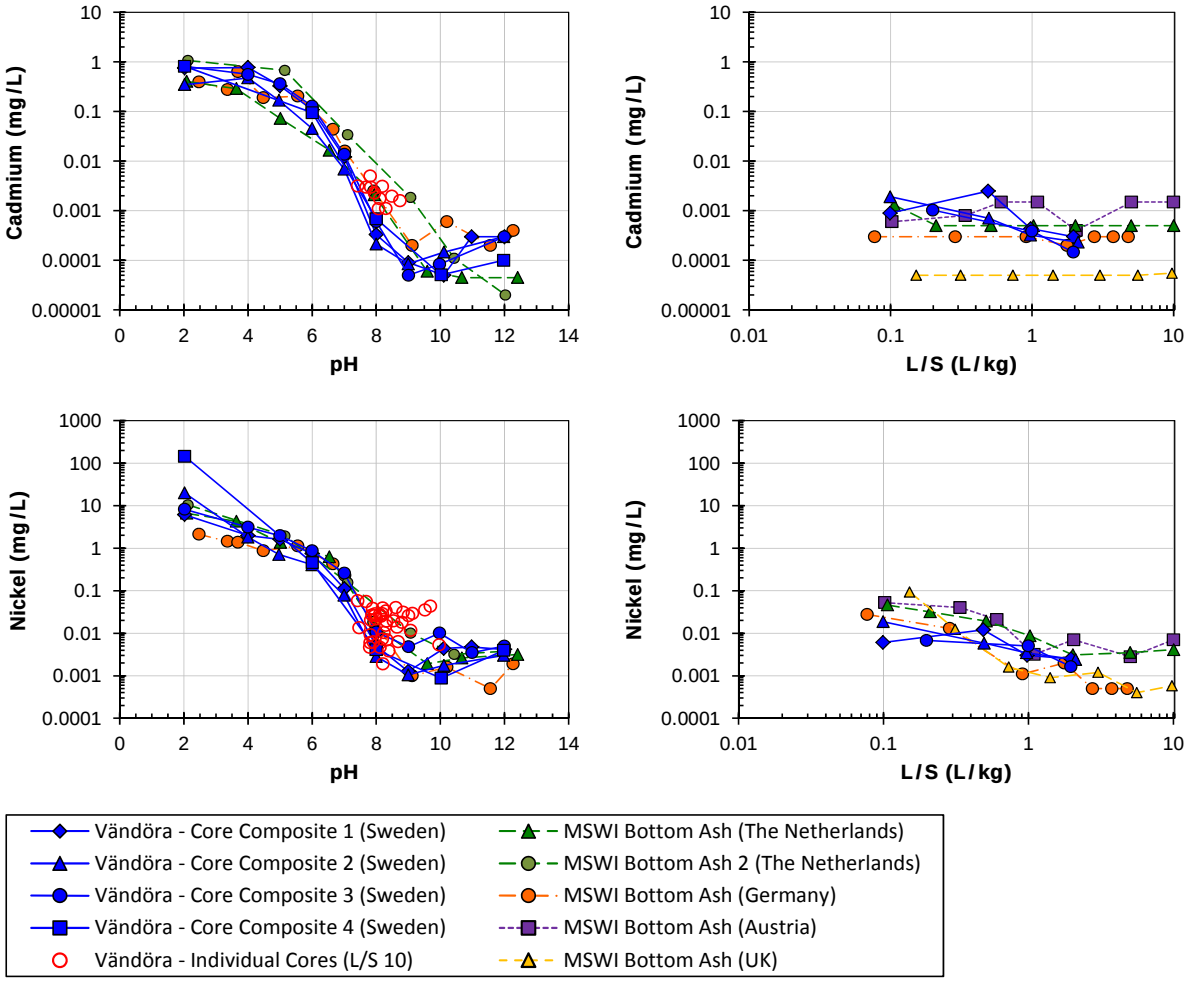


Figure 4-31. Cadmium and nickel results from pH-dependent leaching tests (left) and column leaching tests (right), illustrating consistency of results between field road subbase samples (16-year-old MSWI bottom ash) and for MSWI bottom ash reference samples.

The following are notable relationships between leaching test results for specific constituents:

- The effect of low liquid to solid ratio resulting in higher concentrations in initial column eluates as compared to pH-dependent leaching at L/S of 10 L/kg for highly soluble species is apparent for chloride and sodium (Figure 4-32). When estimating percolation concentrations at low L/S from batch extractions (typically at L/S of 10 L/kg), the upper bound for the expected concentration can be calculated by the ratio of the batch L/S to the initial column L/S or pore water L/S, whichever is greater. Thus, for a batch L/S of 10 L/kg and an initial column L/S of 0.5 L/kg, the initial column eluate concentration would be expected to be up to 20 times greater than the batch concentration (L/S 10 L/kg divided by L/S 0.5 L/kg). In many cases, this theoretical upper bound is not realized because of either preferential flow or the aqueous phase becoming saturated with respect to the constituent of interest.

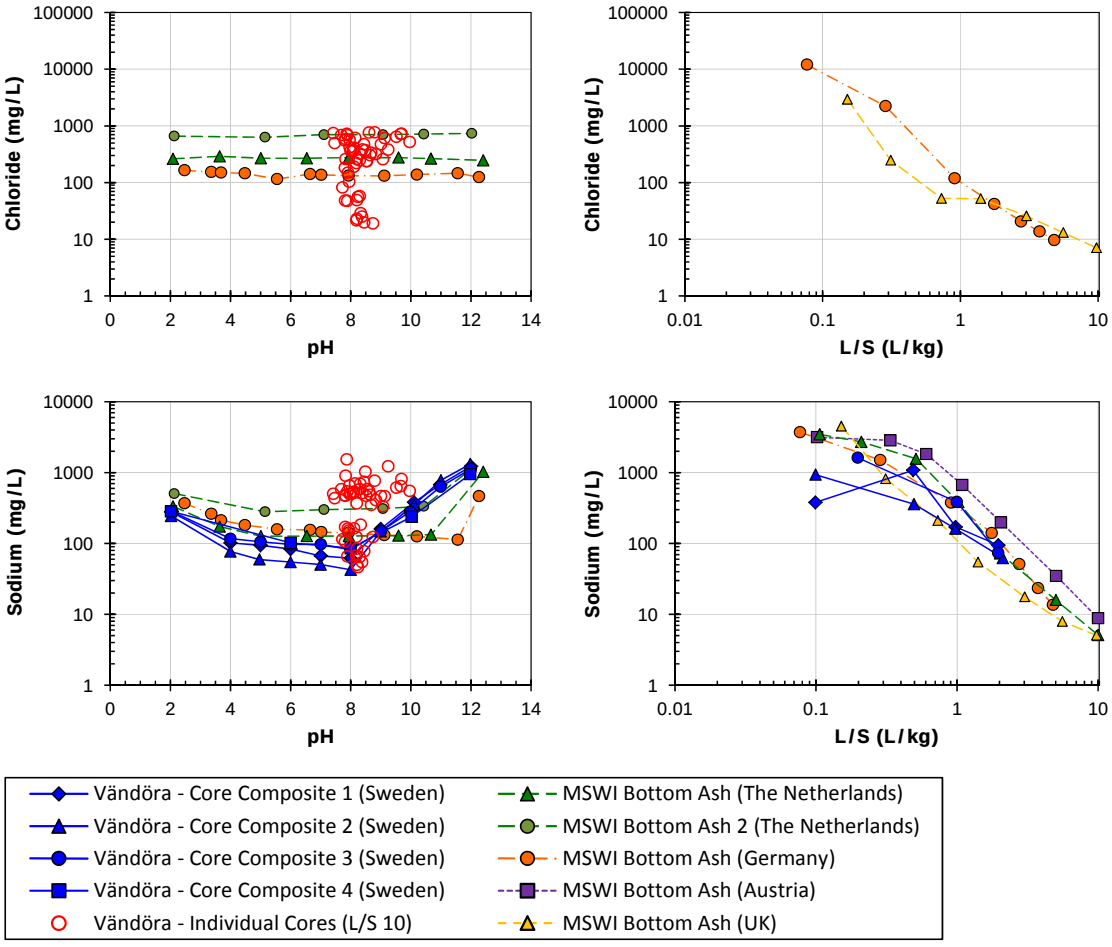


Figure 4-32. Results from pH-dependent leaching test (left) and column leaching tests (right; chloride and sodium), illustrating higher initial eluate concentrations for highly soluble species from column tests (i.e., L/S < 0.2 L/kg) compared to pH-dependent leaching tests

- The effect of washout and depletion of highly soluble species during column testing or percolation compared with solubility controlled leaching during column testing is evident when comparing column test results for potassium and manganese (Figure 4-33).

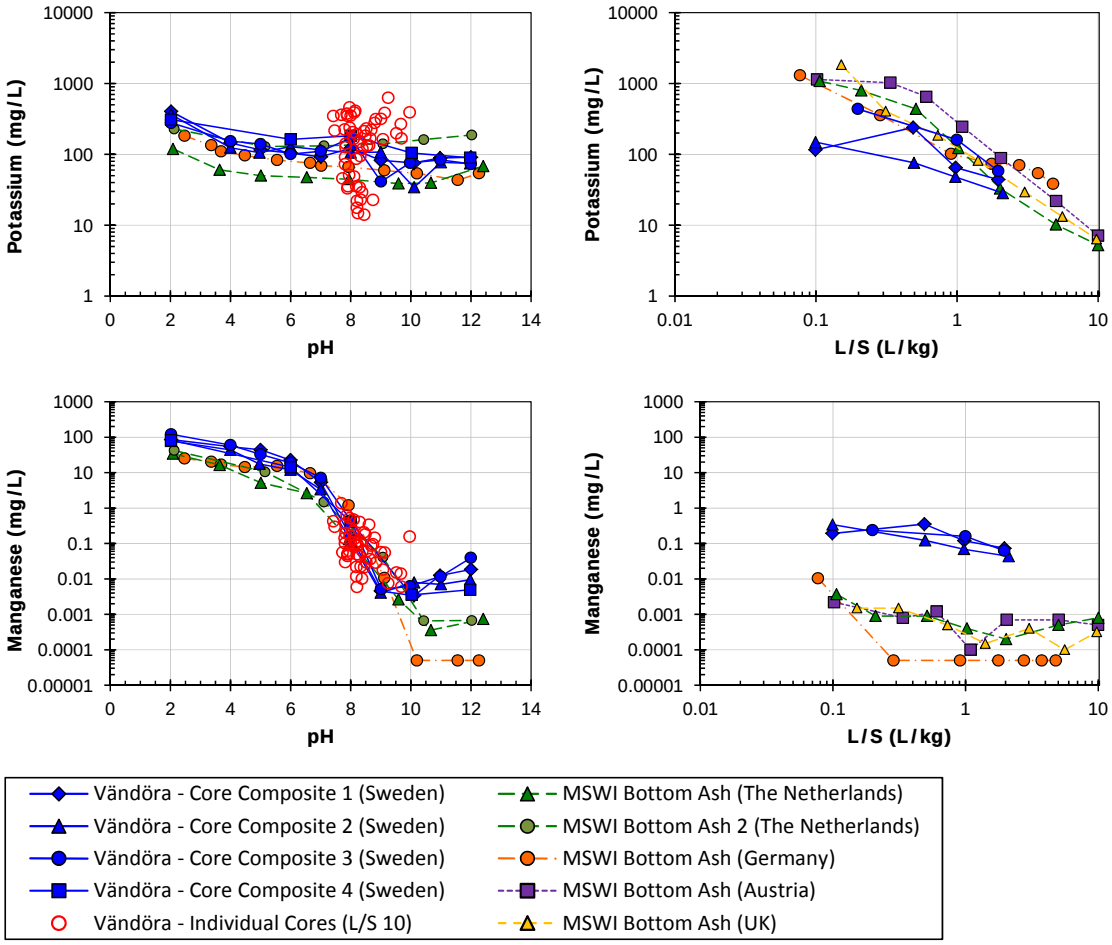


Figure 4-33. Potassium and manganese results from pH-dependent leaching test (left) and column leaching tests (right) illustrating typical results for highly soluble species (potassium) compared to solubility controlled species (manganese).

As indicated earlier, potassium is a highly soluble species with initial column eluate concentrations significantly higher than measured from the batch pH-dependence test at L/S of 10 L/kg, and with eluate concentrations from the pH-dependence test essentially constant as a function of pH. As the column test progresses, potassium eluate concentration decreases rapidly with increasing cumulative L/S, decreasing by more than an order of magnitude by cumulative L/S of 2 L/kg. In contrast, the pH-dependent leaching test results indicate highly pH-dependent solubility for manganese between pH 5 and 13 with consistent results for the subbase composite samples (red symbols and lines) and reference materials (blue symbols and lines). However, column test results for manganese indicate

much higher concentrations for the subbase samples, consistent with manganese solubility at pH~8 compared with the concentrations for the reference samples where the column eluate concentrations are consistent with manganese solubility at pH 10-12.5. For manganese, changes in column eluate concentrations as a function of L/S are consistent with manganese LSP with the changes in eluate pH, rather than the rapid decrease in concentration noted for potassium.

- The effect of carbonation of field samples is evident in pH-dependent leaching of barium (not shown), calcium and strontium at pH greater than 7 by comparison of reference samples to the field subbase composites (Figure 4-34).

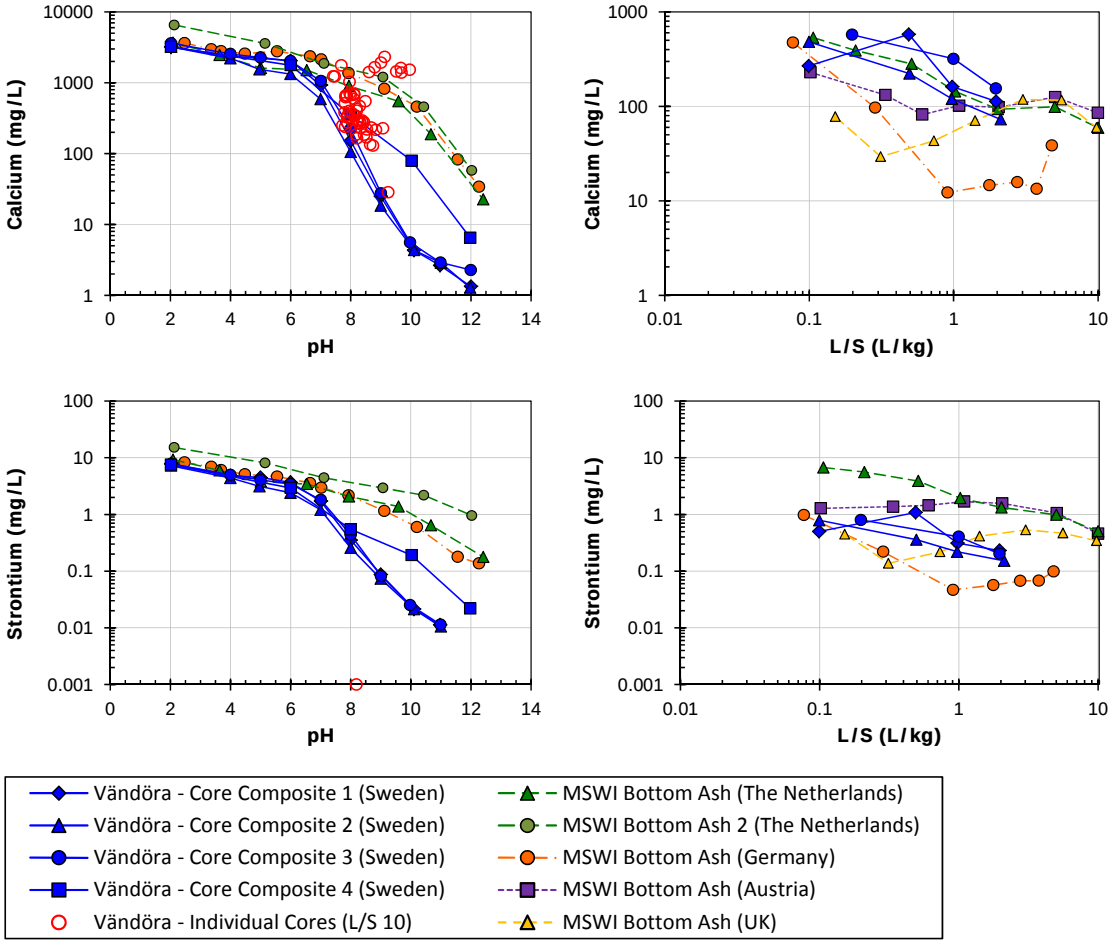


Figure 4-34. Calcium and strontium results from pH-dependent leaching test (left) and column leaching tests (right) illustrating the effects of carbonation to reduce solubility at alkaline pH.

- The effect of pH-dependent solubility on percolation results is evident for aluminum, magnesium, lead (Figure 4-35), and boron, manganese and zinc (not shown). Higher concentrations of lead at neutral pH than observed during pH dependent testing is likely the

result of complexation with DOC that was present in some individual samples and masked in the composites used for pH dependent testing (see Figure 4-36).

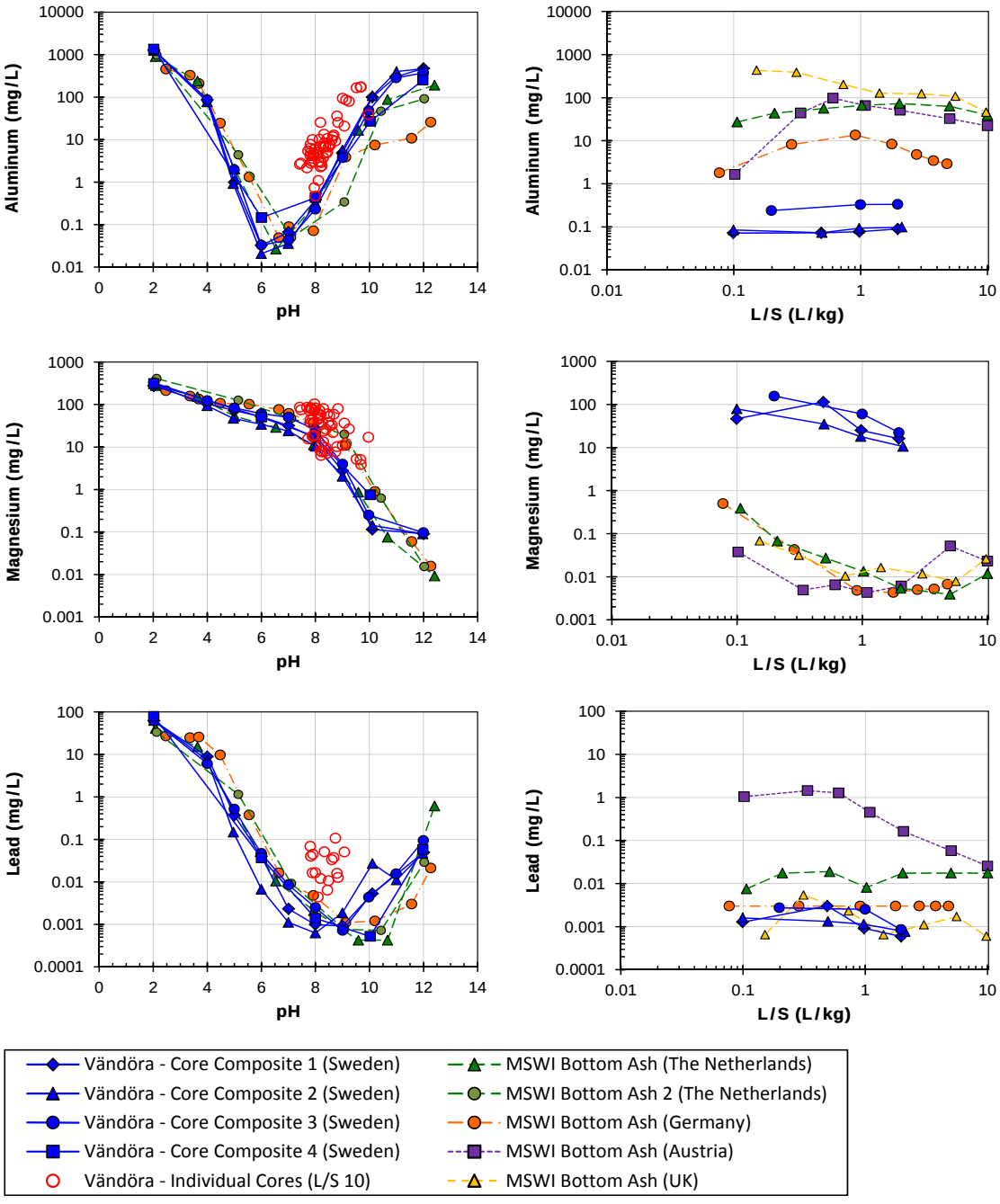


Figure 4-35. Aluminum, magnesium and lead results from pH-dependent leaching test (left) and column leaching tests (right) illustrating the effects of pH-dependent solubility on the eluate concentrations from column tests (also refer to Figure 4-30 for pH of column test eluates).

For aluminum, all of the column eluates for the reference materials are greater than for the subbase composites because the pH-dependent leaching indicates the same leaching as a function of pH, but the column eluates for the reference materials are between pH 10 and 12.5, where aluminum solubility is much greater than at the subbase column eluates between pH 8 and 8.5. A less pronounced but similar effect is observed for lead when comparing the single reference material that had column eluate with pH 12.5 (blue squares) in contrast to the other materials. The effect is less pronounced for lead than aluminum because of the column eluate pH values in comparison with the minimum in LSP that occurs at pH 8 to 10 for lead but at pH 6 to 8 for aluminum. Conversely, for magnesium, the column eluate concentrations for subbase composites are much greater than for the reference materials because magnesium solubility is much greater at pH 8-8.5 than at pH 10-12.5.

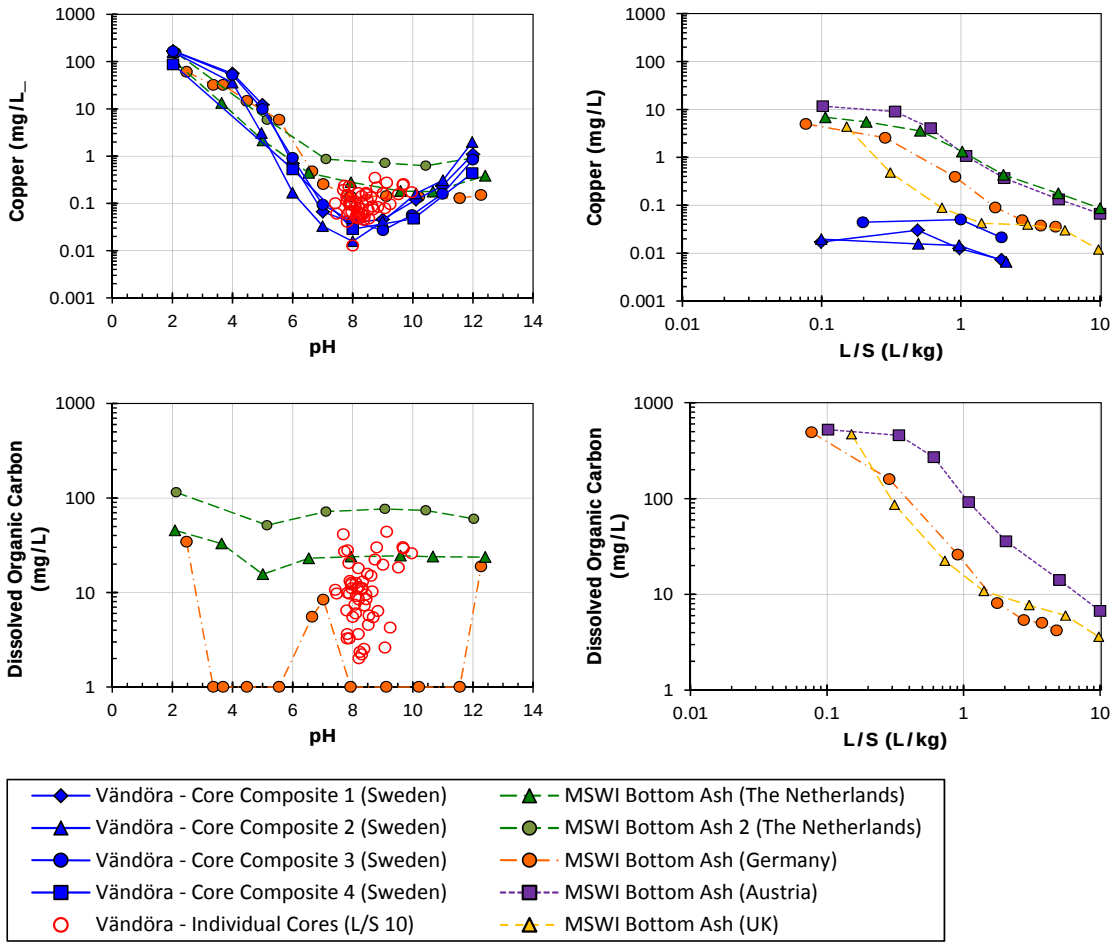


Figure 4-36. Copper and DOC results from pH-dependent leaching test (left) and column leaching tests (right) illustrating the effects of pH-dependent solubility on the eluate concentrations from column tests.

- The effect of complexation leading to increased aqueous solubility is evident for copper leaching from the reference materials during the column tests when viewed in context with the DOC concentrations in column eluates (Figure 4-36).

  Copper has been previously demonstrated to complex strongly with DOC from bottom ash (van Zomeren and Comans, 2004). Higher concentrations of copper are associated with higher DOC concentrations during column tests, with higher concentrations at low L/S decreasing with increasing cumulative L/S.

- The single batch extractions for the individual subbase samples have anomalous results reported for arsenic, when compared to the composite samples, in that the individual samples indicate higher arsenic concentrations at the measured pH, however increased levels of carbonation can result in displacement of arsenic adsorbed to HFO.

4.6.3 MSWI BA Chemical Speciation Insights

Figure 4-37 presents data for pH dependence leaching of copper from MSWI BA (from The Netherlands) from a series of experiments (van der Sloot et al., 2001, van der Sloot et al., 2008). The uppermost red data series results from testing fresh MSWI BA, the lowest blue data series results after heat treating the same MSWI BA to 500 °C to remove organic carbon, and the middle green data series results after 1 wt% organic compost is added to the heat treated MSWI BA to add organic matter back into the material. Clearly, removal or addition of organic matter alters the concentration of copper in solution based on complexation with DOC.

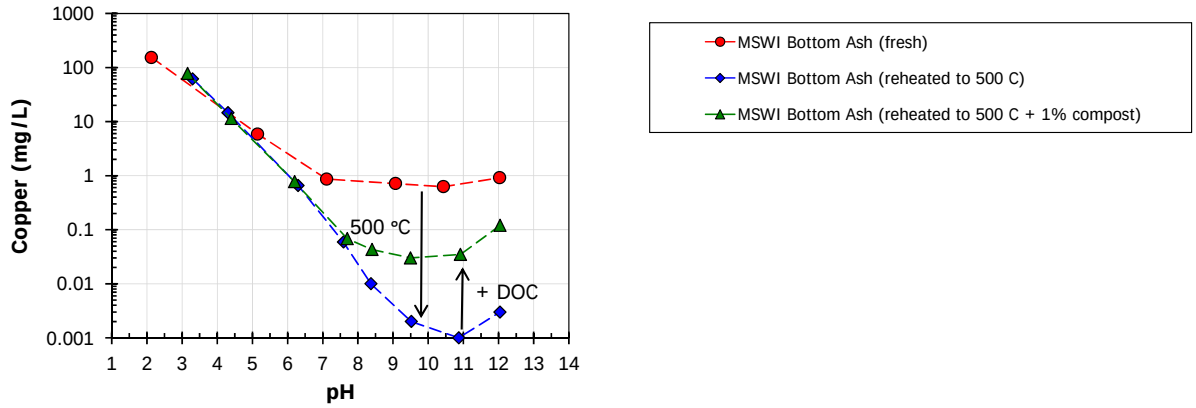


Figure 4-37. pH-dependence leaching (CEN/TS 14429) data for MSWI bottom ash (Netherlands) as "fresh" material (red), MSWI BA after heat treatment at 500 °C (blue), and heat-treated MSWI BA with 1% compost added (green).

Figure 4-38 presents the experimental results of the same set of experiments along with results of using largely the same CSF for all three conditions, but varying the amount of organic matter in the system to correspond with experimental measurements of TOC and DOC for each experimental condition. Partitioning between POM and DOC plays a significant role in LSP between pH 7 to 13,

with increasing amounts of DOC responsible for increased Cu in solution. At a pH between 6 and 9.5, adsorption onto HFO surfaces represents a significant amount of Cu in the solid phase, while tenorite [CuO] or $Cu(OH)_2$ is present as a precipitated phased at pH greater than 7. Note that availability controls the observed Cu in solution at pH less than 6 based on simulation results, but experimental results indicate that the maximum available amount of Cu partitions into solution only at pH 3. This difference between simulation and experimental results suggests that either Cu dissolution is kinetically controlled during the test conditions, i.e., long enough leaching time is not provide to achieve equilibrium at low pH (Dijkstra et al., 2006) or a solid phase that is important between pH 3 and 6 has not been included in the simulation.

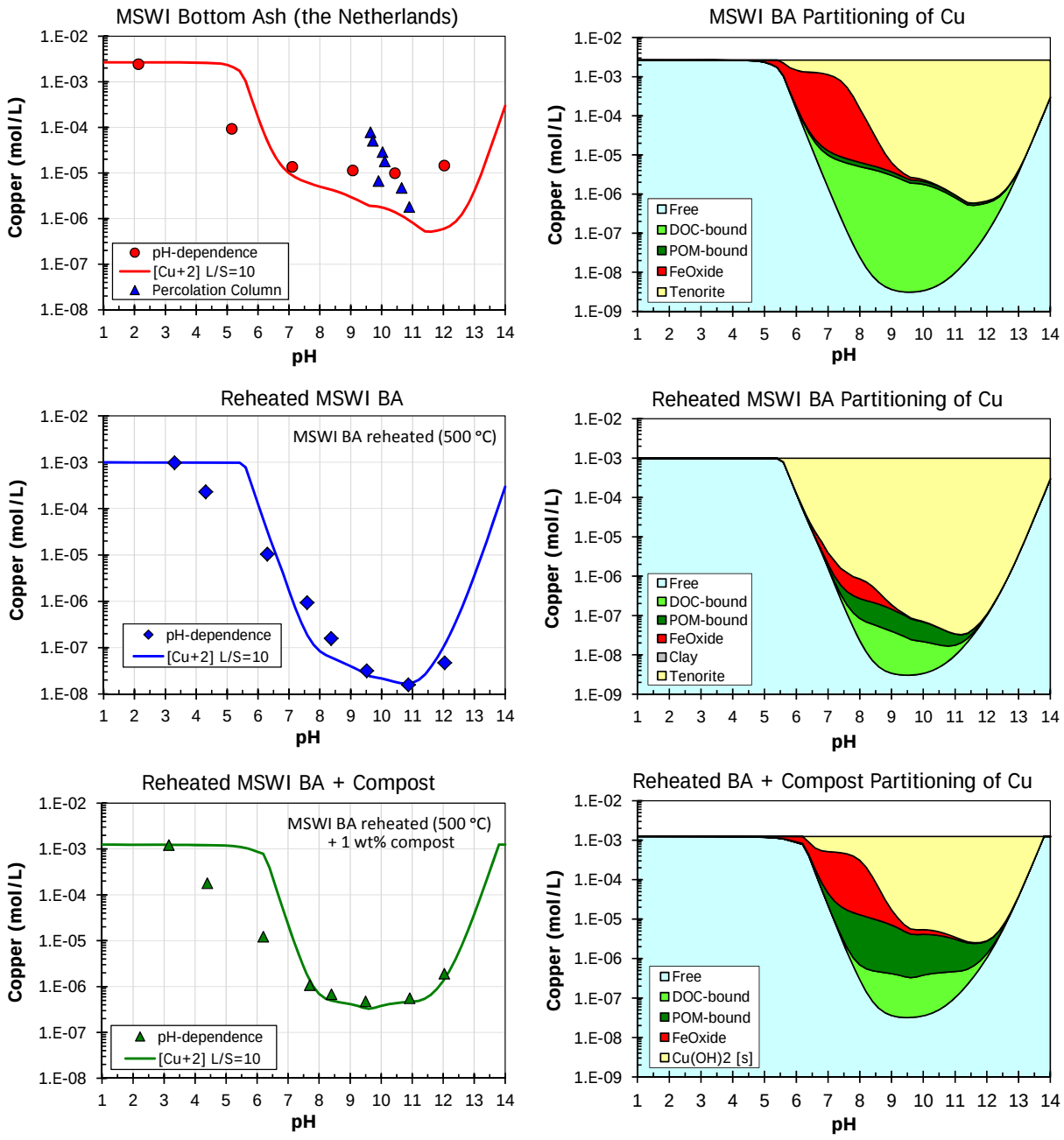


Figure 4-38. Chemical speciation modeling for MSWI bottom ash (Netherlands) as "fresh" material (upper), MSWI BA after heat treatment at 500 °C (middle), and heat-treated MSWI BA with 1% compost added (lower).

Figure 4-39 presents laboratory test data and simulations for pH dependent leaching of Cu from MSWI BA from Austria (van der Sloot et al., 2000). For this figure, the uppermost compares simulation of L/S=0.3 L/kg with experimental data obtained at L/S=10 mL/g, while the middle series provides simulation results at L/S=10 mL/g. This comparison indicates that increased Cu concentrations can be anticipated at lower L/S values because the same amount of Cu is available

for leaching but increased DOC in solution at low L/S values results in increased Cu solubilization between pH 7 and 10, while the same mass of Cu in solution at low pH values results in increased Cu concentrations that are constrained by Cu availability. The bottommost two graphs present the fraction of dissolved Cu complexed with DOC (left graph) and the percent distribution between different solid phases as a function of pH (right graph). Dissolved Cu is predominantly complexed with DOC between pH 7.5 and 11.5, while uncomplexed Cu ("Free") is present in solution outside of this pH range. Precipitated $Cu(OH)_2$ predominates between pH 8.5 and 13.5, while sorption to iron (hydr)oxide surfaces is important between pH 5.5 and 8.5.

Figure 4-40 through Figure 4-42 provide analogous information for Al, V and Zn, respectively, and provide similar insights into expected changes in observed LSP at L/S=0.3 vs. 10 mL/g and speciation in the solid and aqueous phases as a function of pH and L/S. Note that between pH 7 and 11, a significant amount of the Zn is present in solution as complexed with DOC (Figure 4-42, bright green area). Thus, increased amounts of DOC results in increased Zn concentrations in solution over this pH domain. Similar effects are observed for lead (not shown) and these effects are consistent with the field leachate concentrations observed in this case and the prior case (i.e., Figure 4-27 and Figure 4-35)

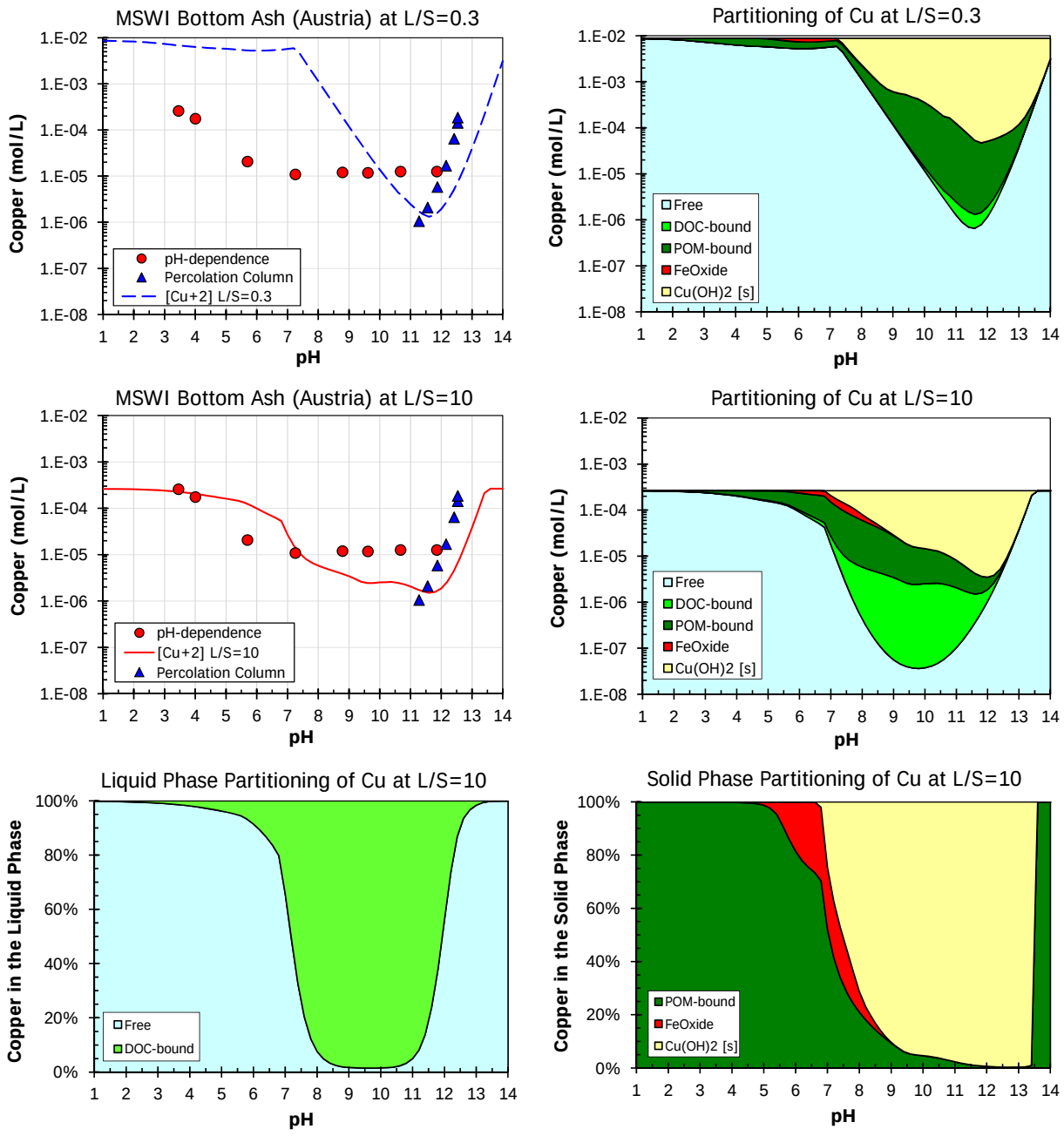


Figure 4-39. Chemical speciation modeling of copper in MSWI bottom ash (Austria) compared to pH-dependence (CEN/TS 14429) and percolation column (CEN/TS 14405) data.

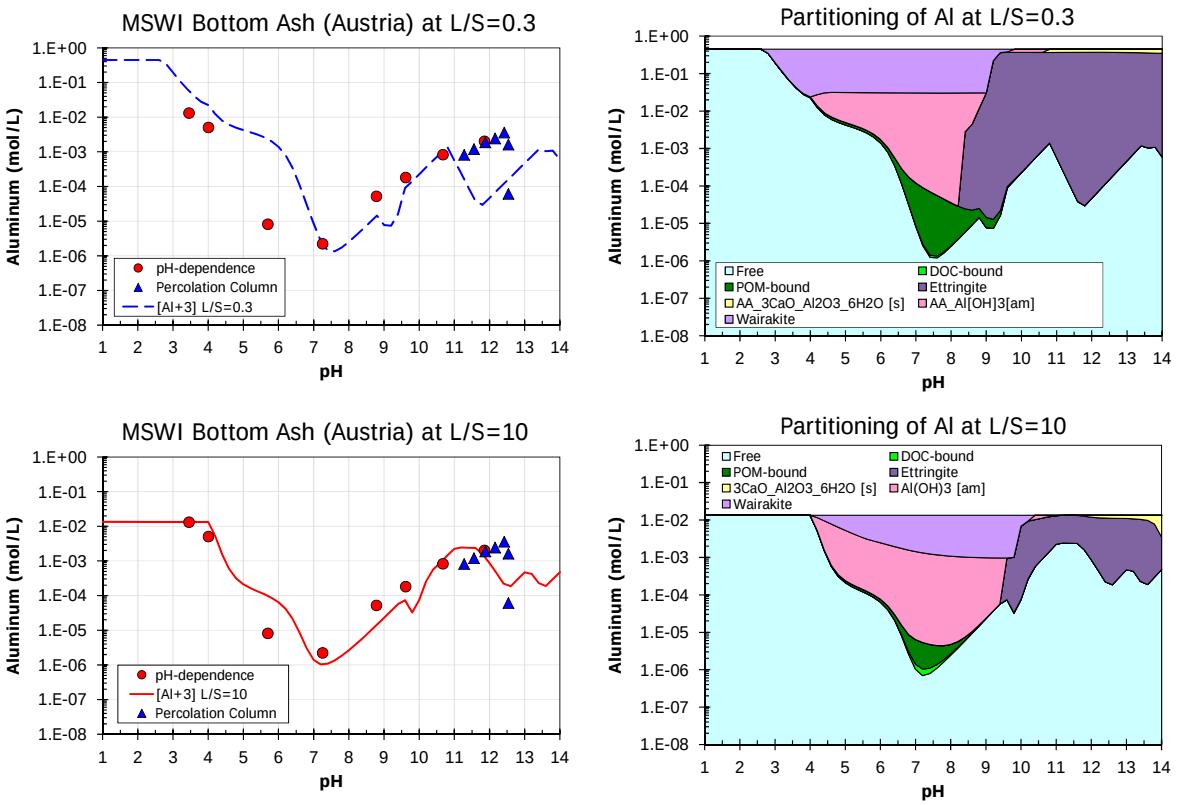


Figure 4-40. Chemical speciation modeling of aluminum from MSWI bottom ash (Austria) at L/S=10 and L/S=0.3.

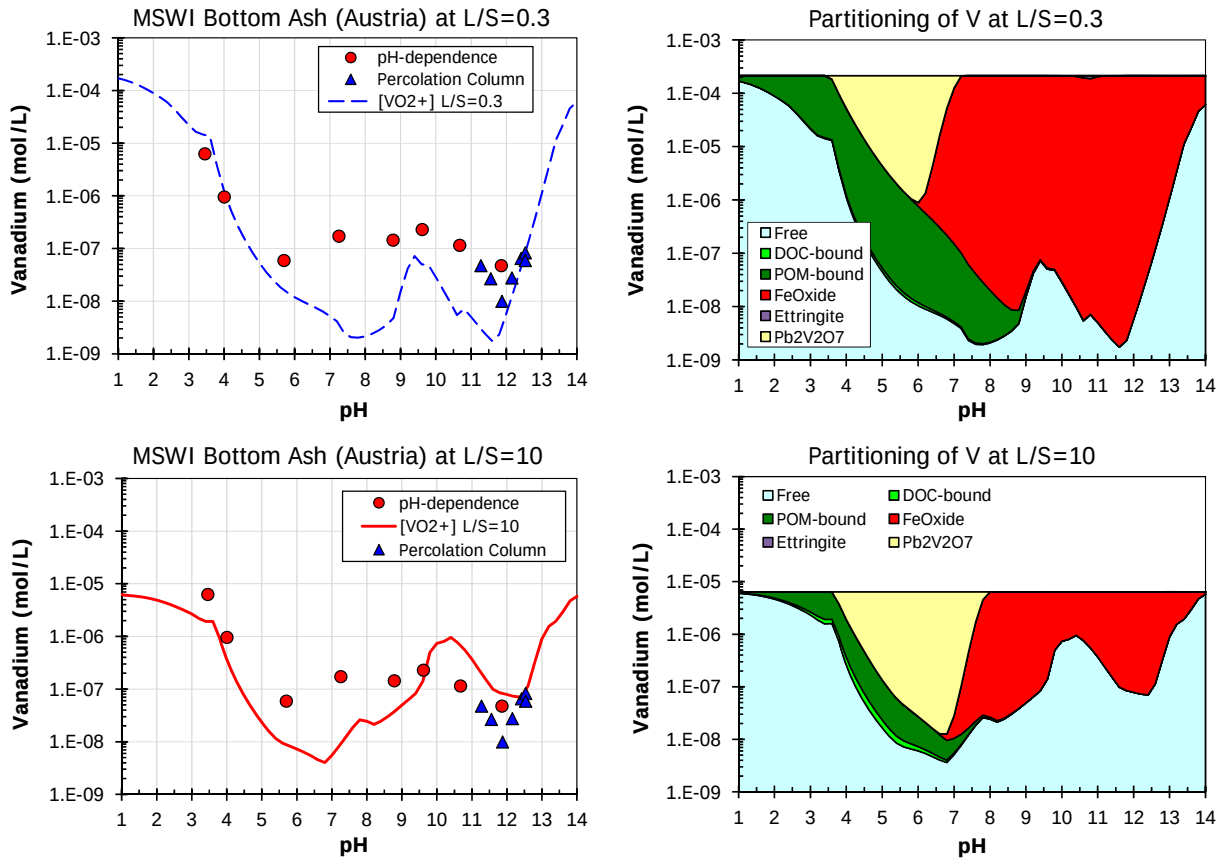


Figure 4-41. Chemical speciation modeling of vanadium from MSWI bottom ash (Austria) at L/S=10 and L/S=0.3.

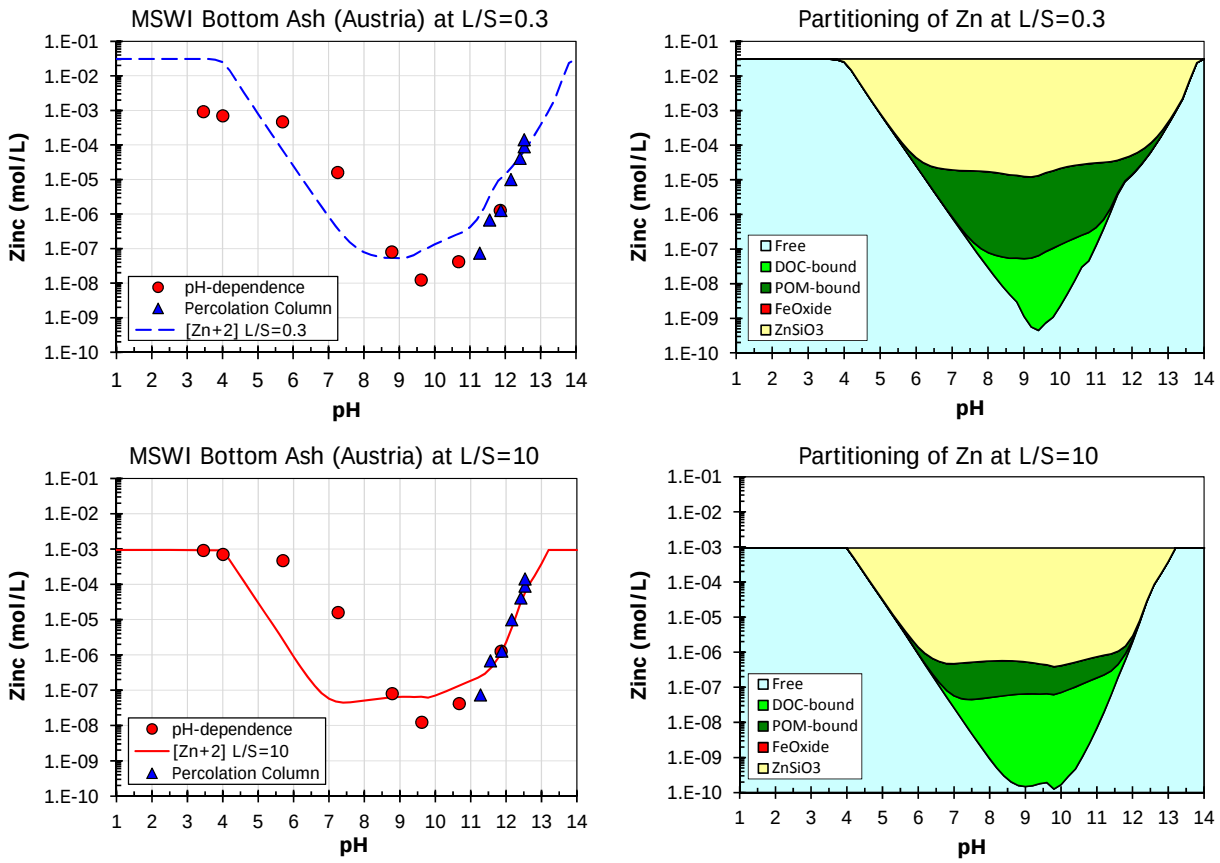


Figure 4-42. Chemical speciation modeling of zinc from MSWI bottom ash (Austria) at L/S=10 and L/S=0.3.

Figure 4-43 and Figure 4-44 present pH dependent leaching data obtained at L/S=10 mg/L and percolation column data obtained from 0.3 to 10 mg/L for a group of selected COPCs. Simulation results are used to illustrate the effect of L/S on expected leaching. For example, sulfate is solubility controlled throughout the pH domain, as indicated by the overlap of simulation curves over the range of simulated L/S values. In contrast, K is availability controlled over the entire pH domain, as indicated by parallel simulation results at increased concentration with decreased L/S corresponding to the same mass of K partitioning into solution. Finally, Ca, Mg, and Mn are solubility controlled at pH greater than 12.5, 9.5 and 8.5 respectively, while they are availability controlled at lower pH values. When percolation column results align with pH dependence test results and simulated LSP, solubility control during percolation column leaching is indicated (e.g., for Ca, Mg, sulfate, Mn, Cu, Mo, Pb, Sb and Zn). However, percolation column results for K (a highly soluble species) indicates washout and depletion by the initial eluate concentration that corresponds with simulation results at L/S=1 (which is consistent with a loose packing for a course material such as bottom ash) and subsequent rapidly decreasing concentrations (also corresponding with decreasing eluate pH).

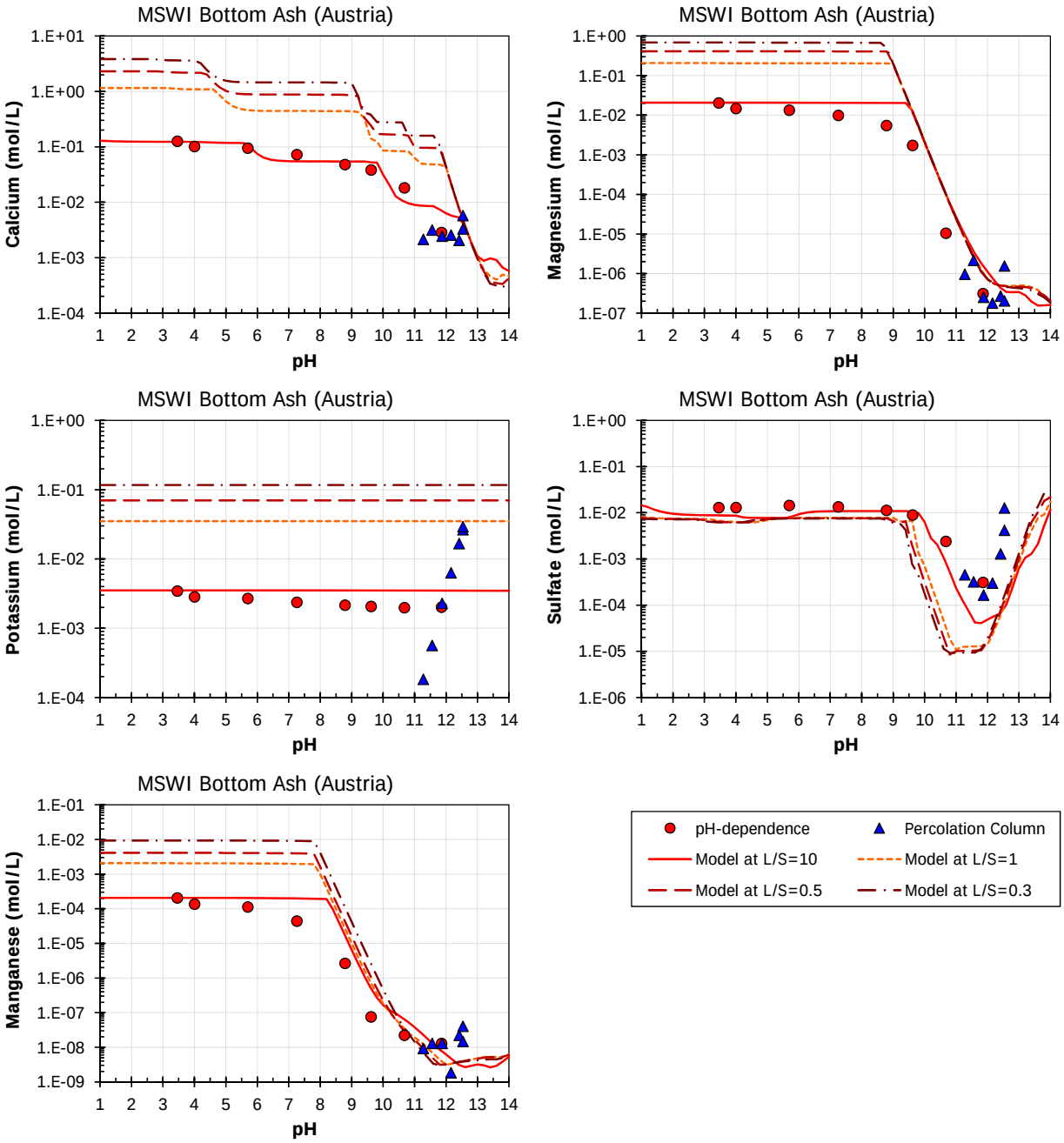


Figure 4-43. Chemical speciation modeling at different L/S compared to pH-dependence (CEN/TS 14429) and percolation column (CEN/TS 14405) data for MSWI bottom ash (Austria).

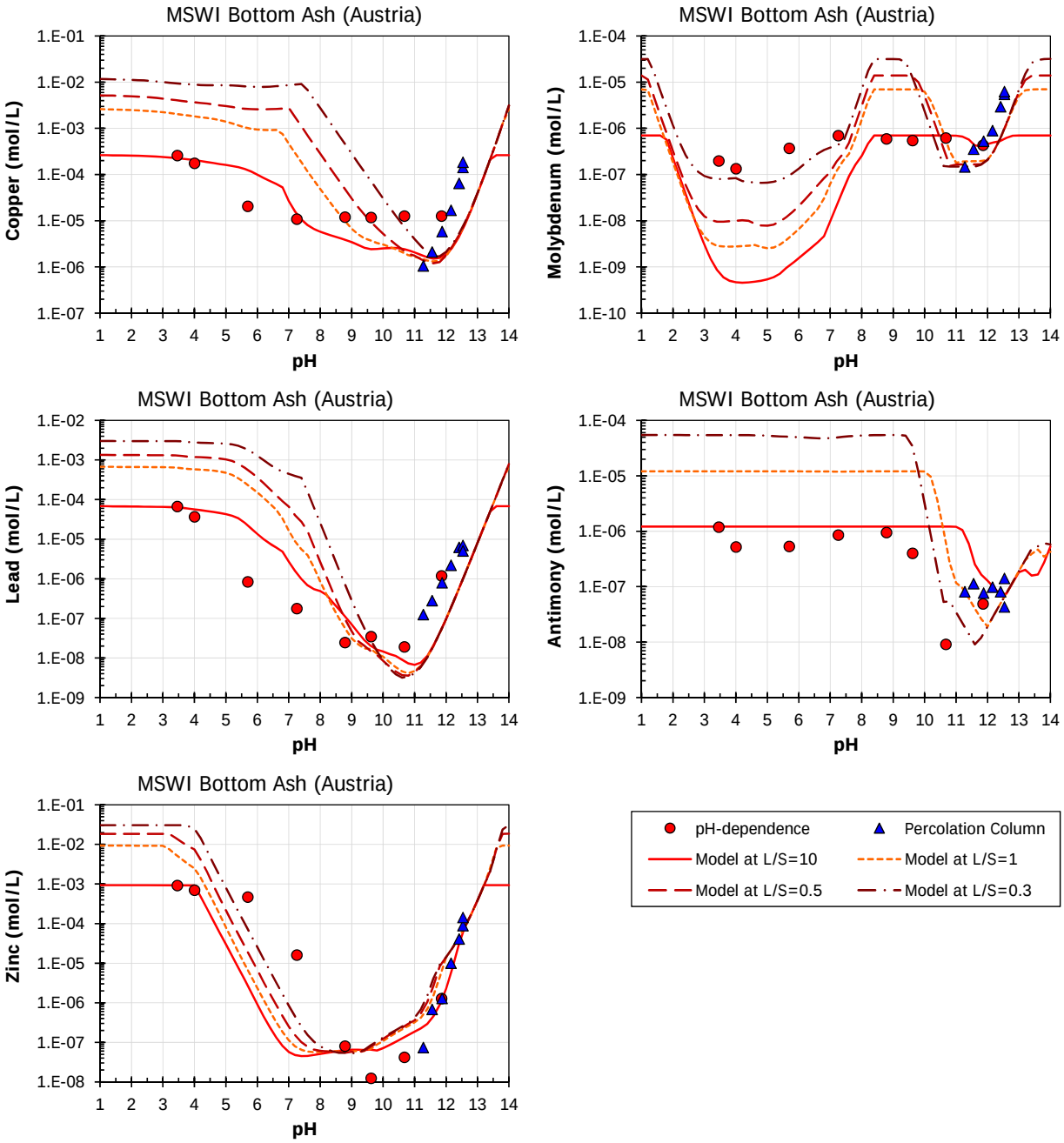


Figure 4-44. Chemical speciation modeling at different L/S compared to pH-dependence (CEN/TS 14429) and percolation column (CEN/TS 14405) data for MSWI bottom ash (Austria).

4.6.4 Case Summary

Case 6 focused on MSWI bottom ash used as a subbase below an unbound base course and surface asphalt layers that was cored and evaluated 15 years after the road construction. The resulting applicable pH domain was approximately pH 7 to 10. Single point leaching of an extensive set of samples (n= 53) illustrates the heterogeneity of material and exposure under field conditions.

Laboratory testing of composite samples from field cores using pH dependent leaching and percolation column tests showed LSP and column elution consistent with descriptions for other materials with respect to both highly soluble constituents (e.g., Na, K, Cl) and constituents where solubility limits LSP as a function of pH (e.g., Ca, Cu, Pb, Zn). A general CSF for MSWI bottom ash has been shown to provide a good description of release behavior of multiple major, minor and trace elements from MSWI bottom ash from several sources and indicates likely solubility controlling phases. Combined leaching test results and chemical speciation modeling illustrated (i) the effects of DOC complexation to increase aqueous concentrations of copper, lead and zinc, and (ii) the effects of L/S on the expected concentrations of highly soluble and solubility limited constituents as a function of pH, with lower L/S conditions resulting in increased aqueous concentrations when the constituent solubility is not limiting leaching.

4.7 Inorganic Industrial Waste Landfill (The Netherlands)

4.7.1 Case Description

In the framework of a Dutch national research project on sustainable landfills, a landfill site in Nauernasche Polder, Nauerna, The Netherlands was the subject of a pilot scale demonstration project and lysimeters studies (van der Sloot et al., 2003; van Zomeren and van der Sloot, 2006b). In addition to the lysimeter and pilot landfill, laboratory experiments on landfill materials were conducted using the CEN/TS 14405 (2004) percolation column test and the CEN/TS 14429 (2005) pH-dependence test.

The filling of a 12,000 m^3 pilot-scale landfill started in April 2000 and was completed in November 2001 (Figure 4-45). The pilot cell was isolated from the rest of the landfill site by a high-density polyethylene membrane. Leachate was collected in the lower corner of the test cell and the amount of leachate pumped out of the test cell was measured. A vertical drain (filled with coarse granular material) was installed in the center of the pilot cell to enhance the drainage of rainwater and to minimize the contact of rainwater with the waste material.



Figure 4-45. Construction of the Nauerna pilot-scale landfill (van Zomeren and van der Sloot, 2006b).

The material placed into the pilot cell was subject to more stringent acceptance criteria than currently required by waste regulation. The disposed material, characterized as "primarily inorganic waste" because it did not contain any municipal solid waste, included wastes from drilling mud (2.8 wt %), wastewater treatment sludge (0.1 wt %), foundry waste (0.5 wt %), blasting waste (1.7 wt %), residues from mechanical soil cleaning (10.2 wt%), contaminated soils, gravel and construction debris (7.2 wt%), mineral production waste (55.4 wt%), filter cake from waste processing (8.2 wt%), sludge from soil cleaning (11.4 wt%), waste from street cleaning (0.4 wt%) and miscellaneous materials (2.1 wt%) as reported in van der Sloot et al. (2003).

Samples were taken from all waste streams deposited in the cell and the landfilled weight of each stream was recorded. From all waste samples collected, a representative waste mixture was prepared by proportionately taking the waste sample mass per waste mass placed into the landfill into account. The resulting inorganic waste composite was used for the laboratory testing of pH-dependent leaching (CEN/TS 14429) and percolation column testing (CEN/TS 14405). In October 2001, representative waste samples were also used to fill three 1.5 m^3 lysimeters with a representative waste mixture (Figure 4-46).



Figure 4-46. Nauerna landfill lysimeters.

The lysimeters were plastic containers of approximately 1 m height, open at the top surface to the atmosphere in order to receive natural precipitation. Leachates from the lysimeters were collected through a system of tubes and subsurface collection vessels. The lysimeters were located adjacent to the pilot landfill. The lysimeters were filled with test material as follows:

- Lysimeter 1 - disposal of wastes in order of delivery as practiced at Nauerna;

- Lysimeter 2 - encapsulation of more contaminated wastes in relatively low permeability wastes (soil cleaning residues); and,
- Lysimeter 3 - disposal of wastes in order of delivery as practiced at Nauerna with addition of 5 wt % each of sewage sludge and car shredder waste to increase organic matter loading.

The material placed into Lysimeter 1 and 2 were not significantly different and, therefore, leachate results are presented together for this evaluation. Lysimeter 3, however, contained a sufficiently different waste composition due to addition of organic matter. Therefore, the results from Lysimeter 3 are not considered for the purposes of this report. The studies at field, lysimeter and laboratory scale represent different time scales through the L/S to which the waste was exposed.

4.7.2 Results and Discussion

A complete set of figures illustrating results from the laboratory pH-dependent leaching tests and column tests of a sample of solid waste material (red solid dots) along with results from the combined Lysimeter 1 and 2 (orange open squares) and the pilot-scale landfill (purple open diamonds) is provided in Appendix E. Field lysimeter and pilot-scale landfill results are graphed both as a function of pH with the laboratory pH-dependent leaching test results (left) and as a function of L/S with the laboratory column test results (right).

An important distinction in redox within the material existed between the laboratory column tests, field lysimeters and pilot-scale landfill. Laboratory column leaching tests exhibited an initial ORP of -100 mV (pE -1.69) that increased to +250 mV (pE 4.23), presumably as a result of using oxygen-saturated water as the column eluent. The leachates from the field lysimeters had an initial ORP of -200 mV (pE -3.38) which increased to a stable value of approximately +200 mV (pE 3.38) after 1.5 years of testing. In contrast, the pilot-scale landfill maintained a relatively constant redox potential of -200 mV (pE -3.38) throughout the observation period of approximately 4 years (van Zomeren et al., 2005).

The following are notable relationships between leaching test and field results for specific constituents:

- There is a difference in the oxidation conditions for (i) the laboratory leaching tests and the field lysimeters where leaching occurs under oxidizing conditions, and (ii) the pilot-scale landfill where leaching occurs under reducing conditions. The difference in these conditions is most easily seen for iron leaching concentrations due to the increased iron solubility under reducing conditions (Figure 4-47, top). Unless a highly reducing material is being tested, oxidizing conditions prevail for most laboratory tests as materials are handled in open to laboratory atmosphere and the CEN/TS 14429 pH-dependent test uses mildly oxidizing nitric acid for pH adjustment. In the case of field lysimeters, the construction of the lysimeter most likely partially limited diffusion and barometric exchange of atmospheric oxygen into the system under unsaturated conditions. Reducing conditions in the pilot-scale landfill were most likely induced by microbial degradation of the limited amount of organic matter introduced with the waste because no reducing waste types (i.e., pyrites, slags) were included with the disposed materials. Furthermore, biogenic reducing conditions are consistent with the observed increase in DOC landfill leachates compared to

the DOC concentrations in laboratory column eluates and lysimeter leachate (Figure 4-47, bottom).

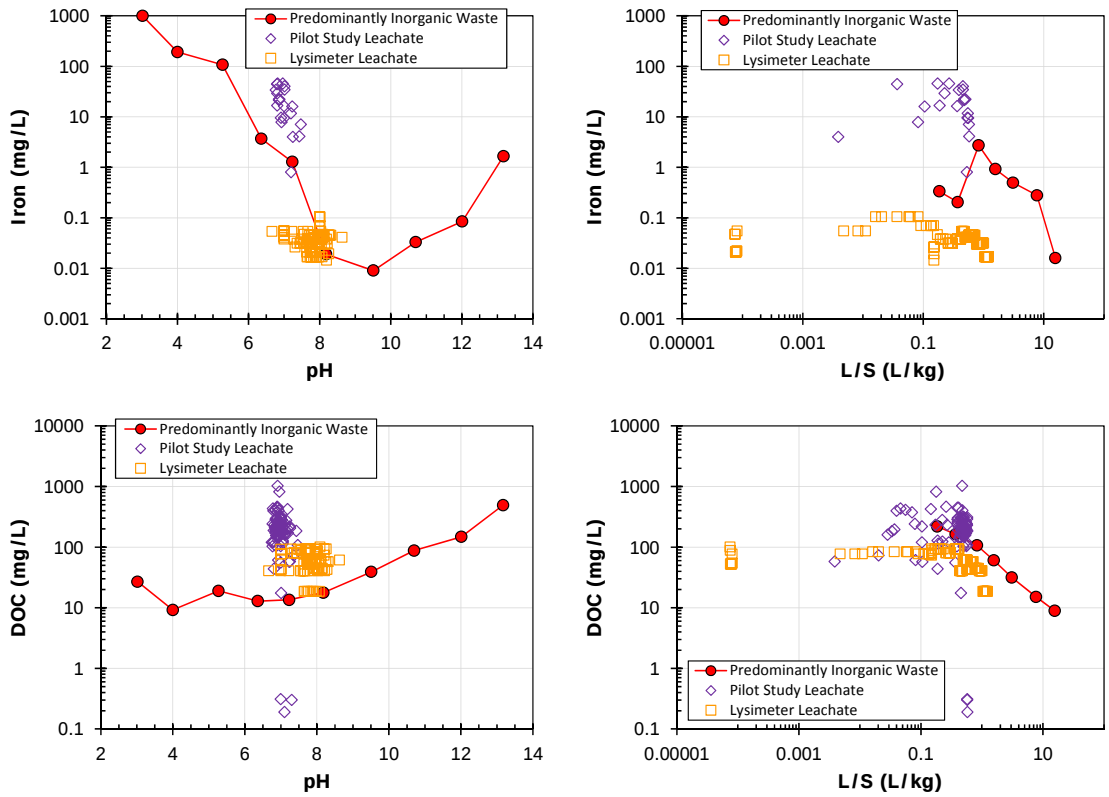


Figure 4-47. Iron and dissolved organic carbon concentrations from Nauerna landfill study.

- Increased concentrations of chromium in leachate from the pilot-scale landfill are most likely the result of Cr(III) complexation with DOC (Figure 4-48, top); a similar effect is indicated for copper. Increased concentrations of arsenic in leachate from the pilot-scale landfill are most likely the result of loss of arsenic adsorption sites on hydrated iron oxide surfaces because of reduction and solubilization of iron (Figure 4-48, bottom).

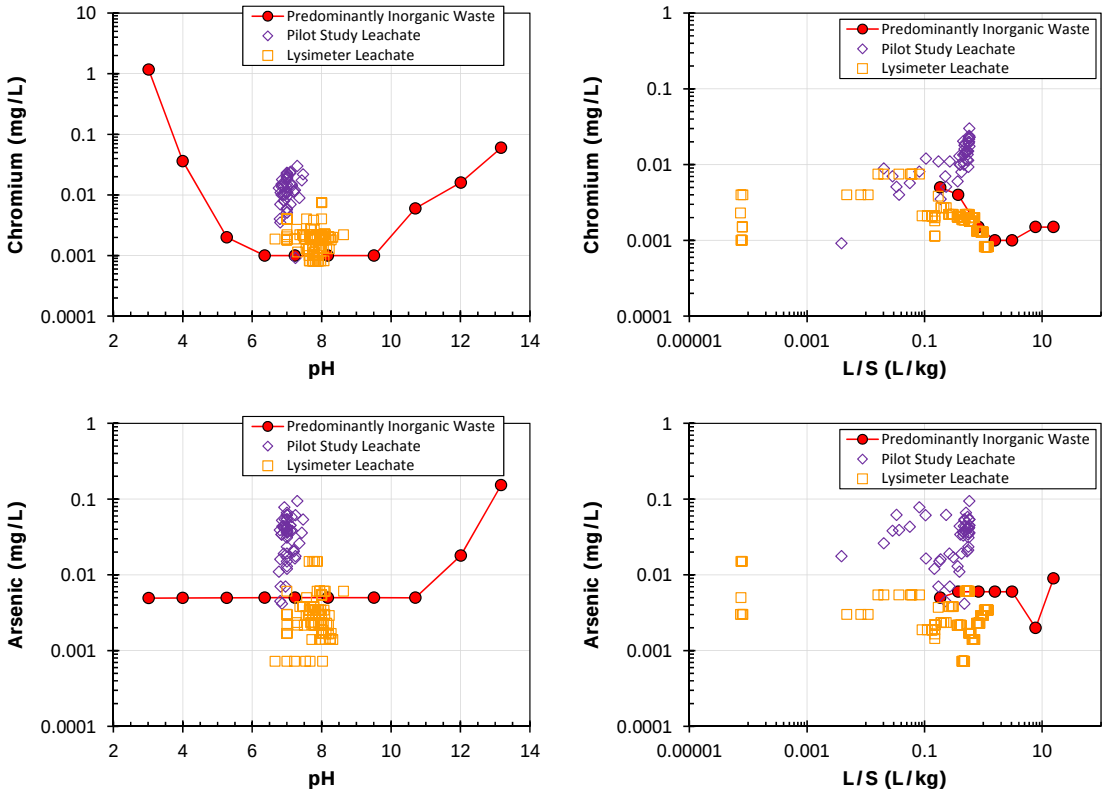


Figure 4-48. Chromium and arsenic concentrations from Nauerna landfill study.

In contrast, increased barium leachability in leachate from the pilot-scale landfill is most likely linked to increased solubilization of phosphate (shown as phosphorus) under reducing conditions (Figure 4-49). Vanadium also had higher concentrations in leachate from the pilot scale landfill under reducing/carbonated conditions than observed from the lysimeters and the laboratory column tests. For these constituents, the maximum concentrations observed in the field pilot-scale landfill were significantly greater than maximum concentrations indicated by the laboratory column testing. These differing effects point to the need of *a priori* knowledge of the adsorption, solubilization and precipitation chemistry of different elements to interpret leaching results and the benefits of using chemical speciation modeling to facilitate interpretation.

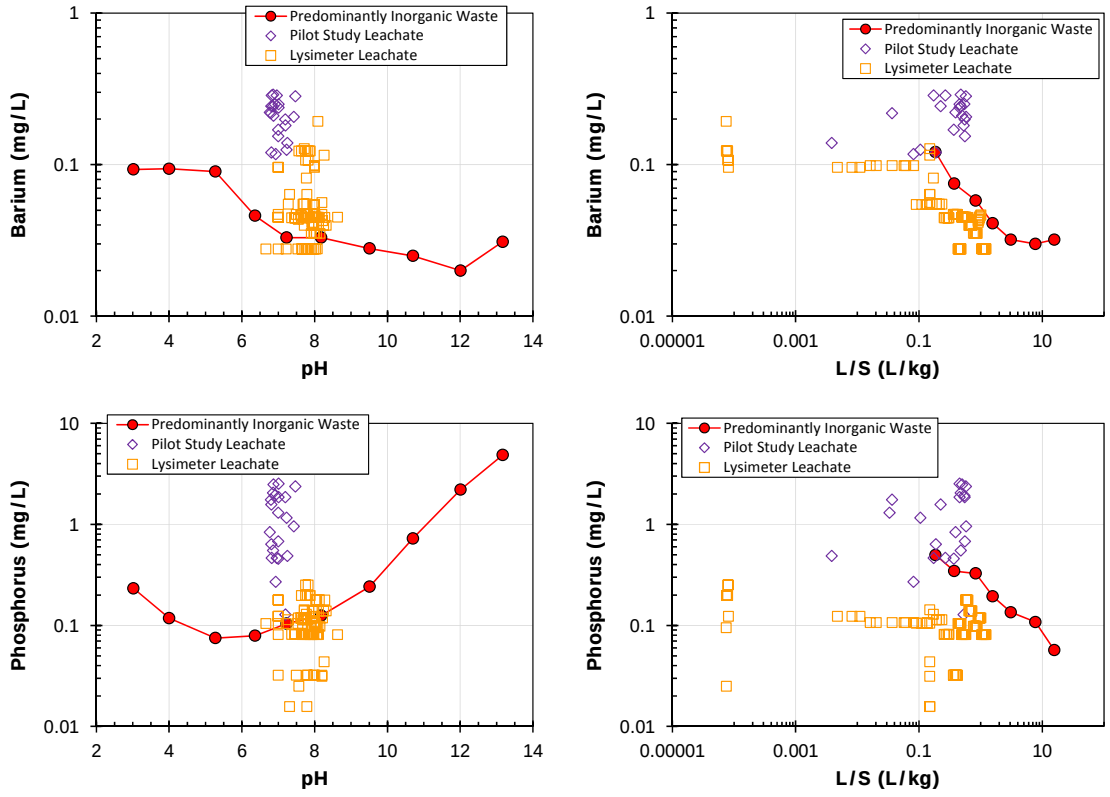


Figure 4-49. Barium and phosphorus concentrations from Nauerna landfill study.

- Increased concentrations at low L/S indicated for chloride, magnesium, potassium, and sodium (illustrated for chloride, magnesium and sodium in Figure 4-50) are observed for leachates from the field lysimeters and the pilot-scale landfill, as well as the laboratory column tests when compared to pH-dependent test results at L/S of 10 L/kg. Peak pilot concentrations for chloride are consistent with laboratory column testing L/S of 0.5 mL/g and a peak concentration 20 times that observed from pH dependent testing at L/S of 10 mL/g. For these constituents, the concentrations in eluates at low L/S from laboratory column tests provide a reasonable indicator of the maximum field leachate concentrations.

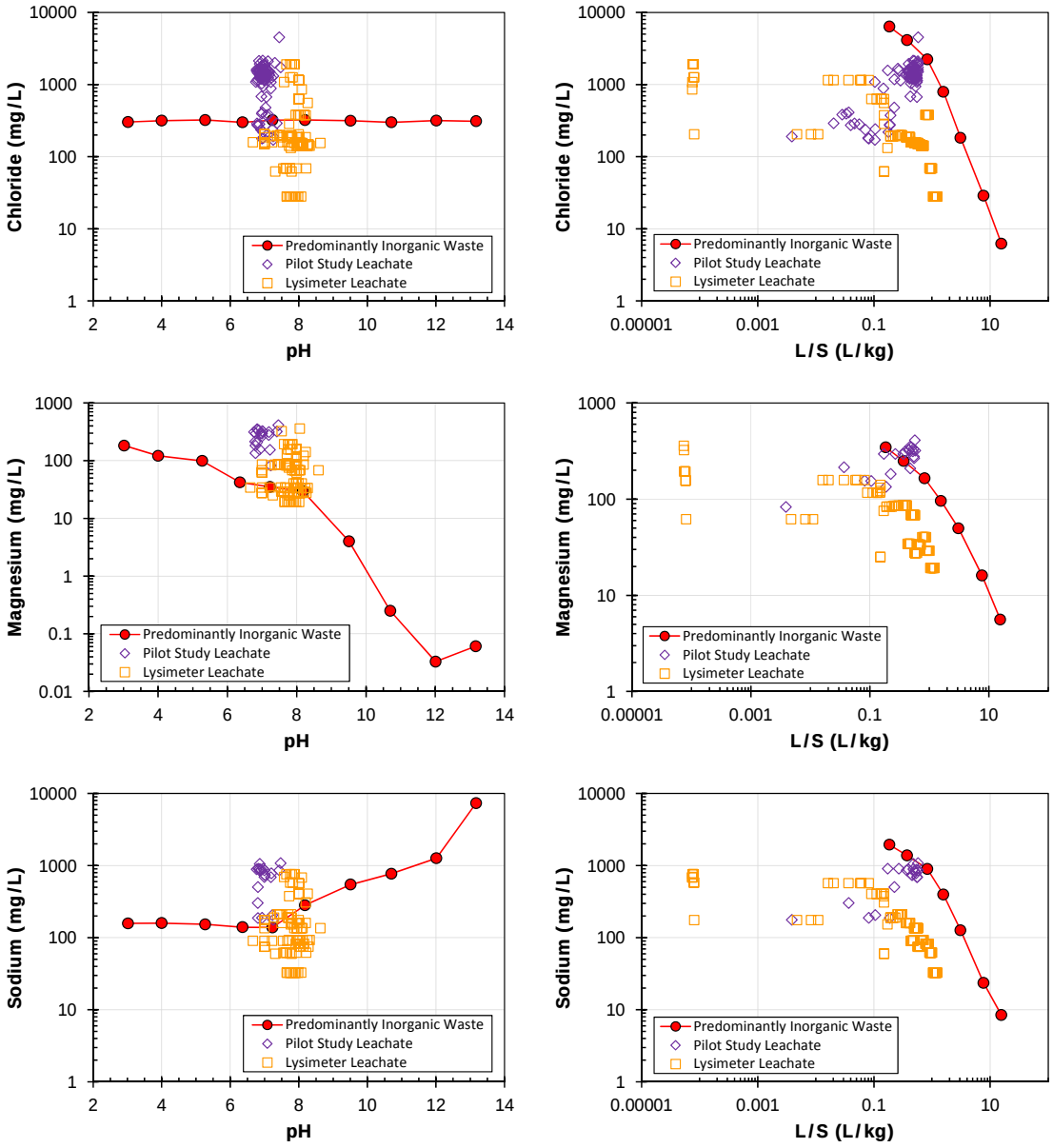


Figure 4-50. Chloride, magnesium and sodium concentrations from Nauerna landfill study.

- Field lysimeter and pilot-scale landfill leachate concentrations for cadmium and zinc are indicated by initial solubility control followed by rapid washout of the fraction of the constituent available for leaching (Figure 4-51). The initial concentrations are similar to the laboratory pH-dependent leaching test results followed by a rapid decrease in concentration with increasing L/S.

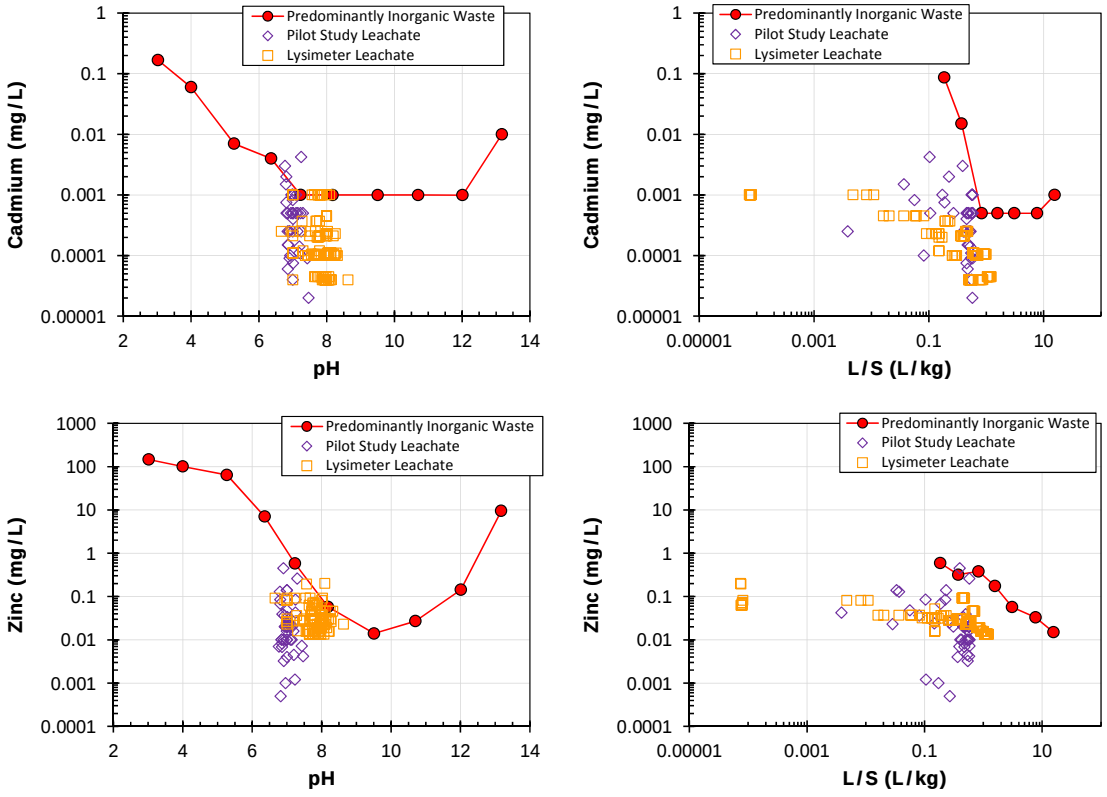


Figure 4-51. Cadmium and zinc concentrations from Nauerna landfill study.

4.7.3 Chemical Speciation Insights - Predominantly Inorganic Industrial Waste

Figure 4-52 through Figure 4-54 compare chemical speciation modeling results for Cr, Cu and Pb, respectively, with pH dependence and percolation column test results. In the left side of each figure, the chemical speciation results are compared to pH-dependent and percolation column test data (red circles and blue triangles, respectively) are compared to chemical speciation model results at L/S 10 mL/g and L/S 0.3 mL/g. The right side panels in each figure show the associate partitioning for controlling solid and aqueous phases. The phase partitioning panels for Cr (Figure 4-52) indicate that adsorption onto solid carbon or POM (dark green area) and complexation in solution with DOC (light green area) dominate the LSP at pH less than 10. This is consistent with the laboratory and field results presented in Figure 4-48 At pH greater than 10, amorphous chromium hydroxide [$Cr(OH)_3(a)$] is the prevalent solid phase. The effect of changing L/S from 10 to 0.3 mL/g on the Cr model result is relatively minor compared to other species.

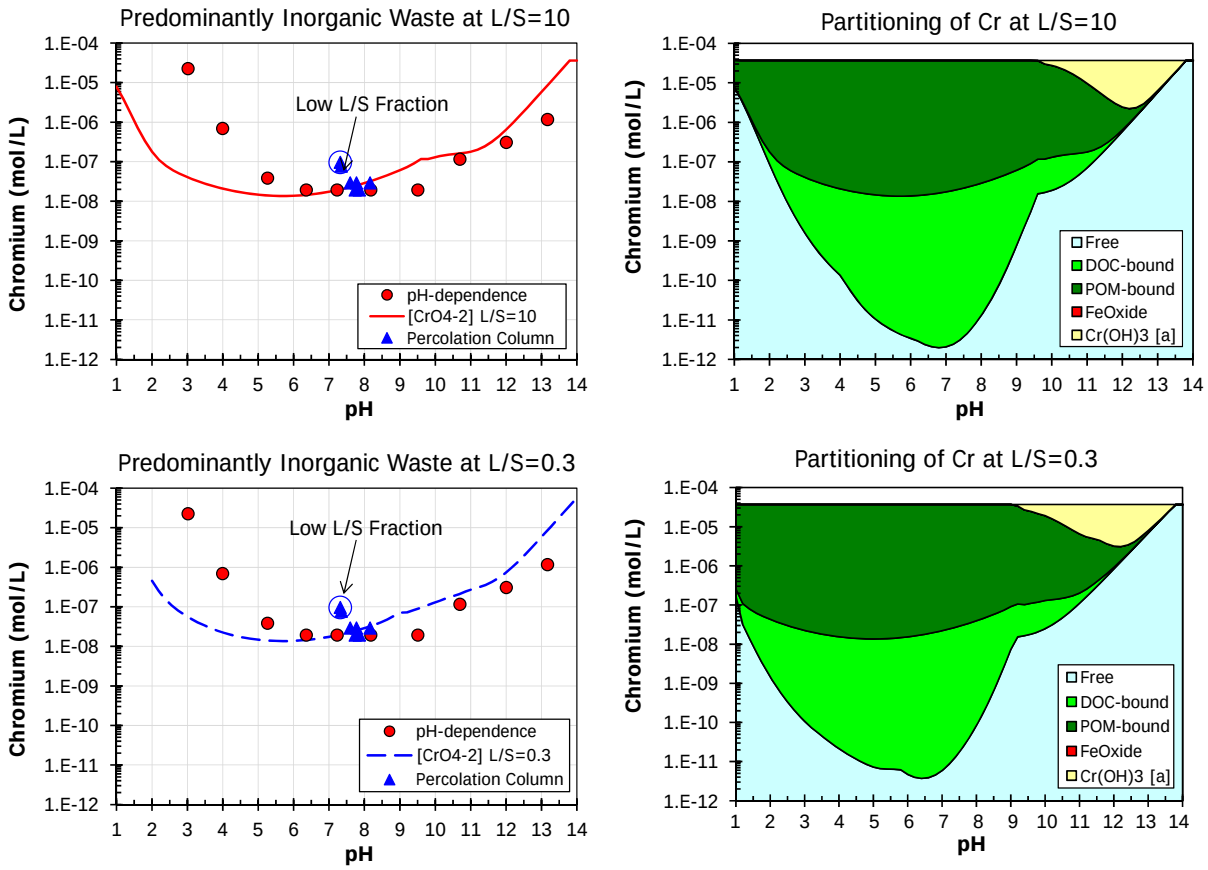


Figure 4-52. Chemical speciation modeling of chromium from predominantly inorganic industrial waste at L/S=10 and 0.3 mL/g compared to pH-dependence and percolation column data.

In an analogous manner to Cr, Cu LSP behavior (Figure 4-53) is driven by association with POM and DOC; however, the role of DOC is significantly diminished at low L/S.

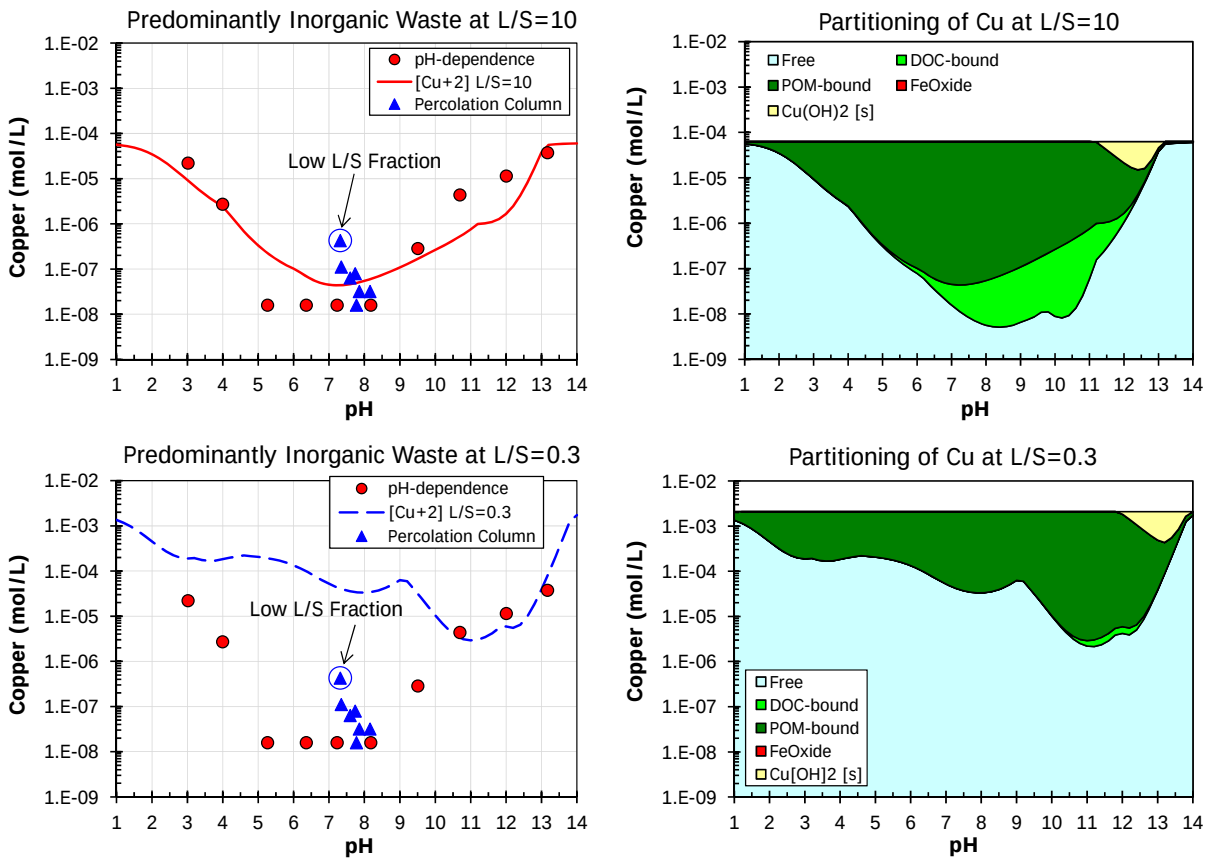


Figure 4-53. Chemical speciation modeling of copper from predominantly inorganic industrial waste at L/S=10 and 0.3 mL/g compared to pH-dependence and percolation column data.

Lead LSP (Figure 4-54) is dominated by formation of crystalline lead hydroxide [$Pb(OH)_2(c)$] (light yellow area) and hinsdalite [$(Pb,Sr)Al_3(PO_4)(SO_4)(OH)_6$] (pink area) at acidic and alkaline pH, respectively. Additionally, Pb LSP is affected by adsorption onto HFO surfaces (red area) and POM which playing significant roles at $6 \leq pH \leq 11$.

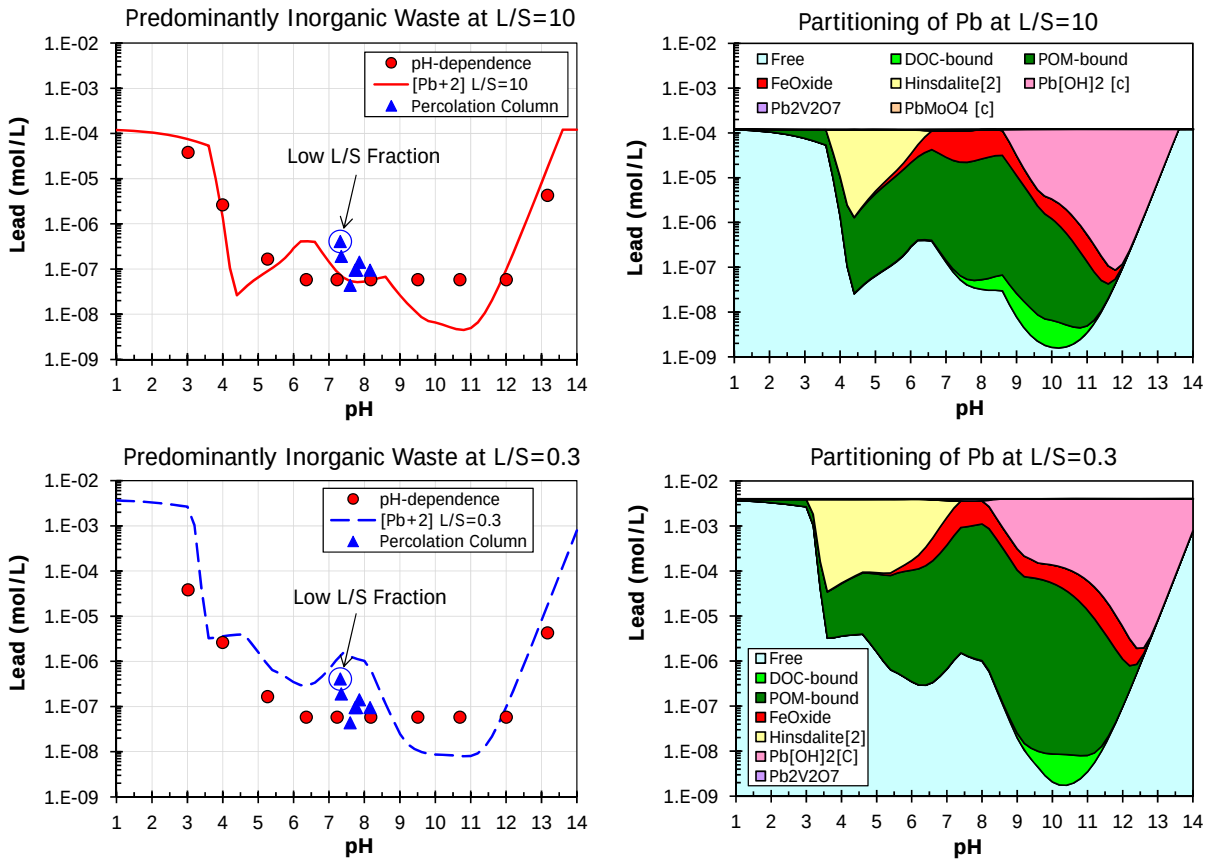


Figure 4-54. Chemical speciation modeling of lead from predominantly inorganic industrial waste at L/S=10 and 0.3 mL/g compared to pH-dependence and percolation column data.

The impact of redox condition on LSP is illustrated for Fe, Cu and total sulfur in Figure 4-55 through Figure 4-57. In each figure, chemical speciation model results are presented for mildly oxidizing (pH+pE=13), reducing (pH+pE=6) and strongly reducing (pH+pE=4) conditions. Comparison of simulations with experimental results from the pH dependence test suggests that the material is mildly reducing to slightly oxidized, most likely closer to pH+pE of 13 than 6 which is reasonable for the laboratory conditions and test method; however, the effect of increasing the reducing condition on the chemical speciation in this material is clear, as would occur to a limited extend during percolation column testing and to a greater extent under field conditions (i.e., between pH+pE of 4 and 6). As conditions become more reducing, Fe solubility increases at neutral to slightly acid pH with a corresponding loss of adsorptive surface area (see loss of ferrihydrite in Figure 4-55) while metal precipitation with sulfides (e.g, pyrite [FeS_2], blaublei [$Cu_{0.6}S_{0.8}$], galena [PbS]) becomes evident. Comparison of simulations with measurements for redox must be treated with a high degree of uncertainty because of the errors that may be introduced during sampling collection and measurement (these errors would bias experimental measurements towards more oxidizing conditions through the unintentional introduction of atmospheric oxygen).

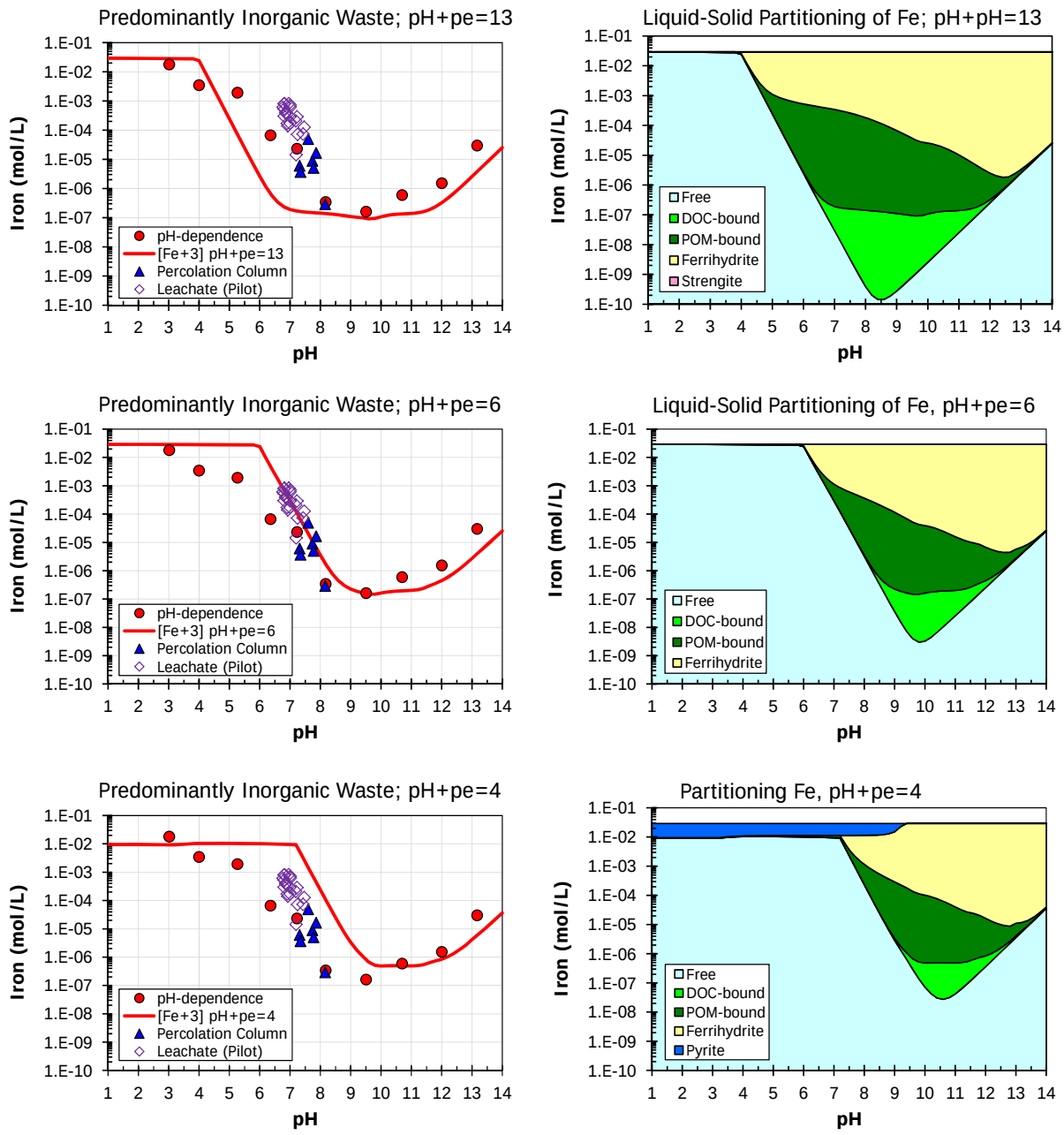


Figure 4-55. Comparing effects of oxidizing and reducing conditions - chemical speciation modeling of iron from predominantly inorganic industrial waste at L/S=10 mL/g compared to pH-dependent and percolation column laboratory data and pilot leachates.

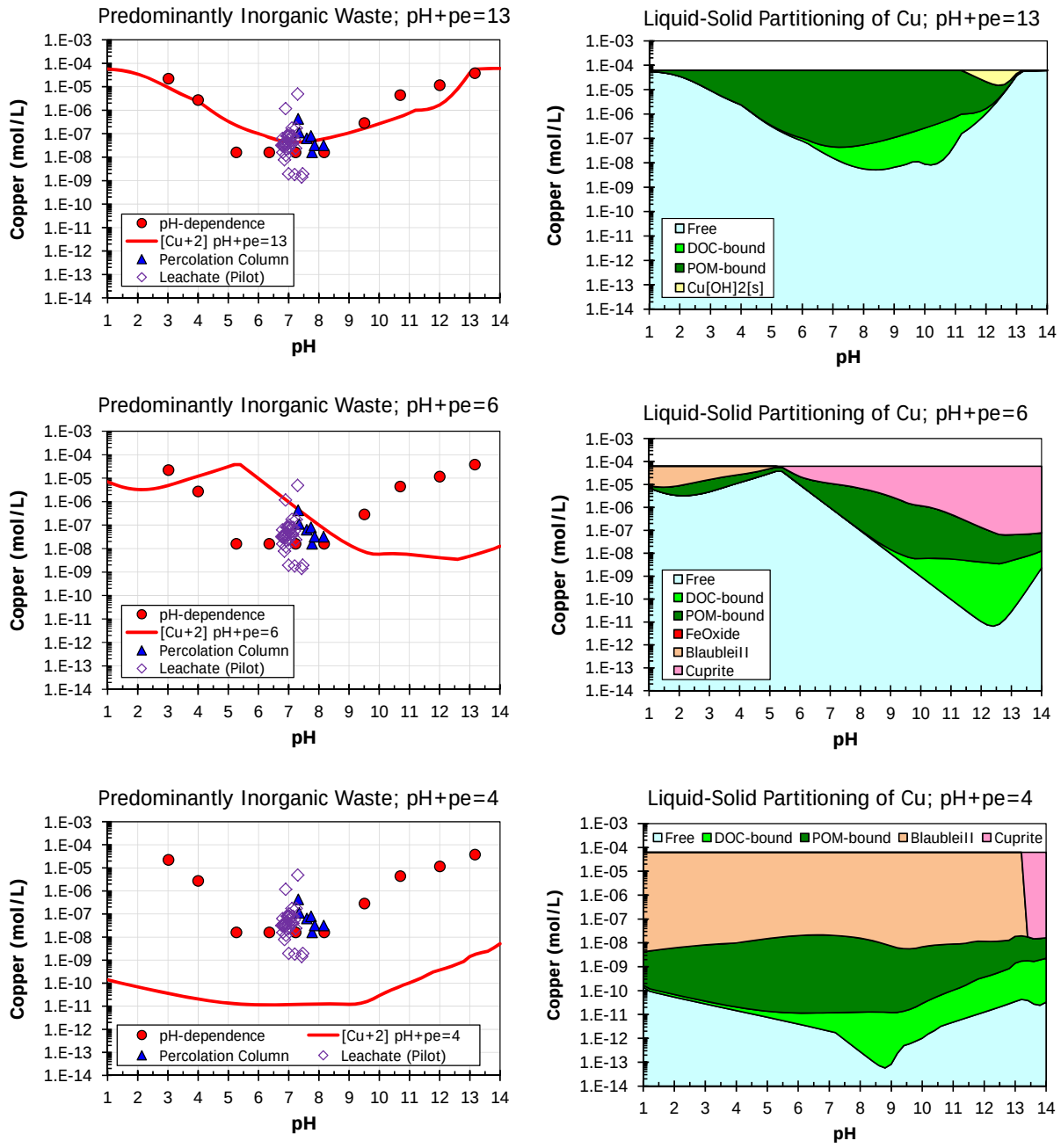


Figure 4-56. Comparing effects of oxidizing and reducing conditions - chemical speciation modeling of copper from predominantly inorganic industrial waste at L/S=10 mL/g compared to pH-dependent (PrEN 14429) and percolation column (PrEN 14405) data.

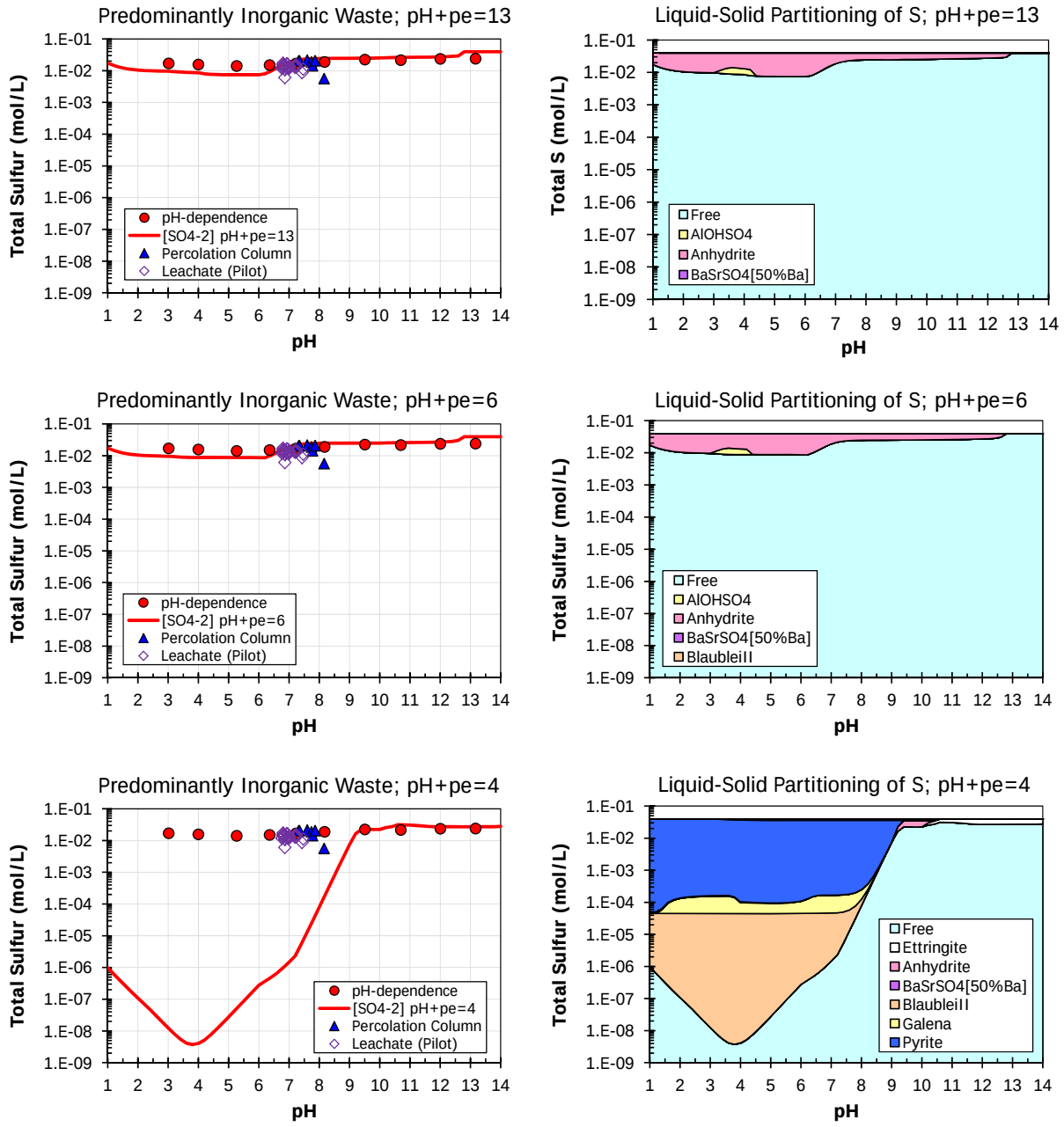


Figure 4-57. Comparing effects of oxidizing and reducing conditions - chemical speciation modeling of sulfur from predominantly inorganic industrial waste at L/S=10 mL/g compared to pH-dependent (PrEN 14429) and percolation column (PrEN 14405) data.

4.7.4 Case Summary

Case 7 focused on comparison of laboratory and field lysimeter results to leaching from a 12,000 m^3 field pilot landfill for a mixture of predominantly inorganic wastes. The applicable pH domain for the material tested was 6.5 to 8.5. In summary, these results emphasize the importance of

understanding the potential impacts of reducing conditions in the field that cannot be captured adequately during laboratory testing (but can be inferred by knowledge and simulation of chemical speciation under reducing conditions). Laboratory test conditions are likely to be oxidizing to mildly reducing, while field conditions for the same material can be mildly to strongly reducing depending on the extent of reducing constituents in the material, biogenic processes and exclusion of atmospheric oxygen. Reducing conditions in the pilot-scale landfill were most likely induced by microbial degradation of the limited amount of organic matter introduced with the waste because no reducing waste types (i.e., pyrites, slags) were included with the disposed materials. The effects of reducing conditions include (i) chemical reduction of iron resulting in loss of HFO sorptive surfaces and increased dissolved iron, (ii) increased biogenic DOC concentrations, and (iii) increased leaching of some species resulting from chemical reduction to more soluble species, loss of iron oxide sorption sites, and/or increased partitioning into the leachate by complexation with DOC. For several constituents (i.e., arsenic, barium, chromium, copper, iron, phosphorous) the maximum concentrations observed in the field pilot-scale landfill were significantly greater than maximum concentrations indicated by the laboratory column testing. These differing effects point to the need of *a priori* knowledge of the adsorption, solubilization and precipitation chemistry of different elements to interpret leaching results and the benefits of using chemical speciation modeling to facilitate interpretation. However, also shown in this case study is that leaching of many constituents was not impacted by the reducing conditions. This case also demonstrates that laboratory testing data obtained under oxidizing to mildly reducing conditions can be used in conjunction with chemical speciation modeling to provide an estimate of expected field leaching under mildly to strongly reducing conditions.

4.8 Municipal Solid Waste Landfill (The Netherlands)

4.8.1 Case Description

The pilot-scale landfill for MSW in Landgraaf, The Netherlands, was established to evaluate the biodegradation of organic matter-rich waste by leachate renewal and recycling. The test cell had a volume of 45,000 m^3 and was filled with a mixture of sewage sludge, construction and demolition (C&D) waste, MSW, industrial waste, car shredder waste, foundry sand, and soil cleanup residue (Table 4-3). Samples of all the wastes accepted at the landfill were sampled proportionally to obtain a representative mixture of the waste in the test cell for laboratory studies. The material collected was homogenized and reduced in volume to manageable quantities by cone and quartering. During the filling of the test cell, lateral infiltration pipes were placed to facilitate the efficient wetting of the waste. During the entire operation of the test cell, leachate samples were collected and analyzed for major, minor and trace elements, as well as parameters to monitor the degradation of waste, for example gas composition, chemical oxygen demand (COD), biological oxygen demand (BOD), DOC. Preparation for the pilot program started in 2000. The actual leachate collection started when the pilot was completely filled in May 2002 (Luning et al., 2006; van der Sloot et al., 2008a).

Table 4-3. Waste composition of the landfilled material in the test cell at Landgraaf (Luning et al., 2006).

Material	Eural Code*	Fraction of Total (%)	Quantity (tonnes)	Fraction-on dry basis (%)	Dry Matter (tonnes)	Water as moisture content (tonnes)
MSW	20.30.01	34.4%	9,000	36%	5,300	3,700
Industrial Waste	20.03.01	11.5%	3,000	12%	1,400	1,600
Shredder Waste	19.10.04	18.3%	4,800	19%	3,800	1,100
Cleaning Residue	19.12.09	6.9%	4,700	19%	3,700	1,000
Foundry Sand	10.09.08	18.3%	1,300	5%	1,300	13
C&D Waste	19.12.09	7.3%	1,900	8%	1,600	330
Sewage Sludge	19.08.12	3.2%	380	2%	260	120
Total		**100%**	**25,200**	**100%**	**17,400**	**7,800**

Note: * European waste code

The shape and layout of the drains and infiltration pipes is given in Figure 4-58. Nine leachate drainage pipes were installed in the bottom of the test cell, which drained into six collection wells. A buffer tank was used for recirculation of leachate, which was connected with the lateral infiltration pipes located at two depths in the landfill test cell. Different cycles of infiltration and discharge of leachate were used during the operation of the cell.

The pH-dependence test (CEN/TS 14429) and the percolation column test (CEN/TS 14405) were carried out on subsamples of the waste mixtures collected and homogenized during initial filling of the test cell. After eight years of operation, core samples of the waste in the landfill were obtained and composited into a sample subjected to pH-dependence and percolation testing using the same

procedures. In addition to the core composite, material from individual cores taken after eight years of operation were subjected to a single step batch leaching procedure in demineralized water at L/S 10 L/kg (EN 12457-2).

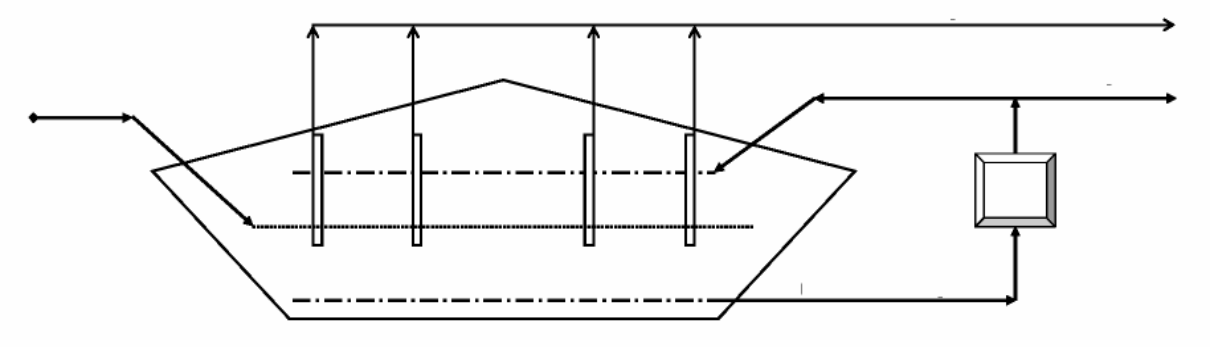


Figure 4-58.Cross-section schematic layout of the landfill test cell with leachate collection drains and infiltration pipes.

4.8.2 Results and Discussion

A complete set of figures illustrating results from the laboratory pH-dependent leaching tests and column tests along with results from the pilot-scale landfill test cell is provided in Appendix F. Comparisons are presented between laboratory test results and field results for the following datasets:

- initial composited waste sample (green triangles with a dashed line) using pH-dependence and percolation column tests,
- field materials composited from landfill cores taken after eight years (blue squares with solid line) using pH-dependence and percolation column tests,
- individual core samples (grey diamonds) using single batch extraction in deionized water at L/S of 10 L/kg
- leachate collected from the landfill (red, open circles).

For each analyte, data are presented as a function of pH (left) and as a function of L/S (right). Leachate concentrations are plotted as a function of leachate pH or as a function of the cumulative L/S of leachate from the landfill (based on collected leachate volumes).

In the context of the other cases discussed in this report, the MSW landfill has the greatest proportion of biodegradable organic matter and therefore has the greatest amount of DOC in the leachate as well as the most chemically reducing conditions within the test material. Interpretation of the constituent concentrations in the landfill test cell leachate is complicated by the recirculation of collected leachate back into the landfill. Leachate recirculation induces higher rates of microbial biodegradation, furthering reducing conditions, and also results in accumulation of soluble constituents in the leachate, rather than washing them out and observing declining concentrations as leaching from the system progresses.

The following are notable relationships between leaching tests and field results for specific constituents:

- Results for pH, DOC and iron are presented in Figure 4-59 and Figure 4-60. The pH as a function of L/S for the column test on the initial composite material indicates near neutral pH (i.e., 7.5) initially, followed by a temporary increase to 8.0, followed by a decrease to 7.0, indicative of the onset of acetogenesis as part of MSW biodegradation. In contrast, the column test on the composite of core samples after eight years was initially near neutral and then increased to pH 8.5 followed by a slight decrease in pH. This behavior was most likely the result of washout of accumulated biogenic volatile fatty acids. DOC and iron concentrations in the eluates further support this assumed behavior (note the increase in dissolved iron at L/S of 10 L/kg for the column test on the initial composite material, signaling the onset of strictly anaerobic biodegradation and strongly reducing conditions).

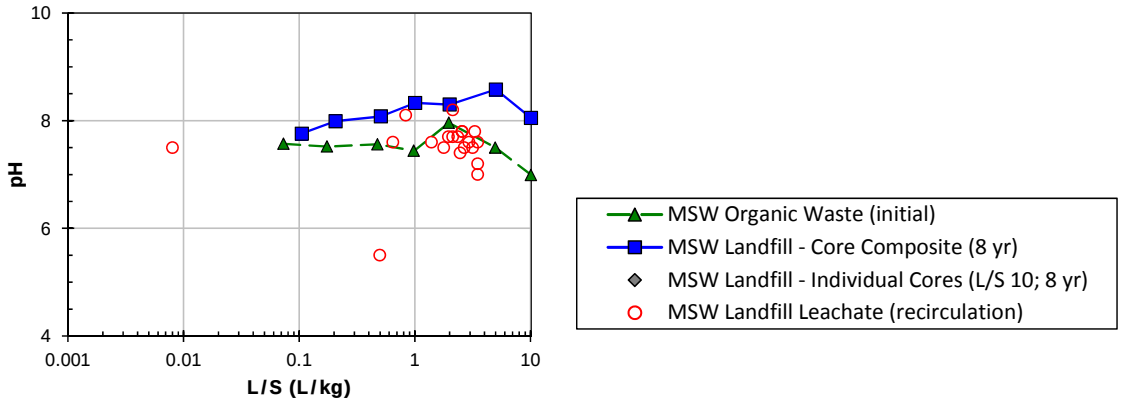


Figure 4-59. Eluate pH from leachates from the Landgraaf MSW landfill (red circles) compared to the pH from percolation column testing for initial material and landfill cores (solid symbols).

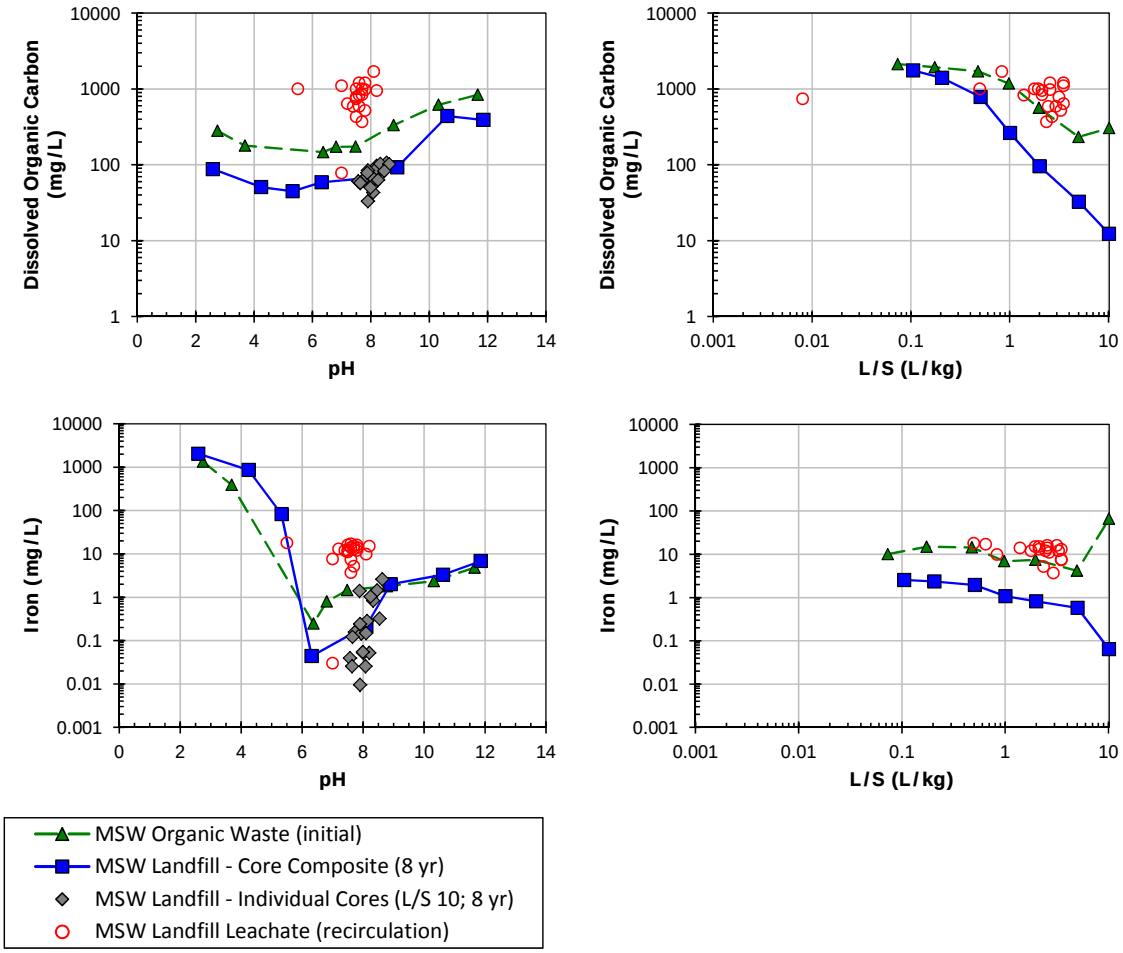


Figure 4-60. Comparison of DOC and iron concentrations from Landgraaf landfill leachates (red circles) with laboratory data (solid symbols) as a function of pH (left) and L/S (right).

- Maximum chloride, potassium and sodium concentrations in the initial column test eluates were good indicators of maximum landfill leachate concentrations, which were a factor of approximately 20 greater than observed in laboratory pH-dependent test eluates (Figure 4-61). This phenomenon was expected because the concentrations measured in leachate and laboratory test eluates reflect a similar mass per volume of constituent dissolved but at different L/S conditions. Unlike the values observed for other cases in this report, the landfill leachate concentrations did not decrease with increasing L/S because of leachate recirculation.

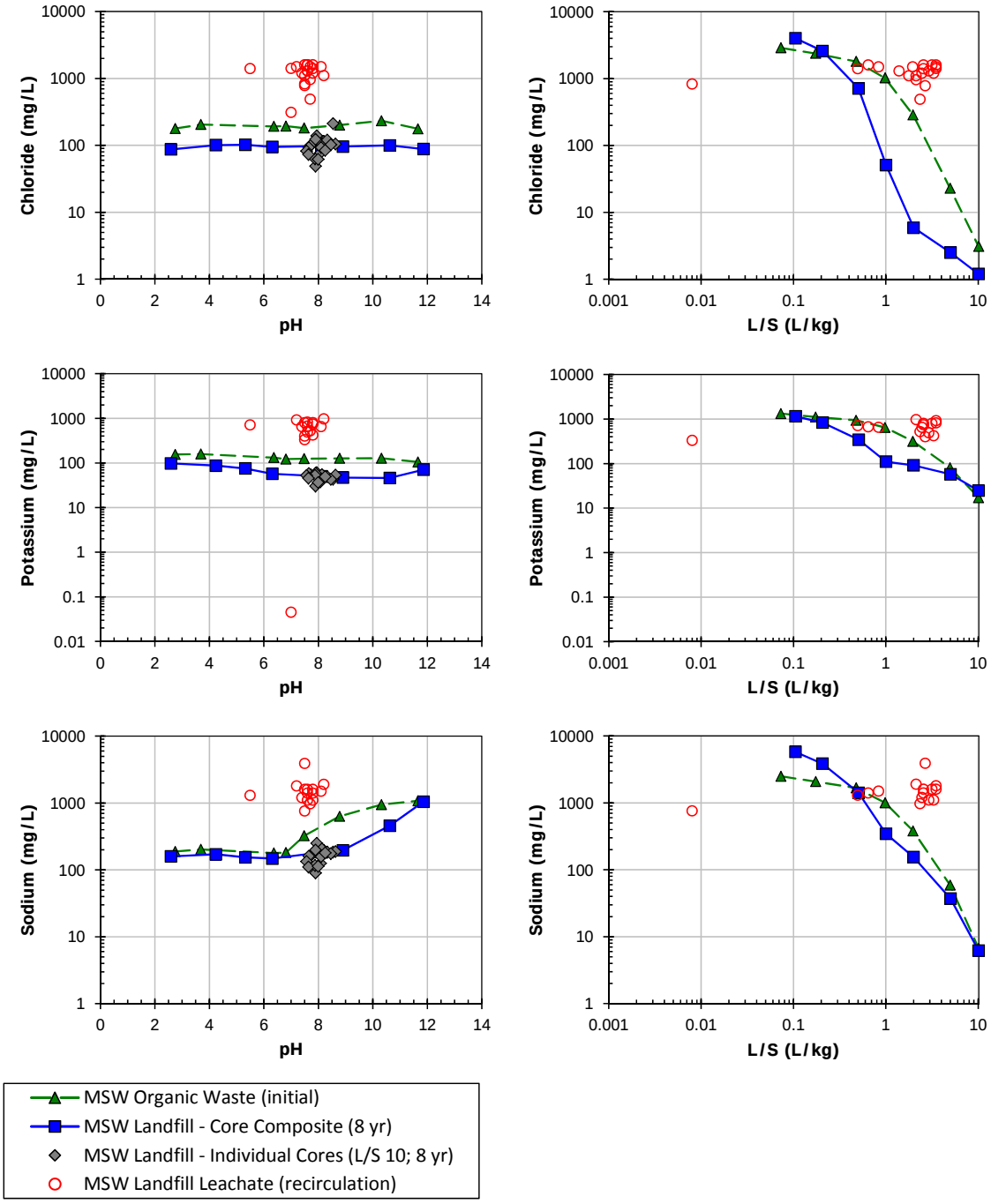


Figure 4-61. Concentrations of highly soluble constituents (chloride, potassium and sodium, upper, middle and lower graphs, respectively) from laboratory test eluates and leachate from the landfill test cell.

- Aluminum, calcium, nickel and zinc concentrations in landfill leachate were consistent with concentrations measured in pH-dependent test eluates, indicating solubility controlled

leaching (i.e., a saturated solution with respect to the constituent at the leachate pH); results for aluminum, calcium and nickel are provided in Figure 4-62).

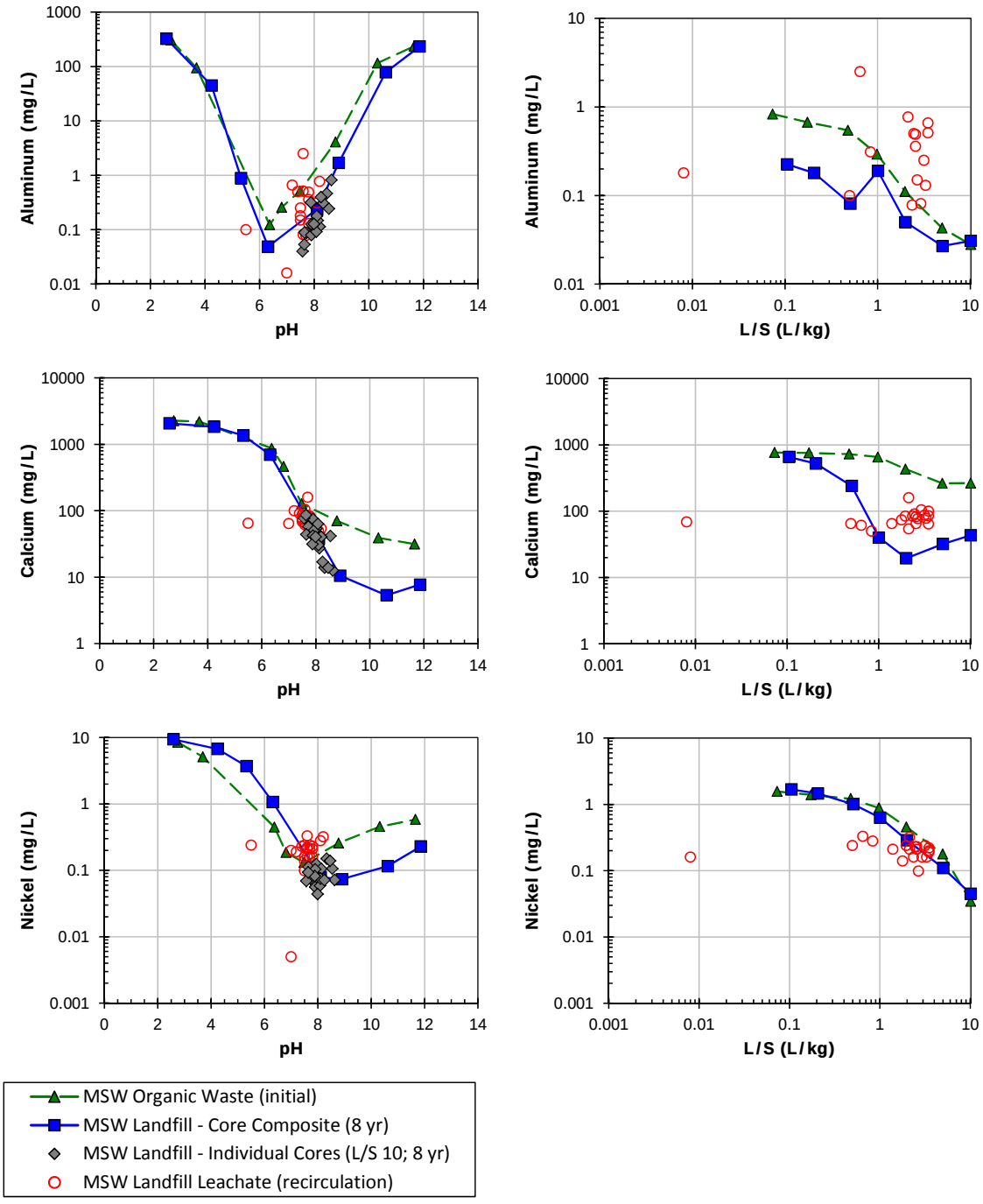


Figure 4-62. Examples of solubility-controlled leaching whereby the measured concentration in leachate and laboratory column tests is closely aligned with results from the pH-dependent leaching test (illustrated by aluminum, calcium and nickel, upper, middle and lower graphs, respectively).

- Increased concentrations of chromium in leachate from the landfill test cell are most likely the result of complexation of Cr^{+3} with DOC (Figure 4-63, top). Increased concentrations of arsenic in leachate from the pilot-scale landfill are most likely the result of loss of arsenic adsorption sites on hydrated iron oxide surfaces because of reduction and solubilization of iron (Figure 4-63, bottom).

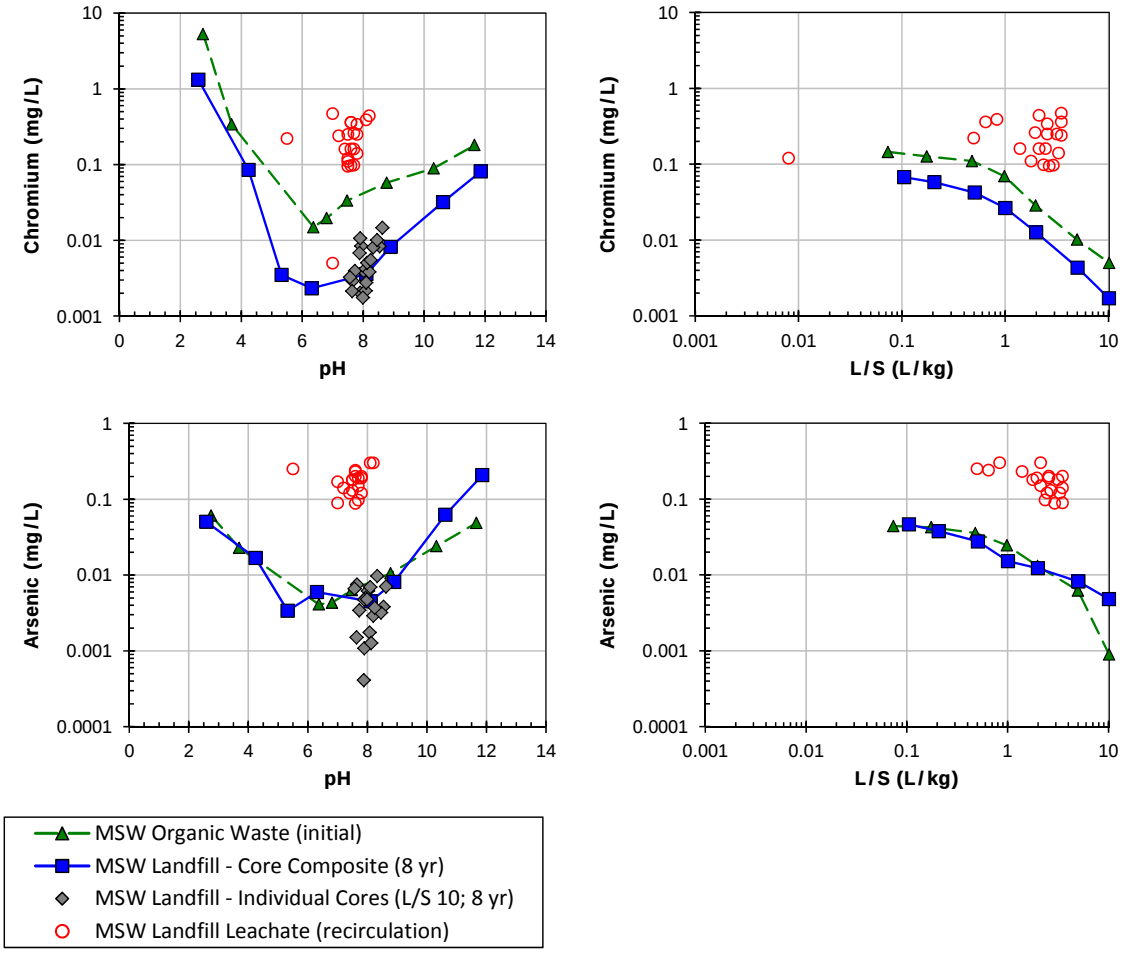


Figure 4-63. Complex interactions as a result of reducing conditions are illustrated by chromium (DOC complexation) and arsenic (loss of iron adsorption), resulting in higher leachate concentrations than indicated by pH-dependent and laboratory column tests.

In contrast, increased barium leachability (Figure 4-64, top) in leachate from the pilot-scale landfill is most likely linked to increased solubilization of phosphate under reducing conditions (Figure 4-64, bottom).

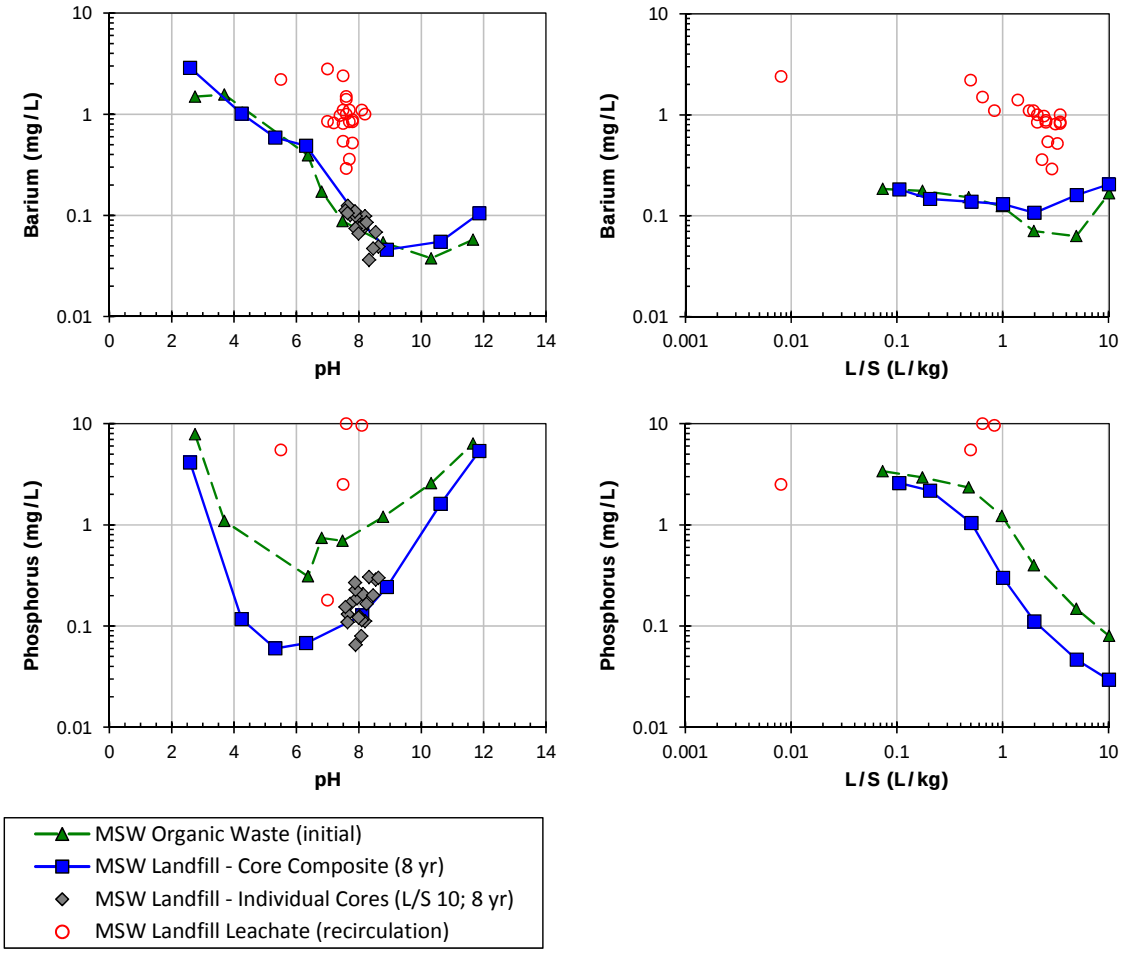


Figure 4-64. Potential relationship between barium (upper graph) and phosphorus (lower graph) solubilization under reducing conditions, resulting in higher leachate concentrations than indicated by pH-dependent and laboratory column tests.

Vanadium also had higher concentrations in the leachate from the pilot scale landfill under reducing conditions than observed from the lysimeters and the laboratory column tests (Figure 4-65). High vanadium is likely due to a shift in oxidation state from V^{+5} to V^{+4} (see Section 2.2.3).

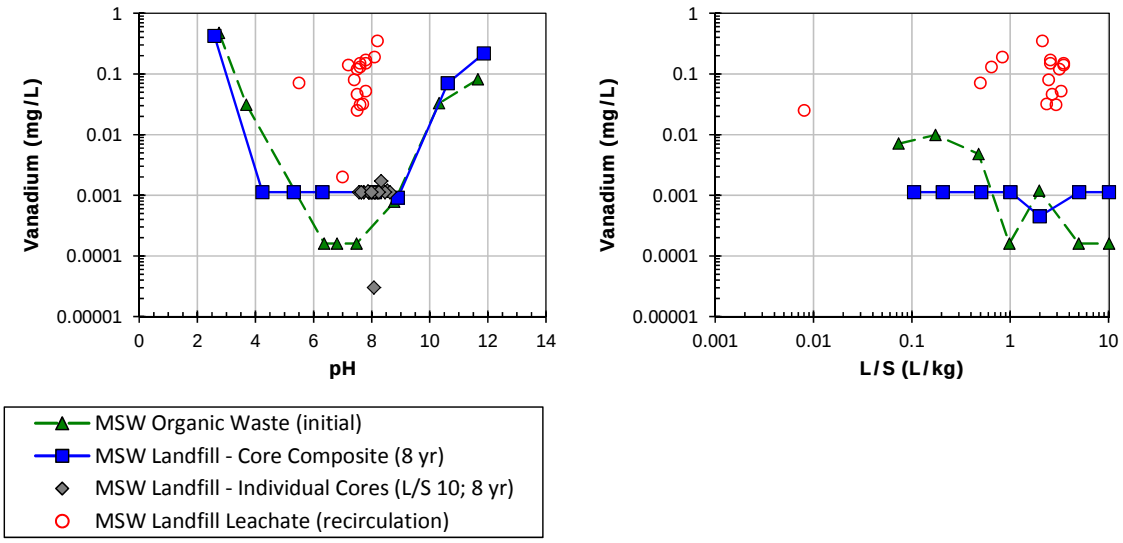


Figure 4-65. Increased vanadium concentrations under reducing conditions, likely the result of chemical reduction of V^{+5}, also resulting in higher leachate concentrations than indicated by pH-dependent and laboratory column tests.

For these constituents, the maximum concentrations observed in the field pilot-scale landfill were significantly greater than maximum concentrations indicated by the laboratory column testing. These differing effects point to the need of *a priori* knowledge of the adsorption, solubilization and precipitation chemistry of different elements to interpret leaching results, and the benefits of using chemical speciation modeling to facilitate interpretation (see Section 2.2.3 and Section 3).

- The strongly reducing conditions existing in the MSW landfill also favor the conversion of sulfate to sulfides with the concurrent precipitation of some metal sulfides. Decreasing sulfur in solution and leachable sulfur from composite samples is a reflection of conversion from sulfate (soluble) to sulfide (insoluble) as a result of biodegradation processes (Figure 4-66, top). The effect of these processes competing with increased solubilization by either DOC complexation for copper or chloride complexation for cadmium results in decreasing concentrations with increasing L/S when leachate results and laboratory column results on eight-year-old material to laboratory (pH-dependent and column testing) on the initial landfill composite (Figure 4-66, middle and bottom).

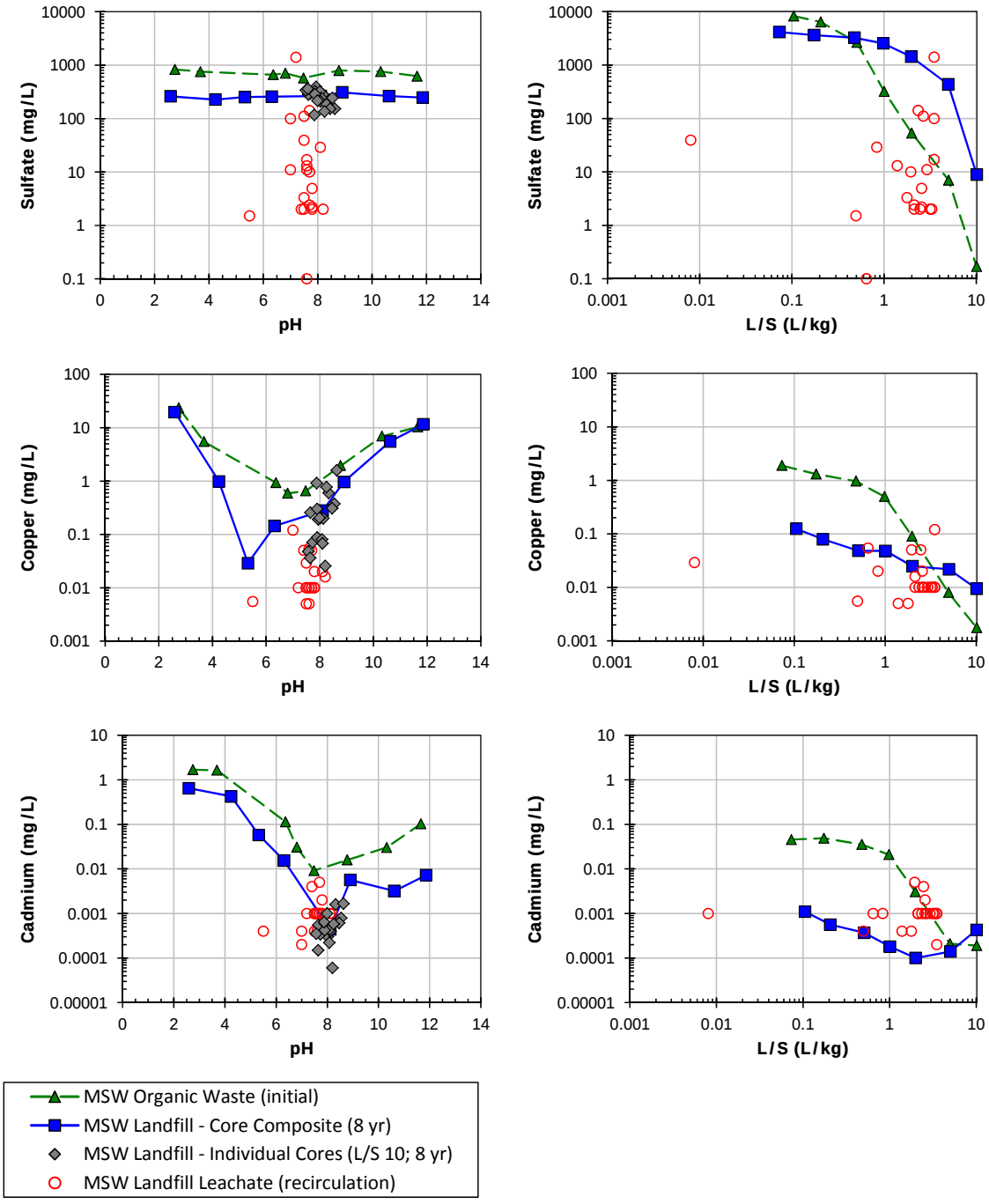


Figure 4-66. Decreasing sulfur in leachate from the landfill test cell and lower initial sulfate concentrations in eluates from laboratory column testing on core samples after eight years indicates conversion of sulfate to sulfides (top) with decreased solubility of copper (middle) and cadmium (bottom).

4.8.3 Chemical Speciation Insights – Municipal Solid Waste Landfills

An extensive review MSW leachate compositions is available (Robinson, 1995). MSW is anticipated to initially be at oxidizing (i.e., pH+pE=13-15) because of open air handling combined with initial biodegradation processes. However, under landfill conditions gradients from mildly reducing to strongly reducing conditions (i.e., pH+pE=5.5 as indicated by sulfate reduction) are present. Thus, chemical speciation modeling of pH dependent test results are simulated at pH+pE=13 (Figure 4-67 and Figure 4-68), while percolation column conditions can rapidly evolve from oxidizing to reducing conditions because of inherent microbial activity (initially aerobic to sulfate reducing or methanogenic) and field conditions are simulated at reducing conditions. Figure 4-67 (Cd, Ni, Pb, Zn) and Figure 4-68 (sulfate, Ca, Cr, F) left side graphs compare simulation of pH dependent leaching at L/S=10 (red line) and 0.3 mL/g (blue dashed line) with pH dependent leaching test data (red dots) and percolation column data (blue triangles) and simulated speciation at L/S=10 mL/g. As indicated with earlier examples, areas where the simulated results at L/S=10 and 0.3 mL/g coincide are anticipated to be solubility controlled pH domains for the indicated element. Domains where simulated concentrations L/S=0.3 mL/g are much greater than simulated concentrations at L/S=10 mL/g can be expected to exhibit higher concentrations in initial percolation column eluates, as indicated for sulfate results. Decreasing concentrations of Cd, Ni, Pb and Zn during the progression of column leaching is a consequence of depletion of the soluble species at near neutral pH, either because of limited available content or transformation under reducing conditions such as formation of a metal sulfide precipitate (i.e., Cd, Ni, Pb, Zn).

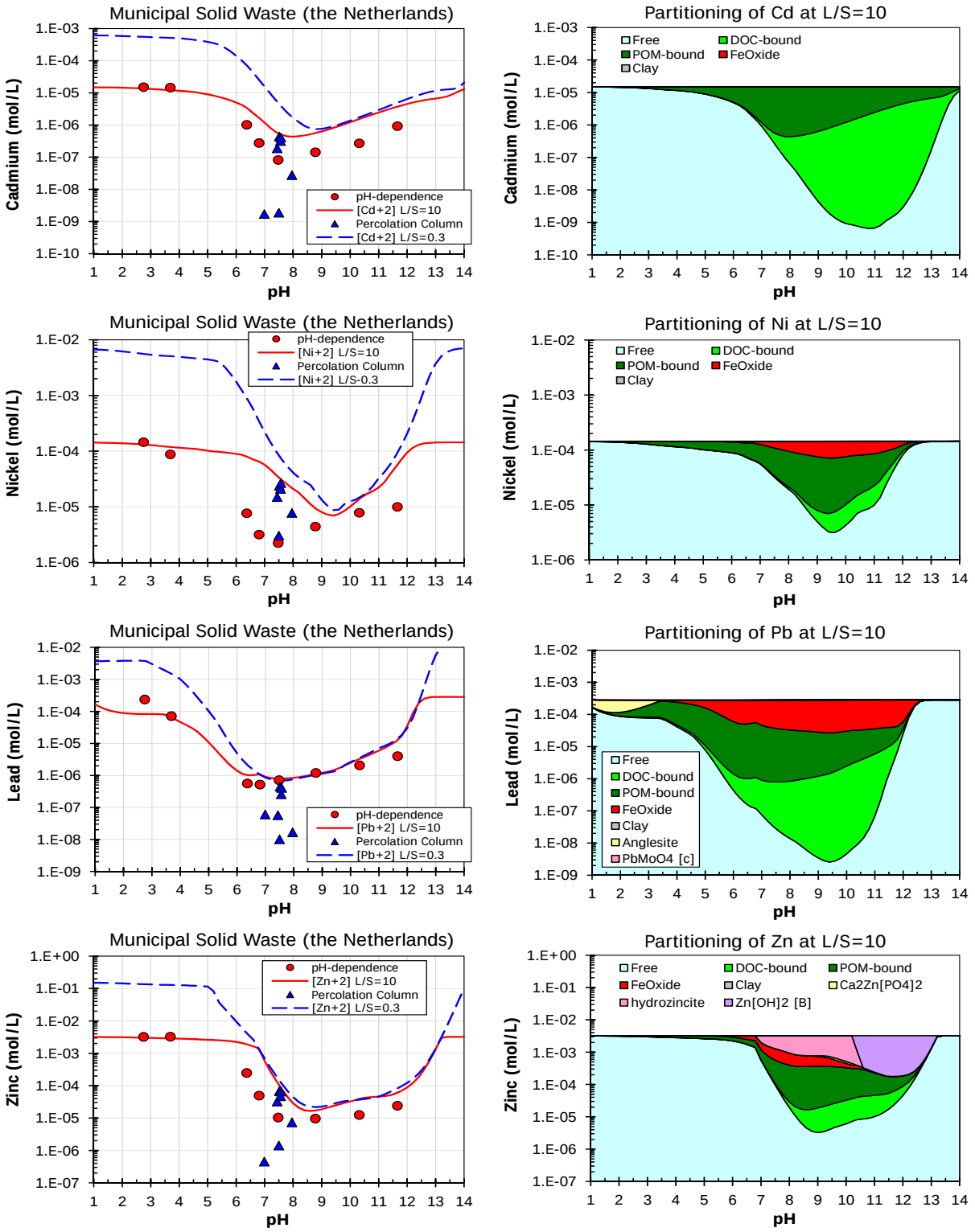


Figure 4-67. Chemical speciation modeling under reducing conditions (pH+pE=13) of municipal solid waste (the Netherlands) compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

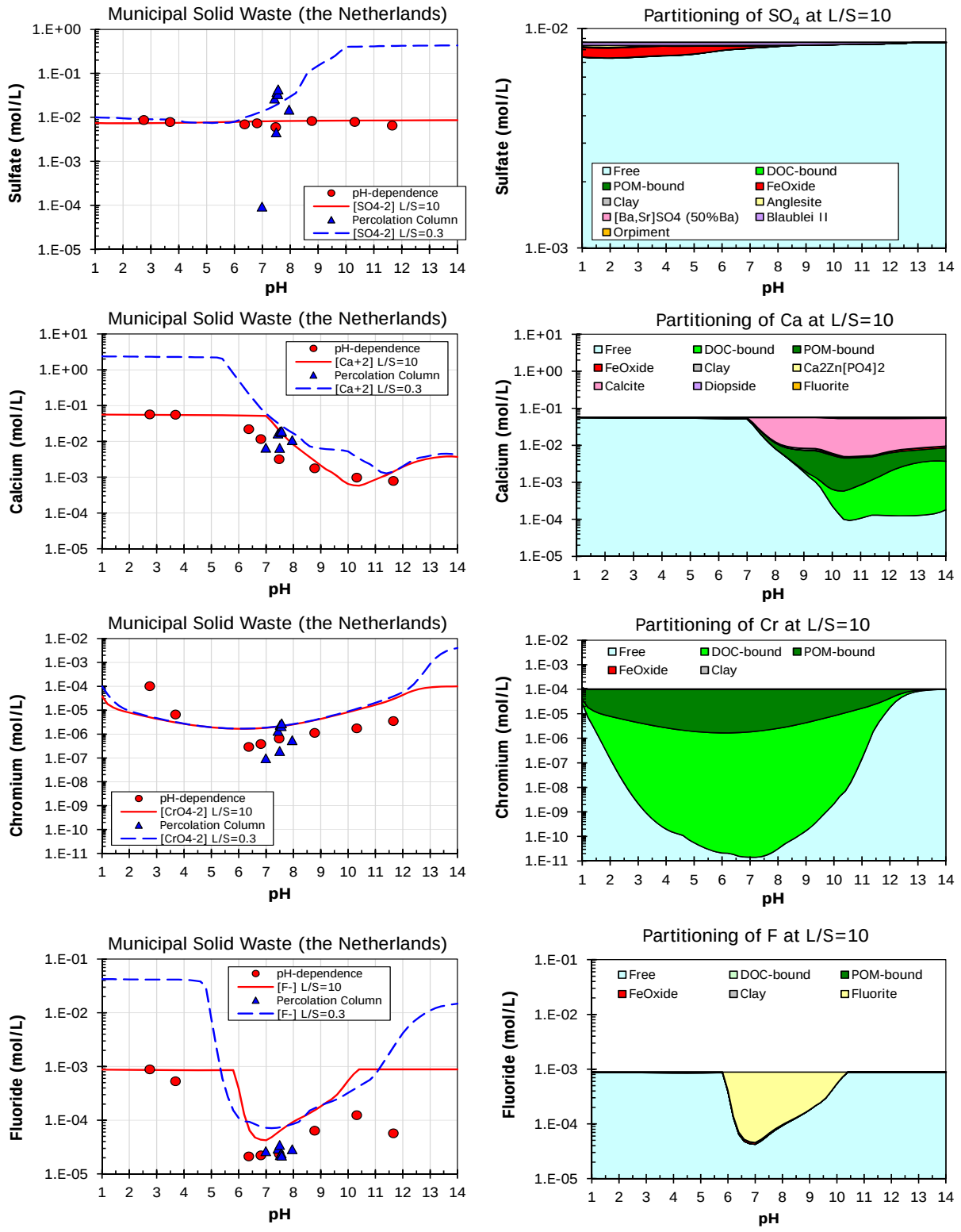


Figure 4-68. Chemical speciation modeling under reducing conditions (pH+pE=13) of municipal solid waste (the Netherlands) compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

The upper panels of Figure 4-69 and Figure 4-70 present the changes in simulated Fe and Cu LSP, respectively, as a function of pH+pE between 13 and 4. The left side panels show the model conducted at L/S=10 while the right side panels shown the model conducted at L/S=0.3. In Figure 4-69, Fe solubility increases at neutral to slightly acid pH values with progressively more reducing conditions in response to the greater solubility of Fe^{2+} compared to Fe^{3+}. Cu solubility (Figure 4-70) decreases with more reducing conditions because of the formation of blaublei [$Cu_{0.6}S_{0.8}$] and cuprite [Cu_2O]. The lower panels in these figures present simulated LSP at L/S=10 indicating dominant speciation in aqueous and solid phases (left side) and fractional distribution of controlling solid phases (right side). POM and DOC association are important contributors to overall observed LSP for both Fe and Cu. Pyrite is an important Fe solid phase at strongly reducing conditions, while the demarcation between the formation of blaublei and cuprite shifts to a higher pH as more strongly reducing conditions are simulated.

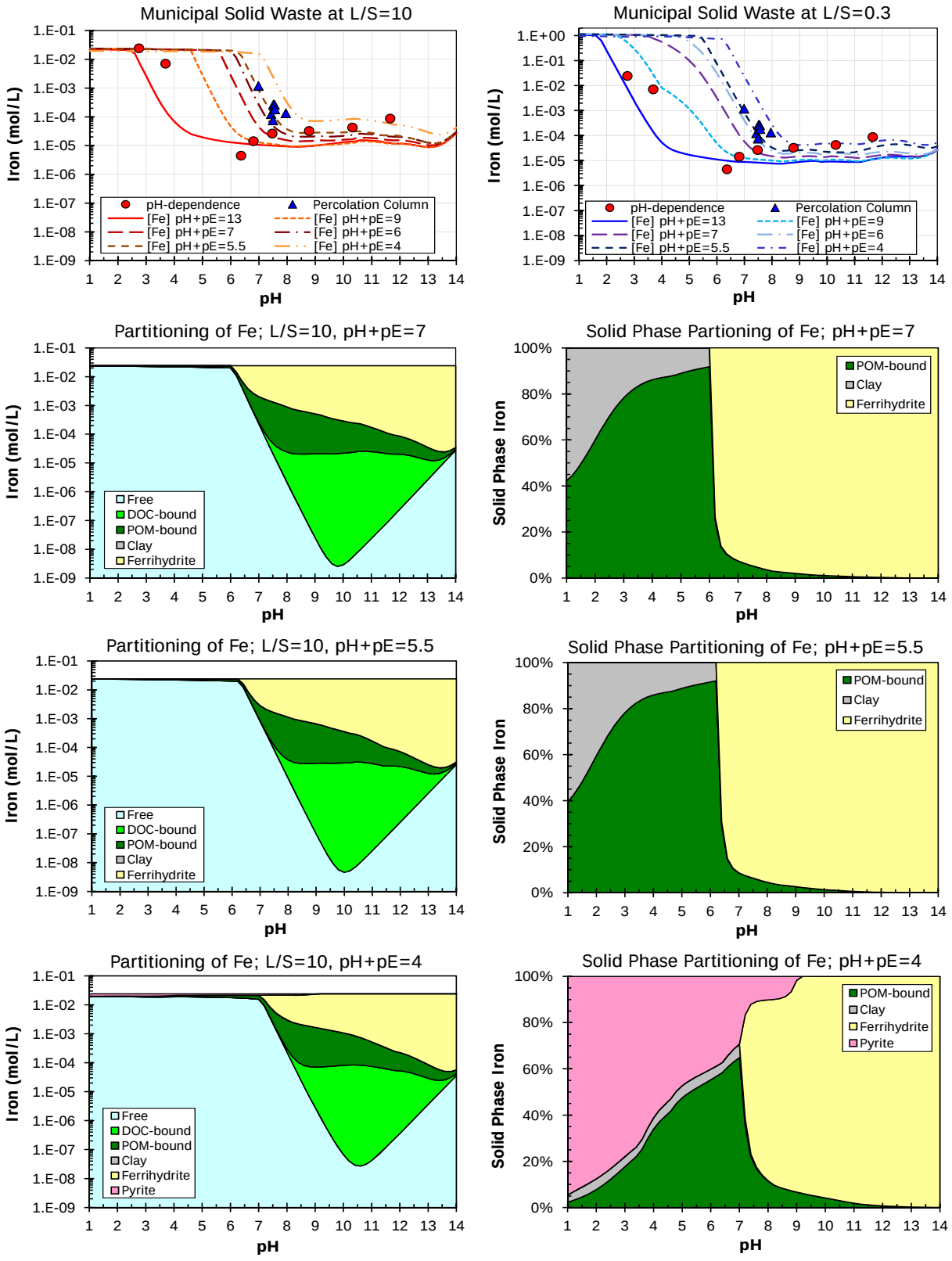


Figure 4-69. The effect of oxidation-reduction (redox) on the chemical speciation of iron from municipal solid waste (the Netherlands).

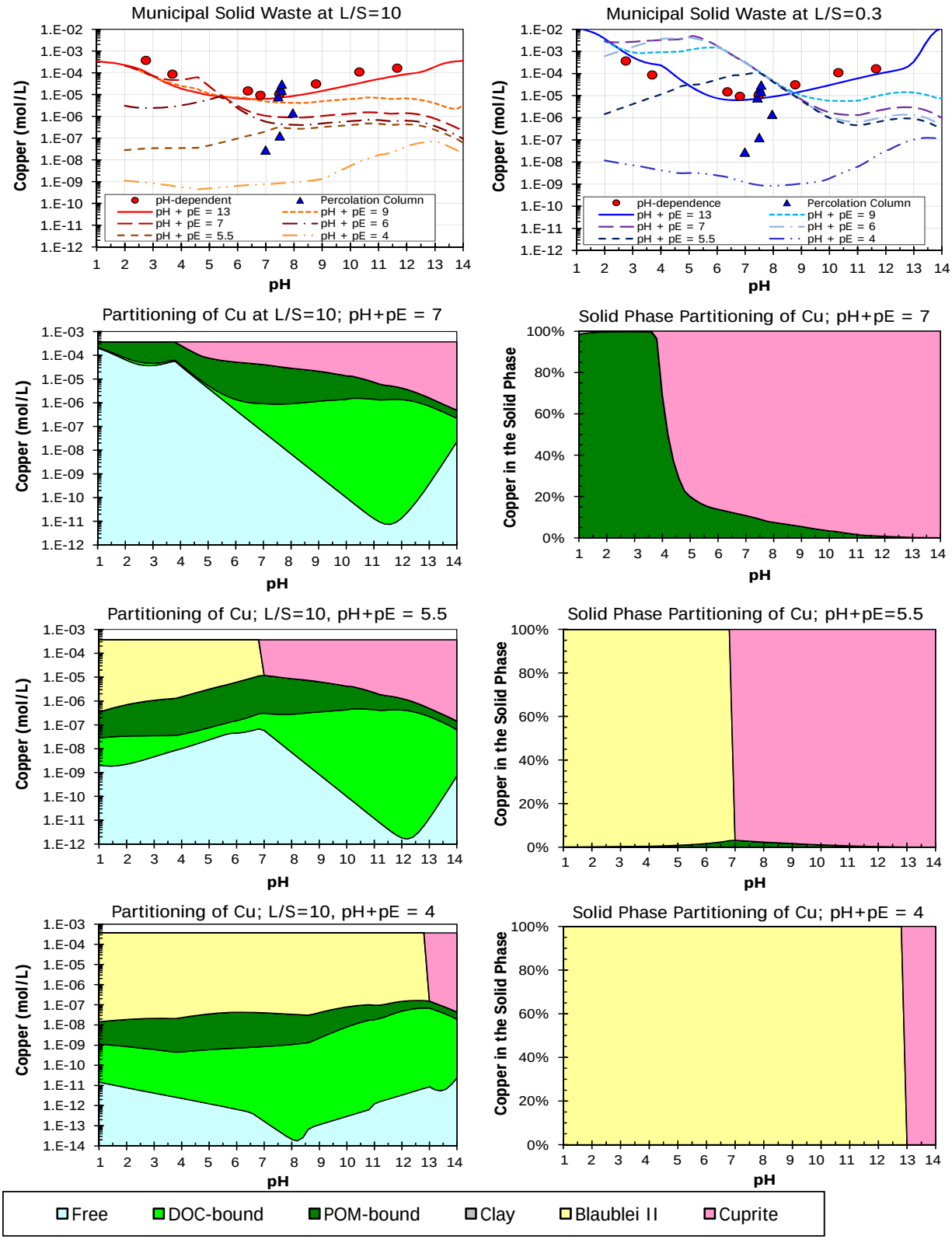


Figure 4-70. The effect of oxidation-reduction (redox) on the chemical speciation of copper from municipal solid waste (the Netherlands).

Figure 4-71 and Figure 4-72 illustrate that impact of biodegradation that results in removal of POM and DOC from the system under initially oxidizing conditions (pH+pE=13) and under reducing conditions (pH+pE=5.5), respectively. Progressive loss of DOC decreases DOC-associated Cu in solution and overall Cu solubility, shifting increasing amounts of Cu to adsorption to TOC and HFO under oxidizing conditions (Figure 4-71) while resulting in amounts of blaublei and cuprite under reducing conditions (Figure 4-72). Also note that initial percolation column eluate concentrations coincide with the simulation under oxidizing conditions with high POM and DOC concentrations while the final percolation column eluate concentrations coincide with reducing conditions where POM and DOC have been substantially depleted.

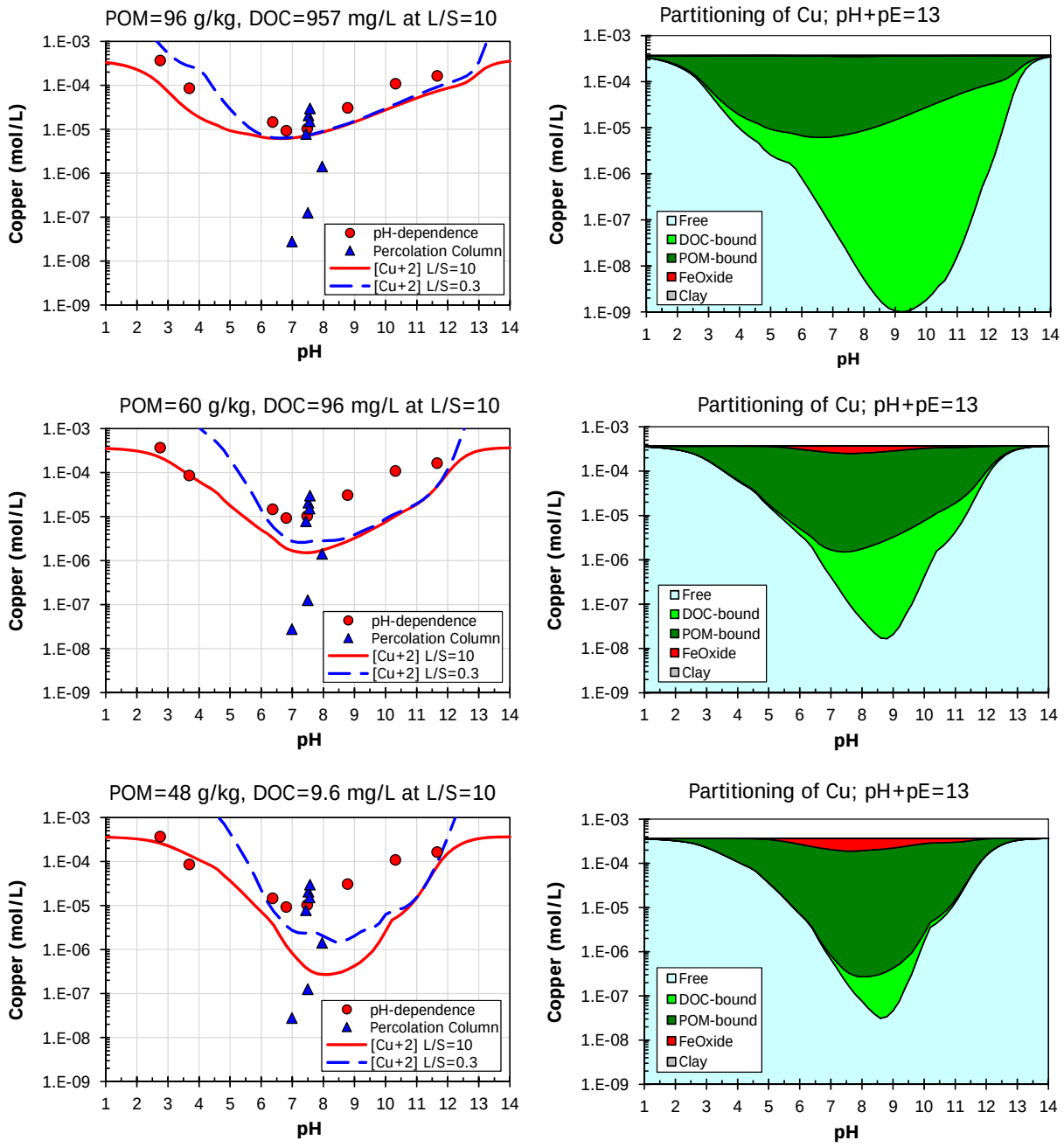


Figure 4-71. Chemical speciation of copper at pH+pE=13 during degradation of municipal solid waste (the Netherlands) through loss of POM and DOC under oxidizing conditions.

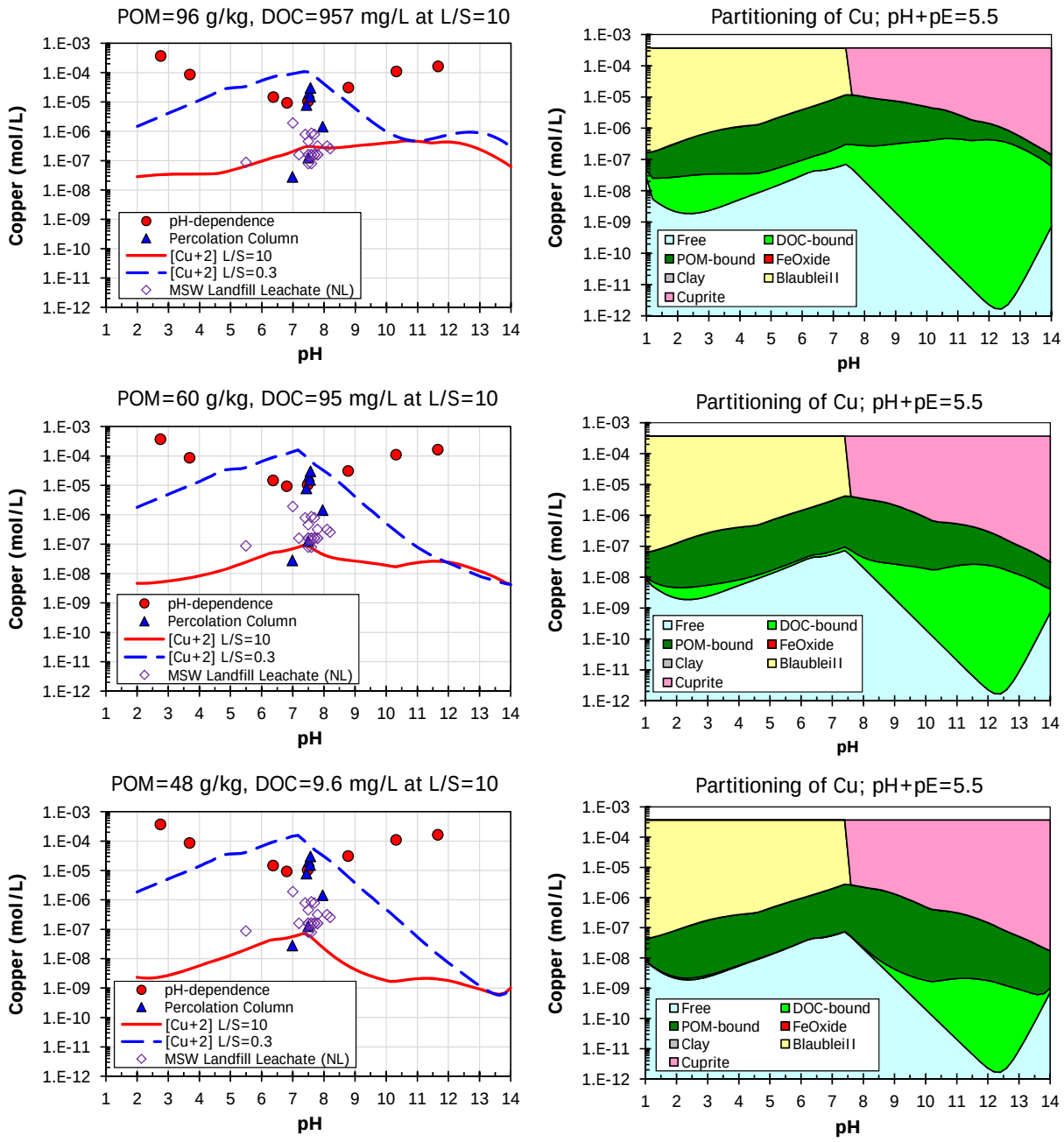


Figure 4-72. Chemical speciation of copper at pH+pE=5.5 during degradation of municipal solid waste (the Netherlands) through loss of POM and DOC under reducing conditions.

Figure 4-73 presents field leachate data in comparison with simulated aqueous concentrations of Fe and Cu based on laboratory testing. The observed field leachate concentrations correspond well with simulations at pH+pE=5.5, with the results for Cu also reflect a range in the amount of DOC present to complex with Cu and increase overall Cu solubility (ranging from coincidence with initial pH dependent leaching test results to orders of magnitude lower concentrations as DOC is depleted).

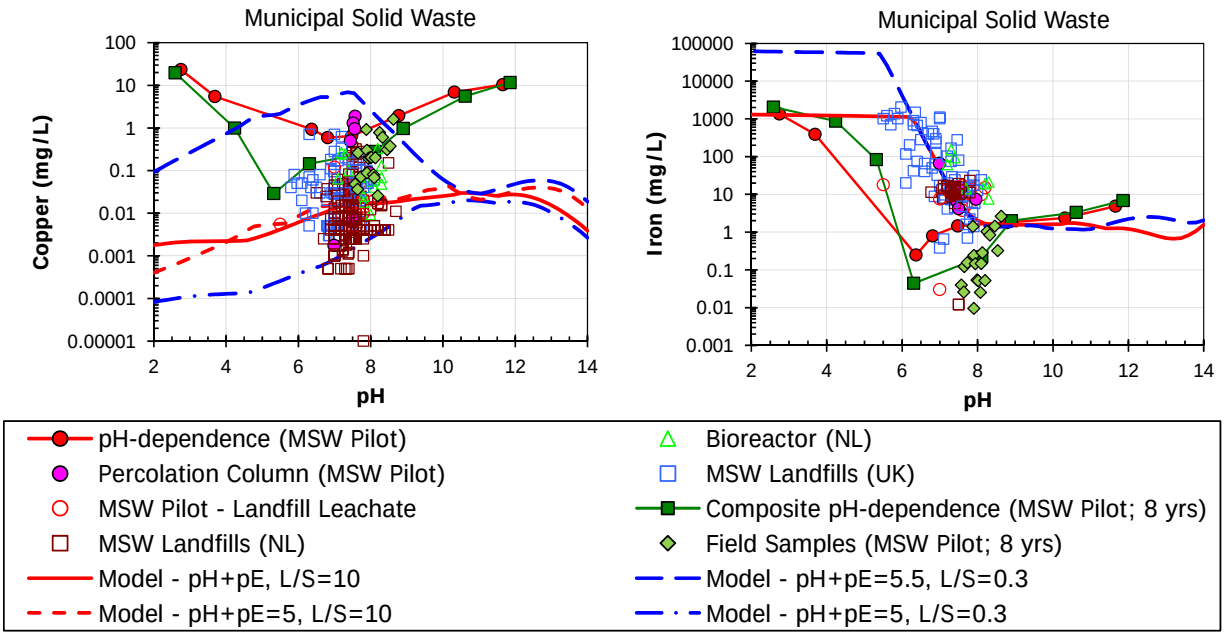


Figure 4-73. Comparison of field leachate concentrations (multiple sources) for Fe and Cu with pH dependence laboratory test data and simulated concentrations at pH+pE=5.5 and L/S=10 and 0.3.

4.8.4 Case Summary

Case 8 focused on a 45,000 m³ pilot-scale landfill for MSW in Landgraaf, The Netherlands, that was filled with a mixture of sewage sludge, construction and demolition (C&D) waste, MSW, industrial waste, car shredder waste, foundry sand, and soil cleanup residue. The pilot study was established to evaluate the biodegradation of organic matter-rich waste by leachate renewal and recycling. The applicable pH domain was between 5.5 and 8.5 based on laboratory testing and field results. Peak concentrations for highly soluble species from laboratory percolation column at L/S 0.5 mL/g agreed well with peak leachate concentrations from the landfill and were a factor of 20 times greater than observed using pH dependent leaching test at L/S 10 mL/g. Reducing conditions in the landfill resulted in higher concentrations in leachate than observed at corresponding pH values during pH dependent laboratory testing. These effects were entirely consistent with those observed for the predominantly inorganic landfill (Section 4.7) and were consistently estimated using a chemical speciation model for municipal solid waste. These results further support the use of chemical speciation-based simulations based on laboratory test results for evaluating the effects of reducing conditions established in the field. Chemical speciation modelling and experimental results also illustrated the importance of particulate organic matter and dissolved organic carbon on the leaching of several trace and major constituents in MSW.

4.9 Stabilized Municipal Solid Waste Incinerator Fly Ash Disposal (The Netherlands)

4.9.1 Case Description

A pilot experiment with four stabilized waste compartments has been carried out in The Netherlands using cement solidified/stabilized municipal solid waste incinerator fly ash (van Zomeren and van der Sloot, 2006a; van der Sloot et al., 2007). Details of the stabilization formula are proprietary but the formulation included portland cement and fuel ash derived pozzolans. Results are also available for the full-scale landfill receiving the same materials after ten years of operation (Keulen, 2010; van Zomeren et al., 2011). Laboratory results from pH-dependence testing and percolation testing on "as produced" cured and crushed material, along with laboratory monolith testing is compared to field pilot results based on leachate and testing of core samples after four years and full-scale landfill leachate and testing of core samples. Laboratory testing consisted of pH-dependent leaching using CEN/TS 14429, up-flow percolation testing using CEN/TS 14405, and monolith mass transfer rate using (NEN 7375, 2004). A full-scale landfill received the same material as the pilot system and was subject to core sampling after ten years of operation. Individual core samples were leached according to EN 12457-2 using single point batch extractions at L/S of 10 L/kg with demineralized water.

A schematic showing the design of the field pilot system is presented in Figure 4-74. Four hydraulically isolated test cells (Cells A to D) were used for the solidified/stabilized waste to examine the effects of waste depth, carbonation and mixing of stabilization formulations.

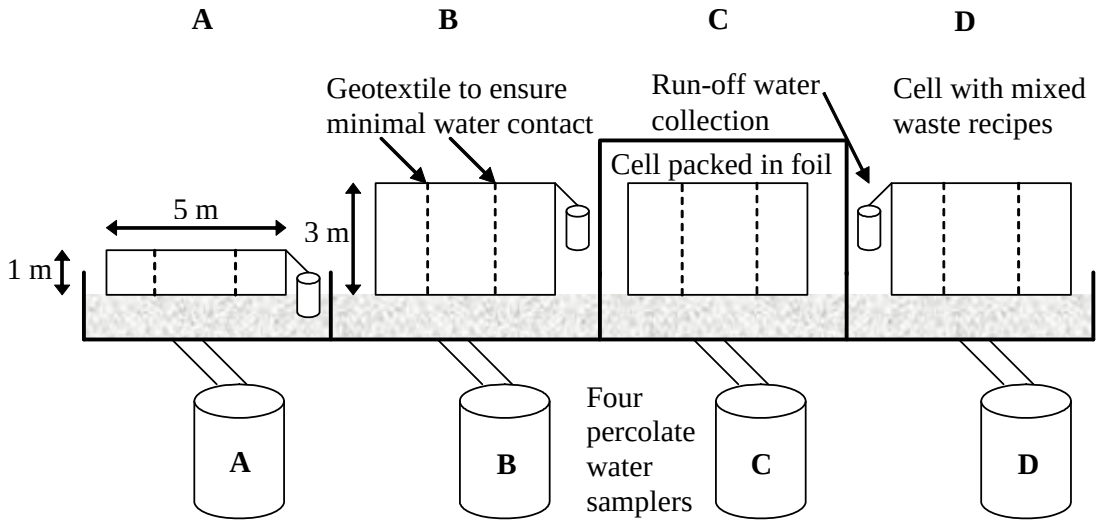


Figure 4-74. Schematic illustration of the front view of the pilot scale experiment using stabilized waste (from van der Sloot et al., 2007). Each test cell was 8 m long, and the space between test cells was filled with sand to maintain physical stability.

The waste was stabilized in situ in layers of approximately 0.5 m. Geotextile membrane was placed vertically at 1.5 m intervals to create preferential flow channels through the stabilized fly ash, facilitating infiltration flow around the monolith at the waste-geotextile interface rather than percolation through the material and thus establishing a "flow around" with diffusion to the interface scenario. A portion of the rainwater that falls on top of the stabilized waste evaporated because of the relatively high porosity of the surface layer and the low permeability (possibly even partial pore sealing) of the deeper layers in the stabilized waste monofill. A layer of mildly contaminated soil underlies the stabilized waste layer for protection of the bottom liner system. This soil layer also had the potential to neutralize the alkaline percolate water and possibly bind leached contaminants (Rietra et al., 2001).

After four years of operation, the four pilot landfill cells were visually inspected and demolished using a hydraulic excavator (van Zomeren et al., 2007). Bulk samples were taken at various spots within the stabilized waste and cores were drilled to sample detailed waste profiles. The three exposed cells (Cells A, B and D) were heavily weathered to a depth of 20-30 cm such that material could be easily removed with a spade. Cracking and swelling of the material was visible on the exposed surfaces. The outer first centimeter was light grey in color and then the material was dark grey to black to a depth of 20-30 cm. The material became much more solid below 40 cm depth. Plant roots grew in the stabilized waste to a depth from a few centimeters (Cell B) to 10-15 cm (Cell D). The material from Cell D (mixed waste) crumbled easily when removed while the material from Cell B below 50 cm was removed as blocks of about 20-50 cm in diameter that also crumbled readily under the bucket of the hydraulic excavator. The unexposed cell (Cell C) was visually unchanged in comparison with the initial condition after placement. The material was solid, grey in color and had no cracks or swelling. The unexposed material came out as large blocks (up to 0.5 m^3) which did not break when they were dropped (on the sand) from 3-4 meter height. These blocks did break after (repeated) hitting with the bucket of the hydraulic crane. These observations clearly showed a significant difference in material properties (i.e., hardness, weathering, color, cracking) between the exposed and unexposed stabilized waste.

4.9.2 Results and Discussion

A complete set of figures showing the results from the laboratory pH-dependent leaching tests and column tests along with results from the pilot-scale test cells and the landfill are provided in Appendix H. Results are presented in the form of concentration as a function of pH (left graphs) including pH-dependent test results on freshly stabilized waste following a 28-day cure interval (connected orange dots), composited core samples obtained after four years from test Cell B (connected blue diamonds) and test Cell C (connected green triangles), leachates from the test cells (individual filled blue, green and fuchsia symbols), leachate from the full-scale landfill (open red circles), single point extractions on test cell cores (open blue diamonds, green triangles and fuchsia squares) and single point extractions on landfill core samples (gold dots). Results are also presented in the form of concentration as a function of L/S (right) including column test results on freshly stabilized waste following a 28-day cure interval (connected orange dots), test cell leachates (open blue diamonds, green triangles and fuchsia squares) and the first fraction at L/S of 0.1 of a column test on two core samples from the landfill (gold dots).

The pH of the fresh material (one week old) in demineralized water was between 12 and 12.5, whereas the pH of the older samples (four months) increased with depth from 10.9 to 11.9 (van der Sloot et al., 2007). After six months, the pH of the stabilized waste at 15–25 cm below the surface had decreased to about 11.7. After four months, Cl was depleted from at least the first 10 cm of the stabilized waste, indicating substantial washout of this mobile element.

The depletion of mobile constituents and, possibly, enhanced carbonation of the outer layer was determined to be due to increased porosity and were the main processes responsible for the observed material properties (van Zomeren et al., 2007). Related research on intermittent wetting and carbonation of solidified/stabilized waste by Garrabrants et al (2002, 2003) and Sanchez et al (2002) indicated that relaxation of internal constituent gradients during non-wetting periods and solubility constrained leaching (i.e., local equilibrium at the surface in the presence of small volumes of contacting water) has a significant impact on leaching under these circumstances. A conceptual model of the processes that occurred during the pilot field experiment is illustrated in Figure 4-75.

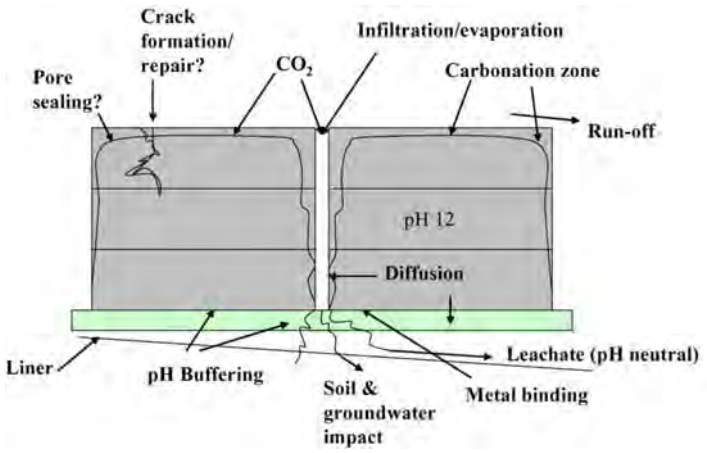


Figure 4-75. Conceptual model of processes occurring during the field pilot study of monolithic waste disposal (from van der Sloot et al., 2007).

The following are notable relationships between leaching test and field results:

- Leachate and runoff from the field pilot and landfill was $6 < pH < 9$ while laboratory column tests indicated $12 < pH < 13$ (Figure 4-76). This difference was most likely due to carbonation on the surface for runoff and a combination of carbonation and neutralization by the underlying soil/buffer material for leachate in the field. Leachate pH values from the full-scale disposal cell were consistent with the values observed from the pilot cells.

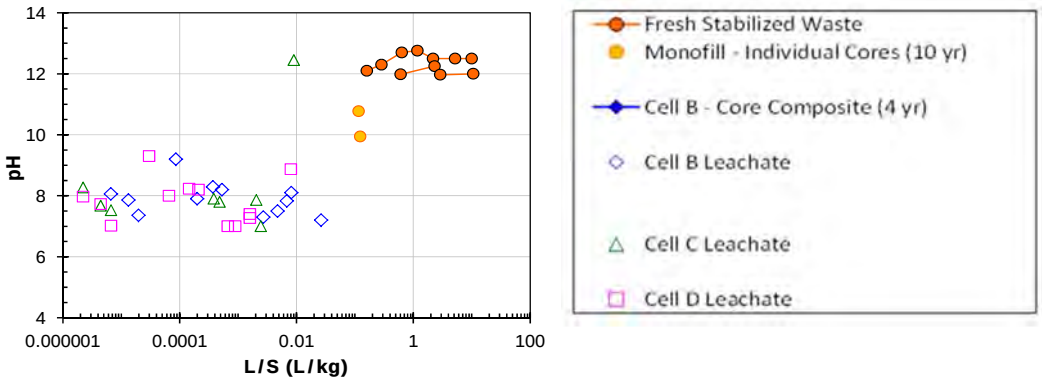


Figure 4-76. Comparison of pH for laboratory testing of waste materials and landfill cores to landfill leachate pH for stabilized waste.

- Reaction of the field material with atmosphere carbon dioxide (i.e., carbonation) is demonstrated by the decreased concentrations of barium, calcium and strontium at 6 < pH < 10 for the field cores as compared to the initially prepared samples (see calcium and strontium in Figure 4-77). The decrease in concentration for these analytes in this pH range is a typical result of the formation of carbonates of barium, calcium and strontium.

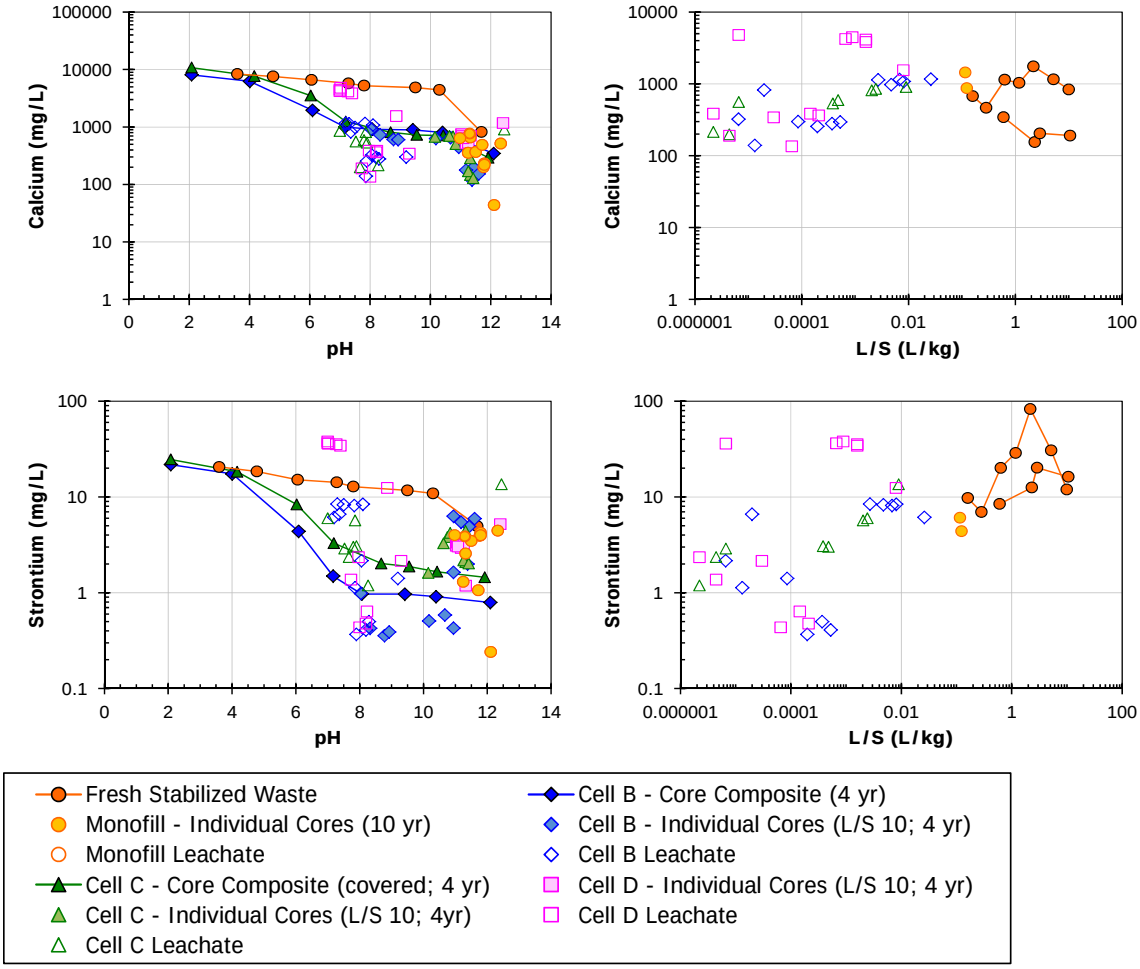


Figure 4-77. Calcium and strontium leaching from laboratory and field materials showing decrease in concentrations in the pH range 6 < pH < 10 consistent with carbonate formation.

Similarly lower concentrations are indicated by pH-dependent leaching testing for lead from aged core samples compared to freshly stabilized material resulting from carbonation to form lead carbonate (see Figure 4-78).

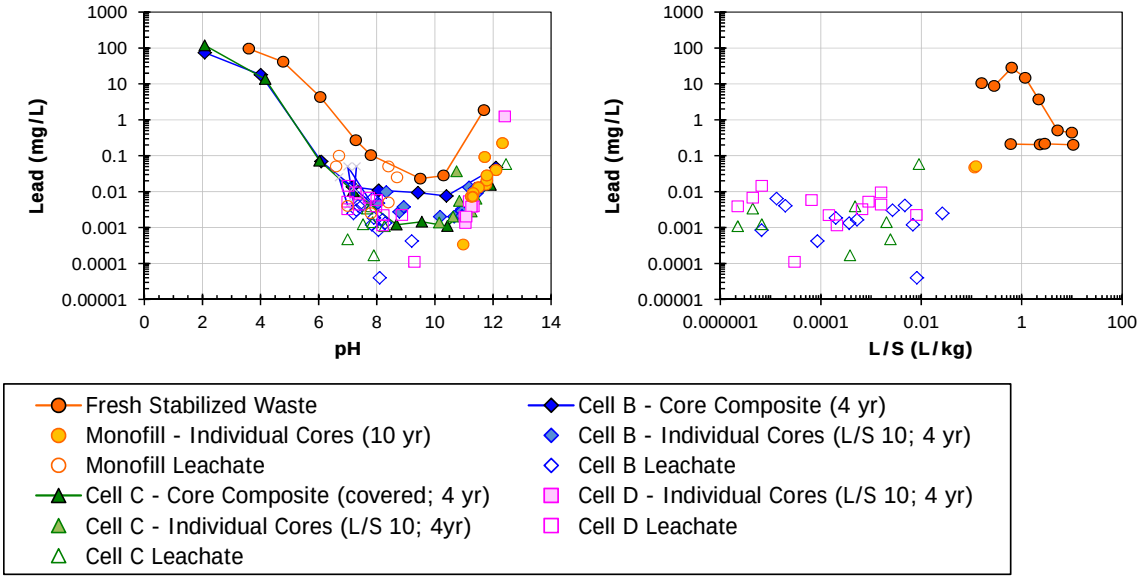


Figure 4-78. Lead leaching from laboratory and field materials showing decrease in concentrations in the pH range 6 < pH < 10 consistent with carbonate formation.

Lower concentrations in pH-dependent solubility curves for core samples from field test after four years indicate effects of washout of highly soluble constituents like chloride, potassium and sodium (see Figure 4-79). However, several other elements are essentially unchanged (i.e., Al, Cu, Mg, S). Similarly, comparison of eluate concentrations from column testing with pH-dependence test results for highly soluble species (e.g., Cl, K, Na) indicates rapid washout as a nearly vertical response at the eluate pH, although initial eluate concentrations from the column test are greater than the concentration indicated by the pH-dependence test results. The initial eluate concentrations from laboratory column tests at L/S≤0.5 mL/g are consistent with the peak concentrations in field leachate and runoff from the pilot and full-scale cases. For column tests, concentrations decline by greater than an order of magnitude by L/S=2 mL/g. Scatter in field leachate and runoff concentrations is attributable to diffusion-controlled release during larger precipitation/infiltration events, dilution and depletion. Although peak concentrations are similar for pilot-scale and full-scale leachate samples, the rate of release of highly soluble salts is substantially slower than observed in laboratory column studies. Peak concentrations reflect pore water equilibration, while extended infiltration events result in a concentration gradient within the monolith, slowing release which is controlled by diffusion within the monolithic material. Dilution is caused by preferential flow paths channeling around the material.

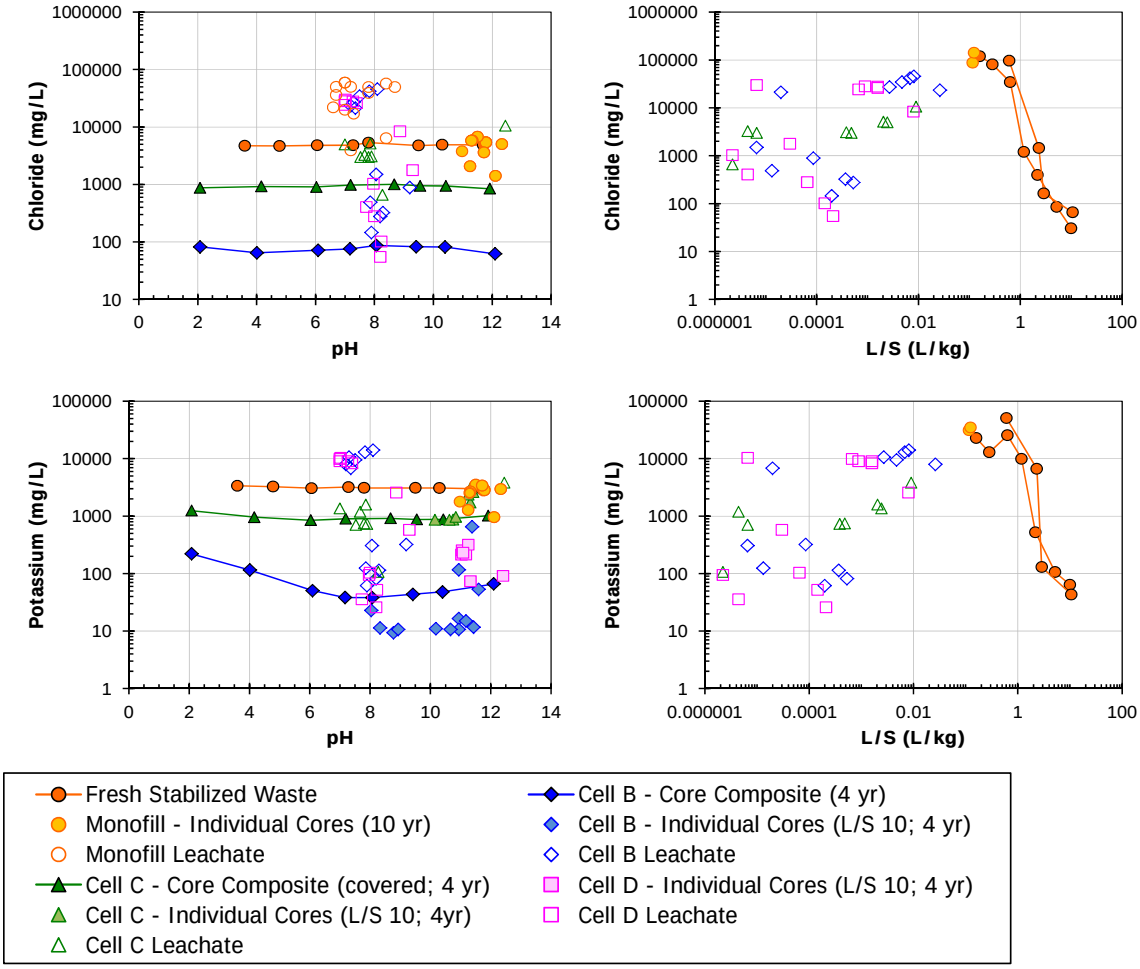


Figure 4-79. Chloride and potassium leaching from laboratory and field materials showing washout of highly soluble species.

- For several anionic species such as sulfate and oxyanions of arsenic, molybdenum, selenium, appreciably higher concentrations, by up to a factor of 20, are observed for field leachate and runoff samples than would be expected by direct comparison to laboratory pH-dependence test results and laboratory column test results due to two factors: (i) speciation is pH-dependent, and (ii) the species present at the field pH is highly soluble. As a result, the observed peak concentrations are indicative of pore-water (L/S ~0.2-0.5 mL/g, based on porosity of ca. 0.2-0.5) and are best approximated as 20 times the concentration observed at corresponding pH in the pH-dependence test (L/S=10 mL/g).
- Laboratory column test results on freshly stabilized waste (near pH 12) are equal to or less than indicated by pH-dependence test results on laboratory samples for several elements, indicating depletion of the soluble species of the element at the eluate pH conditions (e.g., As, Cr, Mo, Se, V); this behavior is typical for oxyanion species. Vanadium and selenium (Figure 4-80) are examples where the more soluble speciation as an oxyanion (e.g., V_2O_5) appears to have been washed out as indicated by the decrease in the near neutral pH range

(e.g., pH 6-8 for vanadium and pH 7-10 for selenium) based on pH-dependent leaching test results on core samples taken after four years compared to freshly stabilized waste.

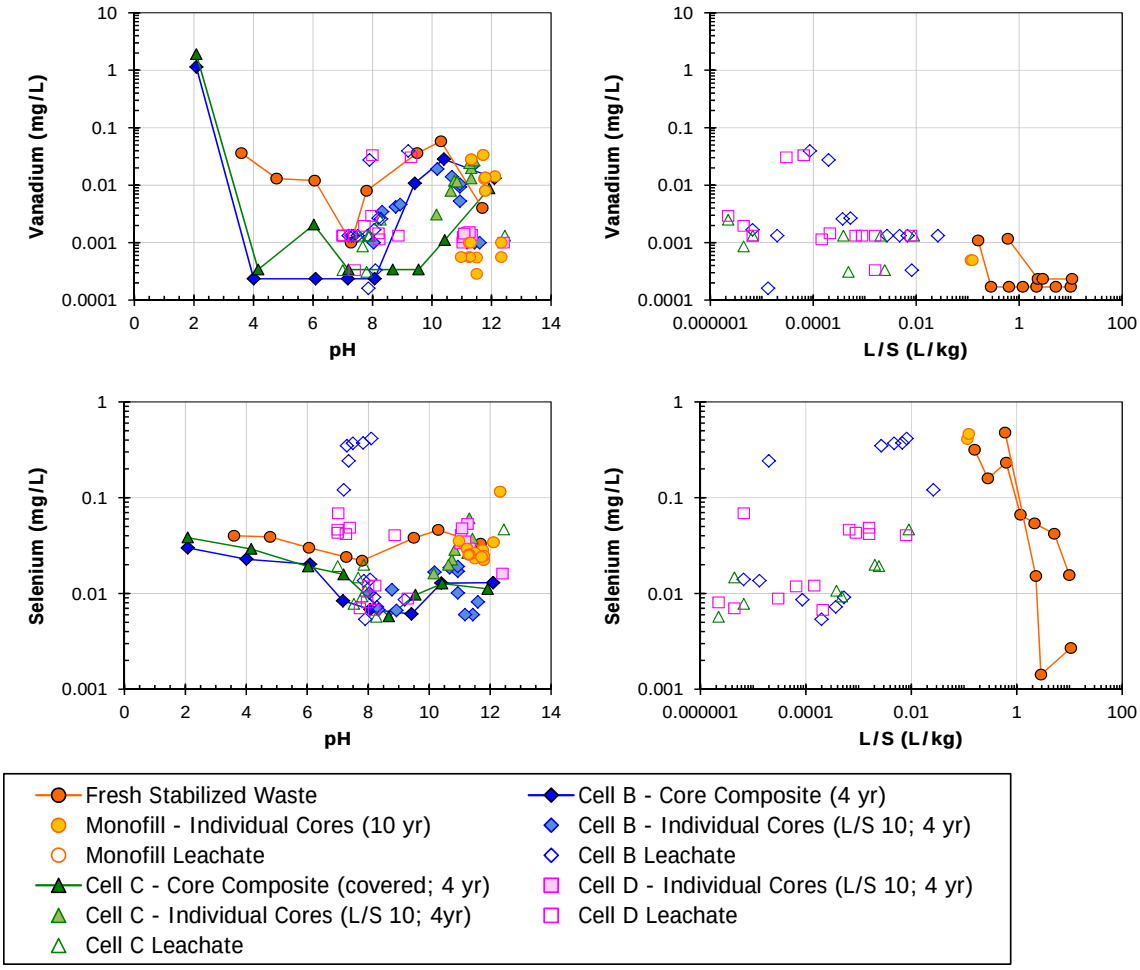


Figure 4-80. Vanadium and selenium leaching from laboratory and field materials showing washout of more soluble oxyanions.

- For many elements, where solubility is highly pH-dependent, the distinctions between laboratory column test results and field leachate and runoff can readily be understood based on the difference between eluate pH under laboratory column test conditions (12<pH<13) and field conditions (6.5<pH<9) as a result of carbonation. These elements and species include aluminum, barium, calcium, chromium, magnesium, manganese, nickel, lead, strontium and zinc. Essentially no change in the pH-dependent solubility curves for several constituents (e.g., copper, chromium and manganese) from core samples after four years compared to freshly stabilized waste indicates solubility controlled leaching behavior (Figure 4-81). Similarly, laboratory column test results are entirely consistent with the pH-dependence test results on laboratory samples, indicating solubility controlled leaching.

Field leachate and runoff results were consistent with the pH-dependence test results for solubility-controlled species but a distinction must be made for elements that are not affected by carbonation and elements significantly affected by carbonation (e.g., Ba, Ca; compare with pH-dependence results of field cores).

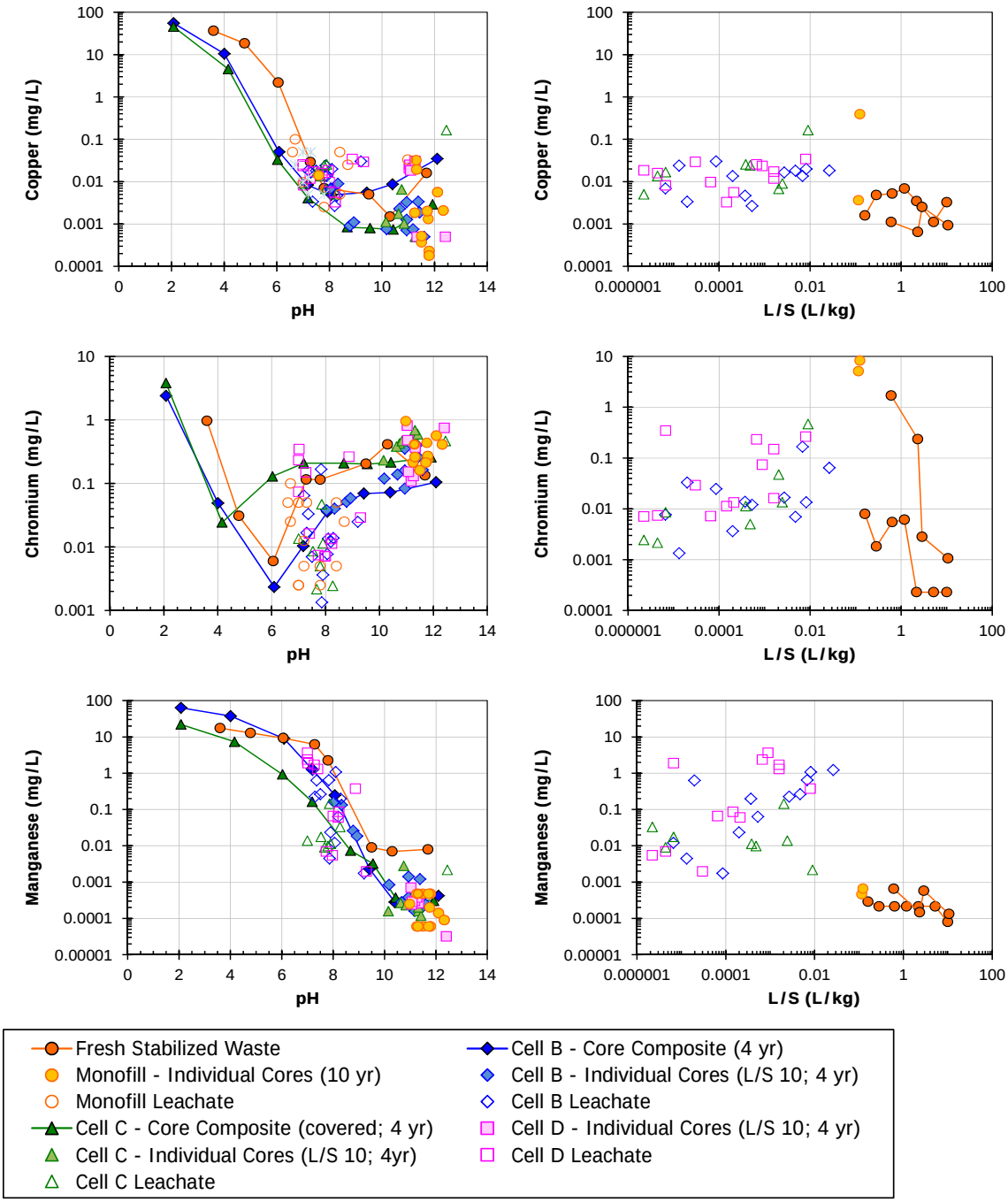


Figure 4-81. Copper, chromium and manganese leaching from laboratory and field samples of stabilized waste.

- Field leachate and runoff results for highly soluble species, oxyanions of arsenic, chromium and molybdenum (Figure 4-82), selenium and vanadium as well as highly soluble species such as chloride, potassium, and sodium, exhibited consistent behavior with column test results although when plotted with pH-dependence results display nearly vertical scatter shifted to correspond with the field pH (e.g., 6 < pH < 9).

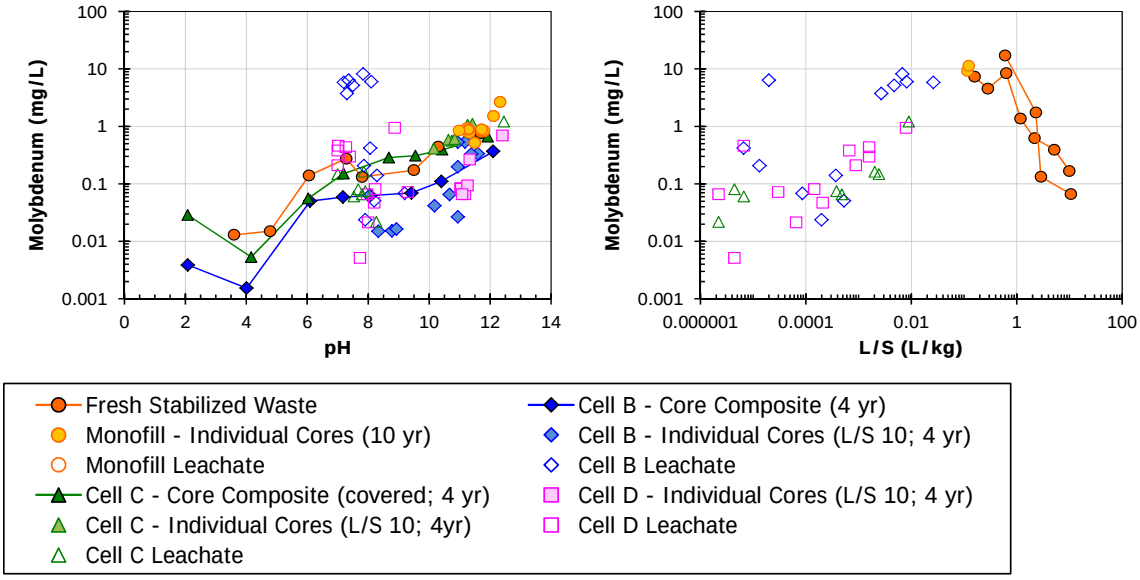


Figure 4-82. Molybdenum leaching from laboratory and field samples of stabilized waste.

- Laboratory leaching of the core samples obtained at depths from 1 to 12 m from the full-scale disposal site after eight years of operation indicated that no significant leaching of any constituents had occurred at a depth of 1 m (minimum sample depth) or greater, including highly soluble salts, and that carbonation had not occurred at that depth (van Zomeren, 2011).
- For several elements (i.e., Al, Ba, Ca, Cu, Fe, Mg, Pb, and Zn), laboratory monolith test results (green squares) fall either on or close to the pH-dependent solubility curve (red lines), indicating chemical saturation in aqueous solution rather than diffusion-controlled constituent release under the test conditions for the monolith test.
- For several elements (i.e., Cd, Cr, Mo, Na, S and Se), the laboratory monolith test results (green squares) are significantly less than the pH-dependent solubility curve (red lines), indicating that either the dissolution rate or diffusion-controlled constituent release dominates leaching of at the test conditions of the monolith test.

4.9.3 Chemical Speciation Insights – Stabilized Waste

Figure 4-83 through Figure 4-85 present chemical speciation modeling results at L/S=10 and 0.3 mL/g for Cu, Pb and SO_4 in comparison to (i) laboratory pH dependent leaching test data from fresh

stabilized waste (ca. 28 days cure) and core samples taken after 4 years from the field test site (i.e., Cell B, Cell C and Cell D) and after 10 years from the full-scale monofill (i.e., Monofill), (ii) leachate from the field test site, and from the full-scale monofill, and (iii) laboratory column percolation data from testing the fresh stabilized waste after curing and crushing. Figure 4-83, providing results for Cu, also compares chemical speciation modeling when the assume copper precipitate is either copper hydroxide [$Cu(OH)_2$] or tenorite [CuO] which are very similar with tenorite being a more stable mineral form. Leaching test results from fresh and aged stabilized waste suggests transformation from copper hydroxide to tenorite as the material ages but this has not been independently confirmed. Comparison of leaching test results for lead from fresh and aged samples also suggests that more stable states as represented by the chemical speciation are formed as the material ages.

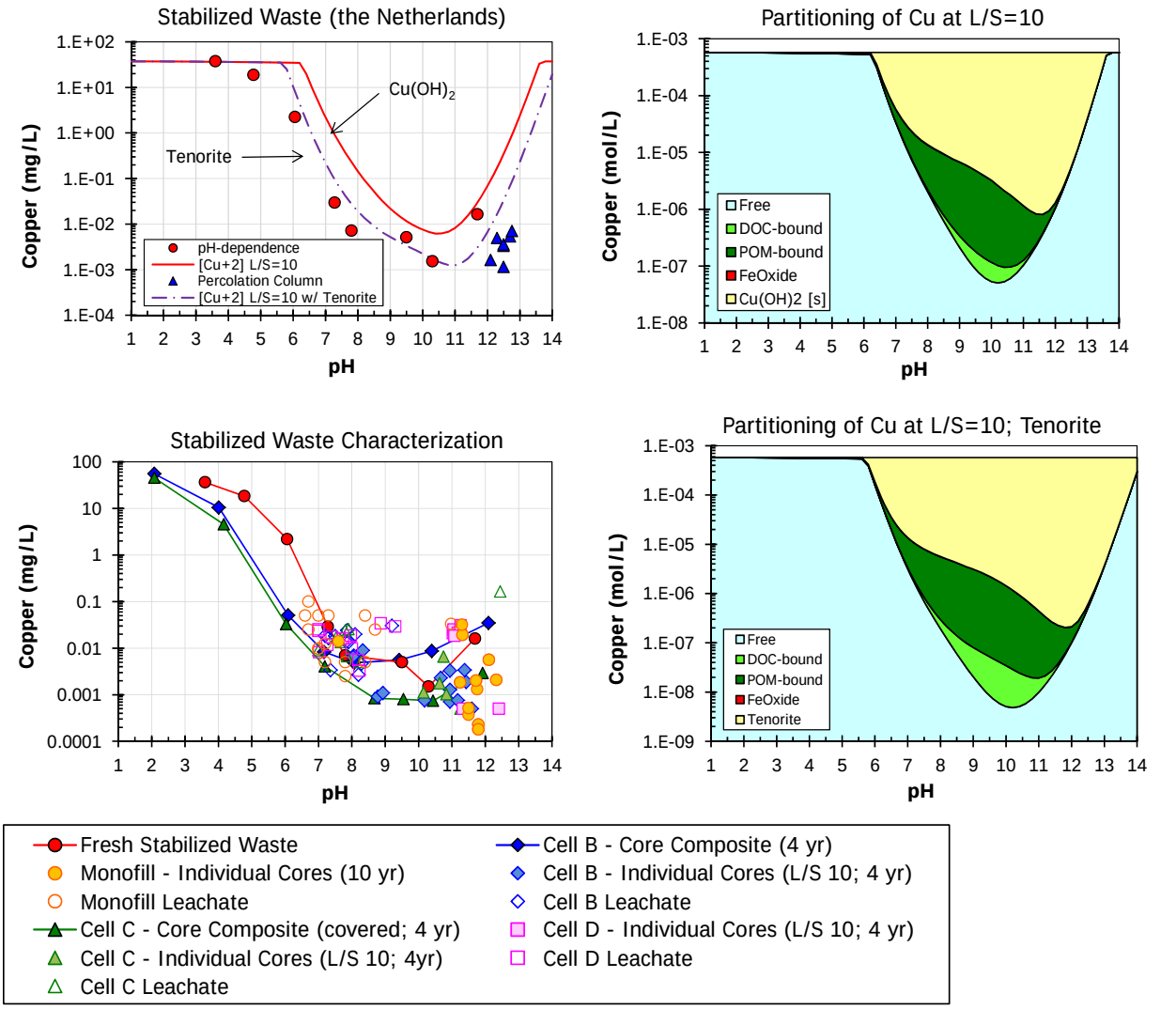


Figure 4-83. Chemical speciation modeling at L/S=10 and 0.3 mL/g for copper from stabilized waste (the Netherlands) compared to field leachate data, laboratory pH dependence test data (CEN/TS 14429) on fresh stabilized waste (ca. 28 day cure) and field core samples after 4 years, and percolation

column data on fresh stabilized waste (CEN/TS 14405). Also included is a comparison of assuming Cu precipitation as $Cu(OH)_2$ and as tenorite [CuO].

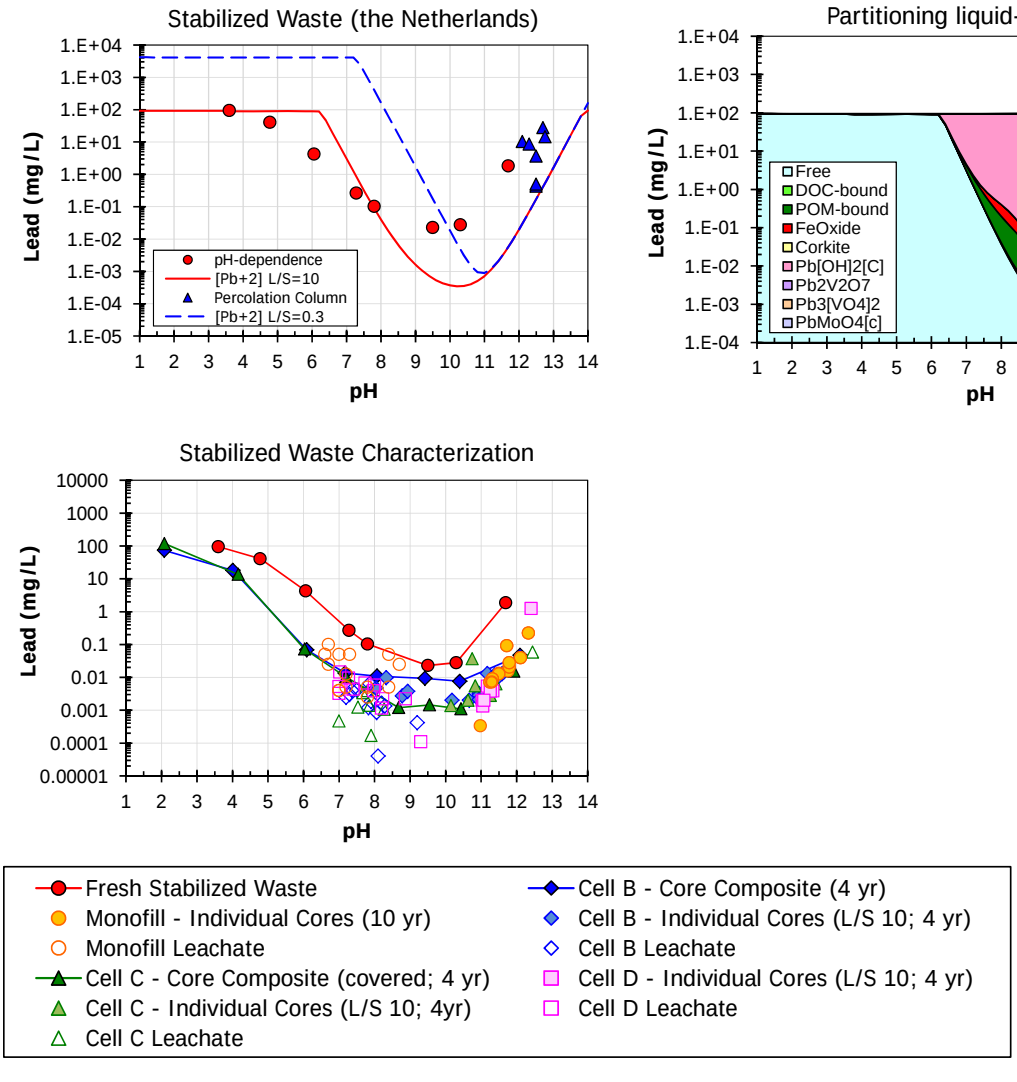


Figure 4-84. Chemical speciation modeling at L/S=10 and 0.3 mL/g for lead from stabilized waste (the Netherlands) compared to field leachate data, laboratory pH dependence test data (CEN/TS 14429) on fresh stabilized waste (ca. 28 day cure) and field core samples after 4 years, and percolation column data on fresh stabilized waste (CEN/TS 14405).

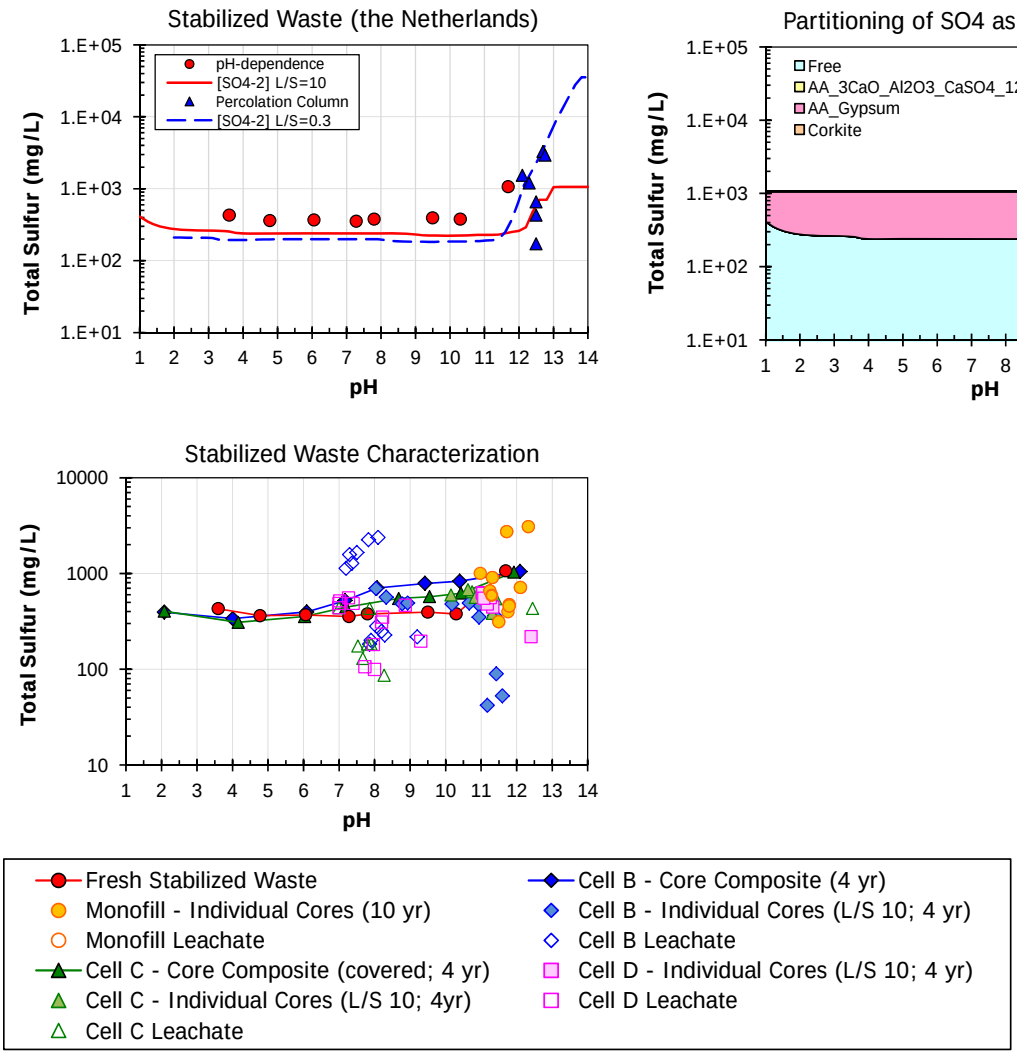


Figure 4-85. Chemical speciation modeling at L/S=10 and 0.3 mL/g for sulfate from stabilized waste (the Netherlands) compared to field leachate data, laboratory pH dependence test data (CEN/TS 14429) on fresh stabilized waste (ca. 28 day cure) and field core samples after 4 years, and percolation column data on fresh stabilized waste (CEN/TS 14405).

Figure 4-86 through Figure 4-90 compare the impact of carbonation from reaction of atmospheric carbon dioxide with the alkaline stabilized waste for Ca, Cu, Cr, Mg and Zn. Most notable is the impact of the loss of ettringite and the formation of calcite reducing the solubility of Ca at alkaline pH with an analogous but less pronounced effect on Mg speciation and solubility. In case of Mg, a significant transformation of the solubility-controlling phases occurs upon carbonation, as brucite effectively disappears and is replaced by CO_3-hydrotalcite. The main effect of carbonation is expected for Group II elements of the periodic table (e.g., Mg, Ca, Sr, Ba). Carbonation has minimal impact on Cu and results in increased Zn leaching over the pH domain from 8 to 11. However, a substantial impact is observed for Cr, where initial oxyanion substitution for sulfate in ettringite is lost with progressing carbonation.

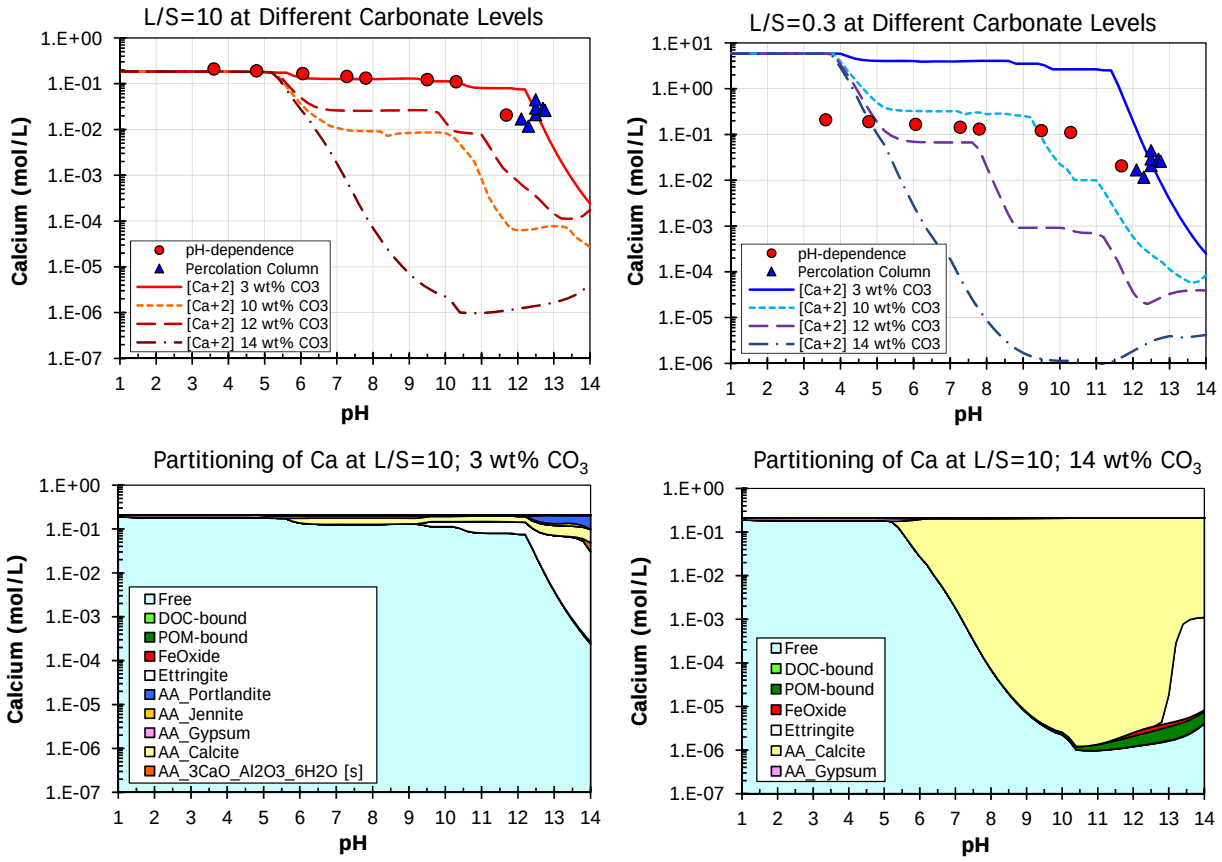


Figure 4-86. Chemical speciation modeling for calcium from stabilized waste (the Netherlands) at different carbonate levels compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405) for cement stabilized fly ash (the Netherlands).

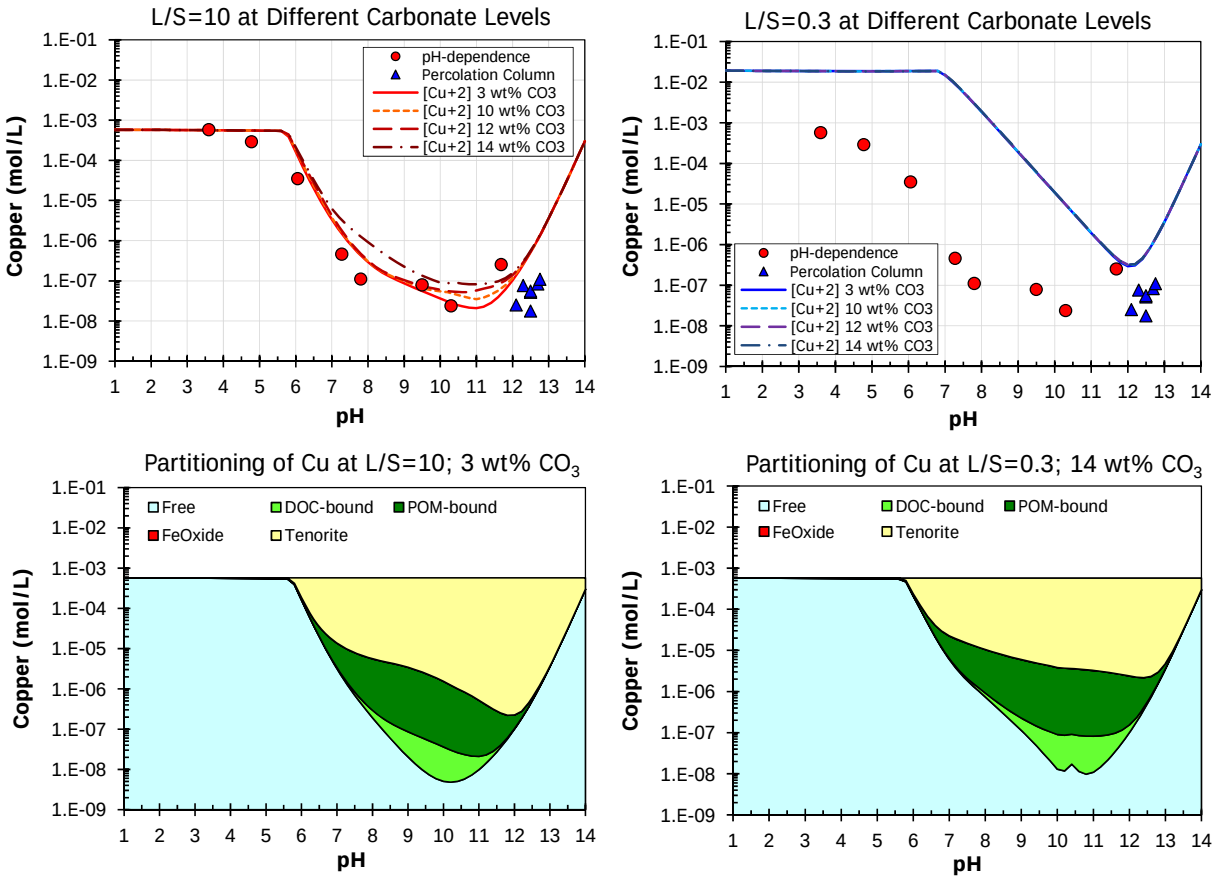


Figure 4-87. Chemical speciation modeling for copper from stabilized waste (the Netherlands) at different carbonate levels compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

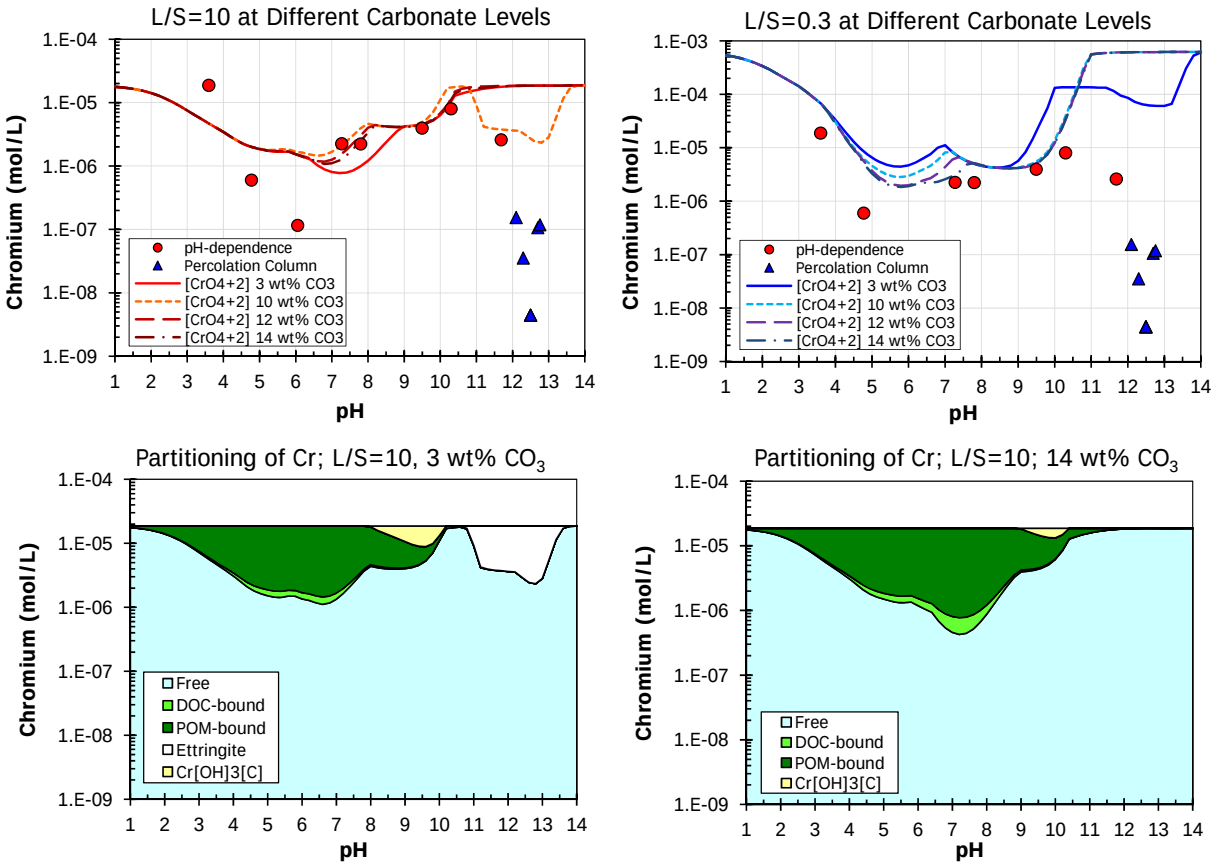


Figure 4-88. Chemical speciation modeling for chromium from stabilized waste (the Netherlands) at different carbonate levels compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

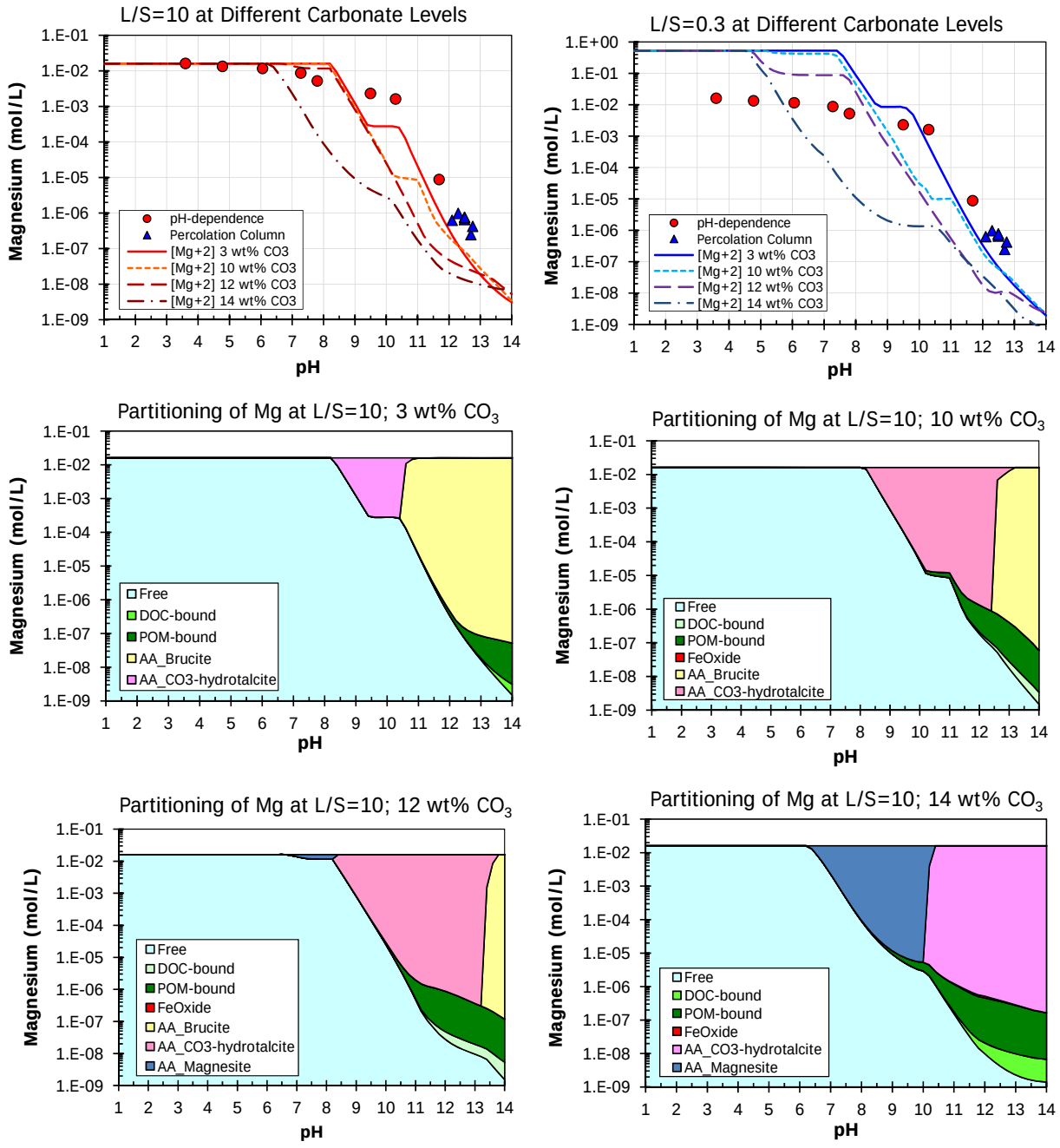


Figure 4-89. Chemical speciation modeling for magnesium from stabilized waste (the Netherlands) at different carbonate levels compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

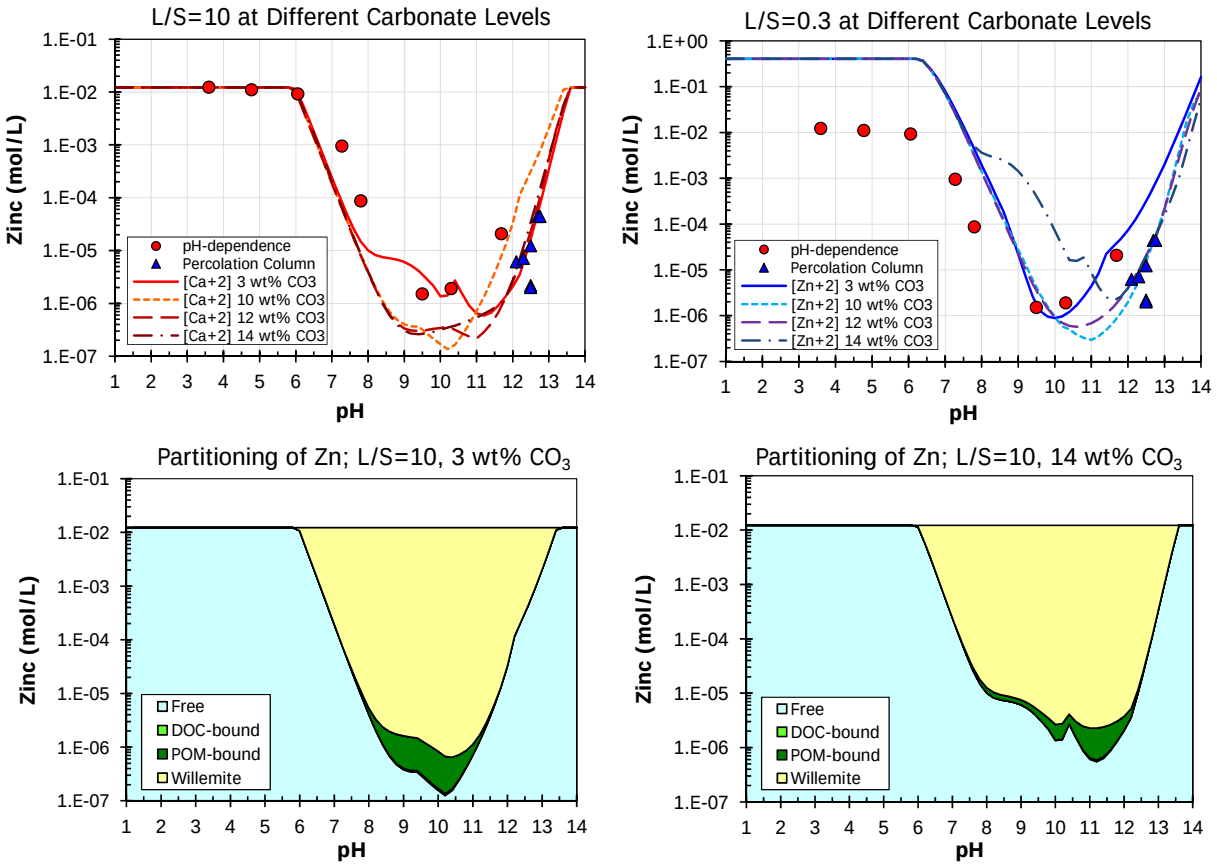


Figure 4-90. Chemical speciation modeling for zinc from stabilized waste (the Netherlands) at different carbonate levels compared to pH-dependence data (CEN/TS 14429) and percolation column data (CEN/TS 14405).

4.9.4 Case Summary

Case 9 focused on a pilot-scale field demonstration of near surface disposal of MSWI fly ash stabilized with a mixture of pozzolonic binders (i.e., multiple ash types). Initial samples of the stabilized material were subjected to laboratory leaching tests. Leachate and runoff was collected during that evaluation period of approximately 4 years, after which cores were taken of the stabilized material for laboratory leaching testing. Comparative results were also available from a full-scale monofill receiving the same stabilized waste. The applicable pH domain was between pH 12.5 for freshly stabilized material to pH 6 for field runoff. For several anionic species such as sulfate and oxyanions of arsenic, molybdenum, selenium, appreciably higher concentrations, by up to a factor of 20, are observed for field leachate and runoff samples than would be expected by direct comparison to laboratory pH-dependence test results and laboratory column test results due to two factors: (i) speciation is pH-dependent, and (ii) the species present at the field pH is highly soluble. As a result, the observed peak concentrations are indicative of pore-water (L/S ~0.2-0.5 mL/g, based on porosity of ca. 0.2-0.5) and are best approximated as 20 times the concentration observed at corresponding pH in the pH-dependence test (L/S=10 mL/g). Peak monofill leachate

concentrations of highly soluble species (i.e., chloride, potassium) were approximately a factor of 10 greater than measured using pH dependent testing on freshly prepared material and approximately half of peak values from percolation column tests, likely because of diffusion controlled release and preferential flow. Carbonation at the surface of the stabilized material from reaction with atmospheric carbon dioxide resulted in lower pH (6-9) for runoff and leachate samples and characteristic reductions in leaching of calcium, barium and strontium. Field leachate concentrations indicate solubility controlled (local equilibrium with the surface) for several constituents (e.g., copper, chromium, manganese). Laboratory leaching of cores obtained from field testing after 10 years from the full-scale facility indicated that no significant leaching had occurred at a depth of 1 m. Chemical speciation modeling was used to illustrate the impact of carbonation on leaching of several constituents.

4.10 Portland Cement Mortars and Concrete

4.10.1 Case Description

One high-volume end use for secondary materials (e.g., coal fly ash, granulated blast furnace slag) is as substitutes for portland cement or admixtures in cement and concrete construction products. In addition, some secondary materials may be used by being included in cement-based materials as fine or coarse aggregate. For example, more than 11 million tons of coal fly ash were used as a cement replacement in concrete in 2010 in the U.S. (ACAA, 2012).

A review of LEAF-analogous laboratory leach testing for portland cement-based mortars and concretes made with and without fly ash indicated that pH-dependent leaching and monolith leaching of COPCs is systematic and fairly consistent between non-amended and fly-ash amended materials with up to approximately 30 wt% of fly ash substituted for cement (van der Sloot et al., 2012). Laboratory testing of commercial formulations of blended concretes and microconcretes (i.e., those where a portion of portland cement is replaced with coal fly ash) using EPA Method 1313 for pH-dependent leaching and EPA Method 1315 for monolithic mass transfer rate leaching demonstrated the following (Kosson et al., 2014 and Garrabrants et al., 2014):

- The pH-dependent leaching of COPCs in amended materials, with up to 45 wt% substitution of fly ash for portland cement and three-month cures, was controlled by the cement chemistry and was significantly different from the LSP measured for the component fly ash material incorporated into the blended sample,
- Eluate concentrations for COPCs in monolithic mass transfer leaching decrease when amended cement-based materials with substitution rates up to 45 wt% fly ash are allowed to cure beyond the typical 28-days used for physical testing of cement-based materials,
- The combination of concrete chemistry and physical retention (e.g., observed diffusivity and tortuosity) provided by the portland cement paste in the blended material controlled the monolithic mass release of COPCs from concrete materials, and

- Most COPCs (e.g., Al, As, B, Ba, Cd, Cr, Mo, Pb, Sb, Se, Tl and V) are well-retained in fly ash-amended concrete materials, resulting in observable monolith leaching from concretes containing 45 wt% fly ash substitution for only a few analytes (e.g., Al, Ba, Cr, Sb and V).

Unanswered questions in the studies described above are the impact of sample aging processes (i.e., carbonation and decalcification) that have the potential to alter the chemistry and physical retention of the concrete.

The laboratory-to-field comparisons for concretes and mortars are based on pH-dependence testing of laboratory prepared concretes and mortars to pH-dependence testing of field samples that have been "in service" for extended time intervals:

1. Two sets of core samples of concrete in place for 40 years obtained from a test site in Stuttgart, Germany (Schießl, 2003)
    a. Core samples from a surface that has been exposed to rain and other weather variations,
    b. Core samples from a surface that was permanently immersed in fresh water.
2. Core samples from a Roman aqueduct, aged for approximately 2,000 years (van der Sloot et al., 2011),
3. Recycled concrete aggregate (RCA) that was used as roadbase in a test road in Norway (Engelsen et al., 2009; 2010)
    a. Fresh recycled concrete sampled from material used in the road base during the field test site preparation,
    b. Field samples of the recycled concrete aggregate from the roadbase after four years of roadway use, < 10 mm sieved from the field material (therefore more carbonated),
    c. Field samples of the recycled concrete aggregate from the roadbase after four years of roadway use, 20-120 mm sieved from field material (and then size-reduced for laboratory testing).

Testing results from these field samples are compared to two laboratory-prepared reference mortars from Germany (sample: Cement mortar CEM I DE) and Norway (sample: Cement mortar CEM I NO).

4.10.2 Results and Discussion

A complete set of figures illustrating available pH-dependent leaching behavior for the comparison materials is provided in Appendix H. In general, LSP was consistent between materials cured for short times (i.e., 28 days) and materials exposed to field conditions for extended time periods (Figure 4-91).

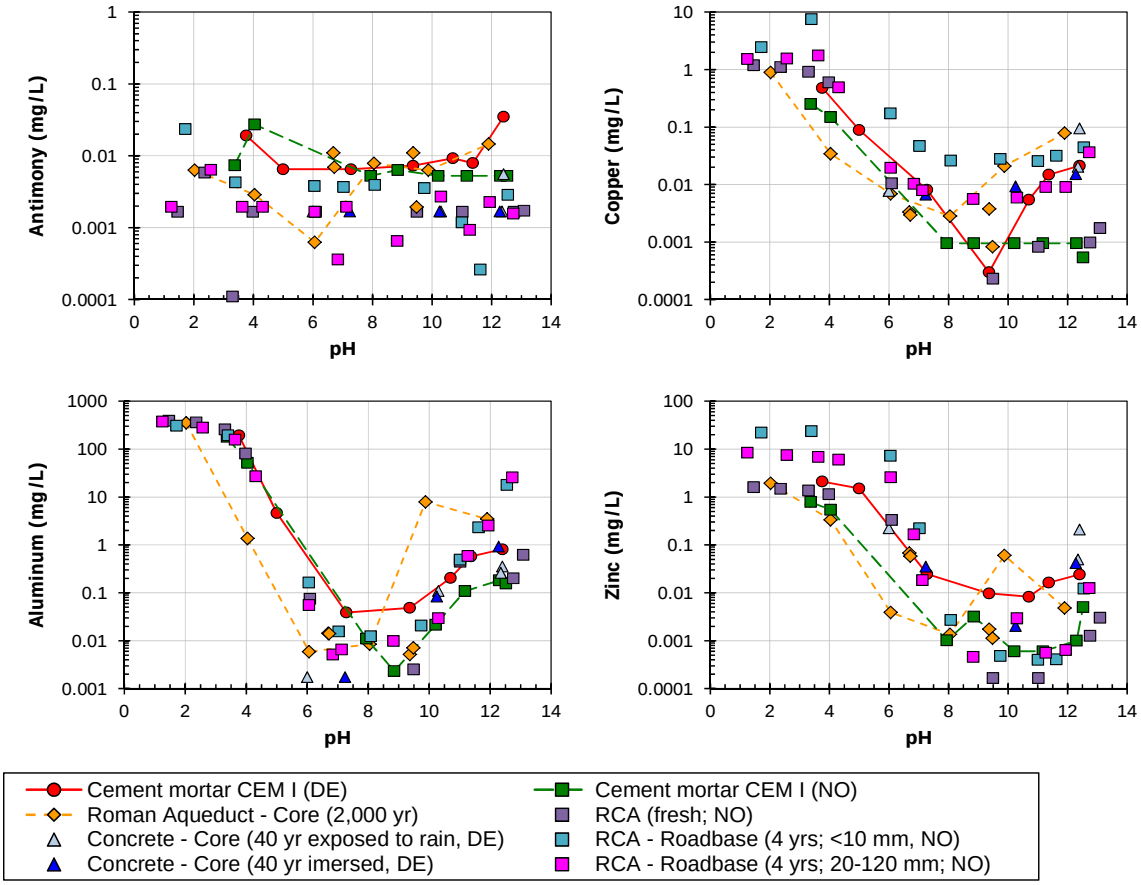


Figure 4-91. Aluminum, antimony, copper and zinc as example results from pH-dependent leaching tests on field core samples of concrete of different ages and exposure conditions in comparison with reference mortars. LSP was consistent between reference materials cured for short times (i.e., 28 days) and materials exposed to field conditions for extended time periods.

The following are notable observed effects of field aging:

- Arsenic and chromium leaching are shown in Figure 4-92. For arsenic, elevated and more erratic leaching was observed for the Roman cement (entire pH domain), possibly the result of combined carbonation and decalcification, and the German reference mortar. Chromium leaching was greatest at neutral to alkaline pH for the Norwegian reference mortar. The German reference sample contained a reducing agent to decrease chromate content to meet EU regulations on occupational exposure.
- The effect of carbonation (Figure 4-93) to decrease leaching of barium, calcium and strontium at neutral to alkaline pH is evident, with assumed increasing extent of carbonation from short cure time reference samples (minimal carbonation), four-year-old Norwegian recycled concrete, and 2,000-year-old Roman cement (complete carbonation).

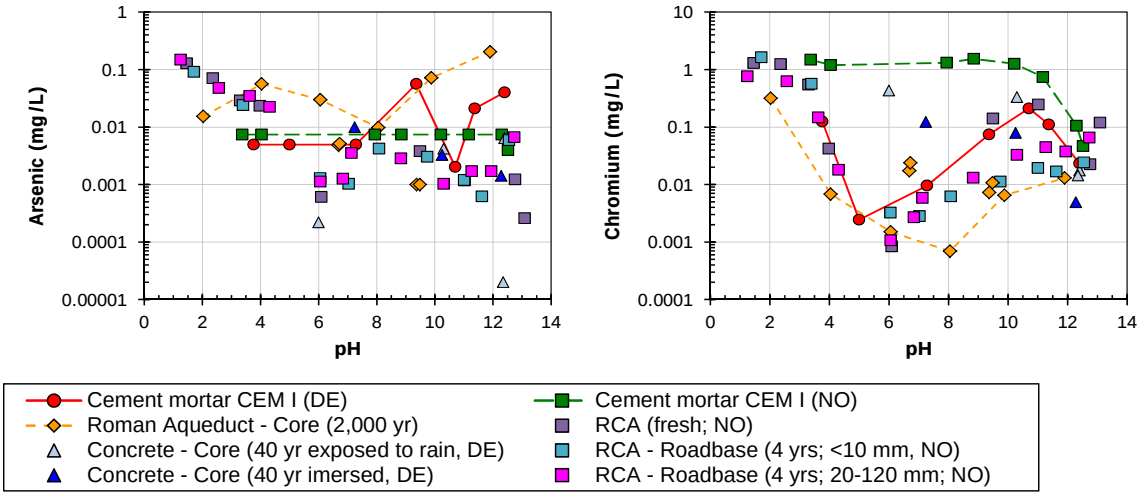


Figure 4-92. Arsenic and chromium results from pH-dependent leaching tests on field core samples of concrete of different ages and exposure conditions in comparison with reference mortars.

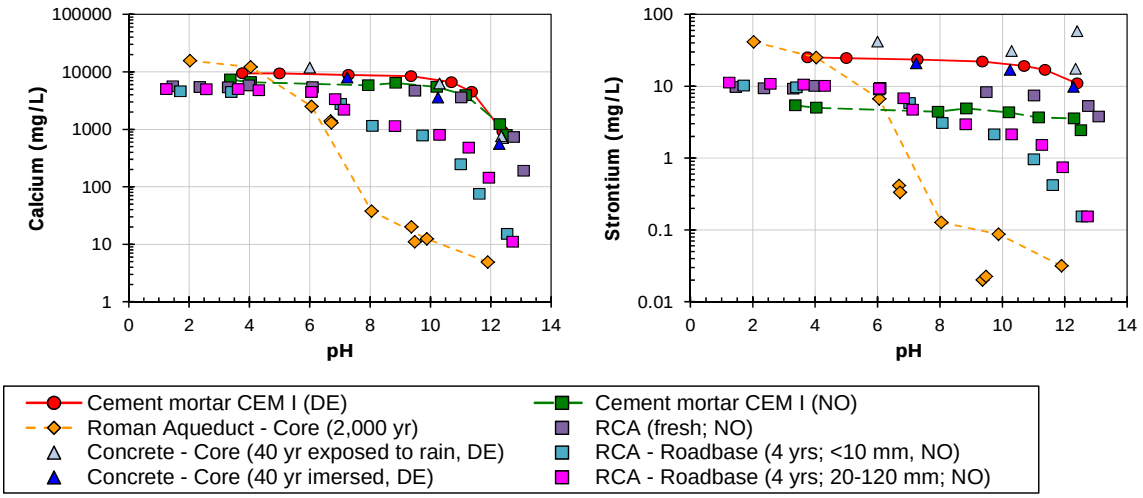


Figure 4-93. Calcium and strontium results from pH-dependent leaching tests on field core samples of concrete of different ages and exposure conditions in comparison with reference mortars. The effect of carbonation to decrease leaching at neutral to alkaline pH is evident.

Chemical Speciation Insights – Cement and Concrete

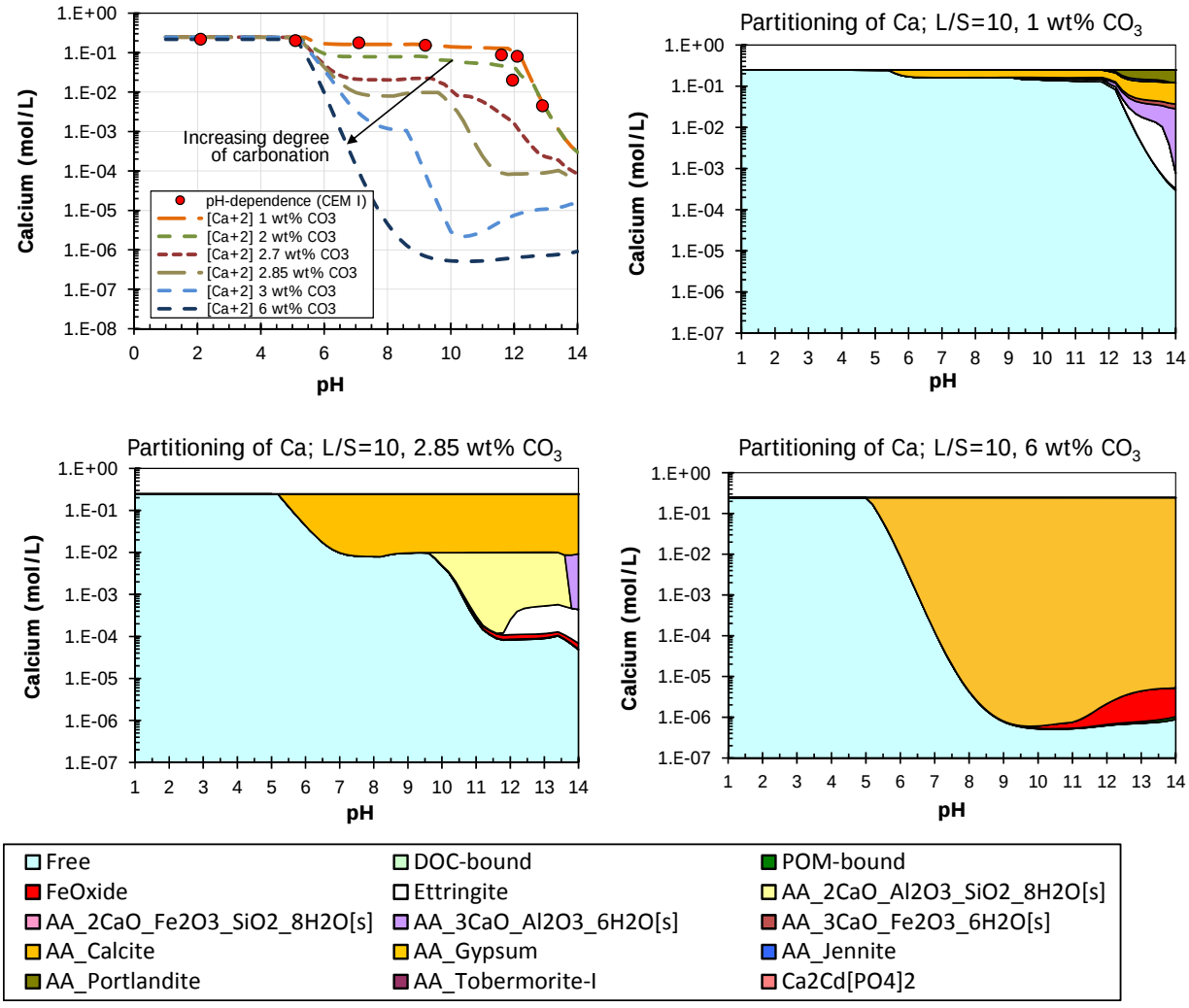


Figure 4-94 presents the impact of progressive extent of carbonation on the observed solubility of Ca (upper left graph) and the change in solid and liquid phase speciation at different extents of carbonation (i.e., 1, 2.85 and 6 percent by mass total carbonate in the initial solid phase). As the extent of carbonation progresses as a result of the alkaline cement material reacting with carbon dioxide (most frequently from either atmospheric or biological sources), the solubility of Ca decreases over the pH domain from 6 to 14. Progressive extent of carbonation results in the conversion of ettringite [$Ca_6Al_2(SO_4)_3(OH)_{12}{\cdot}26(H_2O)$], portlandite [$Ca(OH)_2$] and calcium oxide-aluminates and other alkaline cement phases to calcite [$CaCO_3$].

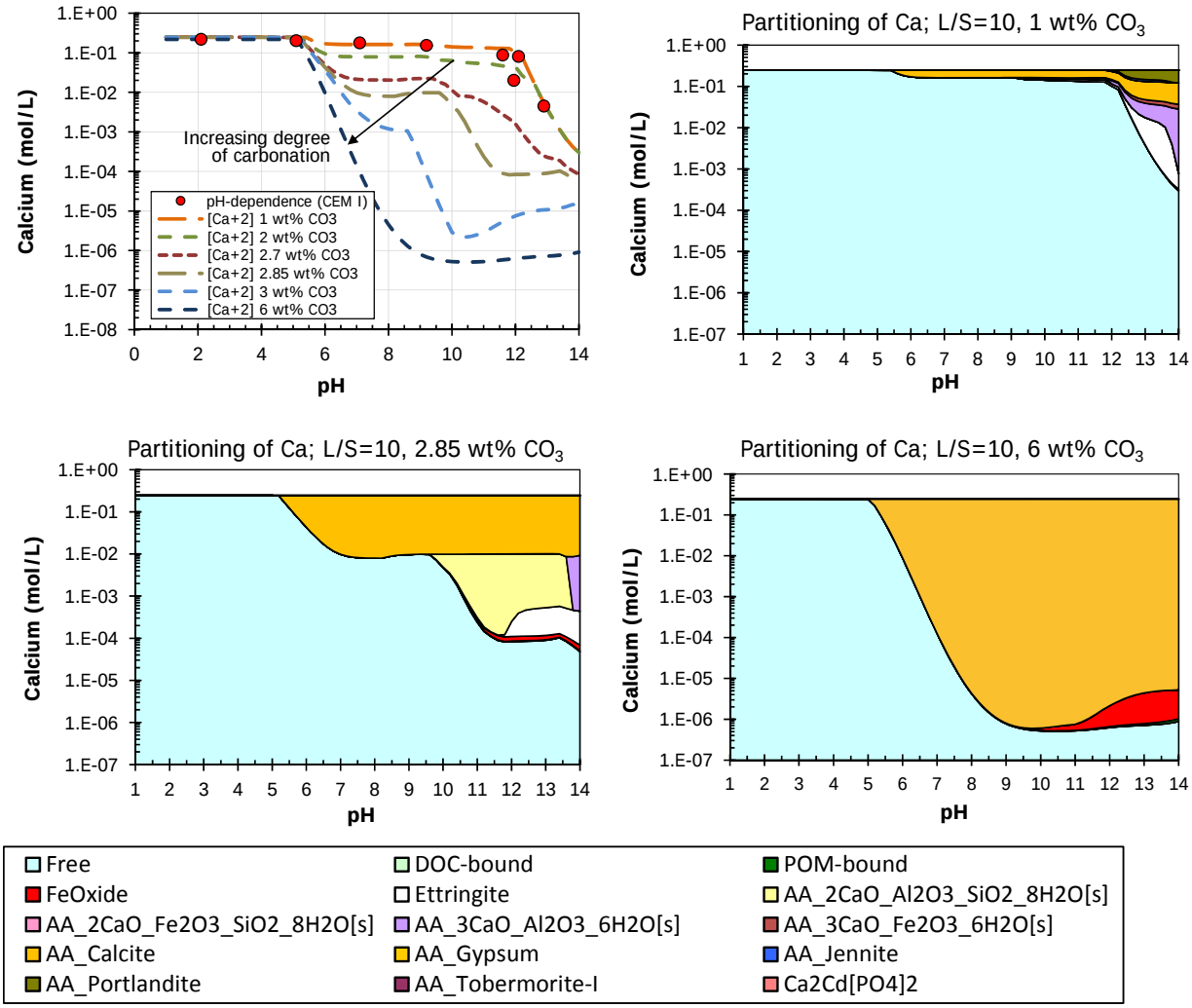


Figure 4-94. Chemical speciation modeling of the impacts of carbonation on solubility of Ca and the resulting solid and aqueous phase speciation compared to pH-dependence leaching test data on portland cement CEM I standard mortar after 28-day cure.

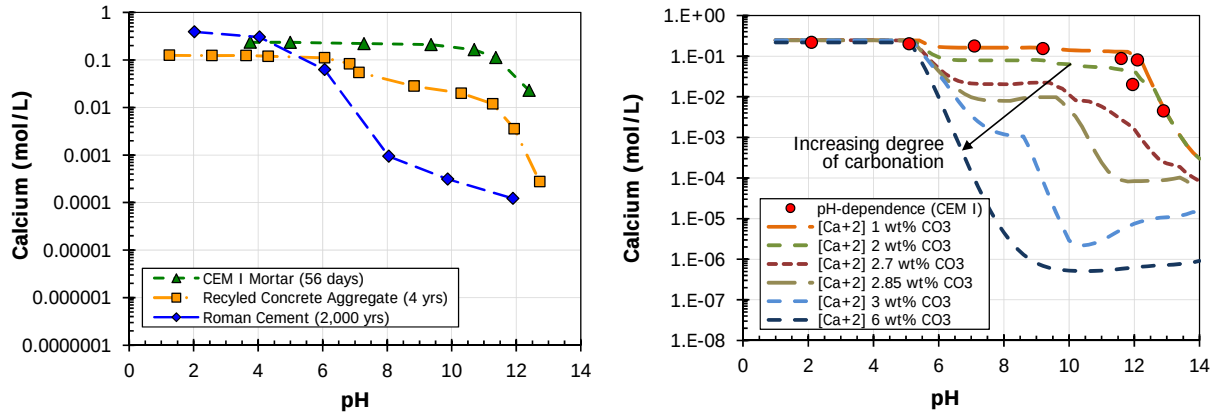


Figure 4-95 compares the laboratory testing and chemical speciation results (from

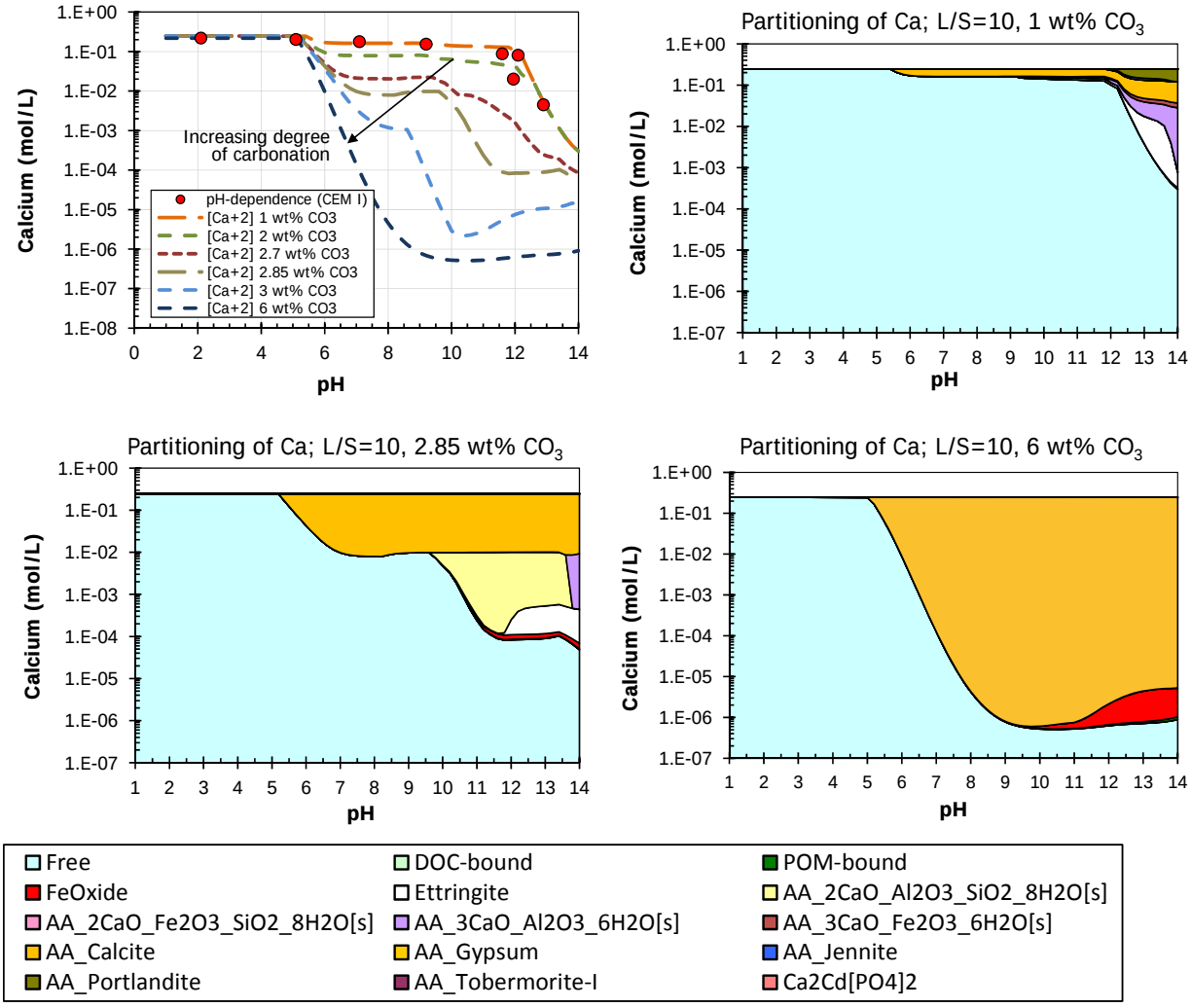
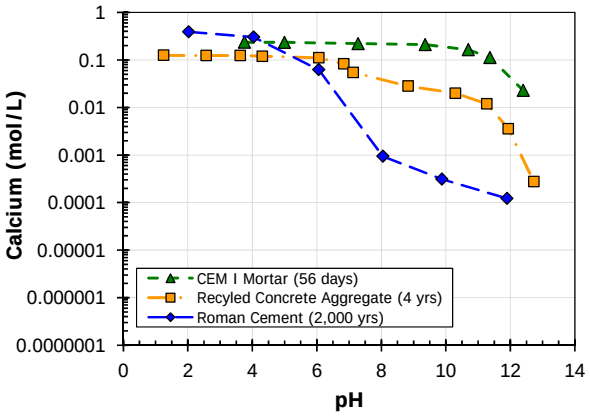


Figure 4-94) for Ca with pH dependence leaching test data from samples of cementitious materials with a range of extent of aging. Older materials are expected to have greater extents of carbonation



because of prolonged exposure. Included in

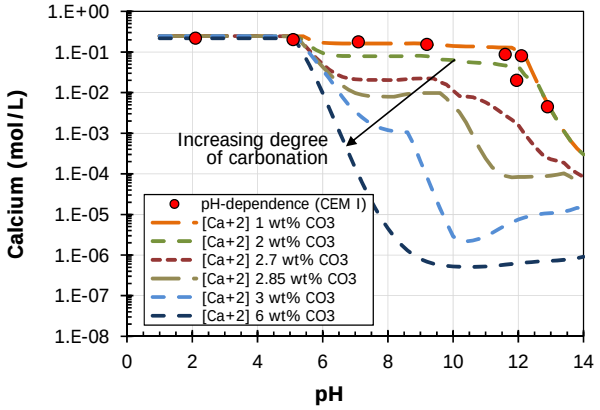


Figure 4-95 are a CEM I standard mortar after 56 days of curing (least extent of carbonation and similar to the CEM I standard mortar in Figure 1), a recycled concrete aggregate (0-32 mm diameter) after field exposure through use in a roadbed for 4 years with Ca leaching behavior similar to 2.7% carbonate content, and Roman cement that had been in service for approximately 2,000 years with Ca leaching behavior similar to between 3 and 6% carbonate content.

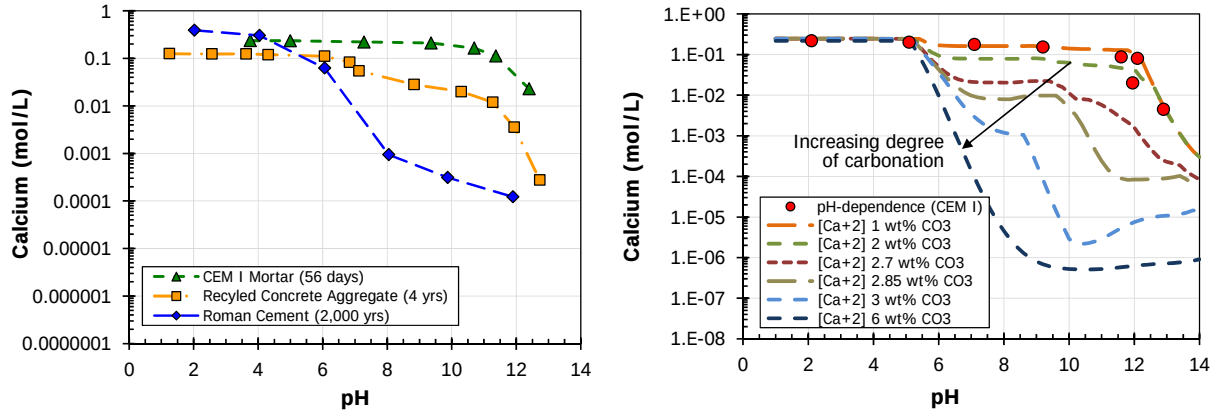


Figure 4-95. Leaching of CEM I mortar (56-day cure) with recycled concrete aggregate (field aged 4 years) and Roman cement (field aged 2,000 years) indicative of different extents of carbonation

compared to chemical speciation modeling of the impacts of carbonation on solubility of Ca and pH-dependence leaching test data on portland cement CEM I standard mortar after 28-day cure.

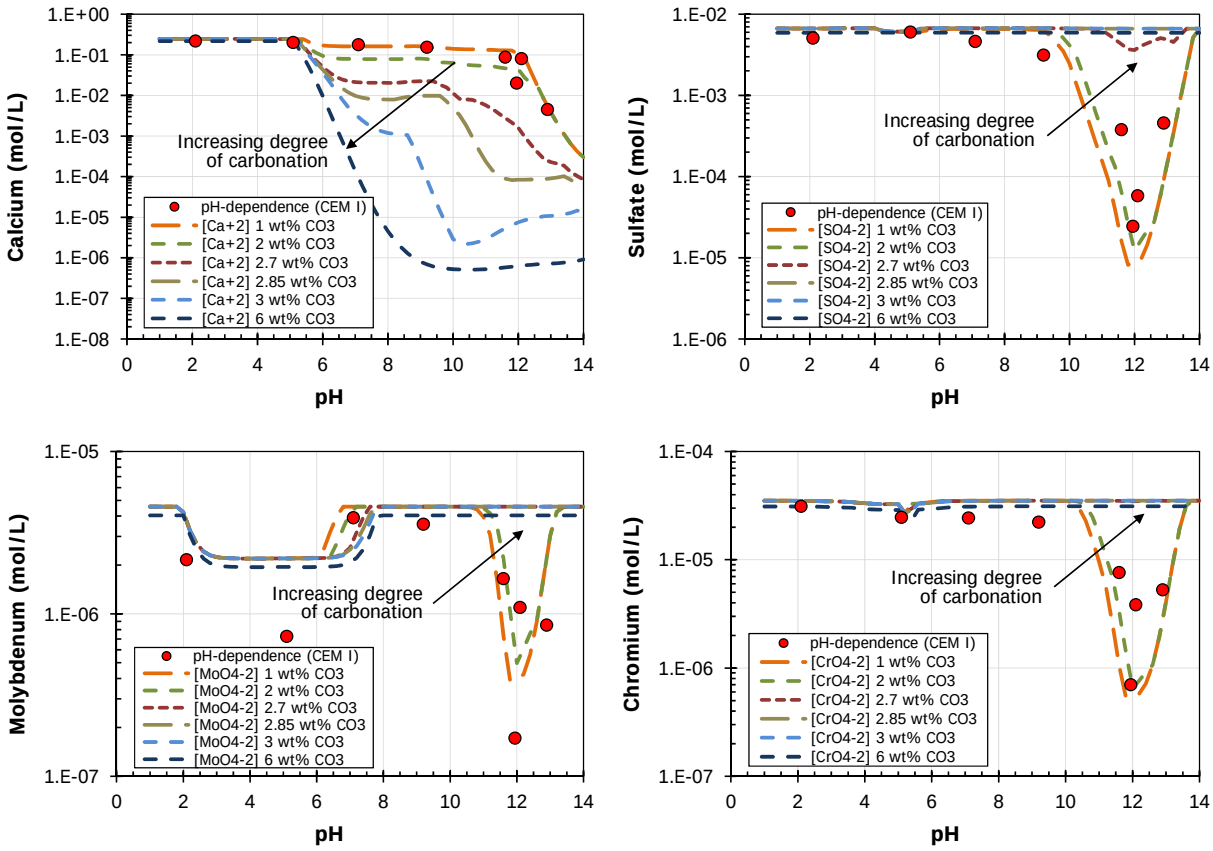


Figure 4-96 presents the impact of progressive extent of carbonation on the observed solubility of Ca, sulfate, Mo and Cr in comparison to pH dependence leaching test data from a standard mortar (ref) prepared from a CEM I portland cement and cured for 28 days prior to testing. Species that are either part of ettringite (i.e., sulfate) or co-precipitated with ettringite (i.e., as part of a solid solution), have relatively low solubility over the pH domain from 10 to 13 where ettringite is sparingly soluble, but have increased solubility when ettringite reacts to form calcite. Thus, progressively increasing solubility of sulfate, Mo and Cr are observed between pH 10 to 13 with increasing extent of carbonation.

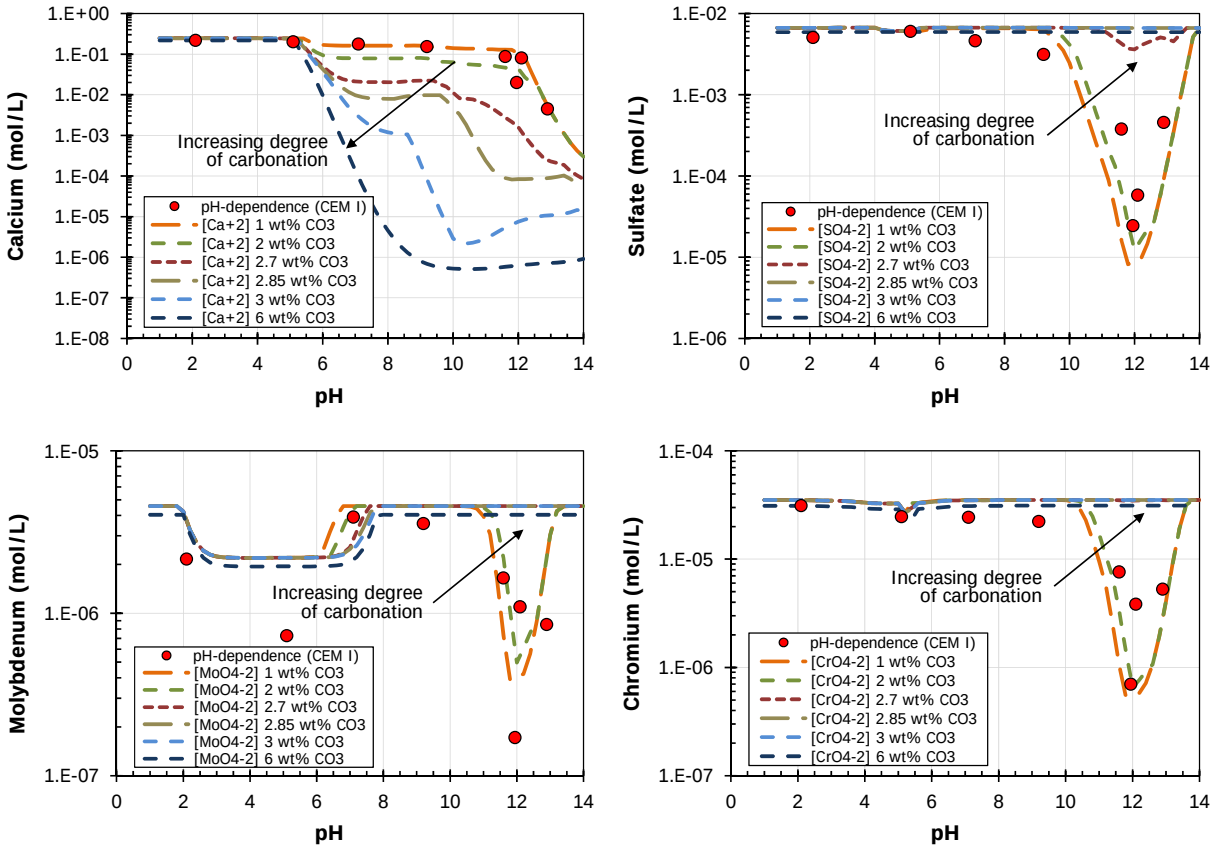


Figure 4-96. Chemical speciation modeling of the impacts of carbonation on solubility of Ca, SO_4, Mo and Cr compared to pH dependence leaching test data on portland cement CEM I standard mortar after 28-day cure.

4.10.3 Case Summary

Case 10 compared the leaching of cement and concrete samples with different aging periods, including 28 days (standard mortar), 4 years (recycled concrete aggregate), 40 years (field test site) and 2,000 years (Roman cement). As the concrete ages, the extent of carbonation from reaction with atmospheric carbon dioxide increases and reduces the natural pH of the material from an initial pH of 12-13 to a pH of approximately 9. Environmental leaching can result in further reduction to pH 7 through decalcification. Increasing extent of carbonation results in the loss of ettringite and the formation of calcite and barium and strontium carbonates, also resulting in decreasing solubility of calcium, barium and strontium at pH greater than 7 with increasing extent of carbonation. Increasing extent of carbonation also results in increases in sulfate solubility and leaching of oxyanions coprecipitated with ettringite (i.e., molybdate and chromate).

5 RECOMMENDATIONS FOR USE OF THE LEAF TEST METHODS FOR BENEFICIAL USE AND DISPOSAL DECISIONS

LEAF test results can be used to provide a reasonably conservative (upper-bound) source-term for a wide range of materials in use and disposal scenarios. The resulting source term should be used in conjunction with additional assessment steps that include consideration of dilution and attenuation from the source to receptor, and relevant receptor thresholds. Information presented in this report supports grouping individual sources of similar materials based on process origin and leaching behavior into material grouping or classes (i.e., coal fly ash from combustion of bituminous coal, coal combustion flue gas desulfurization gypsum, blast furnace slags, MSWI bottom ash, etc.). Accumulation of LEAF testing data for a range of materials and over time can provide useful estimates of uncertainty and variability associated with leaching from specific materials and material classes. Creation of one or more databases containing leaching data used in regulatory decision making and monitoring can facilitate efficient use of leaching data in future assessments, including by reducing testing and evaluation costs for well-studied classes of materials.

5.1 Evaluating New Management Scenarios – Material Combinations and Pilot Studies

Leaching assessment can present two forms of challenges:

1. Evaluating a new use or disposal scenario for a previously evaluated material or material class; and,
2. Evaluating a new material class or specific material without prior characterization of materials within the same material class.

Careful consideration should be given to the extent of prior knowledge about both the material or class of material, and the anticipated use or disposal scenario before proceeding. Consideration should be given to the potential range and changes that may occur with respect to water contact, physical integrity of the material, blending or interfaces with other materials, chemistry within the material and of contacting solutions, and evolution of pH and redox (e.g., from atmospheric exchange, carbonation, sulfide oxidation, organic matter degradation, etc.). Insufficient prior leaching characterization data or experience with sufficiently similar materials under analogous management scenarios should trigger use of a field pilot demonstration project when warranted based on a screening assessment that includes laboratory characterization, to insure that a priori unforeseen conditions do not result in a significant shift in the phenomena controlling leaching for the material and scenario under consideration.

The case studies presented in this report provide the basis for recommending specific components and considerations for initial material characterization and field demonstration projects:

1. Materials being considered should first be characterized using pH dependent leaching (Method 1313) and either percolation column leaching (Method 1314) or as a minimum, leaching at low liquid-to-solid ratio (Method 1316). Monolith leaching (Method 1315) should also be carried out for scenarios where monolith mass transport is anticipated as a significant factor controlling leaching. A sufficient number of samples based on data quality objectives should be characterized to reflect the inherent variability of the material being evaluated.

2. Field demonstration projects should include careful collection and analysis of runoff, pore water, leachate and other contacting water during the demonstration period. All sampling should be carried out using techniques that avoid atmospheric exchange and oxygenation, carbon dioxide uptake, and/or biogenic acidification during sampling. Within the material and for collected fluids, pH, redox and conductivity should be analyzed to the extent practical. Analysis of collected leachates and other aqueous samples should include analysis of major and trace constituents, as well as DOC, DIC and anions.
3. Core samples from the field demonstration project should be obtained at the end of the demonstration period and be considered to be obtained at intermediate time intervals. Laboratory leaching analysis of the cores can provide useful insights into the chemical speciation and physical-chemical status of the material during field aging processes. The comparison of the leaching behavior as function of pH for different ages of the material in combination with leachate data and batch or percolation test data at the appropriate pH provides valuable insight in the leaching behavior over time.
4. An efficient sampling plan consists of preparing a composite of samples taken from different locations from the pilot, lysimeter or field site for pH dependence and percolation and/or monolith leach tests and testing individual samples at L/S=10 and the natural pH to see the variability based on the location of the sampling.
5. Chemical speciation-based LSP and mass-transport modeling should be used to provide insights into leaching conditions that may evolve in the field and are beyond laboratory test conditions.

5.2 Estimating Leaching Source Terms

In Kosson et al. (2002), leaching assessment using a performance or "impact-based approach" was proposed, that subsequently has been referred to as LEAF:

> This approach focuses on the release flux of potentially toxic constituents over a defined time interval. Thus, the management scenario is evaluated based on a source term that incorporates consideration of system design, net infiltration and the leaching characteristics of the material. Basing assessment and decisions on estimated release allows consideration of the waste as containing a finite amount of the constituent of interest, the time course of release, and the ability to adapt testing results to a range of management scenarios. The measure of release would be the mass of constituent released per affected area over time (i.e., release flux). Knowledge of the release flux would allow more accurate assessment of impact to water resources (e.g., groundwater or surface water) by defining the mass input of constituent to the receiving body over time. Results of this impact-based approach can provide direct input into subsequent risk assessment for decision making, either based on site-specific analysis or using a generalized set of default assumptions.

The LEAF testing methodology allows for both empirical use of testing data for specific scenarios as part of a screening assessment, and use of the leaching test data in conjunction with chemical speciation and mass transport models to provide more realistic and refined, scenario-specific

estimate of constituent leaching that can be used as a source-term for risk assessment. While the result is a bounding estimate of leaching potential, consideration of waste and scenario-specific information allows many conservative assumptions to be replaced with data. A tiered-approach was proposed for developing the leaching source term, considering the type of evaluation being carried out, the level of information available, and the extent of conservatism embedded in the estimate (Figure 5-1). Subsequently, the EPA published its *Methodology for Evaluating Encapsulated Beneficial Uses of Coal Combustion Residuals* (2013b; also EPA, 2014) which provides for a tiered approach specifically applied to a more limited set of uses of two secondary materials (i.e., coal fly ash use as a cement replacement in concrete and FGD gypsum use in gypsum board). The observations and information gathered in this report provides a basis for the more detailed recommendations provided below on the use of LEAF test methods, consistent with the initially proposed methodology (2002) and the EPA methodology (2013). Additional relevant details regarding assessment approaches can be found in Kosson et al (2002), Sanchez et al (2002) and Kosson et al (1996), EN 12920 (1996), Verschoor et al (2008), Carter et al (2009), Postma et al (2009), van der Sloot and van Zomeren (2012), and Hjelmar et al (2013) . These methodologies also recognize that decision making typically is based on a water concentration-based comparison to human health or ecologically based standards, or an exposure assessment at a point of compliance. It must be emphasized that these recommendations for use of leach testing data only provide the approach for estimating the leaching source term (i.e., concentrations and amounts of a constituents leaching from the material under a specific scenario). Additional determinations are needed to define or account for (i) the location that serves as the basis for exposure assessment following constituent leaching release from a source scenario (e.g., point of compliance), (ii) dilution and attenuation in the vadose zone and groundwater or surface water from the point of release to the point of compliance, and (iii) appropriate exposure scenarios or reference thresholds (e.g., human health or ecological thresholds). These evaluations are typically incorporated into a model of constituent fate and transport leading to possible receptor exposure (e.g., groundwater transport to a drinking water well, with water ingestion as the exposure pathway).

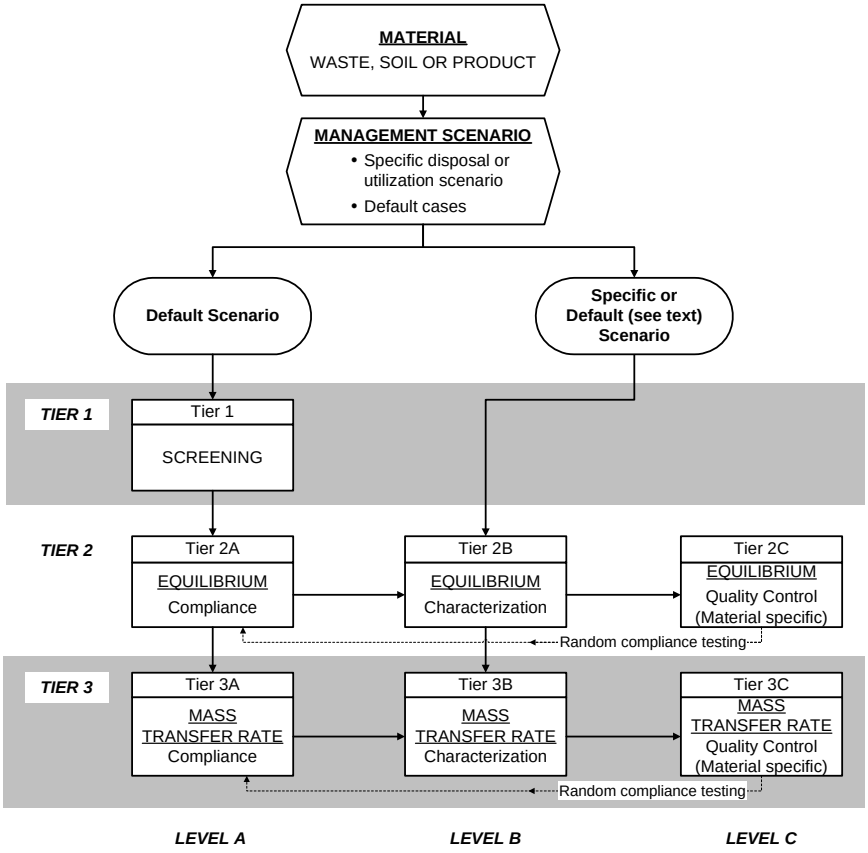


Figure 5-1. A tiered framework for evaluating leaching (Kosson et al, 2002)

5.3 Scenario Definition

Defining the material use or disposal scenario is the first step to selecting the appropriate leaching tests and basis for interpreting the resulting data. The extent of information needed as part of the scenario definition increases as the evaluation seeks to achieve a more detailed and refined estimate of constituent leaching. The initial scenario definition should as a minimum answer the following questions:

1. *What is the applicable pH domain?* The applicable pH domain will extend at least from the material's natural pH to neutral pH (pH 7), and may be further extended based (i) material characteristics that may result in self-acidification through oxidation or biodegradation processes (e.g., materials containing significant amounts of sulfides, other reactive phases or biodegradable organic matter), (ii) commingling with either more alkaline or more acidic materials, (iii) external sources of acid or alkalinity such as from adjacent materials or the chemistry of contacting water. Case studies in this report provide examples of applicable pH domains for several materials and scenarios.
2. *Is the material oxidized as produced and subject to reducing conditions under the proposed use or disposal scenario?* Causes of reducing conditions to form include commingling with other reducing materials such as slags or some mining wastes, presence of significant amounts of biodegradable organic matter and barriers to exchange of atmospheric oxygen.

3. *Is the material chemically reduced and subject to oxidizing conditions?* Causes of oxidizing conditions for initially reduced material include exposure to air and oxygenated water (i.e., infiltration).
4. *Will the primary mode of water contact be through infiltration and percolation through the material or through contact and exchange at the exterior surface of a large mass or monolith (e.g., as would occur for materials compacted to low hydraulic conductivity)?*

5.4 Screening Assessment (Tier 1)

Recommendations for use of LEAF testing in screening assessment (Tier 1) and equilibrium-based assessment (Tier 2) are provided in Table 5-1. Leaching assessment for screening purposes (Tier 1) can be based on the estimated maximum leaching concentration anticipated for each COPC. At this tier, maximum LSP is estimated based on the maximum concentration for each COPC measured over the applicable pH domain as defined by the scenario using the pH dependent leaching test (i.e., Method 1313) and then adjusted for the anticipated pore water L/S, unless it can be demonstrated that the specific COPC is solubility controlled throughout the applicable pH domain. The adjusted (conservative) concentration at the applicable pore water LS can be achieved by

$$C_{i,adjusted} = C_{i,LS=10} * CF$$

Where $C_{i,adjusted}$ is the adjusted concentration of constituent i, $C_{i,LS=10}$ is the maximum concentration over the relevant pH domain at L/S=10 mL/g (as from Method 1313), and CF is the correction factor which is equal to 10 divided by the pore water L/S (which can be approximated as the material porosity.

Cases 5 and 8 demonstrated that an effective pore water L/S of 0.5 L/kg is appropriate for coarse landfilled materials subject to percolation and preferential flow, resulting in a multiplier of 20 to adjust the eluate concentrations measured using Method 1313. This screening approach does not account for the amount of material being evaluated that would be present under the scenario (i.e., it implies an "infinite source" of material or COPCs).

5.5 Equilibrium-based Assessment (Tier 2)

An equilibrium-based leaching evaluation would consider LSP over the applicable pH and redox domains and the maximum amount of each COPC available for leaching. Method 1313 results in conjunction with Method 1316 at L/S of 2 mL/g would be used to assess whether LSP for each COPC was constrained by aqueous solubility or availability. If the COPC exhibits significantly greater concentration at L/S of 2 mL/g (Method 1316) then measured from Method 1313 at the pH corresponding with the pH measured at L/S of 2 mL/g, then the Method 1313 results are considered to be availability constrained and the maximum concentration from Method 1313 over the applicable pH domain that is adjusted to the pore water L/S is used as the peak source concentration. If the COPC at L/S of 2 mL/g is the same as (within uncertainty) the concentration measured at the corresponding pH from Method 1313, then the COPC is considered solubility constrained and the maximum concentration over the applicable pH domain from Method 1313 is used as the peak source concentration.

Table 5-1. Tier 1 Screening Assessment and Tier 2 Equilibrium-Based Assessment - Summary of recommended test methods and analyses.

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 1 – Screening Assessment[1]	Method 1313 (applicable pH range only[2])	pH, EC, COPCs, DOC	Maximum leachate conc.[3] estimated as 20x or 10x maximum eluate conc. for highly soluble constituents in granular materials[4, 5] and the measured maximum eluate conc. for monolithic materials and solubility controlled constituents (all materials).
Tier 2 – Equilibrium-based Assessment			
Tier 2A Compliance	Method 1313 (applicable pH range + pH=2, 7, 9 if not included) Method 1316 (L/S=2 mL/g or lowest L/S eluate)	pH, EC (natural pH only), COPCs, DOC	Availability estimated as maximum release at measured pH intervals including pH=2 and 9; provides basis for finite source by assuming that availability is maximum cumulative release under field conditions. EC used to estimate ionic strength. Acid/base neutralization capacity to pH=7. Maximum leachate conc. estimated as determined from Tier 2B based on Method 1313 results over applicable pH domain. Method 1316 allows identification of solubility controlled vs highly soluble constituents.
Tier 2B Characterization	Method 1313 (full set of eluates) Method 1316 (full set of eluates)	pH, EC & pe (natural pH only)[6], COPCs, DOC, DIC, major and minor constituents (including P and S)	Availability as indicated in Tier 2A. Liquid-solid partitioning as a function of pH used for speciation assessment.[7] Provides baseline understanding of material leaching behavior. Supports chemical speciation simulations to understand effects of changes in L/S, pH, redox, and reactive constituents (e.g., DOC, carbon dioxide, etc.). Maximum leaching concentration as indicated for Tier 1 or based on simulation results at L/S of the material pore solution. Method 1316 provides basis for determination of solubility control and verification of chemical speciation modeling at low L/S.
Tier 2C Quality Control	Method 1313 at natural pH, and pH=2, 7 and/or 9	pH, EC, relevant COPCs[8] (natural pH and for availability) to meet environmental requirements and additional constituents to meet beneficial use requirements	Used to verify leaching over "applicable" pH range, acid/base neutralization capacity to pH=7, and availability of relevant COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Assumes definition after completion of Tier 2B and/or analogous prior information.[9] Chemical analysis only for determination of leaching at natural pH and availability (2 or 3 extracts). Further simplification may be possible based on additional available information.

Notes for Table 5-1:

[1]For regulatory frameworks based on a source term concentration, the maximum estimated leaching concentration is recommended for use in screening assessment. For regulatory frameworks based on the total mass of constituent potentially leached, availability is recommended for use in screening assessment.

[2]The applicable pH range is determined considering the material's natural pH, changes in pH due to material aging processes, infiltration conditions, and interfaces or comingling with other materials.

[3]"conc." is used as an abbreviation for concentration or concentrations.

[4]Twenty times the maximum eluate concentration is recommended for highly soluble species when the material is homogeneous (e.g., coal fly ash) and ten times the maximum eluate concentration is recommended for heterogeneous materials (e.g., MSW incinerator bottom ash) where significant preferential flow is anticipated. Both multipliers are to account for the increased concentrations expected when estimating pore water concentrations (L/S=0.2 to 0.5 L/kg) from test conditions of L/S=10 mL/g).

[5]Highly soluble species are Group IA elements (i.e., Na, K), anions (i.e., bromide, chloride, fluoride, nitrate), and oxyanions (i.e., As, B, Cr, Se, Mo, V.).

[6]Determination of EC and pe is recommended for natural pH eluate only. The sensitivity and uncertainty of pe measurements are recognized but pe measurement will provide a useful indication of whether or not the material is inherently reducing under abiotic and anoxic conditions.

[7]Speciation assessment refers to consideration of the effects of changes in pH, redox conditions, extent of carbonation, complexation with dissolved organic carbon, etc. which may be accomplished heuristically or in combination with geochemical speciation modeling.

[8]Relevant COPCs are those constituents that are present in the material and have been found through Tier 2B characterization and/or prior information to leach at concentrations or release values that approach or challenge regulatory or quality control thresholds.

[9]Prior information, such as characterization information from similar materials, may reduce or supplant the need for or extent of Tier 2B characterization.

The maximum amount of a COPC that is available to leach per unit mass of material (i.e., "finite source") is based on the maximum constituent release (i.e., mg/kg) over the entire pH domain of Method 1313 (typically pH 2 for cations and pH 9 for oxyanions). The amount of each COPC that leaches should be estimated based on the amount of contacting water per unit time (i.e., L/S per year) times the estimated peak concentration.

Initial characterization testing (Tier 2B) should include analysis of both major and trace constituents in all leaching test eluates because knowledge of the major constituents that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. However, prior knowledge from testing of analogous materials may reduce the need for or extent of characterization testing.

For periodic demonstration of compliance with regulatory thresholds, the extent of Method 1313 testing can be reduced to the applicable pH domain and regulatory COPCs, pH and conductivity[23]. For quality control purposes, the extent of Method 1313 testing can be further reduced to only the natural pH value and along with the pH 2 and/or 9 as needed to measure availability for the relevant COPCs (those that are present and leach at concentrations that approach thresholds) and conductivity.

Knowledge of the chemical behavior of the COPCs and the scenario should be used to evaluate if higher leaching concentrations are anticipated because of changes in redox conditions. Anticipated changes in leaching because of changes in L/S, redox or chemical conditions can also be evaluated using chemical speciation modeling as demonstrated for the evaluation cases in this report.

5.6 Mass Transport-based Assessment (Tier 3)

Mass transport-based assessment can be divided into two distinct regimes: (i) percolation through the material as the predominant leaching mechanism, and (ii) mass transport from monolithic materials where diffusion to the exterior surface of the bulk material and surface dissolution control constituent leaching. Intermediate conditions between the percolation and monolith regimes, such as for large aggregates and cracked monolithic materials also exist, but are beyond the scope of this discussion. Summaries of recommended LEAF testing and evaluation are provided for percolation mass transport-based assessment and monolithic mass transport-based assessment in Table 5-2 and Table 5-3, respectively.

Percolation based regimes can be evaluated through use of the pH dependent test (i.e., Method 1313) in conjunction with the percolation column test (i.e., Method 1314) or batch testing (Method 1316) for initial leachate concentrations. Considering the results of Cases 2, 5 and 8 (Sections 4.2, 4.5 and 4.8) initial eluates from Method 1314 or low L/S results from Method 1316 are good indicators of the anticipated COPC concentrations in initial field leachates and Method 1314 provides the evolution of the leachate concentrations over prolonged periods based on the progression of the L/S based on the field material geometry and annual infiltration rates.

[23] Measurement of conductivity is recommended as an indicator of total ionic strength and therefore can also provide an indication if there is a significant change in leaching of total salts over the monitoring interval.

Table 5-2. Tier 3 Percolation Mass Transport-Based Assessment – Summary of recommended test methods and analyses.

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 3 – Percolation Mass Transfer Rate-based Assessment			
Tier 3A Compliance	Method 1313 (pH=2, 9, applicable pH domain) Method 1314 (to L/S=2 mL/g)	pH, EC (natural pH only), COPCs, DOC	Allows verification of liquid-solid partitioning at natural pH and availability (from Method 1313). Maximum leachate conc. estimated as established by Tier 3B as greater of either i) maximum conc. from Method 1314 up to L/S =2 mL/g, or ii) maximum conc. from Method 1316, or iii) maximum conc. from Method 1313 over applicable pH domain.
Tier 3B Characterization	Method 1313 (full set of eluates) Method 1314 (full set of eluates) Method 1316 (L/S=2)	pH, EC (natural pH only), COPCs, DOC, DIC, major and minor constituents	Availability and leaching as a function of pH and evaluation of potential changes in conditions as indicated for Tier 2B. Method 1314 provides leachate evolution as a function of L/S for source term based on test elution curve. Supports reactive transport simulations to consider sensitivity to field conditions such as infiltration chemistry, preferential flow and material aging. Provides basis for verification of chemical speciation modeling at low L/S.
Tier 3C Quality Control	Method 1313 at pH=2, 7 and/or 9 and Method 1316 at L/S = 2	pH, EC, COPCs (1313 for availability and 1314 at L/S of peak release) to meet environmental requirements, additional constituents to meet beneficial use requirements	Method 1313 extractions used to verify acid/base neutralization capacity to pH=7, and availability of selected COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Method 1314 extract at L/S of prior peak concentration to verify maximum leaching conc. Assumes definition after completion of Tier 3B Characterization. Chemical analysis only for determination of leaching at peak release conc. and availability (2 or 3 extracts). Further simplification may be possible based on additional available information.

Table 5-3. Tier 3 Monolith Mass Transport-Based Assessment – Summary of recommended test methods and analyses[1].

Assessment Type	Leaching Methods	Eluate Analyses	Assessment Basis
Tier 3 – Monolith Mass Transport-based Assessment			
Tier 3A Compliance	Method 1313 (pH=2, 9, applicable pH domain) Method 1315 (to 7 days)	pH, EC (natural pH for Method 1313 and all Method 1315 eluates), COPCs, DOC	Allows verification of liquid-solid partitioning at natural pH and availability (from Method 1313). Maximum leachate conc. estimated as established by Tier 3B as greater of either i) maximum conc. from Method 1314 up to L/S =2 mL/g, or ii) maximum conc. from Method 1316, or iii) maximum conc. from Method 1313 over applicable pH domain.
Tier 3B Characterization	Method 1313 (full set of eluates) Method 1314 (full set of eluates) Method 1315 (to 64 days)	pH, EC (natural pH only for Method 1313 and all Method 1314, and 1315 eluates), COPCs, DOC, DIC, major and minor constituents	Availability and leaching as a function of pH as indicated for Tier 2B. Method 1314 (crushed material) up to L/S=2 provides estimate of initial pore water composition. Method 1315 provides cumulative release as a function of leaching time for saturated and intermittent wetting conditions. Also provides basis for estimating reactive transport parameters (e.g., tortuosity) for simulation of evolving conditions (e.g., low liquid to surface area, external solution chemistry, carbonation, oxidation, intermittent wetting, etc.). Provides basis for Tier 3C quality control.
Tier 3C Quality Control	Method 1313 at pH=2, 7 and/or 9 and Method 1315 (to 7 days)	pH, EC, COPCs (1313 for availability and 1314 at L/S of peak release) to meet environmental requirements, additional constituents to meet beneficial use requirements	Method 1313 extractions used to verify acid/base neutralization capacity to pH=7, and availability of selected COPCs and other (if applicable) constituents central to beneficial use application (e.g., Ca, sulfate, etc.). Method 1315 cumulative release to 7 days to verify consistency with characterization results (Tier 2B). Assumes definition after completion of Tier 3B Characterization. Further simplification may be possible based on additional available information.

[1]The cure time prior to testing of monolithic materials is an important consideration because for many cementitious materials, hydration and microstructure development continues for more than a one year, with initial cure times of 90 days recommended prior to Method 1315 testing.

Initial percolation characterization testing should include analysis of both major and trace constituents in all leaching test eluates (Methods 1313 and 1314 or 1316) because knowledge of the major constituents (such as Ca, Fe, DOC or SO_4) that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. For compliance testing, Method 1313 can be used as described above (Equilibrium Based Assessment) and Method 1314 analysis can be simplified to analysis of eluates as prescribed as Option E in Table 1 of the method (i.e. at L/S=0.2 and along with two composite samples) for COPCs, pH and conductivity, thus providing peak eluate concentrations and cumulative release. For quality control purposes, either Method 1313 reduced to only the pH values that result in peak concentrations over the applicable pH domain and the relevant COPCs or Method 1314 testing as described for compliance testing can be used.

Monolith regimes can be evaluated based on use of Method 1315 in conjunction with Method 1313 (Table 5-3). A detailed example of use of this information for evaluation of use of coal combustion fly ash as a substitute for Portland cement in concrete considering intermittent water contact via precipitation is available (EPA, 2013a). An example approach for use of empirical data from Method 1313 (i.e., for availability) and Method 1315 (i.e., for estimated effective diffusivity) is provided for MSWI bottom ash scenarios in Kosson et al (1996). These approaches can also be used in conjunction with chemical speciation based mass transfer models (see Section 3) to provide insights into potential changes in leaching that may occur in response to changing conditions within or on the external surface of the material being evaluated.

Initial monolith characterization testing should include analysis of both major and trace constituents in all leaching test eluates (Methods 1313 and 1315) because knowledge of the major constituents that control release of the trace constituents provides insights into the factors that may result in changes in leaching and allow for calibration of chemical speciation models. For compliance testing, Method 1313 should be used to assess availability and solubility at the natural pH of the material (i.e., no acid or base addition) and Method 1315 analysis can be simplified to analysis of eluates at exchange up to 7 days for COPCs, pH and conductivity. For quality control purposes, Method 1315 can be reduced to only analysis of pH and conductivity and composited eluates up to 7 days for COPCs to determine cumulative release.

6 CONCLUSIONS

This report evaluated the relationships between laboratory leaching tests as defined by the Leaching Environmental Assessment Framework (LEAF) or analogous EU/international test methods and leaching of constituents of potential concern (COPCs) from a broad range of materials during field disposal and beneficial use conditions. This evaluation was achieved by defining a framework for interpretation of laboratory testing results, comparison of laboratory testing on "as produced" material, laboratory testing of "field aged" material, and results from field leaching studies, and illustrating the use of chemical speciation modeling as a tool to facilitate evaluation of scenarios beyond the conditions of laboratory testing.

Ten field evaluation cases for disposal or beneficial use that have a combination of laboratory testing and field analysis were considered that included the following materials: (i) coal fly ash (CFA), (ii) fixated scrubber sludge typically produced by combining coal fly ash with acid gas scrubber residue and lime at some coal fired power plants (FSSL), (iii) municipal solid waste incinerator bottom ash (MSWI-BA), (iv) a predominantly inorganic waste mixture comprised of residues from soil cleanup residues, contaminated soil, sediments, C&D waste and small industry waste(IND), (v) municipal solid waste (MSW), (vi) cement-stabilized municipal solid waste incinerator fly ash (S-MSWI-FA), and (vii) Portland cement mortars and concrete. The field data presented in this report include (i) leachate from field lysimeters, (ii) porewater from landfill or use applications, (iii) eluate from leaching tests on sample cores taken from field sites, and (iv) leachate collected from landfills. Principal uncertainties for field data in many cases include (i) the extent of preferential flow or dilution that may have occurred during water contact within the material and in sampling of landfill leachate, and (ii) the exact exposure and aging conditions that contribute to the field data.

Primary aging processes and reactions that can impact leaching are (i) establishment of reducing conditions from biogenic processes (i.e., degradation of organic matter), (ii) oxidation from atmospheric exchange, and (iii) carbonation from either atmospheric exchange, dissolved carbon dioxide (or carbonates) in contacting water, or reaction with biogenic carbon dioxide. Other slow mineral formation processes, such as with stabilized waste, may result in small changes in leaching relative to freshly prepared material after initial curing periods (i.e., 90 days). Constituents in infiltrating or contacting water, either from natural processes (e.g., DOC in the form of humic substances from leaf decay) or from anthropogenic origin (e.g., leaching from up gradient disposed materials) may have a substantial effect on leaching.

Based on the above comparisons and observations along with results discussed in earlier sections, the following conclusions and recommendations are drawn:

1. The combination of results from pH-dependent leaching tests (i.e., EPA Method 1313 or CEN/TS 14429 or CEN/TS 14997) and percolation column tests (i.e., EPA Method 1314 or CEN/TS 14405) can be used to provide accurate estimates within defined uncertainty bounds of maximum field leachate concentrations, extent of leaching and expected leaching responses over time and to changes in environmental conditions under both disposal and use scenarios. Leaching test results should be evaluated with consideration of the potential for changes in leaching conditions that are beyond the domain of laboratory test conditions,

such as oxidation of reduced materials, reduction of oxidized material, carbonation and introduction of DOC from external sources. When field conditions beyond the domain of laboratory test conditions are plausible, chemical speciation modeling can be used to consider the magnitude of effects from the postulated changing conditions. Peak leaching concentrations and availability of COPCs estimated from laboratory testing can be used to provide a conservative estimate (i.e., reasonable upper bound) of anticipated field leaching. Results from batch testing at low L/S ratios (i.e., EPA Method 1316 or EN 12457) can also be used in place of column test results when column testing is impractical. Thus, the LEAF laboratory leaching tests can be used effectively to estimate the field leaching behavior of a wide range of materials under both disposal and use conditions. Interpretation of the leaching test results should be in the context of the controlling physical and chemical mechanisms of the field scenario.

a. For elements and species that are highly soluble, solubility is not a function of pH and a saturated solution is not expected to occur (e.g., Cl, K, Na). The initial eluates from a column leaching test (i.e., Method 1314) are a reasonable estimate of the expected peak concentration from field leaching and are representative of porewater solutions. Constituent concentrations obtained from the pH-dependent leaching test (i.e., Method 1313) at the material natural pH at L/S=10 mL/g can be multiplied by the ratio of L/S at batch testing conditions to the L/S at porewater conditions based on field porosity (i.e., L/S=0.2-0.5 mL/g with resulting factors of 20-50) to estimate anticipated concentrations under porewater conditions. Similarly, results from an L/S dependence leaching test (i.e., Method 1316) at L/S=0.5 mL/g can provide a reasonable estimate of the expected peak concentration from field leaching. However, for many conditions, because of either solubility constraints or preferential flow, the estimated value under pore water conditions may be overly conservative and not realized in field leachate. Considering these factors, an adjustment factor of 20 has been shown to be a reasonable basis for estimating peak concentrations from LSP data obtained at L/S=10 mL/g. For monolithic materials, peak concentrations are indicative of a “first flush” phenomenon occurring during initial surface wetting after a period without leaching, whereby internal concentration gradients have relaxed. Peak concentrations will decline rapidly during a prolonged wetting event because of diffusion and dissolution limitations on leaching at the external surface. Higher concentrations will return after a non-flow period because of relaxation of internal concentration gradients and re-equilibration of porewater.

b. For elements and species where solubility is pH-dependent and a saturated solution is found to occur based on pH-dependence and column or batch L/S leaching tests, the pH-dependent leaching test (i.e., Method 1313) provides a reasonable estimate of the expected field leachate concentrations over the anticipated pH domain with solubility control, which in turn may be diluted by flow channeling that bypasses contact with the solid material (such as often happens with collection systems or large spatial integration). For monolithic materials, local equilibrium between the porewater and monolith surface can be anticipated as a result of intermittent

infiltration and wetting, followed by diffusion controlled leaching and gradient relaxation.

c. For field percolation scenarios and for elements and species that are highly soluble over a limited portion of the anticipated pH domain (e.g., oxyanions of Cr, As, V), laboratory column test results may be indicative of leaching under initial conditions and as long as oxidized field conditions are anticipated. Peak barium concentrations under oxidized field conditions may be much lower than indicated by laboratory testing because of precipitation with sulfate present at higher concentrations in pore water and leachate. Under field reducing conditions, several oxyanions (e.g., As, Cr, Mo, Se) along with phosphorus and barium exhibit leaching behavior as highly soluble species, a result, in part, of loss of iron oxide sorptive surfaces during iron reduction and mobilization, and therefore high concentrations of iron in leachate should be considered as indicative of reducing conditions. The resulting peak field leachate concentrations are greater than measured during laboratory column testing because the laboratory column test methods typically do not achieve the strongly reduced conditions. As a result, the peak leachate concentration for these constituents under reducing conditions (if anticipated) is best conservatively estimated based on the mass of the constituent available for leaching based on the pH-dependent leaching test multiplied by the correction factor from L/S=10 L/kg to the L/S based on field porosity.

d. Highly alkaline materials (e.g., cement stabilized wastes, alkaline fly ashes, etc.) are likely to exhibit highly alkaline natural pH during laboratory testing ($11 < pH < 13$), but will react with atmospheric carbon dioxide under field conditions, resulting in field leachates and runoff with pH trending from highly alkaline (observed laboratory pH) to near neutral ($pH \geq 7.0$) conditions. Carbonation will result in lower solubility of Group II elements of the periodic table (i.e., calcium, strontium, etc.) due to formation of carbonate minerals, and loss of ettringite can result in increased leaching of co-precipitated oxyanions (e.g., chromate, molybdate, arsenate). Leaching of solubility controlled constituents will reflect the liquid-solid partitioning as indicated by the pH-dependent test results at the resultant pH. Thus, leaching for these constituents should be evaluated based on the pH domain from the initial natural pH of the material to a near neutral pH or the anticipated pH domain anticipated for mixed materials.

e. Dissolved organic carbon (DOC), often in the form of substances analogous to humic substances or volatile fatty acids, can result in complexation of several elements (e.g., copper, chromium), and thereby increase measured aqueous phase concentrations of these elements during laboratory testing and under field conditions. Reducing conditions in the field along with high organic matter content in materials being managed can result in elevated concentrations of DOC in the leachate not observed in results from laboratory test methods.

2. Field testing of new use or disposal scenarios or new classes of materials to be used or disposed in new ways is highly beneficial to understanding the factors that control leaching

for the specific scenario. Thereafter, materials within a given class can be anticipated to behave similarly under the established use or disposal scenario and the LEAF testing approach can be used to distinguish "acceptable" versus "unacceptable" materials and use conditions within the general class of materials and scenario. The EPA guidance on beneficial use of coal fly ash in concrete (EPA, 2014) provides an example of the use of LEAF test results in such decisions.

3. Establishment of a national database of LEAF laboratory leaching test results for materials and leaching observed under field conditions would provide useful insights for evaluation of new cases and material use and disposal decisions.

4. Field testing should include (i) sampling and leaching characterization of the initial material, including pH-dependent, column and monolithic mass transfer rate (where applicable) testing; (ii) field leachate collection and monitoring over extended time frames (i.e., several years); and (iii) collection and characterization of test materials after prolonged field exposure (i.e., core samples from field test sites). Sample collection systems and subsequent handling need to be designed to avoid sample changes prior to analysis that degrade the representativeness of the samples and can result in misleading results (e.g., sample oxidation or carbonation during collection or handling resulting in changes in pH and constituent speciation). Furthermore, sample analysis should include a full suite of major and trace constituents that influence and provide a context for understanding COPC leaching.

5. Chemical speciation modeling of liquid-solid partitioning can be used for understanding the mechanisms (e.g., mineral phases, sorption and aqueous phase complexation phenomena) controlling leaching of the full range of constituents in the laboratory and the field, and understanding material leaching under conditions that are not readily subject to testing. Although the general behavior of many of the major and trace constituents are reasonably represented in relevant scenarios, application of chemical speciation modeling to waste management currently is constrained by the availability of test data for identifying important solid phases and the range of available thermodynamic data available for model parameters. Application of chemical speciation modeling as a tool for understanding waste management should be expanded, along with underlying research to fill data gaps.

6. Single point leaching tests and other common leaching assessment approaches cannot provide needed insights into the expected leaching performance of materials under the range of expected field conditions. The LEAF integrated evaluation of multiple types of leaching test data (i.e., pH dependent LSP along with percolation and/or monolithic mass transport behavior) and field data within the context of understanding fundamental leaching behavior (i.e., processes controlling liquid-solid partitioning and mass transport rates), along with use of chemical speciation based modeling provides extensive insights into the expected leaching behavior over a range of field conditions that cannot be obtained otherwise. The resulting estimates of COPC release reduce the use of conservative assumptions in favor of more complete data and refined speciation models, and consequently expands alternatives and provides a sound scientific basis for making decisions about appropriate disposal or use of secondary materials on the ground.

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APPENDIX A. CHEMICAL SPECIATION MODELS FOR EXAMPLE CASES

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Table A-1. Chemical Speciation Fingerprint for Coal Combustion Fly Ash

Chemical Speciation Fingerprint - Municipal Solid Waste Landfill							**LeachXS**	**2012**
Prediction case	LtoF MSW		**DOC/DHA data**				**Polynomial coeficients**	
Speciation session	Landgraaf mix		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**C0**	-3.446E+00
Material	Mixed organic waste DS NL (P,1,1)		1.00	4.539E-04	0.55	2.496E-04	**C1**	-8.161E-02
			2.75	2.810E-04	0.40	1.124E-04	**C2**	-7.705E-02
Solved fraction DOC	0.2		3.69	1.790E-04	0.30	5.370E-05	**C3**	1.349E-02
Sum of pH and pe	13.00		6.37	1.470E-04	0.25	3.675E-05	**C4**	-5.311E-04
L/S	10.0000	**l/kg**	6.81	1.730E-04	0.20	3.460E-05	**C5**	0.000E+00
Clay	1.000E-01	**kg/kg**	7.48	1.740E-04	0.20	3.480E-05		
HFO	1.000E-02	**kg/kg**	8.78	3.330E-04	0.25	8.325E-05		
SHA	4.000E-02	**kg/kg**	10.32	6.195E-04	0.35	2.168E-04		
Percolation material	Mixed organic waste DS NL (C,1,1)		11.66	8.380E-04	0.55	4.609E-04		
Avg L/S first perc. fracti	0.1240	**l/kg**	14.00	9.574E-04	0.90	8.617E-04		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured	CrO4-2	5.273E+01	Mg+2	1.632E+03	SO4-2	2.769E+03	
Al+3	3.076E+03	Cu+2	2.342E+02	Mn+2	3.392E+02	Sb[OH]6-	1.813E+00	
H3AsO4	6.116E-01	F-	1.680E+02	MoO4-2	7.673E+00	SeO4-2	5.495E-01	
H3BO3	7.289E+01	Fe+3	1.341E+04	Na+	2.079E+03	H4SiO4	1.973E+03	
Ba+2	1.567E+01	H2CO3	3.010E+04	NH4+	not measured	Sr+2	6.760E+01	
Br-	9.010E+00	Hg+2	not measured	Ni+2	8.473E+01	Th+4	not measured	
Ca+2	2.272E+04	I-	not measured	NO3-	not measured	UO2+	not measured	
Cd+2	1.695E+01	K+	1.584E+03	PO4-3	7.881E+01	VO2+	4.727E+00	
Cl-	2.330E+03	Li+	2.670E+00	Pb+2	5.878E+02	Zn+2	2.110E+03	
Selected Minerals								
Al[OH]3[a]	Birnessite	CuCO3[s]	Huntite	Otavite	Wairakite			
alpha-TCP	Brucite	Diopside	hydrozincite	Pb2V2O7	Witherite			
Analbite	Ca2Zn[PO4]2	Dolomite	Magnesite	Pb3[VO4]2	Zn[OH]2[B]			
Anglesite	CaCu2[PO4]2	Fe_Vanadate	Manganite	PbMoO4[c]	ZnCO3:H2O			
Anhydrite	Calcite	Fe2[OH]4SeO3	NiCO3[s]	Rhodochrosite				
Ba[SCr]O4[96%SO4]	CaMoO4[c]	Ferrihydrite	Nsutite	Strontianite				
BaSrSO4[50%Ba]	Cerrusite	Fluorite	OCP	Talc				

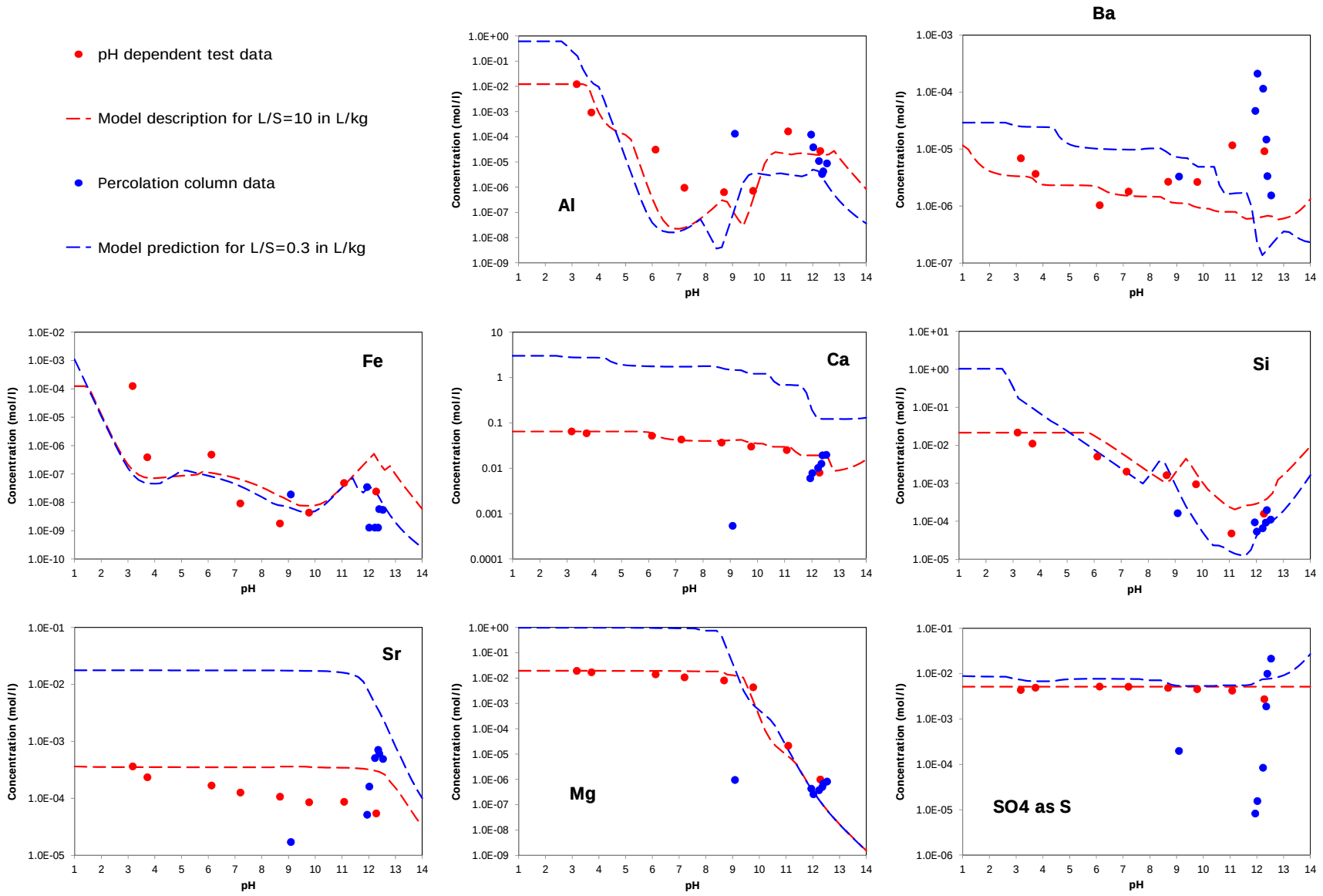

Figure A-1. Chemical speciation model for constituents in coal combustion fly ash.

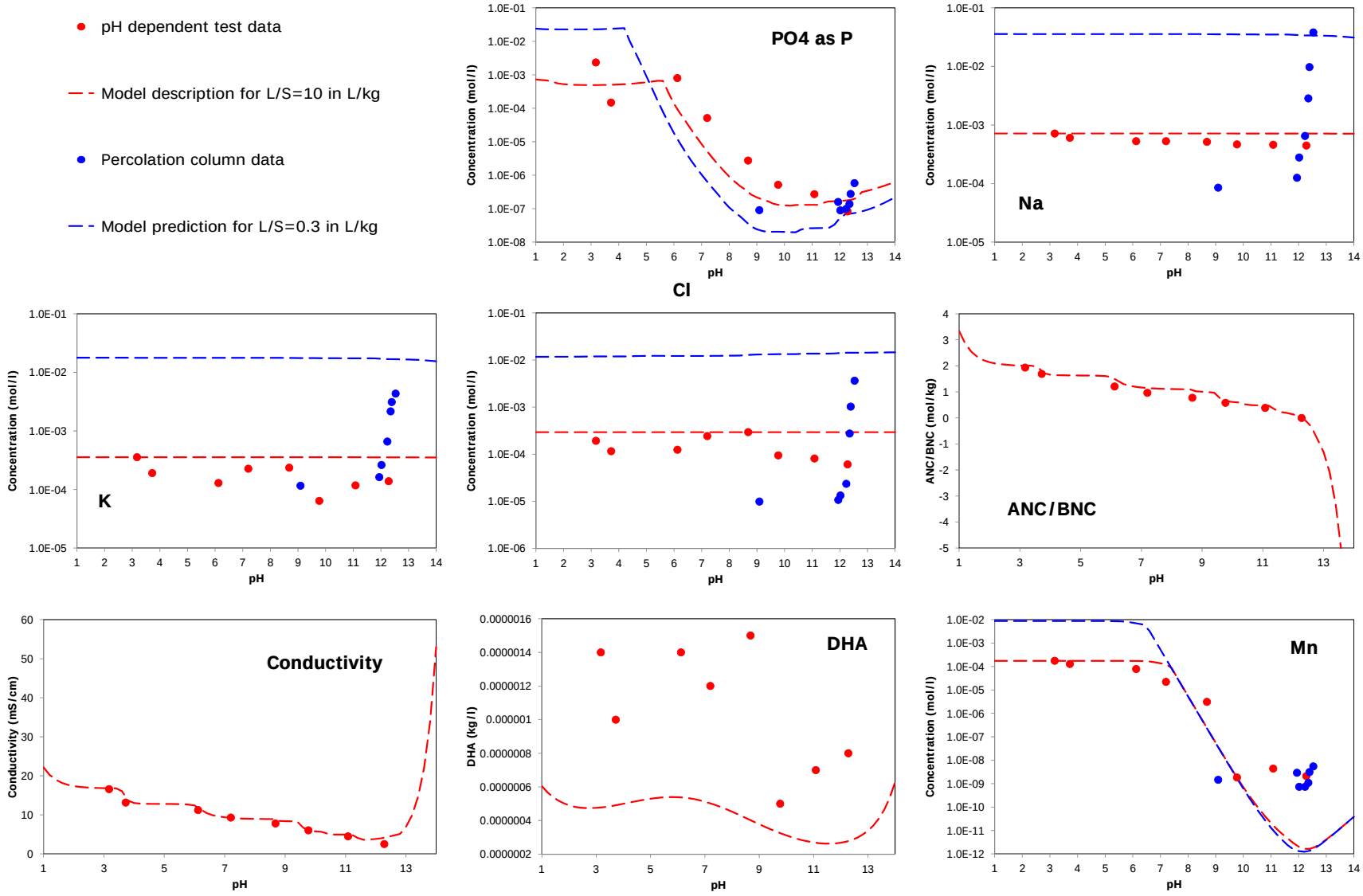

Figure A-2. Chemical speciation model for constituents in coal combustion fly ash.

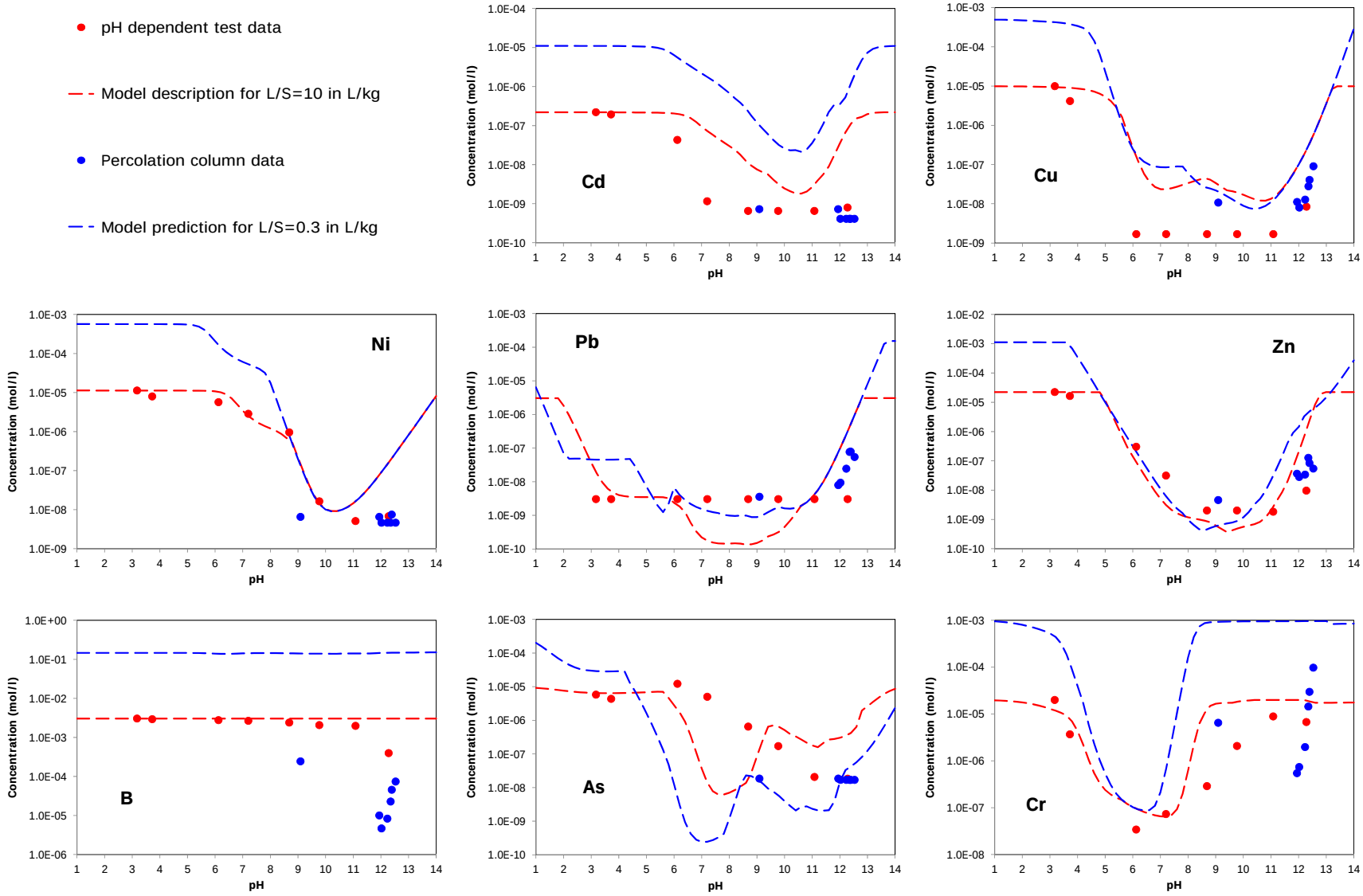

Figure A-3. Chemical speciation model for constituents in coal combustion fly ash.

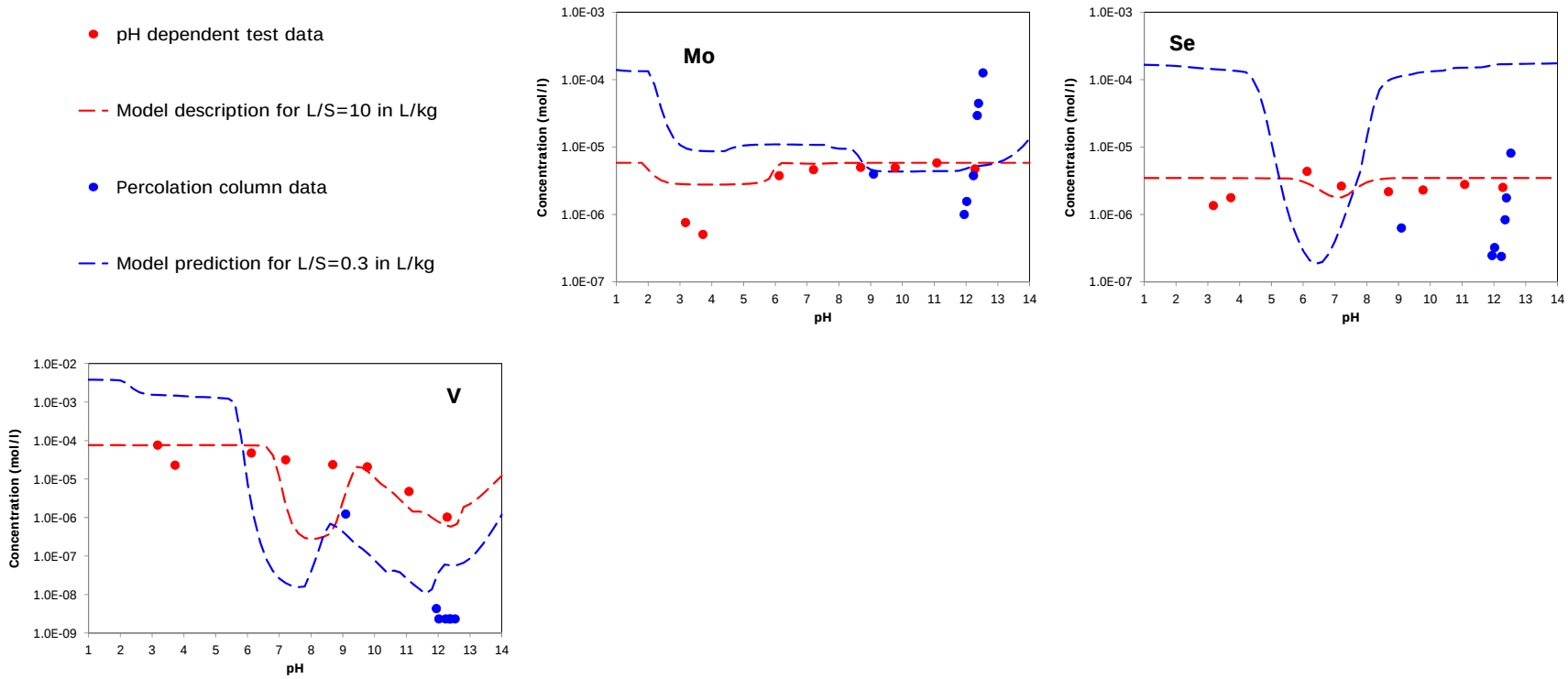

Figure A-4. Chemical speciation model for constituents in coal combustion fly ash.

Table A-2. Chemical Speciation Fingerprint for MSWI Bottom Ash

Chemical Speciation Fingerprint - Municipal Solid Waste Incinerator Bottom Ash							**LeachXS**	**2012**
Prediction case	LtoF MSWI BA Aust + kol							
Speciation session	MSWI BA Austria + kolom AA		**DOC/DHA data**				**Polynomial coeficients**	
Material	MSWI Bottom ash Austria (P,1,1)		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**C0**	-4.230E+00
			1.00	6.711E-05	0.35	2.349E-05	**C1**	-4.461E-01
Solved fraction DOC	0.2		3.46	4.320E-05	0.18	7.776E-06	**C2**	5.797E-02
Sum of pH and pe	13.00		4.01	4.070E-05	0.15	6.105E-06	**C3**	-1.872E-03
L/S	10.0000	**l/kg**	5.70	4.700E-05	0.10	4.700E-06	**C4**	0.000E+00
Clay	0.000E+00	**kg/kg**	7.26	4.880E-05	0.18	8.784E-06	**C5**	0.000E+00
HFO	7.000E-04	**kg/kg**	8.79	4.820E-05	0.24	1.157E-05		
SHA	2.000E-03	**kg/kg**	9.62	4.010E-05	0.35	1.404E-05		
Percolation material	MSWI BA-A A (C,1,1)		10.68	4.900E-05	0.45	2.205E-05		
Avg L/S first perc. fractions	0.2195	**l/kg**	11.86	5.880E-05	0.55	3.234E-05		
			14.00	8.026E-05	0.70	5.618E-05		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured	CrO4-2	9.543E+00	Mg+2	5.026E+03	SO4-2	4.649E+03	
Al+3	3.614E+03	Cu+2	1.674E+02	Mn+2	1.139E+02	Sb[OH]6-	1.472E+00	
H3AsO4	1.837E-01	F-	5.000E+01	MoO4-2	6.727E-01	SeO4-2	9.660E-02	
H3BO3	2.180E+01	Fe+3	2.079E+03	Na+	3.669E+03	H4SiO4	7.279E+03	
Ba+2	1.463E+01	H2CO3	3.800E+04	NH4+	1.000E+01	Sr+2	7.071E+01	
Br-	not measured	Hg+2	not measured	Ni+2	5.628E+00	Th+4	not measured	
Ca+2	5.178E+04	I-	not measured	NO3-	2.000E+02	UO2+	not measured	
Cd+2	4.110E+00	K+	1.373E+03	PO4-3	5.717E+02	VO2+	3.257E+00	
Cl-	2.000E+04	Li+	2.760E+00	Pb+2	1.408E+02	Zn+2	6.088E+02	
Selected Minerals								
AA_3CaO_Al2O3_6H2O[s]		AA_Gypsum	Cd[OH]2[A]	Pb[OH]2[C]	Wairakite			
AA_3CaO_Fe2O3_6H2O[s]		AA_Magnesite	Cr[OH]3[C]	Pb2V2O7	Willemite			
AA_Al[OH]3[am]		AA_Portlandite	Cu[OH]2[s]	Pb3[VO4]2	ZnSiO3			
AA_Brucite		BaSrSO4[50%Ba]	Manganite	PbCrO4				
AA_Calcite		Ca2Cd[PO4]2	Ni[OH]2[s]	PbMoO4[c]				
AA_Fe[OH]3[microcr]		Ca4Cd[PO4]3OH	OCP	P-Wollstanite				

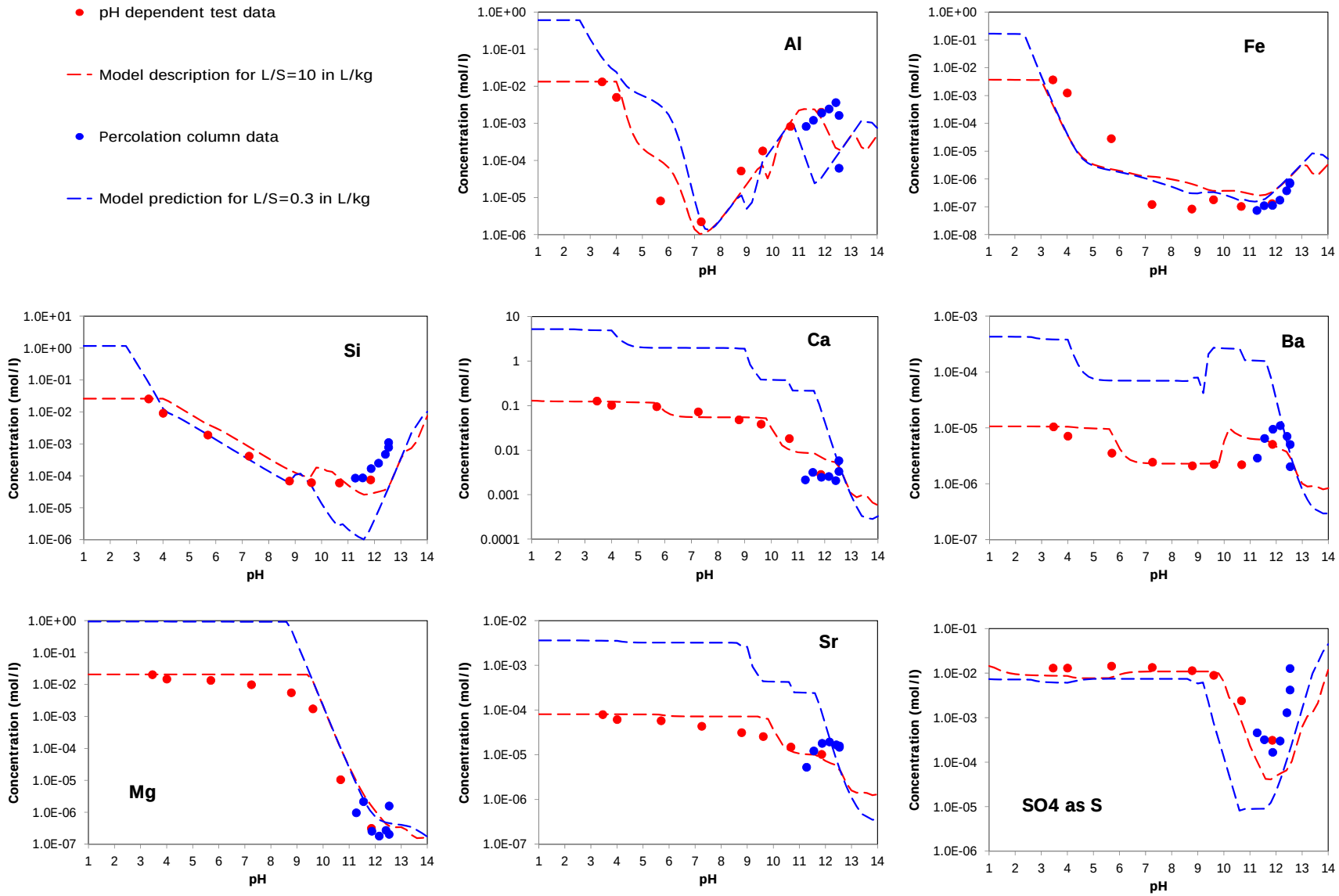

Figure A-5. Chemical speciation model for constituents in municipal solid waste incinerator bottom ash.

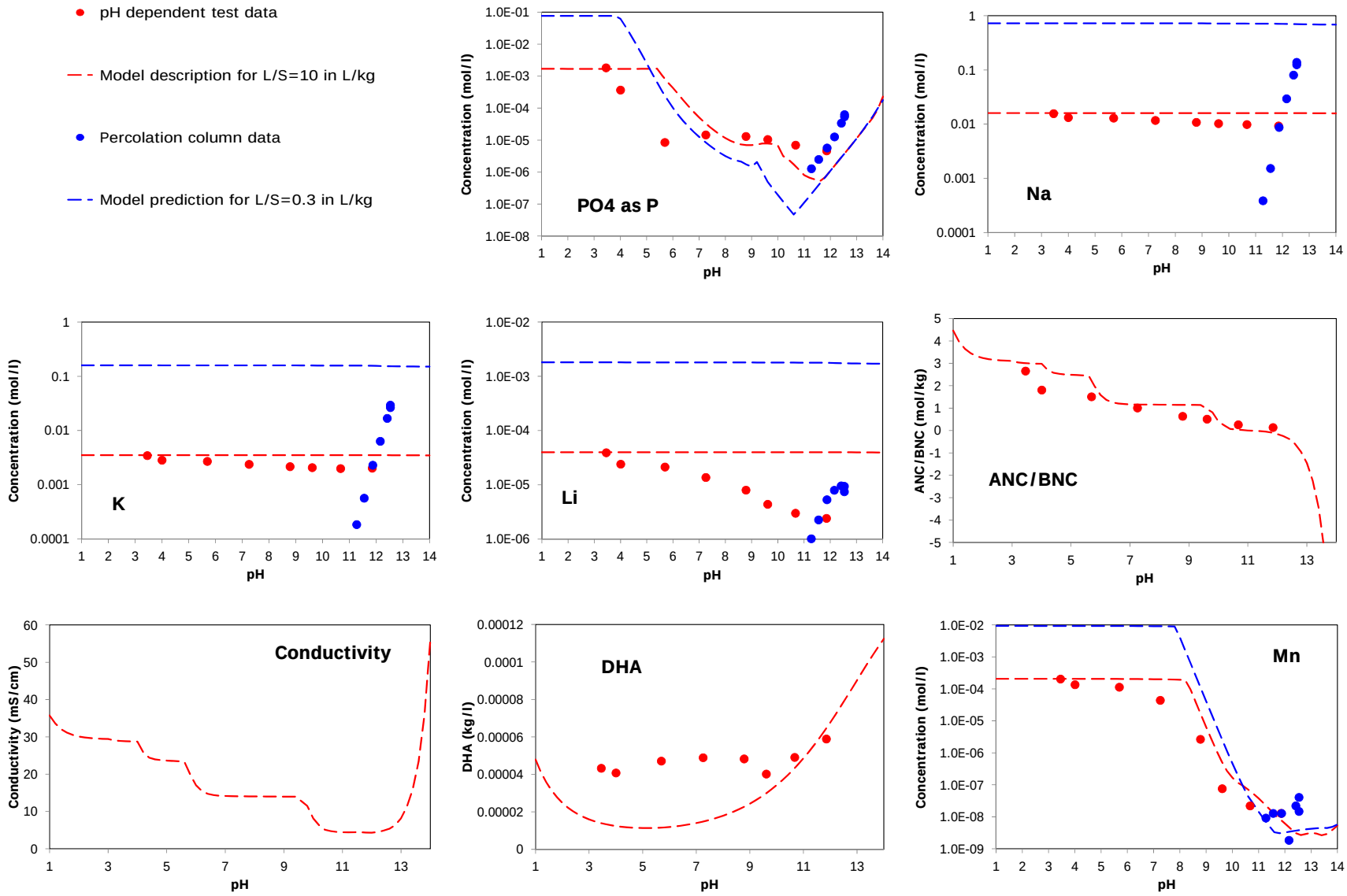

Figure A-6. Chemical speciation model for constituents in municipal solid waste incinerator bottom ash.

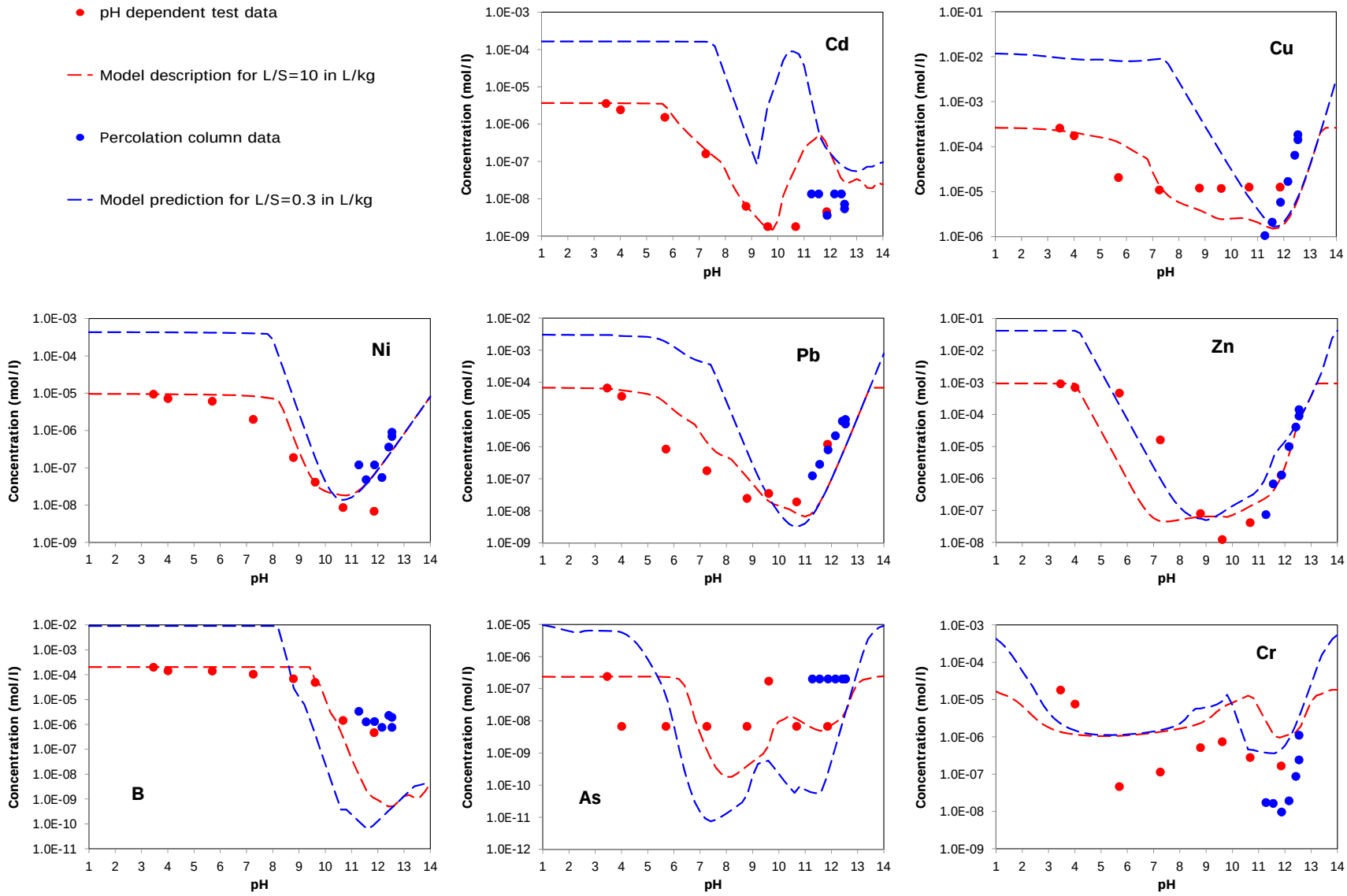

Figure A-7. Chemical speciation model for constituents in municipal solid waste incinerator bottom ash.

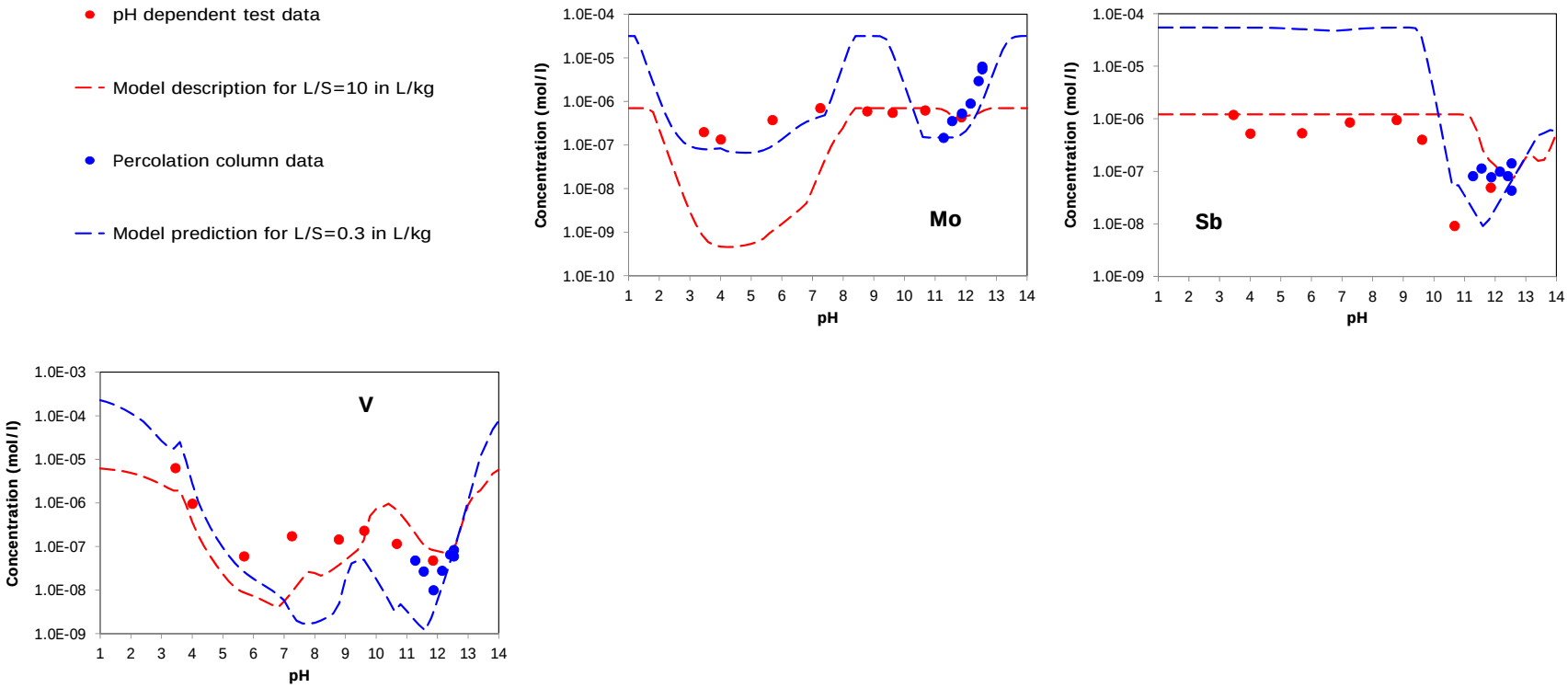

Figure A-8. Chemical speciation model for constituents in municipal solid waste incinerator bottom ash.

Table A-3. Chemical Speciation Fingerprint for Inorganic Waste Landfill at Nauerna (The Netherlands).

Chemical Speciation Fingerprint - Predominantly Inorganic Waste Landfill							**LeachXS**	**2012**
Prediction case	EPA LtoF Predominantly Inorganic Waste Landfill		**DOC/DHA data**				**Polynomial coeficients**	
Speciation session	LtoF Nauerna_pilot		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**C0**	-4.684E+00
Material	Pred Inorg Wastemix NL(P,1,1)		1.00	2.914E-05	0.20	5.828E-06	**C1**	-5.010E-01
			3.02	1.500E-05	0.15	2.250E-06	**C2**	5.562E-04
Solved fraction DOC	0.2		4.00	1.840E-06	0.12	2.208E-07	**C3**	7.768E-03
Sum of pH and pe	10.00		5.27	3.800E-06	0.10	3.800E-07	**C4**	-3.543E-04
L/S	10.0000	**l/kg**	6.36	2.580E-06	0.15	3.870E-07	**C5**	0.000E+00
Clay	0.000E+00	**kg/kg**	7.23	2.700E-06	0.18	4.860E-07		
HFO	1.500E-03	**kg/kg**	8.18	3.560E-06	0.25	8.900E-07		
SHA	1.900E-02	**kg/kg**	9.51	7.800E-06	0.35	2.730E-06		
Percolation material	Pred Inorg Wastemix NL(C,2,1)		10.70	1.756E-05	0.50	8.780E-06		
Avg L/S first perc. fracti	0.2791	**l/kg**	12.01	2.960E-05	0.70	2.072E-05		
			13.17	9.860E-05	0.90	8.874E-05		
			14.00	1.408E-04	0.95	1.338E-04		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured	H2CO3	5.600E+04	Mg+2	3.002E+03	SO4-2	1.272E+04	
Al+3	2.276E+03	CrO4-2	1.919E+01	Mn+2	5.737E+02	Sb[OH]6-	3.863E-01	
H3AsO4	2.570E+00	Cu+2	3.977E+01	MoO4-2	2.872E+00	SeO4-2	3.191E-01	
H3BO3	1.865E+01	F-	5.000E+01	Na+	2.360E+03	H4SiO4	3.015E+03	
Ba+2	1.536E+00	Fe+3	1.636E+04	NH4+	6.096E+02	Sr+2	1.761E+02	
Br-	3.452E+01	Hg+2	not measured	Ni+2	2.323E+01	Th+4	not measured	
Ca+2	5.015E+04	I-	not measured	NO3-	not measured	UO2+	not measured	
Cd+2	2.760E+00	K+	1.059E+03	PO4-3	8.157E+01	VO2+	5.225E+00	
Cl-	5.268E+03	Li+	2.623E+00	Pb+2	2.500E+02	Zn+2	2.401E+03	
Selected Minerals								
Albite[low]	Bunsenite	Ferrihydrite	Ni[OH]2[s]	Portlandite	ZnSiO3			
AlOHSO4	Ca2Cd[PO4]2	Fluorite	NiCO3[s]	Rhodochrosite				
alpha-TCP	Ca4Cd[PO4]3OH	Gypsum	OCP	Sb[OH]3[s]				
Anhydrite	Calcite	Hausmannite	Otavite	Strengite				
Ba[SCr]O4[96%SO4]	CaZincate	Hinsdalite[2]	Pb[OH]2[C]	Strontianite				
BaSrSO4[50%Ba]	Cd[OH]2[C]	Hydromagnesite	Pb2V2O7	Struvite				
Boehmite	Cr[OH]3[A]	Leucite	PbCrO4	Willemite				
Brucite	Cu[OH]2[s]	Manganite	PbMoO4[c]	Zincite				

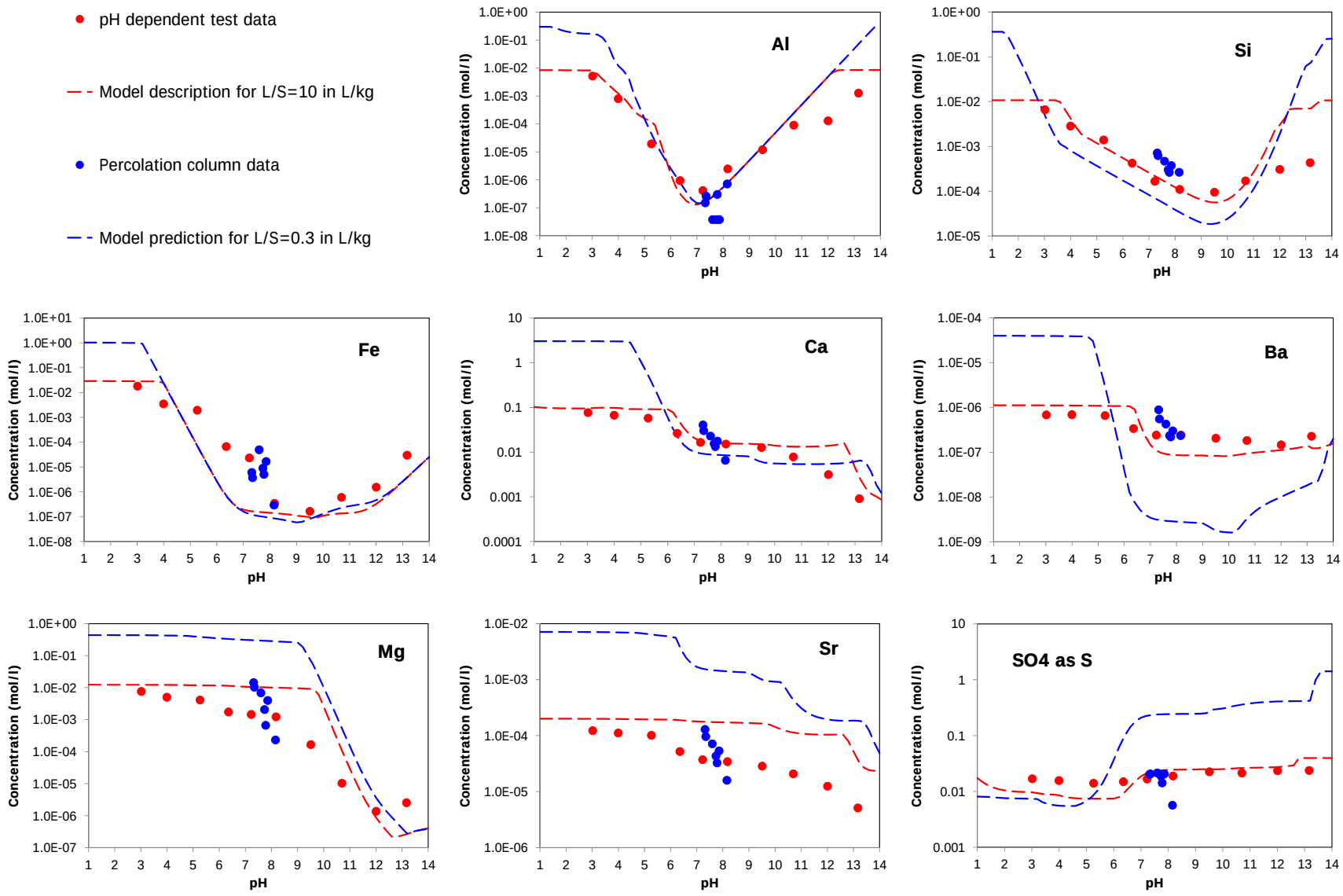

Figure A-9. Chemical speciation model for constituents in inorganic waste landfill material.

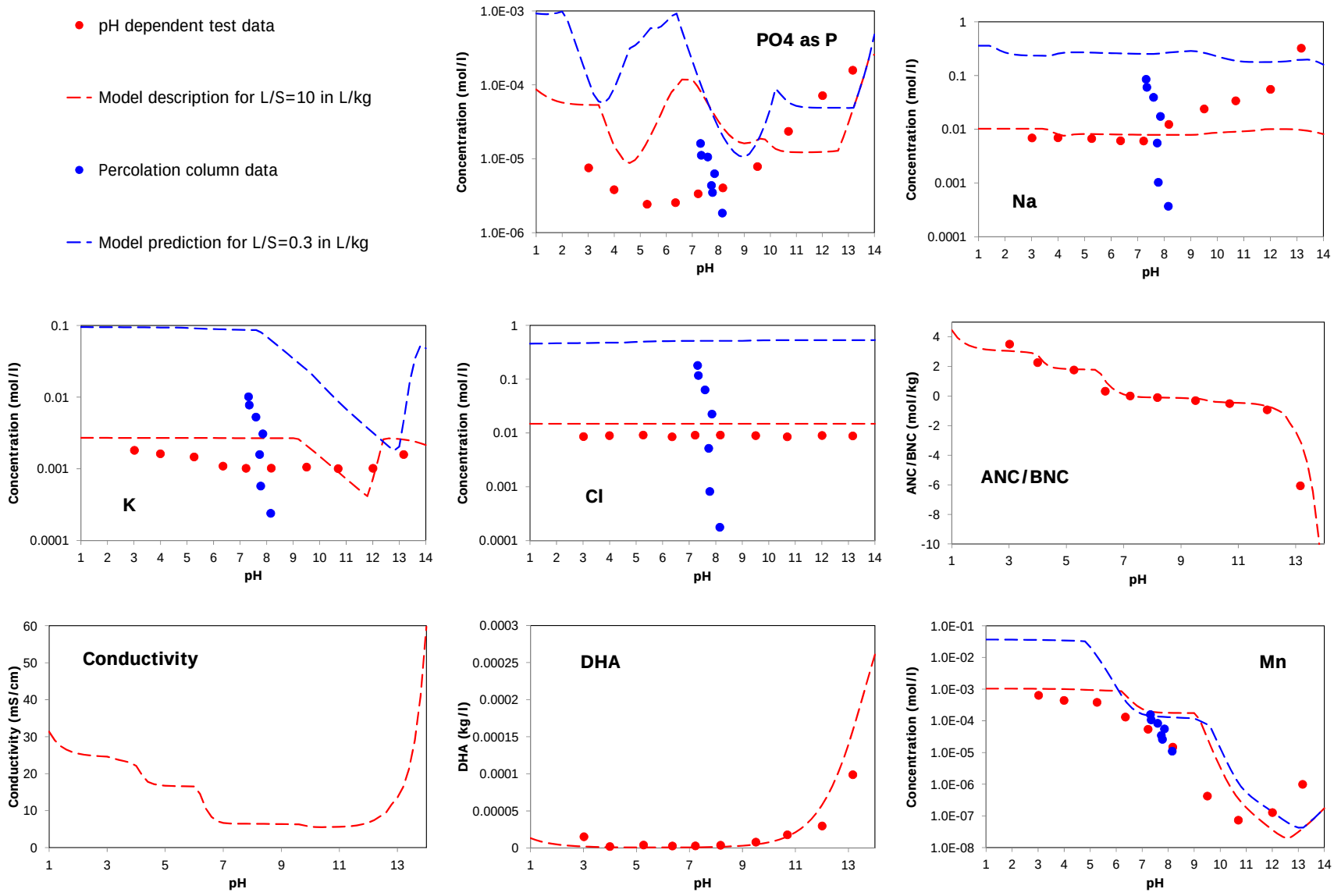

Figure A-10. Chemical speciation model for constituents in inorganic waste landfill material.

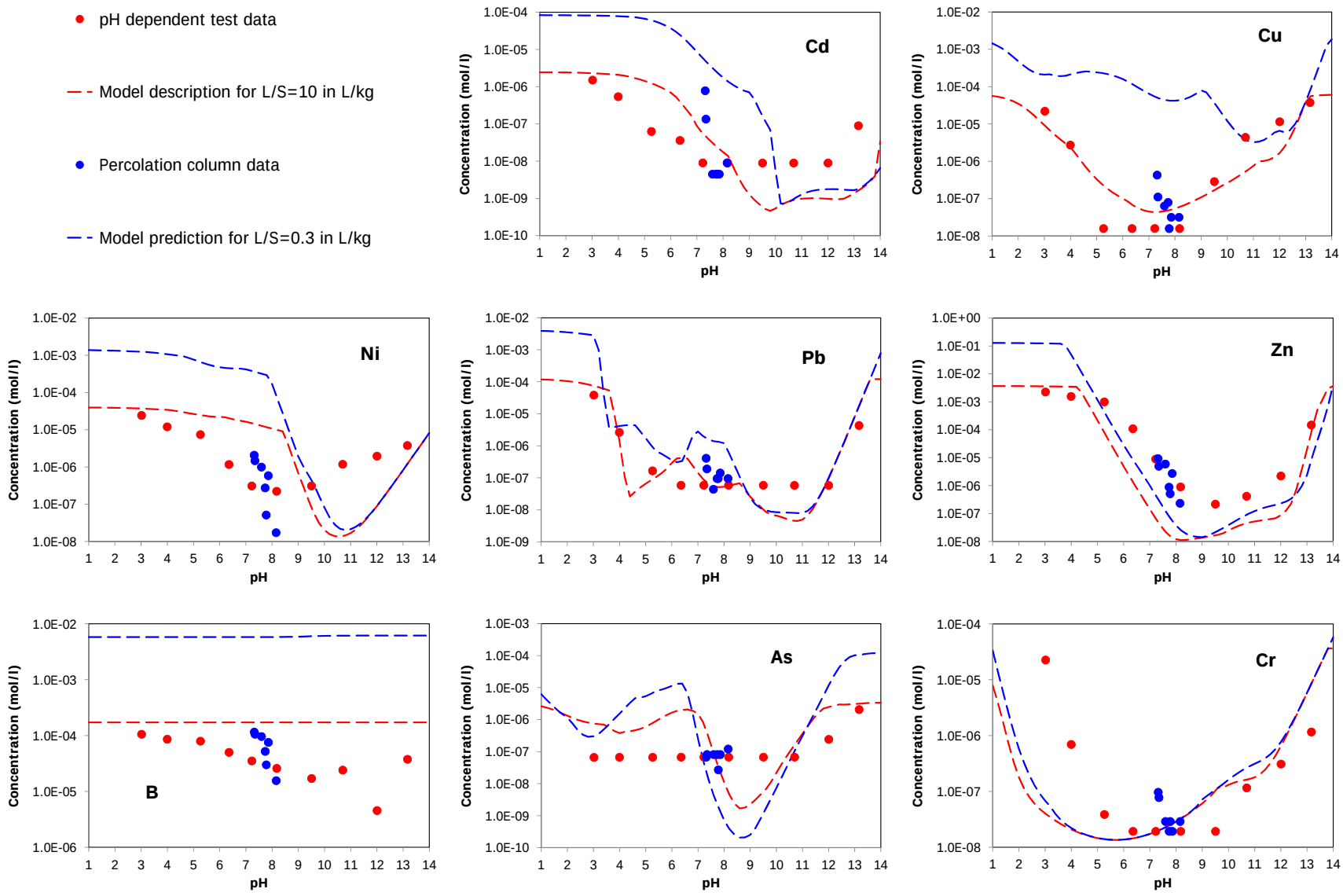

Figure A-11. Chemical speciation model for constituents in inorganic waste landfill material.

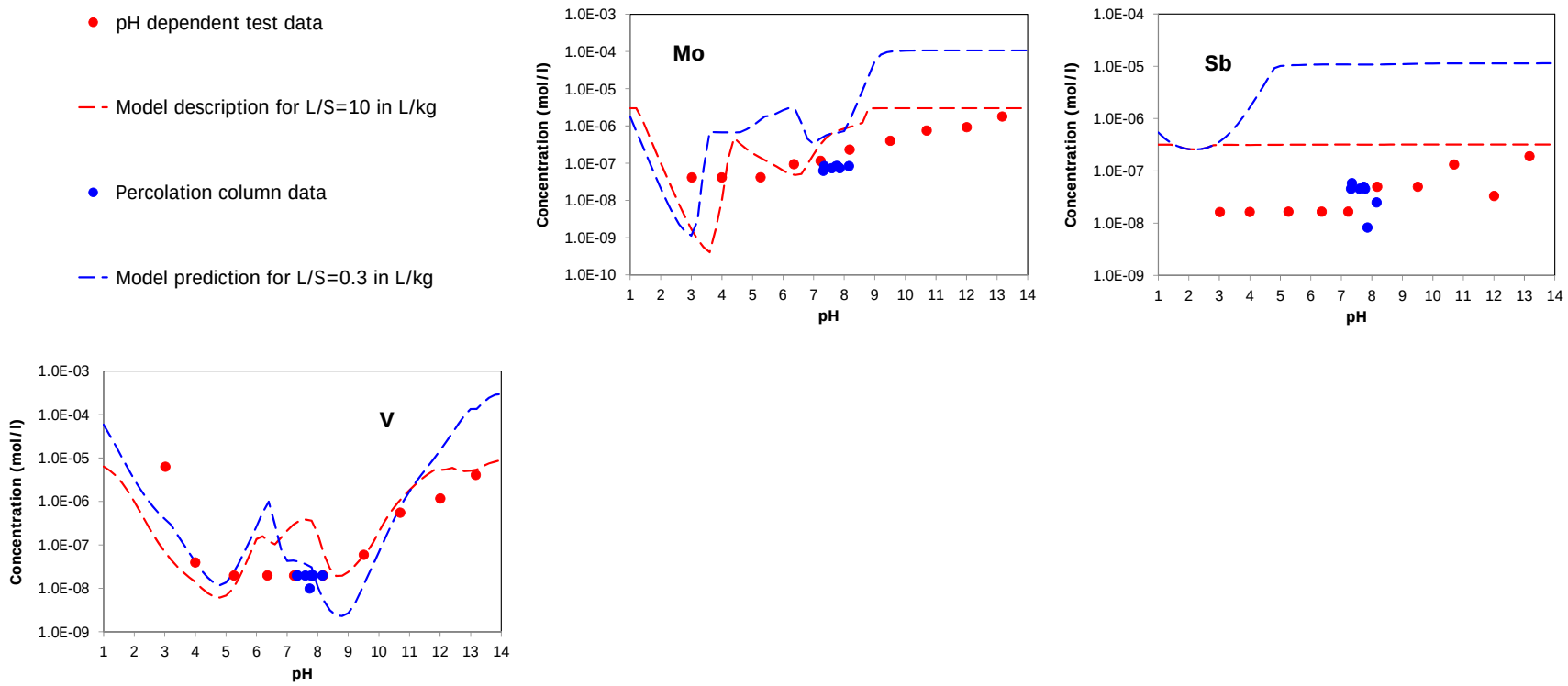

Figure A-12. Chemical speciation model for constituents in inorganic waste landfill material.

Table A-4. Chemical Speciation Fingerprint for Municipal Solid Waste (The Netherlands).

Chemical Speciation Fingerprint - Municipal Solid Waste Landfill							**LeachXS**	**2012**
Prediction case	LtoF MSW		**DOC/DHA data**				**Polynomial coeficients**	
Speciation session	Landgraaf mix		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**C0**	-3.446E+00
Material	Mixed organic waste DS NL (P,1,1)		1.00	4.539E-04	0.55	2.496E-04	**C1**	-8.161E-02
			2.75	2.810E-04	0.40	1.124E-04	**C2**	-7.705E-02
Solved fraction DOC	0.2		3.69	1.790E-04	0.30	5.370E-05	**C3**	1.349E-02
Sum of pH and pe	13.00		6.37	1.470E-04	0.25	3.675E-05	**C4**	-5.311E-04
L/S	10.0000	**l/kg**	6.81	1.730E-04	0.20	3.460E-05	**C5**	0.000E+00
Clay	1.000E-01	**kg/kg**	7.48	1.740E-04	0.20	3.480E-05		
HFO	1.000E-02	**kg/kg**	8.78	3.330E-04	0.25	8.325E-05		
SHA	4.000E-02	**kg/kg**	10.32	6.195E-04	0.35	2.168E-04		
Percolation material	Mixed organic waste DS NL (C,1,1)		11.66	8.380E-04	0.55	4.609E-04		
Avg L/S first perc. fracti	0.1240	**l/kg**	14.00	9.574E-04	0.90	8.617E-04		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured	CrO4-2	5.273E+01	Mg+2	1.632E+03	SO4-2	2.769E+03	
Al+3	3.076E+03	Cu+2	2.342E+02	Mn+2	3.392E+02	Sb[OH]6-	1.813E+00	
H3AsO4	6.116E-01	F-	1.680E+02	MoO4-2	7.673E+00	SeO4-2	5.495E-01	
H3BO3	7.289E+01	Fe+3	1.341E+04	Na+	2.079E+03	H4SiO4	1.973E+03	
Ba+2	1.567E+01	H2CO3	3.010E+04	NH4+	not measured	Sr+2	6.760E+01	
Br-	9.010E+00	Hg+2	not measured	Ni+2	8.473E+01	Th+4	not measured	
Ca+2	2.272E+04	I-	not measured	NO3-	not measured	UO2+	not measured	
Cd+2	1.695E+01	K+	1.584E+03	PO4-3	7.881E+01	VO2+	4.727E+00	
Cl-	2.330E+03	Li+	2.670E+00	Pb+2	5.878E+02	Zn+2	2.110E+03	
Selected Minerals								
Al[OH]3[a]	Birnessite	CuCO3[s]	Huntite	Otavite	Wairakite			
alpha-TCP	Brucite	Diopside	hydrozincite	Pb2V2O7	Witherite			
Analbite	Ca2Zn[PO4]2	Dolomite	Magnesite	Pb3[VO4]2	Zn[OH]2[B]			
Anglesite	CaCu2[PO4]2	Fe_Vanadate	Manganite	PbMoO4[c]	ZnCO3:H2O			
Anhydrite	Calcite	Fe2[OH]4SeO3	NiCO3[s]	Rhodochrosite				
Ba[SCr]O4[96%SO4]	CaMoO4[c]	Ferrihydrite	Nsutite	Strontianite				
BaSrSO4[50%Ba]	Cerrusite	Fluorite	OCP	Talc				

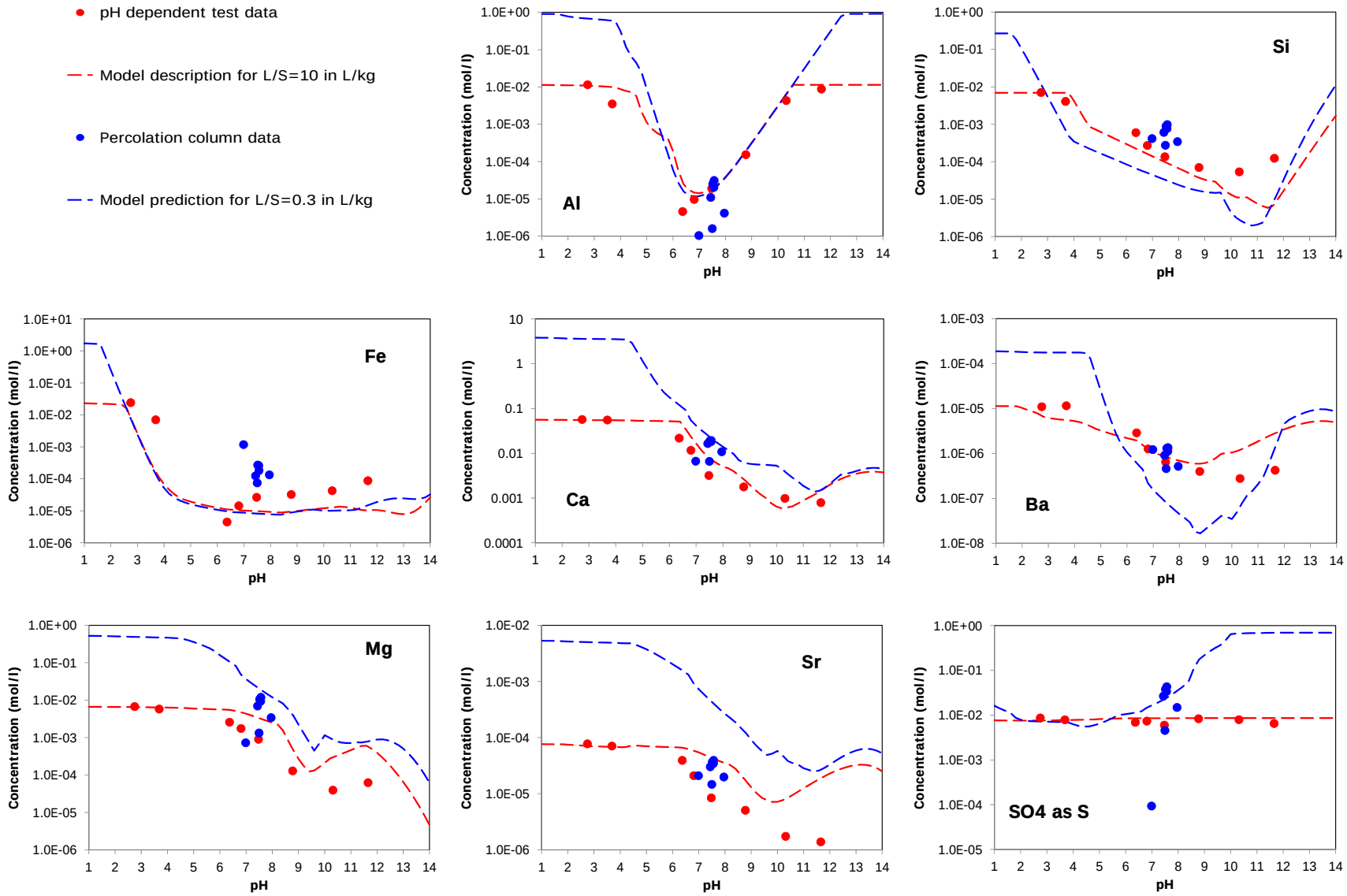

Figure A-13. Chemical speciation model for constituents in inorganic waste landfill material.

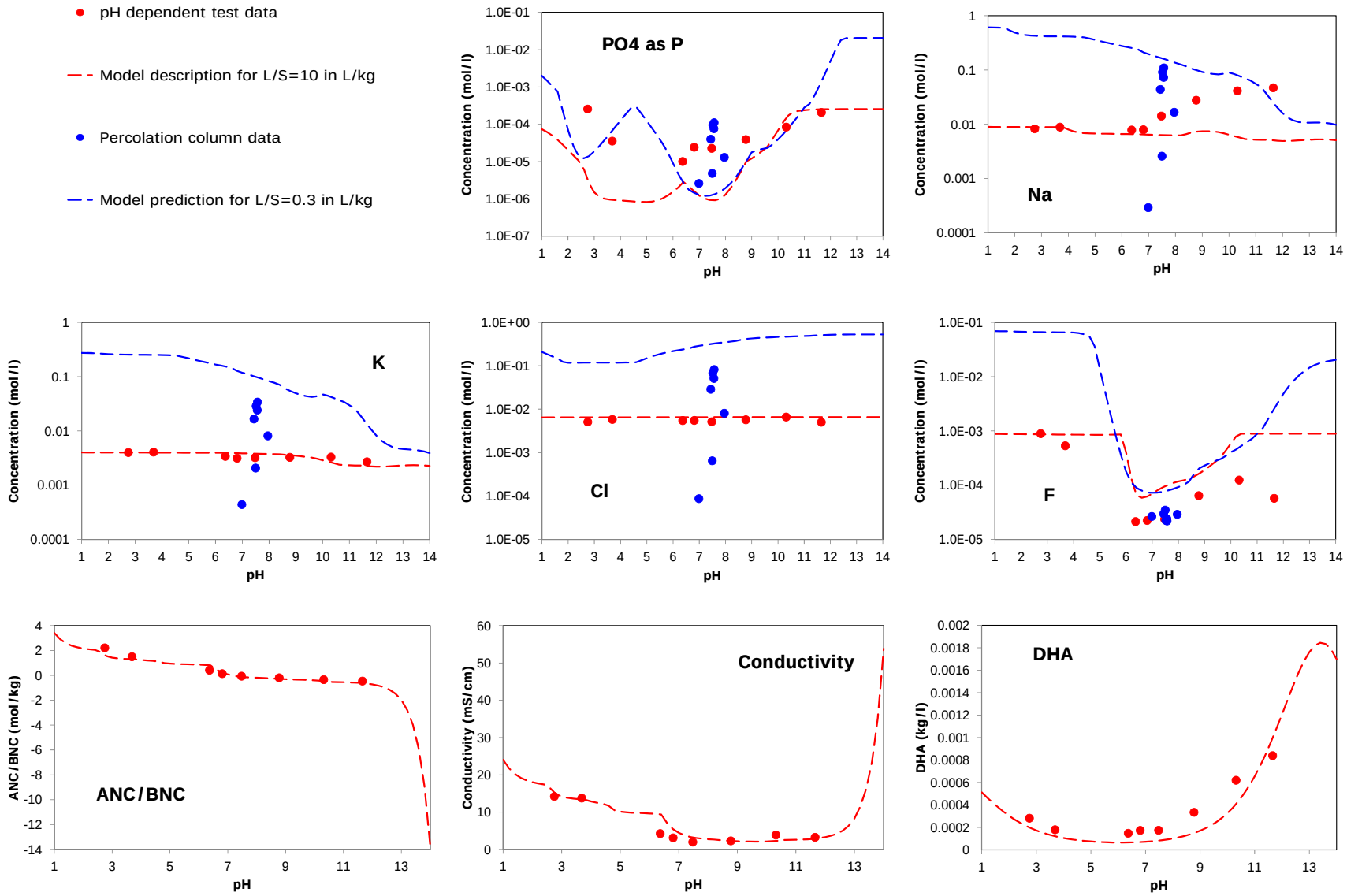

Figure A-14. Chemical speciation model for constituents in inorganic waste landfill material.

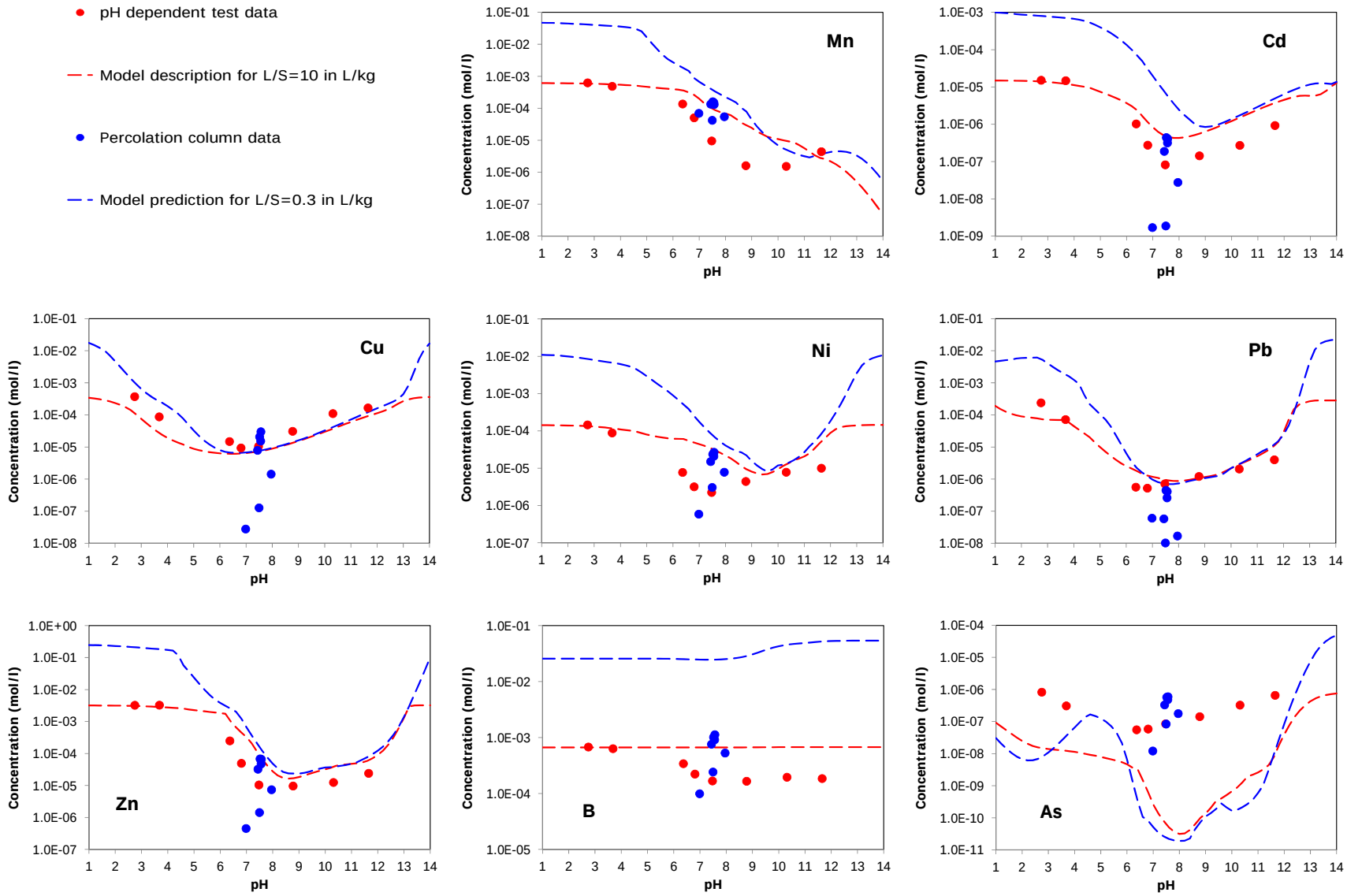

Figure A-15. Chemical speciation model for constituents in inorganic waste landfill material.

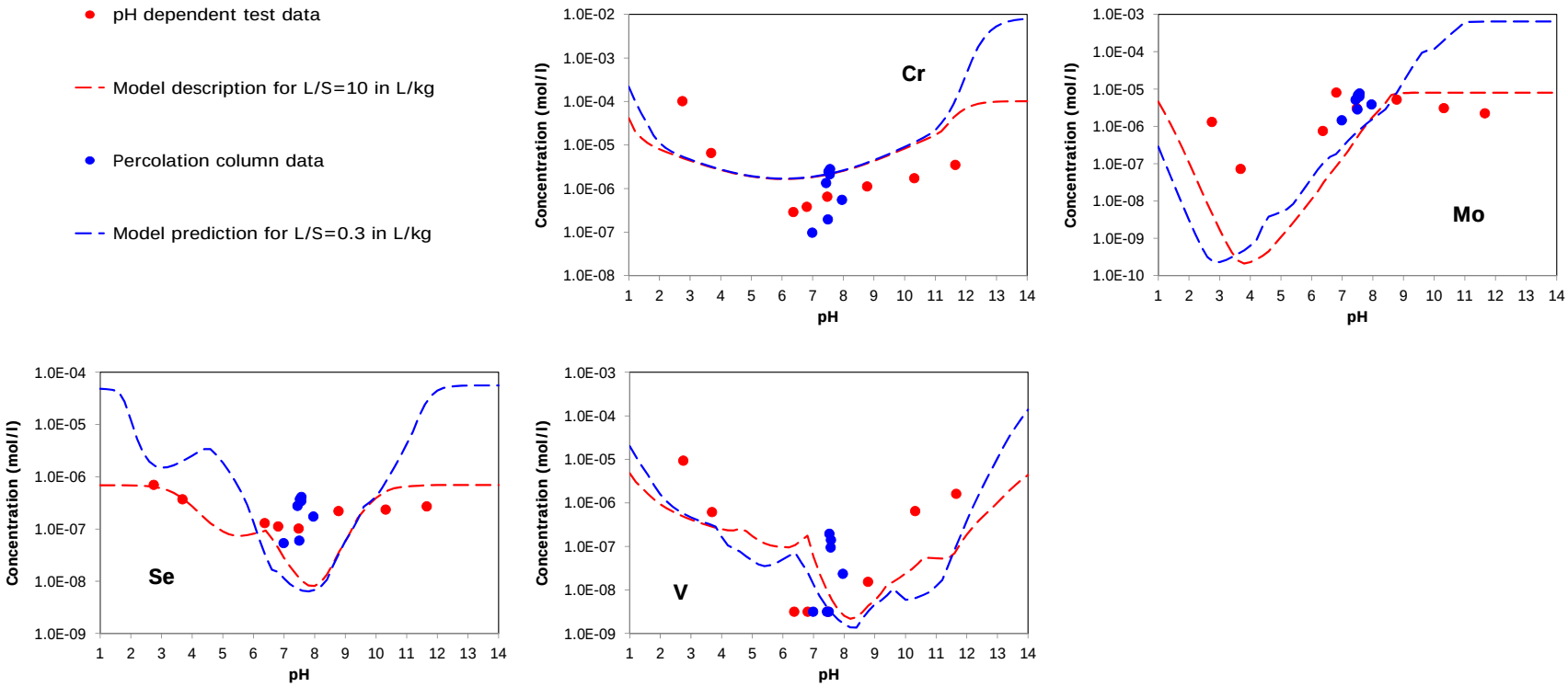

Figure A-16. Chemical speciation model for constituents in inorganic waste landfill material.

Table A-5. Chemical Speciation Fingerprint for Stabilized Waste Landfill Material (The Netherlands).

Chemical Speciation Fingerprint - Stabilised Waste							**LeachXS**	**2012**
Prediction case	LtoF Stabised waste		**DOC/DHA data**					
Speciation session	Stabilised waste		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**Polynomial coeficients**	
Material	Stabilised waste NL (P,6,1)		1.00	4.000E-06	0.20	8.000E-07	**C0**	-6.006E+00
			3.60	3.200E-06	0.20	6.400E-07	**C1**	-7.827E-02
Solved fraction DOC	0.2		4.78	3.100E-06	0.20	6.200E-07	**C2**	4.355E-03
Sum of pH and pe	13.00		6.06	1.900E-06	0.20	3.800E-07	**C3**	5.802E-05
L/S	10.0000		7.28	2.400E-06	0.20	4.800E-07	**C4**	0.000E+00
Clay	0.000E+00	**kg/kg**	7.80	2.200E-06	0.20	4.400E-07	**C5**	0.000E+00
HFO	1.000E-05	**kg/kg**	9.50	3.100E-06	0.20	6.200E-07		
SHA	5.000E-04	**kg/kg**	10.30	2.300E-06	0.20	4.600E-07		
Percolation material	Stabilised waste NL (C,15,1)		11.69	3.000E-06	0.20	6.000E-07		
Avg L/S first perc. fractions	0.2222	**l/kg**	14.00	4.000E-06	0.20	8.000E-07		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured	CrO4-2	9.690E+00	Mg+2	3.903E+03	SO4-2	1.066E+04	
Al+3	6.056E+03	Cu+2	3.650E+02	Mn+2	1.750E+02	Sb[OH]6-	4.920E+00	
H3AsO4	1.450E-01	F-	1.904E+03	MoO4-2	7.700E+00	SeO4-2	4.600E-01	
H3BO3	5.947E+01	Fe+3	7.393E+01	Na+	2.563E+04	H4SiO4	3.556E+03	
Ba+2	1.933E+01	H2CO3	1.500E+04	NH4+	not measured	Sr+2	2.060E+02	
Br-	8.338E+02	Hg+2	not measured	Ni+2	9.290E+00	Th+4	not measured	
Ca+2	8.362E+04	I-	not measured	NO3-	not measured	UO2+	not measured	
Cd+2	1.782E+02	K+	3.381E+04	PO4-3	4.740E+00	VO2+	5.800E-01	
Cl-	5.350E+04	Li+	2.452E+01	Pb+2	9.551E+02	Zn+2	8.015E+03	
Selected Minerals								
AA_2CaO_Al2O3_8H2O[s]			AA_CaO_Al2O3_10H2O[s]		BaSrSO4[50%Ba]		Pb[OH]2[C]	
AA_2CaO_Al2O3_SiO2_8H2O[s]			AA_CO3-hydrotalcite		Cd[OH]2[A]		Pb2V2O7	
AA_2CaO_Fe2O3_SiO2_8H2O[s]			AA_Fe[OH]3[microcr]		Corkite		Pb3[VO4]2	
AA_3CaO_Al2O3[Ca[OH]2]0_5_[CaCO3]0_5_11_5H2O[s]			AA_Gibbsite		Cr[OH]3[C]		PbCrO4	
AA_3CaO_Al2O3_CaCO3_11H2O[s]			AA_Gypsum		CSH_ECN		PbMoO4[c]	
AA_3CaO_Al2O3_CaSO4_12H2O[s]			AA_Jennite		Cu[OH]2[s]		Plgummite[1]	
AA_3CaO_Fe2O3_CaCO3_11H2O[s]			AA_Magnesite		Fe_Vanadate		Rhodochrosite	
AA_4CaO_Al2O3_13H2O[s]			AA_Portlandite		Fluorite		Strontianite	
AA_Al[OH]3[am]			AA_Syngenite		Laumontite		Wairakite	
AA_Brucite			AA_Tricarboaluminate		Manganite		Willemite	
AA_Calcite			Analbite		Ni[OH]2[s]			

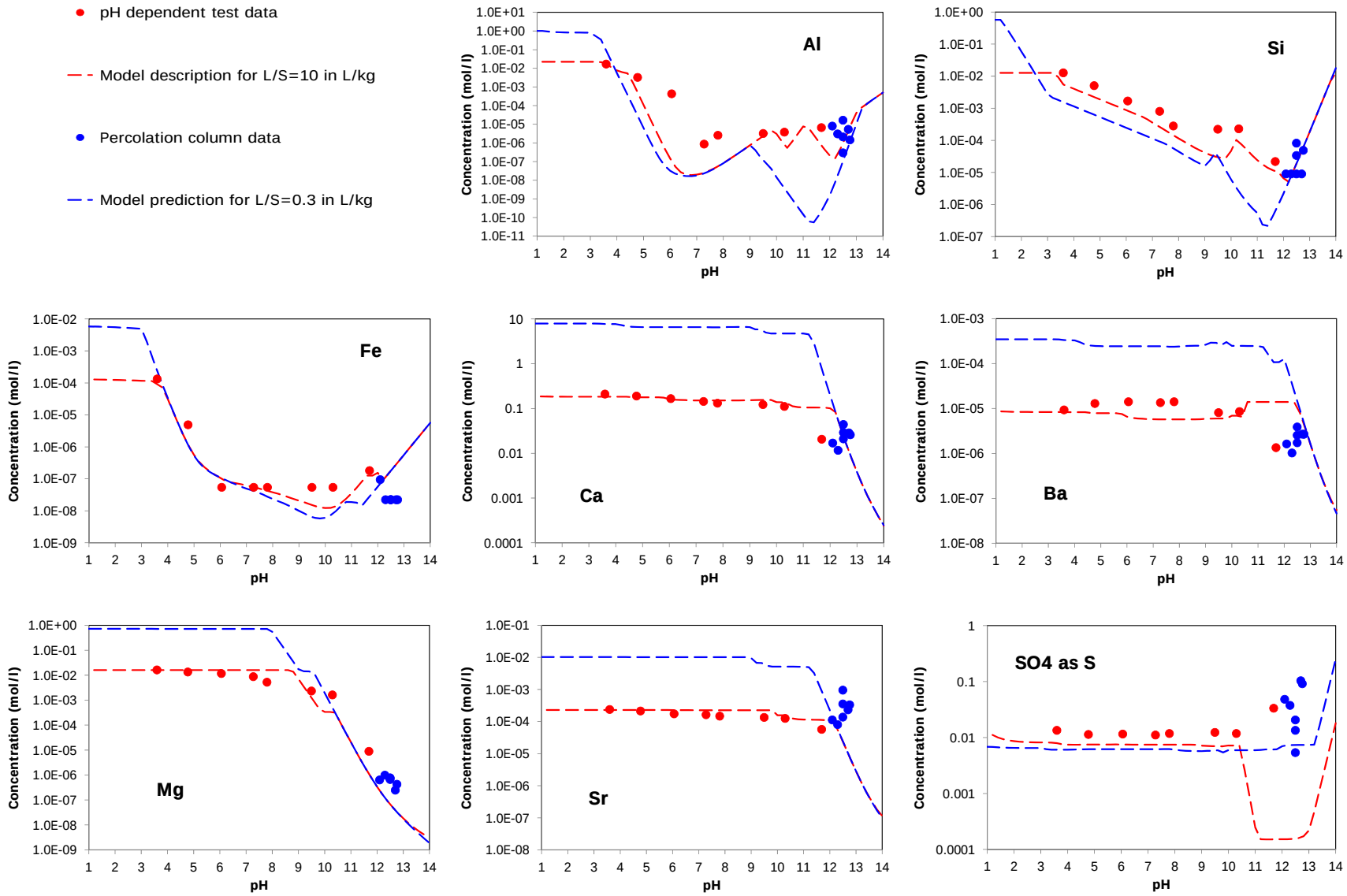

Figure A-17. Chemical speciation model for constituents in stabilized waste landfill material.

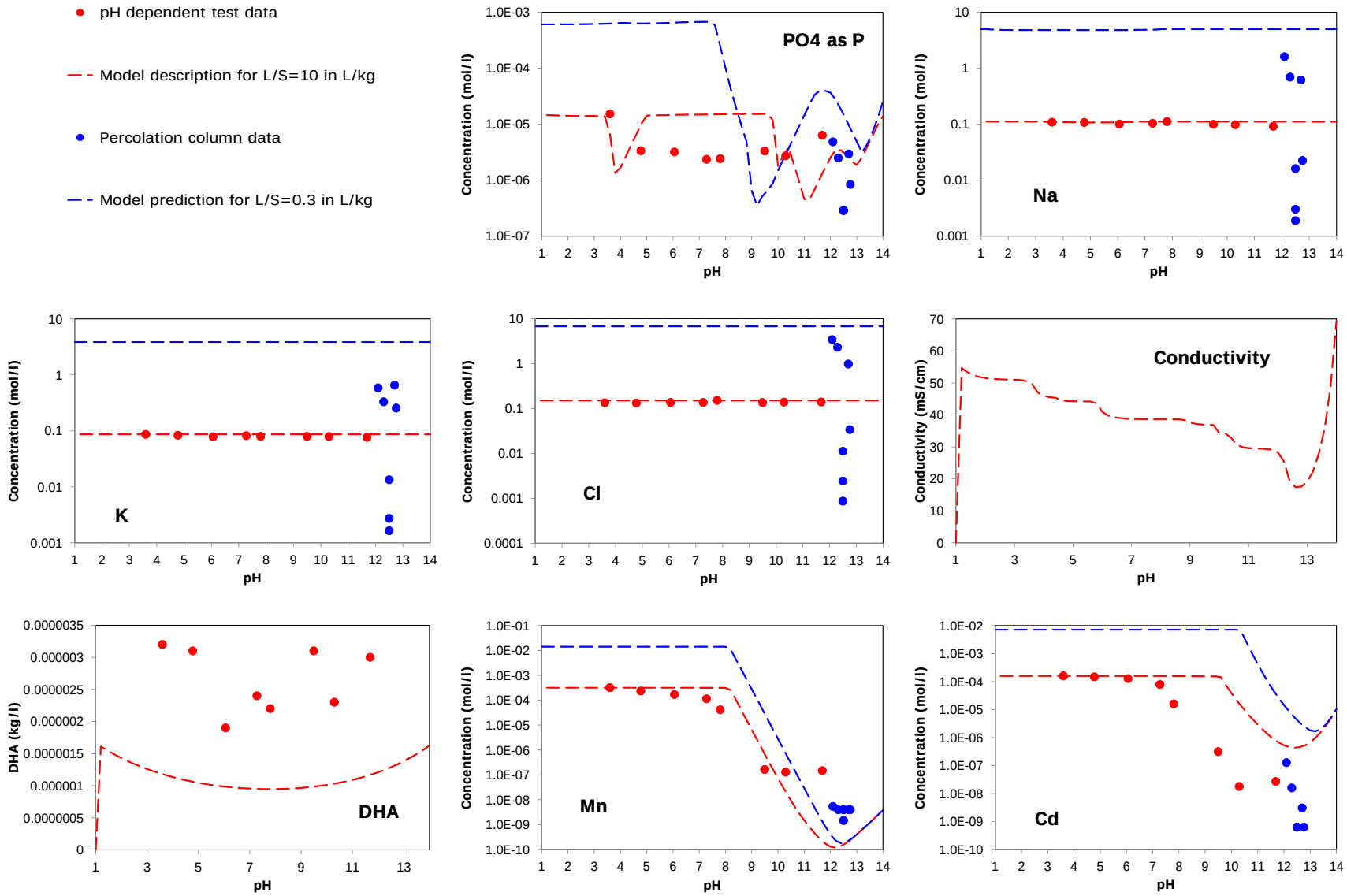

Figure A-18. Chemical speciation model for constituents in stabilized waste landfill material.

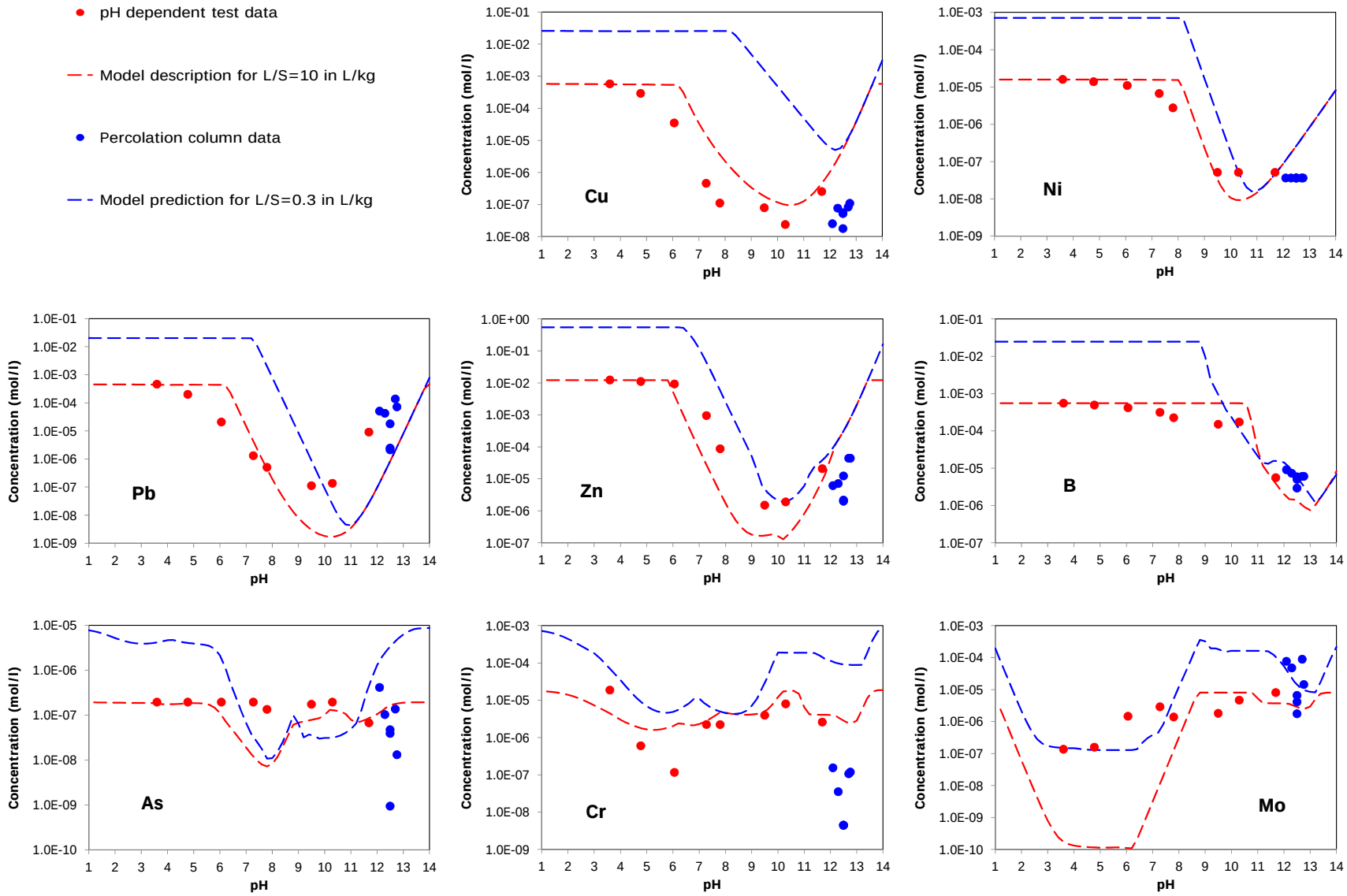

Figure A-19. Chemical speciation model for constituents in stabilized waste landfill material.

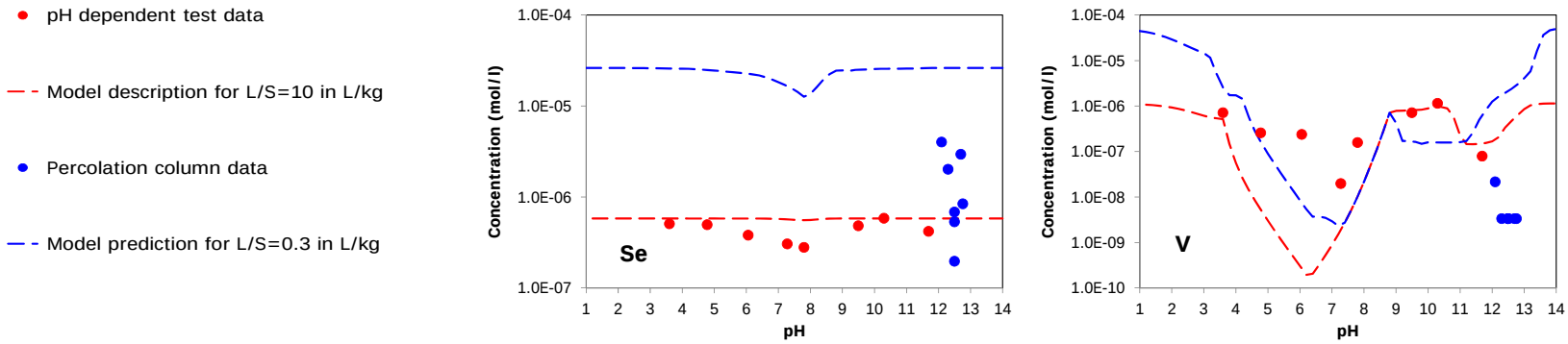

Figure A-20. Chemical speciation model for constituents in stabilized waste landfill material.

Table A-6. Chemical Speciation Fingerprint for Concrete.

Chemical Speciation Fingerprint - Cement Mortar							**LeachXS**	**2012**
Prediction case	LTF Cement Mortar CEM I		**DOC/DHA data**					
Speciation session	Cement Mortar CEM I		**pH**	**[DOC] (kg/l)**	**DHA fraction**	**[DHA] (kg/l)**	**Polynomial coeficients**	
Material	Cement Mortar CEM I_SCCC (P,1,1)		1.00	2.000E-07	0.20	4.000E-08	**C0**	-7.398E+00
			2.10	2.000E-07	0.20	4.000E-08	**C1**	0.000E+00
Solved fraction DOC	0.2		5.10	2.000E-07	0.20	4.000E-08	**C2**	0.000E+00
Sum of pH and pe	17.00		7.10	2.000E-07	0.20	4.000E-08	**C3**	0.000E+00
L/S	10.0000	**l/kg**	9.20	2.000E-07	0.20	4.000E-08	**C4**	0.000E+00
Clay	0.000E+00	**kg/kg**	11.60	2.000E-07	0.20	4.000E-08	**C5**	0.000E+00
HFO	2.000E-04	**kg/kg**	11.95	2.000E-07	0.20	4.000E-08		
SHA	2.000E-05	**kg/kg**	12.10	2.000E-07	0.20	4.000E-08		
Percolation material	Cement Mortar CEM I_SCCC (C,1,1)		12.90	2.000E-07	0.20	4.000E-08		
Avg L/S first perc. fractions	0.1455	**l/kg**	14.00	2.000E-07	0.20	4.000E-08		
Reactant concentrations								
Reactant	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	**Reactant**	**mg/kg**	
Ag+	not measured							
Al+3	5.104E+03	Cu+2	3.035E+01	MoO4-2	4.382E+00	H4SiO4	2.640E+03	
H3AsO4	2.509E+00	H2CO3	5.000E+03	Na+	4.418E+02	SO4-2	6.423E+03	
H3BO3	2.005E+01	Fe+3	3.187E+03	NH4+	not measured	Sr+2	6.665E+01	
Ba+2	1.906E+01	Hg+2	not measured	Ni+2	6.133E+00	Th+4	2.000E+00	
Br-	5.000E+01	I-	not measured	NO3-	not measured	UO2+	2.000E+00	
Ca+2	9.840E+04	K+	1.896E+03	Pb+2	4.936E+00	VO2+	3.805E+00	
Cd+2	2.262E-01	Li+	2.748E+00	PO4-3	1.051E+02	Zn+2	3.314E+01	
Cl-	1.445E+03	Mg+2	1.959E+03	Sb[OH]6-	1.892E-01			
CrO4-2	1.830E+01	Mn+2	6.325E+01	SeO4-2	2.345E-01			
Selected Minerals								
AA_2CaO_Al2O3_SiO2_8H2O[s]		AA_Calcite		AA_Tobermorite-I		Magnesite		PbMoO4[c]
AA_2CaO_Fe2O3_8H2O[s]		AA_CO3-hydrotalcite		Analbite		Manganite		Tenorite
AA_2CaO_Fe2O3_SiO2_8H2O[s]		AA_Fe[OH]3[microcr]		Ca2Cd[PO4]2		Ni[OH]2[s]		Willemite
AA_3CaO_Al2O3_6H2O[s]		AA_Gypsum		Ca4Cd[PO4]3OH		Pb[OH]2[C]		
AA_3CaO_Fe2O3_6H2O[s]		AA_Jennite		Cd[OH]2[C]		Pb2V2O7		
AA_Al[OH]3[am]		AA_Magnesite		Cr[OH]3[A]		Pb3[VO4]2		
AA_Brucite		AA_Portlandite		Fe_Vanadate		PbCrO4		

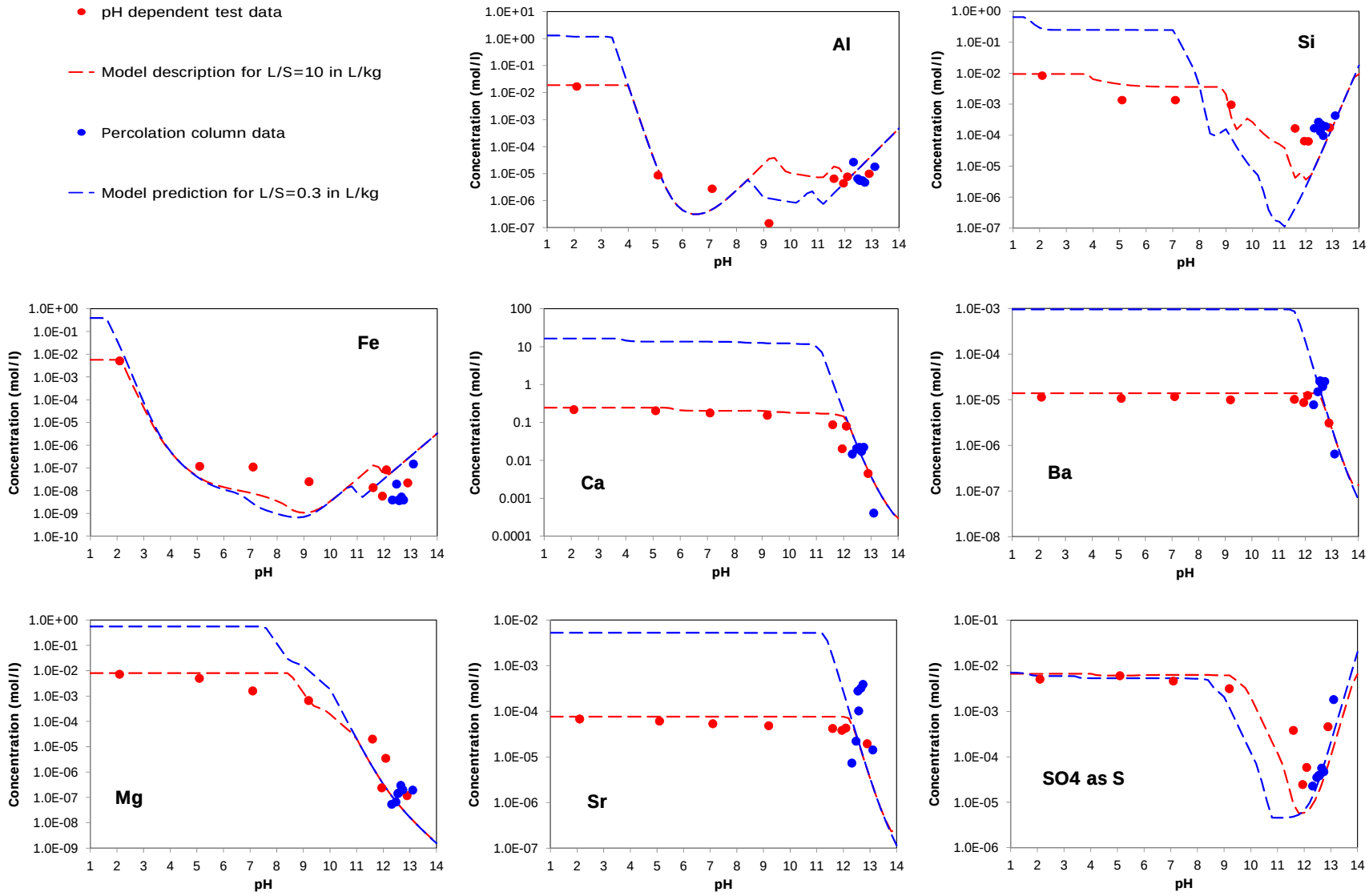

Figure A-21. Chemical speciation model for constituents in concrete.

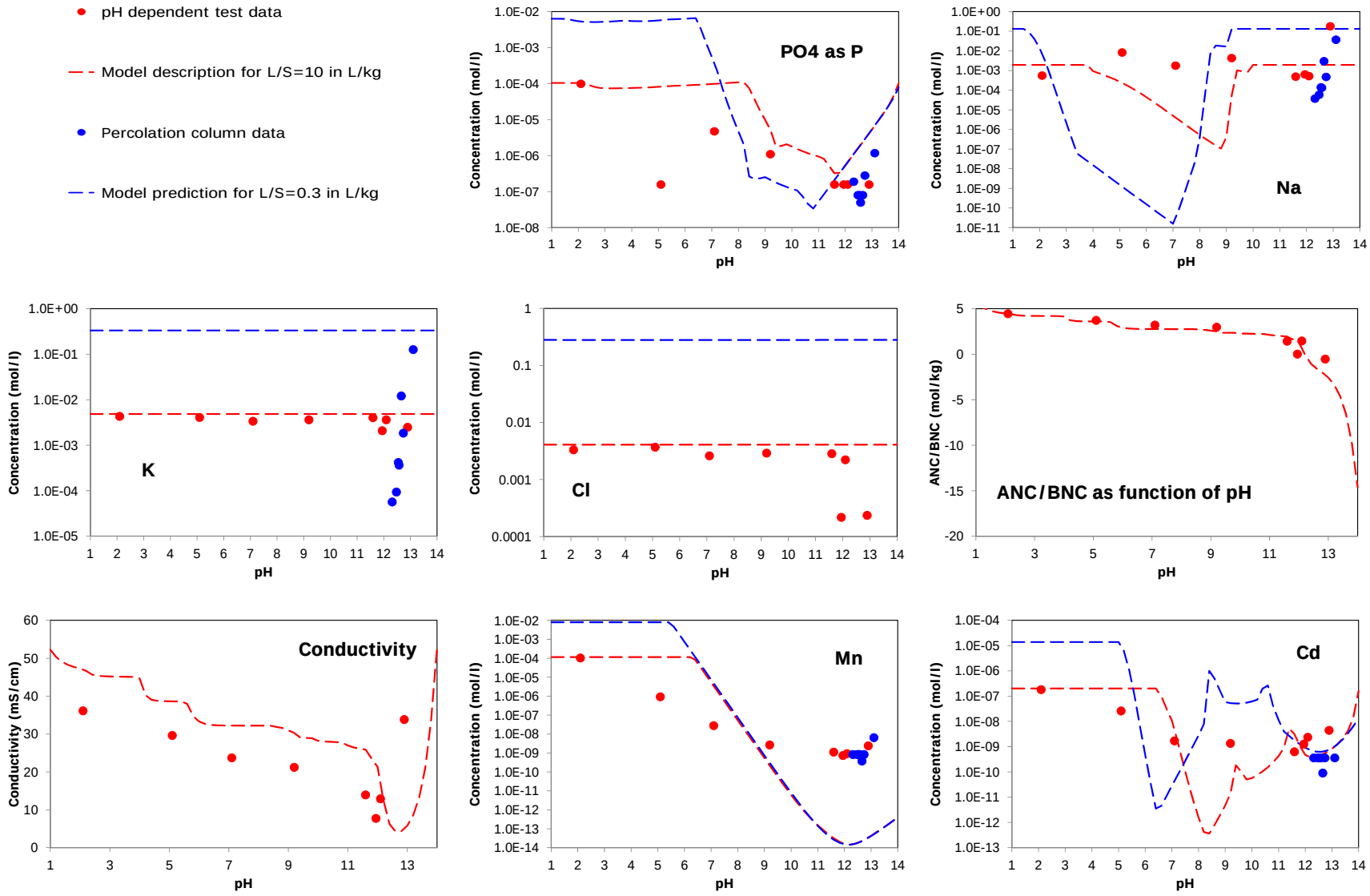

Figure A-22. Chemical speciation model for constituents in concrete.

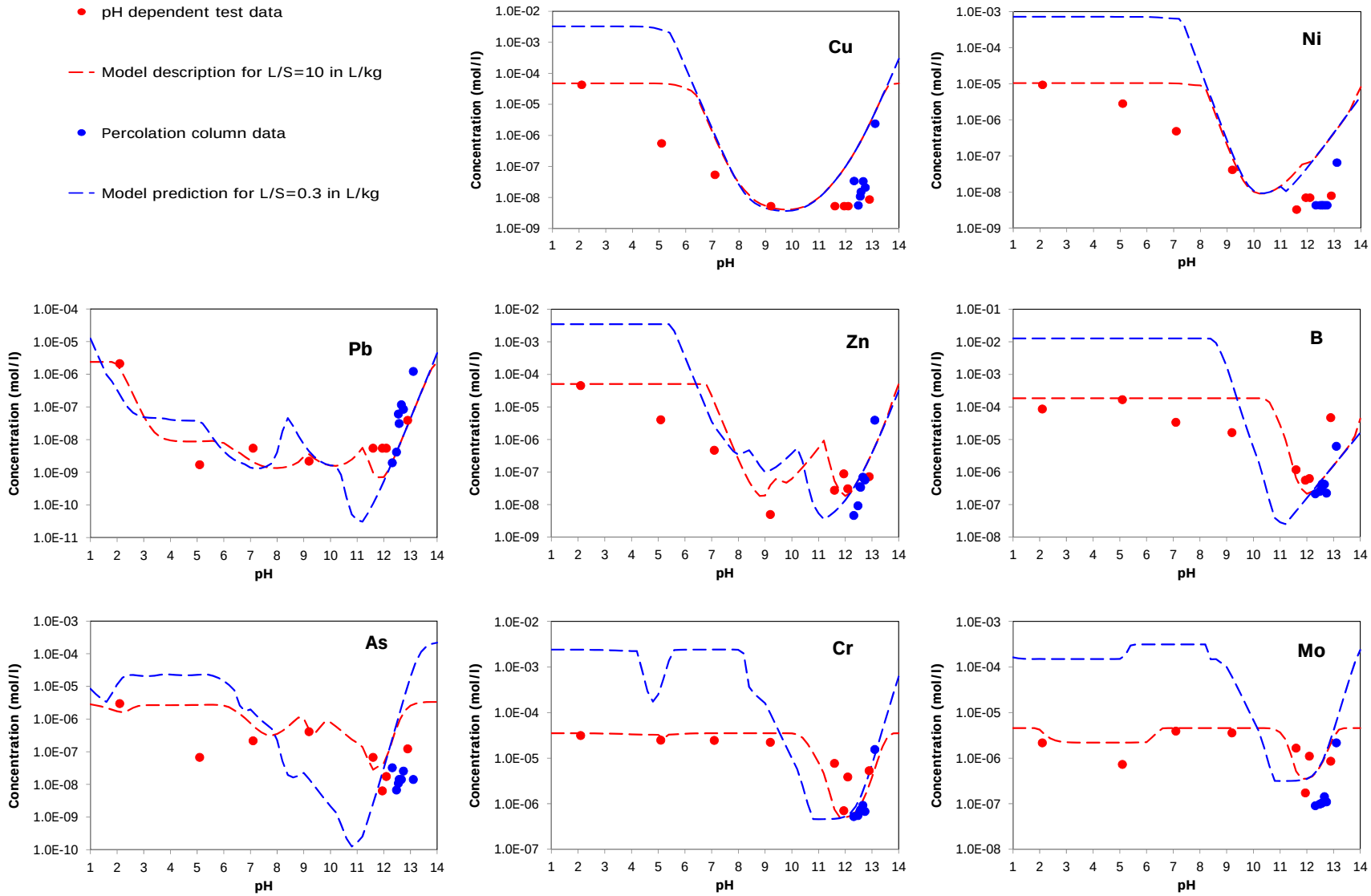

Figure A-23. Chemical speciation model for constituents in concrete.

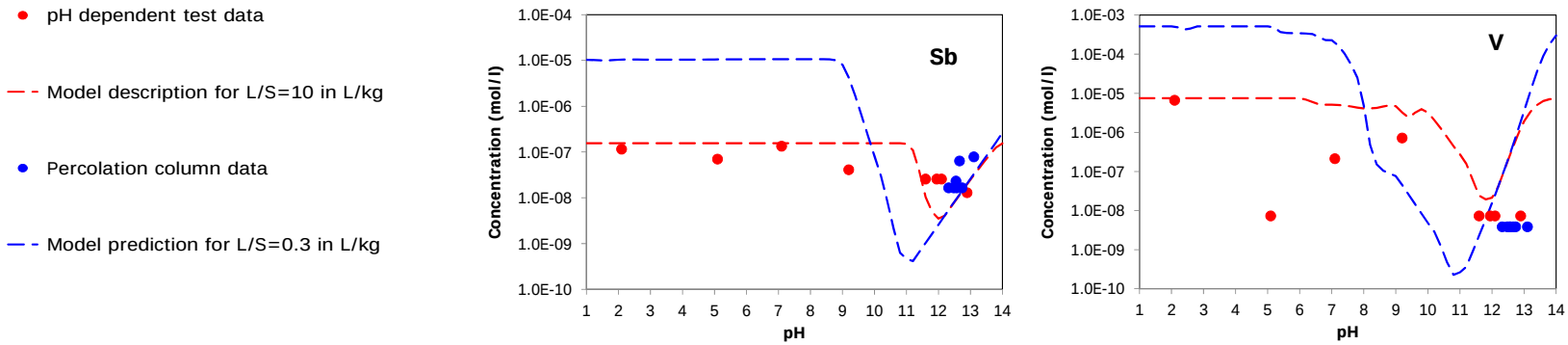

Figure A-24. Chemical speciation model for constituents in concrete.

APPENDIX B. COAL COMBUSTION FLY ASH LANDFILL LEACHATE (U.S.)

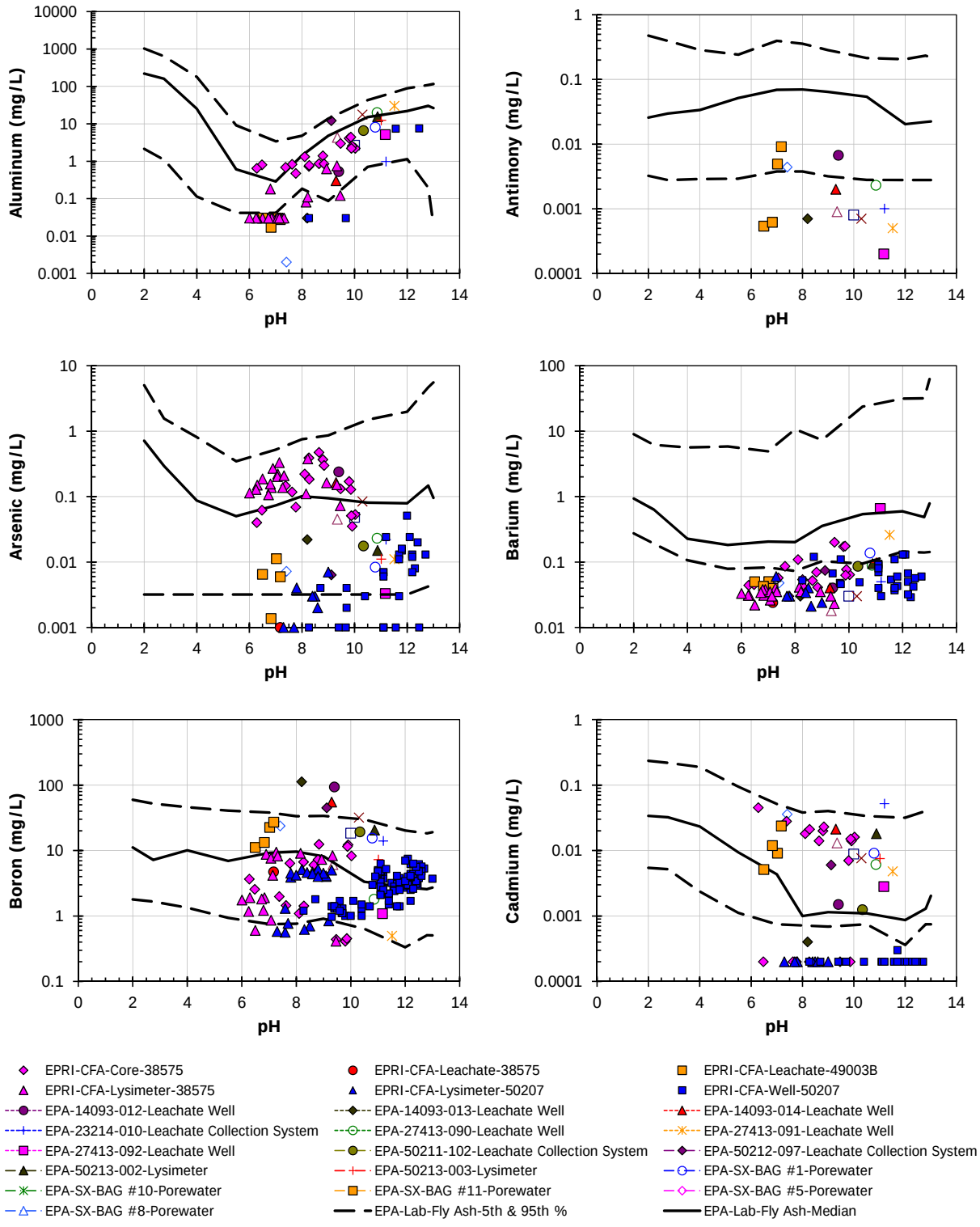

Figure B-1. Comparison of laboratory and field concentration results for coal combustion fly ash landfill (United States).

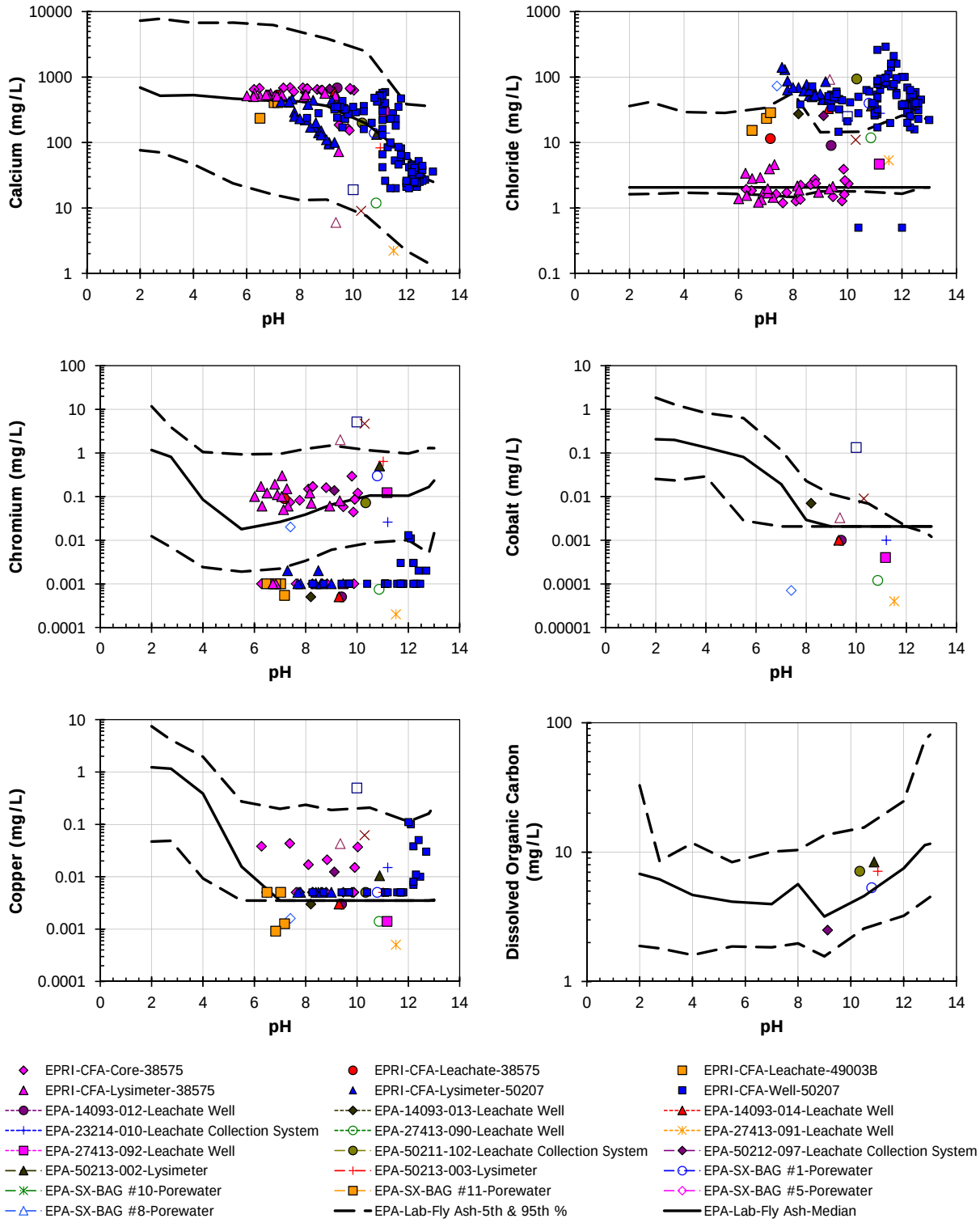

Figure B-2. Comparison of laboratory and field concentration results for coal combustion fly ash landfill (United States).

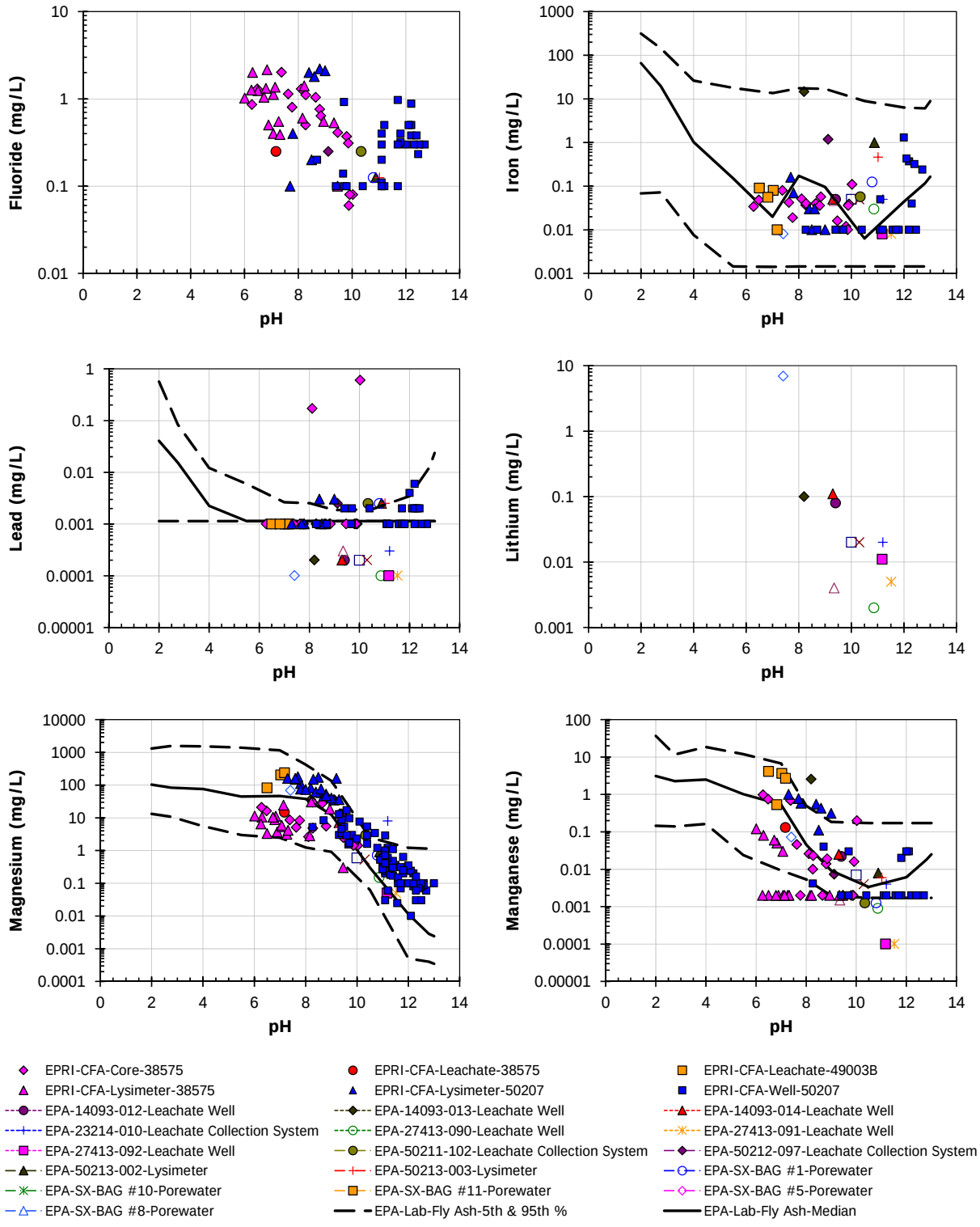

Figure B-3. Comparison of laboratory and field concentration results for coal combustion fly ash landfill (United States).

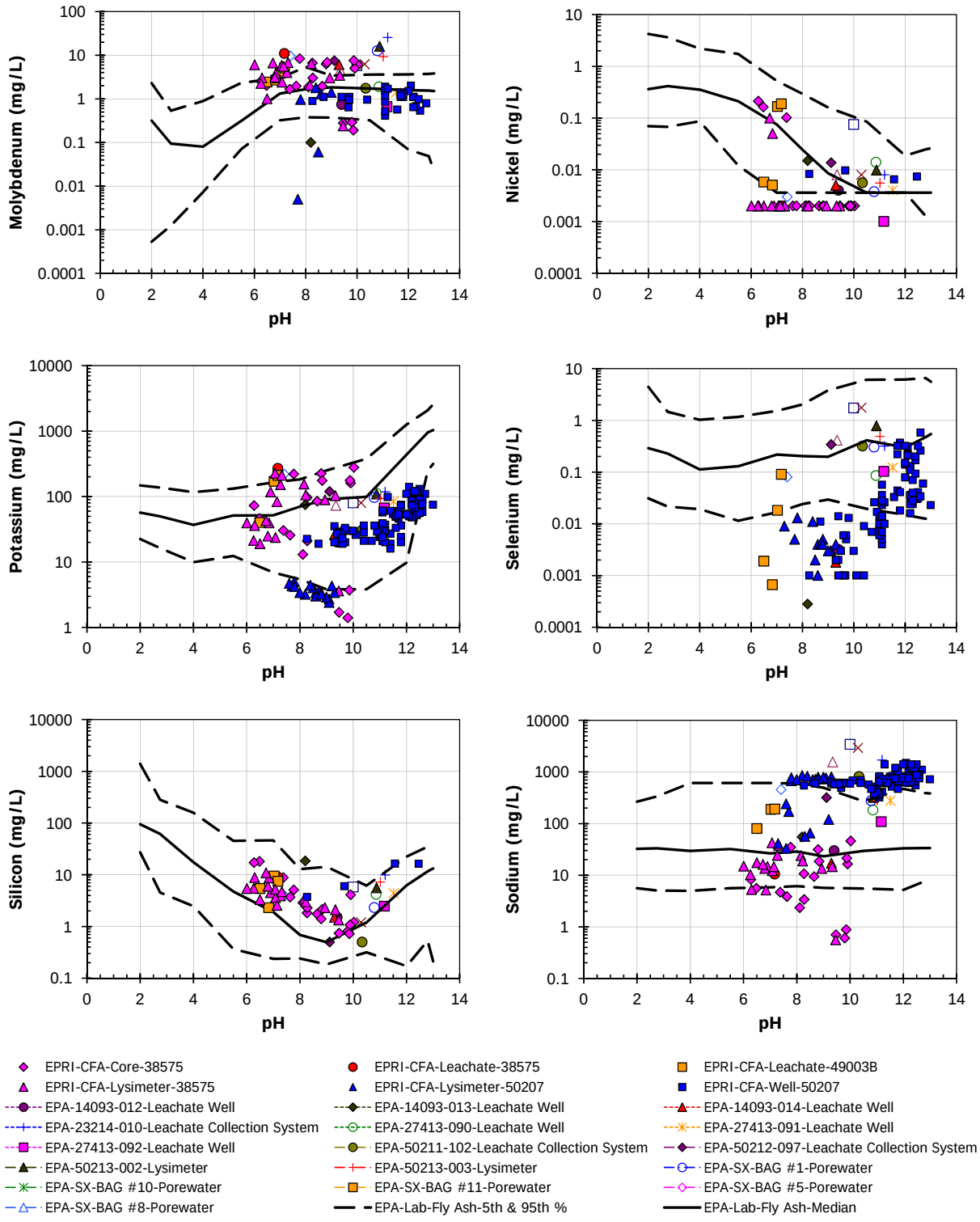

Figure B-4. Comparison of laboratory and field concentration results for coal combustion fly ash landfill (United States).

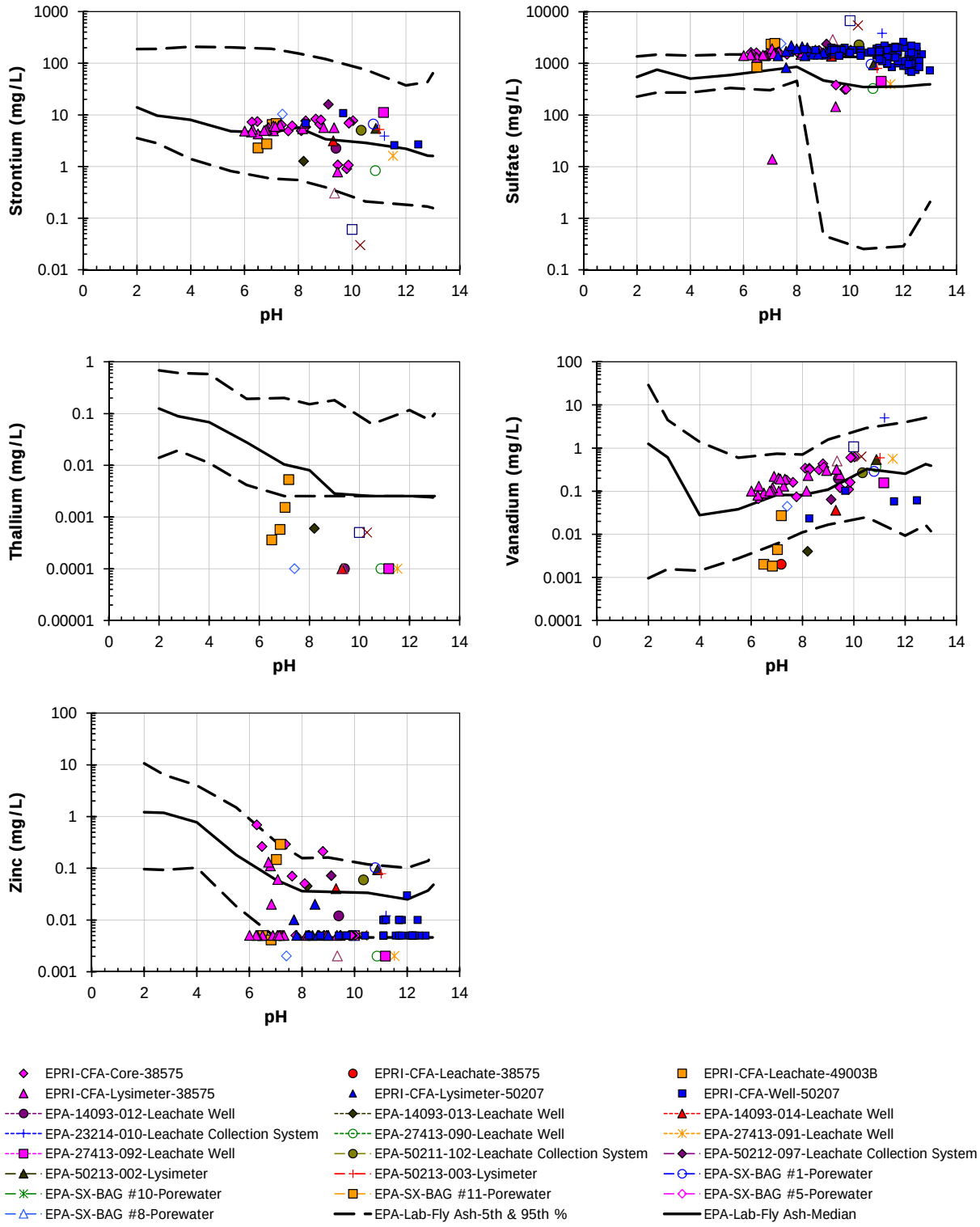

Figure B-5. Comparison of laboratory and field concentration results for coal combustion fly ash landfill (United States).

APPENDIX C. LANDFILL OF COAL COMBUSTION FIXATED SCRUBBER SLUDGE WITH LIME (UNITED STATES)

Table C-1. Data Sources for Laboratory-to-Field Comparisons for Coal Combustion Fixated Scrubber Sludge with Lime.

Legend ID	Source	Material Type	Data Type	Citation
FSSL – "as produced" (MAD)	Pub Mill (fresh 4 hr composite)	Fixated Scrubber Sludge with Lime	pH-dependence (SR002)	Sanchez et al., 2008
FSSL – Field Core (FCM)	FSSL Landfill	Core at depth (3-5 m)	pH-dependence (SR002)	EPRI, 2012 (draft)
Landfill Porewater	FSSL Landfill	Leachate	-	EPRI, 2012 (draft)

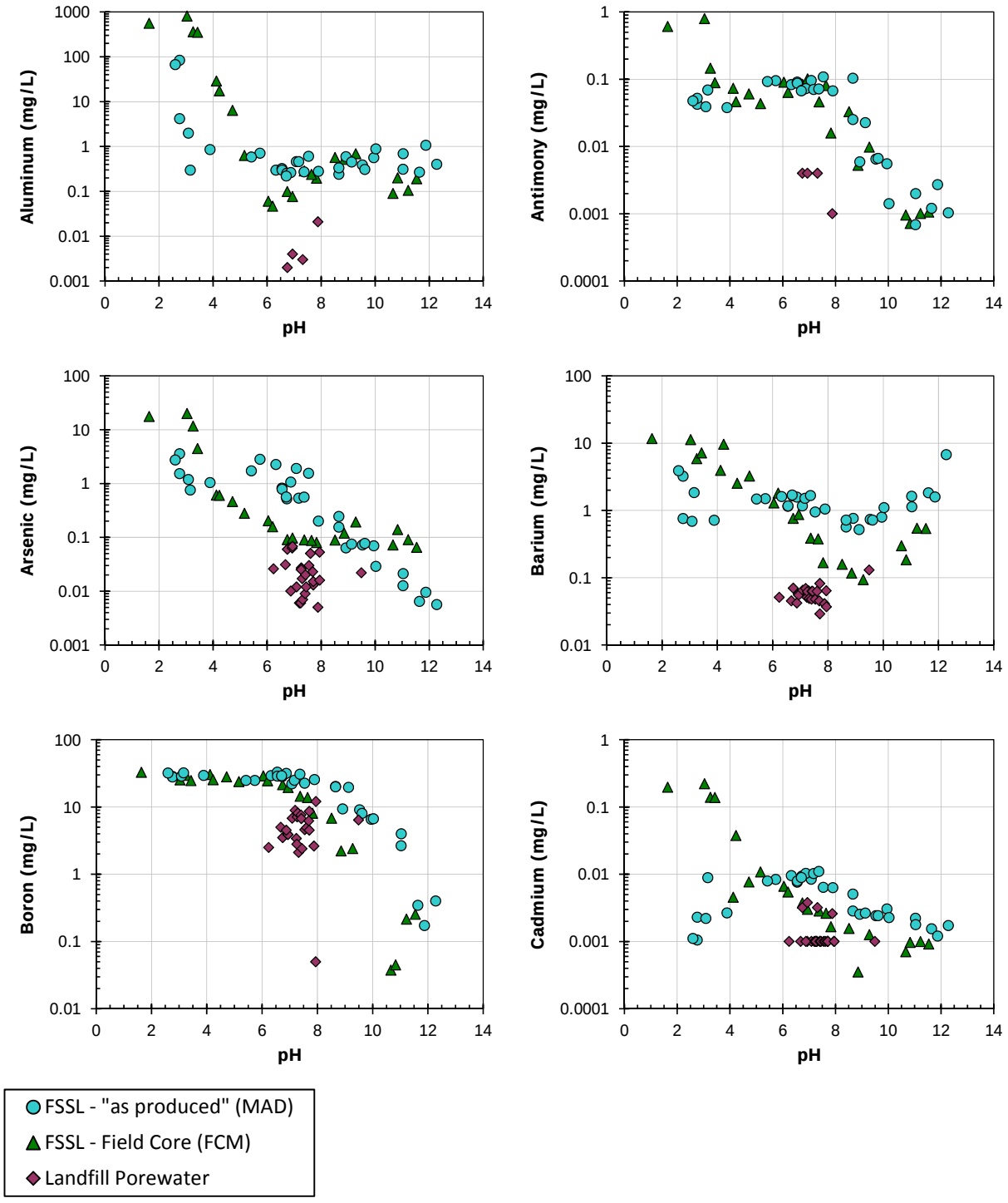

Figure C-1. Comparison of laboratory and field concentration results for a coal combustion fixated scrubber sludge with lime (FSSL) landfill (United States).

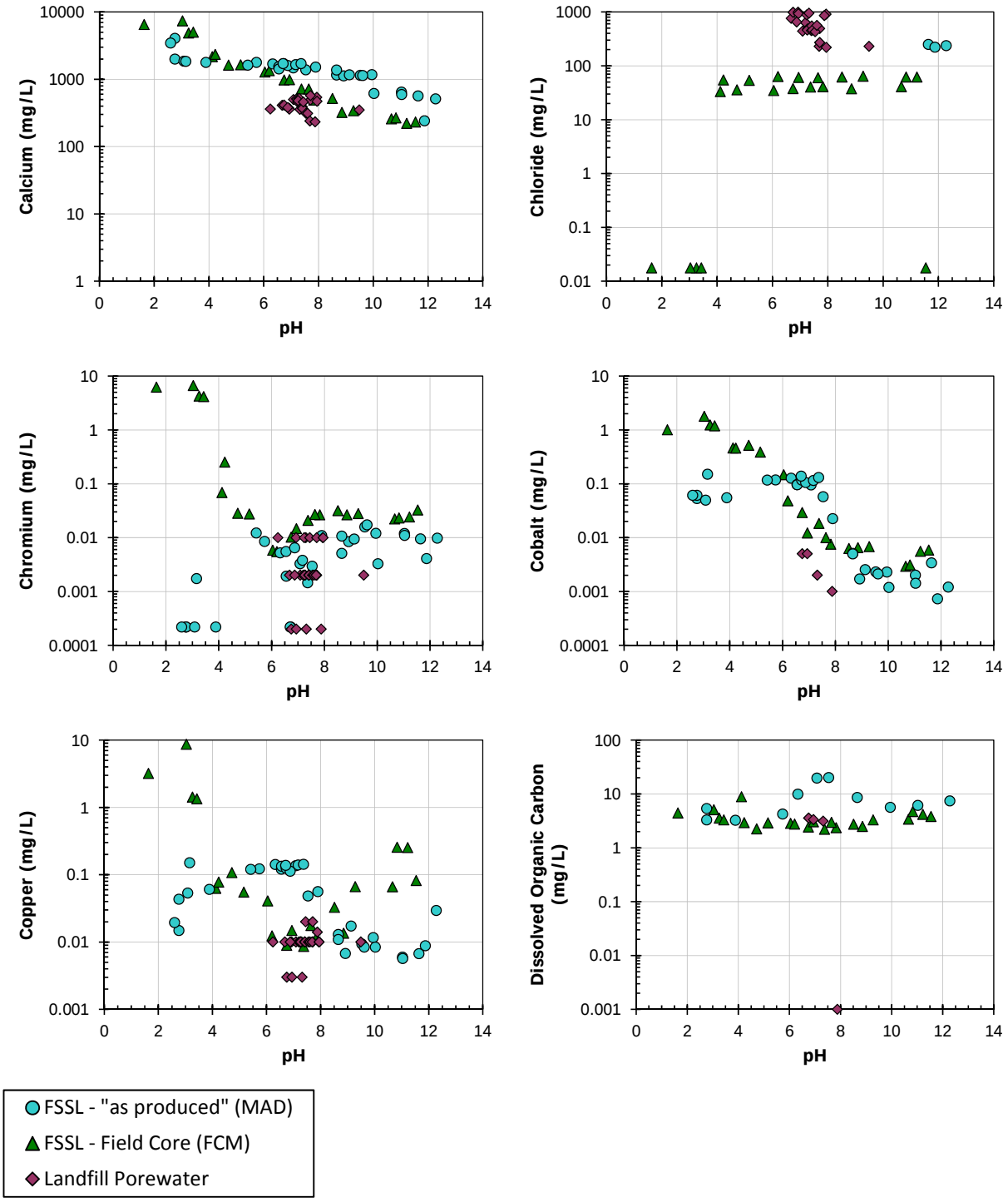

Figure C-2. Comparison of laboratory and field concentration results for a coal combustion fixated scrubber sludge with lime (FSSL) landfill (United States).

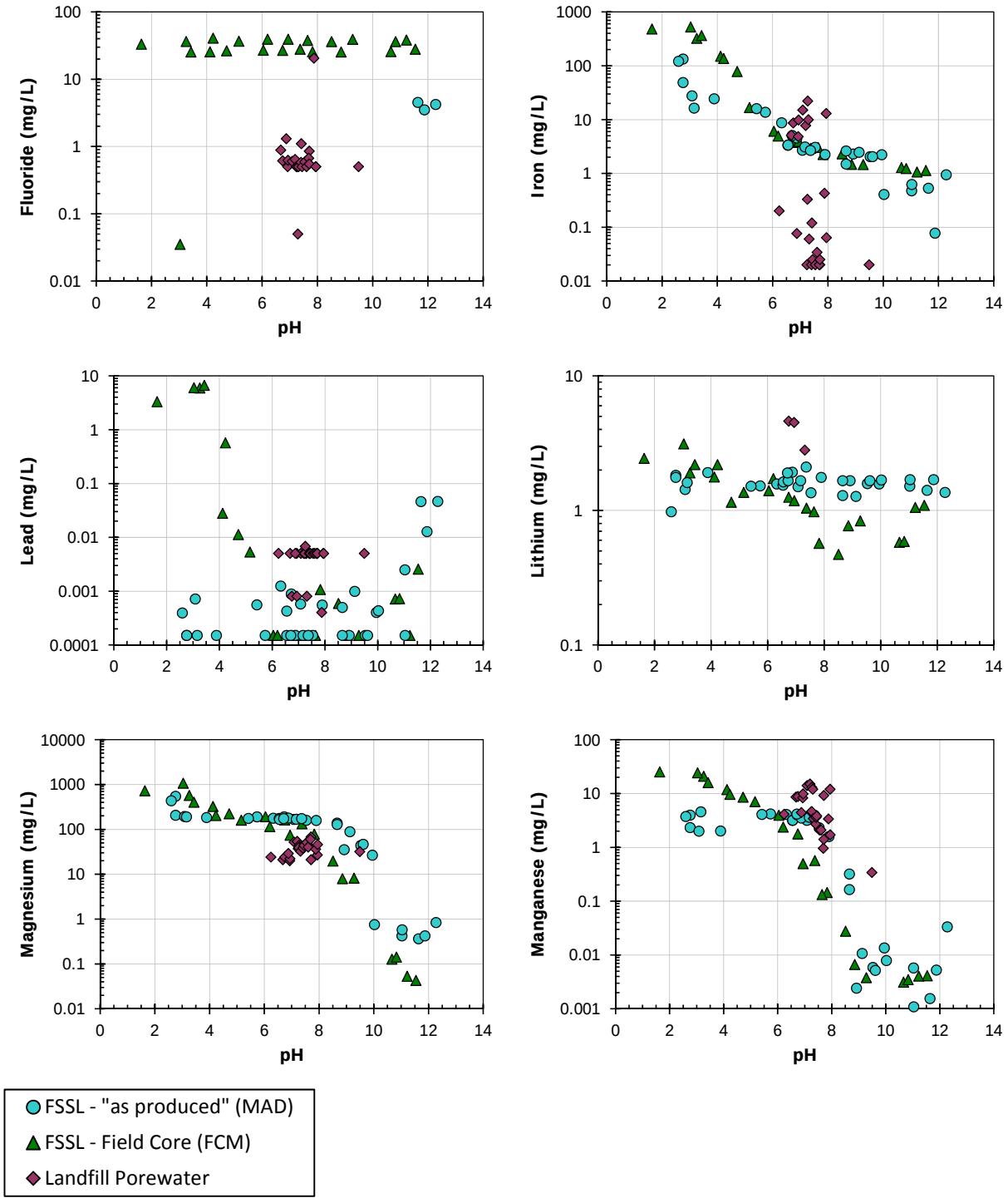

Figure C-3. Comparison of laboratory and field concentration results for a coal combustion fixated scrubber sludge with lime (FSSL) landfill (United States).

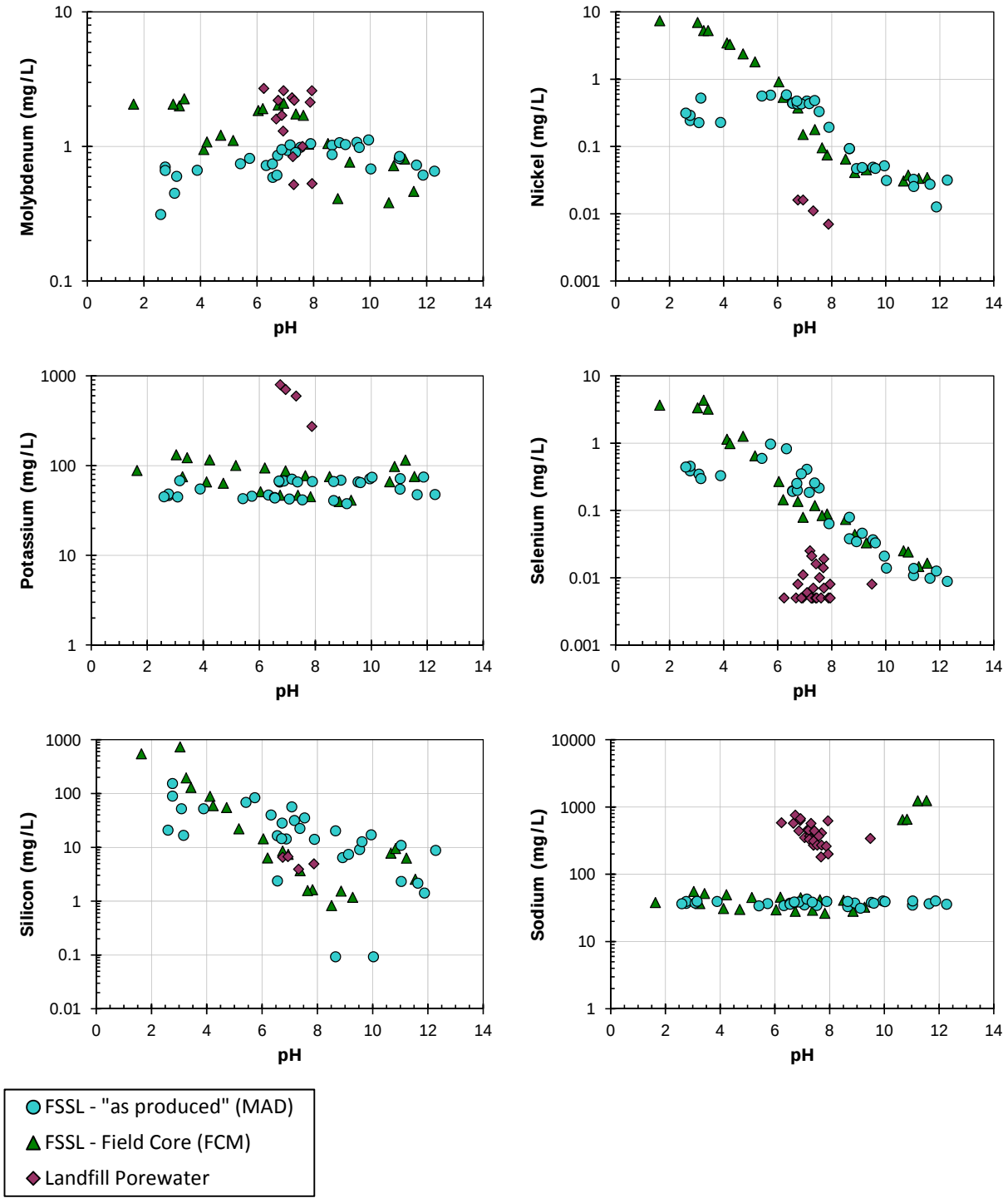

Figure C-4. Comparison of laboratory and field concentration results for a coal combustion fixated scrubber sludge with lime (FSSL) landfill (United States).

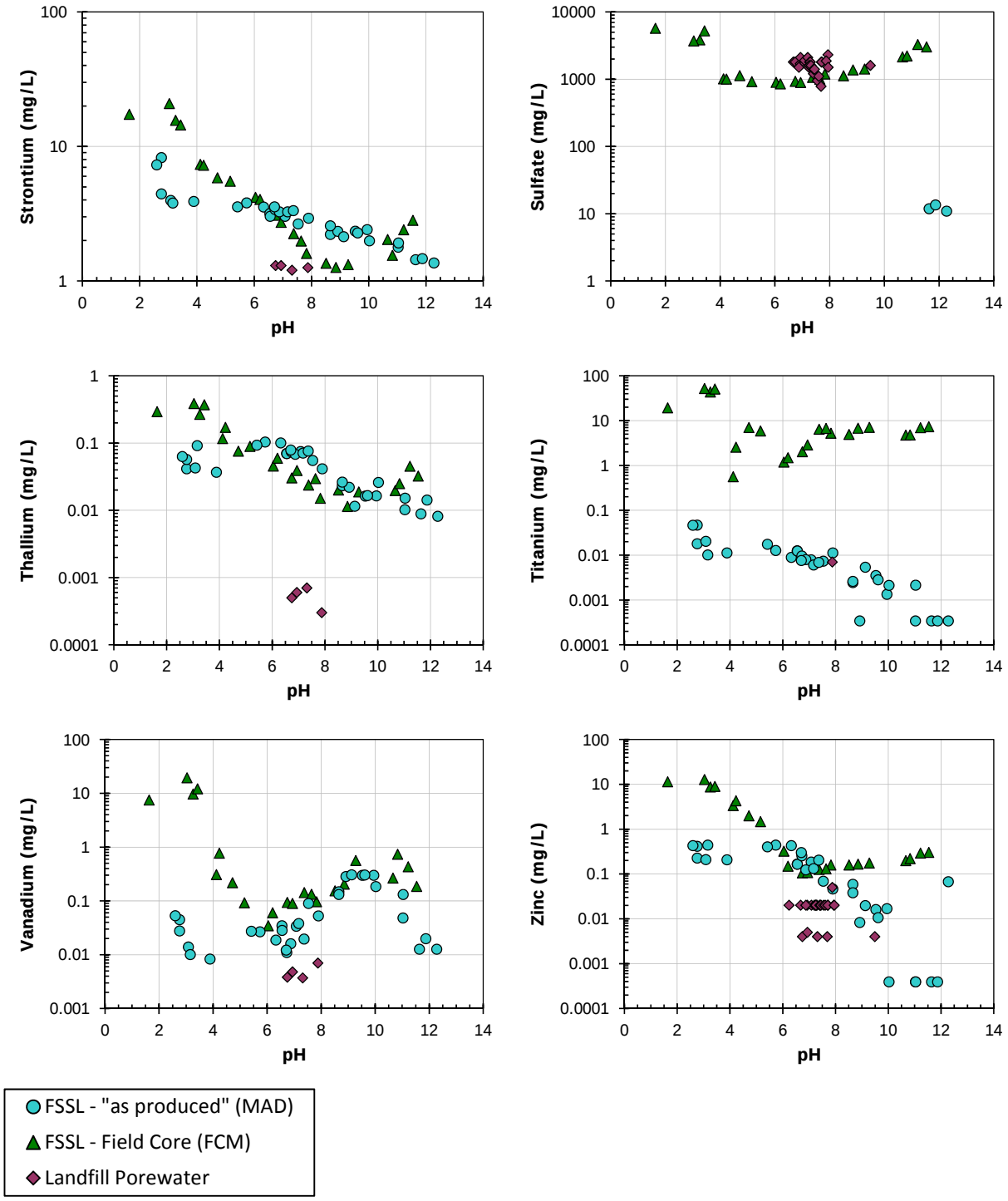

Figure C-5. Comparison of laboratory and field concentration results for a coal combustion fixated scrubber sludge with lime (FSSL) landfill (United States).

APPENDIX D. MUNICPAL SOLID WASTE INCINERATOR BOTTOM ASH LANDFILL (DENMARK)

Table D-1. Data Sources for Laboratory-to-Field Comparisons for MSWI Bottom Ash Landfill

Legend ID	Source	Material Type	Data Type	Citation
MSWI BA (AT)	Austria, MSW Incinerator	MSWI Bottom Ash	pH-dependence Percolation	van der Sloot et al., 2000b
MSWI BA (DE)	Germany, MSW Incinerator 1	MSWI Bottom Ash	pH-dependence Percolation	Berger et al., 2005
Landfill Leachate (DK)	Denmark	Field Leachate	-	Hjelmar et al., 1991
Landfill Core (DK)	Denmark	Landfill Core	Batch L/S	Meima, 1997
MSWI BA (NL)	The Netherlands	MSWI Bottom Ash	pH-dependence Percolation	ECN ongoing studies on MSWI BA
MSWI BA (IT)	Italy	MSWI Bottom Ash	pH-dependence Percolation	ECN ongoing studies on MSWI BA (Italian client)
MSWI BA (UK)	UK, MSW Incinerator	MSWI Bottom Ash	pH-dependence Percolation	ECN studies on UK MSWI BA

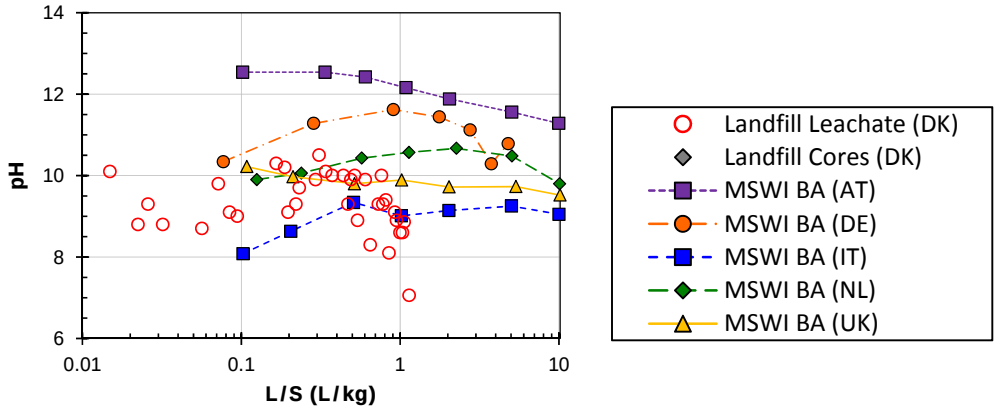

Figure D-1. Eluate pH from leachates from the Vestkoven monofill (red circles) compared to the percolation column pH for comparable bottom ash samples (solid symbols).

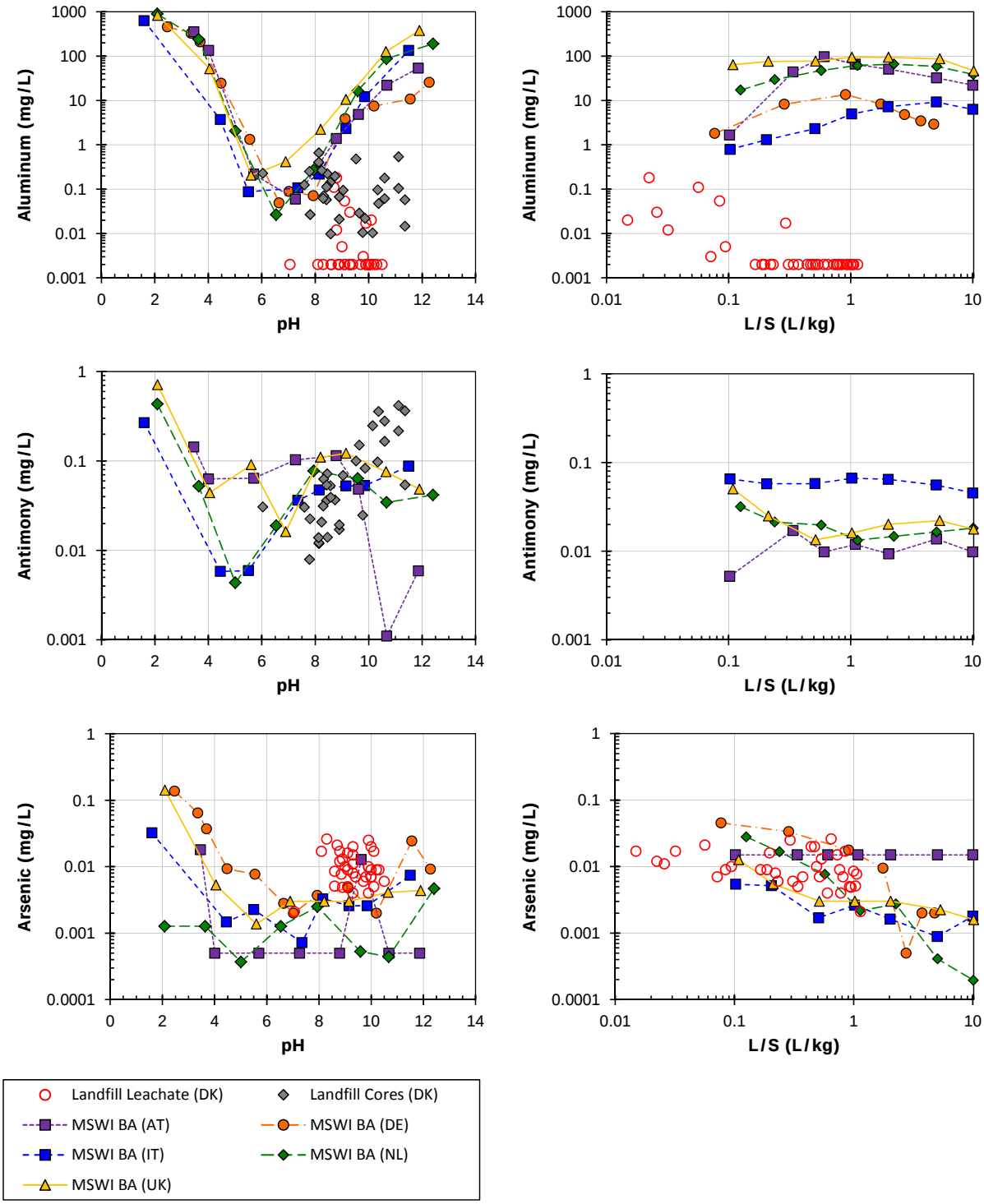

Figure D-2. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

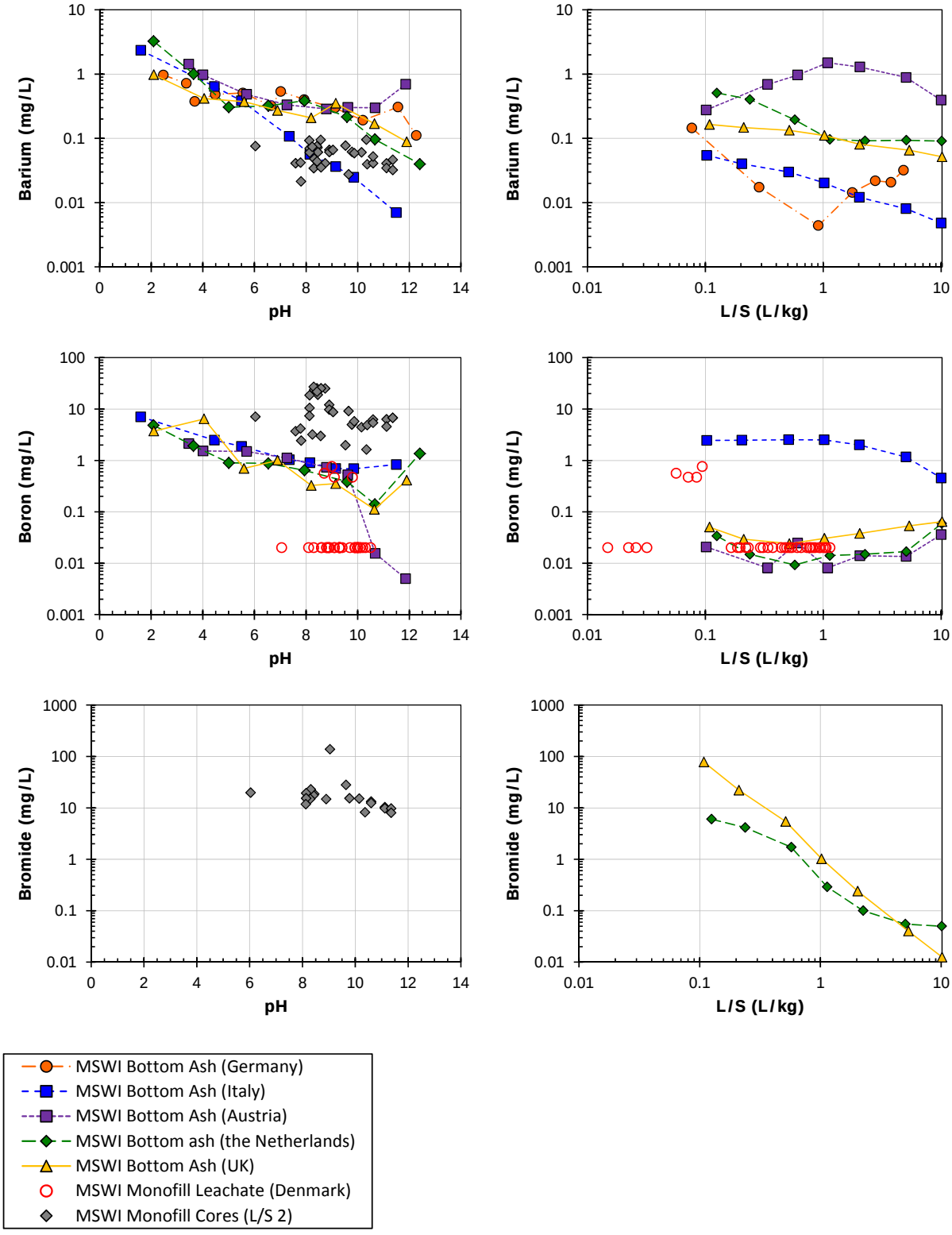

Figure D-3. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

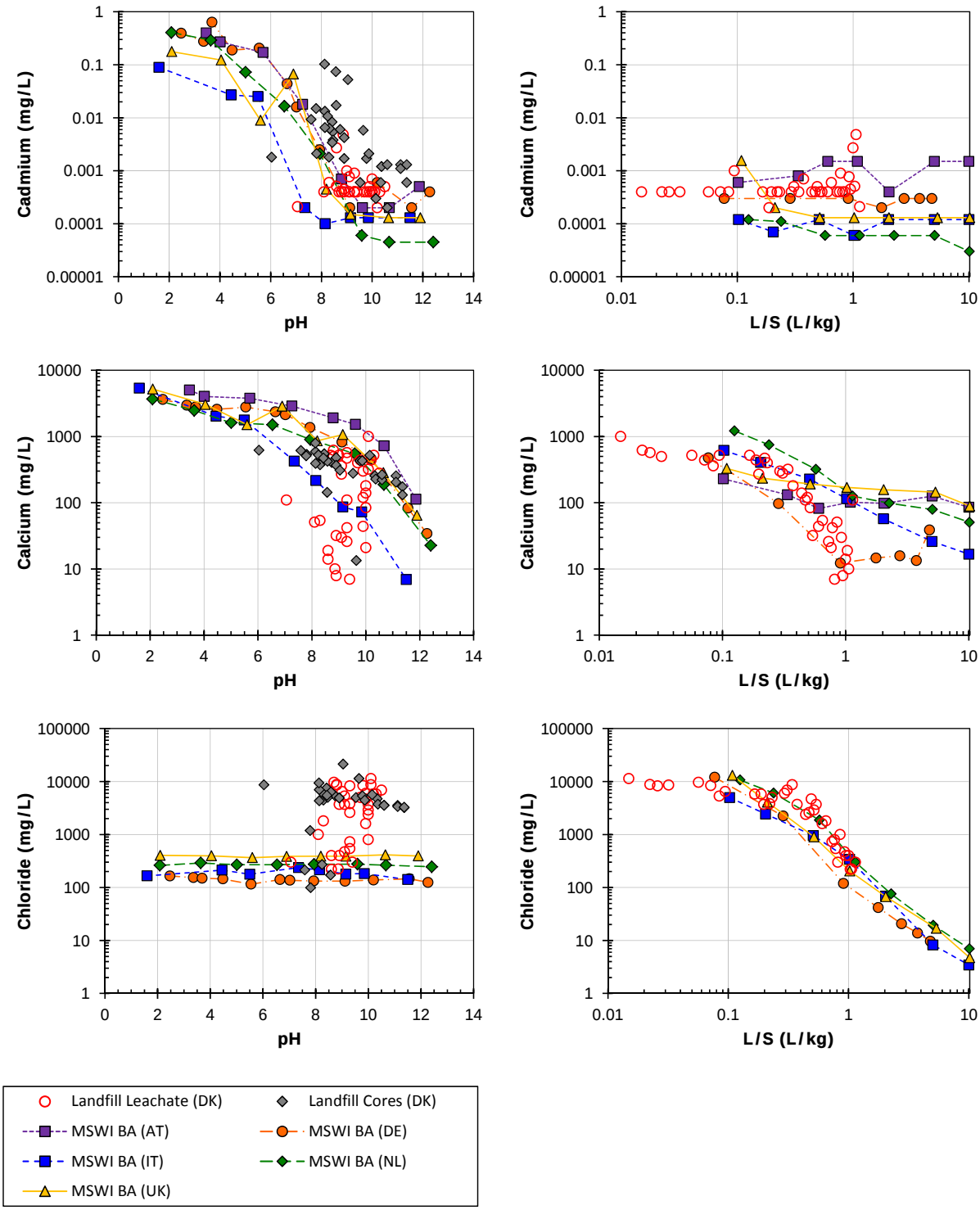

Figure D-4. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

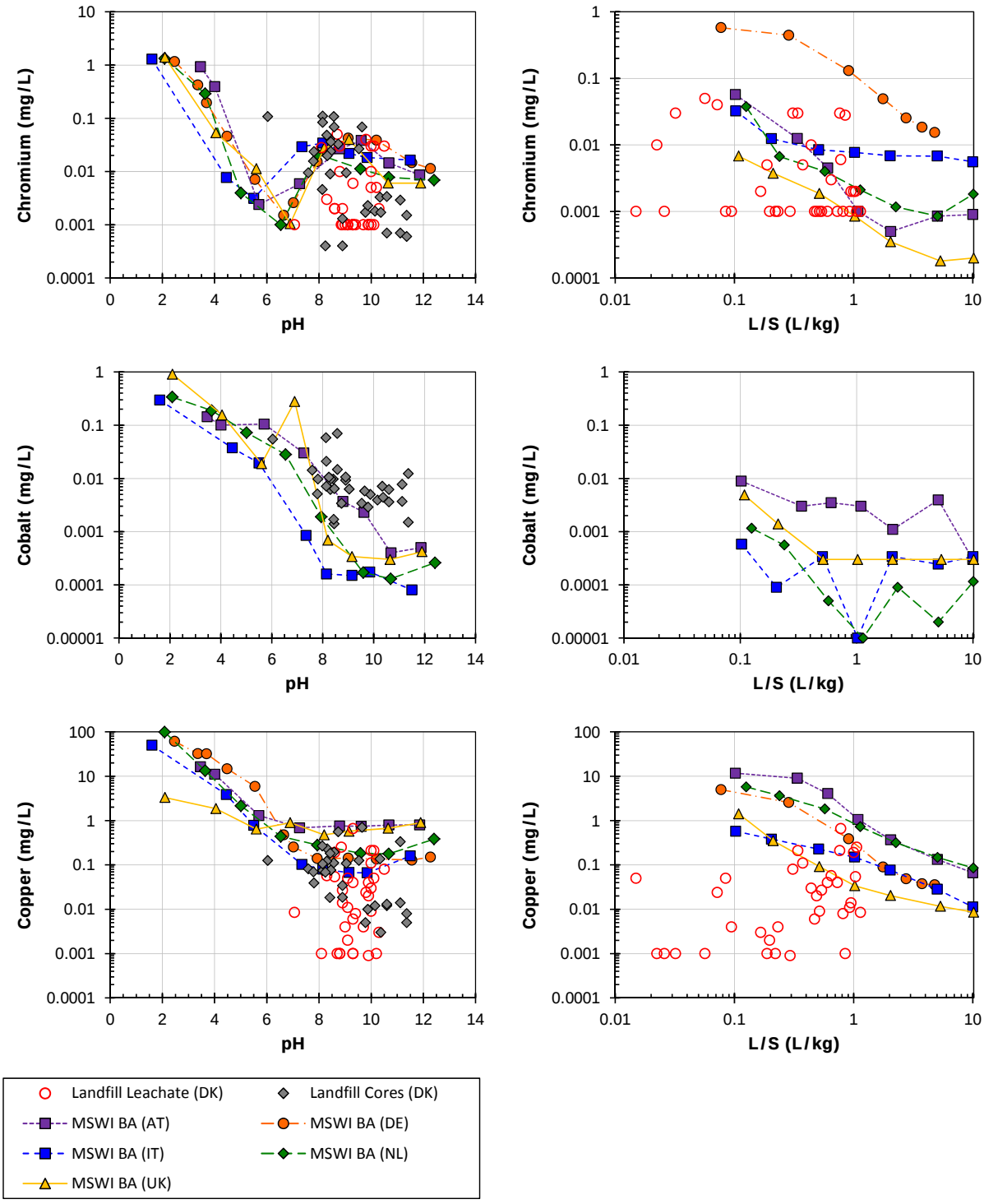

Figure D-5. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

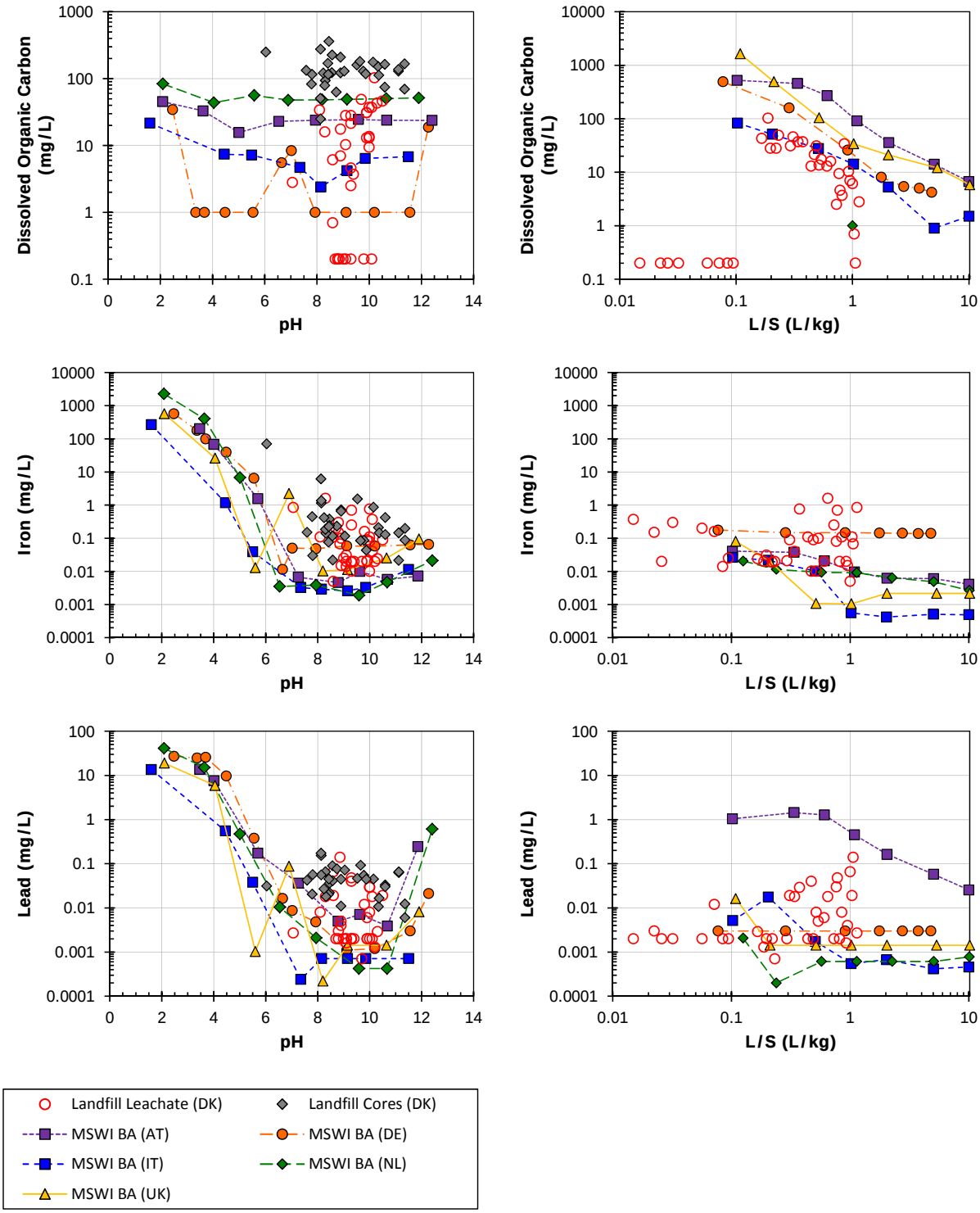

Figure D-6. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

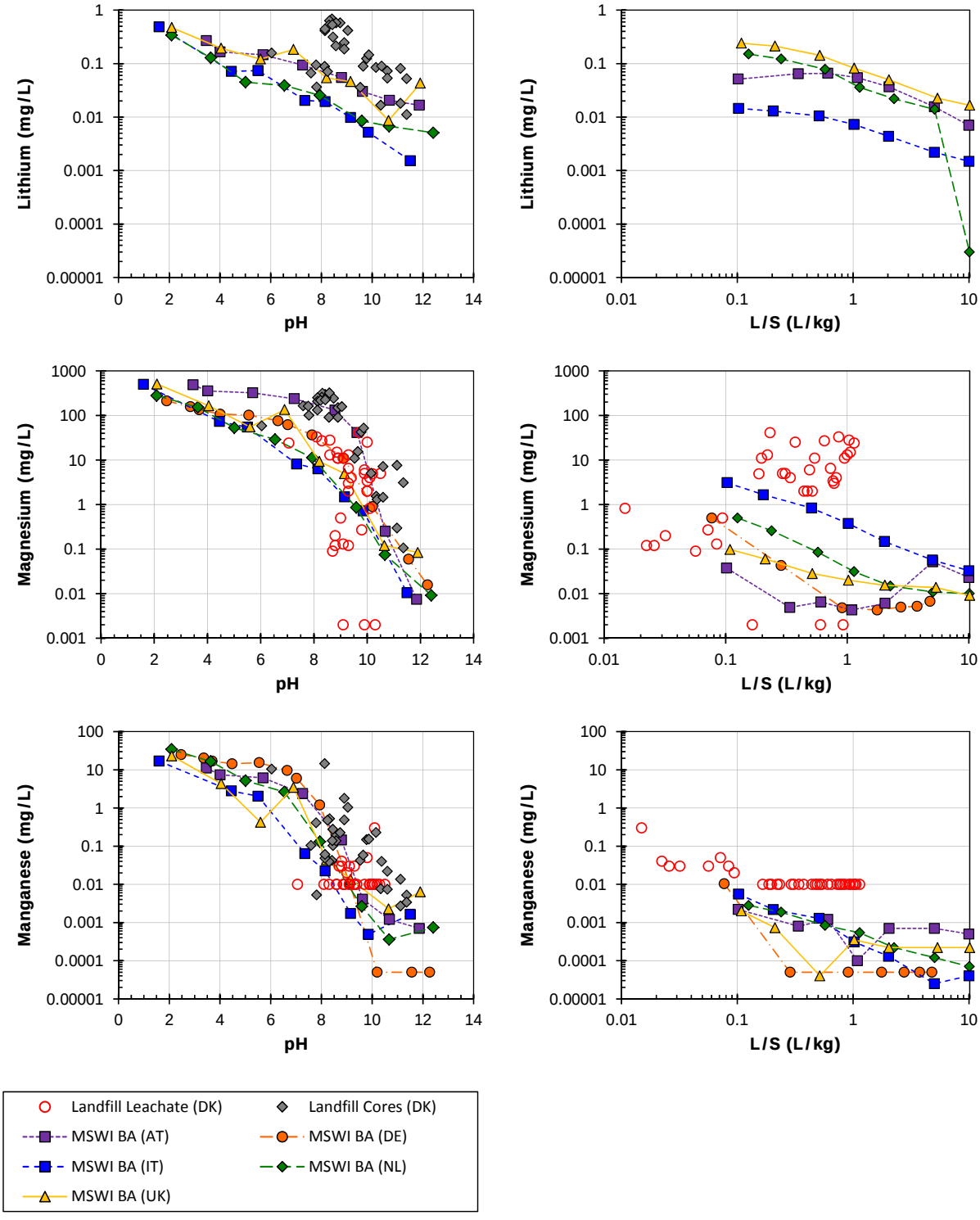

Figure D-7. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

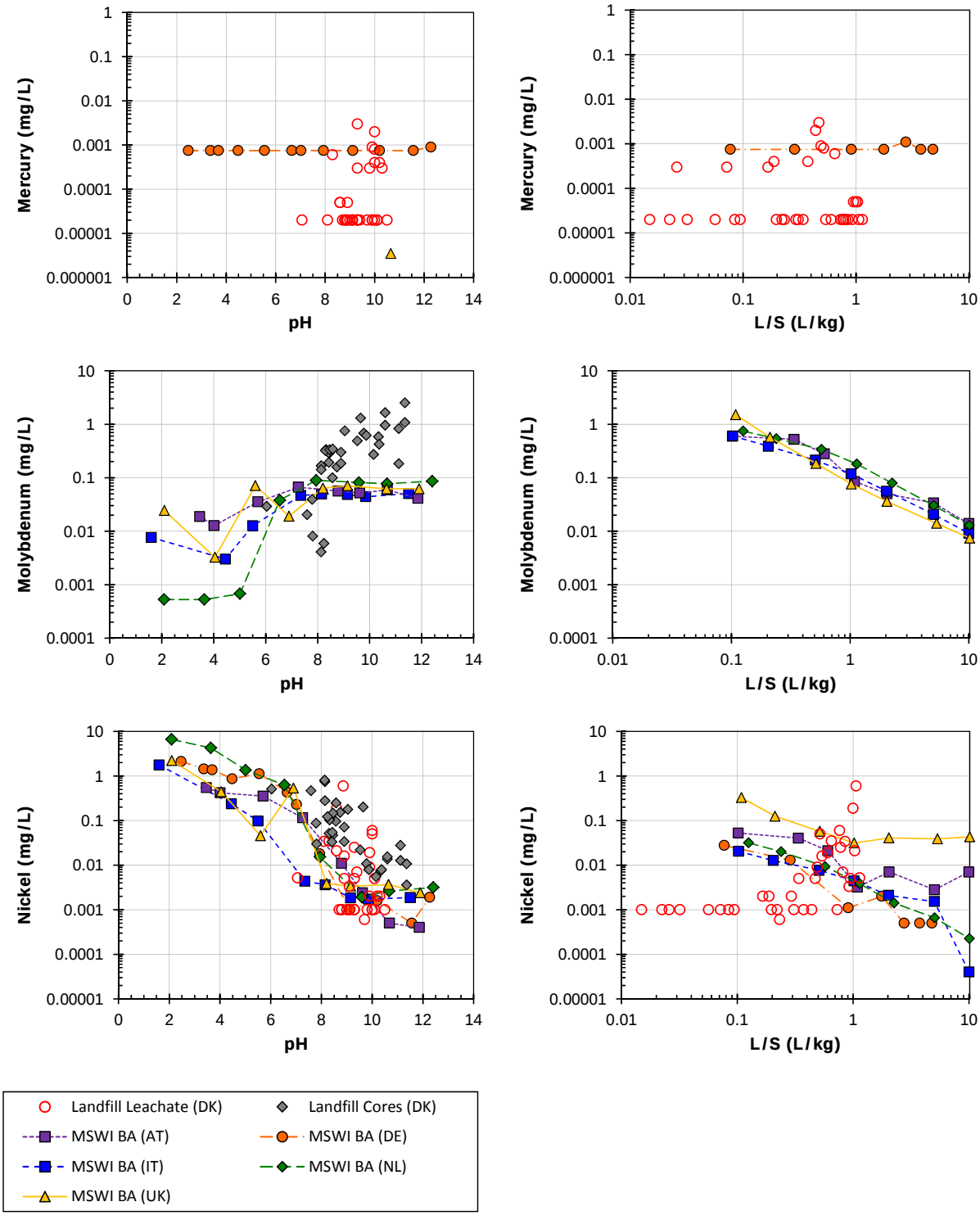

Figure D-8. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

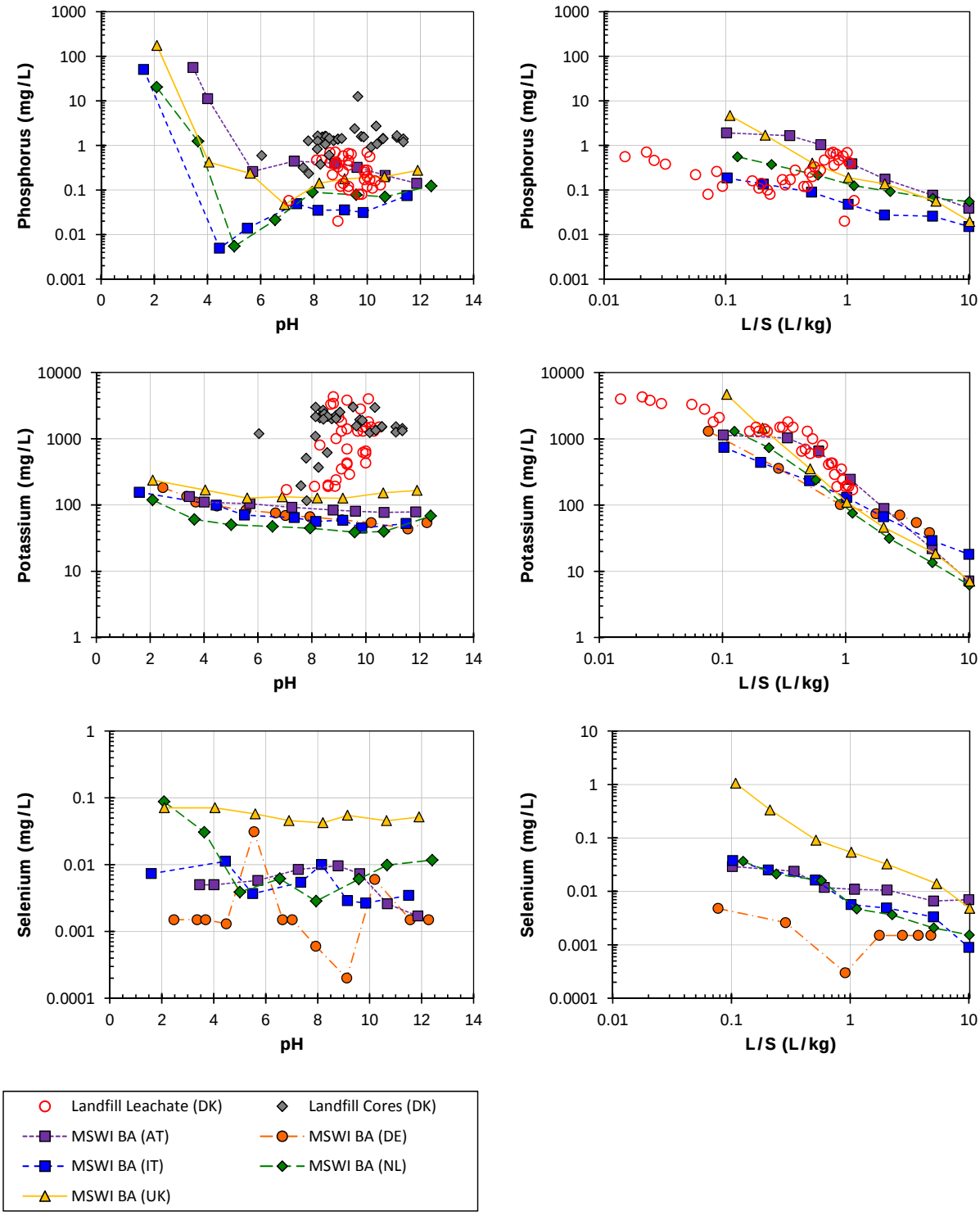

Figure D-9. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

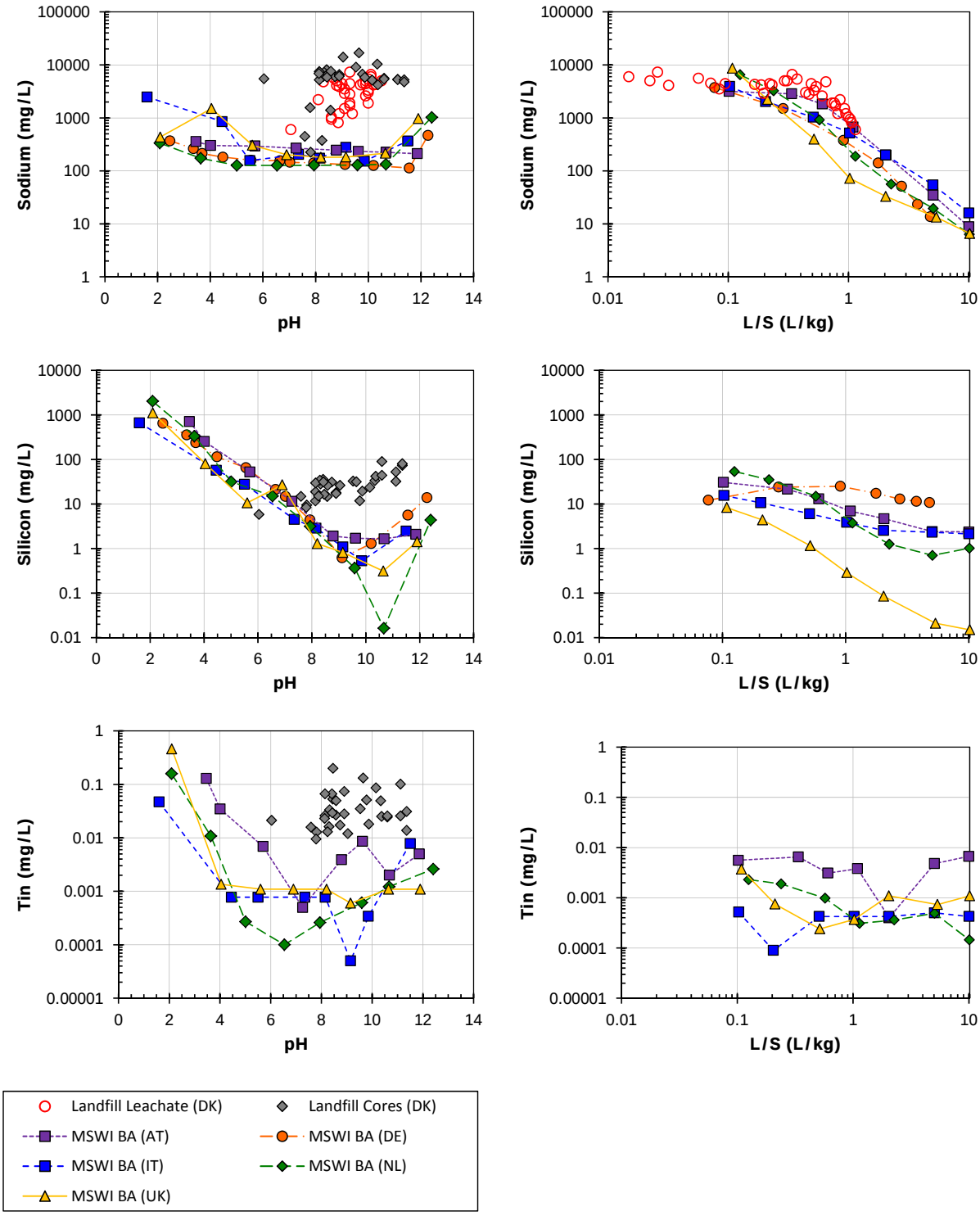

Figure D-10. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

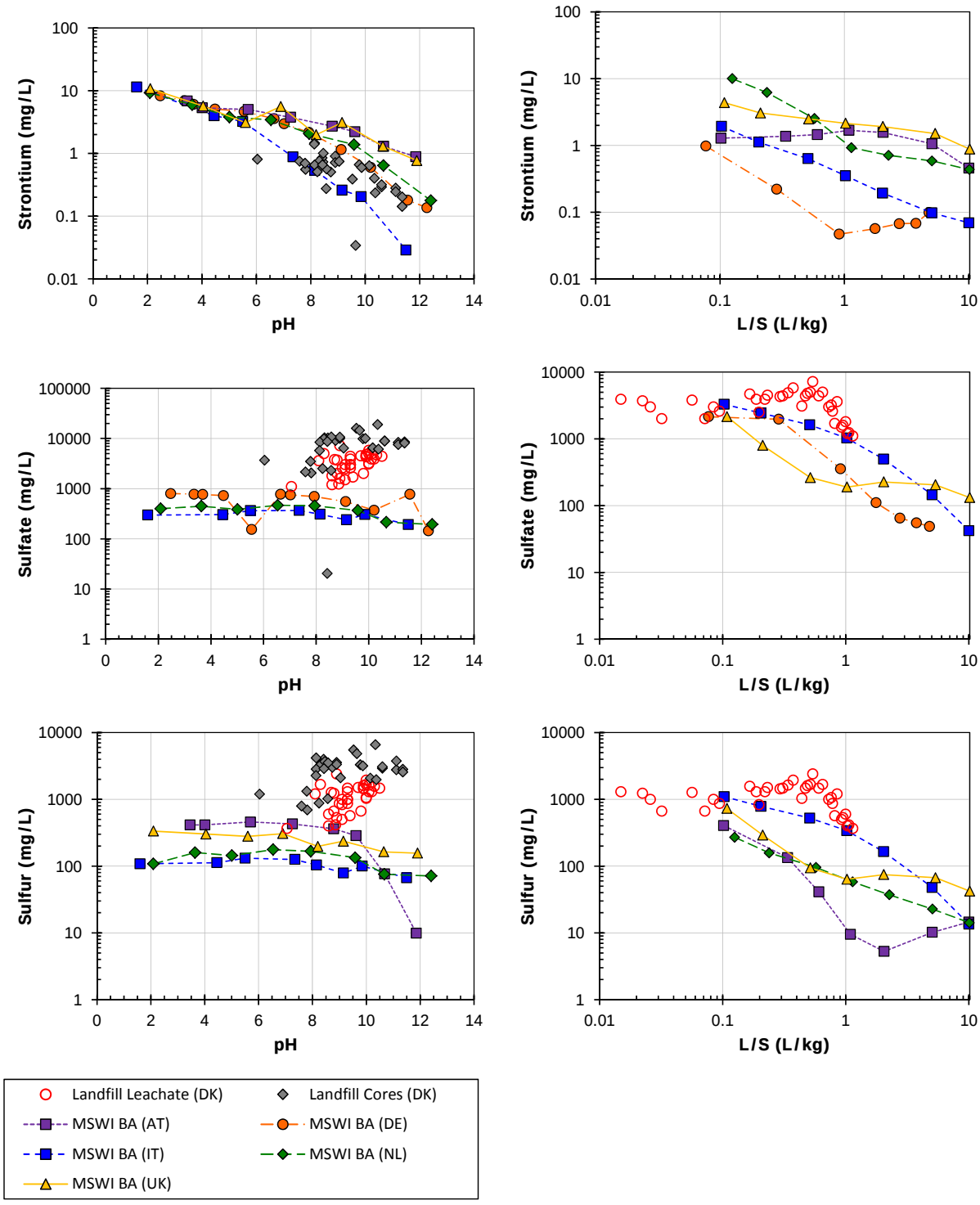

Figure D-11. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

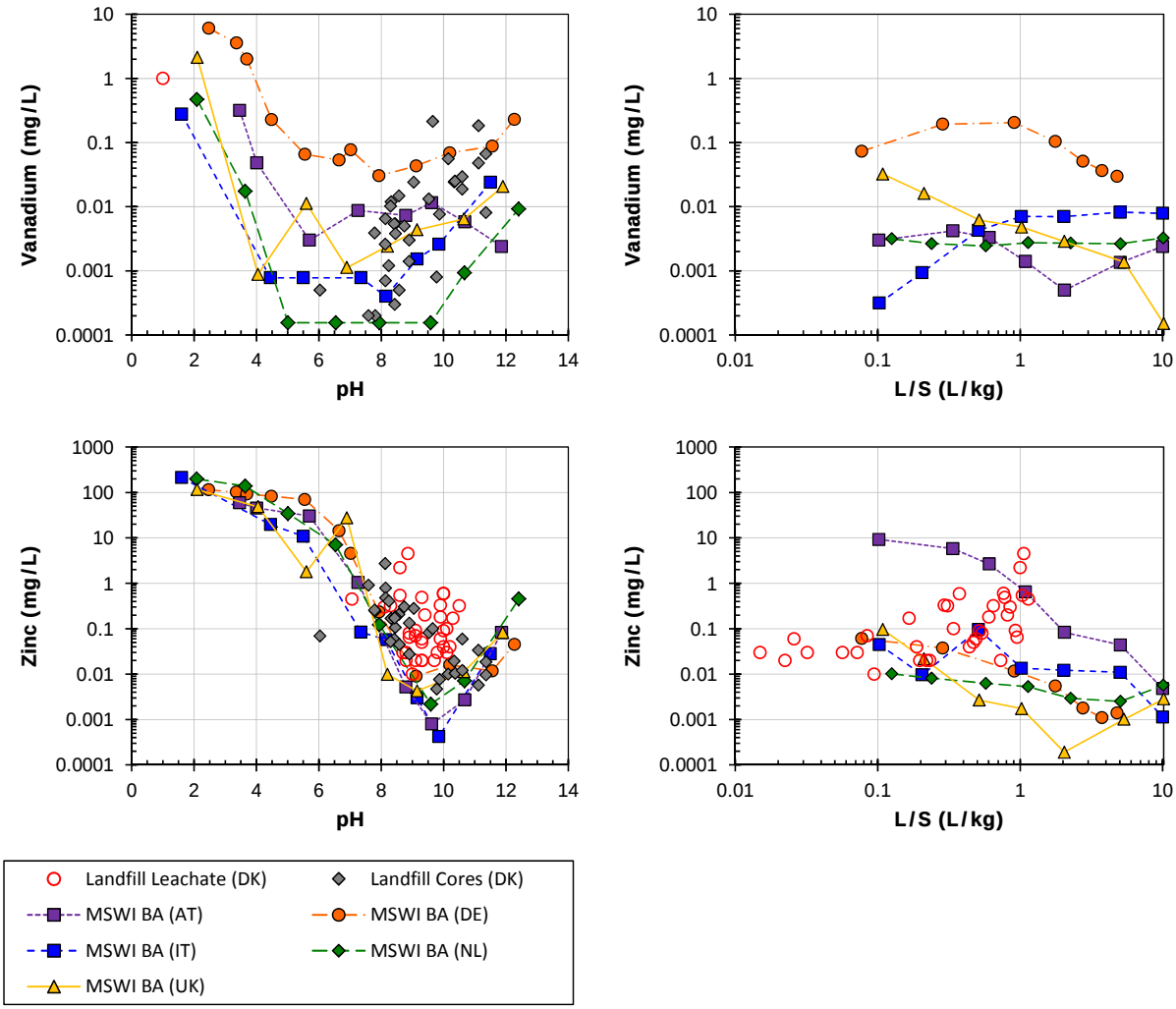

Figure D-12. Comparison of laboratory and field concentration results for a MSWI bottom ash landfill (Denmark).

APPENDIX E. MUNICPAL SOLID WASTE INCINERATOR BOTTOM ASH USE IN ROADBASE (SWEDEN)

Table E-1. Data Sources for Laboratory-to-Field Comparisons for MSWI Bottom Ash used in Roadbase (Sweden).

Legend ID	Source	Material Type	Data Type	Citation
Vändöra – Core 1	Sweden	Core composite from roadbase based on level of carbonation	pH-dependence Percolation	
Vändöra – Core 2	Sweden	Core composite from roadbase based on level of carbonation	pH-dependence Percolation	
Vändöra – Core 3	Sweden	Core composite from roadbase based on level of carbonation	pH-dependence Percolation	
Vändöra – Core 4	Sweden	Core composite from roadbase based on level of carbonation	pH-dependence Percolation	
Vändöra – Individual Cores (L/S 10 16 yrs)	Sweden	Cores from roadbase	Batch L/S (EN 12457-2)	
MSWI BA (NL)	The Netherlands	MSWI Bottom Ash	pH-dependence Percolation	ECN ongoing studies on MSWI BA
MSWI BA 2 (NL)	The Netherlands	MSWI Bottom Ash	pH-dependence Percolation	ECN ongoing studies on MSWI BA
MSWI BA (DE)	SIWAP, Germany	MSWI Bottom Ash	pH-dependence Percolation	Berger et al., 2005
MSWI BA (AT)	Austria, MSW Incinerator	MSWI Bottom Ash	pH-dependence Percolation	van der Sloot et al., 2000b
MSWI BA (UK)	UK, MSW Incinerator	MSWI Bottom Ash	pH-dependence Percolation	ECN studies on UK MSWI BA
MSWI BA (DE)	Germany, MSW Incinerator 1	MSWI Bottom Ash	pH-dependence Percolation	Berger et al., 2005

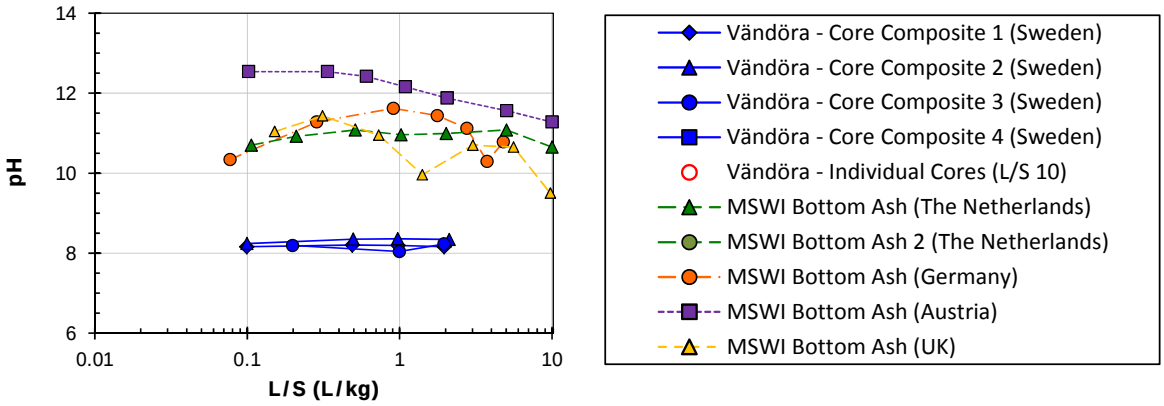

Figure E-1. pH from laboratory testing of Vändöra cores and composites from roadbasel (Sweden).

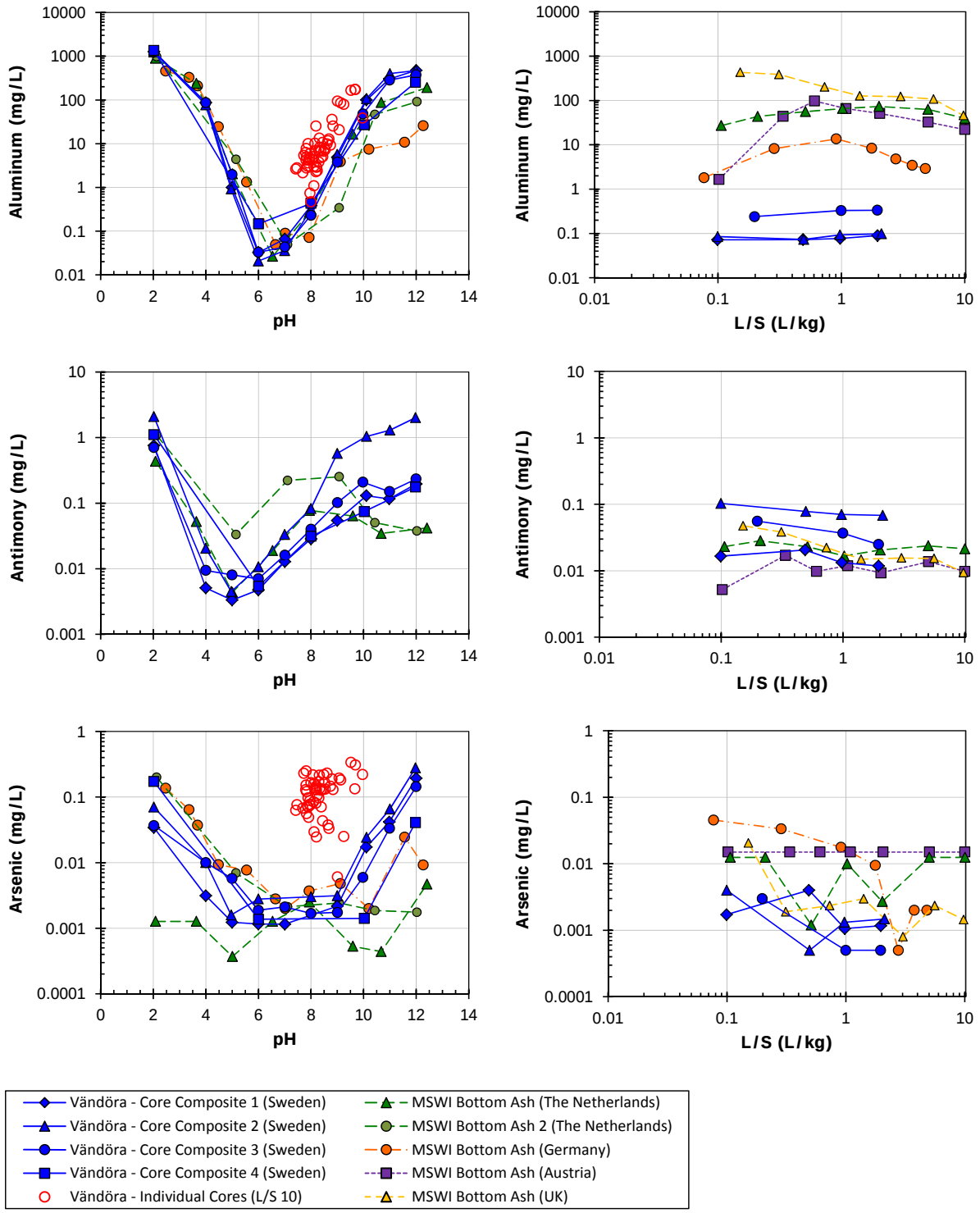

Figure E-2. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

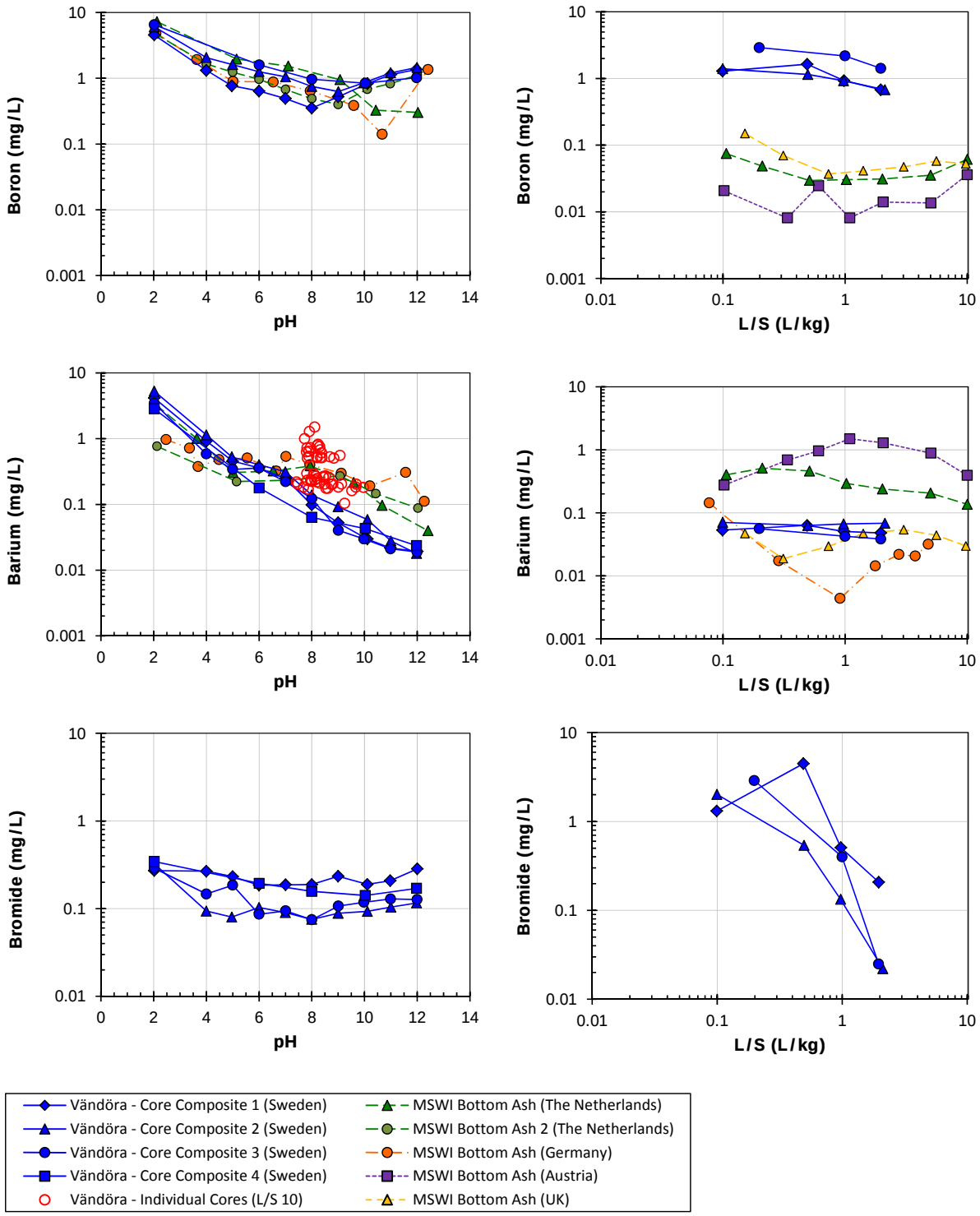

Figure E-3. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

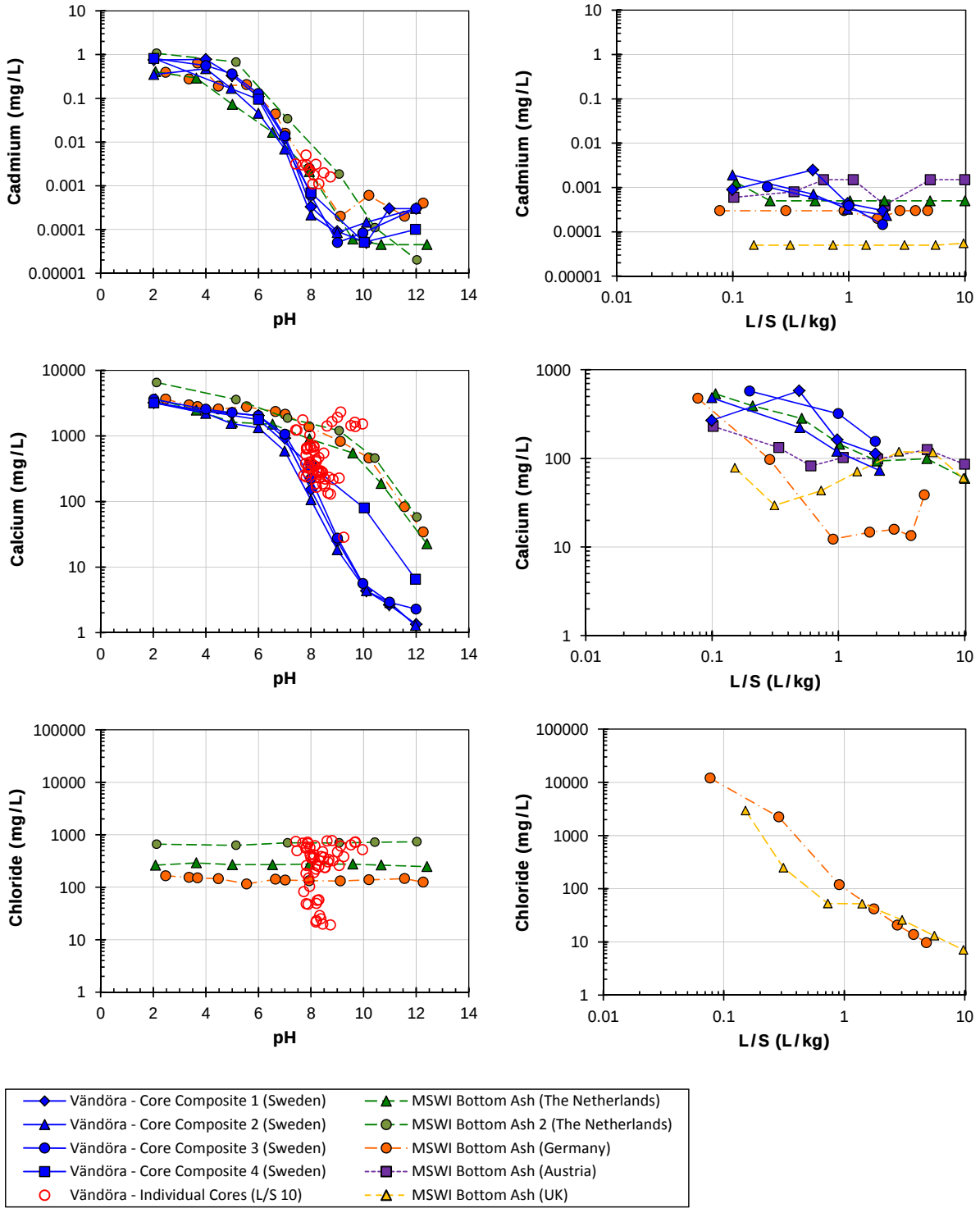

Figure E-4. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

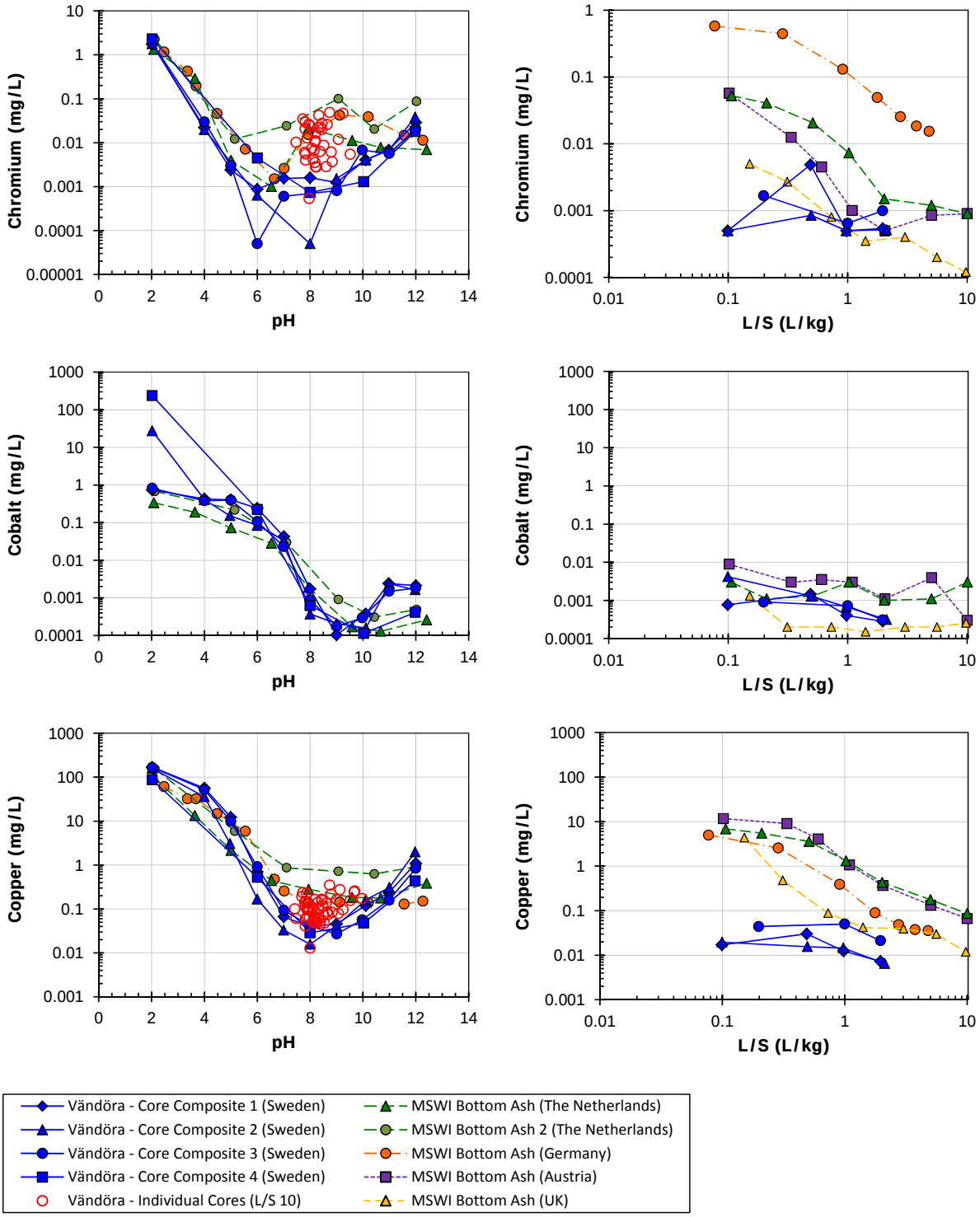

Figure E-5. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

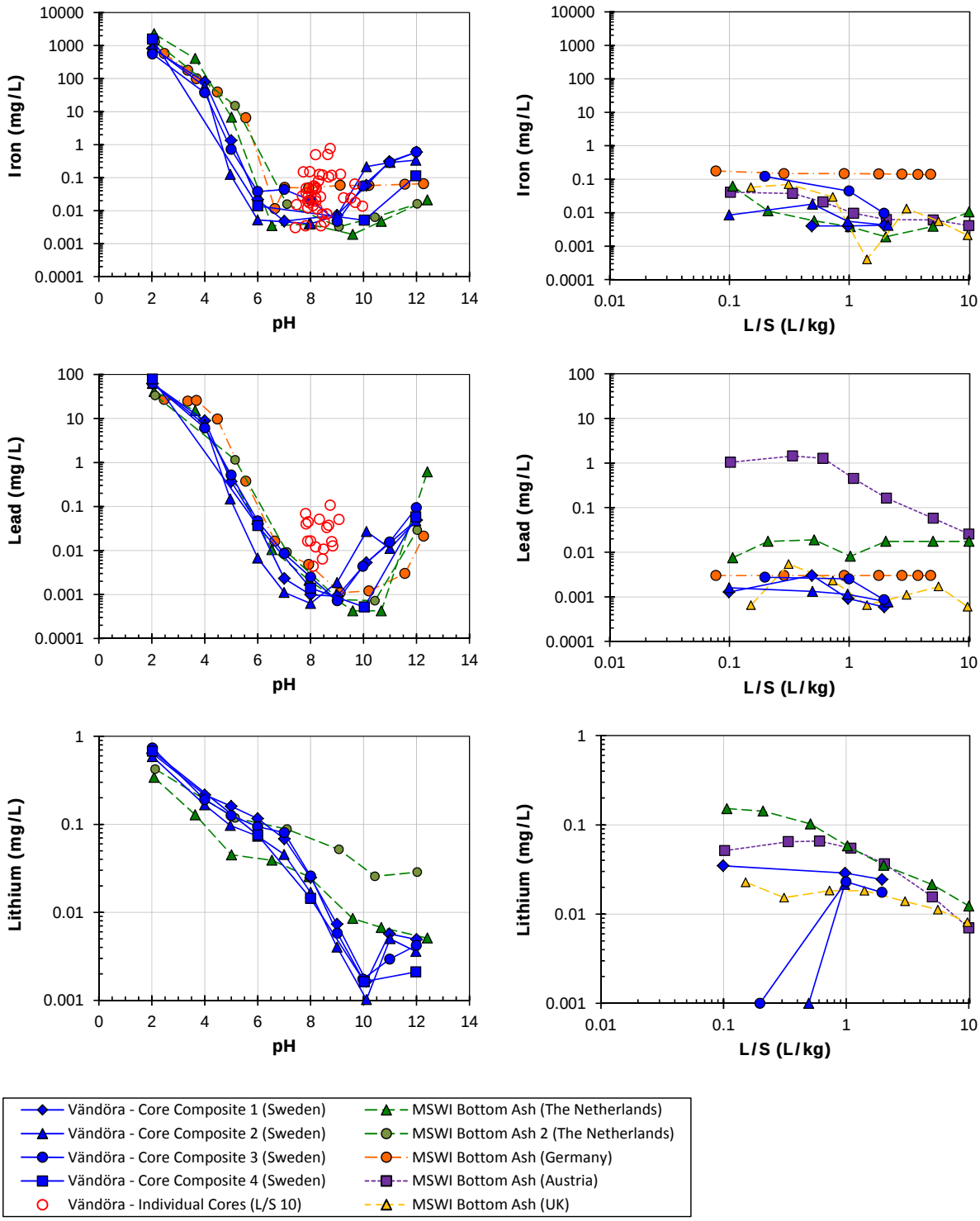

Figure E-6. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

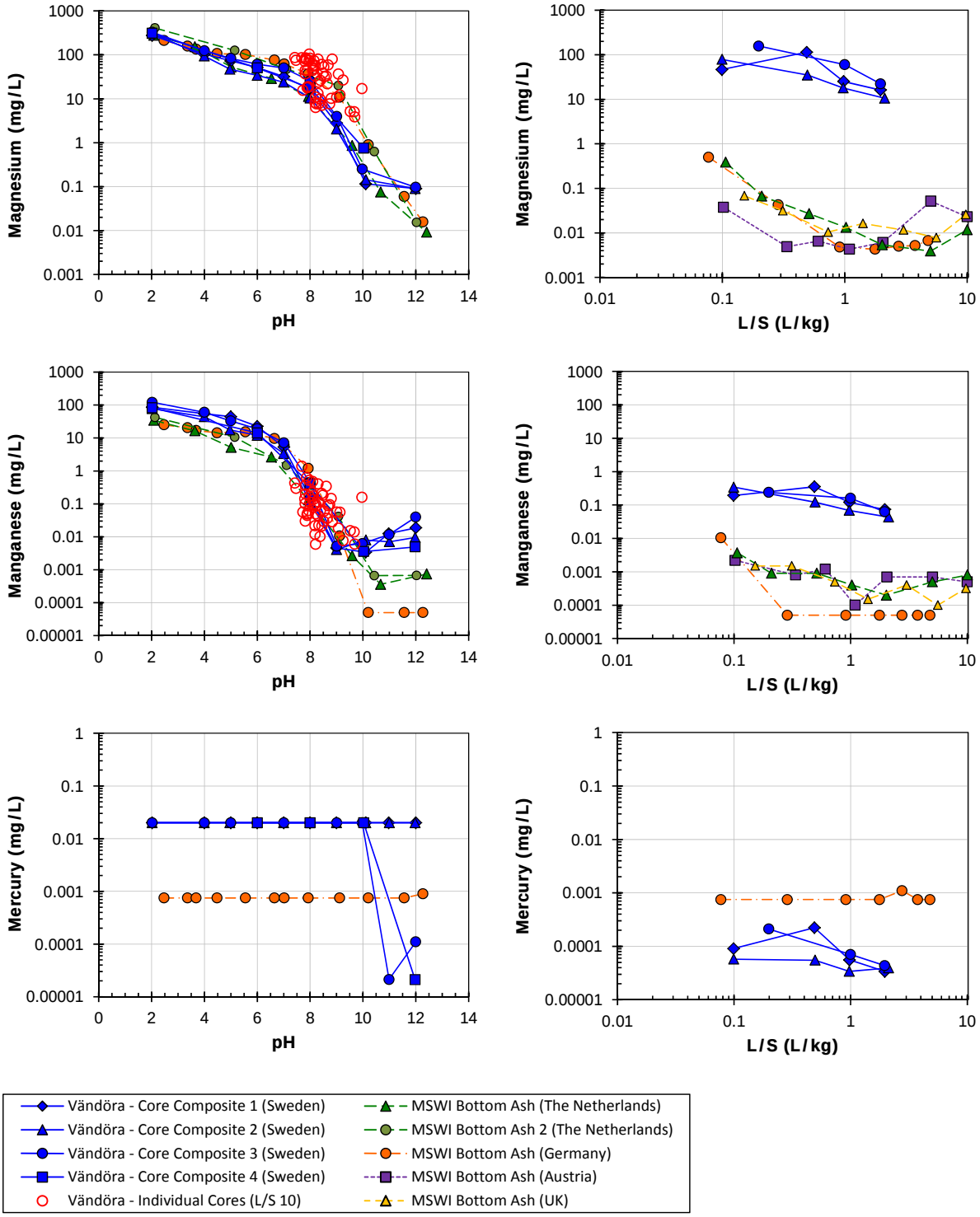

Figure E-7. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

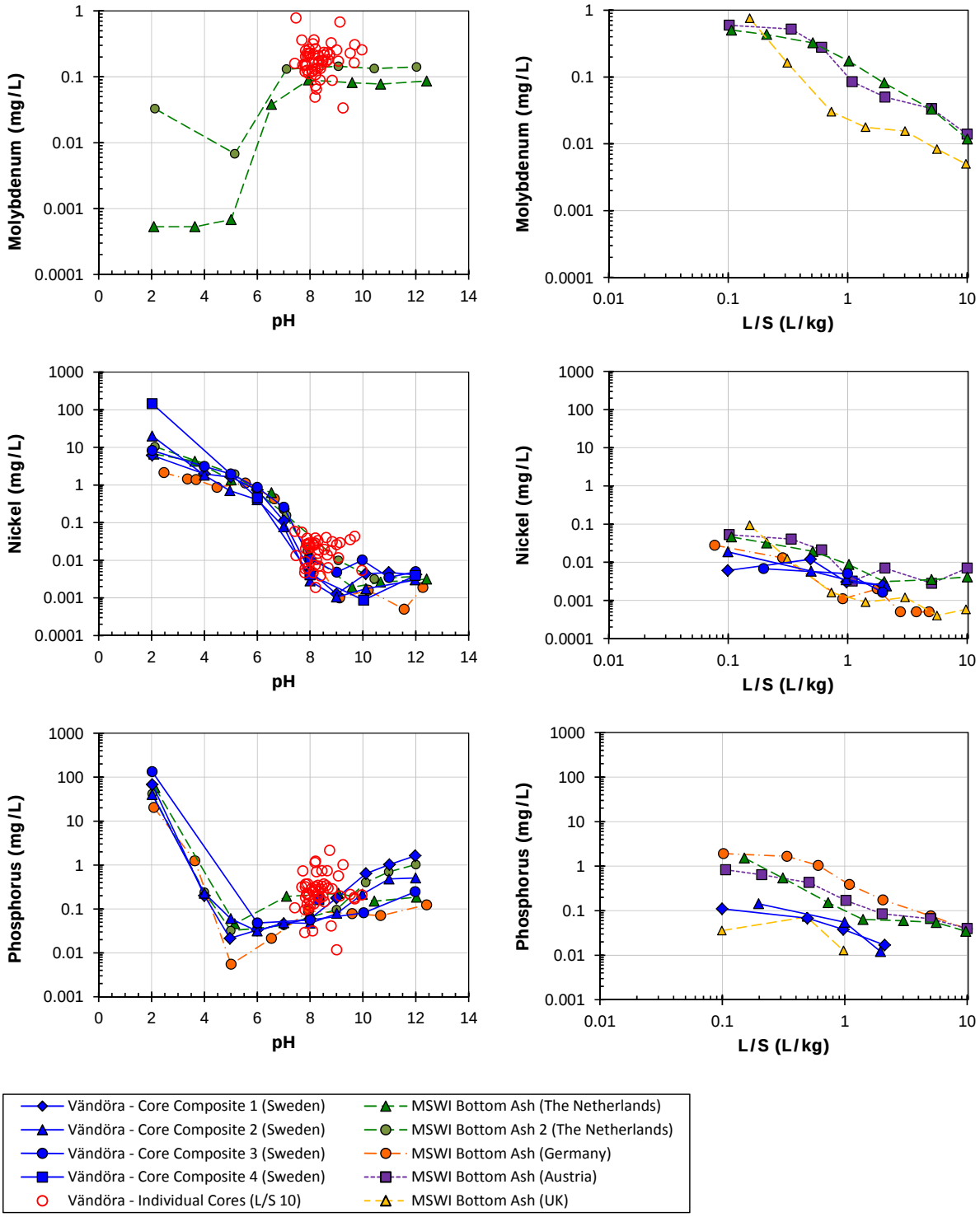

Figure E-8. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

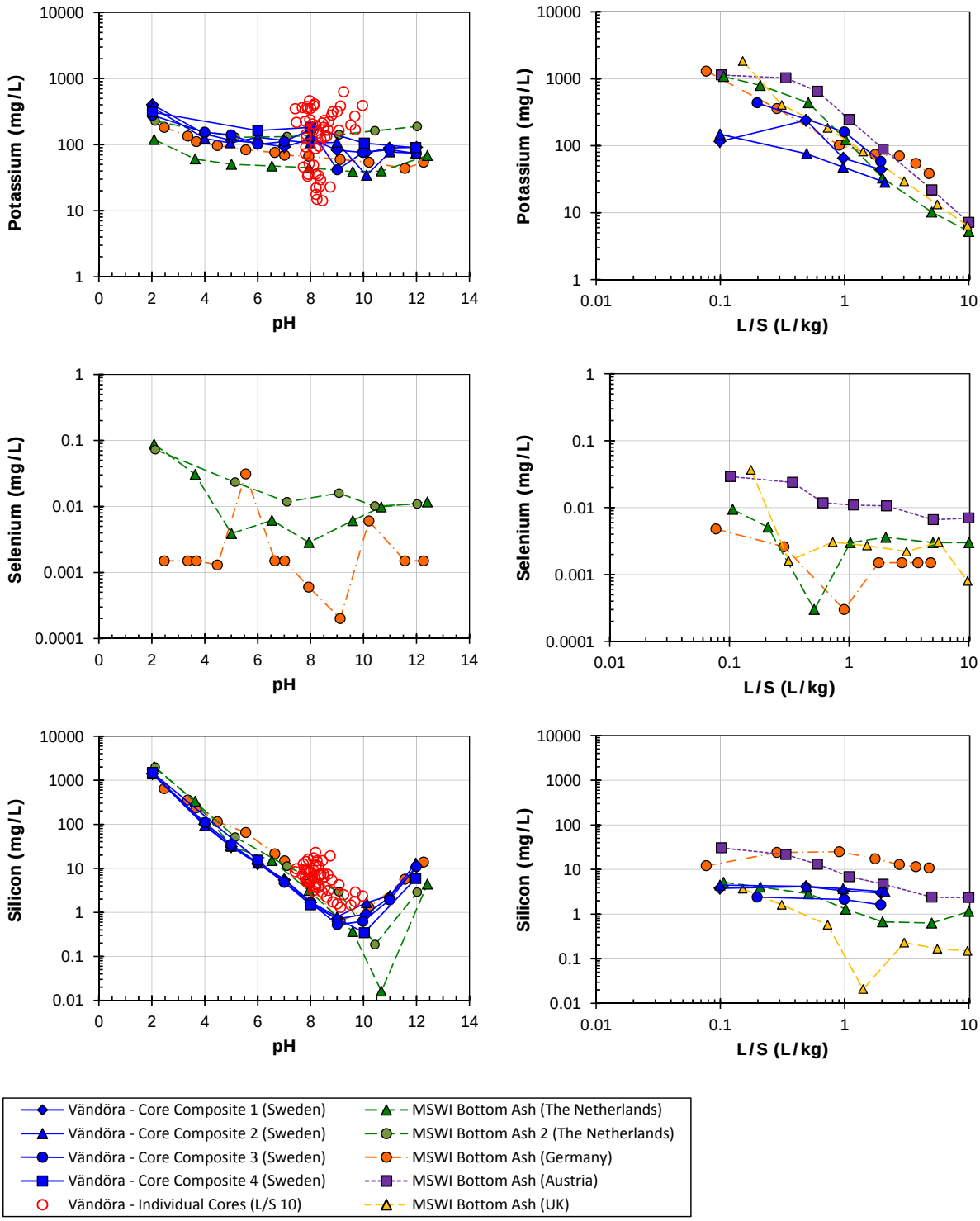

Figure E-9. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

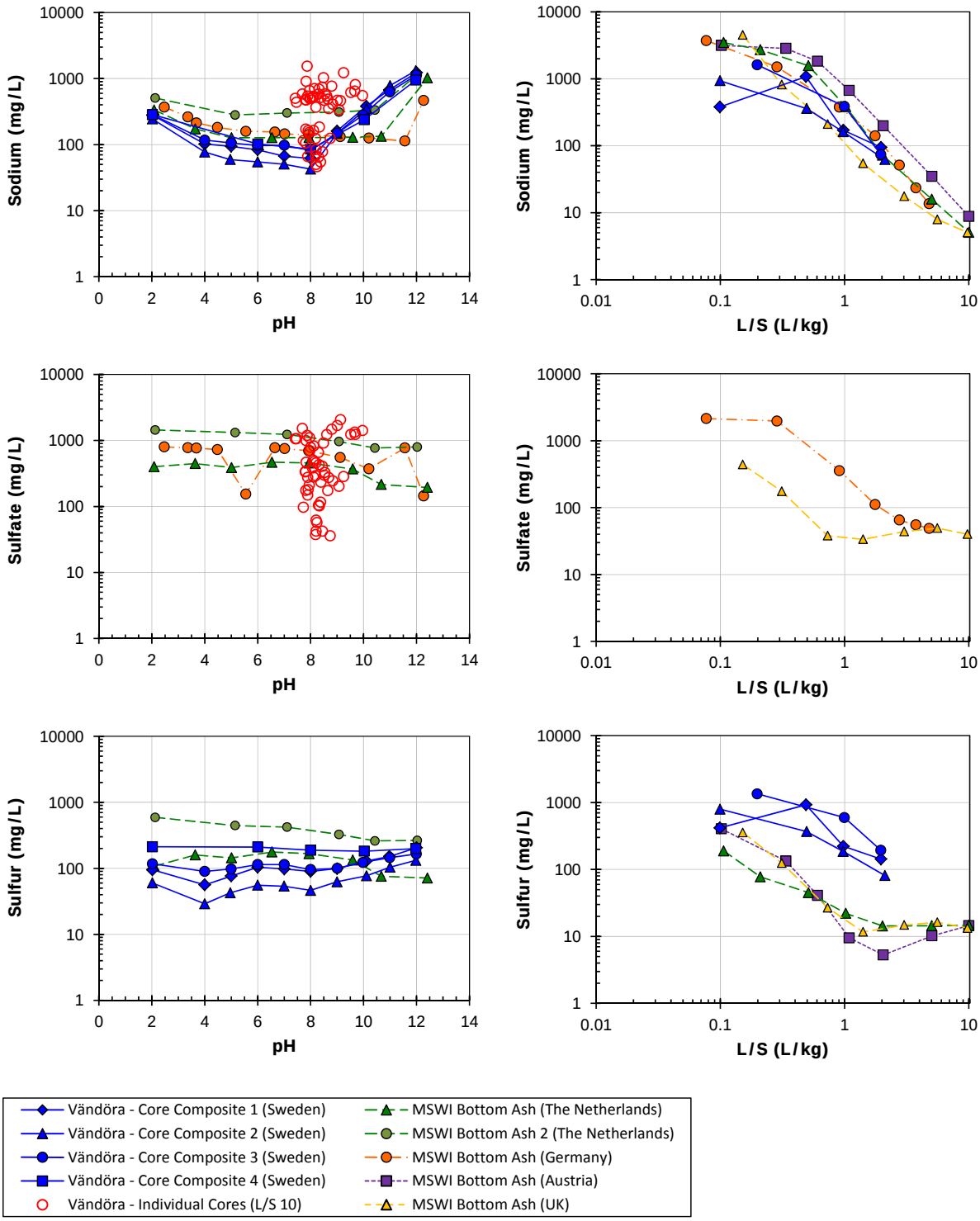

Figure E-10. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

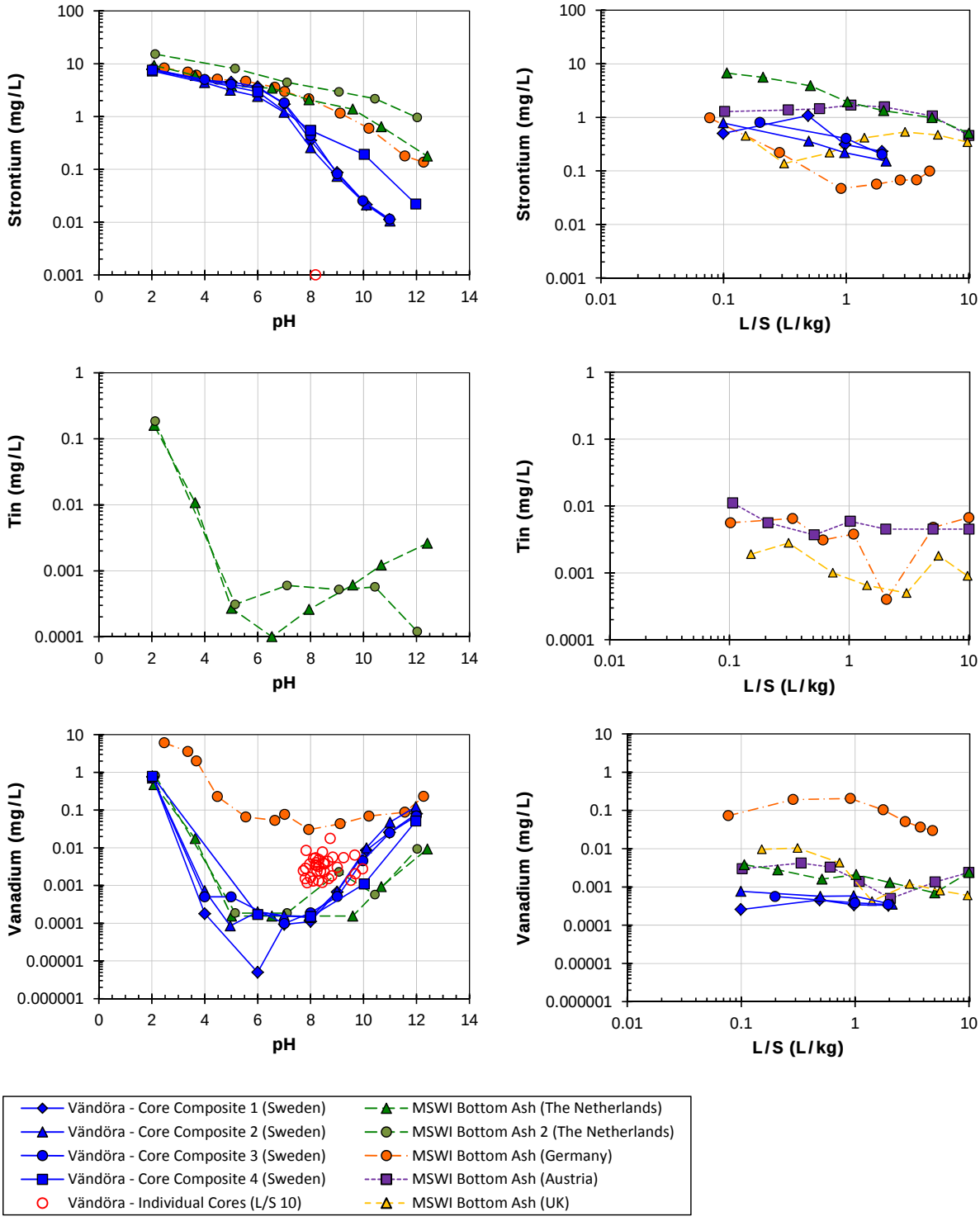

Figure E-11. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

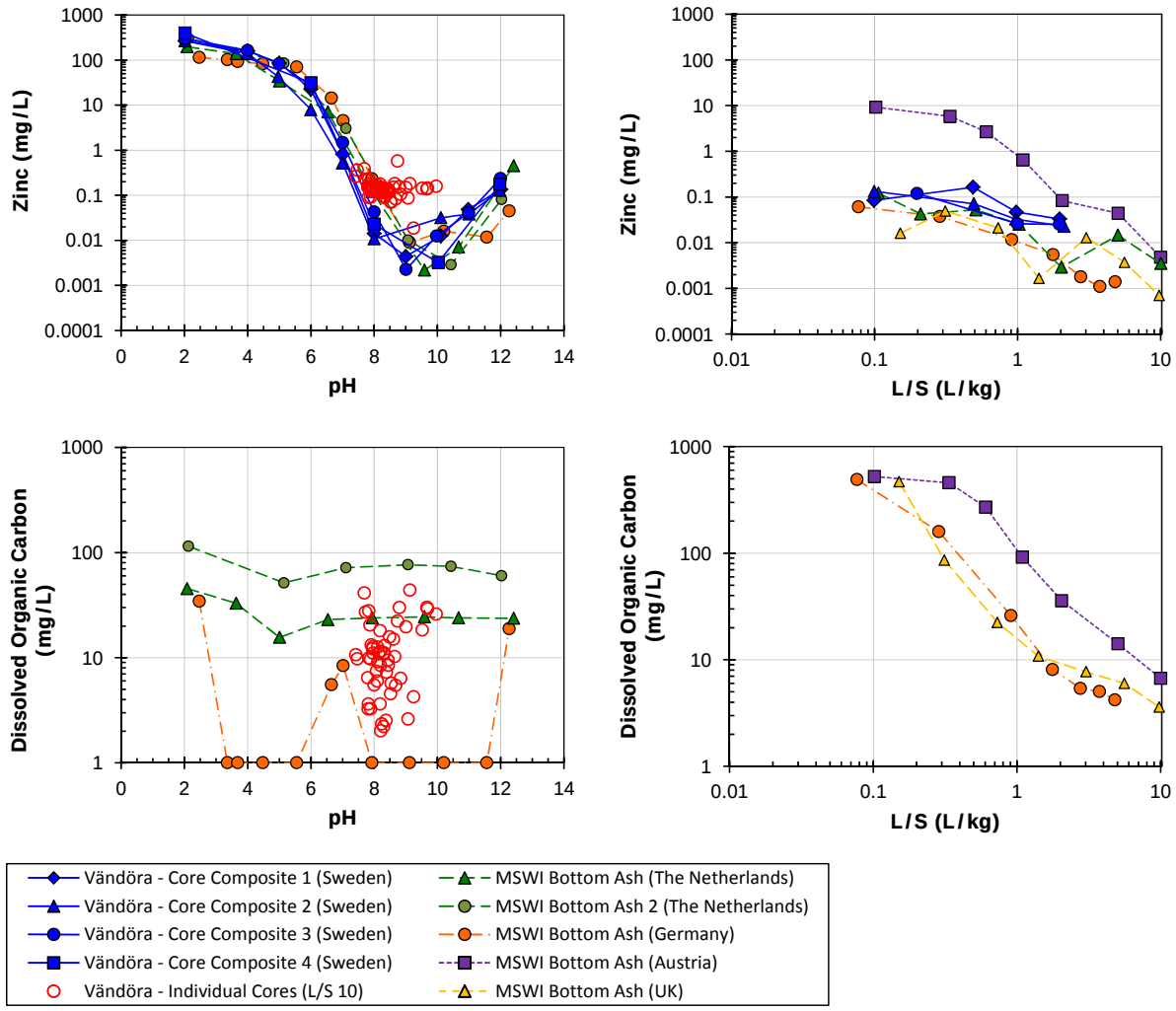

Figure E-12. Comparison of laboratory and field concentration results for MSWI bottom ash used in roadbase (Sweden).

APPENDIX F. INORGANIC INDUSTRIAL WASTE LANDFILL (THE NETHERLANDS)

Table F-1. Data Sources for Laboratory-to-Field Comparisons for Inorganic Waste Landfill.

Legend ID	Source	Material Type	Data Type	Citation
Inorganic Waste Mix	Nauerna Landfill, the Netherlands	Mixed Waste (predominantly inorganic – input to landfill)	pH-dependence (CEN/TS 14429) Percolation (CEN/TS 14405)	van der Sloot et al., 2003 van Zomeren and van der Sloot, 2006b
NAU-Lysimeter 13AA	Nauerna Landfill, the Netherlands	Leachate	-	van der Sloot et al., 2003 van Zomeren and van der Sloot, 2006b
NAU-Lysimeter 1	Nauerna Landfill, the Netherlands	Leachate	-	van der Sloot et al., 2003 van Zomeren and van der Sloot, 2006b

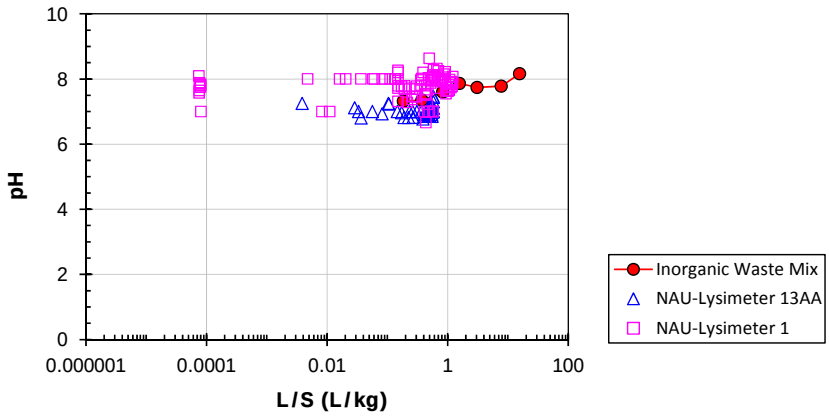

Figure F-1. Comparison of laboratory and field pH results for an inorganic industrial waste landfill (The Netherlands).

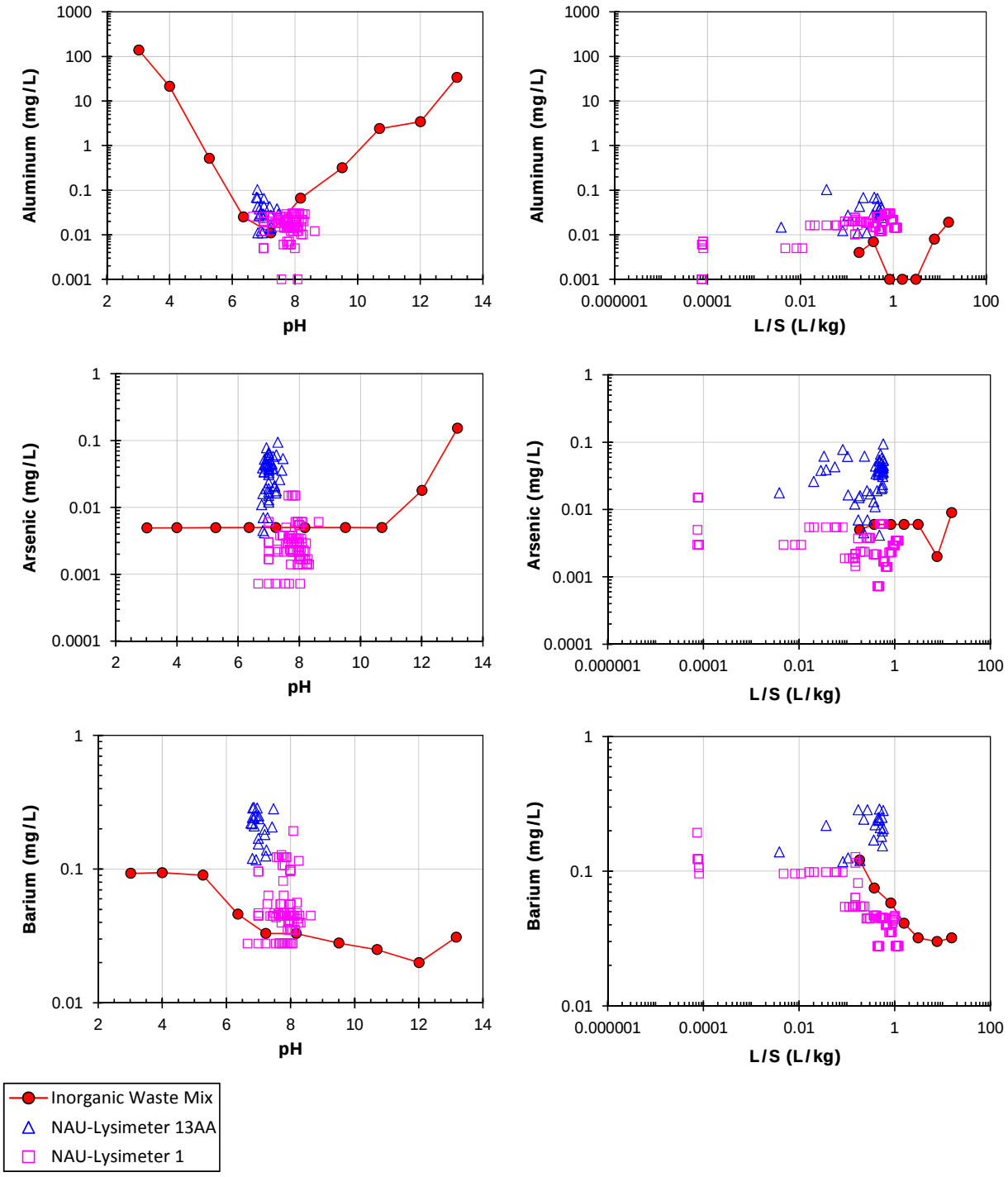

Figure F-2. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

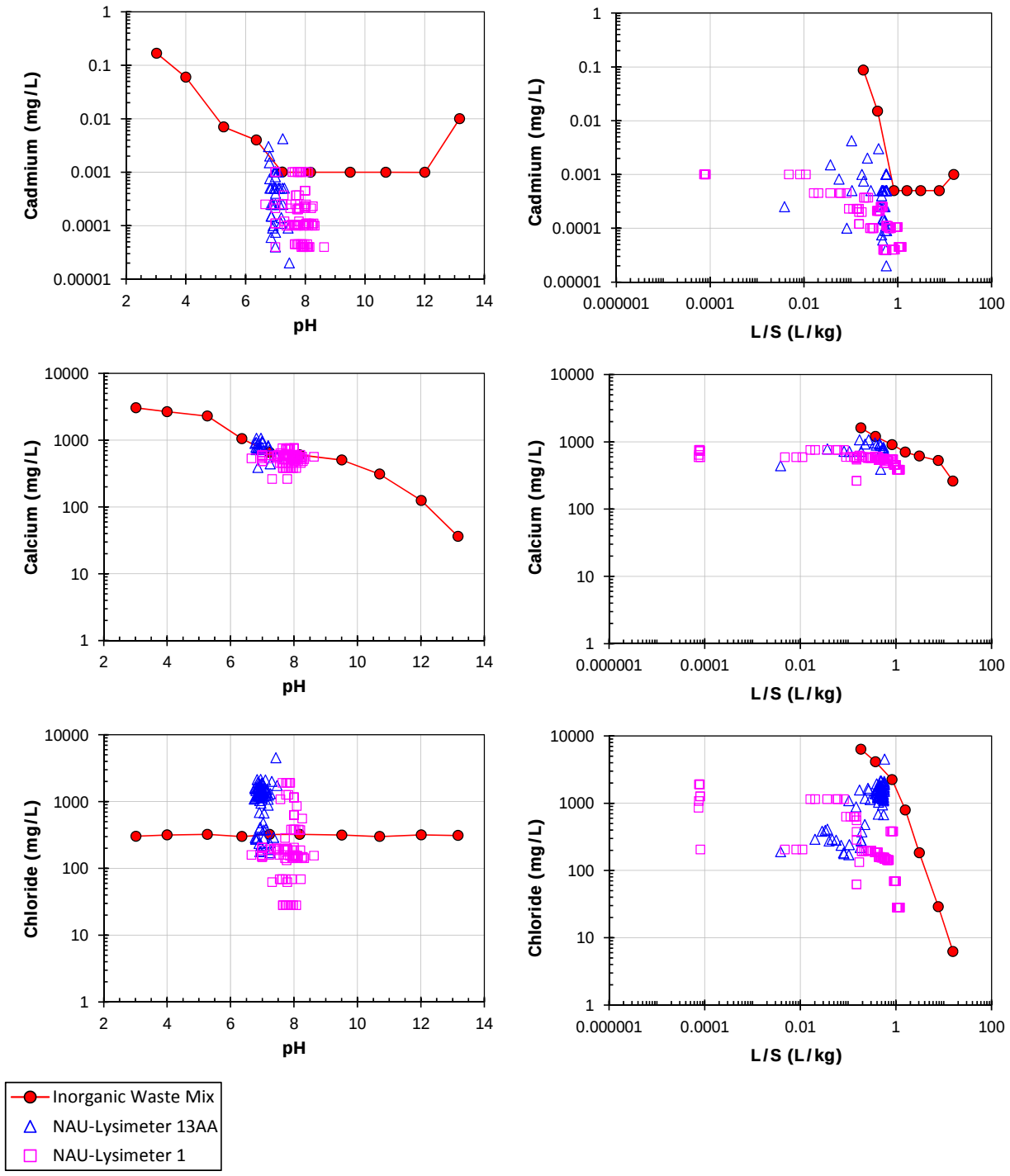

Figure F-3. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

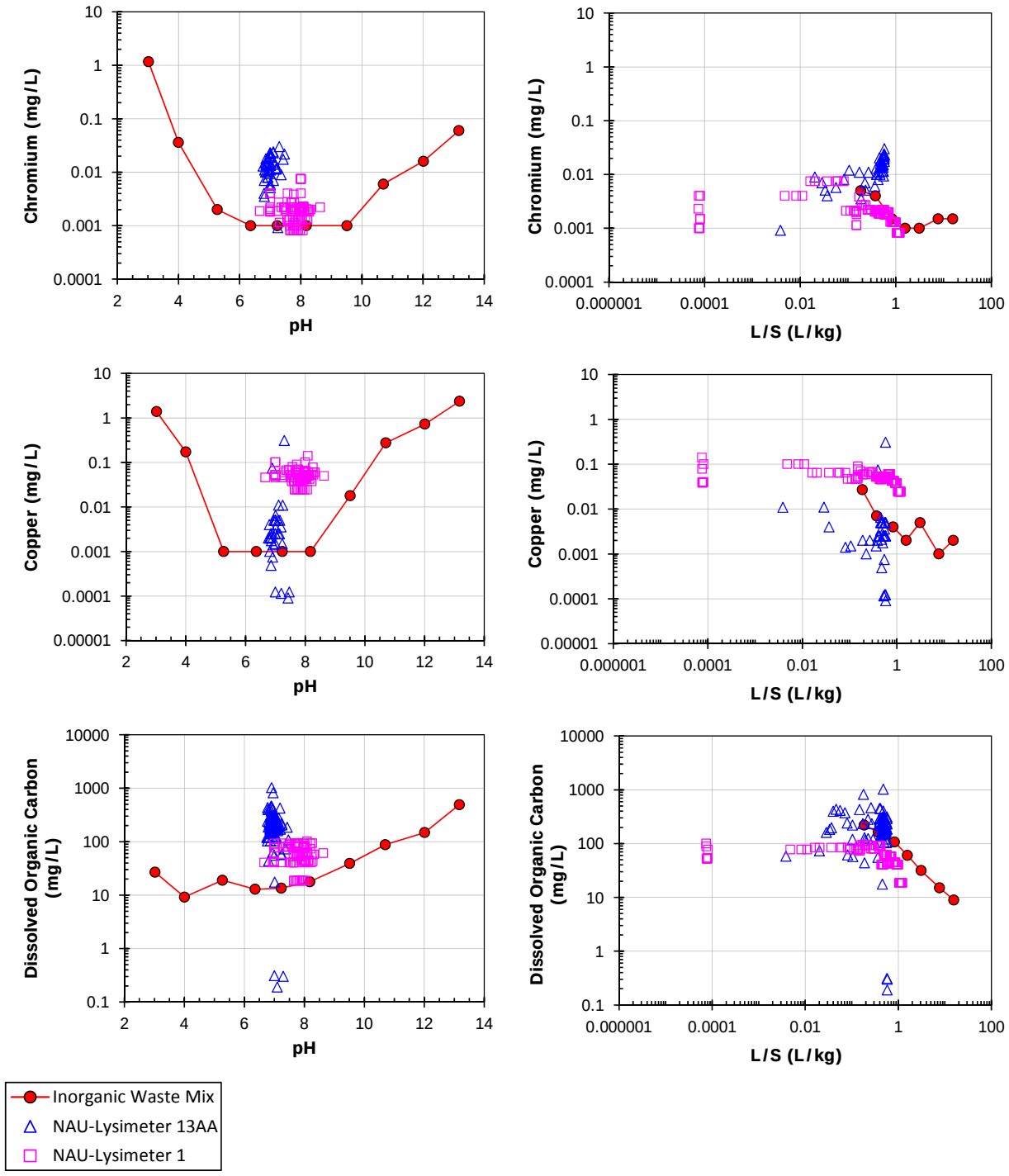

Figure F-4. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

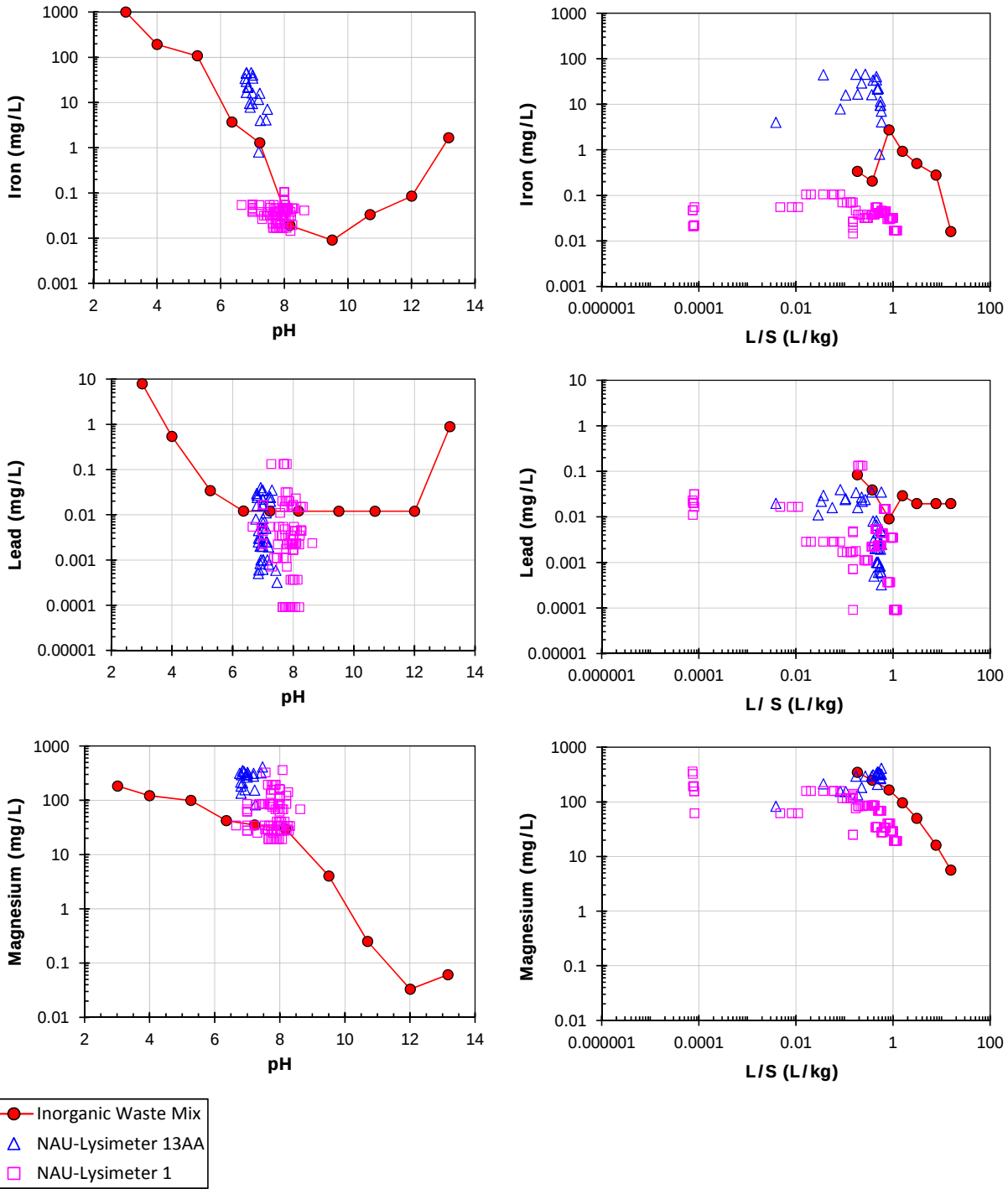

Figure F-5. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

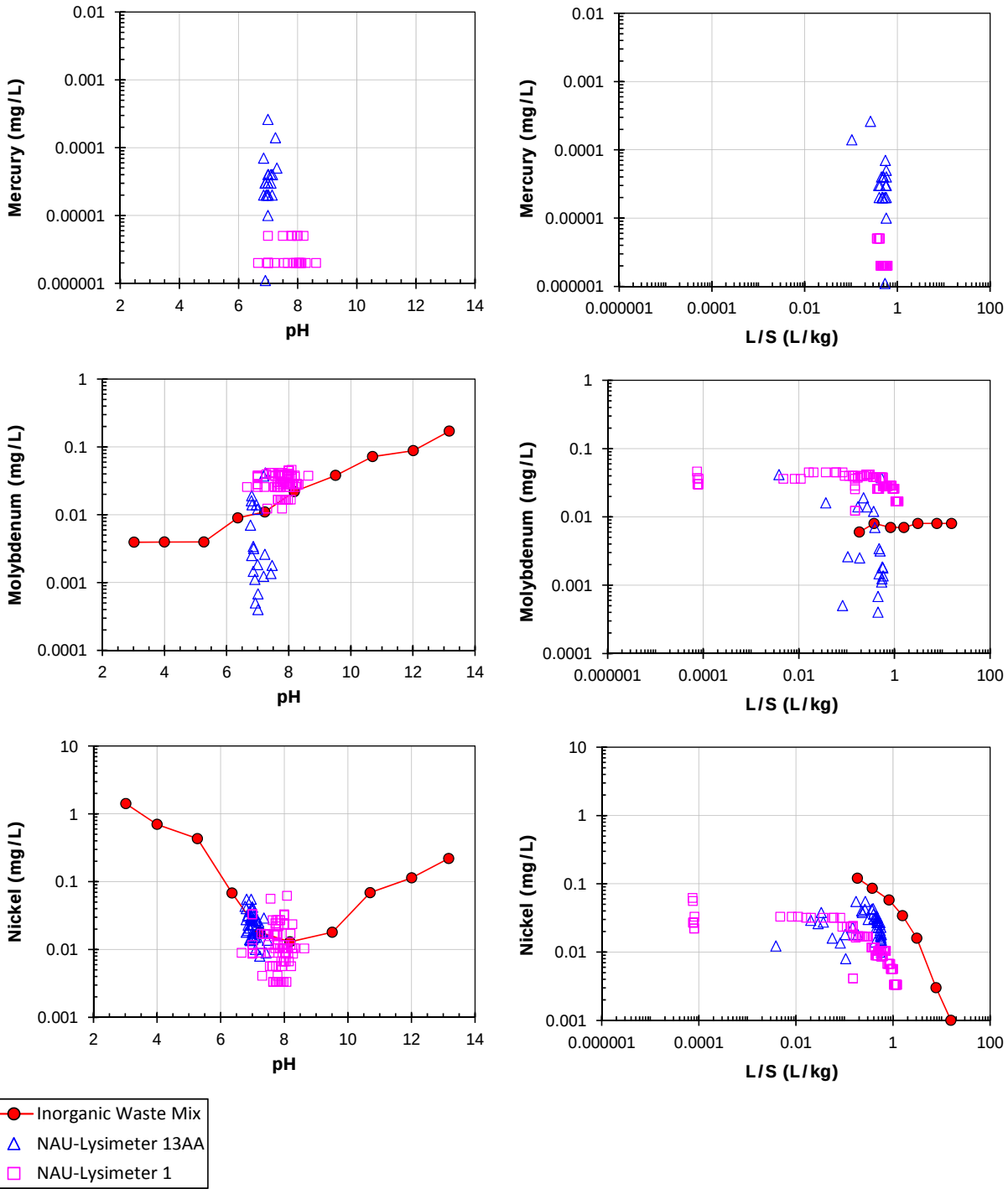

Figure F-6. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

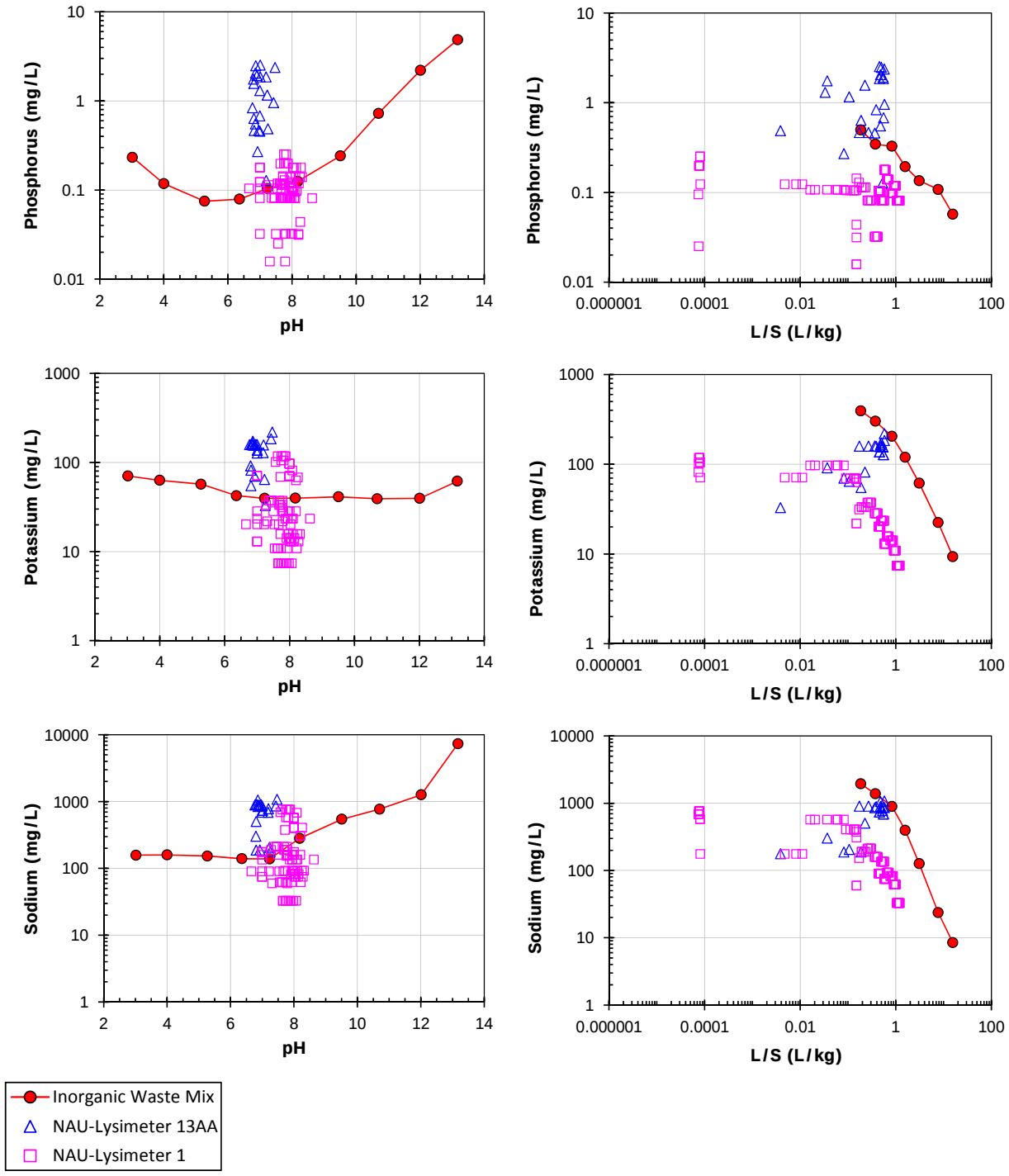

Figure F-7. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

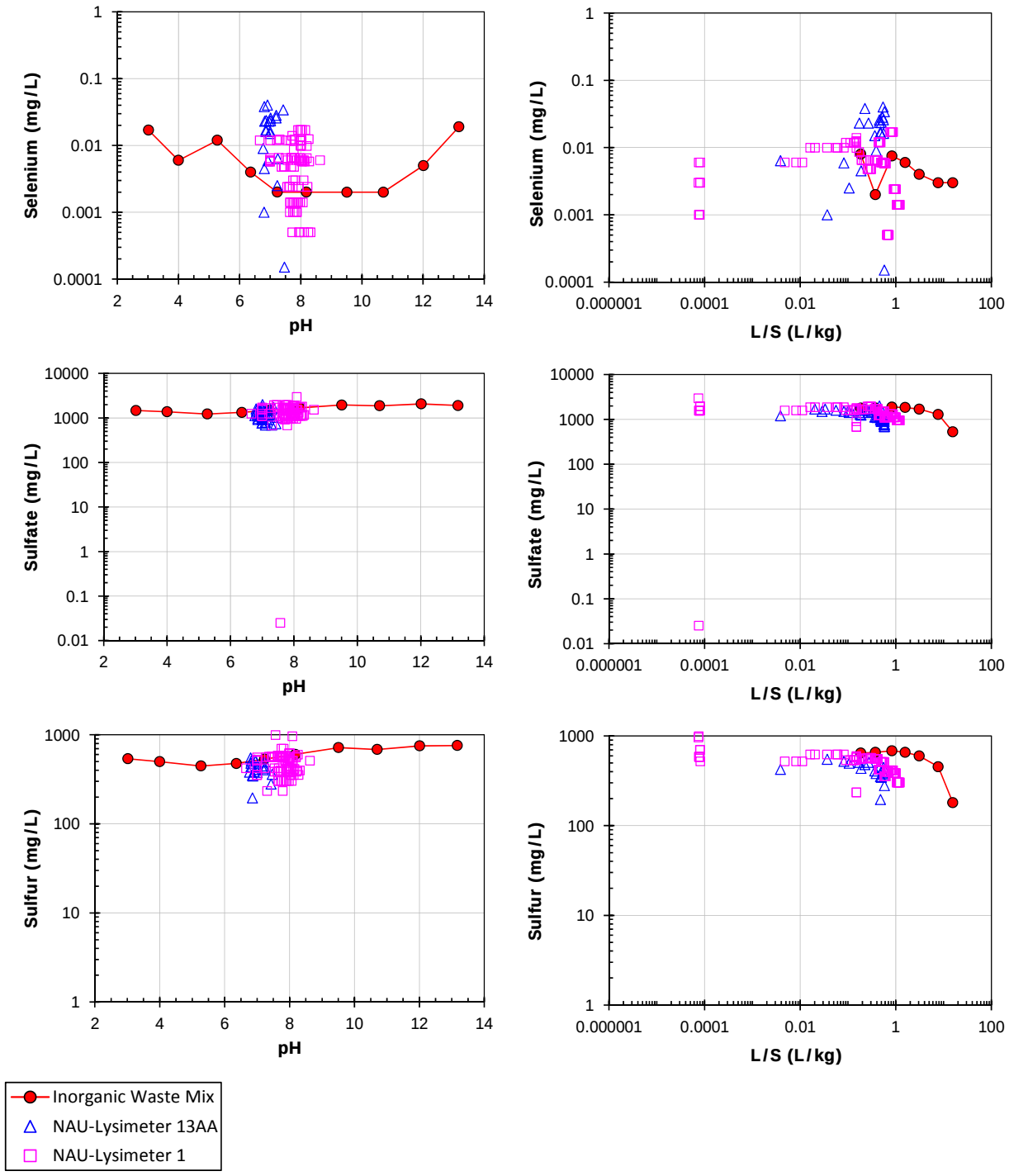

Figure F-8. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

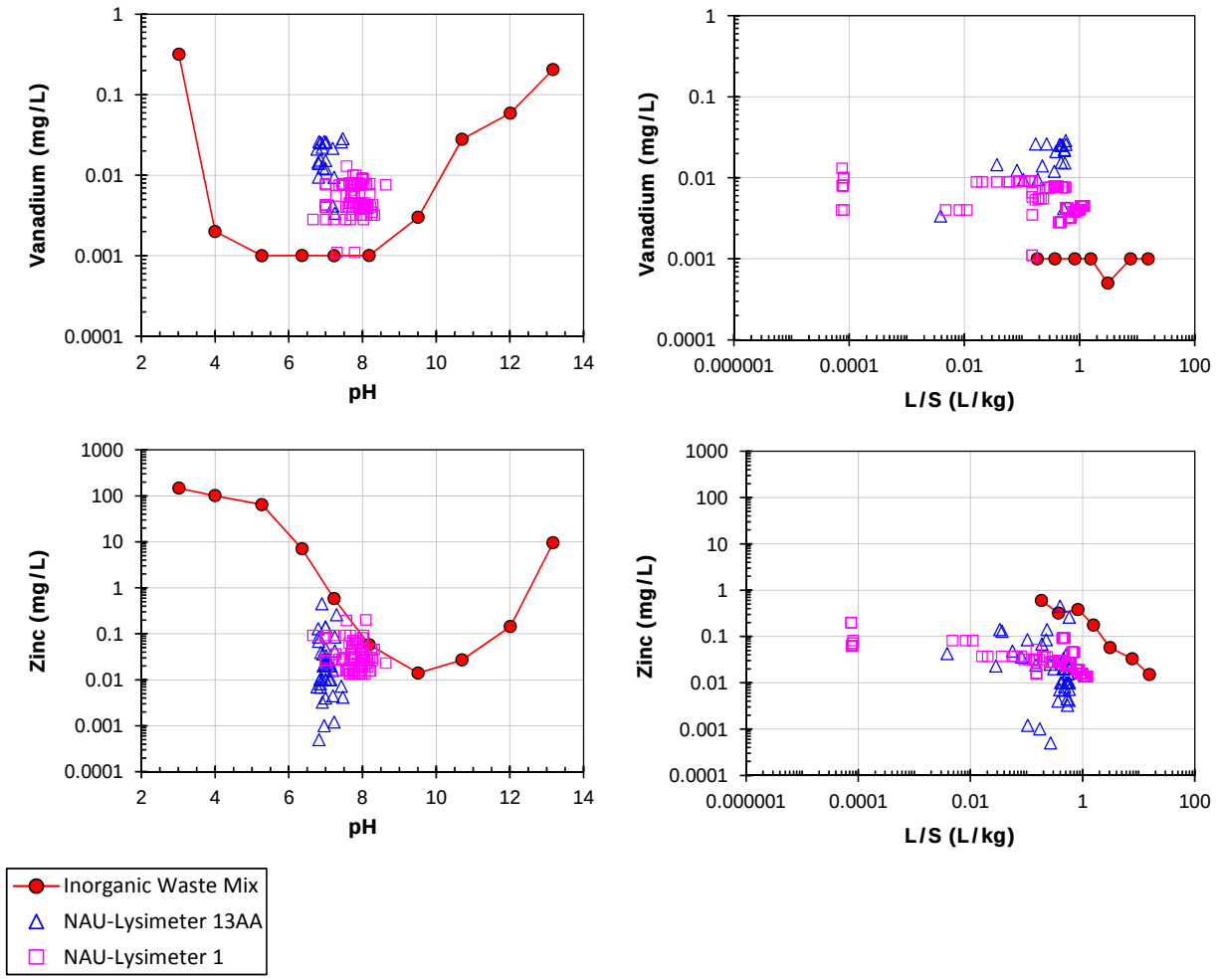

Figure F-9. Comparison of laboratory and field concentration results for an inorganic industrial waste landfill (The Netherlands).

APPENDIX G. MUNICIPAL SOLID WASTE LANDFILL (THE NETHERLANDS)

Table G-1. Data Sources for Laboratory-to-Field Comparisons for MSW Landfill

Legend ID	Source	Material Type	Data Type	Citation
MSW Organic Waste (initial)	Landgraaf, The Netherlands	Mixture of MSW organic waste	pH-dependence (CEN/TS 14429) Percolation (CEN/TS 14405)	Luning et al., 2006 van der Sloot et al., 2008a
MSW Landfill – Core Composite (8 yr)	Pilot-scale landfill, Landgraaf, The Netherlands	Composite of landfill cores after 8 years in landfill	pH-dependence (CEN/TS 14429) Percolation (CEN/TS 14405)	Luning et al., 2006 van der Sloot et al., 2008a
MSW Landfill – Individual Cores (L/S 10; 8 yr)	Pilot-scale landfill, Landgraaf, The Netherlands	Cored material after 8 years in landfill	Batch L/S (EN 12457-2)	Luning et al., 2006 van der Sloot et al., 2008a
MSW Landfill – Leachate (recirculation)	Pilot-scale landfill, Landgraaf, The Netherlands	Landfill Leachate	-	Luning et al., 2006 van der Sloot et al., 2008a

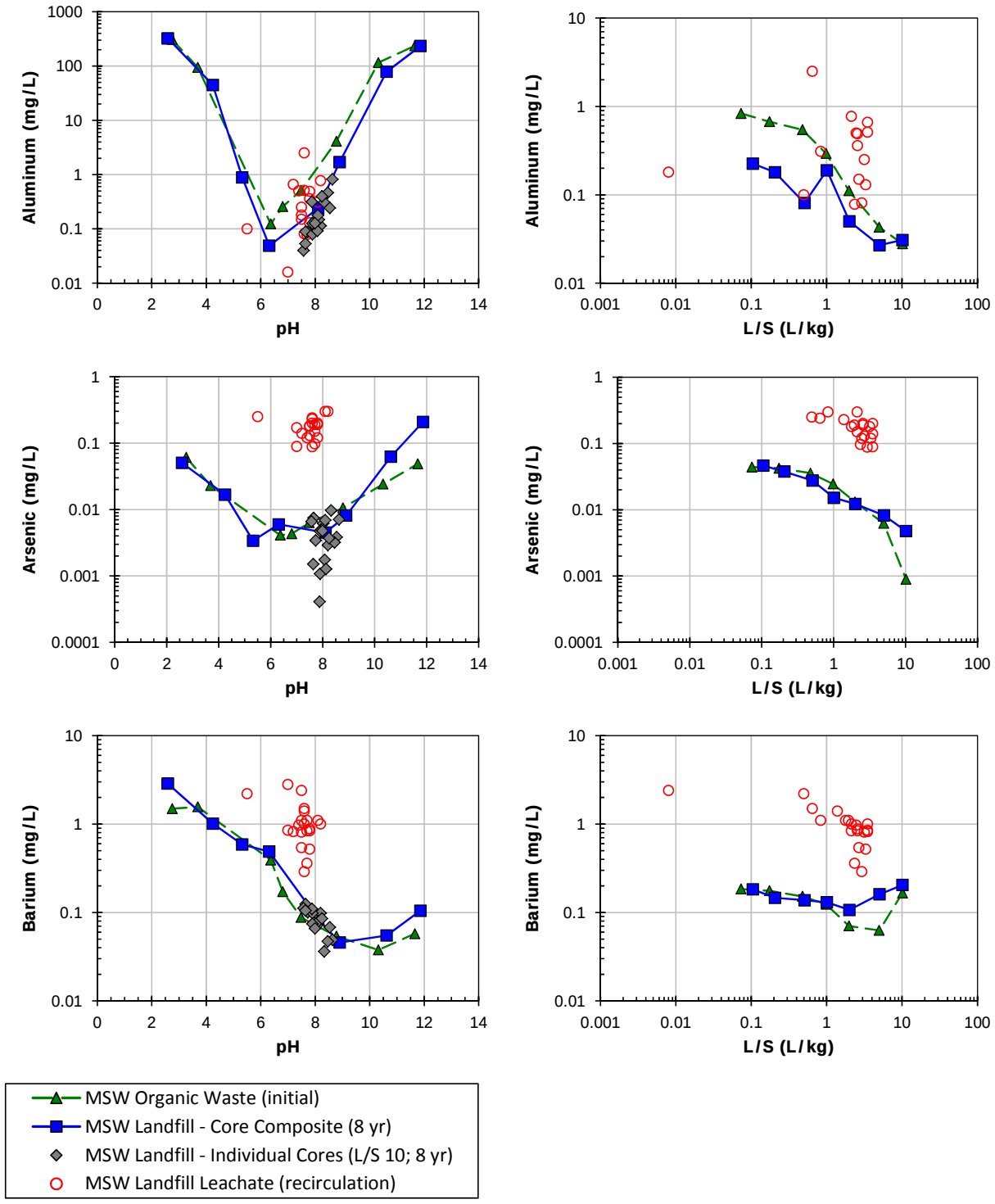

Figure G-1. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

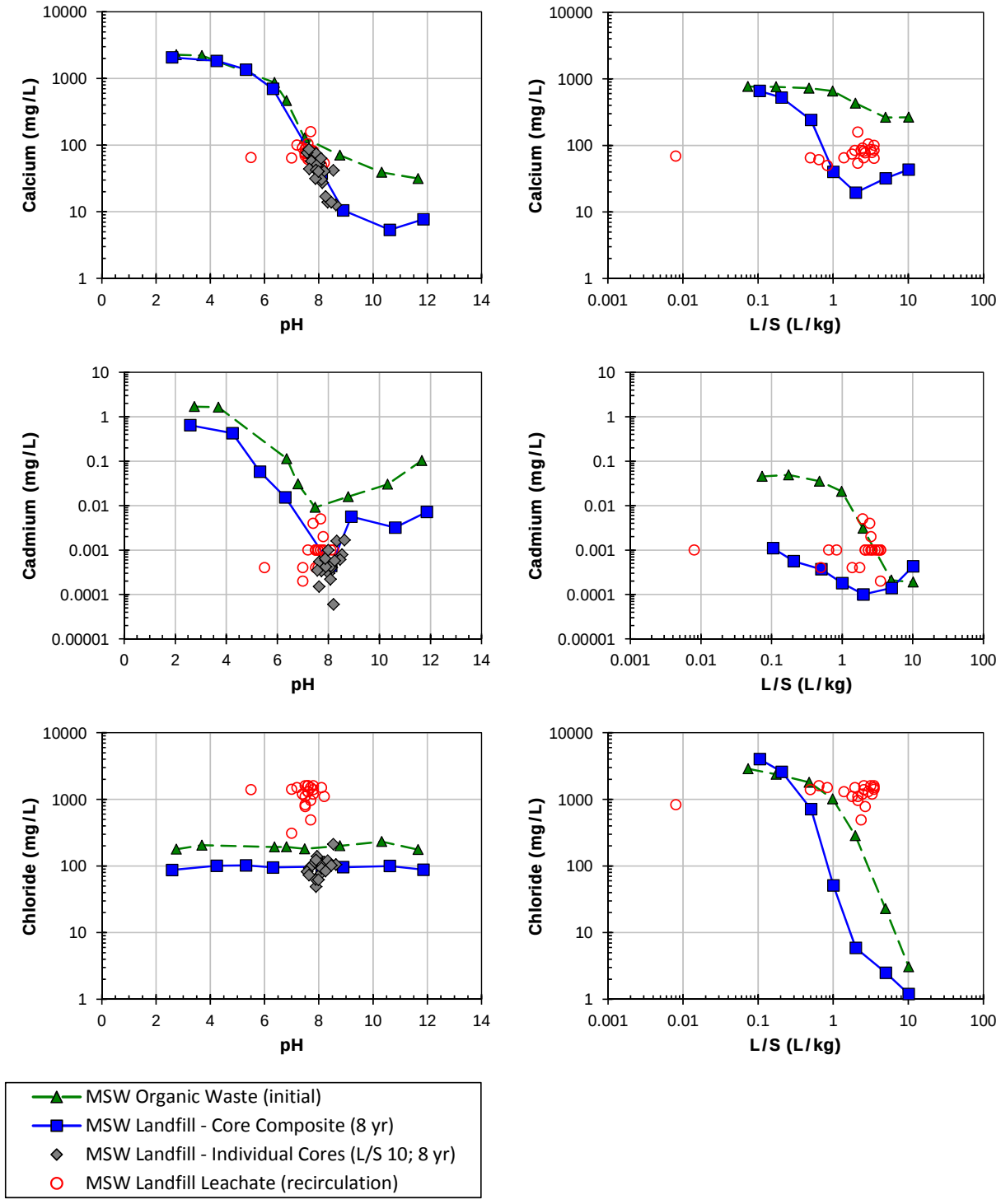

Figure G-2. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

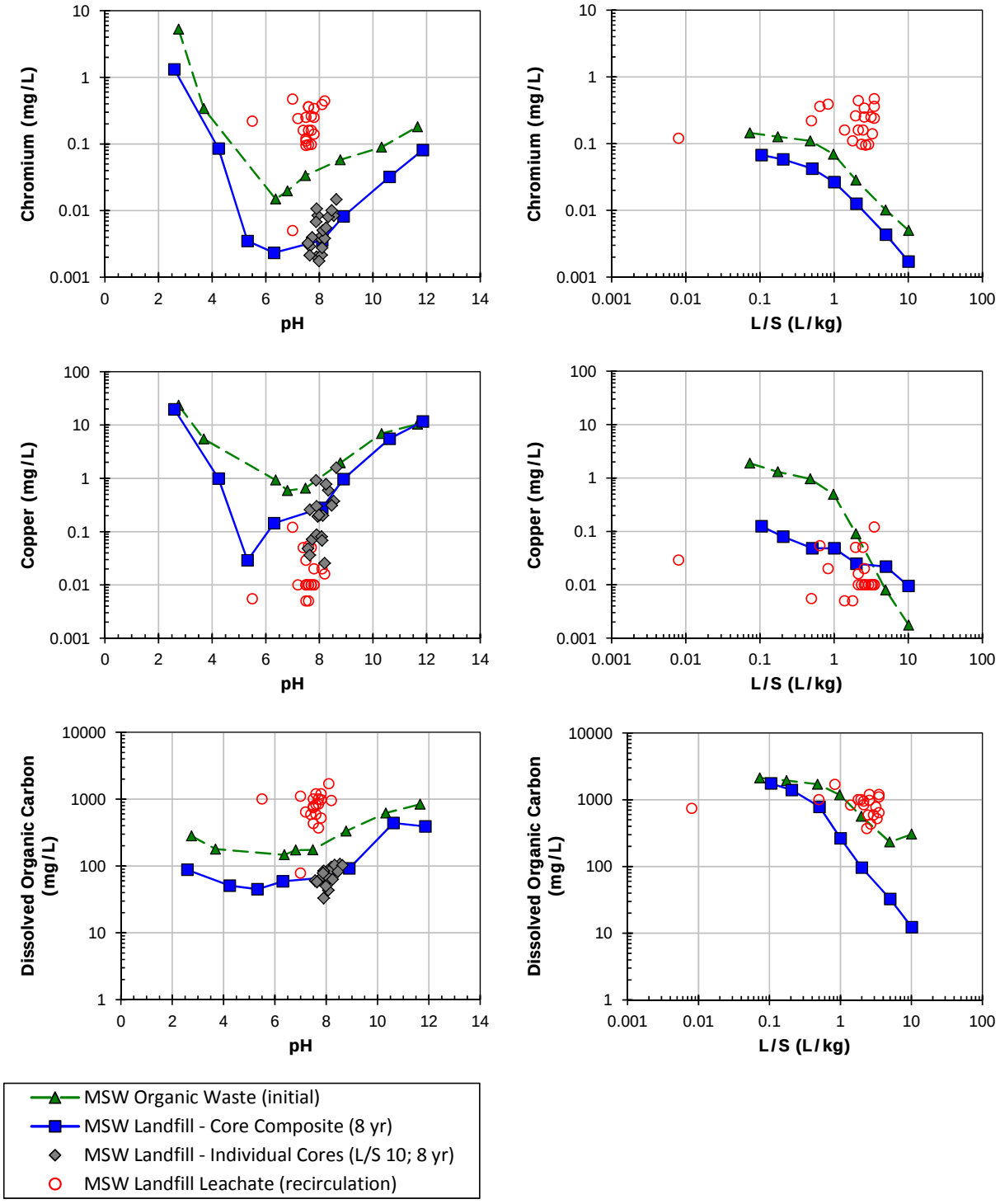

Figure G-3. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

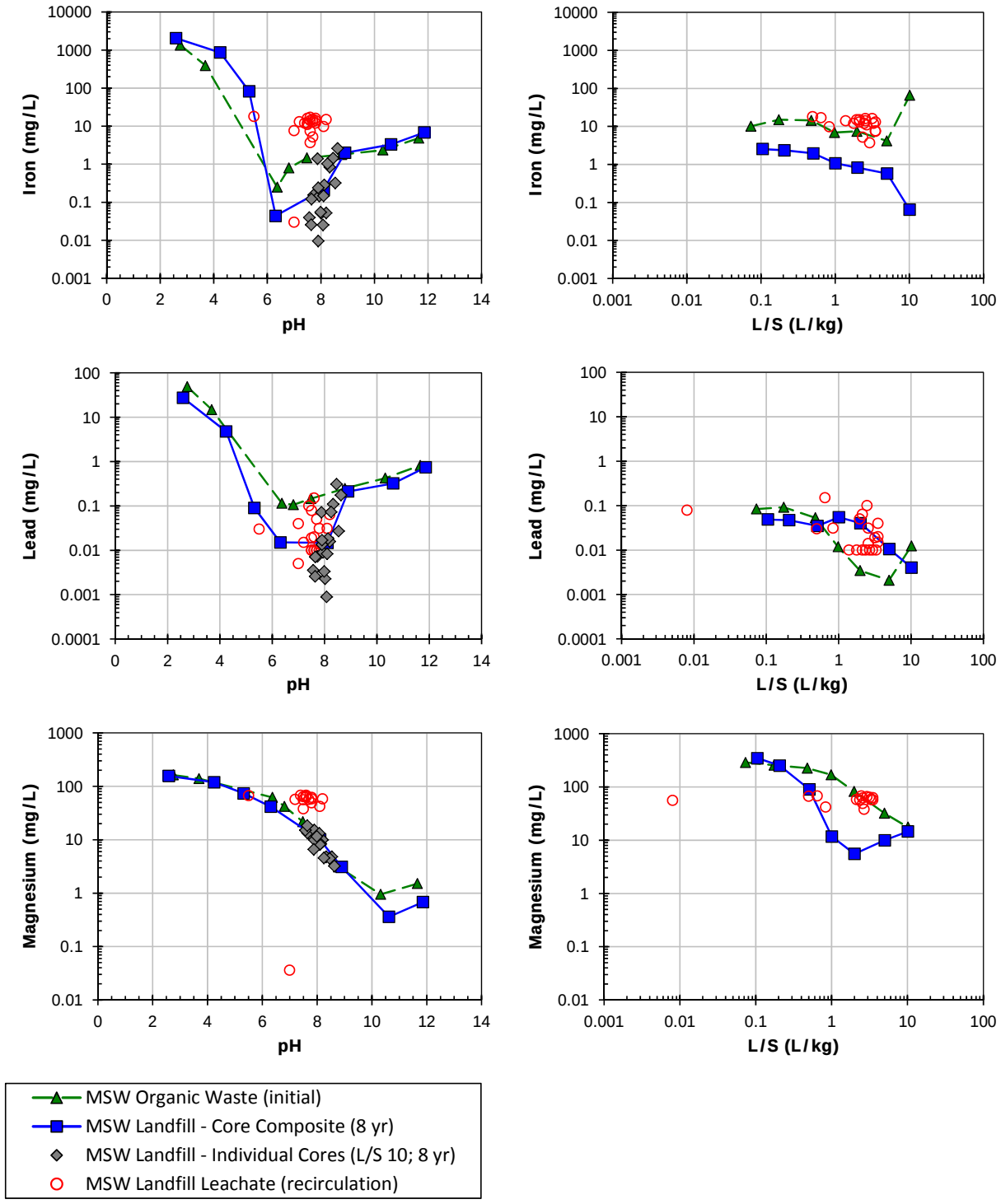

Figure G-4. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

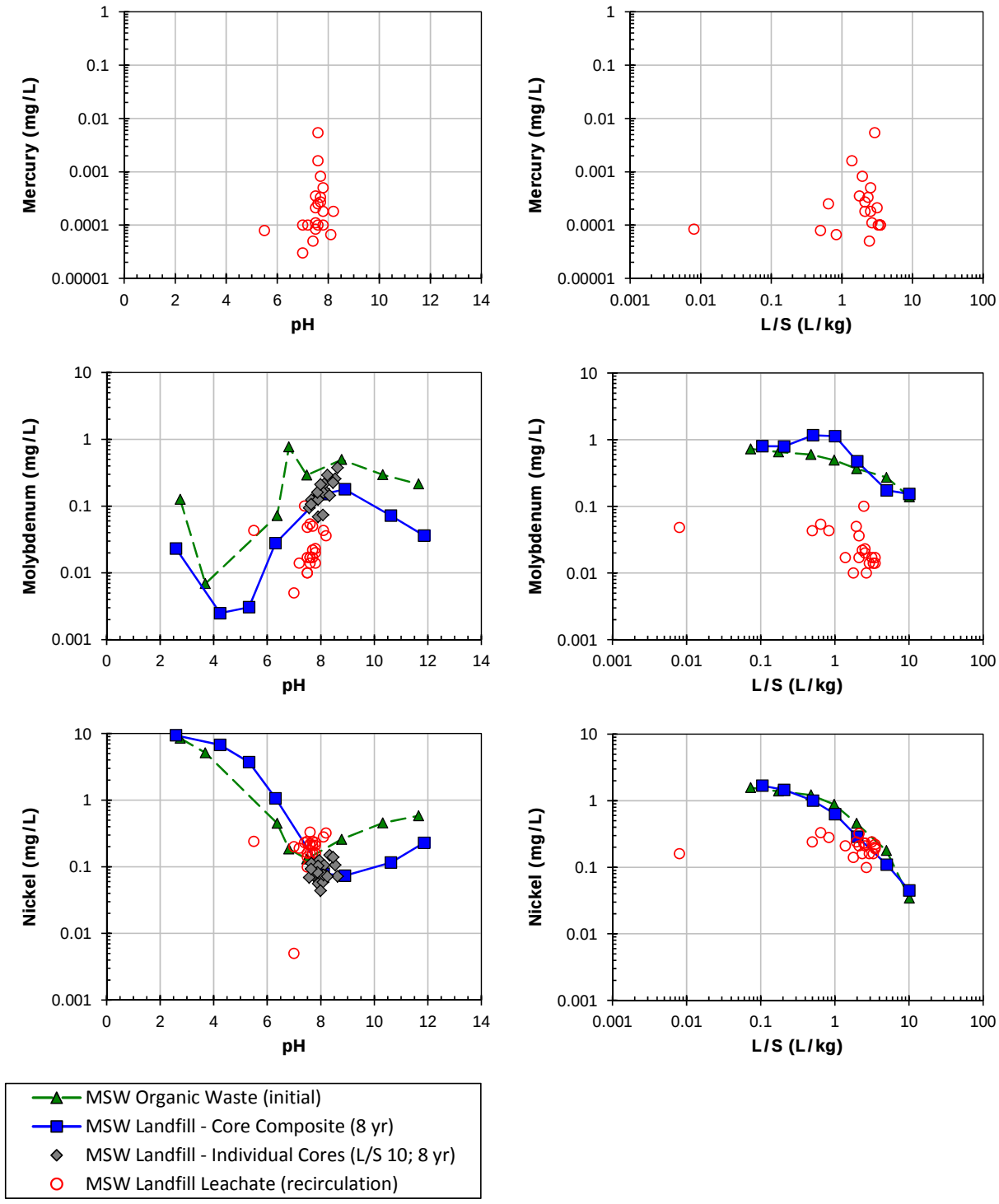

Figure G-5. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

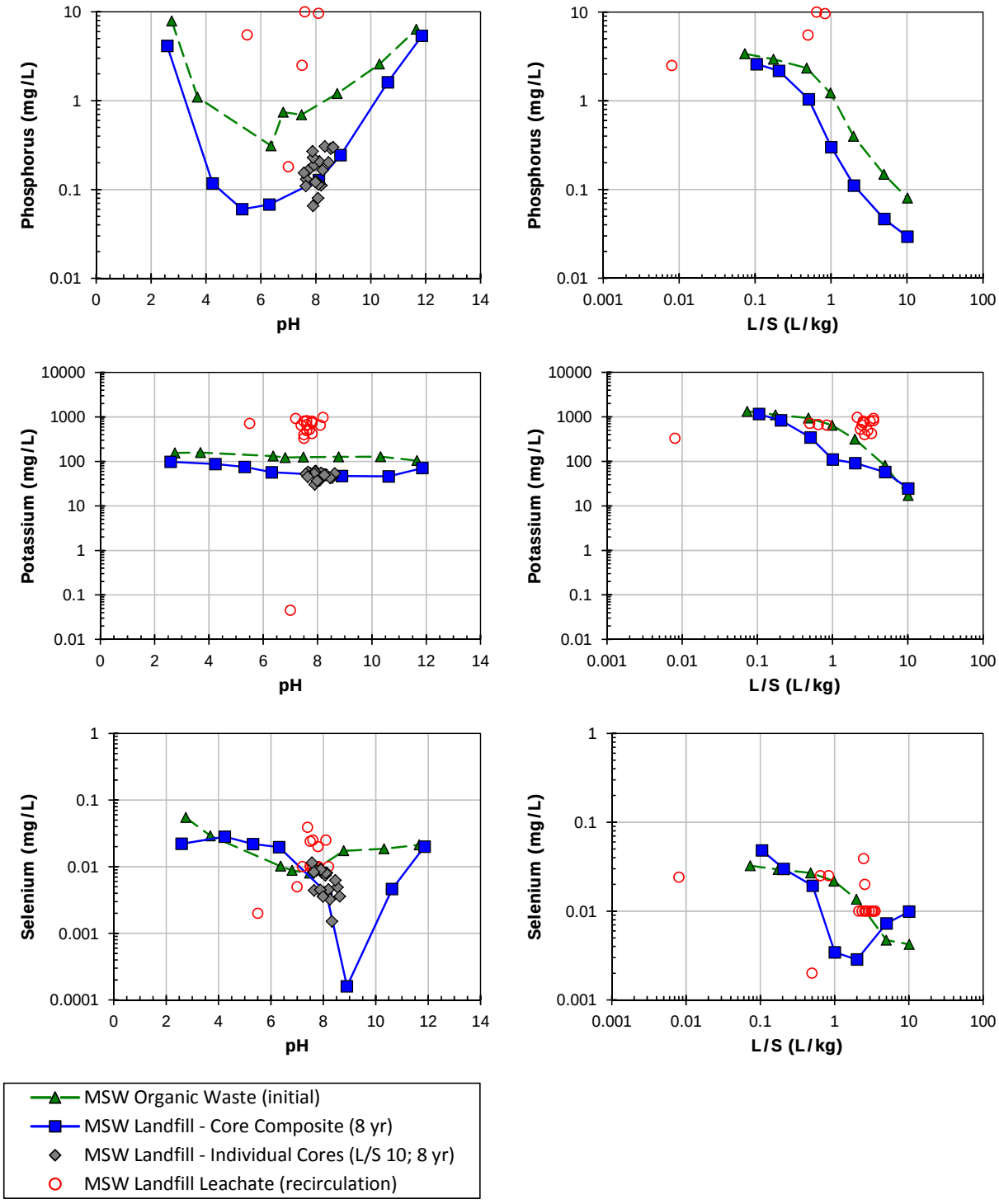

Figure G-6. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

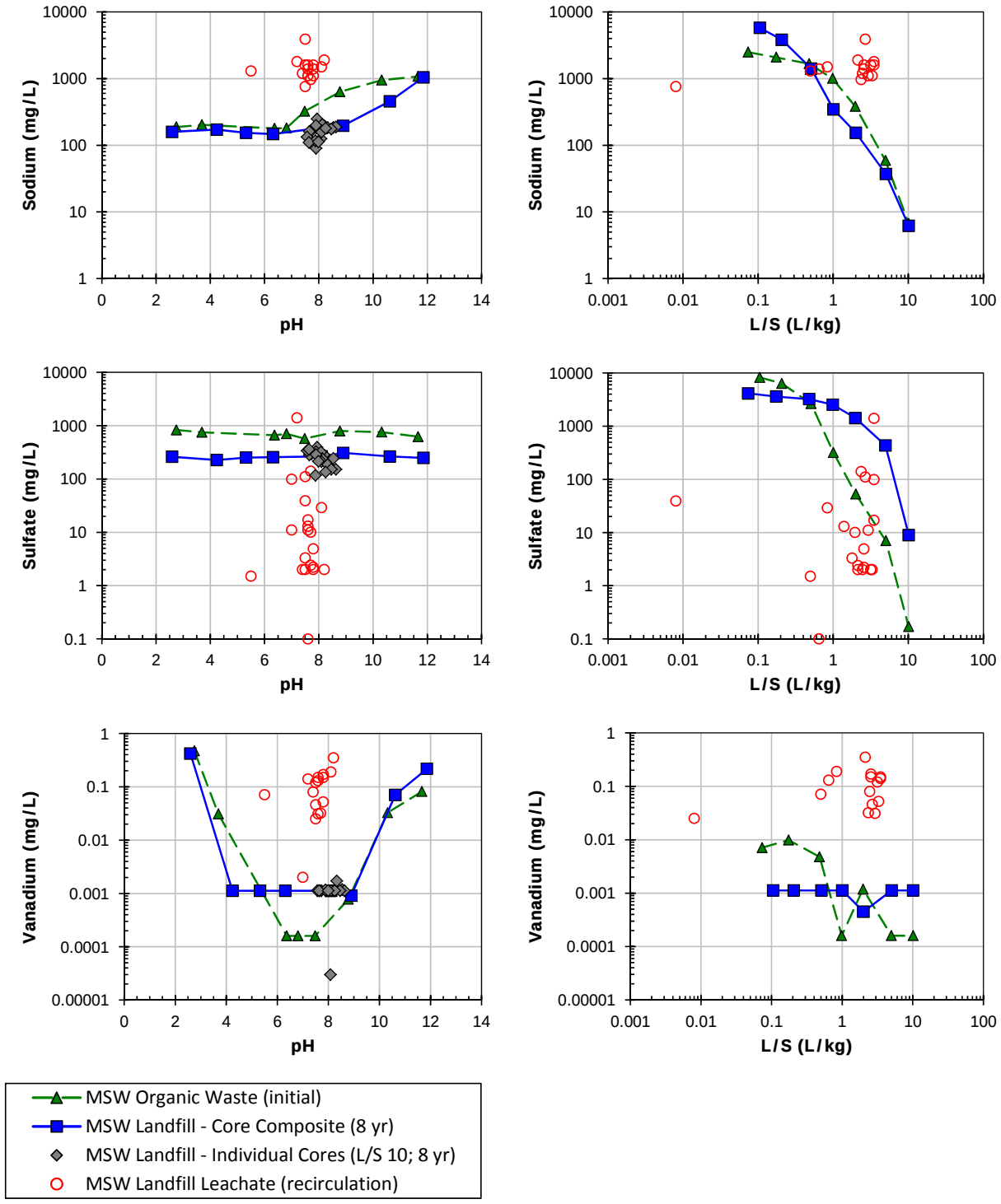

Figure G-7. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

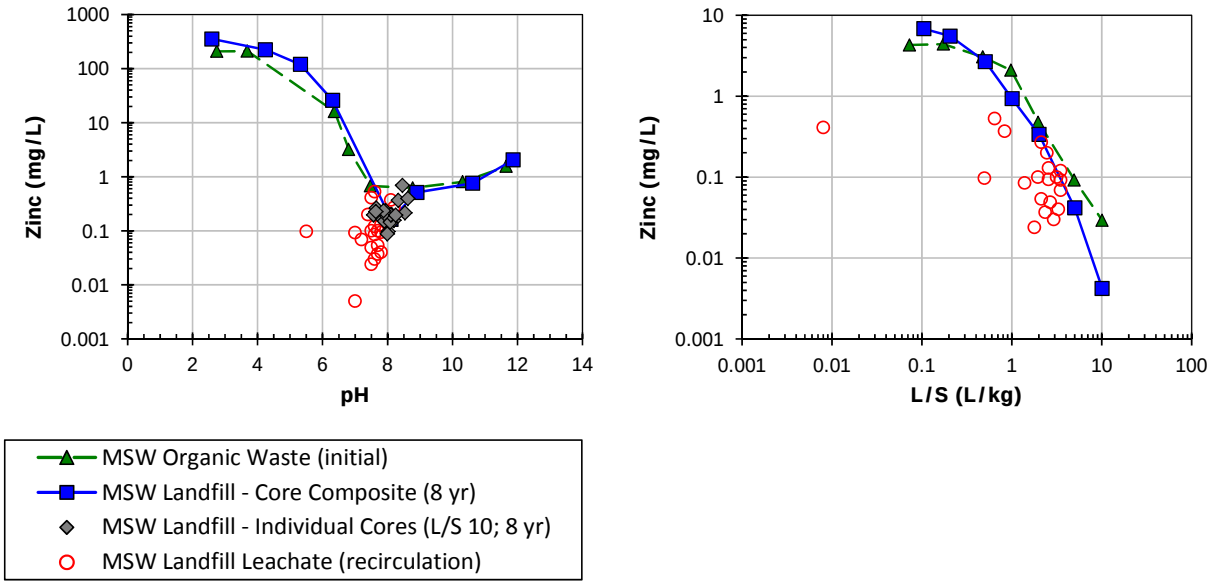

Figure G-8. Comparison of laboratory and field concentration results for a municipal solid waste landfill (The Netherlands).

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APPENDIX H. STABILIZED MUNICIPAL SOLID WASTE INCINERATOR FLY ASH DISPOSAL (THE NETHERLANDS)

Table H-1. Data Sources for Laboratory-to-Field Comparisons for Stabilized Waste (The Netherlands).

Legend ID	Source	Material Type	Data Type	Citation
Fresh Stabilized Waste		S/S MSWI FA	pH-dependence (CEN/TS 14429) Percolation (CEN/TS 14405)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Monofill – Individual Cores (10 yr)	Full-scale monofill,	Individual cores at depth > 12 m	Batch L/S (EN 12457-2) Percolation (CEN/TS 14405)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Monofill Leachate	Full-scale monofill,	Field Leachate (bottom of drain)	-	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell B – Core Composite (4 yr)	Pilot Cell B (MSWI FA, 5x8x2.4m)	Composite – top layer uncovered cell	pH-dependence (CEN/TS 14429)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell B – Individual Cores (L/S 10; 4 yr)	Pilot Cell B	Individual cores at depth	Batch L/S (EN 12457-2)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell B Leachate	Pilot Cell B	Field Leachate (bottom of drain)	-	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell C – Composite (covered; 4 yr)	Pilot Cell C (MSWI FA, 5x8x2.4m)	Composite – top layer covered cell	pH-dependence (CEN/TS 14429)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell C – Individual Cores (L/S 10; 4 yr)	Pilot Cell C	Individual cores at depth	Batch L/S (EN 12457-2)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell C Leachate	Pilot Cell C	Field Leachate (bottom of drain)	-	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell D – Individual Cores (4 yr)	Pilot Cell D (MSWI FA, 5x8x2.4m)	Composite – top layer uncovered cell	pH-dependence (CEN/TS 14429)	van Zomeren and van der Sloot, 2006b Keulen, 2010
Cell D Leachate	Pilot Cell D	Field Leachate (bottom of drain)	-	van Zomeren and van der Sloot, 2006b Keulen, 2010

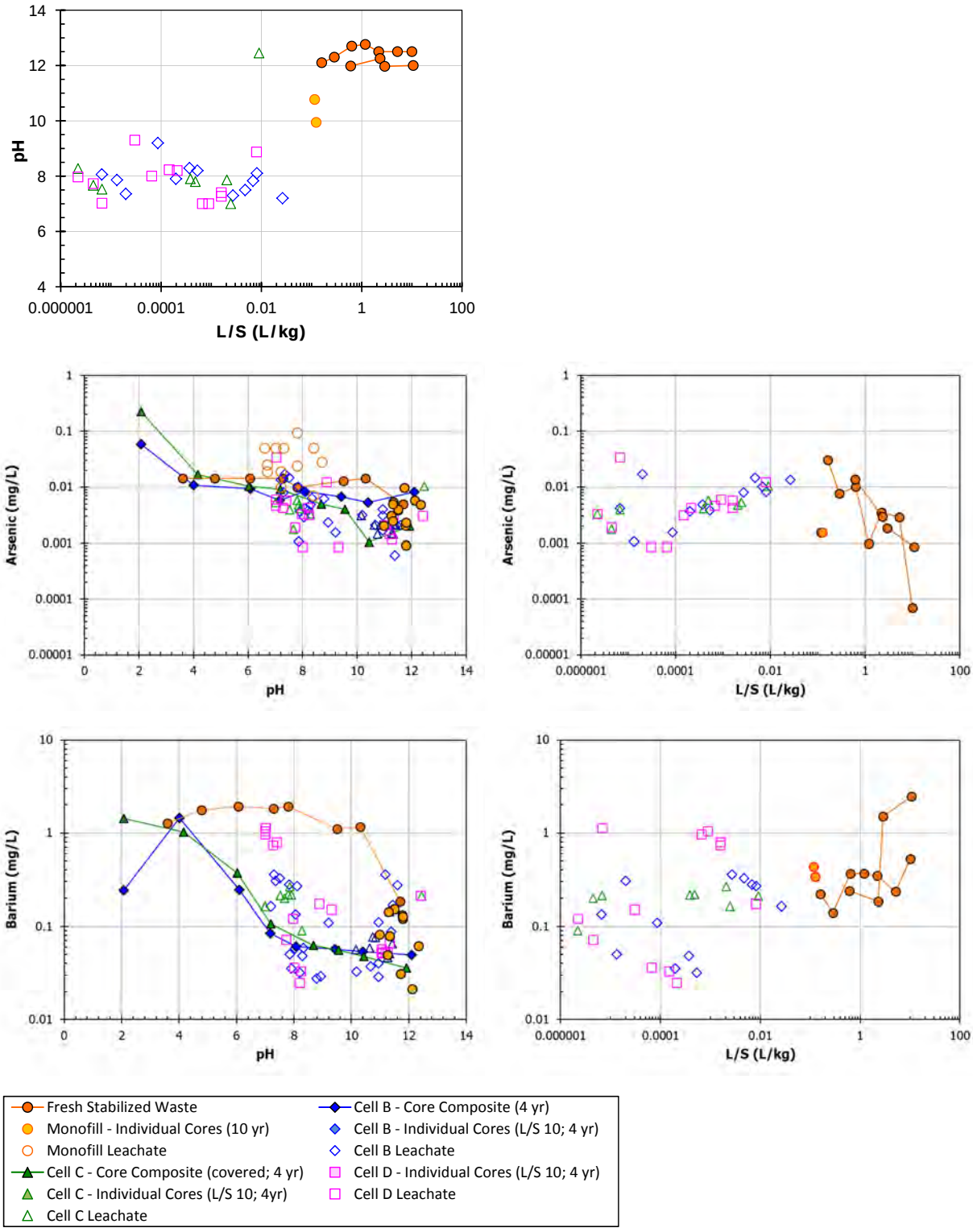

Figure H-1. Comparison of laboratory and field pH for stabilized MSWI fly ash disposal (The Netherlands).

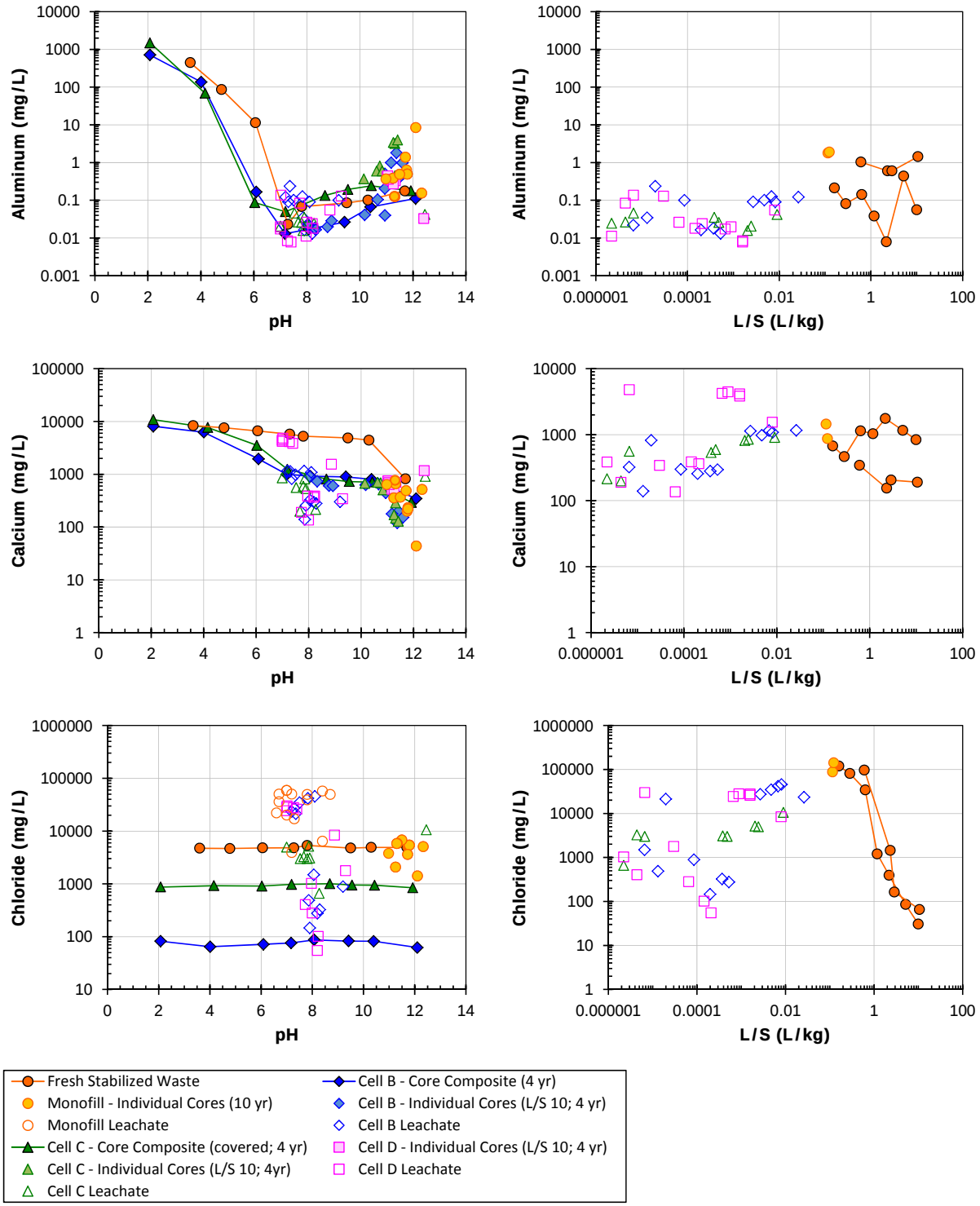

Figure H-2. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

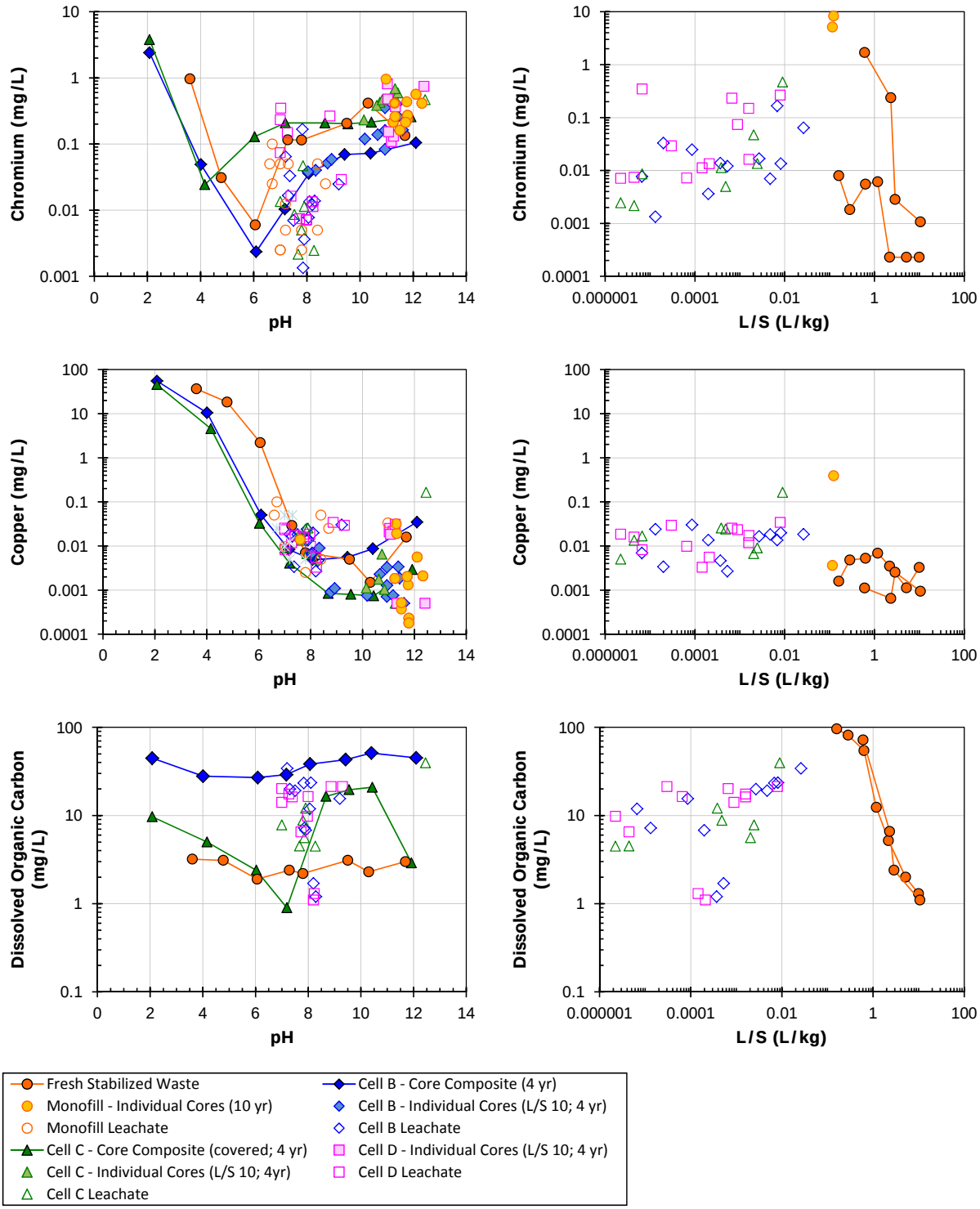

Figure H-3. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

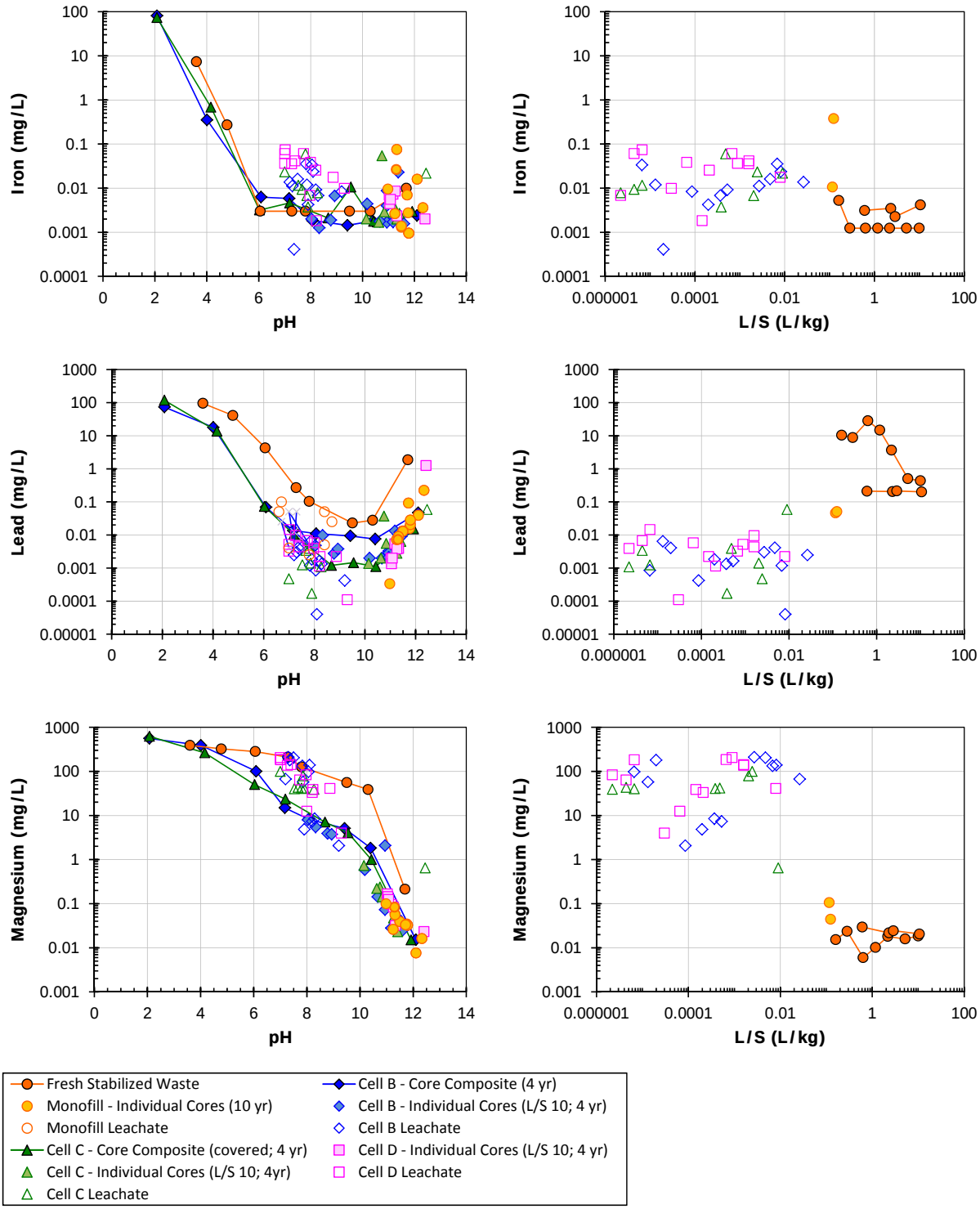

Figure H-4. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

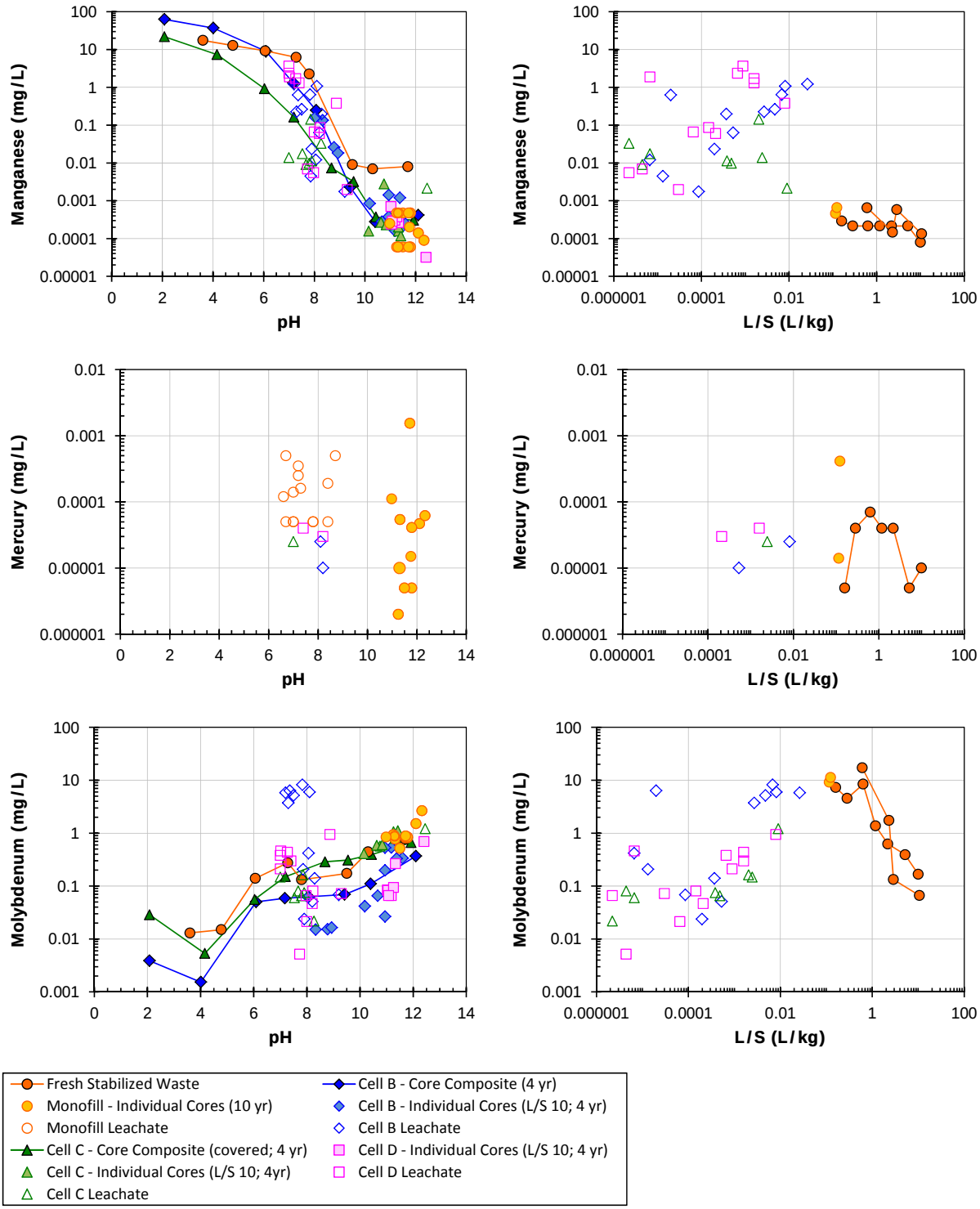

Figure H-5. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

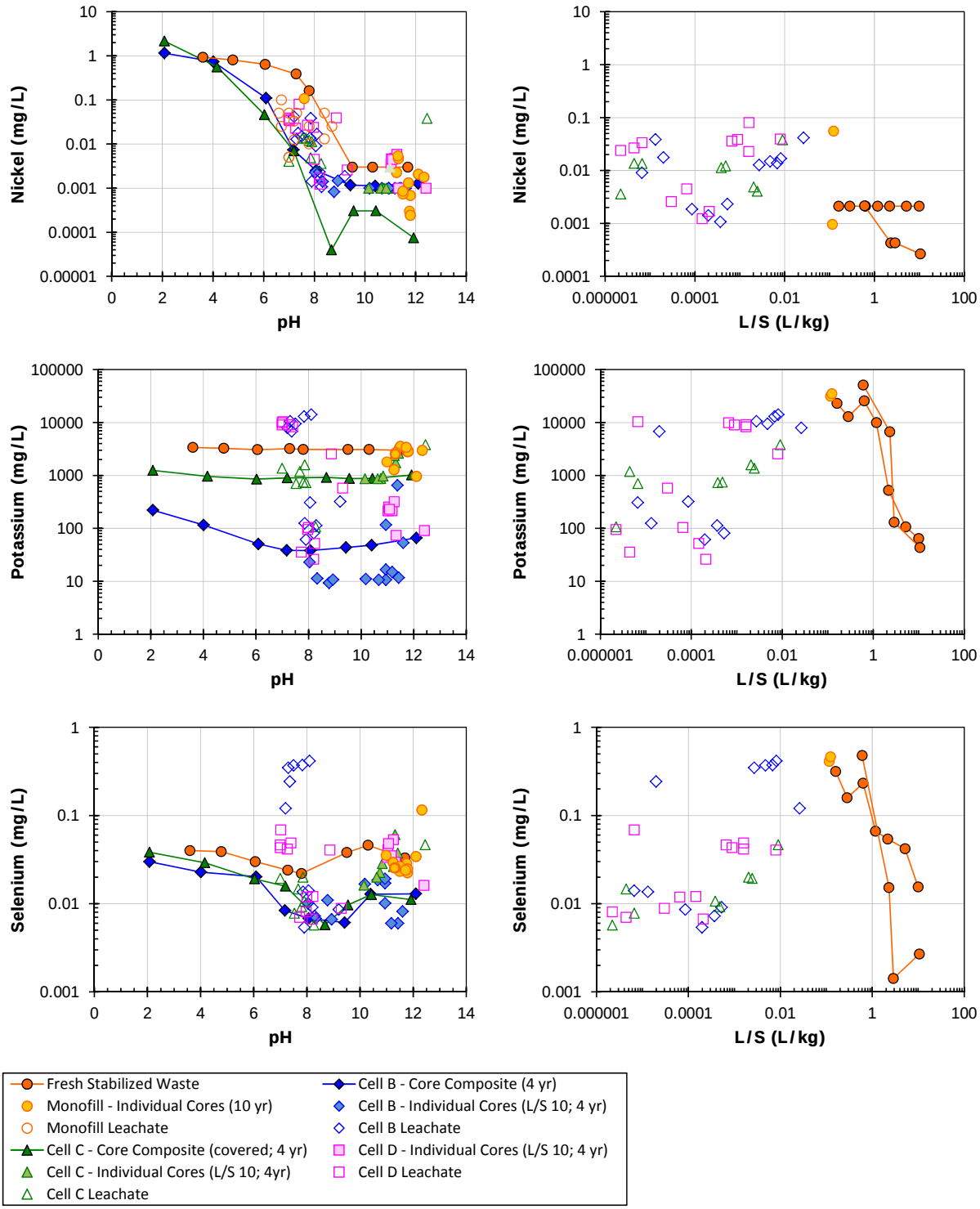

Figure H-6. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

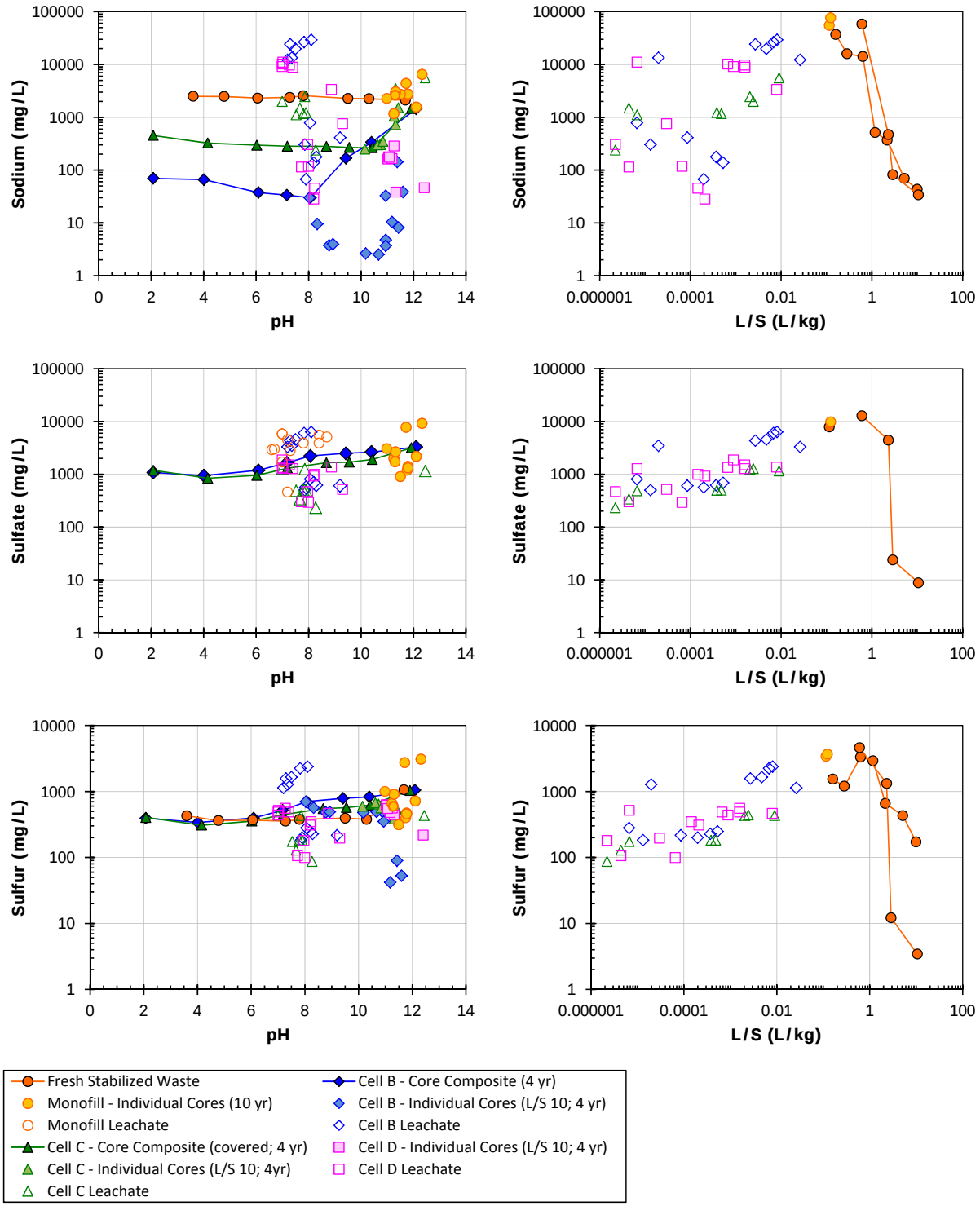

Figure H-7. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

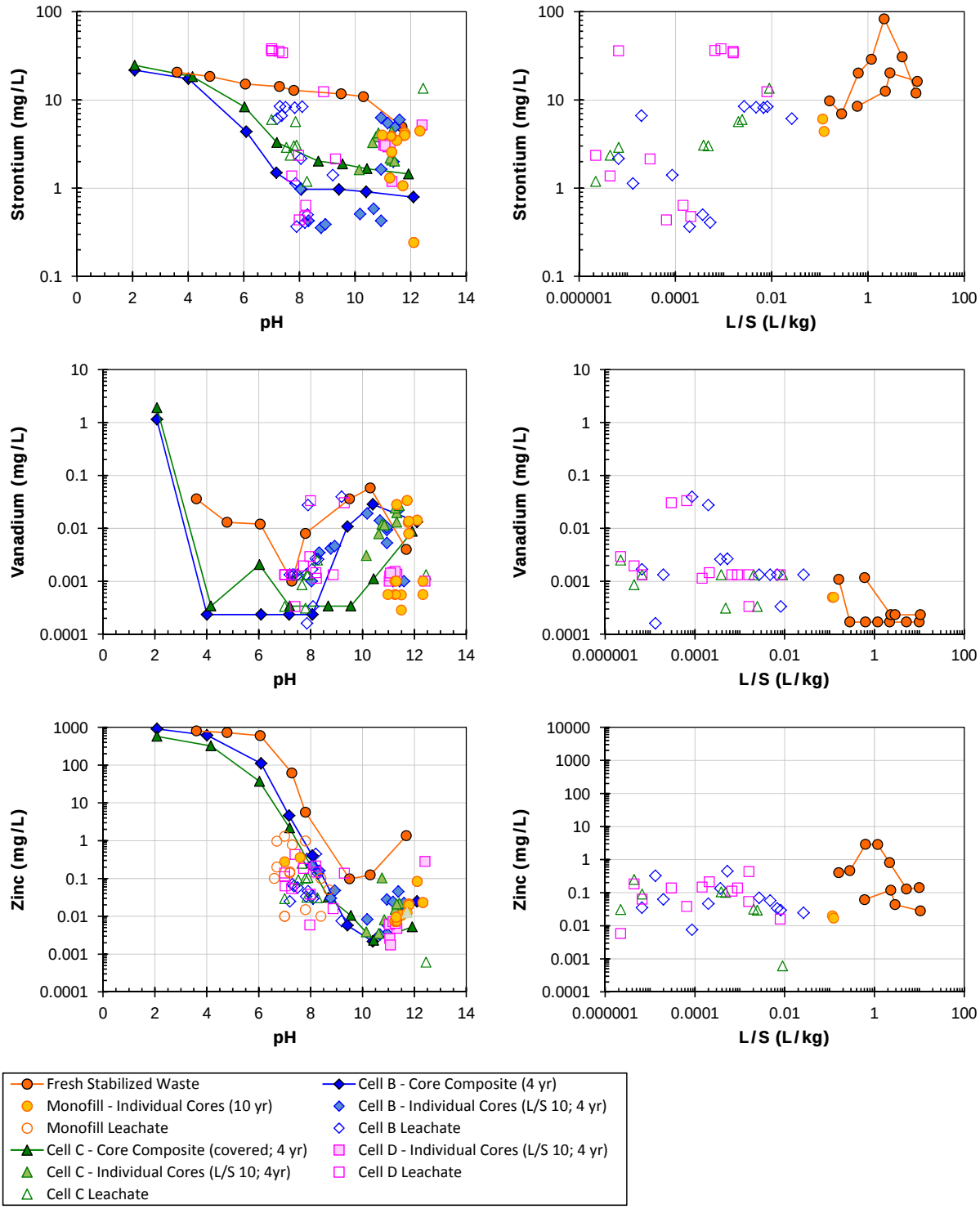

Figure H-8. Comparison of laboratory and field concentration results for stabilized MSWI fly ash disposal (The Netherlands).

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APPENDIX I: PORTLAND CEMENT MORTARS AND CONCRETE

Table I-1. Data Sources for Laboratory-to-Field Comparisons for Portland Cement Mortars and Concrete

Legend ID	Source	Material Type	Data Type	Citation
Cement Mortar CEM I (DE)	Germany	CEM I type cement mortar	pH-dependence	Schießl, 2003
Concrete – Core (40 yr, rain exposed, DE)	Germany		pH-dependence	Schießl, 2003
Concrete – Core (40 yr, immersed, DE)	Germany		pH-dependence	Schießl, 2003
Roman Aqueduct - Core (2,000 yr; DE)		Core from Roman Aqueduct	pH-dependence	van der Sloot et al., 2011
Cement Mortar CEM I (NO)	Norway	CEM I type cement mortar	pH-dependence	Engelsen et al., 2009; 2010
RCA (fresh, NO)	Norway	Recycled Concrete Aggregate	pH-dependence	Engelsen et al., 2009; 2010
RCA – Roadbase (4 yr, <10 mm, NO)	Norway	Recycled Concrete Aggregate, recovered from roadbase (depth < 10 mm	pH-dependence	Engelsen et al., 2009; 2010
RCA – Roadbase (4 yr, 20-120 mm, NO)	Norway	Recycled Concrete Aggregate, recovered from roadbase	pH-dependence	Engelsen et al., 2009; 2010

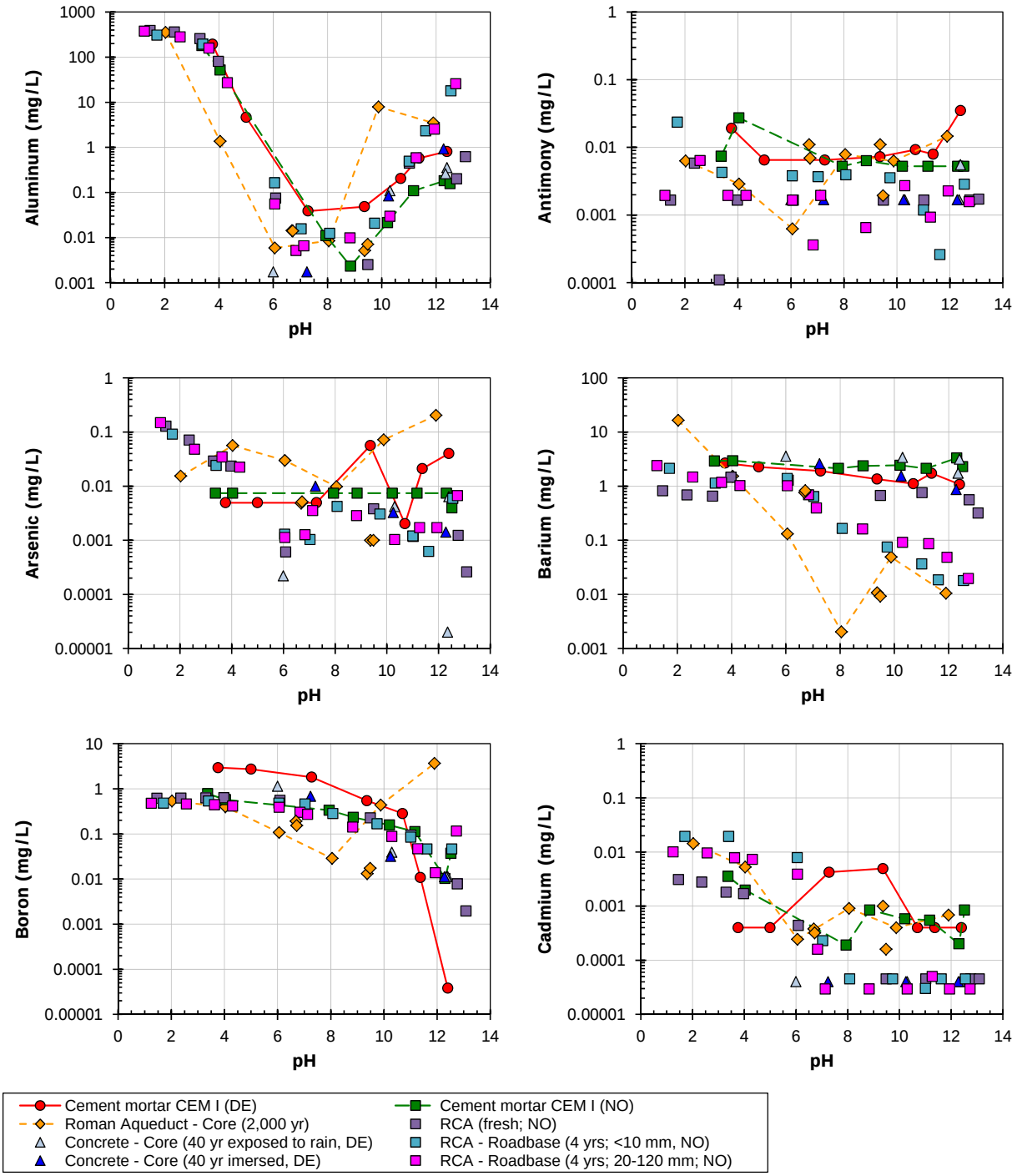

Figure I-1. Comparison of portland cement mortars, concretes and recycled aggregates.

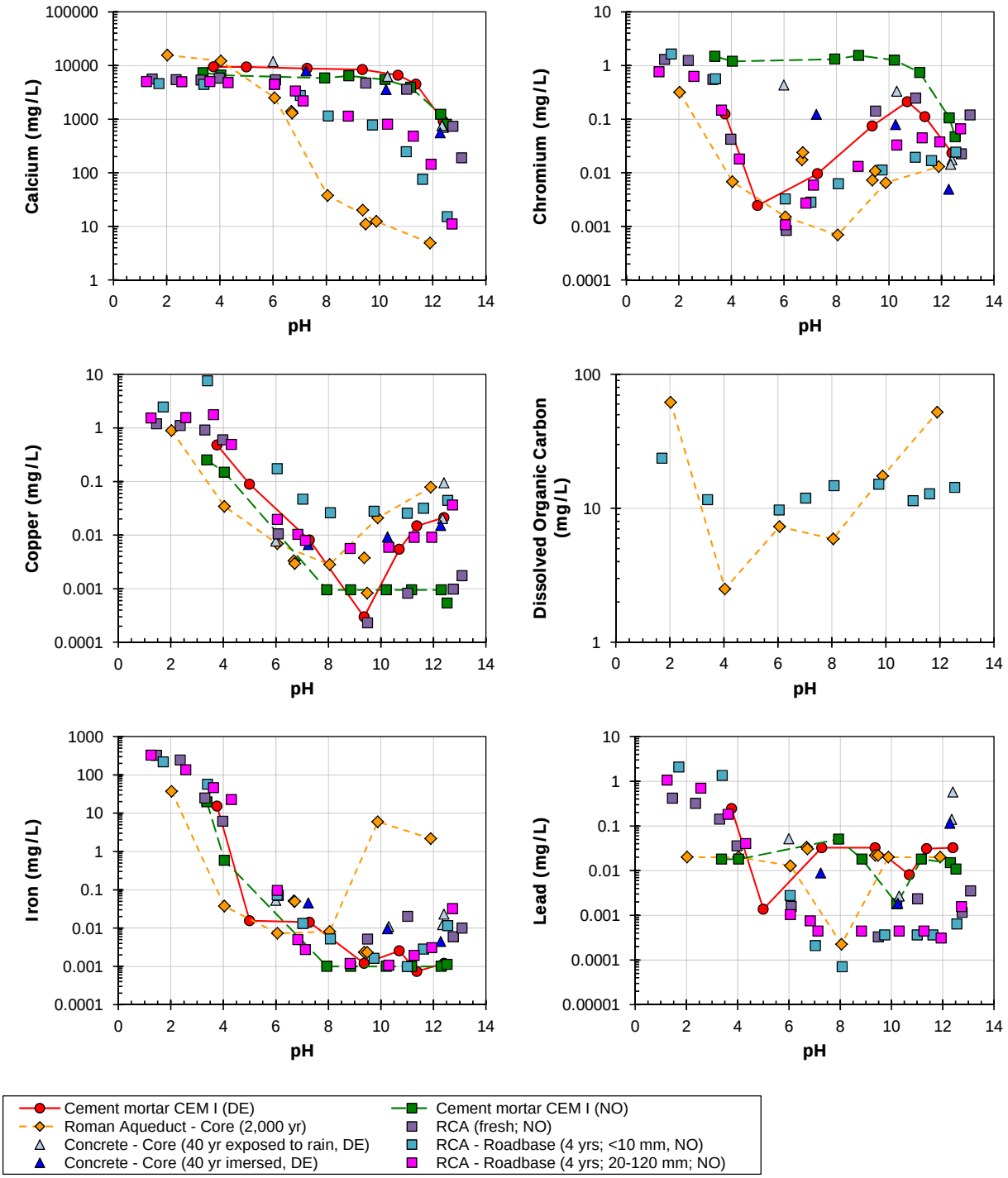

Figure I-2. Comparison of portland cement mortars, concretes and recycled aggregates.

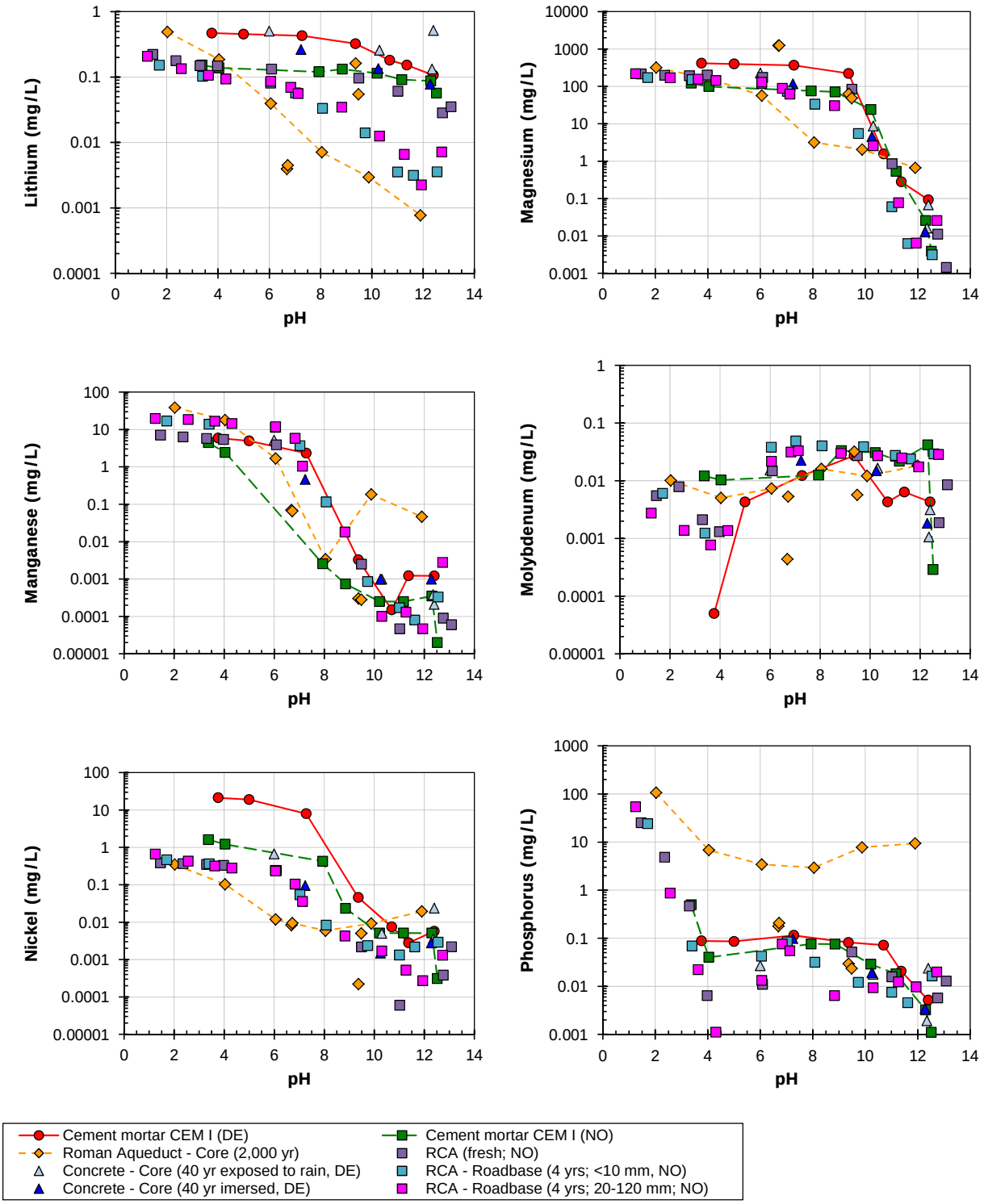

Figure I-3. Comparison of portland cement mortars, concretes and recycled aggregates.

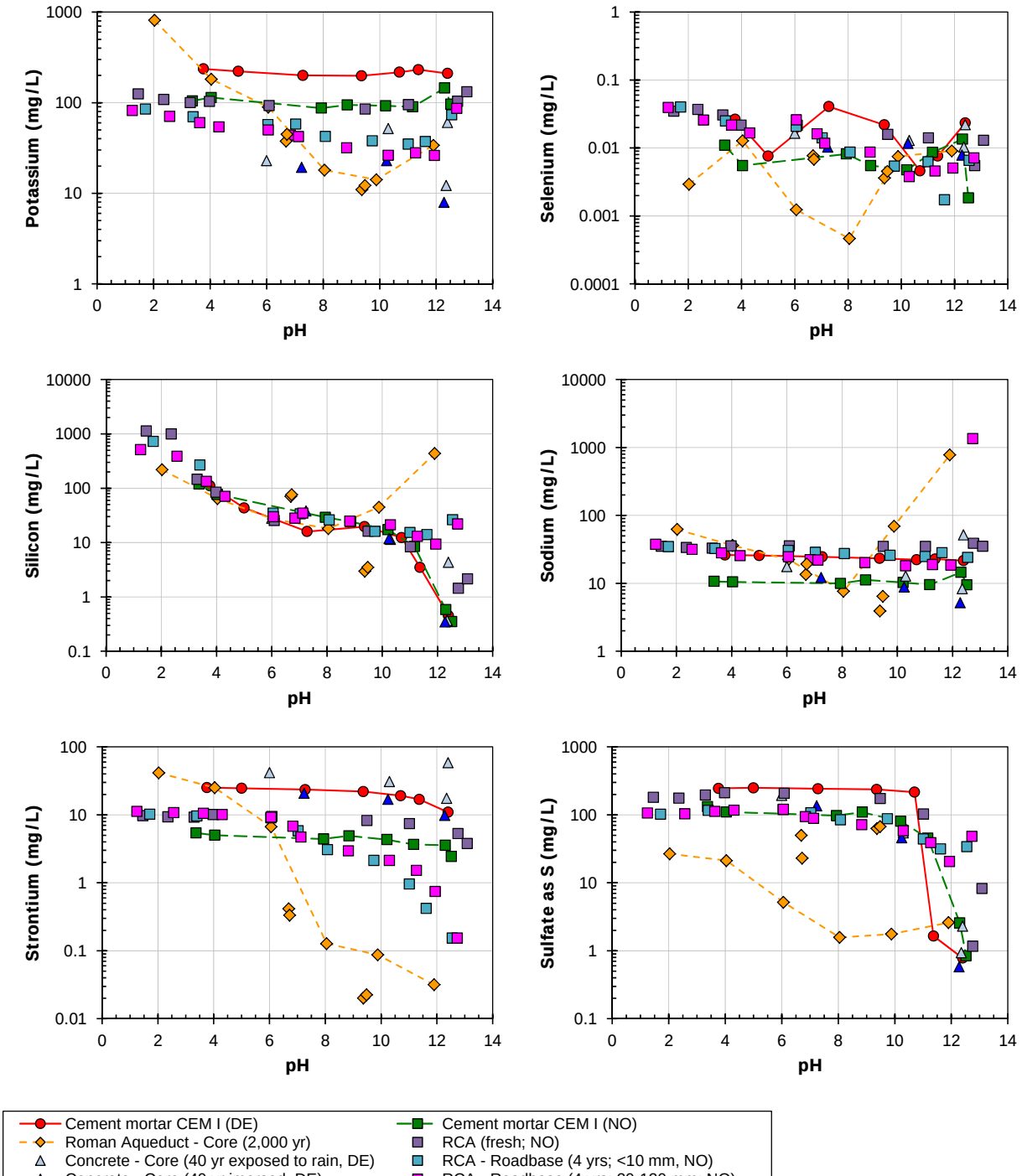

Figure I-4. Comparison of portland cement mortars, concretes and recycled aggregates.

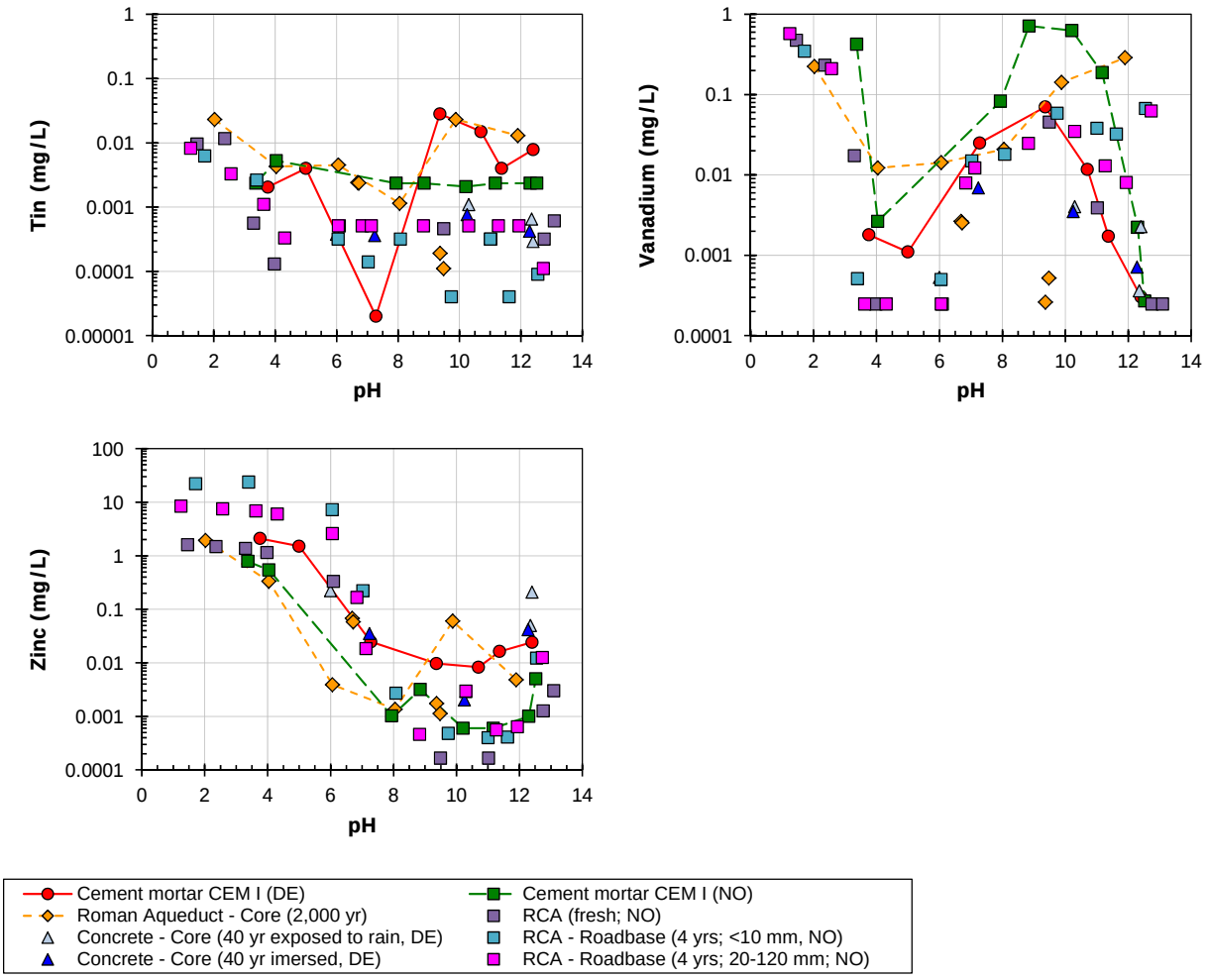

Figure I-5. Comparison of portland cement mortars, concretes and recycled aggregates.

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Appendix 22

United States Environmental Protection Agency (USEPA), 1999. Use of Monitoring Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites. OSWER Directive Number 9200.4-17P.

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United States
Environmental Protection
Agency

Office of
Solid Waste and
Emergency Response

EPA

DIRECTIVE NUMBER: 9200.4-17P

TITLE: Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites

APPROVAL DATE: April 21, 1999

EFFECTIVE DATE: April 21, 1999

ORIGINATING OFFICE: OSWER

[X] **FINAL**

[ ] **DRAFT**

STATUS:

REFERENCE (other documents):

OSWER OSWER OSWER DIRECTIVE DIRECTIVE DIRECTIVE

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EPA	United States Environmental Protection Agency Washington, DC 20460 **OSWER Directive Initiation Request**	1. Directive Number 9200.4-17P

2. Originator Information

Name of Contact Person	Mail Code	Office	Telephone Code
Hal White	5403G	OUST	(703)-603-7177

3. Title
Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites

4. Summary of Directive (include brief statement of purpose)
The purpose of this Directive is to clarify EPA's policy regarding the use of monitored natural attenuation (MNA) for the remediation of contaminated soil and groundwater at sites administered by EPA's Office of Solid Waste and Emergency Response (OSWER).

5. Keywords
natural attenuation, remediation, soil, groundwater, contamination

6a. Does This Directive Supersede Previous Directive(s)?
☒ No ☐ Yes What Directive (number, title)

b. Does It Supplement Previous Directive(s)?
☒ No ☐ Yes What Directive (number, title)

7. Draft Level
☒ A - Signed by AA/DAA ☐ B - Signed by Office Director ☐ C -For Review and Comment ☐ D - In Development

8. Document to be distributed to States by Headquarters? ☒ Yes ☐ No

This Requests Meets OSWER Directives System Format Standards

9. Signature of Lead Office Directives Coordinator	Date
Shuphona Clark	3/29/99
10. Name and Title of Approving Official Timothy Fields, Jr., Acting AA/OSWER	Date 4/21/99

EPA Form 1315-17 (Rev 5-87) Previous editions are obsolete

OSWER DIRECTIVE OSWER DIRECTIVE OSWER DIRECTIVE

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

APR 21 1999

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

MEMORANDUM

SUBJECT: Final OSWER Directive "Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites" (OSWER Directive Number 9200.4-17P)

FROM: Elizabeth Cotsworth, Acting Director
Office of Solid Waste

Walter W. Kovalick, Jr., Director
Technology Innovation Office

Stephen D. Luftig, Director
Office of Emergency and Remedial Response

Sammy Ng, Acting Director
Office of Underground Storage Tanks

James E. Woolford, Director
Federal Facilities Restoration and Reuse Office

TO: Addressees

Purpose

This memorandum accompanies a copy of the Final OSWER Directive regarding the use of monitored natural attenuation for the remediation of contaminated soil and groundwater at sites regulated under all Office of Solid Waste and Emergency Response (OSWER) programs. A draft Interim Final version of this Directive was released on December 1, 1997 for use, and for general public review and comment. In response to comments received on that draft, EPA has incorporated several changes in this final version dealing with topics such as contaminants of concern, cross-media transfer, plume migration, and remediation time frame.

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Implementation

This Directive is being issued in Final form and should be used immediately as guidance for proposing, evaluating, and approving Monitored Natural Attenuation remedies. This Final Directive will be available from the Superfund, RCRA, and OUST dockets and through the RCRA, Superfund & EPCRA Hotline (800-424-9346 or 703-412-9810). The directive will also be available in electronic format from EPA's home page on the Internet (the address is http://www.epa.gov/swerust1/directiv/d9200417.htm).

Questions/Comments

If you need more information about the Directive please feel free to contact any of the appropriate EPA staff listed on the attachment.

Addressees: Federal Facility Forum
Federal Facilities Leadership Council
Other Federal Facility Contacts
OSWER Natural Attenuation Workgroup
RCRA Corrective Action EPA Regional and State Program Managers
State LUST Fund Administrators
State LUST Program Managers
UST/LUST Regional Program Managers
UST/LUST Regional Branch Chiefs
State Superfund Program Managers
Superfund Regional Policy Managers

attachment

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Attachment
EPA Contacts

January 1999

If you have any questions regarding this policy, please first call the RCRA/Superfund Hotline at (800) 424-9346. If you require further assistance, please contact the appropriate staff from the list below:

Headquarters:

Tim Mott—Federal Facilities	(202) 260-2447
Remi Langum—Federal Facilities	(202) 260-2457
Ken Lovelace—Superfund	(703) 603-8787
Guy Tomassoni—RCRA	(703) 308-8622
Hal White—UST	(703) 603-7177
Linda Fiedler—Technology Innovation	(703) 603-7194
Ron Wilhelm—Radiation & Indoor Air	(202) 564-9379

Office of Research and Development:

John Wilson—NRMRL, Ada, OK	(580) 436-8532
Fran Kremer—NRMRL, Cincinnati, OH	(513) 569-7346
Fred Bishop—NRMRL, Cincinnati, OH	(513) 569-7629

Groundwater Forum:

Ruth Izraeli—RCRA, Superfund	(212) 637-3784

Region 1

Joan Coyle—UST	(617) 918-1303
Ernie Waterman—RCRA	(617) 918-1369
Richard Willey—Superfund	(617) 918-1266
Bill Brandon—Federal Facilities	(617) 918-1391
Meghan Cassidy—Federal Facilities	(617) 918-1387

Region 2

Derval Thomas—UST	(212) 637-4236
Ruth Izraeli—Superfund	(212) 637-3784
Jon Josephs—ORD Technical Liaison	(212) 637-4317
Carol Stein—RCRA	(212) 637-4181

Region 3

Jack Hwang—UST	(215) 814-3387
Kathy Davies—Superfund	(215) 814-3315
Deborah Goldblum—RCRA	(215) 814-3432

Region 4

David Ariail—UST	(404) 562-9464
Kay Wischkaemper—Technical Support	(404) 562-8641
Donna Wilkinson—RCRA	(404) 562-8490
Robert Pope—Federal Facilities	(404) 562-8506

Region 5

Gilberto Alvarez—UST	(312) 886-6143
Tom Matheson—RCRA	(312) 886-7569
Luanne Vanderpool—Superfund	(312) 353-9296
Craig Thomas—Federal Facilities	(312) 886-5907

Region 6

Lynn Dail—UST	(214) 665-2234
John Cernero—UST	(214) 665-2233
Mike Hebert—RCRA Enforcement	(214) 665-8315
Arnold Bierschenk—RCRA permitting	(214) 665-7435
Lisa Price—Base Closures	(214) 665-6744

Region 7

William F. Lowe—RCRA	(913) 551-7547
Jeff Johnson—RCRA	(913) 551-7849
Craig Smith—Superfund	(913) 551-7683
Ed Wakeland—UST	(913) 551-7806

Region 8

Sandra Stavnes—UST	(303) 312-6117
Randy Breeden—RCRA	(303) 312-6522
Richard Muza—Superfund	(303) 312-6595

Region 9

Matt Small—UST	(415) 744-2078
Katherine Baylor—RCRA	(415) 744-2028
Herb Levine—Superfund	(415) 744-2312
Ned Black—Superfund	(415) 744-2354
Mark Filippini—Superfund	(415) 744-2395

Region 10

Harold Scott—UST	(206) 553-1587
Dave Bartus—RCRA	(206) 553-2804
Mary Jane Nearman—Superfund	(206) 553-6642
Curt Black — Superfund	(206) 553-1262
Nancy Harney—Federal Facilities	(206) 553-6635

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USE OF MONITORED NATURAL ATTENUATION AT SUPERFUND, RCRA CORRECTIVE ACTION, AND UNDERGROUND STORAGE TANK SITES

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Directive 9200.4-17P

April 1999

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USE OF MONITORED NATURAL ATTENUATION AT SUPERFUND, RCRA CORRECTIVE ACTION, AND UNDERGROUND STORAGE TANK SITES

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NOTICE: This document provides guidance to EPA and state staff. It also provides guidance to the public and to the regulated community on how EPA intends to exercise its discretion in implementing its regulations. The guidance is designed to implement national policy on these issues. The document does not, however, substitute for EPA's statutes or regulations, nor is it a regulation itself. Thus, it does not impose legally-binding requirements on EPA, States, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA may change this guidance in the future, as appropriate.

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PURPOSE AND OVERVIEW

The purpose of this Directive is to clarify EPA's policy regarding the use of monitored natural attenuation (MNA) for the cleanup of contaminated soil and groundwater[1] in the Superfund, RCRA Corrective Action, and Underground Storage Tank programs. These programs are administered by EPA's Office of Solid Waste and Emergency Response (OSWER) which include the Office of Emergency and Remedial Response (OERR), Office of Solid Waste (OSW), Office of Underground Storage Tanks (OUST), and the Federal Facilities Restoration and Reuse Office (FFRRO). Statutory authority for these remediation programs is provided under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA).

EPA remains fully committed to its goals of protecting human health and the environment by remediating contaminated soils, restoring contaminated groundwaters to their beneficial uses, preventing migration of contaminant plumes[2], and protecting groundwaters and other environmental resources[3]. EPA advocates using the most appropriate technology for a given site. EPA does not consider MNA to be a "presumptive" or "default" remedy—it is merely one option that should be evaluated with other applicable remedies. EPA does not view MNA to be a "no action[4]" or "walk-away" approach, but rather

[1] Although this Directive does not address remediation of contaminated sediments, many of the same principles would be applicable. Fundamental issues such as having source control, developing lines of evidence, monitoring and contingency plans are also appropriate for sediments. However, the Agency is developing the policy and technical aspects for sediments, specifically.

[2] The outer limits of contaminant plumes are typically defined for each contaminant of concern based on chemical concentrations above which the overseeing regulatory authority has determined represent an actual or potential threat to human health or the environment.

[3] Environmental resources to be protected include groundwater, drinking water supplies, surface waters, ecosystems and other media (air, soil and sediments) that could be impacted by site contamination.

[4] For the Superfund program, Section 300.430(e)(6) of the National Contingency Plan (NCP) directs that a "no action alternative" (or no further action) "shall be developed" for all feasibility studies (USEPA, 1990a, p. 8849). The "no action" alternative can include monitoring but generally not other remedial actions, where such actions are defined in Section 300.5 of the NCP. In general, the "no action" alternative is selected when there is no current or potential threat to human health or the environment or when CERCLA exclusions preclude taking an action (USEPA, 1991a). As explained in this Directive, a remedial alternative that relies on monitored natural attenuation to attain site-specific remediation objectives is **not** the same as the "no action" alternative.

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considers it to be an alternative means of achieving remediation objectives[5] that may be appropriate for specific, well-documented site circumstances where its use meets the applicable statutory and regulatory requirements. As there is often a variety of methods available for achieving remediation objectives at any given site, MNA may be evaluated and compared to other viable remediation methods (including innovative technologies) during the study phases leading to the selection of a remedy. As with any other remedial alternative, MNA should be selected only where it meets all relevant remedy selection criteria, and where it will meet site remediation objectives within a timeframe that is reasonable compared to that offered by other methods. In the majority of cases where MNA is proposed as a remedy, its use may be appropriate as one component of the total remedy, that is, either in conjunction with active remediation or as a follow-up measure. MNA should be used very cautiously as the sole remedy at contaminated sites. Furthermore, the availability of MNA as a potential remediation tool does not imply any lessening of EPA's longstanding commitment to pollution prevention. Waste minimization, pollution prevention programs, and minimal technical requirements to prevent and detect releases remain fundamental parts of EPA waste management and remediation programs.

Use of MNA does not signify a change in OSWER's remediation objectives. These objectives (discussed in greater detail under the heading "Implementation") include control of source materials[6], prevention of plume migration, and restoration of contaminated groundwaters, where appropriate. Thus, EPA expects that source control measures (see section on "Remediation of Sources") will be evaluated for all sites under consideration for any proposed remedy. As with other remediation methods, selection of MNA as a remediation method should be supported by detailed site-specific information that demonstrates the efficacy of this remediation approach. In addition, the progress of MNA toward a site's remediation objectives should be carefully monitored and compared with expectations. Where MNA's ability to meet these expectations is uncertain and based predominantly on predictive analyses, decision makers should incorporate contingency measures into the remedy.

The scientific understanding of natural attenuation processes continues to evolve. EPA recognizes that significant advances have been made in recent years, but there is still a great deal to be learned regarding the mechanisms governing natural attenuation processes and their ability to address different types of contamination problems. Therefore, while EPA believes MNA may

[5] In this Directive, remediation objectives are the overall objectives that remedial actions are intended to accomplish and are not the same as chemical-specific cleanup levels. Remediation objectives could include preventing exposure to contaminants, preventing further migration of contaminants from source areas, preventing further migration of the groundwater contaminant plume, reducing contamination in soil or groundwater to specified cleanup levels appropriate for current or potential future uses, or other objectives. The term "remediation" as used in this Directive is not limited to "remedial actions" defined in CERCLA §101(24), and includes CERCLA "removal actions", for example.

[6] **"Source material** is defined as material that includes or contains hazardous substances, pollutants or contaminants that act as a reservoir [either stationary or mobile] for migration of contamination to the ground water, to surface water, to air, [or other environmental media,] or acts as a source for direct exposure. Contaminated ground water generally is not considered to be a source material although non-aqueous phase liquids (NAPLS [occurring either as residual- or free-phase]) may be viewed as source materials." (USEPA, 1991b).

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be used where circumstances are appropriate, it should be used with caution commensurate with the uncertainties associated with the particular application. Furthermore, largely due to the uncertainty associated with the potential effectiveness of MNA to meet remediation objectives that are protective of human health and the environment, EPA expects that **source control and long-term performance monitoring will be fundamental components of any MNA remedy**.

This Directive is a policy document and as such is not intended to provide detailed technical guidance on evaluating MNA remedies. EPA recognizes that at present there are relatively few EPA guidance documents concerning appropriate implementation of MNA remedies. Chapter IX of OUST's alternative cleanup technologies manual (USEPA, 1995a) addresses the use of natural attenuation at leaking UST sites. The Office of Research and Development (ORD) has recently published a protocol for evaluating MNA at chlorinated solvent sites (USEPA, 1998a). Additional technical resource documents for evaluating MNA in groundwater, soils, and sediments are being developed by ORD. Supporting technical information regarding the evaluation of MNA as a remediation alternative is available from a variety of other sources, including those listed at the end of this Directive. "References Cited" lists those EPA documents that were specifically cited within this Directive. The list of "Additional References" includes documents produced by EPA as well as non-EPA entities. Finally, "Other Sources of Information" lists sites on the World Wide Web (Internet) where additional information can be obtained. Non-EPA documents may provide regional and state site managers, as well as the regulated community, with useful technical information. However, these non-EPA guidances are not officially endorsed by EPA, EPA does not necessarily agree with all their conclusions, and all parties involved should clearly understand that such guidances do not in any way replace current EPA or OSWER guidances or policies addressing the remedy selection process in the Superfund, RCRA, or UST programs.

BACKGROUND

The term "monitored natural attenuation", as used in this Directive, refers to the reliance on natural attenuation processes (within the context of a carefully controlled and monitored site cleanup approach) to achieve site-specific remediation objectives within a time frame that is reasonable compared to that offered by other more active methods. The "natural attenuation processes" that are at work in such a remediation approach include a variety of physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater. These *in-situ* processes include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants. When relying on natural attenuation processes for site remediation, EPA prefers those processes that degrade or destroy contaminants. Also, EPA generally expects that MNA will only be appropriate for sites that have a low potential for contaminant migration. Additional discussion of criteria for "Sites Where Monitored Natural Attenuation May Be Appropriate" may be found later in this Directive. Other terms associated with natural attenuation in the literature include "intrinsic remediation", "intrinsic bioremediation", "passive bioremediation", "natural

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recovery", and "natural assimilation". While some of these terms are synonymous with "natural attenuation," others refer strictly to biological processes, excluding chemical and physical processes. Therefore, it is recommended that for clarity and consistency, the term "monitored natural attenuation" be used throughout OSWER remediation programs unless a specific process (*e.g.*, reductive dehalogenation) is being referenced.

Natural attenuation processes are typically occurring at all sites, but to varying degrees of effectiveness depending on the types and concentrations of contaminants present and the physical, chemical, and biological characteristics of the soil and groundwater. Natural attenuation processes may reduce the potential risk posed by site contaminants in three ways:

(1) Transformation of contaminant(s) to a less toxic form through destructive processes such as biodegradation or abiotic transformations;

(2) Reduction of contaminant concentrations whereby potential exposure levels may be reduced; and

(3) Reduction of contaminant mobility and bioavailability through sorption onto the soil or rock matrix.

Where conditions are favorable, natural attenuation processes may reduce contaminant mass or concentration at sufficiently rapid rates to be integrated into a site's soil or groundwater remedy. Following source control measures, natural attenuation may be sufficiently effective to achieve remediation objectives at some sites without the aid of other (active) remedial measures. Typically, however, MNA will be used in conjunction with active remediation measures. For example, active remedial measures could be applied in areas with high concentrations of contaminants while MNA is used for low concentration areas; or MNA could be used as a follow-up to active remedial measures. EPA also encourages the consideration of innovative technologies for source control or "active" components of the remedy, which may offer greater confidence and reduced remediation time frames at modest additional cost.

While MNA is often dubbed "passive" remediation because natural attenuation processes occur without human intervention, its use at a site does **not** preclude the use of "active" remediation or the application of enhancers of biological activity (*e.g.*, electron acceptors, nutrients, and electron donors). However, by definition, a remedy that includes the introduction of an enhancer of any type is no longer considered to be "natural" attenuation. Use of MNA does not imply that activities (and costs) associated with investigating the site or selecting the remedy (*e.g.*, site characterization, risk assessment, comparison of remedial alternatives, performance monitoring, and contingency measures) have been eliminated. These elements of the

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investigation and cleanup must still be addressed as required under the particular OSWER program, regardless of the remedial approach selected.

Contaminants of Concern

It is common practice in conducting remedial actions to focus on the most obvious contaminants of concern, but other contaminants may also be of significant concern in the context of MNA remedies. In general, since engineering controls are not used to control plume migration in an MNA remedy, decision makers need to ensure that MNA is appropriate to address **all contaminants** that represent an actual or potential threat to human health or the environment. Several examples are provided below to illustrate the need to assess both the obvious as well as the less obvious contaminants of concern when evaluating an MNA remedial option.

- Mixtures of contaminants released into the environment often include some which may be amenable to MNA, and others which are not addressed sufficiently by natural attenuation processes to achieve remediation objectives. For example, Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) associated with gasoline have been shown in many circumstances to be effectively remediated by natural attenuation processes. However, a common additive to gasoline (*i.e.*, methyl tertiary-butyl ether [MTBE]) has been found to migrate large distances and threaten downgradient water supplies at the same sites where the BTEX component of a plume has either stabilized or diminished due to natural attenuation. In general, compounds that tend not to degrade readily in the subsurface (*e.g.*, MTBE and 1,4-dioxane) and that represent an actual or potential threat should be assessed when evaluating the appropriateness of MNA remedies.

- Analyses of contaminated media often report chemicals which are identified with a high degree of certainty, as well other chemicals labeled as "tentatively identified compounds" (TICs). It is often assumed that TICs will be addressed by a remedial action along with the primary contaminants of concern. This may be a reasonable assumption for an active remediation system (*e.g.*, pump and treat) which is capturing all contaminated groundwater, but might not be acceptable for an MNA remedy that is relying on natural processes to prevent contaminant migration. Where MNA is being proposed for sites with TICs, it may be prudent to identify the TICs and evaluate whether they too will be sufficiently mitigated by MNA.

- At some sites the same geochemical conditions and processes that lead to biodegradation of chlorinated solvents and petroleum hydrocarbons can chemically transform naturally occurring minerals (*e.g.*, arsenic and manganese compounds) in the aquifer matrix to forms that are more mobile and/or more toxic than the original materials (USEPA, 1998). A

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> comprehensive assessment of an MNA remedial option should include evaluation of whether naturally occurring metals will become contaminants of concern.

Addressing the above concerns does not necessarily require sampling and analysis of extensive lists of parameters at every monitoring location in all situations. The location and number of samples collected and analyzed for this purpose should be determined on a site-specific basis to ensure adequate characterization and protection of human health and the environment.

Transformation Products

It also should be noted that some natural attenuation processes may result in the creation of transformation products[7] that are more toxic and/or mobile than the parent contaminant (*e.g.*, degradation of trichloroethylene to vinyl chloride). The potential for creation of toxic transformation products is more likely to occur at non-petroleum release sites (*e.g.*, chlorinated solvents or other volatile organic spill sites) and should be evaluated to determine if implementation of a MNA remedy is appropriate and protective in the long term.

Cross-Media Transfer

Natural attenuation processes may often result in transfer of some contaminants from one medium to another (*e.g.*, from soil to groundwater, from soil to air or surface water, and from groundwater to surface water). Processes that result in degradation of contaminants are preferable to those which rely predominantly on the transfer of contamination from one medium to another. MNA remedies involving cross-media transfer of contamination should include a site-specific evaluation of the potential risk posed by the contaminant(s) once transferred to a particular medium. Additionally, long-term monitoring should address the media to which contaminants are being transferred.

[7] The term "transformation products" in the Directive includes intermediate products resulting from biotic or abiotic processes (*e.g.*, TCE, DCE, vinyl chloride), decay chain daughter products from radioactive decay, and inorganic elements that become methylated compounds (*e.g.*, methyl mercury) in soil or sediment. Some transformation products are quickly transformed to other products while others are longer lived.

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Petroleum-Related Contaminants

Natural attenuation processes, particularly biological degradation, are currently best documented at petroleum fuel spill sites. Under appropriate field conditions, the regulated compounds benzene, toluene, ethylbenzene, and xylene (BTEX) may naturally degrade through microbial activity and ultimately produce non-toxic end products (*e.g.*, carbon dioxide and water). Where microbial activity is sufficiently rapid, the dissolved BTEX contaminant plume may stabilize (*i.e.*, stop expanding), and contaminant concentrations in both groundwater and soil may eventually decrease to levels below regulatory standards. Following degradation of a dissolved BTEX plume, a residue consisting of heavier petroleum hydrocarbons of relatively low solubility and volatility will typically be left behind in the original source (spill) area. Although this residual contamination may have relatively low potential for further migration, it still may pose a threat to human health or the environment either from direct contact with soils in the source area or by continuing to slowly leach contaminants to groundwater. For these reasons, MNA alone is generally not sufficient to remediate petroleum release sites. Implementation of source control measures in conjunction with MNA is almost always necessary. Other controls (*e.g.*, institutional controls[8]), in accordance with applicable state and federal requirements, may also be necessary to ensure protection of human health and the environment.

Chlorinated Solvents

Chlorinated solvents[9], such as trichloroethylene, represent another class of common contaminants. These compounds are more dense than water and are referred to as DNAPLs (dense non-aqueous phase liquids). Recent research has identified some of the mechanisms potentially responsible for degrading these solvents, furthering the development of methods for estimating biodegradation rates of these chlorinated compounds. However, the hydrologic and geochemical conditions favoring significant biodegradation of chlorinated solvents sufficient to achieve remediation objectives within a reasonable timeframe are anticipated to occur only in limited circumstances. DNAPLs tend to sink through the groundwater column toward the bottom of the aquifer. However, they can also occur as mixtures with other less dense contaminants. Because of the varied nature and distribution of chlorinated compounds, they are typically difficult to locate, delineate, and remediate even with active measures. In the subsurface, chlorinated solvents represent source materials that can continue to contaminate groundwater for decades or longer. Cleanup of solvent spills is also complicated by the fact that a typical spill includes

[8] The term “institutional controls” refers to non-engineering measures—usually, but not always, legal controls—intended to affect human activities in such a way as to prevent or reduce exposure to hazardous substances. Examples of institutional controls cited in the National Contingency Plan (USEPA, 1990a, p.8706) include land and resource (*e.g.*, water) use and deed restrictions, well-drilling prohibitions, building permits, well use advisories, and deed notices.

[9] Chlorinated solvents are only one type of halogenated compound. Chlorinated solvents are specifically referenced in this Directive because they are commonly found at contaminated sites. The discussion in this Directive regarding chlorinated solvents may also apply to other halogenated compounds to be remediated.

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multiple contaminants, including some that tend not to degrade readily in the subsurface.[10] Extremely long dissolved solvent plumes have been documented that may be due to the existence of subsurface conditions that are not conducive to natural attenuation.

Inorganics

MNA may, under certain conditions (*e.g.*, through sorption or oxidation-reduction reactions), effectively reduce the dissolved concentrations and/or toxic forms of inorganic contaminants in groundwater and soil. Both metals and non-metals (including radionuclides) may be attenuated by sorption[11] reactions such as precipitation, adsorption on the surfaces of soil minerals, absorption into the matrix of soil minerals, or partitioning into organic matter. Oxidation-reduction (redox) reactions can transform the valence states of some inorganic contaminants to less soluble and thus less mobile forms (*e.g.*, hexavalent uranium to tetravalent uranium) and/or to less toxic forms (*e.g.*, hexavalent chromium to trivalent chromium). Sorption and redox reactions are the dominant mechanisms responsible for the reduction of mobility, toxicity, or bioavailability of inorganic contaminants. It is necessary to know what specific mechanism (type of sorption or redox reaction) is responsible for the attenuation of inorganics so that the stability of the mechanism can be evaluated. For example, precipitation reactions and absorption into a soil's solid structure (*e.g.*, cesium into specific clay minerals) are generally stable, whereas surface adsorption (*e.g.*, uranium on iron-oxide minerals) and organic partitioning (complexation reactions) are more reversible. Complexation of metals or radionuclides with carrier (chelating) agents (*e.g.*, trivalent chromium with EDTA) may increase their concentrations in water and thus enhance their mobility. Changes in a contaminant's concentration, pH, redox potential, and chemical speciation may reduce a contaminant's stability at a site and release it into the environment. Determining the existence, and demonstrating the irreversibility, of these mechanisms is important to show that a MNA remedy is sufficiently protective.

In addition to sorption and redox reactions, radionuclides exhibit radioactive decay and, for some, a parent-daughter radioactive decay series. For example, the dominant attenuating mechanism of tritium (a radioactive isotopic form of hydrogen with a short half-life) is radioactive decay rather than sorption. Although tritium does not generate radioactive daughter products, those generated by some radionulides (*e.g.*, Am-241 and Np-237 from Pu-241) may be more toxic, have longer half-lives, and/or be more mobile than the parent in the decay series. Also, it is

[10] For example, 1,4-dioxane, which is used as a stabilizer for some chlorinated solvents, is more highly toxic, less likely to sorb to aquifer solids, and less biodegradable than some other solvent constituents under the same environmental conditions.

[11] When a contaminant is associated with a solid phase, it is usually not known if the contaminant is precipitated as a three-dimensional molecular coating on the surface of the solid, adsorbed onto the surface of the solid, absorbed into the structure of the solid, or partitioned into organic matter. "Sorption" will be used in this Directive to describe, in a generic sense (*i.e.*, without regard to the precise mechanism) the partitioning of aqueous phase constituents to a solid phase.

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important that the near surface or surface soil pathways be carefully evaluated and eliminated as potential sources of external direct radiation exposure[12].

Inorganic contaminants persist in the subsurface because, except for radioactive decay, they are not degraded by the other natural attenuation processes. Often, however, they may exist in forms that have low mobility, toxicity, or bioavailability such that they pose a relatively low level of risk. Therefore, natural attenuation of inorganic contaminants is most applicable to sites where immobilization or radioactive decay is demonstrated to be in effect and the process/mechanism is irreversible.

Advantages and Disadvantages of Monitored Natural Attenuation

MNA has several potential advantages and disadvantages, and the factors listed below should be carefully considered during site characterization and evaluation of remediation alternatives before selecting MNA as the remedial alternative. **Potential advantages** of MNA include:

- As with any *in situ* process, generation of lesser volume of remediation wastes, reduced potential for cross-media transfer of contaminants commonly associated with *ex situ* treatment, and reduced risk of human exposure to contaminants, contaminated media, and other hazards, and reduced disturbances to ecological receptors;

- Some natural attenuation processes may result in *in-situ* destruction of contaminants;

- Less intrusion as few surface structures are required;

- Potential for application to all or part of a given site, depending on site conditions and remediation objectives;

- Use in conjunction with, or as a follow-up to, other (active) remedial measures; and

- Potentially lower overall remediation costs than those associated with active remediation.

[12] External direct radiation exposure refers to the penetrating radiation (*i.e.,* primarily gamma radiation and x-rays) that may be an important exposure pathway for certain radionuclides in near surface soils. Unlike chemicals, radionuclides can have deleterious effects on humans without being taken into or brought in contact with the body due to high energy particles emitted from near surface soils. Even though the radionuclides that emit penetrating radiation may be immobilized due to sorption or redox reactions, the resulting contaminated near surface soil may not be a candidate for a MNA remedy as a result of this exposure risk.

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The **potential disadvantages** of MNA include:

- Longer time frames may be required to achieve remediation objectives, compared to active remediation measures at a given site;
- Site characterization is expected to be more complex and costly;
- Toxicity and/or mobility of transformation products may exceed that of the parent compound;
- Long-term performance monitoring will generally be more extensive and for a longer time;
- Institutional controls may be necessary to ensure long term protectiveness;
- Potential exists for continued contamination migration, and/or cross-media transfer of contaminants;
- Hydrologic and geochemical conditions amenable to natural attenuation may change over time and could result in renewed mobility of previously stabilized contaminants (or naturally occurring metals), adversely impacting remedial effectiveness; and
- More extensive education and outreach efforts may be required in order to gain public acceptance of MNA.

IMPLEMENTATION

The use of MNA is not new in OSWER programs. For example, in the Superfund program, use of natural attenuation as an element in a site's groundwater remedy is discussed in "Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites" (USEPA, 1988a). Use of MNA in OSWER programs has slowly increased over time with greater program experience and scientific understanding of the processes involved. Recent advances in the scientific understanding of the processes contributing to natural attenuation have resulted in a heightened interest in this approach as a potential means of achieving remediation objectives for soil and groundwater. However, EPA expects that reliance on MNA as the sole remedy will only be appropriate at relatively few contaminated sites. This Directive is intended to clarify OSWER program policies regarding the use of MNA and ensure that MNA remedies are selected and implemented appropriately. Topics addressed include the role of MNA in OSWER remediation programs, site characterization, the types of sites where MNA may be appropriate, reasonable remediation timeframes, source control, performance monitoring, and contingency remedies where MNA will be employed.

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Role of Monitored Natural Attenuation in OSWER Remediation Programs

Under OSWER programs, remedies selected for contaminated media (such as contaminated soil and groundwater) must protect human health and the environment. Remedies may achieve this level of protection using a variety of methods, including treatment, containment, engineering controls, and other means identified during the remedy selection process.

The regulatory and policy frameworks for corrective actions under the UST, RCRA, and Superfund programs have been established to implement their respective statutory mandates and to promote the selection of technically defensible, nationally consistent, and cost effective solutions for the cleanup of contaminated media. EPA recognizes that MNA may be an appropriate remediation option for contaminated soil and groundwater under certain circumstances. However, determining the appropriate mix of remediation methods at a given site, including when and how to use MNA, can be a complex process. Therefore, MNA should be carefully evaluated along with other viable remedial approaches or technologies (including innovative technologies) within the applicable remedy selection framework. **MNA should not be considered a default or presumptive remedy at any contaminated site.**

Each OSWER program has developed regulations and policies to address the particular types of contaminants and facilities within its purview[13]. Although there are differences among

[13] Existing program guidance and policy regarding MNA can be obtained from the following sources: For Superfund, see "Guidance on Remedial Actions for Contaminated Groundwater at Superfund Sites," (USEPA, 1988a; pp. 5-7 and 5-8); the Preamble to the 1990 National Contingency Plan (USEPA, 1990a, pp.8733-34); and "Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, Final Guidance" (USEPA, 1996a; p. 18). For the RCRA program, see the Subpart S Proposed Rule (USEPA, 1990b, pp.30825 and 30829), and the Advance Notice of Proposed Rulemaking (USEPA, 1996b, pp.19451-52). For the UST program, refer to Chapter IX in "How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites: A Guide for Corrective Action Plan Reviewers;" (USEPA, 1995a).

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these programs, they share several key principles that should generally be considered during selection of remedial measures, including:

- Source control measures should use treatment to address "principal threat" wastes (or products) wherever practicable, and engineering controls such as containment for waste (or products) that pose a relatively low long-term threat, or where treatment is impracticable.[14]

- Contaminated groundwaters should be returned to "their beneficial uses[15] wherever practicable, within a timeframe that is reasonable given the particular circumstances of the site." When restoration of groundwater is not practicable, EPA "expects to prevent further migration of the plume, prevent exposure to the contaminated groundwater, and evaluate further risk reduction."[16]

- Contaminated soil should be remediated to achieve an acceptable level of risk to human and environmental receptors, and to prevent any transfer of contaminants to other media (*e.g.*, surface or groundwater, air, sediments) that would result in an unacceptable risk or exceed required cleanup levels.

- Remedial actions in general should include opportunity(ies) for public involvement that serve to both educate interested parties and to solicit feedback concerning the decision making process.

Consideration or selection of MNA as a remedy or remedy component does not in any way change or displace these (or other) remedy selection principles. Nor does use of MNA

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[14] Principal threat wastes are those **source materials** that are "highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur. They include liquids and other highly mobile materials (*e.g.*, solvents) or materials having high concentrations of toxic compounds." (USEPA, 1991b). Low level threat wastes are "source materials that generally can be reliably contained and that would present only a low risk in the event of release." (USEPA, 1991b). Since contaminated groundwater is not source material, it is neither a principal nor a low-level threat waste.

[15] **Beneficial uses** of groundwater could include uses for which water quality standards have been promulgated, (*e.g.*, drinking water supply, discharge to surface water), or where groundwater serves as a source of recharge to either surface water or adjacent aquifers, or other uses. These or other types of beneficial uses may be identified as part of a Comprehensive State Groundwater Protection Program (CSGWPP). For more information on CSGWPPs, see USEPA, 1992a and USEPA, 1997b, or contact your state implementing agency.

[16] This is a general expectation for remedy selection in the Superfund program, as stated in §300.430 (a)(1)(iii)(F) of the National Contingency Plan (USEPA, 1990a, p.8846). The NCP Preamble also specifies that cleanup levels appropriate for the expected beneficial use (*e.g.*, MCLs for drinking water) "should generally be attained throughout the contaminated plume, or at and beyond the edge of the waste management area when waste is left in place" (USEPA, 1990a, p.8713). The RCRA Corrective Action program has similar expectations (see USEPA, 1996b, pp.19448-19450).

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diminish EPA's or the regulated party's responsibility to achieve protectiveness or to satisfy long-term site remediation objectives. EPA expects that **MNA will be an appropriate remediation method only where its use will be protective of human health and the environment and it will be capable of achieving site-specific remediation objectives within a timeframe that is reasonable compared to other alternatives.** The effectiveness of MNA in both near-term and long-term timeframes should be demonstrated to EPA (or other overseeing regulatory authority) through: 1) sound technical analyses which provide confidence in natural attenuation's ability to achieve remediation objectives; 2) performance monitoring; and 3) contingency (or backup) remedies where appropriate. **In summary, use of MNA does not imply that EPA or the responsible parties are "walking away" from the cleanup or financial responsibility at a site.**

It also should be emphasized that the selection of MNA as a remedy does **not** imply that active remediation measures are infeasible, or are "technically impracticable" from an engineering perspective. Technical impracticability (TI) determinations are used to justify a departure from cleanup levels that would otherwise be required at a Superfund site or RCRA facility based on the inability to achieve such cleanup levels using available remedial technologies (USEPA, 1993a). Such a TI determination does not imply that there will be no active remediation at the site, nor that MNA will be used at the site. Rather, such a TI determination simply indicates that the cleanup levels and objectives which would otherwise be required cannot practicably be attained using available remediation technologies. In such cases, an alternative cleanup strategy that is fully protective of human health and the environment must be identified. Such an alternative strategy may still include engineered remediation components, such as recovery of free phase NAPLs and containment of residual contaminants, in addition to approaches intended to restore some portion of the contaminated groundwater to beneficial uses. Several remedial approaches could be appropriate to address the dissolved plume, one of which could be MNA under suitable conditions. However, the evaluation of natural attenuation processes and the decision to rely upon MNA for the dissolved plume should be distinct from the recognition that restoration of a portion of the plume is technically impracticable (*i.e.*, MNA should **not** be viewed as a direct or presumptive outcome of a technical impracticability determination.)

<u>Demonstrating the Efficacy of Natural Attenuation Through Site Characterization</u>

Decisions to employ MNA as a remedy or remedy component should be thoroughly and adequately supported with site-specific characterization data and analysis. In general, the level of site characterization necessary to support a comprehensive evaluation of MNA is more detailed than that needed to support active remediation. Site characterizations for natural attenuation generally warrant a quantitative understanding of source mass; groundwater flow (including preferential pathways); contaminant phase distribution and partitioning between soil, groundwater, and soil gas; rates of biological and non-biological transformation; and an understanding of how all of these factors are likely to vary with time. This information is generally necessary since contaminant behavior is governed by dynamic processes which must be well understood before MNA can be appropriately applied at a site. Demonstrating the efficacy of

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MNA may require analytical or numerical simulation of complex attenuation processes. Such analyses, which are critical to demonstrate natural attenuation's ability to meet remediation objectives, generally require a detailed conceptual site model[17] as a foundation.

EPA recommends the use of conceptual site models to integrate data and guide both investigative and remedial actions. However, program implementors should be cautious and collect sufficient field data to test conceptual hypotheses and not "force-fit" site data into a pre-conceived, and possibly inaccurate, conceptual representation. For example, a common mechanism for transport of contaminants is advection-dispersion, by which contaminants dissolved in groundwater migrate away from a source area. An alternative mechanism of contaminant transport (*i.e.*, NAPL migration) could be associated with a relatively large release of NAPL into the subsurface such that the NAPL itself has the potential to migrate significant distances along preferential pathways. Since NAPL migration pathways are often difficult to locate in the subsurface, one may incorrectly conclude that only the dissolved transport model applies to a site, when a combined NAPL and dissolved phase migration model would be more accurate. Applying a wrong conceptual model, in the context of evaluating an MNA (or any other) remedy, could result in a deficient site characterization (*e.g.*, did not use tools and approaches designed to find NAPLs or NAPL migration pathways), and inappropriate selection of an MNA remedy where long-term sources were not identified nor considered during remedy selection. NAPL present as either free- or residual phase represents a significant mass of contamination that will serve as a long-term source. Sources of contamination are more appropriately addressed by engineered removal, treatment or containment technologies, as discussed later in this Directive. Where the sources of contamination have been controlled, dissolved plumes may be amenable to MNA because of the relatively small mass of contaminants present in the plume.

Site characterization should include collecting data to define (in three spatial dimensions over time) the nature and distribution of contaminants of concern and contaminant sources as well as potential impacts on receptors (see "Background" section for further discussion pertaining to "Contaminants of Concern"). However, where MNA will be considered as a remedial approach, certain aspects of site characterization may require more detail or additional elements. For

[17] A conceptual site model (CSM) is a three-dimensional representation that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The conceptual model provides the basis for assessing potential remedial technologies at the site. "Conceptual site model" is **not** synonymous with "computer model"; however, a computer model may be helpful for understanding and visualizing current site conditions or for predictive simulations of potential future conditions. Computer models, which simulate site processes mathematically, should in turn be based upon sound conceptual site models to provide meaningful information. Computer models typically require a lot of data, and the quality of the output from computer models is directly related to the quality of the input data. Because of the complexity of natural systems, models necessarily rely on simplifying assumptions that may or may not accurately represent the dynamics of the natural system. Calibration and sensitivity analyses are important steps in appropriate use of models. Even so, the results of computer models should be carefully interpreted and continuously verified with adequate field data. Numerous EPA references on models are listed in the "Additional References" section at the end of this Directive.

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example, to assess the contributions of sorption, dilution, and dispersion to natural attenuation of contaminated groundwater, a very detailed understanding of aquifer hydraulics, recharge and discharge areas and volumes, and chemical properties is necessary. Where biodegradation will be assessed, characterization also should include evaluation of the nutrients and electron donors and acceptors present in the groundwater, the concentrations of co-metabolites and metabolic by-products, and perhaps specific analyses to identify the microbial populations present. The findings of these, and any other analyses pertinent to characterizing natural attenuation processes, should be incorporated into the conceptual model of contaminant fate and transport developed for the site.

MNA may not be appropriate as a remedial option at many sites for technological or economic reasons. For example, in some complex geologic systems, technological limitations may preclude adequate monitoring of a natural attenuation remedy to ensure with a high degree of confidence that potential receptors will not be impacted. This situation typically occurs in many karstic, structured, and/or fractured rock aquifers where groundwater moves preferentially through discrete pathways (*e.g.*, solution channels, fractures, joints, foliations). The direction of groundwater flow through such heterogeneous (and often anisotropic) materials can not be predicted directly from the hydraulic gradient, and existing techniques may not be capable of identifying the pathway along which contaminated groundwater moves through the subsurface. MNA will not generally be appropriate where site complexities preclude adequate monitoring. In some other situations where it may be technically feasible to monitor the progress of natural attenuation, the cost of site characterization and long-term monitoring required for the implementation of MNA may be higher than the cost of other remedial alternatives. Under such circumstances, MNA may not be less costly than other alternatives.

A related consideration for site characterization is how other remedial activities at the site could affect natural attenuation. For example, the capping of contaminated soil could alter both the type of contaminants leached to groundwater, as well as their rate of transport and degradation. Another example could be where there is co-mingled petroleum and chlorinated solvent contamination. In such cases, degradation of the chlorinated solvents is achieved, in part, through the action of microbes that derive their energy from the carbon in the petroleum. Recovery of the petroleum removes some of the source of food for these microbes and the rate of degradation of the chlorinated solvents is decreased. Therefore, the impacts of any ongoing or proposed remedial actions should be factored into the analysis of the effectiveness of MNA.

Once site characterization data have been collected and a conceptual model developed, the next step is to evaluate the potential efficacy of MNA as a remedial alternative. This involves collection of site-specific data sufficient to estimate with an acceptable level of confidence both the rate of attenuation processes and the anticipated time required to achieve remediation objectives. A three-tiered approach to such an evaluation is becoming more widely practiced and accepted. In this approach, successively more detailed information is collected as necessary to provide a specified level of confidence on the estimates of attenuation rates and remediation timeframe. These three tiers of site-specific information, or “lines of evidence”, are:

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(1) Historical groundwater and/or soil chemistry data that demonstrate a clear and meaningful trend[18] of decreasing contaminant mass and/or concentration over time at appropriate monitoring or sampling points. (In the case of a groundwater plume, decreasing concentrations should not be solely the result of plume migration. In the case of inorganic contaminants, the primary attenuating mechanism should also be understood.)

(2) Hydrogeologic and geochemical data that can be used to demonstrate **indirectly** the type(s) of natural attenuation processes active at the site, and the rate at which such processes will reduce contaminant concentrations to required levels. For example, characterization data may be used to quantify the rates of contaminant sorption, dilution, or volatilization, or to demonstrate and quantify the rates of biological degradation processes occurring at the site.

(3) Data from field or microcosm studies (conducted in or with actual contaminated site media) which **directly** demonstrate the occurrence of a particular natural attenuation process at the site and its ability to degrade the contaminants of concern (typically used to demonstrate biological degradation processes only).

Unless EPA or the overseeing regulatory authority determines that historical data (Number 1 above) are of sufficient quality and duration to support a decision to use MNA, data characterizing the nature and rates of natural attenuation processes at the site (Number 2 above) should be provided. Where the latter are also inadequate or inconclusive, data from microcosm studies (Number 3 above) may also be necessary. In general, more supporting information may be required to demonstrate the efficacy of MNA at those sites with contaminants which do not readily degrade through biological processes (*e.g.*, most non-petroleum compounds, inorganics), or that transform into more toxic and/or mobile forms than the parent contaminant, or where monitoring has been performed for a relatively short period of time. The amount and type of information needed for such a demonstration will depend upon a number of site-specific factors, such as the size and nature of the contamination problem, the proximity of receptors and the potential risk to those receptors, and other characteristics of the environmental setting (*e.g.*, hydrogeology, ground cover, climatic conditions).

Note that those parties responsible for site characterization and remediation should ensure that all data and analyses needed to demonstrate the efficacy of MNA are collected and evaluated by capable technical specialists with expertise in the relevant sciences. Furthermore, EPA expects that documenting the level of confidence on attenuation rates will provide more technically defensible predictions of remedial timeframes and form the basis for more effective performance monitoring programs.

[18] For guidance on statistical analysis of environmental data, please see USEPA, 1989, USEPA, 1993b, USEPA, 1993d, and Gilbert, 1987, listed in the "References Cited" section at the end of this Directive.

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Sites Where Monitored Natural Attenuation May Be Appropriate

MNA is appropriate as a remedial approach where it can be demonstrated capable of achieving a site's remediation objectives within a timeframe that is reasonable compared to that offered by other methods and where it meets the applicable remedy selection criteria (if any) for the particular OSWER program. **EPA expects that MNA will be most appropriate when used in conjunction with other remediation measures (*e.g.*, source control, groundwater extraction), or as a follow-up to active remediation measures that have already been implemented**.

In determining whether MNA is an appropriate remedy for soil or groundwater at a given site, EPA or other regulatory authorities should consider the following:

- Whether the contaminants present in soil or groundwater can be effectively remediated by natural attenuation processes;
- Whether or not the contaminant plume is stable and the potential for the environmental conditions that influence plume stability to change over time;
- Whether human health, drinking water supplies, other groundwaters, surface waters, ecosystems, sediments, air, or other environmental resources could be adversely impacted as a consequence of selecting MNA as the remediation option;
- Current and projected demand for the affected resource over the time period that the remedy will remain in effect;
- Whether the contamination, either by itself or as an accumulation with other nearby sources (on-site or off-site), will exert a long-term detrimental impact on available water supplies or other environmental resources;
- Whether the estimated timeframe of remediation is reasonable (see section on "Reasonable Timeframe for Remediation") compared to timeframes required for other more active methods (including the anticipated

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effectiveness of various remedial approaches on different portions of the contaminated soil and/or groundwater);

- The nature and distribution of sources of contamination and whether these sources have been, or can be, adequately controlled;

- Whether the resulting transformation products present a greater risk, due to increased toxicity and/or mobility, than do the parent contaminants;

- The impact of existing and proposed active remediation measures upon the MNA component of the remedy, or the impact of remediation measures or other operations/activities (*e.g.*, pumping wells) in close proximity to the site; and

- Whether reliable site-specific mechanisms for implementing institutional controls (*e.g.*, zoning ordinances) are available, and if an institution responsible for their monitoring and enforcement can be identified.

Of the above factors, the most important considerations regarding the suitability of MNA as a remedy include: whether the contaminants are likely to be effectively addressed by natural attenuation processes, the stability of the groundwater contaminant plume and its potential for migration, and the potential for unacceptable risks to human health or environmental resources by the contamination. MNA should not be used where such an approach would result in either plume migration[19] or impacts to environmental resources that would be unacceptable to the overseeing regulatory authority. **Therefore, sites where the contaminant plumes are no longer increasing in extent, or are shrinking, would be the most appropriate candidates for MNA remedies.**

An example of a situation where MNA may be appropriate is a remedy that includes source control, a pump-and-treat system to mitigate the highly-contaminated plume areas, and MNA in the lower concentration portions of the plume. In combination, these methods would maximize groundwater restored to beneficial use in a timeframe consistent with future demand on the aquifer, while utilizing natural attenuation processes to reduce the reliance on active remediation methods and reduce remedy cost. If, at such a site, the plume was either expanding

[19] In determining whether a plume is stable or migrating, users of this Directive should consider the **uncertainty** associated with defining the limits of contaminant plumes. For example, a plume is typically delineated for each contaminant of concern as a 2- or 3-dimensional feature. Plumes are commonly drawn by computer contouring programs which estimate concentrations between actual data points. EPA recognizes that a plume boundary is more realistically defined by a zone rather than a line. Fluctuations within this zone are likely to occur due to a number of factors (*e.g.*, analytical, seasonal, spatial, etc.) which may or may not be indicative of a trend in plume migration. Therefore, site characterization activities and performance monitoring should focus on collection of data of sufficient quality to enable decisions to be made with a high level of confidence. See USEPA, 1993b, USEPA, 1993c, USEPA, 1994b, and USEPA, 1998b, for additional guidance.

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or threatening downgradient wells or other environmental resources, then MNA would **not** be an appropriate remedy.

Reasonable Timeframe for Remediation

EPA recognizes that determination of what timeframe is "reasonable" for **attaining remediation objectives** is a site-specific determination. The NCP preamble suggests that a "reasonable" timeframe for a remedy relying on natural attenuation is generally a "...timeframe **comparable** to that which could be achieved through active restoration" (USEPA, 1990a, p.8734; emphasis added). The NCP preamble further states that "[t]he most appropriate timeframe must, however, be determined through an analysis of alternatives" (USEPA, 1990a, p.8732). To ensure that these estimates are comparable, assumptions should be consistently applied for each alternative considered. Thus, determination of the most appropriate timeframe is achieved through a comparison of estimates of remediation timeframe for **all** appropriate remedy alternatives.

If **restoring groundwaters to beneficial uses** is a remediation objective, a comparison of restoration alternatives from most aggressive to passive (*i.e.*, MNA) will provide information concerning the approximate range of time periods needed to attain groundwater cleanup levels. An excessively long restoration timeframe, using the most aggressive restoration method, **may** indicate that groundwater restoration is technically impracticable from an engineering perspective (USEPA, 1993a). Where restoration **is** technically **practicable** using either aggressive or passive methods, the longer restoration timeframe required by the passive alternative may be reasonable in comparison with the timeframe needed for more aggressive restoration alternatives (USEPA, 1996a).

The advantages and disadvantages of each remedy alternative, including the timeframe, should be evaluated in accordance with the remedy selection criteria used by each OSWER program. Whether a particular remediation timeframe is appropriate and reasonable for a given site is determined by balancing tradeoffs among many factors which include:

- Classification of the affected resource (*e.g.*, drinking water source, agricultural water source) and value of the resource[20];

[20] In determining whether an extended remediation timeframe may be appropriate for the site, EPA and other regulatory authorities should consider state groundwater resource classifications, priorities and/or valuations where available, in addition to relevant federal guidelines. Individual states may provide information and guidance relevant to groundwater classifications or use designations as part of a Comprehensive State Groundwater Protection Program (CSGWPP). (See USEPA, 1992a and USEPA, 1997b).

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- Relative timeframe in which the affected portions of the aquifer might be needed for future water supply (including the availability of alternate supplies);

- Subsurface conditions and plume stability which can change over an extended timeframe;

- Whether the contamination, either by itself or as an accumulation with other nearby sources (on-site or off-site), will exert a long-term detrimental impact on available water supplies or other environmental resources;

- **Uncertainties** regarding the mass of contaminants in the subsurface and predictive analyses (*e.g.*, remediation timeframe, timing of future demand, and travel time for contaminants to reach points of exposure appropriate for the site);

- Reliability of monitoring and of institutional controls over long time periods;

- Public acceptance of the timeframe required to reach remediation objectives; and

- Provisions by the responsible party for adequate funding of monitoring and performance evaluation over the time period required for remediation.

It should be noted that the timeframe required for MNA remedies is often longer than that required for more active remedies. **As a consequence, the uncertainty associated with the above factors increases dramatically. Adequate performance monitoring and contingency remedies (both discussed in later sections of this Directive) should be utilized because of this higher level of uncertainty.** When determining reasonable timeframes, the uncertainty in estimated timeframes should be considered, as well as the ability to establish performance monitoring programs capable of verifying the performance expected from natural attenuation in a timely manner (*e.g.*, as would be required in a Superfund five-year remedy review).

A decision on whether or not MNA is an appropriate remedy for a given site is usually based on estimates of the rates of natural attenuation processes. Site characterization (and monitoring) data are typically used for estimating attenuation rates. These calculated rates may be expressed with respect to either time or distance from the source. Time-based estimates are

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used to predict the time required for MNA to achieve remediation objectives and distance-based estimates provide an evaluation of whether a plume will expand, remain stable, or shrink. For environmental decision-making, EPA requires that the data used be of "adequate quality and usability for their intended purpose." (USEPA, 1998b). Therefore, where these rates are used to evaluate MNA, or predict the future behavior of contamination, they must also be of "adequate quality and usability." Statistical confidence intervals should be estimated for calculated attenuation rate constants (including those based on methods such as historical trend data analysis, analysis of attenuation along a flow path in groundwater, and microcosm studies). When predicting remedial timeframes, sensitivity analyses should also be performed to indicate the dependence of the calculated remedial timeframes on uncertainties in rate constants and other factors (McNab and Dooher, 1998). A statistical evaluation of the rate constants estimated from site characterization studies of natural attenuation of groundwater contamination often reveals that the estimated rate constants contain considerable uncertainty. For additional guidance on data quality, see USEPA, 1993c, 1994c, 1995b, and 1995c.

As an example, analysis of natural attenuation rates from many sites indicates that a measured decrease in contaminant concentrations of at least one order of magnitude is necessary to determine the appropriate rate law to describe the rate of attenuation, and to demonstrate that the estimated rate is statistically different from zero at a 95% level of confidence (Wilson, 1998). Due to variability resulting from sampling and analysis, as well as plume variability over time, smaller apparent reductions are often insufficient to demonstrate (with 95% level of confidence) that attenuation has in fact occurred at all.

Thus, EPA or other regulatory authorities should consider a number of factors when evaluating reasonable timeframes for MNA at a given site. These factors, on the whole, should allow the overseeing regulatory authority to determine whether a natural attenuation remedy (including institutional controls where applicable) will fully protect potential human and environmental receptors, and whether the site remediation objectives and the time needed to meet them are consistent with the regulatory expectation that contaminated groundwaters will be restored to beneficial uses within a reasonable timeframe. **When these conditions cannot be met using MNA, a remedial alternative that more likely would meet these expectations should be selected.**

Remediation of Sources

Source control measures should be evaluated as part of the remedy decision process at **all** sites, particularly where MNA is under consideration as the remedy or as a remedy component. Source control measures include removal, treatment, or containment, or a combination of these approaches. EPA prefers remedial options which remove free-phase NAPLs and treat those source materials determined to constitute "principal threat wastes" (see Footnote 13).

Contaminant sources that are not adequately addressed complicate the long-term cleanup effort. For example, following free product recovery, residual contamination from a petroleum

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fuel release may continue to leach significant quantities of contaminants into the groundwater as well as itself posing unacceptable risks to humans or environmental resources. Such a lingering source often unacceptably extends the time necessary to reach remediation objectives. This leaching can occur even while contaminants are being naturally attenuated in other parts of the plume. If the rate of attenuation is lower than the rate of replenishment of contaminants to the groundwater, the plume can continue to expand thus contaminating additional groundwater and potentially posing a threat to downgradient receptors.

Control of source materials is the most effective means of ensuring the timely attainment of remediation objectives. **EPA, therefore, expects that source control measures will be evaluated for all contaminated sites and that source control measures will be taken at most sites where practicable.** At many sites it will be appropriate to implement source control measures during the initial stages of site remediation ("phased remedial approach"), while collecting additional data to determine the most appropriate groundwater remedy.

Performance Monitoring and Evaluation

Performance monitoring to evaluate remedy effectiveness and to ensure protection of human health and the environment is a critical element of all response actions. Performance monitoring is of even greater importance for MNA than for other types of remedies due to the potentially longer remediation timeframes, potential for ongoing contaminant migration, and other uncertainties associated with using MNA. This emphasis is underscored by EPA's reference to "monitored natural attenuation".

The monitoring program developed for each site should specify the location, frequency, and type of samples and measurements necessary to evaluate whether the remedy is performing as expected and is capable of attaining remediation objectives. In addition, all monitoring programs should be designed to accomplish the following:

- Demonstrate that natural attenuation is occurring according to expectations;
- Detect changes in environmental conditions (*e.g.*, hydrogeologic, geochemical, microbiological, or other changes) that may reduce the efficacy of any of the natural attenuation processes[21];
- Identify any potentially toxic and/or mobile transformation products;
- Verify that the plume(s) is not expanding (either downgradient, laterally or vertically);

[21] Detection of changes will depend on the proper siting and construction of monitoring wells/points. Although the siting of monitoring wells is a concern for any remediation technology, it is of even greater concern with MNA because of the lack of engineering controls to control contaminant migration.

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- Verify no unacceptable impact to downgradient receptors;
- Detect new releases of contaminants to the environment that could impact the effectiveness of the natural attenuation remedy;
- Demonstrate the efficacy of institutional controls that were put in place to protect potential receptors; and
- Verify attainment of remediation objectives.

The frequency of monitoring should be adequate to detect, in a timely manner, the potential changes in site conditions listed above. At a minimum, the monitoring program should be sufficient to enable a determination of the rate(s) of attenuation and how that rate is changing with time. When determining attenuation rates, the uncertainty in these estimates and the associated implications should be evaluated (see McNab and Dooher, 1998). Flexibility for adjusting the monitoring frequency over the life of the remedy should also be included in the monitoring plan. For example, it may be appropriate to decrease the monitoring frequency at some point in time, once it has been determined that natural attenuation is progressing as expected and very little change is observed from one sampling round to the next. In contrast, the monitoring frequency may need to be increased if unexpected conditions (*e.g.*, plume migration) are observed.

Performance monitoring should continue until remediation objectives have been achieved, and longer if necessary to verify that the site no longer poses a threat to human health or the environment. Typically, monitoring is continued for a specified period (*e.g.*, one to three years) after remediation objectives have been achieved to ensure that concentration levels are stable and remain below target levels. The institutional and financial mechanisms for maintaining the monitoring program should be clearly established in the remedy decision or other site documents, as appropriate.

Details of the monitoring program should be provided to EPA or the overseeing regulatory authority as part of any proposed MNA remedy. Further information on the types of data useful for monitoring natural attenuation performance can be found in the ORD publications (*e.g.*, USEPA, 1997a, USEPA, 1994a) listed in the “References Cited” section of this Directive. Also, USEPA (1994b) published a detailed document on collection and evaluation of performance monitoring data for pump-and-treat remediation systems.

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Contingency Remedies

A contingency remedy is a cleanup technology or approach specified in the site remedy decision document that functions as a "backup" remedy in the event that the "selected" remedy fails to perform as anticipated. A contingency remedy may specify a technology (or technologies) that is (are) different from the selected remedy, or it may simply call for modification of the selected technology, if needed. Contingency remedies should generally be flexible—allowing for the incorporation of new information about site risks and technologies.

Contingency remedies are not new to OSWER programs. Contingency remedies should be included in the decision document where the selected technology is not proven for the specific site application, where there is significant uncertainty regarding the nature and extent of contamination at the time the remedy is selected, or where there is uncertainty regarding whether a proven technology will perform as anticipated under the particular circumstances of the site (USEPA, 1990c).

It is also recommended that one or more criteria ("triggers") be established, as appropriate, in the remedy decision document that will signal unacceptable performance of the selected remedy and indicate when to implement contingency remedies. Such criteria should generally include, but not be limited to, the following:

- Contaminant concentrations in soil or groundwater at specified locations exhibit an increasing trend not originally predicted during remedy selection;
- Near-source wells exhibit large concentration increases indicative of a new or renewed release;
- Contaminants are identified in monitoring wells located outside of the original plume boundary;
- Contaminant concentrations are not decreasing at a sufficiently rapid rate to meet the remediation objectives; and
- Changes in land and/or groundwater use will adversely affect the protectiveness of the MNA remedy.

In establishing triggers or contingency remedies, however, care is needed to ensure that sampling variability or seasonal fluctuations do not unnecessarily trigger a contingency. For example, an anomalous spike in dissolved concentration(s) at a well(s) might not be a true indication of a change in trend.

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EPA recommends that remedies employing MNA be evaluated to determine the need for including one or more contingency measures that would be capable of achieving remediation objectives. EPA believes that contingency remedies should generally be included as part of a MNA remedy which has been selected based primarily on predictive analyses rather than documented trends of decreasing contaminant concentrations.

SUMMARY

EPA remains fully committed to its goals of protecting human health and the environment by remediating contaminated soils, restoring contaminated groundwaters to their beneficial uses, preventing migration of contaminant plumes, and protecting groundwaters and other environmental resources. EPA does not view MNA to be a "no action" remedy, but rather considers it to be a means of addressing contamination under a limited set of site circumstances where its use meets the applicable statutory and regulatory requirements. MNA is not a "presumptive" or "default" remediation alternative, but rather should be evaluated and compared to other viable remediation methods (including innovative technologies) during the study phases leading to the selection of a remedy. The decision to implement MNA should include a comprehensive site characterization, risk assessment where appropriate, and measures to control sources. In addition, the progress of natural attenuation towards a site's remediation objectives should be carefully monitored and compared with expectations to ensure that it will meet site remediation objectives within a timeframe that is reasonable compared to timeframes associated with other methods. Where MNA's ability to meet these expectations is uncertain and based predominantly on predictive analyses, decision-makers should incorporate contingency measures into the remedy.

EPA is confident that MNA will be, at many sites, a reasonable and protective component of a broader remediation strategy. However, EPA believes that there will be many other sites where either the uncertainties are too great or there is a need for a more rapid remediation that will preclude the use of MNA as a stand-alone remedy. This Directive should help promote consistency in how MNA remedies are proposed, evaluated, and approved.

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Appendix 24

USEPA, Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals From Electric Utilities; Amendments to the National Minimum Citeria (Phase One); Proposed Rule, 83 Fed. Reg. 11584 (Mar. 15, 2018) (Deposition Exhibit 15)

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ENVIRONMENTAL PROTECTION AGENCY

40 CFR Part 257

[EPA–HQ–OLEM–2017–0286; FRL–9973–31–OLEM]

RIN 2050–AG88

Hazardous and Solid Waste Management System: Disposal of Coal Combustion Residuals From Electric Utilities; Amendments to the National Minimum Criteria (Phase One); Proposed Rule

AGENCY: Environmental Protection Agency (EPA).

ACTION: Proposed rule.

SUMMARY: On April 17, 2015, the Environmental Protection Agency (EPA or the Agency) promulgated national minimum criteria for existing and new coal combustion residuals (CCR) landfills and existing and new CCR surface impoundments. The Agency is proposing a rule that will address four provisions of the final rule that were remanded back to the Agency on June 14, 2016 by the U.S. Court of Appeals for the D.C. Circuit. The Agency is also proposing six provisions that establish alternative performance standards for owners and operators of CCR units located in states that have approved CCR permit programs (participating states) or are otherwise subject to oversight through a permit program administered by EPA. Finally, the Agency is proposing an additional revision based on comments received since the date of the final CCR rule.

DATES: *Comments.* Written comments must be received on or before April 30, 2018. Comments postmarked after the close of the comment period will be stamped ''late'' and may or may not be considered by the Agency.

Public Hearing. EPA will hold a hearing on this proposed rule on April 24, 2018 in the Washington, DC metropolitan area. Additional information about the hearing will be posted in the docket for this proposal and on EPA's CCR website (*https://www.epa.gov/coalash*).

ADDRESSES: *Comments.* Submit your comments, identified by Docket ID No. EPA–HQ–OLEM–2017–0286, at *https://www.regulations.gov.* Follow the online instructions for submitting comments. Once submitted, comments cannot be edited or removed from *Regulations.gov*. The EPA may publish any comment received to its public docket. Do not submit electronically any information you consider to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Multimedia submissions (audio, video, etc.) must be accompanied by a written comment. The written comment is considered the official comment and should include discussion of all points you wish to make. The EPA will generally not consider comments or comment contents located outside of the primary submission (*i.e.*, on the web, cloud, or other file sharing system). For additional submission methods, the full EPA public comment policy, information about CBI or multimedia submissions, and general guidance on making effective comments, please visit *https://www.epa.gov/dockets/commenting-epa-dockets.*

Instructions. Direct your comments on the proposed rule to Docket ID No. EPA–HQ–OLEM–2017–0286. The EPA's policy is that all comments received will be included in the public docket and may be made available online at *https://www.regulations.gov,* including any personal information provided, unless the comment includes information claimed to be CBI or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through *https://www.regulations.gov* or email. The *https://www.regulations.gov* website is an ''anonymous access'' system, which means the EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an email comment directly to the EPA without going through *https://www.regulations.gov,* your email address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, the EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If the EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, the EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses.

Docket. The EPA has established a docket for this action under Docket ID No. EPA–HQ–OLEM–2017–0286. The EPA has previously established a docket for the April 17, 2015, CCR final rule under Docket ID No. EPA–HQ–RCRA–2009–0640. All documents in the docket are listed in the *https://www.regulations.gov* index. Although listed in the index, some information is not publicly available, *e.g.*, CBI or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, will be publicly available only in hard copy form. Publicly available docket materials are available either electronically at *https://www.regulations.gov* or in hard copy at the EPA Docket Center (EPA/DC), EPA WJC West Building, Room 3334, 1301 Constitution Ave. NW, Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding holidays. The telephone number for the Public Reading Room is (202) 566–1744, and the telephone number for the EPA Docket Center is (202) 566–1742.

FOR FURTHER INFORMATION CONTACT: For information concerning this proposed rule, contact Mary Jackson, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5304P, Washington, DC 20460; telephone number: (703) 308–8453; email address: *jackson.mary@epa.gov.* For more information on this rulemaking please visit *https://www.epa.gov/coalash.*

SUPPLEMENTARY INFORMATION:

Submitting CBI. Do not submit information that you consider to be CBI electronically through *http://www.regulations.gov* or email. Send or deliver information identified as CBI to only the following address: ORCR Document Control Officer, Mail Code 5305–P, Environmental Protection Agency, 1200 Pennsylvania Avenue NW, Washington, DC 20460; Attn: Docket ID No. EPA–HQ–OLEM–2017–0286.

Clearly mark the part or all of the information that you claim to be CBI. For CBI information in a disk or DC–ROM that you mail to the EPA, mark the outside of the disk or CD–ROM as CBI and then identify electronically within the disk or CD–ROM the specific information that is claimed as CBI. In addition to one complete version of the comment that includes information claimed as CBI, a copy of the comment that does not contain the information claimed as CBI must be submitted for inclusion in the public docket. If you submit a CD–ROM or disk that does not contain CBI, mark the outside of the disk or CD–ROM clearly that it does not contain CBI. Information marked as CBI will not be disclosed except in accordance with procedures set forth in 40 Code of Federal Regulations (CFR) part 2.

Public Hearing. This notice also announces that EPA will be holding a

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public hearing on this proposed rule. A public hearing provides interested parties the opportunity to present data, views, or arguments concerning the proposed rule. EPA may ask clarifying questions during the oral presentations, but will not respond formally to any comments or the presentations made. Additional information about the hearing will be posted in the docket for this proposal and on EPA's CCR website (*https://www.epa.gov/coalash*).

I. General Information

A. Executive Summary

1. Purpose of the Regulatory Action

The EPA is proposing to amend the regulations for the disposal of coal combustion residuals (CCR) in landfills and surface impoundments in order to: (1) Address provisions of the final rule that were remanded back to the Agency on June 14, 2016; (2) to provide States with approved CCR permit programs (or EPA where it is the permitting authority) under the Water Infrastructure Improvements for the Nation (WIIN) Act the ability to set certain alternative performance standards; and (3) address one additional issue raised by commenters that has arisen since the April 2015 publication of the final rule, namely the use of CCR during certain closure situations.

2. Summary of the Major Provisions of the Regulatory Action

EPA is proposing two categories of revisions plus one additional revision to the regulations at 40 CFR 257 subpart D. The first category is associated with a judicial remand in connection with the settlement agreement entered on April 18, 2016 that resolved four claims brought by two sets of plaintiffs against the final CCR rule. See *USWAG et al.* v. *EPA,* No. 15–1219 (D.C. Cir. 2015). The second category is a set of revisions that are proposed in response to the WIIN Act. The last revision in the proposal deals with an issue that has been raised by commenters since the publication date of the final CCR rule. In the 2015 CCR final rule, EPA organized the regulations for the recordkeeping requirements, notification requirements and publicly accessible internet site requirements into 40 CFR 257.105, 257.106, and 257.107, respectively.[1] There are recordkeeping, notification and internet posting requirements associated with the revisions that are in this proposal. Those requirements have not all been added to the regulatory language. Those requirements will be added to §§ 257.105–257.107 when the final rule is developed.

a. Proposals Associated With Judicial Remand

The Agency is proposing four changes from the CCR final rule that was promulgated on April 17, 2015 associated with the judicial remand. The proposed revisions would: (1) Clarify the type and magnitude of non-groundwater releases that would require a facility to comply with some or all of the corrective action procedures set forth in 40 CFR 257.96–257.98 in meeting their obligation to clean up the release; (2) add boron to the list of constituents in Appendix IV of part 257 that trigger corrective action and potentially the requirement to retrofit or close the CCR unit; (3) determine the requirement for proper height of woody and grassy vegetation for slope protection; and (4) modify the alternative closure provisions.

b. Proposals Associated With the WIIN Act

The Agency is proposing six alternative performance standards that would apply in participating states (*i.e.*, those which have an EPA-approved CCR permit program under the WIIN Act) or in those instances where EPA is the permitting authority. Those alternative performance standards would allow a state with an approved permit program or EPA to: (1) Use alternative risk-based groundwater protection standards for constituents where no Maximum Contaminant Level exists; (2) modify the corrective action remedy in certain cases; (3) suspend groundwater monitoring requirements if a no migration demonstration can be made; (4) establish an alternate period of time to demonstrate compliance with the corrective action remedy; (5) modify the post-closure care period; and (6) allow Directors of states to issue technical certifications in lieu of the current requirement to have professional engineers issue certifications. These alternative standards are discussed in more detail later in this proposal.

Under the WIIN Act, EPA is the permitting authority for CCR units located in Indian County. EPA would also serve as the permitting authority for CCR units located in nonparticipating states subject to a Congressional appropriation to carry out that function. At this time, Congress has not provided appropriations to EPA to serve as the permitting authority in nonparticipating states. EPA is therefore proposing that in those cases where it is the permitting authority, it will have the same ability as a Director of a State with an approved CCR program to apply the alternative performance standards. In addition, EPA seeks comment on whether and how these alternative performance standards could be implemented by the facilities directly (even in States without a permit program), given that the WIIN Act provided authority for EPA oversight and enforcement.

c. Proposal To Allow CCR To Be Used During Certain Closure Situations

EPA is proposing to revise the current regulations to allow the use of CCR in the construction of final cover systems for CCR units closing pursuant to § 257.101 that are closing with waste-in-place. EPA is also proposing specific criteria that the facility would need to meet in order to allow for the use of CCR in the final cover system.

With this action EPA is not reconsidering, proposing to reopen, or otherwise soliciting comment on any other provisions of the final CCR rule beyond those specifically identified as such in this proposal. EPA will not respond to comments submitted on any issues other than those specifically identified in this proposal and they will not be considered part of the rulemaking record.

3. What are the incremental costs and benefits of this action?

This action is expected to result in net cost savings amounting to between $32 million and $100 million per year when discounting at 7 percent and annualized over 100 years. It is expected to result in net cost savings of between $25 million and $76 million per year when discounting at 3 percent and annualized over 100 years. Further information on the economic effects of this action can be found in Unit V of this preamble.

B. Does this action apply to me?

This rule applies to all CCR generated by electric utilities and independent power producers that fall within the North American Industry Classification System (NAICS) code 221112 and may affect the following entities: Electric utility facilities and independent power producers that fall under the NAICS code 221112. This discussion is not intended to be exhaustive, but rather provides a guide for readers regarding entities likely to be regulated by this action. This discussion lists the types of entities that EPA is now aware could potentially be regulated by this action. Other types of entities not listed in the table could also be regulated. To determine whether your entity is regulated by this action, you should

[1] Unless otherwise specified, all references to part 257 in this preamble are to title 40 of the Code of Federal Regulations (CFR).

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carefully examine the applicability criteria found in § 257.50 of title 40 of the Code of Federal Regulations. If you have questions regarding the applicability of this action to a particular entity, consult the person listed in the **FOR FURTHER INFORMATION CONTACT** section.

II. Background

A. CCR Rule

On April 17, 2015, EPA finalized national regulations to regulate the disposal of CCR as solid waste under subtitle D of the Resource Conservation and Recovery Act (RCRA) titled, ''Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities,'' (80 FR 21302) (CCR rule). The CCR rule established national minimum criteria for existing and new CCR landfills and existing and new CCR surface impoundments and all lateral expansions of CCR units that are codified in Subpart D of Part 257 of Title 40 of the Code of Federal Regulations. The criteria consist of location restrictions, design and operating criteria, groundwater monitoring and corrective action, closure requirements and post-closure care, and record keeping, notification and internet posting requirements. The rule also required any existing unlined CCR surface impoundment that is contaminating groundwater above a regulated constituent's groundwater protection standard to stop receiving CCR and either retrofit or close, except in limited circumstances.

The rule was challenged by several different parties, including a coalition of regulated entities and a coalition of environmental organizations. See, *USWAG et al.* v. *EPA,* No. 15–1219 (D.C. Cir. 2015). Four of the claims, a subset of the provisions challenged by the industry and environmental Petitioners, were settled. The rest were briefed and are currently pending before the U.S. Court of Appeals for the D.C. Circuit, awaiting resolution.

As part of that settlement, on April 18, 2016 EPA requested the court to remand the four claims back to the Agency. On June 14, 2016 the U.S. Court of Appeals for the D.C. Circuit granted EPA's motion.

One claim, which was settled by the vacatur of the provision allowing inactive surface impoundments to close early and thereby avoid groundwater monitoring, cleanup, and post-closure care requirements, was the subject of a recent rulemaking. See, 81 FR 51802 (August 5, 2016).

The remaining claims that were remanded back to the Agency are the subject of this proposed rule. As part of the settlement, EPA committed to issue a proposed rule or rules to: (1) Establish requirements for the use of vegetation as slope protection on CCR surface impoundments; (2) Clarify the type and magnitude of non-groundwater releases for which a facility must comply with some or all of the rule's corrective action procedures; and (3) Add Boron to the list of contaminants in Appendix IV, whose detection trigger more extensive monitoring and cleanup requirements. Each of these are discussed further in Unit III of the preamble. As specified in the settlement, EPA presently intends to take final action on these proposals by June 2019. The issue of alternative closure requirements (due to lack of capacity for non-CCR wastestreams) was also remanded, but was not part of the settlement agreement. That issue is also discussed in Unit III of this preamble.

In addition, on September 13, 2017, EPA granted petitions from the Utility Solid Waste Activities Group (USWAG) and from AES Puerto Rico LLP requesting the Agency initiate rulemaking to reconsider provisions of the 2015 final rule.[2] EPA determined that it was appropriate and in the public interest to reconsider provisions of the final rule addressed in the petitions, in light of the issues raised in the petitions as well as the new authorities in the WIIN Act.

This determination raised some questions as to how the remaining issues in the CCR litigation should be handled. In response to various motions filed with U.S. Court of Appeals for the D.C. Circuit, the court ordered EPA to submit a status report indicating which provisions of the final CCR rule were being or were likely to be reconsidered by the Agency and a timeline for this reconsideration. EPA filed that status report on November 15, 2017 indicating that the following provisions were or were likely to be reconsidered. These included issues that were before the court as well as those that were not:

Provision of the CCR rule	Description
Provisions under Reconsideration Subject to Challenge in Litigation	
§ 257.50(c), § 257.100	EPA Regulation of Inactive Surface Impoundments.
§ 257.53—definition of beneficial use	The Criteria for Determining Whether Activities Constitute Beneficial Use or Disposal.
§ 257.95(h)(2)	Use of Risk-Based Alternative Standards for Remediating Constituents Without an MCL.
§ 257.53—definition of CCR pile	The criteria for determining Whether a Pile will be Regulated as a Landfill or as Beneficial Use.
§ 257.96–98	Regulatory Procedures Used to Remediate Certain Non-Groundwater Releases.
§§ 257.73(a)(4), 257.73(d)(1)(iv), 257.74(a)(4), 257.74(d)(1)(iv).	Requirements for Slope Protection on Surface Impoundments, Including Use of Vegetation.
§ 257.103(a) and (b)	Whether to Allow Continued Use of Surface Impoundments Subject to Mandated Closure if No Capacity for Non-CCR Wastestreams.
§ 257.50(e)	Regulation of Inactive Surface Impoundments, Including Legacy Ponds.
§ 257.100	Exemption for Certain Remediation and Post-Closure Requirements for Inactive Surface Impoundments that Close by April 17, 2018. Note: EPA completed reconsideration of the issues associated with this claim. See 81 FR 51802 (August 5, 2016).
Appendix IV to Part 257; §§ 257.93(b), 257.94(b), 257.95(b), 257.95(d)(1).	Addition of Boron to the List of Constituents that Trigger Corrective Action.

[2] A copy of both rulemaking petitions are included in the docket to this proposed rule.

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Provision of the CCR rule	Description
Provisions under Reconsideration Not Before the Court	
§ 257.97	Whether to Allow Modification of the Corrective Action Remedy.
§ 257.90	Whether to Suspend Groundwater Monitoring Requirements Where ''No Migration'' Demonstration is Made.
§ 257.98(c)	Whether to Allow Alternate Period of Time to Determine Remediation is Complete.
§ 257.104	Whether to Allow Modification of the Post-Closure Care Period.
§ 257.101, 257.102	Whether to Allow CCR to be Used to Close Surface Impoundments Subject to Mandated Closure.
§ 257.53	Clarify Placement of CCR in Clay Mines.

EPA further stated that it anticipates it will complete its reconsideration of all provisions identified in two phases. EPA indicated that in the first phase EPA would continue its process with respect to those provisions which were remanded back to EPA in June of 2016. These provisions are: The requirements for use of vegetation as slope protection; the provisions to clarify the type and magnitude of non-groundwater releases that would require a facility to comply with some or all of the corrective action procedures set out in §§ 257.96–257.98 in meeting its obligation to clean up the release; and provisions to add Boron to the list of contaminants in Appendix IV of the final rule that trigger corrective action. As noted elsewhere, the settlement agreement associated with the remand contemplates final action on these by June 14, 2019. EPA also indicated that as part of Phase One it would review the additional provisions to determine whether proposals to revise or amend some of these could be developed quickly enough so that they could be included in this first phase, and meet the schedule set out in the settlement agreement (*i.e.*, final action by June 2019). A number of these are associated with the WIIN Act which is discussed in detail in Unit II.B of this preamble.

EPA also indicated in its status report that it factored in two separate 90-day interagency review periods and assumed a 90-day public comment period as the minimum amount of time needed to provide comment based on the complexity of the issues involved. However, in developing this proposal, EPA now believes that a 90-day public comment period would be unnecessary. Instead, based on its assessment of the contents of the proposal, EPA will seek public comment for a period of 45 days. This proposal addresses four issues that were subject to legal challenge and included in the 2016 judicial remand. The legal authorities and policy options associated with these provisions have been addressed in comments to the 2015 CCR rule, as well as the litigation briefs filed by the United States and the industry and environmental petitioners. The remaining proposals included in this proposed rule largely reflect policy options that were discussed in the preamble to the 2015 final CCR rule and are based in large measure on the established record supporting the longstanding regulations for Municipal Solid Waste Landfills codified at 40 CFR part 258. By focusing this proposal on specific regulatory proposals that are largely rooted in existing requirements for how other nonhazardous waste is already regulated under Part 258, EPA has sought to minimize potential confusion and unnecessary burden on the public by basing many of these proposed changes to the 2015 CCR rule on well-understood legal theories and an existing scientific record.

EPA stated that it plans to complete review of all remaining matters identified on the chart and not covered in the Phase One proposal and determine whether to propose revisions to the provisions. EPA currently expects that if further revisions are determined to be warranted it will sign a Phase Two proposed rule no later than September 2018 and complete its reconsideration and take final action no later than December 2019.

Thus, this proposal includes those provisions where EPA has completed its review and has sufficient information to propose revisions. EPA continues to evaluate the other matters and will make a determination as to whether revisions are appropriate and if so anticipates signing a proposal by September of this year.

B. Water Infrastructure Improvements for the Nation Act

As noted in this preamble, the CCR rule was finalized in April 2015. As discussed in detail in the preamble to the final rule in the **Federal Register** (80 FR 21310–21311, April 17, 2015), these regulations were established under the authority of sections 1006(b), 1008(a), 2002(a), 3001, 4004, and 4005(a) of the Solid Waste Disposal Act of 1970, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984(HSWA), 42 U.S.C. 6900(B), 6907(A), 6912(A), 6944, and 6945(a). ''Subtitle D of RCRA establishes a framework for federal, state, and local government cooperation in controlling the management of nonhazardous solid waste.'' (80 FR 21310, April 17, 2015). EPA's role is to create national minimum criteria; however, states are not required to adopt or implement them; thus under subtitle D, these self-implementing criteria operate even in the absence of a regulatory entity to oversee them. ''As a consequence of this statutory structure—the requirement to establish national criteria and the absence of any requirement for direct regulatory oversight—to establish the criteria EPA must demonstrate, through factual evidence available in the rulemaking record, that the final rule will achieve the statutory standard (''no reasonable probability of adverse effects on health or the environment'') at all sites subject to the standards based exclusively on the final rule provisions. This means that the standards must account for and be protective of all sites, including those that are highly vulnerable.'' (80 FR 21311, April 17, 2015).

Given the existing statutory authorities, the final rule provided very limited site-specific flexibilities and did not provide for a State program which could adopt and be authorized to implement the federal criteria.

In December 2016, the Water Infrastructure Improvements for the Nation (WIIN) Act was enacted, establishing new statutory provisions applicable to CCR units, including: (a) Authorizing States to implement the CCR rule through an EPA-approved permit program; and (b) authorizing EPA to enforce the rule and in certain situations to serve as the permitting authority.[3]

[3] Public Law 114–322.

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The legislation amended RCRA section 4005, creating a new subsection (d) that establishes a Federal permitting program similar to other environmental statutes. States may submit a program to EPA for approval and permits issued pursuant to the approved state permit program operate in lieu of the Federal requirements. 42 U.S.C. 6945(d)(1)(A). To be approved, a State program must require each CCR unit to achieve compliance with the part 257 regulations (or successor regulations) or alternative State criteria that EPA has determined are ''at least as protective as'' the part 257 regulations (or successor regulations). State permitting programs may be approved in whole or in part. 42 U.S.C. 6945(d)(1)(B). States with approved CCR permitting programs are considered ''participating states''.

In states without an approved program, EPA is to issue permits, subject to the availability of appropriations specifically provided to carry out this requirement. 42 U.S.C. 6945(d)(2)(B). In addition, EPA must issue permits for CCR units in Indian Country. The legislation also authorized EPA to use its RCRA subtitle C information gathering and enforcement authorities to enforce the CCR rule or permit provisions, both in nonparticipating and participating States subject to certain conditions. 42 U.S.C. 6945(d)(4).

The statute expressly provides that facilities are to continue to comply with the CCR rule until a permit (issued either by an approved state or by EPA) is in effect for that unit. 42 U.S.C. 6945(d)(3), (6).

C. What is the agency's authority for taking this action?

These regulations are established under the authority of sections 1008(a), 2002(a), 4004, and 4005(a) and (d) of the Solid Waste Disposal Act of 1970, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA) and the Water Infrastructure Improvements for the Nation (WIIN) Act of 2016, 42 U.S.C. 6907(a), 6912(a), 6944, and 6945(a) and (d). While the 2015 final CCR rule, and today's proposed revisions, implement EPA's authority under RCRA, as amended by HSWA and the WIIN Act, EPA does not intend for these proposed revisions to impose any other separate requirements under any other statute or regulation, including under the Clean Water Act and its implementing regulations.

III. What amendments associated with the judicial remand is EPA proposing?

A. Addition of Boron to Appendix IV of Part 257

The final CCR rule establishes a comprehensive system of groundwater monitoring and corrective action so that facilities detect and address groundwater releases. (80 FR 21396, April 17, 2015). The final rule requires facilities to employ a two-stage groundwater monitoring program. The first stage is ''detection monitoring'' for the constituents listed in Appendix III of the rule. Appendix III constituents are intended to provide an early detection as to whether contaminants are migrating from the disposal unit into groundwater.

If during detection monitoring, the facility determines there to be a statistically significant exceedance of any constituent over the established background level, the facility must begin the second stage of the monitoring program, ''assessment monitoring,'' by sampling for an expanded set of constituents, which are listed in Appendix IV of the rule. Appendix IV constituents are those that EPA has determined present risks of concern to human health or the environment. These are generally determined by risk assessment and/or damage cases, and are based on the characteristics of the wastes in the unit.

If an owner or operator determines, based on assessment monitoring, that concentrations of one or more of the constituents listed in Appendix IV have been detected at statistically significant levels above the site's established groundwater protection standards, that facility must initiate corrective action as described in the final rule. This determination (*i.e.*, that constituent concentrations are at statistically significant levels above the site's established groundwater protection standard) also triggers the requirement that an existing unlined CCR surface impoundment retrofit or close. Thus, the primary difference between listing on Appendix III and IV is that detection of a constituent on Appendix III initiates requirements for more extensive monitoring, while detection of a constituent on Appendix IV compels a facility to initiate remedial actions to clean up the contamination and, in some cases, to close the unit.

In the proposed CCR rulemaking (June 21, 2010), EPA included boron in both the detection monitoring (Appendix III) and the assessment monitoring (Appendix IV) lists, 75 FR 35253. The parameters that EPA proposed that facilities use as early indicators of groundwater contamination (Appendix III) were boron, chloride, conductivity, fluoride, pH, sulfate, sulfide, and total dissolved solids (TDS). EPA selected these constituents because they are present in CCR and would move rapidly through the subsurface and thus provide an early detection as to whether contaminants were migrating from the disposal unit. EPA also proposed a list of constituents for inclusion on Appendix IV. The list included all of the constituents found in CCR or leachate based on the data EPA had at the time: Aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, selenium, sulfate, sulfide, thallium, and TDS. EPA then specifically asked for comment on this list and received a number of comments on these specific constituents.

In developing the final rule EPA generally relied on the same considerations it had relied on in the proposed rule. However, in response to comments, the final rule removed boron from Appendix IV, 80 FR 21500, April 17, 2015. The primary reason was that a Maximum Contaminant Level (MCL) had not yet been established under the Safe Drinking Water Act for boron. EPA generally preferred to include on Appendix IV only constituents that had established MCLs, as MCLs provide clear risk-based clean up levels in the event that corrective action is required. EPA also reasoned that because boron would remain on Appendix III it was unnecessary to include it on Appendix IV as facilities would be required to continue monitoring its concentration. Out of all the coal ash constituents modeled by EPA, boron has the fastest travel time, meaning that boron is likely to reach potential receptors before other constituents. Therefore, boron is expected to be one of the earliest constituents detected if releases to groundwater are occurring; consequently, EPA reasoned that retaining boron on Appendix III was more appropriate as it would function as a ''signal'' constituent that would ensure that assessment monitoring was quickly triggered in response to any release.

After the final rule was published, this decision was challenged as one claim in the multiparty litigation on the final rule. *See USWAG* v. *EPA,* No. 15–1219 (D.C. Cir.). In response to the litigation, EPA reexamined its decision to remove boron and concluded at that time that removing boron from Appendix IV had been inconsistent with other actions taken in the final rule. Specifically, fluoride had been included

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on both Appendix III and Appendix IV. Removing boron from Appendix IV because of a lack of a MCL was also inconsistent with the approach to other constituents: Lead, molybdenum, cobalt and lithium were included on Appendix IV, and they lack MCLs. EPA also concluded, as discussed in greater detail below, that the facts independently warranted reconsidering the exclusion of boron from Appendix IV. In light of these conclusions, EPA settled this claim, agreeing to reconsider its decision through a new rule making. The settlement of this claim was presented to the Court without challenge, and on June 14, 2016, the Court severed this claim from the rest of the litigation over the final rule.

Accordingly, EPA is proposing to add boron to Appendix IV of part 257. This proposal is based on a number of considerations. First, the risk assessment (RA) conducted to support the final CCR rule shows that boron is one of nine constituents determined to present unacceptable risks under the range of scenarios modeled.[4] Of these constituents, boron is the only one associated with risks to both human and ecological receptors. Specifically, the 2014 risk assessment shows that boron can pose developmental risk to humans when released to groundwater and can result in stunted growth, phytotoxicity, or death to aquatic biota and plants when released to surfacewater bodies. EPA is proposing to rely on the existing 2014 risk assessment to support this part of this proposal, and EPA seeks public comment on whether this reliance is appropriate. The risks identified therein support including boron on Appendix IV along with arsenic, cadmium, cobalt, fluoride, lithium, mercury, molybdenum and thallium.

Second, when reviewing damage cases collected for the CCR rulemaking, EPA identified one or more ''contaminants of concern'' (COCs) for each damage case. Boron is a COC in more damage cases (approximately 50 percent of the total) than any Appendix IV constituent with the exception of arsenic. The damage cases reflect a range of waste types disposed in both surface impoundments and landfills. These damage cases corroborate the findings of the RA and also capture other risk scenarios that were not modeled in the RA, such as units that intersect with the groundwater table.

Third, as noted, out of all the coal ash constituents modeled by EPA, boron has one of the shortest travel times, meaning that boron is likely to reach potential receptors before other constituents. As such, including it on Appendix IV would ensure corrective action occurs soon after a potential release, prior to the appearance of slower-moving constituents hydrologically downstream from the source of contamination. Early detection and remediation would better protect human health and the environment by allowing for a response to contamination more quickly and preventing further and more extensive contamination, thereby limiting the exposures to human and ecological receptors. And although this consideration is not relevant under RCRA section 4004(a), early action will also have the benefit of reducing the costs to the facility of remediation, as the cost is necessarily greater to remediate more numerous contaminants and more extensive contamination.

Finally, inclusion of boron on Appendix IV would also be consistent with EPA's previous decisions for other constituents. EPA added cobalt, molybdenum, and lithium to Appendix IV even though these constituents do not currently have MCLs because they were found to be risk drivers in the 2014 risk assessment (80 FR 21404, April 17, 2015).

EPA included lithium on Appendix IV even though it does not have an MCL because it was detected in ''several'' damage cases (80 FR 21404, April 17, 2015). Lead was also detected in at least nine damage cases; and, as noted above, boron is a COC in approximately 51 percent of the total damage cases. By contrast, EPA removed aluminum, copper, iron, manganese and sulfide from Appendix IV because ''they lack maximum contaminant levels (MCLs)'' and were not shown to be constituents of concern based on either the risk assessment conducted for the rule or the damage cases (80 FR 21404, April 17, 2015).

In light of all of the information presented above, EPA is proposing to add boron to Appendix IV of part 257 and seeks comment on the appropriateness of including boron on Appendix IV in the absence of an MCL for the constituent.

B. Performance Standards To Increase and Maintain Slope Stability

As part of the Assessment Program [5] EPA determined that slope protection is an essential element in preventing slope erosion and subsequent deterioration of CCR unit slopes, and that the protective cover of slopes was a significant factor in determining the overall condition rating of all units.

So, in the final CCR rule EPA promulgated specific requirements for all CCR surface impoundments (except incised units) to install and maintain adequate slope protection. Specifically, the final rule required facilities to document that ''the CCR unit has been designed, constructed, operated, and maintained with . . . [adequate slope protection to protect against surface erosion, wave action, and adverse effects of sudden drawdown.'' §§ 257.73(d)(1)(ii); and 257.74(d)(1)(ii).

In developing the specific technical requirements for the final rule, EPA relied on existing dam safety technical literature, which universally recommends that vegetative cover not be permitted to root too deeply beneath the surface of the slope. Deep roots can potentially introduce internal embankment issues such as pathways for water intrusion and piping, precipitating erosion internally, or uprooting which is the disruption of the embankment due to the sudden uplifting of the root system. Based on these data, the final rule also required a vegetative cover height limitation to prevent the establishment of rooted vegetation, such as a tree, a bush, or a shrubbery, on the CCR surface impoundment slope, 80 FR 21476, April 17, 2015, and to prevent the obscuring of the slope during routine and emergency inspection. Based on the available information, EPA concluded that a vegetative cover height limitation of six inches above the face of the embankment was adequate to achieve these dual goals of preventing woody vegetation, while allowing inspectors adequate observation of the slope.

After the final rule was published, this provision was challenged on the grounds that EPA had failed to provide adequate notice of this requirement in the proposal. See, *USWAG et al.* v. *EPA,* No. 15–1219 (D.C. Cir. 2015). In response, EPA reexamined its decision, and agreed to reconsider this provision. This claim was settled, and the court vacated the requirement that vegetation on all slopes ''not . . . exceed a height of 6 inches above the slope of the dike'' within §§ 257.73(a)(4), 257.73(d)(1)(iv), 257.74(a)(4), and 257.74(d)(1)(iv). EPA is not proposing to reopen any other

[4] USEPA, ''Human and Ecological Risk Assessment of Coal Combustion Residuals'', December 2014; docket identification number EPA–HQ–RCRA–2009–0640–11993.

[5] In March 2009, the Agency's CCR Assessment Program (herein referred to as the Assessment Program) was initiated to evaluate the structural stability and safety of coal ash impoundments throughout the country. By September 2014, 559 impoundments had been assessed at over 230 coal-fired power plants. 80 FR 21313, April 17, 2015.

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provisions of §§ 257.73 and 257.74, and will not respond to any comments received on those provisions. Because, as described below, slope protection is an essential element in preventing destabilization of a CCR surface impoundment, EPA is proposing to expand on the existing general performance standard with more specific slope protection requirements for existing and new surface impoundments. EPA is also proposing to establish distinct definitions and height limitations for grassy vegetation and woody vegetation to replace the vacated requirement. Finally, EPA is also proposing definitions for engineered slope protection measures, pertinent surrounding areas, slope protection, and vegetative height.

1. Performance Standards

Slope protection is an essential element in preventing destabilization of a CCR surface impoundment. Surficial and internal erosion, wave action, and rapid drawdown are some phenomena that can destabilize a surface impoundment. Surficial erosion is the removal of surface material, typically resulting from regular, intermittent physical phenomena such as surface run-off and wind action. Internal erosion, due to seepage and piping, is the removal of material beneath the surface of an embankment through the infiltration and transmission of water into and through the embankment. Wave action can cause erosion of embankment material typically caused by wave run-up in wind or storm events. Rapid drawdown is the rapid lowering of the water level of a reservoir which may precipitate slope failure due to residual high pore-water pressure in the embankment with a lack of counteracting pressure from the reservoir. In each of these phenomena, slope protection provides mitigating effects to counteract the phenomena through cohesion of the surface of the embankment. Furthermore, slope protection is necessary to ensure that dike or embankment erosion does not occur, both from the surface of the upstream or downstream slope, crest, or adjacent areas or from internal areas of the unit. Erosion of the embankment can precipitate more significant structural or operational deficiencies, such as beaching upstream from wave action, sloughing or sliding of the crest, discharge of solids to adjacent surface waters, and increased internal erosion. Finally, slope protection is necessary to maintain the stability of the CCR surface impoundment slope under rapid drawdown events [6] and low pool conditions of water bodies that may abut the CCR surface impoundment and are outside the reasonable control of the owner or operator, *e.g.,* a natural river which the slopes of the CCR surface impoundment intercept and abut. Accordingly, EPA is proposing to establish a number of new performance standards to ensure the stability of CCR surface impoundments.

First, EPA is proposing to modify the current regulation to require the owner or operator to ensure that both the slopes and the pertinent surrounding areas of any CCR surface impoundment (both existing and new) are designed, constructed, operated, and maintained with one or more of the forms of slope protection specified in the regulation. EPA has defined slope protection for this proposal as measures installed on the upstream or downstream slope of the CCR unit that protect the slope against wave action, erosion or adverse effects of rapid drawdown. Slope protection includes but is not limited to grassy vegetation, rock riprap, concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines. EPA's proposed definition was developed from the available technical literature for dam safety, geotechnical engineering, and hydrology and hydraulics. The definition of slope protection includes examples of common modes of slope protection utilized in embankment dams, levees, dikes, and other engineering structures which interface with water or other impounded fluids.

EPA is proposing to define pertinent surrounding areas because adequate slope protection in surrounding areas is critical to the overall stability of the CCR surface impoundment. EPA has defined pertinent surrounding areas for this proposal as all areas immediately surrounding the CCR surface impoundment that have the potential to affect the structural stability and condition of the CCR surface impoundment, including but not limited to the toe of the downstream slope, the crest of the embankment, abutments, and unlined spillways. EPA intends this term to include all areas in the vicinity of the CCR unit that may influence the condition of the CCR unit. This would include all areas that good engineering practice dictates should be protected against adverse effects of erosion. See *e.g.,* Federal Emergency Management Agency's ''FEMA 534: Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams'' (September 2005), a copy of which is available in the docket to this rulemaking.

However, the slope protection requirement would exclude certain areas on, adjacent, or near the CCR unit for which it is infeasible, impractical, or unsafe to maintain vegetation. These areas include specific design features of the unit that may occupy portions of the surface of the CCR unit. Such design features may include lined spillways, decant structures, access ways such as roads, paths, or stairs, or sluice pipes. Therefore, an owner or operator does not need slope protection to be designed, constructed, operated, and maintained in these areas. Furthermore, by the nature of these engineered structures, the integrity of the slope or pertinent surrounding area is typically maintained through the construction of the structure or the potential adverse effects to the integrity of the slope or pertinent surrounding area are limited by the nature of the structure. For instance, a properly designed, constructed, and maintained sluice pipe or decant structure may include preventative measures, such as a collar or a boot, which prevents the infiltration of water and potential erosion of the slope at the exit-point of the structure on the slope. An additional example of limited potential adverse effects would be that of a road or path on the crest of the embankment of the impoundment. Due to regular vehicle traffic, it may prove difficult to maintain vegetative cover on the surface of the travel path. Furthermore, due to the location and typical characteristics of the road, *e.g.,* located on the crest of the embankment with ample clearance from the edge of the upstream and downstream slopes, EPA does not anticipate substantial adverse effects due to erosion of the roadway based on its observations during the Assessment Program. Finally, the existing inspection and monitoring requirements of the final rule provide protection against the deterioration of the slopes and pertinent surrounding areas of the CCR surface impoundment in the locations where these structures are found. The integrity of these appurtenant design structures must be ensured by the professional engineer (PE) during regular assessments required in § 257.73 and § 257.74, to confirm that effects from erosion, wave

[6] In this provision, EPA is concerned with the rapid drawdown of adjacent water bodies acting upon the downstream slope of the CCR surface impoundment rather than the rapid drawdown of the impounded reservoir of the CCR surface impoundment acting upon the upstream slope of the CCR surface impoundment. Presumably, the water body of concern acting upon the downstream slope of the impoundment is outside the control of the owner or operator.

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action, or other adverse phenomena are not introduced by the structures.

Similar to the original rule, EPA is proposing to require that slope protection consist of either grassy vegetation, engineered slope protection measures, or a combination of such measures. EPA is also proposing to establish specific performance standards that all slope protection measures must meet. First, the proposed rule would require that the owner or operator ensure that the slope protection measures are maintained in such a manner that allows for the adequate observation of and access to the CCR surface impoundment during routine and emergency events. Second, the regulation would require that the cover provide effective protection against surface erosion, wave action, and adverse effects of rapid drawdown.

2. Vegetative Cover

Grassy Vegetation. Adequate slope protection can be achieved in most climates through vegetation, typically a healthy, continuous dense stand of low-growing native grass species, or other similar vegetative cover. The most desirable form of slope protection, based on the technical literature, is a cover of native grass that creates cohesive coverage across the slope; this is due to its feasible maintenance, low cost of installation, and effective performance in maintaining slope integrity. In arid climates or submerged areas of the unit where the upkeep of vegetation is inhibited, alternate engineered slope protection measures, including rip-rap, or rock-armor, are typically used.

EPA is proposing to define grassy vegetation for this proposal as vegetation which develops shallow roots that do not penetrate the slope or pertinent surrounding areas of the CCR unit to a depth that introduces the potential of internal erosion or risk of uprooting and improves on the condition of the slopes and pertinent surrounding areas of the CCR unit. This definition is being proposed to provide a distinction between grassy vegetation—which EPA acknowledges can improve embankment slope stability, provided the vegetation does not inhibit adequate observation of or access to the slope or pertinent surrounding areas of the CCR unit—and woody vegetation, which can create unacceptable adverse risk to the structural stability and operational ability of the CCR unit. EPA has based the definition of grassy vegetation on ''FEMA 534: Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams'' (September 2005) and the U.S. Army Corps of Engineers' ''ETL 1110–2–583: Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures'' (April 30, 2014).[7] This proposed definition helps to ensure that any vegetation installed by the owner or operator has a net positive effect on the condition of the unit. A continuous cover of grassy vegetation will prevent erosion of the surface or interior areas of the embankment, protect against the effects of wave action, and mitigate the effects of run-off from the CCR unit. EPA has identified some species of non-woody vegetation that do not provide protection against these adverse effects. These species would be considered weeds, which typically create a patch work of vegetative cover that do not provide a benefit to slope stability and are not intentionally installed by the owner or operator, and therefore do not meet the definition of grassy vegetation.

Weeds for this proposal can be wild vegetation that develops shallow-roots and are non-woody plants that do not create a contiguous cover, inhibit adequate observation of the slope and pertinent surrounding areas of the CCR unit and do not provide an advantageous effect on the condition of the slopes and pertinent surrounding areas of the CCR unit. EPA's description of weeds is based on FEMA guidance titled ''FEMA 534: Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams'' (September 2005). EPA intends for all non-woody, grassy vegetation that do not provide an advantageous effect to the condition of the CCR unit to fall within this definition. Some examples of commonly found species considered to be weeds are: Herbaceous plants, vines, pigweed, ragweed, and thistle.

Woody Vegetation. EPA has defined woody vegetation for this proposal as vegetation that develops woody trunks, root balls, or root systems which can penetrate the slopes or pertinent surrounding areas of the CCR unit to a substantial depth and introduce the potential of internal erosion or risk of uprooting. Woody vegetation is not desirable when located on slopes or pertinent surrounding areas of CCR units; technical guidance consistently identifies the substantial risk of uprooting and internal erosion as a result of root system development from woody vegetation. This can lead to dam failure. Some examples of woody vegetation, as defined by the rule, include: Trees, bushes, and shrubbery.

Height Restrictions. The Assessment Program showed that the ability to adequately observe the surface of the slope and pertinent surrounding areas of the CCR surface impoundment are critical to early detection of deficiencies and overall maintaining of structural and operational integrity of the CCR units so EPA finalized height limitations in the CCR rule. However, EPA is now proposing new height limitations for any grassy and woody vegetative cover. Based on comments submitted from industry after the final rule was published, relating to the feasibility of vegetation management on CCR surface impoundments and the varied nature of technical guidance from federal agencies and organizations with jurisdiction or oversight over dam safety,[8] [9] EPA has subsequently determined that the 6 inch height limitation for grassy vegetation was overly restrictive and presented implementation problems for owners and operators.

In reviewing technical guidance from federal and state agencies and organizations, EPA found that the original 6 inch vegetative height limitation was a more conservative technical standard than is typically recommended in guidance. The U.S. Army Corps of Engineer's EM 1110–2–583 generally recommends that vegetation be limited to 12 inches in a ''vegetation free zone'' on and around embankment dams. In addition, the U.S. Army Corps of Engineer's EM 1110–2–583 recommends a minimum height of 3 inches to ensure the health of the grass species providing erosion protection and EPA agrees with this recommendation. The FEMA 534 technical manual does not prescribe a specific vegetative height limitation, but recommends that vegetation be maintained on the basis of achieving several dam safety goals, *e.g.*, permitting effective inspection and monitoring of the embankment, allowing adequate access, discouraging rodent, varmint, or other animal activity through elimination of habitat. Industry commenters have stated that maintaining a 6 inch or less vegetative cover in many regions of the United States was impractical during seasons of high precipitation, when the growth of grassy vegetation is at its greatest rate and access to the slopes of the

[7] A copy of these documents are available in the docket of this rulemaking.

[8] U.S. Army Corps of Engineers, EM 1110–2–583, ''Guidelines for Landscape Planting and Vegetation Management at Levees, Floodwalls, Embankment Dams, and Appurtenant Structures,'' April 30, 2014.

[9] Federal Emergency Management Agency, ''FEMA 534: Technical Manual for Dam Owners, Impacts of Plants on Earthen Dams,'' September 2005.

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embankment is limited due to precipitation. They have also stated that when the slopes of the embankments are saturated due to precipitation, mowing may present undue risk of damaging the slopes of the embankment by mowing equipment.

In light of the above, EPA is proposing a vegetative height maximum limitation of 12 inches for grassy and woody vegetation. The 12-inch limit is drawn from the U.S. Army Corps of Engineer's EM 1110–2–583, which as previously noted, generally recommends that grassy vegetation be limited to 12 inches.

EPA is also proposing to define vegetative height as the linear distance measured between the ground surface where the vegetation penetrates the ground surface and the outermost growth point of the vegetation. This definition is being proposed in order to accurately identify the measurable height of vegetation for use in complying with the vegetative height limits of this rule. EPA intends this definition to reflect the maximum exposed length of the vegetative member along the main stalk of the member.

Woody Vegetation Maintenance. Finally, EPA is proposing to require that the vegetative cover be maintained so that all woody vegetation is removed and that any removal of woody vegetation with a diameter greater than ½ inch be directed by a qualified person, who must ensure that removal is conducted in a manner that does not introduce adverse risk to the stability and safety of the CCR unit or personnel undertaking the removal. EPA is proposing the specific numeric value of ½ inch for the maximum diameter of woody vegetation based on ease of reference and because the diameter represents the threshold for what EPA considers substantial woody vegetation. EPA seeks public comment as to whether a specific numeric value of greater than ½ inch for the maximum diameter of woody vegetation would be more appropriate.

Vegetative maintenance, particularly removal of a large tree or a shrubbery, must be undertaken with care so as not to allow for the uprooting of the root system and disturbance of substantial portions of the slope or surrounding pertinent areas of the CCR unit.[10] The removal and maintenance of such vegetation needs to be undertaken under the supervision of personnel familiar with the design and operation of the unit and in consideration of the complexities of removal of a tree or a shrubbery. Furthermore, the removal of vegetation must be conducted in a manner to ensure compliance with relevant environmental statutes, *e.g.*, National Environmental Policy Act, Endangered Species Act. EPA also seeks comment on requiring a specific timeframe in which woody vegetation must be removed.

Alternatives to Vegetative Cover. To accommodate climates or areas where it is infeasible for the owner or operator to maintain a vegetative cover, EPA is proposing to allow alternative forms of slope protection, *i.e.,* engineered cover or combination cover. EPA has proposed these alternative engineered slope protection measures to allow flexibility for owners or operators in maintaining an adequate slope protection cover system in locations where maintenance of vegetation may prove infeasible or where they do not wish to use grassy vegetation. These engineered slope protection measures, *i.e.,* engineered cover or combination cover, are available and effective in certain circumstances, and include but are not limited to rock or concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines.

C. Clarify the Type and Magnitude of Non-Groundwater Releases That Would Require a Facility To Comply With Some or All of the Corrective Action Procedures in §§ 257.96–257.98

The CCR final rule establishes a number of requirements related to the detection and remediation of releases from a CCR unit. First, the groundwater monitoring and corrective action regulations in § 257.90 state that in the event of a release from a CCR unit, the owner or operator must immediately take all necessary measures to control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of contaminants into the environment. The regulation specifies detailed procedures that must be followed in such cases, requiring that the owner or operator of the CCR unit comply with all applicable requirements in §§ 257.96, 257.97, and 257.98.

Section 257.96(a) also establishes two different standards for triggering corrective action, one for groundwater releases and one for non-groundwater releases. The requirement that a facility commence corrective action ''immediately upon detection of a release from a CCR unit'' applies only to non-groundwater releases. By contrast, the regulation requires corrective action for groundwater releases only upon a determination that contaminants are present in concentrations exceeding the groundwater protection standards in § 257.95(h).

In a separate section, the regulations also require that if a deficiency or release is identified during an inspection of a surface impoundment or landfill, the owner or operator must remedy the deficiency or release as soon as feasible, and prepare documentation detailing the corrective measures taken. See, §§ 257.73(d)(2), 257.74(d)(2), 257.83(b)(5), and 257.84(b)(5). However, these provisions do not require the facility to follow a particular process in cleaning up such releases.

After the final rule was published, the requirement that a facility must remediate any non-groundwater release using the same procedures applicable to the corrective action of groundwater releases in §§ 257.96–257.98 was challenged on the ground that EPA had failed to provide adequate notice of this requirement in the proposal. See, *USWAG et al.* v. *EPA,* No. 15–1219 (D.C. Cir. 2015). In response, EPA reexamined the provision and determined that some revision might be warranted to tailor the procedural requirements to the size or magnitude of the release. Specifically, EPA agreed that, in principle, for some non-groundwater releases, it may not be necessary for facilities to follow all of the corrective action procedures in §§ 257.96–257.98 in cleaning up or remedying the releases. Rather, for certain releases, such as releases that are small in scale, it might be preferable for the facility to focus primarily on the rapid remediation of these releases, consistent with §§ 257.90(d), 257.73(d)(2), and 257.83(b)(5), without requiring adherence to all of the corrective action procedures in §§ 257.96–257.98. Accordingly, EPA settled this claim by agreeing to reconsider the procedures a facility must use to clean up non-groundwater releases in a subsequent rulemaking. The settlement of this claim was presented to the Court without challenge, and on June 14, 2016, the Court severed this claim from the rest of the litigation over the final rule.

This portion of the proposed rule addresses whether the entire set of procedural requirements for corrective actions from the final CCR rule should apply to all non-groundwater releases. EPA is proposing to establish a subset of the corrective action procedures currently found in §§ 257.96–257.98 that would apply to non-groundwater releases that can be completely

[10] U.S. Department of Interior, Bureau of Reclamation, ''Water Operation and Maintenance, Bulletin No. 150'' which includes Guidelines for Removal of Trees and Vegetative Growth from Earth Dams, Dikes, and Conveyance Features, December 1989.

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remediated within 180 days from the time of detection. Under these modified procedures, EPA would compress the reporting requirements into two steps: The initial notification of a release and the documentation that the release has been remediated. These revised procedures would be consolidated in a new section at § 257.99.

EPA designed many of the specific procedural requirements for non-groundwater releases in sections §§ 257.96–257.98 based on several notable ''catastrophic'' releases from CCR surface impoundments in recent history, such as the release of CCR materials from CCR surface impoundments from the Tennessee Valley Authority's (TVA) Kingston Fossil Plant in Harriman, TN, and the Duke Energy Dan River Steam Station in Eden, NC. However, EPA recognizes that all non-groundwater releases are not of a ''catastrophic'' nature, and may in some instances, be quite minor. Consequently, EPA is proposing to establish revised provisions to facilitate the most expeditious response to a release from a CCR unit from the owner or operator, and thereby to mitigate degradation.

EPA is proposing a 180-day time limit to complete remediation of the non-groundwater release. This time frame effectively serves to limit these provisions to releases that are expected to have limited potential for harm to human health and the environment. In this regard, EPA considers that the size and magnitude of the release, *i.e.,* the volume of harmful constituents released, is directly related to the time required to remedy the release.

EPA has identified a number of types of releases that may occur at CCR surface impoundments, and from those, identified the subset that EPA believes could be completely remediated under the existing performance standards within 180 days. Releases that can be cleaned up within 180 days are necessarily of a minimal volume. EPA expects that these reduced procedures are most likely to apply to incidental releases (including fugitive dust) that occur from seepage through the embankment, minor ponding of seepage at the toe of the embankment of the CCR unit, seepage at the abutments of the CCR unit, seepage from slopes, or ponding at the toe of the unit, rather than releases that of a ''catastrophic'' nature, as catastrophic releases are normally of a magnitude that remediation cannot be completed within 180 days. EPA seeks comment on whether 180 days is the appropriate timeframe in which an owner/operator would be expected to complete remediation of a non-groundwater release under this proposed provision, or whether a shorter deadline, *e.g.,* 120 days, or a longer deadline, *e.g.,* 240 days, would be more appropriate for remediating non-groundwater releases that are expected to have minimal impact to human health and the environment. EPA anticipates that these releases will typically be detected by qualified personnel or qualified professional engineers during weekly or annual inspections or during periodic assessments, as specified in the design and operating criteria of the CCR rule. These types of releases can indicate concerns regarding the structural stability of the unit and that further assessment for structural stability issues is warranted, but they do not typically constitute a substantial release of constituents to the environment in and of themselves.

On this basis, EPA has preliminarily concluded that this subset of small releases may not warrant all of the corrective action procedures specified in §§ 257.96–257.98. In these cases, it is preferable that the owner/operator focus on the rapid remediation of the release. However, EPA requests comment on whether 180-days is the appropriate time frame that best balances EPA's objective to ensure that small releases are remediated expeditiously, with the public's interest in understanding the practices occurring at the site that have the potential to affect their exposures and their groundwater.

Consistent with the proposed overall 180-day deadline for completing the cleanup, EPA is proposing to remove certain deadlines and to waive or compress certain reporting requirements found in the existing regulation, either because under the current regulation the requirement would fall due after the 180-day deadline, or because EPA considers that the benefit from the additional reporting requirement may be outweighed by the more expeditious clean-up of the site. Specifically, § 257.96 requires a facility to complete a written assessment of corrective measures within 90 days of detecting a release, place that assessment in the operating record, hold a public meeting to discuss the results of the corrective action assessment at least 30 days before selecting a remedy, and post the corrective action assessments to the publicly accessible facility website. Section 257.97 further requires a semiannual report describing the progress in selecting and designing a remedy, as well as a report upon selection of a remedy, describing the selected remedy and how it meets the standards in the regulation. Upon completion of the cleanup, section 257.98 requires the facility to prepare a report stating that the remedy has been completed, along with a certification from a qualified professional engineer attesting that the remedy has been completed in compliance with the regulation. This potentially multi-year structure was designed primarily to address releases that are large scale or that will otherwise require a substantial amount of time to remediate. It is less clear that this full process is truly necessary for smaller scale releases that could easily be completely cleaned up within a short period of time.

In lieu of the existing procedures EPA is proposing that within 15 days of discovering a non-groundwater release, the owner or operator must prepare a notification of discovery of a non-groundwater release, and place it in the facility's operating record as required by § 257.105. EPA is proposing this requirement to provide transparency, consistent with EPA's overall approach to corrective action under the existing regulations. Additionally, EPA is proposing that within 30 days of completing the corrective action of a non-groundwater release, the owner or operator must prepare a report documenting the completion of the corrective action. This report must include: (1) The facility's assessment of corrective measures to prevent further releases, to remediate any releases and to restore the affected area to original conditions; (2) the selected remedy, with an explanation of how it meets the standards specified in § 257.97; and (3) the certification by a professional engineer that the remedy has been completed in accordance with the regulation. Consistent with the existing regulation, the proposal also specifies that the remedy has been completed when the certification has been placed in the facility's operating record. The proposed rule would also require that the owner or operator comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the internet requirements specified in § 257.107(h). In the event the remedy has not been successfully completed within 180 days, the owner or operator must comply with the entire suite of corrective action requirements in §§ 257.96–257.98.

Under these modified procedures, EPA would compress the reporting requirements into two steps: The initial notification of a release and the documentation that the release has been remediated. Note that the same basic analytical steps would continue to apply—*e.g.,* the criteria for assessing the

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corrective measures in § 257.96(c) and for evaluating the effectiveness of the remedy in § 257.97(b) remain in place. EPA is proposing that the facility document these analyses and solicit public input after conducting the cleanup, instead of before the cleanup. EPA is also proposing to waive the requirement in § 257.97(a) to prepare a semiannual report describing the progress in selecting and designing the remedy. Given that the remedy must be entirely completed within 180 days of discovering the release, a semiannual progress report is likely to be superfluous.

EPA recognizes that requiring public notification after the fact is different than requiring public consultation before the remedy is completed, and that in some situations the difference can be quite significant. For small or contained releases, EPA generally believes that the balance of interests is best struck in ensuring that these releases are remediated as quickly as possible, because the potential impact on the public is likewise limited. That balance shifts, however, as the potential for public impact increases. EPA therefore requests comment on whether some limited public involvement prior to completion of the clean-up would be appropriate. This could be achieved, for example, by delaying the initial notification and requiring the facility to provide details about the release and the planned remediation. Another alternative would be to require some kind of brief interim report to provide that information.

As noted, under the existing requirements, remediation is considered complete when a professional engineer has certified that the corrective action has met all the requirements of the section and the certification has been placed in the facility's operating record as required by § 257.105. Following the revisions to RCRA in the WIIN Act, EPA is proposing to expand this to allow a permitting authority in a participating state to make this determination.

As also noted previously, EPA is not proposing to modify the requirement to clean up all non-groundwater releases or the substantive performance standards that all remediation actions must meet. EPA is only proposing to revise the procedures the owner/operator must follow for non-groundwater releases that can be cleaned up within 180 days. However, in the interest of clarity, EPA is considering whether to incorporate the existing performance standards into the new subsection § 257.99 or whether it is sufficient to rely on cross-references to sections §§ 257.96–257.98. EPA specifically solicits comment on which approach would be most useful.

The provisions set forth in this rulemaking are intended solely to facilitate and expedite corrective action, without modifying the existing requirements to address all releases that occur or to ensure the protectiveness of the remedy. Therefore, no risk assessment was conducted to support this provision of the rulemaking.

D. Alternative Closure Requirements

The current regulations require that an owner or operator of a unit closing for cause pursuant to § 257.101, cease placing CCR and non-CCR wastestreams in the unit within six months of an event triggering closure. The current regulations provide a limited exception to this requirement in two narrow circumstances. First, an owner or operator may certify that CCR must continue to be managed in a CCR unit due to the absence of alternative disposal capacity. Section 257.103(a). Second, an owner or operator may certify that the facility will cease operations of the coal-fired boilers no later than dates specified in the final rule. Section 257.103(b). Under either of these alternative closure provisions, owners or operators may continue to place CCR, and only CCR, in a unit designated to close for cause for an extended period of time. Furthermore, the facility must continue to comply with all other provisions of the rule including groundwater monitoring and corrective action.

These exemptions were challenged as part of the litigation on the final rule on the ground that the exemption was too narrow. See, *USWAG et al.* v. *EPA,* No. 15–1219 (D.C. Cir. 2015). Specifically, plaintiffs alleged that during the rulemaking, commenters had informed EPA that facilities were using the same units to manage both CCR and non-CCR wastestreams, but the exemption only allowed the facility to continue to use the unit to dispose of CCR alone. The plaintiffs argued that EPA had failed to address their comments, and to provide any explanation for limiting the exemption to exclude the continued disposal of non-CCR wastestreams.

In response, EPA reexamined the record and concluded that it had failed to address these comments, and to explain the basis for its decision to restrict the exemption to the continued disposal of CCR alone. Accordingly, EPA settled this claim by agreeing to consider whether to expand this provision to situations in which a facility needs to continue to manage wastestreams other than CCR in the waste unit. The settlement of this claim was presented to the Court without challenge, and on June 14, 2016, the Court of Appeals for the D.C. Circuit remanded ''all of 40 CFR 257.103 (a) and (b)'' back to EPA to allow the Agency for further consideration.

Industry-Provided Information

On December 12, 2016, USWAG sent EPA a letter outlining the need for § 257.103 to include non-CCR wastestreams.[11] This letter has been placed in the docket of this proposed rule. The letter laid out four key premises for such an expansion of the alternative closure provisions. First, the letter explained that power plant operations produce volumes of non-CCR wastestreams in excess of the volumes of CCR wastestreams. These include boiler blowdown, boiler cleaning wastes, demineralizer regeneration washwater, cooling tower blowdown, air heater washwater, stormwater, and water treatment plant waste. Second, the letter explained that power plants do not have contingency plans in place to cover the inoperability of CCR surface impoundments. One anonymous company represented that the only time ponds are taken out of service for repairs and maintenance is during unit outages. Third, the letter provided examples of the new wastewater treatment systems that facilities would be forced to construct, including: Brine concentrators, surface impoundments, tank systems, filtration systems, chemical treatment facilities, and wastewater treatment systems. These systems were expected to take between 1.75 years and 7 years to construct. Finally, USWAG represented that 64,000 MW of coal, oil, and gas-fired capacity were at risk of shutdowns as a consequence of the current closure requirements.

USWAG followed up this letter with an executive summary of an EEI (Edison Electric Institute) reliability analysis.[12] This analysis evaluated electric reliability during peak summer electricity usage when removing the capacity of all boilers with unlined CCR impoundments receiving non-CCR wastewaters. This analysis assumed that the CCR impoundments had to be shut down, and that no alternative capacity

[11] USWAG (Utility Solid Waste Activities Group). 2016. Letter from Jim Roewer to Barnes Johnson. *Addition of Non-CCR Waste Streams to Alternative Closure Provision of Coal Combustion Residuals Rule.* December 12.

[12] EEI (Edison Electric Institute). 2017. *Potential Electric Reliability Risks Due to Cessation of Power Generation as a Result of the Closure of Unlined Surface Impoundments Under 40 CFR part 257.101 for the Failure to Meet Groundwater Protection Standards.* This document is available in the docket for this proposal.

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was available for the non-CCR wastewaters. According to the executive summary, the resulting boiler shut downs would result in substantial impacts in three NERC (North American Electric Reliability Corporation) regions (SERC–E (Southeastern Electric Reliability Council-East), SERC–N (Southeastern Electric Reliability Council-North), and MISO (Midcontinent Independent System Operator)), minor impacts in three NERC regions (ERCOT (Electric Reliability Council of Texas), PJM, and SERC–SE (Southeastern Electric Reliability Council-South East)), and no impacts in remaining NERC regions. The analysis considered substantial impacts to be those where peak demand may not be met without shedding load and/or relying on imports. Minor impacts were those where reserves may fall below FERC standards.

EPA Proposal

EPA is not proposing to modify the alternative closure provisions of § 257.103(a) and will not respond to comments on those provisions. EPA is however, proposing to add a new paragraph (b) to allow facilities to qualify for the alternative closure provisions based on the continued need to manage non-CCR wastestreams in the unit. EPA is also not proposing to modify the alternative closure requirements of § 257.103(b) and will not respond to comments on those provisions (although EPA is proposing to redesignate § 257.103(b) as (c) as stated below). EPA is however, proposing to add a new paragraph (b) in this section to allow facilities to qualify for the alternative closure provisions based on the continued need to manage non-CCR wastestreams in a CCR unit that will cease operation of its coal-fired boilers within timeframes specified in the rule. Thus the facility, if it met the conditions, would be allowed to manage both CCR and non-CCR waste streams in the unit. EPA is also proposing to redesignate existing paragraphs (b) and (c) as paragraphs (c) and (e), respectively, and make conforming changes to this paragraph to reflect the non-CCR waste streams.

As noted previously, currently the alternative closure provisions remain unavailable for non-CCR wastestreams. The current regulation is explicit that the alternative closure provisions only allows for continued disposal of CCR, and therefore facilities must continue to comply with the current rule until an amendment is finalized.

EPA is proposing this exemption because substantial volumes of non-CCR wastestreams are generated at power plants, and may currently be managed in CCR surface impoundments. In the 2015 CCR rule, EPA discussed that the risks to the wider community from the disruption of power over the short-term outweigh the risk associated with the increased groundwater contamination from continued use of these units. 80 FR 21423, April 17, 2015. As it did for CCR in the 2015 CCR rule, this same concern would apply to non-CCR wastestreams if the CCR unit were unavailable for use and the community was left without power for an extended period of time. EPA solicits comment on ways to evaluate whether sustained loss of power to community will occur.

Based on the appendix provided in the December 12, 2016 letter from USWAG, these non-CCR wastestreams can range from insignificant (*e.g.,* 300 gallons per day for Company C's polisher regeneration waste) to massive (*e.g.,* 47.99 million gallons per day for Company C's stormwater). However, volumes alone do not adequately explain the difficulties that facilities may face. Some volumes are discharged to surface waters without treatment, and may be more amenable to alternative capacity or recirculation at the facility. For example, cooling water wastestreams may be recirculated.[13] Such wastestreams may be manageable through simple modifications of plant water flows and/or use of other existing capacity. However, other non-CCR wastestream volumes are treated in the CCR surface impoundments through settling of suspended solids to meet Clean Water Act permits. For example, coal pile runoff may be treated through settling in surface impoundments before being discharged.[14] These non-CCR wastestream volumes may require some level of pond or tank treatment that would not be sufficient in other existing, or easily constructible technology. Finally, some waste streams are primarily solids being sluiced for disposal, and require a long-term, permanent resting place of sufficient cumulative volume. For instance, pyrites at some power plants are combined with bottom ash in sluice conveying systems to ponds for their ultimate disposal. This wastestream may continue to be sluiced, in which case disposal impoundment volumes may still be necessary. However, it may also be managed jointly with bottom ash in wet-to-dry conversions, in which case landfill capacity may be necessary.[15]

As a result of the differences between these various non-CCR wastestreams, capacity may mean different things in different contexts. For other non-CCR wastestreams, capacity may mean the capacity to handle daily volumes of wastewater flowing between areas of the facility. Thus, EPA is proposing to provide a definition of capacity for the new section 257.103(b) which would be a basis for qualifying for the exemption. EPA solicits comment on the proposed use of this definition, as well as whether any additional clarification is warranted.

The differences discussed above also demonstrate why various non-CCR wastestreams may require more simple or more complex alternative capacity. This can impact the amount of time necessary to construct or otherwise locate that capacity. In the December 12 USWAG letter, timeframes to construct alternative capacity varied from 1.75 to 7 years. To achieve closure in the fastest practicable timeframe, owners and operators of facilities should transition each non-CCR wastestream to alternative capacity as such capacity becomes available. Thus, EPA is considering adding a condition requiring the facility to demonstrate that it lacks alternative capacity for *each* wastestream that continues to be managed under the alternative closure provisions and seeks comment on the proposed regulatory text. Under this proposed condition, any waste stream for which that finding cannot be made may not be managed in the unit. This condition would apply not only to the original determination, but to any subsequent determinations. Under the existing terms of the current regulation, the ability to continue to use the unit lasts only as long as no alternative capacity is available. Once the alternative capacity is identified, the owner or operator must arrange to use such capacity as soon as feasible. Section 257.103(a)(2)(ii). In addition, the current regulation requires the facility to annually document the continued lack of alternative capacity and the progress towards the development of alternative capacity. Section 257.103(a)(2)(iii). EPA is proposing to clarify that these

[13] ASHRAE (American Society of Heating, Refrigeration, and Air-Conditioning Engineers, Inc.). 2012. *Water/Electricity Trade-Offs in Evaporative Cooling, Part 2: Power Plant Water Use.* Available online at *https://www.ashrae.org/File%20Library/docLib/Journal%20Documents/2012January/065-068_Emerging.pdf.*

[14] TVA (Tennessee Valley Authority) and U.S. EPA (Environmental Protection Agency). 1979. *Characterization of Coal Pile Drainage: Interagency Energy/Environment R&D Program Report.* EPA–600–7–79–051. February.

[15] McDonough, Kevin L. 2014. *Coal Ash Management: Understanding Your Options. Power Engineering.* February 14. Available online at: *http://www.power-eng.com/articles/print/volume-118/issue-2/abma-special-section/coal-ash-management-understanding-your-options.html.*

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conditions apply to each individual waste stream that will continue to be managed in the unit and seeks comment on this approach.

In developing this provision, EPA relied on information from commenters to determine that this five-year period was feasible. The December 12, 2016 USWAG letter provides construction timeframes for a further 10 alternative disposal methods. All but one of these methods takes less than five years to construct. It appears these timeframes are therefore generally consistent with the timeframes on in the existing regulation; however, EPA solicits comment on alternative technologies and associated construction timeframes that have the potential to impact this period.

As noted previously, USWAG submitted an executive summary of an EEI reliability analysis. EPA understands that this analysis indicates that in some instances there may be an impact on electric reliability caused by surface impoundment closure. Consequently, EPA is proposing to limit the new alternative closure requirements to facilities that have the potential to impact electric reliability. Specifically, EPA is proposing to limit the expanded exemption to facilities in one of the three FERC regions that the EEI analysis concludes are likely to suffer substantial reliability impacts.

EPA notes that the EEI executive summary cautioned:

> ''Those reviewing the EEI findings should recognize that our findings were not part of any detailed planning study and provide a very high level review of possible worst case impacts on a regional level.''

Although EPA was able to review only the executive summary of this analysis, and therefore cannot draw definitive conclusions, EPA agrees that these impacts appear to be worst-case for several reasons that were clear from the executive summary alone. First, the EEI analysis assumes that all unlined CCR impoundments leak above the groundwater protection standards and the CCR units would have to be closed for cause. Second, the analysis assumes that non-CCR wastestreams were being managed in all of those CCR impoundments. Third, the analysis assumes that alternative capacity for those non-CCR wastestreams could not be found or constructed within the six-month period for closure to commence. Finally, the analysis assumes that the lack of capacity would cause the associated coal boilers to cease operation. EPA considered each of these assumptions to be worst-case as explained below.

First, the assumption that *all* unlined surface impoundments leak above the groundwater protection standard is contrary to EPA's 2014 risk assessment. This conclusion is further bolstered by the final risk assessment which showed that even input porewater concentrations from some surface impoundments were below the groundwater protection levels. Thus, the assumption that all surface impoundments leak above groundwater protection standards is worst-case rather than a best estimate.

Similarly, not all unlined CCR units manage non-CCR wastestreams. Rather than use either the non-CBI (confidential business information) data available from the 2010 Office of Water (OW) questionnaire or some other industry-provided data set, EEI has assumed that all unlined CCR units also manage non-CCR wastestreams. A quick scan of the information available in the non-CBI OW questionnaire reveals dozens of CCR surface impoundments that do not receive non-CCR wastewaters.[16]

Third, the assumption that no facility could construct alternative capacity within the time frames in the current regulation is contrary to other information presented in the USWAG letter. This letter documents several alternative disposal methods that take only two or three years to construct. It thus appears to generally be feasible for facilities with knowledge of leaking units to begin and complete the construction of these ponds, tanks, and other capacity in the time that the rule lays forth for closure to commence. If the facilities that believe that their units are leaking, or likely leaking, had already begun this construction when they first learned of the regulatory requirements, many would be nearing completion as of this rulemaking.

When taken as a whole, these worst-case assumptions result in an analysis may overestimate the effects to the electricity grid. In EPA's final rule Regulatory Impact Analysis (RIA),[17] EPA modeled electricity impacts using the Integrated Planning Model (IPM). This model exercise showed minimal retirements or effects on total capacity over the timeframe modeled. However, while the EEI analysis may be an overestimate of impacts on reliability, other entities have found that the combination of several environmental regulations may nevertheless contribute to regional reliability issues. For instance, in 2012 the GAO (Government Accountability Office) found that 18 percent of coal-fired capacity in the Midwest could retire.[18] Although the GAO concluded that EPA regulations were not expected to pose widespread concerns, it did find that these regulations could contribute to challenges in some regions. Similarly, NERC reviewed the potential reliability effects of combined EPA regulations on the power sector in 2010 and 2011.[19] [20] In those long-term reliability analyses, NERC made several recommendations. NERC recommended that EPA defer compliance targets and grant extensions where there is a demonstrated reliability need. NERC also recommended that industry make investments to retrofit or replace capacity that might be affected by (at the time) forthcoming EPA regulations.

While the NERC and GAO reports both took account of numerous EPA regulations that have since been stayed, EPA nevertheless acknowledges that the impacts of environmental regulations can potentially affect reliability when deadlines are not flexible. As a result, EPA is considering restricting the alternative closure provisions to facilities in the NERC regions and sub-regions showing the potential for substantial impacts in the EEI report. The three regions are MISO, SERC–E, and SERC–N. For facilities that are located in, or regularly provide the majority of generated electricity to, those regions, the facilities may qualify for the alternative closure provisions due to non-CCR wastestreams provided the other requirements are met.[21] EPA notes that to demonstrate that a facility regularly provides the majority of its generated electricity to one of these regions, it is not necessary that the facility provide such quantities with a high frequency. For instance, if a facility outside of one of these regions only provided a majority of its generation to that region during peak times in summer months, the fact that this is

[16] Available online at: *https://www.epa.gov/eg/steam-electric-power-generating-effluent-guidelines-questionnaire.*

[17] See docket item EPA–HQ–RCRA–2009–0640–12034, available at *https://www.regulations.gov.*

[18] GAO (Government Accountability Office). 2012. *EPA Regulations and Electricity: Better Monitoring by Agencies Could Strengthen Efforts to Address Potential Challenges.* GAO–12–635. July.

[19] NERC (North American Electric Reliability Corporation). 2010. *Special Reliability Scenario Assessment: Potential Resource Adequacy Impacts of U.S. Environmental Regulations.* October 5.

[20] NERC (North American Electric Reliability Corporation). 2011. *Potential Impacts of Future Environmental Regulations.* November.

[21] EPA estimates that the percentage of facilities located in the three NERC Assessment Areas showing the potential for substantial impacts is approximately 40 to 48 percent. This is based on the number of facilities with publically accessible websites.

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done regularly, year after year, would be sufficient.

EPA solicits comment on the proposal to limit the exclusion under proposed new paragraphs (b) and (d) of § 257.103 for non-CCR wastestreams to the three specific NERC regions and sub-regions that have a demonstrated reliability need. Without the EEI analysis, EPA can only conservatively assume, as industry does, that the three regions and sub-regions showing substantial impacts in the EEI analysis have such a demonstrated need. EPA also solicits comment on the appropriateness of allowing facilities outside a NERC region to qualify if they provide electricity to that region, as well as other reasonable standards for determining which facilities qualify.

IV. What amendments associated with the WIIN Act is EPA proposing?

During the rulemaking for the current regulations for CCR in 40 CFR part 257, EPA received numerous comments requesting that EPA adopt alternative performance standards that would allow state regulators (or facilities) to ''tailor'' the requirements to particular site conditions. Many requested EPA adopt particular performance standards found in EPA's municipal solid waste landfill (MSWLF) regulations in 40 CFR part 258. As discussed in the preamble to the final 1991 rule establishing the part 258 requirements, EPA incorporated the concept of ''differential protection of groundwater'' as a basis for allowing regulatory flexibility depending on the quality of the groundwater source.[22] Although the CCR rule was largely modeled on the MSWLF regulations, as explained in both the proposed and final rules, under the statutory provisions relevant to the CCR rule, EPA lacked the authority to establish a program analogous to part 258, which relies on approved states to implement the federal criteria through a permitting program. In the absence of a mandated state oversight mechanism to ensure that the alternative standards would be technically appropriate, EPA concluded it could not adopt many of the ''more flexible'' performance standards in part 258 that commenters requested.

As fully explained in the preamble to the April 2015 CCR rule, the statutory structure established by Congress requires EPA to establish national minimum criteria that ensure there is ''no reasonable probability of adverse effects on health or the environment.'' States may, but are not required to adopt or implement these criteria; thus the national minimum criteria apply to all facilities even in the absence of a regulatory entity to implement or oversee them. EPA in establishing these national minimum criteria had to show through its rulemaking record that the final rule would achieve the statutory standard of ''no reasonable probability of adverse effects on health or the environment'' at all sites subject to the standards. This means that the standards must be protective of all sites, including the most highly vulnerable sites. The statute provided no mechanism for site specific flexibility as in the MSWLF program in part 258.

However, in 2016 Congress amended RCRA to establish a permit program analogous to that established for MSWLFs. See Unit II.B for additional detail. Under these new provisions, States may now apply to EPA for approval to operate a permit program to implement the CCR rule. As part of that process, a State program may also establish alternative State technical standards, provided EPA has determined they are ''at least as protective as'' the CCR regulations in part 257. 42 U.S.C. 6945(d)(1)(B), 6945(d)(1)(C).

In light of the legislation, EPA returned to the existing 40 CFR part 258 regulations to evaluate the performance standards that rely on a state permitting authority. EPA evaluated whether there was sufficient evidence in the record for those regulations to support incorporating either the part 258 MSWLF provision or an analogue into the part 257 CCR regulations. One complication is the statutory standard for the part 258 regulations is different than the standard for the CCR regulations. The CCR regulations are based on RCRA section 4004(a), which requires the regulations to ensure ''there is no reasonable probability of adverse effects on health or the environment from disposal of solid waste at such facility.'' 42 U.S.C. 6944(a). By contrast, EPA was authorized to ''take into account the [facility's] practicable capability'' in developing the part 258 regulations. 42 U.S.C. 6949a(c). As a consequence, the rulemaking record for some part 258 provisions may not fully support a determination that a particular provision meets the RCRA section 4004(a) standard or will be ''at least as protective'' as EPA's CCR regulations.

Based on the results of this evaluation, EPA is proposing to adopt several provisions modeled after the following in part 258: (1) The State Director may establish alternative risk-based groundwater protection standards for constituents for which Maximum Contaminant Levels (MCLs) have not been established (see § 258.55(i) and (j)); (2) The State Director may determine that remediation of a release of an Appendix IV constituent is not necessary under certain conditions (see § 258.57(e) and (f)); (3) The State Director may determine that groundwater monitoring requirements under §§ 257.91–257.95 may be suspended if there is evidence that there is no potential for migration of hazardous constituents to the uppermost aquifer during the active life of the unit and post-closure care (see § 258.50(b)); (4) The State Director may specify an alternative length of time to demonstrate that remedies are complete (see § 258.58(e)(2)); (5) The State Director may modify the length of the post-closure care period (see § 258.61(b)); and (6) The State Director may decide to certify that the regulatory criteria have been met in lieu of the exclusive reliance on a qualified professional engineer. These part 258 provisions in the MSWLF regulations were adopted based solely on a finding that they would protect human health and the environment, which is not appreciably different from the standard under RCRA section 4004(a). See, 75 FR 35193 (June 21, 2010). Thus, in proposing these flexibilities, EPA believes that the statutory standard under RCRA section 4004(a) is met.

In addition, under the WIIN Act, EPA is the permitting authority for CCR units located in Indian County. EPA would also serve as the permitting authority for CCR units located in nonparticipating states subject to a Congressional appropriation to carry out that function. EPA is proposing that where it is the permitting authority, it will have the same authority as the Director in an approved or participating state to apply the alternative performance standards. In order to make this clear, EPA is proposing to revise the definition of State Director in § 257.53 to clarify that the term ''State Director'' includes EPA where EPA is the permitting authority (that is on Tribal lands and in nonparticipating states if EPA were to receive appropriations specifically for the purpose of issuing permits). EPA seeks comment on this approach or on the alternative of adding the words ''or EPA where it is the permitting authority'' to each of the proposed flexibilities.

Further EPA is considering further modifications to these provisions, analogous to the 2010 proposal, and is seeking comment on whether it is appropriate and consistent with the WIIN Act for these alternative performance standards to apply directly to a facility in a nonparticipating State

[22] 56 FR 50978, 50995–96 (Oct. 9, 1991).

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on the basis that the units in the nonparticipating states are subject to oversight by EPA through the enforcement authorities provided directly to EPA under the WIIN Act. As discussed below, EPA seeks comment on alternatives for implementing such flexibilities, for example, through appropriate detailed technical analyses, certification(s) by an independent professional engineer (or other appropriate technical expert or experts), reliance on state ground water standards, notifications to EPA, posting on the facility's publically available website, etc.

In addition, EPA is seeking comment on whether it would be appropriate and consistent with EPA's authority for an approved State or EPA in a nonparticipating state, or an owner or operator subject to EPA oversight, to establish alternative, risk-based location restrictions in lieu of the location restrictions found at §§ 257.60–257.64. For example, in the 2010 proposed CCR rule, EPA proposed a location restriction requiring demonstration that a CCR unit be located a minimum of two feet above the upper limit of the natural water table.[23] The final rule changed the requirement to five feet above the uppermost limit of the uppermost aquifer.[24] An owner or operator could also satisfy the location restriction by demonstrating the absence of an intermittent, recurring, or sustained hydraulic connection between the CCR unit and the uppermost aquifer.[25] EPA seeks comment on whether a State, or an owner/operator through a detailed technical analysis or certification(s) by an independent professional engineer (or other appropriate technical expert or experts), could establish alternative location restrictions that would satisfy the standard in RCRA section 4004(a). EPA also seeks comment on whether the October 17, 2018 compliance deadline for the location restrictions at §§ 257.60–257.64 is appropriate in light of the WIIN Act or whether an alternative deadline, either through a permit program established under the WIIN Act or one that applies directly to the facility itself during an interim period, would be more appropriate to facilitate implementation of the WIIN Act and any changes as a result of this rulemaking.

Moreover, for any adopted site specific performance standards (whether approved by the State, EPA, or implemented by the facility itself), EPA is requesting comments on whether the facility or owner operator should be required to post the specific details of the modification of the performance standard to the facility's publically accessible website or require any other recordkeeping options.

Finally, as described in Unit IV.G below, EPA is proposing one modification to the closure section in a certain situation to allow the use of CCR in construction of the cover system.

A. Alternative Risk-Based Groundwater Protection Standards

The current regulations at § 257.95(h) require the CCR unit owner or operator to set the groundwater protection standard (GWPS) at the MCL or background for all constituents from Appendix IV to part 257 that are detected at a statistically significant level above background. The GWPS must be set at the MCL for all Appendix IV constituents for which there is a promulgated level under section 1412 of the Safe Drinking Water Act. If no MCL exists for a detected constituent, then the GWPS must be set at background. In cases where the background level is higher than the promulgated MCL for a constituent, the GWPS must also be set at the background level.

In the 2010 proposal, EPA proposed allowing an owner or operator to establish an alternative GWPS for constituents for which an MCL has not been established provided that the alternative GWPS has been certified by an independent registered professional engineer and placed in the operating record and on the owner's or operator's publicly available website. In finalizing the GWPS requirements, EPA declined to allow a qualified professional engineer to establish alternative GWPS because EPA determined it was ''inappropriate in a self-implemented rule, as it was unlikely that a facility would have the scientific expertise necessary to conduct a risk assessment, and was too susceptible to potential abuse.'' [26]

In this rulemaking EPA is proposing to adopt a provision analogous to 40 CFR 258.55(i), the regulations applicable to MSWLFs. Under the existing part 258 provision, the Director of a state permitting authority in a state with an approved MSWLF permitting program may establish an alternative GWPS for constituents without an MCL, provided that it is an appropriate health-based level established in accordance with the specific criteria in this regulation. The only constituents listed in Appendix IV of the final CCR rule that currently have no MCL (and therefore, the only ones that fall under this proposal) are cobalt, lead, molybdenum and lithium. Boron, which is proposed for addition to Appendix IV, also does not have an MCL. First, these are ''health based levels,'' which means that the only relevant consideration is whether the alternate standard will protect potential receptors (both human and environmental); costs or any similar considerations may not be considered. In addition, 40 CFR 258.55(i) specifies that all of the following criteria must be met: (1) The level is derived in a manner consistent with Agency guidelines for assessing the health risks of environmental pollutants (51 FR 33992, 34006, 34014, 34028, Sept. 24, 1986); (2) The level is based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR part 792) or the equivalent; (3) For carcinogens, the level represents a concentration associated with an excess lifetime cancer risk level (due to continuous lifetime exposure) within the 1×10^{-4} to 1×10^{-6} range; and (4) For systemic toxicants (*i.e.,* chemicals that cause effects other than cancer), the level represents a concentration to which the human population (including sensitive subgroups) could be exposed to on a daily basis that is likely to be without appreciable risk of deleterious effects during a lifetime. For purposes of this subpart, systemic toxicants include toxic chemicals that cause effects other than cancer or mutation.

The Agency is proposing to allow participating states to set an alternative groundwater protection standard that is largely based on the four criteria specified in this part 258 provision. However, the criteria specified under the proposed revisions to § 257.95(h) would not be identical to those in 40 CFR 258.55(i). Rather EPA is proposing to use modified criteria in the CCR rule that would account for more recent science policies and for the specific characteristics of these wastes. EPA requests comments on the use of the modified criteria for CCR. These proposed modifications are described below.

As in the part 258 MSWLF regulation, EPA is proposing to allow the Director of a state with an EPA-approved CCR permitting program (and EPA where it is the permitting authority) to establish an alternative GWPS ''health-based level'' for constituents without an MCL. Consistent with part 258, this alternative GWPS is to be a health-based standard that will be protective of potential receptors (both human and ecological) and is not based on any non-

[23] 75 FR 35128, 35241 (June 21, 2010).

[24] 80 FR 21302, 21471–72 (April 17, 2015).

[25] Id.

[26] 80 FR at 21405 (April 17, 2015).

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risk based factors, such as the cost to achieve that standard. EPA is proposing to adopt these provisions without change. As an alternative, similar to the language in the 2010 proposal for § 257.95(h), EPA is also considering further modifying this provision and is seeking comment as to whether an alternative risk-based GWPS could be established by an independent technical expert or experts (where there is no approved permitting authority, that is in a ''nonparticipating state''). That expert(s) would be required to derive the standard in a manner consistent with Agency guidelines (as described below); however, that alternative standard could be implemented by the facility without the intervention of a permitting authority, for example, through the use of a certified technical expert(s) or by reliance on state groundwater standards or other risk-based approach. EPA seeks comment on this approach and whether such an approach would satisfy the underlying statutory requirement of no reasonable probability of adverse effects on health or the environment from disposal of solid waste at such a facility and whether the new authorities provided to EPA in the WIIN Act for oversight and enforcement make such an approach feasible and adequate to address the concerns EPA identified in the preamble to the 2015 CCR rule that an owner or operator would not be expected to have the requisite experience necessary to conduct a risk assessment and that such an approach would be susceptible to abuse. Depending on the comments received and EPA's analysis thereof, EPA may ultimately adopt such an approach.

The current § 257.95 establishes the requirements for an assessment monitoring program, including a series of 90-day time periods in which an owner or operator has to perform the required analysis and demonstrations. The 90-day time periods are based on similar requirements and time periods in the part 258 requirements. However, EPA seeks comment on whether 90 days is an appropriate time period for the assessment monitoring requirements for CCR in light of the WIIN Act or whether alternative time periods, e.g., 120 days or 150 days, are necessary to perform the required analysis and demonstrations for CCR and whether such alternative time periods would be more appropriate to facilitate implementation of the WIIN Act and any changes as a result of this rulemaking.

EPA is also proposing to adopt the part 258 provision that requires an alternative groundwater protection standard to be derived in a manner consistent with Agency guidelines. However, some of the guidelines cited in part 258 have since been replaced or supplemented. Therefore, EPA is proposing to replace the citations with the updated versions. Specifically, EPA is proposing to cite to the *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures,*[27] which supplements 51 FR 34014 (September 24, 1986); the *Guidelines for Developmental Toxicity Risk Assessment,*[28] which amends 51 FR 34028 (September 24, 1986); and the *Guidelines for Carcinogen Risk Assessment,*[29] which amends 51 FR 33992 (September 24, 1986). In addition, EPA proposes to add the guidance on deriving a reference dose, *Reference Dose (RfD): Description and Use in Health Risk Assessments.*[30] These are the current guidance documents that are most relevant to the constituents of concern for the wastes at issue. EPA seeks comment on this proposal.

EPA is also proposing to adopt, without modification, the part 258 provision that requires the alternative standard to be based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR part 792) or the equivalent. EPA requests comment on this approach.

EPA is proposing to adopt, with modifications, the part 258 provisions specifying that the alternative standard is set at a level that is associated with an excess lifetime cancer risk within the 1×10^{-4} to 1×10^{-6} range for carcinogens and that is likely to be without appreciable risk of deleterious effects from daily exposures for systemic toxicants. For carcinogens, EPA is also proposing to require that States use a cancer slope factor to establish the alternate GWPS within the relevant risk range. For non-carcinogens, EPA is proposing to require that States use a reference dose to establish the alternative GWPS, with a hazard quotient (HQ) of 1 as the upper bound on risk. This is the same methodology used to establish the technical criteria in the existing CCR regulation. Reliance on his methodology is also reasonable in this regulation as it ensures that this provision (and any alternative GWPS under this provision) will meet the requisite statutory standards. Some examples of groundwater values consistent with these requirements (indeed all of the proposed requirements) are Action Levels promulgated under the Safe Drinking Water Act and the Regional Screening Levels for Chemical Contaminants at Superfund Sites.[31] EPA requests comment on this approach.

In addition, EPA is considering requiring that for systemic toxicants (i.e., for chemicals that cause effects other than of deleterious effects during a lifetime. This is largely the same as the current part 258 requirement; however cancer), the alternate level represents a concentration to which potential receptors (including sensitive subgroups) could be exposed to on a daily basis that is likely to be without appreciable risk, EPA seeks comment on whether it should revise the relevant target from ''human population'' to ''potential receptors.''

Although this proposed rulemaking sets a target risk based on a risk range of 1×10^{-4} to 1×10^{-6} for carcinogens and an HQ = 1 for non-carcinogens, States would not be precluded from setting more stringent standards. The existing regulation in 40 CFR 258.55(j) identifies three other site-specific factors that may indicate the need to establish a risk level for a particular contaminant that is more protective than these levels. These are: (1) The presence of multiple contaminants in the groundwater; (2) exposure threats to sensitive environmental receptors; and (3) other site-specific exposure or potential exposure to groundwater. These factors are equally relevant to CCR facilities, and so EPA is proposing to incorporate them without any modifications. EPA requests comment on this approach.

Because any alternate GWPS will be based on established risk levels, it is reasonable that a state may set a level above background so long that it is equal to or lower than this alternate threshold. Thus, any alternate GWPS that meets the requirements specified in this proposal would still protect potential receptors from the reasonable

[27] USEPA, ''Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures'', EPA/630/R–00/002, August 2000. This document can be accessed at *https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=20533.*

[28] USEPA, ''Guidelines for Developmental Toxicity Risk Assessment'', EPA/600/FR–91/001, December 1991. This document can be accessed at *https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=23162.*

[29] USEPA, ''Guidelines for Carcinogen Risk Assessment'', EPA/630/P–03/001F, March 2005. This document can be accessed at *https://www.epa.gov/risk/guidelines-carcinogen-risk-assessment.*

[30] This document can be accessed at *https://www.epa.gov/iris/reference-dose-rfd-description-and-use-health-risk-assessments.*

[31] This document can be accessed at *https://www.epa.gov/risk/regional-screening-levels-rsls.*

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maximum exposures identified in the final risk assessment.

B. Modification to Corrective Action Remedy

Once corrective action is triggered, the current regulations at § 257.97 require the CCR unit owner or operator to select a remedy for corrective action. In addition, § 257.98 requires the CCR unit owner or operator to begin implementing that remedy within 90 days of remedy selection.

EPA is proposing to adopt a provision analogous to 40 CFR 258.57(e) for municipal solid waste landfills (MSWLF). This part 258 provision allows the Director of a state permitting authority in participating states to determine that remediation of a release of an Appendix II to part 258 constituent from a MSWLF unit is not necessary if the owner or operator can make certain demonstrations to the satisfaction of the Director. Specifically, § 258.57(e) specifies that the Director may determine that remediation is not necessary if the owner or operator demonstrates to the satisfaction of the Director of a participating State that:

(1) The groundwater is additionally contaminated by substances that have originated from a source other than a MSWLF unit and those substances are present in concentrations such that cleanup of the release from the MSWLF unit would provide no significant reduction in risk to actual or potential receptors; or

(2) The constituent is present in groundwater that:

a. Is not currently or reasonably expected to be a source of drinking water; and

b. Is not hydraulically connected with waters to which the hazardous constituents are migrating or are likely to migrate in a concentration that would exceed the groundwater protection standards; or

(3) Remediation of the release is technically infeasible; or

(4) Remediation would result in unacceptable cross-media impacts.

Part 258 also states that even if the Director of a participating state does determine that remediation of the release is not necessary, this shall not affect the authority of the State to require the owner or operator to undertake source control measures or other measures that may be necessary to eliminate or minimize further releases to the groundwater, to prevent exposure to the groundwater, or to remediate the groundwater to concentrations that are technically practicable and significantly reduce threats to human health or the environment. 40 CFR 258.57(f).

EPA is proposing to adopt this same provision into part 257 with one modification. EPA is proposing that a State Director may, on a site-specific basis, decide not to require cleanup of part 257 Appendix IV constituents released to groundwater from a CCR disposal unit where: (1) The groundwater is contaminated by multiple sources and cleanup of the CCR release would provide no significant reduction of risk; or (2) the contaminated groundwater is not a current or potential source of drinking water and is not hydraulically connected with waters to which the part 257 Appendix IV constituents are migrating or likely to migrate in a concentration(s) that would exceed the groundwater protection standards; or (3) remediation is not technically feasible; or (4) remediation would result in cross-media impacts. In part 258, an owner or operator is not required to undertake source control measures unless ordered by a State Director to do so. Although today's proposal includes § 257.97(g), which would make source control measures mandatory in a departure from part 258, EPA is considering making the source control measures for CCR units discretionary, similar to part 258, and seeks comment on this approach. For example, while the Director may determine that total remediation is not required, EPA seeks comment on whether source control measures (*e.g.,* covers and/or flow control measures or closure, if triggered by § 257.101(a)–(c)) to minimize or eliminate further releases could not be waived. In other words, EPA seeks comment on whether a State or EPA as the permitting authority in a nonparticipating state, or a facility directly implementing the requirements of this rule and subject to EPA oversight and public notice, should have discretion not to require or perform source control measures, including closure, in certain situations, *e.g.,* where there is no reasonable probability of adverse effect to human health or the environment. In addition, partial remediation of groundwater to concentrations that are technically feasible and that significantly reduce risks would also be required. EPA also seeks comment on this proposed approach. EPA describes each of these in further detail below. Under part 258, these provisions are discretionary. Depending on the comments EPA receives, EPA may modify the proposed requirements at § 257.97 to more closely reflect the source control measures contained in part 258. If EPA makes any such changes to § 257.97, it may also make conforming changes to § 257.101.

As noted, the Agency is proposing that participating states may waive the clean-up requirements where the groundwater is already contaminated by multiple sources and clean-up of the CCR release would provide no significant reduction of risk. In some cases, CCR units releasing part 257 Appendix IV constituents to the groundwater may be located in areas that already are significantly contaminated by other sources. Where releases from the CCR units are minor compared to the overall area-wide contamination, or where remedial measures aimed at the CCR unit would not significantly reduce risk, EPA believes that remediation of releases from the CCR unit would not be necessary or appropriate. Proposed § 257.97(f) is intended to address such situations.

Section 258.57(e)(1) applies only where sufficient evidence exists that the groundwater is contaminated by a source other than the CCR unit. In such cases, the owner or operator must demonstrate that cleanup of a release from its unit would provide no significant reduction in risk to receptors due to concentrations of constituents from the other source. EPA has previously characterized this provision as requiring facilities to make a robust demonstration that other sources are significant contributors to the contamination; this provision is not intended to provide facilities with a general opportunity to seek a waiver from the existing cleanup requirements under part 257.

The Agency is not proposing to define ''significant reductions'' in risk in this rulemaking, but consistent with the MSWLF rules, believes the decision is best made on a case-by-case basis by the State. The Agency understands and anticipates that states may have difficulties in defining ''significant reduction of risk'' but expects that States will be able to draw from their experience in implementing the analogous requirement in § 258.57(e)(1). Consistent with that provision, participating states should take a protective approach when evaluating requests for such a waiver. As one potential example, EPA considers that where the facility could document that the risks to potential receptors from non-CCR constituents would still exceed acceptable levels of concern (*i.e.,* risks greater than 1×10^{-4} to 1×10^{-6} for carcinogens, or an HQ greater than 1 for non-carcinogens) even if all CCR constituents had been removed, the facility could demonstrate there would be no significant reduction of risk from remediation of the CCR constituents. However, EPA solicits comment on whether there are additional criteria that

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would be useful in further defining the proposed regulatory provision under § 257.97(f)(1), *e.g.,* criteria that states have used in implementing the analogous provision in part 258.

Under proposed § 257.97(f)(2), the State may also determine that a hazardous constituent that has been released from a CCR unit to groundwater does not pose a threat to human health and the environment and, therefore, does not require remediation if: (1) The groundwater is not a current or potential source of drinking water and (2) the groundwater is not hydraulically connected with waters that could be a current or potential source of drinking water or are not likely to migrate in a concentration(s) that would exceed the groundwater protection standards established under § 257.95(h). EPA generally interprets this to require a determination that the quality of the water in the aquifer is such that it could not reasonably be expected to be used as drinking water, even if treated to remove the contaminants. The provision does not allow a waiver on the grounds that the cost of treating the water to remove the contaminants is too high. EPA realizes that it is difficult to predict future improvements in treatment technologies, or to determine hydraulic connection. In interpreting whether the aquifer meets these regulatory criteria, States may use the approach outlined in the Agency's Ground-Water Protection Strategy (August 1984) as guidance.[32] As described in this guidance, typically Class III groundwaters will be considered to meet the requirements specified in § 257.97(f)(2). Class III groundwaters are groundwaters not considered potential sources of drinking water. They are groundwaters with high salinity, total dissolved solids levels over 10,000 mg/l, or are otherwise contaminated beyond levels that allow cleanup using methods reasonably employed in public water system treatment. These groundwaters also must not migrate to Class I or II groundwaters or have a discharge to surface water that could cause degradation. The need to remediate Class III groundwaters should be assessed on a case-by-case basis. Under the second criterion, the owner or operator must also demonstrate that the uppermost aquifer is not hydraulically connected with a lower aquifer. The owner or operator may nevertheless seek an exemption if it can be demonstrated that attenuation, advection/dispersion or other natural processes can remove the threat to interconnected aquifers. The owner or operator may also seek the latter exemption if the contaminated zone is not a current or potential drinking water source.

EPA is also proposing under § 257.97(f)(3) and (4) to allow the State to determine that remediation of a release is not required when remediation is not technically feasible or when remediation presents unacceptable cross-media impacts. Such a determination may be made, for example, in some cases where the nature of the hydrogeologic setting would prevent installation and operation of an effective groundwater pump and treat system (or other effective cleanup technology), *e.g.,* where the installation and operation of such a system could potentially increase environmental degradation by introducing the contaminant into groundwater that was not previously affected by the release. Additional examples of factors that may affect the efficacy of groundwater remediation can be found in EPA Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration (OSWER Directive 9234.2–25, September 1993).[33] The Agency is specifically soliciting comment on the types of situations that might warrant a determination that remediation of a release is technically impracticable or presents unacceptable impacts and would not, therefore, be required.

A successful demonstration that remediation is not technically feasible must document specific facts that attribute to this demonstration. Technical infeasibilities may be related to the accessibility of the groundwater to treatment, as well as the treatability of the groundwater using existing treatment technologies. If the owner or operator can demonstrate that unacceptable cross-media impacts are uncontrollable under a given remedial option (e.g., movement in response to groundwater pumping) and that the no action option is a less risky alternative, then the Director of approved participating state may determine that remediation is not necessary.

As noted, EPA is generally relying on the factual record developed for the part 258 regulations to support this rule. However, the record for that rule does not contain information that would demonstrate that removing the existing regulatory requirement that all CCR units impose source control would meet the RCRA section 4004(a) protectiveness standard. These existing CCR requirements were established to address the well-documented risks associated with CCR units, as detailed in the risk assessment and the numerous damage cases in the rulemaking record.[34] The part 258 regulations apply only to landfills, while the CCR regulations apply to both landfills and surface impoundments, the latter being of particular concern. Surface impoundments by their very nature pose a potential for releases to groundwater that is different than landfills (e.g., presence of a hydraulic head) that may impact the importance of source control for these types of units. As discussed above, EPA requests comment on whether the proposal is appropriate, and whether the record for either the existing CCR rule or the part 258 rules includes information, or whether other information exists, to support adoption of the more flexible corrective action provision based on part 258 for CCR units, which could allow an owner or operator to undertake corrective action for unlined surface impoundments in lieu if closure. Depending on comments received, EPA may revise this provision to more closely reflect the existing source control and corrective actions requirements in part 258 that would allow source control, including closure, to be discretionary in certain situations.

C. Modification of Groundwater Monitoring Requirements

The current regulations at § 257.90 require all CCR units, without exception, to comply with the groundwater monitoring and corrective action requirements of §§ 257.90–257.98. The final CCR rule at § 257.91(a)(2) requires the installation of groundwater monitoring wells at the waste boundary of the CCR unit.

EPA is proposing to adopt a provision analogous to 40 CFR 258.50(b), which allows the Director of an approved participating state to suspend the groundwater monitoring requirements under § 258.51 through § 258.55 if the

[32] In addition to federal guidance, EPA is aware that States may currently use different or more sophisticated groundwater classification systems. In the preamble to the October 9, 1991 Final Rule promulgating the MSW landfill standards, on the matter of groundwater classification EPA noted that ''States are expected to use groundwater classification and resource evaluations in making their State decisions.'' 56 FR 50995.

[33] Additional documents related to technical impracticability may be found at *https://www.epa.gov/superfund/superfund-groundwater-groundwater-response-selection#TI_anchor.*

[34] For example, risk estimates for unlined surface impoundments were the highest of all CCR unit types evaluated (80 FR 21319, April 17, 2015) and EPA's documented record of confirmed damage cases was dominated by ''wet disposal'' (e.g., impoundments; 80 FR 21456, April 17, 2015).

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owner or operator can demonstrate that there is no potential for migration of hazardous constituents from that MSWLF unit to the uppermost aquifer during the active life of the unit and the post-closure care period. Under part 258, the demonstration must be certified by a qualified groundwater scientist and approved by the Director of a participating state, and must be based upon:

(1) Site-specific field collected measurements, sampling, and analysis of physical, chemical, and biological processes affecting contaminant fate and transport, and

(2) Contaminant fate and transport predictions that maximize contaminant migration and consider impacts on human health and environment.

The Agency recognizes that certain hydrogeologic settings may preclude the migration of hazardous constituents from CCR disposal units to groundwater resources. Requiring groundwater monitoring in these settings would provide little or no additional protection to human health and the environment. Therefore, EPA is proposing to incorporate a nearly identical provision into the part 257 regulations. This would allow the Director of a participating state to suspend the groundwater monitoring requirements in § 257.91 through § 257.95 for a CCR unit upon demonstration by the owner or operator that there is no potential for migration of hazardous constituents from the unit to the uppermost aquifer during the active life, closure, or post-closure periods. However, the requirements of § 257.96 through § 257.98 would not be suspended. As discussed below, the provision being proposed for the part 257 regulations would be identical to that in the part 258 regulations with the exception for the requirement to periodically demonstrate that conditions have not changed, that is, there is still no migration of Appendix III or IV constituents from the CCR unit to the uppermost aquifer.

EPA recognizes it may be difficult for many facilities to meet the ''no potential for migration'' standard in the regulations. The suspension of monitoring requirements is intended only for those CCR units that are located in hydrogeologic settings in which hazardous constituents will not migrate to groundwater during the active life of the unit, closure, and post-closure periods. The Agency reminds readers that the ''no migration'' waiver has been a component of both the part 258 and the RCRA subtitle C groundwater monitoring programs for many years, and; based on its experience under these programs, the Agency expects that cases where these criteria are met will be rare.

The part 258 requirements allow the Director of a state program to establish the relevant point of compliance; in an unapproved state, the point of compliance is set by regulation at the waste management unit boundary. EPA does not believe the record for the part 258 requirements would support an alternative means for establishing the relevant point of compliance for CCR groundwater monitoring wells under RCRA section 4004(a). EPA requests comment on whether a State Director or EPA in a nonparticipating state, or an owner/operator subject to EPA oversight and public notice, could establish an alternative point of compliance consistent with the flexibility already allowed under the part 258 rules that would satisfy the standard of no reasonable probability of adverse effect on human health or the environment under section 4004(a).

In this action, EPA is not proposing to provide waivers from groundwater monitoring requirements except where the owner or operator in a participating state can demonstrate no potential for migration of hazardous constituents to the uppermost aquifer during the active life of the unit, closure, or post-closure periods. Consistent with the part 258 regulation, the Agency is proposing to allow this waiver only under the following conditions. EPA seeks comment on the use of each of these conditions. First, the suspension of groundwater monitoring requirements in § 257.91 through § 257.95 is available only for owners and operators of CCR units located in participating states or in those instances where EPA is the permitting authority. The Agency has limited the availability of the waiver because the Agency recognizes the need for the State to review a no-migration demonstration prior to granting a waiver from groundwater monitoring. However, the Agency seeks comment on an approach where a technical expert could make this demonstration (under the criteria described in the following paragraphs) and the facility could implement without the intervention of a permitting authority. In such an approach, the facility would keep records and post its determination on its web site and EPA would use the authorities in the WIIN act to oversee such a determination.

Second, the rule requires demonstrations of no potential for migration to be supported by both predictions that maximize contaminant migration and actual field data collected at the site. Field testing is necessary to establish the site's hydrogeological characteristics and must include an evaluation of unsaturated and saturated zone characteristics to ascertain the flow rate and pathway by which contaminants will migrate to groundwater. Any demonstration must be based on site-specific field measurements and sampling and analyses to determine the physical, chemical, and biological processes affecting the fate and transport of hazardous constituents. Site-specific information must include, at a minimum, the information necessary to evaluate or interpret the effects of the following properties or processes on contaminant fate and transport:

(1) Aquifer Characteristics, including hydraulic conductivity, hydraulic gradient, effective porosity, aquifer thickness, degree of saturation, stratigraphy, degree of fracturing and secondary porosity of soils and bedrock, aquifer heterogeneity, groundwater discharge, and groundwater recharge areas;

(2) Waste Characteristics, including quantity, type, and origin;

(3) Climatic Conditions, including annual precipitation, leachate generation estimates, and effects on leachate quality;

(4) Leachate Characteristics, including leachate composition, solubility, density, the presence of immiscible constituents, Eh, and pH;

(5) Engineered Controls, including liners, cover systems, and aquifer controls (e.g., lowering the water table). These should be evaluated under design and failure conditions to estimate their long-term residual performance.

(6) Attenuation of contaminants in the subsurface, including adsorption/desorption reactions, ion exchange organic content of soil, soil water pH, and consideration of possible reactions causing chemical transformation or chelation.

(7) Microbiological Degradation, which may attenuate target compounds or cause transformations of compounds, potentially forming more toxic chemical species.

Modeling may also be useful for assessing and verifying the potential for migration of hazardous constituents. However, any models used should be based on actual field collected data to adequately predict potential groundwater contamination. When owners or operators prepare a no migration demonstration, they must use transport predictions that are based on the maximum contaminant migration (i.e., worst case scenario) both from the unit and through the subsurface media. Assumptions about variables affecting transport should be biased toward over

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estimating transport and the anticipated concentrations. Assumptions and site-specific data that are used in the fate and transport predictions should conform with transport principles and processes, including adherence to mass-balance and chemical equilibria limitations. Within these physicochemical limitations assumptions should be biased toward the objective of assessing the maximum potential impact on human health and the environment.

Third, the proposed rule would require the demonstrations to be certified by a qualified professional engineer and approved by the Director of a participating state to ensure that there is a high degree of confidence that no contamination will reach the uppermost aquifer.

Finally, the proposed rule would require the owner or operator of the CCR unit to make periodic demonstrations every 10 years in order to retain the suspension of groundwater monitoring. The Agency received comments on suspending the groundwater monitoring requirements for MSWLFs in part 258 that suggested EPA require periodic demonstrations every five or ten years. See, 56 FR 51061 (October 9, 1991). The Agency decided against requiring periodic demonstrations for MSWLFs because the demonstration required must be extremely rigorous and because of the additional costs associated with the continual reapplication for the suspension. As mentioned earlier in this proposed rulemaking, the statutory standard for the part 258 regulations is different than the standard for the CCR regulations: The CCR regulations are based on RCRA section 4004(a), which requires that the regulations ensure ''there is no reasonable probability of adverse effects on health or the environment from disposal of solid waste at such facility.'' 42 U.S.C. 6944(a). This is a risk-only standard. By contrast, EPA was authorized to ''take into account the [facility's] practicable capability'' in developing the part 258 regulations. 42 U.S.C. 6949a(c). Also, the part 258 regulations apply only to landfills, while the CCR regulations apply to both landfills and surface impoundments, the latter being of particular concern. Surface impoundments by their very nature pose a potential for releases to groundwater that is different than landfills (*e.g.,* presence of a hydraulic head) that may impact the importance of source control for these types of units. The risk assessment for the CCR rule found that, even when key variables are controlled (*e.g.,* liner type, waste type) for the long-term risks from surface impoundments are greater than from landfills. This is because the high and sustained hydraulic head present in these surface impoundments drives leachate into the groundwater table at an accelerated rate. Based on these factors, EPA is proposing to require an owner or operator to conduct a new demonstration once every 10 years to show that the suspension of groundwater monitoring continues to be appropriate. See proposed § 257.90(g). This new demonstration should be submitted to the State Director one year before the existing groundwater monitoring suspension is due to expire. If the suspension expires for any reason, the unit must begin groundwater monitoring according to § 257.90(a) within 90 days.

Further guidance for conducting these evaluations can be found in the OSWER Solid Waste Disposal Facility Criteria Technical Manual for MSWLFs (EPA530–R–93–017, 1993) and the Ground-Water Monitoring Guidance Document for Owners and Operators of Interim Status Facilities (1983).

D. Alternate Period of Time To Demonstrate Compliance With Corrective Action

The current regulations at § 257.98(c)(2) require that facilities demonstrate that compliance with the groundwater protection standards (GWPS) established under § 257.95(h) have been achieved by monitoring results documenting that concentrations of constituents listed in Appendix IV to part 257 have not exceeded the groundwater protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in § 257.93(f) and (g). EPA is proposing to modify this by adopting a provision analogous to 40 CFR 258(e)(2). Both the part 258 regulation and the proposed § 257.98(c)(4) counterpart allow the Director of a participating state to specify an alternative length of time during which the owner or operator must demonstrate that concentrations of Appendix II to part 258 constituents (or in the case of the proposed part 257 counterpart, Appendix IV to part 257 constituents) have not exceeded the groundwater protection standard(s). Under the current part 258 regulations, the State must make this determination after taking into consideration: (1) The extent and concentration of the release(s); (2) behavior characteristics of the hazardous constituents in the groundwater; (3) accuracy of monitoring or modeling techniques, including any seasonal, meteorological, or other environmental variabilities that may affect the accuracy; and (4) characteristics of the groundwater.

When establishing an alternative compliance period, the proposed regulation would require a State to consider the following site-specific conditions under § 257.98(c)(4): (1) The extent and the concentration of the release; (2) the behavior characteristics (fate and transport) of the part 257 Appendix IV constituents in the groundwater (e.g., mobility, persistence, toxicity); (3) the accuracy of monitoring or modeling techniques, including any seasonal, geotechnical/geophysical, meteorological, or other environmental variabilities that may affect the accuracy; and (4) the characteristics of the groundwater (e.g., flow rate, pH). These are the same factors included in part 258; consideration of these factors will allow the State to set an appropriate time period for demonstrating compliance with the groundwater protection standards rather than relying on an arbitrary time period for all facilities or all situations at the same facility. In large part, EPA is relying on the longstanding experience with these criteria under part 258 for municipal solid waste landfills.

In summary, § 257.98(c)(2) and (4) of this proposal requires that the groundwater protection standard be achieved for a period of three consecutive years at all points within the plume of contamination unless an alternative period of time is established by a participating state. Those states may set an alternative period of compliance after taking site-specific conditions into consideration. In demonstrating compliance with the groundwater protection standard, the owner or operator would be required to use the statistical procedures in § 257.93.

E. Length of Post-Closure Care Period

The current regulations at § 257.104(c)(1) state that the owner or operator of a closed CCR unit must conduct post-closure care for 30 years unless at the end of the 30 years corrective action is on-going, or the CCR unit is operating under assessment monitoring, in which case the owner or operator must continue to conduct post-closure care until the unit has returned to detection monitoring.

EPA is proposing to adopt a provision analogous to 40 CFR 258.61(b), which allows the Director of a participating state to decrease the length of the post-closure care period if the owner or operator demonstrates that the reduced period is sufficient to protect human health and the environment and this demonstration is approved by the

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Director of approved participating state. It also allows the Director of the participating state to increase the length of the post closure period if the Director determines a lengthened period is necessary to protect human health and the environment.

The Agency is proposing this provision to account for situations where a 30-year post-closure care period may be inappropriate based on site-specific conditions. Overall, providing for variances in the post-closure care period in these states allows the flexibility to accommodate differences in geology, climate, topography, resources, demographics, etc. In all cases, however, these decisions must be reviewed carefully by the State to ensure units are monitored and maintained for as long as is necessary to protect human health and the environment.

In determining whether a revised post-closure care period is warranted, one critical factor is ensuring that the cover will continue to function effectively. EPA recognizes that no final cover, however well-constructed, will last forever. In 1988, EPA stated that ''even the best liner and leachate collection system will ultimately fail due to natural deterioration . . . .'' [35] Although any impermeable barriers used in a final cover system will eventually fail, studies have shown that such natural deterioration can take thousands of years (Needham et al., 2006; Rowe & Islam, 2009).[36] [37] This is consistent with the concept of bathtub (or U shaped) failure rate in reliability analysis (Shehla & Khan, 2016).[38] This failure pattern begins with a wear-in period where failure rates are high due to design and manufacturing problems. The failure rate then decreases to a low, constant rate for a period of time before rising in the third, wear-out phase.

Though this wear-out phase may take thousands of years, the wear-in phase for waste management unit covers is much shorter. In the context of CCR units, the wear-in phase of a closed unit would be due to imperfections in covers, either from a manufacturing defect or faulty installation. Manufacturing defects may include items such as pin holes, whereas faulty installation may be the result of a tear or failure to properly seal joints (Bonaparte et al, 1989).[39]

Settlement resulting from factors, such as the gradual dissolution of more soluble components within the ash mixture, is also a potential issue. Depressions caused by settlement may lead to ponding and should be filled with soil. Excessive settlement may warrant reconstructing or adding to portions of the infiltration layer. Settlement can also damage the cover through tension cracks and tears in the synthetic membrane. For example, topographic surveys of the unit(s) may be used every few years until settlement behavior is established, to determine whether settlement has occurred.

Consequently, EPA is proposing to require that part of determining whether a shorter post-closure care period will protect human health and the environment, a state must ensure that the post-closure care period is long enough to detect such issues. This would require the state to consider not only the type of cover placed on the unit (*e.g.,* compacted soil), but also the placement of the groundwater monitoring wells with respect to the waste management unit. For instance, where a waste management unit is close to the groundwater table and the groundwater monitoring wells are located at the unit boundary, one would generally expect transit time of any contamination to be short, and thus a shorter post-closure monitoring period might be sufficient to catch wear-in defects in the cover system. However, where the unit is located further from the groundwater table, constituents may not have sufficient time to reach the monitoring wells under such a curtailed post-closure period.

In addition, under the current CCR regulations, once detection monitoring yields a statistically significant increase above background levels of any Appendix III constituent, assessment monitoring is triggered, and the unit continues to be subject to the rule's post-closure care requirements so long as the CCR unit is operating under assessment monitoring. Section 257.104(c)(2). EPA is not proposing to amend this requirement, or to allow States to do so as part of this new provision. Thus, the State could not allow a facility to end the post-closure care period, once the detection of contamination above background triggers assessment monitoring. This would hold, even if the State had previously authorized a shorter post-closure care period. EPA is proposing to include language in this provision that clarifies how these two requirements interact.

F. Allowing Directors of Participating States To Issue Certifications in Lieu of Requiring a PE Certification

To ensure that the RCRA subtitle D requirements would achieve the statutory standard of ''no reasonable probability of adverse effects on health and the environment'' in the absence of regulatory oversight, the current CCR regulations require facilities to obtain third party certifications and to provide enhanced state and public notifications of actions taken to comply with the regulatory requirements. Specifically, in the final CCR rule EPA required numerous technical demonstrations made by the owner or operator be certified by a qualified professional engineer (PE) in order to provide verification of the facility's technical judgments and to otherwise ensure that the provisions of the rule were properly applied. While EPA acknowledged that relying upon a third party certification was not the same as relying upon a state or federal regulatory authority and was not expected to provide the same level of independence as a state permit program, the availability of meaningful third party verification provided critical support that the rule would achieve the statutory standard, as it would provide a degree of control over a facility's discretion in implementing the rule. However, the situation has changed with the passage of the WIIN Act, which offers the opportunity for State oversight under an approved permit program. To reflect that, EPA is proposing to revise the regulations to allow the Director of a state with an approved CCR permit program (a participating state) to certify that the regulatory criteria have been met in lieu of the exclusive reliance on a qualified PE. EPA expects that States will generally rely on the expertise of its own engineers to evaluate whether the technical criteria have been met. Alternatively, States might choose to retain the required certification by a qualified PE and use its own expertise to evaluate that certification. Finally, EPA notes that under the existing regulations, a facility may already rely on a certification provided by a qualified PE in a State agency, who reviews the facility actions as part of a purely State-law mandated process. Thus, EPA is confident that the

[35] US EPA, ''Solid Waste Disposal Facility Criteria; Proposed Rule,'' 53 FR 33345 (August 30, 1988).

[36] Needham, A.D., Smith, J.W.N., Gallagher, E.M.G. 2006. *The service life of polyethylene geomembrane barriers. Engineering Geology* 85. 82–90.

[37] Rowe, R.K., Islam, M.Z. 2009. *Impact of landfill liner time-temperature history on the service life of HDPE geomembranes. Waste Management* 29. 2689–2699.

[38] Shehla, R., & Khan, A.A. (2016). Reliability analysis using an exponential power model with bathtub-shaped failure rate function: a Bayes study. *SpringerPlus, 5*(1), 1076. *http://doi.org/10.1186/s40064-016-2722-3.*

[39] Bonaparte, R., J.P. Giroud, and B.A. Gross. 1989. Rates of leakage through landfill liners. *Geosynthetics 1989 Conference.* San Diego, CA.

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additional layer of oversight provided by the State under this proposal will be at least as protective than the status quo under the existing regulations.

G. Revision To Allow the Use of CCR During Certain Closure Situations

EPA is proposing to revise the current regulations to allow the use of CCR in the construction of final cover systems for CCR units closing pursuant to § 257.101 that are closing with waste-in-place. EPA is also proposing specific criteria that the final cover system must meet in order to allow for the placement of CCR in the final cover system. EPA is proposing two performance standards: One that applies directly to facilities in any ''non-participating state'' and a second that applies to facilities that operate in states with an approved CCR permit program (''participating'' state). Specifically, EPA is proposing to allow for the continued placement of CCR in units triggered for closure to construct a cover system under the following conditions: (1) Only CCR generated on-site may be used in the construction of the cover system; (2) CCR may be used exclusively for the purposes of grading and contouring of the cover system; (3) CCR must be placed within the vertical plane of the boundary of the unit; and (4) must be at either no steeper than a 5 percent grade or at a steeper grade, as determined by the Director of an approved program based on a stability analysis. These criteria are intended to ensure that the CCR utilized in construction of the final cover system does not exceed the necessary amount for grading and contouring.

The current CCR rules require that certain units must close for cause, as laid forth in § 257.101(a)–(c). As written, the regulation expressly prohibits ''placing CCR'' in any units required to close for-cause pursuant to § 257.101. This includes unlined CCR surface impoundments whose groundwater monitoring shows an exceedance of a groundwater protection standard (§ 257.101(a)(1)); existing CCR units that do not comply with the location criteria (§ 257.101(b)(1)); and CCR surface impoundments that are not designed and operated to achieve minimum safety factors (§ 257.101(b)(2) and (c)(1)). Note that the rule does not distinguish between placement that might be considered beneficial use and placement that might be considered disposal. All further placement of CCR into the unit is prohibited once the provisions of § 257.101 are triggered. By contrast, the regulations do not restrict further placement or use of CCR when the unit is closing under other provisions.

Proposal for Closure With CCR

After publication of the final rule, EPA received numerous requests that EPA clarify whether use of CCR in completing the closure of a unit was permitted under the regulation, either as part of a closure plan or under the theory that such an activity was ''beneficial use.'' After evaluating the issue, EPA is proposing an exemption that would allow further placement of CCR in a CCR unit closing pursuant to § 257.101 for the purposes of construction of the final cover system. EPA is not proposing any other revisions to the existing closure requirements; therefore, owners and operators who choose to place CCR as part of the final cover system as part of closure ''for cause'' will still need to comply with all of the existing closure requirements in §§ 257.101–104.

EPA is proposing this revision because there are environmental and health benefits in allowing use of CCR in this fashion, and as discussed below in more detail, provided the conditions outlined in this rule are met, the existing information demonstrate that the use of CCR in this fashion would not measurably affect the risks from the unit. Allowing the use of on-site CCR in lieu of other material to construct the cover furthers the general goal in § 257.102(d)(1)(v) of closing as quickly as possible. As EPA identified in the final rule, the process for procuring at-specification earthen material in the volumes necessary for the final cover system construction can complicate completion of closure requirements within the required time frames. This was explicitly described as a factor that could support an extension of the closure deadlines under § 257.102(f)(2)(i)(C). Thus, this proposed revision is expected to allow facilities to complete closure more quickly, and accordingly realize reduced risks more quickly.

This proposal is a narrow modification of the § 257.101 prohibition on CCR placement, and contains four requirements to ensure that the use of CCR is to accelerate closure rather than merely allow the facility continue the disposal of CCR in a deficient unit. First, the material placed under this exemption must have been generated on-site and be present at the time of closure. Second, the material may only be used for the grading and contouring of the cover system, not to fill up a partially full unit. Third, the placement of the material must be within the boundary or the vertical plane of the boundary of the waste management unit. Finally, the material may only be used to construct a cover at either no steeper than a 5 percent grade or at a steeper grade, as determined by the Director of an approved program (or EPA where it is the permitting authority). Each of these requirements is discussed further below.

On-site materials. EPA is proposing that all CCR material utilized for construction of the final cover system must have been generated by the facility, *i.e.,* by the coal-fired boilers that generated electricity at the facility and associated air pollution control devices, and that the CCR be located at the facility since the time of generation. CCR sourced exclusively from on-site will allow for timely construction of the final cover system. Moreover, EPA does not intend this proposed rule to allow owners and operators to continue disposal into a waste management unit that is closing for cause pursuant to § 257.101. Limiting the source of material will help to ensure that. Rather, the exemption is meant to allow for the genuine use of available materials for the closure of a waste management unit.

For grading and contouring. EPA is also proposing to limit the exemption to the design and construction of the final cover system. As noted previously, § 257.102(d)(2) requires that dewatering and stabilization be achieved prior to installation of a cover, and § 257.102(d)(3) requires that several protective layers be constructed at the uppermost areas of the final cover system. As a practical matter, these two existing provisions (which EPA is not proposing to modify or take comment on) would effectively limit the placement of CCR to grading and contouring. Nevertheless, to avoid confusion, EPA is proposing to include a specific condition to make this explicit. For the purposes of this rule, EPA considers grading and contouring as activities specifically related to creating elevation differences and travel pathways to encourage free drainage of liquids out of and away from the CCR surface impoundment. Accordingly, EPA is proposing to define grading to mean placement of CCR for the sole purpose of creating differences in elevation to support positive stormwater drainage. EPA is also proposing to define contouring to mean placement of material to provide a continuous downward slope on the surface of a drainage area (*i.e.,* the final cover system), except for erosion control features (*e.g.,* swales, contour banks).

This proposal would not allow placement of CCR for the purposes of waste stabilization or to otherwise fill

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the unit to capacity. Placement of CCR for these purposes would involve the placement of substantial volumes of CCR into a leaking or otherwise deficient unit, and EPA lacks information that such further placement would be protective. To achieve this, EPA is proposing different criteria based on the construction of the unit. Many surface impoundments consist of an incised portion, or portion which is excavated below the surrounding grade. Incised units are units that hold an accumulation of CCR entirely below the adjacent natural ground surface, and do not consist of any constructed diked portion. For incised CCR surface impoundments, EPA is proposing that any CCR utilized for the final cover system must be placed above the highest elevation of the surrounding natural ground surface where the CCR unit was constructed.

EPA intends for this requirement to account for the preexisting topography in the area where the incised CCR unit was constructed. The owner or operator would be responsible for determining the preexisting topography of the CCR unit through means of historical documentation or by identifying the highest point of the perimeter of the excavated portion of the unit.

A primary purpose of a final cover system is to encourage free surface drainage in order to limit infiltration from precipitation into the underlying waste. CCR units with incised portions can present an issue with free drainage of liquids because much of the unit is located below the surrounding grade and does not allow for drainage by gravity, *i.e.,* the drainage must occur mechanically, by evapotranspiration, or by infiltration. Placement of CCR below the highest elevation of the surrounding topography would no longer serve the purpose of encouraging drainage, and therefore would not be considered part of constructing the final cover system.

For all other units, including CCR surface impoundments that consist of a diked portion, *e.g.,* diked impoundments, cross-valley impoundments, side-hill impoundments, or some combination thereof, EPA is proposing to require the owner or operator to establish a baseline elevation above which all CCR would need to be placed when constructing the final cover system. EPA is proposing that this baseline elevation be defined as the highest elevation of CCR in the unit, following dewatering and stabilization as required by § 257.102(d)(2).[40] From that point forward, CCR material may only be placed above that elevation for grading and contouring.

These requirements are designed to establish clear and objective geometric boundaries for the permissible placement of CCR. With these two performance standards, EPA is effectively establishing a ''lowest bound'' plane; placement below that elevation would be considered to be disposal, and would still be prohibited. EPA is also proposing to establish an upper bound to ensure that only the amount of CCR necessary for grading and contouring is used. The ''upper bound'' is represented by the maximum final grade of the final cover system of 1:20, *i.e.,* 5 percent (discussed further below). Furthermore, the ''vertical plane'' criteria discussed later in this preamble would also establish ''horizontal bounds'' for placement of CCR material in the cover system. In order to fulfill the ''free drainage'' criteria set forth in § 257.102(d)(1)(ii), the geometry of the waste in the unit must allow for free drainage of all water, sediment, and slurry from any point within the CCR surface impoundment out of the breached portion of the embankment.

Collectively, these criteria are designed to ensure owners and operators place only the amount of CCR necessary to achieve adequate grading and contouring for free drainage.

For example, this proposal would not allow the owner or operator to raise the breached invert elevation and place CCR material above the previously placed ''waste-in-place'' CCR and effectively raise the invert elevation for drainage. EPA intends for the final level of CCR within the CCR unit to essentially be the ultimate height of the surface of the final cover system, with allowance for limited addition of material to ensure effective drainage from the unit. EPA does not intend for this proposal to allow the facility to unnecessarily raise the invert elevation of the breached portion of the embankment, as a means of further disposal of CCR in the interim space between initial invert and adjusted invert elevations.

Within the vertical plane. EPA is proposing that CCR used for construction of the final cover system may not be placed outside the vertical plane. The vertical plane for non-incised units is established as the line which extends from the intersection between the crest of the CCR within the surface impoundment and the berm or dike of the CCR surface impoundment. For incised CCR surface impoundments, the vertical plane is established as the line that extends at the intersection where the cap of the CCR surface impoundment with a slope of no steeper than 5 percent meets the natural topography of the land prior the construction of the CCR unit. Placement beyond this boundary would constitute a lateral expansion as defined in § 257.53.[41] EPA is proposing this requirement in order to prevent the potential release of CCR constituents outside of the waste boundary without the protections EPA deliberately included in the final rule for such lateral expansions.

At no steeper than a 5 percent grade. EPA is proposing that the final cover system using CCR for grading and contouring be constructed with slopes no steeper than 1:20. This ratio of vertical rise to horizontal rise is equal to a 5 percent grade. EPA has identified 5 percent to generally be the maximum necessary grade to promote positive drainage in a vegetated slope runoff, as steeper grades may lead to erosion and deterioration of the final cover system.[42] EPA is proposing a maximum grade for the final cover system to minimize the potential for abuse whereby a facility might unnecessarily grade a cover steeply in order to dispose of additional CCR. EPA intends the grade of the final cover system to allow for free drainage to the invert elevation of the breached portion of the embankment.

However, in rare instances it may be possible that a cover requires a steeper grade. Consequently, EPA is proposing that the Director of a participating state may approve a grade steeper than 5 percent in a permit if such a grade is necessary for the proper function of the cover system. To support a steeper grade, a stability analysis must be performed to evaluate possible erosion potential. A stability analysis looks at the ability of soil to resist sliding on itself on the slope. The analysis, at a minimum, must evaluate: (1) The site geology, (2) characterize soil shear strength, (3) construct a slope stability model, (4) establish groundwater and seepage conditions, if any, (5) select loading conditions, (6) locate critical

[40] As noted, under the existing regulations the owner or operator must first breach and dewater the CCR unit, allowing for free drainage of water, sediment, or slurry out of the CCR surface impoundment via surface runoff, prior to construction of the final cover system. Additionally, if the owner or operator intends to leave waste-in-place, the owner or operator must ''preclude the probability of future impoundment of water, sediment, or slurry,'' per the requirements of § 257.102(d)(1)(ii).

[41] *Lateral expansion* means a horizontal expansion of the waste boundaries of an existing CCR landfill or existing CCR surface impoundment made after October 19, 2015.

[42] USEPA, Solid Waste Disposal Facility Criteria-Technical Manual, EPA Document EPA530–R–93–017.

failure surface, and (7) iterate until minimum factor of safety is achieved.

Finally, EPA recently issued an interpretation that under the current regulations, the prohibition on the placement a unit closing for cause did not preclude the movement of additional wastes (stormwater and associated/accompanying CCR) between the units that operate as part of a multiunit treatment system. The current regulations allow the facility to treat such units as a single unit. See, *e.g.,* § 257.91(d)(1). Based the longstanding interpretation that EPA does not regulate the movement of wastes within a unit, EPA concluded that where the impoundments are being treated as a singular system, the movement of CCR within that system (*i.e.,* from one impoundment to another) would not be considered ''placing CCR'' under the prohibitions of § 257.101. Under this same logic, a facility could conceivably consolidate the CCR from other units in the system into a single unit, even though the unit was deficient. There can be benefits to such a practice; for example, it may facilitate clean closure and allow owners and operators to focus their long term monitoring, care, and cleanup obligations on a single unit rather than many units. And presuming the unit meets all of the performance standards for closure with waste in place, it may be the risks associated with such consolidation are acceptable. However, there are also potentially significant risks associated with the continued placement of large volumes of CCR in a deficient unit. As discussed in the next section, although EPA has preliminarily concluded that the use of CCR in the construction of the cover system will meet the RCRA section 4004(a) standard, there were limitations in the assessment that raise questions about further extrapolation of that assessment to support the placement of large volumes of CCR in these units (*e.g.,* EPA's risk assessment did not model the addition of CCR to partially-filled leaking units). Thus an interpretation that allowed consolidation of CCR into a single unit of a multi-unit system could be seen as inconsistent with the approach outlined in this proposal.

EPA has not determined whether allowing such a practice meets the statutory standard, and is therefore soliciting comment on two potential alternatives. Under one approach EPA would rely on its longstanding interpretation to allow the consolidation of CCR from units operating within a multi-unit system, when the facility treats the system as a single unit for purposes of closure (*i.e.,* all units within the system are closing). Alternatively, EPA would revise the regulations to explicitly clarify that only the use of CCR for purposes of grading and contouring is permitted, even between units within a multi-unit system closing for cause. Note that under either approach, EPA does not intend to revise its interpretation that the movement of stormwater (and associated CCR) between units within a multi-unit system that is closing for cause is permissible. EPA is concerned about the potential risks associated with the continued placement of large volumes of CCR, and similar concerns are not raised by the movement of stormwater and de minimis amounts of CCR between units in the process of clean closing.

Analytic Support of Risk Assessment Results

U.S. EPA (2009) [43] used a response-surface regression method to derive a statistical model for groundwater concentration (as the dependent variable) based on the input parameters from the probabilistic analysis (as independent variables). Concentration, rather than risk, was chosen as the dependent variable for the sensitivity analysis because the additional exposure factors used to calculate human health risk from environmental concentration (*e.g.,* body weight) have well established, peer-reviewed distributions based on EPA policy. The outputs of the sensitivity analysis were goodness-of-fit values used to determine the relative importance of each input parameter. The most sensitive parameters identified are presented in Table 1.

TABLE 1—SENSITIVE PARAMETERS

Pathway:	GW to DW pathway		GW to SW pathway
Constituents:	All constituents	Strongly sorbing	All constituents
Sensitive Parameters	• Infiltration rate • Leachate concentration • Hydraulic gradient • Hydraulic conductivity.	• K_d value • Depth to groundwater • Distance to receptor well	• Infiltration rate. • Leachate concentration. • Water body flow rate.

Note: GW = Groundwater; DW = Drinking Water; SW = Surface Water.

As seen in the table above, the groundwater to drinking water exposure pathway had more input parameters that were highly sensitive (seven) than the groundwater to surface water exposure pathways (three). The most sensitive parameters for the groundwater to drinking water pathways were parameters that impact flux (infiltration rate and leachate concentration) and groundwater flow (hydraulic conductivity and gradient). When modeling strongly sorbing constituents, the K_d values and distance to receptor also become important. The most sensitive parameters for the groundwater to surface water exposure pathways were parameters impacting flux (infiltration rate to groundwater and leachate concentration) and the water body flow rate.

Depth to groundwater was a sensitive parameter for strongly sorbing constituents. However, the sensitivity analysis did not find total waste depth (*i.e.,* total thickness of CCRs disposed in a unit filled to capacity) to be a sensitive parameter for closed landfills and surface impoundments. However, EPA sought to verify this through further analysis of the final risk assessment results (U.S. EPA, 2014).[44]

The risks EPA sought to further evaluate were those from surface impoundments closed for cause with waste in place. In Appendix K of the final risk assessment, EPA modeled dewatered surface impoundments post-closure with waste in place as

[43] U.S. EPA (Environmental Protection Agency). 2009. Sensitivity Analysis for the Coal Combustion Waste Risk Assessment. Draft Technical Report. Prepared by RTI International for U.S. EPA, Office of Solid Waste, Washington, DC.

[44] U.S. EPA. 2014. Human Health and Ecological Risk Assessment of Coal Combustion Residuals. Final. Office of Resource Conservation and Recovery. December. RIN: 2050–AE81.

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equivalent to closed landfills. Because the results driving EPA's final rule were those for trivalent arsenic [As(III)] cancer risks, EPA selected As(III) cancer risk results from landfills as the appropriate results on which to conduct this sensitivity analysis.

EPA used the probabilistic model inputs for waste depth to calculate 25th, 50th, and 75th percentile waste depths. These cutoffs were used to filter the model runs into four quartiles. For each quartile EPA calculated a 90th percentile As(III) cancer risk. Below are the As(III) cancer risk results EPA obtained when filtering the landfill risk results for the depth of the waste. As waste depth changed, EPA did not see significant changes in risk for any liner type. This confirms the findings of the sensitivity analysis where depth was not shown to be a sensitive parameter.

TABLE 2—90TH PERCENTILE AS(III) CANCER RISKS ACROSS WASTE DEPTH QUARTILE

	1st Quartile	2nd Quartile	3rd Quartile	4th Quartile
Liner Type:				
Unlined	1.50E–05	1.28E–05	2.66E–05	1.79E–05
Clay Lined	1.28E–05	1.11E–05	1.32E–05	1.93E–05
Composite	1.39E–20	5.34E–29	3.84E–27	<1.00E–30

EPA also notes that the volume of infiltration from precipitation relative to the volume of waste present in a unit is very small. This would lead to a low liquid-to-solid (L/S) ratio for water passing through landfills and dewatered surface impoundments. The low L/S ratio ensures that the leachate is saturated with constituent mass before it exits the bottom of the landfill or surface impoundment. Because the leachate is in equilibrium with the waste, the addition of more mass would not further increase leachate concentrations. Instead, the increased total mass would affect the time necessary for constituent mass to fully deplete from the waste. A majority of the model runs for arsenic already reached a steady state concentration at the well within the modeled timeframe. Therefore, an increase in leaching duration would not substantially alter long-term risks.

The addition of larger volumes of ash for purposes other than expediting closure would result in a greater amount of time without a cap and other appropriate controls in place. This would result in greater opportunity for precipitation to infiltrate into the unit prior to closure. The additional volume of water would increase the hydraulic head within the unit and, ultimately, the rate of infiltration down to the groundwater table. EPA identified infiltration to groundwater as one of the most sensitive variables when modeling risks. Thus, EPA concludes that the addition of ash for purposes other than expediting closure has the potential to increase the transport of constituent mass to groundwater and the associated risks.

Under this proposal, utilities could add ash to construct the cover system for closure of a unit for the purpose of achieving the necessary grade to safely close with waste in place. A review of both the 2009 sensitivity analysis and the final risk assessment found that the comparatively minor addition of CCR mass applied solely for grading purposes would not alter potential risks to receptors. Therefore, EPA finds that the use of ash for grading would remain protective of human health and the environment.

V. The Projected Economic Impacts of This Action

A. Introduction

EPA estimated the costs and benefits of this action in a Regulatory Impact Analysis (RIA) which is available in the docket for this action. The RIA estimates costs and cost savings attributable to the provisions of this action against the baseline costs and cost savings of the 2015 CCR final rule. The RIA estimates that the net annualized impact of these eleven provisions over a 100 year period of analysis will be cost savings of between $32 million and $100 million when discounting at 7 percent and cost savings between $25 million and $76 million when discounting at 3 percent. This action is considered an economically significant action under Executive Order 12866.

B. Affected Universe

The universe of affected entities for this rule consists of the same entities affected by EPA's 2015 CCR final rule. These entities are coal-fired electricity generating plants operated by the electric utility industry. They can be identified by their North American Industry Classification System (NAICS) designation 221112 ''Fossil Fuel Electric Power Generation''. The RIA estimates that there are 414 coal-fired electricity generating plants operating 922 CCR management units (landfills, disposal impoundments, and storage impoundments) that will be affected by this rule.

C. Baseline Costs

The baseline costs for this rule are the costs of compliance with EPA's 2015 CCR final rule, as the provisions of this rule modify the provisions of the 2015 CCR final rule or modify the implementation of the 2015 CCR rule by WIIN Act participating states. The RIA for the 2015 CCR final rule estimated these costs at an annualized $509 million when discounting at 7 percent and an annualized $735 million when discounting at 3 percent.

D. Cost Savings, Other Benefits, and Adjustments to the Baseline

The RIA estimates costs and costs savings for the four proposals associated with the 2015 CCR rule judicial remand as well as the six alternative performance standards that will apply in participating states under the WIIN Act, and the use CCR during certain closure situations. The RIA estimates that the net annualized impact of these eleven provisions over a 100 year period of analysis will be an annualized cost savings of between $32 million and $100 million when discounting at 7 percent, and an annualized cost savings of between $25 million and $76 million when discounting at 3 percent.

The RIA also estimates potential adjustments to the baseline costs of the CCR final rule due to plant closures that occurred after the rule was published but before the effective date of the rule. The RIA accompanying the 2015 CCR final rule assigned compliance costs to these plants, which they are exempt from because they closed before the final rule's effective date. In all, 23 plants closed before the effective date of the final rule that were not accounted for in 2015 final rule RIA. The annualized compliance costs avoided for these plants equals between $22 million and $25 million per year when discounting at 7 percent and between $22 million and $31 million when

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discounting at 3 percent. This cost adjustment is detailed in the RIA that accompanies this rulemaking, however it is not factored into the baseline or the benefit estimates for this rule to keep comparisons with the 2015 CCR final rule straight forward.

E. Solicitation of Comments on the Projected Economic Impacts

EPA is soliciting comments on the following aspects of the Regulatory Impact Analysis (RIA), which is available in the docket for this rulemaking. The Agency is soliciting comment primarily on the assumptions and the data sources used in the analysis.

- Do you have information that would refine the RIA assumptions about the number of facilities both in and serving affected NERC regions that would request alternative closure under Additional Provision 1 (the amendment discussed in Unit III.D of this preamble)?
- Do you have information that would refine the RIA assumption that facilities seeking alternative closure requirements under Additional Provision 1 (the amendment discussed in Unit III.D of this preamble) would delay closure by five years (the maximum allowed under the rule)?
- Do you have information that would refine the RIA assumptions about the maximum or minimum number of states that would likely adopt alternative performance standards under the WIIN Act?
- Do you have information that would refine the RIA assumptions about the changes in total corrective action costs for a release due to the Alternative Performance Standard 1 (the amendment discussed in Unit IV.A of this preamble)?
- Do you have information that would refine the RIA assumptions about the total number of CCR units that may avoid corrective action costs due to the Alternative Performance Standard 2 (the amendment discussed in Unit IV.B of this preamble)?
- Do you have information that would refine the RIA assumptions about the number of units that will receive a ''no migration'' waiver under Alternative Performance Standard 3 (the amendment discussed in Unit IV.C of this preamble)?
- Do you have information that would refine the RIA assumption that states adopting Alternative Performance Standard 4 (the amendment discussed in Unit IV.D of this preamble) would on average reduce the post-remedy monitoring from three years to one year?
- Do you have information that would refine the RIA assumption that states adopting Alternative Performance Standard 5 (the amendment discussed in Unit IV.E of this preamble) would on average reduce the period from 30 years to five years?
- Do you have information that would refine the RIA assumptions about the total number of CCR units that would use CCR as allowed under Additional Provision 2 (the amendment discussed in Unit IV.G of this preamble)?
- Do you have information that would refine the RIA assumptions about the average annual number of CCR units closing (RIA page 4–14)?
- Do you have information that would refine the RIA assumptions about the estimated tonnage of CCR that could be used for closure (RIA page 4–14)?
- Do you have information that would refine the RIA description and estimates of impacts related to interactions among CCR Remand Rule provisions (RIA pp. 5–1 through 5–3)?

VI. Statutory and Executive Order (EO) Reviews

A. Executive Order 12866: Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review

This action is a significant regulatory action that was submitted to the Office of Management and Budget (OMB) for review. Any changes made in response to OMB recommendations have been documented in the docket. The EPA prepared an analysis of the potential costs and benefits associated with this action. This Regulatory Impact Analysis (RIA), entitled *Regulatory Impact Analysis; EPA's 2017 RCRA Proposed Rule; Disposal of Coal Combustion Residuals from Electric Utilities; Amendments to the National Minimum Criteria (October 2017),* is summarized in Unit V of this preamble and the RIA is available in the docket for this proposal.

B. Executive Order 13771: Reducing Regulation and Controlling Regulatory Costs

This action is expected to be an Executive Order 13771 deregulatory action. Details on the estimated cost savings of this proposed rule can be found in EPA's analysis of the potential costs and benefits associated with this action.

C. Paperwork Reduction Act (PRA)

The information collection activities in this proposed rule have been submitted for approval to the Office of Management and Budget (OMB) under the PRA. The Information Collection Request (ICR) document that the EPA prepared has been assigned EPA ICR number 1189.27, OMB control number 2050–0053. This is an amendment to the ICR approved by OMB for the Final Rule: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities published April 17, 2015 in the **Federal Register** at 80 FR 21302. You can find a copy of the ICR in the docket for this action, and it is briefly summarized here. This rulemaking, specifically the provision clarifying the type and magnitude of non-groundwater releases that would require a facility to comply with some or all of the corrective action procedures set forth in §§ 257.96–257.98, reduces the paperwork burden attributable to provisions of the April 17, 2015 CCR Final Rule.

Respondents/affected entities: Coal-fired electric utility plants that will be affected by the rule.

Respondent's obligation to respond: The recordkeeping, notification, and posting are mandatory as part of the minimum national criteria being promulgated under Sections 1008, 4004, and 4005(a) of RCRA.

Estimated number of respondents: 414.

Frequency of response: The frequency of response varies.

Total estimated burden: EPA estimates the total annual burden to respondents to be *a reduction in burden of* approximately 4,267 hours from the currently approved burden. Burden is defined at 5 CFR 1320.3(b).

Total estimated cost: The total estimated annual cost of this rule is a *cost savings* of approximately $5,713,027. This cost savings is composed of approximately $519,832 in annualized avoided labor costs and $5,193,195 in avoided capital or operation and maintenance costs.

An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for the EPA's regulations in 40 CFR are listed in 40 CFR part 9.

D. Regulatory Flexibility Act (RFA)

I certify that this action will not have a significant economic impact on a substantial number of small entities under the RFA. In making this determination, the impact of concern is any significant adverse economic impact on small entities. An agency may certify that a rule will not have a significant economic impact on a

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substantial number of small entities if the rule relieves regulatory burden, has no net burden or otherwise has a positive economic effect on the small entities subject to the rule. This action is expected to result in net cost savings amounting to approximately $32 million per year to $100 million per year when discounting at 7 percent and annualized over 100 years. It is expected to result in net cost savings of between $25 million and $76 million when discounting at 3 percent and annualized over 100 years. Savings will accrue to all regulated entities, including small entities. Further information on the economic effects of this action can be found in Unit V of this preamble and in the Regulatory Impact Analysis, which is available in the docket for this action. We have therefore concluded that this action will relieve regulatory burden for all directly regulated small entities.

E. Unfunded Mandates Reform Act (UMRA)

This action does not contain any unfunded mandate of $100 million or more as described in UMRA, 2 U.S.C. 1531–1538, and does not significantly or uniquely affect small governments. This action imposes no enforceable duty on any state, local or tribal governments or the private sector. The costs involved in this action are imposed only by participation in a voluntary federal program. UMRA generally excludes from the definition of ''federal intergovernmental mandate'' duties that arise from participation in a voluntary federal program.

F. Executive Order 13132: Federalism

This action does not have federalism implications. It will not have substantial direct effects on the states, on the relationship between the national government and the states, or on the distribution of power and responsibilities among the various levels of government.

G. Executive Order 13175: Consultation and Coordination With Indian Tribal Governments

This action does not have tribal implications as specified in Executive Order 13175. For the ''Final Rule: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities'' published April 17, 2015 in the **Federal Register** at 80 FR 21302, EPA identified three of the 414 coal-fired electric utility plants (in operation as of 2012) which are located on tribal lands; however, they are not owned by tribal governments. These are: (1) Navajo Generating Station in Coconino County, Arizona, owned by the Arizona Salt River Project; (2) Bonanza Power Plant in Uintah County, Utah, owned by the Deseret Generation and Transmission Cooperative; and (3) Four Corners Power Plant in San Juan County, New Mexico owned by the Arizona Public Service Company. The Navajo Generating Station and the Four Corners Power Plant are on lands belonging to the Navajo Nation, while the Bonanza Power Plant is located on the Uintah and Ouray Reservation of the Ute Indian Tribe. Moreover, since this action is expected to result in net cost savings to affected entities amounting to approximately $32 million per year to $100 million per year when discounting at 7 percent and annualized over 100 years, or in net cost savings of between $25 million per year and $76 million per year when discounting at 3 percent and annualized over 100 years, it will not have substantial direct effects on one or more Indian tribes. Thus, Executive Order 13175 does not apply to this action.

H. Executive Order 13045: Protection of Children From Environmental Health Risks and Safety Risks

This action is not subject to Executive Order 13045 because the EPA does not believe the environmental health or safety risks addressed by this action present a disproportionate risk to children. This action's health and risk assessments are contained in the document titled ''Human and Ecological Risk Assessment of Coal Combustion Residuals'' which is available in the docket for the final rule as docket item EPA–HQ–RCRA–2009–0640–11993.

As ordered by EO 13045 Section 1–101(a), for the ''Final Rule: Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities'' published April 17, 2015 in the **Federal Register** at 80 FR 21302, EPA identified and assessed environmental health risks and safety risks that may disproportionately affect children in the revised risk assessment. The results of the screening assessment found that risks fell below the criteria when wetting and run-on/runoff controls required by the rule are considered. Under the full probabilistic analysis, composite liners required by the rule for new waste management units showed the ability to reduce the 90th percentile child cancer and non-cancer risks for the groundwater to drinking water pathway to well below EPA's criteria. Additionally, the groundwater monitoring and corrective action required by the rule reduced risks from current waste management units. This action does adversely affect these requirements and, in fact it enhances the groundwater monitoring requirements by adding boron to the list of constituents in Appendix IV that trigger corrective action. Thus, EPA believes that this rule will be protective of children's health.

I. Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution or Use

This action is not a ''significant energy action'' because it is not likely to have a significant adverse effect on the supply, distribution or use of energy. For the 2015 CCR rule, EPA analyzed the potential impact on electricity prices relative to the ''in excess of one percent'' threshold. Using the Integrated Planning Model (IPM), EPA concluded that the 2015 CCR Rule may increase the weighted average nationwide wholesale price of electricity between 0.18 percent and 0.19 percent in the years 2020 and 2030, respectively. As the proposed rule represents a cost savings rule relative to the 2015 CCR rule, this analysis concludes that any potential impact on wholesale electricity prices will be lower than the potential impact estimated of the 2015 CCR rule; therefore, this proposed rule is not expected to meet the criteria of a ''significant adverse effect'' on the electricity markets as defined by Executive Order 13211.

J. National Technology Transfer and Advancement Act (NTTAA)

This rulemaking does not involve technical standards.

K. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

The EPA believes that this action does not have disproportionately high and adverse human health or environmental effects on minority populations, low-income populations and/or indigenous peoples, as specified in Executive Order 12898 (59 FR 7629, February 16, 1994).

The documentation for this decision is contained in EPA's Regulatory Impact Analysis (RIA) for the CCR rule which is available in the docket for the 2015 CCR final rule as docket item EPA–HQ–RCRA–2009–0640–12034.

EPA's risk assessment did not separately evaluate either minority or low income populations. However, to evaluate the demographic characteristics of communities that may be affected by the CCR rule, the RIA compares the demographic characteristics of populations surrounding coal-fired electric utility

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plants with broader population data for two geographic areas: (1) One-mile radius from CCR management units (*i.e.,* landfills and impoundments) likely to be affected by groundwater releases from both landfills and impoundments; and (2) watershed catchment areas downstream of surface impoundments that receive surface water run-off and releases from CCR impoundments and are at risk of being contaminated from CCR impoundment discharges (*e.g.*, unintentional overflows, structural failures, and intentional periodic discharges).

For the population as a whole 24.8 percent belong to a minority group and 11.3 percent falls below the Federal Poverty Level. For the population living within one mile of plants with surface impoundments 16.1 percent belong to a minority group and 13.2 percent live below the Federal Poverty Level. These minority and low-income populations are not disproportionately high compared to the general population. The percentage of minority residents of the entire population living within the catchment areas downstream of surface impoundments is disproportionately high relative to the general population, *i.e.*, 28.7 percent, versus 24.8 percent for the national population. Also, the percentage of the population within the catchment areas of surface impoundments that is below the Federal Poverty Level is disproportionately high compared with the general population, *i.e.*, 18.6 percent versus 11.3 percent nationally.

Comparing the population percentages of minority and low income residents within one mile of landfills to those percentages in the general population, EPA found that minority and low-income residents make up a smaller percentage of the populations near landfills than they do in the general population, *i.e.*, minorities comprised 16.6 percent of the population near landfills versus 24.8 percent nationwide and low-income residents comprised 8.6 percent of the population near landfills versus 11.3 percent nationwide. In summary, although populations within the catchment areas of plants with surface impoundments appear to have disproportionately high percentages of minority and low-income residents relative to the nationwide average, populations surrounding plants with landfills do not. Because landfills are less likely than impoundments to experience surface water run-off and releases, catchment areas were not considered for landfills.

The CCR rule is risk-reducing with reductions in risk occurring largely within the surface water catchment zones around, and groundwater beneath, coal-fired electric utility plants. Since the CCR rule is risk-reducing and this action does not add to risks, this action will not result in new disproportionate risks to minority or low-income populations.

List of Subjects in 40 CFR Part 257

Environmental protection, Beneficial use, Coal combustion products, Coal combustion residuals, Coal combustion waste, Disposal, Hazardous waste, Landfill, Surface impoundment.

Dated: March 1, 2018.

E. Scott Pruitt,

Administrator.

For the reasons set out in the preamble, title 40, chapter I, of the Code of Federal Regulations is proposed to be amended as follows:

PART 257—CRITERIA FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES AND PRACTICES

■ 1. The authority citation for part 257 is revised to read as follows:

Authority: 42 U.S.C. 6907(a)(3), 6912(a)(1), 6944(a), 6945(d); 33 U.S.C. 1345(d) and (e).

■ 2. Section 257.53 is amended by:
■ a. Adding in alphabetical order the definition of ''Contouring'', ''Engineered slope protection measures'', ''Grading'', ''Grassy vegetation'', ''Non-groundwater releases'', ''Participating state'', ''Pertinent surrounding areas'', ''Vegetative height'', and ''Woody vegetation'' in alphabetical order.
■ b. Revising the definition of ''Slope protection'' and ''State director.''

The revisions and additions read as follows:

§ 257.53 Definitions.

* * * * *

Contouring means the placement of material to provide a continuous downward slope on the surface of a drainage area, except for erosion control features (e.g., swales, contour banks).

* * * * *

Engineered slope protection measures means non-vegetative cover systems, which include but are not limited to rock riprap, concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines.

* * * * *

Grading means the placement of CCR only to the extent necessary to create sufficient differences in elevation to support stormwater drainage.

Grassy vegetation means vegetation that meets both of the conditions described in paragraphs (1) and (2) of this definition:

(1) The vegetation develops shallow roots which both do not penetrate the slopes or pertinent surrounding areas of the CCR unit to a substantial depth and do not introduce the potential of internal erosion or risk of uprooting; and

(2) The vegetation creates a continuous dense cover that prevents erosion and deterioration of the surface of the slope or pertinent surrounding areas, thereby preventing deterioration of the surface.

* * * * *

Non-groundwater releases mean releases from the CCR unit other than the releases directly to the groundwater that are detected through the unit's groundwater monitoring system. Examples of non-groundwater releases include seepage through the embankment, minor ponding of seepage at the toe of the embankment of the CCR unit, seepage at the abutments of the CCR unit, seepage from slopes, ponding at the toe of the unit, a release of fugitive dust and releases of a ''catastrophic'' nature such as the release of CCR materials from CCR surface impoundments from the Tennessee Valley Authority's (TVA) Kingston Fossil Plant in Harriman, TN and the Duke Energy Dan River Steam Station in Eden, NC.

* * * * *

Participating state means a state with a state program for control of CCR that has been approved pursuant to Section 4005 of the Resource Conservation and Recovery Act.

Pertinent surrounding areas means all areas of the CCR surface impoundment or immediately surrounding the CCR surface impoundment that have the potential to affect the structural stability and condition of the CCR surface impoundment, including but not limited to the toe of the downstream slope, the crest of the embankment, abutments, and unlined spillways.

* * * * *

Slope protection means measures installed on the slopes or pertinent surrounding areas of the CCR unit that protect the slope against wave action, erosion or adverse effects of rapid drawdown. Slope protection includes grassy vegetation and engineered slope protection measures.

* * * * *

State Director means the chief administrative officer of any State agency operating an approved CCR permit program or the delegated representative of the State Director. If responsibility is divided among two or

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more State agencies, State Director means the chief administrative officer of the State agency authorized to perform the particular function or procedure to which reference is made. On Tribal Lands and in non-participating States where Congress has specifically provided appropriations to EPA to administer a CCR permit program, State Director means the EPA Administrator or their designee.

* * * * *

Vegetative height means the linear distance between the ground surface where the vegetation penetrates the ground surface and the outermost growth point of the vegetation.

* * * * *

Woody vegetation means vegetation that develops woody trunks, root balls, or root systems which can penetrate the slopes or pertinent surrounding areas of the CCR unit to a substantial depth and introduce the potential of internal erosion or risk of uprooting.

■ 3. Section 257.73 is amended by:

■ a. Revising paragraphs (a)(4) and (d)(1)(ii); and

■ b. Removing and reserving paragraph (d)(1)(iv).

The revisions read as follows:

§ 257.73 Structural integrity criteria for existing CCR surface impoundments.

(a) * * *

(4) The slopes and pertinent surrounding areas of the CCR unit must be designed, constructed, operated, and maintained with one of the forms of slope protection specified in paragraph (a)(4)(i) of this section that meets all of the performance standards of paragraph (a)(4)(ii) of this section.

(i) Slope protection must consist of one of the following:

(A) A vegetative cover consisting of grassy vegetation;

(B) An engineered cover consisting of a single form or combination of forms of engineered slope protection measures; or

(C) A combination of the forms of cover specified in paragraphs (a)(4)(i)(A) or (a)(4)(i)(B) of this section.

(ii) Any form of cover for slope protection must meet all of the following performance standards:

(A) The cover must be installed and maintained on the slopes and pertinent surrounding areas of the CCR unit;

(B) The cover must provide protection against surface erosion, wave action, and adverse effects of rapid drawdown;

(C) The cover must be maintained to allow for the observation of and access to the slopes and pertinent surrounding areas during routine and emergency events;

(D) Woody vegetation must be removed from the slopes or pertinent surrounding areas. Any removal of woody vegetation with a diameter greater than ½ inch must be directed by a person familiar with the design and operation of the unit and in consideration of the complexities of removal of a tree or a shrubbery, who must ensure the removal does not create a risk of destabilizing the unit or otherwise adversely affect the stability and safety of the CCR unit or personnel undertaking the removal; and

(E) The vegetative height of grassy and woody vegetation must not exceed 12 inches.

* * * * *

(d) * * *

(1) * * *

(ii) Slope protection consistent with the requirements under paragraph (a)(4) of this section.

* * * * *

■ 4. Section 257.74 is amended by:

■ a. Revising paragraphs (a)(4) and (d)(1)(ii); and

■ b. Removing and reserving paragraph (d)(1)(iv).

The revisions read as follows:

§ 257.74 Structural integrity criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment.

(a) * * *

(4) The slopes and pertinent surrounding areas of the CCR unit must be designed, constructed, operated, and maintained with one of the forms of slope protection specified in paragraph (a)(4)(i) of this section that meets all of the performance standards of paragraph (a)(4)(ii) of this section.

(i) Slope protection must consist of one of the following:

(A) A vegetative cover consisting of grassy vegetation;

(B) An engineered cover consisting of a single form or combination of forms of engineered slope protection measures; or

(C) A combination of the forms of cover specified in paragraphs (a)(4)(i)(A) or (a)(4)(i)(B) of this section.

(ii) Any form of cover for slope protection must meet all of the following performance standards:

(A) The cover must be installed and maintained on the slopes and pertinent surrounding areas of the CCR unit;

(B) The cover must provide protection against surface erosion, wave action, and adverse effects of rapid drawdown;

(C) The cover must be maintained to allow for the observation of and access to the slopes and pertinent surrounding areas during routine and emergency events;

(D) Woody vegetation must be removed from the slopes or pertinent surrounding areas. Any removal of woody vegetation with a diameter greater than ½ inch must be directed by a person familiar with the design and operation of the unit and in consideration of the complexities of removal of a tree or a shrubbery, who must ensure the removal does not create a risk of destabilizing the unit or otherwise adversely affect the stability and safety of the CCR unit or personnel undertaking the removal; and

(E) The vegetative height of grassy and woody vegetation must not exceed 12 inches.

* * * * *

(d) * * *

(1) * * *

* * * * *

(ii) Slope protection consistent with the requirements under paragraph (a)(4) of this section.

* * * * *

■ 5. Section 257.83 is amended by revising paragraph (b)(5) to read as follows:

§ 257.83 Inspection requirements for CCR surface impoundments.

* * * * *

(b) * * *

(5) If a deficiency or release is identified during an inspection, the owner or operator must remedy the deficiency or release in accordance with applicable requirements in §§ 257.96 through 257.99.

* * * * *

■ 6. Section 257.84 is amended by revising paragraph (b)(5) to read as follows:

§ 257.84 Inspection requirements for CCR surface landfills.

* * * * *

(b) * * *

(5) If a deficiency or release is identified during an inspection, the owner or operator must remedy the deficiency or release in accordance with applicable requirements in §§ 257.96 through 257.99.

* * * * *

■ 7. Section 257.90 is amended by revising paragraphs (a) and (d) and adding paragraph (g) to read as follows:

§ 257.90 Applicability.

(a) All CCR landfills, CCR surface impoundments, and lateral expansions of CCR units are subject to the groundwater monitoring and corrective action requirements under §§ 257.90 through 257.99, except as provided in paragraph (g) of this section.

* * * * *

(d) The owner or operator of the CCR unit must comply with all applicable

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requirements in §§ 257.96, 257.97, and 257.98, or, if eligible, must comply with the requirements in § 257.99.

* * * * *

(g) *Suspension of groundwater monitoring requirements.* (1) Except as provided by paragraph (g)(2) of this section, the State Director of a participating state may suspend for up to ten years the groundwater monitoring requirements under §§ 257.90 through 257.95 for a CCR unit if the owner or operator provides written documentation that there is no potential for migration of the constituents listed in appendices III and IV to this part from that CCR unit to the uppermost aquifer during the active life of the CCR unit and the post-closure care period. This demonstration must be certified by a qualified professional engineer and approved by the State Director, and must be based upon:

(i) Site-specific field collected measurements, sampling, and analysis of physical, chemical, and biological processes affecting contaminant fate and transport; and

(ii) Contaminant fate and transport predictions that maximize contaminant migration and consider impacts on human health and the environment.

(2) The owner or operator of the CCR unit may secure an additional ten years for the suspension of the groundwater monitoring requirements provided the owner or operator provides written documentation that there continues to be no potential for migration of the constituents listed in appendices III and IV to this part. The documentation must be supported by, at a minimum, the information specified in paragraphs (g)(1)(i) and (g)(1)(ii) of this section and must be certified by a qualified professional engineer and approved by the State Director. The owner or operator must submit the documentation of their re-demonstration for the state's review and approval of their extension one year before their groundwater monitoring suspension is due to expire. If the existing groundwater monitoring extension expires, the owner or operator must begin groundwater monitoring according to paragraph (a) of this section within 90 days. The owner or operator may obtain additional ten-year groundwater monitoring suspensions provided the owner or operator continues to make the written demonstration. The owner or operator must place each completed demonstration, if more than one ten-year suspension period is sought, in the facility's operating record.

■ 8. Section 257.95 is amended by revising paragraph (h)(2) and adding paragraph (j) to read as follows:

§ 257.95 Assessment monitoring program.

* * * * *

(h) * * *

(2) For constituents for which an MCL has not been established, the background concentration for the constituent established from wells in accordance with § 257.91, except as provided by paragraph (j) of this section; or

* * * * *

(j) The State Director of a participating state may establish an alternative groundwater protection standard for constituents listed in appendix IV to this part for which MCLs have not been established.

(1) The alternative groundwater protection standards must be appropriate health-based levels that are protective of potential receptors (both human and ecological) and satisfy all of the following criteria:

(i) The alternative groundwater protection standard is at a level derived in a manner consistent with EPA guidelines for assessing the health risks of environmental pollutants, including ''Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures'', ''Guidelines for Developmental Toxicity Risk Assessment'', and ''Reference Dose, (RfD): Description and Use in Health Risk Assessments'' (incorporated by reference);

(ii) The alternative groundwater protection standard is at a level based on scientifically valid studies conducted in accordance with the Toxic Substances Control Act Good Laboratory Practice Standards (40 CFR part 792) or equivalent; and

(iii) For systemic toxicants, the level represents a concentration to which the human population could be exposed to on a daily basis that is likely to be without appreciable risk of deleterious effects during a lifetime; this must be the level that ensures a Hazard Quotient no greater than 1. For purposes of this subpart, systemic toxicants are toxic chemicals that cause effects other than cancer.

(2) In establishing alternative groundwater protection standards under paragraph (j)(1) of this section, the State Director may consider the following:

(i) Multiple contaminants in the groundwater;

(ii) Exposure threats to sensitive environmental receptors; and

(iii) Other site-specific exposure or potential exposure to groundwater.

(3) The owner or operator of the CCR unit must document in the annual groundwater monitoring and corrective action report required by § 257.90(e) or § 257.100(e)(5)(ii) the constituent(s) and level(s) for which an alternative groundwater protection standard has been established by the State Director.

■ 9. Section 257.97 is amended by adding paragraphs (f) and (g) to read as follows:

§ 257.97 Selection of remedy.

* * * * *

(f) The State Director of a participating state may determine that remediation of a release of a constituent listed in appendix IV to this part from a CCR unit is not necessary if the owner or operator demonstrates to the satisfaction of the State Director that:

(1) The groundwater is additionally contaminated by substances that have originated from a source other than a CCR unit and those substances are present in concentrations such that cleanup of the release from the CCR unit would provide no significant reduction in risk to actual or potential receptors; or

(2) The constituent(s) is present in groundwater that:

(i) Is not currently or reasonably expected to be a source of drinking water; and

(ii) Is not hydraulically connected with waters to which the constituent(s) is migrating or are likely to migrate in a concentration(s) that would exceed the groundwater protection standards established under § 257.95(h) or (i); or

(3) Remediation of the release(s) is technically impracticable; or

(4) Remediation results in unacceptable cross-media impacts.

(g) A determination by the Director of approved participating state pursuant to paragraph (f) of this section shall not affect the requirement under § 257.90(d) and § 257.97(b) for the owner or operator to undertake source control measures or other measures (including closure if triggered) that may be necessary to eliminate or minimize further releases to the groundwater, to prevent exposure to the groundwater, or to remediate the groundwater to concentrations that are technically feasible and significantly reduce threats to human health or the environment.

■ 10. Section 257.98 is amended by revising paragraph (c) to read as follows:

§ 257.98 Implementation of the corrective action program.

* * * * *

(c) Remedies selected pursuant to § 257.97 shall be considered complete when:

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(1) The owner or operator of the CCR unit demonstrates compliance with the groundwater protection standards established under § 257.95(h) has been achieved at all points within the plume of contamination that lie beyond the groundwater monitoring well system established under § 257.91;

(2) Except as provided by paragraph (c)(4) of this section, compliance with the groundwater protection standards established under § 257.95(h) has been achieved by demonstrating that concentrations of constituents listed in appendix IV to this part have not exceeded the groundwater protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in § 257.93(f) and (g); and

(3) All actions required to complete the remedy have been satisfied.

(4) The Director of a participating state may specify an alternative length of time to that specified in paragraph (c)(2) of this section during which the owner or operator must demonstrate that concentrations of constituents listed in appendix IV to this part have not exceeded the groundwater protection standard(s) taking into consideration:

(i) Extent and concentration of the release(s);

(ii) Behavior characteristics of the constituents in the groundwater;

(iii) Accuracy of monitoring or modeling techniques, including any seasonal, meteorological, or other environmental variabilities that may affect the accuracy; and

(iv) Characteristics of the groundwater.

* * * * *

■ 11. Add § 257.99 to read as follows:

§ 257.99 Corrective action procedures to remedy eligible non-groundwater releases.

(a) *General.* This section specifies the corrective action requirements that apply to non-groundwater releases from CCR units that can be completely remediated within 180 days from the detection of the release. A release is completely remediated when either a qualified professional engineer or the permitting authority of a participating state completes the certification required in subsection (c)(2) of this section. If the owner or operator determines, at any time, that the release will not be completely remediated within this 180-day timeframe, the owner or operator must comply with all additional procedural requirements specified in §§ 257.96, 257.97, and 257.98.

(b) *Corrective action requirements.* Upon detection of a non-groundwater release from a CCR unit, the owner or operator must comply with all of the following requirements:

(1) Meet the requirement in § 257.90(d) to ''immediately take all necessary measures to control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of contaminants into the environment;''

(2)(i) Determine the corrective measures that will meet the substantive standards in §§ 257.96(a) to prevent further releases, to remediate any releases and to restore the affected area to original conditions; and

(ii) Analyze the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described in § 257.96(c);

(3) Select the corrective action that will remedy the non-groundwater release, taking into account, at a minimum, the results of the assessment in paragraph (b)(2)(ii) of this section and the factors specified in § 257.97(c); and

(4) Remediate the non-groundwater release to meet the standards specified in § 257.97(b)(1), (3), (4), and (5).

(5) Complete remedy within 180 days of the date of discovery of the release.

(c) *Required notices and reports.* An owner or operator of a CCR unit that complies with the requirements of this section to remediate a non-groundwater release is responsible for ensuring that the notices and reports specified in paragraphs (c)(1) through (c)(3) of this section are completed in accordance with this section. All required notices and reports must be signed by the owner or operator.

(1) Within 15 days of discovering a non-groundwater release, the owner or operator must prepare a notification of discovery of a non-groundwater release. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(h)(15).

(2) Within 15 days of completing the analysis of the effectiveness of potential corrective measures as required by paragraph (b)(2)(ii) of this section, place the completed analysis in the facility's operating record.

(3) Within 30 days of completion of a corrective action of a non-groundwater release, the owner or operator must prepare a report documenting the completion of the corrective action. The report must, at a minimum, describe the nature and extent of the non-groundwater release, the CCR unit(s) responsible for the non-groundwater release, and how the remedy selected achieves the corrective action requirements specified in paragraph (b) of this section. The notification must include a certification by a qualified professional engineer that the corrective action has been completed in accordance with the requirements of paragraph (b) of this section. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(h)(16).

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the internet requirements specified in § 257.107(h).

■ 12. Section 257.102 is amended by adding paragraph (d)(4) to read as follows:

§ 257.102 Criteria for conducting the closure or retrofit of CCR units.

* * * * *

(d) * * *

(4) *Use of CCR in Design and Construction of Final Cover System.* (i) This paragraph specifies the allowable uses of CCR in the closure of CCR units closing pursuant to § 257.101. Notwithstanding the prohibition on further placement in § 257.101, CCR may be placed in such units but only for the purposes of grading and contouring in the design and construction of the final cover system, based either on:

(A) A determination by the Director of a participating state that the criteria in paragraph (d)(4)(ii) of this section have been met; or

(B) The certification by a qualified professional engineer that the criteria in (d)(4)(ii) of this section have been met, as required in paragraph (d)(4)(iii) of this section.

(ii) *Use of CCR in Design and Construction of Final Cover System Requirements.*

(A) The owner or operator of a CCR unit subject to § 257.101 may continue to place CCR in the unit after initiating closure in order to construct the final cover system required under paragraph (d)(3) of this section but only for the following activities:

(1) Grading; and

(2) Contouring.

(B) The owner or operator of a CCR unit must meet all of the following criteria when placing CCR within a CCR unit for the purposes of grading or contouring:

(1) The CCR placed for construction of the final cover system must have been generated at the facility and be located at the facility at the time closure was initiated;

(2)(i) For incised CCR surface impoundments the CCR must be placed entirely above the highest elevation of

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the surrounding natural ground surface where the CCR surface impoundment was constructed;

(ii) For all other CCR units, CCR must be placed entirely above the highest elevation of CCR in the unit, following dewatering and stabilization as required by § 257.102(d)(2);

(3) The CCR must not be placed outside the plane extending vertically from the line formed by the intersection of the crest of the CCR surface impoundment and the upstream slope of the CCR surface impoundment; and

(4) The final cover system must be constructed with either:

(i) A slope not steeper than 5% grade after allowance for settlement; or

(ii) At a steeper grade, if the Director of a participating state determines that the steeper slope is necessary based on conditions at the site, to facilitate run-off and minimize erosion, and that side slopes are evaluated for erosion potential based on a stability analysis to evaluate possible erosion potential. The stability analysis, at a minimum, must evaluate the site geology; characterize soil shear strength; construct a slope stability model; establish groundwater and seepage conditions, if any; select loading conditions; locate critical failure surface; and iterate until minimum factor of safety is achieved.

(iii) If required by paragraph (d)(4)(i)(B) of this section, the owner or operator of the CCR unit must also include in the notification required by § 257.102(h) a certification by a qualified professional that the CCR unit was closed in accordance with the requirements of paragraph (d)(4) of this section.

* * * * *

■ 13. Section 257.103 is amended by:

■ a. Revising § 257.103 introductory text; and

■ b. Redesignating paragraphs (b), (c), and (d) as (c), (e), and (f); and adding new paragraphs (b) and (d).

The revisions and additions read as follows:

§ 257.103 Alternative closure requirements.

The owner or operator of a CCR landfill, CCR surface impoundment, or any lateral expansion of a CCR unit that is subject to closure pursuant to § 257.101(a), (b)(1), or (d) may continue to receive CCR and/or non-CCR wastestreams in the unit provided the owner or operator meets the requirements of either paragraph (a), (b), (c) or (d) of this section.

* * * * *

(b) *No Alternative capacity for non-CCR wastestreams.* (1) Notwithstanding the provisions of § 257.101(a), (b)(1), or (d), a CCR unit may continue to receive non-CCR wastestreams if the owner or operator of the CCR unit certifies that the wastestreams must continue to be managed in that CCR unit due to the absence of alternative capacity both on-site and off-site the facility. For these non-CCR wastestsreams, capacity means the capacity of impoundments, tanks, and other conveyances to manage daily flows currently handled by the unit that is closing pursuant to § 257.101(a) or (b)(1), or (d). To qualify under this paragraph (b)(1), the owner or operator of the CCR unit must document that all of the following conditions have been met for each non-CCR wastestream that will continue to be received by the CCR unit:

(i) No alternative disposal capacity is available. An increase in costs or the inconvenience of existing capacity is not sufficient to support qualification under this section;

(ii) The owner or operator has made, and continues to make, efforts to obtain additional capacity. Qualification under this subsection requires that efforts to obtain additional capacity were made at the earliest date that an owner or operator knew, or had reason to know, that such a unit may become subject to closure under § 257.101(a), (b)(1), or (d). Qualification under this subsection lasts only as long as no alternative capacity is available. Once alternative capacity is identified, the owner or operator must arrange to use such capacity as soon as feasible;

(iii) The owner or operator must certify that the facility generating any wastestream that continues to be placed into a CCR unit pursuant to this section would need to cease generating power and is located in or regularly provides the majority of generated electricity to, one of the following three North American Electric Reliability Corporation regions and sub-regions: the Midcontinent Independent System Operator, the Southeastern Electric Reliability Council-East, and/or the Southeastern Electric Reliability Council-North;

(iv) The owner or operator must remain in compliance with all other requirements of this subpart, including the requirement to conduct any necessary corrective action; and

(v) The owner or operator must prepare an annual progress report documenting the continued lack of alternative capacity and the progress towards the development of alternative capacity for the given wastestream.

(2) Once alternative capacity is available for a given wastestream, the CCR unit must cease receiving that wastestream, and in the case that alternate capacity has been found for all wastestreams, the facility must initiate closure of the CCR unit following the timeframes in § 257.102(e) and (f).

(3) If no alternative capacity is identified within five years after the initial certification as required under (b)(1) of this section, the CCR unit must cease receiving all wastestreams and close in accordance with the timeframes in § 257.102(e) and (f).

* * * * *

(d) *Permanent cessation of a coal-fired boiler(s) by a date certain.* (1) Notwithstanding the provisions of § 257.101(a), (b)(1), and (d), a CCR unit may continue to receive non-CCR wastestreams if the owner or operator certifies that the facility will cease operation of the coal-fired boilers within the timeframes specified in paragraphs (d)(2) and (3) of this section, but in the interim period (prior to closure of the coal-fired boiler), the facility must continue to use the CCR unit due to the absence of alternative capacity. For wastewaters capacity means the capacity of impoundments, tanks, and other units to manage daily flows currently handled by the unit closing pursuant to § 257.101(a) or (b)(1). To qualify under this paragraph (d)(1), the owner or operator of the CCR unit must document that all of the following conditions have been met for each wastestream that will continue to be received by the CCR unit:

(i) No alternative capacity is available. An increase in costs or the inconvenience of existing capacity is not sufficient to support qualification under this section.

(ii) The owner or operator must certify that the facility is located in or regularly provides the majority of generated electricity to one of the following three North American Electric Reliability Corporation regions and sub-regions: The Midcontinent Independent System Operator, the Southeastern Electric Reliability Council-East, and/or the Southeastern Electric Reliability Council-North.

(iii) The owner or operator must remain in compliance with all other requirements of this subpart, including the requirement to conduct any necessary corrective action; and

(iv) The owner or operator must prepare an annual progress report documenting the continued lack of alternative capacity and the progress towards the closure of the coal-fired boiler.

(2) For a CCR surface impoundment that is 40 acres or smaller, the coal-fired boiler must cease operation and the CCR surface impoundment must have

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completed closure no later than October 17, 2023.

(3) For a CCR surface impoundment that is larger than 40 acres, the coal-fired boiler must cease operation, and the CCR surface impoundment must complete closure no later than October 17, 2028.

* * * * *

■ 14. Section 257.104 is amended by revising paragraph (c) to read as follows:

§ 257.104 Post-closure care requirements.

* * * * *

(c) *Post-closure care period.* (1) Except as provided by paragraphs (c)(2) and (3) of this section, the owner or operator of the CCR unit must conduct post-closure care for 30 years.

(2) If at the end of the post-closure care period the owner or operator of the CCR unit is operating under assessment monitoring in accordance with § 257.95, the owner or operator must continue to conduct post-closure care until the owner or operator returns to detection monitoring in accordance with § 257.95.

(3)(i) The Director of a participating state may establish an alternate post-closure period upon a determination that the alternate period is sufficient to protect human health and the environment.

(ii) To reduce the post closure care period, the Director must ensure that the post-closure care period is long enough to establish settlement behavior and to detect to wear-in defects in the cover system. At a minimum, the Director must consider the type of cover placed on the unit (*e.g.*, geosynthetic clay liner) and the placement of the groundwater monitoring wells with respect to the waste management units and the groundwater table.

(iii) A determination that a reduced post-closure care period is warranted does not affect the obligation to comply with paragraph (b) of this section.

* * * * *

■ 15. Section 257.105 is amended by adding paragraphs (h)(14) through (h)(16) and paragraph (i)(14) to read as follows:

§ 257.105 Recordkeeping requirements.

* * * * *

(h) * * *

(14) The demonstration, including long-term performance data, supporting the suspension of groundwater monitoring requirements as required by § 257.90(g).

(15) The notification of discovery of a non-groundwater release as required by § 257.99(c)(1).

(16) The report documenting the completion of the corrective action as required by § 257.99(c)(2).

(i) * * *

(14) The demonstration, including long-term performance data supporting the reduced post-closure care period as required by § 257.104(c)(3).

* * * * *

■ 16. Section 257.106 is amended by adding paragraphs (h)(11) through (h)(13) and paragraph (i)(14) to read as follows:

§ 257.106 Notification requirements.

* * * * *

(h) * * *

(11) Provide the demonstration supporting the suspension of groundwater monitoring requirements specified under § 257.105(h)(14).

(12) Provide notification of discovery of a non-groundwater release specified under § 257.105(h)(15).

(13) Provide notification of the availability of the report documenting the completion of the corrective action specified under § 257.105(h)(16).

(i) * * *

(14) Provide the demonstration supporting the reduced post-closure care period specified under § 257.105(i)(14).

* * * * *

■ 17. Section 257.107 is amended by adding paragraphs (h)(11) through (h)(13) and adding paragraph (i)(14) to read as follows:

§ 257.107 Publicly accessible internet site requirements.

* * * * *

(h) * * *

(11) The demonstration supporting the suspension of groundwater monitoring requirements specified under § 257.105(h)(14).

(12) The notification of discovery of a non-groundwater release specified under § 257.105(h)(15).

(13) The report documenting the completion of the corrective action specified under § 257.105(h)(16).

(i) * * *

(14) The demonstration supporting the reduced post-closure care period specified under § 257.105(i)(14).

* * * * *

■ 18. Revise Appendix IV to part 257 to read as follows:

Appendix IV to Part 257—Constituents for Assessment Monitoring

COMMON NAME [1]
Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Chromium
Cobalt
Fluoride
Lead
Lithium
Mercury
Molybdenum
Selenium
Thallium
Radium 226 and 228 combined

[1] Common names are those widely used in government regulations, scientific publications, and commerce; synonyms exist for many chemicals.

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Appendix 24

USEPA, Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals from Electric Utilities, Final Rule, 80 Fed. Reg. 21302 (April 17, 2015) (Deposition Exhibit 16)

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ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 257 and 261

[EPA–HQ–RCRA–2009–0640; FRL–9919–44–OSWER]

RIN–2050–AE81

Hazardous and Solid Waste Management System; Disposal of Coal Combustion Residuals From Electric Utilities

AGENCY: Environmental Protection Agency (EPA).

ACTION: Final rule.

SUMMARY: The Environmental Protection Agency (EPA or the Agency) is publishing a final rule to regulate the disposal of coal combustion residuals (CCR) as solid waste under subtitle D of the Resource Conservation and Recovery Act (RCRA). The available information demonstrates that the risks posed to human health and the environment by certain CCR management units warrant regulatory controls. EPA is finalizing national minimum criteria for existing and new CCR landfills and existing and new CCR surface impoundments and all lateral expansions consisting of location restrictions, design and operating criteria, groundwater monitoring and corrective action, closure requirements and post closure care, and recordkeeping, notification, and internet posting requirements. The rule requires any existing unlined CCR surface impoundment that is contaminating groundwater above a regulated constituent's groundwater protection standard to stop receiving CCR and either retrofit or close, except in limited circumstances. It also requires the closure of any CCR landfill or CCR surface impoundment that cannot meet the applicable performance criteria for location restrictions or structural integrity. Finally, those CCR surface impoundments that do not receive CCR after the effective date of the rule, but still contain water and CCR will be subject to all applicable regulatory requirements, unless the owner or operator of the facility dewaters and installs a final cover system on these inactive units no later than three years from publication of the rule. EPA is deferring its final decision on the Bevill Regulatory Determination because of regulatory and technical uncertainties that cannot be resolved at this time.

DATES: This final rule is effective on October 14, 2015.

ADDRESSES: EPA has established three dockets for this regulatory action under Docket ID No. EPA–HQ–RCRA–2009–0640, Docket ID No. EPA–HQ–RCRA–2011–0392, and Docket ID No. EPA–HQ–RCRA–2012–0028. All documents in these dockets are available at *http://www.regulations.gov*. Although listed in the index, some information is not publicly available, *e.g.*, Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Certain other material, such as copyrighted material, is not placed on the Internet and will be publicly available only in hard copy form. Publicly available docket materials are available either electronically in *http://www.regulations.gov* or in hard copy at the OSWER Docket, EPA/DC, WJC West Building, Room 3334, 1301 Constitution Ave. NW., Washington, DC 20460. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744, and the telephone number for the OSWER Docket is 202–566–0276.

FOR FURTHER INFORMATION CONTACT: For questions on technical issues: Alexander Livnat, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5304P; telephone number: (703) 308–7251; fax number: (703) 605–0595; email address: *livnat.alexander@epa.gov*, or Steve Souders, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5304P; telephone number: (703) 308–8431; fax number: (703) 605–0595; email address: *souders.steve@epa.gov*. For questions on the regulatory impact analysis: Richard Benware, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5305P; telephone number: (703) 308–0436; fax number: (703) 308–7904; email address: *benware.richard@epa.gov*. For questions on the risk assessment: Jason Mills, Office of Resource Conservation and Recovery, Environmental Protection Agency, 5305P; telephone number: (703) 305–9091; fax number: (703) 308–7904; email address: *mills.jason@epa.gov*.

For more information on this rulemaking please visit *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/index.htm*.

SUPPLEMENTARY INFORMATION:

A. Does this action apply to me?

This rule applies to all coal combustion residuals (CCR) generated by electric utilities and independent power producers that fall within the North American Industry Classification System (NAICS) code 221112 and may affect the following entities: Electric utility facilities and independent power producers that fall under the NAICS code 221112. The industry sector(s) identified above may not be exhaustive; other types of entities not listed could also be affected. The Agency's aim is to provide a guide for readers regarding those entities that potentially could be affected by this action. To determine whether your facility, company, business, organization, etc., is affected by this action, you should refer to the applicability criteria discussed in Unit VI.A. of this document If you have any questions regarding the applicability of this action to a particular entity, consult the person listed in the preceding **FOR FURTHER INFORMATION CONTACT** section.

B. What actions are not addressed in this rule?

This rule does not address the placement of CCR in coal mines. The U.S. Department of Interior (DOI) and, as necessary, EPA will address the management of CCR in minefills in separate regulatory action(s), consistent with the approach recommended by the National Academy of Sciences, recognizing the expertise of DOI's Office of Surface Mining Reclamation and Enforcement in this area. See Unit VI of this document for further details. This rule does not regulate practices that meet the definition of a beneficial use of CCR. Beneficial uses that occur after the effective date of the rule need to determine if they comply with the criteria contained in the definition of ''beneficial use of CCRs.'' This rule does not affect past beneficial uses (*i.e.*, uses completed before the effective date of the rule.) See Unit VI of this document for further details on proposed clarifications of beneficial use. Furthermore, CCR from non-utility boilers burning coal are also not addressed in this final rule. EPA will decide on an appropriate action for these wastes through a separate rulemaking effort. See Unit IV of this document for further details. Finally, this rule does not apply to municipal solid waste landfills (MSWLFs) that receive CCR for disposal or use as daily cover.

C. The Contents of This Preamble Are Listed in the Following Outline

I. Executive Summary
II. Statutory Authority
III. Background
IV. Bevill Regulatory Determination Relating to CCR From Electric Utilities and Independent Power Producers
V. Development of the Final Rule—RCRA Subtitle D Regulatory Approach

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VI. Development of the Final Rule—Technical Requirements
VII. Summary of Major Differences Between the Proposed and Final Rules
VIII. Implementation Timeframes for Minimum National Criteria and Coordination With Steam Electric ELG Rule
IX. Implementation of the Minimum Federal Criteria and State Solid Waste Management Plans
X. Risk Assessment
XI. Summary of Damage Cases
XII. Summary of Regulatory Impact Analysis
XIII. Uniquely Associated Wastes
XIV. Statutory and Executive Order Reviews

I. Executive Summary

This rule establishes nationally applicable minimum criteria for the safe disposal of coal combustion residuals in landfills and surface impoundments. This section summarizes these criteria. Detailed discussions of the criteria and the Agency's rationale for finalizing these requirements are provided in Unit VI of this document.

A. What are coal combustion residuals?

Coal combustion residuals (CCR) are generated from the combustion of coal, including solid fuels classified as anthracite, bituminous, subbituminous, and lignite, for the purpose of generating steam for the purpose of powering a generator to produce electricity or electricity and other thermal energy by electric utilities and independent power producers. CCR includes fly ash, bottom ash, boiler slag, and flue gas desulfurization materials. A description of the types of CCR can be found in the proposed rule (see 75 FR 35137).

CCR is one of the largest industrial waste streams generated in the U.S. In 2012, over 470 coal-fired electric utilities burned over 800 million tons of coal, generating approximately 110 million tons of CCR in 47 states and Puerto Rico. CCR may be generated wet or dry; however, this composition may change after generation. Some CCR is dewatered while other CCR is mixed with water to facilitate transport (*i.e.*, sluiced). CCR can be sent off-site for disposal or beneficial use or disposed in on-site landfills or surface impoundments. In 2012, approximately 40 percent of the CCR generated was beneficially used, with the remaining 60 percent disposed in surface impoundments and landfills. Of that 60 percent, approximately 80 percent was disposed in on-site disposal units. CCR disposal currently occurs at over 310 active on-site landfills, averaging over 120 acres in size with an average depth of over 40 feet, and at over 735 active on-site surface impoundments, averaging over 50 acres in size with an average depth of 20 feet.

B. Background

The Agency first solicited comments on the regulation of CCR in a proposed rule published in the **Federal Register** on June 21, 2010. This proposal, under the Resource Conservation and Recovery Act (RCRA), addressed the risks from disposal of CCR generated from the combustion of coal at electric utilities and from independent power producers. Two regulatory options were proposed. Under the first option, EPA proposed to list CCR as special waste subject to regulation under subtitle C of RCRA, when destined for disposal in landfills or surface impoundments. Under this option, CCR would require ''cradle-to-grave'' management and would be subject to requirements for, among other things, composite liners, groundwater monitoring, structural stability requirements, corrective action, closure/post closure care and financial assurance. States would be required to adopt the rule before it went into effect and a permitting program would be established with direct federal oversight. The subtitle C option, as proposed, would also effectively result in the closure of all CCR surface impoundments.

Under the second option, EPA proposed to regulate the disposal of CCR under subtitle D of RCRA by issuing minimum national criteria. Similar to the subtitle C option, this option would require composite liners, groundwater monitoring, structural stability requirements, corrective action, and closure/post closure care. However, consistent with the available statutory authority under subtitle D, EPA proposed this option to be a self-implementing rule with no direct federal oversight, with an effective date six months after publication in the **Federal Register**. This option required all unlined surface impoundments to either retrofit to a composite liner or close within five years.

After reviewing all the comments and additional data received, EPA is promulgating this final rule to regulate the disposal of CCR as solid waste under subtitle D of RCRA. This rule addresses the risks from structural failures of CCR surface impoundments, groundwater contamination from the improper management of CCR in landfills and surface impoundments and fugitive dust emissions. The rule has also been designed to provide electric utilities and independent power producers generating CCR with a practical approach for implementation of the requirements and has established implementation timelines that take into account, among other things, other upcoming regulatory actions affecting electric utilities and site specific practical realities. In order to ease implementation of the regulatory requirements for CCR units with state programs, EPA is also providing the opportunity for states to secure approval of its CCR program through the State Solid Waste Management Plan (''SWMP''). EPA strongly recommends that states take advantage of this process by revising their SWMPs to address the issuance of the revised federal requirements in this final rule, and to submit revisions of these plans to EPA for review. EPA would then review and approve the revised SWMPs provided they demonstrate that the minimum federal requirements in this final rule will be met. In this way, EPA's approval of a revised SWMP signals EPA's opinion that the state SWMP meets the minimum federal criteria.

C. What types of CCR units are covered by this rule?

The final rule applies to owners and operators of new and existing landfills and new and existing surface impoundments, including all lateral expansions of landfills and surface impoundments that dispose or otherwise engage in solid waste management of CCR generated from the combustion of coal at electric utilities and independent power producers. The requirements of the rule also apply to CCR units located off-site of the electric utilities' or independent power producers' facilities that receive CCR for disposal. In addition, the rule applies to certain inactive CCR surface impoundments (*i.e.*, units not receiving CCR after the effective date of the rule) at active electric utilities' or independent power producers' facilities, regardless of the fuel currently used at the facility to produce electricity (*e.g.* coal, natural gas, oil), if the CCR unit still contains CCR and liquids.

The requirements do not apply to: (1) CCR landfills that ceased receiving CCR prior to the effective date of the rule; (2) CCR units at facilities that have ceased producing electricity (or electricity and other thermal energy) prior to the effective date of the rule; (3) CCR generated at facilities that are not part of an electric utility or independent power producer, such as manufacturing facilities, universities, and hospitals; (4) fly ash, bottom ash, boiler slag, and flue gas desulfurization materials, generated primarily from the combustion of fuels (including other fossil fuels) other than coal, for the purpose of generating electricity unless the fuel burned

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consists of more than fifty percent coal on a total heat input or mass input basis, whichever results in the greater mass feed rate of coal; (5) CCR that is beneficially used; (6) CCR placement at active or abandoned underground or surface coal mines; or (7) municipal solid waste landfills (MSWLF) that receive CCR.

D. What minimum national criteria are being established for CCR landfills and CCR surface impoundments?

This final rule establishes minimum national criteria for CCR landfills, CCR surface impoundments, and all lateral expansions of CCR units including location restrictions, liner design criteria, structural integrity requirements, operating criteria, groundwater monitoring and corrective action requirements, closure and post-closure care requirements, and recordkeeping, notification, and internet posting requirements.

1. Location Restrictions. To ensure there will be no reasonable probability of adverse effects on health or the environment from the disposal of CCR in CCR landfills, CCR surface impoundments, and all lateral expansions of CCR landfills and CCR surface impoundments (together ''CCR units''), this final rule establishes five location restrictions. The location criteria include restrictions relating to placement of CCR above the uppermost aquifer, in wetlands, within fault areas, in seismic impact zones, and in unstable areas. All of these location restrictions require the owner or operator of a CCR unit to demonstrate that they meet the specific criteria. As discussed elsewhere in this preamble, the five location restrictions apply to all new CCR landfills, all new and existing CCR surface impoundments, and all lateral expansions of CCR units; however, existing CCR landfills are only subject to the location restriction for unstable areas. Units that do not meet these restrictions can retrofit or make appropriate engineering demonstrations to meet this criteria. This final rule requires owner or operators of existing CCR units that cannot make the required demonstrations to close, while owners or operators of new CCR units and all lateral expansions who fail to make the required demonstrations are prohibited from placing CCR in the CCR unit.

2. Liner Design Criteria. The final rule also establishes liner design criteria to help prevent contaminants in CCR from leaching from the CCR unit and contaminating groundwater. All new CCR landfills, new CCR surface impoundments, and lateral expansions of CCR units must be lined with composite liner, which is a liner system consisting of two components—a geomembrane and a two-foot layer of compacted soil—installed in direct and uniform contact with one another. The final rule allows an owner or operator to construct a new CCR unit with an alternative composite liner, provided the alternative composite liner performs no less effectively than the composite liner. In addition, new landfills are required to operate with a leachate collection and removal system which is designed to remove excess leachate that may accumulate on top of the composite (or alternative composite) liner. Existing CCR landfills are not required to close or retrofit with a composite (or alternative composite) liner and a leachate collection and removal system. These existing CCR units can continue to receive CCR after this rule is in effect; however, the CCR units must meet all applicable groundwater monitoring and corrective action criteria to address any groundwater releases promptly. Existing CCR surface impoundments can also continue to operate as designed. However, if the existing CCR surface impoundment was not constructed with a composite (or alternative composite) liner or with at least two feet of compacted soil with a specified hydraulic conductivity, the rule would require the unit to retrofit or close if the CCR surface impoundment detects concentrations of one or more constituents listed in appendix IV at statistically significant levels above the groundwater protection standard established by the rule.

3. Structural Integrity Requirements. To help prevent the damages associated with structural failures of CCR surface impoundments, the final rule establishes structural integrity criteria for new and existing surface impoundments (and all lateral expansions) as part of the design criteria. While the applicability of the structural integrity requirements to individual CCR surface impoundments vary depending on factors such as dike heights and the potential for loss of life, environmental damage and economic loss if there is a dike failure, the final rule establishes requirements for owner or operators to conduct a number of structural integrity-related assessments regularly. These include: (1) Conducting periodic hazard potential classification assessments to assess the potential adverse incremental consequences that would occur if there was a failure of the CCR surface impoundment; (2) conducting periodic structural stability assessments by a qualified professional engineer to document whether the design, construction, operation and maintenance is consistent with recognized and generally accepted good engineering practices; and (3) conducting periodic safety factor assessments to document whether the CCR unit achieves minimum factors of safety for slope stability. If a CCR unit required to conduct a safety factor assessment fails to demonstrate that the unit achieves the specified factors of safety, the owner or operator must close the unit. In addition, certain CCR surface impoundments are required to develop an emergency action plan which defines the events and circumstances involving the CCR unit that represent an emergency and identifies the actions that will be taken in the event of a safety emergency.

4. Operating Criteria. The operating criteria include air criteria for all CCR units, run-on and run-off controls for CCR landfills, hydrologic and hydraulic capacity requirements for CCR surface impoundments, and periodic inspection requirements for all CCR units. These criteria address the day-to-day operations of CCR units and are established to prevent health and environmental impacts from CCR units. The air criteria address the pollution caused by windblown dust from CCR units, and require owners and operators to minimize CCR from becoming airborne at the facility. The run-on controls for CCR landfills minimize the amount of surface water entering the unit that will help prevent erosion, surface discharges of CCR in solution or suspension, and will mitigate the generation of landfill leachate, while run-off controls help prevent erosion, protect downstream surface water from releases from the unit, and minimize storm water run-off volume and velocity. CCR surface impoundments are subject to hydrologic and hydraulic capacity requirements to ensure the unit can safely handle flood flows, which will help prevent uncontrolled overtopping of the unit or erosion of the materials used to construct the surface impoundment. The final rule also requires periodic inspections of CCR units to identify any appearance of structural weakness or other conditions that are not consistent with recognized and generally accepted good engineering standards.

5. Groundwater Monitoring and Corrective Action. The groundwater monitoring and corrective action criteria require an owner or operator of a CCR unit to install a system of monitoring wells and specify procedures for sampling these wells, in addition to methods for analyzing the groundwater data collected, to detect the presence of

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hazardous constituents (*e.g.,* toxic metals) and other monitoring parameters (*e.g.,* pH, total dissolved solids) released from the units. The final rule establishes a groundwater monitoring program consisting of detection monitoring, assessment monitoring and corrective action. Once a groundwater monitoring system and groundwater monitoring program has been established for a CCR unit, the owner or operator must conduct groundwater monitoring and, if the monitoring demonstrates an exceedance of a groundwater protection standard for any of the identified constituents in CCR, must initiate corrective action.

6. Closure and Post-Closure Requirements. The closure and post-closure care criteria require all CCR units to close in accordance with specified standards and to monitor and maintain the units for a period of time after closure, including the groundwater monitoring and corrective action programs. These criteria are essential to ensuring the long-term safety of closed CCR units. Closure of a CCR unit must be completed either by leaving the CCR in place and installing a final cover system or through removal of the CCR and decontamination of the CCR unit. The final rule establishes timeframes to initiate and complete closure activities, and authorize owners or operators to obtain time extensions due to circumstances beyond the facility's control. As discussed elsewhere in this preamble, the rule also establishes alternative closure procedures in situations where an owner or operator is closing a CCR unit, but has no alternative CCR disposal capacity or is permanently closing the coal-fired boiler unit in the foreseeable future. Finally, owners and operators are required to prepare closure and post-closure care plans describing these activities.

7. Record Keeping, Notification, and Internet Posting Requirements. The final rule requires owners or operators of CCR units to record certain information in the facility's operating record. In addition, owners and operators are required to provide notification to States and/or appropriate Tribal authorities when the owner or operator places information in the operating record, as well as to maintain a publicly accessible internet site for this information.

8. Severability. EPA intends that the provisions of this rule be severable. In the event that any individual provision or part of this rule is invalidated, EPA intends that this would not render the entire rule invalid, and that any individual provisions that can continue to operate will be left in place. The following tables provide a summary of the specific technical requirements applicable to existing and new CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units.

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CCR Landfill Requirements				
Requirement	**Existing CCR Landfills**		**New CCR Landfills and Lateral Expansions**	
	Required? [1]	Rule Section	Required? [1]	Rule Section
Location Restrictions:	√	§257.64	√	§257.60 - §257.64
Placement Above the Uppermost Aquifer			√	§257.60
Wetlands			√	§257.61
Fault Areas			√	§257.62
Seismic Impact Zones			√	§257.63
Unstable Areas	√	§257.64	√	§257.64
Floodplains[2]	√	§257.3-1	√	§257.3-1
Endangered Species[2]	√	§257.3-2	√	§257.3-2
Design Requirements:			√	§257.70
Composite Liner			√	§257.70 (b & c)
Leachate Collection and Removal System			√	§257.70 (d)
Groundwater Monitoring and Corrective Action	√	§257.90 - §257.98	√	§257.90 - §257.98
Weekly Inspections	√	§257.84 (a)	√	§257.84 (a)
Annual Inspections	√	§257.84 (b)	√	§257.84 (b)
Fugitive Dust Controls	√	§257.80	√	§257.80
Run-on, Run-off Controls	√	§257.81	√	§257.81
Surface Water Protection[2]	√	§257.3-3	√	§257.3-3
Closure Requirements	√	§257.100 - §257.103	√	§257.100 - §257.103
Post-Closure Care	√	§257.104	√	§257.104
Recordkeeping Requirements	√	§257.105	√	§257.105
Notification Requirements	√	§257.106	√	§257.106
Publicly Accessible Internet Site Requirements	√	§257.107	√	§257.107

[1] √ = required, = not required.
[2] In existing regulations at 40 CFR part 257, subpart A.

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CCR Surface Impoundment Requirements								
Requirement	Existing Surface Impoundments				New Surface Impoundments and Lateral Expansions			
	Five feet high AND 20 acre-feet, or 20 feet high				Five feet high AND 20 acre-feet, or 20 feet high			
	Yes		No		Yes		No	
	Required? [1]	Rule Section	Required? [1]	Rule Section	Required? [1]	Rule Section	Required? [1]	Rule Section
Location Restrictions:	√	§257.60 - §257.64	√	§257.60 - §257.64	√	§257.60 - §257.64	√	§257.60 - §257.64
Placement Above the Uppermost Aquifer	√	§257.60	√	§257.60	√	§257.60	√	§257.60
Wetlands	√	§257.61	√	§257.61	√	§257.61	√	§257.61
Fault Areas	√	§257.62	√	§257.62	√	§257.62	√	§257.62
Seismic Impact Zones	√	§257.63	√	§257.63	√	§257.63	√	§257.63
Unstable Areas	√	§257.64	√	§257.64	√	§257.64	√	§257.64
Floodplains[4]	√	§257.3-1	√	§257.3-1	√	§257.3-1	√	§257.3-1
Endangered Species[4]	√	§257.3-2	√	§257.3-2	√	§257.3-2	√	§257.3-2
Design Requirements:	√	§257.71	√	§257.71	√	§257.72	√	§257.72
Composite Liner	[2]	§257.71	[2]	§257.71	√	§257.72	√	§257.72
Leachate Collection and Removal System								
Groundwater Monitoring and Corrective Action	√	§257.90 - §257.98	√	§257.90 - §257.98	√	§257.90 - §257.98	√	§257.90 - §257.98
Structural Integrity Criteria:	√	§257.73 & §257.83	√	§257.73 & §257.83	√	§257.74 & §257.83	√	§257.74 & §257.83
History of Construction	√	§257.73 (c)						
Construction Plan					√	§257.74 (c)		
Marker [3]	√	§257.73 (a)(1)	√	§257.73 (a)(1)	√	§257.74 (a)(1)	√	§257.74 (a)(1)
Hazard Potential Classification Assessments [3]	√	§257.73 (a)(2)	√	§257.73 (a)(2)	√	§257.74 (a)(2)	√	§257.74 (a)(2)
Structural Stability Assessments	√	§257.73 (d)			√	§257.74 (d)		
Safety Factor Assessments	√	§257.73 (e)			√	§257.74 (e)		
Emergency Action Plan [3]	√	§257.73 (a)(3)	√	§257.73 (a)(3)	√	§257.74 (a)(3)	√	§257.74 (a)(3)
Weekly Inspections	√	§257.83 (a)	√	§257.83 (a)	√	§257.83 (a)	√	§257.83 (a)
Annual Inspections	√	§257.83 (b)			√	§257.83 (b)		
Fugitive Dust Controls	√	§257.80	√	§257.80	√	§257.80	√	§257.80

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CCR Surface Impoundment Requirements								
Requirement	Existing Surface Impoundments				New Surface Impoundments and Lateral Expansions			
	Five feet high AND 20 acre-feet, or 20 feet high				Five feet high AND 20 acre-feet, or 20 feet high			
	Yes		No		Yes		No	
	Required? [1]	Rule Section	Required? [1]	Rule Section	Required? [1]	Rule Section	Required? [1]	Rule Section
Hydrologic & Hydraulic Capacity Requirements	√	§257.82	√	§257.82	√	§257.82	√	§257.82
Surface Water Protection[4]	√	§257.3-3	√	§257.3-3	√	§257.3-3	√	§257.3-3
Closure Requirements	√	§257.100 - §257.103	√	§257.100 - §257.103	√	§257.100 - §257.103	√	§257.100 - §257.103
Post-Closure Care	√	§257.104	√	§257.104	√	§257.104	√	§257.104
Recordkeeping Requirements	√	§257.105	√	§257.105	√	§257.105	√	§257.105
Notification Requirements	√	§257.106	√	§257.106	√	§257.106	√	§257.106
Publicly Accessible Internet Site Requirements	√	§257.107	√	§257.107	√	§257.107	√	§257.107

[1] √ = required, ▒▒ = not required.
[2] Existing CCR surface impoundments are required to be constructed with two feet of compacted soil with a hydraulic conductivity of no more than $1x10^{-7}$ cm/sec, a composite liner that meets the requirements of §257.70(b), or an alternative liner that meets the requirements of §257.70(c).
[3] This requirement does not apply to an incised CCR surface impoundment.
[4] In existing regulations at 40 CFR part 257, subpart A.

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E. When must owners or operators of CCR landfills and CCR surface impoundments meet the minimum national criteria?

The rule becomes effective six months after the publication date of this rule. The final rule establishes timeframes for certain technical criteria based on the amount of time determined to be necessary to implement the requirements (*e.g.*, installing the groundwater monitoring wells and establishing the groundwater monitoring program). In establishing these timeframes, EPA accounted for other Agency rulemakings that are anticipated to also affect the owners or operators of CCR units, namely the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (78 FR 34432; proposed rule issued June 7, 2013) and the Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (79 FR 34830; proposed rule issued June 18, 2014). Specifically, EPA developed implementation timeframes that would ensure that owner or operators of CCR units would not be required to make decisions about those CCR units without first understanding the implications that such decisions would have for meeting the requirements of all applicable EPA rules.

F. Deferral of Final Bevill Determination

This rule defers a final Bevill Regulatory Determination with respect to CCR that is disposed in CCR landfills and CCR surface impoundments until additional information is available on a number of key technical and policy questions. This includes information needed to quantify the risks of CCR disposal, and the potential impacts of recent Agency regulations on the chemical composition of CCR. The Agency also needs further information on adequacy of the state programs.

G. Beneficial Use

The final rule retains the Bevill exclusion for CCR that is beneficially used, and provides a definition of beneficial use to distinguish between beneficial use and disposal.

H. Implementation

Because the regulations have been promulgated under sections 1008(a), 4004(a), and 4005(a) of RCRA, the rule does not require permits, does not require states to adopt or implement these requirements, and EPA cannot enforce these requirements. Instead, states or citizens can enforce the requirements of this rule under RCRA's citizen suit authority; the states can also continue to enforce any state regulation under their independent state enforcement authority. (For a more detailed discussion of EPA authorities under RCRA and its relationship to this rule, see 75 FR 35128, June 21, 2010). EPA recognizes the significant role states play in implementing these requirements and EPA strongly encourages states to revise their SWMPs to show how these new criteria will be implemented. EPA would then review and approve the revised plan provided it demonstrates that the minimum federal requirements in this final rule will be met. In this way, EPA's approval of a revised plan signals EPA's opinion that the State's SWMP meets the minimum federal criteria. For a more detailed discussion on the role of the states in implementing this rule, please refer to Unit IX of this document.

I. Characterization of Baseline Affected Entities and CCR Management Practices

This action will affect CCR generated by coal-fired electric utility plants in the NAICS industry code 221112 (*i.e.*, the ''Fossil Fuel Electric Power Generation'' industry within the NAICS 22 ''Utilities'' sector code). Based on 2012 electricity generation data published by the Energy Information Administration (EIA), the Regulatory Impact Analysis (RIA) for this action estimated that a total of 478 operational coal-fired electric utility plants in this NAICS code could be affected by this action. These plants are owned by 242 entities consisting of 166 companies, 17 cooperative organizations, 58 state or local governments, and one federal agency. A sub-total of 81 of the 242 owner entities (*i.e.*, 33 percent may be classified as small businesses, small organizations, or small governments). The 478 coal-fired electric utility plants operate a total of 1,045 CCR management units (735 surface impoundments and 310 landfills). These 478 plants generate 110 million tons of CCR, consisting of 201 plants (42 percent) disposing in on-site landfills, 169 (35 percent) disposing in on-site ponds, and 197 (41 percent) disposing in off-site landfills. Because some plants use more than one CCR management method, these plant counts exceed 478 total plants. In addition, 293 of the 478 plants supply CCR for beneficial uses in at least 14 industries. Nineteen of the 293 plants solely supply CCR for beneficial uses. As of 2012, CCR beneficial uses (*i.e.*, industrial applications) involved about 52 million tons annually.

J. Summary of Estimated Regulatory Costs and Benefits

The EPA estimated future regulatory compliance costs and expected future human health and environmental protection benefits can be found in the RIA document which is available from the docket for this action. The estimated costs and benefits for the CCR rule are incremental to the baseline (current) practices by the electric utility industry to manage CCR in accordance with (a) existing state government environmental regulations and (b) utility company CCR management methods.

The RIA estimates the cost of the rule over a 100 year period because of: (1) CCR unit lifespans (40 years to 80 years of age); (2) groundwater migration (estimated time to peak potential exposures of CCR through groundwater migration to drinking water wells is 75 years); and (3) latency periods for onset of illness after exposure to CCR, which can average 20 years.

The table below summarizes the estimated incremental costs and benefits of the rule. The RIA estimates costs to comply with the 12 pollution control requirements associated with the rule, as well as estimated monetized values for 11 expected benefits, and discusses 11 other non-monetized benefits.

EPA Estimated Incremental Costs & Benefits of the CCR Rule

[millions 2013$ over 100-year period of analysis 2015–2114]

	3% Discount rate	7% Discount rate
A. Annualized Values		
A1. Total Costs	$735	$509
A2. Total monetized benefits	$294	$236
A3. Net Benefits (A2–A1)	($441)	($441)
A4. Benefit to Cost Ratio (A3/A1)	0.40	0.46

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EPA ESTIMATED INCREMENTAL COSTS & BENEFITS OF THE CCR RULE—Continued

[millions 2013$ over 100-year period of analysis 2015–2114]

	3% Discount rate	7% Discount rate
B. Present Value		
B1. Total Costs	$23,200	$7,260
B2. Total monetized benefits	$8,710	$3,360
B3. Net Benefits (B2–B1)	($14,490)	($3,900)
B4. Benefit to Cost Ratio (B2/B1)	0.38	0.46

II. Statutory Authority

These regulations are established under the authority of sections 1006(b), 1008(a), 2002(a), 3001, 4004, and 4005(a) of the Solid Waste Disposal Act of 1970, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HSWA), 42 U.S.C. 6906(b), 6907(a), 6912(a), 6944 and 6945(a).

RCRA section 1006(b) directs EPA to integrate the provisions of RCRA for purposes of administration and enforcement and to avoid duplication, to the maximum extent practicable, with the appropriate provisions of other EPA statutes. Section 1006(b) conditions EPA's authority to reduce or eliminate RCRA requirements on the Agency's ability to demonstrate that the integration meets RCRA's protectiveness mandate (42 U.S.C. 6005(b)(1)). *See Chemical Waste Management* v. *EPA*, 976 F.2d 2, 23, 25 (D.C. Cir. 1992).

RCRA section 1008(a) authorizes EPA to publish ''suggested guidelines for solid waste management.'' 42 U.S.C. 6907(a). RCRA defines solid waste management as ''the systematic administration of activities which provide for the collection, source separation, storage, transportation, transfer, processing, treatment, and disposal of solid waste.'' 42 U.S.C. 6903(28).

Pursuant to section 1008(a)(3), the guidelines are to include the minimum criteria to be used by the states to define the solid waste management practices that constitute the open dumping of solid waste or hazardous waste and are prohibited as ''open dumping''under section 4005. Only those requirements promulgated under the authority of section 1008(a)(3) are enforceable under section 7002 of RCRA.

RCRA section 4004 generally requires EPA to promulgate regulations containing criteria for determining which facilities shall be classified as sanitary landfills (and therefore not ''open dumps''). The statute directs that, ''at a minimum, the criteria are to ensure that units are classified as sanitary landfills only if there is no reasonable probability of adverse effects on health or the environment from disposal of solid wastes at such facility.'' 42 U.S.C. 6944(a).

RCRA section 4005(a), entitled ''Closing or upgrading of existing open dumps'' generally establishes the key implementation and enforcement provisions applicable to EPA regulations issued under sections 1008(a) and 4004(a). Specifically, this section prohibits any solid waste management practices or disposal of solid waste that does not comply with EPA regulations issued under RCRA section 1008(a) and 4004(a). 42 U.S.C. 6944(a). See also 42 U.S.C. 6903(14) (definition of ''open dump''). This prohibition takes effect ''upon promulgation'' of any rules issued under section 1008(a)(3) and is enforceable through a citizen suit brought pursuant to section 7002. As a general matter, this means that facilities must be in compliance with any EPA rules issued under this section no later than the effective date of such rules, or be subject to a citizen suit for ''open dumping'' 42 U.S.C. 6945. RCRA section 4005 also directs that open dumps, *i.e.*, facilities out of compliance with EPA's criteria, must be ''closed or upgraded.''

Section 7004 lays out specific requirements relating to public participation in regulatory actions under RCRA. Subsection (b) provides that ''[p]ublic participation in the . . . implementation, and enforcement of any regulation under this chapter shall be provided for, encouraged, and assisted by the Administrator.'' 42 U.S.C. 6974(b).

A. Regulation of Solid Wastes Under RCRA Subtitle D

Solid wastes that are neither a listed nor characteristic hazardous waste are subject to the requirements of RCRA subtitle D. Subtitle D of RCRA establishes a framework for federal, state, and local government cooperation in controlling the management of non-hazardous solid waste. The federal role is to establish the overall regulatory direction, by providing minimum nationwide standards that will protect human health and the environment, and to provide technical assistance to states for planning and developing their own environmentally sound waste management practices. The actual planning and any direct implementation of solid waste programs under RCRA subtitle D, however, remains a state and local function, and the Act envisions that states will devise programs to deal with state-specific conditions and needs. EPA has no role in the planning and direct implementation of the minimum national criteria or solid waste programs under RCRA subtitle D, and has no authority to enforce the criteria. However, states are not required to adopt solid waste management programs, and thus, Congress developed a statutory structure that creates incentives for states to implement and enforce the federal criteria, but that does not necessarily rely on or require a regulatory entity to oversee or implement them. While Congress developed the statutory structure to create incentives for states to implement and enforce the federal criteria, it does not require them to do so. As a result, subtitle D is also structured to be self-implementing.

RCRA sections 1008(a)(3) and 4004(a) delegate broad authority to EPA to establish regulations governing the management of solid waste. Under section 4004(a) EPA is charged with establishing requirements to ensure that facilities will be classified as sanitary landfills ''only if there is no reasonable probability of adverse effects on health or the environment from the disposal of solid waste'' at the facility. Or in other words, under section 4004(a) EPA is charged with issuing regulations to address all ''reasonable probabilities of adverse effects'' (*i.e.*, all reasonably anticipated risks) to health and the environment from the disposal of solid waste. Section 1008(a)(3) expands EPA's authority to address the risks from any of the listed activities. Specifically, EPA is authorized to establish requirements applicable to ''storage, transportation, transfer, processing, treatment, and disposal of solid waste.'' (42 U.S.C. 6907(a), 6903(28)).

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EPA interprets the standard in section 4004(a) to apply equally to criteria issued under sections 1008(a)(3) and 4004(a); namely that the criteria must ensure that a facility is to be classified as a sanitary landfill, and thus allowed to continue to operate, ''only if there is no reasonable probability of adverse effects on health or the environment'' from either the disposal or other solid waste management practices at the facility. Thus, under the combined authority conferred by sections 1008(a)(3) and 4004(a), a facility is an ''open dump'' if it engages in any activity involving the management of solid waste that does not meet the standard in section 4004(a); or in other words, any activity involved with the management of solid waste that presents a reasonable probability of causing adverse effects on health or the environment. EPA also interprets these provisions to authorize the establishment of criteria that define the manner in which facilities upgrade or close, consistent with the standard in section 4004(a), to ensure there will be no reasonable probability of adverse effects on health or the environment.

As discussed previously, Congress created a regulatory structure that limited EPA's role to the creation of national criteria that would operate even in the absence of a regulatory entity to oversee or implement the criteria. Under RCRA section 4005(a), upon promulgation of criteria under section 1008(a)(3), any solid waste management practice or disposal of solid waste that constitutes the ''open dumping'' of solid waste is prohibited. The federal standards apply directly to the facility (are self-implementing) and facilities are directly responsible for ensuring that their operations comply with these requirements. States are not required to incorporate or implement these requirements under any state permitting program or other state law requirement, and EPA is not authorized to impose such requirements, directly or indirectly on the states. States and citizens may enforce this prohibition (and therefore, the federal criteria) using the authority under RCRA section 7002.[1]

The statute also creates incentives to states to implement the criteria. Chief among the incentives is a greater role in implementation and enforcement of the solid waste program, including to a limited extent the ability to give facilities that are operating within their state additional time to come into compliance with newly promulgated EPA criteria. Specifically, if the facility is located in a state with a plan that was approved under section 4003(b), the state may grant the facility an extension of up to five years from the date the final rule was published in the **Federal Register** to come into compliance with EPA regulations, provided: (a) The facility is listed in a state inventory of open dumps; and (b) the facility has demonstrated that it has considered other public or private alternatives for solid waste management to comply with the prohibition on open dumping and is unable to utilize such alternative. For facilities that meet these requirements, the state may establish a ''schedule for compliance'' which specifies a schedule of remedial measures, including an enforceable sequence of actions or operations, leading to compliance with the requirements ''within a reasonable time (not to exceed five years from the date of publication of criteria under section [1008] (a)(3) of this title).'' 42 U.S.C. 6945(a).

As a consequence of this statutory structure—the requirement to establish national criteria and the absence of any requirement for direct regulatory oversight—to establish the criteria EPA must demonstrate, through factual evidence available in the rulemaking record, that the final rule will achieve the statutory standard (''no reasonable probability of adverse effects on health or the environment'') at all sites subject to the standards based exclusively on the final rule provisions. This means that the standards must account for and be protective of all sites, including those that are highly vulnerable.

III. Background

A. EPA's Proposed Rule

On June 21, 2010 (75 FR 35128), EPA proposed to regulate CCR under RCRA to address the risks from the disposal of CCR generated from the combustion of coal at electric utilities and independent power producers. As described in the proposal, CCR are residuals generated from the combustion of coal and include fly ash, bottom ash, boiler slag (all composed predominantly of silica and aluminosilicates), and flue gas desulfurization (FGD) materials (predominantly Ca-SO_X compounds) and can be managed in either wet (surface impoundments) or dry (landfills) disposal systems. EPA noted in the proposed rule that the constituents of most environmental concern in CCR are metals, such as antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver and thallium. EPA also presented data showing numerous instances where these constituents (especially arsenic) have leached at levels of concern from unlined and inadequately clay-lined landfills and surface impoundments.

In the proposal, EPA revisited its August 1993 and May 2000 Bevill Regulatory Determinations regarding CCR generated at electric utilities and independent power producers. The results from this effort led the Agency to consider two primary options for the management of CCR and thus, propose two alternative regulatory strategies. Under the first option, EPA proposed to reverse its August 1993 and May 2000 Bevill Regulatory Determinations (58 FR 42466 and 65 FR 32214 respectively) regarding CCR and to list these residuals as special wastes subject to regulation under subtitle C of RCRA when they are destined for disposal in landfills or surface impoundments. Under this proposed option, CCR would be regulated from the point of generation to the point of final disposition and would generally be subject to the existing subtitle C regulations at 40 CFR parts 260 through 268, as well as the permitting requirements in 40 CFR part 270, and the state authorization process in 40 CFR parts 271–272. Among other things, the regulatory requirements included waste characterization, location restrictions, liner and, if applicable, leachate collection requirements for land disposal units, fugitive dust controls, groundwater monitoring and corrective action requirements, closure and post-closure care requirements, financial assurance, permitting requirements, and recordkeeping and reporting requirements. This option also imposed requirements on generators and transporters of CCR destined for disposal, including manifesting (if the CCR destined for disposal is sent off-site). However, in light of practical difficulties in implementing certain subtitle C regulatory requirements, EPA also proposed to revise selected requirements under the subtitle C option. Consequently, EPA proposed, pursuant to its authority under section 3004(x) of RCRA, modifications to the CCR landfill and surface impoundment liner and leak detection system requirements, the effective dates for the land disposal restrictions, and the surface impoundment retrofit requirements. EPA also proposed to establish new land disposal prohibitions and treatment standards for both wastewater and non-wastewater forms of CCR. In part, the proposed

[1] EPA also may act if the handling, storage, treatment, transportation, or disposal of such wastes may present an imminent and substantial endangerment to health or the environment, pursuant to RCRA section 7003.

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modifications to the treatment standards would result in the closure of existing surface impoundments and the prohibition of all new surface impoundments. (See 75 FR 35128 for a complete discussion of this proposed option).

Under the second option, EPA proposed to retain the August 1993 and May 2000 Bevill Regulatory Determinations and to regulate CCR disposal under subtitle D of RCRA by issuing national minimum criteria to ensure the safe disposal of CCR in surface impoundments and landfills. Under this option, CCR would remain classified as a non-hazardous RCRA solid waste. EPA proposed to establish technical requirements, many of which were nearly identical to the technical standards proposed under the subtitle C option. The technical standards included, among other things, locations standards, liner and leachate collection requirements, groundwater monitoring and corrective action standards for releases from the units, operating criteria, such as fugitive dust control, closure and post-closure care requirements, and recordkeeping and reporting requirements. Under this option, EPA did not propose to establish regulatory requirements that would restrict the generation, transportation, storage, or treatment of CCR prior to disposal, nor did EPA propose to establish financial assurance requirements under RCRA.[2] Also, because of subtitle D's limitations, the proposed rule did not require permits; nor could EPA enforce the national minimum criteria. Rather, states or citizens could enforce the national minimum criteria under RCRA's citizen suit authority, and states could continue to enforce any state regulation that applies to CCR under their independent state enforcement authority.

The subtitle D proposed option was designed to be self-implementing, meaning that the requirements were such that facilities could comply with the regulatory requirements without the need to interact with a regulatory authority. EPA sought to enhance the protectiveness of the proposed option by requiring certified demonstrations by an independent registered professional engineer to provide verification that the regulatory requirements were being adhered to. In addition, the option provided for state and public notification of the certifications, as well as required posting of certain information on a Web site maintained by the facility and in the operating record. (See 75 FR 35128 for a complete discussion of this proposed option).[3]

The Agency also described other alternatives considered. For example, one subtitle D option, called ''D-prime'' was structured so that all existing CCR surface impoundments could continue to receive CCR after the effective date of the rule for the remainder of the unit's useful life, irrespective of their liner type, provided the other provisions of the subtitle D option were met (*e.g.,* groundwater monitoring). (See 75 FR 35128 for a complete discussion of this and other possible regulatory alternatives on which the Agency solicited comment.)

Under both the subtitle C and subtitle D alternatives, EPA proposed establishing dam safety requirements to address the structural integrity of surface impoundments. EPA also proposed not to change the May 2000 Regulatory Determination for beneficially used CCR, which are currently exempt from the hazardous waste regulations under section 3001(b)(3)(A) of RCRA. EPA also did not propose to address the placement of CCR in mines, or non-minefill uses of CCR at coal mine sites.

In addition to proposing these two regulatory options for the management of CCR, EPA identified many issues on which it solicited comment, information, and data. Certain solicitations were very general, such as comments on alternative options for regulating CCR, while other requests for comment were very specific in nature, for example, whether clay liners designed to meet a specified hydraulic conductivity might perform differently in practices than modeled in the risk assessment. (The Agency requested comment on issues throughout the preamble; however specific issues for which EPA solicited comment can be found at 75 FR 35221–34224.)

B. Comments Received on the Proposed Rule

The Agency received over 450,000 comments on the proposed rule. The majority of the commenters focused on which regulatory path the Agency should pursue for regulating CCR, *i.e.,* RCRA's subtitle C or subtitle D. A number of commenters, however, argued that no additional regulation was necessary and that the states were adequately regulating the management of CCR. Generally, environmental groups and individual citizens favored a subtitle C rule arguing that state programs have failed and damage cases are growing in number. State organizations, individual states, and industry groups (electric utilities, recycling firms, trade associations), largely favored a subtitle D rule with a permitting program.

One area that received extensive comment was the re-evaluation of the eight Bevill study factors.[4] Numerous commenters provided detailed analysis related to the study factors and provided their own interpretations of the data (*e.g.,* state programs and damage cases). Other areas that received significant comment included beneficial use and the risk assessment.

Discussion of the specific comments germane to this rulemaking are provided in the relevant sections of this document.

C. Other Actions During Which Comment Was Taken

1. Public Hearings

EPA conducted eight public hearings during the months of August, September, and October in 2010. There were over 1300 individual speakers at the eight public hearings that commented on the proposed rule. Testimony at the public hearings focused generally on whether EPA

[2] In the proposal, the Agency stated that the RCRA subtitle D alternative did not include proposed financial responsibility requirements and that any such requirements would be proposed separately. The Agency solicited comment on whether financial responsibility requirements under CERCLA section 108(b) should be a key Agency focus under a RCRA subtitle D approach. While the Agency received numerous comments urging the Agency to establish financial responsibility as part of the subtitle D option, the CERCLA 108(b) option did not receive significant support. As discussed in the proposal and reiterated here, EPA will not be requiring financial assurance requirements as part of this rule. The Agency however will continue to investigate the use of other statutory authorities (*e.g.,* CERCLA) to establish financial responsibility requirements for owners or operators of CCR landfills, CCR surface impoundments and any lateral expansion.

[3] While EPA cannot enforce the subtitle D proposed rules, EPA can take action under section 7003 of RCRA to abate conditions that ''may present an imminent and substantial endangerment to health or the environment.'' EPA can also use the imminent and substantial endangerment authorities under the CERCLA, or under other federal authorities to address those circumstances where a unit(s) may pose a threat.

[4] In considering whether to retain or to reverse the August 1993 and May 2000 Regulatory Determinations regarding the Bevill exemption of CCR destined for disposal, the Agency re-examined the RCRA section 8002(n) study factors. These eight study factors are: (1) Source and volumes of CCR generated per year; (2) present disposal and utilization practices (which includes evaluation of existing state regulatory oversight and beneficial use); (3) potential danger, if any, to human health and the environment from the disposal and reuse of CCR; (4) documented cases in which danger to human health or the environment from surface runoff or leachate has been proved; (5) alternatives to current disposal methods; (6) the cost of such alternative disposal methods; (7) the impact of the alternative disposal methods on the use of coal and other natural resources; and (8) the current and potential utilization of CCR (see 75 FR 35128).

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should adopt a subtitle C or subtitle D approach for regulating CCR. Many commenters were also concerned with fugitive dust emissions and the affect these emissions had on their health and overall well-being. Other commenters were concerned that adopting a subtitle C rule for CCR would negatively affect the beneficial use of the material. In addition to their testimonies that were entered into the rulemaking record, over 1200 additional documents were submitted in hard copy and entered into the docket (see EPA–HQ–RCRA–2009–0640).

2. Notices of Data Availability

Subsequent to the proposed rule, the Agency published several Notices of Data Availability (NODAs), the first on October 21, 2010, (75 FR 64974); the second on October 12, 2011 (76 FR 63252) and the third on August 2, 2013 (78 FR 46940). Specifically:

- The first NODA invited comment on the responses EPA received on Information Collection Requests that were sent to electric utilities on their CCR surface impoundments, as well as reports and materials related to the site assessments EPA had conducted on a subset of these impoundments.
- The second NODA invited comment on a number of topics, including (1) chemical constituent data from coal combustion residuals; (2) facility and waste management unit data; (3) information on additional alleged damage cases; (4) the adequacy of state programs; and (5) beneficial use.
- The third NODA invited comment on (1) supplemental data for the risk assessment; (2) supplemental data for the RIA; (3) information regarding large-scale fill; and (4) data on the CCR Assessment Program. EPA also sought comment on two technical issues associated with the requirements for CCR management units: closure requirements and regulation of overfills (*i.e.,* CCR management units built directly over pre-existing CCR landfills or CCR surface impoundments).

Specific comments received on each of the three NODAs are discussed in the relevant sections of this rule.

3. Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category Proposed Rule

On June 7, 2013 (78 FR 34432), EPA proposed a regulation that would strengthen the controls on discharges from certain steam electric power plants by revising the technology-based effluent limitation guidelines (ELG) and standards for the steam electric power generating point source category. As part of this proposal, EPA discussed its current thinking on how a final RCRA CCR rule might be aligned and structured to account for any final requirements adopted under the ELG for the Steam Electric Power Generating point source category. Two primary means of integrating the two rules were discussed: (1) Coordinating the design of any final substantive CCR regulatory requirements and (2) coordinating the timing and implementation of the rules to allow facilities to coordinate their compliance planning and implementation and to protect electricity reliability for consumers. EPA stated that consistent with RCRA section 1006(b), effective coordination of any final RCRA requirements with the ELG requirements would be sought in order to minimize the overall complexity of the two regulatory structures, and facilitate implementation of engineering, financial, and permitting activities. EPA solicited comments on how any final CCR final rule might be aligned and structured to account for any final requirements adopted under the ELG for the Steam Electric Power Generation point source category.

D. EPA's CCR Assessment Program

In March 2009, the Agency's CCR Assessment Program (herein referred to as the Assessment Program) was initiated. This effort was in response to the December 22, 2008 dike failure of a coal ash impoundment at the Tennessee Valley Authority (TVA) Kingston Fossil Plant in Harriman, Tennessee where over one billion gallons of coal ash slurry were released, affecting more than 300 acres, including residences and infrastructure. The TVA Kingston impoundment failure ignited a nation-wide concern over the safety of coal ash impoundments; and EPA was tasked with determining whether the potential existed for similar impoundment failures at other coal-fired power plants. In response, EPA developed the Assessment Program to evaluate the structural stability and safety of all coal ash impoundments throughout the country.[5] As of September 2014, 559 impoundments had been assessed at over 230 coal-fired power plants.

The Assessment Program began as a separate effort from the development of this final rule.[6] However, the information and experience developed in carrying out the site assessments during the Assessment Program is directly relevant to many of the issues addressed in this rulemaking, and provide further technical support for many of the technical criteria. Consequently, many of the final technical criteria were developed in direct response to findings from the site assessments. For example, several of the technical criteria contained in the proposed rule were modified to account for the widely accepted engineering methodologies and practices used in conducting the site assessments, as well as current facility practices documented during the assessments. In a few instances, the criteria were supplemented to better align the technical requirements with the Assessment Program. Included among the final criteria that directly rely on the Assessment Program are the provisions relating to structural integrity assessments to address factors of safety, periodic reassessments, hazard potential classifications, and the hydrologic and hydraulic capacity of CCR surface impoundments. These requirements are further discussed in Unit VI of this preamble.

The Assessment Program focused on impoundments meeting four general criteria that were designed to identify the units most likely to present the same risks as the collapsed TVA impoundment: (1) Above ground or diked; (2) of sufficient height to be susceptible to structural failure (*i.e.,* six feet); (3) receiving CCR; and (4) located at operating coal-fired power plants selling power to the electric grid. Also included in the assessments were a number of inactive impoundments, *i.e.,* impoundments not receiving CCR but still containing CCR and/or liquid. The Agency included these inactive units in the assessment reasoning that these units would be as susceptible to structural failure as units currently receiving CCR, given that they still contained CCR and maintained an ability to impound liquid (*i.e.,* the unit had not been breached). The Assessment Program did not evaluate, however, incised (not having above ground berms or dikes) impoundments or landfills (not containing liquid slurried CCR wastes). EPA chose not to assess these units because they did not share the characteristics of

[5] The focus of the Assessment Program was to assess the structural integrity of CCR impoundments meeting specified criteria. The Agency did not include, as part of its evaluation, the assessment of other conditions/characteristics of the impoundment that may present potential risks to human health or the environment, *i.e.,* groundwater contamination due to an insufficient liner design.

[6] EPA issued two Notices of Data Availability (75 FR 35128 (October 21, 2010) and 78 FR 46940 (August 2, 2013)) specifically soliciting comment on the information generated by the Assessment Program and the materials posted on our Web site.

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impoundments likely to raise concern for catastrophic releases, and because no known catastrophic structural failures were associated with these types of units.

Prior to initiating the assessments, EPA consulted with two key dam safety organizations, the Association of State Dam Safety Officials (ASDSO) and the Mine Safety and Health Administration (MSHA) to better understand how these federal and state dam inspection programs operated, including how earthen dams and impoundments were assessed.[7] These groups provided the Agency with critical insight and information for inspecting and evaluating CCR impoundments. The Agency also reviewed various technical documents relating to dam safety and conducting impoundment inspections, many of which were recommended by these organizations. They were: (1) U.S. Army Corp of Engineers (USACE) 2008 National Inventory of Dams (NIDS); (2) Federal Emergency Management Agency's (FEMA) Federal Guidelines for Dam Safety—Hazard Potential Classification System for Dams (April 2004); (3) FEMA's Risk Prioritization Tool for Dams User Manual (March 2008); (4) MSHA's Handbook (PH07–01); (5) MSHA's Coal Mine Impoundment Inspection and Plan Review Handbook (October 2007); and (6) MSHA's Engineering and Design Manual: Coal Refuse Disposal Facility (May 2009); (7) ASDSO's ''Summary of State Dam Safety Laws and Regulations,'' (2000); (8) ASDSO's ''Owner Responsible Periodic Inspection Guidance,'' (2005); (9) ''Guidelines for Inspections of Existing Dams.'' New Jersey Department of Environmental Protection—Dam Safety (January 2008).

In developing the criteria that were used to conduct the assessments, a standard rating system was developed to classify the units' suitability for continued safe and reliable operation. EPA modeled its impoundment condition rating criteria on those developed by the State of New Jersey (see reference above).

1. Conducting the Site Assessments

In order to prioritize the assessments, a preliminary hazard potential classification ranking was identified for each impoundment, based on criteria developed by the FEMA and found generally in USACE's NID. EPA elected to evaluate first those impoundments with a high hazard potential classification, which signifies that a failure or mis-operation of the unit would probably result in the loss of human life.

Upon initiation of the Assessment Program, every owner or operator of a CCR impoundment was contacted by the Agency and supplied with information on the objectives of the assessment and how the assessments were to be conducted. Assessments were conducted in rounds, consisting of groups of 12–26 facilities per round.[8] Prior to each site assessment, to ensure uniformity throughout the study, a statement of work and an impoundment field checklist was developed and adhered to during the assessment.

To ensure objectivity, EPA contracted with professional engineers (PEs) in the state where the impoundment was located who were experts in the area of dam safety to perform the site assessments. Each individual assessment was performed by PEs qualified in the areas of geotechnical engineering, hydrology and hydraulics, and overall dam safety. Upon evaluation of a robust set of technical documents addressing dam safety and inspections as well as comprehensive discussions with key dam safety organizations, the Assessment Program developed a comprehensive set of factors that were to be used to evaluate the overall safety of CCR surface impoundments, which concluded that, among other important factors, the static and seismic factors of safety, hydrologic and hydraulic capacity, liquefaction potential analysis and a post-liquefaction stability analysis if the soils of the embankment were identified to be susceptible to liquefaction, and operation and maintenance protocols, *e.g.* instrumentation monitoring, inspection program, emergency response protocols were critical parameters for assessing the overall safety of CCR surface impoundments.

The individual evaluations or assessments were conducted at each impoundment at each facility using standard, accepted engineering practices, including a visual assessment of the CCR surface impoundment, interviews with site personnel, a review of the history of the CCR surface impoundment, and a review of engineering documentation related to the design, construction, operation, and maintenance of the impoundments, including available technical analyses. At each site visit, additional documentation was collected and reviewed as available, including descriptions, along with supporting information, of: (1) The impoundment, including location, size, age, design and/or alterations to the design, and the amount of residuals currently in the unit; (2) known, measured settlement of the impoundment embankment; (3) known, measured movement of the impoundment embankment; (4) observed erosion of the impoundment embankment; (5) seepage; (6) leakage; (7); observed cracking of the impoundment embankment; (8) deterioration, such as scarps, boils, or sloughs, of the — embankment; (9); seismicity; (10) internal stresses; (11) functioning of foundation drains and relief wells; (12) stability of critical slopes adjacent to the units; and (13) regional and site geological conditions. If available, state and federal inspections reports were also reviewed.[9]

In addition, for each assessment, the following factors were identified, to the extent feasible, for evaluation: (1) The presence and adequacy of spillways; (2) hydrologic and hydraulic capacity of the unit; (3) overall structural adequacy and stability of structures under all credible loading conditions through a review of static, seismic, and liquefaction analyses with determined factors of safety; (4) soil, groundwater, surface water, geology, and geohydrology characteristics associated with the unit, including hydrological data accumulated since the impoundment was constructed or last inspected; (5) a history of the performance of the management unit through analysis of data from monitoring instruments, interviews with facility personnel, and review of available operating records; (6) quality and adequacy of maintenance, surveillance, and methods of unit operations for the protection of public safety; (7) location of schools, hospitals, or other critical infrastructures within five miles down gradient of the impoundment; and (8) whether the impoundment is located within federally designated flood plains. Finally, each impoundment and any associated spillways were evaluated to determine whether the impoundment and the spillways could withstand the loading or overtopping from appropriate inflow design flood events.

Each CCR surface impoundment was classified with a hazard potential classification following the New Jersey Department of Environmental Protection

[7] ASDSO identified for EPA key documents to review including Federal Energy Regulatory Commission (FERC) and MSHA guidance.

[8] The results of this effort are either presented on a facility by facility basis or are summarized by round. All of these data have been posted on the Agency Web site.

[9] It is important to note that during the assessment, no physical drilling, coring or sampling was conducted, while on site; however, studies were reviewed that often included such information.

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Bureau of Dam Safety and Flood Control's hazard potential ranking. Each impoundment was classified with a hazard potential classification of either; ''high,'' ''significant,'' ''low,'' or ''less-than-low.'' The hazard potential classification was a qualitative assessment of the potential adverse incremental consequences of a dam failure.

At the conclusion of each assessment, a report was generated and the impoundment was given a condition rating of either; satisfactory, fair, poor, or unsatisfactory. The condition ratings were based on the availability of information on the unit and evaluation of the previously mentioned factors, including the static, seismic, and liquefaction factors of safety. No impoundments received an ''unsatisfactory'' rating. Numerous impoundments were, however, rated as ''poor,'' often for lack of appropriate technical documentation in the aforementioned areas. ''Poor'' or ''fair'' ratings were also an indication that additional measures were needed to improve the stability of the unit. Of 559 impoundments assessed, 241 received a condition rating of ''satisfactory,'' 166 received a condition rating of ''fair,'' and 152 received a ''poor'' condition rating.

It is important to note that the condition rating did not necessarily imply that the unit had inadequate structural integrity. On the contrary, in many instances a structurally sound impoundment may have been given a condition rating or ''fair'' or ''poor'' based on other factors such as a lack of documented information on the unit or insufficient operations and maintenance protocols. For example, an impoundment could be rated as ''poor'' if it lacked the appropriate technical documentation and analyses regarding structural or hydrologic and hydraulic analyses. EPA rated numerous units as ''poor'' based primarily on unavailable technical analyses.

Once the assessment was performed, a draft report was prepared. Draft reports were reviewed by the appropriate state agency, the utility, and by EPA.[10] Once comments were received and incorporated, a final report was issued along with recommendations for additional actions to be taken by the facility (if needed). Facilities then developed action plans and schedules to implement the recommendations. EPA also informed facility owners and operators that in addition to implementing their action plans, they need to adopt an ongoing, routine program to assess each surface impoundment and to take necessary corrective measures to ensure the units' continued structural integrity.

2. Assessment Program Findings

Upon completion of the Assessment Program, a review was undertaken to ascertain the key findings or lessons learned from the effort. These key findings included: (1) The majority of CCR surface impoundments are currently inspected on a periodic basis; (2) most utilities were readily able to supplement outdated or missing information with new or updated evaluations of their impoundments after the on-site portion of EPA's assessment was conducted; (3) in response to the assessment report recommendations, facilities typically willingly conducted remedial actions; (4) interaction with the states and the utilities assured accuracy in the final assessment reports; (5) placing site assessment materials on an internet site assured that the public, states, and utilities had full access to information about the design and operation of CCR impoundments and did not present either homeland security or other confidentiality concerns; (6) static, seismic, and liquefaction analyses did not pose a significant technical or cost burden on facilities since many already routinely conducted these types of evaluations; (7) state regulatory bodies viewed the assessments as a means to further support existing assessment programs; and (8) the use of PEs to certify all final reports ensured that the assessments reflected the PE's best judgments.

3. Assessment Program's Support for the Structural Integrity Requirements of the Rule

As noted, the findings from EPA's Assessment Program provide technical and factual support for many of the final requirements for structural stability in this rule. A more detailed discussion of several of the most significant of these is presented below. Additional discussion of the relevance of these findings is included throughout Unit VI of this document.

a. Periodic Inspections/Assessments

Consistent with the findings from the assessments and with EPA's recommendations to facilities as part of the Assessment Program, this rule requires that all CCR surface impoundments be inspected at intervals not exceeding seven days for any appearances of actual or potential structural weakness and other conditions that are disrupting or have the potential to disrupt the operation or safety of the CCR surface impoundment. Monitoring of instrumentation is also required to be conducted at intervals not exceeding 30 days. The Assessment Program found that virtually all utility companies conduct some sort of periodic inspection or monitoring at CCR surface impoundments, although practices varied among facilities and between states. The Assessment Program also found that while many facilities were conducting regularly scheduled inspections, some did not adequately document the results of these inspections.

In the final rule, CCR surface impoundments exceeding a specified size threshold, *i.e.,* height of five feet or more and capacity of 20 acre-feet or more or a height of 20 feet or more, are required to perform annual inspections as well as two assessments of structural stability quinquennially, (*i.e.,* every five years) that include a structural stability assessment of specified parameters and a factor of safety assessment. Annual inspections are broader in scope than weekly inspections and are conducted to ensure that the design, construction, operation and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering standards. Annual inspections must include a review of available information regarding the status and condition of the unit and a visual inspection to identify signs of distress or malfunction of the unit and appurtenant structures. The annual inspections must be conducted by a qualified professional engineer.

The Assessment Program also reviewed how detailed structural stability reviews and inspections were recommended to be conducted by FEMA, MSHA, and the USACE guidelines and found that such inspections were recommended to take place every three to five years. Review of state dam safety programs demonstrated that similar detailed inspections were also conducted on a three-to-five year cycle. Therefore, in the final rule, EPA is requiring that structural integrity assessments, including the calculation of factors of safety under various loading conditions, be conducted within 18 months of publication of the rule, and be repeated every five years. The five year review timeframe is based on documentation showing that the factual bases for such reviews are only sound for that time

[10] As noted many times in this document, states play a critical role in implementing and overseeing these units. To assist states in this effort, EPA has, in the majority of cases directly provided the states with all of the information from our assessments. The Assessment Program reports may be accessed at: *http://www.epa.gov/wastes/nonhaz/industrial/special/fossil/surveys2/index.htm.*

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period, and is consistent with federal dam safety guidance, specifically FEMA. FEMA recommends in *Federal Guidelines for Dam Safety* that dams be formally assessed at a frequency not to exceed five years by a qualified professional engineer. EPA has adopted this timeframe to maintain consistency with FEMA guidance. The inspection and assessment requirements in this rule will ensure that there are consistent and uniform inspection and assessment practices across states and facilities and will ensure that problems related to their stability will be promptly identified and remediated as necessary.

b. Static, Seismic, and Liquefaction Factors of Safety

(1) Static Factors of Safety.

Factor of safety (FOS) means the ratio of the forces tending to resist the failure of a structure, as compared to the forces tending to cause such failure as determined by accepted engineering practice. This analysis is used to determine whether a CCR surface impoundment's dikes are engineered to withstand the specific loading conditions that can be reasonably anticipated to occur during the lifetime of the unit without failure of the dike, if accepted good engineering practices are employed. Static factors of safety refer to the factors of safety (FOS) under static loading conditions that can reasonably be anticipated to occur during the lifetime of the unit. Static loading conditions are unique from other loading conditions (*e.g.,* seismic, liquefaction) in that static loading conditions are those which are in equilibrium, meaning the load is at rest or is applied with constant velocity.

EPA reviewed a series of USACE guidance documents addressing how to determine static FOS. These documents included, but were not limited to, Engineer Manual EM 1110–2–1902 ''Slope Stability'' (October 2003), and EM 1110–2–1902 ''Stability of Earth and Rock-Fill Dams.'' The Agency also assessed the recommendations on how to conduct static analysis contained in the Engineering and Design Manual for Coal Refuse Disposal Facilities, originally published by the Mining Enforcement and Safety Administration (MESA) in 1975 and updated for MSHA in May 2009, and in particular Chapter 6, ''Geotechnical Exploration, Material Testing, Engineering Analysis and Design.'' Based on recommendations from ASDSO, among others, the Agency adopted the USACE guidance to determine static FOS, both in the Assessment Program and in this rulemaking, as these manuals are recognized throughout industry as the standard routinely used in field assessment of structural integrity.

In EPA's Assessment Program all CCR units were assessed to determine their static FOS. Each assessment classified a CCR unit as having sufficient structural stability under static loading conditions if analysis of critical sections of embankments demonstrated FOS that met or exceeded the values defined by USACE for static specific loading conditions. EPA found that most CCR surface impoundments exhibited sufficient calculated factors of safety under static loading conditions. EPA also found that in those CCR units which insufficient factors of safety against failure due to static loading were calculated, the owner or operator was able to implement actions which increased the factors of safety under static loading conditions to acceptable levels. Oftentimes, these implemented actions were of a simple nature, such as installing riprap (rock armoring the slopes) or buttressing the slopes.

Similarly, this rule adopts the static FOS from USACE Engineer Manual EM 1110–2–1902 ''Slope Stability,'' with the exception of the rapid drawdown loading condition,[11] which was determined not to be relevant to CCR surface impoundments. EPA found the factors of safety identified by EM 1110–2–1902, specifically the Maximum Storage pool, Maximum Surcharge pool, and End-Of-Construction loading conditions, provided consistent, achievable levels of safety in CCR surface impoundment dikes, comprehensively assessed static stability, and provided sufficient consideration of compounding stresses on dikes (*e.g.,* factors of safety values greater than 1.00 to account for unanticipated loadings acting in conjunction or misidentified strength of materials).

(2) Seismic Factor of Safety.

Seismic FOS means the FOS determined using analysis under earthquake conditions for a seismic loading event, based on the U.S. Geological Survey (USGS) seismic hazard maps for seismic events with a specified return period for the location where the CCR surface impoundment is located. The seismic FOS analysis is used to determine whether a dam would remain stable during an earthquake or other seismic event. The Agency relied on guidance from USACE and MSHA to evaluate the appropriate methods to determine if a dam would remain stable during a seismic event. This includes the USACE guidance Engineer Circular 1110–2–6061: Safety of Dams—Policy and Procedures 2204, Engineer Circular 1110–2–6000: Selection of Design Earthquakes and Associated Ground Motions 2008, and Engineer Circular 1110–2–6001: Dynamic Stability of Embankment Dams 2004). EPA also reviewed MSHA's 2009 Engineering and Design Manual for Coal Refuse Disposal Facilities, in particular Chapter 7, ''Seismic Design: Stability and Deformation Analyses.'' These documents are viewed by ASDSO, FEMA and MSHA as generally accepted guidance on how to conduct seismic stability analyses.

As noted earlier, in performing the assessments, EPA directed its engineering contractors to assess seismic stability of CCR impoundments during and following a seismic event with a 2% probability of exceedance in 50 years (*i.e.* probable earthquake within approximately 2,500 years) and a horizontal spectral response acceleration for 1.0-second period (5% of Critical Damping). EPA selected this return period for determining the maximum design earthquake (MDE) by first considering the operating life anticipated for CCR surface impoundments. EPA has identified the operating life of CCR surface impoundments to range between 40–80 years. EPA then consulted the United States Geological Survey (USGS) and ASDSO to determine a conservative probability that should be used in the assessments.[12] To reduce the likelihood of a CCR unit failing during a seismic

[11] Rapid (or sudden) drawdown is a condition in earthen dikes that may develop when the embankment becomes saturated through seepage during a high pool elevation in the reservoir. Rapid drawdown becomes a threat to the dike when the reservoir pool is drawn down or lowered at a rate significantly higher than the excess poor water pressure within the dike can dissipate. Typically, rapid drawdown scenarios are considered for dikes with reservoirs used for water supply and management or agricultural supply. In these scenarios, a high pool elevation is maintained in the reservoir in storage months. Subsequently, the water supply is drawn on in months where there is a demand for the reservoirs contents. This drawing down of the pool can present issues for the structural integrity of the unit. However, the management of CCR surface impoundments differs from that of conventional water supply reservoirs. CCR surface impoundments are never used for water supply, and the only instance in which EPA determined through its Assessment Program that rapid drawdown loading conditions would be relevant to CCR surface impoundments was in the event that the CCR surface impoundment had already released the contents of the impoundment through a breach of the dike or emergency discharge. Since the threat of release of CCR and the reservoir has already been realized, any failure due to rapid drawdown of the embankment is no longer critical to the overall containment of the now-released contents of the CCR unit.

[12] Wieland, M., ''Seismic Design and Performance Criteria for Large Storage Dams'', Proc. 15th World Conf. on Earthquake Engineering, Lisbon, Portugal, Sep. 24–28, 2012.

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event, the Agency assessed various return periods and chose a conservative 2500 year return period. The use of this ''return'' period was chosen because it is conservative, reflects the fact that many CCR impoundments are located in active seismic zones, and the use of a conservative ''return'' period ensures that if a unit meets the seismic FOS it is unlikely to fail under most seismic events. By evaluating seismic stability under a conservative return period and requiring the unit to maintain structural stability under that design seismic event, the likelihood of a seismic event occurring at the location of the CCR surface impoundment in which the strength of the unit is exceeded and the unit fails is considerably reduced. Additionally, the unit can reasonably be anticipated to withstand seismic events of a more frequent return period (*i.e.,* smaller magnitude).

The Agency assessed CCR impoundments and classified them as having seismic stability if modeling results of critical failure surfaces were calculated to have a FOS greater than 1.0 under the specified seismic loading condition. The Assessment Program found that most CCR impoundments did meet the required seismic FOS. This rule also adopts this seismic stability FOS under the 2% probability of exceedance in 50 years event.

The Assessment Program found that many CCR impoundments had not undergone static or seismic analyses in sufficient detail that an independent professional engineer could assert that they were stable. The assessments gave impoundments a condition rating of ''poor'' if the utility was unable to provide static and seismic studies of their units conducted in a fashion which represented acceptable professional engineering practice. As the Assessment Program advanced, many utilities independently conducted new or updated static and seismic analyses of CCR surface impoundments in anticipation of their facilities being assessed. By the end of the program, virtually all facilities had conducted or were in the process of conducting static and seismic analyses. While some utilities noted concern over the costs of conducting additional static or seismic stability studies, none found that completing these studies presented any significant engineering challenges.

(3) Liquefaction Factors of Safety

Liquefaction FOS means the factor of safety determined using analysis under liquefaction conditions. Liquefaction is a phenomenon which typically occurs in loose, saturated or partially-saturated soils in which the effective stress of the soils reduces to zero, corresponding to a total loss of shear strength of the soil. The most common occurrence of liquefaction is in loose soils, typically sands. The liquefaction FOS determination in the final rule is used to determine if a CCR unit would remain stable if the soils of the embankment of the CCR unit were to experience liquefaction. EPA relied primarily on one source to evaluate the appropriate methods to determine if a dam would remain stable under liquefaction conditions. This source was ''Soil Liquefaction during Earthquakes,'' Idriss and Boulanger, Earthquake Engineering Research Institute, 2008.[13] EPA also reviewed several technical resources regarding soil liquefaction, including ''Ground Motions and Soil Liquefaction During Earthquakes,'' Seed and Idriss, 1982,[14] ''Liquefaction Resistance of Soils: Summary report from the 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils,'' Youd and Idriss, 2001,[15] and *Seismic Design Guidance for Municipal Solid Waste Landfill Facilities,* US EPA, Office of Research and Development, 1995.[16] These documents are viewed as generally accepted guidance on how to conduct liquefaction potential analyses and residual strength analyses under post-liquefaction conditions.

As noted earlier, in performing the assessments, EPA assessed the liquefaction potential of soils that compose the embankments of the CCR unit to determine if the soils present in the embankment were of the soil classification and configuration that was susceptible to liquefaction. This determination was based on evidence available through interviews with facility personnel, construction documentation, or representative soil sampling, such as information provided by corings and borings. Identical to the requirements for seismic factor of safety calculation, EPA selected a return period for a seismic event for analysis of liquefaction potential, under a seismic loading which may induce liquefaction in embankments, of a 2% probability of exceedance in 50 years. The discussion of the selection of this return period can be found in the ''Seismic Factor of Safety'' section above.

The Agency assessed CCR impoundments and classified them as having stability under liquefaction conditions if representative soil sampling, anecdotal evidence from interviews with facility personnel, or construction documentation indicated that there was no susceptibility to liquefaction of the embankment soils or if modeling or analysis in critical failure planes in the embankment expected to be susceptible to liquefaction were calculated to have a FOS greater than 1.00 under post-liquefaction conditions. The Assessment Program found that most CCR surface impoundments did not contain soils in detrimental volumes or configurations in the embankment that would indicate susceptibility to liquefaction. However, the assessment effort found that in embankments with a presence of soils susceptible to liquefaction, most CCR surface impoundments did not meet the required liquefaction FOS.

The Assessment Program found that many CCR surface impoundments had not undergone liquefaction potential analyses or post-liquefaction residual strength analyses in those instances in which liquefaction potential was identified (*i.e.,* soils subject to liquefaction were present). The assessments gave impoundments a condition rating of ''poor'' if there was no information available to characterize the soils of the embankment, and a condition rating of ''poor'' or ''fair'' if post-liquefaction residual strength analysis of soils previously identified as being susceptible to liquefaction had not been available, with the rating dependent on the determined severity of the liquefaction potential in the embankment. Impoundments with calculated liquefaction factors of safety which did not meet or exceed 1.00 were given a condition rating of ''poor.''

As the Assessment Program advanced, many utilities independently conducted new or updated liquefaction potential analyses or residual strength analyses of CCR surface impoundments in anticipation of their facilities being assessed. By the end of the program, virtually all facilities had conducted or were in the process of conducting liquefaction potential analyses or residual strength analyses. While some utilities noted concern over the costs of

[13] *https://www.eeri.org/products-page/monographs/soil-liquefaction-during-earthquakes-3/.*

[14] Seed, H. B., and Idriss, I. M., 1982, ''Ground Motions and Soil Liquefaction During Earthquakes,'' Monograph No. 5, Earthquake Engineering Research Institute, Berkeley, California, pp. 134.

[15] Youd, T. L., Idriss, I. M., 2001, ''Liquefaction Resistance of Soils: Summary report from the 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils.'' Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

[16] United States EPA, Office of Research and Development, 1995, EPA/600/R–95/051, RCRA Subtitle D (258) Seismic Design Guidance for Municipal Solid Waste Landfill Facilities. Available as of the Writing of this policy at *www.epa.gov/clhtml/pubtitle.html* on the U.S. EPA Web site.

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conducting additional liquefaction potential or residual strength studies, none found that completing these studies presented any significant engineering challenges.

Based on its experience in the Assessment Program and subsequent review of numerous technical resources, EPA determined that a post-liquefaction residual strength factor of safety in the embankment of 1.00 is not sufficient. Liquefaction potential analysis and post-liquefaction residual strength analysis involves a larger degree of uncertainties, *e.g.,* liquefiable stratum configuration, in assumptions and analysis which must be accounted for with a factor of safety above 1.00. The final rule therefore requires CCR surface impoundments which are constructed of soils determined to be susceptible to liquefaction to meet or exceed a liquefaction factor of safety of 1.20. EPA has determined that 1.20 is an appropriate liquefaction factor of safety based on several technical guidances and memos, including *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams,* Document 65, FEMA May 2005, which states that ''post-liquefaction factors of safety are generally required to be a minimum of 1.2 to 1.3.'' [17] [18] [19] [20] [21]

c. Impoundment Height and Relationship to Regulatory Requirements

During the Assessment Program, the Agency reviewed the stability issues related to various heights of impoundments. The Assessment Program concluded that impoundments with heights less than five feet or those retaining less than 20 acre feet were unlikely to cause significant environmental or economic loss should they undergo a catastrophic failure. The Agency's review of MSHA and FEMA guidance also noted that ''small'' units were unlikely to cause significant losses should they fail. Based on the Agency's experience and FEMA and MSHA's guidance, the Agency has concluded that there is a substantial benefit in having impoundments which exceed a specified size threshold, *i.e.,* height of five feet or more and capacity of 20 acre-feet or more or a height of 20 feet or more determine their static, seismic, and liquefaction FOS on a regular basis. The analyses and experience gained in conducting the Assessment Program indicates that a catastrophic failure of a CCR surface impoundment is unlikely to occur so long as the factors of safety are maintained or exceeded throughout the unit's operating life. This conclusion is also consistent with relevant guidance and regulations which do not require such evaluations for units below a certain size threshold.

d. Hazard Potential Ratings

Each impoundment assessed in the Assessment Program was given a Hazard Potential Classification rating of either *Less-than-Low, Low, Significant, and High.* Previous classifications were reviewed and amended as necessary to reflect guidance developed for the Assessment Program. The hazard potential ratings refer to the potential for loss of life or damage if there is a dam failure. The ratings do not refer to the condition or structural stability of the dam. Four hazard potential classifications were used in assessing the impoundments in the Assessment Program:

High Hazard Potential—Dams assigned the high hazard potential classification are those where failure or mis-operation will probably cause loss of human life.

Significant Hazard Potential—Dams assigned the significant hazard potential classification are those dams where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environment damage, disruption of lifeline facilities, or impact other concerns. Significant hazard potential classification dams are often located in predominantly rural or agricultural areas, but could be located in areas with population and significant infrastructure.

Low Hazard Potential—Dams assigned the low hazard potential classification are those where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the owner's property.

Less Than Low Hazard Potential—Dams which do not pose high, significant, or low hazard potential.

There is a substantial benefit in having owners or operators of all CCR impoundments determine the hazard potential classification of their units. The Assessment Program found that many CCR surface impoundments had not been given a hazard potential classification and consequently, their potential threat to human health and the environment if a failure were to occur was not clearly identified, nor had response plans been developed to respond to any catastrophic failure. Moreover, these classifications should be updated over time, particularly to account for changes such as population growth, construction of key infrastructure, or changes to the impoundment's size or operation. The Assessment Program also found that some states do not classify CCR impoundments as ''dams'' and therefore those units may not be required to determine their hazard potential classification or otherwise evaluate the potential effects of a catastrophic failure. Consistent with the guidance from ASDSO, FEMA, and the state of New Jersey, this rule requires that all diked CCR impoundments determine their hazard potential classification according to the definitions set out in this regulation. For those units with a hazard potential classification of significant or high, the owner or operator of such impoundments is also required to develop an Emergency Action Plan to address the higher potential impacts of a potential failure.

e. Condition Ratings

While the rule does require facilities to evaluate the same engineering factors that went into developing these ratings, the rule does not require that each impoundment be given a condition rating. After evaluation of the use of these ratings, the Agency determined that the rating may have relied too heavily on subjective factors. For that reason, this rule requires that the qualified professional engineer certify, based on quantitative determinations, that an impoundment meets the requirements for FOS and hydraulic and hydrologic capacity. This approach is less subjective and allows the professional engineer to make quantifiable certifications.

IV. Bevill Regulatory Determination Relating to CCR From Electric Utilities and Independent Power Producers

As discussed in the preceding sections, in the proposed rule EPA reopened its August 1993 and May 2000 Regulatory Determinations regarding CCR generated at electric utilities and independent power producers, to re-evaluate whether regulation of CCR under RCRA subtitle C is necessary in light of subsequent information. EPA explained that this was based on several

[17] US Bureau of Reclamation (USBR), ''Water Operation and Maintenance Bulletin No. 222,'' Denver, Colorado, December 2007.

[18] *http://www.oregon.gov/odot/hwy/bridge/docs/bddm/pdfs/psha.pdf.*

[19] Canadian Dam Association. Canadian Dam Safety Guidelines, 2007, 88 pp.

[20] Sonmez, H., 2003. Modification of the liquefaction potential index and liquefaction susceptibility mapping for a liquefaction-prone area (Inegol, Turkey), Env. Geology, (44): 862–871.

[21] Seed, R.B., Cetin, O.K., Moss, R.E.S., Kammerer, A.M., Wu, J., Pestana, J.M., Riemer, M.F., Sancio, R.B., Bray, J.D., Kayen, R.E., Faris, A., 2003. Recent advances in soil liquefaction engineering: a unified and consistent framework, 26th annual ASCE L.A. Geot. Spring Sem., Long Beach, California, April 30, 71 pp.

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relatively recent developments, such as a newly completed quantitative risk assessment that concluded that the disposal of CCR in unlined waste management units posed substantial risks, with upper end risk estimates ranging from 10^{-2}–10^{-4}. Citing to the recent structural failures of surface impoundments, the proposed rule also noted that these wastes have caused greater damage to human health and the environment than EPA originally estimated. Finally, EPA explained that recently collected information regarding the existing state regulatory programs had called into question whether those programs, in the absence of national minimum standards specific to these wastes, had sufficiently improved to address the gaps originally identified in the May 2000 Regulatory Determination. EPA ultimately concluded that federal regulation of this material was necessary, but did not reach any conclusion as to whether regulation under subtitle D would be sufficient or whether regulation under subtitle C would be necessary to adequately address the risks.

Of the over 450,000 comments received on the proposed rule, the vast majority focused on whether the Bevill exemption should be retained, and the corresponding question of whether CCR regulations should be established under RCRA subtitle C or subtitle D. In terms of the sheer numbers, the majority of commenters supported a decision to revoke the Bevill exemption and to regulate CCR under a subtitle C rule. These commenters, largely individual members of the public and environmental groups, generally argued that the Bevill exemption should be revoked because state programs have failed to adequately regulate the disposal of CCR and because the risks associated with the management of these wastes are significant. In support of both points, these commenters pointed to the fact that the number of damage cases that have been discovered has increased substantially since the original 2000 Regulatory Determination, and have continued to grow since publication of the proposed rule in 2010.

By contrast, state organizations, individual states, and industry groups (electric utilities, recycling firms, trade associations), largely favored a subtitle D rule. Overall, these commenters raised concern about the costs of the subtitle C regime, arguing that the subtitle C requirements were more stringent than necessary to address the risks from CCR disposal. Commenters also raised concern that regulation of these wastes under subtitle C would negatively affect the beneficial use of these materials, arguing that the stigma associated with regulating the disposal of CCR as a hazardous waste would ''cripple'' the current beneficial reuse market. Many of these commenters also argued that EPA lacks the legal authority to regulate these wastes under subtitle C on a variety of grounds, including claims that EPA entirely lacks the authority to revisit its Bevill Regulatory Determination, and that EPA had failed to comply with statutory procedures in doing so.

A. Deferral of a Final Decision on the Bevill Regulatory Determination for CCR Destined for Disposal

In determining whether the Bevill exemption should be retained for CCR, EPA must evaluate and weigh eight factors that were enumerated in section 8002(n) of RCRA. 42 U.S.C. 6921(b)(3)(C). The eight factors are: (1) The source and volumes of CCR generated per year; (2) present disposal and utilization practices; (3) potential danger, if any, to human health or the environment from the disposal and reuse of CCR; (4) documented cases in which danger to human health or the environment from surface run-off or leachate has been proved; (5) alternatives to current disposal methods; (6) the cost of such alternative disposal methods; (7) the impact of those alternatives on the use of coal and other natural resources; and (8) the current and potential utilization of CCR. 42 U.S.C. 6982(n).

EPA addressed each of these study factors in the 1988 and 1999 Reports to Congress, and in reaching our decisions in the August 1993 and the May 2000 Regulatory Determinations to maintain the Bevill exemption for CCR. 58 FR 42466 (August 9, 1993); 65 FR 32214 (May 22, 2000). Consequently, in considering whether to reverse these Regulatory Determinations for CCR destined for disposal, EPA reexamined the RCRA section 8002(n) study factors against all of the available data, which included both the data that formed the basis for the May 2000 Regulatory Determination and the most recent data available. (See 75 FR 35150–35156.)

As discussed at length in the proposed rule, three of these factors weighed the most heavily in the Agency's decision to reconsider its previous Regulatory Determinations. (See 75 FR 35133 and 35156–35158.) The first of these related to the extent of the risks posed by the current management of these wastes. Since the 2000 Regulatory Determination, EPA had completed a quantitative risk assessment that estimated significant risks to human health and the environment. EPA's 2010 CCR risk assessment estimated the cancer risk from arsenic that leaches into groundwater from CCR managed in units without composite liners to exceed EPA's typical risk thresholds of 10^{-4} to 10^{-6}. For example, depending on various assumptions about disposal practices (*e.g.,* whether CCR is co-disposed with coal refuse), groundwater interception and arsenic speciation, the 90th percentile risks from unlined surface impoundments ranged from 2×10^{-3} to 1×10^{-4}. The risks from clay lined surface impoundments ranged from 7×10^{-2} to 4×10^{-5}. Similarly, estimated risks from unlined landfills ranged from 5×10^{-4} to 3×10^{-6}, and from 2×10^{-4} to 5×10^{-9} for clay-lined landfills. EPA's risk assessment also estimated Hazard Quotients (HQs)[22] above 1 for other metals, including selenium and lead in unlined and clay-lined units. However, a number of technical questions were raised regarding this quantitative risk assessment that called into question the accuracy of these risk estimates.

A second and equally significant consideration related to how effectively state regulatory programs address the risks associated with the improper management of these wastes. The existing reports on state regulatory programs had called into question whether the trend in improving state regulatory regimes that EPA identified in May 2000 had materialized to the degree anticipated in the Regulatory Determination. EPA noted concern about the lack of substantial details regarding the full extent of state regulatory authority over the disposal of these materials, and the manner in which states have, in practice, implemented this oversight.

The final consideration, which is tightly related to the first two, was the recent information documenting continued instances involving the contamination of ground or surface water from the management of these wastes. Since the 2000 Regulatory Determination EPA had gathered or received information on 67 ''proven or potential'' cases involving damage to (*i.e.,* contamination of) ground and surface water, and to human health and the environment from improper management of CCR in landfills and surface impoundments. These also included cases involving the structural failure of surface impoundments and the catastrophic release of CCR.

[22] For more information on HQs please see Unit X. Risk Assessment of this preamble.

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For each of these key areas, EPA identified a number of issues on which the absence of critical information prevented the Agency from reaching an initial decision on whether to revise the Bevill Determination. Some of these issues or uncertainties have been resolved during the development of the final rule, either as a result of information received from commenters or through additional information and analyses EPA obtained or developed, which were held out for comment in subsequent NODAs. See 75 FR 35128 (October 21, 2010) and 78 FR 46940 (August 2, 2013). However, as discussed in more detail below, critical information necessary to make a final Regulatory Determination is still lacking in two of these three areas. This information bears directly on the extent and magnitude of the risks over the course of the next several years, and the degree to which those risks can be managed sufficiently under each of the two regulatory structures available to the Agency. In the absence of this information, EPA is unable to reach a conclusion on the issue that is central to a Bevill Determination: Whether the risks presented by management of CCR waste streams can only be adequately mitigated through regulation under RCRA subtitle C. As a consequence, EPA is deferring a final Regulatory Determination for these wastes.[23]

Nevertheless, the record is clear that current management of these wastes can present, and in many cases has presented, significant risks to human health and the environment. Although EPA cannot reach conclusions as to the full extent or magnitude of those risks over the long term, the current level of risk clearly warrants the issuance of federal standards to ensure consistent management practices and a national minimum level of safety.

In the following sections, EPA describes the information that was obtained over the course of the rulemaking relating to each area of concern, and the extent to which the new information addressed the issue.

[23] Because EPA is deferring its final Bevill Determination, EPA has not responded to comments that pertain exclusively to that issue. However EPA has responded to significant comments that relate to topics that are otherwise relevant to the final subtitle D regulation. For example, because EPA is relying on the damage cases to support certain aspects of the technical requirements, EPA has responded to comments relating to the accuracy of the facts involved in the damage cases. EPA has not, however, responded to many comments on state programs because the Agency has made no final conclusions on the adequacy of those programs and is not relying on state programs to support any of the final rule's provisions.

1. Risks Posed by Current Management of CCR and Potential Danger to Human Health From the Disposal of CCR

In the proposed rule, EPA specifically noted that several uncertainties remained in the Agency's quantitative risk analysis of the current management of CCR. Chief among these uncertainties was the evolving character and composition of CCR due to electric utility upgrades and retrofits of multi-pollutant controls needed to comply with the emerging Clean Air Act (CAA) requirements, which could present new or otherwise unforeseen contaminant issues (*e.g.,* addition of calcium bromide to coal prior to combustion increasing mercury capture; use of selective catalytic reduction for post-NO_X controls forming hexavalent chromium). As EPA explained, changes to fly ash and other types of CCR is expected to occur as a result of increased use and application of advanced air pollution control technologies in coal-fired power plants. These technologies include flue gas desulfurization (FGD) systems for SO_2 control, selective catalytic reduction (SCR) systems for NO_X control, and activated carbon injection (ACI) systems for mercury control. These technologies are being installed or are expected to be installed in response to federal regulations, state regulations, legal consent decrees, and voluntary actions taken by industry to adopt more stringent air pollution controls. Use of these more advanced air pollution control technologies reduces air emissions of metals and other pollutants in the flue gas of a coal-fired power plant by capturing and transferring the pollutants to the fly ash and other air pollution control residues. Previous EPA studies of whether increased pollutant content would increase the risks correspondingly were inconclusive. For example, EPA evaluated the environmental fate of metals that are captured in CCR through use of enhanced air pollution controls, by characterizing the leaching behavior of 73 air pollution control residues, using the Leaching Environmental Assessment Framework (LEAF) methodology. Materials were tested over the pH conditions and liquid/solid ratios expected during management via land disposal or beneficial use. Leachate concentrations for most metals were highly variable over a range of coal type, facility configurations, and air pollution control residues. In addition, the data showed significantly different leaching behavior for similar residue types and facility configurations. Overall, the variability in leaching of the metals in the CCR was greater than the variability in totals concentrations by several orders of magnitude, suggesting that total pollutant content may not be predictive of leaching behavior, and consequently the risks.[24]

The Agency received no data from commenters that would aid in resolving this uncertainty. To try to establish some parameters around the uncertainty, EPA attempted to develop estimates of the extent to which this issue could meaningfully affect the risks.

As an initial step, EPA focused on mercury pollution controls, as mercury levels in these wastes was an issue of particular concern in the public comments. It has been established that mercury pollution controls can affect both the mercury content and the general leaching behavior of ash (US EPA 2006, 2008, 2009). Using the limited data available, EPA attempted to evaluate the extent to which mercury controlled wastes could ultimately affect the overall risk associated with disposal of CCR.

EPA conducted a sensitivity analysis that filtered the full 2014 risk assessment results for the subset of fly ash samples generated by facilities that have currently installed ACI systems. The samples were collected from five different facilities that were either installing or evaluating an ACI system for increasing mercury capture. At each facility, samples were collected both before and after the installation of an ACI system. Ultimately the results were inconclusive, likely because of the small sample size, and EPA can draw no conclusions about the exact effects of ACI systems on the risks from CCR disposal. Nevertheless, the analysis provided some useful information. Capturing and transferring pollutants from air emission to the fly ash and other air pollution control residues would normally be expected to increase the risks associated with disposal of these wastes. EPA's analyses, however, showed only a marginal difference in risks for ash generated with or without the use of an ACI system, and in some instances the risks decreased slightly with the addition of activated carbon. The significance of these results should not be overstated—the observed decreases were not consistent and were thought to be an artifact of the relatively small number of model iterations. It is also important to remember that these results provide no information about the potential effects from the installation of

[24] Thorneloe, S, Kosson, D., Sanchez, F., Garrabrants, A.C., and Helms, G., Evaluating the Fate of Metals in Air Pollution Control Residues from Coal-Fired Power Plants, Environ. Sci. Technol. 2010, 44, 7351–7356.

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FGD systems for SO_2 control, or SCR systems for NO_X control, any of which could also significantly affect the characteristics of the wastes. But these results also suggest that EPA should be cautious about assuming that the risks will necessarily increase as a result of the imposition of additional air pollution controls.

Other uncertainties in the risk assessment developed for the proposal related to the extent to which some sampled data with high concentrations of constituents used in the risk assessment accurately reflect coal ash leaching from landfills or surface impoundments. For example, as explained in the proposed rule, some data reflected pore water taken in the upper section of a surface impoundment where coal refuse was placed. There were acid generating conditions and high concentrations of arsenic, but the data demonstrated that the underlying coal ash neutralized the acid conditions and greatly reduced the arsenic which leached from the bottom of the impoundment. EPA also noted that much of the pore water samples and leachate data were several years old, and questions had been raised whether these data accurately reflected current management practices. Finally, EPA noted that recent research indicated that traditional leach procedures (*e.g.,* Toxicity Characteristic Leaching Procedure (TCLP) and Synthetic Precipitation Leaching Procedure (SPLP)) may underestimate the actual leach rates of toxic constituents from CCR under different field conditions.

First, regarding the question of appropriate pH conditions in CCR units, and the resulting leachate concentrations in impoundments where coal refuse was placed, EPA obtained data during the development of this rule directly relevant to this issue. A survey conducted by the Electric Power Research Institute (EPRI) in 1995 had shown that 34 percent of unlined landfills and 68 percent of unlined surface impoundments actively managed CCR with coal refuse. However, more recent data collected by EPA as part of the Clean Water Act ELG rulemaking in 2009–2010 indicates that this management practice has declined significantly to approximately five percent of current units.

EPA also obtained sufficient data to resolve concerns about the accuracy of the concentrations in pore water and leachate used in the risk assessment. EPA received a substantial amount of data on CCR chemical constituents from commenters, which included total concentrations, pore water, and leaching test results for various types of CCR, *i.e.,* bottom ash, FGD gypsum, FGD sludge, fly ash cenospheres, boiler slag, and combined waste streams. This included data from several EPRI reports, which provided field leachate results for bottom ash, fly ash, and FGD solids from a number of landfills and surface impoundments. EPA also received leachate data from the Alaska Department of Environmental Conservation, the Michigan Department of Natural Resources and Environment (MI DNRE), and from the Maryland Department of the Environment on total metals, TCLP, and SPLP results for bottom ash and fly ash. Included among these data were TCLP results for 102 CCR samples and 12 FGD gypsum samples, and two landfill leachate samples, as well as several laboratory reports on CCR leachate from 2008 through 2010. EPA also received several reports from the University of North Dakota Energy & Environmental Research Center, with leaching test results for 58 fly ash, five FGD, and four FGD gypsum samples using various leaching methods other than TCLP, and TCLP mercury results for 15 fly ash samples, as well as leaching test results for five fly ash and two bottom ash samples using 18-hr, 30-day, and 60-day leach methods, plus bulk and trace element data for five fly ash samples, two bottom ash samples, and one slag sample. (See 76 FR 63252, October 12, 2011.)

In addition to the data submitted by commenters, EPA's Office of Research and Development (ORD), in collaboration with Vanderbilt University (VU), developed additional CCR leaching data using a revised methodology, the Leaching Environmental Assessment Framework, or LEAF, consisting of four methods that evaluate leaching potential for various waste forms at different plausible pH values and liquid-solid ratios, in order to more accurately simulate leaching potential over a variety of field conditions. The LEAF methods went through validation working with 20 different laboratories, different waste matrices, and documented in two EPA reports finding good agreement between the labs for the four methods.[25] In addition, EPA compiled decades of data for ten different case studies to compare field and laboratory leach data.[26] These data also showed LEAF methods to be a good predictor of field leachate behavior using geochemical speciation modeling for factors such as oxidation that are difficult to account for in the lab. When considered along with the methods validation, the field-to-lab leachate data comparison provides additional confidence that LEAF methods can more accurately predict environmental release over a range of materials, waste form, pH, liquid-solid ratio, and other parameters influencing leaching behavior such as calcium depletion for a material.

In updating the risk assessment for the final rule, EPA relied on surface impoundment pore water data and impoundment wastewater data, including the data submitted by commenters. For landfills, EPA only used LEAF data to characterize the leachate for the range of materials resulting from various air pollution control technologies. The CCR data documented in three EPA reports[27] and summarized in Thorneloe et al, 2010[28]

[25] Garrabrants A.C., D.S. Kosson, H.A. van der Sloot, F. Sanchez and O. Hjelmar (2010) Background information for the Leaching Environmental Assessment Framework (LEAF) Test Methods, EPA–600/R–10/170, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, December 2010.

Garrabrants A.C., D.S. Kosson, L. Stefanski, R. DeLapp, P.F.A.B. Seignette, H.A. van der Sloot, P. Kariher and M. Baldwin (2012a) Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1313 and Method 1316, EPA/600/R–12/623, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, September 2012.

Garrabrants A.C., D.S. Kosson, R. DeLapp, P. Kariher, P.F.A.B. Seignette, H.A. van der Sloot, L. Stefanski and M. Baldwin (2012b) Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1314 and Method 1315, EPA–600/R–12/624, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, September 2012.

[26] Kosson D.S., van der Sloot, H.A., Seignette, P.F.A.B. 2014. Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (LEAF), EPA–600/R–14/061. EPA Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC, 27711. December.

[27] Sanchez F., R. Keeney, D.S. Kosson and R. DeLapp (2006) Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities using Enhanced Sorbents for Mercury Control, EPA–600/R–06/008, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, February 2006.

Sanchez F., D.S. Kosson, R. Keeney, R. DeLapp, L. Turner and P. Kariher (2008) Characterization of Coal Combustion Residues from Electric Utilities using Wet Scrubbers for Multi-pollutant Control, EPA–600/R–08/077, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, July 2008.

Kosson D.S., F. Sanchez, P. Kariher, L.H. Turner, R. DeLapp, and P. Seignette (2009) Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data, EPA–600/R–09/151, U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division, December 2009.

[28] Thorneloe S.A., D.S. Kosson, F. Sanchez, A.C. Garrabrants and G. Helms (2010) ''Evaluating the fate of metals in air pollution control residues from coal-fired power plants,'' *Environmental Science and Technology,* 44, 7351–7356.

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provides a robust characterization of air pollution control residues from coal-fired power plants and indicates that leaching rates can vary by several orders of magnitude, depending on pH levels and the amount of liquid that comes into contact with the CCR solids (*i.e.,* the liquid to solid ratio).

The 2014 risk assessment incorporates these new data, and accounts for both the pH of the waste in field conditions, as well as the liquid-to-solid ratio of the leachate and CCR, which effectively addresses the concerns raised in the proposed rule that TCLP and SPLP methods could underestimate leachate concentrations.

A further area of uncertainty related to one of the primary inputs into the risk assessment. As noted in the proposed rule, the Agency's risk estimates were based on the existing cancer slope factor of 1.5 $mg/kg/d^{-1}$ for arsenic in EPA's Integrated Risk Information System (IRIS). However, EPA noted that was in the process of revaluating the arsenic cancer slope factor in light of recent recommendations from the National Research Council (NRC) of the National Academy of Sciences (NAS) in ''Critical Aspects Arsenic in Drinking Water, 2001 Update.'' In the proposal, EPA estimated that using this NRC data analysis would increase the individual risk estimates by approximately 17 times.

EPA is currently evaluating the arsenic cancer slope factor in light of more recent NRC recommendations, regarding the approach and the science for estimating cancer and non-cancer risk in ''Critical Aspects of EPA's IRIS Assessment of Inorganic Arsenic, (NRC 2013).'' EPA is in the process of implementing these recommendations, but to date has been unable to finalize its IRIS reassessment. Nor did EPA receive any other information during the development of this final rule that would help to resolve this uncertainty.

A final source of uncertainty in the risk assessment developed for the proposed rule related to the potential impact from the interception of contaminated groundwater plumes by surface water bodies that exist between a waste management unit and a down-gradient drinking water well. It is common for coal-fired utilities to be located near water bodies, which are used as a source of cooling water and waste conveyancing. Releases from surface impoundments located in close proximity to water bodies can be intercepted, which can significantly affect the contaminants that reach drinking water wells. For example, surface impoundments are commonly placed next to rivers, which can intercept the leachate plume and prevent contamination of drinking water wells on the other side of the river. Also, in such circumstances the direction of groundwater flow on both sides of the river may be towards the river; thus, the drinking water well on the opposite side of a river may not be impacted.

Over the course of the rulemaking, EPA was able to obtain sufficient data to model the impact from interception of contamination by surface water bodies. The risk assessment developed for the final rule accounts for the interception of the groundwater contamination plume by surface water bodies, and the resulting decrease in constituent mass to downstream drinking water sources. As a consequence of this modeling, the median risks for surface impoundments and landfills were substantially lower than both the high-end and median risks modeled in the 2010 risk assessment, *i.e.,* by approximately an order of magnitude.

2. Adequacy of Existing State Regulatory Oversight

The assessment of state regulatory programs in the proposed rule was based largely on two reports: A joint U.S. Department of Energy (DOE) and EPA study completed in 2006, ''Coal Combustion Waste Management at Landfills and Surface Impoundments, 1994–2004,'' and a 2009 survey conducted by the Association of State and Territorial Solid Waste Management Officials (ASTSWMO). EPA's preliminary conclusion was that while states seem to be regulating landfills to a greater extent than in 2000, significant gaps in state programs appeared to remain, particularly with respect to the oversight of surface impoundments.

In reaching this conclusion EPA noted the following findings from the DOE/EPA study: only 19 percent (three out of 19) of the surveyed surface impoundment permits included requirements addressing groundwater protection standards (*i.e.,* contaminant concentrations that cannot be exceeded) or closure/post-closure care, and only 12 percent (two out of 12) of surveyed units were required to obtain bonding or financial assurance. The EPA/DOE report also concluded that approximately 30 percent of the net disposable CCR generated was potentially exempt from all state solid waste permitting requirements (EPA/DOE Report at pp 45–46). For example, at the time of the report, Alabama did not regulate CCR disposal under any state waste authority and nor had a dam safety program. Texas (the largest coal ash producer) did not require permits for waste managed on-site, which is defined as waste managed at any site owned by the generator, up to 50 miles away from the generating facility. Finally, the report found that a number of states only regulated surface impoundments under CWA authorities, and consequently primarily addressed the risks from effluent discharges to navigable waters, but did not require liners or groundwater monitoring.

The more recent 2009 ASTSWMO survey reached similar conclusions. With respect to liner requirements, 36 percent of surveyed states did not have minimum liner requirements for CCR landfills, while 67 percent did not have CCR liner requirements for surface impoundments. Similarly, 19 percent of states surveyed did not have minimum groundwater monitoring requirements for landfills and 61percent did not have groundwater monitoring requirements for surface impoundments. The 2009 ASTSWMO survey also indicated that only 36 percent of states regulated the structural stability of surface impoundments.

In the proposal, EPA identified several issues that complicated its preliminary assessment and prevented the Agency from reaching overall conclusions as to the adequacy of state regulatory programs. First, EPA raised concern about the absence of any real details in the two reports regarding how states, in practice, oversee the disposal or other solid waste management of CCR. For example, even though the disposal units might not be regulated under the state solid waste provisions, some states may use performance based standards or implement requirements to control CCR landfills and surface impoundments under other state programs. Second, EPA noted that most of the more recent data primarily focused on the requirements applicable to new management units, which only represented approximately 10 percent of currently operating units. EPA had little, if any, information that described the extent to which states and utilities had implemented requirements, such as groundwater monitoring, on the many existing landfills and surface impoundments that receive CCR. Moreover, the information in the record for the proposal with respect to these older units was fifteen years old. EPA assumed it to be unlikely that states would have required existing units to install liners, but suggested states may have been more likely to have imposed groundwater monitoring for such units over the last 15 years.

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EPA also identified several issues that would be relevant to the Agency's evaluation of the overall adequacy of state regulatory programs. Specifically, EPA explained that it would consider how state regulatory programs have, in practice, evaluated and imposed requirements to address: (1) Leachate collection; (2) groundwater monitoring; (3) whether a unit must be lined and the type of liner needed; (4) the effectiveness of existing management units as opposed to new management units; (5) whether the state requires routine analysis of CCR; (6) whether financial responsibility requirements are in place for the management of CCR; (7) the extent of permit requirements, including under what authorities these disposal units are permitted, the types of controls that are included in permits, and the extent of oversight provided by the states, (8) whether state programs include criteria for siting new units; (9) the extent of requirements for corrective action, post-closure monitoring and maintenance; (10) the state's pattern of active enforcement and public involvement; and (11) whether or not these facilities have insurance against catastrophic failures.

EPA received a substantial amount of information on state programs from commenters. Extensive comments were submitted by a coalition of environmental groups, outlining the alleged gaps in state regulatory programs applicable to the management of CCR. These comments contained a comprehensive analysis of 37 state programs based on the findings of the DOE/EPA 2006 report as well as on an independent compilation of state program requirements. According to these commenters' analysis, only four states (representing approximately four percent of the CCR generated in the U.S. in 2005) required groundwater monitoring in all new and existing landfills, and only six states (representing approximately 19 percent of the CCR generated in 2005) required groundwater monitoring in all new and existing surface impoundments; only five states (representing approximately seven percent of the CCR generated in 2005) required composite liners for all new landfills; and only four states (representing approximately 19 percent of the CCR generated) required composite liners for all new surface impoundments. The commenters' analysis discounted any state law that included any provision that granted permit writers discretion to modify the requirement on a case-by-case basis, and/or to grant waivers and exemptions based on the waste's toxicity, onsite location, and management practice.

EPA also received comments from ASTSWMO, the Environmental Council of the States (ECOS), and 36 individual states. In its comments, ASTSWMO submitted a report with revisions of the aggregated statistics in its 2009 report, which they claim demonstrated that state CCR programs were more robust than described in the proposed rule. These commenters generally agreed with EPA's conclusion that state requirements for key CCR requirements are typically more robust for landfills than for surface impoundments. ASTSWMO's comments included the following examples: 71 percent of the surveyed states required a liner for landfills, compared to 65 percent that required that surface impoundments be lined; 87 percent of surveyed states required groundwater monitoring at landfills, compared to 67 percent of states that required groundwater monitoring at surface impoundments; and while 83 percent of surveyed states required structural stability monitoring at landfills, only 64 percent of surveyed states required it at surface impoundments. The sole exception related to permit requirements, where the report claimed that 91 percent of the surveyed states required a permit of some type for surface impoundments, as compared to 86 percent of states that required a permit for landfills. In addition, ASTSWMO claimed that all 42 surveyed states had the authority to require remediation. The report also alleged that in 43 of 44 states, states had the authority to require surface impoundments to implement repair and maintenance efforts during operation. ASTSWMO also claimed that 43 out of 44 states required that steps be taken to protect human health and the environment, and that 41 of 43 states also had authority to require closure.

According to this revised survey, state requirements also vary with respect to whether they applied to all waste units, or only to new units or lateral expansions. ASTSWMO stated that in 34 percent of the surveyed states, liner requirements applied equally to new and existing landfills, and to both existing and new surface impoundments in 46 percent of the surveyed states. Similarly, ASTSWMO stated that groundwater monitoring was required for both existing and new landfills in 82 percent of the surveyed states, and to both existing and new surface impoundments in 74 percent of the surveyed states.

Nineteen states and state organizations also directly responded to the environmental groups' report by submitting comments on their programs, although only four of these states were among the leading CCR generators: Kentucky, North Dakota, Ohio, and Michigan. These states identified specific instances where the assertions made by the environmental groups were factually incorrect or omitted relevant information. In response to both the proposed rule and the NODA (76 FR 63252, October 12, 2011) most states provided only summaries of their regulatory programs rather than detailed descriptions.

As EPA explained in the proposed rule, there are significant limitations to the kind of aggregated survey statistics presented in ASTSWMO's comments. Such statistics fail to provide the information necessary to meaningfully address the question of how, in practice, state programs regulate the relevant risks presented by the management or disposal of CCR, which was the issue that EPA explained was necessary to resolve. For example, even assuming that 91 percent of the surveyed states actually do require a permit of some type for surface impoundments, this provides no information on the nature or extent of the specific requirements in the permit. As noted in the proposal, most CCR surface impoundments are regulated under a NPDES permit, and while the risks from effluent discharges to navigable waters are addressed, these units are not subject to the provisions designed to protect groundwater, such as liners or groundwater monitoring. Nor does it address the extent of the requirement; for example, although Texas generally requires landfills to be permitted and to monitor groundwater, the majority of CCR units are exempt from these requirements because all industrial wastes managed on-site (*i.e.,* any site owned by the generator, up to 50-miles away from the generator's facility) are exempt. Finally, since the ASTSWMO survey does not identify the individual surveyed states but merely presents aggregated statistics, this information cannot be correlated with the amount of CCR generated, which significantly limits its value; for example, information demonstrating the strength of the regulatory program in a state responsible for two percent of the net CCR generated nationally is less significant than similar information on a state responsible for 25 percent of the net CCR generated.

In addition to the information provided by commenters, EPA independently reviewed state statutes and regulations, with a more detailed focus on the 16 states responsible for approximately 74 percent of the CCR generated in 2009. It is clear from this

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review, as well as from information submitted by the commenters, that the degree of state regulatory oversight of these wastes and the overall protectiveness of the particular state programs varies widely.

Overall, the information from commenters and from EPA's own review of state programs generally confirms EPA's original conclusion that significant gaps remain in many state programs. Some programs provide minimal or no regulatory oversight of CCR units. For example, Arizona, New Mexico, and Utah have no regulations applicable to CCR units or entirely exempt CCR from state regulations governing solid waste. Similarly, Mississippi, Montana, and Texas (the largest coal-ash producer) exempt the on-site disposal of CCR (as ''non-hazardous industrial solid waste'') from some or all key requirements, such as permits or groundwater monitoring.[29] Such exemptions would cover most of the disposal of CCR within the state, as the majority of utilities dispose of their CCR on-site. Other states, such as Florida, Indiana, Ohio and Pennsylvania, exempt CCR landfills or ''monofills'' from many requirements. For example, Indiana regulations consider surface impoundments that are dredged at least annually to be ''storage units'' that are exempt from solid waste regulations, including from corrective action requirements. Many of these states are among the leading generators of CCR wastes. In total, EPA estimates that approximately 20 percent of the net disposable CCR is entirely exempt from state regulatory oversight.

State programs that entirely exempt CCR management from regulatory oversight, however, are the exception. Most states do regulate the management of CCR to varying degrees, although the particular requirements can vary significantly. Still, some general conclusions can be drawn.

Most CCR surface impoundments are permitted exclusively under NPDES or other surface water pollution prevention programs. In these states, requirements to protect groundwater, such as liners or groundwater monitoring systems, are frequently less robust than the corresponding requirements applicable to CCR landfills.

Many state programs require that new disposal units be lined and groundwater monitoring systems installed, although many exempt existing waste units from the liner and groundwater monitoring requirements. Consequently, for newer units, the facts are less alarming: 89 percent of the 114 CCR surface impoundments constructed between 1994 and 2010 have liners, and 70 percent have composite liners. Similarly, 37 of 45 CCR surface impoundments EPA surveyed had installed groundwater monitoring systems. By contrast, 79 percent of the landfills constructed during this timeframe had installed liners, but only 58 percent were composite-lined. However the majority of the older (pre-1994) waste units still lack liners; 63 percent of older landfills have no liners and 63 percent and 24 percent of older surface impoundments have either no liners or clay liners, respectively.

Information on the extent of groundwater monitoring at older units was either unavailable, or was too unreliable to support any conclusions as to the overall number or percentage of older units with groundwater monitoring systems in most states. ASTSWMO's comments in response to the October 2011 NODA identified eight states [30] that required groundwater monitoring at existing facilities, but only a few of these states addressed this issue in their comments. EPA has some anecdotal evidence on the status of groundwater monitoring in six states, including four states that are among the leading CCR generators. In the wake of the Kingston TVA spill, groundwater monitoring wells were installed at 12 of Illinois's existing surface impoundments, almost doubling the number of monitored surface impoundments in the state. However, 55 additional surface impoundments, both active and inactive, still lack groundwater monitoring systems. In Ohio, 44 CCR units, out of a total of 57 CCR units in the state (42 surface impoundments and 15 landfills) still lack groundwater monitoring, even though all of the surface impoundments were permitted decades ago under Ohio's NPDES program. Ohio acknowledged in their comments that the extent of groundwater risks in the state is poorly documented, as 40 out of 44 unlined CCR units do not have a groundwater monitoring system. In sum, the available information is limited, but at least some of that information indicates that significant gaps remain with respect to the implementation of groundwater monitoring requirements under some state regulatory programs.

Of the states that require groundwater monitoring, most appear to require monitoring wells to be placed around the waste unit boundary, although the distance from the unit boundary varies from 50 feet to 150 meters. However, some state programs also authorize a buffer zone or a ''zone of discharge,'' which allows the facility to defer remediation of groundwater contamination for some period of time, usually until the contaminant plume has migrated to the facility site boundary. Florida, Illinois, North Dakota, and Tennessee are among that states with such a regulatory provision. For example, under Florida regulations, primary and secondary maximum contaminant levels (MCLs) do not apply even beyond the ''zone of discharge,'' absent a specific order by state regulatory authorities.

Most state programs allow the state regulatory authority to grant variances or exemptions for some or all of the requirements based on site-specific factors. For example, all of the following states require groundwater monitoring at CCR surface impoundments, but also authorize the regulatory authority to exempt or waive those requirements: Alabama, Florida, Georgia, Illinois, Indiana, Kentucky, North Carolina, North Dakota, Pennsylvania, and West Virginia. Contrary to the analysis presented by the environmental groups' comments, the mere fact that state law grants a permit authority the discretion to tailor requirements to account for a facility's site specific conditions does not support a conclusion that the regulatory program is necessarily inadequate. In fact, EPA noted in the proposal that one of the strengths of the subtitle C program was that, as a result of the permit process, requirements could be tailored to account for site specific conditions. Nor does the existence of a waiver process provide any evidence of actual practices; in their comments, a few states acknowledged that state law allowed for variances, but asserted that none had been requested.

To complicate matters further, several states explained that while state law does not mandate certain requirements, state regulatory authorities have, in practice, begun to require them in more recent permits. For example, several states, including Ohio, Texas, Michigan, Florida, and Kentucky, noted that recent practice was to require older disposal units to retrofit or close where they failed to meet relevant standards. Similarly, it appears that in the 16 leading CCR-generating states, 94 percent of new landfills have installed liners (either composite or clay), although only 19 percent of these state programs actually mandate CCR landfills to install a liner. And although only six percent of these state programs require installation of a liner in a new surface impoundment, 75 percent of

[29] See 30 TX ADC 335.2(d);

[30] Georgia, Illinois, Indiana, Iowa, Montana, Ohio, Pennsylvania, and South Carolina.

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new CCR surface impoundments in these states are lined.

All of this information suggests that, at least in some cases, the concerns raised in the proposal regarding the protectiveness of state programs remain warranted. But it also is clear it would be impossible to accurately evaluate whether, in practice, state programs are protective without reviewing individual permit decisions and permit requirements. Such an evaluation would necessarily involve not only a review of the specific permit requirements, but also the site conditions and other factual bases supporting the decision to impose the particular requirements. Unfortunately, this information was not provided by commenters or found in any source currently available to the Agency.

3. Documented Cases in Which Danger to Human Health or the Environment From Surface Run-off or Leachate Has Been Proved

In the proposed rule, EPA described the information it had compiled on specific cases where CCR mismanagement had caused harm to human health or the environment since the 2000 Regulatory Determination. Specifically, EPA explained that it had identified 27 proven damage cases: 17 cases of damage to groundwater, and ten cases of damage to surface water, seven of which are ecological damage cases. Sixteen of the 17 proven damage cases to groundwater involved disposal in unlined units; for the one additional unit, it is unknown whether the unit was lined. EPA also identified 40 potential damage cases to groundwater and surface water. The Agency noted that these numbers likely underestimated the number of damage cases and its expectation that additional cases of damage would be found if a more comprehensive evaluation was conducted, particularly since much of this waste has been (and continues to be) managed in unlined disposal units. EPA also noted its concern that several of the new damage cases involved activities that differ from prior damage cases, including the catastrophic release of waste due to the structural failure of CCR surface impoundments, such as the dam failures that occurred in Martins Creek, Pennsylvania and Kingston, Tennessee, as well as the large-scale placement, akin to disposal, of CCR, under the guise of ''beneficial use.''

EPA noted as well that it had received new reports from industry and environmental and citizen groups regarding damage cases. Industry provided information to demonstrate that many of EPA's listed proven damage cases did not meet EPA's criteria for a damage case to be considered ''a proven damage case,'' that had been developed for purposes of the Bevill Regulatory Determinations. Environmental and citizen groups, on the other hand, had submitted reports alleging the existence of more recent damage cases beyond those EPA had previously documented.

EPA raised questions concerning the following areas associated with the damage cases; first, whether the damage cases discovered to date accurately reflected the true number of damage cases associated with the mismanagement of CCR. Second, EPA highlighted concern regarding the accuracy of the available information on damage cases, as in certain instances, much of the information was largely anecdotal. EPA therefore specifically solicited comments from state regulatory authorities and the facilities involved with the incidents, in the hope of obtaining direct evidence of the facts in each case and to obtain a better understanding of the nature of the damage caused by past and current management practices. For the same reason, on October 12, 2011, EPA published a NODA, soliciting comment on the extensive reports received during the original comment period on the proposed rule. (See 76 FR 63252.)

As discussed in more detail in Unit XI of this document, EPA received a significant number of comments on this topic, both during the original comment period on the proposal, and in response to the NODA. EPA received information on additional damage cases from a number of citizen groups, including the report from Environmental Integrity Project and Earthjustice titled, ''Out of Control: Mounting Damages From Coal Ash Waste Sites,'' which presented information on 31 alleged CCR damage cases that were not included or were not recognized as damage cases in EPA's July 2007 report. EPA also received an August 26, 2010 report by the Environmental Integrity Project, Earthjustice, and the Sierra Club titled ''In Harm's Way: Lack of Federal Coal Ash Regulations Endangers Americans and Their Environment,'' which presented an additional 39 alleged CCR damage cases.[31] EPA also received information on ten additional damage cases from state officials in Michigan and Wisconsin.

[31] EPA also received several additional reports that contained allegations of further damage cases. However, because these were submitted after the close of the comment period, EPA did not evaluate these damage cases for this rulemaking or otherwise consider the information in those reports.

EPRI submitted two draft reports titled ''Evaluation of Coal Combustion Product Damage Cases: Volume 1: Data Summary and Conclusions'' (finalized in July 2010), and ''Evaluation of Coal Combustion Product Damage Cases: Volume 2: Case Summaries'' (finalized in September 2010). In these reports, EPRI provided information that, they claimed, showed that many of EPA's previously identified ''proven'' damage cases did not meet EPA's criteria for a damage case to be considered ''proven.'' In response to the 2010 NODA, USWAG submitted a report that reviewed the 70 additional damage cases submitted by citizen groups as part of their comments on the proposed rule. These reports focused primarily on the degree to which the contamination had been contained ''on-site'' or had migrated off-site of the facility.

In Unit XI of this document, EPA discusses at length all of the comments received and its subsequent analysis of the information obtained throughout the rulemaking. In sum, after analyzing all of the information submitted in response to this rulemaking, EPA has confirmed a total of 157 cases, both proven and potential, in which CCR mismanagement has caused damage to human health and the environment. Although EPA expects that additional damage cases will be discovered in response to the installation of the groundwater monitoring systems required by the final rule, overall EPA has a significantly better understanding of the extent and nature of the damage caused by CCR mismanagement than when the proposed rule was issued. EPA has sufficient confidence in the veracity of the information collected to rely on it in making decisions in this rule.

4. Conclusions

EPA explained in the proposed rule that the decision on whether to retain the Bevill exemption is inherently discretionary, in that it ultimately requires the Agency to make a policy judgment as to the appropriate balance among the eight statutory factors. Chief among the several principles that EPA stated would guide its decision was that any action must protect human health and the environment. To this end, EPA singled out three key areas of analyses that bear directly on that guiding principle: the extent of the risks posed by mismanagement of CCR; the adequacy of state programs to ensure proper management of CCR; and the extent and nature of damage cases.

The first of these largely related to the 2010 quantitative risk assessment of the potential for contamination to

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groundwater. During the rulemaking, EPA received information that allowed the Agency to resolve two of the four primary uncertainties identified in the proposal. The risk assessment has been revised with updated pore water concentration data and with LEAF leachate data, and accounts for the potential reduction of contaminants reaching drinking water sources due to interception of contamination by surface water bodies. However, two sources of uncertainty remain: the potential effect of pollution control technologies on the CCR characteristics, and the appropriate IRIS value for arsenic.

EPA's risk assessment evaluated current management practices, and generally did not attempt to account for or evaluate the potential for future changes in the wastes. While EPA has great confidence in the assessment, its ability to definitively resolve this question is therefore limited, given the very real potential for significant changes in CCR characteristics and constituents in the near future, due to the required installation of pollution control technologies. Changes in the CCR characteristics are particularly significant, as the risk assessment concluded that one of the parameters most likely to affect the agency's risk estimates was the characteristic of the wastes.

With respect to the second area, EPA is unable to reach any definitive conclusions as to whether state regulatory programs are so deficient that the level of federal oversight under subtitle C is necessary. Specifically, EPA cannot determine from the available information how states, in practice, have implemented regulatory requirements. At this point, only limited conclusions are possible.

Clear deficiencies exist in some state regulatory programs, and questions remain with respect to others. And many of these concerns exist with respect to programs in states responsible for the majority of CCR generation and disposal. However, most state programs, although they vary considerably, are not clearly deficient on their face. But it is equally clear that exclusive reliance on the regulatory programs as written, without any examination of how states have implemented those requirements in practice, would not support sweeping conclusions about the overall adequacy of state programs. It is critical to ensure that any decision accurately accounts for how the states have exercised their judgment in implementing those requirements, before concluding that state programs cannot adequately oversee the management of CCR without the degree of federal involvement mandated by subtitle C. Notwithstanding EPA's inability to draw conclusions on the overall adequacy of state programs, the high degree of variation across state programs strongly supports the need for federal requirements to establish a consistent national standard of groundwater and human health protection.

In contrast to the other two areas identified in the proposed rule, while some uncertainty remains with respect to the damage cases—namely, whether the 157 identified to date represent the total number of damage cases caused by CCR mismanagement, and whether some of the ''potential'' damage cases should be classified as ''proven'' damage cases—at this point, EPA has concluded that the available information provides a sufficient evidentiary base on which decisions can be made. In the absence of the necessary information on two of the three critical areas, however, EPA cannot reach any final conclusions regarding the appropriate balance among the eight statutory factors. Consequently, EPA is also not reaching any final conclusions as to whether a damage case is best categorized as ''proven'' or ''potential.'' Such a finding is relevant only to the Bevill Regulatory Determination.

However, as discussed in more detail in Unit XI of this document, the damage cases provide extremely valuable evidence that is directly relevant to the question of whether and how to regulate CCR waste. For example, the damage cases provide ''real world'' evidence against which to compare EPA's risk modeling estimates, such as evidence regarding the frequency with which particular constituents leach into groundwater. They also provide direct evidence regarding specific waste management practices at electric utilities, along with the potential consequences of those practices. Finally, both the specifics of the damage cases and the fact that they continue to occur provide strong evidence of the need for this rule under subtitle D while EPA obtains the information that will allow the Agency to make a final Regulatory Determination for these wastes.

Thus, even though EPA is not able to reach a final conclusion on the Regulatory Determination for these wastes, the totality of the information in the rulemaking record clearly demonstrates that the risks associated with the current management and disposal of CCR remain substantial. EPA's risk assessment concluded that the cancer risks from unlined surface impoundments ranged from 3×10^{-4} for trivalent arsenic to 4×10^{-5} for pentavalent arsenic. Non-cancer risks from these same units also significantly exceeded EPA's level of concern, with estimates ranging from an HQ of 2 for thallium, to HQs[32] of 4 for molybdenum and 8 for trivalent arsenic. The risks associated with unlined landfills were also estimated to be significant, with cancer risks of 2×10^{-5} for trivalent arsenic. It is important to note that these risk numbers are based on national disposal practices. Risks at an individual site may be even higher based on individual site conditions, waste characteristics, and management practices. EPA's risk assessment identified the potential for higher risks based on different waste pH values and management practices. Multiple constituents presented higher risks when considered in waste management units that co-dispose both ash and coal refuse at more acidic pHs or FGD wastes at more basic pHs. For example, the modeled cancer risks for the co-disposal of ash and coal refuse (pH 1.7–8.2) ranged between 10^{-3} for trivalent arsenic to 4×10^{-4} for pentavalent arsenic. Non-cancer risks were similarly high, ranging between and an HQ of 13 for cobalt, and HQs of 14 for pentavalent arsenic to 26 for trivalent arsenic, based on the ingestion of contaminated drinking water. Although this management practice is declining, recent information indicates that approximately five percent of facilities continue to co-dispose of ash and coal refuse in surface impoundments.

Moreover, EPA's risk estimates are consistent with the continued damage cases compiled through this rulemaking. As further discussed in Unit XI of this document, EPA has confirmed that 157 cases of proven or potential contamination of groundwater have occurred in states across the nation since the initial Regulatory Determination. These damage cases were primarily associated with unlined units and were most frequently associated with releases of arsenic. While new units are typically constructed with composite liners, which under EPA's current risk assessment adequately mitigate the risks, older units still comprise the overwhelming majority of currently operating units. EPA's data show that approximately 63 percent of currently operating surface impoundments and landfills are unlined, and thus more prone to leach contaminants into groundwater. Analysis of the information from the damage cases also demonstrates that unlined surface

[32] For more information on HQs please see Unit X. Risk Assessment of this preamble.

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impoundments typically operate for 20 years before they begin to leak. Most of the currently operating surface impoundments are between 20 and 40 years old.

The age of the units also has implications for their structural stability and the potential for catastrophic releases. Of the approximately 735 CCR surface impoundments currently operating in the United States, a certain percentage have a great potential for loss of human life and environmental damage in the event of catastrophic failure. Based on the information collected from EPA's Assessment Program, 318 surface impoundments have either a high or significant hazard potential rating, at least 13 of which were not designed by a professional engineer. Of the total universe of surface impoundments, approximately 186 of these units were not designed by a professional engineer. Surface impoundments are generally designed to last the typical operating life of coal-fired boilers, on the order of 40 years. However, many impoundments are aging; based on the subset of units for which age data were available, approximately 195 active surface impoundments exceed 40 years of age; 56 units are older than 50 years, and 340 are between 26 and 40 years old. In recent years, problems have continued to arise from these units, which appear to be related to the aging infrastructure, and the fact that many units may be nearing the end of their useful lives. For example, as a result of the administrative consent order issued after the December 2008 spill, TVA conducted testing which showed that another dike at TVA's Kingston, Tennessee plant had significant safety deficiencies. Collectively, these facts indicate a high likelihood that in the absence of any regulatory action, such units will leak in the near future, or are currently leaking, undetected, since groundwater monitoring is not installed at many of these older units. Moreover, damage cases continue to occur; in response to EPA's CERCLA 104(e) information request letter, a total of 35 units at 25 facilities reported historical releases. These range from minor spills to a spill of 0.5 million cubic yards of water and fly ash. And as recently as February 2014, CCR slurry was released into the Dan River from an inactive surface impoundment in North Carolina.

All of which demonstrates a compelling need for a uniform system of requirements to address these risks without waiting for the information and analyses necessary to complete a final Regulatory Determination. EPA will continue to monitor these critical areas, and will provide the public with an additional opportunity to comment on any proposed Regulatory Determination, prior to issuing a final Regulatory Determination.

B. Final Regulatory Determination Regarding Beneficial Use

EPA generally proposed to retain the May 2000 Regulatory Determination that beneficially used CCR did not warrant federal regulation under subtitle C of RCRA. As EPA stated in the May 2000 Regulatory Determination, ''In the [Report to Congress], we were not able to identify damage cases associated with these types of beneficial uses, nor do we now believe that these uses of coal combustion wastes present a significant risk to human health and the environment. While some commenters disagreed with our findings, no data or other support for the commenters' position was provided, nor was any information provided to show risk or damage associated with agricultural use. Therefore, we conclude that none of the beneficial uses of coal combustion wastes listed above pose risks of concern.'' (See 65 FR 32230.) EPA noted that since the original Regulatory Determination, the Agency had found no data or other information to indicate that existing efforts of states, EPA, and other federal agencies had been inadequate to address the environmental issues associated with the beneficial use of CCR that were originally identified in the Regulatory Determination. EPA explained that it had proposed this approach in recognition that some uses of CCR, such as encapsulated uses in concrete, and use as an ingredient in the manufacture of wallboard, provide benefits and raise minimal health or environmental concerns. Consequently, EPA preliminarily concluded that encapsulated uses of CCR, which are common in many consumer products, did not merit regulation based on the available information.

However, EPA noted that the issues were more difficult with respect to unencapsulated uses of CCR and specifically solicited comment on whether such uses should continue to be included as ''beneficial use'' under the Bevill exemption. EPA explained that unencapsulated uses have raised concerns and therefore merited closer attention. For example, the placement of unencapsulated CCR on the land, such as in road embankments or in agricultural uses, presented a set of issues similar to those that caused the Agency to propose to regulate CCR destined for disposal. But the Agency also acknowledged that the amounts and, in some cases, the manner in which CCR is used—*i.e.,* subject to engineering specifications and material requirements rather than landfilling techniques—are potentially very different from land disposal.

EPA is retaining the original 2000 Regulatory Determination for CCR that is beneficially used. EPA has made this determination based on consideration of the available information and the RCRA section 8002(n) study factors.

1. Source and Volume of CCR Generated Each Year

The American Coal Ash Association (ACAA) conducts a voluntary, annual survey of the coal-fired electric utility industry to track the quantities of CCR generated and beneficially used. According to the latest survey, the electric utility industry generated nearly 110 million tons of CCR in 2012. Approximately 39 million tons of these CCR was identified by ACAA as beneficially used in either encapsulated or unencapsulated products. An additional 12.8 million tons were placed in mine-fill operations, while the remaining 57.8 million tons were disposed of in landfills and surface impoundments (ACAA, 2013).[33]

2. Present Utilization Practices

Based on the beneficial use rates reported by ACAA, approximately 50 percent of the CCR beneficially used on an annual basis falls into two categories: (1) Fly ash used as a direct substitute for Portland cement during the production of concrete (referred to as ''fly ash concrete''); and (2) FGD gypsum used as a replacement for mined gypsum in wallboard (referred to as ''FGD gypsum wallboard''). Specifically, the 2012 ACAA survey indicates that the largest encapsulated beneficial uses of CCR, by more than a factor of two, are fly ash used in ''concrete/concrete products/grout'' (12.6 million tons) and FGD gypsum used in ''gypsum panel products'' (7.6 million tons).

3. Potential Danger, if Any, to Human Health or the Environment From the Reuse of CCR

The risks associated with the disposal of CCR stems from the specific nature of that activity; that is, the disposal of CCR in (often unlined) landfills or surface impoundments, with thousands, if not millions, of tons placed in a single

[33] ACAA (American Coal Ash Association). 2013. 2012 Coal Combustion Product (CCP) Production & Use Survey Report. Farmington Hills, MI 48331. Available online at: *http://www.acaa-usa.org/Portals/9/Files/PDFs/revisedFINAL2012CCPSurveyReport.pdf*

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concentrated location. And in the case of surface impoundments, the CCR is managed with water, under a hydraulic head, which promotes rapid leaching of contaminants into neighboring groundwater. The beneficial uses identified as excluded under the Bevill exemption for the most part present a significantly different risk profile.

a. Encapsulated Beneficial Uses

An encapsulated beneficial use is one that binds the CCR into a solid matrix that minimizes mobilization into the surrounding environment. Examples of encapsulated uses include, but are not limited to: (1) Filler or lightweight aggregate in concrete; (2) a replacement for, or raw material used in production of, cementitious components in concrete or bricks; (3) filler in plastics, rubber, and similar products; and (4) raw material in wallboard production.

Since publication of the proposal, EPA has developed a methodology for evaluating encapsulated beneficial uses. A copy of the methodology can be found at *http://www2.epa.gov/coalash/methodology-evaluating-encapsulated-beneficial-uses-coal-combustion-residuals*. EPA applied this methodology to the two largest CCR uses—the use of fly ash as a replacement for Portland cement in concrete, and the use of FGD gypsum as a replacement for mined gypsum in wallboard. A complete copy of the evaluation can be found at *http://www.epa.gov/wastes/conserve/imr/ccps/pdfs/ccr_bu_eval.pdf*.

The evaluation considered products that meet relevant physical and performance standards, that conform to standard design specifications, and that incorporate fly ash and FGD gypsum from pollution control devices currently used in the United States. Based on the findings of the evaluation, the Agency concluded that environmental releases of constituents of potential concern from CCR fly ash concrete and FGD gypsum wallboard during use by the consumer are comparable to or lower than those from analogous non-CCR products, or are at or below relevant regulatory and health-based benchmarks for human and ecological receptors.

b. Unencapsulated Uses

EPA acknowledged in the proposal that unencapsulated uses generally presented more difficult issues than encapsulated uses. CCR can leach toxic metals at levels of concern, so depending on the characteristics of the CCR, the amount of material placed, how it is placed, and the site conditions, there is a potential for environmental concern. However, EPA cannot extrapolate from the risk assessments conducted to evaluate the management practices associated with CCR landfills and CCR surface impoundments, because the exposure patterns are too dissimilar: The amounts and manner involved with beneficial use are very different than the thousands, if not millions of tons of CCR that are mounded in a single concentrated location in a landfill. And the potential exposures are entirely unlike surface impoundments, where CCR is managed with water under a hydraulic head, which promotes more rapid leaching of contaminants. By contrast ''beneficial uses,'' even unencapsulated uses, are typically subject to engineering specifications, and for certain uses, federal oversight, and material requirements. For example, fly ash used as a stabilized base course in highway construction is subject to both regulatory standards under the U.S. Department of Transportation (DOT) and the Federal Highway Administration (FHWA), and engineering specifications, such as the ASTM C 593 test for compaction, the ASTM D 560 freezing and thawing test, and a seven day compressive strength above 2760 kPa (400 psi). (See 75 FR 35163–35165 for additional examples.)

In 1999, EPA conducted a risk assessment of certain agricultural uses of CCR, since this practice was considered the most likely to raise human health or environmental concerns.[34] EPA estimated the risks associated with such uses to be within the range of 1×10^{-6}. These results as well as EPA's conclusion that the use of CCR in agricultural settings was the most likely use to raise concerns, caused EPA to conclude that none of the beneficial uses identified in the 2000 Regulatory Determination warranted federal regulation, because ''we were not able to identify damage cases associated with these types of beneficial uses, nor do we now believe that these uses of coal combustion wastes present a significant risk to human health or the environment.'' (65 FR 32230, May 22, 2000.)

EPA also noted that beneficially using secondary materials conserves natural resources, and can serve as an important alternative to disposal.

[34] For more information on this risk assessment see EPA's Notice of Regulatory Determination on Wastes from the Combustion of Fossil Fuels (65 FR 32214, May 22, 2000).

4. Documented Cases in Which Damage to Human Health or the Environment From Surface Run-off or Leachate Has Been Proved

To date, EPA has seen no evidence of damages from the encapsulated beneficial uses of CCR that EPA identified in the proposal. For example, there is wide acceptance of the use of CCR in encapsulated uses, such as wallboard, concrete, and bricks because the CCR is bound into products. However, as of the date of the proposed rule, seven proven damage cases associated with unencapsulated uses have occurred, in which large quantities of unencapsulated CCR were used indiscriminately to re-grade the landscape or to fill old quarries or gravel pits. The proposed rule discussed two of these cases. (See 75 FR 35147.) The first case was in Gambrills, Maryland and involved the disposal of fly ash and bottom ash (beginning in 1995) in two sand and gravel quarries. EPA considers this site a proven damage case, because groundwater samples from residential drinking wells near the site include heavy metals and sulfates at or above groundwater quality standards, and the state of Maryland is overseeing remediation. The second case is the Battlefield Golf Course in Chesapeake, Virginia where 1.5 million yards of fly ash were used as fill and to contour a golf course. Groundwater contamination above MCLs has been found at the edges and corners of the golf course, but not in residential wells. An EPA study in April 2010, established that residential wells near the site were not impacted by the fly ash and, therefore, EPA does not consider this site to be a proven damage case. However, due to the onsite groundwater contamination, EPA considers this site to be a potential damage case.

During the development of this final rule, EPA obtained information on a comparable situation in which large quantities of unencapsulated CCR were placed on the land in a manner that presented significant concerns. The AES coal-fired power plant in Puerto Rico lacked capacity to dispose of their CCR on-site, and off-site landfills in Puerto Rico were prohibited from accepting CCR. In lieu of transporting their CCR off of the island for disposal, AES created an aggregate (''AGREMAX'') with the CCR generated at their facility, and used the aggregate as fill in housing developments and in road projects. Over two million tons of this material was used between 2004 and 2012.

Currently, there is insufficient information to determine whether groundwater has been contaminated as

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a result of this practice, and thus, EPA cannot classify this as either a proven or potential ''damage case.'' Nevertheless, the available facts illustrate several of the significant concerns associated with unencapsulated uses. Specifically, the AGREMAX was applied without appropriate engineering controls and in volumes that far exceeded the amounts necessary for the engineering use of the materials. Inspections of some of the sites where the material had been placed showed use in residential areas, and to environmentally vulnerable areas, including areas close to wetlands and surface waters and over shallow, sole-source drinking water aquifers. In addition, some sites appeared to have been abandoned.

Consistent with the proposed rule, EPA does not consider the practices described in this section to be beneficial use, but rather waste management that would be subject to the requirements of the final rule.

5. Alternatives to Current Disposal Methods, the Costs of Such Alternatives, and the Impact of Such Alternatives on the Use of Coal and Other Natural Resources

The beneficial use of CCR is a primary alternative to current disposal methods. And as EPA has repeatedly concluded, it is a method that, when performed correctly, can offer significant environmental benefits, including greenhouse gas (GHG) reduction, energy conservation, reduction in land disposal (along with the corresponding avoidance of potential CCR disposal impacts), and reduction in the need to mine and process virgin materials and the associated environmental impacts.

a. Greenhouse Gas and Energy Benefits

The beneficial use of CCR reduces energy consumption and GHG emissions in a number of ways. Three of the most widely recognized beneficial applications of CCR are the use of coal fly ash as a substitute for Portland cement in the manufacture of concrete, the use of FGD gypsum as a substitute for mined gypsum in the manufacture of wallboard, and the use of CCR as a substitute for sand, gravel, and other materials in structural fill. Reducing the amount of cement, mined gypsum, and virgin fill produced by substituting CCR leads to large supply chain-wide reductions in energy use and GHG emissions. Specifically, the RIA estimates three-year rolling average of 53,054,246 million British thermal units (MMBtu) per year in energy savings and 11,571,116 tons per year in GHG (*i.e.,* carbon dioxide and methane) emissions reductions in 2015. This estimate is likely to underestimate the total benefits that can be achieved from all beneficial uses. Furthermore, the use of fly ash generally makes concrete stronger and more durable. This results in a longer lasting material, thereby marginally reducing the need for future cement manufacturing and corresponding avoided emissions and energy use.

b. Benefits From Reducing the Need To Mine and Process Virgin Materials

CCR can be substituted for many virgin materials that would otherwise have to be mined and processed for use. These virgin materials include limestone to make cement, and Portland cement to make concrete; mined gypsum to make wallboard, and aggregate, such as stone and gravel for uses in concrete and road bed. Using virgin materials for these applications requires mining and processing, which can impair wildlife habitats and disturb otherwise undeveloped land. It is beneficial to use secondary materials—provided it is done in an environmentally sound manner—that would otherwise be disposed of, rather than to mine and process virgin materials, while simultaneously reducing waste and environmental footprints. Reducing mining, processing and transport of virgin materials also conserves energy, avoids GHG emissions, and reduces impacts on communities.

c. Benefits From Reducing the Disposal of CCR

Beneficially using CCR instead of disposing of it in landfills and surface impoundments also reduces the need for additional landfill space and any risks associated with their disposal. In particular, the United States disposed of over 57.8 million tons of CCR in landfills and surface impoundments in 2012, which is equivalent to the space required of 20,222 quarter-acre home sites under eight feet of CCR.

As discussed in the final rule RIA, the current beneficial use of CCR as a replacement for industrial raw materials (*e.g.,* Portland cement, virgin stone aggregate, lime, gypsum) provides substantial annual life cycle environmental benefits for these industrial applications. Specifically, the three-year rolling average of environmental benefits estimated for 2015 includes: (1) 53,054,246 MMBtu per year in energy savings; (2) 1,661,900 million gallons per year in water savings; (3) 11,571,116 tons per year in GHG (*i.e.,* carbon dioxide and methane) emissions reductions; (4) 45,770 tons of criteria air pollutant (*i.e.,* NO_X, SO_X, particulate matter, and CO) emissions reductions; and (5) 3,207 pounds of toxic air pollutant (*i.e.,* mercury and lead) emissions reductions. All together, the beneficial use of CCR in 2015 is estimated to provide over $2.3 billion in annual national environmental benefits. In addition, since EPA estimates annual baseline disposal costs of approximately $2.4 billion for the just over 50 percent of tons disposed each year, current beneficial use and minefilling also result in annual material and disposal cost savings of approximately $2 billion annually.

6. Current and Potential Utilization of CCR

In 2012, nearly 36 percent (39 million tons) of CCR were beneficially used (excluding minefill operations) and nearly 12 percent (12.8 million tons) were placed in minefills. (This compares to 23 percent of CCR that were beneficially used, excluding minefilling, at the time of the May 2000 Regulatory Determination, and represents a significant increase.)

7. Conclusions

On balance, after considering all of the available information, EPA has concluded that the most appropriate approach toward beneficial use is to retain the May 2000 Regulatory Determination that regulation under subtitle C of the beneficial use of CCR is not warranted. EPA has also determined that regulation under subtitle D is generally not necessary for these beneficial uses.

As discussed in the preceding section, the most important of the section 8002(n) factors are those relating to the potential risks to human health and the environment. See *e.g., Horsehead Resource Development Co.* v. *EPA*, 16 F.3d 1246, 1258 (D.C. Cir, 1994) (Upholding EPA's interpretation that wastes resulting from the combustion of mixtures of Bevill-exempt and non-exempt wastes could only retain Bevill-exempt status so long as the combustion waste remained of low toxicity); *EDF* v. *EPA*, 852 F.2d 1316, 1328–1329 (D.C. Cir. 1988) (Overturning EPA rule that included as Bevill exempt, wastes that were not of low toxicity). EPA is adopting this Regulatory Determination in recognition that many uses of CCR, such as encapsulated uses in concrete, and use as an ingredient in the manufacture of wallboard, provide environmental benefits and raise minimal health or environmental concerns. To date, the information available does not demonstrate the existence of any risks associated with encapsulated uses of CCR that merit

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regulation under either subtitle C or subtitle D of RCRA.

While there can be some risks associated with unencapsulated uses—for example, the placement of unencapsulated CCR on the land, such as in large scale fill operations or in agricultural uses, depending on the specific site conditions—in general the amounts and, in some cases, the manner in which they are used are very different than land disposal. For example, agricultural uses involve the placement of inches rather than tons of CCR, and placement of CCR in a thin layer rather than mounded in a single concentrated location. In addition, these uses are subject to engineering specifications and materials requirements, which will limit the ultimate amount of material placed on the land.

EPA recognizes that several proven damage cases involving the large-scale placement, akin to disposal, of CCR have occurred under the guise of ''beneficial use''— the ''beneficial'' use being the filling up of old quarries or gravel pits, or the re-grading of landscape with large quantities of CCR. EPA did not consider this type of use as a ''beneficial'' use in its May 2000 Regulatory Determination, and still does not consider this type of use to be covered by the exclusion. Therefore, the final rule explicitly removes these types of uses from the category of beneficial use, and from this Regulatory Determination. As discussed in the next section of this preamble, EPA has adopted criteria in the final rule to ensure that inappropriate uses that effectively are disposal will be regulated as disposal. The final rule expressly defines the placement of CCR in sand and gravel pits or quarries as disposal in a landfill. In addition, the final rule provides that the use of large volumes of CCR in restructuring landscape that does not meet specific criteria will constitute disposal.

While EPA has not definitively concluded that all unencapsulated beneficial uses are ''safe,'' based on the current record for this rulemaking, EPA is unable to point to evidence demonstrating that the unencapsulated uses subject to this Determination warrant federal regulation. While the absence of demonstrated harm in this instance is not proof of safety, neither is the lack of information proof of risk.[35]

In this regard, EPA notes that many states have developed beneficial use programs that allow the use of CCR, provided they are demonstrated to be non-hazardous materials; and many require a site specific assessment before authorizing placement on the land of large amounts of unencapsulated CCR. For example, Wisconsin's Department of Natural Resources has developed a regulation (NR 538 Wis. Adm. Code), which includes a five-category system to allow for the beneficial use of industrial by-products, including coal ash, provided they meet the specified criteria. In addition, the ASTSWMO 2006 Beneficial Use Survey Report states that a total of 34 of the 40 reporting states, or 85 percent, indicated they had either formal or informal decision-making processes or beneficial use programs relating to the use of solid wastes. (*http://www.astswmo.org/Files/Policies_and_Publications/Solid_Waste/2007BUSurveyReport11-30-07.pdf*) [36] Because EPA has not identified significant risks associated with the beneficial uses covered by this Regulatory Determination, the adequacy of these state programs does not factor into EPA's Determination. Nevertheless, to the extent that that these materials do have the potential to pose risk at an individual site, the fact that many states exercise regulatory oversight of these materials provides an additional level of assurance.

Finally, EPA does not wish to inhibit or eliminate the measurable environmental and economic benefits derived from the use of this valuable material given the current lack of evidence affirmatively demonstrating an environmental or health risk. Consequently, EPA is confident that the combination of the final rule, EPA guidance, current industrial standards and practices, and in many cases, state regulatory oversight is sufficient to address concerns associated with the beneficial uses to which this Determination applies.

V. Development of the Final Rule—RCRA Subtitle D Regulatory Approach

As previously discussed in Unit II of this document, the authority to develop and promulgate the national minimum criteria governing the disposal of CCR in landfills and surface impoundments is found under the provisions of sections 1008(a), 4004, and 4005(a) of RCRA (*i.e.*, subtitle D of RCRA). These authorities, however, do not provide EPA with the ability to issue permits, require states to issue permits, approve state programs to operate in lieu of the federal program, or to enforce any of the requirements addressing the disposal of CCR. Consequently, EPA designed the proposed RCRA subtitle D option to ensure that the requirements will effectively protect human health and the environment within those limitations. The final rule establishes self-implementing requirements—primarily performance standards—that owners or operators of regulated units can implement without any interaction with regulatory officials.

In developing the subtitle D option for the proposal, EPA considered a number of existing programs as relevant models. EPA drew most heavily on the existing 40 CFR part 258 program applicable to MSWLFs. While this program does not address CCR disposal in surface impoundments, it provided EPA with a general regulatory framework that addressed all aspects of disposal in certain land-based units. Given the Agency's expansive history and experience with these requirements, EPA concluded that the part 258 criteria with certain modifications for other land-based disposal units (*i.e.*, surface impoundments) represented a reasonable balance between ensuring the protection of human health and the environment from the risk of CCR disposal and the absence of any regulatory oversight. (See 75 FR 35192–35195.)

EPA also considered that many of the technical requirements developed to specifically address the risks from the disposal of CCR as part of the subtitle C alternative would be equally justified under a RCRA subtitle D regulatory regime. The factual record—*i.e.*, the risk analysis and the damage cases—supporting such requirements was the same, irrespective of the statutory authority under which the Agency was operating. Thus, several of the provisions under RCRA subtitle D either corresponded to the proposal under RCRA subtitle C, or were modeled after the existing subtitle C requirements; for example, EPA proposed the same MSHA-based structural stability standards for surface impoundments under the subtitle C and subtitle D options. However, because there is no corresponding guaranteed permit mechanism under the RCRA subtitle D requirements, EPA also considered the 40 CFR part 265 interim status requirements for hazardous waste facilities, which were designed to operate in the absence of a permit. These requirements were particularly

[35] The Agency is currently developing a Framework to address the risks associated with the beneficial use of unencapsulated materials. This Framework is expected to be finalized in 2015. See Unit VI of this document for more information.

[36] EPA has worked with the states to support the development of a national database on state beneficial use determinations. Information on the beneficial use determination database can be found on the Northeast Waste Management Officials' Association (NEWMOA) Web site at *http://www.newmoa.org/solidwaste/bud.cfm*. This database helps states share information on beneficial use decisions providing for more consistent and informed decisions.

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relevant in developing the requirements for surface impoundments since such units are not regulated under 40 CFR part 258. Beyond their self-implementing design, these requirements provided a useful model because, based on decades of experience in implementing these requirements, EPA had assurance that these requirements were protective for a variety of waste, under a wide variety of site conditions.

In an effort to ensure that the proposed RCRA subtitle D requirements would achieve the statutory standard of ''*no reasonable probability of adverse effects on health and the environment*'' in the absence of guaranteed regulatory oversight, EPA also proposed to require facilities to obtain third party certifications and to provide enhanced state and public notifications of actions taken to comply with the regulatory requirements. Specifically, EPA proposed that certain technical demonstrations made by the owner or operator be certified by an independent registered professional engineer or hydrologist, in order to provide verification and otherwise ensure that the provisions of the rule were properly applied. EPA also provided a regulatory definition of the term, ''independent registered professional engineer or hydrologist,'' to identify the minimum qualifications necessary to make these certifications. While EPA acknowledged that relying upon a third party certification was not the same as relying upon a state or federal regulatory authority and was not expected to provide the same level of independence as a state permit program, the availability of meaningful third party (*i.e.*, independent) verification provided critical support that the rule would achieve the statutory standard, as it would provide at least some degree of control over a facility's discretion in implementing the rule.

As part of the notification requirements, EPA further proposed that all owners and operators create and maintain an operating record and publically accessible Web site, containing comprehensive documentation of compliance with the rule. EPA also proposed that owners or operators provide notification to the state and the public of third party certifications as well as other information documenting actions taken to comply with the technical criteria of the rule.

A. The Self-Implementing Approach

While the vast majority of state and industry commenters supported regulating the management of CCR under subtitle D of RCRA, a very limited number of commenters favored the proposed self-implementing option. Most commenters argued that if the Agency were to adopt the proposed subtitle D approach it would most certainly result in parallel and redundant regulatory programs for CCR in many states, creating an unworkable situation for industry, as well as the state. Some commenters argued that under this dual regulatory approach, an owner or operator of a CCR unit could conceivably be in non-compliance with both a federal requirement and an independently administered state regulatory requirement, subjecting the owner or operator to both a citizen suit enforcement action in federal court for the alleged violation and to a wholly separate enforcement action in state court for violation of the parallel state requirement. Commenters argued that this regulatory construct made no sense and would waste federal and state judicial resources and company resources, as well as possibly resulting in inconsistent federal and state court determinations with respect to an identical regulatory requirement. It also could result in duplicative federal and state penalties for essentially the same regulatory infraction.

Commenters further argued that the prescriptive one-size-fits-all approach was overly stringent and inflexible and had the potential to greatly disrupt implementation of a state's regulatory programs, which have been tailored to provide for site specific conditions and situations. Moreover, commenters argued that because of the many state regulatory programs addressing CCR disposal, there would be many instances where state requirements could be in conflict with, in addition to, or separate from the federal requirements and it was unclear how these differences would be resolved.

Many commenters simply argued that a permitting program similar to that for MSWLFs was the only viable approach for the regulation of CCR. A significant number of commenters, however, proposed various alternative approaches for regulating CCR disposal under subtitle D of RCRA. One option would have EPA allow qualified state programs to directly administer the subtitle D requirements for CCR when the state regulatory program meets or exceeds the federal requirements, thereby minimizing duplicative regulations and avoiding the self-implementing ''one size fits all'' approach contained in EPA's proposal. This option, commenters reasoned, could be implemented utilizing a process developed by the Agency for evaluating whether the state's CCR regulations were equivalent to the federal minimum criteria (much like EPA does now in the case of MSWLFs under 40 CFR part 258). Another suggested approach involved EPA clarifying that a state can be more restrictive than the federal rule, and that where a state has a subtitle D regulatory program that is more restrictive, the state program and permitting process would take precedence over any self-implementation aspects of a final rule. (The proposed rule had simply stated that an owner or operator must comply with any other applicable federal, state, tribal or local laws or other requirements.) Commenters also proposed a third option, similar to the 40 CFR part 258 program, recognizing that EPA cannot approve state programs in this rule. Specifically, 40 CFR part 258 provides a definition for ''Director of an approved state'' that means they are the chief administrative officer of a state agency responsible for implementing the state permit program that is deemed to be adequate by EPA under regulations published pursuant to sections 2002 and 4005 of RCRA. The commenters suggested that the final rule adopt a similar approach by defining a ''state permit program'' and allowing a state permit program that met the definition to approve compliance with a specified regulatory requirement, *e.g.*, landfill design. The commenter suggested the following definition: ''state permit program means a permit program implemented by a state agency that adopts and implements the minimum requirements for the disposal of coal combustion residuals outlined in this final rule.'' The commenter claimed that such an approach should not affect enforcement through citizen suits under RCRA section 7002 or by EPA under RCRA section 7003. Taking such an approach, commenters reasoned, would allow states to utilize their own enforcement authority and not rely upon the citizen suit authority under RCRA section 7002. Furthermore, allowing states to consider alternative approaches to the technical standards may give states an incentive to adopt the minimum requirements of the final federal rule into their state permit programs.

As noted, many commenters suggested that EPA rely on the same combination of RCRA statutory authorities, *i.e.*, RCRA sections 4010(c) and 4005(c), to establish controls for CCR units that it employed in promulgating federally enforceable subtitle D rules for MSWLFs and for non-MSWLFs that receive household

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hazardous waste and small quantity generator waste under 40 CFR parts 257 and 258. RCRA sections 4010(c) and 4005(c), the commenters reasoned, provides EPA that authority because non-hazardous waste CCR disposal facilities have the potential to receive household wastes or conditionally exempt small quantity generator waste, whether or not such waste is actually received at the CCR disposal facility. Commenters contended that the combination of these two provisions could enable EPA to promulgate non-hazardous waste rules for CCR that could be directly administered through state permitting programs and backed up by direct EPA enforcement powers in those states that fail to adequately implement the federal rules. Such an approach, commenters concluded provides the Agency with the enforcement authority it desires under a subtitle D regulatory program, while enabling states to have a prominent role in the administration of any subtitle D rules, and preventing the duplication of potentially conflicting federal and state controls.

Finally, some commenters encouraged EPA to request from Congress the statutory authority necessary to propose non-hazardous regulations under subtitle D that could be implemented by the states and provide federal enforceability (similar to RCRA's part 258 requirements for MSWLFs). Commenters argued that states should be allowed to enforce compliance through a traditional permitting system, and that solid waste operating permits are critical to ensuring coal ash disposal facilities design, construct, operate and close their waste facilities safely. Commenters argued that permits are important because they can dictate the use of specific operating practices and control technologies that may be essential for minimizing releases. Permits also provide an important enforcement vehicle, as well as a process by which the public can be informed and participate in the siting, operation and closure of the waste disposal unit.

While the Agency appreciates commenters' attempts to craft alternative approaches to address the limitations in the proposed self-implementing subtitle D option, EPA has not ''chosen'' to design standards under subtitle D that are self-implementing. The sections of RCRA that are currently applicable to CCR—sections 1008(a), 4004(a), and 4005(a)—only authorize the Agency to establish minimum national criteria that apply to ''facilities.''

As previously discussed, these provisions do not authorize EPA to require that facilities obtain a permit from EPA or a state. The fact that section 4004(a) does not contain any provision that either expressly requires a permit to manage waste, such as in section 3005, or that requires states to adopt a permit program, such as in section 4004(c)(1), provides strong evidence that Congress did not authorize EPA to impose such a requirement on facilities managing solid waste. Compare 42 U.S.C. 6925(a), 6944(a), and 6945(c)(1). This is further confirmed by the fact that Congress thought it necessary to expressly add provisions to require state permit programs in 4010(c) and 4005(c). And the fact that the HSWA provisions are limited to two specifically enumerated types of units provides further evidence that Congress intended to authorize EPA to require permits only for these units.

The restriction that the criteria apply only to ''facilities'' also means that EPA cannot establish any requirements on states or state programs, either directly or indirectly. This means, for example, that EPA cannot adopt a regulation that restricts certain provisions to those ''state permit programs'' that meet EPA requirements, as one commenter suggested, since this would indirectly regulate state programs—leaving aside that EPA never proposed anything of the sort. This also means that EPA cannot require a facility to obtain state approval, as this not only presupposes the existence of a state permit program, but also that the state will approve the facility action on the basis of EPA's criteria. EPA cannot condition a facility's compliance on actions beyond its control.

However, these provisions restrict EPA's authority only. The legislation is clear that these are minimum requirements only, and without preemptive effect; states may therefore impose more stringent requirements, including the requirement that CCR facilities obtain a permit. This is also wholly consistent with longstanding EPA interpretations. See 44 FR 53438, 53439 (September 13, 1979) (''the standards established in the criteria constitute minimum requirements. These criteria do not preempt other state and federal requirements. Nothing in the Act precludes the imposition of additional obligations under authority of other laws on parties engaged in solid waste disposal.''); see also 44 FR 45066 (July 31, 1979) (''EPA establishes only 'minimum' requirements under this portion of the Act which should not prevent States from developing broader programs or stricter standards under authority of State law.''). States may also incorporate the federal requirements into state law—whether through revisions to existing legislation or regulation, or through incorporating them into any permits issued to CCR facilities. Such an approach would also resolve commenters' concerns about the potential for ''parallel and redundant regulatory programs.''

While subtitle C and 4005(c) provide for state oversight on rule implementation and allow approved state requirements to operate in lieu of federal criteria, the Agency lacks the authority to do so under the subsections of RCRA currently applicable to CCR. The provisions applicable to solid waste—sections 1008(a)(3), 4003, 4004(a) and 4005(a)—establish a regulatory structure that differs in key respects from those established under subtitle C and for MSWLFs under section 4005(c). Under subtitle C and section 4005(c), Congress required EPA to establish federal criteria that will serve as national minimum standards, which is comparable to the authority under section 4004(a). But subtitle C and section 4005(c) also include detailed provisions governing both the state implementation of those requirements and the relationship between the federal requirements and the state programs that implement them. No comparable provisions appear in either section 4004(a) or section 4003, which governs the approval of state SWMPs. And the consequences of these omissions are significant.

Subtitle C of RCRA contains several provisions that establish the relationship between the federal program and state requirements; these include provisions authorizing EPA to approve state programs and to retain a direct role in the implementation of the federal minimum requirements, whether through continued oversight of state implementation or direct implementation of the regulations. See, 42 U.S.C. 6926, 6928(a)(2), and 6929. For purposes of this issue, the most critical of these is the explicit direction in section 3006 that authorized state programs ''operate in lieu of the Federal program.'' 42 U.S.C. 6926(b), (c)(1). See also 42 U.S.C. 6929 (prohibiting the adoption of less stringent state requirements than those in EPA regulations, and authorizing states to establish more stringent requirements).

The provisions for MSWLFs under section 4005(c) are less detailed, but establish a similar regulatory structure. Section 4005(c)(1) expressly directs the states to ''adopt and implement a permit program or other system of prior approval and conditions,'' for covered

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facilities in order to implement federal requirements established for such facilities. 42 U.S.C. 6945(c)(1). The statute directs EPA to determine the adequacy of such programs, and directs EPA to enforce the federal requirements in states that have not adopted an adequate program. 42 U.S.C. 6945(c)(1)(C), (2). While less detailed than the provisions under subtitle C, section 4005(c) establishes a system that is equally predicated on mandated implementation by a state regulatory authority of the federal requirements, rather than the potential coexistence of two separate regulatory systems.

The absence of any similar provisions in the ''solid waste'' provisions of subtitle D demonstrates that Congress intended to create a different regulatory structure. EPA's role under sections 1008(a)(3) and 4004(a) is to establish minimum criteria to determine which facilities ''shall be classified as sanitary landfills and which shall be classified as open dumps,'' and to encourage states to use the criteria as a part of their solid waste management planning. Under this regulatory structure, Congress intended that the federal requirements apply directly to facilities and operate independent of state involvement, unless *the state* chooses to do otherwise. The ability to approve state SWMPs under section 4003 does not alter this relationship. Indeed, the fact that Congress thought it necessary to revise section 4005 to include the specific provisions in subsection (c) confirms that Congress did not believe such authority already existed under sections 4003 and 4004.

Approval of a state's SWMP pursuant to section 4003 qualifies the state to receive federal funds (no longer available) and authorizes the state to issue compliance schedules; but unlike under section 3006 or 4005(c), an authorized plan does not affect the federal minimum standards themselves, or authorize states to do so. Section 4003 contains nothing that explicitly or implicitly authorizes state requirements to operate ''in lieu of'' the federal requirement as a consequence of EPA approval of the state plan. The closest analogue is that states with an approved plan may establish a ''timetable or schedule'' to bring existing open dumps into compliance with the federal requirements; but notably, Congress only authorized the state to modify the timeframes by which such facilities must be in compliance, not the substantive requirements themselves. 42 U.S.C. 6945(a).

The combination of this regulatory structure and the need to demonstrate that the final rule achieves section 4004(a)'s protectiveness standard based on the record at the time the rule is promulgated also effectively limits EPA's ability to establish the kind of regulatory provisions commenters have requested (*i.e.,* establish an alternative that allows a state permit program to approve a less stringent technical requirement based on site specific conditions). Because as discussed in Unit IV of this document, EPA is currently unable to reach a conclusion regarding the adequacy of state programs, EPA cannot demonstrate that such an alternative would meet the section 4004(a) standard. And in the absence of a mandatory mechanism for subsequent public involvement and review, which would create decisions with their own record, subject to judicial review in their own right, the lack of such information is dispositive.

With respect to the proposal to rely on RCRA sections 4010(c) and 4005(c) authorities, EPA also disagrees that this is a viable option. As the comment appears to acknowledge, construing sections 4010(c) and 4005(c) to apply to CCR units on the basis that they could *potentially* receive conditionally-exempt small quantity generator waste is inconsistent with EPA's longstanding interpretation of those sections. EPA directly addressed this issue nearly 20 years ago in the preamble for EPA's final rules at 40 CFR part 257, subpart B. In that discussion which we summarize in the next several paragraphs, EPA explained that the proposed rule was written to provide that only those non-municipal non-hazardous waste disposal units which meet the requirements in §§ 257.5 through 257.30 ''may receive'' CESQG waste, as required by RCRA section 4010(c). Any non-municipal non-hazardous waste disposal unit that did not meet the proposed requirements may not receive CESQG hazardous wastes. The proposal was written to apply to non-municipal non-hazardous waste disposal units that receive CESQG waste for storage, treatment, or disposal, including such units as surface impoundments, landfills, land application units and waste piles. The regulatory definition of the term ''disposal'' cover all placement of wastes on the land. See 40 CFR 257.2.

EPA further noted that several commenters addressed the Agency's interpretation of the statutory language ''may receive.'' One commenter supported the Agency's decision to limit the proposed regulatory requirements to only those non-municipal non-hazardous waste disposal units that receive CESQG wastes. Another commenter, however, stated that a closer reading of section 4010(c) reveals that Congress was not only concerned about modifying the criteria for ''facilities that may receive hazardous household wastes or hazardous wastes from small quantity generators . . .'' but also for ''facilities potentially receiving such wastes.'' According to the commenter, the ''may receive'' clause of the first sentence in section 4010(c) merely refers to whether a facility may legally receive CESQG waste for disposal. The ''potentially receiving such wastes'' clause of the third sentence of Section 4010(c) refers to the actual potential for such facilities to receive CESQG wastes. The potential for CESQG waste to be disposed of at many types of industrial D landfills is high even with the proposed prohibition under § 261.5. It is the ''potentially receiving'' clause that specifically commands the Agency to promulgate provisions for all industrial facilities that could potentially receive CESQG wastes.

EPA disagreed with the commenter's interpretation of the statutory language in RCRA section 4010(c). More specifically, for a number of reasons, the Agency did not believe that the statutory language cited by the commenter evidenced congressional intent that the revised criteria promulgated in the rule should address disposal of solid waste in all industrial disposal facilities. First, EPA believed that the commenter erred by focusing only on the ''facilities potentially receiving'' language in the last sentence of section 4010(c). If one reviews this language together with the statutory language in RCRA section 4010(a), it is clear that Congress did not intend for the revised criteria being promulgated in this rule to apply to all industrial landfills.

RCRA section 4010(a) required EPA to conduct a study of the then existing guidelines and criteria issued under RCRA sections 1008 and 4004 which were applicable to ''solid waste management and disposal facilities, including, but not limited to landfills and surface impoundments.'' 42 U.S.C. 6949a(a). This statutory language does indeed suggest that EPA was to study a wide range of solid waste disposal facilities, including industrial landfills. (As the commenter stated, because the information on industrial disposal facilities was quite limited, EPA's report to Congress did focus on municipal landfills.)

However, the statutory language in section 4010(c) directing EPA to promulgate a rule revising the criteria in 40 CFR part 257 limits the rule's applicability only to those facilities which may receive hazardous

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household waste or small quantity generator waste. 42 U.S.C. 6949a(c). If Congress had intended the revised criteria under section 4010(c) to apply to all solid waste disposal facilities, including industrial landfills and surface impoundments, it clearly could have done so by enacting language similar to that already used in section 4010(a).

Secondly, the legislative history of RCRA section 4010 suggests that Congress expressly rejected a provision that would have required rules to be promulgated under section 4010(c) to apply to the entire universe of RCRA subtitle D solid waste disposal facilities. Indeed, the House version of section 4010 would have required EPA to promulgate revised guidelines and criteria such that they would be applicable to all ''solid waste management and disposal facilities, including, but not limited to landfills and surface impoundments. . . .'' H.R. 2867, section 30, 98th Cong., 1st Sess. (as introduced in the Senate on November 9, 1983). However, the Conference Committee instead adopted a Senate amendment which limited the scope of the revised criteria to those facilities that may receive hazardous household waste or small quantity generator waste. H. Rept. No. 98–1133, 98th Cong., 2d Sess., at 116–117.

Another indication that RCRA section 4010(c) was not intended to cover the entire universe of solid waste disposal facilities is the fact that subsequent to the enactment of section 4010(c) (as part of the Hazardous and Solid Waste Amendments in 1984), a number of bills were introduced in Congress which would have either authorized or required EPA to issue additional regulations that would address all disposal facilities receiving industrial waste as opposed to addressing those which may receive CESQG waste as stated in section 4010(c). See, *e.g.,* H.R. 3735, ''Waste Materials Management Act of 1989,'' section 324 (would have required EPA to promulgate standards for the management of industrial solid waste) (Luken Bill); S. 1113, ''Waste Minimization and Control Act of 1989,'' section 204 (would have required EPA to promulgate requirements for facilities that manage different types of industrial waste) (Baucus Bill). Neither of these provisions (although neither was enacted) would have been necessary if RCRA section 4010(c) required EPA to promulgate revised criteria for all types of industrial disposal facilities. (See 61 FR 34252, 34254–55 (July 1, 1996).)

The commenter on the proposed CCR rule makes essentially the same argument based on the same language in 4010(c) that EPA rejected in the 1996 rule. The commenter provided no legal analysis that contravenes the basis for EPA's interpretation of subtitle D. EPA thus declines to reopen or reconsider this interpretative question. EPA also notes that in any case, information in its record for this rulemaking indicates that CCR landfills or surface impoundments do not actually or potentially receive CESQG wastes.

Nevertheless, EPA recognizes that this regulatory structure gives rise to legitimate concerns about the potential for duplicative or conflicting state and federal regulatory systems. EPA has adopted measures to address these concerns within the confines of the regulatory structure that Congress established in subtitle D. First, EPA has made every effort to ensure that the final rule does not establish any requirements that truly conflict with existing state programs. To clarify, this does not mean that the requirements are necessarily the same, but rather that it is possible to comply with both federal and state requirements simultaneously. Or in other words, compliance with the more stringent standard—whether federal or state—will ensure compliance with the less stringent. Based on the comments received, EPA is aware of no example of a situation in which truly conflicting requirements will exist. Second, as discussed, these regulations do not constrain or direct state action. States can impose more stringent or different requirements, such as requiring a permit. Nor does the regulation require the state to enforce the federal requirements; even with promulgation of the final rule, the decision to bring an action under section 7002 remains entirely within the state's discretion. Third, as discussed in greater detail in Unit IX of this document, EPA has developed a number of measures to clarify the relationship between an individual state program, or particular requirements, and the federal criteria. Specifically, for those states that choose to submit a revised SWMP that incorporates the federal criteria, EPA intends to rely on the existing processes in 40 CFR part 256 relating to approval of SWMPs. EPA expects that approval of a state SWMP, while it cannot prevent a citizen group from filing a lawsuit, will carry substantial weight in any court proceeding charged with determining whether compliance with state requirements constitutes compliance with the federal criteria.

B. Enforceability of the Subtitle D Approach

Numerous commenters raised concern that reliance on a RCRA citizen suit as the basic enforcement mechanism to address non-compliance with the CCR requirements presents environmental justice concerns. Commenters argued that as a practical matter, this self-implementing approach would result in unenforced regulations affecting neighborhoods where environmental, legal, and technical services are unavailable or difficult to obtain. Commenters stated that it would be highly unreasonable for EPA to place the burden of enforcement of the CCR regulations on citizens, arguing that it is EPA's duty to make sure federal regulations protecting human health and the environment are enforced fairly and effectively, and that enforcement by citizen suits puts an unacceptable burden on low income populations located near these facilities. Commenters contended that environmental justice communities were the least likely to mount a serious challenge to the industry because low income people are often less well-educated, have less access to computers and internet technology, are less knowledgeable of how to access and interpret environmental data, and are the least likely to have the resources for a time consuming legal battle. Commenters argued that given the high number of damage cases in this industry, it was clear that the industry cannot police itself and neither can state governments. For these reasons, commenters asserted that the regulations and the enforcement must come from the federal level.

Conversely, other commenters were encouraged by the opportunity to enforce the rule through citizen suits, stating that it would result in very effective regulation since citizens have shown no reluctance to challenge companies that they believe are not responsibly following environmental regulations. Similarly, other commenters noted that other incentives existed to comply with the regulations, including the possibility of state and third party litigation (for both regulatory compliance and actual damages), and the requirements of investors, lenders, and insurers to demonstrate compliance with environmental requirements, *i.e.,* investors and lenders typically condition capital investments and loans on environmental compliance. Commenters also noted that incentives to comply were created by environmental insurance policies, which ''invariably exclude damage claims arising from non-compliance from covered events'' as well as typical corporate policies that call for

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environmental compliance as a standard operating procedure.

Other commenters focused on the role of the professional engineer in the self-implementing framework, arguing that EPA is requiring the certifying professional to inappropriately take on a quasi-regulatory and enforcement role which places the certifying professional at great risk of being subject to nuisance lawsuits from project opponents, creating a scenario where some professionals may decline to be involved in such reviews. Still other commenters argued with EPA's basic premise that the RCRA subtitle D program lacks federal enforceability. Commenters contended that EPA's concerns about the lack of direct federal enforcement authority failed to recognize the significant enforcement opportunities available under existing law, namely the ''imminent and substantial endangerment authority'' under RCRA section 7003 to take action against any CCR unit that posed a risk to human health and the environment, as well as, the imminent and substantial endangerment authorities under CERCLA, as well as other federal authorities, including the federal Clean Water Act, to address circumstances where a CCR unit posed a threat.

EPA acknowledges that the lack of federal enforcement under Subtitle D presents challenges. However, as discussed above, issuing minimum national standards under the authority that is currently applicable to CCR (*i.e.,* subtitle D) is significantly more protective than the current federal standards in part 257 that apply to these wastes. It is more consistent with EPA's obligations under RCRA to put in place the additional protections that, based on the information currently available, are needed to protect health and the environment. As part of those requirements, EPA has developed a number of provisions designed to facilitate citizens to enforce the rule pursuant to RCRA section 7002. Chief among these is the requirement to publicly post monitoring data, along with critical documentation of facility operations, so that the public will have access to the information to monitor activities at CCR disposal facilities. Moreover, as noted elsewhere, a state seeking EPA's approval for a State SWMP would be required to conduct a public comment process to avail itself of the benefits of an EPA's approval.

EPA also agrees that the Agency retains the authority to bring an action under RCRA section 7003, as well as other statutes, when the facts support the necessary findings. However, an action under section 7003 does not enforce the requirements of this rule. Certainly, EPA believes that the failure to comply with the requirements of the rule increases the probability that an imminent and substantial endangerment may arise, but the fact that a facility has not complied with one or more of the requirements of this rule does not *per se* establish that a section 7003 order is warranted.

The Agency also acknowledges that the self-implementing frameworks could potentially place certifying professionals at risk for lawsuits; several of the performance standards in the proposed rule were adopted from part 258, which were designed to operate in the context of an approved state program, under the oversight of a state regulatory authority, rather than a purely private entity. In part due to this concern, the Agency has re-evaluated the performance standards throughout the final rule, and has revised them where necessary to ensure that the requirements are sufficiently objective and technically precise that a qualified professional engineer will be able to certify that they have been met.

C. Reliance on Certification by Independent Qualified Professional Engineers

As previously discussed, the majority of commenters were highly skeptical of a regulatory approach that substituted state oversight with an owner or operator hiring a consultant or professional, *i.e.,* an independent registered professional engineer or hydrologist, to certify compliance with a federal regulatory requirement and posting that information on an internet site. More specifically, commenters were concerned that relying almost entirely on professional certifications for ensuring regulatory compliance did not seem like a reliable way to provide for protection of human health and or the environment.

As explained in Unit IV.A of this document, EPA is issuing national minimum criteria under subtitle D to put in place the technical requirements the Agency has determined are necessary to protect human health and the environment from the disposal of CCR in surface impoundments and landfills, while the Agency completes its Bevill Determination. EPA is relying on the certification in this context to partially compensate for one of the more significant limitations under the authorities currently applicable to CCR: The lack of any guaranteed regulatory oversight mechanism. However, EPA disagrees that the rules rely ''almost entirely'' on professional engineers to protect human health and the environment. The final rule relies on multiple mechanisms to ensure that the regulated community properly implements requirements in this rule. As one part of this multi-mechanism approach, owners or operators must obtain certifications by qualified individuals verifying that the technical provisions of the rule have been properly applied and met. However, a more significant component supporting EPA's determination that the technical requirements will achieve the level of protection required under section 4004(a) is the performance standards that the rules lay out. These standards impose specific technical requirements, and, even where they provide flexibility, will operate to significantly constrain the facility's activities and discretion. The certifications required by the rule supplement these technical requirements, and while they are important, they are not the sole mechanism ensuring regulatory compliance.

The rule also contains a number of provisions requiring the owner or operator to document their compliance with the rule's technical requirements, and to post those documents on a publically available Web site in a timely and transparent manner. The rule also requires owners or operators to notify State Directors of numerous actions, including that certified demonstrations have been completed. This transparency will facilitate citizen and state oversight and overall enforcement of the requirements. Finally, the rule establishes specific timeframes by which these actions must occur, including timeframes by which facilities must document compliance with the various technical requirements in the rule. Timeframes have been established for: (1) Technical compliance demonstrations made by the owner or operator; (2) certifications made by a qualified professional engineer verifying the technical accuracy and veracity of the compliance demonstration; (3) notifications made to the State Director; (4) submittals (*e.g.,* data, reports and other documentation) to the operating record; and (5) postings to the owner or operator's publicly accessible internet site. Further details pertaining to all of these requirements can be found in the Recordkeeping, Notification, and Posting of Information to the Internet section of the regulations published in this rule.

1. Changes to the Definition of Independent Registered Professional Engineer or Hydrologist

EPA proposed to define ''*independent registered professional engineer or*

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hydrologist'' to mean a scientist or engineer who is not an employee of the owner or operator of a CCR landfill or CCR surface impoundment, who has received a baccalaureate or post-graduate degree in the natural sciences or engineering, and who has sufficient training and experience in groundwater hydrology and related fields as may be demonstrated by state registration, professional certifications, or completion of accredited university programs that enable that individual to make sound professional judgment regarding the technical information for which a certification under this subpart is necessary.

Many comments were received on the definition. Some commenters agreed with the proposed definition, but most commenters argued that significant changes were needed. These changes included removing the requirement that the engineer be ''independent,'' adding the word ''qualified,'' and limiting the ability to make certifications to ''licensed'' professional engineers. Still other commenters felt that EPA should broaden the qualifications beyond a professional engineer or hydrologist, to include geologists, hydrogeologists, groundwater scientists or ''other qualified environmental professionals'' among the individuals able to certify regulatory demonstrations.

By far the issue receiving the most comment was whether the Agency should require a professional engineer to be ''independent.'' Commenters disagreed with EPA that the certification must be made by an independent registered professional engineer (*i.e.,* not an employee of the owner or operator of the CCR unit). Commenters argued that most utilities employ a number of professional engineers that typically possess the most relevant experience and knowledge about the unit, and that company-employed engineers and hydrologists were in a much better technical position to certify technical provisions of the rule were being met. Furthermore, commenters asserted that these professionals would be subject to the same state registration and licensing requirements as those not employed by the facility and would have an equally strong incentive to maintain their licenses in good standing as those that are independent of the utility. These commenters also pointed to several EPA rulemakings in which EPA allowed ''qualified'' professional engineers to make the kind of certifications contemplated by this rulemaking, without requiring that they be ''independent.'' Commenters also contended that state licensing and registration programs help to ensure that all professionals exercise proper judgment or ''independence'' regarding the operation of CCR landfills and CCR surface impoundments. Similarly, commenters claimed that a professional engineer without the required expertise would refuse to make any certifications for which they were not qualified. Some commenters suggested that EPA provide some criteria requiring demonstrated experience and training. Commenters also took issue with the fact that the definition focused entirely on groundwater hydrology and failed to include training or experience in other areas that would also be necessary to effectively certify specific technical criteria of the rule (*e.g.,* structural integrity, composite liner design).

The definition EPA proposed for ''independent registered professional engineer or hydrologist,'' focused on three components that were intended to define the minimum qualifications necessary to independently verify that a specific technical standard was met and to provide sufficient objectivity to reduce the opportunity for abuse. These components were: (1) The individual was a scientist or engineer by academic training or education; (2) the individual was not an employee of the owner or operator of the CCR unit; and (3) the individual had sufficient training in groundwater hydrology or related fields. The proposed definition did not require the individual to be a licensed professional engineer or hydrologist; instead the Agency prohibited the individual providing the certification from being an employee of the owner or operator of the CCR unit, reasoning that this requirement would provide some degree of independent verification of facility practices.[37] The Agency stated that the availability of meaningful independent verification was critical to EPA's ability to conclude that the performance standards laid out in the proposed rule would meet the RCRA section 4004 protectiveness standard.

In the course of developing this final rule, the Agency concluded that it needed to better define the connection between the technical requirements of the rule and the technical qualifications an individual must possess to certify the demonstrations being made by the owner or operator of the CCR unit. In doing so, the Agency looked for direction in the following rules, the ''Resource Conservation and Recovery Act (RCRA) Burden Reduction Initiative'' (71 FR 16826, April 4, 2006) and the ''Oil Pollution Prevention and Response; Non-Transportation-Related Onshore and Offshore Facilities rule (67 FR 47042, July 17, 2002). In both of these actions, the Agency had come to similar conclusions. First, that professional engineers, whether independent or employees of a facility, being professionals, will uphold the integrity of their profession and only certify documents that meet the prescribed regulatory requirements; and that the integrity of both the professional engineer and the professional oversight of boards licensing professional engineers are sufficient to prevent any abuses. (For an example see: 67 FR 47084, July 17, 2002.) And second, that in-house professional engineers may be the persons most familiar with the design and operation of the facility and that a restriction on in-house professional certifications might place an undue and unnecessary financial burden on owners or operators of facilities by forcing them to hire an outside engineer.

Reviewing these other regulatory actions and the Agency's rationale for making its decisions, has led the Agency to a similar conclusion with regard to this rule—that it is unnecessary to require the individual making certifications under this rule to be ''independent.'' Thus the final rule does not prohibit an employee of the facility from making the certification, provided they are a professional engineer that is licensed by a state licensing board. The personal liability of the professional engineer provides strong support for both the requirement that certifications must be performed by licensed professional engineers, and for removing the requirement that the engineer be ''independent.''

While other commenters argued that the word ''independent'' should be retained because an independent review and certification avoids any potential of conflict of interest, the Agency is convinced that an employee of a facility, who is a qualified professional engineer and who has been licensed by a state licensing board would be no more likely to be biased than a qualified professional engineer who is not an employee of the owner or operator. Moreover, it is not clear that an in-house engineer faces a greater economic temptation than an independent

[37] While the definition did not require the independent registered professional engineer or hydrologist to be licensed, the preamble did state that EPA expects that professionals in the field will have adequate incentive to provide an honest certification, given that the regulations require that the engineer not be an employee of the owner or operator of the CCR landfill or CCR surface impoundment, and that they operate under penalty of losing their license, implying that the professional was, in fact, licensed. This narrative and the title of independent registered professional engineer caused many commenters to assume that the certifiers indeed had to be licensed professional engineers. (See 75 FR 35194, June 21, 2010.)

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engineer seeking to cultivate an ongoing relationship with a client. EPA has concluded that the programs established by state licensing boards provide sufficient guarantees that a professional engineer, regardless of whether he/she is ''independent'' of the facility, will give a fair technical review.

As an additional protection, the Agency has re-evaluated the performance standards throughout the final rule to ensure that the requirements are sufficiently objective and technically precise that a qualified professional engineer will be able to certify that they have been met.

The Agency agrees with concerns that a professional engineer may not be qualified to address all the varied aspects of CCR landfill and CCR surface impoundment design, and has amended the definition to clarify and strengthen the qualifications of the individual authorized to certify the technical demonstrations under the rule. In the proposed rule, the Agency did not require an independent registered professional engineer to be licensed, only that they be an engineer or hydrologist who had received a baccalaureate or post graduate degree in the natural sciences with training and experience in groundwater hydrology or a related field. While the term ''independent registered professional engineer or hydrologist'' conveyed to some commenters that the individual was in fact ''licensed,'' the definition in the proposal did not require it. Furthermore, as noted by commenters, the proposed definition focused primarily on hydrogeology expertise and did not include training and experience qualifications necessary to accurately certify some of the requirements being promulgated in the rule, *e.g.,* landfill and surface impoundment design and construction, structural stability assessments, analysis of unstable areas. In reviewing this proposed requirement, the Agency has determined that specifying exact qualifications and or experience for the professional engineer is neither necessary nor practical, given the range of technical specifications that will require certification. EPA has therefore adopted a more succinct requirement focused on the professional engineer's qualifications to perform the task or certification.

In making this change, the Agency was again strongly influenced by the ''Resource Conservation and Recovery Act (RCRA) Burden Reduction Initiative'' rule. (See 71 FR 16826, April 4, 2006.) In that rule, EPA amended the majority of RCRA provisions requiring the certification of an ''independent, qualified, registered, professional engineer'' to substitute the phrase, a ''qualified professional engineer,'' reasoning that a requirement for a qualified professional engineer maintains the most important components of any certification requirement: (1) That the engineer be qualified to perform the task based on training and experience; and (2) that she or he be a professional engineer licensed to practice engineering under the title Professional Engineer which requires following a code of ethics with the potential of losing his/her license for negligence (see 71 FR 16868.)

In the ''Burden Reduction Rule'' the Agency concluded that a professional engineer is able to give fair and technical review because of the oversight programs established by the state licensing boards that will subject the professional engineer to penalties, including the loss of license and potential fines if certifications are provided when the facts do not warrant it. In fact, this personal liability of the professional engineer is one of the primary reasons that commenters to the ''Burden Reduction Rule'' supported the idea that RCRA certifications should only be done by licensed professional engineers (See 71 FR 16868.) Upon further analysis and reflection, the Agency sees no reason to deviate from the position EPA held in that rule. Despite some concerns raised by commenters that problems could occur if an owner or operator hires an engineering firm that is small, inexperienced, or operating outside of their past professional practice, the Agency continues to believe that with the protections afforded by the specific performance standards in this rule and the standards and ethics to which a qualified professional engineer is subject, situations in which an unqualified or un-licensed engineer certifies a technical demonstration will be avoided. Furthermore, it is important to reiterate that state licensing boards can investigate complaints of negligence or incompetence on the part of professional engineers, and may impose fines and other disciplinary actions, such as cease-and-desist orders or license revocation. (See 71 FR 16868.) In light of the third party oversight provided by the state licensing boards in combination with the numerous recordkeeping and recording requirements established in this rule, the Agency is confident that abuses of the certification requirements will be minimal and that human health and the environment will be protected.

The Agency wants to make it clear that qualified professional engineers can utilize a qualified team of professionals in performing the analyses that underlie these certifications. In most instances, EPA expects that the basis for certification by a qualified professional engineer will be the result of a team of professionals (*e.g.,* geologists, hydrologists, scientists and engineers) who have collectively worked together in order to provide the data and analyses necessary for the professional engineer to certify the specific demonstration.

The Agency is convinced that the change to the certification requirements to allow the use of in-house expertise will not compromise environmental safety. Professional engineers employed by a facility are more familiar with the facility's particular situation and are in a position to provide more on-site review and oversight of the activity being certified. To this end, the Agency is also requiring that the qualified professional engineer be licensed in the state in which the CCR unit is located. The Agency has made this decision for a number of reasons, but primarily because state licensing boards can provide the necessary oversight on the actions of the professional engineer and investigate complaints of negligence or incompetence as well as impose fines and other disciplinary actions such as cease-and-desist orders or license revocation. Oversight may not be as rigorous if the professional engineer is operating under a license issued from another state.

Finally, the Agency disagrees with comments that professional geologists or geoscientists should be added to the list of those professionals that have expertise and authority to certify compliance with certain RCRA subtitle D regulatory requirements. In developing this final rule, the Agency has re-considered the qualifications necessary to certify compliance with the technical requirements of the rule and is limiting compliance certifications to qualified professional engineers only. While some environmental professionals, *e.g.,* hydrologists, geologists may be qualified to make certain certifications, EPA is not convinced that hydrologists or geologists licensed by a state are held to the same standards as a professional engineer licensed by a state licensing board. For example, it is unclear that hydrologists or geologists are subject to the rigorous testing required by professional engineers or that state licensing boards can investigate complaints of negligence or incompetence. Further, professional engineers have licensing boards in all 50 states, a standard not achieved by other

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professional disciplines. Consequently, hydrologists, geologists, or other professionals may only perform analyses that underlie the certification, but it is the responsibility of a qualified professional engineer to make the actual certification.

D. State and Public Notifications of Certifications

To address concerns about the absence of adequate regulatory oversight under subtitle D, EPA proposed to require state and public notifications of the third party certifications, as well as other information documenting the decisions made or actions taken by the owner or operator to comply with the technical criteria in the rule. As stated in the proposal and reiterated here, the Agency cannot conclude that the regulations promulgated in this rule will ensure there is no reasonable probability of adverse effects on health or the environment unless there is a mechanism for states and citizens, as the entities responsible for enforcing the rule, to effectively monitor or oversee its implementation. Mandated documentation and transparency of the owner or operator's actions to comply with the rule provides this mechanism, and will help to minimize the potential for abuse. The proposal specified that the documentation of how the various technical standards had been met were to be placed in the facility's operating record, along with notification to the appropriate state authority. Additionally, EPA proposed to require the owner or operator to maintain a Web site available to the public that would also provide access to this documentation. EPA proposed that owners or operators post notices and relevant information on the internet site with a link clearly identified as being a link to notifications, reports, and demonstrations required under the regulations. While EPA recognized that the internet is currently the most widely accessible means for gathering and disseminating information, the Agency also solicited comments regarding alternative methods to provide notifications to the public and the states. The Agency also solicited comment on whether to require the establishment of a publicly accessible internet site to provide regulatory information to the public and the states, including whether there could be homeland security implications associated with internet posting of information, and whether the posting would duplicate information that is already available to the public through the state.

In response to most of these proposals, the Agency received little comment. Significant comment, however, was received on the publicly accessible internet site. Commenters argued that absent specific statutory authorization, it was inappropriate for EPA to delegate a regulatory oversight function to the regulated community by requiring the creation of a Web site and posting of regulatory compliance information. Commenters identified at least three substantial problems associated with ''outsourcing information management responsibilities'' to CCR facilities. First, commenters argued that EPA lacked the authority to impose such a requirement. Specifically, the commenters alleged that no statute authorizes EPA to demand that private parties act as an information clearinghouse for information pertaining to EPA's regulatory functions, either generally or in the specific context of CCR. To the contrary, the commenters argued, public information access statutes, such as the Freedom of Information Act are predicated on an assumption that information held by the government is presumptively public, while information held by a private entity presumptively is not.

Second, some commenters were concerned that facilities would not post information the facility deems to be confidential (*e.g.,* the structural stability of ash pond impoundments) and by attempting to outsource the information management role to industry, EPA effectively allows industry to make the initial determination as to confidentiality and places the burden on citizens and EPA to take action to compel disclosure.

Third, commenters were concerned that citizen groups would not accept an electric utility's self-reported information, regardless of the amount of effort the facility exerts to ensure the accuracy of the information, without a regulatory agency acting as the intermediary or providing some degree of oversight (*e.g.,* EPA's Toxic Release Inventory, EPA's Biennial Report of hazardous waste facilities). By requiring citizen groups to obtain their information from industry instead of a regulator, the commenters argued that EPA is inviting conflict as to the adequacy of data and the sufficiency of the utilities' responses to citizen groups' requests for clarification or additional information. The fact that the industry has provided information to a federal agency, subject to criminal penalties for providing false information, provides a useful public assurance of the integrity of the information.

Other commenters stated that the proposed requirement to maintain a Web site was excessive, and generated a regulatory burden upon companies that serves no useful function. Commenters urged that the same purpose could be served simply through making the certification of the registered professional engineer available on the Web site. Other commenters argued that internet posting of information on a surface impoundment's construction raised homeland security issues. These commenters alleged that the information ''can be extremely sensitive and may contain information that could be used by certain individuals with an intent to destroy a dam (*e.g.,* engineering information on the structure's foundation, detailed information on physical and engineering properties, the basis for the structure hazard classification, slope stability information, etc.).''

Finally, some commenters offered an alternative to the requirement to establish and maintain a publicly accessible internet site. Under this alternative the information would be included in the owner or operator's operating record only, and persons with ''legitimate interests in reviewing these data'' could make a written request to the owner or operator or the permitting authority to obtain the information. The commenters alleged that this would also allow the owner, operator, and federal and state authorities to know the names and identities of all organizations requesting information on the facility, which would help protect against the misuse of these data.

EPA disagrees that RCRA section 4004(a) does not authorize EPA to require facilities to disclose all of the information required under these final rule provisions. Section 4004(a) delegates broad authority to EPA to establish criteria governing facilities' management of solid waste, requiring only that such criteria ensure that there will be no reasonable probability of adverse effects on health or the environment from the disposal of solid waste. The statute imposes no limits on the actions EPA may require facilities to perform to achieve that level of protection. Moreover, unlike other statutes, *e.g.,* the Toxic Substances Control Act, or the Federal Insecticide, Rodenticide and Fungicide Act, RCRA contains neither provisions that grant facilities the right to withhold regulatory compliance information from the public, nor provisions that establish any reasonable expectation that such information will be kept confidential. To the contrary, section 7004 explicitly provides that ''[p]ublic participation in

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the . . . implementation, and enforcement of any regulation under this chapter shall be provided for, encouraged, and assisted by the Administrator.'' 42 U.S.C. 6974(b). And in fact, this kind of information would routinely be publically available under the permitting process for hazardous waste facilities. Accordingly, RCRA provides more than ample authority to support these requirements.

As repeatedly discussed throughout this preamble, under section 4004(a) EPA must be able to demonstrate, based on the record available at the time the rule is promulgated that the final rule provisions will achieve the statutory standard. EPA explained in the proposal that a key component of EPA's support for determining that the rule achieves the statutory standard is the existence of a mechanism for states and citizens to monitor the situation, such as when groundwater monitoring shows evidence of potential contamination, so that they can determine when intervention is appropriate. The existence of effective oversight measures provides critical support for the statutory finding, particularly with respect to some of the more flexible alternatives EPA has adopted in certain of the technical standards in response to commenters' requests for greater flexibility. These ''transparency'' requirements serve as a key component by ensuring that the entities primarily responsible for enforcing the requirements have access to the information necessary to determine whether enforcement is warranted. Unlike a federal or state regulatory authority, private citizens cannot access a private facility to conduct inspections. While EPA encourages states to adopt and implement a CCR regulatory program, and seek EPA's approval of it via a state SWMP, EPA cannot require it. The final rule therefore must establish oversight mechanisms that will function effectively even in the absence of a state regulatory authority.

Such notifications will also reduce the incentives for owners or operators to abuse the rule's self-implementing requirements, and can improve compliance. Indeed, the public disclosure of information is an increasingly common and important regulatory tool, as evidenced by the 2010 guidance issued by the Office of Management and Budget (OMB), with principles to assist agencies in using information disclosure to achieve regulatory objectives.

Thus, even if the commenters were correct that there exists a general ''presumption'' that information held by private entities need not be made publically available, that presumption can be, and has been, effectively rebutted by the facts at hand.

None of the alternatives offered by the commenters would fulfill these same objectives. For example, simply making the certification of the qualified professional engineer available on the Web site without the underlying support information fails to provide the same incentives because no one could evaluate the accuracy of that certification. This alternative could also present the same concerns raised in comments on other sections of the rule, *i.e.,* that such a requirement could place the engineer at great risk of being subject to lawsuits. Requiring persons with ''legitimate interests in reviewing these data'' to request the data from the owner or operator also fails to provide an effective guarantee, as facilities that have failed to comply will have a strong incentive to withhold information documenting their non-compliance, however ''legitimate'' the request. And as noted, the absence of a guaranteed state permitting program means that requiring citizens to request information from such entities is also not a viable alternative. Given the absence of a guaranteed regulatory authority, EPA also disagrees that posting such information on a company internet site is necessarily duplicative, particularly in those states that have no regulatory program for controlling CCR. In addition, state requirements, whether pursuant to permits or other regulatory mechanisms, may not necessarily correspond to the requirements of this rule.

EPA acknowledges that parties may be suspicious of information self-reported by regulated entities. However, it is important to remember that facilities that provide information in compliance with these regulation remain subject to the penalties for providing false information under 18 U.S.C. 1001, even though the information will not be submitted to EPA. For example, the Tenth Circuit has held that federal jurisdiction lies under 18 U.S.C. 1001 when a defendant has submitted false information to a state delegated to enforce a federal environmental statute. *United States* v. *Wright,* 988 F.2d 1036 (10th Cir. 1993) (defendant submitted false monitoring reports required by the Safe Drinking Water Act to Oklahoma officials). This is consistent with rulings in other areas that the false statement need not be made directly to the federal government. *United States* v. *Uni Oil Co.,* 646 F.2d 946, 954–55 (9th Cir. 1981); *see also United States* v. *Patullo,* 709 F.2d 1178, 1180 (7th Cir. 1983); *United States* v. *Ross,* 77 F.3d 1525, 1544 (7th Cir. 1996) (''This court has repeatedly found the submission of a fraudulent statement to a private (or non-federal government) entity to be within the jurisdiction of a federal agency where the agency has given funding to the entity and fraudulent statements cause the entity to utilize the funds improperly.''). As commenters recognized, the potential for criminal penalties under 18 U.S.C. 1001 provides a significant guarantee, as well as a strong incentive for compliance.

EPA also disagrees with the comments raising concern about the homeland security implications of posting information on a CCR surface impoundment's construction, as it relates to structural stability. Much of the information relevant to an impoundment's structural stability is currently available through Google Earth or through EPA's Web site. For example, EPA's Web site currently provides access to all of the information from the responses to EPA's original 104(e) information requires and the information obtained through the CCR Assessment Program. This information can be accessed at the following pages: *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys/index.htm*, *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys2/index.htm*, and *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/ccrs-fs/index.htm.* Moreover, the Department of Homeland Security has cleared both the internet posting of all of the information currently on EPA's Web site, as well as, in general, information on the design, hydraulic parameters, volume of contained liquids and solids, and hazard rating of all major CCR surface impoundments across the U.S.

VI. Development of the Final Rule—Technical Requirements

A. Applicability

EPA proposed general provisions to identify those solid waste disposal units subject to the proposed RCRA subpart D requirements (*i.e.,* CCR landfills and CCR surface impoundments as defined under proposed § 257.40(b)). The applicability section also identified three of the existing subpart A criteria that would continue to apply to these facilities: § 257.3–1 *Floodplains,* § 257.3–2 *Endangered Species,* and § 257.3–3 *Surface Water.* Consistent with RCRA section 4004(c), EPA specified an effective date of 180 days after publication of the final rule.

The Agency received numerous comments on this part of the rule. In

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general, commenters were concerned with three specific areas. First, commenters requested additional clarification as to the specific sources of CCR that would be subject to the requirements of the rule, *i.e.,* CCR generated by the electric utilities and independent power producers. Second, commenters requested clarification on the applicability of the proposed regulations to MSWLFs disposing of CCR and third, the definition and status of ''uniquely associated wastes.'' Uniquely associated wastes are addressed in Unit XIII of this preamble. EPA also received numerous comments regarding the proposal to apply the rule to ''inactive'' CCR surface impoundments that had not completed closure prior to the effective date of the rule.

EPA is finalizing minimum national criteria that apply to owners and operators of new and existing CCR landfills and CCR surface impoundments, including any lateral expansions of these units that dispose, or otherwise conduct solid waste management of CCR generated from the combustion of coal at electric utilities and independent power producers. The rule applies only to CCR units at ''active'' electric utilities and independent power producers, *i.e.,* those that generate electricity, regardless of the fuel currently used to produce electricity. However, disposal units at facilities that are ''closed''—*i.e.,* the entire facility has been permanently taken out of service and no longer produces electricity—are outside of the scope of this rule.

Unless otherwise provided, the rule applies to CCR units located both on-site and off-site of the electric utility or independent power producer.

1. CCR Generated by Non-Utility Boilers

The requirements of this rule do not apply to wastes, including fly ash, bottom ash, boiler slag, and FGD materials generated at facilities that are not part of the electric power sector or an independent power producer and that use coal as the fuel in non-utility boilers, such as manufacturing facilities, universities, and hospitals. Industries that primarily burn coal to generate power for their own purposes (*i.e.,* non-utilities), also known as combined heat and power (CHP) plants, are primarily engaged in business activities, such as agriculture, mining, manufacturing, transportation, and education. The electricity that they generate is mainly for their own use, but any excess may be sold in the wholesale market. According to the Energy Information Administration (EIA), CHPs produced less than one percent of the total electricity generated from coal combustion in 2013 and, similarly, burned less than one percent of the total coal consumed for electricity generation or less than 5 million tons (*http://www.eia.gov/electricity/data.cfm*).

EPA never proposed to include these wastes in the rule because EPA lacked critical data from these facilities that would allow us to address key Bevill criteria (see 75 FR 35165). These other industries, and the manufacturing industries in particular, generate other types of wastes which are likely to be mixed or co-managed with the CCR at least at some facilities. As a result, the chemical compositions of the co-managed wastes are likely to be fundamentally different from the chemical composition of CCR generated by electric utilities or independent power producers. In addition, EPA noted that insufficient information was available on non-utility boilers burning coal to determine whether a regulatory flexibility analysis would be required under the Regulatory Flexibility Act, and to conduct one if it is necessary. Without such data, we were unable to fully assess CCR wastes from non-utility operations and indicated that we would decide on an appropriate course of action for these wastes after completing this rulemaking (see 75 FR 35129).

Several commenters stated that EPA's decision to propose limiting the scope of the rule only to CCR generated by the electric power sector (electric utilities and independent power producers) was arbitrary. These commenters claimed that CCR generated by the electric power sector and CCR generated by non-utilities are generally comparable in physical and chemical composition and are typically managed similarly. As a result, these commenters suggested that EPA amend the applicability of the rule to subject all facilities that generate CCR to the same disposal requirements. EPA also received comments maintaining that important differences exist between CCR generated by electric power sector facilities and non-utility facilities, and that supported EPA's proposed decision to exclude CCR generated by non-utilities from the rule. Differences identified by the commenters included waste management issues (*e.g.,* mixing and subsequent co-management of non-utility CCR and other industrial wastes generated by non-utilities), CCR generation rates, CCR management unit design, and CCR management unit operation. In response to our request for additional information, a few commenters provided either waste characterization data for non-utility CCR or information on alleged damage cases involving non-utility CCR.

Based on the proposed rule, EPA cannot include these facilities in this final rule, even if the Agency had concluded that it had received the necessary information from commenters. EPA specifically stated its intention to exclude them, and clearly stated that it had not assessed the operations. (See 75 FR 35166.) The Agency provided no indication of any intention to include such facilities, and did not solicit comment on such an option. Moreover, under the Administrative Procedure Act, the public must be given the opportunity to comment on not only the information that would support such an action, but also EPA's evaluation of that information, and the reasoning behind the Agency's decision. And with respect to this subset of facilities, no such opportunity has been presented. EPA will consider the information provided by commenters at a future point, and will determine whether the information is sufficient to address key Bevill criteria and to decide on the appropriate regulatory scheme for disposal of CCR generated by non-utilities. Accordingly, this rule does not apply to owners and operators of landfills and surface impoundments in which CCR are disposed that were generated by non-utility boilers burning coal.

2. CCR Generated Primarily From the Combustion of Fuels Other Than Coal

These requirements also do not apply to fly ash, bottom ash, boiler slag, and flue gas desulfurization materials, generated primarily from the combustion of fuels (including other fossil fuels) other than coal, for the purpose of generating electricity unless the coal comprises more than fifty percent (50%) of the fuel burned on a total heat input or mass input basis, whichever results in the greater mass feed rate of coal (see § 266.112). Fuel mixtures that contain less than 50% coal are not considered to be CCR, but other fossil fuel wastes. Other fossil fuels that are typically co-combusted with coal are oil and natural gas. In the May 22, 2000 Regulatory Determination, EPA determined that it is not appropriate to establish national regulations applicable to oil combustion wastes (OCW) because: (1) We found in most cases that OCW, whether managed alone or co-managed, are rarely characteristically hazardous; (2) we have not identified any beneficial uses that are likely to present significant risks to human health or the environment; (3) we identified no significant ecological risks posed by

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land disposal of OCW; (4) we identified only one documented damage case involving OCW in combination with coal combustion wastes, and it did not affect human receptors; and (5) except for two unlined surface impoundments, we have not identified any significant risks to human health and the environment associated with any waste management practices. Similarly, EPA determined that regulating natural gas combustion wastes is not warranted because the burning of natural gas produces virtually no solid waste. Therefore, the Agency has determined that regulations for wastes generated primarily from the combustion of fuels (including other fossil fuels) other than coal are not warranted unless the fuel mixture consists primarily of coal.

3. Placement of CCR in Minefilling Operations

Consistent with the approach in the proposed rule, this rule does not apply to CCR placed in active or abandoned underground or surface coal mines. The U. S. Department of Interior (DOI) and EPA will address the management of CCR in minefills in a separate regulatory action(s). EPA will work with the OSM to develop effective federal regulations to ensure that the placement of coal combustion residuals in minefill operations is adequately controlled. In doing so, EPA and OSM will consider the recommendations of the National Research Council (NRC), which, at the direction of Congress, studied the health, safety, and environmental risks associated with the placement of CCR in active and abandoned coal mines in all major U.S. coal basins. The NRC published its findings on March 1, 2006, in a report entitled ''Managing Coal Combustion Residues (CCR) in Mines,'' which is available at *http://books.nap.edu/openbook.php?isbn=0309100496*.

The report concluded that the ''placement of CCR in mines as part of coal mine reclamation may be an appropriate option for the disposal of this material. In such situations, however, an integrated process of CCR characterization, site characterization, management and engineering design of placement activities, and design and implementation of monitoring is required to reduce the risk of contamination moving from the mine site to the ambient environment.'' The NRC report recommended that enforceable federal standards be established for the disposal of CCR in minefills to ensure that states have specific authority and that states implement adequate safeguards. The NRC Committee on Mine Placement of Coal Combustion Wastes also stated that OSM and its SMCRA state partners should take the lead in developing new national standards for CCR use in mines because the framework is in place to deal with mine-related issues. Consistent with the recommendations of the National Academy of Sciences, EPA anticipates that the U.S. Department of the Interior (DOI) will take the lead in developing these regulations. EPA will work closely with DOI throughout that process.

4. Municipal Solid Waste Landfills

The issue receiving the majority of comment in this section focused on the applicability of the rule to MSWLFs accepting CCR. The vast majority of commenters on this issue requested that EPA clarify that permitted MSWLFs, receiving CCR as daily cover or for disposal were not covered by the rule.

While most CCR is currently disposed of at electric utility owned CCR landfills or surface impoundments, there is no prohibition against disposing of CCR in state-permitted MSWLFs. However, many commenters interpreted the proposed CCR subtitle D regulations to apply to a state permitted MSWLF disposing of CCR, which as a consequence would be subject to the additional burden of posting documentation to a Web site, having a professional engineer review certification, etc. (See 75 FR 35210, where the preamble states that under a subtitle D regulation, regulated CCR wastes shipped off-site for disposal would have to be sent to facilities that meet the standards above.) Commenters argued that since MSWLFs were never mentioned in the proposed rule, that it should be made clear that the rule did not apply to these facilities. Commenters further contended that since the requirements for CCR landfills were directly modeled from the MSWLF requirements found at 40 CFR part 258, disposal in MSWLFs would be protective of human health and the environment. Commenters also contended that a benefit of MSWLFs would be their ability to provide additional capacity for the disposal of CCR as utilities seek to close, upgrade, or develop their own compliant CCR disposal sites.

EPA recognizes that there are MSWLFs that either accept CCR for disposal, use CCR for as daily cover, or both. Since the proposed and final RCRA subtitle D standards for CCR landfills are modeled after the standards for MSWLFs found at 40 CFR part 258, EPA has concluded that disposal of CCR in MSWLFs is as protective as disposal in a CCR landfill and that permitted MSWLFs are not subject to the requirements of this rule. Like the MSWLF requirements, the CCR technical criteria require new units to have composite liners or their equivalent, and all units are subject to location restrictions, run-on and run-off controls, fugitive dust controls, groundwater monitoring and corrective action, closure and post-closure care requirements.[38]

While the MSWLF fugitive dust criteria (air criteria) are not as specific as those in this rule, § 258.4(a) states that owners or operators of all MSWLFs must ensure that the units not violate any applicable requirements developed under a State Implementation Plan (SIP) approved or promulgated by the Administrator pursuant to section 110 of the Clean Air Act, as amended. It is expected that states will impose additional requirements to address fugitive dusts, of the sort codified in Illinois' 415 ILCS 5/9(a)(2012)[39] and enforced by the state (see *People of the State of Illinois* v. *KCBX Terminals Company,* Injunction no. 2013CH24788 in the Circuit Court of Cook County, Illinois. Moreover, if used as a daily cover, § 258.21 requires that the alternative cover (*i.e.,* CCR) control disease, vectors, odors, blowing litter, and scavenging without presenting a threat to human health and the environment.

The Agency is not requiring MSWLFs that receive CCR for disposal or for use as daily cover to modify their groundwater monitoring programs to comply with the rule; however the Agency expects that State Directors will require MSWLFs to modify their MSWLF permits to address the addition of CCR to the unit as it relates to groundwater monitoring and corrective action. Section 258.54(a)(2) allows for the Director of an approved state to establish an alternative list of inorganic indicator parameters for a MSWLF unit if the alternative parameters provide a reliable indication of inorganic releases

[38] One significant difference however is that MSWLFs are required to have financial assurance, a requirement not applicable to CCR under the subtitle D requirements.

[39] ''No person shall (a) Cause or threaten or allow the discharge or emission of any contaminant into the environment in any state so as to cause or tend to cause air pollution in Illinois, either alone or in combination with contaminants from other sources, or so as to violate regulations or standards adopted by the Board under this Act; (b) Construct, install or operate any equipment, facility, vehicle, vessel, or aircraft capable of causing or contributing to air pollution or designed to prevent air pollution, of any typed designated by Board regulations, (1) without a permit granted by the Agency unless otherwise exempt by this Act or Board regulations; or (2) in violation of any conditions imposed by such permit.''

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from the MSWLF unit to the groundwater (*i.e.,* as would be the case if CCR was disposed in the MSWLF unit). In determining alternative parameters, the Director shall consider, among other things: (1) The types, quantities, and concentrations in wastes managed at the MSWLF unit; (2) the mobility, stability, and persistence of waste constituents or their reaction products in the unsaturated zone beneath the MSWLF unit; and (3) the detectability of indicator parameters, waste constituents, and reaction products in the groundwater. In situations where the MSWLF unit is receiving CCR for disposal and/or daily cover, EPA expects the controlled management of CCR in these units. Specifically, EPA expects State Directors to utilize the provisions in § 258.54(a)(2) to revise the detection monitoring constituents to include those constituents being promulgated in this rule under § 257.90. These detection monitoring constituents or inorganic indicator parameters are: boron, calcium, chloride, fluoride, pH, sulfate and total dissolved solids (TDS). These inorganic indicator parameters are known to be leading indicators of releases of contaminants associated with CCR and the Agency strongly recommends that State Directors add these constituents to the list of indicator parameters to be monitored during detection monitoring of groundwater if and when a MSWLF decides to accept CCR.

The Agency has concluded that CCR can readily be handled in permitted MSWLFs provided that they are evaluated for waste compatibility and placement as required under the part 258 requirements. Furthermore, consistent with the recordkeeping requirements in § 258.29, the Agency further expects State Directors to encourage MSWLF units receiving CCR after the effective date of this rule to do so pursuant to a ''CCR acceptance plan'' that is maintained in the facility operating record. This plan would assure that the MSWLF facility is aware of the physical and chemical characteristics of the waste received (*i.e.,* CCR) and handles it with the additional precautions necessary to avoid dust, maintain structural integrity, and avoid compromising the gas and leachate collection systems of the landfill so that human health and the environment are protected. While the Agency sees no need to impose duplicative requirements for MSWLFs that receive CCR for disposal or daily cover; development of these acceptance plans as well as a revised list of groundwater detection monitoring constituents will help ensure that CCR is being managed in the most protective manner consistent with the Part 258 requirements.

5. Inactive CCR Surface Impoundments

The final rule also applies to ''inactive'' CCR surface impoundments at any active electric utilities or independent power producers, regardless of the fuel currently being used to produce electricity; *i.e.,* surface impoundments at any active electric utility or independent power producer that have ceased receiving CCR or otherwise actively managing CCR. While it is true that EPA exempted inactive units from the part 258 requirements in 1990, the original subtitle D regulations at 40 CFR part 257 (which are currently applicable to CCR wastes) applied to ''all solid waste disposal facilities and practices'' except for eleven specifically enumerated exemptions (none of which are relevant). 40 CFR 257.1(c). See also, 40 CFR 257.1(a)(1)–(2). And as discussed in greater detail below, subtitle D of RCRA does not limit EPA's authority to active units—that is, units that receive or otherwise manage wastes after the effective date of the regulations. EPA has documented several damage cases that have occurred due to inactive CCR surface impoundments, including the release of CCR and wastewater from an inactive CCR surface impoundment into the Dan River which occurred since publication of the CCR proposed rule. As discussed in the proposal, the risks associated with inactive CCR surface impoundments do not differ significantly from the risks associated with active CCR surface impoundments; much of the risk from these units is driven by the hydraulic head imposed by impounded units. These conditions remain present in both active and inactive units, which continue to impound liquid along with CCR. For all these reasons, the Agency has concluded that inactive CCR surface impoundments require regulatory oversight.

The sole exception is for ''inactive'' CCR surface impoundments that have completed dewatering and capping operations (in accordance with the capping requirements finalized in this rule) within three years of the publication of this rule. EPA considers these units to be analogous to inactive CCR landfills, which are not subject to the final rule. As noted, EPA's risk assessment shows that the highest risks are associated with CCR surface impoundments due to the hydraulic head imposed by impounded water. Dewatered CCR surface impoundments will no longer be subjected to hydraulic head so the risk of releases, including the risk that the unit will leach into the groundwater, would be no greater than those from CCR landfills. Similarly, the requirements of this rule do not apply to inactive CCR landfills—which are CCR landfills that do not accept waste after the effective date of the regulations. The Agency is not aware of any damage cases associated with inactive CCR landfills, and as noted, the risks of release from such units are significantly lower than CCR surface impoundments or active CCR landfills. In the absence of this type of evidence, and consistent with the proposal, the Agency has decided not to cover these units in this final rule.

Under both the subtitle C and subtitle D options, EPA proposed to regulate ''inactive'' CCR surface impoundments that had not completed closure prior to the effective date of the rule. EPA proposed that if any inactive CCR surface impoundment had not met the interim status closure requirements (*i.e.,* dewatered and capped) by the effective date of the rule, the unit would be subject to all of the requirements applicable to CCR surface impoundments. Under the subtitle C option, those requirements would have included compliance with the interim status and permitting regulations. Under subtitle D, such units would have been required to comply with all of the criteria applicable to CCR surface impoundments that continued to receive wastes, including groundwater monitoring, corrective action, and closure.

EPA acknowledged that this represented a departure from the Agency's long-standing implementation of the regulatory program under subtitle C. While the statutory definition of ''disposal'' has been broadly interpreted to include passive leaking, historically EPA has construed the definition of ''disposal'' more narrowly for the purposes of implementing the subtitle C regulatory requirements. For examples see 43 FR 58984 (Dec. 18, 1978); and 45 FR 33074 (May 1980). Although in some situations, post-placement management has been considered to be disposal triggering RCRA subtitle C regulatory requirements, *e.g.,* dredging of impoundments or management of leachate, EPA has generally interpreted the statute to require a permit only if a facility treats, stores, or actively disposes of the waste after the effective date of its designation as a hazardous waste. EPA explained that relying on a broader interpretation was appropriate in this instance given that the

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substantial risks associated with currently operating CCR surface impoundments, *i.e.,* the potential for leachate and other releases to contaminate groundwater and the potential for catastrophic releases from structural failures, were not measurably different than the risks associated with ''inactive'' CCR surface impoundments that continued to impound liquid, even though the facility had ceased to place additional wastes in the unit. EPA noted as well that the risks are primarily driven by the older existing units, which are generally unlined.

In the section of the preamble discussing the subtitle D option, EPA did not expressly highlight the application of the rule to inactive CCR surface impoundments, but generally explained that EPA's approach to developing the proposed subtitle D requirements for surface impoundments (which are not addressed by the part 258 regulations that served as the model for the proposed landfill requirements) was to seek to be consistent with the technical requirements developed under the subtitle C option. (See 75 FR 35193.) (''In addition, EPA considered that many of the technical requirements that EPA developed to specifically address the risks from the disposal of CCR as part of the subtitle C alternative would be equally justified under a RCRA subtitle D regime . . . The factual record—*i.e.,* the risk analysis and the damage cases—supporting such requirements is the same, irrespective of the statutory authority under which the Agency is operating . . . Thus several of the provisions EPA is proposing under RCRA subtitle D either correspond to the provisions EPA is proposing to establish for RCRA subtitle C requirement. These provisions include the following regulatory provisions specific to CCR that EPA is proposing to establish: *Scope and applicability (i.e., who will be subject to the rule criteria/ requirements*) . . .'') (emphasis added).

EPA received numerous comments on this aspect of the proposal. On the whole, the comments were focused on EPA's legal authority under subtitle C to regulate inactive and closed units, as well as inactive and closed facilities. One group of commenters, however, specifically criticized the proposed subtitle D regulation on the grounds that it failed to address the risks from inactive CCR surface impoundments. The majority of commenters, however, argued that RCRA does not authorize EPA to regulate inactive or closed surface impoundments. These commenters focused on two primary arguments: first, that RCRA's definition of ''disposal'' cannot be interpreted to include ''passive migration'' based on the plain language of the statute, and second, that such an interpretation conflicted with court decisions in several circuits, holding that under CERCLA ''disposal'' does not include passive leaking or the migration of contaminants.

In support of their first argument, commenters argued that the plain language of RCRA demonstrates that the requirements are ''prospective in nature'' and thus cannot be interpreted to apply to past activities, *i.e.,* the past disposals in inactive CCR units. They also argued that the absence of the word ''leaching'' from the definition of ''disposal'' clearly indicates that Congress did not intend to cover passive leaking or migration from CCR units. The commenters also selectively quoted portions of past EPA statements, claiming that these demonstrated that EPA had conclusively interpreted RCRA to preclude jurisdiction over inactive units and facilities. In particular, they pointed to EPA's decision in 1980 not to require permits for closed or inactive facilities.

Commenters cited several cases to support their second claim. These include *Carson Harbor Vill.* v. *Unocal Corp.,* 270 F.3d 863 (9th Cir. 2001); *United States* v. *150 Acres of Land,* 204 F.3d 698, 706 (2000); *ABB Industrial Systems* v. *Prime Technology,* 120 F.3d 351, 358 (2d Cir. 1997); *United States* v. *CMDG Realty Co.,* 96 F.3d 706, 711 (3rd Cir. 1996); *Joslyn Mfg. Co.* v. *Koppers Co.,* 40 F.3d 750, 762 (5th Cir. 1994); *Delaney* v. *Town of Carmel,* 55 F. Supp. 2d 237, 256 (S.D.N.Y. 1999); *see also Interfaith Cmty. Org.* v. *Honey-Well Intl Inc.,* 263 F. Supp. 2d 796, 846 n.10 (D.N.J. 2003). The commenters acknowledged that these cases were all decided under CERCLA, but claim that the cases are all equally dispositive with respect to RCRA's definition of disposal because CERCLA specifically incorporates by reference RCRA's statutory definition of disposal.

As an initial matter, it is important to correct certain misunderstandings contained throughout a number of the comments. First, EPA did propose to include inactive units under the subtitle D alternative. EPA clearly signaled its intent to cover the same universe of units and facilities covered under the subtitle C proposal. EPA did not include a corresponding discussion in its explanation of the subtitle D alternative because application of the criteria to inactive units did not represent such a significant departure from EPA's past practice or interpretation. As discussed in more detail below, the original subtitle D regulations applied to all existing disposal units. See 40 CFR 257.1(a)(1)–(2), (c) and 43 FR 4942–4943, 4944.

Second, several commenters criticized EPA's purported proposal to cover both ''closed'' and ''inactive'' surface impoundments, using the terms interchangeably. These same commenters also refer to both ''inactive facilities'' and ''inactive units.'' These are all different concepts, and EPA clearly distinguished between them.

EPA proposed to regulate only ''inactive'' surface impoundments that had not completed closure of the surface impoundment before the effective date. ''Inactive'' surface impoundments are those that contain both CCR and water, but no longer receive additional wastes. By contrast, a ''closed'' surface impoundment would no longer contain water, although it may continue to contain CCR (or other wastes), and would be capped or otherwise maintained. There is little difference between the potential risks of an active and inactive surface impoundment; both can leak into groundwater, and both are subject to structural failures that release the wastes into the environment, including catastrophic failures leading to massive releases that threaten both human health and the environment. This is clearly demonstrated by the recent spill in the Dan River in North Carolina, which occurred as the result of a structural failure at an inactive surface impoundment. Similarly, as demonstrated by the discovery of additional damage cases upon the recent installation of groundwater monitoring systems at existing CCR surface impoundments in Michigan and Illinois, many existing CCR surface impoundments are currently leaking, albeit currently undetected. These are the risks the disposal rule specifically seeks to address, and there is no logical basis for distinguishing between units that present the same risks.

EPA did not propose to require ''closed'' surface impoundments to ''reclose.'' Nor did EPA intend, as the same commenters claim, that ''literally hundreds of previously closed . . . surface impoundments—many of which were properly closed decades ago under state solid waste programs, have changed owners, and now have structures built on top of them—would be considered active CCR units.'' Accordingly, the final rule does not impose any requirements on any CCR surface impoundments that have in fact ''closed'' before the rule's effective date—*i.e.,* those that no longer contain water and can no longer impound liquid.

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Further, EPA never proposed that the rule would apply to inactive facilities. The proposal was clear that the regulations would apply to active facilities—*i.e.,* those that continue to generate electricity for distribution to the public, and those that continue to manage CCR. Consistent with that proposal, the final rule applies only to inactive surface impoundments at active electric utilities, *i.e.,* facilities that are actively generating electricity irrespective of the fuel used.

Finally, some comments focused on issues that were specific to the plain language of subtitle C provisions. While most of the issues the commenters raised relate equally to EPA's authority under both subtitles C and D, because the final rule establishes standards under subtitle D of RCRA, EPA has not addressed comments that are purely relevant or applicable to the extent of EPA's authority under subtitle C.

a. Plain Language of RCRA and EPA's Past Interpretations

Under both subtitle C and subtitle D, EPA's authority to regulate ''inactive'' units primarily stems from the agency's authority to regulate ''disposal.'' The term is defined once in RCRA and applies to both subtitles C and D. Moreover, the definition explicitly includes ''leaking'' and ''placing of any solid waste . . . into or on any land so that such [waste] or any constituent thereof may enter the environment . . . or be discharged into any waters, including groundwaters.'' 42 U.S.C. 6903(3).

Commenters focused on the past statements that EPA cited in the proposal in acknowledging that the Agency was proposing to revise its interpretation for this rulemaking. In general, the comments misconstrue the significance of these past statements. The cited passages merely explain that the *permitting requirements* in subtitle C were written to be ''prospective in nature'' and as a consequence, EPA has chosen to interpret ''disposal'' more narrowly *in that context.* Thus EPA's historic interpretation under subtitle C was not based on an interpretation that the plain language of RCRA's definition of ''disposal'' precluded reaching inactive units, but on a determination that a narrower interpretation would be reasonable in light of specific language in sections 3004 and 3005, and the practical consequences of applying *these* requirements to inactive facilities.[40]

None of EPA's past statements included any interpretation that ''leaking'' does not include leaking from an inactive disposal unit, or that the statutory definition of ''disposal'' cannot be interpreted to apply to the current consequences of past disposals. To the contrary, EPA was clear in the original 1978 proposed hazardous waste regulations that leaking from inactive disposal units constitutes ''disposal'' under RCRA.

Neither RCRA nor its legislative history discusses whether section 3004 standards for owners and operators of hazardous waste treatment, storage, or disposal facilities apply or were intended to apply to inactive facilities, *i.e.,* those facilities which have ceased receiving, treating, storing, and disposing of wastes prior to the effective date of the subtitle C regulations. ''*This is an important issue, however, because some, and perhaps most, inactive facilities may still be ''disposing of waste'' within the meaning of that term in Section 1004(3) of RCRA.* 'Disposal' includes: the discharge, dumping, spilling, leaking, . . . of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including groundwaters. *Many inactive facilities may well be leaking solid or hazardous waste into groundwater and thus be ''disposing'' under RCRA.*'' 43 FR 58984 (emphasis added).

Note as well that EPA declined to impose requirements on ''inactive *facilities*'' not ''inactive *units* at active facilities,'' which are the entities covered in this final CCR rule. Further, the complications discussed in 1978 were specific to inactive or closed facilities: the concern that the present owner of the land on which an inactive site was located might have no connection (other than present ownership of the land) with the prior disposal activities. Id. These considerations are not relevant to inactive CCR surface impoundments at active electric utilities.

EPA further clarified this position in the 1980 final hazardous waste rule, explaining that, while the Agency did not generally intend to regulate those portions of facilities that had closed before the effective date, there were exceptions to this, and that in individual cases, inactive portions of a facility—or in other words, inactive units, might be regulated.

> [O]wners and operators which continue to operate after the effective date of the regulations must ensure that portions of facilities closed before the effective date of these rules do not interfere with the monitoring or control of active portions. This requirement regulates the facility which operates under the RCRA regulations, although it may require the owner or operator before he receives a permit, or, as a permit condition, to take certain measures on portions of his facility closed before the effective date of these regulations.

45 FR 33068. (See also 45 FR 33170.)

In other words, EPA was clear that its jurisdiction under RCRA extended to these portions of the facility but that the Agency had made a policy choice not to exert its regulatory jurisdiction as a general matter over inactive facilities, choosing instead to rely on section 7003 and CERCLA to address the risks and require clean-up of these sites. EPA has adopted a substantially similar approach here, requiring the current owner or operator of an active facility to address the risks associated with an inactive portion of the facility that could potentially interfere with the monitoring or control of the actively operating portion of the facility through leaking contaminants or other releases.

Similarly, in the 1980 final rules, EPA expressly declined to revise the regulatory definition of disposal to exclude accidental or unintentional releases. EPA noted that ''[r]egardless of whether a discharge of hazardous waste is intentional or not, the human health and environmental effects are the same. Thus intentional and unintentional discharges are included in the definition of 'disposal.' '' (See 45 FR 33068.) While EPA revised other provisions to clarify that a permit would not be required for accidental discharges, EPA was clear that such activities are properly considered to be ''disposal.''

By contrast, EPA's past implementation of subtitle D, following from the legislative history and the statutory language, consistently applied regulatory requirements equally to all facilities, without distinguishing between active and inactive or new and existing facilities.

Congress was clear that subtitle D was intended to specifically address the problem of abandoned leaking ''open dumps'' scattered across the country, ''where frequently the use of the site for waste disposal is neither authorized nor supervised.'' H. Rep. No. 94–1491, p 37, 94th Cong., 2d Sess (1976). For example, the report described the consequences when ''the City of Texarcana Arkansas/Texas, abandoned its six open dumps, in 1968'' to support the need to require open dumps to upgrade or close.

[40] It is also clear that certain subtitle C requirements in fact do apply to inactive units, for example, section 3004(u) requires facilities to clean up releases from inactive units located on the facility site.

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Similarly, in describing the need for the legislation, the House report stated:

> Disposal of solid wastes, including hazardous wastes, can have adverse environmental impacts in several ways. The following paragraphs discuss five different types of such impacts.
>
> (i) Perhaps the most pernicious effect is the contamination of groundwater by leachate from land disposal of waste. About half of the U.S. domestic water supply is from underground water, and thus is potentially subject to contamination. Such contamination is particularly vexing because often it is discovered after the damage is done and because the contamination is very long lasting. Thus leachate from a landfill or dump may not show up for years, *maybe not even until after the landfill is closed*.

Id. at 89 (emphasis added).

Consequently, subtitle D of RCRA provides clear authority to address inactive or abandoned disposal sites. The relevant provisions of RCRA subtitle D do not distinguish between ''active'' and ''inactive'' disposal units. Nor do any of the relevant provisions tie jurisdiction to the receipt or disposal of waste after a specific date.

RCRA section 1004(14) defines an ''open dump'' as ''*any* facility or site where solid waste is disposed of which is not a sanitary landfill which meets the criteria promulgated under section [4004] of this chapter and which is not a facility for disposal of hazardous waste.'' 42 U.S.C. 6903(14) (emphasis added). Section 4004(a) delegates broad authority to EPA to determine the facilities that will be considered ''open dumps,'' without any requirement that the units or facilities be in operation. ''[T]he Administrator shall promulgate regulations containing criteria for determining which facilities shall be classified as sanitary landfills and which shall be classified open dumps within the meaning of this chapter.'' 42 U.S.C. 6944(a). Section 4005(a), which is titled, ''Closing or upgrading of existing open dumps,'' is also not limited in scope: ''Upon promulgation of criteria under [1008(a)(3)] of this title, *any* solid waste management practice of disposal of solid waste or hazardous waste which constitutes the open dumping of solid or hazardous waste is prohibited, . . .'' 42 U.S.C. 6945(a) (emphasis added). See also, section 4003(a)(3), requiring state plans to provide for the closing or upgrading of ''*all existing* open dumps''). 42 U.S.C. 6943(a)(3) (emphasis added).

Consistent with the statutory provisions, EPA's current subtitle D regulations at 40 CFR part 257 apply to ''all solid waste disposal facilities and practices'' whether active or inactive, and did not differentiate between new and existing facilities.[41] 40 CFR 257.1(c). See also, 40 CFR 257.1(a)(1)–(2). EPA was clear in both the proposed and final rules that the rules applied to all existing facilities: ''These criteria for the classification of disposal facilities apply to all ''solid waste'' and ''disposal'' facilities, which are defined in the Act [in] (section 1004).'' 43 FR 4942–4943, 4944. The final rule was equally clear: ''These criteria apply to the full range of facilities and practices for ''disposal'' of ''solid waste,'' as those terms are defined in the Act.'' 44 FR 53440. (See also 44 FR 53438.) The final rule describes eight categories of materials or activities that are excluded; inactive facilities or units are not among them. This stands in stark contrast to the hazardous waste regulations, which, as discussed, specifically exempted inactive facilities from the permitting and associated regulatory requirements.

b. Case Law on the Definition of Disposal

EPA also disagrees with the commenters' second claim that regulating inactive surface impoundments would be inconsistent with case law in six circuits. The commenters are correct that some courts have held that the subsequent passive migration of contamination left on-site is insufficient to support liability against a *third party* that merely owned the property *under CERCLA.* But the commenters misconstrue this case law and fundamentally overstate its significance to the issue at hand. Of greater significance, however, is that federal courts have almost universally reached different conclusions under RCRA, holding that the statutory definition of disposal does include the passive migration of contamination from previously disposed of wastes.

As an initial matter, the issue decided by the courts in the cited CERCLA cases was narrower than the commenters allege; these cases generally focused on whether current or past owners of land contaminated by the activities of *other owners* were liable for passive migration that occurred during their ownership of the land. This is very different than the situation at hand, in which regulatory requirements are being imposed to address the existing and future contamination caused by the past and current activities of the current owner.

In addition, these decisions were largely predicated on language that is unique to CERCLA, rather than on a definitive reading of RCRA's definition of disposal. *See, e.g., United States* v. *CMDG Realty Co.,* supra at 712–717. For example, in *CMDG Realty,* the court found that passive migration was not disposal because Congress had clearly distinguished between ''releases,'' and ''disposal,'' defining the two terms differently and imposing liability on different parties for the two activities. Id. *Accord, Carson Harbor Village, supra,* at 880–885; *ABB Industrial Systems* v. *Prime Technology,* supra at 358.

Moreover, even under CERCLA courts have not universally reached the same conclusions on whether ''passive migration'' can be considered ''disposal.'' *See, e.g., Nurad, Inc.* v. *William E. Hooper & Sons Co.,* 966 F.2d 837, 844–46 (4th Cir. 1992) (concluding that because the definition of disposal includes ''leaking,'' prior owners are liable if they acquired a site with leaking barrels or underground storage tanks even though the prior owner's actions are purely passive); *ABB Industrial Systems,* Id., n.3 (expressly declining to decide whether passive migration could ever be considered ''disposal'').

But in any event, courts have consistently interpreted RCRA to apply to passive migration. Two cases under RCRA are the most directly analogous to the current situation as they address the extent of EPA's authority to regulate based on the statutory definition of ''disposal'': *In re Consolidated Land Disposal Regulation Litigation,* 938 F.2d 1386 (D.C. Cir. 1991), and *United States* v. *Power Engineering Co.,* 10 F. Supp. 2d 1145 (D. Colo. 1998), *aff'd* 191 F.3d 1224 (10th Cir. 1999). In both cases, the court considered whether EPA could impose or enforce regulatory requirements to address passive migration under the interpretation that this constituted ''disposal'' under RCRA. And in both cases the court agreed that RCRA's definition encompassed such activities.

The issue in *Consolidated Land Disposal* was whether EPA could require closed hazardous waste facilities to obtain a ''post-closure'' permit. 938 F.2d at 1388–1389. EPA had relied on the definition of disposal to support the regulation, concluding that a facility ''at which hazardous wastes have been disposed by placement in or on the land'' remains subject to both permitting and regulation because ''such hazardous wastes or constituents may continue 'leaking' or 'may enter the environment or be emitted . . . or discharged . . .'" into the environment.'' Id. Similar to the commenters' current arguments, the petitioners argued that under § 3005, a permit can only be required for ''on-

[41] The regulations establish eleven specifically enumerated exemptions, none of which are relevant to the units at issue.

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going activities''—the treatment, storage, or disposal of waste at such facilities—not for the facility itself post-closure. The petitioners argued that linguistically, ''disposal . . . is not a continuing activity but occurs anew each time waste is placed into or on land.'' The D.C. Circuit summarily rejected the petitioners' interpretation, holding that this ''may be one way in which the word is used in ordinary language, but is not necessarily how it is used in the statute; the equation of ''disposal'' with ''leaking,'' which is a continuous phenomenon rather than a discrete event, is enough to blunt the sting of the petitioners' point.'' Id. This case is essentially dispositive of the issue, given the similarities between the requirement for a post-closure permit and the final requirements applicable to inactive CCR surface impoundments. Electric utilities retain ownership and control over these existing CCR units, just as hazardous waste facilities retain ownership and control over the closed units subject to post-closure permitting. In both situations, EPA requirements are designed to address both the existing and future risks of further ''releases'' or ''leaking'' from these units—*i.e.,* further disposal, as that term is defined in section 1004.

Similarly, in *Power Engineering* the court considered whether under section 3008 of RCRA, EPA could bring an action to compel the operator of a metal refinishing plant to comply with the state's RCRA regulations relating to financial assurance.[42] 10 F. Supp.2d at 1159. The defendants argued that since they were not currently disposing of waste, they were operating in compliance with state regulations and were exempt from financial assurance requirements. The court disagreed. It held that the use of the word ''leaking'' in the definition of ''disposal'' indicated that the leaching of hazardous waste into the groundwater constitutes the continuing disposal of hazardous waste. Id. at 1159–60 (''Because the definition of ''disposal'' includes the word ''leaking,'' disposal occurs not only when a solid waste or a hazardous waste is first deposited onto ground or into water, but also when such wastes migrate from their initial disposal location.'').

Courts in several circuits have also considered whether the passive migration of previously dumped waste constitutes a current or ongoing violation of RCRA, *i.e.,* illegal ''disposal,'' under the citizen suit provisions of section 7002(a)(1)(A). Most have concluded that it does. *See, Scarlett & Associates* v. *Briarcliff Center Partners,* 2009 WL 3151089 (N.D. Ga 2009) (deciding to ''follow the majority rule'' and holding that ''the continued presence of migrating waste constitutes a continuing violation under the RCRA''); *Marrero Hernandez* v. *Esso Standard Oil Co.,* 597 F. Supp. 2d 272, 283 (D.P.R. 2009) (holding that unremedied, migrating contamination is not a wholly past violation); *Cameron* v. *Peach County, GA,* No. 5:02–CV–41–1 (CAR), 2004 WL 5520003 (M.D. Ga. 2004) (holding that the continued presence of illegal contamination that remains remedial constitutes a continuing violation, even though the acts of unlawful disposal occurred in the past); *California* v. *M&P Investments,* 308 F. Supp. 2d 1137, 1146–1147 (E.D. CA 2003) (Allowing RCRA 7002 claim of continuing violation to proceed on evidence that wastes ''continue to exist unremediated'' as a result of improper discharge that had ceased over 20 years prior to filing of suit); *Aurora National Bank* v. *TriStar Marketing,* 990 F. Supp. 1020, 1025 (N.D. Ill. 1998) (''Although subsection (a)(1)(A) does not permit a citizen suit for wholly past violations of the statute, the continued presence of illegally dumped materials generally constitutes a 'continuing violation' of the RCRA, which is cognizable under § 6972(a)(1)(A).'') (internal citation omitted); *City of Toledo* v. *Beazer Materials & Servs., Inc.,* 833 F. Supp. 646, 656 (N.D. Ohio 1993) (''[T]he disposal of wastes can constitute a continuing violation so long as no proper disposal procedures are put into effect or as long as the waste has not been cleaned up and the environmental effects remain remediable.''); *Gache* v. *Town of Harrison,* 813 F. Supp. 1037, 1041–42 (S.D.N.Y. 1993) (''The environmental harms do not stem from the act of dumping when waste materials slide off the dump truck but rather after they land and begin to seep into the ground, contaminating soil and water. So long as wastes remain in the landfill threatening to leach into the surrounding soil and water, a continuing violation sure may exist.''); *Acme Printing Ink Co.* v. *Menard, Inc.,* 812 F. Supp. 1498, 1512 (E.D. Wisc. 1992) (''RCRA includes in its broad definition of 'disposal' the continuous leaking of hazardous substances. . . . Accordingly, leaking of hazardous substances may constitute a continuous or intermittent violation of RCRA.''); *Fallowfield Dev. Corp.* v. *Strunk,* No. 89–8644, 1990 WL 52745 (E.D. Pa. 1990) (''If a person disposes of hazardous waste on a parcel of property, the hazardous waste remains in that property insidiously infecting the soil and groundwater aquifers. In other words, the violation continues until the proper disposal procedures are put into effect or the hazardous waste is cleaned up.''). It is particularly notable that these cases were all decided under subsection (A); in contrast to subsection (B), section 7002(a)(1)(A) does not include any reference to liability for past actions or for prior owners. *Compare,* 42 U.S.C. 6972(a)(1)(A) and (B). In reaching their holdings, therefore, the courts necessarily relied [solely] on the reach of the statutory definition of ''disposal,'' which is at the heart of EPA's authority to regulate inactive CCR surface impoundments.

Courts have also addressed the limits of RCRA's definition of ''disposal'' is in the context of an EPA action under RCRA section 7003. Section 7003 authorizes EPA to obtain injunctive relief for actions, including disposal that ''may present an imminent and substantial endangerment to health or the environment.'' 42 U.S.C. 6973(a). Several courts have evaluated whether an inactive disposal site, where no affirmative acts of disposal are occurring, constitute an ''imminent and substantial endangerment'' under this provision. Once again, most courts accept a definition of disposal that encompasses leaking or contaminant migration from previously discarded wastes. *See United States* v. *Price,* 523 F. Supp. 1055, 1071 (D.N.J. 1981), *aff'd United States* v. *Price,* 688 F.2d 204 (3rd Cir. 1982) (''There is no doubt, however, that [section 70003] authorizes the cleanup of a site, even a dormant one, if that action is necessary to abate a present threat to the public health or the environment.'') *citing* S. Rep. No. 96–848, 96th Cong., 2d Sess., at 11 (1980); H. R. Rep. 96–1016 (Part I), 96th Cong., 2nd Sess., at 21 reprinted in [1980] U.S. Code Cong. & Ad. News, 6119, 6124; *United States* v. *Waste Indus.,* 734 F.2d 159 (4th Cir. 1984) (Rejecting district court interpretation that disposal only includes ''active human conduct'' based on the inclusion of ''leaking'' in the definition of disposal, and interpreting the ''movement of the waste after it has been placed in a state of repose [to be] encompassed in the broad definition of disposal''); *United States* v. *Diamond Shamrock Corp.,* 12 Envtl. L. Rep. 20819, 20821 (N.D. Ohio May 29, 1981) (noting that ''a disposal clearly requires no active human conduct''); *United States* v. *Conservation Chemical Co.,*

[42] Under RCRA's financial assurance regulations, owners and operators of hazardous waste facilities must document that they have sufficient resources to close their facilities and pay third-party claims that may arise.

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619 F. Supp. 162, 200 (D. Mo. 1985) (''`disposal' occurs. . .when [wastes] migrate from their initial location''). See also S. Rep. 98–284, p 58 (98th Cong. 1st Sess.) (''The Environmental Protection Agency and the Department of Justice have used the equitable authority and [sic] granted in section 7003 to seek court orders directing those persons whose past or present acts have contributed to or are contributing to the existence of an imminent and substantial endangerment to abate such conditions. This has been an intended use of the section 7003 since 1976. . . . An [sic] evidenced by the definition of `disposal' in section 1004(3), which includes the leaking of hazardous wastes, section 7003 has always provided the authority to require the abatement of present conditions of endangerment resulting from past disposal practices, whether intentional or unintentional.'').

While EPA continues to maintain that the statutory definition of disposal does in fact authorize regulation of inactive CCR surface impoundments, this is not the sole basis for that authority. Under section 1008(a)(3), EPA is authorized to establish criteria governing solid waste management, which includes the ''storage'' of solid waste. 42 U.S.C. 6904(28) and 6908(a)(3). RCRA's definition of ''storage'' is limited to hazardous waste; under subtitle D, therefore, the definition Congress intended was the dictionary definition, which incontrovertibly covers the activities associated with continuing to maintain CCR in inactive surface impoundments. For example, Merriam Webster defines ''storage'' as ''the state of being kept in a place when not being used'' and ''the act of putting something that is not being used in a place where it is available, where it can be kept safely, etc.''

Finally, consistent with the proposed rule and the final Regulatory Determination in Unit IV.B of this document, the final rule does not apply to CCR that is beneficially used.

6. Beneficial Use

The proposed rule generally distinguished between the disposal of CCR and the beneficial use of CCR. Disposal activities would be subject to regulation under one of two alternative regulatory schemes. But under either alternative, beneficial use would remain Bevill exempt and would not be subject to regulation. The proposal identified specific criteria that would be used to distinguish between legitimate beneficial uses of CCR and the disposal of CCR. These criteria were largely drawn from the approach contained in the May 2000 Bevill Regulatory Determination. The criteria were:

—The material used must provide a functional benefit. For example, CCR in concrete increases the durability of concrete—and is more effective in combating degradation from salt water; synthetic gypsum serves exactly the same function in wallboard as mined gypsum, and meets all commercial specifications; CCR as a soil amendment adjusts the pH of soil to promote plant growth.

—The material substitutes for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction. For example, the use of FGD gypsum in the manufacture of wallboard (drywall) decreases the need to mine natural gypsum, thereby conserving the natural resource and conserving energy that otherwise would be needed to mine natural gypsum; the use of fly ash in lieu of Portland cement reduces the need for cement. CCR used in road bed replace quarried aggregate or other industrial materials.

—Where relevant product specifications or regulatory standards are available, the materials meet those specifications, and where such specifications or standards have not been established, they are not being used in excess quantities. For example, when CCR is used as a commercial product, the amount of CCR used is controlled by product specifications, or the demands of the user. Fly ash used as a stabilized base course in highway construction is part of many engineering considerations, such as the ASTM C 593 test for compaction, the ASTM D 560 freezing and thawing test, and a seven day compressive strength above 2760 kPa (400 psi). If excessive volumes of CCR are used—*i.e.,* greater than were necessary for a specific project,—that could be grounds for a determination that the use is not beneficial, but rather is being disposed of. 75 FR 35162–35163.

EPA explained that in the case of agricultural uses, CCR would be expected to meet appropriate standards, constituent levels, prescribed total loads, application rates, etc. EPA has developed specific standards governing agricultural application of biosolids. While the management scenarios differ between biosludge application and the use of CCR as soil amendments, EPA stated that the Agency would consider application of CCR for agriculture uses not to be a legitimate beneficial use if they occurred at constituent levels or loading rates greater than EPA's biosolids regulations allow. (75 FR 35162–35163, June 21, 2010)

EPA proposed to codify these criteria in the term, ''beneficial use of coal combustion products (CCPs).'' This definition stated that the beneficial use of CCPs was the use of CCPs that provides a functional benefit; replaces the use of an alternative material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; and meets relevant product specifications and regulatory standards (where these are available). CCPs that are used in excess quantities (*e.g.,* the field-applications of FGD gypsum in amounts that exceed scientifically-supported quantities required for enhancing soil properties and/or crop yields), placed as fill in sand and gravel pits, or used in large scale fill projects, such as restructuring the landscape, are excluded from this definition. (75 FR 35129–35130, June 21, 2010).

Commenters generally supported the criteria in the proposal but raised concern that the criteria lacked specificity; some commenters stated that the criteria were those that states already considered in doing their beneficial use determination. Commenters also suggested the use of a ''no toxics'' provision and others suggested that the criteria include a requirement that ''environmental benefits'' be achieved. A more general comment raised by several commenters was that the proposed criteria failed to establish any standard that ensured protection of human health and the environment. Finally, one commenter raised concern that EPA's approach to beneficial use, and particularly to large scale fill operations, inappropriately assumed that these operations constituted the disposal of solid waste, which, the commenter claimed was inconsistent with a series of judicial decisions.

There are generally three critical issues in determining whether a material is regulated under RCRA subtitle D: whether the material is a ''solid waste,'' whether the activity constitutes ''disposal,'' and whether regulation of the disposal is warranted. Although there can be some overlap between these issues in that the same facts may be relevant to each of them, understanding the distinction between them is critical to understanding the final approach to the beneficial use of CCR adopted in this rulemaking.

In order to be subject to RCRA, the material must be a solid waste. The statute defines a solid waste as ''any garbage, refuse . . . and other discarded material. . . .'' 42 U.S.C. 6903(27). As EPA noted in the proposed rule, for some beneficial uses, CCR is a raw

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material used as an ingredient in a manufacturing process that have never been ''discarded,'' and thus, would not be considered solid wastes under the existing RCRA regulations. For example, synthetic gypsum is a product of the FGD process at coal-fired power plants. In this case, the utility designs and operates its air pollution control devices to produce an optimal product, including the oxidation of the FGD to produce synthetic gypsum. In this example, after its production, the utility treats FGD as a valuable input into a production process, *i.e.,* as a product, rather than as something that is intended to be discarded. Wallboard plants are sited in close proximity to power plants for access to raw material, with a considerable investment involved. Thus, FGD gypsum used for wallboard manufacture is a product rather than a waste or discarded material. This use and similar uses of CCR that meet product specifications would not be regulated under the final rule.

However, this does not describe the majority of CCR, which are unambiguously wastes; after generation in the boiler, they are placed into landfills or surface impoundments. While they may subsequently be dredged from these units and reused, placement in a landfill or surface impoundment presents prima facie evidence of discard. At the time the material is placed into the unit, the utility is not treating the material as a valuable product or otherwise seeking to protect the material for use. Although the material may subsequently be reused if a buyer is found, the material is originally placed in the unit with the intent to let it remain in place if no buyer is found. The waste designation does not change merely because a material in a surface impoundment or landfill may in the future be beneficially reused.

For those materials that are ''wastes'' the second issue becomes relevant: whether the activities involved with the material constitutes ''disposal'' or ''solid waste management.'' The statute distinguishes between these activities and ''use;'' several activities are listed in the definitions of ''disposal'' and ''solid waste management'' and ''use'' is not among them. See 42 U.S.C. 6903(3) and (28). In general, commenters agreed that the three criteria in the proposal, and discussed above, would identify those activities that were properly considered to be legitimate beneficial uses rather than disposal. As several commenters noted, many state beneficial use programs rely on similar (or identical) criteria. And for encapsulated uses, EPA agrees that these three criteria are sufficient to distinguish between the activities that will be regulated as disposal under this final rule and those that will be considered beneficial use. Accordingly, EPA has adopted them in the final definition of ''beneficial use.''

But as EPA acknowledged in the proposal, the issues are more difficult with regard to unencapsulated uses. Because these uses involve the direct placement of CCR on the land, they are clearly more analogous to activities that have consistently been considered to be ''disposal.'' RCRA defines disposal to specifically include the ''placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment . . .'' 42 U.S.C. 6903(3). The issue is further complicated by the fact that there can be risks associated with placement of unencapsulated CCR on the land. As described in the proposal, CCR can leach toxic metals at levels of concern. The major risks associated with the placement of unencapsulated CCR on the land for beneficial use involved using large volumes of CCR to restructure the landscape, such as occurred at the Battlefield golf course, and placement in quarries and sand and gravel pits, such as occurred at the Gambrills, Maryland site. EPA acknowledged in the proposal that these types of operations would be subject to regulation as disposal, and so were not directly on point. However, because these damage cases involved the placement of unencapsulated CCR on the land, they raised questions regarding the safety of other uses of unencapsulated CCR that involved direct placement on the land. In addition, previous risk analyses do not address many of the use applications currently being implemented, and have not addressed the improved leachate characterization methods. EPA also noted that some scientific literature indicates that the uncontrolled (*i.e.,* excessive) application of CCR can lead to the potentially toxic accumulation of metals.[43]

As noted, several commenters raised concern that EPA's beneficial use criteria did not include any standard that ensured protection of human health and the environment. EPA agrees that a criterion that accounted for the potential risks of the land placement of unencapsulated CCR would be an appropriate element to include in differentiating between disposal and beneficial use. RCRA's definition of disposal includes some elements related to risk: specifically, the definition includes as a relevant concept that the waste or any constituent of concern ''may enter the environment.'' In this regard it is also relevant that not all disposal activities are regulated by EPA under subtitle D; rather, EPA only regulates those that present risks that exceed the Agency's acceptable risk levels.

Building off of these concepts, the Agency has developed an additional criterion to address both the question of whether the activity is appropriately considered to be ''disposal,'' and the question of whether that ''disposal'' warrants regulation. Because uses that fail to meet the beneficial use criteria will be considered disposal and would therefore be considered disposal subject to the final regulation, this fourth criterion was designed to exclude uses likely to present the same risks as the management practices regulated under other sections of the final rule. Thus, the final criterion directly correlates to the practices and the risks that the disposal regulations are designed to address: the risks associated with the placement of large quantities of CCR in a single concentrated location, such as a CCR landfill, as documented in the 2014 risk assessment and the damage cases.

As discussed in more detail below, to be considered a ''beneficial use,'' prior to initiating an activity that involves placing unencapsulated CCR on the land in amounts greater than 12,400 tons, in non-roadway applications, the user must demonstrate that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use.

EPA acknowledges that there may be risks associated with uses that are below this threshold, depending on the characteristics of the CCR, the amount of material and the manner in which it is placed, and (perhaps most important) the site conditions. Consequently, all unencapsulated uses, including use in road construction and agriculture, should be conducted with care, according to appropriate management

[43] See, for example, ''Effects of coal fly ash amended soils on trace element uptake in plant,'' S.S. Brake, R.R. Jensen, and J.M. Mattox, Environmental Geology, November 7, 2003 available at *http://www.springerlink.com/content/3c5gaq2qrkr5unvp/fulltext.pdf*; See information regarding the Town of Pines Groundwater Plume at *http://www.epa.gov/region5superfund/npl/sas_sites/INN000508071.htm.* Also see additional information for this site at *http://www.epa.gov/region5/sites/pines/#updates.*

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practices, and with appropriate characterization of the material and the site where the material will be placed. However, as discussed in the previous section, because the amounts and, in some cases, the manner in which the CCR are used are very different from the land disposal modeled in the risk assessment, EPA cannot extrapolate from the risk assessment to reach conclusions regarding the risks these uses may pose. And in the absence of such information, EPA cannot establish criteria to regulate these uses.

a. Final Definition of the Term ''Beneficial Use of CCR''

The final beneficial use criteria are as follows: (1) The CCR must provide a functional benefit; (2) The CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices such as extraction; (3) the use of CCR must meet relevant product specifications, regulatory standards, or design standards when available, and when such standards are not available, CCR are not used in excess quantities; and (4) when unencapsulated use of CCR involves placement on the land of 12,400 tons or more in non-roadway applications, the user must demonstrate and keep records, and provide such documentation upon request, that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. Any use that fails to comply with all of the relevant criteria will be considered to be disposal of CCR, subject to all of the requirements in the disposal regulations, and the user will be considered to be the owner or operator of a CCR disposal unit. Encapsulated uses need only comply with the first three criteria. Unencapsulated uses involving placement on the land of 12,400 tons or more in non-roadway applications that fail to meet all of the beneficial use criteria are considered a CCR unit. As previously noted, the first three criteria were discussed in the proposal and commenters generally supported these criteria, which establish flexible performance standards. As discussed above, the Agency has developed an additional criterion in response to comments, which generally reflects the issues discussed in the proposal. This additional criterion is designed to address the environmental and human health concerns associated with large-scale, unencapsulated uses that have features similar to landfills. These four criteria are discussed in greater detail in the sections below. Any user of CCR that, at a later time, believes that there could be a health or environmental issue associated with their beneficial use should work with their state agency to address any potential issue.

As noted above, encapsulated uses of CCR must only comply with the first three criteria. Encapsulated beneficial uses are those that bind the CCR into a solid matrix that minimizes their mobilization into the surrounding environment. Examples of encapsulated uses include, but are not limited to: (1) Filler or lightweight aggregate in concrete; (2) a replacement for, or raw material used in production of, cementitious components in concrete or bricks; (3) filler in plastics, rubber, and similar products; and (4) raw material in wallboard production.

Compliance with the first three criteria suffices because, as discussed in Unit IV of this document, the available information demonstrates that encapsulated uses of CCR raise minimal health or environmental concerns. The Agency did not receive any data to contradict this assessment during any of the comment periods. In addition, since publication of the proposal, the Agency conducted a study of FGD gypsum in wallboard and fly ash concrete, which further supports this conclusion. This study ''*Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard*'' (February 2014) concluded that ''environmental releases of constituents of potential concern (COPCs) from CCR fly ash concrete and FGD gypsum wallboard during use by the consumer are comparable to or lower than those from analogous non-CCR products, or are at or below relevant regulatory and health-based benchmarks for human and ecological receptors.''

Criteria 1: CCR must provide a functional benefit. This criterion is designed to ensure that the material performs a genuine function in the product or use; while it need not improve product performance when compared to the material for which it is substituting, CCR must genuinely be a necessary component of the product. In other words, there must be a legitimate reason for using CCR in the product other than the fact that it is an alternative to disposal of the material, *e.g.,* the material fulfils material specifications. For example, CCR provides a functional benefit when used as a replacement for cement in concrete because the CCR increases the durability of the concrete and is also more effective against degradation from salt water. FGD gypsum serves the same function in the production of wallboard as mined gypsum, and meets all product specification. Additionally, CCR can be used to adjust the pH of soils thereby increasing and promoting plant growth.

One commenter noted that many states already consider whether the material provides a functional benefit when making beneficial use determinations under their regulatory programs. The Agency agrees that this is an important criterion in determining whether a use is a ''beneficial use.'' To the extent that a state regulatory program has determined that a particular use provides a functional benefit, this may serve as evidence that this criterion has been met.

Criteria 2: CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction. This criterion is intended to ensure that the use is truly ''beneficial'' from an environmental perspective. Examples of CCR used as a substitute for a virgin material include FGD gypsum for mined gypsum and the use of fly ash in lieu of Portland cement thereby reducing the need for cement. The use of FGD gypsum in the manufacture of wallboard reduces the need to use virgin gypsum, thereby conserving natural resources (virgin gypsum) while conserving valuable energy that would be needed to mine the virgin gypsum. Similarly, the use of CCR fly ash in lieu of Portland cement reduces the overall need for cement. CCR used in a road bed application substitutes for the use of quarried natural materials that provide structural support for the road surface.

One commenter again highlighted that many states consider this criterion in their current state beneficial use programs. The Agency agrees that this second criterion is appropriate, and that conserving natural resources is an important function that should be encouraged. Here as well, potential users of CCR materials may choose to rely on a state determination to provide evidence that this criterion has been met.

Criteria 3: The use of CCR must meet relevant product specifications, regulatory standards, or design standards, when available, and where such specifications or standards have not been established, CCR may not be used in excess quantities. This criterion was intended to address both the legitimacy of the use and the potential environmental and human health

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consequences associated with the use of excess quantities of CCR, particularly unencapsulated CCR. If excessive volumes of CCR are used—*i.e.,* greater than necessary for a specific project—that calls into question whether the purpose of the application was in fact a sham to avoid compliance with the disposal regulations. In addition, the record demonstrates that the risks from use of CCR are more likely to be associated with large volumes, particularly for unencapsulated uses.

The Agency has modified this criterion slightly from the proposed rule. The proposed rule merely referenced ''relevant product specifications or regulatory standards'' and EPA was concerned that this was too narrow, and might not incorporate all of the relevant technical information currently available that provides guidance on what constitutes an excess amount. Consequently, in the final definition the Agency has added the phrase ''design standards.'' Design standards are different from product specifications, because they include things other than ''products.'' An example of a ''design standard'' would be technical guidance specifying that six inches of CCR is to be used in constructing a road.

EPA received several comments on this provision, several of which criticized the sole reliance on engineering performance standards. For example, one commenter questioned how the Agency would quantify acceptable amounts for each use if no specifications or standards were in place. One commenter stated that the Agency needs to rely on more than the existence of engineering performance standards or comparisons to typical application rates of mined materials as coal combustion wastes are unique materials and comparisons to typical rates of application of natural gypsum or other soil amendments are inappropriate. Another commenter suggested a provision that would require users to follow a plan to only use what is necessary to reach the desired effect, in lieu of product specifications.

EPA purposely did not attempt to establish product specifications for each potential beneficial use application. The potential products are too varied, and in many instances EPA lacks the necessary expertise (*e.g.,* to develop manufacturing specifications for individual products.). Nor is such an approach necessary. When CCR substitutes for other materials, the amount used is typically controlled by product specifications, particularly for encapsulated uses. Product specifications currently exist for many, if not most, of the significant uses of CCR and can be found in a variety of sources. For example, as previously described, fly ash used as a stabilized base course in highway construction is subject to both regulatory standards under DOT/FHWA, and engineering specifications, such as the ASTM C 593 test for compaction, the ASTM D 560 freezing and thawing test, and a seven-day compressive strength above 2760 kPa (400 psi).

Similarly, in an agricultural setting, EPA expects all appropriate standards, constituent levels, prescribed total loads, and application rates to be met. For example, EPA has developed specific standards governing the agricultural application of biosolids. While the management scenarios differ between biosludge application and the use of CCR as soil amendments, EPA would consider application of CCR for agriculture uses not to be a legitimate beneficial use if they occurred at constituent levels or loading rates greater than EPA's biosolids regulations. Several commenters also noted that agronomic rates currently exist for certain items such as peanuts, cotton, tomatoes, corn and soybeans.[44] EPA would generally consider application of CCR above these rates, or any other rate that has been scientifically justified, to constitute disposal rather than beneficial use.

Many other sources of technical reports and documents exist for other uses. ASTM Standard E2277–03 provides standard guidance and a methodology for using CCR in a structural fill and includes a consideration of engineering properties and behaviors, testing procedures, and design considerations relevant to constructing a structural fill project using CCR. Industry guidance, such as USWAG's ''*Engineering and Environmental Guidance on the Beneficial Use of Coal Combustion Products in Engineered Structural Fill Projects*'' may also provide information relevant to this issue. Further, some states, such as Wisconsin and Virginia, have developed environmental guidance for evaluating the suitability of a site prior to construction of a CCR structural fill.

While many of these documents do not establish binding requirements, nor is EPA seeking to make them binding on users, they provide evidence of the design and construction practices, including the amounts that are typically used throughout the industry, and provide a basis on which to evaluate whether excessive quantities have been used in a particular application. These types of documents are also relevant in making judgments on the larger question—whether the activity is legitimate reuse or merely sham disposal. In essence, product specifications serve the same function as the requirement suggested by a commenter for a plan to only use what is necessary to reach the desired effect.

Commenters were also concerned that the proposed standards, and particularly this criterion, did not include any provision that would ensure that CCR reuse was protective of human health and the environment. One commenter stated that product specifications and engineering standards do not speak to environmental risk or consumer exposure. This same commenter was concerned that the proposed criteria used circular logic by stating that excess materials were not to be used in cases where specifications or standards have not been established. Another commenter criticized this criterion because it did not include threshold levels that protect public health from the range of toxicants routinely found in coal ash.

EPA generally disagrees that the requirement to ensure that excessive volumes have not been used is unrelated to environmental and safety concerns. Minimizing the amount of material used in a product or released to the environment decreases potential exposures to the material. EPA agrees, however, that an additional criterion that more directly addresses the potential health and environmental risks is appropriate for unencapsulated uses, which present the greater potential for exposures of concern. As discussed in more detail below, the Agency has added a criterion to specifically require users of unencapsulated CCR to demonstrate that environmental and health related standards have been met. The criterion is a general performance standard that is equally applicable to all sites and uses and will account for a wide variety of potential exposures. By contrast, in order to establish toxicant ''threshold levels,'' EPA would need to develop risk assessments that account for the wide variety of potential uses and exposures. This is neither practical nor feasible, given the site specific nature of the potential risks and the myriad of potential uses. In addition, EPA disagrees that this is necessary, as the performance standard laid out in the fourth criterion will appropriately address the risks documented in the current record for these uses.

[44] Commenters argued that, at least in agronomic settings, there is no incentive to use excess amounts because it simply increases the grower's cost.

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Furthermore, as the Agency has previously stated in the May 2000 Regulatory Determination and the 2010 proposal, leaving the Bevill determination in place for beneficial use does not conflict with EPA's view that certain beneficial uses, *e.g.,* use in road construction and agriculture, should be conducted with care, according to appropriate management practices, and with appropriate characterization of the material and the site where the materials will be placed. EPA has concluded that the potential risks of these uses do not warrant federal regulation, but can be addressed, if necessary, in other ways.

State programs exist and have the expertise to address beneficial use applications. In addition, the Agency is currently developing a framework to address the risks associated with the beneficial use of unencapsulated materials. This framework is expected to be finalized in 2015; the framework will be available to assist in the implementation of issues associated with the unencapsulated uses of CCR. The Agency has also been working with the U.S. Department of Agriculture to address the risks associated with the agricultural use of CCR. In conclusion, the Agency believes that sufficient tools are available (or will soon be available) to address the site-specific risks associated with the beneficial use of CCR.

Criteria 4: When unencapsulated use of CCR involving placement on the land of 12,400 tons or more in non-roadway applications, the user must demonstrate and keep records, and provide such documentation upon request, that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. The Agency has established an environmental criterion to protect human health and the environment in response to numerous comments received on the proposal raising concern that additional provisions were necessary to ensure that unencapsulated uses of CCR needed to be conducted in an environmentally protective manner. The Agency discussed in the proposed rule the ways in which the use of CCR in an unencapsulated manner could affect groundwater, surface water, air and be associated with dust emissions. This fourth ''environmental'' criterion requires potential users to addresses potential risks from all of these pathways in order to avoid compliance with the final disposal requirements. Existing sources of guidance and standards (*e.g.,* ASTM E2277–03 and USWAG's ''*Engineering and Environmental Guidance on the Beneficial Use of Coal Combustion Products in Engineered Structural Fill Projects,*'' to name just two that are currently available), are available and may provide useful assistance for determining if the use of CCR are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. Information (*e.g.,* modeling results, proposed designs, risk assessments, etc.) that have been proposed or developed to comply with state standards that explicitly address the environmental impacts of unencapsulated uses may also be relevant to this determination.

i. Source of the 12,400 Ton Threshold and Fill Operations.

As discussed earlier in this section, the fourth criterion was designed to address whether the activity is appropriately considered to be ''disposal'' and whether that ''disposal'' warrants regulation. Thus, the final criterion correlates to the practices and the risks at issue: The placement of large quantities of CCR in a single concentrated location, as documented by the 2014 risk assessment and the damage cases.

In the proposed rule, EPA explained that the risks of greatest concern from unencapsulated beneficial uses were associated with the placement of CCR in quarries and sand and gravel pits, and with large scale fill operations used to re-grade the landscape. EPA generally proposed to define these operations as ''disposal'' rather than ''beneficial use.'' As discussed below, EPA has retained that approach with respect to the placement in sand and gravel pits and quarries; consequently the fourth criterion need not account for these uses. By contrast, EPA has not definitively concluded that ''large scale fill operations,'' per se, constitute the disposal of CCR. This is because EPA agrees with commenters that, if constructed correctly, large scale fill operations can meet all of the criteria for a beneficial use. But EPA also agrees that these applications can present risks to human health and the environment, and therefore has drafted the fourth criterion to specifically address the risks presented by these operations. The fourth criterion is thus tied to the Agency's general approach to large scale fill.

The Agency acknowledged in the proposal that additional guidance was warranted on what would constitute a large scale fill operation, and received numerous comments on this issue in response to the proposal. EPA requested comments again on the topic of large scale fills in a Notice of Data Availability (NODA). 78 FR 46940 (August 2, 2013). The NODA discussed the fact that many commenters on the proposed CCR rule stated that EPA should have developed a size criterion to define large scale fill operations. One commenter suggested 5,000 cubic yards as a size criterion for a CCR landfill, but did not provide a basis for this. Other commenters suggested size criteria but for different reasons than defining disposal criteria; for example, Wisconsin has a standard where all CCR used for unconfined and confined ''fill projects exceeding 5,000 cubic yards require concurrence by the State prior to commencement of the project.'' Similarly, West Virginia stated that ''unencapsulated use of CCR as structural fills not exceeding 10,000 cubic yards are approvable on a case-by-case basis.''

In the NODA, EPA identified three different types of data sets that could provide information relevant to developing appropriate criteria or to otherwise defining what constitutes a ''large scale'' fill operation. EPA solicited comment on the adequacy of the data sets and whether EPA should consider them for the purpose of creating criteria or a definition. The three data sets were: (1) The size of the structural fills that have resulted in damage cases; (2) the distribution of landfill sizes, derived either from an EPA Office of Water's questionnaire or from the landfill size distribution used in the proposed rule; and (3) the size distribution for large scale fills that have been constructed in North Carolina. Many commenters argued that it was entirely inappropriate for EPA to specify in the rule when a project constitutes beneficial use simply by volume or amount of structural fill necessary to construct a stable base for a building. Commenters argued that a large scale fill operation, if designed appropriately, constituted a legitimate beneficial use. In fact, industry commenters universally claimed that they were not aware of any damage cases or adverse environmental impacts associated with structural fills that had adhered to industry guidance (*e.g.,* ASTM standard E2277–03 for structural fills and the USWAG *Engineering and Environmental Guidance on the Beneficial Use of CCPs*

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in Engineered Structural Fill Projects), and argued that the history of well-designed and implemented engineered structural fills demonstrate that CCR can serve as a valuable resource in avoiding disturbing native ground to secure borrow soils where fill materials are needed to establish a final grade for a project site that meets the need of the proposed final use. To this end, the commenters also acknowledged that site characterization and characterization of the CCR are fundamental to the construction of fills across the U.S. Similarly, other commenters stated that size should not be the only criterion used to define large scale fill operations and highlighted that the site conditions, including such features as the hydraulic conductivity of the area, should also be an important criterion to consider. Still other commenters stated that CCR landfills cannot include large scale fill CCR beneficial use projects because such operations do not involve disposal of a solid waste. Rather, industry commenters argue that the determination as to what is disposal as opposed to beneficial use should be a determination that rests solely with state agencies. These commenters suggested that the determination as to whether a particular fill project constituted disposal, rather than beneficial use should be based on a series of factors, and not simply a size-cut-off. Finally, other commenters argued that the Agency incorrectly presumed that only large scale fill operations could cause environmental damage, and suggested that rather than regulating large scale fill operations solely on the basis of the volume or the amount of CCR involved, the information available to EPA from damage cases and monitoring data suggests that an additional, if not primary criteria for regulating fill operations, including those involved in highway construction, should include the prevention of CCR coming into contact with water. Focusing on the risks of concern—that large scale fills were effectively operating as landfills—the Agency reviewed the database of landfills used in the 2014 risk assessment and has established a threshold limit that corresponds to the smallest size landfill in the risk assessment database. EPA selected this threshold as the trigger for requiring an affirmative demonstration by the user that there will be no releases of concern as a consequence of the land application, because the available evidence in the record (*i.e.,* the 2014 risk assessment) demonstrates that at these volumes the potential risks are of such significance to warrant regulation. Based on this evidence, the burden then shifts to the potential user to demonstrate that these potential risks do not exist at the particular site or have been adequately mitigated. Under this approach, unencapsulated beneficial use applications greater than or equal to 12,400 tons can still be conducted without becoming subject to the disposal regulations by using engineering principles, such as a liner system, and demonstrating that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors. EPA agrees that the volume of CCR involved should not be the sole basis for determining whether an operation constitutes disposal. As such, the Agency is requiring the use of the fourth criterion in order to address any potential risks associated with unencapsulated uses of CCR that are in excess of 12,400 tons. Users will be required to make an affirmative demonstration relating to the potential environmental releases and the potential risks of the application (in addition to requiring compliance with the other three criteria). Specifically, users will be required to demonstrate that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. EPA expects such determinations to take into account a wide variety of factors, including the hydraulic conductivity of the area, proximity of the material to water, and the likelihood of contact with water. EPA also expects that such determinations would take into account, as many commenters acknowledged to be appropriate and necessary, the need for site characterization and characterization of the CCR. The fourth criterion was adopted in part, to address commenters' concern that the EPA should include a criterion that prevents the placement of CCR in water sources. These are legitimate concerns; existing damage cases show that the placement of CCR in sand and gravel pits was almost always associated with CCR being placed in contact with water. The fourth criterion will require the user to demonstrate that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. As a consequence of this requirement, EPA expects that significant changes may need to be made in order to proceed with a proposed use; for example, conducting the required assessment, may demonstrate that the only way to achieve the performance standard is to install engineering features, such a liner, as part of the proposed project.

Application of unencapsulated CCR to the land in volumes less than the 12,400 tons will not require an affirmative demonstration to be considered a beneficial use. While the Agency has sufficient information to document that unencapsulated uses can present a hazard, based on the current rulemaking record, EPA lacks the information necessary to demonstrate that unencapsulated uses in smaller amounts are likely to present a risk.[45] In other words, the evidence relating to these uses is not sufficient to shift the burden to the potential user to affirmatively demonstrate the safety of the proposed use. Nevertheless, the Agency expects potential users of unencapsulated CCR below this threshold to work with the states to determine the potential risks of the proposed use at the site and to adopt the appropriate controls necessary to address the risks. In this regard, EPA notes that the composition and leaching behavior of CCR being beneficially used may change over time due to upgrades in air pollution controls devices at coal-fired power plants. Further, initial determinations for existing beneficial use (BU) applications may have relied on single-point pH test methods (*e.g.,* TCLP, SPLP) that, depending on actual field conditions in which the applications are occurring, can under- or over-estimate leachate concentrations. Scientific advancements

[45] In November 2014, EPA received reports alleging that extensive groundwater monitoring data collected by the Wisconsin Department of Natural Resources demonstrated a correlation between beneficial uses of unencapsulated CCR below these thresholds and contaminated drinking water wells in southeastern Wisconsin. Insufficient time was available to allow EPA to evaluate these reports as part of this rulemaking. However, EPA will continue to evaluate the issues associated with unencapsulated uses of CCR, and to the extent available data demonstrate the need for revisions to these criteria, EPA will initiate the necessary rulemaking procedures.

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in leach test protocols have found that the degree of leaching can vary by several orders of magnitude. Accordingly, states overseeing CCR BU programs are encouraged to closely evaluate existing BU applications in light of ongoing scientific advances in tools and technologies to ensure these applications remain protective of human health and the environment. In addition, the Agency is working to provide assistance to states and potential users; this includes the release of the Agency's *Industrial Waste Evaluation Model* (IWEM), and the development of a framework for systematically assessing unencapsulated BU applications to aid in assessing whether there are environmental risks associated with site specific structural fills.

ii. Exclusion of Roadway Applications from the 4th Criterion. In the 2010 proposal, the Agency stated that the placement of unencapsulated CCR on the land, such as in road embankments, presented concerns, but that the amount and the manner in which they are used—subject to engineering specifications and material requirements rather than landfilling techniques—are very different from land disposal. The Agency highlighted the 2005 guidance that was developed by EPA, FHWA, DOE, ACAA, and USWAG, addressing the appropriate methodologies and engineering requirements for the use of coal ash in highway construction. Lastly, the Agency noted the difference in terms of volume; the difference between the amounts of CCR that could be disposed of in a landfill vs. the amount of CCR used in the construction of a roadbase (typically on the order of six to twelve inches thick).

EPA received a number of comments requesting that the definition of a CCR landfill exclude CCR used in highway and road construction projects and similar beneficial use projects authorized by an appropriate state agency. These commenters reasoned that the ''arbitrary cutoff' discussed in the NODA would inappropriately capture such uses.

The Agency has excluded roadways and associated embankments from the fourth criterion because the methods of application are sufficiently different from CCR landfills that EPA cannot extrapolate from the available risk information to determine whether these activities present similar risks. Roadways are subject to engineering specifications that generally specify CCR to be placed in a thin layer (*e.g.,* six to 12 inches) under a road. The placement under the surface of the road limits the degree to which rainwater can influence the leaching of the CCR.

There are also significant differences between the manner in which roadways and landfills can potentially impact groundwater. These include the nature of mixing in the media, the leaching patterns, and how input infiltration rates are generated. First, CCR landfills are typically a homogenously mixed system, and as a result, there are no spatial variations of the chemical and physical properties of the media (for example, bulk density, hydraulic conductivity and contaminant concentration). By contrast, roadways are generally constructed of several layers with different material properties (heterogeneity). This difference affects the hydraulic conductivity of a mass of CCR in a landfill, as compared to CCR placed in an embankment. Any potential leaching will tend to spread over the length of the embankment, as opposed to the leaching in a downward motion that would occur in a homogenously filled landfill.

Finally, (and perhaps most critically) the construction of roads and associated embankments are supervised and approved by State and/or Federal Department of Transportation (DOT) engineers who ensure compliance with engineering specifications

While EPA is exempting roadbed applications of 12,400 tons or larger from the fourth criterion, EPA is mindful of situations where large quantities of CCR have been used without appropriate engineering controls or where placement on the land has apparently far exceeded those necessary for the engineering use of the materials. One such situation occurred in Puerto Rico with CCR generated by the AES Coal Fired Power Plant in Guayama. As discussed in Unit IV.B of this document, CCR and an aggregate created from them (''AGREMAX'') were being used as fill in housing developments and in road projects. Over two million tons of this material was used between 2004 and 2012. When made aware of the situation, EPA raised concerns over the use of CCR and AGREMAX based on the fact that the Environmental Quality Board had not imposed engineering controls, specified appropriate uses, or otherwise limited the use of AGREMAX by the end users. Inspections of some of the sites where the material had been placed showed use in residential areas, areas close to wetlands and surface waters and/or over shallow sole source drinking water aquifers. In addition, in some cases the volumes appeared to be in excess of what was necessary for engineering uses and some sites appeared to be abandoned. This kind of situation will be directly addressed by the new beneficial use criteria promulgated in the final rule. To qualify as a beneficial use, the use of AGREMAX would need to meet all four of the criteria—that is, it must provide a functional benefit, substitute for a virgin material, meet product specifications, and in this case, the user would be required to make the environmental demonstration for the non-roadbed applications.

iii. Kinds of unencapsulated uses of CCR required to comply with the fourth criterion.

Unencapsulated uses of CCR are numerous and range, in total use, from hundreds of thousands of tons to millions of tons per year. These applications include, as examples, the following: (1) Flowable fill; (2) structural fills; (3) soil modification/ stabilization; (4) waste stabilization/ solidification; (5) use in agriculture as a soil amendment; and (6) aggregate.

Many of these unencapsulated uses, other than structural fills, are not generally expected to be used in amounts that would require an environmental demonstration under the fourth criterion. And for several of these applications, which can be structurally very different from landfills, EPA expects that even if these applications are used in amounts greater than 12,400 tons, potential users will be easily able to meet the performance standard. For example, the use of CCR for soil modification or stabilization, agriculture, waste stabilization/ solidification, aggregate or flowable fill applications, is generally not similar to the mounding that occurs in a landfill situation. These differences can have a tremendous bearing on the leaching potential of the CCR materials.

Structural fills, however, can be larger applications and so may be required to demonstrate compliance with the environmental standards in the fourth criterion more frequently. In addition, because structural fills can be similar to the landfills regulated in the final disposal rule, some proposed applications may need to install engineering features to meet the performance standard.

iv. Demonstration that ''environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use.''

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The environmental fourth criterion requires a potential use of CCR to compare analogous products or to perform an environmental assessment evaluating whether releases to the environment are at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use. A demonstration should consider the development of a conceptual model to assist in the determination of whether the environmental criteria contained in the definition of the term ''beneficial use of CCR'' can be demonstrated. Numerous potential pathways exist and these should be evaluated as necessary depending on the potential application of the CCR. Potential exposure pathways include exposure to groundwater, surface water, air, and soils. Generation of dust, leaching to groundwater and surface water, inhalation of mercury, and plant uptake are areas that need to be evaluated. A complete evaluation of the types of releases, the types of exposure and the receptors that may be potentially affected by a potential application will need to be conducted. A screening comparison will need to be performed comparing the concentrations of individual constituents of potential concern to the following benchmarks: human soil ingestion, ecological soil, tap water ingestion, fish ingestion, surface water, sediment, and inhalation. As an example, a user could compare a mercury concentration to a human health screening benchmark with an inhalation value of 300 ng/m^3. Existing documents that can be used to gain an understanding of conceptual models, pathways and regulatory limits include: *Risk Assessment Guidance for Superfund, Exposure Factors Handbook, Volumes I, II and III, Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual Part A, Industrial Waste Management Model (IWEM) Technical Backgrounds Document, Exposure Factors Handbook, Human and Ecological Risk Assessment of Coal Combustion Wastes*. In addition, although it is not directly applicable, a potential user of unencapsulated CCR may find it useful to consult the previously mentioned ''*Coal Combustion Residual Beneficial Use Evaluation: Fly Ash Concrete and FGD Gypsum Wallboard''* and the ''*Methodology for Evaluating Encapsulated Beneficial Uses of Coal Combustion Residuals*'' to assist in the determination of whether the unencapsulated CCR is comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use.

After the effective date of the final rule, any potential user of CCR that makes the demonstration in the fourth criterion must keep records and provide such documentation upon request.

b. Placement in Sand and Gravel Pits and Quarries

EPA proposed that, without exception, unencapsulated CCR placed in sand and gravel pits, and quarries should not constitute beneficial use, but disposal. The Agency highlighted a number of damage cases that involved the filling of old, unlined quarries or gravel pits with large quantities of unencapsulated CCR, under the guise of ''beneficial use.'' Because of the damage cases and the concern that in such instances, sand and gravel pits and quarries were essentially operating as landfills, EPA proposed to define the placement of CCR in sand and gravel pits or quarries as land disposal that would be subject to regulation under either of the proposed regulatory options. The proposal specifically defined a *CCR landfill* as a disposal facility or part of a facility where CCR are placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this part, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills.

Commenters stated that there were numerous examples of harm caused by the unencapsulated ''reuse'' in sand and gravel pits and quarries, which demonstrate that these unencapsulated uses were merely disposal in disguise, and must be regulated stringently under Subtitle C of RCRA to prevent the risks they pose of contaminating groundwater, surface water, and ecological systems with heavy metals and other harmful pollutants. In particular, they argue that ''There have already been at least 13 damage cases caused by the disposal of coal ash in sand and gravel pits or former quarries that led to contamination of water sources and/or ecological damages.'' Some commenters also agreed that placement in sand and gravel pits and quarries should not be considered beneficial use. For example, one commenter agreed that CCR placement in sand and gravel pits and quarries is ''disposal'' and not beneficial use while another commenter wrote that it concurs that large-scale fills in quarries in poorly engineered applications can cause negative impacts. Other commenters highlighted that damage cases related to sand and gravel pits and quarries were old practices that no longer take place. These commenters argued that while sand and gravel quarries have been used to dispose of CCR, it is not correct to assume that with proper engineering and environmental standards that CCR cannot be used beneficially to reclaim quarries for uses such as recreational areas, commercial or industrial uses, or to aesthetically improve the characteristics of the land.

EPA is finalizing its proposal that placement of CCR in sand and gravel pits constitutes disposal, rather than beneficial use. The final definition of a CCR landfill explicitly includes placement of CCR in sand and gravel pits and quarries. EPA has adopted this approach because the practice has resulted in numerous damage cases as a result of the highly permeable strata typically present at such sites. Moreover, while the commenters may be correct that ''with proper engineering measures, placement in sand and gravel pits and quarries can be conducted safely'', they submitted no data to support this contention. The only engineering features the available information demonstrate would be protective are those that have been determined to be necessary for CCR landfills—*i.e.,* composite liners and groundwater monitoring. And in the absence of these features, any future placement in sand and gravel pits and quarries could not meet the performance standard in the fourth criterion: *i.e.,* that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use.

B. Definitions

EPA proposed definitions for a number of key terms used in the proposed subtitle D rule that the Agency determined were necessary for the proper interpretation of the proposed requirements, *e.g., coal combustion residuals, existing CCR landfill.* (See 75 FR 35196–97, June 21, 2010.) In addition, EPA also proposed definitions for terms that were specific to certain regulatory requirements, *e.g., seismic impact zone*.

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EPA is finalizing many of the regulatory definitions that were proposed, some with modifications. Several definitions that were proposed have been removed because they are no longer relevant to this rulemaking and a number of new definitions have been added. Specifically, definitions that have been removed from the final rule include: natural water table, probable maximum precipitation, surface water, systemic toxicants and upstream toe. New definitions are discussed in the technical section of the rule for which they apply. The majority of the regulatory definitions contained in the proposed rule have been retained in the final rule, as proposed or with minor clarifying changes. These definitions are codified in § 257.53 and include the following: *acre foot, active life, aquifer, area capacity curves, areas susceptible to mass movement, coal combustion residuals (CCR), displacement, facility, factor of safety, fault, freeboard, groundwater, hazard potential classification, high hazard potential surface impoundment, significant hazard potential surface impoundment, low hazard potential surface impoundment, holocene, hydraulic conductivity, karst terrain, lithified earth material, maximum horizontal acceleration in lithified earth material, new CCR landfill, new CCR surface impoundment, operator, owner, poor foundation conditions, recognized and generally accepted good engineering practices, representative sample, run-off, run-on, sand and gravel pit or quarry, seismic impact zone, state, structural components, unstable area, uppermost aquifer,* and *waste boundary*.

Several definitions received a significant number of comments and upon further evaluation by EPA have been modified to better explain their meaning or intent. This includes the definitions for the following terms: *CCR landfill or landfill, CCR surface impoundment or impoundment, existing CCR landfill* and *existing CCR surface impoundment*. These comments, along with the revisions made in response are discussed in more detail below. In addition, EPA has revised a number of definitions, or added new definitions, to be consistent with revisions made in the corresponding technical requirements. These are discussed in the various sections of the preamble that address the specific technical requirement. For example, as discussed in Unit V of this document, EPA has revised the definition of ''independent registered professional engineer or hydrologist'' to ''qualified professional engineer'' to address the concerns raised in comments.

1. Definition of *CCR Landfill*

EPA proposed to define a *CCR landfill* as a disposal facility or part of a facility where CCR is placed in or on land and which is not a land treatment facility, a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground mine, a cave, or a corrective action management unit. For purposes of this subpart, landfills also include piles, sand and gravel pits, quarries, and/or large scale fill operations. Sites that are excavated so that more coal ash can be used as fill are also considered CCR landfills. (See 75 FR 35239.) The Agency received a significant number of comments on the proposed definition. These comments focused almost exclusively on the inclusion of ''large-scale fill operations'' and ''piles'' within the definition of CCR landfill. Regarding large-scale fills, commenters argued that one of the fundamental problems with the proposed definition was that it assumed all CCR placed in large scale fill operations constituted ''disposal'' of CCR (and that these operations therefore constitute CCR landfills) rather than beneficial use. Commenters further argued that CCR is often used in engineered fills, such as road base and road embankments and that these legitimate beneficial use operations should not be subject to the CCR landfill regulations.

Commenters also argued that ''piles'' should be omitted from the definition of a CCR landfill for a variety of reasons. Several commenters argued that including the word ''pile'' was overly broad and insufficiently prescriptive and would inappropriately capture on-going or short-term CCR management activities that did not constitute disposal, such as storage for beneficial use. These commenters also raised concern that including ''piles'' in the definition of CCR landfill without further clarification or specificity, *i.e.,* when used as part of a beneficial use operation, would negatively affect beneficial use activities. Other commenters raised concern that the term ''piles'' was too vague, and suggested that whether piles were treated as CCR landfills should be determined by the size of the piles, or the intent for which such piles exist. These commenters suggested the Agency should exclude small piles of CCR that are staged and/or consolidated prior to transport or placement for disposal. These commenters argued that subjecting all CCR piles to all of the landfill requirements was ''illogical and inappropriate.''

Certain commenters argued that piles should not be regulated under this rule because they do not present a significant risk to the environment, as evidenced by a lack of damage cases. Alternately, other commenters suggested that if EPA were to regulate piles, the Agency should consider a regulatory strategy other than regulation as a CCR landfill. One alternative regulatory strategy suggested was to include an option establishing a limit (*e.g.,* 180 days) on the amount of time that the CCR could be allowed to be maintained in a pile without regulation as a CCR landfill. Another option suggested was to develop a set of reasonable design and operating standards consistent with the uses and risks posed by piles. Such design standards could include the requirement for a low permeability underlayment or base such as asphalt, concrete or a high density polyethylene (HDPE) liner. Operating standards could include such provisions as labeling, and the requirement to remove at least 90 percent of the contents every 90 days, with a full cleanout annually.

EPA believes the suggested option to establish a time limit would be difficult to oversee and verify. States and citizens would have no way to determine when CCR is placed in a pile and when the CCR was subsequently removed. Therefore, EPA is rejecting this suggested option. The suggested option to develop appropriate design and operating standards is essentially the approach EPA has adopted, as discussed in more detail below. However, the final design and operating standards differ according to the management practices, and include measures to control fugitive dust, and for certain practices, require the installation of a composite liner and leachate collection system.

EPA discussed its final approach to large-scale fill operations in Unit V of this document; the definition of a CCR landfill has been revised to be consistent with the approach described in that section. As explained at length, EPA has adopted a final approach that distinguishes between beneficial use and the ''disposal'' of CCR. Activities that meet the definition of beneficial use are not subject to these regulations. Activities that do not meet all of the criteria in the definition of a beneficial use—and in particular, such activities that involve the placement of unencapsulated CCR on the land—are considered disposal and are subject to the requirements of this final rule. Consistent with this approach the final definition of a CCR landfill has been revised to clarify that it includes ''the

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use of CCR that does not meet the definition of a beneficial use of CCR.'' Waste piles, including those used to temporarily store or manage CCR on-site prior to disposal in a CCR landfill or subsequent beneficial use, have been retained within the definition of a CCR landfill. In making this determination the Agency was strongly influenced by the similarities in the potential risks posed by both waste piles and CCR landfills to human health, groundwater resources, or the air if improperly managed. Both CCR piles and CCR landfills are subject to external factors such as rain and wind, which can adversely affect human health and the environment. For example, uncontrolled run-on and run-off can result in ponding of water in and around the unit resulting in increased leachate which has the potential to affect groundwater. Similarly, absent dust control measures, such as the conditioning of CCR, both CCR landfills and CCR piles have the potential to generate significant amount of fugitive dust. Indeed, CCR piles are generally more susceptible to the creation of fugitive dusts. And contrary to the commenters' contention about the absence of damage cases, the single most frequent issue presented during the public hearings was the allegation by individual citizens of damage caused by fugitive dusts from neighboring CCR facilities. Moreover, the same pollution control measures, such as liners, leachate collection systems, and groundwater monitoring, will address the potential adverse effects from both of these units. As such, the Agency sees no reason to treat piles and landfills differently.

EPA also disagrees that the inclusion of CCR piles would capture on-going or short-term CCR management activities that do not constitute disposal. Irrespective of whether the facility is using the pile as ''temporary storage'' or ultimately intends to direct the CCR to beneficial use, by placing the CCR on the land with no containment or other method of preventing environmental exposures, the facility is engaging in an activity that clearly falls within the statutory definition of disposal. See 42 U.S.C. 6903(3)(''placing of solid waste . . . on any land, so that such solid waste . . . or any constituent thereof may enter the environment.'') Moreover, even where the facility intends the pile to be ''temporary,'' some amount of CCR inevitably remains in place. And if this was not the case, under section 1008(a)(3), EPA is authorized to establish criteria governing all aspects of solid waste management—which explicitly is defined to include ''storage'' as well as all of the other activities identified by the commenters—to ensure the protection of human health and the environment. See 42 U.S.C. 6903(28).

Nevertheless, EPA agrees that not every activity that involves the management of CCR must occur in a unit that meets all of the technical requirements of a CCR landfill (*e.g.,* groundwater monitoring). The key concern EPA is seeking to address with the inclusion of piles is the uncontrolled exposure from the extended, repeated, or indefinite placement of large amounts of unconsolidated CCR directly on the land. To the extent those exposures are controlled, whether through the use of tanks or some other kind of containment measures, the practice is neither considered to be a ''pile'' nor disposal in a landfill.

To clarify this, and in response to the concern that the term ''piles'' was too vague, EPA has adopted a definition of the term ''CCR pile'' to identify those ''piles'' that are subject to the disposal requirements in this regulation. The final regulation specifies that a CCR pile means any non-containerized accumulation of solid, non-flowing CCR that is placed on the land. This definition mirrors the existing definition of ''waste pile or pile'' from the part 257 regulations, (*i.e.,* the regulations that currently apply to CCR facilities), as well as the definition in part 260. The use of the phrase ''non-containerized'' is not intended to require that all activities occur within tanks or containment structures, but merely that specific measures have been adopted to control exposures to human health and the environment. This could include placement of the CCR on an impervious base such as asphalt, concrete, or a geomembrane; leachate and run-off collection; and walls or wind barriers. CCR managed in such a fashion would not be CCR piles and, therefore, not CCR landfills subject to this regulation. To further clarify how this relates to EPA's overall approach to beneficial use it is important to distinguish between CCR that is actually being used beneficially and CCR that may someday be used beneficially. CCR that is currently being used beneficially—for example, fly ash that has been transferred to a cement manufacturer and that is stored off-site in a ''temporary pile,'' and that complies with all of the criteria in the definition to be considered a beneficial use including the fourth criterion relating to the placement of large quantities of unconsolidated CCR on the land—would not be subject to the regulations applicable to CCR disposal. Accordingly, the final regulation specifies that practices that meet the definition of beneficial use of CCR are not subject to the 'disposal'' requirements of the rule.

By contrast, CCR located on-site that may someday be used beneficially but is not yet beneficially used remains subject to the disposal rule. Given that landfills and surface impoundments can be periodically dredged to provide material for beneficial use, any other approach would be impracticable, and would exclude from regulation many of the greatest sources of risk. An example of a ''pile'' that is not yet beneficially used is unconsolidated CCR placed on the land, that have been designated by the CCR facility to be transferred to another location for subsequent beneficial use (*e.g.,* use as road bed) in the near future.

Several commenters also suggested that the definition of a CCR landfill should explicitly exclude the use of CCR at surface coal mining and reclamation operations, to reflect the Agency's intention not to cover such activities. The Agency agrees and has revised the definition to explicitly provide that the term CCR landfill does not include the use of CCR at coal mining and reclamation operations.

Consequently, the Agency is finalizing a definition of ''CCR landfill or landfill'' that can be found in § 257.73. On a related matter, the definition of CCR landfill or landfill contains the terms ''sand and gravel pits or quarries.'' EPA proposed a ''sand and gravel pit and/or quarry'' to mean an excavation for the commercial extraction of aggregate for use in construction projects. The Agency received comments on the definition of sand and gravel pit and/or quarry suggesting that the term ''commercial extraction'' was too narrow. Specifically commenters were concerned it would exclude non-commercial extraction, such as gravel pits operated by municipalities, and exclude metallic mineral mines, nonmetallic mining for other than sand and gravel, and coal mines. EPA agrees that the use of the term ''commercial extraction'' renders the proposed definition too narrow, as there is no basis for distinguishing between commercial and non-commercial extraction, either because of the risks these activities pose, or any other consideration relevant to this rulemaking. EPA is, therefore, revising ''sand and gravel pit and/or quarry'' to mean an excavation for the extraction of aggregate, minerals, or metals. The term sand and gravel pit and/or quarry does not include subsurface or surface coal mines.

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2. Definition of CCR Surface Impoundment

EPA proposed to define a CCR surface impoundment to mean a facility or part of a facility which is a natural topographic depression, man-made excavation, or diked area formed primarily of earthen materials (although it may be lined with man-made materials) which is designed to hold an accumulation of CCR containing free liquids, and which is not an injection well. Examples of CCR surface impoundments are holding, storage, settling, and aeration pits, ponds and lagoons. CCR surface impoundments are used to receive CCR that have been sluiced (flushed or mixed with water to facilitate movement), or wastes from wet air pollution control devices, often in addition to other solid wastes.

The Agency received many comments on the proposed definition of CCR surface impoundment. The majority of commenters argued that the definition was overly broad and would inappropriately capture surface impoundments that are not designed to hold an accumulation of CCR. Commenters were concerned that the proposed definition could be interpreted to include downstream secondary and tertiary surface impoundments, such as polishing, cooling, wastewater and holding ponds that receive only de minimis amounts of CCR. Commenters reasoned that these types of units in no practical or technical sense could be described as units ''used to receive CCR that has been sluiced.''

Other commenters raised concern that the definition did not differentiate between temporary and permanent surface impoundments. Commenters stated that many facilities rely on short-term processing and storage before moving CCR off-site for beneficial use or permanent disposal and that these units should not be required to comply with all of the technical criteria required for more permanent disposal impoundments.

Upon further evaluation of the comments, the Agency has amended the definition of CCR surface impoundment to clarify the types of units that are covered by the rule. After reviewing the comments, EPA reviewed the risk assessment and the damage cases to determine the characteristics of the surface impoundments that are the source of the risks the rule seeks to address. Specifically, these are units that contain a large amount of CCR managed with water, under a hydraulic head that promotes the rapid leaching of contaminants. These risks do not differ materially according to the management activity (*i.e.,* whether it was ''treatment,'' ''storage'' or ''disposal'') that occurred in the unit, or whether the facility someday intended to divert the CCR to beneficial use. However, EPA agrees with commenters that units containing only truly ''de minimis'' levels of CCR are unlikely to present the significant risks this rule is intended to address.

EPA has therefore revised the definition to provide that a CCR surface impoundment as defined in this rule must meet three criteria: (1) The unit is a natural topographic depression, man-made excavation or diked area; (2) the unit is designed to hold an accumulation of CCR and liquid; and (3) the unit treats, stores or disposes of CCR. These criteria correspond to the units that are the source of the significant risks covered by this rule, and are consistent with the proposed rule. EPA agrees with commenters that relying solely on the criterion from the proposed rule that the unit be designed to accumulate CCR could inadvertently capture units that present significantly lower risks, such as process water or cooling water ponds, because, although they will accumulate any trace amounts of CCR that are present, they will not contain the significant quantities that give rise to the risks modeled in EPA's assessment. By contrast, units that are designed to hold an accumulation of CCR and in which treatment, storage, or disposal occurs will contain substantial amounts of CCR and consequently are a potentially significant source of contaminants. However, EPA disagrees that impoundments used for ''short-term processing and storage'' should not be required to comply with all of the technical criteria applicable to CCR surface impoundments. By ''short-term,'' the commenters mean that some portion of the CCR is removed from the unit; however, in EPA's experience these units are never completely dredged free of CCR. But however much is present at any given time, over the lifetime of these ''temporary'' units, large quantities of CCR impounded with water under a hydraulic head will be managed for extended periods of time. This gives rise to the conditions that both promote the leaching of contaminants from the CCR and are responsible for the static and dynamic loadings that create the potential for structural instability. These units therefore pose the same risks of releases due to structural instability and of leachate contaminating ground or surface water as the units in which CCR are ''permanently'' disposed.

The final definition makes extremely clear the impoundments that are covered by the rule, so an owner or operator will be able to easily discern whether a particular unit is a CCR surface impoundment. CCR surface impoundments do not include units generally referred to as cooling water ponds, process water ponds, wastewater treatment ponds, storm water holding ponds, or aeration ponds. These units are not designed to hold an accumulation of CCR, and in fact, do not generally contain significant amounts of CCR. Treatment, storage, or disposal of accumulated CCR also does not occur in these units. Conversely, a constructed primary settling pond that receives sluiced CCR directly from the electric utility would meet the definition of a CCR surface impoundment because it meets all three criteria of the definition: It is a man-made excavation and it is designed to hold an accumulation of CCR (*i.e.,* directly sluiced CCR). It also engages in the treatment of CCR through its settling operation. The CCR may be subsequently dredged for disposal or beneficial use elsewhere, or it may be permanently disposed within the unit. Similarly, secondary or tertiary impoundments that receive wet CCR or liquid with significant amounts of CCR from a preceding impoundment (*i.e.,* from a primary impoundment in the case of a secondary impoundment, or from a secondary impoundment in the case of a tertiary impoundment), even if they are ultimately dredged for land disposal elsewhere are also considered CCR surface impoundments and are covered by the rule. To illustrate further, consider a diked area in which wet CCR is accumulated for future transport to a CCR landfill or beneficial use. The unit is accumulating CCR, while allowing for the evaporation or removal of liquid (no free liquids) to facilitate transport to a CCR landfill or for beneficial use. In this instance, the unit again meets all three definition criteria, it is a diked area (*i.e.,* there is an embankment), it is accumulating CCR for ultimate disposal or beneficial use; and it is removing any free liquids, (*i.e.,* treatment). As such, this unit would meet the definition of CCR surface impoundment. In all of these examples significant quantities of CCR are impounded with water under a hydraulic head that will be managed for extended periods of time. This gives rise to the conditions that both promote the leaching of contaminants from the CCR and are responsible for the static and dynamic loadings that create the potential for structural instability. These units therefore all pose the same risks of

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releases due to structural instability and of leachate contaminating ground or surface water.

3. Definition of Existing CCR Landfill

EPA proposed to define an existing CCR landfill to mean a CCR landfill which was in operation on, or for which construction commenced prior to the effective date of the final rule. The proposed definition specified that a CCR landfill has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction; and either: (1) A continuous on-site, physical construction program has begun; or (2) the owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

In response to the proposed definition, the Agency received several comments arguing that the use of the phrase ''was in operation on, or for which construction commenced prior to'' would lead to confusion. Commenters contended that most units defined as CCR landfills at some point in time ''were in operation'' and had ''commenced construction'' prior to the effective date of the regulation. Commenters claimed that this definition would unnecessarily capture thousands of closed structural fill projects, including residential properties, commercial properties used by small businesses, and many recreational facilities. Furthermore, commenters doubted that EPA intended for the rule to cover all of these units and urged the Agency to clarify that closed units are excluded from the definition of existing CCR landfill.

Other commenters argued that the proposed definition of *existing CCR landfill* should be modified to include lateral expansions of operation units where such an expansion is within the site footprint of an area already approved and permitted by the state for the landfill. Commenters contended that while the proposed definition included undeveloped areas within the footprint of an approved permitted site, it also required that the construction be initiated at the site or that some type of binding contractual obligation be present. Commenters contended that the existence of a contractual obligation unfairly subjects undeveloped, yet approved permitted areas to design and operating standards for new CCR landfills based merely on the existence of a contract to commence construction. Commenters argued that such a distinction was arbitrary and capricious and provided no practical benefit. Other commenters questioned the usefulness of requiring a contractual obligation at all. As written, the commenters argued, that the definition was vague, unenforceable, and thus, not protective of human health and the environment. Commenters reasoned that there was no definitive or generally accepted meaning for the term ''substantial loss'' or the term ''reasonable time'' and an owner or operator, sensing that these proposed rules may be passed, could sign a contract now with minimum predetermined cancellation or modification penalties and a contract term of say five years or even longer to avoid the new unit requirements, *i.e.,* a composite liner.

The commenters are correct that EPA did not intend to cover inactive landfills under this rule. The Agency agrees that, as drafted, the proposed definition could cause confusion. EPA therefore deleted the phrase ''was in operation on the effective date of the rule'' and has substituted the phrase ''that receives CCR both before and after [the effective date of the rule].'' EPA also agrees that the phrase ''commenced construction prior to the effective date of the rule'' could similarly cause confusion. Therefore, the Agency has made a similar revision, by adding the phrase ''and receives CCR on or after [the effective date of the rule]'' after the phrase ''for which construction commenced prior to [the effective date of the rule].'' These revisions will clarify which units are covered by the technical requirement of the rule and alleviate any confusion. EPA is also making conforming modifications to the definition of *existing CCR surface impoundment.*

EPA disagrees that lateral expansions should be considered to be ''existing'' based solely on the fact that such an expansion is within the site footprint of an area already approved and permitted by the state. EPA has frequently distinguished between the types of requirements applicable to new and existing units, reasoning that in many instances, risk mitigation measures would be adequate such that existing units need not wholly retrofit to meet the new ''state of the art.'' For new units, however, the balance is generally struck in favor of requiring a greater degree of risk prevention, rather than relying solely on risk mitigation measures. In determining whether a unit is ''new'' or ''existing,'' EPA has historically considered that the equities lie in favor of considering a unit to be ''existing'' when there has been an irretrievable commitment of resources on the part of the facility. That has not occurred merely because permits have been obtained. While admittedly resources have been committed, at this stage modifications to the design and construction of the unit are still feasible. Specifically, the critical differences between the requirements applicable to new and existing CCR landfills are the type of liner that must be installed and the location restrictions that apply. Compliance with these requirements can be addressed through modifications to the design and construction of the unit, and are therefore readily feasible until construction has begun.

EPA agrees with those commenters who were concerned that the phrase, ''the owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time,'' is vague and potentially subject to abuse. While this phrase has been included in other EPA regulations, those regulations operate within a regulatory program overseen by a regulatory authority. No similar guarantee exists under these regulations. EPA could not discover a definitive or generally accepted meaning for the terms ''substantial loss'' or ''reasonable time,'' or develop sufficiently objective and determinate criteria for these concepts. Consequently, the Agency has decided to remove this provision from the definition of *existing CCR landfill.* EPA is retaining the two most important elements of the definition that will effectively determine whether the facility has irretrievably committed resources such that it would not reasonable to require compliance with all of the requirements applicable to new units. Accordingly, a unit will be considered to be existing if, first, the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction; and second, that a continuous on-site, physical construction program has begun (*i.e.,* groundbreaking has occurred). Therefore, EPA is finalizing the definition of *existing CCR landfill* that can be found in § 257.53.

4. Definition of *Existing CCR Surface Impoundment*

EPA proposed to define an *existing CCR surface impoundment* to mean a surface impoundment which was in operation on, or for which construction commenced prior to the effective date of the final rule. The proposal also specified that a CCR surface impoundment has commenced

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construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction; and either: (1) A continuous on-site, physical construction program has begun; or (2) the owner or operator has entered into contractual obligations—which cannot be cancelled or modified without substantial loss—for physical construction of the CCR landfill to be completed within a reasonable time.

EPA received many of the same comments on the definition of an existing CCR surface impoundment that were received on an existing CCR landfill. This included comments requesting clarification that the term did not include impoundments that had ceased receiving CCR before the effective date of the rule. Commenters also suggested that EPA modify the definition to include the phrase that the surface impoundment ''was in operation and had not yet ceased receiving CCR prior to the effective date of the rule'' to make clear that the definition did not encompass units that are no longer receiving CCR on the effective date of the rule, even though the unit may not have completed final closure prior to the rule's effective date. Commenters reasoned that units no longer receiving CCR on the effective date of the rule are not ''in operation'' and therefore should not be subject to the standards applicable to active units. Commenters also requested that EPA clarify that the definition of ''existing CCR surface impoundment'' include units that were in operation on the effective date of the rule and that periodically dredged out during the operating life of the impoundment. Commenters contended that while this may seem self-evident, EPA needed to clarify that these impoundments would not be characterized as ''new CCR surface impoundments.''

The Agency is generally conforming the definition of an existing CCR surface impoundment to the revised definition of an existing CCR landfill. Although inactive CCR surface impoundments are covered by the final rule (unlike inactive CCR landfills), EPA decided it would provide greater clarity to establish a section specific to inactive CCR surface impoundments rather than merely including such units within the definition of an existing CCR surface impoundment. As discussed in greater detail in Unit VI.A of this document, under § 257.100, any CCR surface impoundment that continues to impound CCR and water after the effective date of the rule, must either (1) breach, dewater, and place a cover on the unit within three years or (2) must comply with all of the requirements applicable to existing CCR surface impoundments. Without the need to account for inactive CCR surface impoundments within the definition, the definitions of ''existing'' landfills and surface impoundments should be the same.

Thus, the Agency has removed the term ''in operation'' from the definition and has instead focused on when the surface impoundment received or will receive CCR. EPA has also deleted the provision that would have allowed a unit to be considered to be ''existing'' based on the existence of a contract. Accordingly, for purposes of this rule, a CCR surface impoundment will be considered to be ''existing'' if the unit received CCR both before and after the effective date of the rule. For example, if a CCR surface impoundment received CCR prior to the effective date and was in the process of dredging on the effective date with the intent of receiving additional CCR after the effective date, the unit would still be considered to be an ''existing'' rather than a new unit. Conversely, if a unit received CCR prior to the effective date and was no longer receiving CCR, this unit would be considered ''inactive,'' and would only be subject to the technical criteria applicable to ''existing'' CCR surface impoundments if they had not completed closure within three years. Similarly, if a CCR surface impoundment had commenced construction prior to the effective date with the intention of receiving CCR on or after the effective date of the rule, the unit would be considered an ''existing'' unit only if the physical construction program had begun (*e.g.,* groundbreaking had occurred) with the appropriate federal, state and local approvals or permits in place. But if prior to the effective date of the rule, the permits had been obtained but the physical construction of the unit had not begun (*e.g.,* groundbreaking had not occurred), the unit would be considered ''new'' and would be subject to all the applicable technical criteria for new CCR surface impoundments. Therefore, the Agency is finalizing the definition of *existing CCR surface impoundment* that can be found in § 257.53.

C. Location Restrictions and Individual Location Requirements

In the proposed rule, EPA stated that any RCRA subtitle D regulation would need to ensure that CCR landfills, CCR surface impoundments and all lateral expansions were appropriately sited to ensure that no reasonable probability of adverse effects on health or the environment from the disposal of CCR would occur. Under the subtitle D option, EPA proposed location restrictions for CCR units which included requirements relating to the placement of CCR in five general locations: (1) Above the natural water table; (2) wetlands; (3) fault areas; (4) seismic impact zones; and (5) unstable areas. The proposed requirements relied in large measure, on the record EPA developed to support the 40 CFR part 258 requirements for MSWLFs and on EPA's Guide for Industrial Waste Management (EPA530–R–03–001, February 2003). EPA also chose to add one additional location restriction that would ban the placement of CCR units within two feet of the upper limit of the natural water table. This proposed requirement was originally included in the proposed rule, *Standards for the Management of Cement Kiln Dust* (64 FR 45631, August 20, 1999) because of the potential damage to groundwater caused by the management of cement kiln dust at sites located below the natural water table. While the proposed cement kiln dust rule has not yet been finalized, EPA extended this reasoning to CCR by applying the same location restriction to CCR units. The proposed applicability of these location requirements varied depending on whether the unit was an existing or new CCR landfill, an existing or new CCR surface impoundment, or a lateral expansion of such units. For example, for existing CCR landfills, the Agency proposed that only the location requirement for unstable areas would apply. By contrast, the proposed rule applied all of the location restrictions to new CCR landfills and all CCR surface impoundments, both existing and new—an approach consistent with RCRA subtitle C and Congressional distinctions between the risks presented by landfills and surface impoundments. (See 75 FR 35198–35199.) This meant that owners or operators would need to close existing CCR surface impoundments located less than two feet above the natural water table, or for existing CCR units in sensitive but not prohibited locations, make a technical demonstration that the unit met the requirements of a performance standard that serves as the alternative to the location restriction, retrofit the unit so that it could meet the performance standard, or close. For those CCR units that need to close (*i.e.,* owners or operators that could not make the necessary technical demonstrations), EPA proposed that the unit must close within five years of the effective date of the rule. If closure could not occur within the five year timeframe, the

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Agency proposed allowing for a case-by-case extension for up to two more years if the facility demonstrated that there was no alternative disposal capacity and no immediate threat to health or the environment.

EPA proposed not to impose all of the location requirements on existing CCR landfills based on the conclusion that CCR landfills pose less risk and are structurally less vulnerable than existing CCR surface impoundments. EPA also raised concern that a significant number of these CCR landfills could be located in areas subject to these requirements, (particularly wetlands), which could cause disposal capacity shortfalls in certain regions of the U.S., if existing CCR landfills in these locations were required to close. Disposal capacity shortfalls can pose significant environmental and public health concerns based on the potential for significant disruption of solid waste management state-wide from the closure of these units. EPA concluded that these risks would be greater than the potential risks from allowing existing CCR landfills to remain in these locations, given that these units would be subject to all of the design and operating requirements of the rule. To ensure the accuracy of its preliminary conclusions, the Agency requested commenters to provide any available information regarding the number of existing CCR landfills located in these sensitive areas. The Agency also sought information regarding the extent to which CCR landfill capacity would be affected by applying all of the location restrictions to existing CCR landfills, the extent to which facilities could comply with the proposed performance standards, and the costs that would be incurred to retrofit existing CCR landfills to meet these standards.

The Agency received numerous comments in response to the Agency's request for additional information regarding the extent to which landfill capacity would be affected by applying all the proposed subtitle D location restrictions to existing CCR landfills. Commenters generally agreed with the Agency that applying the other location restrictions to existing CCR landfills would cause a significant decrease in disposal capacity across the country, although they did not provide any data or information which would support this concern. Commenters noted, however, that if existing CCR landfills located in these areas were to close, it would greatly complicate operations at many utilities. Affected facilities would need to find additional disposal capacity, which would require utilities to procure new real estate on which to site a new CCR landfill (which may be a significant distance from a power plant), obtain a new disposal permit for the CCR landfill (which can take an extended period of time), and potentially transport significant volumes of CCR great distances to newly-permitted facilities. Commenters argued that there was simply no environmental basis for causing this level of disruption to utility CCR disposal practices.

EPA received no data or information in response to the Agency's request for the costs associated with retrofitting a CCR surface impoundment or CCR landfill to meet the demonstrations for existing units. Similarly, the Agency received little to no information in response to EPA's request for additional information on the location of these facilities. Some commenters acknowledged that specific states were located in some of these restricted areas but did not provide specific information on specific units.

Overwhelmingly, the issue receiving the most comment was EPA's intention to subject existing CCR surface impoundments to all of the new location criteria. Commenters contended that subjecting existing units to all of the location criteria was a radical departure from the location restriction provisions of the existing MSWLF rules on which the subtitle D option is based (*i.e.,* existing MSWLFs are only subject to the floodplains and unstable areas restrictions) without any justification for regulating CCR surface impoundments more stringently than existing CCR landfills. Commenters argued that EPA must demonstrate that there are increased risks posed by each CCR surface impoundments based on its location; otherwise, they claimed, there was no justification for EPA to subject CCR surface impoundments to more stringent location restrictions. Some commenters suggested that a more reasonable approach would be to limit the restrictions for existing CCR surface impoundments to unstable areas, consistent with the approach proposed for existing CCR landfills. Finally, commenters raised concern about the inconsistency between the preamble language and the corresponding regulatory text. Specifically, the preamble stated EPA's intention to apply all of the location criteria to all CCR surface impoundments (existing and new) while the proposed regulatory language applied all location criteria only to new CCR surface impoundments and lateral expansions.

1. Applicability of the Location Criteria to Existing CCR Surface Impoundments

EPA acknowledges the discrepancies between the preamble language and the regulatory text regarding the proposed regulatory language for the location restrictions as it applies to existing CCR surface impoundments. In the proposed rule, the regulatory language should have included, ''all surface impoundments'' as opposed to only ''new surface impoundments.''

EPA disagrees that in order to justify national minimum standards applicable to existing CCR surface impoundments, the Agency must demonstrate an adverse impact to human health and the environment from each individual unit, based on the specific risks posed at each location. As an initial matter, it is well established that an agency may regulate a class of similarly situated entities through rulemaking, rather than on the basis of an individualized assessment of every entity that will be subject to the rule. And indeed, Congress specifically directed EPA to proceed by rulemaking to establish minimum national standards under RCRA sections 1008(a) and 4004(a). Moreover, section 4004(a) does not require a demonstration of actual impacts, merely that these units present an unacceptable *risk* of harm. Thus, it is sufficient for EPA to establish a factual record demonstrating that the specific location restrictions in the final rule are necessary for CCR units (landfills and surface impoundments), as a class, to ensure that there will be no reasonable probability of adverse effects on health or the environment. As discussed in greater detail in the next section and in Unit X of the preamble, the factual record supports the need for all of the location standards for existing CCR surface impoundments imposed by this rule.

The Agency also rejects the suggestion that EPA establish the same location restrictions for both existing CCR landfills and CCR surface impoundments. As laid out in the proposal and elsewhere in this final rule in greater detail, the risks associated with CCR surface impoundments are substantially higher than the risks associated with CCR landfills, by approximately an order of magnitude. Surface impoundments are utilized by 45 percent of coal-fired power plants and in 2000 accounted for disposal of one-third of all CCR generated.[46] Unlike landfills, CCR surface impoundments

[46] Rowe, C.L., Hopkins, W.A., Congdon, J.D., 2002. Ecotoxicological Implications of Aquatic Disposal of Coal Combustion Residues in the United States: A Review. Environmental Monitoring and Assessment, Vol. 80, pp. 207–276.

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contain slurried residuals that remain in contact with ponded waters until closure. In a statewide investigation of impacts to groundwater quality from CCR disposal sites, the Wisconsin Department of Natural Resources reported that closed sites which originally contained sluiced coal-combustion residuals displayed extremely elevated mean arsenic levels (as high as 364 µg/l).[47] The highest contaminant concentrations in the study were associated with sluiced CCR residuals. In addition, releases of toxic contaminants to surface water and groundwater from mostly unlined CCR surface impoundments and ponds are a relevant factor in 34 of 40 cases of proven damage to the environment (as well as in several cases of ''potential'' damage to the environment) from mismanagement of CCR.[48] In many of these cases, effluent discharges from the surface impoundments caused significant ecological damage to aquatic life in nearby streams and wetlands. In one case, in 2002, the structural stability of a CCR surface impoundment was directly compromised by sinkhole development, leading to the release of 2.25 million gallons of CCR slurry. In another, an unusually weak foundation of ash and silt beneath a CCR surface impoundment (*i.e.,* man-made unstable ground) was identified as one of several likely factors contributing to the dike failure that in 2008 resulted in the largest CCR spill in United States history.

Unlike RCRA subtitle C, subtitle D does not explicitly authorize EPA to establish different standards for existing and new units, and Congress specifically intended subtitle D to address the risks from existing, abandoned ''open dumps.'' In the proposed rule preamble, EPA explained the rationale for applying these provisions to existing CCR surface impoundments, and the commenters have submitted nothing to rebut that rationale. Thus, EPA maintains its determination that application of the location standards to existing CCR surface impoundments is necessary to achieve the standard in section 4004(a). Absent these location restrictions, the risk of impacts to human health and the environment from releases from CCR units, including from the rapid and catastrophic destruction of CCR surface impoundments, sited in these sensitive areas would exceed acceptable levels. Given that the risks associated with CCR surface impoundments are substantially higher than the risks posed by CCR landfills, this is the appropriate regulatory course for existing CCR surface impoundments.

In this rule, EPA is finalizing location restrictions that will ensure that CCR units are appropriately sited, that the structure of the CCR unit will not be adversely impacted by conditions at the site, and that overall there will be ''no reasonable probability of harm to human health or the environment'' due to the location of the CCR unit. EPA is finalizing different sets of location restrictions depending on whether the unit is a CCR landfill or CCR surface impoundment and whether it is an existing or new unit. Lateral expansions fall within the definitions of new units and are treated accordingly. These standards provide minimum national siting and performance criteria for all CCR units. The location restrictions under § 257.60 through § 257.64 include: (1) Placement above the uppermost aquifer; (2) wetlands; (3) fault areas; (4) seismic impact zones; and (5) unstable areas. Each of these locations is generally recognized as having the potential to impact the structure of any disposal unit negatively and as such, increase the risks to human health or the environment through structural failures or leaching of contaminants into the groundwater. Under the final rule and as proposed, new CCR landfills, existing and new CCR surface impoundments, and all lateral expansions will be required to comply with all of the location restrictions. Existing CCR landfills however, will be subject to only two of the location restrictions—floodplains, and unstable areas. As noted in the proposed rule, and restated here, existing landfills and surface impoundments are already subject to the location standards in subpart A of 40 CFR part 257 for floodplains, endangered species and surface waters. The final rule does not change this requirement, and so facilities should already be in compliance. The Agency is finalizing, as proposed, the unstable area location restriction for existing CCR landfills because the record clearly shows that failure of CCR units in these areas (*e.g.,* due to instabilities in Karst terrains) have and in all likelihood would continue, in the absence of the restrictions in the final rule, to result in damage caused by the release of CCR constituents, affecting both groundwater and surface waters. As the Agency stated in the proposed rule, the impacts resulting from the failure of CCR units from location instability are of far more concern than any disposal capacity concerns resulting from the closure of existing CCR units in unstable areas.

Conversely, and also consistent with the proposed rule, EPA is not applying the following location restrictions to existing CCR landfills: The requirement to construct a unit with a base located no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer, as well as the siting restrictions applicable to wetlands, fault areas, and seismic impact areas. Existing CCR landfills pose lower risks and are structurally less vulnerable than existing CCR surface impoundments. In addition, disposal capacity shortfalls, which could result if existing CCR landfills in these locations were required to close, raise greater environmental and public health concerns than the potential failure of the CCR landfills in these locales.

2. Placement Above the Uppermost Aquifer

Under § 257.60(a) EPA is requiring new CCR landfills, existing and new CCR surface impoundments and all lateral expansions to be constructed with a base that is located no less than 1.52 meters (five feet) above the uppermost aquifer, or to demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including groundwater elevations during the wet season). Existing surface impoundments that fail to achieve this standard must close. New CCR landfills, new CCR surface impoundments and all lateral expansions of existing and new CCR landfills and CCR surface impoundments cannot be constructed unless they meet one of these two standards. In response to comment, the Agency has modified the criteria in two ways. First, EPA has replaced ''a base that is located a minimum of two feet above the upper limit of the natural water table'' with ''a base no less than 1.52 meters (five feet) above the uppermost aquifer.'' EPA received comment explaining that fluctuations in groundwater levels in many geological settings can exceed ten feet over the course of the year, and alleging that the proposed two foot minimum buffer between the base of the unit and the top of the water table would therefore be insufficiently protective. The

[47] Zillmer, M. and Fauble, P., 2004. Groundwater Impacts from Coal Combustion Ash Disposal Sites in Wisconsin. Waste & Materials Management, Wisconsin Department of Natural Resources, PUB–WA 1174 2004.

[48] Cases of damage attributable to disposal of coal combustion residuals are summarized in the appendix to the preamble of the proposed rule, 75 FR 35230–35239, June 21, 2010, and can be found in the RCRA Docket.

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commenter recommended that the minimum vertical separation be at least three to five feet from the base of the liner components. After additional research, EPA is finalizing a minimum buffer of five feet instead of two feet. EPA's research confirmed the commenter's claims. In addition, EPA determined that several states consider five feet between the base of the surface impoundment and the top of the uppermost aquifer to be the minimum distance that is protective of human health and the environment. These are California, Michigan, Nebraska, New York, West Virginia, and Wisconsin. The Agency has concluded from geographic and climatic spacing of these states that the hydrogeologic conditions within them encompass the range of conditions found in the United States. Therefore, EPA is finalizing a minimum buffer of five feet instead of two feet.

EPA is also clarifying the definition of the natural water table. As some commenters noted, there are many factors (hydrologic and geologic settings, nearby pumping, etc.) that influence the location of the groundwater table making it difficult to determine the ''natural'' level. In addition, as noted, local site-specific hydrogeologic conditions within the aquifer may cause the natural groundwater table to exceed five feet and vary as much as ten feet. To account for the possibility of such large seasonal fluctuations, EPA is revising the definition of ''uppermost aquifer'' to specify that the measurement of the upper limit of the aquifer must be made at a point nearest to the natural ground surface to which the aquifer rises during the wet season. This definition of ''uppermost aquifer'' will encompass large seasonal variations, and is a more appropriate parameter than ''seasonal high groundwater table'' as suggested by several commenters and the proposed ''natural water table'' because it is more clearly defined.

In § 257.60(a) the term *uppermost aquifer* has the same definition as under the general provisions of § 257.40: The geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary. This definition includes a shallow, deep, perched, confined or unconfined aquifer, provided it yields usable water. Although EPA originally proposed that all CCR surface impoundments be located ''. . . . above the upper limit of the natural water table'', the Agency is amending this requirement and replacing ''water table'' with ''uppermost aquifer'' to make it consistent with the way natural underground water sources are described elsewhere in the rule. EPA made a second revision to the criteria that were originally proposed. As an alternative to requiring that the CCR units described in this section be constructed with a base that is located no less than five feet above the uppermost aquifer, owners and operators may instead demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including groundwater elevations during the wet season).

This alternative standard was developed in response to concerns from commenters that a single depth to the aquifer failed to account for the wide variations in the level of water table fluctuations in different regions of the country. For example, arid regions of the country, such as Arizona, under normal conditions generally do not experience the same degree of fluctuations in groundwater elevations as more temperate regions, such as Minnesota. Accordingly, EPA developed an alternative performance standard focused on the conditions identified in the damage cases and the risk assessment that this location criterion was designed to prevent: Specifically, where the groundwater elevation is high enough to intersect the base of the waste management unit. In such situations, this hydraulic connection can enhance the transport of contaminants of concern from the CCR unit into groundwater. By requiring owners and operators to ensure that these conditions do not occur, the alternative standard to allow owners and operators to account for situations where there are relatively small variations in groundwater levels and a buffer of five feet is not necessary. This will also ensure that a CCR unit need not address situations where an infrequent, unexpected event (*e.g.,* hurricane) could cause a brief, temporary condition where the uppermost aquifer rises to less than the prescribed five feet but which would not in and of itself constitute a long-term threat to the aquifer. However, where normal fluctuations in groundwater elevation (including, but not limited to, seasonal or temporal variations, groundwater withdrawal, mounding effects,[49] etc.) will result in the failure of the unit to meet the performance standard (*i.e.,* no intermittent, recurring, or sustained hydraulic connection between the base of the CCR unit and the uppermost aquifer), the unit must close.

In some recent damage cases, placement of large volumes of CCR into highly permeable strata in the disposal area promoted CCR-water interactions. For example, from 1995 to 2006 in Anne Arundel County, Maryland 4.6 million tons of CCR were placed directly in two sand and gravel quarries without a geomembrane liner or leachate collection system. Rainwater infiltration into exposed CCR coupled with groundwater-CCR interactions and the transmissivity characteristics of local strata contributed to rapid migration of heavy metals, including antimony, arsenic, cadmium, nickel, and thallium to residential drinking water wells located near the mine pits and significant deterioration of water quality as a result of placement of CCR. Similarly, from 1980 to 1997 in Lansing, Michigan, around 0.5 million tons of coal ash was dumped for disposal into a gravel pit with an elevated water table. A remedial investigation has established that groundwater mounding has immersed the CCR into the upper aquifer resulting in on-site exceedances of groundwater quality protection standards for sulfate, manganese, lead, selenium, lithium, and boron. Placement of CCR into un-engineered, unlined units in permeable strata has plainly led to adverse impacts to groundwater. The phrase ''normal fluctuations'' has been used to clarify that EPA does not intend for the facility to account for extraordinary or highly aberrant conditions (*e.g.,* one-in-a million or ''freak'' events). Normal fluctuation can include those resulting from natural as well as anthropogenic sources. Natural sources that could affect groundwater levels include, but are not limited to precipitation, run-off, and high river levels. Anthropogenic sources that could affect groundwater levels include groundwater withdrawal, pumping, well(s) abandonment, and groundwater mounding. In satisfying this location restriction, it may be necessary for a professional engineer to model these effects before he can make the necessary certifications.[50] EPA also

[49] A phenomenon usually created by the recharge of groundwater from a manmade structure, such as a surface impoundment, into a permeable geologic material, resulting in outward and upward expansion of the free water table. Mounding can alter groundwater flow rates and direction; however, the effects are usually localized and may be temporary, depending upon the frequency and duration of the surface recharge events.

[50] For example, evaluations can be done to estimate groundwater mounding such as *pubs.usgs.gov/sir/2010/5102/*, *www.groundwatersoftware.com/calculator_9_*

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notes that this modeling may include the same considerations already evaluated under some state programs.[51] EPA expects that owners and operators will have sufficient information to determine whether their CCR unit meets either performance standard. Most, if not all, of this information would be information a facility would typically have as part of normal operations (*e.g.,* the depth of the CCR unit itself), or that will be developed as part of implementing other rule requirements. For example, through the groundwater monitoring system required under §§ 257.90–257.98, the facility can obtain water level measurements in a sufficient number of locations (*e.g.,* monitoring wells, piezometers) to use in determining whether they satisfy either performance standard. Similarly, under § 257.91 a thorough characterization of the geology and hydrogeology of the site must be conducted. Finally, EPA notes that available technology and guidance are available for using existing groundwater monitoring wells, like those required under this final rule, to measure groundwater levels.[52]

3. Wetlands

In § 257.61 of this rule, EPA is finalizing the regulatory text essentially as proposed. Specifically, EPA is adopting a prohibition on locating all CCR surface impoundments and new CCR landfills, as well as lateral expansions of existing CCR units, in wetlands as defined in 40 CFR 232.2, absent specific demonstrations made by the owner or operator that ensure the CCR unit will not degrade sensitive wetland ecosystems. These provisions place the burden of proof for these demonstrations directly on the owner or operator (the discharger). The owner or operator must make the results of these demonstrations available in the facility record. Failure to make any of the demonstrations will bar siting of the CCR unit in a wetland.

In 2003, disposal of CCR in natural or man-made aquatic basins accounted for nearly one-third of all CCR land disposal. Historically, aquatic disposal of CCR has been attractive economically to facilities because of its lower overall cost relative to dry management and the ease of handling of residuals. During aquatic disposal, CCR is commonly piped as a slurried mixture to surface impoundments designed to retain the solids in contact with water for the life of the unit. Particulate solids from the waste stream gravitationally settle while clarified waters ultimately discharge into nearby streams and wetlands.

The term 'wetlands' refers to those areas inundated or saturated by surface or groundwater at a frequency and over a duration sufficient to support a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands include marshes, swamps, bogs and similar areas that are commonly located between open water and dry land. Under the CWA, wetlands are considered 'special aquatic sites' deserving of special protection because of their ecologic significance. Wetlands are very important, fragile ecosystems that must be protected, and EPA has long identified wetlands protection as a high priority.

Undisturbed, natural wetlands provide many benefits to society by improving water quality, providing essential breeding, rearing, and feeding grounds for fish and wildlife, reducing shoreline erosion, and absorbing flooding waters and pollution. Wetlands are also commercial source areas of products for human use such as timber, fish, and shellfish. Recreational hunters harvest wetland-dependent waterfowl. Wetland environments, however, may be adversely impacted by releases of wastes from co-located industrial facilities. Wetland ecosystems can be degraded by accidental discharges that can change the habitat value for fish and wildlife by obstructing surface water circulation patterns, altering substrate elevation, dewatering, or permanent flooding.

In support of the provisions finalized in this rule, EPA is citing several damage cases, including 30 cases of ''proven'' damage to the environment that involve aquatic disposal of CCR, 14 of which involve impacts to wetlands from release of CCR. For example, at the Hyco Reservoir in Roxboro, North Carolina from 1966 to 1990 the lake received contaminated effluent from coal ash disposal basins that were authorized by National Pollutant Discharge Elimination System (NPDES) permits under the CWA. High levels of the trace element selenium bioaccumulated in aquatic food chains (phytoplankton), poisoning invertebrates and fish in the lake, particularly species of sport fish (bluegill, largemouth bass), causing reproductive failure and severe declines in fish populations in the late 1970's and early 1980's. Consequently, from 1988–2001 the North Carolina Department of Health and Human Services (NCDHHS) issued a consumption restriction advisory for selenium contamination in fish from the reservoir. In 1990, a dry ash handling system was implemented resulting in lower selenium discharge and reduced mean selenium concentration in reservoir waters. As of 2005, concentrations of selenium in fish tissues remained above a toxic threshold even with reduced influx of selenium, due to migration of the element from contaminated sediments to benthic food chains. The total monetized value of damage can be divided among ecologic factors (*e.g.,* major impacts on fish), recreational factors (*e.g.,* fishing trips not taken), depreciated real estate values, aesthetic factors, and human health damages (*e.g.,* losses due to stress and anxiety from knowing ecosystem is poisoned) and is estimated at $877 million.[53]

Although this consideration is not relevant for purposes of establishing the minimum national criteria under RCRA sections 1008(a) and 4004(a), the rulemaking record demonstrates that the monetary cost of environmental damage from releases of CCR at surface impoundments could be considerable. A report on the environmental damage caused by releases of CCR at 22 sites estimates the total cost of poisoned fish and wildlife at the surface impoundment sites at $2.32 billion. At twelve of these sites the releases were legally permitted under the CWA. Five of the 22 cases were caused by structural failures, two resulted from an unpermitted discharge, and one was from a landfill.[54] Effluent contaminated with coal combustion residues is directly linked with high loadings of toxic metals in the discharge areas of aquatic basins, where some metals (primarily arsenic, cadmium, chromium, copper, lead, and selenium) have accumulated in aquatic food chains.[55] In a research overview (literature synthesis) on the environmental effects of disposal of CCR, Rowe et al. (2002) listed adverse biological responses, including histopathological, behavioral, and physiological (reproductive, energetic, and endocrinological) effects, that have been observed in some vertebrates and invertebrates following exposure to and bioaccumulation of CCR-related contaminants.

Under the criteria finalized in this rule, in order to locate a CCR unit or

hantush_mounding.htm, and *www.ndwrcdp.org/documents/wu-ht-02-45/wuht0245_electronic.pdf.*

[51] See, *e.g., dnr.wi.gov/topic/stormwater/standards/gw_mounding.html.*

[52] See, *e.g.,* U.S. EPA (Environmental Protection Agency). 2013. Groundwater Level and Well Depth Measurement. SESDPROC–105–R2. Region 4. Athens, GA. Available online at: *www.epa.gov/region4/sesd/fbqstp/Groundwater-Level-Measurement.pdf.*

[53] Lemly, A.D. 2010. Op.cit.

[54] Lemly, A.D.2010. Op. cit.

[55] Rowe, C.L. et. al. 2002. Op. cit.

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lateral expansion in a wetland, the owner or operator must: (1) Successfully rebut the presumption that an alternative site (*i.e.,* one that does not involve a wetland) is reasonably available for the CCR unit or lateral expansion; (2) show that the construction or operation of the unit will not cause or contribute to violations of any applicable state water quality standard, violate any applicable toxic effluent standard or prohibition, jeopardize the continued existence of endangered or threatened species or critical habitats, or violate any requirement for protection of a marine sanctuary; (3) show that the CCR unit or lateral expansion will not cause or contribute to significant degradation of wetlands; and (4) demonstrate that steps have been taken to attempt to achieve no net loss of wetlands.

In addition to these requirements, other federal laws may be applicable in siting a CCR unit in a wetland. These include: Sections 401, 402, and 404 of the CWA; the Rivers and Harbors Act of 1989; the National Environmental Policy Act; the Migratory Bird Conservation Act; the Fish and Wildlife Coordination Act; the Coastal Zone Management Act; the Wild and Scenic Rivers Act; and the National Historic Preservation Act. In addition, the use of a wetlands location for a CCR unit may require a permit from the U.S. Army Corps of Engineers. To the extent these are applicable, compliance with these RCRA criteria does not alleviate the need to comply with these other federal requirements, and the owner or operator of the facility remains responsible for ensuring compliance with all applicable federal and state requirements.

The rule adopts a regulatory presumption that a less damaging alternative to locating a disposal unit in a wetland exists, unless the owner or operator can demonstrate otherwise. Thus, when proposing to locate a new facility or lateral expansion in a wetland, owners and operators must be able to demonstrate that alternative sites are not available and that the impact to wetlands is unavoidable. If this presumption is not clearly rebutted, then the CCR unit may not be sited in a wetland location. Such an analysis necessarily includes a review of reasonable alternatives to locating or laterally expanding CCR units in wetlands. As part of the evaluation of reasonable (that is, available and feasible) alternatives the owner or operator must show, and a qualified professional engineer must verify, that operation or construction of the CCR unit will not: (1) Violate any applicable state water quality standards; (2) cause or contribute to the violation of any applicable toxic effluent standard or prohibition; (3) cause or contribute to violation of any requirement for the protection of a marine sanctuary; and jeopardize the continued existence of endangered or threatened species or critical habitats.

When evaluating the impacts of a CCR unit on a wetland, the owner or operator must ensure that the unit cannot cause or contribute to significant wetland degradation. Therefore, the owner or operator and the qualified professional engineer must: (1) Verify the integrity of the CCR unit, and its ability to protect ecological resources by addressing the erosion, stability, and migration potential of native wetland soils, and dredged and fill materials used to support the unit; (2) verify that the design and operation of the CCR unit minimizes impacts on fish, wildlife, and other aquatic resources and their habitat(s) from any release of coal combustion residuals; (3) evaluate the effects of catastrophic release of CCR to the wetland and the resulting impacts on the environment; and (4) verify that ecological resources in the wetland are sufficiently protected, including consideration of the volume and chemistry of the CCR managed in the unit; and any additional factors, as necessary.

When a wetland functions properly, it provides water quality protection, fish and wildlife habitat, natural floodwater storage, and reduction in the erosive potential of surface water. A degraded wetland is less able to effectively perform these functions. For this reason, wetland degradation is as big a problem as outright wetland loss, though often more difficult to identify and quantify. Any change in hydrology can significantly alter the soil chemistry and plant and animal communities. The common hydrologic alterations that can lead to significant degradation in wetland areas include: (1) Deposition of fill material, including CCR; (2) drainage for development; (3) dredging and stream channelization for development; (4) diking and damming to form ponds or impoundments; (5) diversion of CCR-bearing waters or other flows to or from wetlands; (6) addition of impervious surfaces in the watershed, thereby increasing water and CCR-bearing run-off into wetlands. These activities can mobilize CCR-bearing sediment; and once the sediment is discharged into the environment, toxic metals in CCR can become available to organisms within the wetland. Consequently, while the mere presence of one or more of these activities does not necessarily demonstrate that the CCR unit causes or contributes to significant degradation, the fact that they may do so means these activities need to be carefully evaluated.

In determining what constitutes ''significant'' degradation, it is important to understand that although wetlands are capable of absorbing pollutants from the surface water, there is a limit to their capacity to do so. For the purposes of this rule, the primary pollutants of concern are CCR-bearing sediment and toxic metals. Although the risk assessment did not assess the exposure and hazard to wetlands, these can originate from uncontrolled run-off from the facility, fugitive dust from uncovered CCR landfills and piles, and uncontrolled discharge from CCR units (landfills, waste piles, surface impoundments). A clear example of biologically significant degradation in wetlands is when these toxic metals accumulate in benthic and aquatic food chains as a result of uncontrolled runoff. Another is obrution (smothering) of benthic organisms from discharge(s) of CCR to surface water, thereby jeopardizing the continued existence of organisms or critical habitats within the wetland. EPA notes that there are other requirements established under this rule that can also be relevant in this context, as they have the potential to reduce the likelihood that facility operations will cause or contribute to significant wetland degradation. EPA anticipates that as the facility begins to implement all of the requirements under this rule, the facility will consider how modifications to facility operations to address one requirement can affect compliance with other requirements.

After consideration of these factors, if an existing CCR unit cannot meet all of the requirements in paragraphs (1)–(3) (*i.e.,* if it causes or contributes to significant degradation, or if no reasonable alternative to locating a new CCR unit in wetlands is available), the facility can comply with the location criterion by compensatory steps that must be taken to achieve no net loss of wetlands (as defined by acreage and function). Owners or operators must first take measures to avoid impacts to wetlands. If potential impacts cannot be avoided, all reasonable steps are to be taken to minimize such impacts to the extent feasible. Appropriate measures (for example, engineered containment systems to control discharge of leachate or surface water run-off to wetlands) will likely be site-specific and should be incorporated into the design and operation of the CCR unit. Any remaining unavoidable impacts must be offset, or compensated for through all appropriate and feasible compensatory mitigation actions. This compensatory

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mitigation may take the form of restoration (re-establishment or rehabilitation of a wetland), establishment (creation of a man-made wetland where one did not previously exist), enhancement (improving one or more wetland functions), and preservation (permanent protection of important wetlands through implementation of appropriate legal and physical mechanisms). The functions and values of a wetland will vary based on any number of site specific characteristics, including location, wetland type, hydrology, degradation, and whether it is natural or constructed to treat waste. Strictly limited to the application of the wetlands location requirements under this rule, any assessment of the nature and extent of mitigation required under the CCR rule shall consider these kinds of characteristics, including wetlands designed for the treatment of CCR. The Agency recognizes that the function and value of a particular man-made wetland constructed to perform a wastewater treatment function may present a unique situation that may affect both the determination of whether the wetland is significantly degraded, and the nature and extent of any required compensatory mitigation. This discussion refers only to the wetlands-related requirements of this rule and does not affect any requirements or obligations under the Federal Water Pollution Control Act (33 U.S.C. 1251, *et seq.*) and its implementing regulations.

Although EPA is not finalizing an outright ban on siting of existing or new CCR units in wetlands, the Agency continues to believe that discharges to wetlands of pollutants that can be reasonably avoided should be avoided. Therefore, the amount and quality of compensatory mitigation may not substitute for avoiding and minimizing impacts. For purposes of this rule, EPA assumes CCR units that are designed to avoid discharge of CCR into wetlands have less adverse impact to the aquatic environment than CCR units that ultimately discharge such residuals in wetlands.

4. Fault Areas

In § 257.62 of this rule, EPA is banning the location of new CCR landfills, existing and new CCR surface impoundments, and all new lateral expansions within 60 meters (200 feet) of a fault that has had displacement in Holocene time, unless the owner or operator demonstrates that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the unit. For existing surface impoundments, the demonstration is required only if the unit is located closer than 60 meters (200 feet) to an active Holocene fault. If a demonstration cannot be made, the existing surface impoundment must close. These requirements have been adopted with only minor changes from the proposal, and will minimize the risks associated with CCR units located in fault areas.

Stresses produced during earthquake motion can cause serious damage to landfill integrity via seismically induced ground failure and associated rupture of liner systems and subsequent damage to leachate collection systems. Or if the unit is unlined, seismic motion could disrupt landfill caps and foundation soils that impede migration of percolating water. Potential damage to CCR units resulting from structures located across a fault include surface breakage, cracks and fissures between fill and confining slopes, slope failure via landslides, liquefaction-induced lateral spreading and settlement of the pile, disruption of surface water and drainage control systems, and rupture of leachate collection systems. In impoundments, for example, interior dike failure and leakage, and rupture of multilayer liner systems would also be of concern. Failure of the leachate collection system may prevent removal of generated leachate, allowing it to pond on the liner. If the liner system is ruptured, this may create a pathway for leachate to migrate into and contaminate the uppermost aquifer. In addition to the potential damage to leachate collection and liner systems, the integrity of the landfill slopes could also be impaired by fault rupture, potentially exposing coal combustion residuals to surface run-off.

The best protection is to avoid locating new CCR landfills and all CCR surface impoundments across faults and fault zones subject to displacement. For new units or lateral expansions there is no need to construct units in these areas. For existing surface impoundments, the Agency has been unable to find any way to retrofit or engineer the unit to be protective. A setback distance of 60 meters (200 feet) from the outermost damage zone of a Holocene fault will provide an adequate margin of safety to protect the facility from displacements due to surface faulting and any associated damage because 60 meters typically covers the zone of deformation where the ground may be bent or warped as a consequence of fault movement. By including this as a siting requirement for new units the risk of rupture of the unit, including any liner and leachate collection systems, due to surface faulting will be minimized.

Observations of engineered landfill response during earthquake motion come primarily from California where field data have been reported from MSWLFs (including some meeting the current part 258 standards) affected by strong shaking from six major nearby earthquakes. In these large magnitude events ($M \geq 6.7$), bedrock peak horizontal ground accelerations, an index of the intensity of earthquake motion, endured by the landfills were in excess of 0.3g. Engineered dry MSWLFs in California are reported to have performed well after strong earthquake motion (no documented incidence of an earthquake-induced release of contaminants harmful to human health or to the environment). Minor cracking of cover soils and breaking of vertical wells and headers were among the most common types of damage reported at MSWLFs subject to strong ground shaking. In the 1994 Northridge earthquake, only one landfill compliant with RCRA Part 258 standards experienced tears in a liner (a geomembrane liquid barrier): One tear 23 meters in length. However, there is little data on seismic stability and performance from industrial solid waste landfills with geosynthetic liners or units with water-saturated CCR waste. The Agency, therefore, remains concerned over the potential instability of engineered disposal units, and particularly CCR surface impoundments, under seismic loadings. Accordingly, EPA is prohibiting new CCR landfills, CCR surface impoundments, and any new extensions from sites located within an active fault zone, unless the owner or operator makes a demonstration, certified by a qualified professional engineer, that an alternative setback distance of less than 60 meters will prevent damage to the structural integrity of the unit.

EPA is clarifying its definition of fault to incorporate updated technical information.[56] Although a fault can be thought of as a simple planar surface across which there has been measurable displacement of one side relative to the other, field-based observations show fault architecture to often be complex. In the geologic literature faults developed in the upper crust are characterized as zones of brittle deformation composed of linked fault segments, with each segment composed of one or more subparallel, curved, or anastomosing fault cores nested within

[56] Sibson, R.H. 2003. Thickness of the Seismic Slip Zone. Bulletin of the Seismological Society of America, Vol. 93, No. 3, pp. 1169–1178.

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a damage zone. Some fault zones may contain broad deformational features such as pressure ridges and sags rather than clearly defined fault scarps or shear zones.[57] Fault cores are regions of high strain slip that have accommodated most of the displacement and are marked by mylonites, cataclastites, and gouge, whereas the damage zone is characterized by low strain structures mechanically related to the growth of the fault zone such as small faults, fractures, veins and folds. To avoid displacement that would damage unit integrity, it is best to restrict new CCR landfills and surface impoundments, and all new extensions, to locations no less than 60 meters from the outermost damage zone created by an active fault. Fault zones can range from one meter to several kilometers in width.

For purposes of this section, a fault is considered active if it has moved during Holocene time. Holocene time is defined as the geological epoch which began at the end of the Pleistocene, at 11,700 years BP (before present), and continues to the present. In the field, evidence for Holocene activity may be hard to obtain. Therefore, the Agency cautions that faults which show no evidence for Holocene activity may not necessarily be inactive.

To investigate active faults, EPA expects owners and operators of CCR units to follow standard engineering and geologic practices. Technical considerations include: (1) A geologic reconnaissance of the site to determine the location of active faults. Such a reconnaissance would include utilizing the seismic analysis maps and tools (Quaternary fault maps, earthquake probability maps) of the United States Geological Survey (USGS) Earthquake Hazards Program (*http://earthquake.usgs.gov/hazards/apps/*); and (2) a site fault characterization within 1000 meters of a site to determine whether it is within 60 meters of an active fault. Such characterizations would include subsurface exploration, including drilling or trenching, to locate any fault zones and evidence of faulting, trenching perpendicular to any faults or lineaments found within 60 meters of the site, and determination of the age of any displacements. Based on this information, the qualified professional engineer would prepare a report that delineates the location of any active (Holocene) fault, including any damage zones, and the associated 60 meter setback. To take advantage of an alternative setback distance of less than 60 meters, the owner or operator must make a demonstration, certified by a qualified professional engineer, that the CCR landfill, surface impoundment, or lateral expansion has a foundation or base capable of providing support for the structure, and capable of withstanding hydraulic pressure gradients to prevent failure due to settlement, compression, or uplift, and all effects of ground motions resulting from at least the maximum surface acceleration expected from a probable earthquake.

5. Seismic Impact Zones

In § 257.63, EPA is adopting the provisions applicable to seismic impact zones, as proposed. The rule prohibits new CCR landfills, existing and new CCR surface impoundments and all lateral extensions from being located in seismic impact zones unless the owner or operator makes a demonstration, certified by a qualified professional engineer, that all containment structures, including liners, leachate collection systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material from a probable earthquake. A *Seismic impact zone* means an area having a 2% or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10 g in 50 years. Seismic zones, which represent areas of the United States with the greatest seismic risk, are mapped by the U.S. Geological Survey and readily available for all the U.S. (*http://earthquake.usgs.gov/hazards/apps/*).

Maximum Horizontal Acceleration in lithified earth material means the maximum expected horizontal acceleration at the ground surface as depicted on a seismic hazard map, with a 98% or greater probability that the acceleration will not be exceeded in 50 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment. This requirement translates to a 10% probability of exceeding the maximum horizontal acceleration in 250 years.

For units located in seismic impact zones, as part of any demonstration, owners and operators should include: (1) A determination of the expected peak ground acceleration from a maximum strength earthquake that could occur in the area; (2) a determination of the site-specific seismic hazards such as soil settlement; and (3) a facility design that is capable of withstanding the peak ground acceleration. Seismic designs broadly should include a response analysis to quantify the demands of earthquake motion on facility structures (*i.e.,* landfills, surface impoundments, liners, covers, leachate collection systems, surface water handling systems), liquefaction analyses of both waste and foundation soils to evaluate stability under seismic loading, and a slope stability and deformation analyses. Design modifications to accommodate seismic risks should include use of conservative design factors, use of ductile materials, built-in redundancy for critical system components, and other measures capable of mitigating the potential for seismic upset.[58]

Following trends in earthquake engineering, seismic design criteria for new CCR landfills, new CCR surface impoundment and all lateral expansions should be based on a ''withstand without discharge'' standard.[59] EPA interprets the performance standard in this criterion (''designed to resist the maximum horizontal acceleration in lithified earth material from a probable earthquake'') to require any new CCR unit located in a seismic impact zone to be designed to withstand seismic motion from a credible earthquake without damage to the foundation or to the structures that control leachate, surface drainage, or erosion. In other words, the CCR unit must be able to withstand an expected earthquake without discharging waste or contaminants. The owner or operator must make a demonstration, certified by a qualified professional engineer, that the CCR unit has a foundation or base capable of providing support for the structure, and capable of withstanding hydraulic pressure gradients to prevent failure due to settlement, compression, or uplift and all effects of ground motions resulting from at least the maximum surface acceleration expected from a probable earthquake. In practice, the Agency recognizes that the CCR unit may sustain some limited damage during an earthquake, but ultimately, the CCR unit design must remain

[57] Bryant, W.A. and Hart, E.W., 2007. Fault-Rupture Zones in California. Special Publication 42 (Interim Revision), California Division of Mines and Geology, Sacramento, California.

[58] The *seismic location standard* requires a demonstration that a CCR disposal unit can withstand the stresses imposed by peak ground acceleration during earthquake motion. The *seismic factor of safety* is a unitless measure of strength calculated for fill material assuming earthquake conditions. It is the ratio of material shear strength relative to the magnitude of shear forces acting on the material. For a CCR disposal unit, the *seismic location demonstration* could be composed of numerous *factor of safety* calculations showing that the structural components of the unit have factors of safety greater than or equal to 1.00.

[59] Kavazanjian, E., 1999. Seismic Design of Solid Waste Containment Facilities. Proceedings of the Eight Canadian Conference on Earthquake Engineering Vancouver, BC, pp. 51–89.

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capable of preventing harmful release of CCR, leachate, and contaminants both during and after the seismic event.

6. Unstable Areas

EPA laid out its rationale for these requirements in the proposal at 75 FR 35201. No significant comments were received on either this rationale or the specific regulatory provisions. Consequently, EPA is adopting the regulatory text as proposed. Specifically, under § 257.64(a) new and existing CCR landfills, new and existing CCR surface impoundments and all lateral expansions are prohibited from sites classified as unstable areas unless the owner or operator makes a demonstration, certified by a qualified professional engineer, that engineering measures have been incorporated into the CCR unit's design to ensure that the structural components will not be disrupted. EPA considers a structural component to include any component used in the construction and operation of CCR landfill or CCR surface impoundment that is necessary to ensure the integrity of the unit and to ensure that the contents will not be released to the environment, including liners, leachate collection system, embankments, spillways, outlets, final covers, inflow design flood controls systems. Liners and leachate collection systems require a firm, secure foundation to maintain their integrity, and may be disrupted as a result of uneven settlement induced by hydrocompaction. Similarly, sudden differential movement resulting from CCR placement and the consequent exceedance of the weight-bearing strength of subsurface materials in unstable areas can destroy liners and damage the unit's structural integrity, resulting in catastrophic release of CCR. It is essential for the owner or operator of any CCR unit to extensively evaluate the adequacy of the subsurface foundation support for the structural components of the unit. Therefore, the Agency is making this demonstration mandatory for all CCR units; existing CCR units for which a demonstration cannot be made must be closed.

EPA has adopted the following definitions without material change from the proposal: *Unstable area* means a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity of some or all of the structural components responsible for preventing releases from a CCR unit. Natural unstable areas include those areas that have poor soils for foundations, areas susceptible to mass movements, and karst terrains. *Structural components* mean liners, leachate collection systems, final covers, run-on/run-off systems, and any other component used in the construction and operation of a CCR unit. *Poor foundation conditions* means those areas where features exist which may result in inadequate foundation support for the structural components of a CCR unit. *Areas susceptible to mass movement* means those areas of influence (*i.e.,* areas characterized as having an active or substantial possibility of mass movement) where the movement of earth material at, beneath, or adjacent to the CCR unit, because of natural or man-induced events, results in the downslope transport of soil and rock material by means of gravitational influence. Areas of mass movement include, but are not limited to, landslides, avalanches, debris slides and flows, solifluction, block sliding, and rock fall. *Karst terrain* means an area where karst topography, with its characteristic erosional surface and subterranean features, is developed as the result of dissolution of limestone, dolomite, or other soluble rock. Characteristic physiographic features present in karst terrains include, but are not limited to, dolines (sinkholes), vertical shafts, sinking streams, caves, seeps, large springs, and blind valleys.

The owner or operator must consider at a minimum, the following factors when determining whether an area is unstable: (1) On-site or local soil conditions that may result in significant differential settling; (2) on-site or local geologic or geomorphologic features; and (3) on-site or local human-made features or events (both surface and subsurface). To evaluate subsurface conditions for purposes of § 257.64(c)(3), EPA considers it essential that the owner or operator conduct a geotechnical site investigation, certified by a qualified professional engineer, to identify any potential thick layers of soil that are soft and compressible (*e.g.,* loess, unconsolidated clays, wetland soils), which could cause a significant amount of post-construction differential settlement of foundation soils, adjacent embankments, and slopes unless improved. In addition, it is essential that the investigation identify on-site or local soil conditions that are conducive to downslope movement of soil, rock, and/or debris (alone or mixed with water) under the influence of gravity. Local topography, surface and subsurface soils, surface slope angles, surface drainage and run-off patterns, seepage patterns, rock mass orientations, joint patterns, fissures, and any other landscape factors that could influence downslope movement should be identified. Anthropogenic activities that could induce instability include mining, cut and fill activities during construction, excessive drawdown of groundwater, which may cause excessive settlement or bearing capacity failure of foundation soils, and use of an old landfill as the foundation for a new landfill without verification of complete settlement of the underlying wastes.

In designing a new CCR unit located in an unstable area, recognized and generally accepted good engineering practices dictate that a stability assessment should be conducted to prevent a destabilizing event from damaging the structural integrity of the component systems. For CCR units this involves three components: (1) An evaluation of subsurface conditions, (2) an analysis of slope stability, and (3) an examination of related design needs. In addition to explaining site constraints, identifying any soft soils, and recommending any appropriate ground improvement techniques, the assessment report should include a description of: The site, site geology; and investigative methodology; the results from all site investigations including subsurface exploration, field and laboratory tests, and test results; the subsurface profile, recommended foundation types, depths, and bearing capacities; the water content, grain-size distribution, shear strength, plasticity, and liquefaction potential of foundation soils and subsoils; and other foundation consolidation and settlement issues relevant to site development.

In addition to assessing the ability of soils and rocks to serve as a foundation, it is essential that the report also include a stability assessment of excavated sideslopes, aboveground embankments or dikes, and retaining structures. The slope stability analyses are performed as part of an evaluation of the design configuration under all potential hydraulic and loading conditions, including conditions that may exist during construction of a lateral or vertical expansion. As part of any demonstration, owners and operators should make an assessment, certified by a qualified professional engineer, that finalized site embankments and slopes are able to maintain a stable condition. In addition to evaluating the potential for post-construction differential settlement, the stability assessment should also consider seepage-induced saturation and softening of soils, particularly at CCR surface impoundments and CCR landfill sites that manage effluent.

Engineering considerations for CCR landfills and lateral expansions located in unstable areas are expected to be

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similar to those for MSWLFs, which can be found in EPA's 1993 Technical Manual on Solid Waste Disposal Facility Criteria (EPA530–R–93–017). For surface impoundments the relevant design criteria are found in the Agency's 1991 Technical Resource Document on Design, Construction and Operation of Hazardous and Non-Hazardous Waste Surface Impoundments (EPA/530/SW–91/054). Any stability assessment should consider the following: (1) The adequacy of the subsurface exploration program; (2) the liquefaction potential of the embankment, slopes and foundation soils; (3) the expected behavior of the embankment slopes, and foundation soils when they are subjected to seismic activity; (4) the potential for seepage-induced failure; and (5) the potential for differential settlement.

For facilities in areas of karst, to support the demonstration required under the regulations, the owner or operator would need to evaluate the subsurface conditions to ensure that the unit is located away from the influence of potential sinkholes. For areas where the solution-weathered limestone is close to the surface (*e.g.,* Florida) recognized and generally accepted good engineering practices dictate that there must be no conduits beneath the CCR unit that allow piping of groundwater into the karst aquifer, or shallow caves that could cause sudden collapse of the unit foundation. Where unconsolidated sediments cover underlying limestone, piping is commonly marked by paleosinks where sands and clays from the overburden have filled solution cavities in the underlying limestone.[60] Local hydraulic gradients in paleosinks typically point downward. EPA generally expects the potential for sinkhole development to be minimal at locations in karst areas where there are no paleosinks, or historical record of sinkhole development, and where there are no local hydraulic gradients that point downward.

In making a demonstration, it is important for owners and operators of CCR landfills and surface impoundments in karst areas to adequately characterize subsurface conditions. Karst hydrogeology is complex, since contaminant flows can occur along paths and networks that are discreet and tortuous, and groundwater monitoring wells must be capable of detecting any contaminants released from the CCR unit into the karst aquifer. Therefore, the owner or operator will need to ensure, with verification by a qualified professional engineer, that monitoring wells installed in accordance with § 257.91 will intercept these pathways. Verification will usually necessitate the use of tracers to track groundwater flow towards offsite seeps or springs from the uppermost aquifer beneath the facility.

Any engineered solution employed to mitigate weak ground strength in karst areas must be able to prevent the kind of foundation collapse and settlement that could lead to sudden release to the environment of CCR with its toxic constituents and associated leachate. Solution cavities present at the site should be filled with grout or other suitable stiff material to avoid further crumbling and erosion. Where necessary, CCR unit foundations could be reinforced with engineered ground supports such as concrete footings that bridge voids. Larger caverns could be filled with concrete to underpin the CCR unit foundation by transferring load to the cavern floor. However, such engineered solutions are complex and costly, and the best protection is not to site CCR landfills and surface impoundments in karst areas. Nevertheless, this rule does not ban the location of CCR landfills, surface impoundments, or lateral extensions in karst areas.

7. Closure of Existing CCR Landfills and Existing CCR Surface Impoundments

The final provisions of § 257.60 require owners or operators of an existing CCR surface impoundment to demonstrate that the unit meets the minimum requirements for placement above the uppermost aquifer (*i.e.,* constructed with a base located no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer) no later than 42 months after the date of publication of this rule in the **Federal Register**.

Owners and operators of existing CCR surface impoundments subject to §§ 257.61–257.64 of this rule and existing CCR landfills subject to § 257.64, must complete demonstrations by the date corresponding to 42 months from publication of this rule. The Agency is setting the compliance deadline at 42 months to allow owners and operators time to complete the requisite studies (*e.g.,* to adequately characterize seasonal variations in the elevation of the top of the uppermost aquifer) and to complete any engineering measures necessary to allow the CCR unit to meet the performance standards. If closure is warranted, it must be initiated no later than 48 months from publication of this rule. Closure and post-closure care must be done in accordance with §§ 257.100–103; which allow certain regulatory flexibilities provided specific conditions are met.

D. Design Criteria—Liner Design

EPA proposed that existing CCR landfills without a composite liner could continue to operate and receive CCR without violating the open dumping prohibition. Conversely, EPA proposed that existing CCR surface impoundments would be required to retrofit with a composite liner system, as defined in the proposed rule, within five years of the effective date of the rule or to close. EPA also proposed that all new CCR units must be constructed with a composite liner and leachate collection and removal system.

In the proposal, EPA defined a *composite liner* to mean a liner system consisting of two components; the upper component consisting of a minimum 30-mil flexible membrane liner (FML), and the lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec.[61] FML components consisting of high density polyethylene (HDPE) were required to be at least 60-mil thick; and the FML component was required to be installed in direct and uniform contact with the compacted soil component.

EPA solicited comment on a number of issues, including: (1) Whether EPA should allow facilities to use an alternative design for new CCR units; (2) whether clay liners designed to meet a 1×10^{-7} cm/sec hydraulic conductivity might perform differently in practice than modeled in the risk assessment, including a request for specific data on the hydraulic conductivity of clay liners associated with CCR units; and (3) whether the effectiveness of such additives as organosilanes, would allow the use of these additives in lieu of composite liners. (See 75 FR 35203 and 35222.)[62] With respect to the last two issues, the Agency received little comment. However, in response to the use of alternative liner designs in lieu of a composite liner (as defined in the rule), significant comment was received. Commenters advocated for a number of alternative composite liner designs, with a majority recommending that a

[60] For examples, see Garlanger, J.E., Foundation Design in Florida Karst. Online presentation by Ardaman & Associates. *http://www.ardaman.com/foundation_design.htm.*

[61] The definition of *hydraulic conductivity* is being promulgated as proposed, and will mean the rate at which water can move through a permeable medium (*i.e.,* the coefficient of permeability).

[62] The terms compacted soil and compacted clay are used interchangeably, *i.e.,* when referring to a compacted soil liner this is the same as referring to a compacted clay liner (CCL).

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geosynthetic clay liner (GCL) be allowed as an alternative to the lower component of the composite liner. Other commenters stated that GCLs alone should be allowed as an alternative to the proposed composite liner. Still others argued that alternative liner designs, such as an FML/FML [63] provided a level of performance similar to the proposed composite liner system and should be allowed. Conversely, there were also comments opposing the use of any alternative liners, claiming that alternatives have not been proven to be effective.

EPA also received significant comment on the actual design of the composite liner system proposed by the Agency as it pertained to CCR surface impoundments (see 75 FR 35202–35203).[64] Commenters argued that the proposed requirement for a leachate collection and removal system in a CCR surface impoundment was illogical since it would have to be constructed between the lower component (two feet of compacted soil) and upper component (flexible membrane liner) and the proposed rule specifically states that the flexible membrane liner component must be installed in direct and uniform contact with the compacted soil component. Commenters reasoned that the inclusion of a leachate collection and removal system between the upper and lower components precluded direct and uniform contact between the two components and that placing a leachate collection and removal system between the lower and upper components of a composite liner would compromise the integrity of the composite liner. With regard to this last point, the Agency has reviewed the requirements for a proposed composite liner system as it would pertain to CCR surface impoundments and agrees that the leachate collection and removal system requirements proposed for CCR surface impoundments would be counterproductive; EPA proposed this requirement in error. The integrity of the composite liner system is indeed dependent upon the direct and uniform contact of the upper GM component with the lower soil component. The proposed requirement for CCR surface impoundments to construct a leachate collection system between the FML and soil components would prevent the direct and uniform contact of the upper and lower components and, therefore, compromise the integrity of the composite liner. For this reason, EPA is not requiring a leachate collection and removal system for new surface impoundments or any lateral expansion of a CCR surface impoundment.

While EPA agrees with those commenters arguing that new CCR units should only be installed with a composite liner system of some kind, the Agency has concluded that not all alternative designs for a composite liner system should necessarily be rejected as insufficiently protective. Many commenters provided strong and compelling evidence that the specific composite liner system described in the proposed rule was not always feasible or necessary to protect groundwater resources and that alternate composite liner designs could be equally protective, and may be a necessity in many areas of the country where soil with the appropriate hydraulic conductivity may not be available (*e.g.,* Alaska).[65]

In re-evaluating the proposed requirement for a composite liner system, EPA was influenced by a number of factors.[66] First, the data provided by commenters showing the performance of a GM/GCL design. Second, EPA's own studies showing that a GM/GCL liner can be constructed to achieve hydraulic efficiencies in the range of 99 to 99.9% which meets or exceeds the hydraulic performance of a GM/compacted clay liner (CCL) design.[67] In addition, these high efficiencies demonstrate that the GCL component of a GM/GCL composite liner is at least as effective in impeding leakage through holes in the GM component of the composite liner system as a CCL with a hydraulic conductivity no more than 1×10^{-7} cm/sec.[68] In fact, EPA has developed guidance for the selection and installation of various types of liners including a GM/GCL.[69] And third, EPA was influenced by the many comments arguing that a ''one-size-fits all'' approach to liner design stifles design innovation and regulatory flexibility in addressing site specific factors such as geologic or climatic conditions. These commenters reasoned that if EPA established some type of performance standard for composite liners, it would mitigate the negative impacts of a ''one-size fits all'' regulatory framework.

1. Development of Composite Liner Design Criteria

In this final rule EPA is requiring all new CCR units to be designed and constructed with a composite liner as specified in § 257.70. EPA is also providing the owner or operator with an option to install an alternative composite liner provided it meets the required performance standard and it is certified by a qualified professional engineer. EPA has concluded, consistent with many of the comments received and its own analysis, that an alternative composite liner for new CCR units is warranted if it can be shown to be equivalent to the performance of a composite liner and affords the same protections to groundwater resources as a composite liner. The Agency is promulgating this alternative option to provide flexibility in designing and constructing a protective composite liner system that addresses site specific conditions and situations. The Agency acknowledges that it was overly prescriptive by requiring one particular type of liner rather than relying on a performance standard to define the lower component of the composite liner. The overwhelming amount of data supporting the effectiveness of a GC/GCL liner has convinced the Agency that the final rule should allow for some flexibility in composite liner designs. As such, the Agency is allowing new CCR units to be designed and constructed

[63] Current terminology favors the use of geomembrane liner or GM when referring to flexible membrane liners or FMLs. Hereafter in the preamble, except when referring to specific comments or the proposed rule, and in the final rule, the Agency will use the term geomembrane liner or GM in place of flexible membrane liner or FML.

[64] See proposed § 257.71 which states that an existing CCR surface impoundment shall be constructed with a composite liner and a leachate collection system between the upper and lower components of the composite liner; where a composite liner means a system consisting of two components; the upper component consisting of a minimum 30-mil flexible membrane liner (FML) and a lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. The FML component would be required to be installed in direct and uniform contact with the compacted soil component (see 75 FR 35243).

[65] See for example comments from the states of Alaska (EPA–HQ–RCRA–2009–0640–06409); Florida (EPA–HQ–RCRA–2009–0640–06846); and North Carolina (EPA–HQ–RCRA–2009–0640–09282) available at *www.regulations.gov.*

[66] Geomembranes (GMs), which are flexible membrane liners (FMLs), are thin materials manufactured from polymers and reinforced with woven fabric or fibers which are used as hydraulic barriers. Resins used to manufacture geomembrane liners typically include high density polyethylene (HDPE), linear low density polyethylene (LLDPE), low density linear polyethlene (LDLPE), very low density polyethylene (VLDPE) and polyvinyl chloride (PVC). Geomembranes manufactured using HDPE are the least flexible of the geomembranes.

[67] USEPA, ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems,'' EPA 600/R–02/029, December 2002. *http://nepis.epa.gov/Adobe/PDF/P1001O83.pdf.*

[68] USEPA, ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems,'' EPA 600/R–02/029, December 2002.

[69] USEPA, ''Guide for Industrial Waste Management,'' Chapter 7 (*http://www.epa.gov/osw/nonhaz/industrial/guide/pdf/chap7b.pdf*).

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with an alternative composite liner, as described below, provided the lower component of the composite liner meets a specified performance standard that ensures it functions in a manner equivalent to the composite liner system defined in the rule.

Composite liner systems installed in either a CCR landfill or CCR surface impoundment provide an effective hydraulic barrier by combining the complementary properties of the two different liner components. The geomembrane provides a highly impermeable layer that can maximize leachate collection and removal in a CCR landfill or minimize infiltration of leachate in a CCR surface impoundment, while the soil component (*e.g.,* CCL) serves as a backup in the event of any leakage/infiltration from the geomembrane occurs. Data indicate that alternatives to the lower component of the composite liner system (*e.g.,* GCLs) are available and can perform at a level equivalent to a compacted soil liner, based on a comparison of their flow rates with two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec.

2. Liner Designs That Would Not Meet the Requirements of a Composite Liner or Alternative Liner

Contrary to the arguments made by several commenters, EPA has concluded that a composite liner consisting of two 30-mil GMs (GM/GM) will not provide an equivalent degree of protection as a composite liner consisting of a GM and two feet of compacted soil, or an alternative composite liner such as a GM/GCL. While GMs have the advantages of extremely low rates of water permeation, the disadvantages of a composite liner consisting of two GMs include leakage through occasional GM imperfections and punctures, potential for slippage along the interface between the GMs, and GM embrittlement over time. Furthermore, a critical component of a composite liner is the compacted soil or GCL component beneath the GM layer that will impede the flow of liquid that may leak through a hole or defect in the GM. This added protection cannot be achieved using two GMs for the composite liner. Additionally, the potential exists for liquid transport through the GMs through holes caused by punctures, tears, flawed seams, etc. If a puncture occurs, the puncture could compromise both GMs and create a conduit for liquid flow to underlying permeable soil. Moreover, a liner system consisting of two GMs in contact with each other poses the risk of creating a slip plane that may compromise the stability of the disposal unit (although EPA acknowledges that using textured GMs would reduce or eliminate this particular risk). These data are documented in EPA research.[70]

Consistent with the previous determination, EPA has also determined that the double liner system set forth in Florida regulations (see Florida Rules 62–701.400(3)(c), F.A.C) also does not meet the level of performance achieved by EPA's composite liner system or the alternative liner system. While this double liner system provides the advantage of a leak detection system between the two GMLs, the lower composite liner, consisting of a 60-mil HDPE over six inches of soil with a saturated hydraulic conductivity of less than or equal to 1×10^{-5} cm/sec, is not equivalent to a GM over two feet of compacted soil with a hydraulic conductivity of less than or equal to 1×10^{-7} cm/sec. To be hydraulically equivalent, soil with a hydraulic conductivity of 1×10^{-5} cm/sec would need to be on the order of 100 times thicker than soil with a hydraulic conductivity of less than or equal to 1×10^{-7} cm/sec. Similarly, a lower composite liner consisting of a 60-mil HDPE over a GCL with a hydraulic conductivity not greater than 1×10^{-7} cm/sec would require a GCL thickness of 24 inches to be equivalent to a GM over two feet of compacted soil with a hydraulic conductivity of less than or equal to 1×10^{-7} cm/sec.

EPA has also examined the performance of GCLs approved for use as alternatives to composite liners in MSWLFs.[71] The EPA report titled ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems,''[72] concluded that if a CCL or GCL is used alone, liquid migration can occur over the entire area of the liner that is subject to a hydraulic head. The report also concluded that in a composite liner, leakage will only occur at the location of the geomembrane penetration (*e.g.,* hole, tear), and will be much slower than flow through an orifice due to the hydraulic impedance provided by the CCL or GCL alone. The report also evaluated, among other characteristics, the hydraulic efficiencies of a GM/GCL composite liner system for 28 cells at seven landfills. Liner hydraulic efficiencies were reported between 97% and 100%. However, potential stability problems were reported with GCLs constructed on slopes greater than 10 H:1 V (5.7°), and GCLs may not be appropriate for the disposal of liquid wastes or sludges. The Agency is also concerned that GCLs, being much thinner than the two feet of compacted soil required for composite liners, may allow for the flow of liquids through the GCL at a faster rate than through two feet of compacted soil. Taking all of this information into account, the Agency remains unconvinced that a GCL alone is a viable alternative to a composite liner.

3. Design Requirements

a. Existing CCR Landfills

As proposed, the final rule allows existing CCR landfills as defined in § 257.54, to continue to operate without retrofitting with a composite liner and leachate collection and removal system. As previously discussed, given the volume of the material currently managed in CCR landfills, the potential for disruption in CCR disposal capacity if existing CCR landfills were required to retrofit would be significant. Significant disruptions in the state-wide solid waste management (and possibly power generation) are associated with significant risks to public health and the environment in their own right. EPA has concluded that these risks are greater than the risks associated with allowing unlined CCR landfills to continue to operate. Further, existing CCR landfills will be required to comply with the extensive groundwater monitoring and corrective action requirements, among others, to ensure that any groundwater releases from the CCR unit are identified and promptly remediated, which will significantly mitigate the risks from these existing units. By themselves, the risk assessment results and the risk migration from the other regulatory requirements in this rule would not support a decision to allow these CCR units to continue to operate on a national basis. But when the risks associated with the level of disruption EPA estimates to be possible from requiring existing CCR landfills to retrofit are also included, the totality of the evidence supports a determination that allowing these units to continue operating meets the section 4004(a) standard.

[70] ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems.''

[71] ''Geosynthetic Clay Liners Used in Municipal Solid Waste Landfills,'' *http://www.epa.gov/wastes/nonhaz/municipal/landfill/geosyn.pdf*; ''Geosynthetic Clay Liners in Waste Containment,'' *http://www.epa.gov/superfund/remedytech/tsp/download/2001_meet/prez/carson.pdf*; and ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems,'' *http://nepis.epa.gov/Adobe/PDF/P1001O83.pdf.*

[72] ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems.''

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b. Existing CCR Surface Impoundments

In a departure from the proposed rule and after considerable evaluation and analysis, the Agency is finalizing a provision to allow all existing CCR surface impoundments to remain in operation provided certain conditions are met.[73] Owners or operators of existing CCR surface impoundments are required, within one year of the effective date of the rule, to document, certified by a qualified professional engineer, whether the unit is constructed with any one of the three liner types: (1) A liner consisting of a minimum of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec; (2) a composite liner that meets the requirements of § 257.70(b); or (3) an alternative liner that meets the requirements of § 257.70(c). In some instances, owners or operators may have information readily available to determine if an existing CCR surface impoundment is constructed with one of the three liner types listed above. On the other hand, this information may not be readily available and may require an owner or operator to conduct an engineering evaluation to determine if the unit was constructed with any of the three liner type. Factors such as the availability of engineering personnel and weather may impede the engineering evaluation. Therefore, EPA believes that 12 months from the effective date, or 18 months from publication of the rule, is a reasonable amount of time to make the determination of whether the existing CCR surface impoundment was constructed with one of the three liner types described above. Existing surface impoundments with liners that meet the criteria established for any of the three specified liner types are considered to be an ''existing lined CCR surface impoundments.'' These existing lined surface impoundments can continue to operate until the owner or operator decides to initiate closure, provided the unit does not meet other requirements of the rule that independently mandate closure of the unit (*e.g.,* location criteria (§§ 257.60–257.64) or structural integrity factors of safety (§ 257.73)). Existing unlined CCR surface impoundments must also cease receiving CCR and initiate closure if an owner or operator determines, at any point in time, as part of its groundwater monitoring program that the concentrations of one or more constituents listed in appendix IV to part 257 are detected at a statistically significant level above the groundwater protection standard established for that unit. EPA agrees with the many commenters who argued that existing unlined CCR surface impoundments should not be required to close prematurely if they are operating as designed and are complying with all of the requirements of the rule, including all groundwater protection standards. Taking into account the additional protections required under this rule (*e.g.,* location restrictions, groundwater monitoring, corrective action, structural integrity criteria, inspections and fugitive dust controls), the Agency has concluded that the risks posed by unlined CCR surface impoundments that are not ''leaking'' (*i.e.,* exceeding any groundwater protection standard) are not sufficient to warrant requiring these units to close. However, once a groundwater protection standard is exceeded (*i.e.,* the unit is leaking), without any type of liner system in place, leachate will flow through the unit and into the environment unrestrained and the only corrective action strategy that EPA can determine will be effective at all sites nation-wide requires as its foundation the closure of the unit.

EPA acknowledges that it may be possible at certain sites to engineer an alternative to closure of the unit that would adequately control the source of the contamination and would otherwise protect human health and the environment. However, the efficacy of those engineering solutions will necessarily be determined by individual site conditions. As previously discussed, the regulatory structure under which this rule is issued effectively limits the Agency's ability to develop the type of requirements that can be individually tailored to accommodate particular site conditions. Under sections 1008(a) and 4004(a), EPA must establish national criteria that will operate effectively in the absence of any guaranteed regulatory oversight (*i.e.,* a permitting program), to achieve the statutory standard of ''no reasonable probability of adverse effects on health or the environment'' at all sites subject to the standards. EPA was unable to develop a performance standard that would allow for alternatives to closure, but would also be sufficiently objective and precise to minimize the potential for abuse. There are too many factors that determine whether a particular engineering solution will meet the section 4004(a) standard at a particular site. And the risks of these units are simply too high.

Conversely, existing lined surface impoundments that exceed their groundwater protection standard are in a better position to manage the leak because it is usually caused by some localized or specific defect in the liner system that can more readily be identified and corrected. Consequently, this rule is not requiring existing lined CCR surface impoundment to close if an exceedance of a groundwater protection standard is detected; rather the Agency is affording the owner or operator with the opportunity to rely on corrective action measures to bring the risks back to acceptable levels (*i.e.,* control the source of the release and remediate the contamination), without mandating closure of the unit.

c. New CCR Landfills and New CCR Surface Impoundments and All Lateral Expansions

Both the CCR damage case history and the risk assessment clearly show the need for and the effectiveness of appropriate liners in reducing the potential for groundwater contamination at CCR landfills and CCR surface impoundments. Accordingly, EPA is finalizing liner and leachate collection and removal system requirements for new CCR landfills and all lateral expansions of these units. Similarly, EPA is finalizing liner requirements for new CCR surface impoundments and all lateral expansions of these units.

Specifically, EPA is requiring new CCR landfills, new CCR surface impoundments, and all lateral expansions be constructed with a composite liner (see § 257.70). The composite liner must consist of two components; an upper component consisting of a minimum 30-mil geomembrane liner (GM), and a lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} centimeters per second (cm/sec). GM components consisting of high density polyethylene (HDPE) must be at least 60-mil thick and the GM or upper liner component must be installed in direct and uniform contact with the compacted soil or lower liner component

New CCR landfills or lateral expansions of these units are also required to be constructed with a leachate collection and removal system designed to maintain less than a 30-centimeter depth of leachate over the composite liner. A leachate collection and removal system is not required for new CCR surface impoundments

[73] Existing CCR surface impoundments will not be required, as was proposed, to retrofit to a composite liner or close within five years of the effective date of the rule (see 57 FR 35202).

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because, as previously discussed, a leachate collection system installed between a single composite liner system is not practicable and would compromise the integrity of the composite liner system.

In addition, in response to comments on the proposed rule, EPA is allowing alternatives to the lower component of the composite liner system provided the flow rate through the lower component is no greater than the flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. The lower component must also be a recognized liner material; *e.g.,* soil, clay, or GCL. Alternative composite liners using compacted soil or clay as the lower component must be constructed with the upper component in intimate contact with the lower component; *i.e.,* the geomembrane must be installed to ensure good and uniform contact with the lower component. The hydraulic conductivity for the two feet of compacted soil used in the flow rate comparison must be no greater than 1×10^{-7} cm/sec. The hydraulic conductivity of the lower component must be determined using recognized and generally accepted engineering methods, for example, ASTM D5084–10, ''Standard Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter,'' ASTM International, West Conshohocken, PA, 2012, DOI: 10.1520/D5084–10, *www.astm.org* for compacted soils or clays, or ASTM Standard D6766–12, ''Standard Test Method for Evaluation of Hydraulic Properties of Geosynthetic Clay Liners Permeated with Potentially Incompatible Aqueous Solutions,'' ASTM International, West Conshohocken, PA, 2012, DOI: 10.1520/D6766–12, *www.astm.org* for GCLs. The flow rate comparison for the lower component must be made using Darcy's Law for gravity flow through porous media, which is an empirical law which states that the velocity of flow through porous media is directly proportional to the hydraulic gradient. The use of Darcy's Law to calculate fluid flow through porous media is a well-established and generally accepted engineering methodology, and is the foundation for EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) and is generally recognized to evaluate steady state flow of liquids through soils and GCLs.[74] EPACMTP is a subsurface fate and transport model EPA uses to simulate the impact of the release of constituents present in waste that is managed in land disposal units. Accordingly, the flow rate comparison for the lower component of alternative composite liner must be made using the following equation which is derived from Darcy's Law.

$$\frac{Q}{A} = q = k\left(\frac{h}{t} + 1\right)$$

where:

Q = flow rate,
A = surface area of the liner,
q = flow rate per unit area,
k = hydraulic conductivity of the liner,
h = hydraulic head above the liner, and
t = thickness of the liner.

A qualified professional engineer must certify that the design and construction of either the composite liner or the alternative composite liner meets the requirements of §§ 257.70(b) or (c).

EPA has also supplemented the composite liner criteria for landfills with performance standards that provide more precise direction to the professional engineer regarding the ''recognized and generally accepted good engineering practices'' that need to be used in the design and construction of composite liner systems to ensure that the liner system will continue to perform as designed. These criteria, which have been codified at §§ 257.70(b) and 257.70(c), have been adopted in response to comments requesting that EPA provide the professional engineers that will be required to certify that CCR units meet the requirements of the rule, with more precise and objective criteria. These criteria reflect the engineering specifications necessary to prevent liner failures resulting from improper design and construction and to ensure that the liner will continue to perform correctly. These provisions will ensure not only that the liner is properly designed and constructed, but also that the system will continue to safely perform throughout the landfill's active life and through post closure care. The criteria have been adopted from the technical provisions proposed under the subtitle C provisions for CCR landfills, and are consistent with design requirements set forth for hazardous waste landfills regulated under part 265 of RCRA, as well as existing guidance and recognized good engineering practices for the design and construction of MSWLFs.[75]

Specifically, the Agency is modifying the composite and alternative liner design requirements by requiring the composite or alternative liner to be chemically compatible with the CCR and of adequate strength and thickness to prevent failure. The liner system must also provide appropriate shear strength between the two components to prevent sliding of the upper component. In addition, the Agency is requiring that liners be placed on an adequate foundation and installed to cover all areas that might come into contact with the CCR.

For new CCR landfills, which are required to have a leachate collection and removal system designed and operated to maintain less than a 30 centimeter depth of leachate, the Agency is also requiring, that the leachate collection and removal system be constructed of sufficient strength and thickness to prevent collapse from the pressure of the CCR and to minimize clogging during the active life and post closure care period.[76]

4. Vertical Expansions of New and Existing CCR Landfills and All Lateral Expansions

In the proposed rule, EPA stated that CCR landfills could vertically expand without retrofitting, in order to alleviate concerns with regard to CCR disposal capacity in the short term. In the few comments to the proposed rule which mentioned vertical expansions of landfills, commenters requested that the Agency clarify the design standards that vertical expansions would have to meet. Information collected to date, which is included in the docket supporting the final rule, leads the Agency to conclude there are no issues unique to vertical expansions of CCR landfills that warrant modifications to the technical standards

[74] See for example EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) at *http://www.epa.gov/epawaste/nonhaz/industrial/tools/cmtp/*, ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems.'' Giroud, J.P., Badu-Tweneboah, K. and Soderman, K.L., 1997, ''Comparison of Leachate Flow Through Compacted Clay Liners and Geosynthetic Clay Liners in Landfill Liner Systems,'' Geosynthetics International, Vol. 4, Nos. 3–4, pp. 391–431 (*http://www.geosyntheticssociety.org/Resources/Archive/GI/src/V4I34/GI-V4-N3&4-Paper7.pdf*), and ''Design Considerations for Geosynthetic Clay Liners (GCLs) in Various Applications,'' Geosynthetic Research Institute, January 9, 2013 (*http://www.geosynthetic-institute.org/grispecs/gcl5.pdf*).

[75] ''Technical Guidance Document: Quality Assurance and Quality Control for Waste Containment Systems.'' U.S. Environmental Protection Agency. Risk Reduction Engineering Laboratory, Office of Research and Development, Cincinnati, OH 45268. EPA/600/R–93/182. September 1993.

[76] Hardin, PE, Christopher D, and Perotta, PE Nick L. ''Operations and Maintenance Guidelines for Coal Ash Landfills—Coal Ash Landfill are NOT the Same as Subtitle D Solid Waste Landfills''. Presented at the 2011 World of Coal Ash Conference; May 9–12, 2011 in Denver, Colorado. *http://www.flyash.info/2011/127-Hardin-2011.pdf.*

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being promulgated in this rule. Therefore, vertical expansions of existing CCR landfills are not subject to the provisions governing new units, but are subject to all applicable requirements for existing CCR landfills. To be clear however, while the location requirements relating to the placement above the water table, wetlands, fault areas, and seismic impact zones do not apply to existing CCR landfills, all of these restrictions apply to lateral expansions of existing CCR units, as well as new CCR units. Consequently, under this rule, owners or operators of existing CCR landfills can continue to vertically expand their existing facilities in these locations, but must comply with the provisions governing new units if they wish to laterally expand.

5. Construction of New CCR Landfills or Any Lateral Expansion Over an Existing CCR Unit

On August 2, 2013, EPA published a NODA that among other things, solicited comment regarding a particular type of CCR management unit described by some commenters in the proposed rule as ''overfills'' (see 78 FR 46940). Overfills are CCR landfills constructed over a closed CCR surface impoundment. As discussed in the NODA, in developing the proposed rule, EPA was not aware that CCR was managed in this fashion and so did not either evaluate this specific management scenario or propose technical requirements specifically tailored to this type of unit. Under the proposed rule, these types of units would need to comply with both the requirements applicable to the closure of surface impoundments or landfills, and with all of the technical requirements applicable to new landfills. Information collected since the proposal confirmed that the practice of constructing overfills for the disposal of CCR is conducted with some regularity, and raised questions as to whether overfills would be effectively regulated under the proposed technical requirements of the rule. In the NODA, to aid in the development of final technical requirements, EPA solicited data and information that directly addressed existing engineering guidelines or practices applicable to this units, as well as any regulatory requirements governing the siting, design, construction, and long-term protectiveness of these units for the disposal of CCR.

The Agency received numerous comments on the NODA. The majority of commenters agreed that overfills are commonly employed to allow continuing use of CCR disposal sites and to avoid the need to develop CCR management units at other sites. Some commenters added that: (1) The engineering design of an overfill can increase the stability of the underlying surface impoundment or landfill; (2) the use of an overfill facility reduces the need for new infrastructure construction; and (3) an overfill avoids having to transport CCR significant distances for off-site disposal.

Other commenters mentioned that several states had experience with overfills and have applied requirements such as liner systems, monitoring wells, and stormwater modeling on a case-by-case basis using best engineering practices. They added that overfills pose unique construction and operational issues depending on the site and the characteristics of the underlying unit, and that the construction of these units will therefore vary to account for these conditions. Commenters identified several issues requiring additional attention during design and construction of overfills including seismic and static liquefaction, settlement, foundation improvement, partial overfills, groundwater upwelling, groundwater monitoring, and wastewater infrastructure.

Upon review of these comments and further evaluation, the Agency has concluded that while there may be technical issues relating to the design, construction, and maintenance of overfills, the technical standards for CCR landfills are sufficiently flexible that no modifications are necessary to accommodate such units. For example, while the design and construction of groundwater monitoring systems may be technically more challenging, the final standards already allow for the construction of a multi-unit system. The performance standards and technical specifications laid out in the technical criteria developed for this rule are equally as applicable to overfills (and as protective) as to other new units. In essence, EPA is retaining the approach from the proposal that overfills will need to comply with both the requirements applicable to the closure of surface impoundments or landfills, and with all of the technical requirements applicable to new landfills. Thus, overfills cannot be constructed unless the underlying foundation—*i.e.,* the existing CCR surface impoundment has first been dewatered, capped, and completely closed. And because overfills are considered to be ''new CCR landfills,'' the design and construction of such units must comply with the technical requirements that address foundation settlement, overall and side slope stability, side slope and subgrade reinforcement, and leachate collection and groundwater monitoring system requirements, which will all need to be evaluated independent of the underlying CCR unit to ensure that the overfill design is environmentally protective. This evaluation must also be certified by a qualified professional engineer.

Under the location standards applicable to new CCR units, subgrade soils must be capable of providing stable structural support to the new liner system. A foundation composed of unconsolidated materials, such as CCR that is susceptible to slip-plane failure, is an unstable area (man-made) and, under provisions of this rule, is therefore a prohibited location for new CCR units. The TVA Kingston ash fill failure was at least partly attributable to slip-plane failure of saturated CCR that made up the subgrade and foundation beneath the unit.

Similarly, prudent and standard engineering practice for new CCR landfills requires that the base and side slopes of the overlying CCR landfill be able to maintain the structural integrity of the unit. If necessary, the subgrade should be reinforced with a geotextile fabric, or otherwise improved, to stabilize existing CCR in the underlying unit and to minimize tensile strain in the liner system. Slopes should be reinforced to prevent downhill sliding and to protect the leachate drainage system.

EPA is aware from comments that at least one facility is consolidating wet CCR in an active CCR surface impoundment through placement of dry ash over the wet CCR, and thereby converting the impoundment to a dry landfill, without stabilizing the CCR in the unit or capping the unit. This practice will no longer be permitted under the final rule criteria. Although no modifications were determined to be necessary to the individual technical criteria, EPA has added specific provisions that clarify the status of overfills, and clearly prohibit construction of a CCR landfill over a CCR surface impoundment unless the CCR in the underlying unit has first been dewatered and the unit is capped and completely closed. Dewatering, capping and closure of the underlying CCR unit prior to construction of the overlying CCR landfill renders the CCR overfill less susceptible to slip-plane failure. Conversion of an impoundment to a landfill without these measures involves a complex construction process that is highly site specific; EPA was unable to develop sufficiently objective performance standards that could be

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independently verified outside of a supervised permit program. Because this rule is self-implementing EPA is, therefore, prohibiting construction of new CCR landfills over operational CCR surface impoundments to prevent the creation of structurally unstable units that could lead to catastrophic failures.

E. Design Criteria—Structural Integrity

Under the design criteria requirements, EPA proposed to establish structural stability standards for existing and new CCR surface impoundments and lateral expansions of these units based on a combination of existing federal programs and requirements applicable to dam safety. The proposed rule was largely based on the requirements promulgated for coal slurry impoundments regulated by the MSHA at 30 CFR 77.216. (See 75 FR 35176.) EPA also developed aspects of the proposal based on the USACE and FEMA's dam safety programs. Consistent with the MSHA requirements, EPA proposed that existing and new CCR surface impoundments that could impound CCR to an elevation of five feet or more above the upstream toe of the structure and have a storage volume of 20 acre feet or more, or that impound CCR to an elevation of 20 feet or more above the upstream toe of the structure would be required to provide detailed information on the history of construction of the existing CCR surface impoundment and to meet certain performance standards. Specifically, facilities would need to (1) develop plans for the design, construction, and maintenance of existing impoundments, (2) conduct periodic inspections by trained personnel knowledgeable in impoundment design and safety, and (3) provide an annual certification by an independent registered professional engineer that all construction, operation, and maintenance of impoundments is in accordance with the approved plan.

EPA also proposed to require the facility to obtain certification from a professional engineer that the ''design of the CCR surface impoundment is in accordance with current, prudent engineering practices for the maximum volume of CCR slurry and CCR wastewater which can be impounded therein and for the passage of run-off from the design storm which exceeds the capacity of the CCR surface impoundment. To support this performance standard, EPA proposed to require the facility to conduct specific analyses, and to provide information on critical structures. This includes the proposed requirements to compute the minimum factor of safety for slope stability of the retaining structures of the unit, including the methods and calculations used to determine each factor of safety, and to provide information on the physical and engineering properties of the foundations of the CCR surface impoundment, any foundation improvements, drainage provisions, spillways, diversion ditches, outlet instrument locations and slope protections, and area capacity curves. EPA proposed to require more extensive information from new CCR surface impoundments addressing the design, construction, and maintenance of the new CCR unit, recognizing that such information may not be available for existing units.[77] In addition, EPA proposed to require existing and new CCR surface impoundments of a specified size to calculate and report the hazard potential classification of the unit. Finally, EPA proposed that any CCR surface impoundments classified as having a high or significant hazard potential, as certified by an independent registered professional engineer, be required to develop and maintain an Emergency Action Plan defining the responsible persons and actions to be taken in the event of a dam safety emergency.

The Agency solicited comment on a number of issues relating to the proposed structural stability requirements. In particular, the Agency solicited comment on the scope of these requirements and whether they should apply to all CCR surface impoundments regardless of height and/or storage volume or whether EPA should adopt, as proposed and consistent with the MSHA requirements, the size cut-off described in the proposed rule; *i.e.,* impounding CCR to an elevation of five feet or more above the upstream toe of the structure and have a storage volume of 20 acre feet or more, or impounding CCR to an elevation of 20 feet or more above the upstream toe of the structure.

EPA also solicited comment on several alternative strategies for regulating the structural stability of CCR surface impoundments in lieu of regulation under RCRA subtitle D. The first alternative involved using NPDES permits rather than RCRA regulations to address dam safety and structural integrity. The second strategy would eliminate the structural integrity requirements from the RCRA subtitle D rule and, instead, have EPA establish and fund a program for conducting annual (or at some other frequency) structural stability assessments of CCR surface impoundments having a ''high'' or ''significant'' hazard potential rating as defined by criteria developed by the USACE for the NID. EPA would conduct these assessments and, using appropriate authorities already available under RCRA, CERCLA, and/or the Clean Water Act, would require facilities to respond to issues identified with their CCR surface impoundments. The rationale behind this suggested approach was that annual inspections would be far more cost effective than the phase-out of CCR surface impoundments—approximately $3.4 million annually for annual assessments, as compared to the $876 million annual cost of a rule that also phased out CCR. EPA also solicited comments on the effectiveness of this approach in ensuring the structural integrity of CCR surface impoundments. (See for example: 75 FR at 35176, 35223.)

On October 21, 2010, EPA published a NODA announcing that EPA intended to consider the information that had been developed through the Agency's Assessment Program as part of the CCR rulemaking. The NODA described the Assessment Program, and solicited comment on ''the extent to which both the CCR surface impoundment information collection request responses and assessment materials on the structural integrity of these impoundments should be factored into EPA's final rule on the Disposal of Coal Combustion Residuals from Electric Utilities.'' (See 75 FR 35128.) This included the responses to information requests that EPA originally sent to electric utilities, as well as reports and materials related to the site assessments developed through the Assessment Program. At that time, EPA had completed the assessments and the final reports for 53 units. On August 2, 2013, EPA published another NODA soliciting public comment on the additional assessments that had been completed since the 2010 NODA. In all, this included draft and final reports for a total of 522 units and 209 facilities. EPA again solicited comment on the extent to which this information should be taken into account as part of this rulemaking.

EPA received numerous comments on the proposed structural stability requirements. Many of these fell within two general areas: (1) EPA's approach of

[77] In the proposed rule under proposed § 257.71—Design criteria for existing CCR surface impoundments, the Agency only required the hazard potential classification for which the facility is designed and a detailed explanation of the basis for the classification (§ 257.71(d)(1)) ''as may be available'' (§ 257.71(d)). Similarly the computed minimum factor of safety for slope stability of the CCR retaining structure(s) and the analyses used in the determination (§ 257.71(d)(11) ''as may be available'' (§ 257.71(d)).

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establishing the structural stability requirements, along with EPA's proposed reliance on MSHA's size thresholds to determine the applicability for the majority of structural stability requirements; and (2) the level of detail laid out in the technical criteria themselves.

With respect to the overall regulatory approach, the majority supported both the concept of structural stability requirements for existing and new CCR surface impoundments, and the adoption of the MSHA size threshold for complying with the majority of the structural stability requirements. EPA received comments from a number of state entities (the Association of State Dam Safety Officials (ASDSO) and the Association of State and Territorial Solid Waste Management Officials (ASTSWMO)) suggesting that EPA incorporate federal dam safety guidelines rather than rely solely on MSHA's dam safety guidelines. Commenters were concerned that the MSHA regulations ''only exist to protect miners on mine property, and not the downstream public.'' They urged that any EPA regulation also include consideration of hazards to the downstream public. These commenters also requested that EPA ''incorporate specific safety standards consistent with the Federal Guidelines for Dam Safety,'' referencing standards contained in FEMA documents 93, 333, 64, 94 and 65.

Little support was expressed for the alternative strategies presented in the proposal for addressing structural stability. Some comments were received suggesting additional alternatives. One commenter suggested that EPA consider limiting the volume of ''primary containment ponds'' to 10 acre-feet, reasoning that this provision would likely eliminate much of the concern regarding catastrophic failures, like TVA, and actually reduce the amount of slurry released in the event of a structural failure. Other commenters argued that EPA should limit the structural requirements to CCR surface impoundments both meeting the proposed size threshold and having a hazard potential classification of ''high'' or ''significant'' hazard potential rating based on FEMA's criteria for dam safety.[78] Commenters argued that a failure of a CCR surface impoundment with a ''low hazard potential classification'' posed only a low risk for on-site economic or environmental losses and would avoid the imposition of costly, arbitrary and unnecessary regulatory burdens on the owner or operator. In addition, commenters contended that this regulatory approach would be consistent with many state dam regulatory programs that apply dam integrity standards only to ''high'' or ''significant'' potential hazard facilities and would promote consistency with existing state controls.[79] Several commenters also suggested that EPA consider adding regulatory language or preamble discussion to assist owners or operators of CCR surface impoundments in interpreting the specific technical requirements in the regulation.

EPA disagrees with the suggestion that the Agency finalize a mandatory size limitation for operating CCR surface impoundments. While limiting the volume of CCR surface impoundments to ten acre-feet would limit the volume of CCR released in the event of a structural failure, limiting the size of CCR surface impoundments to 10 acre-feet may not always be practicable; nor does EPA believe that such a restriction is truly necessary to ensure that the section 4004(a) standard will be met. Many CCR surface impoundments are much larger than ten acre-feet and have been operating for many years without a structural failure. While EPA acknowledges that this fact in no way guarantees that a failure will not occur, the Agency is convinced that the implementation of all of the combined regulatory requirements in this rule (*e.g.,* location criteria, structural integrity, inflow design flood controls and inspection requirements) provides the necessary safeguards that will ensure that CCR surface impoundments are designed, constructed, operated, and maintained to minimize the risks associated with a catastrophic release of impounded CCR due to structural failure. While limiting the size of CCR surface impoundments will reduce risks because there will be a lower volume of waste in the unit, the Agency is not convinced that, in practice, such a requirement would meaningfully reduce the risks at many facilities. EPA expects that such a restriction would only cause facilities to construct either several small units or a multi-unit system. Failure of one unit can lead to progressive failure of other units in the system, and thus, ultimately this may not reduce the total volume of waste that could be released into the environment. EPA also disagrees that structural stability requirements should only apply to ''high'' or ''significant'' potential hazard facilities. Similarly, EPA disagrees with commenters that structural integrity requirements should only apply to owners or operators of CCR surface impoundments that both meet the specified size criteria and have either a high hazard or significant hazard potential classification. Even for CCR units with a low hazard potential classification, EPA is still concerned with the risk to human health and the environment from any structural failure of a CCR unit. As discussed previously in Unit VI.C of this document, the environmental effects of the failure of even a low hazard potential impoundment can still be significant, given the size of these units, the nature of the material in the unit, and the potential volumes that could be released. Contamination of surface waters and groundwater resources is still a significant threat when CCR units of this size fail, irrespective of the lower likelihood that a release will affect human health, as reflected in the low hazard potential classification. Consequently, one focus of this rule is preventing any release, catastrophic or otherwise, of CCR to the environment, and limiting all structural stability requirements commenters suggested would be inconsistent with this goal.

The Agency agrees that the final regulation should incorporate provisions that address the hazards to the downstream public. Accordingly, the final rule incorporates a number of provisions consistent with the FEMA Guidelines, including a requirement that owners and operators know each CCR unit's hazard potential classification, as this is part of owners and operators' responsibility to actively ensure the integrity of their CCR unit(s) and that their operations do not endanger human health or the environment. EPA also agrees that the requirements should be differentiated based on the potential severity of the consequence posed by the unit's failure, and therefore the hazard potential can be relevant in determining the stringency of particular requirements. However, the hazard potential is, at best, only an indicator of the potential damage that may be incurred from the

[78] See: *Federal Guidelines for Dam Safety: Hazard Potential Classification for Dams,* Federal Emergency Management Agency (''FEMA'') (reprinted January 2004). Under the FEMA dam safety classification system, a ''low hazard potential classification'' means that failure or mis-operation of the impoundment ''results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to owner's property.''

[79] See *e.g.,* New Mexico Rules and Regulations Governing Dam Design, Construction and Dam Safety (*e.g.,* requiring dam site security, an instrumentation plan for monitoring and evaluating dam performance, and an operation and maintenance manual and emergency action plan only for dams with a high or significant hazard potential); see also NMAC sections 19.25.12.11(G)–(J).

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structural failure of the unit, and so EPA has generally not relied on hazard potential as the sole basis for determining the structural integrity requirements that are necessary for a CCR unit.[80] Although the hazard potential classification can serve as a proxy for the amount of water and CCR that could potentially be released to the environment in the event of a CCR surface impoundment failure, the amount of water and CCR potentially released is more directly correlated to the actual height and storage volume of the CCR surface impoundment. In addition, it is widely recognized that the hazard potential classification of an individual unit can often fail to encompass the overall magnitude of a release on human health and the environment. CCR surface impoundments can frequently be part of a facility's run-off system that is responsible for routing surface waters to a drainage basin or watershed. As previously discussed, the failure of a CCR unit that is part of such a system has the potential to inundate downstream surface water units and water bodies, resulting in progressive failures of other units, including other CCR surface impoundments at the facility, which in turn can have a much greater environmental impact than the failure of just the one unit for which a hazard potential classification was made. Using a ''height and/or volume'' threshold to determine the applicability of the structural integrity criteria ensures that CCR units with the potential to cause these progressive failures in downstream surface water management units are appropriately overseen and regulated. CCR surface impoundments exceeding a specified height and/or capacity threshold also pose a higher degree of risk of release of CCR to the environment than other types of CCR surface impoundments (*e.g.,* incised or ''small'' CCR units). For all of these reasons, the size of the CCR unit, rather than the hazard potential classification, is the best indicator of potential severity of release of CCR to the environment and should therefore be the primary basis on which structural integrity criteria are applied. As such, EPA is promulgating, as proposed, a regulatory strategy that establishes some requirements for all CCR surface impoundments, but relies primarily on size as the basis for determining the majority of the specific technical criteria for minimizing risk from structural failure.

Regarding the second major issue presented in the comments, as noted previously, EPA received comments requesting the Agency to provide either more specific regulatory language or further guidance in the preamble, so that parties could certify that the CCR surface impoundment met the rule's overall performance standard. Commenters contended that guidance would be particularly critical if EPA did not establish more specific technical criteria, as owners or operators will be vulnerable to lawsuits for non-compliance. In addition, state officials requested that EPA adopt more specific standards consistent with those adopted under FEMA's Federal Guidelines for Dam Safety. As discussed throughout this section in more detail, EPA has adopted clarifications to the regulation, particularly in the sections on structural stability and safety factors, to more precisely lay out the specific technical standards that are considered to be the ''generally accepted and recognized good engineering practices'' that must be met. EPA relied extensively on existing MSHA requirements, FEMA's Federal Guidelines for Dam Safety, and guidance issued by the U.S. Army Corps of Engineers, as they were applied throughout EPA's Assessment Program, to supplement the technical detail originally contained in the proposed rule. EPA has also modified the criteria, where necessary, so they better reflect the information and experience developed through the Assessment Program, *e.g.,* the engineering criteria used to evaluate the CCR surface impoundments and to make recommendations to improve the structural stability of the units.

In this rule, the Agency is finalizing structural integrity criteria to ensure that CCR surface impoundments are designed, constructed, operated, and maintained in a manner that ensures the structural integrity of the CCR surface impoundment throughout its active life (*i.e.,* through closure of the CCR unit), detects actual or potential releases of CCR as early as practicable, and prevents catastrophic failures. Many of the requirements have been adopted without revision from the proposed rule for some requirements, however, as noted EPA has provided additional language to clarify the final regulation. These clarifications have been made in response to comments urging EPA to finalize regulatory requirements that were more precise or sufficiently objective (*i.e.,* a specific standard of performance) to allow a qualified professional engineer to reasonably certify that the requirements of the rule have been met. These specific regulatory clarifications are discussed throughout this section.

A further change is that the final rule requires facilities to periodically reassess several elements of the structural integrity performance standards (*i.e.,* re-assess every five years). Finally, in contrast to the programs established by MSHA and FEMA, the final rule establishes certain minimum requirements for all CCR surface impoundments. This is based on the fact that, unlike the dams regulated under other federal programs, the material in all CCR units is harmful, so even small releases can present environmental and human health concerns. But the majority of the structural integrity requirements vary depending on whether the CCR surface impoundment or lateral expansion exceeds particular size thresholds. The rulemaking record clearly demonstrates that these larger CCR surface impoundments present a greater risk of catastrophic failure, and therefore require a more robust set of regulatory requirements to ensure their continued structural integrity. The final rule's implementation of a size threshold for structural integrity requirements is consistent with the approach taken by the majority of dam safety programs and regulation.

These modifications are being made to better reflect the protections necessary to ensure that: (1) Structural integrity is maintained throughout the operational life of a CCR unit; and (2) the risk of catastrophic failure is minimized. The changes being made in this rule have been directly influenced by comments received, the observations and the conclusions drawn from EPA's Assessment Program, and the recommendations made by both MSHA and FEMA regarding dam safety. They are also generally consistent with the regulatory requirements of many other state and other federal agencies regulating dam safety.

1. Overview of Technical Criteria

Except for incised units, owners or operators of all existing and new CCR surface impoundments and any lateral expansion of these CCR units are required to: (1) Place a permanent identification marker on or immediately adjacent to the CCR units with the name associated with the CCR unit and the name of the owner or operator of the CCR unit; (2) conduct an initial hazard potential assessment to determine the current hazard potential classification of

[80] For example, EPA relied on hazard potential to trigger the requirement for an Emergency Action Plan, which will identify the actions necessary to minimize damage to life and property. As damage to life and property are the factors directly addressed in hazard potential classification, reliance on the classification is an appropriate determinant for this requirement.

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the CCR unit; (3) conduct periodic (*i.e.,* every five years) hazard potential re-assessments; (4) develop an Emergency Action Plan (EAP) if the hazard potential classification of the CCR unit is classified as either a high- or significant hazard potential; and (5) maintain the CCR unit with vegetated slopes or other forms of slope protection.

Owners or operators of CCR surface impoundments that either have a height of five feet or more and a storage volume of 20 acre feet or more, or a height of 20 feet or more are required to comply with the following additional structural integrity criteria: (1) Document the design and construction of the CCR surface impoundment; (2) conduct an initial structural stability assessment; (3) conduct an initial safety factor assessment; and (4) conduct periodic (not to exceed five years) structural stability and safety factor assessments.[81] Owners and operators of CCR units that fail to make the safety factor assessment or fail to meet the factors of safety specified in the rule must stop placing CCR in the unit and initiate closure.

The structural integrity requirements of the final rule require the compilation of construction history of the existing CCR surface impoundment within one year of the effective date of the rule.

Within two months of the effective date of the rule, the structural integrity requirements (§ 257.73) state that the owner or operator must install a permanent marker on the existing CCR surface impoundment. This timeframe is being promulgated as proposed, as EPA did not receive comments on the timeframe for installation of a permanent marker.

2. Structural Integrity Requirements Applicable to All CCR Surface Impoundments

a. Hazard Potential Classification Assessments

A hazard potential classification provides an indication of the potential for danger to life, development, or the environment in the event of a release of CCR from a surface impoundment. In this rule, an owner or operator of any existing or new CCR surface impoundment or any lateral expansion of a CCR surface impoundment must determine which of the following hazard potential classifications characterizes their particular CCR unit.[82] These classifications are: a high hazard potential CCR surface impoundment, a significant hazard potential CCR surface impoundment; and a low hazard potential CCR surface impoundment and are defined as follows:

- *High hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.
- *Significant hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.
- *Low hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation results in no probable loss of life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment's owner's property.

Owners and operators of all CCR surface impoundments must determine each unit's hazard potential classification through a hazard potential classification assessment. Hazard potential classification assessments must be certified by a qualified professional engineer and documentation must be provided that supports the basis for the current hazard potential rating. An initial hazard potential assessment must be conducted within one year of the effective date of the rule for existing units and prior to the initial receipt of CCR in the unit for new units or lateral expansions. Hazard potential classifications, structural stability assessments, and safety factor assessments require significant planning and coordination, such as detailed site-work and investigations, modeling and analysis, design and construction planning and implementation, and post-construction investigation. Many of these efforts take several months to complete, compounded by the fact that much of the work cannot be completed in cold-weather or heavy-rain seasons.

As commenters noted, it is imperative that the owner or operator maintain a current assessment of a unit's hazard potential classification, rather than develop a single one-time classification ''for which the facility was designed.'' (See proposed § 257.71(d)(10).) Moreover, FEMA recommends that a unit's hazard potential classification should be reviewed no less frequently than every five years in order to take into account changes in the factors that are the basis for which a hazard potential classification is made (*e.g.,* changed reservoir or downstream development).[83] Based on this information, EPA determined that a periodic reassessment of a CCR surface impoundment's hazard potential classification is a necessary component in maintaining the accuracy of the unit's hazard potential classification, as well as the overall safety of the unit. Consequently, EPA is requiring the owner or operator of a CCR surface impoundment to reassess the hazard potential classifications of their CCR unit and to have that classification, certified by a qualified professional engineer, at least every five years.

EPA has continued to rely on FEMA requirements as the basis for general CCR surface impoundment safety requirements, *e.g.,* inflow design flood selection, inspection criteria, earthquake analyses and design for several reasons: (1) Structural failure risks for CCR surface impoundments are similar to the risks from the larger dam universe for which FEMA intends its guidance; and (2) risks to downstream development from CCR surface impoundment failures are equal or similar to those presented by other types of dams' failures.

In this rule, hazard potential classifications define the consequences in the event of a failure of a CCR surface impoundment. The classification is separate from the structural stability of a CCR unit or the likelihood of the impoundment failing. A surface impoundment that meets or exceeds all of the structural stability criteria and safety factors of this rule would still be classified as ''high hazard potential'' if, in the event of failure, loss of life would be likely to occur.

[81] *Height* means the vertical measurement from the downstream toe of the CCR surface impoundment at its lowest point to the lowest elevation of the crest of the CCR surface impoundment.

[82] Incised CCR surface impoundments are not required to perform a hazard potential classification assessment because hazard potential classifications are based on the failure of a dam, diked surface impoundment, or other water-retaining structure and the adverse incremental impacts that may result from the failure. Because incised CCR surface impoundments, as defined in this rule, do not have a diked portion which may fail, the incised CCR surface impoundment cannot have a hazard potential classification. This final rule covers CCR surface impoundment failures and releases due to other potential failure modes (*i.e.,* which do not pose an immediate catastrophic threat to human health or the environment), such as a release through the liner of the unit or through failure of underlying structures, in the location restrictions, design criteria, and operating criteria of the rule.

[83] See: *Federal Guidelines for Dam Safety: Hazard Potential Classification for Dams,* Federal Emergency Management Agency (''FEMA'') (reprinted January 2004). Under the FEMA dam safety classification system, a ''low hazard potential classification'' means that failure or mis-operation of the impoundment ''results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to owner's property.''

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The hazard potential classification of the CCR surface impoundments is an essential element in determining how to properly design, construct, operate, and maintain a CCR surface impoundment. As such, the final rule bases the stringency of some technical requirements, in part, on the potential for adverse impacts on the failure of the CCR unit, as quantified by the hazard potential classification of this rule. Specifically, the requirements become more stringent as the potential for loss of life and/or property damage increases. This is reflected in both the criteria established under the structural stability assessments, *.e.g.,* where the combined capacity of all spillways must adequately manage flow during and following peak discharge from the specified inflow design flood based on the hazard potential classification of the unit—and in the hydrologic and hydraulic capacity requirements, which are similarly specified based on the hazard potential classification of the CCR unit (see §§ 257.73(d)(2)(v); 257.74(d)(2)(v) and 257.82 respectively).[84] Additionally, high and significant hazard potential CCR surface impoundments must develop a written Emergency Action Plan which establishes emergency action procedures in the event of a previously defined emergency.

b. Emergency Action Plan

An Emergency Action Plan (EAP) is a document that identifies potential emergency conditions at a CCR surface impoundment and specifies actions to be followed to minimize loss of life and property damage. Typically an EAP includes: (1) Actions the owner or operator will take to moderate or alleviate a problem at the CCR unit; (2) actions the owner or operator will take, in coordination with emergency management authorities, to respond to incidents or emergencies related to the CCR surface impoundment; (3) procedures owner or operators will follow to issue early warning and notification message to responsible downstream emergency management authorities; (4) inundation maps to allow owners and operators of the CCR unit and emergency management authorities to identify critical infrastructure and population-at-risk sites that may require protective measures, warning and evacuation planning; and (5) delineation of the responsibilities of all those involved in managing an incident or emergency and how the responsibilities should be coordinated and implemented.[85] As FEMA guidance suggests, and EPA reiterates here, the level of detail in the EAP should be commensurate with the potential impact of a surface impoundment failure or other operational incident (*e.g.,* its hazard potential classification). A surface impoundment with low potential hazard impact should not require an extensive evaluation or be subject to an extensive planning process, while high-hazard and significant hazard surface impoundments would typically require a much larger emergency planning effort. In addition, high hazard and significant hazard surface impoundments tend to involve more entities that must coordinate responsibilities and greater efforts would generally be necessary to effectively respond to an incident with such a surface impoundment than to a similar incident involving a low-hazard surface impoundment. As such, every EAP must be tailored to specific site conditions.

EPA is promulgating, as proposed, a provision that requires any CCR surface impoundment that is determined by the owner or operator, through the certification by a qualified professional engineer, to be either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment to prepare and maintain a written EAP. While EPA agrees that the level of detail contained in an EAP should be commensurate with its hazard potential rating, EPA has concluded that at a minimum, the EAP must: (1) Define responsible persons and the actions to be taken in the event of a CCR surface impoundment-safety emergency; (2) provide contact information for emergency responders, including a map which delineates the downstream area which would be affected in the event of a failure and a physical description of the CCR surface impoundment; (3) include provisions for an annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders; and (4) define conditions that initiate implementation of the EAP and define emergency response actions which must be implemented upon the detection of these conditions, including all persons responsible for the implementation of the emergency response actions. The first three of these four requirements were proposed as part of the EAP and are being promulgated without revision. The fourth requirement, which requires facilities to explicitly define the conditions by which the EAP is activated, was inadvertently omitted from the proposal, and is being added to the final rule to ensure that the EAP includes at least the basic requirements necessary to function effectively.

The owner or operator must amend the written EAP whenever there is a change in conditions that would substantially affect the written EAP in effect, *e.g.,* change in personnel, change in emergency responder contact information, a change in the CCR surface impoundments' designation from a significant-hazard potential classification to a high-hazard potential classification, or the vertical expansion of the CCR unit (*i.e.,* increase in the amount of CCR that potentially could be released.) Consistent with the requirements for hazard potential classification reassessments, the Agency is requiring, at a minimum that the EAP be reassessed at least every five years. If an owner or operator determines that, as part of it periodic hazard potential re-assessment that the unit no longer is classified as a high-hazard or a significant-hazard potential classification, but is now classified as a low hazard potential CCR surface impoundment, then the owner or operator of the CCR unit is no longer subject to the requirement to prepare and maintain an EAP, effective when such documentation is placed into the facility's operating record. If, however, during the reassessment effort it is determined that an existing CCR unit classified as a low hazard potential has been re-classified as either a significant-hazard or high-hazard potential, the owner or operation must prepare an EAP for the CCR unit within six months of completing such a periodic hazard potential re-assessment.

Although the owner or operator is responsible for developing and maintaining the EAP, which must be certified by a qualified professional engineer, the plan should be developed and implemented in close coordination with all applicable emergency management authorities, including the appropriate local, state, and federal authorities. Generally, these coordination efforts, along with the EAP, provide emergency management authorities with the necessary information to facilitate the implementation of their responsibilities, and so, it is vital that the development of the EAP be coordinated with emergency responders and other entities, agencies, and jurisdictions, as

[84] A high-hazard potential impoundment, for example, must be designed with sufficient spillway capacity to manage flow from the probable maximum flood, whereas a low hazard potential unit need only account for a 100 year flood.

[85] See: ''Federal Guidelines for Dam Safety: Emergency Action Planning for Dams,'' FEMA 64/July 2013.A.

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appropriate. After the initial EAP has been developed and placed in the operating record and on the owner or operator's internet site, it should be periodically reviewed and updated on a regular basis, as it can become outdated and ineffective. While the Agency is only requiring the EAP to be re-assessed every five years, it is recommended that the EAP be reviewed at least annually for appropriateness, accuracy, and adequacy so as to remain current. EPA recommends that the EAP be promptly updated to address changes in personnel, contact information and/or significant changes to the facility or emergency procedures. Even if no revisions are necessary, the review should be documented.

The initial EAP must be prepared within 18 months from the effective date of the rule. In order to prepare an EAP, the owner or operator must accurately and comprehensively identify potential failure modes and at-risk development, and therefore completion of the emergency action plan needs to follow the completion of the initial hazard potential classification, structural stability assessment, and safety factor assessments, during which this information will be generated.

c. Vegetated Slopes of Dikes and Surrounding Areas

EPA proposed to require both new and existing CCR surface impoundments that exceed the MSHA size thresholds to document the slope protection measures that have been adopted and to compute the minimum factors of safety for slope stability, in order to support the certification from an independent professional engineer that the unit has been designed in accordance with ''generally accepted engineering standards.'' EPA is promulgating the requirement that all CCR surface impoundments have adequate slope protection because EPA determined through the Assessment Program that slope protection is an essential element in preventing slope erosion and subsequent deterioration of CCR unit slopes. EPA is requiring slope protection for all units, not just units exceeding the size threshold of the final rule, because EPA has identified that slope protection on CCR units is a generally accepted good practice which reduces the occurrence of erosion, degradation of surface waters due to run-off from the CCR unit, enhances slope stability, and that vegetated cover is an easily accomplished practice in the vast majority of climates where CCR surface impoundments are located. In conducting the Assessment Program, the protective cover of slopes of the CCR surface impoundment was determined to be relevant to the overall condition rating of all units, irrespective of size. This is consistent with FEMA guidance, which also lays out specifications for the ideal vegetative cover for a dam. EPA has adopted this requirement to be consistent with its findings from the Assessment Program, and in response to comments, and has elaborated on the slope protection measures necessary to achieve the factors of safety. The final rule provides performance standards drawn primarily from FEMA guidance, as applied during the Assessment Program.

All CCR surface impoundments are required to be designed, constructed, operated, and maintained with adequate slope protection to protect against surface erosion at the site. Slope protection is necessary to ensure that dike or embankment erosion does not occur. Additionally, slope protection is required of all CCR surface impoundments to maintain the stability of the CCR surface impoundment slope under rapid drawdown events [86] and low pool conditions of water bodies that may abut the CCR surface impoundment and are outside the control of the owner or operator, *e.g.,* a natural river which the slopes of the CCR surface impoundment run down to and abut. The slope protection can act as a stabilizer in the slope of the embankment during rapid drawdown events. Adequate slope protection can be achieved in most climates through simple vegetation, typically a healthy, dense stand of low-growing grass, or other similar vegetative cover. In arid climates where the upkeep of vegetation is inhibited, alternate forms of slope protection, including rip-rap, or rock-armor is typically used. Additional slope protective measures are available and effective in certain circumstances, including but not limited to rock, wooden pile, or concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines.

The owner or operator must ensure that the slopes of the CCR surface impoundment are protected from erosion by appropriate engineering slope protection measures. It is recommended throughout embankment technical literature that vegetative cover not be permitted to root too deeply, precipitating internal embankment issues. The rule requires a vegetative cover limit to prevent the establishment of rooted vegetation, such as a tree or a bush on the CCR surface impoundment slope. EPA has concluded that a vegetative cover of no more than six inches above the face of the embankment is adequate and is the uppermost limit for vegetative cover height for this final rule. In developing this requirement, EPA was strongly influenced by information contained in the FEMA document entitled, ''Technical Manual for Dam Owners: Impacts of Plants on Earthen Dams'' [87] in determining an appropriate vegetative cover height for CCR surface impoundments. Six inches represents a vegetative height which prevents any trees, bushes, or shrubbery from rooting deeply enough to warrant additional removal measures outside of simple mowing. Furthermore, the height prescribed by the final rule represents a maximum height of vegetative cover to allow for adequate observation of the slope of the CCR unit during inspection. Vegetative cover in excess of six inches above the slope of the dike would prevent the adequate observation of the slope of the CCR unit and detection of structural concerns such as animal burrows and minor sloughs, amongst others concerns. Consistent with FEMA guidance, as applied during the Assessment Program, other slope protection, such as rock armoring or vegetated berms, would also be considered adequate.[88]

3. Structural Integrity Criteria Applicable to CCR Surface Impoundments Exceeding a Specific Size Threshold

The structural integrity criteria discussed in this section of the preamble apply to existing and new CCR surface impoundments and any lateral expansion with: (1) A height of five feet or more and a storage volume of 20 acre-feet or more; or (2) a height of 20 feet or more. The rule defines *height* as the vertical measurement from the downstream toe of the CCR surface impoundment at its lowest point to the lowest elevation of the crest of the CCR surface impoundment. The *downstream toe* is defined as the junction of the downstream slope or face of the CCR surface impoundment with the ground surface. This final rule considers the lowest elevation of the crest of the CCR

[86] This rapid drawdown is not included in the rule's factors of safety assessments. The protection against rapid drawdown requirement of this provision is concerned with the rapid drawdown of adjacent water bodies acting upon the downstream slope of the CCR surface impoundment rather than the rapid drawdown of the impounded reservoir of the CCR surface impoundment acting upon the upstream slope of the CCR surface impoundment.

[87] *http://www.fema.gov/media-library-data/20130726-1446-20490-2338/fema-534.pdf.*

[88] *http://www.fema.gov/media-library-data/20130726-1446-20490-2338/fema-534.pdf.*

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surface impoundment to be the maximum storage elevation of the reservoir or pool of the CCR unit, *e.g.,* the invert of the lowest-elevation spillway. EPA is implementing this size threshold because it comports with thresholds established by other federal and state agencies regulating dam integrity and/or safety. Specifically, for the implementation of the size threshold of this final rule, EPA relied on the identical size parameters, *i.e.,* height of five feet and capacity of 20 acre-feet, which is promulgated in MSHA coal slurry impoundment regulations in 30 CFR 77.216.

In the proposed rule, EPA used the size cut-off promulgated by MSHA in their dam safety requirements for coal slurry impoundments at 30 CFR part 77. In proposing this cut-off, EPA reasoned that the MSHA requirements affecting coal slurry impoundments were directly applicable and relevant to CCR surface impoundments and provided a size threshold that, when applied to the rule's structural integrity criteria, would generally meet RCRA's mandate to ensure protection of human health and the environment by minimizing the potential for catastrophic failure. Specifically, EPA proposed that surface impoundments: (1) Impounding CCR to an elevation of five feet or more above the upstream toe of the structure and can have a storage volume of 20 acre-feet or more; or (2) impounding CCR to an elevation of 20 feet or more above the upstream toe of the structure would be subject to the structural stability criteria. EPA also proposed to define *upstream toe* as the junction of the upstream slope of the dam with the ground surface, with the height of the CCR unit measured from the upstream toe or water-borne toe of the CCR unit.

While little comment was received on adopting this size threshold or the accompanying definition of *upstream toe,* the Agency was concerned that the size threshold presented in the proposed rule did not reflect standard measuring protocols used by other federal agencies and the dam sector in determining the size of a dam or, in the case of this rule, surface impoundment. Of particular concern to the Agency was the fact that EPA's own Assessment Program was measuring the height of a CCR unit from the downstream toe rather than the upstream toe, which was specified in the MSHA regulatory requirement and the subsequent CCR proposed rule.

A review of MSHA, FEMA and the USACE regulations and guidance, as well as the guidance of several state agencies that oversee dam safety, revealed that dam or surface impoundment height is more appropriately measured from the downstream and not the upstream toe of the unit. EPA based this conclusion on the near-universal position of dam safety guidance that the downstream slope height of the dike is of primary concern in the design, construction, operation, and maintenance of the dam or surface impoundment. Virtually all of the dam safety regulations, including state and federal guidance and regulations, that EPA reviewed considered measured dam height to be taken from the downstream slope of the dike. Some of these guidance and regulations include FEMA ''Federal Guidelines for Dam Safety,'' U.S. Army Corps ''National Inventory of Dams,'' and MSHA Metal and Nonmetal Tailings and Water Impoundment Inspection requirements in 30 CFR part 56 and § 57.20010.[89] This information, coupled with the information on the methodology used in the Assessments Program, convinced the Agency that a revised description of the CCR surface impoundment size cutoff was necessary, specifically requiring the height of the CCR unit to be measured from the downstream toe.

a. Design and Construction Information

The first element of the structural integrity criteria applicable to CCR units exceeding the specified size threshold requires the owner or operator to compile and place in the operating record design and construction information pertaining to the CCR unit. Among other things, this provision requires the following documentation to be provided by the owner or operator: (1) The name of the owner or operator of the unit; (2) the name of the unit; and (3) any identification number assigned by the state. In addition, it requires that the owner or operator identify: (5) The location of the CCR unit on a U.S. Geological Survey Map or a topographic map of equivalent scale; (6) provide dimensional drawings of the CCR unit with pertinent engineering structures and appurtenances identified; (7) describe the purpose of the CCR unit; and (8) identify the name and size of the watershed affecting the CCR unit, if any. Detailed information is also required documenting: (9) The design and construction of the unit including dates and descriptions of each zone or stage constructed; (10) instrumentation used to monitor the operation of the CCR unit, (11) spillway and diversion design descriptions and construction specifications; and (12) provisions for surveillance, maintenance and repair of the CCR unit.

While these requirements apply to both existing and new CCR surface impoundments, existing CCR surface impoundments are required to compile this information only ''to the extent available,'' within one year of the effective date of the rule. Conversely, new CCR surface impoundments or any lateral expansion must compile all of the information listed prior to the initial receipt of CCR. For existing CCR surface impoundments, EPA acknowledges that much of the construction history of the surface impoundment maybe unknown or lost. EPA's Assessment Program confirmed that many owners or operators of CCR units did not possess documentation on the construction history or operation of the CCR unit. Information regarding construction materials, expansions or contractions of units, operational history, and history of events was frequently difficult for the owners or operators to obtain. The Assessment Program also confirmed the Agency's initial assumption that this information, in many instances, will be difficult to compile. Therefore, in this rule, EPA is using the phrase ''to the extent available'' and clarifying that the term requires the owner or operator to provide information on the history of construction only to the extent that such information is reasonably and readily available. EPA intends facilities to provide relevant design and construction information only if factual documentation exists. EPA does not expect owners or operators to generate new information or provide anecdotal or speculative information regarding the CCR surface impoundment's design and construction history.

There are several other requirements under the design and construction criteria requiring clarification. First, the Agency is amending the requirement that all dimensional drawings of the CCR unit (see § 257.73(b)(vii) and § 257.74(b)(vii)) use a uniform scale of one inch equals 100 feet. After further consideration, EPA has deleted this requirement and has replaced the proposed scale of 1 inch equals 100 feet with the phrase ''at a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit.'' EPA made this change in response to comments arguing that this level of detail was unnecessary. EPA agrees that, given the extremely large variety in the size of CCR units, a prescriptive scale for all drawings of all CCR units is not necessary in many cases; this level of detail would be excessive for most

[89] *http://www.msha.gov/regs/complian/PILS/2013/PIL13-IV-01.asp.*

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units. The Agency is also clarifying, (see § 257.73(b)(2) and § 257.74(b)(2)) that if an owner or operator determines that a significant change has occurred in the information/documentation previously compiled under this provision, the owner or operator must update the relevant information and place it in the operating record.

b. Types of Assessments

A second element of the structural integrity criteria is the requirement for specific technical assessments of the CCR unit. Consistent with the requirements outlined in the proposed rule, two technical assessments are required for all CCR units exceeding the specified size threshold: (1) A structural stability assessment; and (2) a safety factor assessment. The owner or operator of an existing CCR surface impoundment is required to conduct an initial assessment addressing both structural stability and safety factors within one year of the effective date of the rule. New CCR surface impoundments or any lateral expansion of a CCR unit are required to complete the initial assessment prior to placing CCR into the unit. Following the initial assessments, EPA is also requiring periodic re-assessments of both a CCR surface impoundment's structural stability and factors of safety. EPA proposed to require an annual recertification, but in a departure from the proposed rule, EPA is only requiring these re-assessments to be conducted on a regular basis, not to exceed once every five years. In making this regulatory change, the Agency has relied heavily on the dam safety guidance established by FEMA in the document titled, *Federal Guidelines for Dam Safety* that a formal inspection, including ''. . . a review to determine if the structures (*i.e.,* CCR surface impoundments) meet current accepted design criteria and practices . . .'' be taken at an interval not to exceed five years. EPA has interpreted this guidance to be applicable to both the structural stability assessment and the safety factor assessment.

A demonstration must be completed within the assessment period for the specific type of assessment. This means that, within this timeframe the owner or operator must demonstrate that the CCR unit meets all of the requirements of each type of assessment, as certified by a qualified professional engineer. It also means that the owner or operator must have taken all measures necessary to bring the unit into compliance with all of the requirements for assessments of this final rule within the assessment period. If the owner or operator cannot demonstrate that the unit meets these factors of safety (or otherwise fails to comply with the structural stability requirements) within the appropriate timeframe, the unit must initiate closure.

i. Periodic Structural Stability Assessments

In order to ensure the proper upkeep and operation of the CCR unit, the owner or operator must demonstrate that the CCR surface impoundment has been designed, constructed, operated and maintained to provide structural stability. Specifically, consistent with the proposal, the final rule requires the owner or operator to demonstrate that the design, construction, operation, and maintenance of the CCR surface impoundment is consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR and water that can be impounded therein. As discussed previously, EPA has elaborated on this overall performance standard in response to comments from the engineers who would be required to make these certifications, urging EPA to specify more precisely the standards that must be met. Specifically the final rule focuses on the critical structural aspects of the CCR surface impoundment that EPA identified in the proposed rule, and identifies the minimum elements that a professional engineer must provide engineering details on or otherwise address. In certain cases, the final criteria identify specific engineering performance standards. EPA relied on existing MSHA requirements, FEMA dam safety guidance, and guidance issued by the USACE, as applied throughout EPA's Assessment Program to develop these criteria. Consistent with the proposal, these demonstrations must be certified by a qualified professional engineer. Each of these criteria is discussed in more detail below.

In addition to implementing adequate slope protection against erosion, which is a structural stability requirement applicable to all CCR units, the owner or operator of a CCR surface impoundment exceeding the specified size threshold must demonstrate that the unit, including any vertical and lateral expansions, is constructed with ''stable foundations and abutments.'' A stable foundation is an essential element of surface impoundment construction and prevents differential settlement of the embankment which can result in adverse internal stresses with the embankment cross-section. Soils tend to consolidate when subjected to loadings for extended periods, which can lead to strain incompatibility, a phenomena which prevents the full development of peak strength of the foundation. The stability of foundations and abutments can be determined by engineering monitoring, representative soil sampling, and modeling. Similarly, cohesion between the abutments of the CCR surface impoundment and the embankment of the CCR surface impoundment is critical. Frequently, CCR surface impoundments are subject to cracking and excessive seepage and piping in the groins where the abutment and embankment meet. These adverse conditions may lead to further structural deficiencies which threaten the safety of the CCR surface impoundment.

Consistent with general engineering construction methodologies, the structural stability assessment also requires the owner or operator to determine whether the CCR surface impoundment has been mechanically compacted to a density sufficient to withstand the range of loading conditions in the CCR unit.[90] Compaction of a dike or embankment is considered essential, as the compaction of soils leads to an increase in density and subsequently strength. Soil mechanics theory has established that the density of a soil corresponds to the moisture content and strength of the soil. The rule requires the owner or operator make this determination for all dikes of a CCR surface impoundment.

EPA notes that a number of existing voluntary consensus standards are available that can be useful in making this determination. For example, ASTM D 698 establishes a performance standard of 95% of the maximum standard Proctor density. Similarly, ASTM D 1557 establishes a standard of 90% of the maximum modified Proctor density. Alternatively, in certain instances, such as soils consisting of more than 30% material retained on the ¾ in. sieve, Proctor testing is not appropriate and the relative density criteria can be met. In such cases, EPA recommends a 70% relative density. These specific soil compaction criteria are ubiquitous throughout engineering construction as sufficient to support engineered works based on the requirements. They are also consistent with the standards promulgated by the state of New Mexico's dam safety program in order to ensure proper compaction during construction of new CCR surface impoundments.

EPA recognizes that it would be highly difficult for owners or operators

[90] *http://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2300.pdf.*

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of older units to certify with any certainty that the unit's construction meets the specific numeric compaction criteria found in the ASTM standards. New units, however, can easily meet these standards, and should therefore be designed and constructed to meet the numeric compaction criteria.

The owner or operator must also design, construct, operate, and maintain the CCR surface impoundment spillway or spillways with appropriate material so as to prevent the degradation of the spillway, as well as to ensure that the CCR surface impoundment has adequate spillway capacity to manage the outflow from a specific inflow design flood. In addition, a demonstration must be made that the CCR surface impoundment has been designed, constructed, operated, and maintained with inflow design flood controls and/or spillway capacity to manage peak discharge during and following inflow design floods. This demonstration is required to ensure the CCR surface impoundments will have adequate hydrologic and hydraulic capacity to prevent such failures as overtopping and excessive internal seepage and erosion. Spillways must be designed to withstand discharge from the inflow design flood without losing their structural form and leading to discharge issues, such as erosion or overtopping of the embankment. This requirement is covered in more detail in the hydrologic and hydraulic capacity requirements for CCR surface impoundments section of this rule.

EPA is not requiring a facility to include any demonstration relating to the potential for rapid, or sudden, drawdown loading condition. Rapid or sudden drawdown is a condition in earthen embankments in which the embankment becomes saturated through seepage in an extended high pool elevation in the reservoir. A threat to the embankment emerges when the reservoir pool is drawn down or lowered at a rate significantly higher than the excess poor water pressure within the embankment can diminish. Typically, rapid drawdown scenarios are considered for embankments with reservoirs used for water supply and management, emergency reservoirs, or agricultural supply, in which the reservoir is rapidly discharged from the structure. In these scenarios, a high pool elevation is maintained in the reservoir in storage months. Subsequently, the water supply is drawn on in months where there is a high demand for the reservoir's contents. This drawing down of the pool can affect the structural stability of the unit. However, the management of CCR surface impoundments differs from that of conventional water supply, emergency, and agricultural reservoirs. The only instance of a rapid drawdown of a CCR surface impoundment which EPA has identified is in the event of a massive release of the reservoir of the CCR surface impoundment due to a failure of the dike of the CCR surface impoundment. In this instance, a massive release has occurred or is occurring. A subsequent failure of the upstream or internal embankment due to this rapid drawdown would only precipitate further embankment failure and not any further release of the contents of the impoundment, as the contents of the surface impoundment would have already been released. In these instances, remediation of a failure in a rapidly drawn-down section would be necessary prior to filling of the unit, but is not a concern precipitating a release of impounded contents.

A second consideration regarding rapid drawdown, however, is the rapid drawdown of a water body adjacent to the slope of the CCR surface impoundment which may periodically inundate the slope. Many CCR surface impoundments are located in areas in which the downstream slope of the CCR surface impoundment runs down to a lake, stream, or river. In such instances, rapid drawdown must be considered for the stability of the downstream slope of the embankment in the event of a rapid drawdown in the lake, stream, or river pool elevation or stage. Because the water ponded against the downstream slope of the CCR surface impoundment provides a stabilizing load on the slope of the CCR surface impoundment, the rapid or gradual loss of this stabilizing force must be considered in the analysis of the CCR surface impoundment. The rule, therefore, requires that existing and new CCR surface impoundments and any lateral expansions of such units with a downstream slope that can be inundated by an adjacent water body, such as rivers, streams, or lakes, be constructed with downstream slopes that will maintain structural integrity in events of low pool or rapid drawdown of the adjacent water body. This ensures that the structural integrity of the downstream slope of the CCR surface impoundment will be maintained, even though the conditions of an adjacent surface water body may be outside the owner or operator's control.

ii. Periodic Safety Factor Assessments

As previously discussed, EPA received comment requesting the Agency to supplement the proposed technical criteria to assist owners or operators of CCR surface impoundments in interpreting the factor of safety determination required by proposed § 257.71(d)(12). EPA proposed that facilities compute ''a minimum factor of safety for slope stability of the CCR retaining structure(s),'' and to provide the methods and calculations used to determine each factor of safety. In reviewing the proposed requirement, the Agency agrees that further elaboration on the requirement is necessary to ensure that engineers can accurately assess a CCR unit's structural stability using factor of safety calculations, and would be valuable to ensure a consistent national standard. EPA has therefore revised the criteria to be consistent with the criteria developed and used to assess these impoundments as part of the Assessment Program.

Accordingly, the final rule requires demonstrations of structural integrity using accepted engineering methodologies under specific loading conditions. Owners or operators must conduct and have certified by a qualified professional engineer, an initial assessment, supported by the appropriate engineering calculations, documenting whether the CCR unit achieves the following minimum factors of safety: (1) The calculated static factor of safety under the long-term, maximum storage pool loading condition, which must equal or exceed 1.50; (2) the calculated static factor of safety under the maximum surcharge pool loading condition, which must equal or exceed 1.40; (3) the calculated seismic factor of safety, which must equal or exceed 1.00; and (4) the calculated liquefaction factor of safety, which must equal or exceed 1.20. In addition to the safety factors specified for existing CCR surface impoundments, new CCR surface impoundments and any lateral expansion must also comply with a fifth safety factor, the calculated static factor of safety under the end-of-construction loading condition, which must equal or exceed 1.30.

The minimum static factors of safety are adopted directly from the USACE's Engineer Manual EM 1110–2–1902 entitled, ''Slope Stability.'' As discussed in more detail in Unit III of this document, EPA relied heavily on this manual and applied these specific factors of safety during its Assessment Program, and it is widely considered the benchmark in the dam engineering community for slope stability and methodology and analysis.

The seismic factor of safety is adopted from review of several dam safety guidance documents, including USACE guidance Engineer Circular 1110–2–6061: Safety of Dams-Policy and Procedures 2204, Engineer Circular

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1110–2–6000: Selection of Design Earthquakes and Associated Ground Motions 2008, and Engineer Circular 1110–2–6001: Dynamic Stability of Embankment Dams 2004. EPA also reviewed MSHA's 2009 Engineering and Design Manual for Coal Refuse Disposal Facilities, in particular Chapter 7, ''Seismic Design: Stability and Deformation Analyses.'' These documents are viewed by ASDSO, FEMA and MSHA as generally accepted guidance on how to conduct seismic stability analyses. EPA chose the factor of safety of 1.00 because the 1.00 quantity represents the condition of the slope in which the strength of resistance to loading is equal to the anticipated loading stress acting upon the embankment, or the value which represents stability under the appropriate loading condition.

The liquefaction factor of safety is adopted from review of several dam safety guidance and liquefaction guidance, including ''Soil Liquefaction During Earthquakes,'' Idriss and Boulanger, Earthquake Engineering Research Institute, 2008,[91] ''Geotechnical and Stability Analyses for Ohio Waste Containment Facilities,'' Ohio EPA, Sept. 14, 2004, Chapter 5,[92] and *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams,* Document 65, FEMA May 2005.[93] EPA also reviewed several technical resources regarding soil liquefaction, including ''Ground Motions and Soil Liquefaction During Earthquakes,'' Seed and Idriss, 1982,[94] ''Liquefaction Resistance of Soils: Summary report from the 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils,'' Youd and Idriss, 2001,[95] and *Seismic Design Guidance for Municipal Solid Waste Landfill Facilities,* US EPA, Office of Research and Development, 1995. EPA chose a liquefaction factor of safety of 1.20, identifying that consideration of liquefaction potential and post-liquefaction residual strength slope stability included several uncertainties in assumptions and analysis which must be accounted for in a factor of safety above unity (*i.e.,* 1.00). FEMA guidance explicitly states that ''post-liquefaction factors of safety are generally required to be a minimum of 1.2 to 1.3.''

In conjunction with this requirement, EPA continues to require periodic re-assessments of the safety factor calculations, but as discussed, has modified the frequency to be no less than once every five years for all affected CCR units. Periodic reassessments are necessary to account for factors that are subject to change and can adversely affect the structural stability of a CCR unit, *e.g.,* age, use, volume of material contained within, and to reflect the dynamic nature of a CCR surface impoundment and the loads to which the dikes of the CCR surface impoundment may reasonably be expected to become subject to both the requirement to periodically reassess safety factor calculations and the five-year timeframes are consistent with the guidance set forth by other federal agencies in assessing dam safety, including MSHA, FEMA, and the USACE. For example, FEMA's Federal *Guidelines for Dam Safety* explicitly recommends that a dam be formally reassessed at an interval not to exceed every five years, and EPA has adopted this minimum frequency of assessment in this final rule.

(a) General Safety Factor Assessment Considerations

Generally accepted engineering methodologies specify that the determination of the structural stability factors of safety specified above is to be calculated by the qualified professional engineer using conventional analysis procedures or, if necessary, special analysis procedures. Conventional analysis procedures include, but are not limited to, limit equilibrium methods of slope stability analysis, whereas, special analysis procedures include, but are not limited to, finite element methods, finite difference methods, three-dimensional methods, or probabilistic methods. Whichever methodology is used to determine the factors of safety of the CCR surface impoundment, the qualified professional engineer must document the methodology used, as well as the basis for using that methodology, and the analysis must be supported by appropriate engineering calculations.

Limit equilibrium methods compare forces, moments, and stresses which cause instability of the mass of the embankment to those which resist that instability. The principle of the limit equilibrium method is to assume that if the slope under consideration were about to fail, or at the structural limit of failure, then one must determine the resulting shear stresses along the expected failure surface. These determined shear stresses are then compared with the shear strength of the soils along the expected failure surface to determine the factor of safety. Limit equilibrium methods include, but are not limited to, methods of slices. The most commonly applicable method of slices are the ordinary method of slices or Modified Swedish Method, Bishop's Modified Method, force equilibrium methods, Janbu's method, Morgenstern and Price's method, or Spencer's Method.

If conventional analysis procedures yield results that indicate complex failure mechanisms or the need for estimation of displacements, such as the need to determine internal stresses or displacements in an embankment or account for 3-dimensional effects in an embankment, special analysis procedures may be necessary to calculate factors of safety. Special analysis procedures include, but are not limited to: (1) The finite element method; (2) the finite difference method; (3) the three-dimensional limit equilibrium analysis method; or (4) the probabilistic method.[96]

Structural stability factors of safety need to be met in all cross-sections of the CCR surface impoundment since the failure of any cross-section of the CCR surface impoundment can result in the loss of the reservoir and stored CCR material in the CCR surface impoundment. However, it is not necessary to require the facility to fully analyze and calculate factors of safety for all cross sections under the specific loading conditions identified above. Rather, it is sufficient to calculate the factors of safety under both static, seismic, and liquefaction loading conditions only for the critical cross section of the CCR surface impoundment embankment, provided the facility carefully analyzes each cross section to properly identify the critical cross section. EPA has adopted this approach because the critical cross-section(s) represents a ''most-severe'' case and it is reasonably anticipated that all other cross-sections of the embankment will exceed the calculated factors of safety of the critical cross-section(s). The final rule therefore adopts this approach. The final rule

[91] *https://www.eeri.org/products-page/monographs/soil-liquefaction-during-earthquakes-3/.*

[92] *http://epa.ohio.gov/portals/34/document/guidance/gd_660.pdf.*

[93] *http://www.ferc.gov/industries/hydropower/safety/guidelines/fema-65.pdf.*

[94] Seed, H.B., and Idriss, I.M., 1982, ''Ground Motions and Soil Liquefaction During Earthquakes,'' Monograph No. 5, Earthquake Engineering Research Institute, Berkeley, California, pp. 134.

[95] Youd, T.L., Idriss, I.M., 2001, ''Liquefaction Resistance of Soils: Summary report from the 1996 and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils.'' Journal of Geotechnical and Geoenvironmental Engineering, ASCE.

[96] Additional information regarding special analysis methodologies can be found in publications from the U.S. Army Corps of Engineers Engineering Publications or geotechnical journals and scholarly articles.

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defines the critical cross section of the embankment of a CCR surface impoundment to be that which is anticipated to be most susceptible amongst all cross sections of the embankment to structural failure based on several engineering considerations for the given loading condition, such as soil composition of the cross-section, phreatic surface level within the cross section, grade of the upstream and downstream slopes of the cross section, and presence or lack of reinforcing measures in the cross-section as opposed to other cross-sections, such as buttressing or slope protection on the slopes of the cross section. Due to the variance of qualitative and quantitative properties of embankment structural strength, EPA expects that a prudent engineering analysis will need to consider multiple cross sections to ensure proper selection of a critical cross section.

(b) The Calculated Static Factor of Safety Under the Long-Term, Maximum Storage Pool Loading Condition

It is generally accepted practice to analyze the stability of the downstream slope of the dam embankment for steady-state seepage (or steady seepage) conditions with the reservoir at its normal operating pool elevation (usually the spillway crest elevation) since this is the loading condition the embankment will experience most. This condition is called steady seepage with maximum storage pool. The maximum storage pool loading is the maximum water level that can be maintained that will result in the full development of a steady-state seepage condition. Maximum storage pool loading conditions need to be calculated to ensure that the CCR surface impoundment can withstand a maximum expected pool elevation with full development of saturation in the embankment under long-term loading. The final rule requires that the calculated static factor of safety for the critical cross section of the CCR surface impoundment under the long-term maximum storage pool loading condition meet or exceed 1.5. The generally accepted methodology for determining the long-term, maximum storage pool loading condition considers conditions at the CCR surface impoundment that exist for a length of time sufficient for steady-state seepage or hydrostatic conditions to fully develop within the embankment of the CCR unit.[97] The maximum storage pool loading needs to consider a pool elevation in the CCR unit that is equivalent to the lowest elevation of the invert of the spillway, *i.e.,* the lowest overflow point of the perimeter of the embankment. The generally accepted methodology for the calculation of the factors of safety uses shear strengths expressed as effective stress and with pore water pressures that correspond to the long-term condition. Pore-water pressures should be estimated from the most reliable of the following sources: (1) Field measurements of pore pressures in existing slopes; (2) past experience and judgment of the qualified professional engineer; (3) hydrostatic pressure computation for conditions of no flow; or (4) steady-state seepage analysis using flow nets or finite element analyses.

(c) The Calculated Static Factor of Safety Under the Maximum Surcharge Pool Loading Condition

The maximum surcharge pool loading condition is calculated to evaluate the effect of a raised level (*e.g.,* flood surcharge) on the stability of the downstream slope. This ensures that the CCR surface impoundment can withstand a temporary rise in pool elevation above the maximum storage pool elevation for which the CCR surface impoundment may normally be subject under inflow design flood stage, for a short-term until the inflow design flood is passed through the CCR surface impoundment. The final rule requires that the calculated static factor of safety for the critical cross section of the CCR surface impoundment under the long-term maximum surcharge pool loading condition meet or exceed 1.4.

Similar to the long-term, maximum loading condition, a prudent evaluation of the maximum surcharge pool loading condition needs to consider conditions at the CCR unit to exist for a length of time sufficient for steady-state seepage or hydrostatic conditions to fully develop within the embankment of the CCR surface impoundment. The maximum surcharge pool is considered a temporary pool that is higher than the maximum storage pool; the maximum surcharge loading condition should therefore consider a temporary condition in the pool at which the pool exists temporarily above the maximum storage pool elevation in the event of an inflow design flood and spillway discharge condition in the reservoir, *i.e.,* above the lowest invert of the spillway during the anticipated inflow design flood.

(d) The Calculated Seismic Factor of Safety

All CCR surface impoundments, including any lateral expansions that exceed the size threshold must meet a seismic factor of safety equal to or greater than 1.0. EPA has included this requirement because the mechanics and response phenomena of geotechnical structures vary radically under dynamic loading from those under static loading. Consequently, reliance on the factors of safety under static loading is not sufficient to evaluate the structural stability of a CCR surface impoundment. Standard engineering methodology and guidance support EPA's conclusion that adequate seismic analysis of embanked structures is essential to ensure the continued structural stability of a geotechnical structure under dynamic, or seismic, loading is warranted.[98]

As discussed in the section of this preamble addressing the location criteria, all CCR surface impoundments must also be capable of withstanding a design earthquake without damage to the foundation or embankment that would cause a discharge of its contents. To further support the location criteria established in this rule, CCR surface impoundments and any lateral expansion exceeding a specific height and/or volume threshold must be assessed under seismic loading conditions for a seismic loading event with a 2% probability of exceedance in 50 years, equivalent to a return period of approximately 2,500 years, based on the USGS seismic hazard maps for seismic events with this return period for the region where the CCR unit is located. EPA chose the 2% exceedance probability in 50 years event based on its common use in seismic design criteria throughout engineering. See for example, ASCE 7 *Minimum Design Loads for Buildings and Other Structures, International Building Code.* Moreover, USGS seismic hazard maps, dictate that the life of a structure and the realistic probability of event occurrence be considered in the design of lateral force resisting systems for structures. As discussed in the Regulatory Impact Assessment, the expected life of a CCR surface impoundment can exceed 50 years. Consistent with the location criteria for seismic impact zones, EPA adopted 2% as a reasonable probability of occurrence.

Under standard engineering methodologies, seismic analysis includes several procedures to adequately analyze the structural

[97] U.S. Army Corps of Engineers ''Slope Stability'' manual.

[98] *E.g.,* FEMA's *Federal Guidelines for Dam Safety: Earthquake Analyses and Design of Dams.*

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strength of a CCR surface impoundment during dynamic, *i.e.,* seismic, loading. Such analyses would typically need to include the appropriate characterization of ground motions at the site of the CCR surface impoundment for the 2% probability in 50 years seismic event.[99] In addition, the peak ground acceleration (PGA), velocity, and displacement should be selected using historic records, site-specific observations, or magnitude-distance attenuation relations. Additionally, the analysis would need to include an appropriate duration of earthquake, considering accelerograms for the anticipated event. Appropriate elastic response spectra should be selected using engineering methodology for selection, such as the Newmark-Hall Spectrum or other appropriate published spectra, USGS Probabilistic Maps, or site-specific response spectra.

(e) The Calculated Liquefaction Factor of Safety

All CCR surface impoundments, including any lateral expansions that exceed the size threshold and have been determined to contain soils susceptible to liquefaction must meet a liquefaction factor of safety equal to or greater than 1.20. A prudent engineering analysis of structural stability also includes a liquefaction potential analysis and analysis of post-liquefaction static factors of safety. As discussed previously, liquefaction is a phenomenon which typically occurs in loose, saturated or partially-saturated soils in which the effective stress of the soils reduces to zero, corresponding to a total loss of shear strength of the soil. The most common occurrence of liquefaction is in loose soils, typically sands. The liquefaction FOS determination in the final rule is used to determine if a CCR unit would remain stable if the soils of the embankment of the CCR unit were to experience liquefaction. Liquefaction analysis is only necessary in instances where CCR surface impoundments show, through representative soil sampling, construction documentation, or anecdotal evidence from personnel with knowledge of the CCR unit's construction, that soils of the embankment are susceptible to liquefaction.

EPA has included this requirement because the mechanics and response phenomena of geotechnical structures vary radically following induced liquefaction, *i.e.,* post-liquefaction. Similar to the requirement for seismic factors of safety, liquefaction factors of safety are necessary because reliance on static loading is not sufficient to evaluate the structural stability of a CCR surface impoundment. Standard engineering methodology and guidance support EPA's conclusion that adequate liquefaction potential analyses and post-liquefaction residual strength slope stability analyses of embanked structures is essential to ensure the continued structural stability of a geotechnical structure following dynamic loading.

Under standard engineering methodologies, liquefaction potential analysis and post-liquefaction stability analysis includes several procedures to adequately analyze the structural strength of a CCR surface impoundment. Because only certain soils, such as loose sands, are susceptible to liquefaction, the rule requires only embankments constructed of such soils identified through liquefaction potential analysis to meet liquefaction factors of safety. Such liquefaction potential analysis would need to include proper soil characterization of the embankment soils for soil age and origin, fines content and plasticity index, water content, saturation, and maximum current, past, and anticipated future phreatic surface levels within the embankment, foundation, or abutments, location beneath the natural ground surface, and penetration resistance whether through standard penetration testing (SPT) or, ideally, cone penetration testing (CPT). Post-liquefaction stability analysis would need to include detailed characterization of the site conditions, identification of the minimum liquefaction-inducing forces based on soil characterization, determination of seismic effect on liquefied layers of the embankment, and calculation of factors of safety against each liquefied layer of the embankment.

(f) The Calculated Static Factor of Safety Under the End-of-Construction Loading Condition

The End-of-Construction loading condition must be calculated for new CCR surface impoundments to ensure that the CCR surface impoundment can withstand a ''first-filling'' of the embankment, during which time the embankment first become saturated and is subject to phreatic flow through the cross-section.

Embankments are typically constructed in layers with soils at or above their optimum moisture content that undergo internal consolidation because of the weight of the overlying layers. Embankment layers may become saturated during construction as a result of consolidation of the layers or by rainfall. Because of the low permeability of fine-grained soils of which many embankments are constructed and the relatively short time for construction of the embankment, there can be little drainage of the water from the soil during construction: resulting in the development of significant pore pressures. Soils with above optimum moisture content will develop pore pressures more readily when compacted than soils with moisture contents below optimum. In general, the most severe construction loading condition is at the end of construction.

The final rule requires that the calculated static factor of safety for the critical cross section of the CCR surface impoundment under end of construction loading conditions meet or exceed 1.30. The End-of-Construction loading condition is analyzed for new construction under their initial filling condition, following the completion of construction. Undrained shear strength conditions are typically assumed for the End-of-Construction loading condition. Both the upstream and downstream slopes of the embankment are analyzed for this condition

(g) Failure To Demonstrate Minimum Safety Factors or Failure To Complete a Timely Safety Factor Assessment

As previously discussed, the rule requires an owner or operator to document that the calculated factors of safety for each CCR surface impoundment achieve the minimum safety factors specified in the rule. For any CCR surface impoundment that does not meet these requirements, the owner or operator must either take any engineering measure necessary to ensure that the unit meets the requirements by the rule's deadlines, or cease placement of CCR and non-CCR waste into the unit and initiate closure of such CCR unit as provided in section 257.102 within six months. Similarly, if an owner or operator fails to complete the initial safety factor assessment or any subsequent periodic factor safety assessment by the deadlines established in the rule, the owner or operator must cease placing CCR and non-CCR waste into the unit and initiate closure within six months.

(h) Vertical Expansions of CCR Surface Impoundments and Structural Integrity Criteria

It is not uncommon for the owner or operator to raise the crest of a CCR surface impoundment to accommodate the additional capacity needs of the

[99] FEMA Doc. 65 ''Earthquake Analyses and Design of Dams;'' *http://www.ferc.gov/industries/hydropower/safety/guidelines/fema-65.pdf.*

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facility. The record documents that CCR surface impoundments are commonly expanded from the original design or as-built construction, through such ''vertical expansions,'' including where a CCR surface impoundment changes from a ''small'' CCR unit (*i.e.,* below the height and/or volume threshold) to a ''large'' CCR unit (*i.e.,* exceeding the height and/or volume threshold). In these situations, the owner or operator of the CCR unit becomes subject to additional structural integrity requirements as a result of the vertical expansion. Realizing that these newly created CCR units will require some time to meet the structural integrity requirements, the Agency is allowing one year from the completion of the vertical expansion for the owner or operator to comply with the requirements of §§ 257.73 or 257.74, as applicable.

F. Operating Criteria—Air Criteria

EPA proposed to require CCR landfills, CCR surface impoundments and any lateral expansion to control the creation of fugitive dust. Specifically, EPA proposed that facilities must ensure that fugitive dust either not exceed the standard of 35 μg/m^3, established as the level of the 24-hour National Ambient Air Quality Standards (NAAQS) for fine particulate matter (PM–2.5), or any alternative standard established pursuant to applicable requirements developed under a State Implementation Plan (SIP) approved or promulgated by the Administrator pursuant to section 110 of the CAA (see 75 FR 55175). Consistent with the numerical standard, EPA proposed to require that CCR units be managed to control the wind dispersal of dust, and that CCR landfills also be required to emplace wet conditioned CCR (*i.e.,* wetting CCR with water to a moisture-content that prevents wind dispersal and facilitates compaction, but does not result in free liquids) into the unit. EPA also required that documentation of the measures taken to comply with the requirements be certified by an independent registered professional engineer. EPA proposed these requirements based on the results of a screening level analysis of the risks posed by fugitive dust from CCR landfills, which showed that without fugitive dust controls, levels at nearby locations could exceed 35 μg/m^3, established as the level of the 24-hour PM 2.5 NAAQS for fine particulate. These measures were also intended to reduce the excessive cancer risks associated with the inhalation of hexavalent chromium. This potential risk would apply to over six million people who live within the census population data ''zip code tabulation areas'' for the 495 rule-affected electric utility plant locations. (See 75 FR 35215.) [100]

As part of the proposal, EPA solicited comments on the following fugitive dust issues: (1) The location of air monitoring stations near CCR landfills or CCR surface impoundments; and (2) information on any techniques, such as wetting, compaction, or daily cover that are or can be employed to reduce exposures to fugitive dust. The Agency received no information from commenters on either of these issues.

The majority of comments received, however, took issue with the proposed technical standard of 35 ug/m^3. Commenters argued that, as proposed, the standard would be impossible to implement because the Agency provided no information on particle size, form of the standards, whether an averaging period is available, point of compliance or how one considers upwind sources. More generally, however, commenters argued that the proposed provisions were unnecessary because fugitive dust issues were adequately addressed by existing air rules through the development and implementation of NAAQS, such as PM_{10} and $PM_{2.5}$. These same commenters acknowledged, however, that if the Agency established a criterion to control fugitive dusts, a more appropriate and reasonable standard could be based on best management practices or BMPs. To that end, commenters offered information suggesting that CCR landfills typically used compaction, regular wetting and temporary covers in conjunction with visual air monitoring to effectively control fugitive dust at their facilities, and that these practices were included in facility operating plans.

As discussed in the proposed rule, EPA's decision to address fugitive dust was based on a peer review of the 2010 draft Risk Assessment, 2007 NODA stakeholder comments, photographic documentation of fugitive dust associated with the management of CCR, Agency actions to control fugitive emissions during the clean-up of the December 2008 TVA Kingston spill, and OSHA's Material Safety Data Sheets (now *Safety Data Sheets* (*SDS*)) requirements for coal ash. These lines of evidence have been bolstered since the proposal, by evidence collected during the eight 2010 CCR public hearings, where stakeholders provided extensive feedback about fugitive dust impacts associated with CCR management at facilities adjacent to their residences, and by documented reports on fugitive dust issues provided by citizen groups.[101] The stakeholders called for federal oversight to address those instances where complaints were seemingly ignored by state regulators and/or where state administrative enforcement measures failed to compel the utilities to effectively amend their dust emission control management practices. The Agency followed up on the complaints with state agencies and compiled a preliminary database on documented and alleged fugitive dust damage cases.[102]

In support of this rule, EPA compiled records of over 20 documented fugitive dust cases, in addition to several alleged cases that could not be verified. The documented cases indicate that fugitive dust concerns arise in all phases of the CCR life cycle—from conveyor belt transfer at the coal-fired power plant, through stockpiling and transport for disposal/beneficial use, and up to final disposition. Fugitive dust also is a potential concern associated with both—landfills and surface impoundments. Whereas a nexus between fugitive dust impacts and CCR landfill operations was to be expected, EPA discovered that fugitive dust was also of concern at CCR surface impoundments, either under conditions of windy winter spells affecting CCR exposed above or next to the CCR surface impoundment boundary, or due to the total CCR surface impoundment evaporation in arid areas.

Very few studies have been undertaken to test the health impacts caused by fugitive dust emissions, and of those few, due to inherent limitations, all failed to prove that fugitive dust was the cause of the documented health concerns. For example, in the wake of the January

[100] As evidenced in 42 U.S.C. 6971(f), Congress intended that the Occupational Safety and Health Administration (OSHA) be able to enforce its regulations to protect workers exposed to hazardous waste and that EPA and OSHA would work together to ensure that. EPA is clarifying that it intends that the CCR disposal rule not preempt applicable OSHA standards designed to protect workers exposed to CCRs; thus EPA's final rule on CCR disposal will apply in addition to any applicable OSHA standards. The Agency has added specific regulatory language in this section to address this intent.

[101] For instance, photographic evidence provided by Susan Holmes, the Bokoshe Environmental Cause Group (B.E. Cause), Bokoshe, Oklahoma. See Earthjustice's brief background coverage at: *http://earthjustice.org/blog/2011-april/not-having-fun-in-bokoshe-ok*, and ABC News' *Oklahoma Town Fears Cancer, Asthma May Be Linked to Dump Site,* March 29, 2011: *http://abcnews.go.com/US/oklahoma-town-fears-cancer-asthma-linked-dump-site/story?id=13240312*.

[102] A compilation of damage cases can be found in the docket supporting this rule.

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2005 coal ash pile collapse at the Rostosky Ridge Road, in Allegheny County, Pennsylvania, both the federal and county studies [103] failed to test during this period and missed the narrow exposure window that would have possibly demonstrated a link between the event and the short-term health symptoms (*e.g.,* sore throat, cough, fever, nausea, fatigue, diarrhea, and headaches) contracted by residents who ultimately removed approximately 1,500 tons of fly ash from their properties immediately after the incident without the benefit of any protective respiratory gear. The federal and county studies also found no evidence of long-term arsenic poisoning of the tested individuals. For recurring instances of CCR dispersion in the air at the Indian River Power Plant, Millsboro, Delaware, three consecutive state studies tentatively established other risk factors as the probable cause for a lung cancer cluster in a down-wind location of the presumable source term (CCR fugitive dust blowing of a landfill and stack emissions).[104] Critics claim that these studies used too small of a sample, and were not designed to capture the impact of long-term exposure to pollution.[105]

Nevertheless, in eleven other cases, states adopted measures to address concerns from fugitive dust emissions; these included conducting lung-cancer cluster and other health studies, conducting particle dispersion studies, issuing Notices of Violation and Consent Orders to the responsible facilities, waiving landfill cover exemptions, and requiring dust management plans for newly permitted CCR landfills. In addition, in several instances, citizens filed lawsuits or reached an out-of-court settlement with the primary responsible party; and in one case, OSHA imposed a steep fine on the owners of a facility manufacturing abrasive blasting and roofing materials from slag produced at a nearby coal-fired power plant, for willfully exposing their workers to dangerously high levels of hazardous dust, and for failing to provide adequate breathing protection and training for workers at the facility. According to stakeholder allegations, fugitive dusts generated by these same materials also adversely impacted residents in the facility's immediate vicinity.

As previously stated, many commenters argued that the proposed numeric particulates standard was incompatible with the air quality requirements established under the States' Implementation Plans (SIPs) or with provisions set up by the states in their Title V Clean Air Permits to the power producers. In addition, the commenters argued that the proposed standard lacked technical details to facilitate effective implementation, and that implementation of the standard required specialized equipment and advanced training to carry out a judicious reading and interpretation of opacity, a proxy measure for the level of fugitive dust emissions. In light of these comments, EPA re-evaluated the existing CAA standards applicable to these units; 40 CFR 70.2 identifies fossil-fuel-fired steam electric plants of more than 250 million BTU/hour heat input as potential sources of fugitive dust (PM sources) that must be covered by state permitting, and 40 CFR 70.3 stipulates that fugitive emissions from a part 70 source shall be included in the permit application and the part 70 permit in the same manner as stack emissions, regardless of whether the source category is included in the list of sources contained in the definition of major source. Based on these applicable CAA requirements, the Agency agrees that the adoption of a PM standard under the final rule would entail a potential for duplication or inconsistency with applicable state-established standards in SIP permits.

EPA also acknowledges the challenges involved in measuring the proposed compliance standard. Because fugitive dust is emitted from non-point sources, it cannot be easily measured by conventional methods. Usually, regulations developed by the states to control fugitive dust stipulate that no person or source shall cause or allow, from any activity, any emissions of fugitive particulate matter that are visible to an observer who looks horizontally along the source's property line. A quantitative measurement of fugitive dust levels (EPA's Reference Method 9) would require measuring opacity, which, as the commenters noted, necessitates specialized technical training, trainee certification, and judicious application of instrumentation.

Therefore, rather than requiring a potentially redundant and challenging-to-implement quantitative standard, EPA is substituting a performance standard for fugitive dust control. This standard requires owners or operators of a CCR unit to adopt measures that will effectively minimize CCR from becoming airborne at the facility, including CCR fugitive dust originating from CCR units, CCR piles, roads, and other CCR management activities. The Agency considers this standard to be consistent with the intent of the proposed rule, with the added advantage of allowing facilities the flexibility to determine the appropriate measures to achieve regulatory compliance at their individual site. This standard and the accompanying regulatory requirements supporting its implementation, will achieve the statutory obligation of ''*no reasonable probability of adverse effects on human health and the environment.''*

As in the proposal, the Agency is also requiring documentation of the measures taken to comply with the technical standard in a ''CCR fugitive dust control plan'' (herein referred to as ''plan''). Consistent with the proposal, the plan must be certified by a qualified professional engineer and placed in the operating record and on the owner or operators publicly accessible internet site. The plan requires owners or operators to elaborate on the types of activities applicable and appropriate for the conditions at the facility that will be employed to minimize CCR from becoming airborne at the facility. Examples of control measures that may be appropriate include: Locating CCR inside an enclosure or partial enclosure; operating a water spray or fogging system; reducing fall distances at material drop points; using wind barriers, compaction, or vegetative covers; establishing and enforcing reduced vehicle speed limits; paving and sweeping roads; covering trucks transporting CCR; reducing or halting operations during high wind events; or applying a daily cover.

The initial plan must be completed by the effective date of the rule (*i.e.,* within six months of publication). Because this is an initial plan, and because it must be completed within a short timeframe, EPA acknowledges that the facility may only be able to present its initial judgment of the measures that it anticipates are likely to be effective based on the information that is readily available within this six month

[103] (i) *Coal Fly Ash Landslide, Forward Township, Allegheny County, Pennsylvania,* ASTDR Health Consultation June 1, 2006: *http://www.atsdr.cdc.gov/HAC/pha/CoalFlyAshLandslide/CoalFlyAshLandslideHC060106.pdf* (ii) *Results of the Health Investigation Following Fly Ash Contamination in Forward Township, Allegheny County, Pennsylvania,* Allegheny County Health Department, July 2005: *http://www.achd.net/air/pubs/pdf/Forward%20Fly%20Ash%20Study%202005.pdf.*

[104] *Millsboro Inhalation Exposure and Biomonitoring Study.* State of Delaware Department of Natural Resources and Environmental Control, Department of Health and Social Services, Dover (RTI Project 0213061), DE, May 2013: *http://www.dnrec.delaware.gov/Admin/Documents/Millsboro_Inhalation_Exposure_and_Biomonitoring_Study_Final_Repor_05282013.pdf.*

[105] *Critic chides cancer study: Indian River plant results called lame.* Delawareonline, May 28, 2013: *http://www.delawareonline.com/article/20130528/NEWS/305280081/.*

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timeframe. EPA anticipates that owners or operators may need to revise the plan as they gain additional information and experience implementing the regulations. In recognition of this, the final rule also requires that the CCR fugitive dust control plan include a description of the procedures the owner or operator will follow to periodically assess the effectiveness of the control plan. Consistent with other plans required in this rule, the owner or operator may amend the written CCR fugitive dust control plan at any time. However, the owner or operator must amend the written plan whenever there is a change in conditions that would substantially affect the written plan in effect, such as the construction and operation of a new CCR unit. The plan and any subsequent amendments must be certified by a qualified professional engineer.

In addition, the Agency is promulgating with a slight modification the requirement for owners and operators of all CCR landfills and any lateral expansion to emplace CCR as conditioned CCR, as well as the definition of conditioned CCR. *Conditioned CCR* has been defined to mean CCR wetted with water to a moisture content that will prevent wind dispersal, but will not result in free liquids, consistent with the definition in the proposed rule. In response to several commenters' requests, and upon further evaluation the Agency is allowing that in lieu of water, CCR conditioning may be accomplished with an appropriate chemical dust suppression agent.[106] As with other requirements of this rule, in order to ensure that the provisions of the fugitive dust criteria are maintained throughout the operating life of the CCR unit, the Agency is requiring that the owner or operator prepare an annual CCR fugitive dust control report, describing the actions taken to control CCR fugitive dust, a record of all citizen complaints, and a summary of any corrective measures taken. The first annual report must be completed no later than 14 months after placing the initial CCR fugitive dust control plan in the facility's operating record. The owner or operator has completed the annual CCR fugitive dust control report when the plan has been placed in the facility's operating record.

The general public, as well as the Agency, is highly concerned with potential risks associated with CCR fugitive dusts. This was readily apparent during the public hearings and from the many comments received on this issue. The Agency continues to receive information regarding this human health and environmental concern. While the subtitle D provisions of this rule lack permitting oversight mechanisms to control fugitive dust from CCR units, it is clear to the Agency that additional substantive actions was needed to facilitate citizen suit enforcement of this criteria. Consequently, the Agency are adding a specific requirement to the CCR fugitive dust control plan to require owners and operators of all CCR units to develop and implement formal procedures to log citizen complaints involving CCR fugitive dust events. These complaints must, then, be included as part of the annual CCR fugitive dust control report. This report must be placed in the operating record and on the owner or operator's publicly accessible internet site. Promulgation of these measures will subject the owner or operator of the CCR disposal facility to public and state scrutiny, and create an incentive for the owner or operator of the CCR disposal facility to improve compliance with the fugitive dust control requirements.

G. Operating Criteria—Run-On and Run-Off Controls for CCR Landfills

EPA's proposal required owners or operators of CCR landfills and all lateral expansions to design, construct and maintain a run-on control system to prevent flow onto the active portion of these units during the peak discharge from a 24-hour, 25-year storm. As described in the proposed rule, run-on controls are designed to prevent erosion, which may damage the physical structure of the landfill, prevent the surface discharge of CCR in solution or suspension; and to minimize the downward percolation of run-on through wastes, creating leachate. Similarly, EPA proposed run-off controls in order to collect and control, at a minimum, the water volume resulting from a 24-hour, 25-year storm. This standard was proposed in order to protect surface waters from contamination. Under the existing 40 CFR part 257 requirements, to which CCR units are currently subject, run-off must not cause a discharge of pollutants into waters of the United States that is in violation of the National Pollutant Discharge Elimination System (NPDES) under section 402 of the Clean Water Act. EPA did not propose to revise the existing requirement, but merely incorporated it for ease of the regulated community.

The Agency proposed the 24-hour period because it was a timeframe that included storms of high intensity with short duration and storms of low intensity with long duration. EPA believed that this was a widely used standard that had been incorporated into the hazardous waste landfills and MSW landfills regulatory requirements. At the time, EPA had no information that warranted a more restrictive standard for CCR landfills. EPA received no significant comment on the proposed requirements, and for the most part, is adopting the proposed requirements without revision. However, in an effort to clarify and provide more direction to the owner or operator and the certifying qualified professional engineer, the Agency has added additional regulatory language that more specifically describes the technical criteria established under this section of the rule.

The run-on and run-off controls of the final rule require that the owner or operator prepare the initial run-on and run-off control system plan within 18 months of publication of the rule. Run-on and run-off control system plan reporting may require design, construction, and post-construction implementation. In instances where run-on and run-off capacity is insufficient, installing additional capacity may involve construction of diversion structures such as swales or ditches. Many of these efforts may require several months of design and construction, compounded by the fact that much of the work cannot be completed in cold-weather or heavy-rain seasons.

1. Run-On and Run-Off Controls for CCR Landfills and All Lateral Expansions[107]

All CCR landfills and all lateral expansions must be designed, constructed, operated, and maintained with a run-on control system to prevent flow onto the active portion of the CCR unit from the peak discharge from a 24-hour, 25-year storm and a run-off control system to collect and control at

[106] Spray-on adhesives, surfactants, aqueous foamers, humectants (calcium, magnesium, ad sodium chloride and their mixtures), and polymer solutions and emulsions. See, for instance ''The Role of Chemicals in Controlling Coal Dust Emissions'' Benetech, Inc. available at *http://pdf.ebooks6.com/download.php?id=139860* or Peterson, Edwin. ''An Aid to Fugitive Materials Control in Coal Ash Applications'' presented at the World of Coal Ash (WOCA) conference—May 9–12, 2011 in Denver, Colorado.

[107] In the proposed rule under the RCRA subtitle D option, EPA jointly proposed run-on and run-off requirements for CCR landfills and CCR surface impoundments under proposed § 257.81. In this final rule, EPA has modified the ''run-on and run-off'' requirements and is providing separate requirements for CCR landfills and CCR surface impoundments. CCR surface impoundments are now subject to the hydrologic and hydraulic capacity requirements at § 257.82. This new section of the rule more appropriately addresses flow management issues at CCR surface impoundments.

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least the volume of water resulting from a 24-hour, 25-year storm from the active portion of the CCR unit.[108]

Consistent with the proposal, the rule requires the owner or operator of a CCR landfill or lateral expansion to prepare an initial run-on and run-off control system plan for the CCR unit. For existing CCR landfills, the plan must be prepared by the owner or operator no later than one year from the effective date of the rule. For new CCR landfills and any lateral expansion of a CCR landfill, the plan must be prepared no later than the date of initial placement of CCR in the landfill or lateral expansion. The plan must document how the run-on and run-off control systems have been designed and constructed to meet the requirements of rule and must be supported by appropriate engineering calculations. The run-on and run-off control system plan must be certified by a qualified professional engineer and is considered prepared when the owner or operator has placed the plan in the facility's operating record.

The rule also provides for the owner or operator to amend the plan at any time (*e.g.,* prior to receipt of CCR in the CCR unit, during the operating life of the CCR unit, during closure of the CCR unit, or following closure of the CCR unit) provided the revised plan is placed in the facility's operating record. The owner or operator must, however revise the plan whenever there is a change in the conditions that would substantially affect the written plan in effect (*e.g.,* closure of an existing portion or cell of the CCR landfill, resulting in a possible change in the size of the ''active portion'' of the CCR landfill).

In addition, consistent with other provisions in this rule, the Agency is requiring that the run-on and run-off control system plan be reviewed, and where necessary, revised or updated at least every five years. The Agency is specifying this periodic review in order to address factors having the potential to influence the run-on and run-off control system. Among other things, CCR landfills can be subject to build-out, operational changes, and surface cover changes, all of which have the potential to significantly alter run-on and run-off flows to and from the active portion of the CCR landfill. Changes in storm intensity and duration, as well as upstream catchment area characteristics, can alter flows that may significantly affect a previously adequate run-on and run-off control system. A mandated five year review of a control system plan is consistent with accepted good engineering practices and protocols for proper maintenance of operational systems supporting the overall performance of a CCR landfill. It is also consistent with the proposed requirement that an owner or operator ''maintain'' the run-on and run-off control system. EPA interprets this to require the owner or operator to ensure that the run-on and run-off control system is kept in a condition that meets the requirements of the rule, *i.e.,* that the run-on and run-off control system both prevents flow onto the active portion of the unit during the peak discharge from a 24-hour, 25-year storm and collects and controls at least the water volume resulting from a 24-hour, 25-year storm event for the duration of the CCR landfill's operational life. A requirement to conduct a review of the control plan at least once every five years merely provides an explicit mechanism to ensure this occurs in a manner that facilitates citizen and state oversight.

The date of preparing the initial plan is the basis for establishing the deadline to complete the first subsequent plan; *i.e.,* the subsequent plan must be completed within five years of the prior plan. The owner or operator may complete any required plan prior to the required deadline and must place the completed plan into the facility's operating record within the five year timeframe. A qualified professional engineer must certify that the run-on and run-off control system plan, including any subsequent amendments, meets the run-on and run-off control system requirements of this final rule.

a. Run-On Control

Consistent with the proposal, EPA is defining *run-on* to mean any liquid that drains over land onto any part of a CCR landfill or any lateral expansion of a CCR landfill. In surface water hydrology, run-on is a quantity of surface run-off, or excess rain, snowmelt, or other sources of water, which flows from an upstream catchment area onto a specific downstream location. This rule requires that the CCR landfill be designed, constructed, operated, and maintained to prevent flow onto the active portion of the CCR landfill during the peak discharge from a 24-hour, 25-year storm. EPA has adopted this requirement to minimize the amount of surface water entering the CCR landfill and to minimize disruption of the CCR landfills operation due to storm water inflow. Uncontrolled or undesirable storm water run-on may have significant impacts on the stability of the slopes of a CCR landfill and continued safe operation of the CCR landfill, due to such phenomena as erosion and infiltration.

b. Run-Off Control

EPA has adopted the definition of run-off from the proposal without revision. *Run-off* means any liquid that drains over land from any part of the CCR landfill. Effectively, run-off is the portion of rainwater, snowmelt, or other liquid which does not undergo abstraction, such as infiltration, and travels overland. Typically, run-off is the product of the inability of water to infiltrate into soil due to saturation or infiltration rate capacity being exceeded. The rule requires that the CCR landfill be designed, constructed, operated, and maintained to collect and control at least the water volume resulting from a 24-hour, 25-year storm. The owner or operator must design, construct, operate, and maintain the CCR landfill in such a way that any run-off generated from at least a 24-hour, 25-year storm must be collected through hydraulic structures, such as drainage ditches, toe drains, swales, or other means, and controlled so as to not adversely affect the condition of the CCR landfill. EPA has promulgated these requirements to minimize the detention time of run-off on the CCR landfill and minimize infiltration into the CCR landfill, to dissipate storm water run-off velocity, and to minimize erosion of CCR landfill slopes. An additional concern with run-off from CCR landfills is the water quality of the run-off, which may collect suspended solids from the landfill slopes. EPA acknowledges that the run-off requirements will also minimize the amount of run-off related pollution generated by the landfill run-off.

c. Run-On and Run-Off Control System Plan

The owner or operator of any CCR landfill must prepare an initial run-on and run-off control system plan documenting, with supporting engineering calculations, how the control systems have been designed and constructed to meet the requirements of the rule. This has been adopted without revision from the proposal. In most cases, EPA expects this documentation will include in addition to the supporting engineering calculations, references and drawings regarding the

[108] Under existing part 257 requirements, to which CCR units are currently subject, runoff must not cause a discharge of pollutants into waters of the United States that is in violation of the National Pollutant Discharge Elimination System (NPDES) under section 402 of the Clean Water Act (40 CFR 257.3–3). EPA did not propose to revise this requirement but is merely incorporating it here for ease of the regulated community.

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identification of the 24-hour, 25-year storm for the location of the CCR landfill, a characterization of the rainfall abstractions, including but not limited to depression storage and infiltration, the selection and basis of an appropriate run-off model, the selection and basis of an appropriate run-on or run-off routing model, and the selection and design of an appropriate run-on and run-off management system (*e.g.,* swales, ditches, retention or detention ponds). Consideration of the above factors would generally constitute a comprehensive review of the hydraulic and hydrologic processes associated with the design of a run-on and run-off control system plan. EPA recognizes that over time, any number of factors, *e.g.,* expansion of the facility, could affect a change in the run-on and run-off control system plan. Consequently in the final rule EPA is providing for flexibility in this area by stating that the plan can be amended by the owner or operator at any time during the life of the CCR landfill, provided the amendments are placed in the operating record and on the facility's publicly accessible Internet site.

H. Operating Criteria—Hydrologic and Hydraulic Capacity Requirements for CCR Surface Impoundments

As discussed in the previous section, EPA proposed to require owners or operators of CCR landfills to design, construct, operate, and maintain: (1) A run-on control system to prevent flow onto the active portion of the unit during the peak discharge from a 24-hour, 25-year storm; and (2) a run-off control system to collect and control, at a minimum, the water volume resulting from the same 24-hour, 25-year storm. EPA also proposed to apply these same run-on and run-off requirements to all CCR surface impoundments and lateral expansions.

Commenters overwhelmingly disagreed with EPA's decision to apply the same run-on and run-off requirements to both CCR landfills and CCR surface impoundments, arguing that a ''control system to prevent flow onto the active portion of the surface impoundment'' was at odds with a commonly employed practice of using CCR surface impoundments to manage incoming storm water and other inflow. While some commenters reasoned that preventing run-on may be appropriate for CCR landfills and CCR surface impoundments surrounded by above-ground dikes, the proposed requirement was entirely inappropriate for units specifically designed to retain storm water from an adjoining watershed or to operate as part of a facility's overall storm water management system. Numerous commenters suggested that instead of the run-on prevention provision for CCR surface impoundments, EPA adopt a requirement specifying that CCR surface impoundments be designed to accommodate ''peak discharge events.'' Other commenters argued that storm water run-on controls were only appropriate during and after the closure of CCR surface impoundments; while still other commenters suggested that EPA remove entirely the run-on and run-off requirements because CCR surface impoundments were typically designed to impound and discharge storm water flow far in excess of a 25-year/24-hour storm event.

In evaluating the arguments against the requirements to prevent flow onto the CCR surface impoundment, the Agency was strongly influenced by guidance developed by FEMA for selecting and accommodating hydraulic and hydrologic inflow and outflow as well as the application of this guidance to the CCR surface impoundments evaluated as part of EPA's Assessment Program.[109] A review of FEMA guidance confirmed commenters' contentions that managing flow both to and from dams and impoundments was a widely used practice, and a preferable management strategy for accommodating storm water flows. This was further confirmed by observations made during EPA's Assessment Program; EPA frequently observed units designed to detain or retain storm water inflows of an upstream catchment area to manage CCR, and/or to receive storm water inflow as part of the facility's overall storm water management system. Moreover, EPA relied on the same FEMA guidance to assess the adequacy of the hydrologic and hydraulic capacity of the CCR surface impoundments. In conducting these assessments, EPA considered a number of factors including operating freeboard, catchment area, hydrologic structures' inflow and outflow ratings, design precipitation event, spillway presence and capacity, and unit operating procedures to make this determination. The adequacy of the capacity was determined using FEMA guidance for selecting and accommodating inflow design floods (IDF) for dams. (Note: The use of the terminology related to ''inflow design flood'' for CCR surface impoundments rather than ''run-on'' and ''run-off'' is more directly applicable to the hydraulic and hydrologic capacity of CCR surface impoundments to adequately manage both the inflow and outflow from a design flood.)

During its assessment effort, EPA also found that, contrary to commenter's arguments CCR surface impoundments were often not designed to address floods in excess of a 24-hour, 25-year storm event. Rather many CCR surface impoundments were deficient in their hydrologic and hydraulic capacity requirements due to factors such as lack of operating freeboard, misunderstanding of the actual contributory area, lack of documentation, undersized decant structures, undersized spillways, and lack of spillways.

EPA also disagrees with the comment asserting that storm water controls are only appropriate during and after closure of CCR surface impoundments. Hydrologic and hydraulic capacity, as determined by an effective design flood control system, is an essential element of the overall structural integrity and safety of a CCR surface impoundment. CCR surface impoundments are subject to any number of stresses throughout their operational life; one of the most common causes of a dike or embankment failure being the inability of the CCR unit to adequately pass or manage flood flows resultant from direct or indirect precipitation. These failures can occur at any point in the CCR unit's life, not solely during and after closure, and are usually due to inadequate hydrologic and hydraulic capacity, leading to internal erosion due to seepage and piping, erosion of spillways, overtopping erosion, and overstressing of the embankment. Furthermore, according to the U.S. Bureau of Reclamation, a common dam failure mode is due to overtopping, accounting for 30% of the failures in the U.S. over the last 75 years.[110] Overtopping is the direct result of lack of adequate hydrologic and hydraulic capacity of a dam or surface impoundment. Therefore, EPA is not modifying the regulation as suggested by the commenter.

In light of comments received, observations made during EPA's Assessment Program, and guidance developed by FEMA, EPA has concluded that it was inappropriate to propose to prohibit all run-on discharge or inflow from storm water to CCR surface impoundments. EPA has also

[109] EPA referred to FEMA's ''Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams'' in evaluating the adequacy of the CCR surface impoundment's hydrologic and hydraulic capacity during its assessment effort.

[110] *http://www.usbr.gov/ssle/damsafety/Risk/BestPractices/16-FloodOvertoppingPP20121126.pdf.*

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concluded that run-on and run-off criteria are inappropriate for CCR surface impoundments, and that a more appropriate standard involves determining the hydrologic and hydraulic capacity of a unit, measured by its inflow design flood or IDF. Therefore, EPA is amending the proposed run-on and run-off requirements for CCR surface impoundments to require owners or operators of all CCR surface impoundments to design, construct, operate, and maintain hydraulic and hydrologic capacity to adequately manage flow both into and from a CCR surface impoundment during and after the peak discharge resulting from the inflow design flood, based on the Hazard Potential Classification of the CCR surface impoundment.

The final rule requires the preparation of the initial inflow design flood control system plan within 18 months of publication of the final rule. In many cases, inflow design flood control system plan reporting may require design, construction, and post-construction implementation in order to provide sufficient hydrologic and hydraulic (H/H) capacity for the CCR unit. In instances where H/H capacity is insufficient, installing additional capacity may involve spillway construction or decant structure construction or installation. Many of these efforts may require several months of design and construction, compounded by the fact that much of the work cannot be completed in cold-weather or heavy-rain seasons.

1. Inflow Design Flood Controls for CCR Surface Impoundments and All Expansions

The Agency has concluded that the proposed requirement preventing run-on to a CCR surface impoundment was both impractical and unwarranted and could possibly disrupt effective storm water management systems operating at CCR facilities. Therefore, consistent with FEMA guidance, the Agency is modifying this requirement to require an owner or operator of an existing or new CCR surface impoundment or any lateral expansion to design, construct, operate, and maintain H/H capacity of CCR surface impoundments to: (1) Adequately manage flow into the CCR surface impoundment during and following the peak discharge of the inflow design flood; and (2) adequately manage flow from the CCR unit to collect and control the peak discharge resulting from the inflow design flood. The inflow design flood is based on the hazard potential classification of the unit as required by § 257.73 and § 257.74 of this rule.[111] The inflow design floods for specific hazard potential classifications are as follows: (1) The probable maximum flood (PMF) for high hazard potential CCR surface impoundments; (2) the 1000-year flood for significant hazard potential CCR surface impoundments; (3) the 100-year flood for low hazard potential CCR surface impoundments; and (4) the 25-year flood for incised CCR surface impoundments.[112]

EPA has based this revised requirement on the FEMA's guidance entitled, ''Selecting and Accommodating Inflow Design Floods for Dams,'' which represents current and accepted practices in dam engineering and provides a consistent and uniform standard that has been adopted throughout dam engineering.

Incised CCR surface impoundments, as defined in this rule, are also required to meet inflow design flood requirements.[113] While incised units do not pose the same potential for release as a diked unit, *i.e.,* breach of dike and release of CCR, overtopping of an incised unit does represent a potential environmental hazard warranting control. EPA acknowledges, however, that overtopping of an incised unit would result in a release of CCR material through a surcharge flow, *i.e.,* flow of a temporary stage overtopping the ''crest'' of the incised CCR surface impoundment, and would not precipitate the degradation of a dike and potential subsequent breach of a dike and massive release of contents of the CCR surface impoundment. To reflect the lower risks associated with such releases, and because incised CCR surface impoundments are not required to determine their hazard potential classification, the Agency is requiring that incised CCR surface impoundments only must accommodate a 25-year flood for the hydrologic and hydraulic capacity requirements of the rule. EPA chose the 25-year flood for incised CCR surface impoundments to maintain consistency with the proposed rule, which required that all units accommodate a 25-year storm event. As part of these requirements, EPA is also finalizing a definition of *inflow design flood* and *flood hydrograph. Inflow design flood* has been defined to mean the flood hydrograph that is used to design or modify the CCR surface impoundment and its appurtenant works, and *flood hydrograph* has been defined to mean the temporal distribution of inflow into a CCR surface impoundment.

2. Inflow Design Flood Control Systems

Controlling the inflow and outflow of the CCR surface impoundment reduces the risks of hydrologic failure, which include overtopping erosion, internal excessive seepage and piping, erosion of spillways, and overstressing of the structural components of the CCR surface impoundment. The CCR surface impoundment's H/H capacity is to be designed based on the unit's hazard potential classification as determined by a qualified professional engineer. To meet the performance standard in the rule, the CCR surface impoundment must be designed to have adequate H/H capacity to ensure that rainfall and watershed characteristics have been accounted for, the hydraulic ratings of all intake structures are adequate and free of obstruction, operating freeboard is adequate, all spillways and decant structures have adequate capacity, and all downstream hydraulic structures have adequate capacity. While not required, an antecedent flood study may be necessary to characterize the condition of the CCR surface impoundment under normal operating conditions.

EPA recognizes that in many impoundment configurations, an inflow design flood may be limited to the direct precipitation that falls within the perimeter of the CCR surface impoundment during a storm event, due to the lack of storm water inflow routing from adjacent catchment areas. Other CCR surface impoundments may have storm water or other hydrologic contributions from various catchment areas or other sources. The final rule's hydraulic and hydrologic capacity standards require all CCR surface impoundments to have adequate hydraulic and hydrologic capacity to accommodate all contributory inflow to CCR surface impoundments, regardless of the inflow's origin.

The hydraulic and hydrologic capacity requirements will minimize the potential for overtopping to occur from normal or abnormal operations, overfilling, wind and wave action, rainfall, and run-on, and will ensure that the unit is operated with appropriate consideration of these potentially adverse conditions. The Agency notes, however, that the operating freeboard of a CCR surface

[111] *Federal Guidelines for Dam Safety: Selecting and Accommodating Inflow Design Floods for Dams.* August 1, 2013. FEMA P–94.

[112] All discharge from the CCR surface impoundment must be handled in accordance with the surface water requirements under § 257.3–3.

[113] *Incised CCR surface impoundment* means a CCR surface impoundment which is constructed by excavating entirely below the natural ground surface, holds an accumulation of CCR entirely below the adjacent natural ground surface, and does not consist of any constructed diked portion.

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impoundment is subject to fluctuations, deviating from original design assumptions and specifications. Additionally, EPA notes that routine maintenance and alterations of hydraulic structures associated with the CCR surface impoundments, *e.g.,* decant structures and spillways, can adversely impact the hydrologic and hydraulic capacity of the CCR surface impoundment. At no point should the inflow design flood exceed the capacity of the CCR surface impoundment, regardless of fluctuations in freeboard, maintenance of hydraulic structures, or other potential obstructions to the hydraulic and hydrologic capacity of the unit. The owner or operator must account for operational changes or diminished capacity in the calculation of hydraulic and hydrologic capacity of the CCR unit.

3. Inflow Design Flood Control System Plan

The owner or operator of an existing CCR surface impoundment must prepare an initial inflow design flood control system plan to document that the design and construction of the system will achieve the rule's performance standards no later than 18 months after the publication of this rule in the **Federal Register**. New CCR surface impoundments or lateral expansions of CCR surface impoundments must prepare an initial inflow design flood control system plan no later than the date of initial receipt of CCR in the unit. The owner or operator must obtain a certification from a qualified professional engineer that the plan meets all applicable requirements of the rule for inflow design flood control system plans. The plan must also be supported by appropriate engineering calculations. This documentation should also include references, and drawings regarding the identification of the design storm for the catchment area affecting the CCR surface impoundment and the CCR surface impoundment itself, a characterization of the rainfall abstractions, including but not limited to depression storage and infiltration in the upstream catchment area affecting the CCR surface impoundment. In addition, EPA expects supporting documentation to address the selection and basis of an appropriate run-off model and an appropriate run-on or run-off routing model; the identification and characterization of any intake or decant structures of the CCR surface impoundment; an appropriate characterization of the spillway(s) of the CCR surface impoundment and their capacity; and characterization of downstream hydraulic structures which ultimately receive the discharge from the CCR surface impoundment. Finally, the owner or operator must comply with the recordkeeping, notification and internet requirements specified in the rule for the plan.

The owner or operator may amend the written inflow design flood control system plan at any time prior to receipt of CCR in the CCR unit, during the operating life of the CCR unit, during closure of the CCR unit, or following closure of the CCR unit provided the revised plan is placed in the facility's operating record. The owner or operator must amend the written inflow design flood control system plan whenever there is a change in the conditions that would substantially affect the written plan in effect. The owner or operator of the CCR surface impoundment must also periodically update the inflow design flood control system plan. The owner or operator must review or update an existing plan at a frequency no less than every five years. Changes in storm characteristics (*e.g.,* intensity and duration) and upstream catchment area characteristics, hazard potential classifications, as well as build-out, operational changes, and diminishing available capacity, all have the potential to influence inflow design flood volumes and therefore the effectiveness of the existing inflow design flood control systems. A periodic review of the plan to address these and other factors is necessary to ensure that the hydrologic and hydraulic capacity of the unit is maintained over time. An update of the inflow design flood control system plan should document any modifications pertinent to the inflow design flood control system.

The owner or operator may amend the written inflow design flood control system plan at any time and must place the revised plan in the facility's operating record. However, the owner or operator must amend the written inflow design flood control system plan whenever there is a change in the conditions that would substantially affect the written plan in effect. The owner or operator of the CCR unit must also review and, where necessary, update an inflow design flood control system plan every five years. As part of this review, the owner or operator must obtain certification from a qualified professional engineer must certify that the inflow design flood control system plan, and any subsequent amendments continues to meet the requirements of the rule. The date of completion of the initial plan is the basis for establishing the deadline to complete the first subsequent plan. The owner or operator may complete any required plan prior to the required deadline, and must place the completed plan into the facility's operating record within a reasonable amount of time.

I. Operating Criteria—Inspection Requirements for CCR Surface Impoundments

EPA proposed structural stability requirements for CCR surface impoundments based on the long-standing MSHA requirements, with only minor modifications. These structural stability requirements were covered in various sections of the proposed rule (see specifically proposed §§ 257.71, 257.72, 257.83, and 257.84). Section 257.83 addressed requirements for periodic inspections of CCR surface impoundments. In proposing these requirements, the Agency concluded that periodic inspections were critical to ensure that any problems relating to structural stability are quickly identified and remedied to prevent catastrophic releases, such as occurred at Martins Creek, Pennsylvania and TVA's Kingston, Tennessee facility. The proposed rule required owners or operators to conduct: (1) Weekly inspections to detect potentially hazardous conditions or structural weakness; and (2) annual inspections to assure that the design, operation, and maintenance of the surface impoundment was in accordance with generally accepted engineering standards. EPA proposed that weekly inspections be conducted by a person qualified to recognize specific signs of structural instability and other hazardous conditions by visual observation and, if applicable, to monitor instrumentation. The proposed rule also required annual inspection reports from an independent registered professional engineer, certifying that the design, operation, and maintenance of the CCR surface impoundment was in accordance with generally accepted engineering standards. Consistent with the annual inspection requirements, EPA, as part of its recordkeeping requirements also proposed that owners or operators of CCR surface impoundments annually document and report on, among other things: (1) Changes in the geometry of the impounding structure; (2) location and type of instrumentation monitoring the unit; (3) the minimum, maximum and present depth and elevation of the impounded water, sediment or slurry for the reporting period; and (4) storage capacity of the impounding structure (see 75 FR at 35246).

The annual inspection provisions also required that if a potentially hazardous

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condition developed, the owner or operator must immediately take several actions: Eliminate the potentially hazardous condition; notify potentially affected persons and state and local first responders; notify and prepare to evacuate, if necessary, all personnel from the property who may be affected by the potentially hazardous condition(s); and direct a qualified person to monitor all instruments and examine the structure at least once every eight hours, or more often as required by an authorized representative of the state. Finally, the proposed rule required that inspection and monitoring reports be maintained in the facility operating record and placed on the facility's publicly accessible Internet site as well as promptly reporting the results of the inspection or monitoring to the state.

EPA specifically requested comment on whether to cover all CCR impoundments for stability (including the inspection requirements), regardless of height and storage volume, whether to use the cut-offs in the MSHA regulations, or whether other regulations, approaches, or size cut-offs should be used. The Agency further requested commenters who believed that other regulations or size cut-offs should be used (and not the size cut-offs established in the MSHA regulations) to provide the basis and technical support for their position. (75 FR 35176, 35223). In response to EPA's general solicitation for alternative size cut-offs, the Agency received little response. However, many commenters questioned EPA's decision to require inspections for all CCR surface impoundments, given that the other structural stability requirements were triggered only if the CCR unit exceeded the proposed size threshold (consistent with MSHA requirements). Commenters argued that there was no basis to require inspections of all CCR surface impoundments given that units below the specified size threshold had a much lower risk of catastrophic failure. A more limited requirement the commenter's argued, was supported by MSHA's decision to regulate only those ''larger'' sized units. Other commenters argued that inspection timeframes should take into account site specific conditions at the site and be based on the recommendations of an independent registered professional engineer. Commenters reasoned that while, in theory, a short inspection interval (*i.e.,* a weekly inspection) should increase the chances of finding an adverse condition, the judgment of a qualified professional engineer to establish the frequency and focus, as well as the purpose of the dam safety inspection was a far more effective method for detecting and preventing the development of a potentially adverse situation. Still other commenters questioned the overall value of a weekly inspection if, as proposed, no documentation of the results was required.

In reviewing the proposed regulatory language, it appears an error was made. Although the preamble generally stated that the proposed regulatory requirements addressing stability (which included inspections) applied only to those CCR surface impoundments exceeding the specified size threshold established by the MSHA regulations, the regulatory text required inspections for all CCR units. The final rule requires weekly general inspections and monthly instrumentation inspections to be conducted for all CCR surface impoundments. Periodic inspections of all CCR units are a necessary practice to ensure that the overall structural integrity of the CCR unit is maintained and that actual and potential structural weaknesses and other hazardous conditions are quickly identified and remediated throughout the active life of the unit. All CCR surface impoundments pose some risk of release—whether from a catastrophic failure or from a more limited structural failure, such as occurred at Duke Energy's Dan River plant. Periodic inspections are a generally accepted, prudent engineering practice that will significantly reduce the risks of such failures; during the Assessment Program, EPA discovered that many facilities routinely conduct some sort of periodic inspection and monitoring, although the frequency varied widely between facilities. The final rule merely codifies this practice, by establishing a consistent minimum timeframe. EPA is therefore requiring that all CCR surface impoundments be inspected by a qualified person both weekly (for visual signs of a potentially adverse condition) and monthly (for instrumentation monitoring). Consistent with the proposed rule, EPA is also requiring annual inspections for all CCR surface impoundments that exceed the specified size threshold of: (1) A height of five feet and a storage capacity of 20 acre-feet; or (2) a height of 20 feet, must also be inspected no less than annually by a qualified professional engineer. These inspection requirements are generally being promulgated as proposed, with minor technical clarifications.

The final inspection requirements have been drawn heavily from guidelines established by FEMA for dam safety, under which maintaining structural integrity involves continuous evaluation of the unit, based on periodic inspections. To be most effective, FEMA suggests, and EPA concurs, that inspections be varied with respect to both the time interval between inspections and the level of detail of the inspection. FEMA guidance, in part, suggests that inspections can be categorized as either: Visual observations to identify abnormal conditions (*i.e.,* informal inspections); field inspections by a professional engineer (*i.e.,* intermediate inspections); and a technical review to determine if the unit meets current and accepted design criteria and practices (*i.e.,* formal inspection).[114] In general, FEMA recommends that inspections focusing on visual observations should be conducted often (*e.g.,* weekly) while more substantive technical evaluation should be conducted every year to every five years depending on the engineering analyses required. (See also the preamble discussion on the requirements specified in §§ 257.73 and 257.74 of this rule, in particular the discussion addressing the five year time interval for structural stability and factor of safety reassessments.)

For the reasons discussed above, EPA has concluded, consistent with FEMA guidelines, that routine inspections of all CCR units are necessary to ensure that the units are safely operated and that issues that could disrupt the safety and continuing operation of these units are promptly identified and remediated. Accordingly, the final rule requires both weekly inspections and monthly instrumentation inspections to be conducted at all CCR surface impoundments to confirm that they are operating safely. These inspections must be conducted by a qualified person trained to recognize specific signs of structural instability and other hazardous conditions by visual observation and if, applicable monitor instrumentation. EPA is also retaining the annual inspection requirement for CCR surface impoundments exceeding the specified size threshold established in this rule. This inspection must be conducted and certified by a qualified professional engineer. Units exceeding this size threshold pose a higher degree of risk of release of CCR to the environment than other types of CCR surface impoundments (*e.g.,* incised or ''small'' CCR units) and as such warrant additional regulatory control and oversight.

[114] See ''*Federal Guidelines for Dam Safety*'' Federal Emergency Management Agency. (Reprinted April 2004).

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The final rule requires that both weekly inspections of the CCR unit and monthly monitoring of CCR unit instrumentation be initiated within 6 months of the publication of the rule.

Within nine months of the publication of the rule, the owner or operator must complete the initial annual inspection of the CCR unit. Initial annual inspection requires the retaining of a professional engineer along with the familiarization of the engineer with the facility and CCR units. Additionally, the annual inspection should not be conducted unless weekly inspection and monthly instrumentation monitoring has been initiated and established in order to generate a body of information for the professional engineer to consider. Furthermore, in some cold-weather regions of the United States, weather may inhibit adequate inspection of CCR units, whether through snow or ice cover. EPA is establishing a timeframe of nine months after the publication of the rule so as to allow for adequate weather conditions for inspection.

1. Surface Impoundment Inspection Requirements

a. Weekly Inspections

As presented in the proposed rule and finalized here, this rule requires all CCR surface impoundments to be examined by a qualified person at least once every seven days for any appearance of actual or potential structural weakness or other conditions that are disrupting or that have the potential to disrupt the operation or safety of the CCR unit. The results of the inspection by a qualified person must be recorded in the facility's operating record.

Weekly inspections are intended to detect, as early as practicable, signs of distress in a CCR surface impoundment that may result in larger, more severe conditions. They are also designed to identify potential issues with hydraulic structures that may affect the structural safety of the CCR surface impoundment and impact the hydraulic and hydrologic capacity of the CCR surface impoundment. The early detection of signs of structural weaknesses is an essential preventative measure which helps to impede structural failure. The required weekly inspections are designed to identify such signs of structural weakness before they develop into larger, debilitating concerns in the structural stability of the dike.

Appearances of structural weakness may include, but are not limited to: (1) Excessive, turbid, or sediment-laden seepage; (2) signs of piping and other internal erosion; (3) transverse, longitudinal, and desiccation cracking; (4) slides, bulges, boils, sloughs, scarps, sinkholes, or depressions: (5) Abnormally high or low pool levels; (6) animal burrows; (7) excessive or lacking vegetative cover; (8) slope erosion; and (9) debris.

In addition, EPA is also adopting a new provision that requires the qualified person to inspect the discharge of all outlets of hydraulic structures which pass underneath the base of the CCR surface impoundment or through the dike of the CCR unit for abnormal discoloration, flow, or discharge of debris or sediment. The requirement is being added to aid in the identification of any internal or sub-surface issues which cannot be reasonably identified in a routine visual inspection. Abnormal discharges from hydraulic structures are often an indication of potential issues with the sub-surface or internal integrity of the structure. Hydraulic structures, particularly corrugated metal pipe, are subject to deterioration and corrosion over time and, as deterioration proceeds, the hydraulic structure becomes more susceptible to collapse, translation, or malfunction. Issues with hydraulic structures within the dike may exacerbate structural or operational issues with the CCR surface impoundment due to the significant internal deterioration of the dike via the hydraulic structure. As an example, on February 2, 2014, Duke Energy's Dan River Fossil Plant experienced a structural collapse of a corrugated metal storm water discharge pipe which passed underneath the interior of a CCR surface impoundment. The subsequent collapse of the base of the CCR surface impoundment led to a massive release of CCR to the environment. Additionally, the adjacent dike of the CCR surface impoundment was severely damaged due to the erosion of the upstream slope.

Further, an owner or operator may want to consider inspections outside of the weekly, seven-day schedule if an unanticipated event, such as a flood, earthquake, or vandalism occurs on the site. While rare in occurrence, these events may increase the chances that a potential structural stability issue has arisen. Prudent CCR management practices dictate that a visual assessment is warranted after such events. For example, after a large flood (considered a flood with a return period of equal or greater frequency of ten years) there is potential for damage, including structural damage to the CCR surface impoundment, caused by increased reservoir levels that inundate areas infrequently inundated. The slopes of the dike should be inspected to ensure that no significant erosion has occurred due to the flood, or that any large debris or sediment has been deposited on the dike. An inspection should also be conducted following an earthquake where earthquake damage is observed or can be reasonably expected, where ground motion is felt at the CCR surface impoundment or in nearby locations, or following established magnitude-epicenter distance relationships.[115]

b. Monthly Instrumentation Inspection

In a departure from the proposed rule, EPA is requiring the monitoring of all instrumentation supporting the operation of the CCR unit to be conducted by a qualified person no less than once per month. This is a change from the proposal which required instrumentation to be monitored no less than every seven days.

Many commenters argued that requiring inspections every seven days was excessive, and that, based on FEMA guidelines for dam safety, a more reasonable timeframe would be once per month for CCR surface impoundments with a hazard potential rating of ''high'' and quarterly for those CCR surface impoundments with a hazard potential rating of ''significant.'' In considering these comments, the Agency was influenced by a number of factors including the FEMA guidelines suggested by the commenters. Also weighing heavily in EPA's decision were the observations made as part of the Assessment Program, which revealed that many CCR units are equipped with only ''basic'' measuring devices such as piezometers and pool elevation and freeboard instrumentation and not the more sophisticated (*i.e.,* sensitive) measuring devices for measuring pressure, seepage, internal movement, slope movement; and vibration. These findings strongly suggested to the Agency that, given the status of current instrumentation employed at CCR facilities, weekly monitoring would be excessive, impractical, and—of greatest significance—unlikely to indicate any measurable changes in structural stability in such a short timeframe. EPA, therefore, agrees that a monthly timeframe is a more appropriate interval for detecting discernible or significant changes in the operation of the CCR

[115] The U.S. Army Corps of Engineers have developed useful criteria for post-earthquake inspections, specifically their published magnitude-epicenter distance criteria in Table 11.1 of ''Safety of Dams—Policy and Procedures,'' ER 1110–2–1156, 31 March 2014.[115] The criteria stipulate when the dam (or in the case of this rule, CCR surface impoundment) should be inspected.

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unit. EPA has not, however, differentiated between high, significant, and low hazard potential CCR surface impoundments in the requirement that instrumentation be monitored monthly, as commenters suggested. Through the assessment effort, EPA identified that typically low hazard potential CCR surface impoundments were monitored less frequently than high- or significant hazard potential CCR surface impoundments by the owner or operator. Additionally, these low hazard potential CCR surface impoundments less commonly were equipped with sophisticated monitoring instrumentation, including remote monitoring instrumentation which would allow the owner or operator to monitor the unit from a remote location. Based on these observations, along with the limited burden that instrumentation monitoring places on the owner or operator, the rule requires all CCR surface impoundments with instrumentation to be monitored monthly.

c. Annual Inspections

The rule requires owners or operators of any CCR surface impoundments exceeding the MSHA size threshold (*i.e.,* a height of five feet or more and a storage volume of 20 acre-feet or more; or a height of 20 feet or more) to conduct annual inspections of the CCR unit throughout its operating life. These annual inspections are focused primarily on the structural stability of the CCR surface impoundment and must ensure that the operation and maintenance of the CCR surface impoundment is in accordance with recognized and generally accepted good engineering standards. Inspections must be conducted and certified by a qualified professional engineer.[116] Incised CCR surface impoundments, as defined in § 257.53 are not subject to the annual inspection requirements. Incised units present lower risks of structural failure, and so weekly inspections are sufficient to address any risks associated with these CCR units.

Annual inspections of any CCR surface impoundment must include, at a minimum: (1) A review of all previously generated information regarding the status and condition of the CCR unit, including, but not limited to, all operating records and publicly accessible internet site entries, design and construction drawings and other documentation; (2) a thorough visual inspection to identify indications of distress, unusual or adverse behavior, or malfunction of the CCR unit and appurtenant structures; and (3) a thorough visual inspection of hydraulic structures underlying the base of the CCR unit and passing through the dike of the CCR unit for structural integrity and continued safe and reliable operation. Additionally, following each inspection, the qualified professional engineer must prepare an inspection report which documents the following: (1) Any changes in geometry of the impounding structure since the previous annual inspection; (2) the location and type of existing instrumentation and the maximum recorded readings of each instrument since the previous annual inspection; (3) the approximate minimum, maximum, and present depth and elevation of the impounded water and CCR since the previous annual inspection; (4) the storage capacity of the impounding structure at the time of inspection; (5) the approximate volume of the impounded water and CCR at the time of the inspection; and (6) any appearances of an actual or potential structural weakness of the CCR unit, in addition to any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the CCR unit and appurtenant structures; and (7) any other change(s) which may have affected the stability or operation of the impounding structure since the previous annual inspection.

This last set of requirements was originally presented in § 257.84 of the proposed rule (*i.e.,* recordkeeping requirements), however, the Agency has moved these requirements to the annual inspection section of the rule because (1) these requirements apply only to CCR surface impoundments exceeding the specified size threshold, rather than all CCR surface impoundments, as proposed; (2) must be reported annually; and (3) are more appropriately housed in the inspection section.

The owner or operator of existing CCR surface impoundments must ensure that the initial annual inspection by a qualified professional engineer is completed and documented with a report no later than nine months after the publication of the rule. EPA established this timeframe for completing an initial annual inspection based on its experience with the Assessment Program. In an effort similar to conducting an initial annual inspection, the following tasks were generally completed within three months: Retaining the services of a qualified professional engineer, developing a scope of work, reviewing existing documentation on the CCR unit, conducting a thorough field inspection, and completing an inspection report. Owners and operators of new CCR surface impoundment must commence annual inspections no later than one year from the initial placement of CCR into the new unit. An annual inspection is not required in any calendar year in which the five year structural stability reassessment is also required to be completed. (See §§ 257.73 and 257.74.) The report which the qualified professional engineer has certified must be placed in the facility's operating record and placed on the facility's publicly accessible internet site. An annual inspection is considered complete when the inspection report has been placed in the facility's operating record. Finally, if a deficiency is identified during an inspection, the owner or operator must take immediate measures to remedy the structural weakness or disrupting condition as soon as feasible.

J. Operating Criteria—Inspections for CCR Landfills

Under 40 CFR part 258, EPA does not require specific inspection requirements for MSWLFs. Rather, EPA relies on states to establish their own inspection criteria and frequency of inspections to ensure protection of human health and the environment. It is the Agency's understanding that many states require owners or operators of MSWLFs to conduct either daily, weekly, quarterly and annual inspections of these units to ensure that the design, construction, operation, and maintenance complies with all requirements. In addition, based on a review of selected state regulations most states conduct state inspections of operating landfills no less than annually.

Under the proposed subtitle D option, EPA did not propose to require mandatory inspections of new or existing landfills or any lateral expansion. However, under the subtitle C option, EPA proposed to apply the requirements of § 264.303 to permitted CCR landfills. Specifically, these requirements stated that CCR landfills while in operation would be required to be inspected weekly and after storms to detect evidence of any of the following: (1) Deterioration, malfunctions, or improper operation of run-on and run-off control systems; (2) proper functioning of wind dispersal control systems, where present; and (3) the presence of leachate in and proper functioning of the leachate collection and removal system where present. (See proposed § 264.1306, 75 FR 35257).

[116] For purposed of this requirement, qualified means an individual experienced in the operation and maintenance of dams and who has been trained to recognize signs of concern and structural weakness by visual observation, and if applicable, to monitor instrumentation.

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Upon further evaluation, the Agency has decided, consistent with the weekly inspection requirements proposed for CCR landfills under the subtitle C option, as well as many state requirements for MSWLFs, to require all existing and new CCR landfills and any lateral expansion to conduct, at intervals not exceeding seven days, inspections by a qualified person for any appearances of actual or potential structural weakness or any other conditions which are disrupting or have the potential to disrupt the operation or safety of the CCR landfill. In addition, EPA is also requiring inspections by a qualified professional engineer at intervals not exceeding one year to ensure that the design, construction, operation, and maintenance of the CCR landfill is consistent with recognized and generally accepted good engineering standards. This inspection must include a review of all data in the operating record as well as a visual inspection of the unit to identify signs of distress or malfunction that is or potentially could affect the safe operation of the unit. The qualified professional engineer must then also prepare a report to identify and discuss the findings of the inspection as well as a discussion of potential remedies for addressing any deficiencies discovered during the inspection. The Agency has concluded that all CCR landfills should be routinely inspected to ensure that they are operating as designed and are being maintained in compliance with the federal criteria.

The Agency is promulgating these inspection requirements based on: (1) A review of state municipal landfill inspection requirements; and (2) comments from parties that clearly supported inspections of all CCR landfills. The Agency reviewed MSWLF inspection checklists in a selected number of states to assess the scope of these inspections. The Agency also conducted a preliminary review of state MSWLF regulations for New York, Pennsylvania, Ohio, Wisconsin, Illinois, Missouri, North Dakota and California. All of these states require MSWLF owners or operators to conduct a either daily, weekly, monthly, quarterly and annual inspections addressing the following: (1) Proper placement of the waste; (2) slope stability and erosion control; (3) surface water percolation is minimized (*i.e.* reduce ponding); (4) liner systems and leachate collection systems are properly operated and maintained; (5) water quality monitoring systems are maintained and operating; (6) dust is controlled; and (7) a plan is in place to promptly address and correct problems and deficiencies discovered during the inspection. The Agency also noted during its review of state regulations that states reserve the right to inspect landfills at any time and routinely conduct state inspections on a no less than annual basis. CCR landfills present at least the same level of risks as MSWLFs, and while the operations may differ, both operating systems are equally susceptible to malfunction. Weekly inspections of all CCR landfills by a qualified person are therefore equally necessary to ensure that groundwater monitoring, run-on and run-off controls, liner systems, and leachate collection systems are operated and maintained to reduce adverse environmental and human health impacts.

This rule also requires that owners or operators of all existing and new CCR landfills and any lateral expansion conduct an annual inspection, certified by a qualified professional engineer, to assure that these units are designed, constructed, operated, and maintained throughout their operating life to ensure protection of human health and the environment. The Agency finds that annual inspections for these units are justified for a number of reasons. First, CCR landfills are large engineered units that require that a variety of design and operating parameters be assessed to assure that the CCR landfill is operating as designed. Of particular concern to the Agency is the fact that coal ash is a fine grained material that may have the potential to compact and clog leachate collection systems (see: ''Operations and Maintenance Guidelines for Coal Ash Landfills'' Christopher Hardin, et. al. 2011 World of Coal Ash Conference. May 2011). It is reasonable therefore that the rule requires annual inspections to assure that these liner and leachate systems are assessed to assure that they are performing their functions as designed. Second, a formal annual inspection would review data collected during weekly inspections and determine if any remedial actions are need to address deficiencies. Third, the annual review by a qualified professional engineer ensures that a detailed level of engineering analysis of operating conditions are evaluated which could lead to recommendations to address design or operating issues that need attention.

K. Groundwater Monitoring and Corrective Action

EPA is finalizing groundwater monitoring and corrective action requirements to ensure that groundwater contamination at new and existing CCR units will be detected and cleaned up as necessary to protect human health and the environment. These requirements reflect Congressional intent that protection of groundwater be a prime objective of any new solid waste regulations. As stated in the proposal, EPA's damage cases and risk assessments indicate there is significant potential for CCR landfills and CCR surface impoundments to leach hazardous constituents into groundwater, impair drinking water supplies and cause adverse impacts on human health and the environment. Indeed, groundwater contamination is one of the key environmental and human health risks EPA has identified with CCR landfills and CCR surface impoundments. Groundwater monitoring is a key mechanism for facilities to verify that the existing containment structures, such as liners and leachate collection and removal systems, are functioning as intended. Thus, in order for a CCR landfill or CCR surface impoundment to show no reasonable probability of adverse effects on health or the environment, a system of routine groundwater monitoring to detect any contamination from a CCR unit, and corrective action requirements to address identified contamination, are essential.

EPA proposed to require that a system of monitoring wells be installed at all new and existing CCR units. The regulation would also provide procedures for sampling these wells and methods for statistical analysis of the analytical data derived from the well samples to detect the presence of hazardous constituents released from these CCR units. The Agency proposed a groundwater monitoring program consisting of detection monitoring and assessment monitoring, and a corrective action program. This phased approach to groundwater monitoring and corrective action programs provides for a graduated response over time to the problem of groundwater contamination as the evidence of such contamination increases. This allows for proper consideration of the transport characteristics of CCR constituents in groundwater, while protecting human health and the environment.

EPA largely based these proposed groundwater monitoring requirements on those for MSWLFs in the 40 CFR part 258 criteria, albeit with certain modifications to tailor the requirements to the case at hand. In particular, the possibility that a state may lack a permit program for CCR units made it impossible to include some of the alternatives available in 40 CFR part 258, which establish alternative standards that allow a state, as part of

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its permit program to tailor the default requirements to account for site specific conditions at the individual facility. EPA also sought to tailor the proposed requirements for CCR units, by incorporating certain provisions from the interim status regulations, which operate in the absence of a permit, and by including in several of the proposed requirements, a certification by an independent registered professional engineer that the rule's requirements had been met.

In the proposed rule, the Agency required facilities to install a groundwater monitoring system that met a specified performance standard and that consisted of a minimum of one upgradient and three downgradient wells at all CCR units. EPA acknowledged in the proposal that the design of an appropriate groundwater monitoring system is particularly dependent on site conditions relating to groundwater flow, and on the development of a system that has a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer that represent the quality of background groundwater that has not been affected by contaminants from a CCR unit. EPA's existing requirements under 40 CFR parts 258 and 264 recognize this, and because they operate in a permitting context, these requirements provide more flexibility in establishing groundwater monitoring systems. But because the same guarantee of permit oversight is not available under the criteria developed for the proposal, EPA proposed to establish a minimum requirement based on the part 265 interim status regulations, which are self-implementing. Long experience demonstrates that these monitoring requirements will be protective of a wide variety of conditions and wastes, and that facilities can feasibly implement these requirements. EPA also noted that in many instances a more detailed groundwater monitoring system will need to be in place, and EPA therefore proposed requiring a certification by the independent registered professional engineer that the groundwater monitoring system is designed to detect all significant groundwater contamination.

EPA also proposed to require that owners and operators of CCR units establish consistent sampling and analysis procedures to determine whether a statistically significant increase in the level of a hazardous constituent(s) has occurred, indicating the presence of groundwater contamination.

As noted, EPA proposed a phased approach to monitoring. The first phase is detection monitoring where indicators would be monitored to determine whether groundwater was potentially being contaminated. The parameters EPA proposed to be used as indicators of groundwater contamination were the following: Boron, chloride, conductivity, fluoride, pH, sulfate, sulfide, and total dissolved solids (TDS). In selecting the parameters for detection monitoring, EPA chose constituents that are present in CCR and would rapidly move through the subsurface, and thus provide an early detection of whether contaminants were migrating from the CCR unit. Under the proposed rule, monitoring would be required no less frequently than semiannually.

When a statistically significant increase over background levels is detected for any of these parameters, the proposed rule required the facility to begin an assessment monitoring program to determine if releases of CCR constituents of concern had occurred. The parameters that were proposed for assessment monitoring were aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, copper, fluoride, iron, lead, manganese, mercury, molybdenum, pH, selenium, sulphate (sic), sulfide, thallium, and total dissolved solids.

The proposed rule also required that whenever monitoring results indicate a statistically significant level exceeding the groundwater protection standard for any of these parameters, the owner or operator must start the process for cleaning up the contamination, and initiate an assessment of corrective action remedies. The proposed rule required that the assessment of correction action remedies be initiated within 90 days and then completed within 90 days.

EPA proposed that the assessment of corrective measures must consider a number of factors, including the effectiveness, performance, and time needed for the potential remedies. As part of the assessment of corrective measures, the owner or operator was required to identify the source of the release. The owner or operator was also required to gather data on plume definition, fate of the contaminants, stratigraphy and hydraulic properties of the aquifer. The owner or operator also was required to consider whether immediate measures to limit further plume migration or measures to minimize further introduction of contaminants to groundwater would be necessary. EPA also proposed to require the owner or operator to provide notification of the corrective measures assessment to the State Director, place the corrective measures assessment in the operating record and on the owner's or operator's publicly accessible internet site, and discuss the results of the corrective measures assessment in a public meeting with interested and affected parties.

Based on the results of the corrective measures assessment, EPA proposed to require the owner or operator to select a remedy based on a number of factors, including: the long- and short-term effectiveness and protectiveness of the potential remedy, along with the degree of certainty that the remedy will prove successful; the effectiveness of the remedy in controlling the source to reduce further releases; the ease or difficulty of implementing a potential remedy; the degree to which community concerns are addressed by a potential remedy; and potential risks to human health and the environment from exposure to contamination prior to completion of the remedy. The owner or operator was also required to specify as part of the selected remedy a schedule for initiating and completing remedial activities.

Under the proposed rule, implementing the corrective action program required the owner or operator to establish and implement a corrective action groundwater monitoring program; implement the corrective action remedy selected; and take any interim measures necessary to ensure the protection of human health and the environment, all according to the schedule the owner or operator developed during the assessment of corrective measures.

The proposed rule also required that the owner or operator must demonstrate that concentrations of constituents have not exceeded the groundwater protection standards for three consecutive years in order to support a determination that the remedy is complete.

The majority of the commenters supported ''appropriate groundwater monitoring standards for CCR waste management units'' and the development of such standards under a RCRA subtitle D framework. Comments were received on various parts of the groundwater monitoring scheme laid out in the proposed rule. The majority of comments received requested EPA to provide ''more flexibility'' to the proposed requirements. Many commenters wanted the states to be more involved with the process and provided comments suggesting that additional ''flexibility,'' such as is provided in the 40 CFR part 258

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regulations for MSWLFs as part of the permitting process, be extended to CCR units. For example, commenters wanted states to have the authority to add or drop monitoring constituents; approve alternative schedules; modify the number of wells needed; allow variances; allow alternatives to the point of compliance specified in the rule; employ alternative methods to detect potential groundwater contamination, such as leak detection systems; allow alternatives to the statistical methods used to determine whether groundwater contamination has occurred; and to replace the qualified professional engineer role in the certification process.

For the final rule, EPA has developed a groundwater monitoring program that is flexible and allows facilities to design a system that accounts for site specific conditions within specific parameters. The final rule establishes an overall performance standard that the system must meet, lays out the minimum requirements of an effective system, and requires the owner or operator to design a system that achieves that overall performance standard based on a full characterization of site conditions.

As described in more detail below, in certain cases, EPA was able to develop performance standards to serve as ''more flexible'' alternatives to the technical specifications laid out in the proposal. In these instances, the available information allowed the Agency to develop performance standards that were sufficiently objective and determinate that EPA could conclude that the 4004(a) standard would be met nationwide.

However, many of the commenters' requests related to alternatives that would be less stringent than the minimum criteria laid out in the proposal and were based on arguments that state regulators (or facilities) should be allowed to ''tailor'' those requirements to sites that did not need those particular requirements. As explained at length in the proposal, EPA is concerned that provisions allowing such modifications are particularly susceptible to abuse, since in many cases the provisions could allow substantial cost avoidance. In the absence of a mandated state oversight mechanism to ensure that the suggested modifications are technically appropriate, these kinds of provisions can operate at the expense of protectiveness. In Unit II of this preamble, EPA explains the extent of our authority to establish criteria under RCRA sections 1008(a)(3) and 4004(a), including the implications associated with the lack of any authority to establish a program analogous to part 258, which relies on approved states to implement the federal criteria through a permitting program. As a result of the statutory structure, this rule is self-implementing and is designed to operate to ensure that facilities will manage CCR in a manner that achieves the 4004(a) standard even in the absence of any regulatory entity available to judge the reasonableness of the desired alternatives. While some states currently do have programs for the regulation of CCR, which in some cases may be more stringent than this final rule, the federal program must be defensible on the record in place at the time the final rule is adopted. Based on the current rulemaking record, in most cases EPA lacked the information necessary to defend the commenters' less stringent alternatives (*i.e.,* the commenters' requested ''flexibilities'') to the minimum technical criteria specified in this rule for these units. Under both the subtitle C and part 258 programs, EPA can rely on subsequent proceedings to develop the information necessary to support such tailoring. This is clearly neither contemplated nor authorized under the regulatory program relevant to this rule.

In addition, given the extremely technical nature of these requirements, EPA remains concerned that such provisions would render the requirements appreciably more difficult for citizens to effectively enforce. Nevertheless, working within these constraints this rule specifically allows the qualified PE to design a system that accounts for site conditions within the parameters of the minimum technical criteria, and EPA has added language to the regulation that expressly clarifies this. Moreover, states that have programs can continue to impose more stringent requirements, and thus can require, for example, additional monitoring wells, monitoring of additional aquifers, and inclusion of additional parameters to the detection monitoring list or the assessment monitoring list. The following discussion addresses in more detail the technical requirements under groundwater monitoring and corrective action in the final rule.

1. Applicability

Consistent with the provisions in the proposed rule, the final rule requires a system of monitoring wells to be installed at all CCR landfills, CCR surface impoundments and lateral expansions. Existing CCR units must install the groundwater monitoring system, develop their groundwater sampling and analysis procedures, develop background levels for appendix III and appendix IV constituents, and begin detection monitoring (§ 257.90 through § 257.94) within two years of the effective date of this rule. The proposed rule required that existing CCR units comply with the groundwater monitoring requirements within one year of the effective date. EPA proposed one year believing that it would be feasible for facilities to install the necessary systems. EPA also believed that a one year timeframe would ensure that existing CCR disposal facilities begin monitoring groundwater as soon as possible, so that releases from existing CCR units are detected and addressed. Comments received on this issue argued that the one-year timeframe was not sufficient to complete a hydrogeologic study and develop a monitoring plan. Several commenters requesting more time mentioned staffing shortages and limited contractor and lab resources. One state, referencing its experience relating to development and implementation of groundwater monitoring systems, said that a one year timeframe to investigate, design and submit and obtain approval for the installation of an effective groundwater monitoring system was unreasonable. Most commenters thought that a timeframe of two years was reasonable. After review of the comments received on this issue and careful reexamination of the actual requirements in the final rule, EPA agrees that a one-year timeframe is not feasible, and has decided to extend the timeframes for completing installation of the system, including background monitoring, to two years. As important as it is to begin detecting and addressing releases to groundwater, it is equally important that these complex systems be designed and installed correctly. That generally entails a number of activities, many of which must occur sequentially, including: determining the uppermost aquifer, deciding whether to install a single or multi-unit monitoring system, collecting and evaluating hydrogeological information that can be used to model the site, characterizing the site geology, characterizing the groundwater flow beneath the site, determining the flow direction and hydraulic gradient, establishing horizontal and vertical flow direction, determining hydraulic conductivity, determining groundwater flow rate, determining the monitoring wells placement, selecting the drilling method, designing the monitoring wells, developing sampling and analysis procedures, choosing a statistical method for evaluating the data and

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beginning detection monitoring. We also recognize that in some states, the state may require the owner or operator to receive state approval before they can install a groundwater monitoring system. Two years is a more reasonable timeframe in which to carry out these activities. New CCR landfills, new CCR surface impoundments and any lateral expansion must comply with these same requirements (§§ 257.90 through 257.94) before any CCR can be placed in the CCR unit.

Consistent with the proposal, the final rule also requires that the owner or operator of the CCR facility annually certify that each CCR unit is in compliance with the groundwater monitoring and corrective action provisions and provide a copy of this certification to the State Director. Because this is a self-implementing rule that relies on citizen enforcement, it is important for the owner or operator of the facility to periodically document that they are in compliance with the existing groundwater monitoring requirements, and an annual certification is the easiest and most effective way to achieve this. While the groundwater monitoring data will be made available on the owner or operator's publicly accessible Web site and in the operating record of the facility, the analysis of these data is complicated and requires a certain level of scientific expertise to analyze the data correctly. As such, a document that serves as both an interpretative record of scientific analysis and regulatory compliance is critically important to the successful implementation of a self-implementing rule that is to be enforced exclusively by citizens and the states. For similar reasons, the certification must also be placed in the operating record, provided to the State Director, and posted on the owner or operator's publicly accessible Web site.

The groundwater monitoring requirements must be met throughout the active life of the CCR unit, as well as during the closure and post-closure care period.

EPA has added a new provision to § 257.90 to address the corrective action requirements that apply when CCR have been released into the environment, such as from the kind of structural failure that occurred with TVA's Kingston Fossil Fuel plant release, or from the kind of release that occurred in North Carolina at the Dan River. EPA inadvertently drafted the corrective action requirements in the proposed rule to apply exclusively upon detection of groundwater contamination caused by a leaking unit. However, there is no reason to establish different corrective action provisions for conducting clean-up operations for different kinds of releases; the same general process is applicable to all kinds of releases.

The new provision requires that in the event of a release from a CCR unit, the owner or operator must immediately take all necessary measures to control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of contaminants into the environment. The owner or operator of the CCR unit is also required to comply with all of the relevant corrective action requirements in §§ 257.96, 257.97, and 257.98.

2. Groundwater Monitoring System Requirements

EPA received comments that supported establishing more prescriptive requirements for the design of the groundwater monitoring system. For example, one commenter argued that three downgradient wells are insufficient to ensure detection of leakage from the very large disposal units typically used for CCR; due to uncertainty in flow directions, the perimeter of the CCR unit must be monitored on its cross-gradient, as well as downgradient sides. The commenter suggested that the minimum number of non-background monitoring wells should instead be three, plus one for every 500 feet of downgradient and cross-gradient perimeter of the CCR unit (*i.e.,* if the perimeter length adds up to 1200 feet, the minimum number of wells would be five), and that wells should be spaced no more than 500 feet apart along the downgradient and cross-gradient perimeter. EPA also received many comments arguing that the minimum requirements were overly prescriptive, and that the final rule should instead allow a professional engineer or hydrologist to design ''an alternative, but equally effective, groundwater monitoring program.'' The majority of comments on groundwater monitoring systems requested that EPA not promulgate requirements that would be incompatible with state requirements.

The final rule provisions are fundamentally the same as those in the proposal, although EPA has also added language to the regulations to better clarify how the requirements in the various sections collectively operate. The final rule establishes a general performance standard that all groundwater monitoring systems must meet: All groundwater monitoring systems must consist of a sufficient number of appropriately located wells (at least one upgradient and three downgradient wells) in order to yield groundwater samples from the uppermost aquifer that represent the quality of background groundwater and the quality of groundwater passing the waste boundary. This is the same performance standard included in the proposed rule. The objective of a groundwater monitoring system is to intercept groundwater to determine whether the groundwater has been contaminated by the CCR unit. Early contaminant detection is important to allow sufficient time for corrective measures to be developed and implemented before sensitive receptors are significantly affected. To accomplish this, the rule requires that wells be located to sample groundwater from the uppermost aquifer at the waste boundary. These requirements have been adopted without fundamental change from the proposal.

Because hydrogeologic conditions vary so widely from one site to another, the rule does not prescribe the exact number, location and depth of monitoring wells needed to achieve the general performance standard. Rather, the rule requires the owner or operator to install a minimum of one upgradient and three downgradient wells, and any additional monitoring wells necessary to achieve the general performance standard of accurately representing the quality of the background groundwater and the groundwater passing the waste boundary. The number, spacing, and depths of the monitoring wells must be determined based on a thorough characterization of the site, including a number of specifically identified factors relating to the hydrogeology of the site (*e.g.,* aquifer thickness, groundwater flow rates and direction). Further, any owner or operator who determines that the specified minimum number of wells is adequate must provide a factual justification for that decision. Factors that may substantiate a reduced density of groundwater monitoring wells includes simple geology (*i.e.,* horizontal, thick, homogenous strata that are continuous across site, with no fractures, faults, folds, or solution channels), a flat and constant hydraulic gradient, uniform hydraulic conductivity, low seepage velocity, and high dispersivity potential.

In essence, the rule establishes a presumption that the minimum of one upgradient and three downgradient wells is not sufficient, and requires the owner or operator to rebut that presumption in order to install only this minimum. This is fundamentally consistent with the proposed rule, which required the installation of a system that would achieve the general performance standard, as well as the

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''minimum'' of one upgradient and three downgradient wells. The final regulation merely makes more explicit that both of these requirements must be met.

EPA considered establishing a more prescriptive set of requirements, including a specified number, location, and design of monitoring wells, but because of the highly site specific nature of developing an adequate groundwater monitoring system, determined that it lacked sufficient information to be able to design a single groundwater monitoring system that would be nationally protective at all sites. A properly designed system must account for many variables, most of which are highly dependent on the individual characteristics of the unit and the facility site. Consequently, the final rule leaves the exact system design to be determined by those at the site, including a qualified professional engineer, who can tailor the design of the system to the unit and site conditions.

Nevertheless, EPA is confident that the parameters laid out in the regulation will ensure that the design of groundwater monitoring systems at CCR facilities will be protective. As a practical matter, EPA expects that there will be few cases, if any, where four wells will be sufficient, given that this requirement was originally developed for hazardous waste management units that are typically much smaller than CCR units. As mentioned above, a small unit with simple geology, a flat and constant hydraulic gradient, uniform hydraulic conductivity, low seepage velocity, and high dispersivity potential would be the type of unit for which the minimum number of wells could be sufficient to meet the overall performance standard. Although EPA is finalizing a requirement for one upgradient and three downgradient wells as a regulatory minimum, the Agency expects large CCR units to have many more wells because most CCR sites have hydrologic settings that are too complex for the regulatory minimum to be adequate. Facilities with large CCR units could have as many as thirty or more downgradient wells. This is because the placement and spacing of detection monitoring wells along the downgradient perimeter of the CCR unit must be based on the abundance, extent, and physical/chemical characteristics of the potential contaminant pathways. All potential pathways need to be monitored.

Therefore, even though EPA is not requiring a specific number of wells, the Agency is confident that the combination of the requirements will ensure that protective groundwater monitoring systems will be installed. The owner or operator is required to install a sufficient number of wells to meet the performance standard in § 257.91(a)(1) and (2), provide a justification if they determine the required minimum is adequate, and have a qualified professional engineer certify that their groundwater monitoring system has been designed and constructed to ensure that the groundwater monitoring will meet this performance standard—*i.e.,* accurately represent the quality of groundwater that has not been affected by leakage from any CCR unit—that is, groundwater from background wells and the quality of groundwater passing the waste boundary.

The final rule establishes certain parameters regarding the location of the wells. Upgradient background wells must be located beyond the upgradient extent of potential contamination. However, groundwater quality in areas where the geology is complex can be difficult to characterize. If the facility is new, groundwater samples collected from both upgradient and downgradient locations prior to waste disposal can be used to establish background water quality. Downgradient wells to monitor for any contaminants leaking into the groundwater must be located at the hydraulically downgradient perimeter (*i.e.,* the edge) of the CCR unit or at the closest practical distance from this location.

Determining background groundwater quality by sampling wells that are not hydraulically upgradient may be necessary where hydrogeologic conditions do not allow the owner or operator to determine which wells are hydraulically upgradient (*e.g.,* floodplains, where nearby surface water can influence groundwater). In such cases, the rule allows the owner or operator to establish groundwater quality at existing units by locating wells that are not upgradient under certain conditions (§ 257.91(a)(1)). This provision may be used when hydrogeologic conditions do not allow the owner or operator to determine which wells are hydraulically upgradient and when sampling at other wells will provide data establishing background groundwater quality that is equally or more representative than that provided by upgradient wells. These conditions could include one or more of the following:

- The facility is located above an aquifer in which groundwater flow directions change seasonally.
- The facility is located near production wells that influence the direction of groundwater flow.
- Upgradient groundwater quality is affected by a source of contamination other than the CCR unit.
- The proposed or existing CCR unit overlies a groundwater divide or local source of recharge.
- Geologic units present at downgradient locations are absent at upgradient locations.
- Karst terrain or fault zones modify flow.
- Nearby surface water (*e.g.,* rivers) influences groundwater flow directions.

Additionally, there is nothing in the rule that would prevent the owner or operator from monitoring multiple aquifers in addition to the uppermost significant aquifer. Certain site conditions warrant more extensive monitoring requirements, as discussed in ''Technical Manual Solid Waste Disposal Facility Criteria'', EPA530–R–93–017, USEPA, November, 1993, Chapter 5, Subpart E, Ground-Water Monitoring and Corrective Action.

Each CCR unit must have its own groundwater monitoring system, unless the owner or operator chooses to install a multiunit groundwater monitoring system. The final rule specifies that if a multiunit system is installed, it must be based on the consideration of several factors, including the number, spacing, and orientation of the CCR units, the hydrogeologic setting, the site history and the engineering design of the CCR units. A multiunit groundwater monitoring system must be equally capable of detecting background and groundwater contamination at the waste boundary as an individual monitoring system. This documentation must be certified by a qualified professional engineer. Whether a single or multi-unit system has been installed, the monitoring wells must be cased in a manner maintaining the integrity of the borehole and must be maintained so as to meet design specifications. Both of these provisions have been adopted from the proposal without revision.

3. Sampling and Analysis Requirements

EPA received comment on several aspects of its proposed requirements for conducting groundwater sampling and analyses. Specifically mentioned here, commenters raised concern about the number of samples required to establish background concentrations and about the statistical test methodologies specified in the proposal. As discussed below, EPA has modified the rule to account for the issues raised by these commenters. The sampling and analysis requirements in the final rule have

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otherwise been adopted from the proposed rule with only minor clarifications.

The rule provides procedures for sampling monitoring wells and methods for the statistical analysis of groundwater monitoring of appendix III (detection monitoring) and appendix IV (assessment monitoring) constituents that may be released from CCR units. The sampling and analysis program must include procedures and documentation for sample collection (including the frequency, water level measurements, well purging, field analyses, and sample withdrawal and collection); sample preservation and handling (including sample containers, sample preservation, sample storage and shipment); chain of custody control; analytical procedures (appropriate methods can be found in ''*Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,*'' SW–846 (USEPA, 1986), *http://www.epa.gov/waste/hazard/testmethods/sw846/online/index.htm*); and quality assurance/quality control. More information and guidance can be found in ''*Technical Manual Solid Waste Disposal Facility Criteria,*'' EPA530–R–93–017, USEPA, November, 1993, Chapter 5, Subpart E, Ground-Water Monitoring and Corrective Action, as well as the ''*Unified Guidance Document: Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,*'' March 2009, EPA 530/R–09–007.

Similar to the approach used in designing a groundwater a number of system, the final rule adopts a combination of a general performance standard for groundwater sampling and analytical methods, along with particular technical specifications that must be met. The general performance standard requires that the method used must accurately measure hazardous constituents and other monitoring parameters. In addition, the rule specifies that groundwater elevations must be measured in each monitoring well immediately prior to sampling. Also, the rate and direction of the groundwater flow in the uppermost aquifer must be determined each time groundwater is sampled. Further, the rule specifies that the background groundwater quality must be established at a hydraulically upgradient well for each of the monitoring parameters or constituents required by the applicable groundwater monitoring program, except as provided in § 257.91. The number of samples collected to establish groundwater quality data must be consistent with the appropriate statistical procedures determined for the specific statistical method chosen. The sampling must also be conducted to account for both seasonal and spatial variability in groundwater quality.

To establish background levels, the proposed rule required that ''a minimum of four independent samples from each background and downgradient well must be collected and analyzed . . .'' 75 FR 35247–35248 (proposed §§ 257.93(f) and 257.94(b)). This is the same sampling protocol that EPA adopted for both the subtitle C and part 258 groundwater monitoring requirements.

EPA received comments criticizing this sampling protocol. Several commenters stated that more than the required four samples were needed in order to adequately represent background water quality and reduce the number of false negatives. For example, one commenter argued that EPA should require a minimum of one year of monthly monitoring of background concentrations to characterize fluctuations in parameters that will be evaluated statistically. The commenter claimed that this would also help to ensure that quarterly monitoring events are properly timed. Another comment stated that more data points and time were needed to ensure statistical confidence in the data. By contrast, another commenter objected to the requirement to obtain four independent samples, arguing that this requirement was unnecessary and should be deleted. The commenter argued that this requirement was inconsistent with EPA's Unified Guidance (EPA, 2009) for Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, which specifies that replicate samples (*i.e.,* multiple samples from the same location during a given sampling event) should typically be limited to the collection of two samples from the same location, rather than four. Another commenter requested clarification on the number of samples required when establishing background levels that would serve as the point of comparison in determining whether a statistically significant increase over background levels had occurred.

In response to these comments, EPA reviewed the available information to determine whether revisions to the proposed requirements were warranted.

More recent information developed since the promulgation of the subtitle C and part 258 groundwater monitoring requirements indicates that statisticians now generally consider sample sizes of four or less to be insufficient for good statistical analysis because the observations are too few to adequately characterize the parameters of the population. Tests utilizing a small background sample size have low statistical performance in terms of power and per-test false positive rates. In 2009, EPA issued a guidance document that accounts for more recent scientific developments, ''*Unified Guidance Document: Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,*'' March 2009, EPA 530/R–09–007. This guidance recommends a minimum of eight to ten independent background observations be collected before performing the first statistical test. Sample sets of 20 are considered optimal.

RCRA regulations are predicated on having appropriate and representative background measurements. Samples should be tested against data which best represent current uncontaminated conditions. In addition, as discussed further in Unit VI.K.5 below, the detection of a statistically significant increase over background concentrations of the constituents of concern will have serious implications for unlined surface impoundments, as these units will be required to close whenever the facility makes such a finding. EPA is also cognizant of the significant differences between the subtitle C and part 258 regulations and the final regulations being promulgated for CCR units. Both the subtitle C and the part 258 MSWLF requirements are implemented under permit programs, under which regulatory authorities are specifically authorized to establish more stringent requirements to account for scientific advances (among other things). EPA expects that current permits generally specify a greater number of samples than the minimum laid out in the regulations (*i.e.,* more than four) to determine background concentrations. And because of this it is less critical that those regulations (subtitle C and part 258) reflect the most current science. By contrast, as previously discussed, the provisions adopted under this rule are self-implementing, and will only be updated through a subsequent rulemaking. Accordingly, the Agency agrees with the comments that four samples would be insufficient and has amended the rule to require the owner or operator to collect, at a minimum, eight statistically independent and identically distributed (spatially invariant) samples from each well for each monitoring parameter. Although still a small sample size by statistical standards, eight independent observations allows for minimally acceptable estimates of variability and evaluation of trend and goodness-of fit. While more samples, including a full

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year of background monitoring, would be scientifically ideal, the Agency selected eight samples by balancing the minimum number needed to ensure the scientific accuracy of the results against the need to expedite initiating the groundwater monitoring process of detecting exceedances, along with any necessary corrective action at these facilities.

Background sampling (*i.e.,* the requirement to collect eight statistically independent samples from each well) must be completed for all appendix III and IV constituents by the end of the 24 month period to begin implementation of the groundwater monitoring program.

EPA has also revised the regulatory text relating to the number of samples that must be collected during subsequent sampling events after background concentrations have been established to clarify how the various provisions collectively operate. Consistent with the proposal, the final rule requires the owner or operator to collect and analyze the number of samples from each well necessary to be consistent with the statistical test selected under § 257.93(e) and with the unique characteristics of the site, but at minimum, to collect at least one sample from each background and downgradient well. In cases where the groundwater is ''well-behaved'' one sample from each compliance well could be all that the owner or operator would need to conduct the necessary comparisons. But if statistical assumptions are not met (*e.g.,* the observations are not statistically independent or background well data show trends) a comparison based on a single observation will not yield a significant result, and will likely result in a false positive. Further, detection monitoring tests, such as Student's t-test, look at the difference between the sample means (*e.g.,* upgradient vs downgradient) to determine when an observed difference should be considered more than a chance fluctuation. Every t-test assumes that the observations that make up each data group meet the requirements of statistical independence and stationarity. Therefore, the larger the sample size the more significant the result. In other words, a facility can choose to use only one observation (a group size of one), but the chances are good that the result derived would be non-significant, since there are many reasons sample means can vary. Consequently, it is likely to be in the facility's best interest to take more samples than the minimum, particularly in the early stages of monitoring. As monitoring continues, each successive sample will be added to the sampling data base, which will increase the confidence in the statistical analyses performed. Additional guidance on sample size can be found in the ''*Unified Guidance Document: Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,*'' March 2009, EPA 530/R–09–007.

The requirements for applying statistical procedures in the rule are the same as those included in the proposed rule, which were based on the statistical procedures used in the MSWLF regulations. The rule requires the owner or operator to select from among the listed statistical procedures based on a determination that the test is appropriate for evaluating groundwater at that site. The statistical method chosen must be appropriate for the distribution of chemical parameters or hazardous constituents. The rule has been revised to include the clarification that normal distributions of data values shall use parametric methods and non-normal distributions shall use non-parametric methods. The rule identifies four statistical procedures, along with an alternative procedure that must meet the performance standard of § 257.93(g). The four specific statistical procedures provided in this final rule are: (1) A parametric analysis of variance followed by multiple comparison procedures to identify statistically significant evidence of contamination; (2) an analysis of variance based on ranks followed by multiple comparison procedures to identify statistically significant evidence of contamination; (3) a tolerance or prediction interval procedure; and (4) a control chart approach. The performance standard for the alternative method in subsection (g) is the same as the performance standard in the proposal, with minor revisions. EPA has deleted the performance standard ''protect human health and the environment'' in subsections (3), (4) and (5). While that standard is perfectly appropriate in a context in which a regulatory authority will apply the standard, EPA is concerned that a qualified professional engineer will be unable to certify that any alternative statistical method meets that standard. EPA received comments from professional engineers raising concern about their ability to certify that many of the requirements in the proposed rule had been met without further specification or clarification. To address those concerns, in those three provisions EPA has substituted a more objective performance standard that more precisely defines the relevant issues to be considered. Specifically, the subsections now specify that those approaches must be ''at least as effective as any other approach in this section for evaluating groundwater.''

The data objectives of the monitoring, in terms of the number of samples collected and the frequency of collection, must be consistent with the statistical method selected. Guidance on selecting a specific method is described in ''*Unified Guidance Document: Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,*'' March 2009, EPA 530/R–09–007. The owner or operator must indicate in the operating record the statistical method that will be used in the analysis of groundwater monitoring results.

The owner or operator must conduct the statistical comparisons between upgradient and downgradient wells within 90 days of completion of each sampling event and receipt of validated data. The statistical comparison must be conducted in order to determine if a statistically significant increase has occurred over background levels for each parameter or constituent required in the particular groundwater monitoring program that applies to the unit as determined under §§ 257.94(a) or 257.95(a). This has been adopted without revision from the proposal.

EPA is finalizing as proposed the prohibition in § 257.93(b) on field filtering groundwater samples because filtration of samples for metals analyses will not provide accurate information concerning the mobility of metals contaminants, the primary objective of groundwater sampling. Metal contaminants may move through fractured and porous media not only as dissolved species, but also as precipitated phases, polymeric species, or adsorbed to particles of colloidal dimensions (<10 microns). For an assessment of mobility, all mobile species must be considered, including suspended or colloidal particles acting as absorbents for contaminants. Filtration of groundwater samples for metals analyses will not provide accurate information concerning the mobility of metal contaminants because some mobile species in solution are likely to be removed by filtration before chemical analysis. Significant underestimations of mobility may result if filters (typically 0.45 micron) are used to separate dissolved and particulate phases.

In its approach to sampling EPA is specifying in the final rule that owners and operators use 'total recoverable metals' concentrations in measuring groundwater quality. Measurement of total recoverable metals captures both the particulate fraction and dissolved

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fraction of metals in natural waters. Exceedances of ambient water criteria on a total recoverable basis are an indication that metal loadings could be a stress to an ecosystem.

One commenter argued that to prohibit field filtering would potentially bias the results artificially high, particularly at sites where low yielding formations or naturally high levels of turbidity in groundwater are encountered. However, high turbidity can also be the consequence of faulty well design and/or construction, which causes the introduction of foreign materials (high turbidity) through created fracture pathways. A properly designed well should allow for sufficient groundwater flow for sampling, minimize the passage of materials into the well, and exhibit sufficient structural integrity to prevent collapse of the intake structure. It is vital that the well provide a representative hydraulic connection to the geologic formation of interest. Otherwise the water chemistry information cannot be correctly interpreted in relation to groundwater flow or transport of chemical constituents.

Sampling with no filtration means that increased importance is placed on proper well construction and purging sampling procedures to eliminate or minimize sources of sampling artifacts. There should be nothing in the well design that will lead to high levels of turbidity. Groundwater sampling should be conducted utilizing EPA protocol low stress (low-flow) purging and sampling methodology, including measurement and stabilization of key indicator parameters prior to sampling. For purposes of sampling, this final rule presumes that a properly constructed well is capable of yielding groundwater samples with low turbidity (≤5 Nephelometric Turbidity Units (NTU)), and by knowing the cause of turbidity the qualified professional engineer will be able to optimize well performance and reduce turbidity levels, eliminating the need for filtration.

EPA is revising § 257.93(i)(2) to specify a time period of 90 days to determine if a statistically significant increase over background concentrations of one of more of the contaminants has been detected. As proposed, this section specified: ''Within a reasonable period of time after completing sampling and analysis, the owner or operator of the CCR landfill or surface impoundment must determine whether there has been a statistically significant increase over background at each monitoring well.'' Commenters pointed out that this section of the regulation was very vague, and potentially unenforceable. Several commenters suggested that once sampling and analysis had been completed, 90 days would be a reasonable amount of time to complete the statistical analysis to determine whether an exceedance had occurred. No commenter suggested a longer period of time was necessary and that timeframe is consistent with the Agency's experience of the timeframes necessary to complete such analyses. Accordingly, we have revised the provision to require the determination of a statistically significant increase to be made within 90 days of sampling and analysis.

4. Detection Monitoring Program

With three exceptions, EPA is finalizing the regulatory provisions relating to detection monitoring as proposed. The three revisions are the appendix III list of monitoring parameters; the required number of samples to determine background concentrations; and the availability of an option to conduct detection monitoring on a less frequent basis due to a lack of groundwater.

The detection monitoring phase of the groundwater monitoring program in this rule requires that the owners or operators of CCR units establish background concentrations for all monitoring parameters (appendix III and IV of part 257) and sample at least semiannually during the active life of the facility, closure, and post closure periods for a set of detection monitoring indicator parameters (appendix III of part 257).

In response to comments, EPA has revised appendix III to delete conductivity and sulfide from the list of monitoring parameters and to add calcium. Thus, the list of parameters included on the detection monitoring list is boron, calcium, chloride, fluoride, pH, sulfate and total dissolved solids (TDS). The Agency has deleted conductivity from the detection monitoring program because it is merely a proxy for TDS, which is already included on the list of parameters to analyze during detection monitoring. The Agency has also deleted sulfide because it occurs in groundwater only under strongly reducing conditions, and such conditions are rather rare at CCR disposal facilities. Calcium is being added to appendix III because it is an indicator of the extent of leaching from fly ash and FGD gypsum and because of the strong demonstrated link between the leaching of calcium and arsenic, which is one of the primary risk drivers identified in the risk assessment.

As discussed in the preceding section, in detection monitoring, a minimum of eight independent samples from each background and downgradient well must be collected and analyzed for the appendix III and IV parameters no later than 24 months from the effective date of the rule. During subsequent sampling events, at least one sample from each background and downgradient well must be collected and analyzed, although the total number of samples must be consistent with the statistical procedures selected and with the performance standard in § 257.93(g). See discussion above in section 3. Sampling and Analysis Requirements.

Under the proposed rule, monitoring would be required no less frequently than semiannually. In the final rule, semiannual sampling remains the general requirement; however, in response to comments, EPA has decided to include a provision that would allow an alternative sampling frequency if there is not adequate groundwater to flow to sample wells semiannually. Specifically, EPA received comment stating that there may be instances where there simply is not enough water available to collect and analyze on a semiannual basis, especially in western climates where the rate of groundwater recharge may be too slow or a lack of precipitation exists. The commenter also provided an example demonstrating that mining practices in adjacent areas can greatly alter the groundwater flow. Accordingly, EPA has included a provision to address the situations where there is insufficient groundwater available to collect and analyze samples around CCR units on a semiannual basis.

An owner or operator seeking to establish an alternative frequency must demonstrate that less frequent monitoring is necessary based on the following three factors: (1) Lithology of the aquifer and the unsaturated zone; (2) hydraulic conductivity of the aquifer and the unsaturated zone; and (3) groundwater flow rates. In addition, the rule requires the owner or operator to demonstrate that any alternate sampling frequency would be no less effective in ensuring that any leakage from the CCR unit will be discovered within a timeframe that does not materially delay the initiation of any necessary remediation measures. The owner or operator must have a qualified professional engineer certify that the alternative (*i.e.,* less frequent) monitoring will achieve this performance standard. The final rule also specifies that any alternate frequency during the active life (including closure) and the post-closure

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care period shall be no less than annual. As noted, the owner or operator will bear the burden of justifying an alternate frequency under this regulation, and in any court proceeding brought to enforce these requirements. This means that any uncertainty or lack of information will be weighed against the entity seeking to justify the alternate frequency.

Consistent with the proposed rule, if the owner or operator determines that there is a statistically significant increase (SSI) over background for one or more of the parameters listed in appendix III at any monitoring well at the waste boundary, the owner or operator must place a notice in the operating record and on the facility's internet site indicating which parameters have shown statistically significant changes from background levels and notify the State Director.

The facility must also then establish an assessment monitoring program and begin monitoring within 90 days. The owner or operator has the opportunity to demonstrate that a source other than the CCR unit caused the statistically significant increase or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation or a natural variation in groundwater quality. Within 90 days, the owner or operator must prepare a report documenting this demonstration which must then be certified by a qualified professional engineer verifying the accuracy of the information in the report. If a successful demonstration is made within 90 days, the owner or operator may continue detection monitoring. If a successful demonstration is not made within 90 days, the owner or operator must initiate assessment monitoring.

Commenters raised concern that 90 days would not be sufficient to complete all of the activities necessary to determine whether the detection of an SSI was from another source than the CCR unit or was based on inaccurate results. The Agency recognizes that in some circumstances it could take more than 90 days to resample and have laboratories conduct new analyses, or to conduct field investigations to determine that another source is causing the contamination. As a result, § 257.94(e)(3) does not place an ultimate time limit for owners and operators to complete the demonstration. However, if after 90 days the owner or operator has not made a successful demonstration, (s)he must begin an assessment monitoring program. At this stage, there is evidence to indicate that a release has occurred from the CCR unit, and while EPA agrees that the facility may want to confirm that the information is accurate, it is critical that the facility not delay indefinitely the more targeted monitoring to determine whether a constituent of concern is contaminating groundwater. It would not be consistent with the statutory standard to allow a facility unlimited time to delay taking reasonable steps to assess, and if necessary, address potential contamination by continuing to resample until they obtain a ''better'' answer. Moreover, initiation of an assessment monitoring program does not involve an irretrievable commitment of resources or even a significant investment by the facility, but only requires the facility to begin more targeted sampling for constituents of concern. This represents a reasonable first step to address a potential threat to groundwater. This requirement is also in the MSWLF part 258 regulations. For more information see 56 FR 51078 (October 9, 1991).

Subsequent to initiating the assessment monitoring program, if an owner or operator demonstrates that the statistically significant increase resulted from an error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality, or was caused by a source other than the CCR unit, the owner or operator may cease assessment monitoring and return to detection monitoring. If the demonstration is successful, the owner or operator must have the demonstration certified by a qualified professional engineer, and is required by § 257.94(e)(3) to place a notice in the operating record, and on publicly accessible Internet site and send a copy of the report to the State Director.

5. Assessment Monitoring Program

EPA is adopting an assessment monitoring program that is largely identical to the program laid out in the proposal. However, as discussed in more detail below, some revisions have been made; some were made in response to comments, but most are conforming changes made to be consistent with changes adopted in other provisions, such as the detection monitoring program described previously.

Consistent with the proposed rule, if any of the detection monitoring parameters are detected at a statistically significant level over the established background concentrations, the owner or operator must proceed to the next step, assessment monitoring. Assessment monitoring requires annual sampling and analysis for the full list of constituents included in appendix IV. The number and frequency of samples required for assessment monitoring are the same as those established for detection monitoring. See discussion above in 3. Sampling and Analysis Requirements.

EPA has also revised the list of constituents in appendix IV by deleting the following constituents and parameters: Aluminum, boron, chloride, copper, iron, manganese, pH, sulfate, sulfide, and TDS; and adding the following constituents: Cobalt, lithium, and radium 226 and 228 combined. The following constituents and parameters are being removed from appendix IV because they are on appendix III and therefore will continue to be monitored throughout assessment monitoring: Boron, chloride, pH, sulfate and TDS. Although fluoride is on appendix III, we are also retaining it on appendix IV because it does have an MCL and was found to pose risks in the 2014 risk assessment, and therefore is appropriately considered to be a constituent that is relevant for purposes of corrective action. Aluminum, copper, iron, manganese, and sulfide have been removed because they lack maximum contaminant levels (MCLs) and were not shown to be constituents of concern based on either the risk assessment conducted for this rule or the damage cases (see Units X and XI of this document). Cobalt has been added to appendix IV because cobalt was found to be a risk driver in the 2014 risk assessment, based on certain waste management disposal practices that lead to highly acidic wastes conditions. Lithium is being added to appendix IV because it has been detected in several proven and potential damage cases at levels exceeding EPA's Regional Screening Level (RSL) of soil to groundwater and has been determined as potentially toxic if consumed concurrently with certain drug types.[117] Radium 226 and 228 combined (the sum of the radioactive isotopes radium-226 and radium-228) is being added because there is evidence from several damage cases of exceedances of gross alpha, indicating that radium from the disposal of CCR may be problematic. Appendix IV now contains antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, fluoride, lead, lithium, mercury, molybdenum,

[117] *EPA's Regional Screening Level (RSL) Soil to Groundwater Supporting Table (TR = 1E–6, HQ = 1)* May 2014/Mid-atlantic Risk assessment: *http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/index.htm; and Health Consultation: Chesapeake ATGAS 2H Well Site Leroy Hill Road, Leroy, Leroy Township, Bradford County, Pennsylvania,* October 29, 2013. U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry Division of Community Health Investigations Atlanta, Georgia. *http://www.atsdr.cdc.gov/.*

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selenium, thallium and radium 226 and 228 combined.

If any appendix IV constituents are detected in any appendix IV analyses, the owner or operator must notify the State Director and continue to monitor, at least semiannually, for both the specific constituents in appendix IV that were detected and all parameters in appendix III. EPA has decided to also include a provision to allow an alternative sampling frequency if there is not adequate groundwater to flow to sample wells semiannually, consistent with the revised provision adopted for the detection monitoring program. If the owner or operator demonstrates at any time during assessment monitoring that all of the detected appendix III and IV constituents are at or below background values for two consecutive sampling events, (s)he must notify the state and may return to detection monitoring. In general, EPA expects that appendix III constituents are unlikely to remain elevated once measures have been taken to address the release of the detected appendix IV constituents. But should appendix III constituent levels remain elevated, detection monitoring continues to be necessary to determine whether another source of contamination is present.

After obtaining the sampling results the owner or operator must place a notice in the operating record and on the facility's internet site indicating which appendix IV constituents have been detected and notify the State Director. Within 90 days and on at least a semiannual basis thereafter, the owner or operator must resample all wells, conduct analyses for all parameters in appendix III and for those constituents in appendix IV that were detected in the initial assessment monitoring sampling event. The results of this resampling must be placed in the owner or operator's operating record, as well as its publicly accessible internet site. The results of the resampling must also be sent to the State Director. These provisions have been adopted without change from the proposal.

For each appendix IV constituent that is detected, a groundwater protection standard must be set. The groundwater protection standards must be the MCL or the background concentration level for the detected constituent, whichever is higher. If there is no MCL promulgated for a detected constituent, then the groundwater protection standard must be set at background. The proposed rule would have allowed the owner or operator to establish an alternative groundwater protection standard for constituents for which MCLs have not been established provided that the alternative groundwater protection standard has been certified by an independent registered professional engineer and the state has been notified that the alternative groundwater protection standard has been placed in the operating record and on the owner's or operator's publicly accessible internet site. This provision had been adopted from the part 258 regulations, but was determined to be inappropriate in a self-implementing rule, as it was unlikely that a facility would have the scientific expertise necessary to conduct a risk assessment, and was too susceptible to potential abuse. Additionally, numerous comments were received suggesting that only those constituents with MCLs be included in appendix IV. The commenters were concerned that only MCLs are enforceable. With the exception of cobalt, lead, lithium and molybdenum (included on appendix IV because of their relevance in the risk assessment and damage cases), all appendix IV constituents have an MCL. In the proposed rule, as stated above, owner or operators were allowed to establish certain types of alternative groundwater protection standards. In the final rule, if a constituent has no MCL (*i.e.,* cobalt, lead, lithium and molybdenum), their groundwater protection standards will be their background levels. These background standards are sufficiently precise that they are enforceable.

The owner or operator must compare the levels of any detected appendix IV constituents to the appropriate groundwater protection standard. If the concentrations of all appendix IV constituents are shown to be at or below background values for two consecutive sampling events using the statistical procedures required by § 257.93, the owner or operator of the CCR disposal facility must place that information in the operating record and on the facility's publicly accessible internet site and notify the State Director. The owner or operator may then return to detection monitoring.

If the concentrations of any appendix III or IV constituents are above background values, but all concentrations are determined to be below the groundwater protection standard using the statistical procedures required by this rule, the owner or operator must continue assessment monitoring program.

If, however, the monitoring indicates a statistically significant increase for any appendix IV constituent over the groundwater protection standard, the owner or operator is required to notify the State Director and local officials of this finding and place a notice in the operating record and on the owner or operator's publicly accessible internet site.

The owner or operator also must characterize the nature and extent of the release. As part of characterizing the nature and extent of the release, the owner or operator must install additional wells, as necessary to define the contaminant plume(s) and collect data on the nature and estimated quantity of the material released. Adequate characterization of the release is critical in designing and effectively implementing a protective corrective action program if groundwater remediation is necessary. The purpose of these additional wells is to delineate the contaminant plume boundary and to eventually demonstrate the effectiveness of corrective action in meeting the groundwater protection standard.

Because the requirements for additional monitoring are entirely specific to the site conditions and the size and nature of the release, the Agency is not able to set requirements that precisely specify the location or the number of additional wells that must be installed. Instead EPA has adopted an approach that corresponds to the approach to designing the original groundwater monitoring system under § 257.91. The regulations establish a general performance standard (''install additional wells as necessary to define the contaminant plume'') and specify a true minimum of installing at least one well at the facility boundary in the direction of contaminant migration in order to ascertain whether the contaminants have migrated past the facility boundary. The regulations also establish a rebuttable presumption that this minimum is insufficient, requiring the owner or operator to justify a decision to install only this minimum. The requirement to justify the decision to only install the minimum number of additional wells is a revision from the proposal that has been adopted to be consistent with the Agency's overall approach to developing an effective groundwater monitoring system.

The Agency has also added some clarification to the proposed requirement to characterize the nature and extent of the release, by requiring the owner or operator to collect data on the nature and estimated quantity of material released, including specific information on the constituents listed in appendix IV and the levels at which they are present in the material released. This information will be necessary to help the owner or operator characterize the release and assist in ultimately deciding on a remedy.

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If contamination has migrated off-site, the owner or operator must notify individuals who own land or reside on land overlying the plume.

In addition to characterizing the nature and extent of the release, the owner or operator must initiate an assessment of corrective measures within 90 days of finding a statistically significant increase over background concentrations, and select the appropriate remedy. During this phase, the owner or operator is required to continue at least semiannual monitoring (or an alternative frequency, no less than annually) for all appendix III constituents and for those appendix IV constituents exceeding the groundwater protection standard. To be consistent with the provisions in detection monitoring, EPA has included a provision that would allow the owner or operator to demonstrate that a source other than their CCR unit caused the contamination or that the statistically significant increase above groundwater protection standards resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. This alternative option will not delay compliance with the next phase of the groundwater monitoring and corrective action program. Thus, until such a demonstration is made, the owner or operator must comply with the other requirements of this section, including initiating the assessment of corrective measures. At this stage, the evidence that the CCR unit is leaking is stronger, and the owner or operator has previously had the opportunity to demonstrate that the finding was made in error under the detection monitoring program, so no further delay in initiating measures to address any groundwater contamination is warranted.

Another change since the proposal is that in addition to complying with all of the corrective action requirements—*i.e.,* initiating an assessment of corrective measures, followed by selection of a remedy and implementation of a corrective action program—if the unit is an unlined surface impoundment, it must either retrofit or initiate closure. Further, where the facility has chosen to install a multi-unit groundwater monitoring system, the detection of an SSI of an appendix IV constituent would trigger the corrective action and closure (or retrofit) of all of the unlined surface impoundments covered by that monitoring system, as there will be no way to isolate a particular unlined unit as the source of the contamination. These requirements are discussed in more detail in the Closure section.

6. Assessment of Corrective Measures

This section of the regulations also largely mirrors the analogous provisions in the proposed rule. EPA added some language to reflect that this section is not limited to the remediation of groundwater from a leaking CCR unit but will also apply to contamination caused by any kind of release from a CCR unit. EPA also made some minor revisions in response to comments, and some editorial changes to conform this provision to changes made in other sections of the rule.

Consistent with the proposal, § 257.96(a) specifies that the assessment of corrective measures must be initiated within 90 days of detecting a statistically significant increase of any of the constituents listed in appendix IV, at a level exceeding the groundwater protection standard(s), or of otherwise documenting a release of contaminants from the CCR unit. The regulation also requires the assessment of corrective measures to be completed in 90 days of such a finding, but in response to comments, EPA is adopting a provision that will allow for a single 60 day extension. Multiple commenters argued that 90 days was not adequate to complete the assessment of corrective measures. Commenters stated that for situations with complex hydrogeology, additional studies and sampling may be required in order to assess potential contributing offsite sources, background levels, and possible remedies. They stated that identification of remedy alternatives, collection and analysis of data used to evaluate remedy alternatives, and discussions with vendors/contractors regarding availability of labor and materials are all critical steps in the remedy selection process. As explained in the ''Technical Manual Solid Waste Disposal Facility Criteria,'' EPA530–R–93–017, USEPA, November, 1993, Chapter 5, Subpart E, Ground-Water Monitoring and Corrective Action, the owner or operator will need to: (1) Identify and remediate the source of contamination; and (2) identify and remediate the known contamination. The factors that must be considered in assessing corrective measures include source evaluation, plume delineation, groundwater assessment and source control. Based on the comments received, as well as the Agency's own experience, EPA recognizes that there may be complex situations that require more time to develop a careful and well-thought out corrective measures assessment. Therefore, the final rule has been modified to allow up to an additional 60 days to complete the assessment of corrective measures, provided that a qualified professional engineer certifies that the additional time is necessary. The initial 90 days plus the additional 60 days, which is within the range of time suggested by the commenters, would provide the owner or operator up to 150 days to complete the corrective measures assessment, which EPA expects will be sufficient. The certification must be placed in the operating record, on the owner's or operator's publicly accessible internet site and submitted to the proper state official.

The rule requires the owner or operator to assess the effectiveness of potential remedies in meeting the objectives of § 257.97 by addressing at least: (1) Performance, reliability, ease of implementation and potential impacts; (2) time requirements; and (3) institutional requirements. The proposed rule also included consideration of the costs of remedy implementation. However, that language came directly from the MSWLF rule in part 258. Because Congress did not authorize the consideration of costs in establishing minimum national standards under RCRA section 4004(a), we have removed this factor. In evaluating the performance, reliability, ease of implementation, and potential impacts of each remedy, the owner or operator should evaluate whether specific remedial technologies are appropriate to the problem and the ability of those technologies to achieve the groundwater protection standards. Analysis of a remedy's reliability should include an assessment of the effectiveness of the remedy in controlling the source of the release and its long-term reliability. Source control measures need to be evaluated to limit the migration of the plume, and to ensure an effective remedy. The regulation does not limit the definition of source control to exclude any specific type of measure to achieve this. Remedies must control the source of the contamination to reduce or eliminate further releases by identifying and locating the cause of the release. Source control measures may include the following: Modifying the operational procedures (*e.g.,* banning waste disposal); undertaking more extensive and effective maintenance activities (*e.g.,* excavate waste to repair a liner failure); or, in extreme cases, excavation of deposited wastes for treatment and/or offsite disposal. Construction and operation requirements also should be evaluated. The analysis of the timing of potential remedies should include an evaluation of construction, start-up, and

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completion time. Timing is particularly important if contamination has migrated off-site. Institutional requirements such as local permit or public health requirements may affect implementation of the remedies evaluated and should be assessed by the owner or operator.

The proposed rule included a provision that would allow an owner or operator to determine that compliance cannot be reasonably achieved with any currently available methods. This has been deleted from the final rule. The Agency determined that without state oversight or a permitting program, that provision was potentially subject to abuse and thus, inappropriate to include in a self-implementing rule.

As part of evaluating potential remedies, the owner or operator must hold a public meeting to discuss the remedies under consideration (prior to selecting a final remedy). Once the owner or operator has selected a remedy, he must place a description of the selected remedy in the operating record, on the owner or operator's publicly accessible internet site and notify the State Director.

7. Selection of Remedy

This section of the final rule has been adopted with only minor changes from the proposal. As in the prior section, EPA has revised certain provision to reflect that this section will also apply to the cleanup of contamination caused by a release from a CCR unit. EPA also deleted a provision that had been adopted from the part 258 regulations, but that was determined to be inappropriate in a self-implementing rule as it was too susceptible to potential abuse.

Based on the results of the corrective measures assessment conducted, the owner or operator must select a remedy. The selected remedy must attain all of the performance standards listed in subsection (b). Specifically, the remedy must protect human health and the environment, attain the groundwater protection standards, control the sources of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of appendix IV constituents into the environment, and comply with any relevant standards for management of wastes generated as a result of the remedial activities. EPA included an additional criterion more directly related to remediation of contamination associated with a release, such as from a collapse or structural failure of a CCR unit, which requires the remedy to ''remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, taking into account factors such as avoiding the inappropriate disturbance of sensitive ecosystems.'' Together, these criteria reflect the major technical components of any kind of clean up remedy.

The rule also specifies decision criteria to be considered by the owner or operator in selecting the most appropriate remedy. These include: (1) Long and short term effectiveness, and degree of certainty of success; (2) effectiveness of remedy in controlling the source to reduce further releases; (3) ease or difficulty of implementation; and (4) community concerns. Additionally, the rule requires the owner or operator to specify a schedule for implementing and completing the remedial activities. The rule requires the owner or operator to set the schedule because it is impossible for EPA to establish a single schedule appropriate for all possible situations; the schedule will necessarily depend on the nature and size of the contamination, among other factors. The rule outlines six factors to be considered in establishing a schedule for completing remedies (§§ 257.97(d)(1–6)). These factors are: (1) Extent and nature of contamination; (2) reasonable probabilities of remedial technologies in achieving compliance with the groundwater protection standards; (3) availability of treatment or disposal capacity for CCR managed during implementation of the remedy; (4) potential risks to human health and the environment; (5) resource value of the aquifer; and (6) other relevant factors. EPA had included one additional factor in the proposal: ''The desirability of utilizing technologies that are not currently available, but which may offer significant advantages over already available technologies in terms of effectiveness, reliability, safety, or ability to achieve remedial objectives.'' EPA considered that this provision, which could be used to justify delaying remediation measures, was potentially subject to abuse and thus, inappropriate to be included in a self-implementing rule.

For similar reasons, EPA deleted the provisions in the proposal, subsections (e) and (f) that would authorize a facility to determine that remediation of a release is not necessary. These sections which came from the MSWLF rule in part 258 are appropriate where there is state oversight. The preamble to the final MSWLF rule specifically discusses situations in which an approved state may decide not to require cleanup of hazardous constituents released to groundwater from a MSWLF (see 56 FR 51090). However, there is no similar guarantee that an individual facility will act in the public interest.

8. Implementation of the Corrective Action Program

The proposed rule required the owner or operator to include a schedule for initiating the remedial activities in the schedule for implementing the remedy (§ 257.97(d)). The Agency understands that selecting a remedy is closely related to the assessment process and cannot be accomplished unless a sufficiently thorough evaluation of alternatives has been completed. The process of documenting the rationale for selecting a remedy requires that a report be placed in the operating record that clearly defines the corrective action objectives and demonstrates why the selected remedy is anticipated to meet those objectives. The report must identify how the remedy will be protective of human health and the environment, attain the groundwater protection standards (either background or MCLs), attain source control objectives, and comply with waste management standards.

The selection of a remedy also involves a public meeting with interested parties before finally selecting a remedy. For these reasons, the Agency is not establishing a deadline for completing the remedy selection process, but rather expects it to be completed as soon as practicable. Once the assessment of corrective measures has been completed within the timeframe specified in this rule, and the public meeting has occurred, the facility owner or operator must select a remedy and begin implementing that remedy as soon as is practicable. It is vitally important that the facility selects a remedy as soon as practicable and begins designing and implementing that remedy, so that releases to groundwater are addressed without unnecessary delay. EPA understands that there are a variety of activities that may be necessary in order to select the appropriate remedy (*e.g.,* discussions with affected citizens, state and local governments; conducting on-site studies or pilot projects); and, once selected, to implement the remedy (*e.g.,* securing on-site utilities if needed, obtaining any necessary permits, etc.). That is why EPA does not find it appropriate to set specific timeframes for selecting the remedy or to begin implementing the selected remedy. However, in order to ensure that the community is kept informed as to the progress of selecting and implementing the remedy, EPA is requiring that the facility owner or operator, on a semiannual basis, post status reports/updates on their progress

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to their publicly accessible internet site and submit these to the state.[118]

However, the Agency has concluded that it is reasonable to require that once a remedy has been chosen, the owner or operator of the CCR unit must begin to implement that remedy within a specified period of time. Consistent with the timeframes throughout this section, the final rule requires that within 90 days of selecting a remedy, the owner or operator must have initiated corrective measures, including any interim measures determined to be appropriate, and have established a corrective action groundwater monitoring program (and begin following it). (§ 257.98). This is a reasonable timeframe in which to begin these activities based on EPA's long experience in conducting and overseeing cleanup activities.

The remedy would be considered complete when the owner or operator demonstrates compliance with the groundwater protection standards for a period of three consecutive years, and all other actions required to meet the performance standards in § 257.97(b) have been satisfied (*e.g.,* source control). The owner or operator must obtain certification that the remedy is complete from a qualified professional engineer, and must notify the State Director. The certification must also be placed in the operating record and on the owner or operator's publicly accessible Internet site.

The Agency deleted the provision that allows an owner or operator to determine that compliance cannot be reasonably achieved with any currently available methods. The Agency determined that without state oversight or a permitting program, that provision was potentially subject to abuse and thus, inappropriate to be included in a self-implementing rule.

9. Timing Overview

The groundwater monitoring regulations require that the owner or operator of existing CCR units must comply with § 257.90–§ 257.94 within 30 months of the date of publication of the rule. Essentially, that means that by the end of 30 months, the owner or operator must (1) install the groundwater monitoring system; (2) document the sampling and analysis procedures; (3) establish which statistical tests will be used to determine exceedances; (4) sample all wells to have a minimum of 8 samples for all appendix III and IV parameters; and (5) determine if there is a statistically significant exceedance of any appendix III parameter, which would trigger assessment monitoring.

New CCR units must comply with §§ 257.90–257.93, including the requirement under § 257.94(b) to collect and analyze eight independent samples from each well for the parameters listed in appendix III and IV to this part to determine background levels for all appendix III and IV constituents, before commencing operation. Essentially, that means that before receiving CCR waste, the owner or operator must (1) install the groundwater monitoring system; (2) document the sampling and analysis procedures; (3) establish which statistical tests will be used to determine exceedances; and (4) sample all wells to have a minimum of eight samples for all appendix III and IV parameters.

If assessment monitoring is triggered, within three months the owner or operator must sample all wells for all appendix IV constituents (minimum of one sample) and resample (minimum of one sample) all wells for all appendix III parameters and those appendix IV constituents that were detected in the first round of sampling. The owner or operator could also simultaneously use this three month timeframe to demonstrate that the statistically significant increase found in detection monitoring was due to another source or sampling and analysis error. While conducting assessment monitoring, the owner or operator must continue sampling for all appendix III constituents and any appendix IV detected constituents semiannually. The owner or operator must sample for all appendix IV constituents annually.

The owner or operator must also establish groundwater protection standards (MCL or background levels) for all appendix IV constituents detected during sampling.

If one or more appendix IV constituents are detected at statistically significant levels above the groundwater protection standards established, or a release from a CCR unit has been detected, corrective action is triggered. The owner or operator must characterize the nature and extent of the release by installing additional monitoring wells, collecting data on the quantity and concentration levels of regulated constituents in the released material, sampling and notifying the State Director, local government officials, and any persons who own land or reside on the land that overlies the plume if the plume has migrated off site. The owner or operator must also place the notification in their operating record and on their publicly accessible Internet site.

If corrective action is triggered, within three months the owner or operator must initiate an assessment of corrective measures. If the CCR unit is an unlined surface impoundment, the unit must stop receiving CCR and non-CCR wastes and initiate closure of the unit or begin to retrofit the unit within six months. The owner or operator could also simultaneously use these three months to initiate an assessment of corrective measures to demonstrate that the statistically significant increase found during assessment monitoring was due to another source or sampling and analysis error.

The assessment of corrective measures must be completed in three months, with the possibility of an additional two months if the owner or operator demonstrates the need for additional time. The owner or operator must continue assessment monitoring and provide notification of the corrective measures assessment to the State Director and place the assessment in the operating record and on the owner's or operator's publicly accessible Internet site. The owner or operator also must discuss the results of the corrective measures assessment at least one month prior to selection of remedy in a public meeting.

Within three months of selecting a remedy, the owner or operator must initiate remedial activities. Corrective action is completed when the owner or operator demonstrates compliance with the groundwater protection standards for three consecutive years.

L. Closure of Inactive Units.

As discussed in Unit VI.A of this document, EPA proposed that inactive CCR surface impoundments that had not completed closure in accordance with specified standards by the effective date would be subject to all of the requirements applicable to existing CCR surface impoundments. EPA adopted this approach to create an incentive to expedite the closure of these units, with all of the significant risk mitigation that such a measure would entail. EPA is retaining this general approach in the final rule, but has revised the provision to grant inactive CCR surface impoundments more time to complete closure, consistent with the other closure provisions in the final rule. The

[118] As evidenced in 42 U.S.C. 6971(f), Congress intended that the OSHA be able to enforce its regulations to protect workers exposed to hazardous waste and that EPA and OSHA would work together to ensure that. EPA is clarifying that it intends that the CCR disposal rule not preempt applicable OSHA standards designed to protect workers exposed to CCRs; thus EPA's final rule on CCR disposal will apply in addition to any applicable OSHA standards. The Agency has added specific regulatory language in this section to address this intent.

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final rule extends the deadline to three years from publication of the rule in the **Federal Register**.

The proposal was based on EPA's belief that the timeframes between publication of the final rule and the effective date would be sufficient for facilities to close inactive CCR surface impoundments. This was particularly true under the subtitle C option, where the timeframe between publication and the effective date could be as long as 18 months, due to the need for subsequent action by authorized states. Under the proposed rule, the maximum amount of time a facility would have to initiate and complete closure of a disposal unit was seven months. However, as discussed elsewhere in this preamble, EPA received numerous comments raising concern that these timeframes would essentially be ''impossible to meet'' for surface impoundments located in certain geographic and climatic conditions, as well as for all of the larger units. These comments convinced EPA that it had not adequately accounted for the complexities inherent in electric generating facility operations, and the different characteristics of CCR surface impoundments in designing the closure provisions in the proposal. EPA has revised the timeframes applicable to closures in the final rule accordingly in light of these issues. See Unit VI.M of this document. These same considerations apply with respect to this provision, and additional time is therefore necessary to make this option truly viable.

EPA selected three years based primarily on two factors. EPA initially focused on the minimum amount of time necessary to close a CCR surface impoundment. As discussed in more detail in Unit VI.M of this document, there can be a substantial range in the amount of time needed to close a surface impoundment, depending on, for example, the size and location of the unit.

However, a critical factor in EPA's decision is that under this approach these units will not be subject to the rule's groundwater monitoring or structural stability requirements (provided they complete closure within three years). Moreover, based on the information in the record, it appears highly unlikely that groundwater monitoring is currently being conducted at these units (as discussed in Unit IV.A of this document, the information on groundwater monitoring requirements applicable to existing units was extremely sparse, but many older units appear to lack effective groundwater monitoring systems). EPA considered that allowing these inactive units to remain in place without taking measures to address the continuing threat that these units present for a substantial amount of time could not be justified. EPA therefore focused on the amount of time authorized under the rule for implementation of the groundwater monitoring requirements (*i.e.,* 2 years from the effective date) and for key structural stability requirements (*i.e.,* 18 months to complete key analyses).

As discussed in more detail in the next section, the information in the record demonstrates that it is feasible to complete the closure of CCR surface impoundments within three years. EPA recognizes that larger CCR surface impoundments (*i.e.,* above 40 acres) may not be able to close within this timeframe. However, to be able to support this provision, EPA must balance the risk mitigation achieved by closure of CCR surface impoundments against the risks inherent in allowing inactive CCR surface impoundments to remain in place for longer periods of time. The longer inactive CCR impoundments remain without all of the protections provided by the final rule, the greater the potential for significant health and environment impacts. Larger units are also the ones more likely to present the highest risks, and so warrant the greater oversight provided by application of all of the technical criteria to their operation (and closure). Consequently, EPA is unable to justify expanding this option to include the longer timeframes available under §§ 257.102 or 257.103.

The criteria for conducting the closure of inactive CCR surface impoundments are essentially the same as those applicable to active CCR units. Inactive units can either clean close units, or close with waste in place, subject to same performance standards in § 257.102 for all other CCR units. If an inactive CCR surface impoundment is completely closed within the three year timeframe, no other requirements apply to that unit. This means that no groundwater monitoring or other post-closure care requirements would apply to these units. Once an inactive CCR surface impoundment has been breached and dewatered, the risks are essentially the same as the risks associated with an inactive CCR landfill, which are not subject to any requirements under the final rule.

However, owners or operators of inactive CCR surface impoundments that have not completed closure within this timeframe must comply with all of the requirements applicable to existing CCR impoundments. If the facility intends to maintain the inactive unit indefinitely, whether to provide potential future capacity, or to continue to dredge the unit to provide material for beneficial use, or with the idea that it may be repurposed for other facility operations (*e.g.,* to manage stormwater), there is no basis for distinguishing between these units and actively managed units on the basis of the potential risks. Thus, such units would need, for example, to meet all of the location and structural stability criteria (which could independently compel closure of the unit), install the groundwater monitoring system, and begin to monitor within the timeframes established in the final rule. This also means that any facility that initiates closure under this provision but fails to complete it within this timeframe, must comply with all groundwater monitoring requirements in §§ 257.90–98 (*e.g.,* install groundwater monitoring wells) as well as all of the post-closure care requirements.

M. Closure and Post-Closure Care

Closure and post-closure care are an integral part of the design and operation of CCR landfills and CCR surface impoundments.[119] EPA solicited public comment on closure and post-closure care requirements under a subtitle D approach in the proposed rule and sought additional comment on specific closure requirements in a subsequent notice of data availability.

For CCR landfills, the proposed closure and post-closure care requirements were modeled on current regulations that apply to municipal solid waste landfills, which are codified in part 258. In some cases, the proposed requirements were modified to reflect the lack of a mandatory permitting mechanism (see Unit V.A. of this preamble for additional information), in addition to other changes EPA believed were appropriate to ensure that there would be no reasonable probability of adverse effects from the wastes that remain after a CCR unit had closed. For CCR surface impoundments, the Agency modeled the proposed requirements on current regulations that apply to interim status hazardous waste surface impoundments, which are codified in part 265. Some additional proposed provisions were based on requirements currently applicable to water, sediment, or slurry impoundments and

[119] As discussed in the proposed rule, EPA's ''Guide for Industrial Waste Management'' documents the general consensus on the need for effective closure and post-closure care requirements (Chapter 11). This guide can be accessed at *http://www.epa.gov/epawaste/nonhaz/industrial/guide/.*

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impounding structures that are regulated by the MSHA. See 30 CFR part 77, subpart C.

The proposed rule included a number of closure and post-closure criteria, including: (1) Requirements to prepare closure and post-closure plans; (2) requirements for conducting closure of a CCR unit when the CCR is removed and when the CCR is left in place, including design criteria for a final cover system; (3) timeframes to commence and complete closure activities; (4) closure and post-closure care certification requirements; and (5) requirements for conducting post-closure care. The Agency received numerous comments on the proposed closure and post-closure criteria, with the majority of comments pertaining to the proposed timeframes for closure (*i.e.,* timeframes for commencing and completing closure) of a CCR surface impoundment. As a result of these comments, EPA solicited additional comments on the timeframes for closure in a NODA published on August 2, 2013 (NODA 3). See 78 FR at 46944. The sections below explain the approach and rationale for the final rule closure and post-closure care criteria based on the comments received in response to the proposed rule and the NODA.

1. Closure Plan

The Agency proposed to require that the owners or operators of CCR landfills and CCR surface impoundments prepare a written closure plan describing the closure of the unit and providing a schedule for implementation of the plan. 75 FR at 35207–08. The closure plan would describe the steps necessary to close the CCR unit at any point during the active life based on recognized and generally accepted good engineering practices. The proposal also identified the minimum information necessary to include in the closure plan. This information included: (1) An estimate of the largest area of the CCR unit that would ever require a final cover during the active life of the CCR unit; (2) an estimate of the maximum inventory of CCR that would ever be present on-site over the active life of the CCR unit; (3) a description of the final cover and the procedures to be used to install the final cover; (4) a description of how the facility will provide for major slope stability following closure; (5) a description of the measures the owner or operator will adopt to preclude the probability of future impoundment of water, sediment, or slurry; and (6) a schedule for the implementation of the closure plan. See proposed § 257.100(a) and (g). The proposed rule would also have required each owner or operator to develop the closure plan by the effective date of the final rule. Finally, EPA proposed to require the owner or operator to have the closure plan certified by an independent registered professional engineer, in addition to complying with all of the notification and posting requirements under the rule.

EPA received few public comments on either the proposal to develop a closure plan or the individual elements of the closure plan. Some commenters generally supported the requirement for an owner or operator to develop a closure plan for the CCR unit, and no commenters opposed it. However, one commenter requested that EPA include more specific requirements for slope stability in the regulatory language beyond the general requirement to address major slope stability in the closure plan for units that close with waste in place.

The Agency agrees that the proposed regulatory language should provide more specific criteria defining the expectations with regard to major slope stability. The proposed regulation merely required the owner or operator to ''provide for major slope stability'' in the closure plan, or in other words, to include measures to ensure that slope stability issues will be accounted for in designing the final cover. See 75 FR 35252.

EPA explained that unit closure must provide for major slope stability to prevent the sloughing of the cover system over the wastes that will remain in the CCR unit over the long term. Sloughing of a land slope can occur when the earth material becomes saturated with water and incapable of maintaining the slope resulting in the movement or sliding of the earth material. 75 FR at 35209. Slope stability is a critical issue in the design of final cover systems for both surface impoundments and landfills because cover system slope instability has been attributed to a number of final cover system failures.[120] More specifically, the primary causes of final cover system slope failure during construction have been identified as: (1) Placing soil over the sideslope geosynthetics from the top of the slope downward, rather than the toe of the slope upward; (2) using presumed values for critical interface shear strengths that were not conservative; and (3) using interface shear strength values from laboratory tests performed under conditions not representative of the actual field conditions. For final cover system slope failures after rainfall or thaw, the primary causes of failure have been identified as: (1) Not accounting for seepage forces; (2) clogging of the internal drainage layer, which leads to increased seepage forces; and (3) not accounting for moisture at the geomembrane and compacted clay liner interface (which weakened the interface) due to both rain falling on the compacted clay liner surface during construction and freeze-thaw effects.

Given that slope stability is a critical issue in the design and eventual performance of a final cover system, EPA has adopted a new criterion in the performance standard that all closures must meet: The owner or operator must ensure that the CCR unit is closed in a manner that will ''provide for major slope stability to prevent the sloughing or movement of the final cover system during closure and throughout the post-closure care period.'' See § 257.102(d)(1)(iii). Or in other words, the owner or operator must design a final cover system with any measures necessary to ensure that the major slopes of the closed CCR unit remain stable. Consistent with the proposal, the closure plan must discuss how the final cover system will achieve the performance standards specified in the regulation, which will necessarily include how the measures taken to address major slope stability. As explained in the proposed rule, the original provision was based on existing MSHA standards, specifically the requirements under 30 CFR 77.216–5 which apply to abandoned water, sediment or slurry impoundments and impounding structures.[121] 75 FR 35208–09. Under these requirements major slope stability includes long term stability considerations, such as ''erosion control, drainage, etc.'' These issues are equally relevant to the closure of CCR units, and EPA expects facilities to account for these factors in their final closure plans.

The remaining information elements of the closure plan have been adopted without revision (although EPA has reorganized the final regulatory text for greater clarity). These are briefly summarized below:

a. An estimate of the largest area of the CCR unit ever requiring a final cover during the active life of the CCR unit. If

[120] USEPA, ''Assessment and Recommendations for Improving the Performance of Waste Containment Systems,'' EPA/600/R–02/099, December 2002.

[121] The term ''abandoned'' is defined in the MSHA regulations under 30 CFR 77.217, and as applied to an impoundment or impounding structure such term means that work on the structure has been completed in accordance with a plan for abandonment approved by the District Manager.

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the owner or operator routinely closes portions of a CCR unit as the design capacity is reached, the closure plan should indicate the largest area of the CCR unit that will be open (and requiring a final cover) at one time.

b. An estimate of the maximum inventory of CCR ever on-site over the active life of the CCR unit. If the owner or operator routinely closes portions of a CCR unit as the design capacity is reached, the closure plan should indicate the maximum inventory of CCR that will be open (and requiring a final cover) at one time.

c. A description of the final cover and the procedures to be used to install the final cover. The closure plan should also discuss how the closure performance standard will be achieved.

d. A description of the provisions to preclude the probability of future impoundment of water, sediment, or slurry. The final grades of the final cover system should promote surface water run-off and minimize erosion. The closure plan should also discuss the steepness of the slopes of the final cover system, in addition to the vertical spacing and width of benches.

e. A schedule for the implementation of the closure plan.

This rule also provides new procedures for amending an existing written closure plan. While the proposed rule did not specifically allow or require the owner or operator to revise an existing closure plan, EPA recognizes that available information and conditions known at the time the closure plan is prepared may very well change during the active life of the CCR unit, which could be decades in some cases. In order to eliminate any potential confusion over whether an owner or operator is allowed under this rule to revise the closure plan to reflect a change in conditions or circumstances, the final rule adopts new procedures for amending a written closure plan. These new procedures allow the owner or operator to revise the closure plan at any time provided the revised plan is placed in the facility's operating record, in addition to complying with all of the notification and posting requirements under the rule. Furthermore, the final rule requires the closure plan be amended any time there is a change in conditions that would substantially affect the written closure plan in effect.

Finally, in a departure from the proposed rule, the final rule provides owners and operators one year from the rule's effective date to prepare the initial written closure plan, which is one year longer than proposed. EPA made this change as part of its effort to coordinate the compliance and implementation timeframes in the CCR rule with another Agency rulemaking—the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (ELG) rulemaking—that may affect owners and operators of CCR units. See 78 FR 34442. As explained in that proposal, consistent with RCRA section 1006(b), EPA has sought to effectively coordinate any final RCRA requirements with the ELG requirements, to minimize the overall complexity of these two regulatory structures, and to facilitate the implementation of engineering, financial and permitting activities. EPA's goal is to ensure that the two rules work together to effectively address the discharge of pollutants from steam electric generating facilities and the human health and environmental risks associated with the disposal of CCRs, without creating avoidable or unnecessary burdens.

EPA proposed to require facilities to complete a closure plan by the rule's effective date, or six months following the rule's publication. However, this would have required owners or operators to prepare closure plans approximately three months prior to publication of the ELG final rule. Given that an understanding of the ELG rule would likely affect the details and content of a closure plan, the Agency concluded that it would make no sense to require an owner or operator to prepare a closure plan within six months, only to have them update it months later, after the owner or operator understands the requirements of both the CCR and ELG final rules. No measureable environmental or health benefit would be gained by having a closure plan in place for those three months. Moreover, EPA wants to ensure that closure plans are well considered, and the knowledge that a plan may need to be substantially revised in the near future could create a contrary incentive.

By extending the deadline for preparation of the closure plan by one year, owner or operators will have slightly more than six months after the ELG rule is published to complete a closure plan. This is consistent with the six month timeframe EPA originally proposed, which as noted, would have required completion of the closure plan within six months of publication of the final CCR rule.

2. Closure of a CCR Unit Through Removal and Decontamination

The proposed rule would have allowed facilities to close a CCR unit either through CCR removal and decontamination of all areas affected by releases from the CCR unit (''clean closure'') or with CCR in place with a final cover system. The Agency proposed that if the owner or operator elects to clean close a CCR unit, CCR removal and decontamination are complete when constituent concentrations throughout the CCR unit and any areas affected by releases from the CCR unit do not exceed the numeric cleanup levels for those constituents found in CCR established by the state in which the CCR unit is located, to the extent that the state has established cleanup levels. 75 FR 35208. In the absence of state cleanup levels, the proposal stated that metals should be removed to either statistically equivalent background levels, or to maximum contaminant levels or health-based numbers. Once a facility had completed clean closure of a CCR unit, EPA proposed that post-closure care would not be required for that unit. EPA also noted that it was considering whether to adopt a further incentive for clean closure, under which the owner or operator could remove the deed notation required under the proposed rule, once all CCR has been removed from the facility and notification provided to the state.

Several commenters urged EPA to not require clean closure as the only method of closing a CCR unit, arguing that clean closure is not feasible or not necessary. Others acknowledged that clean closure is not only a viable option for their CCR units, but in some cases it would be ''the only prudent closure option.'' A few commenters suggested criteria to determine the conditions under which clean closure would be appropriate. For example, one commenter agreed with EPA that the risk-based corrective action process (RBCA) would be useful in determining whether waste removal is appropriate at the site.

EPA received relatively few comments on the specific standards for conducting clean closure. One commenter identified six criteria that should be included in any final regulation in order to allow a facility to have been deemed to have completed clean closure of a CCR surface impoundment and thereby avoid post-closure care. Some of the commenter's suggestions were comparable to requirements in the proposal. However the commenter also included requirements to ensure that adequate engineering controls were used to prevent contamination of soil and groundwater during excavation, and requirements for quarterly monitoring of shallow groundwater beneath the surface impoundment for a period of five years to demonstrate that no

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residual CCR was left in place. Finally, a number of commenters supported a provision that would allow the owner or operator to remove the deed notation required provided all CCR is removed from the site.

EPA did not propose to require clean closure nor to establish restrictions on the situations in which clean closure would be appropriate. As EPA acknowledged in the proposal, most facilities will likely not clean close their CCR units given the expense and difficulty of such an operation. Because clean closure is generally preferable from the standpoint of land re-use and redevelopment, EPA has explicitly identified this as an acceptable means of closing a CCR unit. However, both methods of closure (*i.e.,* clean closure and closure with waste in place) can be equally protective, provided they are conducted properly. Thus, consistent with the proposal, the final rule allows the owner or operator to determine whether clean closure or closure with the waste in place is appropriate for their particular unit. EPA agrees that the RBCA process, using recognized and generally accepted good engineering practices such as the ASTM Eco–RBCA process, can be a useful tool to evaluate whether waste removal is appropriate at the site. It is, however, not a necessary prerequisite.

EPA has adopted the provisions governing clean closure from the proposed rule with only one revision. The final provisions consist of two performance standards: First, the owner or operator must remove all CCR from the unit and decontaminate all areas affected by releases from the CCR landfill or surface impoundment. As part of meeting this performance standard, the final rule requires facility owners or operators to remove all wastes from the closing unit, and remove all liners contaminated with CCR waste and CCR waste leachate. The final rule also requires the owner or operator to remove and decontaminate all areas affected by releases from the CCR unit. This would require removal or decontamination of the underlying and surrounding soils and flushing, pumping, and/or treating the aquifer. The Agency interprets the term ''soil'' broadly to include both unsaturated soils and soils containing groundwater.

Second, the final rule specifies that closure has been completed when all CCR in the unit and any areas affected by releases from the CCR unit have been removed and groundwater monitoring demonstrates that all concentrations of the assessment monitoring constituents listed in appendix IV to part 257 do not exceed either statistically equivalent background levels or MCLs. This standard encompasses both saturated and unsaturated soils, as well as the groundwater. As part of attaining this standard, facility owners and operators will need to document that any contaminants left in the subsoils (*i.e.,* contaminated groundwater left in soils below the former landfill or impoundment) will not impact any environmental media including groundwater, surface water, or the atmosphere in excess of Agency-recommended limits or factors. Typically, any metals in these ''subsoils'' in excess of background levels are allowed to either naturally attenuate, or are removed by flushing. Once the facility has removed all of the assessment monitoring constituents listed in appendix IV down to background levels or MCLs the groundwater is considered to be ''clean'' and closure is complete.

EPA disagrees that specific provisions requiring the use of adequate engineering controls to prevent contamination of soil and groundwater during excavation are necessary to ensure that closure will be protective. To the extent that any contamination of soil or groundwater has occurred during CCR removal, this would constitute a release (or an ''area affected by a release'') from the CCR unit, and the final performance standard requires the facility to ensure that this has been removed before closure is deemed to be complete.

Contrary to the commenter's suggestion that quarterly monitoring for five years is necessary to demonstrate that no residual CCR was left in place, the rule requires a facility to document that all appendix IV concentrations are below MCL or background levels for two consecutive sampling events, using the statistical procedures in § 257.93(g). This is the same sampling required to demonstrate under the groundwater monitoring program that there is no longer a reason to suspect a source of contamination, and that consequently assessment monitoring can cease. EPA selected these provisions as the most factually analogous to the circumstances surrounding the clean closure of a CCR unit. Once a facility has removed the waste and any liner, the presumption is that the source of contamination has been removed as well. Although there may be site-specific factors that could support the need for a longer monitoring period, there is no factual basis to require a longer minimum period of sampling on a national basis.

This represents a change from the proposal. EPA proposed a performance standard that required decontamination to either any state established numeric cleanup levels for CCR constituents, or in the absence of state cleanup levels, the removal of metals to either statistically equivalent background levels, or to MCLs, or health-based numbers. This was taken directly from the current part 258 standards for MSWLFs. EPA has deleted both of these standards as inappropriate for these units.

The reference to state established clean up levels was inadvertently carried over from the existing part 258 regulations. As explained throughout this preamble, EPA is unable to rely on state programs to establish the specific standards under this rule; the record does not contain information on all state cleanup standards, and there is no mechanism for states to operate approved programs in lieu of federal programs.

EPA determined that the requirement to clean all soils to background levels was equally inappropriate. In practice, EPA does not routinely require complete removal of all contamination (that is, cleanup to 'background') from a closing unit even for hazardous waste units. Requiring CCR units to clean up soils to levels before the site was contaminated, would be more stringent than current hazardous waste policies. There is no basis in the current record to impose provisions for the remediation of CCR units that are more stringent than those imposed on hazardous wastes.

Upon completion, the unit is exempt from the groundwater monitoring and any other post-closure care requirements. In addition, the final rule adopts the proposal to allow the owner or operator to remove the deed notation required under § 257.102(i)(4), upon certification that clean closure has been completed. EPA proposed this option to create a further incentive for clean closure, and it is clear from the commenters, who uniformly supported this option, that it does so. Some commenters raised concern about the effect this option will have on state laws, which may not allow the deed notation to be removed. EPA notes that these criteria do not preempt state laws; to the extent state law requires the facility to retain a deed notation despite the completion of clean closure, those requirements will remain in place, notwithstanding this final rule.

3. Closure of a CCR Unit With CCR in Place

The proposed rule would have also allowed facilities to close a CCR unit by leaving the CCR in place and installing a final cover system. The final cover

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system would have been required to be designed and constructed to a have a permeability less than or equal to the permeability of any bottom liner system or the natural subsoils present, or a permeability no greater than 1×10^{-5} centimeters per second (cm/sec), whichever is less. The proposal would have also required an infiltration layer that contains a minimum of 18 inches of earthen material and an erosion layer containing a minimum of six inches of earthen material that is capable of sustaining native plant growth to help minimize erosion of the final cover. These proposed requirements were generally modeled after the performance standard and technical requirements contained in § 258.60 for MSWLFs. 75 FR 35208. EPA also proposed that the final cover system would have to be designed to minimize the disruption of the final cover through a design that accommodates settling and subsidence and provides for major slope stability to prevent the sloughing of the closed CCR unit over the long term. These last two criteria are based on existing requirements for interim status units under RCRA part 265 and MSHA requirements under 30 CFR part 77, subpart C, respectively.

As proposed, CCR surface impoundments would have been subject to an additional set of performance standards. The owner or operator of a CCR surface impoundment would have been required to either drain the CCR unit or solidify the remaining wastes. In addition, the owner or operator would have been required to stabilize the wastes to a bearing capacity to support the final cover. The proposed criteria would also have required that the final cover for all CCR units be designed to minimize the migration of liquids through the closed CCR surface impoundment over the long term; promote drainage, and accommodate settling and subsidence so that the final cover's integrity is maintained. Finally, closure of the CCR unit would also have been subject to the general performance standard that the probability of future impoundment of water, sediment, or slurry be precluded.

The Agency also proposed to allow owners or operators of CCR units to select an alternative final cover design. As proposed, the alternative final cover design would have required an infiltration layer that achieves an equivalent reduction in infiltration, and an erosion layer that would provide equivalent protection from wind and water erosion, as the infiltration and erosion layers specified for final covers described above. In addition, the proposed approach for alternative final cover designs would have also required certification by an independent registered engineer, notification being provided to the state that the alternative final cover design has been placed in the facility's operating record, and placement of the alternative final cover design on the owner or operator's publicly accessible Internet site.

a. Final Cover System Design

EPA received comments supporting the proposed approach, while other commenters opposed the proposed final cover system design requirements. One state commenter generally supported using the part 258 final cover design requirements as a general model for CCR units. This commenter also requested that the Agency clarify whether new CCR units would be required to install a composite final cover system given that it was proposed that new CCR units would be required to designed and constructed with a composite bottom liner. Another state indicated that its state regulations allow final cover designs similar to that proposed by EPA, although the state requires a 24 inch infiltration layer and a 12 inch erosion layer. Another commenter referenced current research showing that soil-only covers may not be effective in minimizing infiltration over the long term under certain climates. This commenter recommended that a geomembrane should be made a standard component of the cover system. Other commenters stated that the final cover system should be a composite system consisting of a synthetic component and a low permeability clay component. A state commenter offered that post-closure maintenance of composite cap system incorporating a geomembrane has been challenging in that state. Another commenter stated that a compacted clay liner should not be used as a final cover for landfills due to the potential for settlement cracking, desiccation cracking, and root and animal penetration. Instead, it was suggested that if a single barrier system is used, then a benefit-cost analysis favors a geomembrane, and if a composite barrier is to be used, a benefit-cost analysis favors a composite system of a geomembrane and geosynthetic clay liner.

The Agency also received many comments on the proposed approach to allow the use of alternative final cover systems. Most commenters supported allowing the use of alternative covers. One commenter stated that the use of geosynthetic clay liners in lieu of 18 inches of earthen material for the infiltration layer is a commonly accepted for cover systems for MSWLFs. This commenter also noted that that geosynthetic clay liners have documented permeability characteristics on the order of 1×10^{-9} cm/sec. Another commenter supported allowing the use of alternative cover systems because a one-size-fits-all approach is not appropriate for final cover system designs. A state also offered that appropriately designed alternative final covers such as capillary barrier covers and evapotranspiration covers are being successfully used at facilities in the state.

After considering comments received regarding final covers, the Agency is essentially finalizing the approach in the proposed rule with minor revisions. The final rule allows owners or operators to use a final cover system consisting of an infiltration layer and an erosion layer, provided the infiltration layer has a permeability less than or equal to the bottom liner or natural subsoils. However, regardless of the bottom liner or natural subsoils present, the final cover must have a permeability no greater than 1×10^{-5} cm/sec.

To address the commenters' concerns that the final cover system may not function effectively as designed over the long term under certain circumstances, the rule also includes a performance standard that any final cover system must meet. This standard is modeled after the closure performance standard applicable to interim status hazardous waste units under § 265.111. The final rule requires that any final cover system control, minimize or eliminate, to the maximum extent practicable, post-closure infiltration of liquids into the waste and releases of leachate (in addition to CCR or contaminated run-off) to the ground or surface waters. Thus, a facility must ensure that in designing a final cover for a CCR unit they account for any condition that may cause the final cover system not to perform as designed. This could include accounting for site conditions that may increase the likelihood that a cover would be susceptible to desiccation cracking or settlement cracking. Under this performance standard, if the cover system results in liquids infiltration or releases of leachate from the CCR unit, the final cover would not be an appropriate cover. The final rule requires the final cover system design to be certified by a qualified professional engineer that the design meets both the performance standard and cover system criteria.

The final rule does not require the use of composite final covers, such as a geomembrane underlain by a compacted soil infiltration layer. This is also the

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case in situations for a CCR unit that is designed with a composite bottom liner or if the permeability of the soil underlying the unit is comparable to the permeability of a geomembrane. As EPA has concluded for municipal solid waste landfills, in certain site-specific situations it may be possible to construct an infiltration layer that achieves an equivalent reduction in infiltration without matching the permeability in the bottom liner material. 62 FR 40710.

Nonetheless, in certain locations, composite cover systems may be necessary to achieve the rule's performance standards. EPA acknowledges that under certain circumstances issues can arise with compacted clay barriers, particularly when used alone. These can include desiccation, freeze-thaw sensitivity, and distortion due to total and differential settlement of the underlying wastes. These issues can generally be addressed through proper maintenance of the cover system; and in fact the final rule requires as part of post-closure care that the owner or operator maintain the integrity and effectiveness of any final cover, including making repairs to the final cover to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover. Consequently, EPA is not mandating the installation of a composite liner system.

However, fewer problems are typically seen with the use of composite cover systems. And while ongoing oversight and proper maintenance is necessary to ensure the efficacy of any cover system, less effort is generally involved to ensure the continued performance of a composite cover system. EPA therefore generally recommends that facilities install a composite cover system, rather than a compacted clay barrier, as the composite system has often proven to be more effective (and cost effective) over the long term. For these reasons, EPA also anticipates that composite cover systems will be recommended in many circumstances by qualified professional engineers.

The final rule also allows the use of an alternative final cover. The rule requires that the alternative final cover must include infiltration and erosion layer that achieve equivalent performance as the minimum designs specified for final cover systems as discussed above. As discussed in the proposed rule, EPA included this provision to increase the flexibility for an owner or operator of a CCR unit to account for site-specific conditions. Moreover, these provisions will provide an opportunity to incorporate future technology improvements that would be missed if the rule required prescriptive design measures. In addition, these requirements would not supersede more stringent state requirements. Thus, if a state either has more prescriptive or more stringent standards in its state regulations applicable to CCR units, those state requirements would control any final cover system or alternative final cover system design.

While the rule provides the owner or operator flexibility in selecting the final cover for the unit, EPA remains concerned about the lack of guaranteed state oversight on final cover selection. A final cover system that does not perform as designed may result in unacceptable infiltration of water into the closed CCR unit that may lead to leachate and releases from the unit. To address this concern, as well as the concerns raised by commenters regarding the long-term performance of certain cover systems by providing further assurance that the final cover system will perform over the long term, EPA has deleted the proposed provision that would have allowed owners or operators to shorten the length of the post-closure care period. As discussed in Unit M.9 below, the final rule requires facilities to conduct post-closure care for all CCR units for 30 years.

b. Performance Standards When Leaving CCR in Place

EPA received no significant comments on the proposed performance standards. The Agency is therefore finalizing these requirements without revision from the proposal (although EPA has reorganized the final regulatory text for greater clarity). The performance standards are summarized below:

i. As discussed in the previous section, the CCR unit must be closed in a manner that will control, minimize or eliminate, to the maximum extent practicable, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters.

ii. The CCR unit must be closed in a manner that will preclude the probability of future impoundment of water, sediment, or slurry.

iii. The CCR unit must be closed in a manner that will provide for major slope stability, which is discussed is Unit M.1 of this document for closure plans above.

iv. The CCR unit must be closed in a manner that will minimize the need for further maintenance of the unit.

v. The CCR unit must be closed in the shortest amount of time consistent with recognized and generally accepted good engineering practices. The Agency added this performance standard to be consistent with the final provisions applicable for the timeframes for initiating and completing the closure of CCR units.

4. Timeframes for Closure

The Agency proposed that closure of a CCR landfill or CCR surface impoundment must be initiated by the owner or operator no later than 30 days following the known final receipt of CCR. To address concerns about ''inactive'' or abandoned units, the proposed rule also provided that a CCR unit must initiate closure no later than one year after the most recent receipt of CCR if the CCR unit had remaining capacity and there was a reasonable likelihood that the CCR unit would receive additional CCR (*i.e.,* the rule would have forced the facility to close the CCR unit). See 77 FR at 35209 and proposed § 257.100(j). In addition, the proposed rule would have required an owner or operator to complete closure activities within 180 days of initiating closure. See proposed § 257.100(k). Thus, the maximum amount of time a facility would have had to initiate and complete closure of a CCR unit was seven months.

While the existing closure criteria for MSWLFs allow the Director of an approved State to grant time extensions for closure (both to initiate and to complete closure) if steps are taken to prevent threats to human health and the environment from the unclosed unit, EPA proposed not to include similar provisions for owners or operators of CCR units. At proposal, the Agency believed that extending the closure deadlines was inappropriate because, in the absence of an approved state program, the owner or operator could unilaterally decide to extend the time for closure of a CCR unit, without any basis, or oversight by a regulatory authority. 75 FR 35209.

EPA received numerous comments in response to the proposed deadlines under the subtitle D proposed approach. Industry and state commenters stated that the proposed deadlines to begin and complete closure activities (30 and 180 days, respectively) are technically impracticable and simply too short for the vast majority of CCR units, especially for CCR surface impoundments to complete closure. Commenters stated that a 30-day deadline to initiate closure activities may not be workable in situations such as when there are construction

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limitations due to seasonal or climatic conditions, and should not be required in circumstances when a coal-fired generating unit is temporarily idled (*e.g.,* maintenance related outages or an outage corresponding with a CCR handling system conversion). Regarding the amount of time needed to close a unit, numerous commenters noted that it would be impossible to properly complete closure activities within the proposed 180 days at most CCR surface impoundments due to the length of time needed to dewater an impoundment and stabilize the wastes prior to constructing the final cover system. For example, commenters pointed out that dewatering of a surface impoundment alone can take several years to complete because impoundments can be hundreds of acres in size. One commenter provided information related to an ongoing CCR surface impoundment closure where the dewatering and ash stabilizing phases of closure took two years to complete. Commenters also stated that because a large number of CCR units will have to be closed during roughly the same timeframe, facilities may not be able to obtain the necessary specialized personnel, equipment, and materials (*e.g.,* clay or fill material, liner materials) to close multiple units simultaneously. This issue may be further complicated in locations where multiple facilities are competing for the same limited resources. Commenters further argued that adopting the same closure deadlines applicable to MSWLFs is not appropriate given differences in size, design, and operation (*e.g.,* CCR surface impoundments contain large volumes of water, MSWLFs typically close each component cell when it reaches its disposal capacity). As a result of these concerns, commenters recommended that EPA extend the deadlines both to commence and complete closure activities. The majority of the these commenters, however, urged EPA not to establish specific deadlines for closure and instead require facilities to close a CCR unit consistent with a closure plan approved by a state, or developed and certified by a qualified professional, such as a professional engineer.

In a subsequent NODA, the Agency solicited additional public comment on several different options to address these concerns. 78 FR at 46944–46. With respect to the deadline to initiate closure, EPA presented several examples of routine and legitimate circumstances in which CCR units would not receive CCR for periods longer than one year, even though the facility intended to continue to use the unit. For example, EPA discussed circumstances in which the facility alternates between two surface impoundments, only one of which is operational at a time. Once the impoundment has reached capacity, the facility dewaters the unit, and begins to send CCR to the second impoundment. Once the unit is dewatered, the CCR is excavated and disposed in an adjacent landfill. The time to fill these units has varied over the years as demand has fluctuated, but a typical time to fill a unit with CCR is two years, perhaps longer, during which the other unit is ''idle,'' in that it does not ''receive CCR,'' but it remains operational.

The Agency also solicited comment on a revised approach to the deadline to initiate closure. The approach entailed establishing a rebuttable presumption that if the CCR unit has not received waste within a particular period of time (*e.g.,* 18–24 months), the CCR unit would be considered inactive and unit closure would be required to begin within a specified time. However, if the facility could substantiate that there was a reasonable likelihood that the CCR unit would again receive CCR in the future and also was able to document certain findings, the owner or operator would not need to immediately commence closure of the CCR unit. In the NODA, EPA discussed several examples of situations that could support a demonstration that immediate closure of the CCR unit was not necessary. One example was if an owner or operator could document that a CCR unit had been dedicated to a temporarily idled coal-fired generating unit and there was a reasonable likelihood that CCRs would be disposed in the CCR unit once the coal-fired generating unit resumed operation. Another situation presented was a CCR unit dedicated to a coal-fired generating unit that was not burning coal at the time (*e.g.,* electricity was being generated with other fuels such as natural gas), but the facility needed the CCR unit following resumption of coal burning. A final example involved normal facility operations that include periods during which the CCR unit does not receive CCR for extended periods (*e.g.,* the alternating use of two CCR surface impoundments discussed above). As part of this approach, the Agency solicited comment on whether to limit the length of time an owner or operator can maintain an idle CCR unit.

With respect to the deadline for completing closure, EPA acknowledged in the NODA that different deadlines, at least for the larger CCR units, were warranted. Information that the Agency has obtained throughout the rulemaking confirmed commenters' claims that the timeframes originally proposed to complete closure of CCR surface impoundments will be practicably infeasible for the larger impoundments. However, the Agency cautioned that any ultimate timeframe provided in the rule that would be practicable for the largest CCR units would be far too long to justify as timeframes for closure of the smaller impoundments. EPA explained that it intended to examine available closure plans for CCR surface impoundments to determine whether there are consistent timeframes or other factors that EPA could adopt as part of the regulations. EPA specifically identified two closure plans of CCR units that were scheduled to close as a possible source of useful information. These plans projected that closure would take multiple years to complete for modestly-sized CCR surface impoundments (*i.e.,* less than 50 acres).

a. Deadlines To Initiate Closure

In response to the NODA, most utility commenters stated that the time to initiate closure should be tied to reasonable triggers that account for the diverse uses of CCR surface impoundments and CCR landfills. In particular, these commenters recommended that closure not be initiated for an idled CCR unit if the CCR unit was expected to receive additional waste in the future, whether CCR or any other waste the unit may be authorized to manage. These commenters also supported the scenarios EPA described in the NODA as examples of legitimate situations that could warrant delaying the immediate closure of a CCR unit. Many of these commenters generally agreed that the rebuttable presumption alternative discussed in the NODA could be an appropriate approach for closure, in particular for CCR units not covered by a state-approved operating plan, provided the regulatory approach would be implemented in a manner that did not restrict other legitimate uses of the CCR unit. Many of these commenters also asserted that a limit on the length of time a CCR unit can remain idle is not practical because the owner or operator will not be able to predict with any degree of certainty how long a CCR unit will be idled. Several of these commenters also urged EPA to specify in the final rule what EPA intended by the phrase ''initiation of closure;'' that is, that EPA define the activities or actions the owner or operator must take by the deadlines specified in the rule.

A trade organization and other commenters warned that strict restraints on the initiation (and completion) of

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closure of CCR units would pre-empt opportunities for reclaiming CCR from these CCR units for beneficial use of CCR. These commenters recommended that the final rule create meaningful incentives for the beneficial use of CCR already in CCR units which will become unavailable to reclamation once a final cover system is put in place. For example, one commenter suggested that an incentive could be deferring deadlines for closure of a CCR unit if an owner or operator reduces its net tonnage by a set amount, such as 10,000 tons per year, if the CCR is beneficially used. EPA also received comments from several states that generally supported the rebuttable presumption concept. One state supported a longer rebuttable presumption time period of three years that could be extended if approved by the state on a case-by-case basis.

After consideration of all of the public comments, the Agency is adopting an approach that largely mirrors the approach outlined in the NODA. Closure of a CCR unit is triggered in one of three ways. The first is upon the known final receipt of waste (CCR or otherwise), or when an owner or operator removes the known final volume of CCR from the CCR unit for the purpose of beneficial use of CCR. Under these scenarios, the final rule requires an owner or operator to commence closure of the CCR unit within 30 days of such known final receipt or known final volume removal, whichever date is later.

The second way closure can be triggered relates to ''idled'' CCR units. This applies to situations in which the CCR unit has remaining disposal, treatment, or storage capacity, or there has been a temporary pause in the removal activities of CCR from the CCR unit. In these situations, the rule establishes a presumption that the owner or operator must initiate closure of the CCR unit no later than two years after the most recent receipt of CCR or any non-CCR waste stream, or no later than two years after the most recent date that CCR was removed from the CCR unit for the purpose of beneficial use, whichever date is later. The rule, however, provides procedures for an owner or operator of the CCR unit to rebut this presumption and obtain additional time, provided the owner or operator can make the prescribed demonstrations.

The final way closure is triggered is when a CCR unit fails to meet certain of the technical criteria. Specifically, an owner or operator may be compelled to close a CCR unit in the following circumstances: (1) If the CCR unit has been sited inappropriately; *i.e.,* cannot meet the applicable location criteria; (2) if an unlined CCR surface impoundment is found to contaminate groundwater in excess of a groundwater protection standard; or (3) if a CCR surface impoundment cannot demonstrate the minimum factors of safety regarding structural integrity of the CCR unit. When closure is triggered under these circumstances, the owner or operator must initiate closure of the CCR unit within six months. Each of these is discussed in more detail below.

i. ''Known Final Receipt'' of CCR

Several commenters suggested that the rule not link the deadlines to initiate closure solely to when a CCR unit ceases to receive CCR. Many of these commenters provided information that CCR units also serve functions other than managing CCR, including the management of other wastes or water treatment. Thus, while there are periods of time that certain CCR units will receive both CCR and non-CCR wastes, there are also other times when the same CCR unit will only receive non-CCR wastes or perform other forms of active waste management in the unit, *e.g.,* specific water treatment functions. EPA agrees that these are legitimate waste management activities, and EPA is aware of no risks that would warrant cessation of such activities simply because the unit is no longer receiving CCR. Therefore, in response to these comments, the final rule no longer requires closure based solely upon the receipt of CCR. Instead, the final rule requires closure to be initiated after the CCR unit ceases to receive any waste or waste stream into the CCR unit. See § 257.102(e)(1) and (e)(2) in the rule.

The Agency also agrees with those commenters that supported delaying the commencement of closure of a CCR unit if substantial quantities of CCR are removed from the CCR unit for the beneficial use of the waste. This could include, for example, removal of CCR from a CCR unit followed by its use as a partial replacement for Portland cement. As discussed in Unit IV.B of this preamble, EPA has identified significant benefits from reducing the disposal volumes of CCR in CCR landfills and CCR surface impoundments, including reduced risks associated with the practice of CCR disposal, benefits from reducing the need to mine and process virgin materials, and energy and greenhouse gas benefits. EPA finds these potential benefits compelling and is therefore revising the closure requirements in the rule to accommodate the removal and beneficial use of CCR. EPA has therefore revised the rule to provide that closure of an otherwise idled CCR unit is not immediately triggered, as long as the owner or operator is removing substantial quantities of CCR from the unit. However, once removal of CCR for beneficial use is no longer taking place, the rule would require the owner or operator to initiate closure of the CCR unit. See § 257.102(e)(1) and (e)(2) in the rule.

After considering comments received regarding the specific timeframe by which closure must be initiated following known final receipt of wastes, the Agency is finalizing the 30 day timeframe from the proposed rule. Several commenters expressed concern that 30 days is too short because it does not account for the potential that weather or seasonal concerns may interfere or cause substantial delay. The Agency acknowledges that weather or seasonal effects can delay certain activities, but disagrees that the rule provision needs to be revised to account for those. This provision does not require that specific actions or activities must be initiated during this 30-day period. For example, the rule does not require the installation of the final cover system (or the commencement of removal of CCR from the CCR unit) necessarily begin within this 30-day period. Instead, the provision is more flexible; the owner or operator can initiate closure by taking other actions necessary to implement the closure plan that are not weather or seasonal dependent, such as turning off pumps supporting sluice lines or taking any steps necessary to comply with any state or other agency standards that are a prerequisite to initiating closure. Provided the owner or operator has started to take the measures to implement the closure plan that can be feasibly undertaken, the facility will have complied with this requirement.

The 30-day period remains equally appropriate under the wider provision that allows closure to be triggered either by the known final receipt of all wastes in the unit, or upon the known final volume removal of CCR for beneficial use of CCR. There are no facts unique to these circumstances that would necessitate an extension beyond the 30 day timeframe. Furthermore, as the terms ''known final receipt'' and ''known final volume removal'' suggest, the owner or operator has made the determination to cease managing waste in the CCR unit, or to cease removing CCR from the CCR unit for beneficial use purposes. This will likely occur in situations where the CCR unit is reaching its disposal capacity (or treatment capacity when the CCR unit is receiving non-CCR waste streams) or the

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owner or operator intends to close the CCR unit for other purposes (*e.g.,* the closing of a CCR surface impoundment following conversion to dry handling of CCR). Given that these situations can generally be anticipated and planned for in advance, EPA is not aware of circumstances that would prevent owners or operators from at least commencing closure within this 30-day period. In summary, the owner or operator must commence closure of the CCR unit with 30 days of known final receipt of CCR or any non-CCR waste stream, or within 30 days of known final removal of CCR for beneficial use, whichever date is later.

ii. Temporarily Idled Units

This situation involves CCR units with remaining CCR disposal or storage capacity (or treatment capacity for non-CCR waste streams) that may sit idle for extended periods of time (*e.g.,* potentially years at a time); however, the owner or operator intends to continue to maintain the idled unit to receive CCR or non-CCR waste streams in the future. EPA proposed that these CCR units could remain idle for up to one year, but that closure of the CCR unit would have to be initiated no later than one year after the most recent receipt of CCRs. See 75 FR 35252 (proposed § 257.100(j)). The majority of commenters claimed that one year was too short and would require the premature closure of CCR units that would be needed in the future. In response to these comments and new information documenting examples of legitimate circumstances in which CCR units were idled for more than one year, EPA solicited comment on a revised approach to establish longer timeframes to initiate closure for temporarily idled CCR units. As discussed previously, this approach entailed establishing a rebuttable presumption that if the CCR unit has not received waste within a specified period of time (*i.e.,* 18 months to two years), the CCR unit would be considered inactive and closure of the CCR unit would be required. However, this time could be extended beyond the 18 months or two years if the facility could substantiate certain findings. See 78 FR at 46945.

After considering comments received, the Agency is essentially finalizing the approach presented in the 2013 NODA. Specifically, in situations where the CCR unit has remaining disposal or storage capacity (or treatment capacity for non-CCR wastestreams) and there is a reasonable likelihood that the CCR unit will receive additional CCR or non-CCR waste in the future, the final rule allows the owner or operator to keep the CCR unit available for use for up to two years. However, if the CCR unit has not received CCR or any non-CCR waste within two years of the last receipt of CCR or any non-CCR waste, whichever date is later, the rule requires closure of the CCR unit unless the owner or operator can document that additional time is necessary to accommodate routine operations and legitimate waste management activities.

The Agency agrees that it is not necessary to require closure of temporarily idled CCR units after one year. Information in the record documents numerous examples of legitimate circumstances in which CCR units were idled for more than one year. In most of the examples provided CCR units are temporarily idled for periods that can last more than one year, but typically use of the CCR units resumes within approximately two years. Based on this information EPA has concluded that a two year timeframe before presumptively requiring closure of a CCR unit would be more consistent with current practice, and is better supported by the available information.

This same information documented that there can be situations in which a CCR unit is idled for longer periods of time (*e.g.,* a coal-fired boiler may be idled for years during which another fossil fuel is burned (*e.g.,* natural gas), and the CCR unit will be needed when the utility returns to coal burning. In order to obtain additional time beyond two years, the owner or operator must document in writing both that the CCR unit has remaining disposal or storage capacity and the facts that support a conclusion that there is a reasonable likelihood that the CCR unit will accept CCR or non-CCR waste in the foreseeable future. The facility would need to substantiate those findings, including the specific reasons the owner or operator believes ''that there is a reasonable likelihood that CCR will be disposed in the waste disposal unit.'' These findings would need to be certified by the owner or operator of the CCR unit.

The rule identifies examples of specific scenarios that would support a determination that there is a continuing need for the unit to support future waste management activities (*e.g.,* that the CCR will resume receiving CCR or non-CCR waste in the future). These are intended to be illustrative rather than an exclusive list; there may well be additional circumstances in which routine operations or legitimate waste management practices would support the necessary determination. The particular situations identified in the rule generally match those discussed in the NODA or reflect situations identified in public comments. Specifically, the rule identifies four particular circumstances: (1) Normal plant operations include periods during which the CCR unit does not receive wastes (CCR or non-CCR waste streams). This may include the alternating use between one CCR unit that receives CCR while dewatering or removing CCR from a second unit. (2) The CCR unit is dedicated to a coal-fired boiler unit that is temporarily idled (*i.e.,* CCR is not being generated) and there is a reasonable likelihood that the coal-fired boiler will resume operations in the future. (3) The CCR unit is dedicated to an operating coal-fired boiler (*i.e.,* CCR is being generated); however, no CCR is being placed in the CCR unit because the CCR is being entirely diverted to beneficial uses, but there is a reasonable likelihood that the CCR unit will again be used in the foreseeable future. (4) The CCR unit currently receives only non-CCR waste streams and those non-CCR waste streams are not generated for an extended period of time, but there is a reasonable likelihood that the CCR unit will again receive non-CCR waste streams in the future. As noted, a facility must substantiate these findings; it is not sufficient to merely repeat the words of the regulation and conclude that additional time is warranted.

The final rule allows an owner or operator to obtain additional two-year time extensions for as long as the owner or operator continues to be able to provide a factual basis to justify the need for additional time via a written demonstration. Because these idled units must continue to comply with all applicable technical requirements, including those for groundwater monitoring, corrective action, and structural stability, a fixed or definitive limit on the amount of time that a CCR unit can sit idle is not necessary.

In addition, the Agency agrees that the final rule should better define the actions or activities that constitute ''initiation of closure'' of a CCR unit. A clear definition will assist in the implementation and understanding of the rule. Commenters suggested a number of actions or activities, any one of which would be sufficient to show that closure of the CCR unit has been initiated. Examples provided by the commenters included the removal of CCR sluice lines; beginning the necessary permitting processes (*i.e.,* submitting a completed permit application); turning off pumps supporting the sluice lines; preparing a bid for contractors; or procuring capping materials such as clay or top soil.

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The final rule specifies that closure has been initiated when the owner or operator takes two actions. The first action is that the owner or operator must have permanently ceased placing CCR and non-CCR waste streams in the CCR unit. As suggested by commenters, permanent removal of CCR sluice lines or inactivation of the pumping system supporting the sluicing operation would be evidence that placement of CCR and non-CCR waste streams has ceased. The second action is that the owner or operator must have taken steps to implement the written closure plan required by the rule. This second action would include submitting a completed application for any required state or agency permit or permit modification in order to implement closure of the CCR unit, or taking any steps necessary to comply with any state or other agency standards or regulations that are a prerequisite to initiating or completing the closure of the CCR unit. Once the owner or operator has completed both of these actions, closure of the CCR unit has been initiated for purposes of this rule. See § 257.102(e)(3) in this rule.

iii. Closure for Cause

Finally, the Agency is clarifying that the closure initiation timeframes specified above—the 30 day period for known final receipt or known final volume removal and the 2 year period for temporarily idled CCR units—do not apply to closures initiated for cause. As discussed elsewhere in the preamble, the final rule requires certain CCR surface impoundments and CCR landfills to close. The situations include: Unlined CCR surface impoundments whose groundwater monitoring shows an exceedance of a groundwater protection standard; existing CCR surface impoundments that do not comply with the location criteria; CCR surface impoundments that are not designed and operated to achieve minimum safety factors; and existing CCR landfills that do not comply with the location criteria for unstable areas. In these situations, the final rule specifies that the owner or operator must initiate closure activities within six months of making the relevant determination that the CCR unit must close.

b. Deadlines To Complete Closure

In response to the August 2013 NODA, many utility commenters stated that the time period to complete closure must be sufficiently flexible to account for the inherent uncertainties in predicting a closure schedule. These commenters pointed to potentially innumerable complications and circumstances beyond the control of the owner or operator that render it nearly impossible to predict with precision when the closure of a CCR unit will be completed. These commenters also believe it is impractical and unrealistic for the rule to subject the closure of CCR units to any type of fixed regulatory structure. They maintained their position from the proposed rule that it would be impossible to properly complete closure of most CCR surface impoundments within 180 days. Their recommendation is to allow closure timeframes to be governed by the a state-approved closure process, which would include the owner or operator developing and submitting a closure plan to the state and mechanisms for the state to verify and enforce compliance with all closure requirements, including the closure plan. Under this approach, the owner or operator's compliance with the requirements of the state-approved closure process (including following the closure plan, completing mitigation, etc.) would represent compliance with this rule's closure requirements. For CCR units not subject to a state-approved closure process, these commenters recommended that the owner or operator should demonstrate compliance with the CCR closure requirements by submitting a closure plan to the state that is certified by an independent professional engineer. In this case, because there is not direct state oversight and administration of the closure process, the timelines in the closure plan could be subject to a modified set of tiered timeframes for completing closure, provided owners or operators could demonstrate that more time is needed to close the unit on a case-by-case basis.[122] These commenters also opposed any closure approach with firm and inflexible timeframes because no single factor (*e.g.,* the acreage of the CCR unit or the volume of CCR in the unit) is determinative in all instances of how long it will take to complete closure of the CCR unit. Commenters also cautioned that pre-closure closure plans (and the closure schedules contained therein) may not be an actual reflection of the time it will take to close the unit due to unforeseen or variable conditions. Finally, these commenters also generally opposed the idea discussed in the NODA of petitioning the Agency for a site-specific rule to vary from a generally applicable deadline.

Many commenters described the numerous factors that could affect timeframes for closure of a CCR unit. Most comments were specific to CCR surface impoundments where closures are typically more complex as compared to CCR landfills due to the presence of water in impoundments. Factors most often cited by the commenters that may affect the time required to close a CCR unit included: (1) The size and volume of CCR in the unit; (2) the geotechnical characteristics of the CCR; (3) the type or design of the surface impoundment (*i.e.,* diked, incised, valley fill, and side hill); (4) the need to coordinate or obtain approvals from state permitting officials; (5) the availability of qualified engineers, contractors, and materials since closing a CCR unit is a specialized activity, especially given that many units may be required to close simultaneously; (6) climate and weather that can affect dewatering operations and the length of a construction season; (7) the time needed to obtain replacement disposal capacity for a closing unit that would ensure ongoing facility operations; and (8) dam safety considerations during closure. Many of commenters identified that the dewatering process (an early necessary step in the closure process) as being a site-specific issue, as the time that will be needed to dewater an impoundment can vary considerably depending on the type of CCR unit, the volume of CCR in unit, and the geotechnical properties of the CCR. Several commenters also cited that closure times for some CCR units will require substantial volumes of fill material to properly grade a closing surface impoundment to facilitate positive drainage from the closed unit. These commenters provided estimates on the volumes of fill material needed and showed that the earthmoving aspect of this step alone can take many years to complete in some cases.

Several state commenters generally supported the tiered closure alternative discussed in the NODA. However, these commenters urged EPA to include provisions in the rule to provide flexibility for closing units to demonstrate the need for additional time on a case-by-case basis.

i. Timeframes for Completing Closure

In the August 2013 NODA the Agency solicited comment on ways to establish categories of timeframes that would adequately account for the various factors that can affect the amount of

[122] The tiered timeframes for completing closure could be based on the size of the CCR unit (after obtaining necessary state and local approvals): (1) Within 3 years for an impoundment with an area less than 20 acres; (2) Within five years for an impoundment between 20 and 50 acres; (3) Within 8 years for an impoundment between 50 and 75 acres; (4) Within 10 years for an impoundment with an area of 75 acres or more; and (5) Within 180 days for a landfill. Under this approach, the owner or operator could demonstrate the need for additional time to close the CCR unit.

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time needed to properly close a CCR surface impoundment. One approach discussed in the NODA was called the ''tiered approach'' that was based on comments received in response to the proposed rule. Under that approach, the final rule would establish fixed timeframes to complete closure that varied depending on the size of the impoundment (*i.e.,* surface area acreage). The Agency stated in the NODA that the concept of a tiered approach was appealing; however, the precise basis for the distinctions (*i.e.,* unit size cutoffs) and timeframes were not clear. EPA further explained its concern that factors other than size (*e.g.,* climate, geography, unit configuration) would also appear to be relevant, and that any timeframes should account for those other factors. EPA encouraged commenters interested in supporting a tiered approach to provide the rationale and data to support any suggested categories of timeframes. 78 FR 46946. Most commenters opposed the tiered approach by itself (*i.e.,* an approach without an accompanying process by which an owner or operator could obtain additional time due to site-specific circumstances) because they felt there simply are too many factors that can affect closure timeframes. These commenters concluded that basing closure timeframes on a subset of factors would not be appropriate. As one commenter noted, a 20 acre impoundment 10 feet deep can likely be dewatered and closed more quickly than a 20 acre impoundment 30 feet deep.

After considering comments and information available on closure timeframes, EPA has concluded that there are insufficient data and information to adopt the kind of tiered approach discussed in the NODA. EPA is convinced that the available information does not support an approach that would establish fixed and definitive timeframes for closure, based on a select subset of factors that distinguish between surface impoundments (*e.g.,* a 50 acre diked impoundment holding 500 acre-feet of CCR with a hydraulic conductivity of 1×10^{-5} centimeters per second located in a state in the southwest with a permitting program would be required to close in four and one-half years, while a 50 acre cross valley impoundment holding 1,500 acre-feet of CCR with a hydraulic conductivity of 1×10^{-6} centimeters per second located in a state in the upper midwest with a permitting program would be required to close in seven years, etc.). While information is available for surface impoundments on certain factors, such as the size and type of the unit and geographic information, the Agency has little to no data for a number of other key factors. For example, EPA has no information on the geotechnical properties of the CCR that can affect the time needed to dewater a unit, the volumes of clays, soils, and other materials that will be needed for closure, and information on the time needed to obtain state approvals (in accordance with state CCR programs) related to closure of a unit.

In discussing the tiered approach EPA noted that commenters had suggested that the largest CCR surface impoundments (*i.e.,* those having a surface area greater than 75 acres) should be subject to a site-specific deadline to complete closure. In the NODA, the Agency explained that a site-specific deadline may not be practicable unless the rule were to establish a ''variance'' process as part of the rule. 78 FR 46946. Under a variance approach, EPA would establish a specific deadline (*e.g.,* closure must be completed no later than five years from the date closure activities are initiated), but would allow facilities to petition EPA for a site-specific rule to establish an alternate deadline. In response to the NODA, some commenters expressed interest in such an approach, but other commenters found the approach not practicable since each owner or operator would need to petition the Agency for a site-specific rule. Some commenters believed that a site-specific rule process, which would necessarily involve a notice and comment process, would be an unwieldy process leading to unnecessary delays. The Agency agrees that this is also not a practical alternative to establish timeframes to complete closure.

Recognizing the numerous factors that can affect the amount of time needed to close an impoundment, many commenters suggested EPA not establish any type of fixed regulatory deadline for closure. Instead, these commenters recommended that the rule allow closure timeframes to be governed by a state-approved closure process. Under this process suggested by commenters, an adequate state-approved closure process would include one where the owner or operator developing and submitting a closure plan to the state and mechanisms for the state to verify and enforce compliance with all closure requirements, including the closure plan. Under the commenter's recommendation, compliance with the requirements of the state-approved closure process would not be compliance with the closure requirements of this rule. As discussed elsewhere in this preamble, under subtitle D of RCRA, the Agency cannot rely on the existence of a state permitting authority to implement the subtitle D requirements.

Some other commenters suggested EPA not establish any type of fixed regulatory deadline for closure in the rule, and instead rely on the closure plan developed and certified by a professional engineer. The Agency disagrees that this approach would meet the protectiveness standard of RCRA section 4004(a). CCR units present significant risks, and it is critical that facilities complete closure expeditiously—particularly those that are closing because they are structurally unsound or are contaminating groundwater. To be able to determine that the rule will be protective, the final rule must limit the discretion of individual facilities, many of whom may have significant incentives for delay, and avoid the potential for abuse. Moreover, in contrast to corrective action, where EPA was truly unable to establish an outer limit on the necessary timeframes—including even a presumptive outer bound—closures, while complex, do not vary to the same degree as site remediation actions. Consequently, as discussed later in this section, the available data were sufficient to support the establishment of definitive timeframes.

Most commenters, however, were generally supportive of an approach that would establish timeframes for closure, whether in a tiered-like approach (*i.e.,* timeframes for closure based on one or more characteristics of the unit) or under a ''rebuttable presumption'' approach, so long as the rule would provide the owner or operator a process or procedures to demonstrate the need for additional time. As explained in the NODA, such an approach could be implemented by establishing a presumption that facilities complete closure within a specified timeframe, such as five years, unless the facility could document that closure is not feasible to complete within the presumptive timeframe.

After consideration of all of the public comments, EPA is adopting an approach that takes elements from two of the alternatives discussed in the NODA: The concept of tiered timeframes based primarily on the size of the surface impoundment, and the concept of a rebuttable presumption. The final rule establishes a presumption that the owner or operator must complete the closure of a CCR surface impoundment within five years of initiating closure activities. For CCR landfills the presumption is that the owner or

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operator must complete closure within six months of initiating closure activities. The rule, however, provides procedures for an owner or operator to rebut either presumption and obtain additional time, provided the owner or operator can make the prescribed demonstrations. For CCR surface impoundments, the amount of additional time beyond the five years varies based on the size (using surface area acreage of the CCR unit as the surrogate of size) of the unit. For impoundments 40 acres or smaller, the maximum time extension is two years. For impoundments greater than 40 acres, the maximum time extension is five two-year extensions (ten years) and the owner or operator must substantiate the factual circumstances demonstrating the need for each two year extension. For a CCR landfill, the amount of additional time beyond the six months does not vary according to the size of the landfill, rather the maximum time extension is two one-year extensions (two years) for any CCR landfill. The owner or operator must substantiate the factual circumstances demonstrating the need for each one-year extension.

ii. CCR Surface Impoundment Timeframes

To develop these timeframes the Agency began by identifying the period of time in which most surface impoundments could feasibly complete closure. EPA intended this period of time to serve as the basis for the rebuttable presumption of the rule. As EPA recognized in the NODA, a timeframe that would be feasible for the largest units would grant more time than could be justified to complete the closure of smaller units. The closure of CCR units, and particularly the closure of CCR units that are compelled to close because they fail to comply with the rule's requirements (*e.g.,* are structurally unstable or are contaminating groundwater), needs to occur as expeditiously as is feasible. While these units (and particularly the larger CCR surface impoundments) are in the process of closing, they continue to present risks to human health and the environment. On the other hand a presumptive time period that is feasible for a small percentage of units would simply result in a greater number of facilities that would need to obtain time extensions. It is well established that the law cannot compel actions that are physically impossible, ''*lex non cogit ad impossibilia,*'' and it is incumbent on EPA to develop a regulation that does not in essence establish such a standard.

The available information shows that CCR surface impoundments can vary in size by orders of magnitude (*i.e.,* from less than one acre to nearly 1,000 acres). EPA evaluated the information on the size distribution of CCR surface impoundments in its database of survey results from EPA's 2009 Information Request.[123] Through this effort, EPA received a substantial amount of factual information from 240 facilities covering 676 surface impoundments, including surface area information on over 650 impoundments. The database of survey responses shows that the median surface impoundment is approximately 14 acres in size, 75 percent of impoundments are 50 acres or smaller, 80 percent of impoundments are 66 acres or smaller, and 90 percent of impoundments are 111 acres or smaller.

Available information on actual and projected timeframes needed to close CCR surface impoundments of varying sizes (using surface area as the surrogate for size) is summarized below. Much of this information came from public comments from utilities. The largest CCR surface impoundment in this data set that has actually completed closure is a 40-acre unit that closed over a period of approximately five years (*i.e.,* the surface impoundment at PPL Corporation's Martins Creek Power Plant).[124] This facility closed with waste in place, and included installation of a final cover system. According to the facility, this CCR unit ceased receiving wastewater in January 2008, and the closure work began with dewatering the unit and preparing the revised closure plan and permit modification applications. Installation of the final cover, in addition to final soil grading and seeding of the unit was completed in spring 2012. By early 2013, all remaining closure actions were completed and state regulators issued final approvals in July 2013. EPA gave substantial weight to this information because (1) it was a CCR surface impoundment—the units of greatest relevance to the issue at hand; (2) the closure was recently completed, and so would accurately reflect current and available engineering practices; and (3) the facility actually completed closure of the unit. See EPA–HQ–RCRA–2012–0028–0103 and EPA–HQ–RCRA–2012–0028–0113.

As another example, American Electric Power (AEP) provided some information on the recent closure of a CCR surface impoundment in 2013. This 21-acre unit had been inactive for several years and was closed over the course of two construction seasons. The impoundment was closed by leaving CCR in place and installing a composite cap, in addition to the installation of hydraulic appurtenances to control the design storm events. See EPA–HQ–RCRA–2012–0028–0067.

Cleco Corporation provided planned closure timeframes contained in existing permits for its CCR surface impoundments. For three of its CCR surface impoundments, which in aggregate totaled 66 acres, Cleco Corporation estimated that it could take approximately one year to complete closure, which would be accomplished by leaving CCR in place and installing a final cover system. Cleco Corporation also estimated that it would take approximately nine months to complete closure of two additional CCR surface impoundments, with an aggregate acreage of 5.5 acres, by removing CCR from the CCR units, (*i.e.,* clean closure of the units). Information on the size of any of the five CCR units was not provided, which complicates the Agency's ability to assess the closure of any of the individual CCR units. In addition, the time period appears to begin when dewatering operations are initiated and the comments do not discuss how much time may be needed to obtain any necessary approvals from the state prior to commencing closure activities. See EPA–HQ–RCRA–2012–0028–0106.

Similarly, Xcel Energy stated in its comments to the NODA that it closed four CCR surface impoundments at its Northern States Power of Minnesota's Minnesota Valley Plant by removing all of their contents. See EPA–HQ–RCRA–2012–0028–0079. While the commenter did not provide any information on the time needed to close the four CCR units, other information available to the Agency indicated that closure took place sometime after May 2009 and was completed prior to September 2013. Based on information obtained from Xcel Energy in response to EPA's request for information from May 2009, the four CCR units at the Minnesota Valley Plant each have a surface area less than one acre. In addition, the response to the information request showed that one CCR surface impoundment was nearly full of ash, a second was more than half full, and the final two CCR units were less than one quarter full.

In the August 2013 NODA, the Agency solicited comment on a draft plan to close two CCR surface

[123] More information on EPA's Information Request, including a data base of survey responses, can be accessed at *http://www.epa.gov/epawaste/nonhaz/industrial/special/fossil/surveys/index.htm.*

[124] EPA included information on the planned closure of this CCR surface impoundment in the NODA. 78 FR 46945. The closure plan estimated that the closure process would take approximately three years to complete.

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impoundments at Santee Cooper's Grainger Generating Station in South Carolina. 78 FR 46945. The plan estimated that closure of the two CCR units, approximately 42 and 39 acres in surface area, could be accomplished during a three year period. This original estimate was based on closing the unit with waste in place and installing a final cover. However, Santee Cooper has since amended its draft plan and is now pursuing closure by removal of CCR and transport off-site for either disposal or beneficial use.[125] The revised draft envisions the complete removal of CCR from both CCR units and also one foot of underlying soil beneath the units. In total, the draft closure plan estimates that approximately 1.3 million cubic yards of CCR and underlying soil will be removed from both units—approximately 900,000 cubic yards from one unit and 400,000 cubic yards from the second—over a period of six to ten years.

The Florida Electric Power Coordinating Group (FCG) claimed that, based on FGC member experience, closing a 30 acre CCR surface impoundment is expected to take approximately two years to complete, but provided no additional information or details. See EPA–HQ–RCRA–2012–0028–0064.

The Utility Solid Waste Activities Group (USWAG) provided another projected closure schedule for a 20 acre CCR surface impoundment operated by Luminant. This facility was in the process of closing the unit when the comments were prepared. The schedule estimated that completion of all closure activities, would take approximately 45 months (3 years, 9 months) to complete. However, the commenter also states that, when complete, the ''full closure period will take approximately 84 months (seven years) due to the unique circumstances of that closure.'' No other information was provided on this closure to explain the ''unique circumstances'' that warrant such an extended period of time. See EPA–HQ–RCRA–2012–0028–0113.

There is other information in these data that indicates that larger impoundments may be able to complete closure within approximately the same timeframes as smaller units. For example, the data included the projected closure of a 100-acre CCR surface impoundment over a four and one-half year period, which seems to indicate that larger units may be able to close in approximately the same period of time. However, the Agency gave substantially less weight to this information for a number of reasons. Most critically, this information merely demonstrated projected timeframes for CCR surface impoundments, not actual timeframes that had been achieved. In addition, for some of these data, it was unclear whether the circumstances that allowed for completion within this timeframe were generally applicable to the majority of CCR surface impoundments. In one instance, the commenter noted that the time to complete closure was shorter than would normally be expected because the impoundment was being closed well before it reached full capacity and because water in the impoundment could be pumped into an adjacent impoundment. The commenter also noted that the impoundment had been built with a leachate collection system to facilitate dewatering at closure. See EPA–HQ–RCRA–2012–0028–0113.

Moreover, the majority of commenters claimed that it would take substantially longer than five years to close the largest impoundments. For example, USWAG stated that one of its members obtained ''approval for a closure plan for a 343-acre surface impoundment that provided for a twelve-year closure period to ensure adequate time to complete dewatering of the impoundment, assure the stability of the dewatered CCRs, and uniformly construct the slope of the final cover materials.'' No other information was provided on this closure example. See EPA–HQ–RCRA–2009–0640–10483. USWAG also provided information on the closure of the CCR surface impoundment at First Energy's Little Blue Run Disposal Area. This 950 acre surface impoundment, which is the largest CCR surface impoundment in the country, has a projected closure period of 15 years.

Similarly, to illustrate the time required simply for earthmoving operations to close a large CCR surface impoundment (in their example, 350 acres), Duke Energy Corporation estimated that the time needed in the schedule to deliver and place the necessary volume of materials for construction of the final cover and the sub-base to the cover system could take between nine and 12 years. This estimate is based on the need for approximately 10 to 11 million cubic yards of fill to construct and shape the sub-base of the final cover and the cover system itself that would require nearly 500,000 truckloads to deliver. See EPA–HQ–RCRA–2012–0028–0095.[126]

Collectively, this information formed the basis for the five year presumptive default. As noted the median size of CCR surface impoundments is approximately 14 acres, and 75 percent of impoundments are 50 acres or smaller. The information presented by the utilities documents that impoundments as large as 66 acres under normal circumstances can close within two to three years. EPA therefore expects that most, if not all, units should be able to complete closure within five years. For all but the very largest units, this timeframe would even accommodate potential delays caused by weather or any other unpredictable variables. This is clearly demonstrated by the examples presented by public comments, and by the recent example of the 40-acre CCR surface impoundment in Martins Creek that closed within five years.

EPA also notes that five years is the timeframe Congress mandated for the completion of open dumps to close or upgrade. While the closure times apply generally to all units—both those whose closure is mandated by this final rule and those that close because the facility decides to do so—the statutory directive provides further support for EPA's decision.

But as many commenters stated, initial estimates can and often do vary from actual closure times due to unforeseen or variable conditions. EPA acknowledges that a host of variables can, and frequently do, delay closure activities, such that the initial time estimates to complete closure of the unit are ultimately exceeded. For example, the 40 acre impoundment at Martins Creek Power Plant discussed above was initially scheduled in its closure plan to be completed within three years; however, closure ultimately took five years to complete. The additional two

[125] ''Amended Closure Plan Wastewater Ash Ponds, Grainger Generating Station, Conway, South Carolina,'' January 2014.

[126] EPA also received information from Consumers Energy Company on the closure of three former fly ash surface impoundments at the JR Whiting plant. These surface impoundments (combined) totaled approximately 52 acres and are scheduled to be closed with a final cover over an approximately 12-year period. The commenter claimed that the extended time for closure ''was necessary to allow dewatering and the filling of numerous voids, but principally to allow the generation of fly ash to allow the placement of structurally placed, low permeability ash to provide minimal required slopes for closure and to serve as the select layer for the flexible membrane liner.'' See EPA–HQ–RCRA–2012–0028–0068. Information on the individual size of any of the three CCR units was not provided in the comments, which complicates any assessment of the time needed to complete closure of any single CCR unit. Because the facility appears to be continuing to use the unit to actively manage waste, EPA does not consider this to be representative of a typical closure process.

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years was due to the need to obtain approval of a modified closure plan from the state, as well as modifications to three permits, in addition to obtaining other local planning approvals. Further time was also needed to accommodate the public notice and comment processes for several of the permits and approvals.

EPA recognizes that there are a number of unpredictable or variable conditions that can affect the time needed to close a CCR unit and that those conditions are not within the control of the owner or operator. For example, some states require review and approval of a closure plan prior to initiating of closure activities. See, for example, 25 Pa. Code sections 288.292(b) and 289.311(b) for CCR landfills and CCR surface impoundments, respectively. Another commenter noted that in Illinois, permits from several different authorities may need to be obtained to commence closure, including the Illinois Department of Natural Resources, the U.S. Army Corps of Engineers, and the U.S. Fish and Wildlife Services.

Climate and weather can also impact the time needed to complete closure. For example, an unusually wet or short construction season can result in schedule delays; one commenter noted that in certain regions of the Midwest, it is possible for as much as 40 inches of rain to fall in a given season.

To account for these conditions, a substantial majority of commenters requested that the final rule include the potential for time extensions, and several specifically referenced the need for a ''force majeure'' provision. One commenter also recommended that a ''force majeure'' clause specifically include delays caused by court order (*i.e.,* appeals of permits issued by state agencies causing judgments in court). Another commenter provided an example of a ''force majeure'' provision that could serve as a model:

> An extension shall be granted for any scheduled activity delayed by an event of force majeure which shall mean any event arising from causes beyond the control of the owner that causes a delay in or prevents the performance of any of the conditions under this rule including but not limited to: acts of God, fire, war, insurrection, civil disturbance, explosion; adverse weather conditions that could not be reasonably anticipated causing unusual delay in transportation and/or field work activities; restraint by court order or order of public authority; inability to obtain, after exercise of reasonable diligence and timely submittal of all applicable applications, any necessary authorizations, approvals, permits, or licenses due to action or inaction of any governmental agency or authority; and delays caused by compliance with applicable statutes or regulations governing contracting, procurement or acquisition procedures, despite the exercise of reasonable diligence by representatives of the owner.
>
> Events which are not force majeure include by example, but are not limited to, unanticipated or increased costs of performance, changed economic circumstances, normal precipitation events, or failure by the owner to exercise due diligence in obtaining governmental permits or performing any other requirement of this rule or any procedure necessary to provide performance pursuant to the provisions of this rule.

EPA agrees that the rule should include procedures to obtain extensions of time to complete closure of the unit, based on the complexity of the activity. As previously noted, the law, including a regulation, cannot compel the impossible. However, because the record demonstrates that most units, even the larger units, can close within that five year timeframe, the rule establishes a high threshold to obtain additional time. To account for those instances of true physical impossibility, the rule limits extensions to circumstances in which the owner or operator can demonstrate that the additional time is needed due to factors that are truly beyond the facility's control—*i.e.,* could fairly be characterized as an example of ''force majeure.'' To obtain additional time, the owner or operator of the CCR unit must document in writing the exact reasons why additional time is needed. The regulation specifies that such reasons could include: (1) Complications stemming from the climate and weather, such as unusual amounts of precipitation or a significantly shortened construction season; (2) the time required to dewater a surface impoundment due to the volume of CCR contained in the CCR unit or the geotechnical characteristics of the CCR in the unit; (3) the geology and terrain surrounding the CCR unit will affect the amount of material needed to close the CCR unit; or (4) the time required or delays caused by the need to obtain State permits and/or to comply with other State requirements. These findings would need to be certified by the owner or operator of the unit, as well as by a qualified professional engineer.

The final rule limits the amount of time that closure can be extended based on the size of the CCR unit. Specifically, the rule allows CCR surface impoundments 40 acres or smaller a time extension of up to two years, while CCR surface impoundments larger than 40 acres can obtain up to five two-year extensions. The 40 acre size demarcation is based on the available information showing that surface impoundments of 40 acres or smaller routinely have either completed closure or are projected to be able to complete closure within a timeframe shorter than five years. EPA expects that facilities will account for all potential delays that can reasonably be foreseen in planning their closure activities, and that this is feasible within this five year timeframe. Consequently the final rule restricts facilities with units of this size to a single extension to account for truly exception circumstances (*e.g.,* Acts of God).

The Agency also recognizes that there is increased uncertainty for CCR surface impoundments larger than 40 acres. First, while available information documents that some CCR surface impoundments larger than 40 acres can be closed within this same five year period, the Agency has other information indicating that closure of units larger than 40 acres can be expected to take much longer than five years. For example, the largest surface impoundment in the country is approximately 950 acres and is scheduled to cease receiving CCR by December 31, 2016 and commence closure in 2017. The facility's projected closure period is 15 years. However, EPA currently has no data (anecdotal or otherwise) on the actual timeframes in which a surface impoundment of that size has completed closure. Given that closure for the largest of surface impoundments could reasonably be expected to take more than five years to complete, the Agency has concluded that surface impoundments larger than 40 acres need to be provided with the possibility of additional time extensions beyond the two years provided to impoundments less than 40 acres. Based on available information, in particular the current estimates of the time needed to close the largest unit in the country, the rule authorizes a facility to obtain a maximum of five time extensions, totaling as much as ten years in two year increments to close a CCR surface impoundment greater than 40 acres. However, the owner or operator must substantiate the factual circumstances demonstrating the need for each two-year extension.

Several commenters also urged EPA to specify in the final rule what EPA intended by the phrase ''completion of closure;'' and to define the activities or actions the owner or operator must complete to satisfy the closure requirements. For purposes of this rule, closure of a CCR unit is complete when the unit meets all of the requirements of this rule and the owner or operator

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obtains certification from a qualified professional engineer verifying that closure has indeed been completed, consistent with all of the performance standards in the rule. While EPA recognizes that under some state programs closure is not considered complete until the owner or operator receives certification from the state, this is not a prerequisite to completion of closure under these federal rules.

iii. Closure Timeframes for CCR Landfills

Similar to the approach for CCR surface impoundments, EPA recognizes that there can be unforeseen and extraordinary circumstances that warrant additional time to close a CCR landfill. Accordingly, the rule adopts procedures analogous to those for CCR surface impoundments that allow the owner or operator to obtain additional time to complete the closure of a CCR landfill, provided the owner or operator can make the prescribed demonstrations. However, the amount of additional time the facility can obtain beyond the presumptive six month timeframe does not depend on the size of the landfill; rather the maximum time extension is two one-year extensions (two years) for any CCR landfill. As with the procedures for CCR surface impoundments, the owner or operator must substantiate the factual circumstances demonstrating the need for each one-year extension.

EPA developed this timeframe based on its review of the available information in the record regarding the timeframes for completing the closure of CCR landfills, some of which is summarized below. Additional information may also be found in the comment response document.

In response to the August 2013 NODA, Nebraska Public Power District (NPPD) provided information documenting that it completed closure of a 10 acre CCR landfill within 180 days after the final volume of fly ash and bottom ash was placed in the CCR landfill. Closure was accomplished by leaving CCR in place and installing a final cover system. NPPD's comments do not indicate what year closure of this CCR landfill was completed. See EPA–HQ–RCRA–2012–0028–0076.

The Florida Electric Power Coordinating Group (FCG) stated in its comments that FCG member experience with CCR landfill closure has ''demonstrated the need for a period of time greater than 180 days to complete closure activities.'' However, the commenter did not provide any information indicating how long such closures actually took, nor any information to substantiate their claim. See EPA–HQ–RCRA–2012–0028–0064.

Overall, the closure of CCR landfills is less complex than the closure of CCR surface impoundments. Portions of the CCR landfills that reach final grade can be closed as other areas of the CCR landfill continue to receive CCR, which is typically not possible at CCR surface impoundments. Nor does the owner or operator need to dewater the unit, which appears to be the aspect of closure most likely to be a source of unanticipated circumstances. Finally, there is substantially less uncertainty with respect to the timeframes to complete the closure of CCR landfills, which are not all that different (in this respect) than landfills containing other forms of solid or hazardous waste. EPA therefore has greater confidence that a fixed period of two years will be adequate to account for the vast majority of circumstances.

c. Alternative Closure Requirements

The Agency is finalizing alternative closure requirements in two narrow circumstances for a CCR landfill or CCR surface impoundment that would otherwise have to cease receiving CCR and close, consistent with the requirements of § 257.101(a), (b)(1), or (d). The first is where the owner or operator can certify that CCR must continue to be managed in that CCR unit due to the absence of both on-site and off-site alternative disposal capacity. § 257.103(a). The second is where the owner or operator of a facility certifies that the facility will cease operation of the coal-fired boilers no later than the dates specified in the rule, but lacks alternative disposal capacity in the interim. § 257.103(b). Under either of these alternatives, CCR units may continue to receive CCR under the specified conditions explained below. In addition, under either alternative, the owner or operator must continue to comply with all other requirements of the rule, including the requirement to conduct any necessary corrective action.

1. No alternative CCR disposal capacity (§ 257.103(a)).

The Agency recognizes that the circumstance may arise where a facility's only disposal capacity, both on-site and off-site, is in a CCR unit that has triggered the closure requirements in § 257.101(a), (b)(1), or (d). As a result, the facility may be faced with either violating the closure requirements in § 257.101 by continuing to place CCR in a unit that is required to close, or having to cease generating power at that facility because there is no place in which to dispose of the resulting waste. For example, while it is possible to transport dry ash off-site to alternate disposal facility that simply is not feasible for wet-generated CCR. Nor can facilities immediately convert to dry handling systems. As noted previously, the law cannot compel actions that are physically impossible, and it is incumbent on EPA to develop a regulation that does not in essence establish such a standard.

Should a facility choose to comply with the regulation and stop generating power, there would be significant risks to human health that would arise if a community would be left without power for an extended period of time. As information in the record demonstrates, obtaining alternative capacity can sometimes require a substantial amount of time (*e.g.,* if the facility needs to construct alternative capacity, including potentially the need to locate an alternative site or purchase additional property). EPA recognizes that there are also significant risks to human health and the environment, as demonstrated throughout this preamble, from a leaking or improperly sited CCR unit, and that these risks justify requiring those units to either retrofit to meet the federal criteria established in the final rule or close. EPA also acknowledges that in the interim period while the owner or operator seeks to obtain additional capacity, the risks associated with the continued use of these units will be significant. However, the Agency believes that the risks to the wider community from the disruption of power over the short-term outweigh the risks associated with the increased groundwater contamination from continued use of these units. This conclusion is further buttressed by the fact that during this interim period the risks associated with allowing these units to continue to receive CCR are mitigated by all of the other requirements of the rule with which the facility must continue to comply, including the requirements to continue groundwater monitoring and corrective action.

Under § 257.103(a)(1), a CCR unit that would otherwise be required to cease receiving CCR under § 257.101(a), (b)(1), or (d), may continue to receive CCR provided the owner or operator certifies that the CCR generated at that facility must continue to be managed in that unit due to the absence of alternative disposal capacity both on-site and off-site. The rule also requires the owner or operator to document this claim, and the claim must be based on the real absence of an alternative and not justified based on the costs or inconvenience of alternative disposal capacity. § 257.103(a)(1)(i). The owner

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or operator must also remain in compliance with all other requirements of this rule, including the requirement to take any necessary corrective action. § 257.103(a)(1)(ii). Because this alternative is only available as long as the absence of disposal capacity exists, the owner or operator must document its efforts to obtain additional capacity. If any additional capacity is identified, the owner or operator must arrange to use it as soon as is feasible. § 257.103(a)(1)(iii). The owner or operator is also required to prepare an annual progress report documenting the continued absence of disposal capacity and must also document the progress made toward developing alternative capacity. § 257.103(a)(1)(iv).

Once alternative disposal capacity is available, the CCR unit must cease receiving CCR and must initiate closure following the timeframes in § 257.102(e) and (f). Finally, if the owner or operator has not identified alternative capacity within five years after the initial certification the CCR unit subject to this section must cease receiving CCR and must initiate closure following the timeframes in § 257.102(e) and (f). As discussed elsewhere in this preamble, several commenters provided information to document the length of time needed to obtain additional capacity. Based on this information, the five year timeframe provided for under this alternative is expected to provide sufficient time to obtain alternative disposal capacity and to avoid the consequences of a forced immediate closure of a power plant.

2. Permanent cessation of a coal-fired boiler by a date certain. (§ 257.103(b)).

Under this provision, the Agency addresses the circumstance where a facility's only disposal capacity, both on-site and off-site, is in a CCR unit that has triggered the closure requirements in § 257.101(a), (b)(1), or (d), but the owner or operator of coal-fired power plant has decided to permanently cease operation of that plant within one of two timeframes specified in the regulation. For the same reasons discussed immediately above, EPA has concluded that the provisions of § 257.103(b) represent the most reasonable balance between the competing risks.

Additionally, EPA anticipates that some owners or operators will decide to permanently cease operation of a coal-fired power plant in response to the combined effects of new and/or existing statutory or regulatory requirements promulgated under the Clean Air Act and under the Clean Water Act (*e.g.* the proposed Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category. See 78 FR 34442, in combination with market dynamics. As discussed earlier in this preamble, RCRA section 1006(b) directs EPA to integrate the provisions of RCRA for purposes of administration and enforcement and to avoid duplication, to the maximum extent practicable, with the appropriate provisions of other EPA statutes, including the CAA and the CWA. As noted earlier, section 1006(b) conditions EPA's authority to reduce or eliminate RCRA requirements on the Agency's ability to demonstrate that the integration meets RCRA's protectiveness mandate (42 U.S.C. 6005(b)(1)). *See Chemical Waste Management* v. *EPA,* 976 F.2d 2, 23, 25 (D.C. Cir. 1992). The provisions of § 257.103(b) are fully consistent with the direction in section 1006(b) to account for the provisions of other EPA statutes which may lead an owner or operator to close a coal-fired power plant.

EPA has also concluded that the provisions of § 257.103(b) meet RCRA's protectiveness mandate. As stated above, EPA recognizes that there are long-term risks to human health and the environment, as demonstrated throughout this preamble, from a leaking CCR unit and those risks justify requiring those units to either meet the federal criteria established in this rule or close. However, the risks associated with allowing these units to continue to receive CCR are mitigated by the requirement that the facility must comply with all other requirements of the rule, including initiating groundwater monitoring and corrective action where necessary. And a critical factor is that facilities that choose to rely on this alternative will be required to *complete* closure of their disposal unit in an expedited timeframe. Thus, the risks from these units will be fully addressed sooner. Consequently, while over the short term the risks will be higher, overall, the risks will be at least equivalent to, or potentially lower than if the CCR unit had closed in accordance with the normal closure timeframes.

Under § 257.103(b)(1), a CCR unit that would otherwise be required to cease receiving CCR under § 257.101(a), (b)(1), or (d), may continue to receive CCR provided the owner or operator of the facility certifies that the facility will cease operation of the coal-fired boilers within the timeframes specified in paragraphs (b)(2) through (b)(4) and that the CCR generated at that facility (before the plant ceases to operate) must continue to be managed in that unit due to the absence of alternative disposal capacity both on-site and off-site. The rule also requires the owner or operator to document the facts that support this claim. The regulation specifies that the claim must be based on the real absence of alternative disposal capacity, and not justified based on the costs or inconvenience of alternative disposal capacity. § 257.103(b)(1)(i). The owner or operator must also remain in compliance with all other requirements of this rule, including the requirement to take any necessary corrective action. § 257.103(b)(1)(ii). The owner or operator is also required to prepare an annual progress report documenting the continued absence of disposal capacity and must also document the progress made toward the closing of the coal-fired boiler. § 257.103(b)(1)(iii).

Under § 257.103(b)(1), the owner or operator does not need to demonstrate any efforts to develop alternative capacity because of the impending closure of the power plant itself.

Consistent with the general timeframes provided for the closure of CCR surface impoundments, EPA has established different timeframes based on the size of the CCR unit. Under § 257.103(b)(2), where the disposal unit is a CCR surface impoundment 40 acres or smaller in size, the coal-fired boiler must cease operation and the disposal unit must have completed closure within 8.5 years of the publication date of the rule. Where the disposal unit is a CCR surface impoundment larger than 40 acres in size, the coal-fired boiler must cease operation and the disposal unit must have completed closure within 13.5 years of the publication date of the rule. § 257.103(b)(3). Finally, under § 257.103(b)(4), where the disposal unit is a CCR landfill, the coal-fired boiler must cease operation and the disposal unit must have completed closure within 6 years of the publication date of the rule. These timeframes were selected to ensure that closure of these units will be completed in a measurably shorter timeframe, and that overall the risks will be lower, or at least equivalent to, the level of risk that would be achieved under the rule's ''standard'' closure provisions.

5. Notation on the Deed to Property

The proposed rule would have required, following closure of the CCR unit, the owner or operator to record a notation on the deed or some other instrument normally examined during a title search. This notation would notify any potential purchaser in perpetuity that the property has been used as a CCR landfill or CCR surface impoundment and that use of the land is restricted under the rule's post-closure care provisions. After the

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notation was completed, the proposed rule would have required the owner or operator to notify the state that the notation has been recorded and a copy has been placed in the facility's operating record and on its publicly accessible internet site. In addition, the Agency solicited public comment on adding a provision to the rule to allow removal of the deed notation once all CCR are removed from the CCR unit, and notification is provided to the state of this action. The EPA solicited comment on this potential approach as a way to create a further incentive for clean closure of the facility. 75 FR at 35208–09. The proposal further encouraged commenters who are interested in supporting such an option to suggest alternatives to state oversight to provide for facility accountability.

EPA received few public comments on the proposed requirement to record a deed notation to the property (or some other instrument that is normally examined during title search). One commenter provided general support for the proposed requirement to record a deed notation to the property. Another commenter urged EPA to ensure that any deed notation requirements should not interfere or conflict with existing state property laws that provide for environmental covenants.

EPA did receive several comments in response to the Agency's solicitation of comment on adding a provision to the rule to allow removal of the deed notation when all CCR are removed from the facility, and notification is provided to the state of this action. One commenter supported the addition of this provision, stating that the licensure requirements of the Professional Engineer provide an assurance of integrity because the Professional Engineer would be required to verify that closure has been completed in accordance with the closure plan. This commenter also stated that it would be sufficient to allow removal of a deed notation upon an application to the state agency supported by a declaration of a licensed professional, subject to state agency review and approval. Another commenter supported providing the incentive for clean closure and allowing the facility to demonstrate the ''cleanliness of the closure.'' The commenter also recommended that the information provided by the facility should be followed by a review from an independent third party with knowledge of the industry and associated environmental issues.

After considering comments, the final rule requires an owner or operator to record a notation on the deed or some other instrument normally examined during a title search. This notation notifies any potential purchaser in perpetuity that the property has been used as a CCR landfill or CCR surface impoundment and that use of the land is restricted under the rule's post-closure care provisions. See § 257.102(i). In response to the commenter that urged EPA to ensure that any deed notation requirements should not interfere or conflict with existing state property laws, the Agency has no information that the proposed requirement would create such a conflict. In addition, the commenter did not provide any information or suggest that EPA's proposed approach would actually interfere or conflict with existing state property laws. Therefore, the Agency is finalizing the deed notation requirement as proposed.

In addition, regarding the Agency's solicitation of comment on adding a provision to the rule to allow removal of the deed notation when all CCR are removed from the facility, as discussed in Unit VI.M.2 of this preamble, the final rule adopts the proposal to allow the owner or operator to remove the deed notation required under § 257.102(i)(4), upon certification that clean closure has been completed. The rationale for this decision is discussed in that unit of the preamble.

6. Notification of Intent To Close and Certification of Closure Completion

The Agency proposed to require owners or operators to notify the state that a notice of intent to close a CCR unit has been placed in the facility's operating record and on the publicly accessible internet site. This notification had to be completed prior to beginning closure of the CCR unit. Following closure of a CCR unit, the proposed rule would also have required the owner or operator to obtain a certification from an independent registered professional engineer verifying that closure has been completed in accordance with the written closure plan. As proposed, this certification would be placed in the facility's operating record and on the publicly accessible Internet site.

The Agency received no public comments on the proposed requirements to develop a notification of intent to close or the certification of completion of closure. Therefore, the Agency is finalizing these requirements as proposed. See § 257.102(g) and (h).

7. Post-Closure Care Plan

The Agency proposed to require that the owners or operators of CCR landfills and CCR surface impoundments prepare a written post-closure care plan describing how the CCR unit would be maintained after closure. See proposed § 257.101(c). The proposal also identified the minimum information necessary to include in the post-closure care plan. This information included: (1) A description of the monitoring and maintenance activities for the CCR unit and the frequency at which these activities would be performed; (2) the name, address, and telephone number of the person or office to contact about the facility during the post-closure care period; and (3) a description of the planned uses of the property during the post-closure care period.

The proposed rule further provided that the post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other components of the containment system, or the function of the post-closure monitoring systems unless necessary to comply with the requirements of the rule. The proposal would have allowed a disturbance if the owner or operator of the CCR unit demonstrated that disturbance of the final cover, liner, or other component of the containment system, including any removal of CCR, would not increase the potential threat to human health or the environment. A professional engineer would have been required to certify such a demonstration.

The Agency received no significant comments on the proposed post-closure care requirements. The Agency's responses to these comments are addressed in the closure comment response document, which is available in the rulemaking docket. Therefore, the Agency is finalizing these requirements substantially as proposed. See § 257.102(g) and (h).

8. Post-Closure Care Activities

Following closure of a CCR landfill or CCR surface impoundment, EPA proposed that the owner or operator would be required to conduct post-closure care of the closed unit. At a minimum, the proposal would have required the owner or operator to conduct at least the following: (1) Maintain the integrity and effectiveness of any final cover, including making repairs to the final cover to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover; (2) maintain the integrity and effectiveness of the leachate collection and removal system and operating the leachate collection and removal system in accordance with applicable requirements under the design criteria for such systems; and (3) maintain the groundwater monitoring system in

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accordance with applicable requirements under the groundwater monitoring and corrective action rule provisions.

EPA received few public comments on the proposed activities to conduct during the post-closure care period. These commenters were supportive of the activities and specifically urged the rule to require the monitoring of groundwater throughout the post-closure care period. The Agency received no comments opposing the proposed post-closure care activities. Therefore, EPA is finalizing the same post-closure care activities in this rule. See § 257.104(b). In addition, consistent with the proposal, the rule clarifies that certain CCR units are not subject to these post-closure care activities. Specifically, owners or operators that elect to close a CCR unit by removing CCR (*i.e.,* clean close the CCR unit) are not subject to any post-closure care requirements. See § 257.104(a)(2) and Unit M.2 of this preamble. In addition, owners or operators of inactive CCR surface impoundments that elect to complete closure of the unit within 30 months of the rule's effective date are not subject to any post-closure care requirements. See § 257.104(a)(3).

9. Length of Post-Closure Care Period

The Agency proposed that the owner or operator of a CCR unit conduct post-closure care for 30 years. EPA also proposed to allow utilities to conduct post-closure care for a decreased length of time if the owner or operator demonstrates that the reduced period is sufficient to protect human health and the environment. The owner or operator would have been required to have this demonstration certified by a professional engineer, in addition to complying with all of the notification and posting requirements under the proposed rule. The proposed rule would also have allowed an increase in the post-closure care period if the owner or operator of the CCR unit determined that it is necessary to protect human health and the environment. EPA also recognized in the proposed rule that state oversight can be critical to ensure that post-closure care is conducted for the length of time necessary to protect human health and the environment; however the Agency also recognized that there is no set length of time for post-closure care that will be appropriate for all possible sites, and all possible conditions. Therefore, EPA solicited comment on alternative methods to account for different conditions, yet still provide methods of oversight to assure facility accountability.

Some commenters supported the proposed approach because it provided flexibility to increase or decrease the post-closure care period of 30 years. EPA also received comments from a number of states documenting the current state requirements; some states require a post-closure care period of less than 30 years, some require 30 years, and one state currently requires 40 years for CCR units. Other commenters opposed the shortening of the 30-year period without state involvement and approval.

After considering public comments, and in a departure from the proposed rule, the Agency is requiring that post-closure care be conducted for a minimum of 30 years. EPA is making this change due to the lack of guaranteed state oversight for this rule. The Agency has concluded that providing the owner or operator the flexibility to shorten the post-closure care period is no longer appropriate, particularly given the flexibility being provided for the selection of a final cover system or alternative final cover system. As discussed in Unit M.3 above, the information available to the Agency supports the need to proceed cautiously. By not allowing the post-closure care period to be shortened, EPA better ensures that the final cover system will be properly maintained. In addition, a mandatory 30 year period ensures that if problems do arise with respect to a final cover system, the groundwater monitoring and corrective action provisions of the rule will detect and address any releases from the CCR unit, at least during the post-closure care period.

10. Notification of Completion of Post-Closure Care Period

The Agency proposed to require owners or operators of CCR units to notify the state that a notice of completion of the post-closure care period has been placed in the facility's operating record and on the publicly accessible Internet site. The proposed approach would have required the owner or operator to obtain a certification from an independent registered professional engineer verifying that post-closure care has been completed in accordance with the written post-closure care plan.

The Agency received no public comments on the proposed requirement to develop a notification of completion of the post-closure care period. Therefore, the Agency is finalizing these requirements as proposed. See § 257.104(e).

N. Recordkeeping, Notification and Posting of Information to the Internet

In response to EPA's lack of authority to require a state permit program or to oversee state programs, EPA has sought to enhance the protectiveness of the regulatory requirements by providing for state and public notifications of the third party certifications, as well as requiring a robust set of other information that documents the decisions made or actions taken to comply with the technical requirements of the rule. Consistent with the proposed rule, owners or operators of CCR units are required to document how the various provisions of the rule have been met by placing information (*e.g.,* plans, records, notifications, reports) in the operating record and providing notification of these actions to the State Director/or appropriate Tribal authority. The owner or operator is also required to establish and maintain a publicly accessible Internet site that posts documentation that has, in many instances, also been entered into the operating record. The owner or operator is required to maintain a copy of the current Emergency Action Plan, the current fugitive dust control plan, and the current written closure plan as long as the facility remains active. EPA believes that the establishment and maintenance of this information in both the operating record and on a publicly accessible Internet site is appropriate so as to allow states and citizens access to all of the information necessary to show that the rule has been implemented in accordance with the regulatory requirements.

With regard to the specific recordkeeping and reporting requirements outlined in the proposal, the Agency received very little comment. Commenters were primarily concerned not with the specific recordkeeping requirements but rather how the recordkeeping requirements aligned with the overall approach of the RCRA subtitle D regulatory scheme. These comments and the Agency's responses are discussed in Unit V of this preamble.

The combined mechanisms of recordkeeping, notifications, and maintaining a publicly accessible Internet site will serve to provide interested parties with the information necessary to determine whether the owner or operator is implementing and is operating in accordance with the requirements of the rule. As stated in the proposal and reiterated here, EPA believes that it cannot conclude that the RCRA subtitle D regulations will ensure there is no reasonable probability of

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adverse effects on health or the environment, unless there are mechanisms for states and citizens to monitor the situation, such as when groundwater monitoring shows exceedances above the groundwater protection standard specified in the rule, so they can determine when intervention is appropriate. EPA also believes that the recordkeeping and notification requirements will minimize the danger of owners or operators abusing the self-implementing system being established in this rule through increased transparency and by facilitating the citizen suit enforcement provisions applicable to the rule.

In contrast to the proposed rule, the Agency has identified for ease of implementation each recordkeeping, notification and Internet posting required in this rule. The proceeding section provides a summary of the requirements for each reporting mechanism.

1. Recordkeeping Requirements

This rule requires the owner or operator of a CCR landfill or CCR surface impoundment and any lateral expansion to maintain files of all required information (*e.g.,* demonstrations, plans, notifications, and reports) that supports the implementation of this rule in an operating record located at the facility. Each file must be maintained in the operating record for a period of at least five years following submittal of the file into the operating record. In certain instances, however, files must be maintained until the CCR unit completes closure. For example, the initial and periodic structural stability assessments as required under section § 257.73(d) and § 257.74(d) must be maintained for five years consistent with the timeframe for periodic reassessments. Whereas, information on the construction of a CCR surface impoundment must be maintained until the CCR unit completes closure (see 257.73(c) and 257.102.) These timeframes are generally consistent with the timeframes required for maintaining hazardous waste compliance records under subtitle C of RCRA and with the timeframes outlined in the proposed subtitle C option for the regulation of CCR. (See specifically 40 CFR 264.73 and 265.73.)

Owners or operators with more than one CCR unit may elect to consolidate all files into one operating record provided that each unit is identified and files for that unit are maintained separately in different sections of the operating record. The owner or operator of the CCR unit must place files documenting compliance with the location restrictions; design criteria; operating criteria; groundwater monitoring and corrective action; closure and post closure care, into the operating record, with the specific documentation requirements found in § 257.105. In the development of this final rule, the Agency has included in the regulatory language a comprehensive listing of each recordkeeping and notification required by the rule. The Agency anticipates that this effort will facilitate owners or operators efforts in complying with the reporting provisions of the rule, and will provide other interested parties with a guide to the reporting provisions of the rule.

2. Notification Requirements

As previously discussed, owners or operators are required to notify State Directors and/or the appropriate Tribal authority when specific documentation has been placed in the operating record and on the owner or operator's publicly accessible Web site. In most instances these notifications must be certified by a qualified professional engineer and may, in certain instances will be accompanied with additional information and or data supporting the notification. For example under § 257.106(f)(1), within 60 days of commencing construction of a new CCR unit, a notification of the availability of the design criteria specified under § 257.105(f)(1) or (f)(3) in the operating record and on the owner or operator's publicly accessible Internet site. If however, the owner or operator of the CCR units elects to install an alternative composite liner, the owner or operator must also submit to the State Director and/or appropriate Tribal authority a copy of the alternative composite liner design which has been certified by a qualified professional engineer.

Notification requirements can be found in § 257.106, and are required for location criteria, design criteria, operating criteria, groundwater monitoring and corrective action and closure and post closure care.

3. Publicly Accessible Internet Site Requirements

The Agency is finalizing, as proposed a requirement for owners and operators of any CCR unit to establish and maintain a publicly accessible Internet site, titled ''CCR Rule Compliance Data and Information.'' As with the operating record, owners or operators that maintain multiple CCR units may elect to use one Internet site in order to comply with these requirements, provided that the Web site clearly and distinctly identifies information from each of the CCR units by name and location. Unless provided otherwise in the rule, information posted to the Internet site must be available for a period no less than three years from the initial posting date. Posting of information must be completed no later than 30 days from submittal of the information to the operating record. This timeframe is consistent with the notification requirements of the rule. As with the other criteria in this section, Internet postings are required for various elements identified in the following sections: Location restrictions; design criteria; operating criteria; groundwater monitoring and corrective action; closure and post closure care. These requirements are enforceable by citizen suits.

VII. Summary of Major Differences Between the Proposed and Final Rules

The basic regulatory framework outlined in the proposed rule under the subtitle D option, is being adopted in this final rule for the regulation of CCR landfills and CCR surface impoundments and any lateral expansion. However, as discussed in Unit VI of this document, the Agency has made a number of revisions to several of the provisions in the proposed rule, including (1) the timeframes for closure; (2) locations restrictions—placement above the uppermost aquifer; (3) the use of an alternative composite liner design; (4) revisions to align the structural stability criteria with the experience and data generated by the Assessment Program; and (5) air criteria. These changes have been made in response to public comments and additional information collected and analyses conducted by EPA in the course of responding to those comments. These are discussed in greater detail below. Under the proposed rule, all new CCR landfills and all CCR surface impoundments that had not completed closure would be required to retrofit to a composite liner or close within five years. However, after reviewing comments and further evaluation, the Agency has concluded that this regulatory approach was unnecessary in light of the protections afforded by the other technical provisions of the rule (*e.g.,* groundwater monitoring, corrective action). In the final rule, EPA is allowing unlined CCR surface impoundments to continue to operate for the remainder of the active life, provided that the facility documents through groundwater monitoring that the CCR surface impoundment is not contaminating groundwater. However, if groundwater

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monitoring at the facility demonstrates that the unlined CCR surface impoundment has exceeded any groundwater protection standard, the owner or operator must initiate corrective action, and either remove all CCR from the unit and install a composite liner (*i.e.,* ''retrofit'') or close within five years. In a departure from the proposed rule, CCR surface impoundments less than 40 acres may receive one two-year extension, providing for a maximum of seven years to complete closure. Units greater than 40 acres may receive up to five two-year extensions providing a maximum of 15 years to complete closure. These units are also eligible for alternative closure timeframes to account for site specific operational constraints.

In addition, under the proposed rule, CCR surface impoundments that had not closed in accordance with the rule would be subject to all the provisions of the rule. After further evaluation, EPA has revised the provision to allow an inactive CCR surface impoundment three years from publication of the rule in the **Federal Register** to complete closure. Owners or operators of inactive CCR surface impoundments that have not completed closure within this timeframe are subject to all the applicable requirements of the rule.

In response to comment and upon further evaluation the Agency is amending the location restriction relating to the placement of the CCR unit above the natural water table. Under the proposal, new landfills, any CCR surface impoundment, and all lateral expansions would have been required to have a base located a minimum of two feet above the upper limit of the natural water table. In the final rule, the Agency has amended this requirement to require that new CCR landfills and all CCR surface impoundments, and all lateral expansions be constructed with a base no less than 1.52 meters (five feet) above the uppermost aquifer or must demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table.) EPA has made this change in response to comments and further evaluation demonstrating that this standard is the minimum distance necessary to demonstrate that no reasonable probability of adverse effects on human health and the environment will occur.

EPA proposed to require all new CCR landfills, CCR surface impoundments and any lateral expansion to be constructed with a composite liner. A composite liner was defined as a system consisting of two components; the upper component consisting of a minimum 30-mil FML and the lower component consisting of at least two feet of compacted soil. Based on public comments and further evaluation, the Agency is finalizing a new requirement that allows an owner or operator to install an alternative composite liner provided it meets the performance standard established in the rule. EPA has concluded that this alternative composite liner affords the same protection to groundwater resources as a composite liner.

Under the proposed rule, all CCR landfills and CCR surface impoundments would have been required to manage fugitive dusts in a manner not to exceed 35 μg/m3. The proposal also required owners or operators to control the wind dispersal of dusts consistent with the standard, and to document the measures taken to comply with the requirements. In response to comments and upon further evaluation, the Agency has removed the numerical standard of 35 μg/m3 from the rule and is establishing a performance standard for fugitive dust control. This standard requires owners or operators of any CCR unit to adopt measures that will effectively minimize CCR from becoming airborne at the facility. The Agency considers this standard to be generally consistent with the proposed rule with the added advantage of allowing for flexibility in achieving compliance. The owner or operator must also prepare an annual CCR fugitive dust control report that describes actions taken by the owner or operator to control CCR fugitive dust and to present a record of all citizen complaints during the previous year, as well as a summary of the corrective action measures taken.

VIII. Implementation Timeframes for Minimum National Criteria and Coordination With Steam Electric ELG Rule

The final rule generally establishes timeframes for the technical criteria based on the amount of time determined to be necessary to implement the requirements (*e.g.,* installing the groundwater monitoring wells). In establishing these timeframes, EPA also accounted for other Agency rulemakings that may affect owners or operators of CCR units, namely the Effluent Limitations Guidelines and Standards for the Steam Electric Power Generating Point Source Category (ELG) (78 FR 34432 (June 7, 2013)) and the Carbon Pollution Emission Guidelines for Existing Stationary Sources: Electric Utility Generating Units (Clean Power Plan) (79 FR 34830 (June 18, 2014)). Specifically, the implementation timeframes in this rule will not require owners or operators of CCR units to make decisions about those CCR units without first understanding the implications that such decisions would have for meeting the requirements of each rule. For example, this final rule requires the closure and post-closure plans to be prepared following the anticipated publication of the ELG and Clean Power Plan final rules so that owners or operators of CCR units can take into consideration those final rules as they prepare the closure and post-closure care plans.

This is also particularly true in the situation where the minimum criteria in the CCR rule could potentially require a surface impoundment to either undergo RCRA closure or retrofit with a composite liner. A decision on what action to take with that unit may ultimately be directly influenced by the requirements of the ELG rule; for example, if the final ELG rule requires a conversion to dry handing of fly ash, then it may not make economic sense for an electric utility to retrofit a surface impoundment that contains wet-handled fly ash since it would be required to cease that practice under the ELG rule. Thus, under the final timeframes in this rule, any such decision will not have to be made by the owner or operator of a CCR unit until well after the ELG rule is final and the regulatory requirements are well understood. In this example, the earliest date that a CCR surface impoundment may be triggered into a retrofit or closure decision is approximately February 2017 (the exact date would be 24 months following publication of this final rule), which would apply to a CCR surface impoundment that fails to achieve minimum safety factors for the CCR unit. This is due to the fact that the owner or operator must complete the initial safety factor assessment within 18 months of the publication of this rule plus an additional six months to initiate closure of the CCR unit if the minimum factors or safety are not achieved. The ELG rule is scheduled to be finalized in September 2015 and its effective date is 60 days following its publication. Thus, there is ample time for the owners and operators of CCR units to understand the requirements of both regulations and to make the appropriate business decisions.

The tables below summarize the implementation timeframes for the minimum criteria for existing CCR

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surface impoundments and for existing CCR landfills being promulgated in this rule.

IMPLEMENTATION TIMEFRAMES FOR THE MINIMUM CRITERIA FOR EXISTING CCR SURFACE IMPOUNDMENTS

Requirement	Implementation timeframe (number of months after publication of rule)	Description of requirement to be completed
Location Restrictions (§ 257.60–§ 257.64)	42 months	—Complete demonstration for placement above the uppermost aquifer. —Complete demonstrations for wetlands, fault areas, seismic impact zones, and unstable areas.
Design Criteria (§ 257.71)	18 months	—Document whether CCR unit is either a lined or unlined CCR surface impoundment.
Structural Integrity (§ 257.73)	8 months	—Install permanent marker.
	18 months	—Compile a history of construction, complete initial hazard potential classification assessment, initial structural stability assessment, and initial safety factor assessment.
	24 months	—Prepare emergency action plan.
Air Criteria (§ 257.80)	6 months	—Prepare fugitive dust control plan.
Hydrologic and Hydraulic Capacity (§ 257.82)	18 months	—Prepare initial inflow design flood control system plan.
Inspections (§ 257.83)	6 months	—Initiate weekly inspections of the CCR unit.
	6 months	—Initiate monthly monitoring of CCR unit instrumentation.
	9 months	—Complete the initial annual inspection of the CCR unit.
Groundwater Monitoring and Corrective Action (§ 257.90–§ 257.98).	30 months	—Install the groundwater monitoring system; develop the groundwater sampling and analysis program; initiate the detection monitoring program; and begin evaluating the groundwater monitoring data for statistically significant increases over background levels.
Closure and Post-Closure Care (§ 257.103–§ 257.104).	18 months	—Prepare written closure and post-closure care plans.
Recordkeeping, Notification, and Internet Requirements (§ 257.105–§ 257.107).	6 months	—Conduct required recordkeeping. —Provide required notifications. —Establish CCR website.

IMPLEMENTATION TIMEFRAMES FOR THE MINIMUM CRITERIA FOR EXISTING CCR LANDFILLS

Requirement	Implementation timeframe (number of months after publication of rule)	Description of requirement to be completed
Location Restrictions (§ 257.64)	42 months	—Complete demonstration for unstable areas.
Air Criteria (§ 257.80)	6 months	—Prepare fugitive dust control plan.
Run-On and Run-Off Controls (§ 257.81).	18 months	—Prepare initial run-on and run-off control system plan.
Inspections (§ 257.83)	6 months	—Initiate weekly inspections of the CCR unit.
	9 months	—Complete the initial annual inspection of the CCR unit.
Groundwater Monitoring and Corrective Action (§ 257.90–§ 257.98).	30 months	—Install the groundwater monitoring system; develop the groundwater sampling and analysis program; initiate the detection monitoring program; and begin evaluating the groundwater monitoring data for statistically significant increases over background levels.
Closure and Post-Closure Care (§ 257.103—§ 257.104).	18 months	—Prepare written closure and post-closure care plans.
Recordkeeping, Notification, and Internet Requirements (§ 257.105—§ 257.107).	6 months	—Conduct required recordkeeping. —Provide required notifications. —Establish CCR website.

IX. Implementation of the Minimum Federal Criteria and State Solid Waste Management Plans

As explained earlier in this document, the final regulations EPA is promulgating under RCRA subtitle D impose minimum federal criteria with which CCR units must comply without any additional action by a state or federal regulator. As discussed previously in this document, under the provisions of subtitle D applicable to solid waste, states are not required to adopt or implement these regulations, to develop a permit program, or submit a program covering these units to EPA for approval and there is no mechanism for EPA to officially approve or authorize a state program to operate ''in lieu of'' the federal regulations.

EPA has, however, received numerous comments regarding the potential implementation challenges that this statutory and resulting regulatory structure may pose, particularly in states that already have a comprehensive regulatory program governing CCR units. These concerns include the fact that facilities may need to comply with two sets of potentially differing regulations, perhaps resulting in confusion for the regulated community and the general public, and also potentially resulting in inconsistent results from citizens seeking enforcement of the criteria. The

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commenters were also concerned that there is no explicit mechanism for EPA to officially approve a state program (as there is in subtitle C or in the municipal solid waste provisions of subtitle D). In addition, in states without a current formal program for overseeing CCR landfills and surface impoundments at coal fired electric utilities, stakeholders have expressed a preference for a state mechanism for implementing the federal requirements. Finally, many stakeholders expressed a strong preference for a permit program with its opportunities for public input and transparency.

Moreover, EPA recognizes the critical role that our state partners play in implementation and ensuring compliance with environmental regulations. This is particularly important in complex situations, such as presented by CCR landfills and surface impoundments that involve corrective action and requirements and timelines for closure of units. EPA expects that states will be active partners in overseeing the regulation of CCR landfills and CCR surface impoundments, and has adopted a number of provisions to ensure that States have the information necessary to undertake this role. First, the final regulations require owners or operators of regulated CCR units to notify the state of actions taken to comply with the requirements of the rule (see § 257.106). Facilities will also be required to maintain a publicly accessible internet site that will document the facility's compliance with the requirements of the rule; states (along with other members of the public) will be able to access this site to monitor facility activities (see § 257.107). (For a detailed discussion of these requirements, please see Unit VI.N of this document.)

In order to ease implementation the regulatory requirements for CCR landfills and CCR surface impoundments, EPA strongly encourages the states to adopt at least the federal minimum criteria into their regulations. EPA recognizes that some states have already adopted requirements that go beyond the minimum federal requirements; for example, some states currently impose financial assurance requirements for CCR units, and require a permit for some or all of these units. This rule will not affect these state requirements. The federal criteria promulgated today are minimum requirements and do not preclude States' from adopting more stringent requirements where they deem to be appropriate.

As noted above, commenters on the proposal voiced concerns that because EPA does not have the authority to approve a state program under subtitle D of RCRA, there is no document in which EPA formally provides its judgment that a state solid waste program substantially incorporates the minimum federal criteria. However, a mechanism for this has been available for many years through the solid waste management planning process already in the regulations at 40 CFR part 256 ''Guidelines for Development and Implementation of state Solid Waste Management Plans.'' This process, designed early in the development of the waste management infrastructure, was structured to encourage states to effectively plan for and manage their solid wastes, including upgrading or closing any units that were considered ''open dumps'' through the development of SWMPs. Currently most states have SWMPs that have previously been submitted to and approved by EPA. EPA strongly recommends that states take advantage of this process by revising their SWMPs to address the issuance of the revised federal requirements in this final rule, and to submit revisions of these plans to EPA for review, using the provisions contained in 40 CFR part 256. To be clear, EPA is not suggesting that states revise their entire SWMPs, but only that states revise their plans to address the revised federal requirements being promulgated today. EPA would then review and approve the revised SWMPs provided they demonstrate that the minimum federal requirements in this final rule will be met. In this way, EPAs approval of a revised SWMP signals EPA's opinion that the state SWMP meets the minimum federal criteria.

As noted above, the part 256 regulations established the system for the development and approval of initial SWMPs as well as their revisions. For the convenience of the reader, we describe these regulations in the following paragraphs. The regulations lay out a series of requirements that a plan must meet to be approved, as well as a number of recommendations that should also be reflected in the solid waste management plan. (*e.g.,* 40 CFR 256.01–256.04 and 256.20–256.27.) For example, § 256.02 sets out the scope of the SWMPs, requiring that the plans address ''all solid waste in the state that poses potential adverse effects on public health or the environment or provides an opportunity for resource conservation or resource recovery.'' The regulations also specify that the plan must require that all solid waste shall be disposed of in ''sanitary landfills,''—*i.e.,* units that meet any federal requirements promulgated under RCRA section 4004(a)—or otherwise disposed of in an environmentally sound manner. 40 CFR 256.01(a)(2). The plan must also prohibit the establishment of new open dumps, and provide for the closing or upgrading of all existing open dumps within the state, pursuant to the requirements of RCRA section 4005. 40 CFR 256.01(a)(2)–(3). State plans must also ''set forth an orderly and manageable process for achieving the objectives of the Act and meeting the requirements of these guidelines.'' 40 CFR 256.02(d). The regulations further specify that the plan ''shall describe as specifically as possible the activities to be undertaken, including detailed schedules and milestones.'' Id.

The part 256 regulations further require a SWMP to identify the state's legal authorities, and regulatory powers, including any revisions that may be necessary to implement the plan. 40 CFR 256.02(e). The plan must also identify and set out the responsibilities of state, local, and regional authorities that will implement the state plan. 40 CFR 256.10(a). Thus, the SWMP is the comprehensive compendium, developed and adopted with public participation, setting forth how solid waste is managed in a particular state. As such, SWMPs have been a key component of solid waste programs for many years. As stated above, states that have approved plans will only need to address these requirements for CCR landfills and surface impoundments.

In addition to the substantive requirements, the part 256 regulations impose a number of procedural obligations. Before submission to EPA, the SWMP must be adopted by the state pursuant to state administrative processes and developed in accordance with the public participation requirements set out in § 256.60. In addition, all SWMPs were to contain procedures for revisions. 40 CFR 256.03(e). EPA anticipates that states would rely on their existing procedures to revise their SWMPs to implement the new federal criteria.

Currently, most states have approved SWMPs. These approvals were based on the requirements applicable to solid waste management that were in force at the time of approval. Now, because EPA is promulgating revised federal criteria, the facilities that will be considered to be ''sanitary landfills'' and ''open dumps'' is changing. Thus, EPA expects that SWMPs in many states will need to be revised to account for these revised Federal requirements. Consistent with the provisions in § 256.01(a)(2)–(3) and with the requirement in § 256.03(e) that such plans are to be revised where

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necessary, in order to maintain approval of these plans EPA expects that states will revise their SWMPs to account for the promulgation of revised federal criteria for CCR landfills and surface impoundments.

As fully explained later in this section, the plans are generally the best tool available for demonstrating how CCR units will be regulated in a state, including how the state intends its state requirements to relate to the federal regulations. In addition, EPA anticipates that the public participation processes will have substantial benefit, by involving all sectors of the community in addressing the management of CCR in a particular state.

EPA believes that the revised SWMPs will have significant benefits and provide the best mechanism available to respond to the concerns expressed by commenters regarding the role of states in management of this waste. First, the revised plans will enable states to set out, as part of their overall solid waste program, how the State intends to regulate CCR landfills and surface impoundments; that is, these plans can demonstrate how, if at all, the state program has incorporated the minimum national criteria and can highlight those areas where the state regulations are more stringent than or otherwise go beyond the federal minimum criteria. For example, the plan can describe the actions the state will take to oversee CCR units, particularly those units undergoing closure or corrective action, and how the State intends to review or use the notices and other information pertaining to the units that the facility owners will be providing to the state (as required in the federal regulations). Providing this detail can greatly assist the regulated community to understand the regulatory structure under which they will be operating. It can also assist the general public in understanding the regulations and thereby their ability to monitor industry's compliance with the rule.

Second, substantial benefits will be gained through the public participation process required as part of revising the state plans. See 40 CFR 256.60. At a minimum, these processes will promote greater awareness of the federal regulatory requirements, as well as how these fit into the overall context of solid waste management in the State, which will be very valuable as the new minimum criteria for CCR are implemented. In addition, these processes will provide the public and communities near CCR landfills and surface impoundments with an opportunity to participate in the decision making about how CCR are managed in their state. Finally, the record generated by the public participation process has an inherent value to states, the utilities, and the general public in that it can demonstrate explicitly the manner in which issues related to the regulation of CCR landfills and surface impoundments were raised and resolved in the state. This record would be a value in any later proceedings seeking enforcement of the rule.

Third, once EPA has approved a SWMP that incorporates or goes beyond the minimum federal requirements, EPA expects that facilities will operate in compliance with that plan and the underlying state regulations. In those circumstances, EPA's view is that facilities adhering to the requirements of a state program that is identical to or more stringent than an approved SWMP will meet or exceed the minimum federal criteria. In addition, EPA anticipates that a facility that operates in accord with an approved SWMP will be able to beneficially use that fact in a citizen suit brought to enforce the federal criteria; EPA believes a court will accord substantial weight to the fact that a facility is operating in accord with an EPA-approved SWMP. In addition, as noted above, the record generated by the public participation process in developing the SWMP has an inherent value to the states, the utilities, and the general public in any such litigation. The more specific the record is on the public process regarding how the SWMP would incorporate the minimum federal requirements and any state oversight the more valuable it would be in any court proceedings to complement EPA's approval of the SWMP. As fully explained earlier, EPA approval of a state SWMP does not mean that the state program operates ''in lieu of'' the federal program as EPA does not have the authority to make such a determination.

The process and criteria for approval of SWMPs are set out in 40 CFR part 256. The part 256 regulations state that EPA has six months from submittal of a plan to either approve or disapprove it. The regulations further state that EPA will approve a plan if the agency determines that the plan: (a) Meets the requirement set out in RCRA Section 4003(a)(1), (2), (3), and (5); (b) and contains provisions for revisions. Those requirements of 4003(a) are: The identification of the responsibilities of state, local, and regional authorities in the implementation of the plan and the means for coordinating regional planning and implementation; prohibition on the establishment of new open dumps and the requirement that all solid waste be utilized for resource recovery or disposed of in landfills meeting the minimum federal criteria; provision of the closing or upgrading of all existing open dumps; and no prohibition on negotiating or entering into contracts for the supply of solid waste to resource recovery facilities. In this rule, EPA has established minimum national criteria for CCR disposal facilities, which effectively define when CCR disposal facilities are open dumps. In order for EPA to approve a revised state SWMP, it must determine that the state plan provides enforceable regulatory requirements for the closing or upgrading of CCR disposal facilities that constitute open dumps. A state SWMP can do so through direct incorporation and implementation of the minimum federal criteria established by this rule or through incorporation of alternative requirements that are at least as protective of public health and the environment.

EPA anticipates that it will be able to review and approve state SWMPs that adopt the federal regulations in total or go beyond the federal minimum criteria very quickly; EPA's review of plans that do not adopt the federal minimum criteria or alter them substantially is likely to be more difficult and therefore more time consuming. EPA's review of and decision to approve or disapprove a state solid waste management plan will be based on the record before the Agency at the time of that decision. This record includes the record developed during the public participation process in which the state engaged prior to submitting the revised SWMP to EPA for approval. Should information come to EPA's attention at a later date that a state is not implementing its approved plan or taking actions at variance with the plan's provisions, EPA will take appropriate steps including potentially withdrawing approval of the SWMP.

Because SWMPs form a critical part of the implementation of this rule, EPA intends to engage the states very soon after promulgation of the minimum criteria to develop a streamlined, efficient process for review and approval of these revised plans. EPA also intends to develop both guidance for states to use to submit revisions and for EPA to use in its review of the revisions.

In addition, EPA is exploring options for developing and publishing the statutorily required inventory of open dumps. Specifically, within one year of the promulgation of federal criteria under RCRA section 4004(a), section 4005(b) directs EPA ''to assist the states in complying'' with the directive in section 4003(a)(3) that state SWMPs

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shall provide for closure and upgrading of open dumps (*i.e.,* facilities that do not meet the revised federal criteria) by publishing an inventory of all ''open dumps'' in the US. 42 U.S.C. 6945(b). Because the minimum criteria promulgated today include implementation timelines, it is possible for a facility to become an open dump in the future for failure to meet the minimum criteria. Thus, EPA anticipates publishing an initial inventory and likely subsequent periodic updates.

Finally, in addition to benefits just described of a revised SWMP, RCRA Section 4005 provides an incentive in certain circumstances for states to obtain EPA approval on revised SWMPs. Under section 4005, States with approved SWMPs can provide additional time for facilities that do not meet the national minimum criteria (*i.e.,* ''open dumps''), to come into compliance. As noted above, within one year of the promulgation of federal criteria under RCRA section 4004(a), section 4005(b) directs EPA ''to assist the states in complying'' with the directive in section 4003(a)(3) that state SWMPs shall provide for closure and upgrading of open dumps (*i.e.,* facilities that do not meet the revised Federal criteria) by publishing an inventory of all ''open dumps'' in the US. 42 U.S.C. 6945(b). Facilities on this inventory are eligible to obtain a ''schedule of compliance'' from a state with an approved management plan, provided certain additional criteria have been met. Specifically, the facility must demonstrate that it is unable to use other ''public or private alternatives'' to manage its waste in the non-compliant unit. In such cases, the state may establish a schedule of remedial measures that includes ''an enforceable sequence of actions or operations'' which must lead to compliance within a ''reasonable time (not to exceed five years from the date of publication of criteria).'' 42 U.S.C. 6945(a). Such a schedule would shield the facility from any suit brought to enforce the criteria. Thus, if a State receives EPA approval on its revised plan, it can offer facilities additional time, albeit limited, to come into compliance with the federal requirements. EPA expects, however, that few facilities will either be eligible for or need to take advantage of this flexibility. First, as a practical matter, only a limited number of facilities or units will fall into the category of open dumps within the relevant timeframes. As noted, an open dump is defined as a solid waste facility that does not meet the federal minimum criteria. 42 U.S.C. 6903(14). As also explained, the final criteria establish timeframes for facilities to implement the technical requirements, ranging between six months to several years, including certain provisions that authorize extensions. Until those deadlines pass, the facility is not an open dump and therefore would not be eligible for or need a compliance schedule under section 4005. Because the statute limits the states' ability to set compliance schedules to five years from the publication of the criteria, if a facility is out of compliance with the criteria either shortly before or after this time five-year timeframe, from a purely practical perspective, compliance schedules are no longer a viable option. Thus for certain of the provisions (*e.g.,* closure, which generally must be completed within five years) compliance schedules would never be available.

Second, the timeframes in the regulation reflect EPA's considered judgment of the amount of time that would realistically be needed under normal circumstances for a facility to come into compliance, based on standard engineering practices used throughout the industry. Most facilities will, in fact, be able to comply with the federal criteria within the specified timeframes, and so will not need to seek a compliance schedule. For example, as part of its Dam Safety Assessment program, EPA evaluated all CCR surface impoundments with a dam hazard potential rating of ''high'' or ''significant,'' using criteria that were essentially the same as the technical criteria adopted in the final rule. As of the completion of that program, all units were either rated satisfactory, or were taking steps to ensure the structural stability of the unit. EPA acknowledges that ensuring the structural stability of these units requires continued maintenance and oversight, so past compliance is no guarantee of future compliance. However, our experience from the Assessment Program leads us to expect that the vast majority of CCR surface impoundments will be able to demonstrate compliance with the structural stability requirements in the final criteria within the specified timeframes. Any facility that seeks to justify an extension would have a heavy burden to demonstrate that anything longer than a minor amount of time is needed to implement the structural stability requirements would meet the statutory standard (*i.e.,* be ''reasonable''). Similarly, absent factors beyond the facility's control (i.e, ''Acts of God'') EPA is unable to envision the circumstances that would support a decision that additional time beyond the 30 months already provided in the criteria to comply with the groundwater monitoring requirements would be ''reasonable.''

Third, RCRA section 4005(a) imposes a number of requirements that will further limit both the circumstances in which a compliance schedule may be granted, and the amount of time that states will ultimately be authorized to grant. 42 U.S.C. 6945(a). Section 4005(a) requires that to obtain a compliance schedule, the facility must first demonstrate that it has considered other public or private alternatives to comply with the prohibition on open dumping and is unable to utilize such alternatives.[127] At a minimum, this means that the facility must demonstrate that there are no alternative units that meet the federal requirement, either on-site or off-site, that can be used to dispose of the CCR. EPA also interprets this provision to require the facility to demonstrate that it has made a good faith effort to comply with the criteria, which would include documenting the actions that had been taken, along with the facts demonstrating the reasons that compliance was not feasible within the criteria's timeframes. As has been previously discussed, cost is not a factor that is appropriately considered under sections 1008(a)(3), 4004(a), or 4005(a), and so would not provide an adequate justification for these purposes either.

Further, the statute requires that a schedule for compliance specify ''a schedule of remedial measures, and an enforceable sequence of actions, leading to compliance within a reasonable time.'' Id. This means that any compliance schedule must lay out precisely the activities that remain to be completed, along with clear and enforceable deadlines for each. Again, this will effectively serve to limit the ultimate amount of time that would be granted in any individual case.

Finally, as stated earlier, the statute requires that any schedule to bring an open dump into compliance is to be limited to a ''reasonable time,'' that is not to exceed five years from the date of publication of the federal criteria. Whether a particular period of time is ''reasonable'' depends on the facts of the particular situation, but, generally speaking, it should take into account the technical complexity of the requirement, the activities that remain

[127] Upon promulgation of criteria under sections 1008(a)(3) and 4004(a), the continued use of any unit that does not comply with these criteria is prohibited, as ''open dumping,'' unless a compliance schedule has been established.

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to be completed, the reasons for the lack of compliance, and other particular factors such as geology, geography, weather, and engineering circumstances. For example, EPA expects that a significantly lower amount of time would be reasonable for a facility that simply chose to delay implementation than for a facility whose compliance was complicated by factors beyond its control. Overall, to be consistent with the statute, EPA expects that facilities seeking to establish an alternative compliance schedule would need to provide a factual justification that not only documents the reasons that compliance within the criteria's timeframes was not feasible, but carefully documents the facts that would support a determination that any significant extension of time to come into compliance is ''reasonable.''

EPA expects that as part of any revised solid waste management plans, a state would explain the criteria it intended to use to determine whether and how much additional time to comply with the federal criteria should be granted. See 40 CFR 256.04(f) and 256.26. Consistent with the statute's directives, EPA expects that any extension would be limited to the time absolutely necessary to bring a unit into compliance, and that five years would not automatically be granted. Nor would a revised solid waste management plan that granted all ''open dumps'' an additional five years generally meet the regulatory criteria for approval. Id. EPA also expects that states would consider the original timeframes laid out in the criteria. As previously discussed, in developing these time frames EPA sought to achieve a balance between the minimum amount of time that would realistically be needed to properly and adequately implement the technical requirements, and the need to expeditiously address the significant risks associated with CCR units. EPA therefore expects that in granting additional time under compliance schedules, states will be guided by the same considerations. As documented throughout this preamble, CCR disposal units do pose significant risks to public health and the environment; it is therefore critical that actions to implement these criteria be taken expeditiously to address these risks. EPA intends to closely review those portions of a state solid waste management plan that address the processes and criteria for establishing compliance schedules.

In conclusion, EPA believes that the use of the solid waste management plan revision process is the best mechanism available under RCRA subtitle D to address the states' interest in obtaining formal EPA ''approval'' of their solid waste management plans. EPA will continue to work with the states as the rules are implemented to ensure that this process is streamlined and efficient.

X. Risk Assessment

EPA revised and updated the 2010 draft risk assessment using mathematical models to determine the rate at which chemical constituents may be released from different waste management units (WMUs), to predict the fate and transport of these constituents through the environment, and to estimate the resulting risks to human and ecological receptors. Modeling was conducted in a step-wise fashion, with more refined analyses used at each subsequent step. Below, EPA discusses how the risk assessment was revised and updated in response to the various public comments received. The Agency also provides a summary of the analyses conducted as part of the risk assessment and the final conclusions drawn from these analyses. For further discussion, see the revised risk assessment and response to comments documents available in the docket.

A. Response to Public Comments

EPA received numerous, general comments on both the draft risk assessment and subsequent NODAs. These comments tended to express general support or disapproval for the risk assessment methodology, data, or results. However, these comments did not provide any specific technical recommendations or data that could be used to improve the risk assessment. EPA appreciates the overwhelming interest of the public regarding the Agency's risk assessment. However, without any substantive critique that could be acted upon, EPA could not alter the risk assessment in response to these more general comments. To the extent that any commenter mentioned substantive issues regarding a specific aspect of the risk assessment, these comments are further addressed in subsequent sections of this preamble.

1. Comments Related to Fate and Transport Modeling

COMMENT: Commenters wondered how realistic results may be using a risk assessment model that assumes current conditions will be maintained for 10,000 years. Specifically, commenters were concerned about the assumption that constituent concentrations in the leachate remain constant throughout that timeframe. In addition, commenters questioned the assumption that well use and climate conditions will remain constant for 10,000 years.

EPA RESPONSE: EPA acknowledges that the 10,000-year groundwater modeling time horizon required further clarification in the revised risk assessment. Thus, the text in the revised risk assessment has been updated to make it clear that the selection of a *maximum* 10,000-year time horizon does not mean that all model simulations continue for the full 10,000 years. Specifically, Section 4 states:

EPA ran the model until either the observed groundwater concentration of a constituent at the receptor point reached a peak and then fell below a model-specified minimum concentration (10^{-16} mg/L), or the model had been run for a time period of 10,000 years.

Although groundwater concentrations are modeled beyond the observed peak or maximum average concentrations, these post-peak or post-maximum average predictions are not used in estimates of risk. In many cases the leachate plume reaches the receptor point much sooner than 10,000 years. As discussed in Section 5 and appendix K of the revised risk assessment, on a national scale, both unlined and clay-lined surface impoundments consistently pose peak risks within 100 years. Meanwhile, composite liners show much longer peak arrival times, close to 10,000 years for most surface impoundment runs. Peak arrival times are longer for landfills, and more than 10,000 years for composite-lined landfills. Under such timeframes, EPA acknowledges that surface conditions may change significantly, compounding the uncertainty associated with the predicted exposures and risks. However, EPA also notes that the time to first exceedance of selected risk criteria is typically considerably less than the time to the greatest exceedance.

EPA acknowledges that future groundwater use patterns may shift as the number and location of receptors changes, and that it is unknown whether future changes in receptor locations and other surface conditions would result in greater, lesser, or the same risk as predicted in this analysis. However, no known data exist that would allow EPA to do more than speculate about future population dynamics. Thus, the Agency relied on the best available data on the current population to conduct the revised risk assessment. The approach used to place residential groundwater wells is further discussed in Section 4 and appendix B of the revised risk assessment, and the associated uncertainties are discussed in Section 5.

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COMMENT: Comments related to the specifics of the groundwater transport modeling were received from commenters. Issues covered in their comments included the following:

Geochemical Modeling:

- The way that soil and aquifer K_d values were determined and used, including the fact that the risk assessment did not explicitly model oxidation/reduction reactions and precipitation-dissolution processes that may influence the chemical fate and transport.
- Whether hydrogeologic settings were assigned correctly.

Selection of Sorbents:

- The selection of iron oxides, and dissolved organic matter (DOM) and particulate organic matter (POM) to represent all sorbents in soil and aquifer materials.
- The selection of goethite as the iron oxide mineral used to estimate sorption to vadose zone and aquifer materials.
- The treatment of POM and DOM in the MINTEQA2 modeling used to generate the K_d values (sorption isotherms) used in the analysis.
- The adequacy of sensitivity and uncertainty analyses for the MINTEQA2 modeling.

K_d Values:

- The approach used to determine the value of pH in the aquifer for selecting K_d.
- The subsequent calculation of the retardation factor.

Arsenic Speciation:

- The assumption that arsenic III is the only or dominant form of arsenic is too conservative, as arsenic III readily converts to the less mobile arsenic V species under aerobic conditions.
- A commenter requested time to exceedance results for arsenic species and other constituents, as well as distance versus concentration output from EPACMTP.

EPACMTP Assumptions and Simplifications:

—The appropriateness of EPACMTP and its various assumptions and simplifications for groundwater modeling, including:
—Not altering the chemistry of the aquifer receiving leachate.
—Not simulating variable oxidation-reduction potential conditions or multiple chemical species during a model run.
—Not evaluating the potential mobilization of non-waste related metals from soils when exposed to leachate with potentially different geochemistry compared to ambient conditions.
—Not considering the potential occupation of adsorption sites by naturally occurring metals or competition from multiple contaminants.
—Not considering mounding-induced reduction of the unsaturated zone thickness or other cases where the groundwater table is in direct contact with the bottom of the WMU.
—Not considering fractured rock, karst, and other complex hydrogeologic settings.

The comments also addressed the general need for more transparency in the data and methods used in the analysis and the need for validation and/or comparison of model inputs and results to site-specific field data.

EPA RESPONSE: The following is EPA's response broken out by subtopic.

Geochemical Modeling:

EPA recognizes that explicit reactive/geochemical modeling would be more realistic than using linear and nonlinear partitioning coefficients. EPA considered the use of the Objects Representing Chemical Speciation and Transport (ORCHESTRA) model during revisions to the risk assessment because it can account for geochemical interactions, such as aqueous complexation, precipitation, surface complexation, and ion exchange.[128] However, such modeling is not a practical approach for a nationwide analysis because the data collection effort necessary to populate such a model on a nationwide, location-based level would be prohibitively expensive. Even assuming such data were available to populate ORCHESTRA or a similar model, the complexity of the algorithms necessary to account for highly variable geochemical and hydrogeologic conditions nationwide and the time required to run such a model would also be impractical. Furthermore, the use of K_d as a surrogate for dilution/sorption/precipitation processes is a widely used and accepted method in both the scientific literature and the groundwater modeling community, provided the values of K_d used are appropriate to account for the range of potential attenuation processes.[129] Therefore, for a nationwide analysis, the use of K_d is a practical and necessary simplification. EPA has added discussion to the risk assessment to clarify K_d-related issues raised by the commenters. Appendix H of the revised risk assessment displays select percentiles of the K_d values used in the analysis. These values were derived from the isotherm sampling performed by EPACMTP and used in the modeling (including effective K_d values for the unsaturated zone). A listing of all individual K_d values available in the MINTEQA2 isotherms used in these analyses would not be practicable. Instead, the full input and output files are available to the public in the docket.

Some commenters suggested that EPA should focus on the effect of redox potential in the groundwater on fate and transport. While this is possible, it would take significant effort to set up this type of approach for every inorganic constituent considered in the risk assessment, and it was determined not to be necessary. EPA did indirectly account for some of the major effects of redox potential when modeling arsenic and other constituents for which speciation is known to have a significant impact on mobility. For these constituents, a model run was conducted for each species under the assumption that all of the constituent mass was present as that speciation. Therefore, EPA did not evaluate redox, and acknowledges this is a source of uncertainty for the groundwater transport modeling approach. Commenters expressed concern about the assumption of a single speciation, noting that it is likely that constituents will be present as some combination of the different species. EPA acknowledges that this approach is a simplification of real world conditions; however, the Agency believes this approach is useful because it provide bounding estimates that can inform the risk assessment.

Regarding the concern that there were possible errors in hydrogeological assignments, these assignments have been updated in the revised risk assessment based on a more robust and accurate dataset for waste management units (WMU) and facility locations. These data are discussed in Section 3 and appendix B of the revised risk assessment. Because these assignments were based on more complete GIS coverages of soils and aquifers across the U.S., they are more consistent and reliable than the previous ones in representing the spatial variability in hydrogeologic environments needed by the EPACMTP model.

Selection of Sorbents:

In recent years, databases of equilibrium sorption reactions have been compiled in the literature for several of the dominant potential sorbents in the environment, including two common iron oxide minerals: hydrous ferrous oxides (HFO) and

[128] Meeussen, J.C.L. 2003. ORCHESTRA: An Object-Oriented Framework for Implementing Chemical Equilibrium Models. *Environmental Science & Technology* 37(6):1175–1182.

[129] U.S. EPA. 1999. *Understanding Variation In Partition Coefficient, Kd, Values Volume I: The Kd Model, Methods of Measurement, and Application of Chemical Reaction Codes.* EPA 402–R–99–004A. OAR. Washington, DC. August.

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goethite.[130] [131] Because of the availability of these data and their prevalence in the environment, these are the sorbent types available for MINTEQ2 modeling used to develop constituent sorption isotherms. Other common hydrous oxides that can sorb chemicals include hydrous oxides of aluminum, manganese, and silicon (Dzombak and Morel, 1990); however, there were insufficient data on these to consider their use. To determine the most appropriate iron oxide sorbent, EPA chose goethite as the most appropriate form of hydrous iron oxide for the risk assessment to avoid an underestimation of risk. While both goethite and HFO are common forms of iron oxide in soils, goethite is a much poorer adsorbent than HFO, thereby leading to relatively greater groundwater plume concentrations. EPA acknowledges that HFOs are common as well and there is the potential for HFOs with greater sorption affinities than goethite to be present at some CCR disposal sites. In reaching this conclusion, EPA consulted experts who published on this subject (specifically, Dr. David Dzombak, Dr. Samir Mathur and Dr. Jerry Allison), developer of MINTEQA2. EPA agrees that this was a necessary assumption.

EPA also recognizes that limiting MINTEQA2 to two types of sorptive materials (iron oxide and organic matter [DOM and POM]) is a simplification given the wide range or soil and aquifer materials that actually adsorb metals (*e.g.,* clay and other soil minerals). However, given that the extensive sorption databases needed to perform MINTEQA2 are available for POM, DOM, and goethite, they are the best representation of subsurface sorption processes active in soils and aquifer materials. This decision and the actual approaches used to model DOM, POM, and goethite are described in detail in MINTEQA2 background documents and the associated Response to Peer Review Comments for those documents.

Finally, with respect to the adequacy of sensitivity and uncertainty analyses for MINTEQA2, EPA notes that the 2009 sensitivity analysis showed that only results for strongly sorbing constituents were sensitive to the K_d values output from MINTEQA2. In contrast, the three risk drivers identified in the revised risk assessment (arsenic, lithium, and molybdenum) all tend to be weakly sorbing, with the exception of arsenic in the pentavalent state. Furthermore, to the extent K_d affects the risks, Section 5 of the revised risk assessment evaluated these effects by examining alternate speciation (*e.g.,* trivalent and pentavalent arsenic) as well as the effect of waste type and waste pH. For these reasons, EPA finds that sufficient sensitivity and uncertainty analyses were conducted.

K_d Values:

The approach adopted in the risk assessment to determine the value of pH in the aquifer (used to select K_d) and the subsequent calculation of the retardation factor assumed that, after entering the aquifer, the leachate plume would thoroughly mix with the ambient, uncontaminated groundwater. One commenter stated that the mixing zone would only be present at the periphery of the groundwater plume. This is consistent with the general conceptual model used in this risk assessment of uniform subsurface flow with recharge. However, EPACMTP requires a constant groundwater pH in each model run to model transport with nonlinear sorption isotherms. EPA assumed full mixing as a more conservative approach to selecting pH because, for most metals, sorption/precipitation tends to increase (*i.e.,* K_d goes up) with higher pH, which is characteristic of much CCR leachate (*i.e.,* assuming full mixing lowers the groundwater pH and, thus, decreases sorption). To characterize the potential effect of this simplifying assumption on calculated risk results, EPA conducted an uncertainty analysis that is presented in Section 5 of the revised risk assessment.

EPA considered comparing the modeled K_d values to available estimates in the published literature, but did not do so for three reasons. First, there are many individual values within each K_d isotherm that depend both on constituent concentrations and MINTEQA2 master variables, such as pH, organic carbon, and iron oxide concentrations. Second, measured values are limited to specific sites where conditions that may not be fully documented, and because such variables can vary from site to site, it can be very difficult to determine exactly how well the collected values represent conditions across the country. Third, field and laboratory methods for measuring K_d vary greatly and are not easy to compare, adding a significant measurement uncertainty to the variability issues mentioned above. Therefore, not only would this comparison be complicated to perform, it would also be subject to its own numerous uncertainties and unknown biases, making it unlikely to provide a basis for definitive conclusions about the representativeness of the current approach.

With respect to comments on the calculation of the retardation factor, EPA points commenters to U.S. EPA (2003) [132] which discusses how EPA uses K_d values to model sorption in the subsurface environment.

Arsenic Speciation:

Commenters also pointed out that literature on arsenic V often shows that it is orders of magnitude less soluble than arsenic III, which appears inconsistent with the results of the 2010 Draft Risk Assessment. The draft assessment found similar exposure concentrations for both arsenic species. As a result of a combination of different updates to the revised risk assessment, the modeled concentrations of arsenic III and V are now generally an order of magnitude different, although the specific results vary between pathways. One cause of this difference is likely the increased distances to receptors in the revised risk assessment. The increased distance would lead to additional arsenic V attenuation because this species sorbs more readily (*i.e.,* has greater K_d values) than arsenic III. Section 5 of the revised risk assessment discusses the uncertainty associated with modeling both species of arsenic. For the specific concentrations at various distances, EPA directs the commenter to review the input and output files available in the docket.

EPA did not model the time to first exceedance of risk criteria, but did conduct a sensitivity analysis for the time to peak groundwater concentration. The time to peak results for arsenic species and other select constituents are presented in Section 5 of the revised risk assessment. The distance to nearest well receptors is also discussed in Section 5 of the revised risk assessment. The relation of distance versus concentration was not explicitly evaluated on a per simulation basis, rather all receptor well locations within one mile from the WMU footprint were included in the analysis to provide a conservative risk estimate.

EPACMTP Assumptions and Simplifications:

Comments on the treatment of dispersivity within EPACMTP highlighted the need for greater transparency about the model's

[130] Dzombak, D.A and F.M.M. Morel. 1990. Wiley-Interscience, New York, 393 pp.

[131] Mathur, Samir S. 1995. *Development of a Database for Ion Sorption on Goethite using Surface Complexation Modeling.* Carnegie Mellon University, M.S. Thesis, Department of Civil and Environmental Engineering.

[132] U.S. EPA (Environmental Protection Agency). 2003. *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP).* Technical Background Document. EPA 53–R–03–002. Office of Solid Waste, Washington, DC.

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underlying assumptions and input data sources. The documentation for the 2010 Draft Risk Assessment did not include comprehensive tables detailing model input parameters, their values or distributional characteristics, and the sources of the data used. These values are, in many cases, publicly available in the EPACMTP Background and Parameters/Data Background documents.[133] [134] EPA still finds it inappropriate to duplicate this large amount of data. Instead, the revised risk assessment includes an increase in the number of references to these documents, and directs readers to refer to these documents for further information. Additionally, the full input and output files are available to the public in the docket.

With respect to the fundamental questions raised about the assumptions and simplifications built into EPACMTP, EPA acknowledges some limitations within the model. Some simplifications are necessary to complete a large, national scale risk assessment, and the model provides the most appropriate available tool to complete this type of analysis. As discussed in Section 5 of the revised risk assessment, EPACMTP has been thoroughly peer reviewed and tested for application in large-scale risk assessments. This section also provides additional documentation on these internal and external reviews of the model, its limitations, and the associated uncertainties. With respect to particular criticisms levied:

- EPA alters the chemistry of the aquifer receiving leachate by changing the aquifer pH in response to full mixing. Alternatively, EPA conducts an analysis in Section 5 using the alternate assumption of partial mixing;
- EPA evaluates alternative species in separate model runs. As described in the revised risk assessment, EPA believes that presentation of these two results bound the range of possible risks from a constituent. To the extent that EPA does not model oxidation-reduction potential, EPA notes that this would require geochemical modeling, which was not feasible for the reasons discussed above;
- Full mixing of the leachate plume did not demonstrate significant potential to affect aquifer pH. Thus, since pH is one of the most significant factors affecting constituent mobilization EPA does not believe significant constituent mass from the underlying soils will be mobilized in most cases. Instead, it is a site-specific consideration that is not possible to include in a nationwide risk assessment.
- A discussion of sorbent competition as a limitation of the analysis is discussed in Attachment H–1 of appendix H in the revised risk assessment.
- EPA did not consider groundwater mounding, groundwater in contact with the waste management unit, fractured rock, karst, and other complex hydrogeologic settings as these are site-specific considerations that could not be accommodated in a nationwide risk assessment.

COMMENT: Several commenters discuss the use of site-specific analysis to increase confidence in the risk assessment results. They expressed concern that the results are difficult to evaluate given the significant variability and uncertainty associated with the national scope of the analysis, and that validation or calibration of EPACMTP results with actual data is needed, including the potential use of damage cases.

EPA RESPONSE: Commenters expressed concern about validation of the EPACMTP model with actual field data and some commenters suggested that EPA should use actual monitoring data rather than modeling to assess potential risks. EPA recognizes the importance of monitoring data in characterizing specific sites. EPA agrees with the commenters that confidence in the results of an environmental fate and transport model increase significantly when model predictions can be compared favorably with measured field results. However, site-specific modeling involves extensive data collection and detailed modeling (representing site-specific conditions and processes), which was not possible for this large, national-scale risk assessment. Available site-specific data are limited to a relatively small fraction of locations and settings. This risk assessment was intended to represent a broad range of potential conditions. Consequently, EPA validated the model results with actual field data by comparing the results of the national probabilistic, Monte Carlo analysis to proven/potential damage cases from across the United States. These damage cases represent real-world instances of contamination from CCR WMUs that provide the best available comparison for the results of the risk assessment. This comparison is presented in Section 5 of the revised risk assessment. EPA also provided extensive EPACMTP validation results relative to theoretical models and field data in appendix D of the EPACMTP technical background document (U.S. EPA, 2003a,b).[135]

COMMENT: Comments relating to the number of wells contaminated, the realistic risk of exposure, well placement within the plume, distance to receptor wells, identification of surface water receptors, surface water interception modeling, the appropriateness of receiving water reaches (*e.g.* the nearest surface water body), and other receptor or well-related issues were received from public commenters.

Surface Water Interception Modeling: Regarding surface water interception, many comments were supportive of EPA's approach for simulating the interception of groundwater by surface water bodies, which has been added to the revised risk assessment. However, some commenters indicated that a meaningful allocation of the groundwater plume between a surface water body and a downgradient well receptor can only be determined reliably with assessment of the system at a local scale.

Commenters also raised questions regarding the specific surface water interception methodology, including the base data and algorithms used to calculate stream base flow, net groundwater flow, and the contaminant mass loss to groundwater. Concern was expressed about the large range of possible values used for Monte Carlo sampling without calibrating models to site specific conditions and the potential to mismatch parameters. Additionally, concerns were raised that the assessment assumed transport directly to the nearest water body without reflecting complexities that are often present and could lead to longer transport pathways or to pathways to water bodies other than the nearest.

Commenters noted that the vicinity of many WMUs is serviced by a municipal water supply, and; therefore, there would be no drinking water receptors associated with these WMUs. Comments were also received that the one mile distance considered by the transport model is not sufficient, because actual receptor wells in many cases are further than one mile from facilities. Comments also highlighted the possibility that modeled receptor well concentrations may incorrectly represent actual

[133] U.S. EPA. 2003. *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP): Parameters/Data Background Document.* EPA 530–R–03–003. Office of Solid Waste, Washington, DC. April.

[134] U.S. EPA. 2003. *EPACMTP Technical Background Document.* Office of Solid Waste, Washington, DC.

[135] U.S. EPA (Environmental Protection Agency). 2003a. *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP).* Technical Background Document. EPA 53–R–03–002. Office of Solid Waste, Washington, DC.

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exposures by sampling from a single aquifer depth. Comments on dispersivity noted the need for greater transparency in the report.

Placement of Receptor Wells, EPACMTP Well Inputs and Assumptions:

Comments related to the risk assessment's use of water well distances from MSWLFs and the Agency's belief that these distances would be protective for CCR WMUs. Additional comments focused on the assumption that the wells used in this assessment are contaminated (*i.e.,* located within the plume), even if the well location used reflects a deeper well that may be screened in an uncontaminated aquifer; the manner in which the assessment handles uncontaminated wells, plume characteristics, groundwater-surface water interactions, vertical contaminant concentration across a screened interval in an aquifer; and the values used for plume dispersivity.

EPA RESPONSE: The following is EPA's response broken out by subtopic.

Surface Water Interception Modeling:

In cases where receptor wells are located downgradient from a surface water body that intersects the groundwater table, some or all of the groundwater, along with the mass of constituents contained therein, is intercepted by the water body before it can reach the well. This interception was not modelled in the 2010 Draft Risk Assessment. However, a review of the input database for the 2010 Draft Risk Assessment found that such a water body was present in approximately two-thirds of the Monte Carlo runs. Furthermore, ignoring the loss of constituent mass had the effect of overestimating exposures. Thus, in the revised risk assessment an EPACMTP model post-processor was created to account for surface water interception by removing constituent mass flowing into the water body from the groundwater plume, and leaving only the remaining groundwater available to migrate to a drinking water receptor. The approach used to account for interception is discussed in further detail in Section 4 and appendix J of the revised risk assessment.

While commenters were generally supportive of the proposed approach, some indicated that a meaningful allocation of constituent mass from groundwater into a surface water body required site-specific data. Concerns were raised about the assumption that transport occurred directly to the nearest water body without reflecting complexities that are often present and could lead to longer transport pathways or to pathways to water bodies other than the nearest. EPA acknowledges that local conditions can make groundwater flow conditions complex, and detailed, local-scale assessments would be required to describe these conditions accurately. While EPA agrees that local-scale conditions must be considered for precise estimation for specific systems, it was impractical for EPA to characterize, simulate, and calibrate models for the numerous locations across the nation. Discussion of the uncertainties associated with this approach has been added to Section 5 of the revised risk assessment.

Several questions about the surface water interception methodology were raised by the public. The qBaseflow input parameter was derived from the NHDplus mean recharge parameter (MEAN_RCHRG) [136] and the size of the water body catchment and reach (see appendix B of the revised risk assessment). The approach assumes that all streams intersect the shallow aquifer and that all streams either gain water from the aquifer or do not interact with the aquifer at all (for simplicity and conservatism). As the commenter indicates, qNetflow is a key result calculated by subtracting the stream baseflow from the average groundwater flow upgradient of the stream. The qNetflow value becomes the adjusted groundwater flow beyond the stream, reflecting groundwater losses to the stream. One commenter raised a specific question about how the methodology handles cases where qNetflow is less than zero, but greater than the average groundwater flow. This case does not occur with the methodology adopted by EPA, because qNetflow is always equal to or less than the average groundwater flow (*i.e.* streams are assumed not to be losing). If qNetflow is negative (*i.e.,* a losing stream), all of the groundwater is assumed to migrate to any wells on the opposite side of the stream.

Model Validation/Calibration:

Concern was expressed about the large range of possible values used in the probabilistic analysis for certain parameters and the potential for this to result in a mismatch of input parameters without proper site-specific calibration. EPA notes that the revised risk assessment is not intended to capture the exact risks at each disposal site. Instead, the revised assessment combines the best resolution of site-based, regional and national data available to provide an estimate of potential risks that may occur from current disposal practices. While the assigned data for any given model iteration may not reflect the exact conditions at a real-world site, the resulting sum of all model iterations reflect the range of potential conditions near each WMU, weighted by prevalence, across the conterminous United States.

Placement of Receptor Wells, EPACMTP Well Inputs and Assumptions:

Comments regarding placement of receptor wells in the probabilistic analysis (also known as the appropriateness of receiving water reaches) are the result of a fundamental misinterpretation regarding the constraints placed on groundwater receptor location to be, as described in the 2010 Draft Risk Assessment, ''within the contaminant plume.'' This constraint is more fully explained in Section 4.4.3.6 of the EPACMTP technical background document.[137] A citation referring readers to that document has been placed in Section 4 of the revised risk assessment. Because the comment resulted from a misunderstanding, EPA does not believe the sensitivity analysis suggested by the commenter is necessary.

Some commenters were concerned that many residents in the vicinity of some WMUs may be serviced by a municipal water supply. Because these residents would not be exposed to groundwater, the risk assessment could overestimate exposures. EPA acknowledges that there may be a large percentage of the population that does not rely on groundwater as a source of potable water; however, the aim of the risk assessment is to estimate the magnitude of potential risk to the exposed population. Thus, this does not represent a significant source of uncertainty in the risk assessment.

Comments were also received that the one-mile distance considered by the transport model is not sufficient, because actual receptor wells in many cases are further distant than one mile from facilities. EPA conducted a sensitivity analysis, discussed in Section 5 of the revised risk assessment, which indicates that risks beyond the one-mile distance are appreciably lower than risks within one mile. Given that the highly exposed population was adequately captured by a one-mile radius, the significant additional effort required to extend the analysis further downgradient was unjustified.

[136] Available online at: *water.usgs.gov/GIS/metadata/usgswrd/XML/nhd_recharge.xml.*

[137] U.S. EPA (Environmental Protection Agency). 2003a. *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP).* Technical Background Document. EPA 53–R–03–002. Office of Solid Waste, Washington, DC.

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With respect to comments related to the placement of wells within deeper aquifers, EPA has a policy of addressing uncertainty by erring in favor of the protection of human health and environmental quality. Consistent with this practice, wells screened within vulnerable, surficial aquifers (*i.e.,* the top 10 meters of the saturated zone) continue to be the primary focus of the Agency's national-scale modeling efforts. Comments also highlighted the possibility that modeled receptor well concentrations may incorrectly represent actual exposures by sampling from a single aquifer depth. Wells are typically screened across an extended depth, and may capture both contaminated and pristine groundwater. Due to the constraints of EPACMTP, EPA maintained the current approach of modeling exposures at a single depth. A discussion of the uncertainties associated with this approach has been added to Section 5 of the revised risk assessment.

In response to comments on the use of MSW landfill data to predict the distance to private wells, EPA did not use the MSW data in the revised risk assessment. Instead, EPA used synthetic population representations of U.S. Census data to place each household and its occupants at discrete points across the landscape surrounding CCR WMUs. Synthetic populations are realistic representations of households and individual residents and their attributes in a given census area, and are based on methods that identify realistic locations within each block by using LandScan 90-meter night-time population distributions to place each household across the landscape.[138] From these households, a distribution of the distances to the nearest well was created. This approach is discussed in more detail in appendix B of the revised risk assessment. Some commenters suggested that EPA develop site-specific estimates of actual populations around facilities rather than relying on synthetic populations to determine potential receptor locations. The synthetic approach provides the maximum spatial resolution possible for publically available population data from the U.S. Census. More site-specific estimates would be costly, but not necessarily more accurate.

Some commenters were also concerned that the assessment did not consider direct discharges from surface impoundments to surface water. This pathway was outside the scope of the assessment, because it is regulated by the NPDES program. However, this pathway was evaluated in *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category,*[139] which will be revised in support of final effluent limitation guidelines due to be released in September of 2015.

2. Comments Related to Source Modeling

COMMENT: The majority of the public commentary in this subcategory was dominated by the assertion that Toxicity Characteristic Leaching Procedure (TCLP), Synthetic Precipitation Leaching Procedure (SPLP) and other laboratory leachate test data are not applicable to CCR wastes. Comments specifically regarding the use of Leaching Environmental Assessment Framework (LEAF) data for modeling leaching behavior noted that the data should be applied appropriately and pointed out the following: (1) That the range of conditions (*i.e.,* range of pH) encompassed by the LEAF data is broader than those conditions found in the field for CCR disposal; (2) high pH limits the mobility of leaching constituents; (3) the need for validating LEAF leachate concentrations against field data if available; and (4) the reliability of the LEAF data is questionable as a result of inconsistencies identified in the LeachXS Lite™ database.

EPA RESPONSE: Only pore water and impoundment water data were used to characterize surface impoundments. Therefore, the comments received on the use of laboratory leachate data are not relevant for the surface impoundment scenario. For landfills, EPA agrees that TCLP, SPLP and other single pH test methods may not be the most appropriate leachate extraction methods for all waste streams and all disposal scenarios. The 2010 Draft Risk Assessment relied on a hierarchy of dissolved concentration data to characterize leaching from landfills, ranging in order of preference from field leachate data to TCLP. However, new data collected using the LEAF test methods have been made available through a series of EPA reports.[140] [141] [142] LEAF were collected with three LEAF methods, specifically:

- SW–846 Method 1313 (and its predecessor, Method SR02);
- SW–846 Method 1314; and
- SW–846 Method 1316 (and its predecessor, Method SR03).[143]

With the availability of the LEAF data, EPA no longer relied on other data sources to model landfills because the inability to identify trends in leaching behavior from single pH tests made it impossible to link these data together with the LEAF data in the probabilistic analysis. The LEAF data provide information on the leaching behavior of CCR for a range of pH values observed in CCR landfills, as well as the liquid-to-solid ratio of the pore water. The data from these three methods were used in conjunction to characterize landfill leaching. While the natural pH range for any individual sample may be narrower than the full range analyzed with the LEAF methods, many facilities burn a range of coal types under varying operating conditions, and co-dispose with other materials, so the range of pH for a specific CCR sample may be exposed to is wider than the pH estimated based on one sample alone.

EPA agrees that appropriate use of the data is needed to ensure that data represent likely conditions of leaching occurring at range of facilities nationwide taking into account local specific environmental conditions, the geometry of monofill, type of coal, air pollution control, and other factors that affect leaching. Since the NODAs were released, a report comparing leachate from field and laboratory analyses has been completed.[144] The report includes the use of geochemical speciation modeling as needed to reflect site-

[138] Bhaduri, B., E. Bright, P. Coleman, and M. Urban. 2007. LandScan USA: A high resolution geospatial and temporal modeling approach for population distribution and dynamics. *GeoJournal 69*:103–117.

[139] U.S. EPA. 2013. Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category. EPA–821–R–13–003. Office of Water. Washington, DC. 20460. April.

[140] U.S. EPA. 2006. *Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control. EPA–600/R–06/008.* Prepared by F. Sanchez, R. Keeney, D. Kosson, and R. DeLapp for the U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division. February.

[141] U.S. EPA. 2008. *Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control. EPA/600/R–08/077.* Prepared by F. Sanchez, D. Kosson, R. Keeney, R. DeLapp, L. Turner, and P. Kariher for the U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division. July.

[142] U.S. EPA. 2009. *Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data.* EPA–600/R–09/151. Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC. December.

[143] Methods SR02 and SR03 are predecessor methods to SW–846 Methods 1313 and 1316.

[144] U.S. EPA. 2014. *Leaching Test Relationships, Laboratory-to-Field Comparisons and Recommendations for Leaching Evaluation using the Leaching Environmental Assessment Framework (LEAF).* EPA–600/R–14/061. EPA Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC 27711. November.

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specific factors affecting leaching, and shows that LEAF methods provide realistic predictions of environmental releases across the range of pH.

All three LEAF methods are summarized in appendix C, with the leachate data provided in Attachment C–5 of the revised risk assessment. Additionally, the inter-laboratory validation for these methods are described in U.S. EPA (2012a, b) [145] [146] while Kosson et al. (2002) [147] provides the detailed test methodology for the predecessor methods, SR02 and SR03. The noted discrepancies and classification errors within LeachXS Lite have been corrected.

COMMENT: Public comments focused on the general relevance of the facility data based on age and noted that newer data should be used to more accurately reflect the current state of CCR management. Related comments cited that the grouping of waste and liner types by facility is not representative of current conditions. Another commenter suggested that the outcomes for different liner types were not comparable and should not be used to make relative conclusions about liner performance. It was also suggested that the assumed three-foot clay layer underlying composite liners is too thick, and two feet would be more representative of current practice. Commenters also described existing management controls required in some geographical locations that mitigate potential risks (*e.g.,* liners, leachate collection) and requested that EPA reflect the existence of those controls in their analysis, as well as mismanagement scenarios when these controls are not in place.

EPA RESPONSE: Since the purpose of the risk assessment was to evaluate risks for the universe of currently operating facilities and WMUs, EPA generally agrees with the commenter that the 1995 EPRI and 2006 DOE survey data relied on in the 2010 Draft Risk Assessment may be outdated. Thus, EPA collected data from several new sources of information on the facilities, WMUs, and liners that are present at the time of this analysis. Further discussion of these data sources is available in Section 2 and appendix A of the revised risk assessment.

Regarding the inclusion of mismanagement scenarios, EPA reviewed the high-end pore water concentrations and determined that these data represent actual CCR samples and therefore represent possible high-end risks from current management practices. To better understand which practices may lead to the highest risks, EPA conducted sensitivity analyses that consider the influence of liner type, liner design, waste type and other variables on model results. The results of these analyses are presented in Section 5 of the revised risk assessment.

Several commenters described existing management controls required in some geographical locations that mitigate potential risks (*e.g.,* liners, leachate collection) and requested that EPA reflect the existence of those controls in the final risk analysis. The Agency's analysis reflects the presence of different management scenarios at WMUs to the extent the available data allowed (*e.g.,* WMUs were assumed to have liners if the information indicated such). A key objective of the analysis was to compare the effectiveness of management options (*e.g.,* liners; surface impoundments versus landfills) at preventing potential releases and exposures. Because the population of WMUs considered in the analysis included a range of management controls, the analysis does provide such comparative results between management options. The uncertainties associated with the updated facility, WMU and liner data are discussed in Section 5 of the revised risk assessment.

COMMENT: One commenter suggested that the risk assessment applied risk results for fly ash to bottom ash, FGD sludge, and other CCR wastes, which may result in an incorrect estimate of risks for these other wastes. Other commenters called for EPA to evaluate each CCR waste independently. A public commenter expressed concern about whether the risk assessment adequately considered alternative CCR disposal scenarios. Specifically, it was noted that CCR codisposed with coal refuse generate more acidic conditions (*i.e.,* lower pH) due to higher-levels of sulfide minerals, which may significantly impact the mobility of metals.

EPA RESPONSE: In the revised risk assessment, EPA modeled a combined ash waste types for the majority of surface impoundments and all landfills. Although commenters are correct that different CCR wastes may behave differently when monofilled, the 2009/2010 EPA survey data indicates that the CCR are codiposed in a majority of units. Thus, EPA believes this approach appropriately reflects current disposal practices.

With regard to the evaluation of CCR codisposed with coal refuse, EPA notes that the pore water data used to characterize surface impoundments were broken out separately for this waste type evaluation. These data reflect samples collected in the field and are representative of the pH at which these samples are managed. While some ash and coal refuse samples are highly acidic, others are more neutral or slightly basic (full pH range of 1.7 to 8.2). The development and application of these waste types is discussed in Section 3, Section 4 and appendix H of the revised risk assessment, while the associated uncertainties are discussed in Section 5. For landfills, waste pH, which is the major driver of variations in K_d values used to distinguish waste types, was known with great accuracy for CCR nationwide because U.S. EPA (2009a) [148] compiled a full, nationwide distribution of CCR pH. In this distribution, disposal of ash with coal refuse is reflected is the acidic tail of the distribution. For the national probabilistic analysis, EPA aggregated model runs for ash and coal refuse (surface impoundments) and acidic waste (landfills) with other wastes so that risks reflected the prevalence of these disposal practices. However, EPA also performed sensitivity analyses to understand the extent that the lower pH of co-managed wastes could affect risks, which is discussed in Section 5 of the revised risk assessment.

COMMENT: Commenters stated that it is unclear why EPA chose to approximate infiltration through composite liner systems based on leak detection system flow rates from industrial landfills that use a different construction design than projected for CCR landfills.

EPA RESPONSE: The composite liner leakage rates used for this risk assessment correspond to leakage rates developed for the peer-reviewed Industrial Waste Management

[145] U.S. EPA. 2012. *Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1314 and Method 1315.* EPA/600/R–12/624. Prepared by A.C. Garrabrants, D.S. Kosson, R. DeLapp, P. Kariher, P.F.A.B. Seignette, H.A. van der Sloot, L. Stefanski, and M. Baldwin for the U.S. EPA Office of Research and Development, Air Pollution Control Division. September.

[146] U.S. EPA. 2012b. *Interlaboratory Validation of the Leaching Environmental Assessment Framework (LEAF) Method 1313 and Method 1316. EPA/600/R–12/623.* Prepared by A.C. Garrabrants, D.S. Kosson, L. Sefanski, R. DeLapp, P.F.A.B. Seignette, H.A. van der Sloot, P. Kariher, and M. Baldwin for the U.S. EPA Office of Research and Development, Air Pollution Control Division. September.

[147] Kosson, D.S., H.A. van der Sloot, F. Sanchez and A.C. Garrabrants. 2002. An integrated framework for evaluating leaching in waste management and utilization of secondary materials. *Environmental Engineering Science 19*(3):159–204.

[148] U.S. EPA. 2009. *Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data.* EPA–600/R–09/151. Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC. December.

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Evaluation Model (IWEM).[149] The types of synthetic liners used are likely to be the same, regardless of the type of waste present. EPA is unaware of any factors specific to CCR that would exacerbate leakage rates, nor did the commenter provide any. Thus, in the absence of any information to the contrary, EPA finds these to be the best available data.

Because there is currently no approach for differentiating between flow from unimpacted water released by the consolidation of clay and from contaminated leakage through the liner, EPA excluded data on the subset of composite liners constructed with natural clay from the distribution of composite liner leakage rates. EPA did consider the potential impact of incorporating these additional data into the risk assessment as part of sensitivity analysis, presented in Section 5 of the revised risk assessment.

COMMENT: Concerning the treatment of non-detect values in the risk assessment, one commenter recognized that the use of one half the detection limit in calculations has become an accepted protocol. However, it was suggested that this approach may not be appropriate in all cases, and that newer or more straightforward methods can be applied to improve precision and minimize biasing of the dataset. Another commenter noted that mercury was excluded from the analysis due to the high number of non-detects.

EPA RESPONSE: Additional constituent data measured with lower detection limits have been made available to EPA since completion of the 2010 Draft Risk Assessment. However, the overall CCR constituent database still contains a large number of non-detect data for some constituents. EPA continues to incorporate all available with the use half the reported detection limit as the most appropriate method to account for these non-detects. The commenter is correct that much of the pre-2010 mercury data has high detection limits and a large proportion of non-detects. In this one instance, EPA relied only on the newer data made available to the Agency since the 2010 Risk Assessment, which was collected through newer methods with significantly lower detection limits. A more detailed rationale for this approach is provided in Section 3 of the revised risk assessment, along with further discussion of the uncertainty in Section 5.

COMMENT: Comments received related to the effect of waste compaction in landfills focused on changes to hydrologic properties of waste materials, such as porosity and hydraulic conductivity. These changes may result from compaction, consolidation, hydration or geochemical changes, and have the potential to result in either an underestimation or overestimation of risks.

EPA RESPONSE: EPA acknowledges that the landfill source model does not consider the compaction of CCR waste that may occur over time as a result of anthropogenic activities, gravity or infiltrating water. However, no data on either the rate or degree to which these processes may occur were provided by commenters or identified elsewhere. EPA considered the impacts of this uncertainty in Section 5 of the revised risk assessment.

COMMENT: Public comments focused on assumptions relating to the variability of unlined landfill design, landfill clay liner materials, and construction of landfill cover materials and construction. Specific comments emphasized that the clay liner and cover thickness assumptions (three feet) were too conservative and not conservative enough, respectively. Commenters also questioned why composite covers and leachate collection systems were not considered for clay-lined landfills. Additionally, commenters stated that there was a high degree of variability in the material and design and construction for unlined landfills that was not accounted for in the HELP modeling. One commenter also pointed out that the assessment may overestimate percolation rates from landfills by underestimating the use of engineering controls. In addition, a commenter stated that the assessment assumes that States will require liners in all cases which may not be the case, thereby weakening the regulation.

EPA RESPONSE: For both unlined and clay-lined landfills, EPA used Hydrologic Evaluation of Landfill Performance (HELP) model-derived infiltration rates. These infiltration rates assume that the cap placed on top of the landfill at the end of its useful life will remain intact for the duration of the risk assessment, up to a maximum 10,000 years of modeling. A commenter pointed out that hydraulic conductivity of a clay liner is likely to increase by orders of magnitude due to desiccation resulting from natural temperature cycles. Additionally, commenters stated that there was a high degree of variability in the material and design and construction for unlined landfills that was not accounted for in the HELP modeling. EPA has adopted the use of the HELP model, which was subject to both peer and administrative review, as the source of unlined and clay-lined infiltration rates for landfill for nearly two decades. EPA acknowledges that there are limitations in using HELP. However, the model has been tested and verified as discussed in the EPACMTP Parameter/Data Background Document.[150] To the extent that the performance of the cap will decrease over time, EPA acknowledges that unlined and clay-lined infiltration rates calculated by HELP may be underestimated, however the degree of that underestimate is unknown. Discussion of this uncertainty has been added to Section 5 of the revised risk assessment.

COMMENT: One commenter expressed concern over the fact that the assessment modeled all disposal sites above the water table. The commenter indicated that many surface impoundments and landfills are deep and can come in direct contact with the water table. This will result in an underestimation of peak concentrations, arrival times and risks for these WMUs. Furthermore, the commenter emphasized that the use of the unsaturated zone flow module to calculate infiltration from the bottom of impoundments underestimates true risks in the consolidated sediment, and noted that clogged soil layers should be treated as saturated rather than unsaturated.

EPA RESPONSE: EPA acknowledges that EPACMTP is not designed to handle scenarios where the water table is above the bottom of the landfill. However, EPACMTP can accommodate surface impoundments in direct contact with the water table. If unit geometry and the selected depth to the water table create a scenario where the bottom of the unit is in contact with the water table, then the entire soil column is considered saturated. Otherwise, even for very high infiltration rates, regions beneath impoundments will remain partially saturated when there is sufficient distance between the unit and the water table. EPA has added a discussion of the uncertainties associated with WMU source terms and EPACMTP in Section 5 of the revised risk assessment.

EPA believes the commenter misunderstood how the sediments were modeled for surface impoundments. The EPACMTP unsaturated zone

[149] U.S. EPA. 2002. *Industrial Waste Management Evaluation Model (IWEM) Technical Background Document.* EPA530–R–02–012. Office of Solid Waste, Washington, DC. August.

[150] U.S. EPA. 2003. *EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP): Parameters/Data Background Document.* EPA 530–R–03–003. Office of Solid Waste, Washington, DC. April.

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module assumes that the 0.2 m of consolidated sediments at the bottom of a surface impoundment are always saturated whereas the 0.5 m of clogged native soil are assumed to be unsaturated when the bottom of the surface impoundment is above the water table.

COMMENT: Public commenters recommended that EPA address the future increase in mercury and NO_X compounds levels in CCR that will result from mercury capture from flue gas under new emission control regulations. Commentary pointed out that the recent Vanderbilt study should provide data that could be used to expand the risk assessment in this area.

EPA RESPONSE: The risk assessment was designed to evaluate the risks associated with current management practices and, as such, draws no conclusions about the potential for future air pollution technologies to alter the composition or leaching behavior of CCR wastes. However, it has been shown that newer mercury pollution control technologies currently in place have the potential to affect leaching behavior.[151] [152] [153] Thus, EPA conducted a sensitivity analysis to evaluate the risks associated with existing units that dispose of this waste; however, the data were too few to allow EPA to draw conclusions about the effect of pollution control technologies on the risks. This sensitivity analysis is presented in Section 5 of the revised risk assessment.

COMMENT: Multiple public commenters noted that additional pore water will improve the risk assessment, but TCLP and SPLP data are not appropriate for use as source concentrations. Additionally, commenters stated that EPA applies the LEAF data to pH conditions that are not realistic to CCR disposal scenarios. Although LEAF provides a more representative and scientifically sound approach, it must be correctly adapted. Alternative statistical methods to represent the input data as a range is certainly feasible and could enhance the risk assessment if the range of data is used as an input to the risk assessment.

Commenters agree that the LEAF data does provide useful information, but point out that it is associated with the potential for leaching and does not represent actual leaching of a specific CCR under actual field conditions. Commenters argues that field leaching data should not be mixed with laboratory data, and that EPA's field leachate dataset (for landfills and impoundments) is not adequate for use in the CCR risk assessment. Specific efforts recommended to properly utilize the LEAF data include: Use of probability density functions for leachate concentrations based on pH and/or L/S ratios in the Monte Carlo process; selection of leachate concentrations based on pH and L/S and tied to the geographic location of the WMU and CCR type; and geochemical modeling to incorporate reactions once leachate impacts groundwater.

A few commenters pointed out that the pore water data are generally representative, although concerns were raised about the highest arsenic concentration (81 mg/L) in the dataset. One commenter believed that although the addition of new data is an improvement, EPA could greatly improve the accuracy of the model's results by removing the extreme and unsubstantiated outlier data driving its high risk cases. Another commenter believed the assumption that concentration of contaminants in the sediment pores (applicable to a post closure scenario) would be equal to the concentration assigned to in the impoundment water would result in underestimated risks. Additionally, commenters noted that EPA should classify the data according to CCR type and coal type.

Overall, commenters support updates to the pore water data and the use of statistical method to normalize the data curve. However, one commenter noted that EPA should not use commenter-submitted CCR pore water data unless it meets requisite applicable data quality requirements. Another commenter stated that EPA needs to provide better clarity on these solicited comments (on the use of older pore water data) and provide these documents in the docket. Without these documents, the reader does not have a complete understanding of co-managed material containing CCR. Another comment noted that properly collected field pore water (freely draining) samples should take priority over any of the laboratory generated data and freely draining pore water is more representative of leachate releases than tightly held pore water.

EPA RESPONSE: The use of pore water data is still considered the most appropriate approach to estimate constituent fluxes to groundwater for CCR surface impoundments. This is because pore water better represents the leachate seeping from the bottom of the impoundment than impoundment water samples. EPA did not use available LEAF data for surface impoundments because a national distribution of pH was not available to allow the Agency to probabilistically assign LEAF concentrations to these units, and because there was no way to account for partitioning of the leachate into wastewater versus porewater. Thus, EPA has continued to rely on pore water data, supplemented with data from the 2010 comments. EPA appreciates commenter support on the use of pore water data and statistical methods for data analysis for surface impoundments. EPA agrees that data available for minefill sites may not be representative of disposal in surface impoundments. Thus, these data were not considered in the revised risk assessment. The specific handling of pore water concentration data with site quartiles, rather than site averages, is discussed in Section 4 and Section 5 of the revised risk assessment report.

EPA agrees that TCLP and SPLP data are less appropriate for CCR disposal scenarios and no longer uses these data in the revised risk assessment. EPA adapted the LEAF methods and data for landfills, as this is the best available approach and data to represent CCR landfill leachates, and does not mix or use field data with LEAF laboratory results for landfill leachate. The LEAF data are considered the most robust and technically defensible data available. As noted in the 2010 Environmental Science and Technology publication,[154] the data represents the largest collection of comprehensive characteristic leaching data to date.

A commenter noted that the LEAF data provide the potential for leaching and not actual leaching of a specific CCR under actual field conditions. The commenter suggests using probability distribution of key factors affecting leaching behavior [*i.e.,* pH and liquid/solid ratio (L/S)] and site specific data tied to the geographic location of the management unit and the type of CCR being managed. In the revised risk assessment, pH is expressed as a

[151] U.S. EPA. 2006. *Characterization of Mercury-Enriched Coal Combustion Residues from Electric Utilities Using Enhanced Sorbents for Mercury Control. EPA–600/R–06/008.* Prepared by F. Sanchez, R. Keeney, D. Kosson, and R. DeLapp for the U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division. February.

[152] U.S. EPA. 2008. *Characterization of Coal Combustion Residues from Electric Utilities Using Wet Scrubbers for Multi-Pollutant Control. EPA/600/R–08/077.* Prepared by F. Sanchez, D. Kosson, R. Keeney, R. DeLapp, L. Turner, and P. Kariher for the U.S. Environmental Protection Agency, Air Pollution Prevention and Control Division. July.

[153] U.S. EPA. 2009. *Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data.* EPA–600/R–09/151. Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC. December.

[154] Thorneloe, S., D. Kosson, F. Sanchez, A. Garrabrants, and G. Helms. 2010. Evaluating the Fate of Metals in Air Pollution Control Residues from Coal-Fired Power Plants. *Environ. Sci. Technol. 44:*7351–7356.

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national distribution for selecting leachate concentrations developed to represent CCR nationally, and L/S is considered in estimating washout leachate concentrations based on field data observations. The use of the pH distribution developed in U.S. EPA (2009) [155] does capture the range of potential variability in pH conditions at CCR sites nationwide and is the best approach possible given the current availability of information on site-specific coal ash chemistry. Although leachate concentrations were selected considering pH and L/S conditions that are nationally representative, EPA does not have the detailed and extensive site-specific measurements that would be needed to tie CCR and leachate concentrations to specific WMU locations. Instead, EPA adopted a national probabilistic approach that is site-based and representative of risks to human and ecological health across the country. The revised risk assessment also provides details regarding how the LEAF data are used in combination of geographical specific data such as hydrology, precipitation, fill configuration, CCR type, pH, L/S ratio, and other factors that take the leaching potential as an input to fate and transport models accounting for attenuation and dilution. Additionally, an effort was made to collect CCR samples that characterize the range and quantity of coal usage in the U.S. along with likely air pollution control configurations. While the data is not statistically representative on a site-specific basis, it is adequate to identify trends in leaching behavior that relate to differences in materials types, APC technology, and coal rank. Geochemical speciation modeling was not conducted because the source term as measured and interpreted is conservative, provided that oxidizing conditions occur.

Regarding the number and concentration of pore water samples, EPA reviewed the high-end pore water concentrations and determined that these represent actual CCR samples that therefore represent possible high-end risks if CCR is inadequately regulated and managed. EPA recognizes that more pore water data would potentially improve the representativeness of the dataset, but is convinced that the current dataset adequately captures the possible high end risks that are of most interest in the rulemaking, including risks from the mismanagement of CCR through codisposal with coal refuse.

The assumption that saturated contaminant concentrations in surface impoundment sediments are at equilibrium with the impoundment waters is a conservative assumption that is unlikely to significantly underestimate risks. This assumption is further discussed in Section 5 of the revised risk assessment report.

Regarding commenter-submitted pore water data, EPA conducted a review of the additional datasets provided by the commenters with respect to relevance and data quality. Based on the available information, EPA determined that the selected datasets were relevant and acceptable in terms of data quality requirements. However, EPA does not have sufficient data to distinguish between freely draining and tightly bound pore water data at this time. Overall, EPA agrees that the use of these data introduces some uncertainty into the analysis, which is discussed in Section 5 of the revised risk assessment.

COMMENT: One commenter questioned the assumption that there will be no net addition of waste into a surface impoundment during and after the operational life, noting that impoundments are frequently deepened. Additionally, many surface impoundment wastes are left in place at the time of closure, so that the waste behaves more as a landfill than a surface impoundment (and increasingly, with new landfills being constructed on top of previous surface impoundments). Another commenter questioned why the conceptual model assumes that impoundments are always full during their operating life, which overestimates releases to the subsurface. Additionally, a commenter noted that the assumption of only 0.2 m of sediment accumulation underestimates the amount of sedimentation and subsequently overestimates the amount of percolation to the subsurface. The commenter stated that in actual operation, ash thickness can increase up to 30 feet or more, eventually filling the impoundment, which results in a significant decrease in percolation through the base. Furthermore, the commenter questioned the assumption that post-closure percolation continues at the same rate as during active operations.

EPA RESPONSE: Based on the 2009/2010 EPA surveys, it was assumed that the majority of the surface impoundments are storage impoundments, which are continuously dredged. Because these facilities have other units (whether onsite or offsite) established for disposition, it likely that the majority of waste in the dredged impoundments would be removed by the end of the unit's operating life. Regardless, an uncertainty analysis provided in appendix K demonstrates that the risks during the operating life of surface impoundments are greater because the higher hydraulic head drives leachate into underlying soils with greater force than gravity alone post-closure. Therefore, EPA did not explicitly model the post-closure phase of surface impoundments. The uncertainties resulting from this decision are discussed in Section 5 of the revised risk assessment.

EPA acknowledges that EPACMTP is restricted to modeling flow as steady state with the assumption that an impoundment always has a fixed depth of wastewater. EPA further acknowledges that such an assumption may overestimate infiltration. The surface impoundment conceptual model assumes that sediments are periodically dredged and removed and that the long-term average thickness of the sediment is approximately 0.4 m, with half of that layer consolidated. EPA has used EPACMTP and its predecessor model versions for a longstanding time period and it has undergone multiple rounds of internal and external review. The reviews associated with EPACMTP and its limitations are further discussed in Section 5 of the revised risk assessment report.

COMMENT: Public commenters suggested that risks from operating landfills should be considered along with those that occur post-closure. These commenters questioned whether greater risks may occur during site operations when wastes are uncovered and exposed directly to precipitation. Additional commenters noted that complete leaching of all constituent mass at a constant concentration is overly conservative.

EPA RESPONSE: The landfill source model used in this risk assessment is not able to address landfills during operation because the non-linear sorption isotherms used require a constant, annualized infiltration rate throughout the duration of leaching. Instead, the revised risk assessment assumed that the full footprint of the landfill is filled to capacity with a cap no less permeable than the soil or liner underlying the WMU is present at the start of leaching. EPA acknowledges that this approach introduces some uncertainty into the analysis, the potential impacts of which are discussed in Section 5 of the revised risk assessment.

With respect to comments that complete leaching of all constituent mass is overly conservative, EPA now

[155] U.S. EPA. 2009. *Characterization of Coal Combustion Residues from Electric Utilities—Leaching and Characterization Data*. EPA–600/R–09/151. Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC. December.

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models landfills using leachable mass as discussed in Section 4 and appendix C of the revised risk assessment. Alternatively, EPA presents a sensitivity analysis of these results compared with the results generated using total mass in Section 5.

3. Comments Related to Exposure Scenarios

COMMENT: The commenter emphasized that the risk assessment does not consider direct discharges to ground and surface water systems other than groundwater infiltration (*e.g.,* direct injection to groundwater, point and nonpoint discharges to surface water systems). It was recommended that EPA consider combining contributions from these sources with CCR groundwater leaching impacts to calculate the full load of CCR constituents to groundwater and surface water systems. The commenter continues by suggesting that the use of liners in impoundments does not reduce overall hazards if direct discharges are considered in the risk assessment.

EPA RESPONSE: RCRA waste disposal risk assessments do not address direct discharges from impoundments to surface waters because they are regulated as permitted point source discharges under the Clean Water Act by EPA's Office of Water. Since this pathway is outside the scope of the risk assessment, the revised risk assessment does not consider these releases. However, this pathway was evaluated in the Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category,[156] which will be revised in support of final effluent limitation guidelines (ELG) due to be released in September of 2015. The revised risk assessment was updated to note this fact.

EPA is not aware of any CCR disposal where waste is directly injected into groundwater aquifers, and absent any data on this practice declines to evaluate it.

COMMENT: Public comments were received on the methodology applied to evaluate exposure to fugitive dust during landfill operations (before closure). The majority of these comments focused on the fugitive analysis as presented in *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills,*[157] and EPA's proposed approach for refining the analysis. Comments received on the initial fugitive dust analysis methodology and modeling ranged from emphasizing that the approach was overly conservative in some cases to underestimating risk in other cases.

Multiple comments were provided on the proposed methodology for refining the fugitive dust analysis that was applied in the revised risk assessment. One commenter recommended that 2010/2011 EPA survey data should be used to refine the fugitive dust analysis for landfills. Specifically, the current OW data indicate that active portions of the landfills are significantly smaller than the landfills identified in the 1995 EPRI survey. Several comments were received that pointed out that the application of AERSCREEN and AERMOD is appropriate if representative or realistic inputs are used including meteorological data, material silt content, source areas for subcells of ash management units and consideration of common operating and control practices, which are in some cases defined by the states (*e.g.,* Virginia). However, one commenter expressed concern that no previous or current EPA regulatory model; including SCREEN3, AERSCREEN or AERMOD; has been rigorously tested and evaluated for performance in modeling fugitive emissions associated with CCR landfills.

In general, the commenters supported or recommended the use of appropriate AP–42 factors and other techniques to estimate emissions. Others noted that consideration of deposition impacts and constituent-specific modeling is appropriate. One commenter recommended that EPA should conduct a full-scale assessment that considers fugitive dust as well as emissions from landfills and emissions of diesel particulate matter from haul trucks, on-site heavy-duty landfill equipment, and diesel-powered pumps and generators, with potential receptors of interest as residents and sensitive subpopulations living near the power plant, along the transportation route and at the landfill. Another commenter expressed concern over the lack of metal speciation data, while another comment concerned gas emissions from the landfills (*e.g.,* hydrogen sulfide). One final commenter voiced concern that insufficient information was provided on the modeling approach and the model inputs to support evaluation and allow comments on the overall validity or propriety of the suggested modeling.

EPA RESPONSE: The majority of the comments received concerning exposures during landfill operation (before closure) focused on the assessment of fugitive dust. EPA acknowledges that the 2010 Draft Risk Assessment did not evaluate the inhalation pathway, relying instead on the findings of a previous evaluation, *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills.*[158] This previous evaluation only considered releases from windblown emissions and the potential to exceed national ambient air quality standards (NAAQS) for particulate matter.

Based on the comments received, EPA updated the screening analysis of fugitive dust. EPA agrees that there are potential risks posed by fugitive emissions from sources beyond wind and revised the analysis to consider emissions from a range of activities, such as vehicular activity, unloading operations and spreading/compacting operations. Emissions from these sources were calculated using techniques that have undergone extensive peer-review, including *AP–42: Compilation of Air Pollutant Emission Factors.*[159] Screening level modeling was performed with a combination of AERSCREEN and AERMOD to estimate dust dispersion and deposition rates. Model inputs were selected to be representative of current landfills, environmental settings (*e.g.,* meteorological conditions) and common dust management practices. Estimated air concentrations were used to screen acute and chronic health risks from inhalation, as well as the potential to exceed NAAQS standards. Furthermore, EPA considered exposures that may result from the offsite deposition on and accumulation in downgradient media. This was done for all relevant metal species. In contrast, EPA did not evaluate emissions of hydrogen sulfide to air as EPA has no data on the extent to which this constituent is present in CCR or released into the surrounding environment. Further discussion of this screening analysis is presented in

[156] U.S. EPA. 2013. Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category. EPA–821–R–13–003. Office of Water. Washington, DC 20460. April.

[157] U.S. EPA. 2010. *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills.* OSWER. Washington, DC. September.

[158] U.S. EPA. 2010. *Inhalation of Fugitive Dust: A Screening Assessment of the Risks Posed by Coal Combustion Waste Landfills.* OSWER. Washington, DC. September.

[159] U.S. EPA. 1985. *Compilation of Air Pollutant Emission Factors. Volume I: Stationary Point and Area Sources (Fourth Edition).* AP–42. U.S. Environmental Protection Agency, Office of Air and Radiation and Office of Air Quality Planning and Standards, Research Triangle Park, NC. September.

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Section 3 and appendix F of the revised risk assessment.

COMMENT: Comments both supported and disagreed with the appropriateness of a screening analysis to eliminate pathways from consideration in the full-scale probabilistic analysis. One commenter pointed out that the EPA conducted a very conservative, but appropriate, screen to identify constituents to include in the full-scale probabilistic analysis. Another commenter emphasized that a full-scale risk assessment should be conducted that assesses exposures concurrently through all pathways (*e.g.,* including surface pathways with inhalation exposure) for all chemical constituents. In particular, they emphasized that inhalation exposures to human carcinogens, such as hexavalent chromium, as well as noncarcinogens may occur through the aboveground pathway. Although the commenters disagreed over the use of a screening approach, both expressed concerns over the use of risk attenuation factors to scale screening risks to the full-scale risks for the subset of constituents that did not pass the screen and were not evaluated under the full scale assessment. Both commenters believe that this approach ignores the unique fate and transport properties of the omitted constituents and that the use of a simplistic, attenuation factor is not an appropriate way to estimate risk.

EPA RESPONSE: By first conducting the screening analysis presented in Section 3 of the revised risk assessment, EPA was able to focus available resources on the characterization of risks for exposure routes and constituents with the greatest potential to pose risks. The screening analysis conducted for the revised risk assessment considered all of the potential exposure routes identified in the conceptual models for surface impoundments and landfills, which included aboveground exposures to ambient air, soil, sediment, produce, and animal products. Each exposure pathway was evaluated for all constituents (and individual species, as appropriate) for which both concentration and toxicity data were available.

The screening analysis was developed to be protective of highly exposed individuals. Due to the conservative nature of the screening, the calculated risks represent a protective, but unlikely, combination of conditions that most likely reflect an upper bound on potential exposures for each individual constituent. The revised screening assessment did not rely on risk attenuation factors to screen out constituents. All constituents that resulted in screening-level risks above human health or ecological criteria, and for which characterization of fate and transport could be refined, were carried forward for further consideration in the probabilistic analysis, described in Section 4 of the revised risk assessment. It is possible that consideration of exposure to multiple constituents through a single pathway or to the same constituent through multiple pathways may have resulted in the retention of some additional constituents. However, it is highly unlikely that these additional constituents would remain risk drivers once more realistic dilution and attenuation in the environment is considered.

COMMENT: Multiple commenters noted that there may be additional constituents present in CCR wastes beyond those quantitatively evaluated in the risk assessment. In particular, multiple commenters referenced organics and radionuclides. Some commenters called on EPA to quantify the risks associated with these additional constituents. Others claimed that these constituents are present in low levels and do not pose risk to receptors.

EPA RESPONSE: In the *Report to Congress: Wastes from the Combustion of Fossil Fuels: Volume 2—Methods, Findings, and Recommendations,*[160] EPA reviewed the available data on organic constituents, such as polyaromatic hydrocarbons and dioxins. These data indicated that concentrations of all organics are near or below analytical detection limits both in CCR and in the leachate released from CCR. Based on the findings of this report, the Agency concluded that organic constituents were not risk drivers and did not require further evaluation. In the absence of additional data that demonstrate the organic composition of CCR wastes have markedly changed, EPA continues to rely on these findings.

EPA acknowledges that, like other inorganic constituents, naturally-occurring radionuclides may be concentrated in CCR waste through the combustion of coal. However, due to a lack of data that could be used to characterize leachate concentrations for individual radionuclides, a quantitative evaluation of risk was not conducted. To address this data gap, EPA has included radionuclides in the list of constituents for groundwater monitoring. Furthermore, potential transport of these constituents downgradient by windblown dust and storm run-off are addressed through requirements for fugitive dust controls and run-on/run-off controls.

4. Comments Related to Human Exposure and Toxicity

COMMENT: Some commenters argued that EPA underestimated risks by not considering combined chemical effects, additive risk and concurrent exposures through multiple pathways. One commenter indicated that EPA should conduct a full scale assessment that considers concurrent exposure from ingestion of fish and groundwater. Commenters also raised concerns that some chemical constituents share a common mechanism of toxicity and may affect the same body organ or system, resulting in greater risks than predicted through the consideration of each constituent separately.

One commenter noted that the combination of risks from different constituents would not change the overall results of the risk assessment. Constituents concentrations found to result in an HQ less than 1 in the screening analysis are unlikely to make a meaningful contribution to overall risk regardless of whether multiple compounds share the same toxicological endpoints. Additionally, the commenter expressed that it would be inappropriate to add the risks from different constituents as modeled because the constituents do not all arrive at a hypothetical receptor at the same time, due to differing mobility in the subsurface environment.

EPA RESPONSE: EPA acknowledges that this risk assessment considered potential risks to human health from individual constituents and individual pathways. EPA acknowledges that not explicitly evaluating cumulative risk is a source of uncertainty that may result in some underestimation of risks. It is possible that an individual could be exposed to risks from drinking contaminated groundwater, as well as eating contaminated fish from a local surface water body, but it is unlikely that these two exposure pathways would occur simultaneously with any appreciable frequency in the real world. It is even more unlikely that a receptor would be exposed to both media at the high-end concentrations modeled. Therefore, the magnitude of the uncertainty introduced into the risk assessment is likely to be small. It is also possible for an individual to be exposed to multiple constituents through a single pathway. This is a more likely scenario because, as demonstrated

[160] U.S. EPA (Environmental Protection Agency). 1999b. Report to Congress: Wastes from the Combustion of Fossil Fuels: Volume 2—Methods, Findings, and Recommendations (EPA 530–R–99–010). Office of Solid Waste and Emergency Response. Washington, DC.

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by the available data, CCR typically leach multiple inorganic constituents. Where exposure to multiple constituents is likely to occur, EPA policy is to assume that the risks resulting from these exposures are additive.[161] The current probabilistic analysis identified individual constituents above risk criteria. Many of the other constituents modeled resulted in risks an order of magnitude or more below risk criteria. Thus, the consideration of additive risk, even with the high-end risks modeled in this risk assessment, is unlikely alter the principal results of the probabilistic analysis. Similarly, because the risks for individual constituents were found to be above levels of concern, consideration of additive risk is unlikely to meaningfully change the results of the analysis. EPA updated the revised risk assessment to include a discussion of the associated uncertainties in Section 5.

COMMENT: Some commenters identified incorrect and inconsistent reporting of toxicity benchmark values and recommended conducting a thorough review of literature to ensure the use of the most current values were used. One commenter expressed concern over the use of the current IRIS value for arsenic carcinogenic effects and believes it underestimates risk. Other commenters emphasized that it would be inappropriate for EPA to consider using the draft oral cancer slope factor (CSF) for arsenic and the oral CSF for hexavalent chromium [chromium (VI)] published by the New Jersey Department of Environmental Protection (NJDEP). Concerning lead, one commenter supported a peer reviewer's recommendation to use the Integrated Exposure Uptake Biokinetic (IEUBK) model to calculate human health risks, especially for young children. Additionally, a commenter requested chemical-specific information on toxicity criteria derivation, as well as information on the relationship between environmental exposures to specific chemicals and adverse health effects. The commenter emphasized that this information would provide an uncertainty discussion regarding toxicity values, facilitate communication with the public, and provide a balanced perspective on risk.

EPA RESPONSE: Human health benchmarks were chosen based on the Office of Solid Waste and Emergency Response hierarchy (OSWER Directive 9285.7–53).[162] EPA reviewed the benchmarks to confirm their accuracy and determine whether newer values have become available from EPA or other sources used by EPA since the CCR draft risk assessment was conducted. The current, updated list of human health benchmarks is provided in appendix E of the revised risk assessment, and the references cited in that appendix provide further information on the potential adverse effects and derivation of toxicity criteria.

For lead, EPA used the drinking water maximum contaminant level (MCL) to estimate risks from drinking water exposure in the draft risk assessment. In the revised risk assessment EPA continued to rely on the MCL, but also used IEUBK model for lead in children as described in Section 5 of the revised risk assessment. While lead failed the screening assessment, risks from lead exposure in the probabilistic assessment were well below the risk criterion, and did not drive risks in either the probabilistic or any sensitivity analyses.

COMMENT: The commenters questioned why the cancer benchmark of 1×10^{-5} was selected while the typical range used by OSWER and EPA guidance is a range from 1×10^{-4} to 1×10^{-6}. The commenters suggested that an explanation is necessary. In particular, one commenter requests clarification on the phrase ''point of departure'' when supporting the use of the cancer benchmark of 1×10^{-5}. Concerning non-cancer criteria, a commenter suggested that non-cancer risks should be report as follows: Worst Case—Assume maximum exposure scenarios including exposure 24-hours/day, 365 days/year for 70 years; High End—95th percentile based on national human activity pattern distributions; Central Tendency—50th percentile (or median) risk based on national human activity pattern distributions. Furthermore, another commenter believed that it is more appropriate to consider 95th percentiles, rather than 90th percentile, of exposure and risk estimates for humans and ecological receptors.

EPA RESPONSE: The rationale for the selected cancer and non-cancer risk criteria, based on Agency policy, is discussed in Section 2 of the revised risk assessment. A citation to the where ''point of departure'' was originally defined is provided for reference. The rationale for use of 90th percentile risk generated by a Monte Carlo simulation is discussed in Section 4 of the revised risk assessment.

COMMENT: Commenters questioned the evaluation of only the reasonable maximum exposure scenario. Specifically, it was noted that the receptor placement downgradient of an unlined management unit does not represent the entire population exposure distribution. One commenter suggested that EPA clearly define the exposed population of interest.

EPA RESPONSE: In risk assessments used to develop regulations under RCRA, EPA has historically assessed potential risks resulting from a reasonable maximum exposure (RME) scenario in order to ensure that the resulting regulation is adequately protective of human health without being excessively conservative. The types of data necessary to define the exact population that relied on groundwater wells as a source of drinking water or consumes fish from impacted water bodies are not available. EPA believes that consideration of RME is a reasonable and protective alternative, given the available data. Uncertainties associated with the revised risk assessment are further discussed in Section 5 of the revised risk assessment.

COMMENT: The commenters questioned the use of data from the 1997 Exposure Factors Handbook in the development of intake rate distributions for various exposures, because more current data are currently available. Commenters recommended that EPA make updates to these parameters using more current sources of information, including the recently released 2011 Exposure Factors Handbook.[163] In addition, some commenters pointed out the potential for the available exposure factor data to underestimate or overestimate exposures. One commenter noted that the risk assessment did not fully account for the dependence of input variables (*e.g.,* the interdependence of body weight and water ingestion rates for children and link between the rate of fish consumed from a water body). Another commenter suggested that a sensitivity analysis of human health exposure factors be conducted to add to the sensitivity analysis conducted by EPA in 2009.

Regarding fish consumption rates, commenters questioned the representativeness of a fixed fish consumption rate drawn from a single

[161] U.S. EPA. 2000. *Supplementary Guidance for Conducting Health Risk Assessment of Chemical Mixtures.* Risk Assessment Forum, Washington, DC. August.

[162] U.S. EPA. 2003. *Human Health Toxicity Values in Superfund Risk Assessments.* Office of Solid Waste and Emergency Response Directive 9285.7–53. December.

[163] U.S. EPA. 2011. *Exposure Factors Handbook: 2011 Edition.* EPA/600/R–090/052F. National Center for Environmental Assessment, Office of Research and Development, Washington, DC. September.

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study. It was suggested for transparency that the risk assessment provide the results of the chi-square tests to demonstrate how well the fish consumption rate data fit a log normal distribution. Additionally, it was suggested that fish consumption rates should be determined from other studies and more robust data sets. One commenter suggested the incorporation of fish consumption rates representative of subsistence fishers, such as Native American populations that harvest and consume fish as part of their native traditions and culture.

Regarding drinking water ingestion rates, one commenter voiced concern about the assumption that groundwater is the source of all drinking water. The commenter indicated that this is an overly conservative and atypical assumption, as a majority of individuals will consume liquids from other sources (*e.g.,* milk, juice, sodas, bottled water, sports and energy drinks).

EPA RESPONSE: This revised risk assessment relied on both the 1997 *Exposure Factors Handbook (EFH)* [164] and the 2008 *Child-Specific Exposure Factors Handbook* (*CSEFH*) [165] for information on human exposure factors for the U.S. population. The 2011 *Exposure Factors Handbook* [166] has been completed and updates some of the data from the 1997 EFH. During the finalization of this risk assessment, EPA released *OSWER Directive 9200.1–120.*[167] Although this document provides default exposure factors to use for point estimates, EPA is still in the process of updating the full distributions necessary for probabilistic analysis. Therefore, this risk assessment does not incorporate the data from the 2011 EFH.

Exposure data used for the fish ingestion rates are described in appendix D of the revised risk assessment. Data on site-specific fish consumption rates were not available for use in this analysis. Instead, the full distribution of fish consumption rates were drawn from a study of adult anglers from Maine that fished from streams, rivers, and ponds. Because age-specific data for children were not available, all child cohorts were assumed to consume fish at the same rate as the adult cohort. Data on fish ingestion rates for Native American subsistence fishers are currently limited and can vary widely geographically, to the point that the 2011 EFH makes no recommendation for representative values. EPA acknowledges that these issues introduce uncertainty into the analysis, which are further discussed in Section 5 of the revised risk assessment.

COMMENT: Commenters emphasized the need to update exposure factors for childhood exposures and recommended that updates include data from the 2011 EFH. One commenter stated that the risk assessment appropriately considered the potential fish exposures for children. However, they pointed out that the fish consumption rates for children should be lower than those applied for adults. Another commenter suggested that the risk assessment should provide a clear description of how the exposure duration of child cohorts were used in the risk calculations. Specifically, the commenter questioned whether exposure durations were truncated at the end of each age cohort or aged through the different cohorts.

EPA RESPONSE: The revised risk assessment makes use of the 1997 EFH [168] and the 2008 CSEFH [169] for information on human exposure factors for the U.S. population. Although, as discussed in the preamble sections above, the revised risk assessment does not incorporate data from the recent 2011 EFH,[170] all child data included in this document was derived from the 2008 EFH. In addition to child ingestion of drinking water, EPA's evaluation has been revised to also account for infant exposures that may occur from formula mixed with contaminated groundwater. These data are presented in appendix D of the revised risk assessment. Consistent with the commenter's recommendation for cohort aging, the risk assessment aged receptors through each age cohort using age-specific data for exposure factors and physical characteristics that were weighted proportionally by the corresponding time period and then summed. Specific discussion of truncation values is provided in later in this preamble.

COMMENT: Public commenters recommended updating BCF values with more current references. One commenter questioned why bioconcentration factors were zero for some constituents that are essential nutrients (*i.e.,* cobalt and copper). Another commenter voiced concern that EPA had not fully considered the appropriateness of using BCFs to describe metals bioaccumulation, suggesting that current science (including EPA guidance documents) indicates that BCFs are poor predictors of tissue metal concentrations due to wide variation in uptake patterns governed by several chemical and biological factors. Another commenter recommended the use of an approach that would be more robust than the single BCF approach, establishing and applying distributions of BCFs. This commenter also recommended that the assessment adhere to the EPA policy of using dissolved metals in the calculating the bioconcentration of metals in fish, or should provide the rationale for using a different approach.

EPA RESPONSE: EPA recognizes that the use of BCFs may not represent the most current approaches available to estimate metal bioaccumulation at individual sites, where fish tissue data can be collected. However, as noted by public commenters, BCFs are useful in a screening-level assessment and EPA believes they are also appropriate for a national-level risk assessment, where site-specific data are not available and collection of site-specific data is not viable.

In some cases, insufficient data to determine a BCF value meant that these constituents could not be quantitatively evaluated for this pathway. Regarding the concern expressed with respect to zero BCF values, the commenter did not provide alternative BCFs that EPA could consider for the constituents at issue. Additionally, EPA agrees that, given the latest scientific information, distributions of BAFs/BCFs may be better than single BAFs/BCFs because they account for changes in bioaccumulation/bioconcentration at different water concentrations. EPA is working to develop BAF/BCF distributions for several CCR pollutants of concern but does not yet have a robust enough dataset for use for the final CCR Rule. In lieu of this, EPA is proceeding with the single BAF/BCF approach for the current analysis. EPA does recognize this issue as a limitation for the BCF calculations and considers it as an uncertainty in the risk

[164] U.S. EPA. 1997. *Exposure Factors Handbook, Volume III, Activity Factors.* EPA/600/P–95/002Fa. Office of Research and Development, Washington, DC. August.

[165] U.S. EPA. 2008. *Child-Specific Exposure Factors Handbook.* EPA/600/R–06–096F. National Center for Environmental Assessment, Cincinnati, OH.

[166] U.S. EPA. 2011. *Exposure Factors Handbook: 2011 Edition.* EPA/600/R–090/052F. National Center for Environmental Assessment, Office of Research and Development, Washington, DC. September.

[167] U.S. EPA. 2014. *Human Health Evaluation Manual, Supplemental Guidance: Update of Standard Default Exposure Factors.* OSWER Directive 9200.1–120. February.

[168] U.S. EPA. 1997. *Exposure Factors Handbook, Volume III, Activity Factors.* EPA/600/P–95/002Fa. Office of Research and Development, Washington, DC. August.

[169] U.S. EPA. 2008. *Child-Specific Exposure Factors Handbook.* EPA/600/R–06–096F. National Center for Environmental Assessment, Cincinnati, OH.

[170] U.S. EPA. 2011. *Exposure Factors Handbook: 2011 Edition.* EPA/600/R–090/052F. National Center for Environmental Assessment, Office of Research and Development, Washington, DC. September.

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characterization. Overall, EPA agrees that the use of this older data introduces some uncertainty into the analysis. These uncertainties are discussed in greater detail in Section 5 of the revised risk assessment.

With the exception of mercury, EPA evaluated bioconcentration based on water column concentrations that include contributions from dissolved and solid phases because available BCFs represent contributions from both. Because a BAF based only on dissolved-phase concentrations was available for mercury, EPA evaluated this constituent using only dissolved concentrations. Applying this conservative approach for most constituents ensured protection of human health. Even with this conservative assumption, the 90th percentile risks for the probabilistic analysis (Section 4) did not exceed risk criteria for the fish ingestion pathway. Therefore, this approach is unlikely to have affected the principal findings of the risk assessment.

For the revised risk assessment, EPA reviewed the available literature and identified BCFs for additional constituents that previously had no values. As noted in appendix G of the revised risk assessment, the following source hierarchy was used for fish BCFs:

- Primary literature: These are generally papers focused on a single chemical [171] [172] [173] [174] or may contain data on multiple chemicals.[175] [176]
- U.S. EPA databases/publications: These included ECOTOX [177] and the Mercury Report to Congress.[178]
- Other government agency resources: These included ATSDR Toxicological Profiles [179] and the Hazardous Substances Data Bank.[180]

EPA also finds that the references provided by commenters provided primarily phytotoxicity and accumulation data for terrestrial plants, and were therefore not relevant to EPA's explicit solicitation on whether the bioconcentration factors drawn from Baes et al. (1984) should be considered in the final risk assessment.[181]

5. Comments Related to Ecological Exposure and Toxicity

COMMENT: Public commenters emphasized the potential importance of cumulative ecological risk, whereby an ecological receptor may be exposed to multiple constituents and/or pathways concurrently. For example, amphibians may be subject to both dermal and ingestion exposure. Public commenters noted that ecological risks were underestimated because the following scenarios were not considered for ecological receptors: Aboveground pathways, contaminant transport to nearby uncontaminated environments, and the inclusion of field data in the analysis.

EPA RESPONSE: EPA acknowledges that cumulative effects can be important for ecological receptors. However, just as EPA did not consider cumulative human health risks from exposures to groundwater (discussed in the previous sections of this preamble), they were not modeled for ecological receptors. In the national, probabilistic analysis (Section 4 of the revised risk assessment), risks for all constituents fell below the ecological criteria. Even the sum of modeled risks for all constituents fell below the ecological criteria. In sensitivity analyses (Section 5 of the revised risk assessment), which considered different subsets of national disposal practices that may drive risks, boron and cadmium were the two constituents found to result in risks above ecological criteria. To the extent that cumulative exposures were not evaluated, EPA acknowledges that ecological risk could be underestimated to some degree. However, these uncertainties are unlikely to affect the principal findings of the risk assessment. In addition, EPA also notes that all surface water risks are orders of magnitude lower than the risks resulting from direct discharges modeled in U.S. EPA (2013).[182]

In contrast to the surface water and sediment exposures, ecological risks for individual constituents were appreciably above risk criteria for direct exposure to impoundment wastewater. As a result, it is clear that CCR disposal in surface impoundments have the potential to pose risk to ecological receptors, even without consideration of cumulative exposures.

COMMENT: Public commenters stated that the risk assessment does not consider sensitive habitats or species. Commenters requested additional consideration of threatened and endangered species and the inclusion of ecological field data.

EPA RESPONSE: EPA did not evaluate these sensitive habitats and sensitive/endangered ecological receptors because these are inherently site-specific issues for which data on potential impacts are often not available and can be difficult to quantify, even on a site-specific basis. EPA acknowledges that the inability to quantitatively evaluate the potential for these adverse effects represents a source of uncertainty. Discussion of these uncertainties is presented in Section 5 of the revised risk assessment.

COMMENT: Public commenters were concerned that a more conservative approach was needed to derive the ecological benchmarks. Multiple commenters also stated that the use of risk attenuation factors to scale the screening risks to full-scale risks was inappropriate. Several commenters noted that the ecological boron benchmark used for surface water exposures contained incorrect units based on an incorrect transcription in the peer-reviewed article. Another commenter noted that the ecological

[171] Eisler, R. 1989. *Molybdenum Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review.* Contaminant Hazard Reviews, Report No. 19, Biological Report 85(1.19). Laurel, MD. August.

[172] Kumada, H., et al. 1973. Acute and chronic toxicity, uptake and retention of cadmium in freshwater organisms. Bull. *Freshwater Fish.* Res. Lab. 22: 157

[173] Lemly AD. 1985. Toxicology of selenium in a freshwater reservoir: implications for environmental hazard evaluation and safety. *Ecotoxicology and Environmental Safety.* 10(3): 314–338.

[174] Murphy, B.R., G.J. Atchison, and A.W. McIntosh. 1978. Cadmium and zinc in muscle of bluegill (Lepomis macrochirus) and largemouth bass (Micropterus salmoides) from an industrially contaminated lake. *Environmental Pollution* 17:253–257.

[175] Barrows ME, Petrocelli SR, Macek KJ, Carroll JJ. 1980. Bioconcentration and elimination of selected water pollutants by bluegill sunfish (Lepomis macrochirus). In: Haque R, ed. Dynamics, exposure and hazard assessment of toxic chemicals. Ann Arbor, Michigan, U.S.A.: American Chemical Society. p. 379–392.

[176] Stephan, C.E. 1993. Derivation of Proposed Human Health and Wildlife Bioaccumulation Factors for the Great Lakes Initiative. Draft. Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Duluth, MN. March.

[177] U.S. EPA (Environmental Protection Agency). 2009b. E*COTOX User Guide: ECOTOXicology Database System*. Version 4.0. Available online at *www.epa.gov/ecotox/*.

[178] U.S. EPA (Environmental Protection Agency). 1997d. *Mercury Study Report to Congress. Volume III—Fate and Transport of Mercury in the Environment.* EPA 452/R–97/005. Office of Air Quality Planning and Standards and Office of Research and Development, Washington, DC.

[179] ATSDR (Agency for Toxic Substances and Disease Registry). 2008. Minimal Risk Levels (MRLs) for Hazardous Substances. Available at *www.atsdr.cdc.gov/mrls.html*.

[180] U.S. NLM (National Library of Medicine). 2011. *Hazardous Substances Data Bank (HSDB).* Available online at: *toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB*.

[181] Baes, C.F., III, R.D. Sharp, A.L. Sjoreen, and R.W. Shor. 1984. *A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides Through Agriculture.* ORNL–5786. Oak Ridge National Laboratory, Oak Ridge, TN. September.

[182] U.S. EPA. 2013. Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category. EPA–821–R–13–003. Office of Water. Washington, DC 20460. April.

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cadmium benchmark used for direct contact with surface water was incorrect.

EPA RESPONSE: Ecological benchmarks were obtained for CCR constituents when available and compared with the modeled media concentrations (*e.g.,* surface water, sediment) to estimate the HQs used to characterize ecological risk. These benchmarks represent the best available estimates of receptor responses based ''no effects'' (NOAEL) or ''lowest effects'' (LOAEL) study data. In some scenarios, these benchmarks may represent species not actually present in the field. In others, these benchmarks may not capture the most sensitive possible receptor at every site or for each constituent. While some benchmarks have factors of safety included to account for these or other uncertainties, there remains the potential for these ecological benchmarks to underestimate risks for the specific species and communities that live in surface waters impacted by CCR WMUs. The magnitude of this uncertainty is unknown. Consideration of any additional sensitive species not captured by the current benchmarks may result in some additional constituents above risk criteria in the probabilistic analysis. EPA notes that ecological risks to some of these additional sensitive receptors may be reflected in damage cases. However, this site-specific uncertainty is unlikely to affect the national conclusions of the risk assessment.

Regarding incorrect benchmark values, an updated boron benchmark was used in the revised risk assessment. The units in the fish study from which the previous SCV was derived [183] had been erroneously transcribed in Suter and Tsao (1996) [184] as µg/L instead of mg/L. The updated SCV was recalculated using the corrected units. The revised value has been corroborated with the authors. Additionally, a continuous criteria concentration (CCC) was used for the cadmium surface water benchmark in the revised risk assessment, replacing the previous value. The updated values are presented in appendix E of the revised risk assessment report.

[183] Hamilton, S.J. 1995. Hazard assessment of inorganics to three endangered fish in the Green River, Utah. *Ecotoxicol Environ Saf 30*:134–142.

[184] Suter, G.W., and C.L. Tsao. 1996. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision.* U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN. June.

6. Comments Related to the Monte Carlo Analysis Approach

COMMENT: While some public commenters stated that the human health probability distributions appeared appropriate, others expressed concern regarding a conservative bias in input parameter probability distributions used and the resulting potential for overestimation of risks. These commenters noted that the ideal approach would be to estimate the actual risk and associated uncertainty rather than weighting the results conservatively.

EPA RESPONSE: The revised risk assessment conducted a full-scale, probabilistic Monte Carlo analysis to quantify human and ecological risks. EPA agrees it would be ideal to produce best estimates of actual risk. All input data distributions (*e.g.,* aquifer data, soil type, WMU data, climate data, distance to groundwater wells, distance to surface water bodies, constituent concentrations, water flow data, human exposure factors) were developed in line with this objective. However, these distributions were developed from available data and are subject to the limitations of these data. In cases where data were not sufficient to fully characterize the input distribution, conservative values and assumptions were used to fill data gaps to remain protective of human health and the environment. Further discussion of these uncertainties has been added to Section 5 of the revised risk assessment.

COMMENT: Public commenters pointed out that the risk assessment does not formally differentiate variability from uncertainty or show confidence limits for risk results, which makes it challenging to identify opportunities to reduce uncertainty. One commenter requested that EPA discuss the implications of the relatively wide risk distributions, including the reasons why some risk distributions are larger than others based on the Monte Carlo results.

EPA RESPONSE: EPA acknowledges it would be ideal to separate variability from uncertainty when possible in a probabilistic risk assessment. EPA was able to reduce a substantial number of the uncertainties in the revised risk assessment through the acquisition of additional data on facilities, environmental parameters, and constituent concentrations. Variability and uncertainty are still comingled in a large number of cases due to remaining data gaps; however, EPA conducted multiple sensitivity analyses to determine the potential for different inputs to affect risk results. Additional discussion of the differences between parameter variability, data uncertainty, and model error, as well as discussions of the sensitivity and uncertainty analyses, is presented in Section 5 of the revised risk assessment.

EPA disagrees that there are wide risk distributions. While the commenter correctly points to other risk assessments that had closer central tendency and high-end results, those were either site-specific assessments or involved no fate or transport modeling. National-scale risk assessments will necessarily have wider variability in their results compared to risk assessments that are specific to a single site. Thus, the ''wider'' risk distributions simply reflect the fact that different sites with different CCR can have very disparate impacts on human health and the environment.

7. Miscellaneous Comments

COMMENT: Some commenters stated that the documentation is incomplete and that an independent reviewer could not reproduce the analysis. Another commenter performed an independent review and cancer risk estimate and noted that the EPA used a reasonable approach for calculating cancer cases in the risk assessment.

EPA RESPONSE: EPA acknowledges that the documentation of the inputs and intermediate outputs could have been more transparent for the 2010 Draft Risk Assessment. In the revised risk assessment, many of the inputs EPA used are directly discernible from the appendices. A summary of the data available in each appendix is presented in Section 1 of the revised risk assessment. EPA also acknowledges that the additions and discussions of inputs in the document were not sufficient for complete duplication of the results. Thus, the input and output files for the draft risk assessment were made available in the docket of the proposed rule via an FTP site,[185] and final input and output files are being placed in the docket for the final rule.

COMMENT: Commenters requested improvement on the graphical presentation of risk results. Additionally, commenters requested further explanation of the minimum and maximum truncating values, as truncated values may reduce risk estimates.

EPA RESPONSE: While EPA did not provide a graphical presentation of the risk results, this information is more clearly discernible from the full input and output files. For discussion of the

[185] Available online at: *ftp://ftp.epa.gov/coal-combustion-residues.*

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full inputs and outputs files, see the responses in the preamble section above. With regard to truncation, EPA no longer manually truncates input distributions for the human exposure factors. Instead, exposure factor distributions in the revised risk assessment were generated with the @ Risk software (Palisade Co., Newfield, NY),[186] as described in appendix D. EPA has also added further discussion of the cohorts to revised risk assessment, with tables comparing each cohort's risk presented in Section 5 of the revised risk assessment.

COMMENT: Commenters requested more complete documentation of the sensitivity analysis. Other comments included a request to add human health exposure factor variables to the sensitivity analysis, and to conduct additional sensitivity analyses on different topics (*e.g.,* well distance distribution).

EPA RESPONSE: EPA acknowledges the omission of the original sensitivity analysis from the docket. EPA updated the sensitivity analysis [187] so that it clearly describes the methodology that underlies the results summarized in Section 5 of the revised risk assessment. This sensitivity analysis was placed in the docket for the proposed rule.

Human health exposure factor variables were not evaluated in the sensitivity analysis. Human exposure factor variables have well-established, peer-reviewed, national distributions that are regularly used in probabilistic risk analyses conducted by EPA based on Agency policy. Therefore, the contribution of variability in the exposure factors to the variability in risk was not particularly useful for understanding the aspects of CCR disposal practices that may drive risk. Additional sensitivity analyses such as leachate duration versus leachable content and liner performance by thickness were conducted in the revised risk assessment and are summarized in Section 5.

B. Summary of Risk Assessment and Results

1. Problem Formulation

EPA first developed conceptual models to illustrate a general layout of surface impoundments and landfills, the chemical constituents that may be released from these WMUs, the routes through which these constituents may migrate through environmental media, and the types of exposures that may result. These conceptual models were used as the basis for all subsequent data collection efforts. EPA first collected data on the coal-fired power plants and CCR WMUs located across the United States. EPA then collected regional and national data to characterize the environment and receptor population surrounding each WMU. The data assembled represent the most current and comprehensive information available to the Agency at the time this risk assessment was conducted. Using the data collected, EPA first conducted a simplified hazard identification to determine which constituents warranted further evaluation. At this stage, EPA considered the presence of a constituent in CCR waste, combined with the availability of at least one toxicity benchmark, sufficient evidence of hazard potential. Table 1 presents a summary of the different chemical constituents retained as constituents of potential concern (COPCs) for further analysis.

TABLE 1—LIST OF CHEMICAL CONSTITUENTS EVALUATED IN THE CCR RISK ASSESSMENT

Aluminum
Ammonia
Antimony
Arsenic
Barium
Beryllium
Boron
Cadmium
Calcium
Chloride
Chromium
Cobalt
Copper
Fluoride
Iron
Lanthanum
Lead
Lithium
Magnesium
Manganese
Mercury
Molybdenum
Nickel
Nitrate/Nitrite
Selenium
Silicon
Silver
Sodium
Strontium
Sulfate
Sulfide
Thallium
Uranium
Vanadium
Zinc

All risks identified in subsequent analyses were compared against risk criteria of cancer risk greater than 1×10^{-5} or a noncancer hazard quotient (HQ) greater than 1. EPA typically relies on a risk range to determine the point at which regulation is appropriate. EPA uses as an initial cancer risk ''level of concern'' a calculated risk level of 1×10^{-5} (one in one hundred thousand) or an HQ above 1.0 for any noncarcinogens. For example, waste streams for which the calculated high-end individual cancer-risk level is 1×10^{-5} or higher generally are considered candidates for regulation. Waste streams whose risks are calculated to be 1×10^{-4} or higher generally will be considered to pose a substantial present or potential hazard to human health and the environment and generally will be regulated. Waste streams for which these risks are calculated to be 1×10^{-6} or lower, and lower than 1.0 HQs or EQs for any noncarcinogens, generally will be considered not to pose a substantial present or potential hazard to human health and the environment and generally will not regulated. See 59 FR 66075–66077, December 22, 1994.

2. Screening Analysis

EPA conducted separate screening analyses for each exposure pathway to identify which COPCs are most likely to pose risk to receptors. The results of this screening generally do not provide a precise characterization of individual risks that may occur, but rather identify those COPCs that are most likely to exceed risk criteria. In cases where well established, post-construction management practices (''controls'') have been shown to minimize releases from WMUs, EPA considered exposures for both an uncontrolled and controlled management scenario.

This screening analysis identified potential risks to human and ecological receptors resulting from the releases of particulate matter and the chemical constituents contained therein through wind and run-off. Under an uncontrolled management scenario, risks to human receptors resulted from the inhalation of windblown particulates in ambient air and the ingestion of soil and animal products (*i.e.,* meat and dairy), while risks to ecological receptors resulted from exposures to soil and sediment. Under a controlled management scenario, which consisted of fugitive dust controls and run-on/run-off controls, all risks associated with these exposure pathways decreased to below the criteria. Due to the conservative nature of the screening, there is a great deal of uncertainty surrounding the specific risks calculated for these exposure pathways. These risks represent a protective, but unlikely, combination of conditions that reflect at least an upper

[186] Available online at: *www.palisade.com/risk/*.

[187] U.S. EPA. 2009. *Sensitivity Analysis for the Coal Combustion Waste Risk Assessment.* Draft Technical Report. Prepared by RTI International for U.S. EPA, Office of Solid Waste, Washington, DC.

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bound on potential exposures. Thus, the cumulative effect of these uncertainties results in an overestimation of nationwide risks to most or all receptors. Therefore, EPA makes no direct findings concerning the magnitude of the risks that may occur under either an uncontrolled or controlled management scenario, but concludes with a high degree of confidence that the reductions achievable with standard management practices are sufficient to be protective even under this conservative screening assessment. Based on these lines of evidence, EPA concluded that no further characterization was warranted for these exposure pathways.

These screening analyses identified potential risks to human and ecological receptors from leaching of chemical constituents from CCR waste into surrounding environmental media. Risks to human health resulted from ingestion of groundwater and fish, while risks to ecological receptors resulted from exposure to surface water. There was no simple method to estimate the effect controls may have for these pathways. However, considerable dilution and attenuation may occur before COPCs reach downgradient private wells and surface water bodies. Therefore, EPA retained all of the COPCs found to be above risk criteria in groundwater and surface water for further characterization. In addition, EPA used the uncontrolled screening results for the above ground sediment pathway as a conservative proxy for the groundwater to surface water sediment pathway. As a result, sediment exposures of four COPCs were retained for further characterization. Table 2 presents a summary of the chemical constituents retained as COPCs for each pathway.

TABLE 2—LIST OF CHEMICAL CONSTITUENTS RETAINED FOR PROBABILISTIC ANALYSIS

Human health		Ecological	
Ingestion of groundwater	Ingestion of fish	Surface water exposure	Sediment exposure
Antimony	Arsenic	Aluminum	Antimony
Arsenic	Cadmium	Arsenic	Arsenic
Boron	Mercury	Barium	Silver
Cadmium	Selenium	Beryllium	Vanadium
Cobalt	Thallium	Boron	
Fluoride		Cadmium	
Lead		Chloride	
Lithium		Chromium	
Molybdenum		Cobalt	
Thallium		Copper	
		Iron	
		Lead	
		Molybdenum	
		Nickel	
		Selenium	
		Silver	
		Vanadium	
		Zinc	

These screening analyses also identified potential risks to ecological receptors from direct exposure to impoundment wastewater. Unlike the other exposure pathways, no dilution or attenuation will occur within impoundment wastewater prior to ecological exposures. Thus, the direct exposures considered in the screening analysis provide a reasonable estimate of the relative magnitude of risks. Based on the screening analyses, EPA concluded that HQs for ecological receptors exceeded 1 for the following constituents (listed from highest to lowest potential): Arsenic (100), barium (50), aluminum (30), boron (30), selenium (20), cadmium (10), vanadium (10), beryllium (2), chloride (2) and chromium (2). Because the screening analysis provides sufficient characterization of these exposures, this pathway was not carried forward for further analysis.

3. Probabilistic Analysis

EPA conducted a national-scale, probabilistic analysis to better characterize the potential risks to human and ecological receptors associated with leachate released from surface impoundments and landfills. The specific exposure routes evaluated for these releases were human ingestion of groundwater used as a source of drinking water and fish caught from freshwater lakes or streams, as well as ecological contact with and ingestion of surface water and sediment. A combination of models was used to predict COPC fate and transport through the environment, receptor exposures, and the resulting risks. Site-specific data were used, supplemented by regional and national data sets, to capture the national variability of disposal practices, environmental conditions and receptor behavior. EPA modeled risks for both highly exposed individuals (90th percentile risks) and more moderately exposed individuals (50th percentile risks). In instances where the speciation of a COPC has been shown to greatly affect fate and transport, EPA modeled multiple species to provide a bounding on potential exposures.

Table 3 shows the 90th percentile human health risks to the most sensitive age cohorts for constituents that exceeded the risk criteria. Risks are presented for arsenic modeled entirely as two different species (III and V) to provide a bounding on potential risks. Values that exceed the selected risk criteria are shown in bold. No 90th percentile risks above ecological criteria were identified for either surface impoundment or landfills. No 50th percentile risks above human health or ecological criteria were identified for either surface impoundment or landfills.

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TABLE 3—90TH PERCENTILE NATIONWIDE PROBABILISTIC RISK RESULTS

COPC	Ingestion of groundwater	
	Surface impoundments	Landfills
Cancer Risks		
Arsenic III	2×10^{-4}	5×10^{-6}
Arsenic V	1×10^{-5}	7×10^{-8}
Noncancer Risks		
Arsenic III	5	0.1
Arsenic V	0.4	<0.01
Lithium	2	[a]
Molybdenum	2	<0.01

[a] Leachate data were not available to model this COPC for landfills.

• Surface Impoundments:

Ingestion of groundwater was the only exposure pathway that resulted in risks above 1×10^{-5}. 90th percentile cancer risks above 1×10^{-5} were identified for arsenic III (2×10^{-4}). The 90th percentile noncancer risks above an HQ of 1 were identified for arsenic III (5), lithium (2), and molybdenum (2).

• Landfills:

All 90th percentile cancer and noncancer risks were below human health criteria.

High-end risks identified for surface impoundments are consistently higher than those for landfills. These results are attributed to the higher infiltration rates through surface impoundments, which are driven by the hydraulic head of the ponded water. Median risks for both surface impoundments and landfills were substantially lower than both the high-end risks in this risk assessment and the median risks modeled in the 2010 Risk Assessment. This decrease is attributed primarily to the interception of groundwater by surface water bodies, which is accounted for in the revised risk assessment to provide a more accurate mass balance of constituent mass during transport. It is common for coal-fired utilities to be located near water bodies, which are used as a source of cooling water and conveyance of waste. As a result, in the majority of model iterations, the interception of groundwater by surface water bodies resulted in negligible downstream well concentrations.

Based on the results of the probabilistic analysis, EPA concludes that leaching from CCR waste management units has the potential to pose risk to receptors. Arsenic, lithium, and molybdenum are the chemical constituents found to pose the greatest risks from surface impoundments, while arsenic posed the greatest risks from landfills. Available toxicological profiles indicate that risks from arsenic ingestion are linked to an increased likelihood of cancer in the skin, liver, bladder and lungs, as well as nausea, vomiting, abnormal heart rhythm, and damage to blood vessels;[188] risks from lithium ingestion are linked to neurological and psychiatric effects, decreased thyroid function, renal effects, cardiovascular effects, skin eruptions, and gastrointestinal effects;[189] and risks from molybdenum ingestion are linked to higher levels of uric acid in the blood, gout-like symptoms, and anemia.[190]

4. Sensitivity and Uncertainty Analysis

The modeled probabilistic risks capture the range of current, nationwide CCR disposal practices. However, because of the broad scope of the analysis, there are a number of sources of variability and uncertainty present. Therefore, to confirm the results of the probabilistic analysis and to better understand whether any particular subset of disposal practices drives the risks identified, EPA conducted additional sensitivity and uncertainty analyses.

EPA reviewed the models used, as well as the data and assumptions input into these models, to better understand the sources of variability and uncertainty inherent in the probabilistic analysis. The Agency then qualitatively and, to the extent possible, quantitatively analyzed these sources to understand the potential effects each may have on the modeled risk results. During this review, specific attention was focused on the parameters shown to have the greatest influence on model results. As a further method of validation, EPA compared the results of the sensitivity and uncertainty analyses with proven and potential damage cases. Together these analyses and comparisons show that there is a high degree of confidence in the principal findings of the probabilistic analysis. However, the review of sensitive parameters revealed some specific disposal practices that may result in greater risks than identified in the probabilistic modeling.

Through these additional sensitivity and uncertainty analyses, which explored different subsets of national disposal practices, EPA identified the potential for higher risks than those identified in the broader, national analysis. In particular, consideration of different waste pH values showed higher risks for arsenic at more acidic and basic pH values, as well as additional risks for boron, cobalt, fluoride and mercury at these more extreme pH values. Consideration of specific liner types showed that groundwater risks are driven by disposal in unlined units and, in particular, unlined surface impoundments. For these units, EPA identified higher risks for arsenic, lithium, and molybdenum, as well as additional risks for thallium. Clay-lined units were found to pose lower risks than unlined units. Composite-lined units were found to be the most protective disposal practice, resulting in risks far below all criteria identified in this risk assessment.

C. Conclusions

Based on the analyses presented in this document, EPA concludes that current management practice of placing CCR waste in surface impoundments and landfills poses risks to human health and the environment within the range that OSWER typically regulates. On a national scale, surface impoundments presented higher risks than landfills. Risks to ecological receptors were identified from exposures to aluminum, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, selenium and vanadium through direct exposure to impoundment wastewater. Risks to residential receptors were identified primarily from exposures to arsenic, lithium, and molybdenum in groundwater used as a source of drinking water, but additional risks from boron, cadmium, cobalt, fluoride, mercury and thallium were identified for specific subsets of national disposal practices.

Sensitivity analyses on liner type indicate that disposal of CCR wastes in unlined surface impoundments and landfills presents the greatest risks to human health and the environment. As modeled, the national risks from clay-lined units are lower than those for unlined units, but such units can exceed risk criteria at individual sites. Composite liners were the only liner type modeled that effectively reduced risks from all pathways and constituents far below human health and ecological criteria in every sensitivity analysis conducted. Sensitivity analyses on waste type indicate that the acidic conditions that result from codisposal of CCR waste with coal refuse and the basic conditions that result from disposal of FGD waste result in higher

[188] Profile for arsenic available online at: *www.epa.gov/iris/subst/0278.htm* and *www.atsdr.cdc.gov/toxprofiles/tp2.pdf.*

[189] Profile for lithium available online at: *hhpprtv.ornl.gov/issue_papers/Lithium.pdf.*

[190] Profile for molybdenum available online at: *www.epa.gov/iris/subst/0425.htm.*

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risks from arsenic and other constituents than CCR waste disposed alone.

The risk results are consistent with the groundwater damage cases compiled by EPA. These damage cases were primarily associated with unlined units and were most frequently associated with releases of arsenic. Recent surveys of the industry indicate the majority of newly constructed units are lined, and that that the practice of codisposal with coal refuse has declined. However, this risk assessment presents a static snapshot of current disposal practices. While newer units may be managed in a more protective manner, older units, which still comprise the majority of current units, continue to operate in a manner that poses risks to human health and the environment that OSWER typically regulates.

XI. Summary of Damage Cases

EPA has a long history of considering damage cases in its regulatory decisions under RCRA. As discussed earlier in this preamble, the statute specifically directs EPA to consider ''documented cases in which danger to human health and the environment from surface run-off or leachate has been proved,'' in reaching its Regulatory Determination for these wastes, demonstrating that such information is to carry great weight in decisions under this section. 42 U.S.C. 6982(n)(4). Damage cases, even if only potential damage cases, are also relevant under the third Bevill factor: ''potential danger, if any, to human health and the environment from the disposal and reuse of such materials.'' 42 U.S.C. 6982(n)(4). In addition, damage cases are among the criteria EPA must consider under its regulations for determining whether to list a waste as a ''hazardous waste.'' See 40 CFR 261.11(a)(3)(ix). Damage cases generally provide extremely potent evidence in hazardous waste listings. In this regard, EPA notes that the number of damage cases collected for this rulemaking (157) is by far the largest number of documented cases in the history of the RCRA program.

EPA considers that both proven and potential damage cases provide information directly relevant to this rulemaking. First, damage cases provide evidence of both the extent and nature of the potential risks to human health and the environment. The primary difference between a proven and a potential damage case is whether the contamination has migrated off-site of the facility. But the mere fact that groundwater contamination has not yet migrated off-site does not change the fact that a potentially harmful constituent has leached from the unit into groundwater. Whether the constituent ultimately causes further damage by migrating into drinking water wells does not diminish the significance of the environmental damage caused to the groundwater under the site, even where it is only a future source of drinking water. As EPA explained in the preamble to the original 1979 open dumping criteria, which are currently applicable to these facilities, EPA is concerned with groundwater contamination even if the aquifer is not currently used as a source of drinking water. Sources of drinking water are finite, and future users' interests must also be protected. (See 44 FR 53445–53448.) (''The Act and its legislative history clearly reflect Congressional intent that protection of groundwater is to be a prime concern of the criterion. . . . EPA believes that solid waste activities should not be allowed to contaminate underground drinking water sources to exceed established drinking water standards. Future users of the aquifer will not be protected unless such an approach is taken.'')

In the June 21, 2010 proposed rule, EPA presented for public comment an assessment of CCR damage cases, and requested comments and other information related to damage cases EPA had previously received from industry, environmental groups, and citizen groups. EPA later requested public comment on additional damage case information in a Notice of Data Availability (NODA) published in the **Federal Register** on October 12, 2011 (76 FR 63252). As discussed in Section IV of this preamble, the Agency is deferring making a Bevill determination; however, EPA is still presenting its findings with regard to damage cases (including information submitted during the comment periods for the June 2010 proposal and the October 2011 NODA) because as described above, this information supports actions taken in the present final rule.[191]

A. Damage Cases Presented in June 21, 2010 Proposed Rule

In the June 2010 proposed rule, the Agency summarized its database on damage cases that had expanded since the May 2000 Regulatory Determination.[192] This summary included two cases of CCR slurry spill caused by surface impoundment dike failures (the 2005 Martins Creek, Pennsylvania, and the 2008 TVA Kingston, Tennessee), and two cases involving structural fill (the use, between 1995–2007, of CCR in the reclamation of two sand and gravel pits in Gambrills, Maryland; and for contouring the Battlefield Golf Course, in Chesapeake, Virginia, in the early 2000s). In the June 2010 proposed rule, the Battlefield Golf Course site was designated as a potential damage case, whereas the other three sites were designated as proven damage cases.[193]

B. Additional Information and Studies

Shortly prior to the publication of the June 2010 proposed rule and immediately thereafter, several stakeholder groups provided the Agency with new information on damage cases. In November 2009, the Electric Power Research Institute (EPRI) issued a two-volume draft report [194] analyzing the 24 proven and 43 potential damage cases established in EPA's 2007 damage case report [195] accompanying the August 2007 Notice of Data Availability (NODA).[196] EPRI claimed that in the great majority of damage cases there is no record of primary MCL contaminants migrating off-site that would justify designating them as proven damage cases. EPRI also disagreed with several ecologic damage cases that had been predicated on fish advisories in Texas, on the grounds that the selenium toxicity standard that triggered these fish advisories was later revised by the state, and subsequently the fish advisories were rescinded. In February and August 2010, The Environmental Integrity Project (EIP), jointly with other citizen groups, issued two reports, identifying 70 alleged damage cases.[197] [198] Fifty of these cases were submitted to EPA for the first time.

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[191] Damage Case Compendium (Technical Support Document on Damage Cases), U.S. EPA, December 2014.

[192] See June 21, 2010 **Federal Register**—Appendix to the Preamble: Documented Damages from CCR Management Practices (75 FR 35230).

[193] See 75 FR at 35131 for definitions of ''proven'' and ''potential'' damage cases.

[194] *Evaluations of CCP Damage Cases:* These two volumes were finalized in July and September 2010, respectively: *http://my.epri.com/portal/server.pt?open=512&objID=413&&PageID=230509&mode=2&cached=true.*

[195] *Coal Combustion Waste Damage Case Assessments,* July 9, 2007. EPA–HQ–RCRA–2006–0796–0015.

[196] Notice of Data Availability on the Disposal of Coal Combustion Wastes in Landfills and Surface Impoundments, 72 FR 49714, August 29, 2007.

[197] *In Harm's Way: Lack of Federal Coal Ash Regulations Endangers Americans and Their Environment.* Environmental Integrity Project, Earthjustice, and Sierra Club: *http://www.environmentalintegrity.org/news_reports/08_26_10.php.*

[198] *Out of Control: Mounting Damages from Coal Ash Waste Sites.* Environmental Integrity Project and EarthJustice: *http://www.environmentalintegrity.org/news_reports/news_02_24_10.php.*

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In response to EPRI's report, EPA reassessed the 24 proven damage cases identified in EPA's 2007 Damage Case report, as well as three additional proven damage cases cited in the proposed rule. In addition, in response to EIP's reports, the Agency assessed the 70 alleged damage cases, to independently confirm the allegations in the report. In reviewing [199] these alleged damage cases, EPA took a number of measures. First, to the extent the information was available, EPA consulted tabulated monitoring well data to validate the exceedance data presented in comments; and studied well- and waste-unit location maps, geohydrologic studies, and groundwater potentiometric maps to validate both whether the wells were up-gradient or down-gradient wells and instances of groundwater mounding. EPA also contacted state regulators to confirm the reports' claims of contamination, particularly contamination exceeding state or federal water quality standards, and conducted internet research (focusing on state regulatory information) pertaining to the sites in question. EPA also thoroughly assessed state comments submitted to EPA in response to the June 2010 proposed rule and the October 2011 NODA. Third, EPA identified state or federal administrative measures applied to utilities (*e.g.,* consent orders, notices of violation, penalties for non-compliance, etc.) and/or legal motions (*e.g.,* law-suits, motions for injunctive relief, and out-of-court settlements) filed by the states or citizen groups in order to identify any instances of non-compliance by the utilities that have resulted in documented impacts to water resources.

EPA's review confirmed that 13 of the 27 damage cases previously designated as proven did meet the criteria used by EPA for identifying proven damage cases; however, EPA also found that six of the 27 cases only meet the criteria for a potential damage case, while the remaining eight cases were altogether rejected (*i.e.,* EPA determined that a damage case has not occurred, and/or test of proof criteria were not satisfied, and/or CCR was not the only or predominant waste component). Regarding the 70 alleged damage cases in the two EIP reports, EPA concluded that ten of them qualify as proven damage cases, 45 as potential damage cases, and the remainder were either rejected or, due to the lack of adequate information, defined as indeterminate.

In November 2011, the Utility Solid Waste Activities Group (USWAG) submitted to the docket of the October 2011 NODA a critical review of EIP's 70 alleged damage cases from 2010. USWAG's review concluded that ''the overwhelming majority of the allegations regarding the 70 sites . . . fail to provide the requisite 'test of proof' documentation necessary for EPA to characterize virtually any of the sites as proven damage cases.'' Also, in November 2011 EIP submitted to the docket of the October 2011 NODA a report alleging 20 new damage cases.[200]

Following review of the comments on the proposed rule and the October 2011 NODA, EPA has revisited some of its earlier damage case findings. Our post-proposal studies have resulted in: (1) Rejection of 17 of the previously-established and newly-alleged damage cases, either due to inappropriate scope (*e.g.,* oil combustion waste, non-utility CCR, or CCR disposed-off in abandoned coal mine pits), co-mingling with non-CCR waste, or inadequate information to ascertain that contaminants are derived from CCR; (2) two of the damage cases that had been previously designated as 'rejected' in EPA's 2007 damage case report were re-categorized as proven damage cases and six others were re-categorized as potential damage cases; and (3) one damage case site reported in *Risky Business* occurred next to a site that had already been previously reported.

In summary, at the present time the Agency has established 40 proven and 113 potential damage cases. In addition, the rulemaking docket contains four additional, state-endorsed damage cases from Wisconsin. While EPA has insufficiently-detailed information (including the extent, if any, that the contaminants have migrated off site) to designate these four additional sites as potential or proven, because the state has identified them to us as damage cases, we have included them in our overall total of 157.

C. Stakeholder Comments on Damage Cases

All of the comments submitted by stakeholders to the dockets of the proposed rule and the October 2011 NODA, as well as EPA's responses, are included in the Technical Support Document to CCR Damage Cases which is available in the RCRA docket supporting this rule. The following is a summary of the salient comments submitted by the various stakeholder groups.

1. Utility Industry's Comments

EPA received several comments from utilities arguing that an incident should not be considered to be a ''damage case'' if the environmental damage has been addressed or is no longer occurring and/or if the State Director is satisfied that no further action is required. (Note: For those damage cases known to the Agency prior to EIP's 2010 reports, remediation is completed or underway at *all* sites where remediation was known to be required.) These commenters also argued that EPA should disregard cases in which there are no downstream contaminant receptors to be harmed by the contamination. These commenters also alleged that only ''proven'' damage cases should be considered to be relevant as only these are ''*documented cases in which danger to human health or the environment from surface runoff or leachate has been proved,*'' 42 U.S.C. 6982(n)(4).

Industry commenters also made a number of other points. They stated that most damage cases occurred in older facilities commissioned before current state landfill regulations were promulgated, where most waste units lack liners and leachate collection systems, and that in most cases, exceedances of state or federal water quality standards were contained on site, and these exceedances are mostly for constituents (*e.g.,* sulfate and boron) that do not have federal, health-based drinking water quality standards. These commenters also claimed that the number of proven damage cases is very sparse: Of the 24 proven damage cases in EPA's 2007 report,[201] they argued that only three had documented off-site groundwater exceedances of health-based MCLs that can be attributed to CCR impacts. They also claimed that of the 70 alleged damage cases in EIP's 2010 reports (*In Harm's Way* and *Out of Control*), 64 did not meet EPA's ''test of proof'' criteria for characterizing the site as a proven damage case. For the remaining six sites, where the allegations on their face arguably met EPA's definition of a proven damage case, these commenters claimed that these cases should be discounted because they involved sites that are either no longer active or where the damages had been already remediated

[199] See *Assessment of Previously Identified Proven Damage and Recently Alleged Damage Cases,* October 2010.

[200] EPA–HQ–RCRA–2011–0392–0259. Nineteen of the cases involve groundwater impact, and one involves soil contaminated by the placement of coal ash and clinkers from train engine boilers for railroad tracks bed. A hard copy of the report, *Risky Business: Coal Ash Threatens America's Groundwater Resources at 19 More Sites,* was issued on December 12, 2011.

[201] *Coal Combustion Waste Damage Case Assessments,* ibid.

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or are undergoing remediation with federal/state oversight. These commenters also said that 12 of the 70 EIP-alleged damage cases were previously addressed in EPA's 2007 Damage Case report, and of these, five sites had been rejected by the EPA due to lack of evidence of damage or lack of evidence of damage uniquely associated with CCR, and seven sites had been characterized as indeterminate due to insufficient information. According to these commenters, no new information regarding these 12 sites was contained in the two EIP reports that warrants their designation as proven damage cases.[202]

2. Individual State Comments

EPA also received a significant number of comments from individual states. In their comments, many of the states addressed selected damage cases that occurred within their jurisdiction, subject to their authority. Several states agreed with EPA's assessment of the damage cases; for instance, Wisconsin and Michigan complimented EPA's database of damage cases. Other commenters agreed with some of the newly alleged damage cases' reports of groundwater contamination exceeding regulatory standards, but disagreed with EIP's conclusions that enforcement was inadequate, tardy, or absent. According to some state commenters, enforcement was not necessary or appropriate in those instances. For example, some states (*e.g.,* North Carolina, Oklahoma, Tennessee, and Florida) argued that the contamination did not pose public health risks because the contaminants were confined to state-established Compliance Boundaries (known also as Groundwater Mixing Zones) [203] and/or because there was no evidence the contamination had migrated off-site. Several other states (*e.g.,* Maryland, Virginia, and Texas) confirmed EPA's established damage cases as well as some of the newly alleged damage cases, but claimed that these cases were associated with presently outdated practices, and that regulatory requirements have since been revised to prohibit such practices. Two states (South Dakota and Pennsylvania) confirmed that contamination above federal or state regulatory standards had occurred, but attributed the contaminant(s) to sources other than CCR units, *e.g.,* coal mining pits associated with coal refuse; and/or nearby, up-gradient unlined MSWLFs, cooling water evaporation ponds, or natural background soil compositions. For certain cases, the states explained that required assessment monitoring was still ongoing to establish the source, scope, and extent of the contamination, and so had reached no conclusions about the specific allegations (North Carolina, North Dakota, and Tennessee). Finally Ohio acknowledged that the extent of groundwater contamination risk within the state is poorly-documented due to the scarcity of monitoring wells down gradient from unlined disposal units.

3. State Association Comments

The Association of State and Territorial Solid Waste Management Officials (ASTSWMO) argued that the 24 proven damage cases reported in EPA's 2007 Damage Case report do not reflect current land disposal practices, and so are irrelevant to the proposed rule. For example, disposal ''units'' involved in several damage cases included five sand and gravel pits, two quarries, and one lake impoundment. ASTSWMO commented that half of these sites began operating in 1970 or earlier, including at least six sites that began operating in the early 1950s. ASTSWMO claimed that much of the information cited in the two EIP 2010 alleged damage case reports is incomplete, incorrect and/or misleading. For example, their comments alleged that EIP failed to provide pertinent information on specific monitoring wells, sample/analytical dates, and hydrogeological data. ASTSWMO also claimed that many of the assumptions about groundwater flow were based on a topographic maps rather than on potentiometric maps that are based on subsurface groundwater flow data. They also claim that data in state files contradicted claims in the reports, and that EIP's reports contained numerous technical errors, such as reporting values for naturally occurring constituents as contamination, reported data without distinguishing between down-gradient and up-gradient wells, ignoring the potential contribution from sources other than CCR-related units (*e.g.,* coal mining legacy), and claims that information provided by state program staff was misconstrued/misrepresented.

4. Citizens Group Comments

Citizen groups generally argued that the fact that damage has occurred should be part of the weight of evidence documenting the potential for harm at all CCR disposal sites, without regard to whether the damage cases were categorized as ''proven'' or ''potential.'' These commenters also raised a number of arguments in direct response to the comments provided by the utilities and the states. For example, these commenters argued that the presence of downstream receptors is a valid factor to consider when setting priorities for mitigating damage, but does not justify allowing contamination to migrate off of the disposal site. These commenters claimed that about one-fifth of EPA's damage cases preceding the 2010 EIP reports show evidence of contamination of private and public drinking water wells. In addition, these commenters allege that state regulatory agencies have done little to respond to contamination from CCR disposal sites, and, even in those cases where action has been taken, rarely is any action taken beyond assessment monitoring. According to these commenters, off-site monitoring has only occurred at a limited number of sites, and mostly such monitoring was performed voluntarily by the utilities and was not reported to state regulators. These commenters also claimed that although less than half of EPA's damage cases preceding the 2010 EIP reports involve active landfills, almost three-quarters of the newly alleged damage cases (EIP's 2010 reports) involve active landfills. They further alleged that a large majority of EPA's surface impoundment damage cases preceding the 2010 EIP reports are active sites, indicating that the absence of liners is contributing to the contamination problems. They noted that one quarter of the damage cases in EIP's 2010 reports involved units with liners, indicating that the mere presence of any liner provides no assurance that migration of contaminated groundwater from a waste unit is not occurring. Overall, they claimed that surface impoundments remain ''woefully unregulated'' when compared to landfills. Over one third of EIP's alleged groundwater damage cases show migration of contamination off-site. Also, a quarter of EPA's damage cases preceding the 2010 EIP reports involve contamination of surface water, and 15 percent of these damage cases show ecologic damage. Finally, these commenters note that several of the Secondary Contaminant Maximum Levels (SMCLs) constituents still might

[202] EPA–HQ–RCRA–2011–0392–0211, ibid.

[203] A Zone of Discharge or Zone of Mixing is a three dimensional region containing groundwater being managed to mitigate impairment caused by the release of contaminants from a waste disposal site; by definition, it is inside the detection boundary area, hence it is exempt from compliance with MCL and SMCL standards (*e.g.,* in Florida, Illinois, South Carolina, Tennessee, North Carolina, and Pennsylvania).

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cause harm to recipients residing next to CCR disposal sites.[204]

D. Response to Key Stakeholder Comments

In many instances EPA did not have access to information that would either substantiate or refute the claims in EIP's reports. In many instances public commenters submitted information that clarifies, rebuts or otherwise calls into question some of the allegations contained in the various damage case reports. For example, there are instances in which claims were made that a contaminant plume had migrated offsite even though there were no offsite monitoring wells to confirm the claim. Due to the dearth of groundwater monitoring on facilities' boundaries (or beyond) EPA could not identify offsite plume migration for most sites, except in the rare instances drinking water wells had been contaminated. Consequently, only 10 of the 70 alleged cases submitted by EIP in 2010 were designated as proven damage cases.

In addition, factual errors were identified in certain instances; for example, certain allegations of groundwater contamination were based on surface water standards (rather than groundwater standards). Corrections or updated facts are reflected in EPA's damage case assessment. Nevertheless, EPA was able to validate a significant number of EIP's claims; for example, as of 2011, EPA was able to confirm that a significant portion of the damage cases in EIPs 2010 report involved both landfills and surface impoundments, most of which involved units with either no liner or a substandard liner system. And for many of EIP's damage cases, EPA was able to confirm sufficient details to classify them as potential damage cases.

However, EPA disagrees with most of the arguments minimizing the significance of the damage case record. First, cases where contamination has been remediated remain relevant to this rulemaking. EPA is relying on the damage cases to evaluate the extent and nature of the risks associated with particular CCR management practices. Facts demonstrating the consequences from particular activities therefore remain relevant, particularly (although not solely) where the management practices continue to occur. In other words, what matters in this regard are facts that provide information on the reasons that unit leaked, the particular contaminants that were present, the levels of those contaminants, and the nature of any impacts caused by that contamination. None of these facts are affected by whether the damage is ultimately mitigated or remedied. This is entirely consistent with RCRA section 8002(n), which requires EPA to evaluate the ''potential danger, if any, to human health and the environment from the disposal and reuse of such materials'' in addition to ''documented'' damage cases. 42 U.S.C. 6982(n)(3)–(4). Accordingly, the fact that any contamination has subsequently been remediated is not a basis for disregarding a damage case. Moreover, EPA is not relying on these damage cases to evaluate the adequacy of state programs, although it may ultimately provide information relevant to such findings. Therefore the adequacy of the state's response, or the lack thereof, is also not relevant to whether particular damage cases are appropriately considered as part of this rulemaking.

EPA also disagrees that only the presence of receptors within the impact sphere of a contaminating facility merits consideration of a particular damage case. EPA's longstanding and consistent policy across numerous regulatory programs has been that groundwater contamination is a significant concern that merits regulatory action in its own right, whether or not the aquifer is not currently used as a source of drinking water. Sources of drinking water are finite, and future users' interests must also be protected. The absence of current receptors is therefore also not an appropriate basis on which to discount damage cases. And for all of the reasons discussed above, EPA also disagrees that only exceedances of health-based standards of contaminants that have migrated off-site (*i.e.,* only proven damage cases) should be accounted for as part of this rulemaking.

The Agency also disagrees with the claims that the number of damage cases is ''sparse,'' the majority of which involve only ''outdated CCR management practices'' in older facilities, and therefore are not relevant to determining the current risks from CCR mismanagement. Even assuming that only ''proven'' damage cases were relevant, to date, EPA has confirmed a total of 40 proven damage cases, which is hardly ''sparse.'' And when ''potential'' damage cases are considered, the totals rise to 157; this is the largest number of damage cases in the history of the RCRA program. Further, these numbers likely underestimate the true number of cases in which CCR units are contaminating groundwater. In reality, the damage case record represents only a subset of those CCR waste units that have effective groundwater monitoring. As discussed in Unit IV.A of this document, a significant portion of CCR surface impoundments still lack groundwater monitoring, and only approximately 80% of the recently commissioned impoundments (*i.e.,* since about 1994) have groundwater monitoring.

In addition, under many state programs existing impoundments are exempt from groundwater monitoring and once monitoring is put in place, new damage cases quickly emerge. This is illustrated by two lines of evidence: First, in the wake of the 2008 TVA Kingston CCR spill two states required utilities for the first time to install groundwater monitoring. Illinois required facilities to install groundwater monitoring down gradient from their surface impoundments. As a result, within only about two years, Illinois detected seven new instances of primary MCL exceedances and five additional instances with exceedances of SMCLs. The data for all twelve sites were gathered from onsite; it appears none of these facilities had been required to monitor groundwater off-site, so whether the contamination had migrated off-site is currently unknown.[205] Similarly, North Caroline required facilities to install additional down gradient wells. In January 2012, officials from the North Carolina Department of Environment and Natural Resources disclosed that elevated levels of metals have been found in groundwater near surface impoundments at all of the State's 14 coal-fired power plants.[206]

Second, states with effective programs for groundwater monitoring tend to have a larger record of damage cases (*e.g.,* Wisconsin, nationally ranked as the 32nd CCR disposer in 2011, has 14 damage cases) as compared to states with less stringent groundwater

[204] Examples include boron's One-Day and Ten-Day Health Advisory (3.0 mg/L) and the Longer Term Health Advisory (2.0 mg/L) levels for children; manganese's Long Term Health Advisory (LTHA: 0.3 mg/L) level; and sulfate's Drinking Water Advisory (DWA: 500 mg/L) level in groundwater have been exceeded each in between over 60 and close to 80 of both the alleged and damage case sites and those sites preceding the 2010 EIP reports.

[205] See EIP's December 2011 *Risky Business: Coal ash Threatens America's Groundwater Resources at 19 More Sites,* docket document EPA–HQ–RCRA–2011–0392–0259, appendix A3. *www.environmentalintegrity.org/.../121311EIPThirdDamageReport.pdf* and *Illinois EPA's Ash Impoundment Strategy Progress Reports,* February 10 and October 2011, accessed Online July 15, 2014: *http://www.epa.state.il.us/water/groundwater/publications/ash-impoundment-progress.pdf and http://www.epa.state.il.us/water/ash-impoundment/documents/ash-impoundment-progress-102511.pdf.*

[206] Groundwater Monitoring Data for Coal Ash Ponds, NC DENR: *http://portal.ncdenr.org/web/wq/hot-topics/coalashregulation/gwatermonitoring.* Accessed Online July 15, 2014.

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monitoring requirements (*e.g.,* Texas, nationally ranked as the second largest CCR disposer in 2011, has only three confirmed, potential damage case).

Nor is it accurate that the majority of these damage cases involve older units that no longer reflect current management practices or state requirements. The commenters point to the fact that the majority of cases involve units constructed before current state landfill regulations were promulgated, and thus lack liners and leachate collection systems. EPA agrees that the majority of cases do involve such units, but this hardly reflects ''outdated'' or irrelevant management practices. As discussed in Unit IV.A of this document, the majority of CCR continues to be managed in older (*i.e.,* constructed pre-1994) units that lack liners and leachate collection systems, and will in fact continue to be managed in such units for at least the near future.

Approximately six percent of the waste units associated with groundwater impacts have been constructed from 1990 onwards. Considering there is a lag time between the construction of many of the disposal units and the first detection of their groundwater impact by subsequently installed groundwater monitoring wells, the absence of damage cases associated with newer units is neither unexpected nor dispositive as to the level of risk such units pose.

Finally, a number of other factors support the conclusion that the current number of damage cases likely underestimate the current risks. First, the combined effect of a number of current state regulatory provisions is to decrease the instances in which off-site contamination will be detected (or on-site contamination will need to be remediated). For example, several states have adopted ''buffer zones'' where certain standards may not apply; Florida designates certain areas as a ''Zone of Discharge'' (ZOD), in which numerical primary and secondary drinking water standards do not apply; this exemption extends even beyond the ZOD, unless ordered specifically by the state. In addition, secondary maximum contaminant levels (SMCLs) are not applicable to existing industrial facilities discharging to groundwater in the state.[207] In other instances, states grant waivers to certain facilities that exceed health-based standards several-fold.[208] Certain states (*e.g.,* Indiana) consider surface impoundments as temporary storage facilities as long as they are dredged on a periodic basis (*e.g.,* annually). Under these states' rules, such impoundments are exempt from any solid waste regulations that would require groundwater monitoring, and from requirements for corrective action.[209] Such requirements are likely to decrease the instances in which contamination above an MCL has migrated off-site will be detected. Second, the record documents several instances where, once the contaminant plume has migrated off-site and impacted private water wells, the utility has purchased these properties, thereby rendering the off-site contamination, ''on-site.'' At times, this practice (which is condoned by the state) has expanded the ZOD to well beyond its original boundary. Once the status of the contaminant plume changes from off-site migration, which typically requires remedial action, back to onsite containment, this can affect the kind of corrective action the state requires of the utility (or indeed whether any will be required).

E. Characterization of Impacts Associated With CCR Units

1. CCR Waste Unit Types Associated With Damage Cases

EPA's documented record of confirmed damage cases is dominated by wet-disposal and treatment modes: Surface impoundments, cooling ponds, and artificial wetlands constitute close to half of the total number of implicated waste units. In comparison, dry disposal modes such as landfills, sand and gravel pits, storage piles for coal ash and FGD, and certain structural fills account for about one third of the confirmed damage cases.[210] Sand and gravel pits and quarries as well as structural fills, comprise about ten percent of all the unit types that are associated with damage cases.

2. Contaminants of Concern (COCs)

Because the list of constituents to be monitored in groundwater varies from permit to permit and among states, accurate estimates of the frequency of constituents associated with groundwater impacts nationwide cannot be made with confidence. Based on the available monitoring records, the most prevalent contaminant among the primary MCLs identified in damage cases is arsenic, whereas the most prevalent contaminants identified among the secondary MCLs are sulfate and boron. Similarly, disparities from one permit to another as to which constituents are monitored in NPDES discharges from CCR impoundments limit EPA's ability to identify trends associated with contaminants of concern. Based on the Agency's record of all of the confirmed damage cases, it can be only established that the most prevalent COCs with respect to Primary Water Quality Criteria (WQCs) exceedances in surface water, and/or of cleanup standards in sediments and soils are selenium and arsenic, and for Secondary WQCs or cleanup standard exceedances, are boron and iron.[211]

The high mobility of boron and sulfate explains the prevalence of these constituents in damage cases that are associated with groundwater impacts. Damage cases impacting surface water that have also a documented ecologic impact comprise the largest subset of proven damage cases (over 40 percent). The most prevalent COC here is selenium, the bioaccumulative effects of which have caused abnormal mortality rates and sublethal effects such as histopathological changes and damage to reproductive and developmental success, adversely impacting aquatic populations and communities of fish and amphibians. Such impacted communities, residing both in lentic (*e.g.,* cooling water lakes) and lotic (*e.g.,* small to medium-size streams) settings that receive regulated (*i.e.,* via permitted outfalls) and unregulated (*i.e.,* via seepage) discharge from CCR impoundments were documented and rather extensively studied in several sites (*e.g.,* in Texas, North Carolina, and South Carolina).[212] [213]

[207] Illinois uses a similar concept: Groundwater Mixing Zone; North Carolina waives any compliance requirements for constituents in exceedance of the state's groundwater standards that are confined to monitoring wells within the Compliance Boundary; and in Pennsylvania and Tennessee, state laws do not require state response to onsite exceedances of secondary MCLs.

[208] The observations cited in the following pertain to groundwater quality. Regarding surface water quality, NPDES permits in many states commonly have very limited requirements for monitoring discharge constituents, excluding all or most of the heavy metals.

[209] E.g., Duke Energy's Gibson Generating Station, Princeton, Indiana, a proven damage case.

[210] Facilities with both wet and dry disposal waste units are implicated in less than twenty percent of the cases.

[211] For a list of the key metals found in CCR wastewater and examples of the environmental concerns associated with them, see *Steam Electric Power Generating Point Source Category: Final Detailed Study Report;* EPA 821–R–09–008, October 2009: *http://water.epa.gov/scitech/wastetech/guide/steam-electric/upload/Steam-Electric_Detailed-Study-Report_2009.pdf.*

[212] In validation of the findings of the Risk Assessment accompanying this rule, EPA has documented numerous damage cases where selenium in CCR wastewater discharge into surface waters triggered the issuance of fish-consumption advisories as well as selenium MCL exceedances in groundwater, suggesting that selenium concentrations in CCR wastewater constitute a human health risk.

[213] According to the draft Steam Industry's Effluent Guidelines EA, the steam electric power

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There are fewer recorded instances of surface water damage cases involving the heavy metal COCs such as antimony, beryllium, mercury, and thallium than of groundwater damage cases. It is unclear whether this genuinely reflects lower potential risks via this route of exposure. Intrinsic differences between the chemical and physical parameters of surface water and groundwater (*e.g.,* the higher redox potential and the larger flow-rate of the former) would accelerate the removal of many metals from surface water through precipitation and/or adsorption and facilitate a greater dilution. However, as noted, NPDES permits in many states commonly have very limited requirements for monitoring discharge constituents, excluding all or most of the heavy metals, so this cannot be ruled out as at least a contributing factor.[214]

3. Failure/Impact Modes

The CCR damage case record shows the following prevalent impact modes (more than one possible impact type per generating facility site is possible): Slightly over half of the recorded impact cases are associated with groundwater; about ten percent are associated with surface water, which quite frequently is also accompanied by documented ecological impacts and/or with the contamination of soils and/or river sediments; over one third are associated with both groundwater and surface water impacts; and about four percent are associated with catastrophic surface impoundment failures.

The established damage case record includes ten sites involving exceedances of primary MCLs that have impacted drinking water wells. In all of these cases, the implicated utility provided alternative potable water to well water users.[215] Three of the damage cases were listed on the National Priority List as Superfund sites,[216] and one is a Superfund Alternative (SA) site.[217] In the course of reassessing the pre-EIP 2010 damage cases and vetting EIP's alleged damage cases, the Agency rejected two other Superfund damage cases, because in addition to CCR, these site had also accepted large volume of non-CCR waste.[218]

Four major releases of CCR sludge associated with surface impoundment dike or pipe failure resulted in significant coal slurry releases,[219] causing fish kills and other ecologic damage, and in some instances damage to infrastructure. In the Clinch River spill, for instance, it was estimated that 217,000 fish were killed in a 90-mile stretch of the river in Virginia and Tennessee. The Clinch River plant coal ash had a high free lime content, which reacted with water in the settling pond to form an alkaline calcium hydroxide. As a result, during the release, pH was elevated to levels as high as 12.7. The high-toxicity shock also decimated benthic macro-invertebrate populations for a distance of over three miles below the spill site, and snails and mussels were eliminated for over 11 miles below the Clinch River power plant.

As demonstrated in the aftermath of the 2008 coal ash spill in TVA Kingston, Tennessee, large impoundment dike breach incidents result in impacts to soil and river sediments. In a study conducted few months after the spill, Emory River's downstream sediments showed high mercury concentrations similar to those detected in the coal ash (115–130 μg/kg).[220] According to this study, the ecological effects of mercury in the coal ash and sediments depend on the chemical mobility of mercury in the solids and the potential for mercury methylation in the impacted area. Previous studies have shown that sulfate addition can promote methylation in freshwater ecosystems by stimulating sulfate reducing bacteria, the primary organisms responsible for producing methylmercury in the environment. In coal-ash-containing waters, a 10- to 20-fold increase in SO_4^{-2} concentrations was observed in the Emory River Cove area relative to unaffected upstream sites. Therefore, the methylation potential of mercury from this material could be high because the coal ash also provides an essential nutrient (SO_4^{-2}) that encourages microbial methylation. In addition, leaching of contaminants from the coal ash caused contamination of surface waters in areas of restricted water exchange and slight elevation down gradient. The accumulation of arsenic-rich fly ash in bottom sediment in the Emory River's aquatic system could cause fish poisoning via both food chains and decrease of benthic fauna that is a vital food source. Another recent study estimates that the damage to fish and other wildlife incurred by both permitted and unpermitted CCR effluent discharge at some 22 sites amounts to over $2.3 billion.[221]

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sector is responsible for a significant fraction of the toxic pollutants reported to be discharged in industrial National Pollutant Discharge Elimination System (NPDES) permits.

[214] This issue is illustrated by the very limited monitoring record on mercury exceedances in surface water as compared to the extensive documentation of mercury impacts revealed in studied surface water that receive steam industry effluents. These studies have documented fish and invertebrates exposed to mercury from CCR wastewater exhibiting elevated levels of mercury in their tissues and developing sublethal effects such as reduced growth and reproductive failure. For an excellent summary of surface water ecologic and human health risks and impacts study results, see the cited Steam Electric Power study report.

[215] These proven damage cases include eight cases where the utility was directed by the state to provide an alternative water supply (NIPSCO Yard 520, IN; Constellation Energy Gambrills, MD; Don Frame Trucking, NY; Bruce Mansfield, PA; Trans Ash Landfill, TN; VEPCO Chisman Creek, VA; Stoneman, WI; and WEPCO Highway 59, WI); and two instances in which the utility provides substitute water to residents on a voluntary basis (Gibson Station, IN, and Colstrip, MT). In three additional, potential damage cases (Oak Creek, WI; Battlefield Golf Course, VA; and Joliet Station 9, IL), the utilities provide substitute water—out of abundance caution—to adjacent residential properties whose water wells were impacted by secondary MCL exceedances, and in two additional cases, the electrical utility was instructed by state regulators to provide substitute water to residential properties which either have had their drinking water wells impacted by trace amounts of thallium, within the State and the federal standards (Asheville, NC) or by exceedances of boron (Sutton, NC). Finally, in one case (Belews Creek, NC) the electric utility agreed to co-fund upgrading of potable water treatment plants in two municipalities to eliminate trihalomethanes, a carcinogenic by-product of power plant scrubber, bromide-containing river water subject to water treatment employing chlorine.

[216] OU–12, Oak Ridge, Tennessee (an NPL site between 1989 and 1997); VEPCO, Chisman Creek, Virginia (an NPL site between 1983 and 1988); and the Lemberger Landfill, Wisconsin (1986 to present).

[217] Town of Pines Groundwater Plume, Indiana (SA: 2003–Present): *http://www.epa.gov/region5/superfund/npl/sas_sites/INN000508071.htm.* The Site is not listed on the National Priority List (NPL) although it qualifies for such listing. The SA approach uses the same investigation and cleanup process and standards that are used for sites listed on the NPL, while it can potentially save the time and resources associated with listing a site on the NPL. As long as a PRP enters into an SA approach agreement with EPA, there is no need for EPA to list the site on the NPL.

[218] These are the formerly proven damage case of Salem Acres, Massachusetts (originally addressed in the 2007 *Coal Combustion Waste Damage Case Assessments* Report), and Industrial Excess Landfill, Uniontown, Ohio, an alleged damage case submitted by EIP in *In Harm's Way,* 2010.

[219] These catastrophic releases involved the release of 1.1×10^9, 2.7×10^8, 1.3×10^8, and 1×10^8 gallons of CCR slurry at the spills of the 2008 Kingston TVA, Tennessee; the 2014 Dan River, North Carolina; the 1967 Clinch River, Virginia; and the 2005 Martins Creek, Pennsylvania, respectively.) In addition, the possible ecologic impacts of two consecutive, 30 million gallons each, of CCR slurry releases (in 2007 and 2008) by the Eagle Valley power plant in Indiana have not been assessed.

[220] *Survey of the Potential Environmental and Health Impacts in the Immediate Aftermath of the Coal Ash Spill in Kingston, Tennessee.* Laura Ruhl et al., Environ. Sci. Technol. Published online on May 4, 2009. Volume *43* (16), pp 6326–6333: *http://pubs.acs.org/doi/abs/10.1021/es900714p.*

[221] A. Dennis Lemly and Joseph P. Skorupa: *Wildlife and the Coal Waste policy Debate: Proposed Rules for Coal Waste Disposal Ignore Lessons from 45 Years of Wildlife Poisoning.* Environ. Sci. Technol., 27 July, 2012.

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a. Construction Year and First Detection Year

Slightly over half of the CCR waste units identified as the source of groundwater contamination in the damage cases were commissioned in the 1970s and 1980s, two boom decades of coal-fueled power generation growth in the U.S. Whereas the majority of the CCR waste units associated with damage cases were constructed before 1990, approximately six percent of the units in the damage cases (where the commissioning date is known) became operational after 1990. For 61 units with known commissioning dates, the median lag time between commissioning and the first detection of impact to groundwater is about 20 years. However, considering the large range of lag time values (between less than one year and 50 years) the recorded median lag time most probably reflects additional variables. Possible variables include monitoring wells that were installed after many of the waste units were already well into their operating stage, and the variable hydraulic conductivity of the impoundment's substrate (including the effectiveness of its liner, if any), both of which will determine how quickly groundwater contamination is first detected. Overall, the evidence about the lag time between the commissioning of a waste unit and the first detection of the impact of its leakage implies that most likely there are prospective damage cases that have not yet been identified, challenging industry's claims that the damage cases represent the legacy of a bygone regulatory regime.

b. Liners

Of the waste units implicated in damage cases to groundwater with information on liners, over 90 percent have either no liners, some sort of ash-based liners (*e.g.,* Poz-O-Tec, an FGD/lime-conditioned liner), or only partial- or high-permeability (*e.g.,* concrete) liners. The majority of the remaining CCR waste units is either clay-lined and/or has a recognizably-failed liner. Considering that over a half of CCR waste units associated with groundwater impacts were constructed in the 1970s and 1980s, historic information on liner prevalence and composition is highly pertinent. According to the February 1988 Report to Congress on coal combustion wastes (''RTC I''), before 1975 less than 20 percent of all generating facility units managed their CCR in lined disposal units, and in generating facility units constructed since 1975, the share of lined units grew to over 40 percent.[222] However, as late as in the mid-1980s, about three-quarters of all CCR units (87 percent of surface impoundments and 39 percent of landfills) were still unlined.[223]

In the mid-1990s, the estimated prevalence of unlined landfills still ranged between 43–57 percent, and between 71–72 percent for surface impoundments.[224] According to the March 1999 Report to Congress on wastes from the combustion of fossil fuels (RTC II), the most prevalent liner type was compacted clay (about one-half of all lined landfills, and about 80-percent of all lined surface impoundments). Composite and/or synthetic liners were significantly more prevalent in landfills than in surface impoundments. Based on recent EPA data,[225] the use of liners is still more prevalent in landfills than in surface impoundments.

c. Geographic Distribution

Close to 70 percent of all the established damage cases occur in EPA Regions 5, 4, and 3 (in descending frequency, Region 5: 34 percent; Region 4: 28 percent; and Region 3: seven percent).[226] This distribution correlates well with the regional distribution of *unlined* CCR units in the mid-1980s.[227]

d. Current CCR Waste Unit Status

As of mid-2011, close to half of the combined (proven and potential) damage case CCR waste units were still active; about a quarter were inactive due to either closure of the individual disposal unit, a fuel switch (*e.g.,* from coal to gas) by the generating facility, or the decommissioning of the facility. Another quarter or so represented power generating facilities where CCR waste units (primarily impoundments) that failed to comply with state requirements had been closed and replaced by other, new disposal units, and/or the generating facilities switched from wet- to dry disposal. Since mid-2011, the percentage of inactive CCR units associated with groundwater damage cases has further increased, due to the continued drop in power demand during the economic recession, which has resulted in power station temporary removal from active service (*i.e.,* mothballing) and closures, combined with an increasing switch by many facilities to a more cost-effective fossil fuel (*i.e.,* natural gas).

F. Conclusions

EPA now has a significantly better understanding of CCR damage cases than when the proposed rule was issued. First, damage cases are more numerous than previously contemplated and as more monitoring well systems are installed, the number of damage cases is likely to increase. Second, the CCR damage case record corroborates the findings of the risk analysis by demonstrating the greater vulnerability of groundwater (and surface water) to wet disposal (*i.e.,* surface impoundments). Third, the damage cases show a direct correlation between the absence of liners and groundwater impacts, and illustrate that whereas in general the design of waste units—particularly surface impoundments—has improved over time, a notable portion of CCR impoundments constructed in the last two decades still lack a protective liner, thus presenting a potential threat to groundwater. Finally, a recent CCR spill incident[228] demonstrates that inactive surface impoundments that have not been properly decommissioned (*i.e.,* by breaching, dewatering, and capping or by clean-closing) continue to pose a

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[222] Wastes from the Combustion of Coal by Electric Utility Power Plants (First Report to Congress), EPA/530–SW–88–002, February, 1988, pages 4–30 to 4–33: *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/coal-rtc.pdf*.

[223] These statistics are based on about 42 percent of the total CCR units at that time, for which liner information was available. RTC I attributes this low percentage to the common practice of disposal in off-site units, for which liner information was not available.

[224] Based on three different partial surveys cited in the Second Report to Congress (RTC II, 1999): *Wastes from the Combustion of Fossil Fuels, Volume 2—Methods, Findings, and Recommendations* (Second Report to Congress), EPA 530–R–99–010, March 1999: *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/volume_2.pdf*.

[225] EPA compiled the baseline use of bottom liners by CCR landfills and surface impoundments from the following sources: (1) Impoundment data from EPA/OSWER's 2009–2011 impoundment dam integrity site inspections; *http://www.epa.gov/waste/nonhaz/industrial/special/fossil/surveys2/index.htm*; (2) Impoundment data from ORCR's 2009 Information Collection Request (ICR) addressing power plants with impoundments; *http://www.epa.gov/waste/nonhaz/industrial/special/fossil/coalashletter.htm*; and (3) Landfill and impoundment data from EPA Office of Water's 2010 ICR addressing power plants to be affected by the Steam Electric Power Generating Effluent Guidelines: *http://water.epa.gov/scitech/wastetech/guide/steam_index.cfm#point6*.

[226] See *http://www.epa.gov/aboutepa/#regional* for a list of states covered by each EPA Regional office.

[227] According to the Report to Congress I (1988), in the mid-1980s, the distribution of unlined CCR waste units across EPA regions was as follows: For surface impoundments: 31.7 percent (Region 4); 18.6 percent (Region 5); 6.2 percent (Region 7); and 3.5 percent (Region 3). For landfills: 11.1 percent (Region 5); 2.9 percent (Region 3); and 2.4 percent (Region 4).

[228] The Duke Energy's Dan River, North Carolina, February 2, 2014 CCR slurry spill.

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significant risk to human health and the environment.

XII. Summary of Regulatory Impact Analysis

EPA estimated the costs and benefits of the final rule. The Regulatory Impact Analysis (RIA) is available to the public in the docket for this action.

A. Costs of the Final Rule

The estimated costs of the final rule are summarized in Table XII–A below. These are the incremental costs above the ''baseline.'' *i.e.,* the current costs for managing CCR absent this regulation. The baseline takes into account existing state regulations for managing CCR now and into the future. To the extent that some states may have granted waivers or variances for certain provisions of State requirements, or in other instances may have added extra pollution control requirements above existing regulatory requirements to some specific permits issued to electric utility plants for operating CCR management units, the RIA did not take those actions into account.

EPA used the following data sources to create a model for the RIA that estimates the costs and benefits of the rule: (1) 2012 DOE EIA–923 database; (2) ORCR's 2009–2012 CCR impoundment site inspections; (3) impoundment data from ORCR's 2009 mail survey to plants with CCR impoundments; (4) landfill and impoundment data from EPA Office of Water's 2010 mail survey to power plants in support of the 2013 proposed Steam Electric Power Generating Effluent Limitation Guidelines; (5) Integrated Planning Model (IPM) v. 5.13 (for the future projection of coal consumption by electric utility plants); and (6) the 1995 Electric Power Research Institute (EPRI) Co-management Survey.

TABLE XII–A—ESTIMATED COST OF POLLUTION CONTROLS REQUIRED BY THE CCR FINAL RULE

[Millions 2013$]

CCR pollution control	@ 3% discount rate		@ 7% discount rate	
	Annualized values	Present values	Annualized values	Present values
1. Groundwater monitoring	$4.79	$151	$2.80	$39.9
2. Bottom liners	491	15,500	297	4,230
3. Leachate collection system (landfills only)	51.6	1,630	18.4	263
4. Fugitive CCR dust controls	7.09	224	3.36	48.0
5. Stormwater run-on/run-off controls	18.8	594	13.0	186
6. Location restrictions	43.6	1,380	20.0	285
7. Closure capping	20.1	630	12.0	171
8. Post-closure groundwater monitoring (30 years)	0.08	2.40	0.04	0.61
9. Impoundment structural integrity requirements	10.9	344	11.1	158
10. Corrective action (CCR contaminated groundwater cleanup)	19.0	600	19.1	273
11. Reporting and recordkeeping	26.3	831	27.3	389
12. Conversion to dry CCR handling	29.0	916	57.3	818
13. Inactive impoundments (dewater and closure cap)	12.0	380	26.7	381
14. Subtotal industry costs (1+...+13)	734	23,200	508	7,240
State Agency Burden Costs				
15. Impoundment structural integrity requirements	0.22	6.88	0.22	3.16
16. Corrective action	0.38	12.0	0.38	5.45
17. Reporting and recordkeeping	0.53	16.6	0.55	7.78
18. Subtotal State agency burden costs (15+16+17)	1.12	35.5	1.15	16.4
19. Total cost (14+18)	735	23,200	509	7,260

B. Benefits of the Final Rule

The RIA contains two categories of benefits (1) benefits that are monetized and (2) non-monetized benefits. The RIA estimates 11 categories of expected future human health and environmental benefits for the CCR rule. These include reduced future CCR impoundment structural failure releases; reduced future CCR groundwater contamination; improved air quality from reduced power plant air pollution; and surface water quality benefits. The estimated value of each of the 11 monetized benefits is presented in Table XII–B below.

TABLE XII–B—EPA ESTIMATED MONETIZED BENEFITS FOR THE CCR FINAL RULE

[Millions 2013$ over 100-year period of analysis 2016–2114]

	3% discount rate		7% discount rate	
	Annualized	Present value	Annualized	Present value
1. Reduced CCR impoundment structural failure releases	$156	$4,910	$143	$2,040
2. Reduced CCR landfill & impoundment groundwater contamination	12.8	405	9.86	141
3. Induced increase in future annual CCR beneficial uses	117	3,130	79.0	1,120
4. Reduced incidence of cancer from CCR exposure	<0.1	0.17	<0.1	<0.1
5. Avoided IQ losses from mercury in CCR	0.28	8.80	<0.1	0.35
6. Avoided IQ losses from lead in CCR	0.186	5.87	<0.1	0.23
7. Reduced need for specialized education (associated with 5 & 6 above)	<0.1	<0.1	<0.1	<0.1
8. Non-market surface water quality benefits	2.26	71.4	1.89	27.0

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TABLE XII–B—EPA ESTIMATED MONETIZED BENEFITS FOR THE CCR FINAL RULE—Continued

[Millions 2013$ over 100-year period of analysis 2016–2114]

	3% discount rate		7% discount rate	
	Annualized	Present value	Annualized	Present value
9. Protection of threatened & endangered species near CCR impoundments	0.91	28.7	0.76	10.8
10. Improved air quality from induced changes to power plant emissions	4.66	147	2.04	29.1
11. Reduced power plant groundwater withdrawals	<0.1	<0.1	<0.1	<0.1
12 Total monetized benefits (1 + . . . + 11)	294	8,710	236	3,360

In addition to the monetized benefit categories, the RIA describes 11 additional non-monetized benefit categories. Due to uncertainties and weaknesses in supporting documentation for quantifying and monetizing these benefits, the RIA presents these benefits separately from the benefits listed above, and does not include them in the quantified comparison of benefits and costs. These non-monetized benefits include:

1. Financial market benefits
2. Reduced community dread of CCR impoundment structural failure releases
3. Reduced health and property nuisance impacts from CCR fugitive dust
4. Cancer and non-cancer human health benefits from reduced CCR contamination of fish consumed by recreational anglers and subsistence fisher households in surface waters near power plants (additional to monetized avoided health effects)
5. Cancer and non-cancer human health benefits from reduced CCR exposure by other recreational users of surface waters near power plants (additional to monetized avoided health effects)
6. Avoided CCR contamination of sediments in surface waters near power plants
7. Water quality benefits from avoided CCR contamination treatment costs for use of surface waters for drinking and irrigation water supply
8. Commercial fisheries benefit in surface waters near power plants
9. Increased participation in water-based recreation near power plants
10. Avoided fish impingement and entrainment mortality from power plant water intakes (induced conversion to dry CCR handling reduces future water demand for CCR sluicing)
11. Increased property values surrounding electric utility plants (from closure capping and re-vegetation of CCR surface impoundments)

The total monetized benefits less the total costs of the rule provide the net monetized benefits of the rule. Table XII–C summarizes the total costs and benefits as well as the net benefits of the rule.

TABLE XII–C—EPA ESTIMATED INCREMENTAL COSTS & BENEFITS OF THE CCR RULE

[Millions 2013$ over 100-year period of analysis 2015–2114]

	3% discount rate	7% discount rate
A. Annualized Values.		
A1. Total Costs	$735	$509
A2 Total monetized benefits	294	236
A3. Net Benefits (A2–A1)	(441)	(273)
A4. Benefit to Cost Ratio (A3/A1)	0.40	0.46
B. Present Value.		
B1. Total Costs	23,200	7,260
B2 Total monetized benefits	8,710	3,360
B3. Net Benefits (B2–B1)	(14,490)	(3, 900)
B4. Benefit to Cost Ratio (B2/B1)	0.38	0.46

XIII. Uniquely Associated Wastes

By way of this rule, EPA is codifying in § 261.4(b)(4) a list of low volume waste that when co-disposed with CCR are not subject to hazardous waste regulations. These wastes are also referred to as uniquely associated wastes. However, these uniquely associated wastes are subject to hazardous waste regulations when they are not co-disposed with CCR.

In a letter to EPA dated October 10, 1980 the Utility Solid Waste Activities Group (USWAG) suggested interpretive language that EPA should adopt regarding the amendments to the Solid Waste Disposal Act Amendments of 1980 which address fossil fuel combustion wastes. EPA replied to USWAG by letter dated January 13, 1981 (known as the 1981 Dietrich letter), and addressed, among other issues, other associated wastes generated in conjunction with the burning of fossil fuels.[229] EPA stated that ''We believe it is appropriate, in the light of Congressional intent, to interpret the § 261.4(b)(4) exclusion to include other wastes that are generated in conjunction with the burning of fossil fuels and mixed with and co-disposed or co-treated with fly ash, bottom ash, boiler slag and flue gas emission control wastes.'' When amendments to the 1980 Solid Waste Disposal Act were introduced, Congressmen Bevill and Rahall stated, respectively:

It is the sponsor's intention that this list of waste materials in the amendment be read broadly, to incorporate the waste products generated in the real world as a result of the combustion of fossil fuels. We do not believe that these terms should be narrowly read and thus impose regulatory burdens upon those who seek to assist the Nation by burning coal. EPA should recognize that these ''waste streams'' often include not only the

[229] See letter from Gary N. Dietrich to Paul Elmer, USWAG, available in the docket for this rule.

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byproducts of the combustion of coal and other fossil fuels, but also relatively small proportions of other materials produced in conjunction with the combustion, even if not derived directly from these fuels. EPA should not regulate these waste streams because of the presence of these materials, if there is no evidence of any substantial environmental danger from these mixtures. *(126 Cong. Rec. H1102).*

In the real world, these waste materials do not include solely fly ash, bottom ash, slag, or scrubber sludge. Quite often, other materials are mixed with these large volume waste streams, with no environmentally harmful effects, and often with considerable benefit-as when, for example, boiler cleaning-acids are neutralized by being mixed with alkaline fly ash. These appear to me to be environmentally beneficial practices, which EPA should encourage. At the very least, however, the Agency should take no steps to discourage them until it has developed a full factual understanding of the situation. This amendment would assure that EPA allows all persons burning coal to avoid unnecessary regulation of the byproducts produced by that combustion, as those byproducts are currently being managed in the real world, by real people, with real sense. *(126 Cong. Rec. H1104).*

As such, EPA interpreted 40 CFR 261.4(b)(4) (the Bevill exemption) to mean that wastes produced in conjunction with the combustion of fossil fuels, which are necessarily associated with the production of energy, and which traditionally have been, and which actually are, mixed with and co-disposed or co-treated with fly ash, bottom ash, boiler slag, or flue gas emission control wastes from coal combustion are not hazardous wastes. In the Deitrich letter EPA stated that these other associated wastes include, but are not limited to the following wastes: (1) Boiler cleaning solutions; (2) boiler blowdown; (3) demineralizer regenerant; (4) pyrites; and (5) cooling tower blowdown.

In a February 1988 Report to Congress on Wastes from the Combustion of Coal by Electric Utility Power Plants EPA listed the following low-volume wastes commonly produced in conjunction with the burning of fossil fuels to produce electricity: (1) Boiler blowdown; (2) coal pile run-off; (3) cooling tower blowdown; (4) demineralizer regenerants and rinses; (5) metal and boiler cleaning wastes; (6) pyrites; and (7) sump effluents. Presented for each type of low-volume waste is a brief description of how the waste is generated, typical quantities produced, and the physical and chemical composition of the waste.[230] The source of this information was primarily an August 1981 USWAG/Edison Electric Institute report in response to a request for information in the 1981 Dietrich letter.

In an August 1, 1993 Regulatory Determination the Agency emphasized that co-management of low-volume wastes and large-volume wastes (fly ash, bottom ash, boiler slag, or flue gas emission control wastes from coal combustion) makes the combined waste stream a remaining waste that would be subject to a subsequent Regulatory Determination and provided the list below of management practices that result in combined waste streams that are remaining wastes.[231]

- Discharge of boiler blowdown to a large-volume waste impoundment,
- Discharge of demineralizer regenerant to a large-volume waste impoundment,
- Discharge of metal cleaning wastes to a large-volume waste impoundment,
- Discharge of boiler chemical cleaning wastes to a large-volume waste impoundment,
- Discharge of plant wastewater treatment effluent to a large-volume waste impoundment,
- Discharge of coal mill rejects to a large-volume waste impoundment,
- Disposal of oil ash in a large-volume waste landfill or impoundment,
- Disposal of plant wastewater treatment sludge in a large-volume waste landfill.

In a 1999 Report to Congress on wastes from the combustion of fossil fuels [232] EPA stated that low-volume wastes are generated as a result of supporting processes that are ancillary to, but a necessary part of, the combustion and power generation processes and provided the following list of low-volume wastes.

- Coal pile run-off
- Coal mill rejects/pyrites
- Boiler blowdown
- Cooling tower blowdown and sludge
- Water treatment sludge
- Regeneration waste streams
- Air heater and precipitator washwater
- Boiler chemical cleaning waste
- Floor and yard drains and sumps
- Laboratory wastes
- Wastewater treatment sludge

The concept of uniquely associated wastes with respect to CCR was first introduced in the May 22, 2000 Regulatory Determination. Prior to this, these wastes were referred to as other wastes, remaining wastes, or low-volume wastes, that are generated in conjunction with the burning of fossil fuels and mixed with and co-disposed or co-treated with fly ash, bottom ash, boiler slag and flue gas emission control wastes. For the May 22, 2000 Regulatory Determination, the Agency proposed the uniquely associated wastes concept with the intent of being consistent with other wastes covered under the Bevill Amendment (a.k.a., the Bevill exemption), such as mining and mineral processing wastes that the Agency refers to as uniquely associated wastes, and under the Bentsen Amendment for oil and gas exploration and production wastes which are referred to as associated wastes. The Agency recognized that determining whether a particular waste is uniquely associated with fossil fuel combustion involves an evaluation of the specific facts of each case. In the Agency's view, the following qualitative criteria should be used to make such determinations on a case-by-case basis:

(1) Wastes from ancillary operations are not ''uniquely associated'' because they are not properly viewed as being ''from'' fossil fuel combustion.

(2) In evaluating a waste from non-ancillary operations, one must consider the extent to which the waste originates or derives from the fossil fuels, the combustion process, or combustion residuals, and the extent to which these operations impart chemical characteristics to the waste.

EPA proposed the following list of wastes that the Agency considered to be uniquely associated wastes (*i.e.,* uniquely associated with the combustion of coal for the generation of electricity at electric utilizes and independent power producers and, therefore, covered by the Bevill exemption).

- Coal Pile Run-off
- Coal Mill Rejects and Waste Coal
- Air Heater and Precipitator Washes
- Floor and Yard Drains and Sumps
- Wastewater Treatment Sludges
- Boiler Fireside Chemical Cleaning Wastes

EPA also proposed the following list of wastes that would not be considered uniquely associated wastes.

- Boiler Blowdown
- Cooling Tower Blowdown and Sludges
- Intake or Makeup Water Treatment and Regeneration Wastes
- Boiler Waterside Cleaning Wastes
- Laboratory Wastes
- General Construction and Demolition Debris

[230] See *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/coal-rtc.pdf,* pages 3–41 to 3–62. This report addressed wastes generated from the combustion of coal by electric utility power plants, and did not address comanaged utility coal combustion wastes, other fossil fuel combustion wastes, and wastes from non-utility boilers.

[231] *http://www.epa.gov/osw/nonhaz/industrial/special/mineral/080993.pdf.*

[232] *http://www.epa.gov/osw/nonhaz/industrial/special/fossil/volume_2.pdf.*

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- General Maintenance Wastes

EPA requested comments on these proposed lists and received several comments from states, industry, and the environmental community. Industry opposed the ''uniquely associated'' waste framework, and favors retaining the 1981''Dietrich Policy.''

Many commenters argued that the Dietrich policy has provided clear guidance on the scope of the Bevill exemption for the past 20 years, and that appropriate waste management practices have been implemented for these wastes. The Dietrich Policy has proven itself effective in furthering congressional intent to recognize certain historic co-management practices provided they are not environmentally harmful. The Association of State and Territorial Solid Waste Management Officials recommended that EPA contact States that have management programs for fossil fuel combustion wastes to determine how to best manage the waste that are uniquely associated or not uniquely associated with fossil fuel combustion wastes. The Hoosier Environmental Council opposed exempting coal wastes and stated that ''coal mill rejects and coal pile run-off would not be uniquely associated wastes . . . because neither of these wastes is derived from coal combustion.''

EPA acknowledges that the Deitrich letter has been longstanding policy with regard to CCR uniquely associated wastes and that the Agency has not sought input from States on the issue. Moreover, as evident from the Congressional Record, the Congressional intent was to ''include not only the byproducts of the combustion of coal and other fossil fuels, but also relatively small proportions of other materials produced in conjunction with the combustion, even if not derived directly from these fuels.'' These other materials would include many of those listed in the Dietrich letter as well as many of those listed in the May 2000 Regulatory determination.

After considering the 1981 Dietrich letter, a copy of which is included in the docket for this rule, the proposed guidance in the May 2000 Regulatory Determination, comments received on the May 2000 Regulatory Determination and the July 2010 proposed rule, EPA has concluded that the 1981 Dietrich letter accurately reflects the intent of Congress when they exempted CCR from hazardous waste regulations. EPA also believes that many of the wastes listed as uniquely associated wastes in the May 22, 2000 Regulatory Determination are also consistent with the Congressional intent. Therefore, the Agency is finalizing the following list of uniquely associated wastes that includes materials from both the Dietrich letter and the May 2000 Regulatory Determination.

- Coal pile run-off
- Boiler cleaning solutions
- Boiler blowdown
- Process water treatment and demineralizer regeneration wastes
- Cooling tower blowdown
- Air heater and precipitator washes
- Effluents from floor and yard drains and sumps, and
- Wastewater treatment sludges

This list is being codified in 40 CFR 261.4(b): Solid wastes which are not hazardous wastes.

XIV. Statutory and Executive Order Reviews

A. Executive Order 12866: Regulatory Planning and Review and Executive Order 13563: Improving Regulation and Regulatory Review

Under section 3(f)(1) of Executive Order 12866 (58 FR 51735, October 4, 1993), this action is an ''economically significant regulatory action'' because it is likely to have an annual effect on the economy of $100 million or more. The total annual cost of this final rule is estimated to be $509 million a year using a 7% discount rate. Accordingly, EPA submitted this action to the Office of Management and Budget (OMB) for review under Executive Orders 12866 and 13563 (76 FR 3821, January 21, 2011) and any changes made in response to OMB recommendations have been documented in the docket for this action.

In addition, EPA prepared an analysis of the potential costs and benefits associated with this action. The Regulatory Impact Analysis (RIA) estimated the costs and benefits for this action. The RIA estimated 12 regulatory costs: (1) Groundwater monitoring; (2) bottom liner installation; (3) leachate collection system installation and management; (4) fugitive dust controls; (5) rain and surface water run-on/run-off controls; (6) disposal unit location restrictions (including water tables, floodplains, wetlands, fault areas, seismic zones, and karst terrain); (7) closure capping to cover units; (8) post-closure groundwater monitoring requirements; and (9) impoundment structural integrity requirements; (10) corrective actions (CCR contaminated groundwater cleanup); (11) paperwork reporting/recordkeeping; and (12) impoundment closures and conversion to dry handling. Using a 7% discount rate, the annualized costs are estimated at $509 million, and using a 3% discount rate, annualized costs are estimated to be $735 million. Using a 7% discount rate, the total present value costs are estimated at $7.3 billion, and using a 3% discount rate the present value of estimated costs is $23.2 billion.

The RIA estimated 11 monetized benefits: (1) CCR impoundment release prevention; (2) CCR landfill & impoundment groundwater contamination prevention; (3) induced increase in CCR beneficial uses (*e.g.,* concrete, wallboard); (4) reduced incidence of cancer from CCR exposure; (5) avoided IQ losses from mercury; (6) avoided IQ losses from lead; (7) reduced need for specialized education; (8) non-market surface water quality benefits; (9) protection of threatened & endangered species near CCR impoundments; (10) improved air quality from induced changes to power plant emissions and (11) reduced power plant groundwater withdrawals. The annualized monetized benefits are estimated at $294 million (@ 3% discount rate) and $236 million (@ 7% discount rate). The total present value monetized benefits are estimated at $8.7 billion (@ 3% discount rate) and $3.4 billion (@ 7% discount rate).

B. Paperwork Reduction Act (PRA)

The information collection activities in this rule will be submitted for approval to the Office of Management and Budget (OMB) under the PRA. The Information Collection Request (ICR) document that the EPA prepared has been assigned EPA ICR number 1189.25, OMB control number 2050–0053. You can find a copy of the ICR in the docket for this rule, which will be available in the docket once the ICR has been submitted to OMB for review, and it is briefly summarized here. The information collection requirements are not enforceable until OMB approves them.

These regulations, promulgated under subtitle D of RCRA, constitute national minimum criteria with which facilities must comply without oversight or intervention by a federal or state authority. To address concerns about the absence of regulatory oversight under a subtitle D regulation, EPA has developed a combination of mechanisms, including recordkeeping, notification, and maintaining a publicly accessible Internet site. The increased transparency resulting from these requirements will minimize the potential for owners or operators to abuse the self-implementing system established in this rule. In addition, these requirements provide interested parties the information necessary to

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determine whether the owner or operator is operating in compliance with the requirements of the rule and thus will facilitate enforcement by States and private citizens. EPA has consolidated the recordkeeping, notification, and Internet posting requirements into a single section of the regulations in an effort to make these requirements easier to follow. It is important to note that EPA will not be collecting any information under this rule—instead, facilities must keep records, notify the state, and post information on a publicly available Web site. EPA has taken steps to minimize the burden to the regulated community while at the same time achieving the transparency needed to ensure proper implementation of this rule. In addition to the burden to owner and operators of CCR landfills, in an effort to ease implementation, EPA has reporting and recordkeeping requirements for certain beneficial uses and states. For beneficial use that meets the fourth criteria, the user must maintain records and provide documentation upon request. For states, states are encouraged to voluntarily adopt at least the federal minimum criteria through the revision of SWMPs. In addition, EPA estimated the burden on state government agencies associated with the receipt of various notification requirements in the rule.

The respondents/affected entities are the owners/operators of electric utilities and independent power producers that fall within the NAICS code 221112. Specifically, these regulations apply to owners and operators of new and existing landfills and new and existing surface impoundments, including lateral expansions that of all landfills and surface impoundments that dispose or otherwise engage in solid waste management of CCR generated from the combustion of coal at electric utilities. The rule also applies to CCR units located off-site of the electric utilities' or independent power producers' facilities that receive CCR for disposal. The rule applies to certain inactive CCR surface impoundments at active electric utilities' or independent power producers' facilities, if the CCR unit still contains CCR and liquids. Finally, the rule applies to certain beneficial users of CCR. The rule may also impact States that choose to revise their SWMPs.

Respondents are obligated to keep records, make the required notifications, and maintain the publicly available Internet site. These requirements are part of the minimum federal criteria under 40 CFR part 257 and promulgated under the authority of sections 1006(b), 1008(a), 2002(a), 3001, 4004, and 4005(a) of the Solid Waste Disposal Act of 1970, as amended by the Resource Conservation and Recovery Act of 1976 (RCRA), as amended by the Hazardous and Solid Waste Amendments of 1984 (HAS), 42 U.S.C. 6906(b), 6907(a), 6912(a), 6944, and 6945(a).

Respondents/affected entities: EPA estimates the total number of respondents to be 486. This number represents the estimated number of coal-fired electric utility plants that will be affected by the rule.

Respondent's obligation to respond: The recordkeeping, notification, and posting are part of the minimum national criteria being promulgated under Sections 1008, 4004, and 4005(a) of RCRA.

Estimated number of respondents: 486.

Frequency of response: The frequency of response varies.

Total estimated burden: EPA estimates the total annual burden to respondents to be approximately 358,957 hours with a three year total estimated burden of 1,076,871 hours. Burden is defined at 5 CFR 1320.3(b).

Total estimated cost: The total estimated annual cost is approximately $64,007,121; this is composed of approximately $22,894,608 in annualized labor costs and $41,112,513 in annualized capital or operation and maintenance costs. The three year total estimated costs are $192,021,364 composed of $68,683,824 in labor costs and $123,337,540 in operations and maintenance.

In addition, developing a state SWMP (see Unit IX of this preamble) is not a requirement under this rule, however, EPA is encouraging states to develop these plans and has developed a burden estimate associated with this activity. The estimate for this one-time activity has been annualized over the three-year period covered by the ICR. The total estimated annual burden (for the 47 states and Puerto Rico where CCR are generated) is approximately 10,880 hours, and approximately $429,414 in annualized labor costs; this estimate assumes no annualized capital or operations and maintenance costs.

An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number. The OMB control numbers for the EPA's regulations in 40 CFR are listed in 40 CFR part 9. When OMB approves this ICR, the Agency will announce that approval in the **Federal Register** and publish a technical amendment to 40 CFR part 9 to display the OMB control number for the approved information collection activities contained in this final rule.

C. Regulatory Flexibility Act

The Regulatory Flexibility Act (RFA) generally requires an agency to prepare a regulatory flexibility analysis of any rule subject to notice and comment rulemaking requirements under the Administrative Procedure Act or any other statute unless the agency certifies that the rule will not have a significant economic impact on a substantial number of small entities (SISNOSE). Small entities include small businesses, small organizations, and small governmental jurisdictions.

For purposes of assessing the impacts of this rule on small entities, small entity is defined as: (1) A small business, based on the U.S. Small Business size standard for NAICS code 221112 (fossil fuel electric utility plants), with fewer than 750 employees; (2) a small government jurisdiction, based on the RFA/SBREFA's definition (5 U.S. Code section 601(5)), is the government of a city, county, town, township, village, school district, or special district with population under 50,000; (3) a small organization that is any not-for-profit enterprise which is independently owned and operated and is not dominant in its field.

After considering the economic impacts of this final rule on small entities, I certify that this action will not have a significant economic impact on a substantial number of small entities.

The small entities directly regulated by this final rule consist of one small county, 31 small cities, 32 small companies, and 13 small cooperative owner entities that own at least one coal-burning power plant. There are 91 coal-burning power plants that are owned by the 77 small owner entities. Those plants fall into the following categories: One small county plant, 31 small city plants, 42 plants owned by small companies, and 17 small cooperative plants.

The RIA estimated CCR compliance costs as a percentage of revenues for each entity and found that for almost all small entities affected by the rule the estimated annualized costs were less than 1% of revenues.

Although this final rule will not have a significant economic impact on a substantial number of small entities, EPA nonetheless has tried to reduce the impact of this rule on small entities.

D. Unfunded Mandates Reform Act (UMRA)

Title II of the Unfunded Mandates Reform Act of 1995 (UMRA), 2 U.S.C. 1531–1538, requires Federal agencies, unless otherwise prohibited by law, to assess the effects of their regulatory

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actions on state, local, and tribal governments and the private sector. This rule contains a federal mandate that may result in expenditures of $100 million or more for state, local, and tribal governments, in the aggregate, or the private sector in any one year. Accordingly, EPA has prepared under section 202 of the UMRA a written statement which is summarized below.

The RIA estimates the rule may affect 414 coal-fired electric utility plants, and may have a nationwide average annualized cost of approximately $509 million per year (at a 7% discount rate). Of this amount, average annualized costs to State/local governments total $36 million, and the average annualized cost to the private sector totals approximately $436 million per year (the remainder of the total costs are the costs associated with compliance at federally-owned electric utility plants.)

Consistent with the intergovernmental consultation provisions of section 204 of the UMRA, EPA initiated pre-proposal consultations with governmental entities affected by this rule. In developing the regulatory options for the CCR rule, EPA consulted with small governments according to EPA's UMRA interim small government consultation plan developed pursuant to section 203 of UMRA. EPA's interim plan provides for two types of possible small government input: Technical input and administrative input. According to this plan, and consistent with section 204 of UMRA, early in EPA's 2009 process for developing the CCR rule, EPA implemented a small government consultation process consisting of two consultation components: (1) A series of meetings in 2009 for purposes of acquiring technical input from State government officials, and (2) letters to 10 organizations representing elected State and local government officials to inform and seek input for the rule's development, as well as to invite them to a meeting held September 16, 2009 in Washington DC to provide input on the rule. Following are the meetings held with state officials in 2009: (1) February 27 with the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) Coal Ash Workgroup (Washington DC), (2) March 22–24 with the Environmental Council of States (ECOS) Spring Meeting (Alexandria VA), (3) April 15–16 with the ASTSWMO Mid-Year Meeting (Columbus OH), (4) May 12–13 with the EPA Region IV State Directors Meeting (Atlanta, GA), (5) June 17–18 with the ASTSWMO Solid Waste Managers Conference (New Orleans, LA), (6) July 21–23 with the ASTSWMO Board of Directors Meeting (Seattle, WA), and (7) August 12 with the ASTSWMO Hazardous Waste Subcommittee Meeting (Washington DC). ASTSWMO is an organization with a mission to work closely with the EPA to ensure that its state government members are aware of the most current developments related to state waste management programs. ECOS is a national non-profit, non-partisan association of state and territorial environmental agency leaders. As a result of these meetings EPA received letters in mid-2009 from 22 state governments as well as a letter from ASTSWMO expressing their stance on CCR regulatory options.

On August 24, 2009 letters were mailed to the following 10 organizations, which include representation from small government elected officials, to inform and seek input for the rule development, as well as to invite them to a meeting held September 16, 2009 in Washington DC: (1) National Governors Association, (2) National Conference of State Legislatures, (3) Council of State Governments, (4) National League of Cities, (5) U.S. Conference of Mayors, (6) County Executives of America, (7) National Association of Counties, (8) International City/County Management Association, (9) National Association of Towns and Townships, and (10) Environmental Council of the States. These 10 organizations representing State and local government officials are identified in EPA's November 2008 Federalism guidance as the ''Big 10'' organizations appropriate to contact for purpose of consultation with small government elected officials.

Consistent with section 205, EPA identified and considered a reasonable number of regulatory alternatives in the June 2010 proposed rule, and is adopting the least-costly approach (*i.e.* a modified version of the ''D Prime'' least costly approach presented in the 2010 proposed CCR rule).

This rule is not subject to the requirements of section 203 of UMRA because it contains no regulatory requirements that might significantly or uniquely affect small governments. The threshold amount established for determining whether regulatory requirements could significantly affect small governments is $100 million annually. The RIA estimates a $1.2 million annual cost for state/local government implementation of the rule and $36 million in annual direct compliance costs on 57 state or local governments. These estimates are well below the $100 million annual threshold established under UMRA. However this rule does have over a $100 million dollar impact on industry. EPA selected one of the lower industry cost options for the final rule by selecting a RCRA subtitle D rule instead of a RCRA subtitle C rule.

E. Executive Order 13132—Federalism

The EPA has concluded that this action may have federalism implications because it imposes substantial direct compliance costs on state or local governments, and the Federal government will not provide the funds necessary to pay those costs. Based on the estimates in EPA's RIA for this action, the final rule, if promulgated, may impose a $1.2 million annual cost for state/local government implementation of the rule and $36 million in annual direct compliance costs on 57 state or local governments. This amount exceeds the $25 million per year ''substantial compliance cost'' threshold defined in section 1.2(A) (1) of EPA's November 2008 ''Guidance on Executive Order 13132: Federalism.'' There are 57 State and local governments which own 68 coal-burning power plants or 16% of the 414 electric utility plants expected to be affected by this rule. These 57 local governments consist of 7 state governments, 31 small municipality governments, 18 non-small municipal governments and 1 (small) county government owner.

The EPA provides the following federalism summary impact statement. The EPA consulted with state and local officials early in the process of developing the proposed action to permit them to have meaningful and timely input into its development. In developing the regulatory options described in this final action, EPA consulted with 10 national organizations representing state and local elected officials to ensure meaningful and timely input by state/local governments, consisting of two consultation components. This consultation is described and summarized in the UMRA section above.

In the spirit of Executive Order 13132, and consistent with EPA policy to promote communications between EPA and state and local governments, EPA specifically solicited comment on the proposed action from state and local officials. EPA received comments from over two hundred (200) entities representing state and local governments. The comments submitted primarily addressed the issue presented in the proposal of which approach to regulating CCR was appropriate—a regulation under subtitle C or under subtitle D of RCRA. The state and local government commenters overwhelming

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voiced their opposition to a regulation under subtitle C, citing impacts to state programs if EPA were to bring such a large number of facilities and a large volume of waste into the subtitle C universe. State governments were very concerned with the resources which would be required to issue subtitle C permits to these facilities and to develop and obtain EPA approval of revisions to their authorized RCRA subtitle C programs. They also expressed concerns about the limits in the existing hazardous waste disposal capacity in the United States to absorb such a large volume of new wastes, also citing the financial burden and potential liability problems for cities and towns that operate landfills or use landfills to dispose of waste that might include coal ash.

In addition, states and local governments expressed concern that a subtitle C rule would have a negative effect on beneficial use of CCR and on state beneficial use programs. State and local governments fully supported continued beneficial use of CCR and continuation of the Bevill exemption for CCR beneficial use. They requested that EPA establish standards to ensure that beneficial uses are protective of human health and the environment and ensure consistency in management of these materials throughout the country. They specifically cited the use of CCR in cement and concrete applications, highway construction projects and wallboard manufacture (among other uses) and the impacts to municipalities through increased costs and potential job loss if CCR is classified as a hazardous waste. They also noted an expectation that utility rates would rise as a result of CCR being disposed of in landfills rather than being used for beneficial purposes, due to limited availability of commercial hazardous waste disposal facilities and costs of transporting high volumes of CCR to these facilities. State Departments of Transportation expressed particular concern that a subtitle C rule would negatively affect the use of CCR in road bed. Commenters further supported continued beneficial use of CCR to reduce the need for mining for substitute products in cement and concrete. Finally, should CCR be classified as a hazardous waste, they indicated the need for EPA to clarify that products made using CCR are new products and not considered hazardous wastes, and may be treated in the same manner as similar products made without CCR.

Since EPA is promulgating this regulation under subtitle D, the concerns over the potential effect of a subtitle C regulation on beneficial use are moot. Moreover in this final rule, EPA has established a definition for beneficial use which we believe makes clear the distinction between beneficial use and disposal. This is fully discussed in Unit VI of this document.

While States supported a rule under subtitle D, they also voiced concern about the need for flexibility to address site-specific situations, as would be available under a state permitting program, and concern about potential inconsistencies between the new federal requirements and existing State programs. States suggested that regulation under subtitle D should embrace the existing state permitting programs—allowing state permitting programs as the foundation for regulating CCR disposal—and requested financial incentives to implement federal criteria through state solid waste programs. They also emphasized the need to allow time for states to make necessary changes in existing state rules and statutes to incorporate federal criteria. A few expressed the desire that financial assurance for closure, post closure care, and corrective action should be included in the final rule as a mechanism to ensure that funds will be provided by owners and operators to carry out these activities.

As fully explained earlier in this document, EPA is promulgating this rule under subtitle D of RCRA. As such, these regulations constitute the minimum federal requirements which apply to CCR units. States are not required to adopt these regulations or to revise their state programs to incorporate the new federal requirements. As fully discussed in Unit V of this document, ''Development of the RCRA Subtitle D Regulatory Approach,'' sections 1008(a), 4004, and 4005(a) of RCRA (*i.e.,* subtitle D) does not provide EPA with the ability to require states to issue permits, to approve state programs to operate in lieu of the federal program, or to enforce any of the requirements addressing the disposal of CCR. Consequently EPA designed the final rule to ensure protection of public health and the environment within these limitations. In addition, to help address potential implementation challenges that this statutory and resulting regulatory structure impose, as fully set out in Section IX of this document, EPA is encouraging states to revise their Solid Waste Management Plans and to submit these to EPA for approval.

A complete list of the comments from state and local governments has been provided to the Office of Management and Budget and has been placed in the docket for this rulemaking. In addition, the detailed response to comments from these entities is contained in EPA's response to comments document on this rulemaking.

As required by section 8(a) of Executive Order 13132, EPA included a certification from its Federalism Official stating that EPA had met the Executive Order's requirements in a meaningful and timely manner when it sent the draft of this final action to OMB for review pursuant to Executive Order 12866. A copy of this certification is included in the public version of the official record for this final action.

F. Executive Order 13175—Consultation and Coordination With Indian Tribal Governments

Subject to the Executive Order 13175 (65 FR 67249, November 9, 2000) EPA may not issue a regulation that has tribal implications, that imposes substantial direct compliance costs, and that is not required by statute, unless the Federal government provides the funds necessary to pay the direct compliance costs incurred by tribal governments, or EPA consults with tribal officials early in the process of developing the proposed regulation and develops a tribal summary impact statement.

EPA has concluded that this action may have tribal implications. However, it will neither impose substantial direct compliance costs on tribal governments, nor preempt Tribal law. As identified in EPA's Regulatory Impact Analysis for this action, there are no known tribal owner entities of the coal-fired electric utility plants affected by this action. Although there are three of the 414 coal-fired electric utility plants (in operation as of 2012) which are located on tribal lands, they are not owned by tribal governments. These are: (1) Navajo Generating Station in Coconino County, owned by the Arizona Salt River Project; (2) Bonanza Power Plant in Uintah County, Utah, owned by the Deseret Generation and Transmission Cooperative; and (3) Four Corners Power Plant in San Juan County, New Mexico owned by the Arizona Public Service Company. The Navajo Generating Station and the Four Corners Power Plant are on lands belonging to the Navajo Nation, while the Bonanza Power Plant is located on the Uintah and Ouray Reservation of the Ute Indian Tribe.

EPA consulted with tribal officials early in the process of developing this regulation to permit them to have meaningful and timely input into its development.

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G. Executive Order 13045: Protection of Children From Environmental Health Risks and Safety Risks

This action is subject to E.O. 13045 (62 FR 19885, April 23, 1997) because it is an economically significant regulatory action as defined by E.O. 12866, and EPA believes that the environmental health or safety risks addressed by this action may have a disproportionate effect on children. Accordingly, we have evaluated the environmental health or safety effects of Coal Combustion Residual constituents of potential concern on children. The results of this evaluation are contained in the *Human and Ecological Risk Assessment of Coal Combustion Wastes* available in the docket for this action.

As ordered by E.O. 13045 Section 1–101(a), EPA identified and assessed environmental health risks and safety risks that may disproportionately affect children in the revised risk assessment. Pursuant to U.S. EPA's Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants, children are divided into seven distinct age cohorts: 1 to <2 yr, 2 to <3 yr, 3 to <6 yr 6 to <11 yr, 11 to <16 yr, 16 to <21 yr, and infants (<1 yr). Using exposure factors for each of these cohorts, EPA calculated cancer and non-cancer risk results in both the screening and probabilistic phases of the assessment. In general, risks to infants tended to be higher than other childhood cohorts, and also higher than risks to adults. However, for drinking water cancer risks, the longer exposures for adults led to the highest risks. Screening risks exceeded EPA's human health criteria for children exposed to contaminated air, soil, and food resulting from fugitive dust emissions and run-off. Similarly, 90th percentile child cancer and non-cancer risks exceeded the human health criteria for the groundwater to drinking water pathway under the full probabilistic analysis (Table 5–17 in the *Human and Ecological Risk Assessment of Coal Combustion Wastes*). As ordered by E.O. 13045 Section 101(b) EPA has ensured that the standard addresses disproportionate risks to children that result from environmental health risks. The results of the screening assessment finds that risks fell below the criteria when wetting and run-on/runoff controls required by the rule are considered. Under the full probabilistic analysis, composite liners required by the rule for new waste management units showed the ability to reduce the 90th percentile child cancer and non-cancer risks for the groundwater to drinking water pathway to well below EPA's criteria. Additionally, the groundwater monitoring and corrective action required by the rule will reduce risks from current waste management units. Thus, EPA believes that this rule will be protective of children's health.

In general, because the pollution control requirements under the CCR rule will reduce health and environmental exposure risks at all coal-fired electric utility plants, the CCR rule is not expected to create additional or new risks to children.

H. Executive Order 13211: Actions Concerning Regulations That Significantly Affect Energy Supply, Distribution, or Use

Executive Order 13211 (66 FR 28355 (May 22, 2001)) requires EPA to prepare and submit a Statement of Energy Effects to the Administrator of the Office of Information and Regulatory Affairs, Office of Management and Budget (OMB), for actions identified as ''significant energy actions.'' This action, which is a significant regulatory action under Executive Order 12866, is not likely to have a significant adverse effect on the supply, distribution, or use of energy based on the results of the electricity price impact estimates of the Regulatory Impact Analysis (RIA) for this action. We have prepared a Statement of Energy Effects for this action.

According to Executive Order 13211, the statement should address (i) any adverse effects on energy supply, distribution, or use, (including a shortfall in supply, price increases, and increased use of foreign supplies) should the proposal be implemented, and (ii) reasonable alternatives to the action with adverse energy effects and the expected effects of such alternatives on energy supply, distribution, and use.

The potential impact of the final CCR rule on electricity prices is analyzed relative to the ''in excess of one percent'' threshold which is one of nine alternative numerical indicators established by OMB for defining ''significant adverse effect'' under Executive Order 13211.[233] The integrated planning model (IPM) estimates potential increases in wholesale electricity prices for 22 National Energy Modeling System (NEMS) regions. In addition, the analysis focuses on potential changes in electricity prices in 2020, 2025, and 2030. The analysis focuses on these relatively early year in the analytic time horizon examined in the RIA to minimize uncertainty in the estimated electricity price impacts. In addition, under the provisions of the rule, the year 2018 is when impoundments begin to undergo closure or wet/dry conversion if they are found to be leaking. Therefore, 2020, 2025, and 2030 represent high-cost year relative to other years in the analytic time horizon, and the analysis presented here will likely yield conservative estimates of the rule's impact on electricity prices.

Using IPM, the weighted average nationwide potential increase in the wholesale price of electricity is not expected to exceed one percent (between .18% and 0.19% in the years 2020 through 2030). However, for one of the 22 NEMS regions (AZNM), the RIA projects a potential price increase above one percent (between 0.78% and 1.05% in the years 2020 through 2030).

Finally, any retail electricity price increases, if they occur, would have the effect of offsetting a portion of the compliance costs to electric utilities estimated in the RIA, as the utilities would be recovering costs through price increases to customers. Therefore, these impacts are not additive to total rule costs, but would instead offset costs to utilities estimated in the RIA.

Only one region may slightly exceed a one percent electricity price increase, which the RIA estimated without considering the potential reduction in such impact with the compliance deadline flexibility of this action for CCR surface impoundments. Thus all regions are likely to experience less than one percent electricity price impacts of this action. Therefore, this statement does not address reasonable alternatives to the action because EPA does not expect this action to have adverse energy effects as defined by OMB.

I. National Technology Transfer and Advancement Act

Section 12(d) of the National Technology Transfer and Advancement Act of 1995 (''NTTAA''), Public Law 104–113, 12(d) (15 U.S.C. 272 note) directs EPA to use voluntary consensus standards in its regulatory activities unless to do so would be inconsistent with applicable law or otherwise impractical. Voluntary consensus standards are technical standards (*e.g.,* materials specifications, test methods, sampling procedures, and business practices) that are developed or adopted by voluntary consensus standards bodies. NTTAA directs EPA to provide Congress, through OMB, explanations when the Agency decides not to use

[233] OMB defines nine alternative numerical indicators of ''significant adverse effect'' on energy supply, distribution, or use in Section 4 of its ''Memorandum for Heads of Executive Departments and Agencies, and Independent Regulatory Agencies,'' M–01–27, July 13, 2001.

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available and applicable voluntary consensus standards.

This rulemaking involves technical standards. EPA has decided to use the following technical standards in this rule: (1) RCRA Subpart D, Section 257.70 liner design criteria for new CCR landfills and any lateral expansion of a CCR landfill includes voluntary consensus standards developed by ASTM International and EPA test methods such as SW–846, (2) Section 257.71 liner design criteria for existing CCR surface impoundments include voluntary consensus standards developed by ASTM International and EPA test methods such as SW–846, (3) Section 257.72 liner design criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment include voluntary consensus standards developed by ASTM International and EPA test methods such as SW–846, and (4) Section 257.73 structural stability standards for new and existing surface impoundments use the ASTM D 698 and 1557 standards for embankment compaction.

J. Executive Order 12898: Federal Actions To Address Environmental Justice in Minority Populations and Low-Income Populations

Executive Order (E.O.) 12898 (59 FR 7629, Feb. 16, 1994) establishes federal executive policy on environmental justice. Its main provision directs federal agencies, to the greatest extent practicable and permitted by law, to make environmental justice part of their mission by identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of their programs, policies, and activities on minority populations and low-income populations in the United States.

EPA has determined that this final rule will not have disproportionately high and adverse human health or environmental effects on minority or low-income populations because it increases the level of environmental protection for all affected populations without having any disproportionately high and adverse human health or environmental effects on any population, including any minority or low-income population.

EPA's risk assessment for this action did not separately evaluate either minority or low income populations. However, to evaluate the demographic characteristics of communities that may be affected by the CCR rule, the RIA compares the demographic characteristics of populations surrounding coal-fired electric utility plants with broader population data for two geographic areas: (1) One-mile radius from CCR management units (*i.e.,* landfills and impoundments) likely to be affected by groundwater releases from both landfills and impoundments; and (2) watershed catchment areas downstream of surface impoundments that receive surface water run-off and releases from CCR impoundments and are at risk of being contaminated from CCR impoundment discharges (*e.g.,* unintentional overflows, structural failures, and intentional periodic discharges).

For the population as a whole 24.8% belong to a minority group and 11.3% falls below the Federal Poverty Level. For the population living within one mile of plants with surface impoundments 16.1% belong to a minority group and 13.2% live below the Federal Poverty Level. These minority and low-income populations are not disproportionately high compared to the general population. The percentage of minority residents of the entire population living within the catchment areas downstream of surface impoundments is disproportionately high relative to the general population, *i.e.,* 28.7%, versus 24.8% for the national population. Also, the percentage of the population within the catchment areas of surface impoundments that is below the Federal Poverty Level is disproportionately high compared with the general population, *i.e.,* 18.6% versus 11.3% nationally.

Comparing the population percentages of minority and low income residents within one mile of landfills to those percentages in the general population, EPA found that minority and low-income residents make up a smaller percentage of the populations near landfills than they do in the general population, *i.e.,* minorities comprised 16.6% of the population near landfills versus 24.8% nationwide and low-income residents comprised 8.6% of the population near landfills versus 11.3% nationwide. In summary, although populations within the catchment areas of plants with surface impoundments appear to have disproportionately high percentages of minority and low-income residents relative to the nationwide average, populations surrounding plants with landfills do not. Because landfills are less likely than impoundments to experience surface water run-off and releases, catchment areas were not considered for landfills.

Because the CCR rule is risk-reducing, with reductions in risk occurring largely within the surface water catchment zones around, and groundwater beneath, coal-fired electric utility plants, the rule will not result in new disproportionate risks to minority or low-income populations.

K. Congressional Review Act

The Congressional Review Act, 5 U.S.C. 801 *et seq.,* as added by the Small Business Regulatory Enforcement Fairness Act of 1996, generally provides that before a rule may take effect, the agency promulgating the rule must submit a rule report, which includes a copy of the rule, to each House of the Congress and to the Comptroller General of the United States. EPA will submit a report containing this rule and other required information to the U.S. Senate, the U.S. House of Representatives, and the Comptroller General of the United States prior to publication of the rule in the **Federal Register**. A Major rule cannot take effect until 60 days after it is published in the **Federal Register**. This action is a ''major rule'' as defined by 5 U.S.C. 804(2). This rule will be effective 180 days after its publication in the **Federal Register**.

List of Subjects

40 CFR Part 257

Environmental protection, Beneficial use, Coal combustion products, Coal combustion residuals, Coal combustion waste, Disposal, Hazardous waste, Landfill, Surface impoundment.

40 CFR Part 261

Environmental protection, Hazardous waste, Recycling, Reporting and recordkeeping requirements.

Dated: December 19, 2014.

Gina McCarthy,

Administrator.

For the reasons set out in the preamble, title 40, chapter I, of the Code of Federal Regulations is amended as follows:

PART 257—CRITERIA FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES AND PRACTICES

■ 1. The authority citation for part 257 continues to read as follows:

Authority: 42 U.S.C. 6907(a)(3), 6912(a)(1), 6944(a); 33 U.S.C. 1345(d) and (e).

■ 2. Section 257.1 is amended by:

■ a. Adding a sentence at the end of paragraph (a) introductory text;

■ b. Revising paragraphs (a)(1) and (2); and

■ c. Adding paragraph (c)(12).

The revisions and additions read as follows:

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§ 257.1 Scope and purpose.

(a) * * * Unless otherwise provided, the criteria in §§ 257.50 through 257.107 are adopted for determining which CCR landfills and CCR surface impoundments pose a reasonable probability of adverse effects on health or the environment under sections 1008(a)(3) and 4004(a) of the Act.

(1) Facilities failing to satisfy any of the criteria in §§ 257.1 through 257.4 or §§ 257.5 through 257.30 or §§ 257.50 through 257.107 are considered open dumps, which are prohibited under section 4005 of the Act.

(2) Practices failing to satisfy any of the criteria in §§ 257.1 through 257.4 or §§ 257.5 through 257.30 or §§ 257.50 through 257.107 constitute open dumping, which is prohibited under section 4005 of the Act.

* * * * *

(c) * * *

(12) Except as otherwise specifically provided in subpart D of this part, the criteria in subpart A of this part do not apply to CCR landfills, CCR surface impoundments, and lateral expansions of CCR units, as those terms are defined in subpart D of this part. Such units are instead subject to subpart D of this part.

■ 3. Section 257.2 is amended by adding in alphabetical order definitions for ''CCR landfill'' and ''CCR surface impoundment'' to read as follows:

§ 257.2 Definitions.

* * * * *

CCR landfill means an area of land or an excavation that receives CCR and which is not a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground or surface coal mine, or a cave. For purposes of this subpart, a CCR landfill also includes sand and gravel pits and quarries that receive CCR, CCR piles, and any practice that does not meet the definition of a beneficial use of CCR.

CCR surface impoundment means a natural topographic depression, man-made excavation, or diked area, which is designed to hold an accumulation of CCR and liquids, and the unit treats, stores, or disposes of CCR.

* * * * *

■ 4. Part 257 is amended by:

■ a. Adding and reserving subpart C; and

■ b. Adding subpart D.

The additions read as follows:

Subpart C—[Reserved]

Subpart D—Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments

General Provisions

Sec.
257.50 Scope and purpose.
257.51 Effective date of this subpart.
257.52 Applicability of other regulations.
257.53 Definitions.

Location Restrictions

257.60 Placement above the uppermost aquifer.
257.61 Wetlands.
257.62 Fault areas.
257.63 Seismic impact zones.
257.64 Unstable areas.

Design Criteria

257.70 Design criteria for new CCR landfills and any lateral expansion of a CCR landfill.
257.71 Liner design criteria for existing CCR surface impoundments.
257.72 Design criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment.
257.73 Structural integrity criteria for existing CCR surface impoundments.
257.74 Structural integrity criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment.

Operating Criteria

257.80 Air criteria.
257.81 Run-on and run-off controls for CCR landfills.
257.82 Hydrologic and hydraulic capacity requirements for CCR surface impoundments.
257.83 Inspection requirements for CCR surface impoundments.
257.84 Inspection requirements for CCR landfills.

Groundwater Monitoring and Corrective Action

257.90 Applicability.
257.91 Groundwater monitoring systems.
257.92 [Reserved]
257.93 Groundwater sampling and analysis requirements.
257.94 Detection monitoring program.
257.95 Assessment monitoring program.
257.96 Assessment of corrective measures.
257.97 Selection of remedy.
257.98 Implementation of the corrective action program.

Closure and Post-Closure Care

257.100 Inactive CCR surface impoundments.
257.101 Closure or retrofit of CCR units.
257.102 Criteria for conducting the closure or retrofit of CCR units.
257.103 Alternative closure requirements.
257.104 Post-closure care requirements.

Recordkeeping, Notification, and Posting of Information to the Internet

257.105 Recordkeeping requirements.
257.106 Notification requirements.
257.107 Publicly accessible internet site requirements.

Subpart D—Standards for the Disposal of Coal Combustion Residuals in Landfills and Surface Impoundments

§ 257.50 Scope and purpose.

(a) This subpart establishes minimum national criteria for purposes of determining which solid waste disposal facilities and solid waste management practices do not pose a reasonable probability of adverse effects on health or the environment under sections 1008(a)(3) and 4004(a) of the Resource Conservation and Recovery Act.

(b) This subpart applies to owners and operators of new and existing landfills and surface impoundments, including any lateral expansions of such units that dispose or otherwise engage in solid waste management of CCR generated from the combustion of coal at electric utilities and independent power producers. Unless otherwise provided in this subpart, these requirements also apply to disposal units located off-site of the electric utility or independent power producer. This subpart also applies to any practice that does not meet the definition of a beneficial use of CCR.

(c) This subpart also applies to inactive CCR surface impoundments at active electric utilities or independent power producers, regardless of the fuel currently used at the facility to produce electricity.

(d) This subpart does not apply to CCR landfills that have ceased receiving CCR prior to October 19, 2015.

(e) This subpart does not apply to electric utilities or independent power producers that have ceased producing electricity prior to October 19, 2015.

(f) This subpart does not apply to wastes, including fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated at facilities that are not part of an electric utility or independent power producer, such as manufacturing facilities, universities, and hospitals. This subpart also does not apply to fly ash, bottom ash, boiler slag, and flue gas desulfurization materials, generated primarily from the combustion of fuels (including other fossil fuels) other than coal, for the purpose of generating electricity unless the fuel burned consists of more than fifty percent (50%) coal on a total heat input or mass input basis, whichever results in the greater mass feed rate of coal.

(g) This subpart does not apply to practices that meet the definition of a beneficial use of CCR.

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(h) This subpart does not apply to CCR placement at active or abandoned underground or surface coal mines.

(i) This subpart does not apply to municipal solid waste landfills that receive CCR.

§ 257.51 Effective date of this subpart.

The requirements of this subpart take effect on October 19, 2015.

§ 257.52 Applicability of other regulations.

(a) Compliance with the requirements of this subpart does not affect the need for the owner or operator of a CCR landfill, CCR surface impoundment, or lateral expansion of a CCR unit to comply with all other applicable federal, state, tribal, or local laws or other requirements.

(b) Any CCR landfill, CCR surface impoundment, or lateral expansion of a CCR unit continues to be subject to the requirements in §§ 257.3–1, 257.3–2, and 257.3–3.

§ 257.53 Definitions.

The following definitions apply to this subpart. Terms not defined in this section have the meaning given by RCRA.

Acre foot means the volume of one acre of surface area to a depth of one foot.

Active facility or *active electric utilities or independent power producers* means any facility subject to the requirements of this subpart that is in operation on October 14, 2015. An electric utility or independent power producer is in operation if it is generating electricity that is provided to electric power transmission systems or to electric power distribution systems on or after October 14, 2015. An off-site disposal facility is in operation if it is accepting or managing CCR on or after October 14, 2015.

Active life or *in operation* means the period of operation beginning with the initial placement of CCR in the CCR unit and ending at completion of closure activities in accordance with § 257.102.

Active portion means that part of the CCR unit that has received or is receiving CCR or non-CCR waste and that has not completed closure in accordance with § 257.102.

Aquifer means a geologic formation, group of formations, or portion of a formation capable of yielding usable quantities of groundwater to wells or springs.

Area-capacity curves means graphic curves which readily show the reservoir water surface area, in acres, at different elevations from the bottom of the reservoir to the maximum water surface, and the capacity or volume, in acre-feet, of the water contained in the reservoir at various elevations.

Areas susceptible to mass movement means those areas of influence (*i.e.,* areas characterized as having an active or substantial possibility of mass movement) where, because of natural or human-induced events, the movement of earthen material at, beneath, or adjacent to the CCR unit results in the downslope transport of soil and rock material by means of gravitational influence. Areas of mass movement include, but are not limited to, landslides, avalanches, debris slides and flows, soil fluctuation, block sliding, and rock fall.

Beneficial use of CCR means the CCR meet all of the following conditions:

(1) The CCR must provide a functional benefit;

(2) The CCR must substitute for the use of a virgin material, conserving natural resources that would otherwise need to be obtained through practices, such as extraction;

(3) The use of the CCR must meet relevant product specifications, regulatory standards or design standards when available, and when such standards are not available, the CCR is not used in excess quantities; and

(4) When unencapsulated use of CCR involving placement on the land of 12,400 tons or more in non-roadway applications, the user must demonstrate and keep records, and provide such documentation upon request, that environmental releases to groundwater, surface water, soil and air are comparable to or lower than those from analogous products made without CCR, or that environmental releases to groundwater, surface water, soil and air will be at or below relevant regulatory and health-based benchmarks for human and ecological receptors during use.

Closed means placement of CCR in a CCR unit has ceased, and the owner or operator has completed closure of the CCR unit in accordance with § 257.102 and has initiated post-closure care in accordance with § 257.104.

Coal combustion residuals (CCR) means fly ash, bottom ash, boiler slag, and flue gas desulfurization materials generated from burning coal for the purpose of generating electricity by electric utilities and independent power producers.

CCR fugitive dust means solid airborne particulate matter that contains or is derived from CCR, emitted from any source other than a stack or chimney.

CCR landfill or landfill means an area of land or an excavation that receives CCR and which is not a surface impoundment, an underground injection well, a salt dome formation, a salt bed formation, an underground or surface coal mine, or a cave. For purposes of this subpart, a CCR landfill also includes sand and gravel pits and quarries that receive CCR, CCR piles, and any practice that does not meet the definition of a beneficial use of CCR.

CCR pile or pile means any non-containerized accumulation of solid, non-flowing CCR that is placed on the land. CCR that is beneficially used off-site is not a CCR pile.

CCR surface impoundment or impoundment means a natural topographic depression, man-made excavation, or diked area, which is designed to hold an accumulation of CCR and liquids, and the unit treats, stores, or disposes of CCR.

CCR unit means any CCR landfill, CCR surface impoundment, or lateral expansion of a CCR unit, or a combination of more than one of these units, based on the context of the paragraph(s) in which it is used. This term includes both new and existing units, unless otherwise specified.

Dike means an embankment, berm, or ridge of either natural or man-made materials used to prevent the movement of liquids, sludges, solids, or other materials.

Displacement means the relative movement of any two sides of a fault measured in any direction.

Disposal means the discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste as defined in section 1004(27) of the Resource Conservation and Recovery Act into or on any land or water so that such solid waste, or constituent thereof, may enter the environment or be emitted into the air or discharged into any waters, including groundwaters. For purposes of this subpart, disposal does not include the storage or the beneficial use of CCR.

Downstream toe means the junction of the downstream slope or face of the CCR surface impoundment with the ground surface.

Encapsulated beneficial use means a beneficial use of CCR that binds the CCR into a solid matrix that minimizes its mobilization into the surrounding environment.

Existing CCR landfill means a CCR landfill that receives CCR both before and after October 14, 2015, or for which construction commenced prior to October 14, 2015 and receives CCR on or after October 14, 2015. A CCR landfill has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical

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construction and a continuous on-site, physical construction program had begun prior to October 14, 2015.

Existing CCR surface impoundment means a CCR surface impoundment that receives CCR both before and after October 14, 2015, or for which construction commenced prior to October 14, 2015 and receives CCR on or after October 14, 2015. A CCR surface impoundment has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction and a continuous on-site, physical construction program had begun prior to October 14, 2015.

Facility means all contiguous land, and structures, other appurtenances, and improvements on the land, used for treating, storing, disposing, or otherwise conducting solid waste management of CCR. A facility may consist of several treatment, storage, or disposal operational units (*e.g.,* one or more landfills, surface impoundments, or combinations of them).

Factor of safety (Safety factor) means the ratio of the forces tending to resist the failure of a structure to the forces tending to cause such failure as determined by accepted engineering practice.

Fault means a fracture or a zone of fractures in any material along which strata on one side have been displaced with respect to that on the other side.

Flood hydrograph means a graph showing, for a given point on a stream, the discharge, height, or other characteristic of a flood as a function of time.

Freeboard means the vertical distance between the lowest point on the crest of the impoundment dike and the surface of the waste contained therein.

Free liquids means liquids that readily separate from the solid portion of a waste under ambient temperature and pressure.

Groundwater means water below the land surface in a zone of saturation.

Hazard potential classification means the possible adverse incremental consequences that result from the release of water or stored contents due to failure of the diked CCR surface impoundment or mis-operation of the diked CCR surface impoundment or its appurtenances. The hazardous potential classifications include high hazard potential CCR surface impoundment, significant hazard potential CCR surface impoundment, and low hazard potential CCR surface impoundment, which terms mean:

(1) *High hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.

(2) *Low hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

(3) *Significant hazard potential CCR surface impoundment* means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.

Height means the vertical measurement from the downstream toe of the CCR surface impoundment at its lowest point to the lowest elevation of the crest of the CCR surface impoundment.

Holocene means the most recent epoch of the Quaternary period, extending from the end of the Pleistocene Epoch, at 11,700 years before present, to present.

Hydraulic conductivity means the rate at which water can move through a permeable medium (*i.e.,* the coefficient of permeability).

Inactive CCR surface impoundment means a CCR surface impoundment that no longer receives CCR on or after October 14, 2015 and still contains both CCR and liquids on or after October 14, 2015.

Incised CCR surface impoundment means a CCR surface impoundment which is constructed by excavating entirely below the natural ground surface, holds an accumulation of CCR entirely below the adjacent natural ground surface, and does not consist of any constructed diked portion.

Indian country or *Indian lands* means:

(1) All land within the limits of any Indian reservation under the jurisdiction of the United States Government, notwithstanding the issuance of any patent, and including rights-of-way running throughout the reservation;

(2) All dependent Indian communities within the borders of the United States whether within the original or subsequently acquired territory thereof, and whether within or without the limits of the State; and

(3) All Indian allotments, the Indian titles to which have not been extinguished, including rights of way running through the same.

Indian Tribe or *Tribe* means any Indian tribe, band, nation, or community recognized by the Secretary of the Interior and exercising substantial governmental duties and powers on Indian lands.

Inflow design flood means the flood hydrograph that is used in the design or modification of the CCR surface impoundments and its appurtenant works.

In operation means the same as *active life.*

Karst terrain means an area where karst topography, with its characteristic erosional surface and subterranean features, is developed as the result of dissolution of limestone, dolomite, or other soluble rock. Characteristic physiographic features present in karst terranes include, but are not limited to, dolines, collapse shafts (sinkholes), sinking streams, caves, seeps, large springs, and blind valleys.

Lateral expansion means a horizontal expansion of the waste boundaries of an existing CCR landfill or existing CCR surface impoundment made after October 14, 2015.

Liquefaction factor of safety means the factor of safety (safety factor) determined using analysis under liquefaction conditions.

Lithified earth material means all rock, including all naturally occurring and naturally formed aggregates or masses of minerals or small particles of older rock that formed by crystallization of magma or by induration of loose sediments. This term does not include man-made materials, such as fill, concrete, and asphalt, or unconsolidated earth materials, soil, or regolith lying at or near the earth surface.

Maximum horizontal acceleration in lithified earth material means the maximum expected horizontal acceleration at the ground surface as depicted on a seismic hazard map, with a 98% or greater probability that the acceleration will not be exceeded in 50 years, or the maximum expected horizontal acceleration based on a site-specific seismic risk assessment.

New CCR landfill means a CCR landfill or lateral expansion of a CCR landfill that first receives CCR or commences construction after October 14, 2015. A new CCR landfill has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction and a continuous on-site, physical construction program had begun after October 14, 2015. Overfills are also considered new CCR landfills.

New CCR surface impoundment means a CCR surface impoundment or lateral expansion of an existing or new CCR surface impoundment that first receives CCR or commences construction after October 14, 2015. A

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new CCR surface impoundment has commenced construction if the owner or operator has obtained the federal, state, and local approvals or permits necessary to begin physical construction and a continuous on-site, physical construction program had begun after October 14, 2015.

Operator means the person(s) responsible for the overall operation of a CCR unit.

Overfill means a new CCR landfill constructed over a closed CCR surface impoundment.

Owner means the person(s) who owns a CCR unit or part of a CCR unit.

Poor foundation conditions mean those areas where features exist which indicate that a natural or human-induced event may result in inadequate foundation support for the structural components of an existing or new CCR unit. For example, failure to maintain static and seismic factors of safety as required in §§ 257.73(e) and 257.74(e) would cause a poor foundation condition.

Probable maximum flood means the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the drainage basin.

Qualified person means a person or persons trained to recognize specific appearances of structural weakness and other conditions which are disrupting or have the potential to disrupt the operation or safety of the CCR unit by visual observation and, if applicable, to monitor instrumentation.

Qualified professional engineer means an individual who is licensed by a state as a Professional Engineer to practice one or more disciplines of engineering and who is qualified by education, technical knowledge and experience to make the specific technical certifications required under this subpart. Professional engineers making these certifications must be currently licensed in the state where the CCR unit(s) is located.

Recognized and generally accepted good engineering practices means engineering maintenance or operation activities based on established codes, widely accepted standards, published technical reports, or a practice widely recommended throughout the industry. Such practices generally detail approved ways to perform specific engineering, inspection, or mechanical integrity activities.

Retrofit means to remove all CCR and contaminated soils and sediments from the CCR surface impoundment, and to ensure the unit complies with the requirements in § 257.72

Representative sample means a sample of a universe or whole (*e.g.,* waste pile, lagoon, and groundwater) which can be expected to exhibit the average properties of the universe or whole. See EPA publication SW–846, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, Chapter 9 (available at *http://www.epa.gov/epawaste/hazard/testmethods/sw846/online/index.htm*) for a discussion and examples of representative samples.

Run-off means any rainwater, leachate, or other liquid that drains over land from any part of a CCR landfill or lateral expansion of a CCR landfill.

Run-on means any rainwater, leachate, or other liquid that drains over land onto any part of a CCR landfill or lateral expansion of a CCR landfill.

Sand and gravel pit or quarry means an excavation for the extraction of aggregate, minerals or metals. The term sand and gravel pit and/or quarry does not include subsurface or surface coal mines.

Seismic factor of safety means the factor of safety (safety factor) determined using analysis under earthquake conditions using the peak ground acceleration for a seismic event with a 2% probability of exceedance in 50 years, equivalent to a return period of approximately 2,500 years, based on the U.S. Geological Survey (USGS) seismic hazard maps for seismic events with this return period for the region where the CCR surface impoundment is located.

Seismic impact zone means an area having a 2% or greater probability that the maximum expected horizontal acceleration, expressed as a percentage of the earth's gravitational pull (g), will exceed 0.10 g in 50 years.

Slope protection means engineered or non-engineered measures installed on the upstream or downstream slope of the CCR surface impoundment to protect the slope against wave action or erosion, including but not limited to rock riprap, wooden pile, or concrete revetments, vegetated wave berms, concrete facing, gabions, geotextiles, or fascines.

Solid waste management or management means the systematic administration of the activities which provide for the collection, source separation, storage, transportation, processing, treatment, or disposal of solid waste.

State means any of the fifty States in addition to the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands.

State Director means the chief administrative officer of the lead state agency responsible for implementing the state program regulating disposal in CCR landfills, CCR surface impoundments, and all lateral expansions of a CCR unit.

Static factor of safety means the factor of safety (safety factor) determined using analysis under the long-term, maximum storage pool loading condition, the maximum surcharge pool loading condition, and under the end-of-construction loading condition.

Structural components mean liners, leachate collection and removal systems, final covers, run-on and run-off systems, inflow design flood control systems, and any other component used in the construction and operation of the CCR unit that is necessary to ensure the integrity of the unit and that the contents of the unit are not released into the environment.

Unstable area means a location that is susceptible to natural or human-induced events or forces capable of impairing the integrity, including structural components of some or all of the CCR unit that are responsible for preventing releases from such unit. Unstable areas can include poor foundation conditions, areas susceptible to mass movements, and karst terrains.

Uppermost aquifer means the geologic formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically interconnected with this aquifer within the facility's property boundary. Upper limit is measured at a point nearest to the natural ground surface to which the aquifer rises during the wet season.

Waste boundary means a vertical surface located at the hydraulically downgradient limit of the CCR unit. The vertical surface extends down into the uppermost aquifer.

Location Restrictions

§ 257.60 Placement above the uppermost aquifer.

(a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must be constructed with a base that is located no less than 1.52 meters (five feet) above the upper limit of the uppermost aquifer, or must demonstrate that there will not be an intermittent, recurring, or sustained hydraulic connection between any portion of the base of the CCR unit and the uppermost aquifer due to normal fluctuations in groundwater elevations (including the seasonal high water table). The owner or operator must demonstrate by the dates specified in paragraph (c) of this section

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that the CCR unit meets the minimum requirements for placement above the uppermost aquifer.

(b) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of paragraph (a) of this section.

(c) The owner or operator of the CCR unit must complete the demonstration required by paragraph (a) of this section by the date specified in either paragraph (c)(1) or (2) of this section.

(1) For an existing CCR surface impoundment, the owner or operator must complete the demonstration no later than October 17, 2018.

(2) For a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit, the owner or operator must complete the demonstration no later than the date of initial receipt of CCR in the CCR unit.

(3) The owner or operator has completed the demonstration required by paragraph (a) of this section when the demonstration is placed in the facility's operating record as required by § 257.105(e).

(4) An owner or operator of an existing CCR surface impoundment who fails to demonstrate compliance with the requirements of paragraph (a) of this section by the date specified in paragraph (c)(1) of this section is subject to the requirements of § 257.101(b)(1).

(5) An owner or operator of a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit who fails to make the demonstration showing compliance with the requirements of paragraph (a) of this section is prohibited from placing CCR in the CCR unit.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(e), the notification requirements specified in § 257.106(e), and the internet requirements specified in § 257.107(e).

§ 257.61 Wetlands.

(a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in wetlands, as defined in § 232.2 of this chapter, unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that the CCR unit meets the requirements of paragraphs (a)(1) through (5) of this section.

(1) Where applicable under section 404 of the Clean Water Act or applicable state wetlands laws, a clear and objective rebuttal of the presumption that an alternative to the CCR unit is reasonably available that does not involve wetlands.

(2) The construction and operation of the CCR unit will not cause or contribute to any of the following:

(i) A violation of any applicable state or federal water quality standard;

(ii) A violation of any applicable toxic effluent standard or prohibition under section 307 of the Clean Water Act;

(iii) Jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of a critical habitat, protected under the Endangered Species Act of 1973; and

(iv) A violation of any requirement under the Marine Protection, Research, and Sanctuaries Act of 1972 for the protection of a marine sanctuary.

(3) The CCR unit will not cause or contribute to significant degradation of wetlands by addressing all of the following factors:

(i) Erosion, stability, and migration potential of native wetland soils, muds and deposits used to support the CCR unit;

(ii) Erosion, stability, and migration potential of dredged and fill materials used to support the CCR unit;

(iii) The volume and chemical nature of the CCR;

(iv) Impacts on fish, wildlife, and other aquatic resources and their habitat from release of CCR;

(v) The potential effects of catastrophic release of CCR to the wetland and the resulting impacts on the environment; and

(vi) Any additional factors, as necessary, to demonstrate that ecological resources in the wetland are sufficiently protected.

(4) To the extent required under section 404 of the Clean Water Act or applicable state wetlands laws, steps have been taken to attempt to achieve no net loss of wetlands (as defined by acreage and function) by first avoiding impacts to wetlands to the maximum extent reasonable as required by paragraphs (a)(1) through (3) of this section, then minimizing unavoidable impacts to the maximum extent reasonable, and finally offsetting remaining unavoidable wetland impacts through all appropriate and reasonable compensatory mitigation actions (*e.g.,* restoration of existing degraded wetlands or creation of man-made wetlands); and

(5) Sufficient information is available to make a reasoned determination with respect to the demonstrations in paragraphs (a)(1) through (4) of this section.

(b) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of paragraph (a) of this section.

(c) The owner or operator of the CCR unit must complete the demonstrations required by paragraph (a) of this section by the date specified in either paragraph (c)(1) or (2) of this section.

(1) For an existing CCR surface impoundment, the owner or operator must complete the demonstration no later than October 17, 2018.

(2) For a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit, the owner or operator must complete the demonstration no later than the date of initial receipt of CCR in the CCR unit.

(3) The owner or operator has completed the demonstration required by paragraph (a) of this section when the demonstration is placed in the facility's operating record as required by § 257.105(e).

(4) An owner or operator of an existing CCR surface impoundment who fails to demonstrate compliance with the requirements of paragraph (a) of this section by the date specified in paragraph (c)(1) of this section is subject to the requirements of § 257.101(b)(1).

(5) An owner or operator of a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit who fails to make the demonstrations showing compliance with the requirements of paragraph (a) of this section is prohibited from placing CCR in the CCR unit.

(d) The owner or operator must comply with the recordkeeping requirements specified in § 257.105(e), the notification requirements specified in § 257.106(e), and the Internet requirements specified in § 257.107(e).

§ 257.62 Fault areas.

(a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located within 60 meters (200 feet) of the outermost damage zone of a fault that has had displacement in Holocene time unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that an alternative setback distance of less than 60 meters (200 feet) will prevent damage to the structural integrity of the CCR unit.

(b) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of paragraph (a) of this section.

(c) The owner or operator of the CCR unit must complete the demonstration

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required by paragraph (a) of this section by the date specified in either paragraph (c)(1) or (2) of this section.

(1) For an existing CCR surface impoundment, the owner or operator must complete the demonstration no later than October 17, 2018.

(2) For a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit, the owner or operator must complete the demonstration no later than the date of initial receipt of CCR in the CCR unit.

(3) The owner or operator has completed the demonstration required by paragraph (a) of this section when the demonstration is placed in the facility's operating record as required by § 257.105(e).

(4) An owner or operator of an existing CCR surface impoundment who fails to demonstrate compliance with the requirements of paragraph (a) of this section by the date specified in paragraph (c)(1) of this section is subject to the requirements of § 257.101(b)(1).

(5) An owner or operator of a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit who fails to make the demonstration showing compliance with the requirements of paragraph (a) of this section is prohibited from placing CCR in the CCR unit.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(e), the notification requirements specified in § 257.106(e), and the Internet requirements specified in § 257.107(e).

§ 257.63 Seismic impact zones.

(a) New CCR landfills, existing and new CCR surface impoundments, and all lateral expansions of CCR units must not be located in seismic impact zones unless the owner or operator demonstrates by the dates specified in paragraph (c) of this section that all structural components including liners, leachate collection and removal systems, and surface water control systems, are designed to resist the maximum horizontal acceleration in lithified earth material for the site.

(b) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of paragraph (a) of this section.

(c) The owner or operator of the CCR unit must complete the demonstration required by paragraph (a) of this section by the date specified in either paragraph (c)(1) or (2) of this section.

(1) For an existing CCR surface impoundment, the owner or operator must complete the demonstration no later than October 17, 2018.

(2) For a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit, the owner or operator must complete the demonstration no later than the date of initial receipt of CCR in the CCR unit.

(3) The owner or operator has completed the demonstration required by paragraph (a) of this section when the demonstration is placed in the facility's operating record as required by § 257.105(e).

(4) An owner or operator of an existing CCR surface impoundment who fails to demonstrate compliance with the requirements of paragraph (a) of this section by the date specified in paragraph (c)(1) of this section is subject to the requirements of § 257.101(b)(1).

(5) An owner or operator of a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit who fails to make the demonstration showing compliance with the requirements of paragraph (a) of this section is prohibited from placing CCR in the CCR unit.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(e), the notification requirements specified in § 257.106(e), and the Internet requirements specified in § 257.107(e).

§ 257.64 Unstable areas.

(a) An existing or new CCR landfill, existing or new CCR surface impoundment, or any lateral expansion of a CCR unit must not be located in an unstable area unless the owner or operator demonstrates by the dates specified in paragraph (d) of this section that recognized and generally accepted good engineering practices have been incorporated into the design of the CCR unit to ensure that the integrity of the structural components of the CCR unit will not be disrupted.

(b) The owner or operator must consider all of the following factors, at a minimum, when determining whether an area is unstable:

(1) On-site or local soil conditions that may result in significant differential settling;

(2) On-site or local geologic or geomorphologic features; and

(3) On-site or local human-made features or events (both surface and subsurface).

(c) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the demonstration meets the requirements of paragraph (a) of this section.

(d) The owner or operator of the CCR unit must complete the demonstration required by paragraph (a) of this section by the date specified in either paragraph (d)(1) or (2) of this section.

(1) For an existing CCR landfill or existing CCR surface impoundment, the owner or operator must complete the demonstration no later than October 17, 2018.

(2) For a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit, the owner or operator must complete the demonstration no later than the date of initial receipt of CCR in the CCR unit.

(3) The owner or operator has completed the demonstration required by paragraph (a) of this section when the demonstration is placed in the facility's operating record as required by § 257.105(e).

(4) An owner or operator of an existing CCR surface impoundment or existing CCR landfill who fails to demonstrate compliance with the requirements of paragraph (a) of this section by the date specified in paragraph (d)(1) of this section is subject to the requirements of § 257.101(b)(1) or (d)(1), respectively.

(5) An owner or operator of a new CCR landfill, new CCR surface impoundment, or any lateral expansion of a CCR unit who fails to make the demonstration showing compliance with the requirements of paragraph (a) of this section is prohibited from placing CCR in the CCR unit.

(e) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(e), the notification requirements specified in § 257.106(e), and the Internet requirements specified in § 257.107(e).

Design Criteria

§ 257.70 Design criteria for new CCR landfills and any lateral expansion of a CCR landfill.

(a)(1) New CCR landfills and any lateral expansion of a CCR landfill must be designed, constructed, operated, and maintained with either a composite liner that meets the requirements of paragraph (b) of this section or an alternative composite liner that meets the requirements in paragraph (c) of this section, and a leachate collection and removal system that meets the requirements of paragraph (d) of this section.

(2) Prior to construction of an overfill the underlying surface impoundment must meet the requirements of § 257.102(d).

(b) A *composite liner* must consist of two components; the upper component

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consisting of, at a minimum, a 30-mil geomembrane liner (GM), and the lower component consisting of at least a two-foot layer of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} centimeters per second (cm/sec). GM components consisting of high density polyethylene (HDPE) must be at least 60-mil thick. The GM or upper liner component must be installed in direct and uniform contact with the compacted soil or lower liner component. The composite liner must be:

(1) Constructed of materials that have appropriate chemical properties and sufficient strength and thickness to prevent failure due to pressure gradients (including static head and external hydrogeologic forces), physical contact with the CCR or leachate to which they are exposed, climatic conditions, the stress of installation, and the stress of daily operation;

(2) Constructed of materials that provide appropriate shear resistance of the upper and lower component interface to prevent sliding of the upper component including on slopes;

(3) Placed upon a foundation or base capable of providing support to the liner and resistance to pressure gradients above and below the liner to prevent failure of the liner due to settlement, compression, or uplift; and

(4) Installed to cover all surrounding earth likely to be in contact with the CCR or leachate.

(c) If the owner or operator elects to install an alternative composite liner, all of the following requirements must be met:

(1) An *alternative composite liner* must consist of two components; the upper component consisting of, at a minimum, a 30-mil GM, and a lower component, that is not a geomembrane, with a liquid flow rate no greater than the liquid flow rate of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. GM components consisting of high density polyethylene (HDPE) must be at least 60-mil thick. If the lower component of the alternative liner is compacted soil, the GM must be installed in direct and uniform contact with the compacted soil.

(2) The owner or operator must obtain certification from a qualified professional engineer that the liquid flow rate through the lower component of the alternative composite liner is no greater than the liquid flow rate through two feet of compacted soil with a hydraulic conductivity of 1×10^{-7} cm/sec. The hydraulic conductivity for the two feet of compacted soil used in the comparison shall be no greater than 1×10^{-7} cm/sec. The hydraulic conductivity of any alternative to the two feet of compacted soil must be determined using recognized and generally accepted methods. The liquid flow rate comparison must be made using Equation 1 of this section, which is derived from Darcy's Law for gravity flow through porous media.

$$\text{(Eq. 1)} \qquad \frac{Q}{A} = q = k\left(\frac{h}{t} + 1\right)$$

Where,

Q = flow rate (cubic centimeters/second);
A = surface area of the liner (squared centimeters);
q = flow rate per unit area (cubic centimeters/second/squared centimeter);
k = hydraulic conductivity of the liner (centimeters/second);
h = hydraulic head above the liner (centimeters); and
t = thickness of the liner (centimeters).

(3) The alternative composite liner must meet the requirements specified in paragraphs (b)(1) through (4) of this section.

(d) The *leachate collection and removal system* must be designed, constructed, operated, and maintained to collect and remove leachate from the landfill during the active life and post-closure care period. The leachate collection and removal system must be:

(1) Designed and operated to maintain less than a 30-centimeter depth of leachate over the composite liner or alternative composite liner;

(2) Constructed of materials that are chemically resistant to the CCR and any non-CCR waste managed in the CCR unit and the leachate expected to be generated, and of sufficient strength and thickness to prevent collapse under the pressures exerted by overlying waste, waste cover materials, and equipment used at the CCR unit; and

(3) Designed and operated to minimize clogging during the active life and post-closure care period.

(e) Prior to construction of the CCR landfill or any lateral expansion of a CCR landfill, the owner or operator must obtain a certification from a qualified professional engineer that the design of the composite liner (or, if applicable, alternative composite liner) and the leachate collection and removal system meets the requirements of this section.

(f) Upon completion of construction of the CCR landfill or any lateral expansion of a CCR landfill, the owner or operator must obtain a certification from a qualified professional engineer that the composite liner (or, if applicable, alternative composite liner) and the leachate collection and removal system has been constructed in accordance with the requirements of this section.

(g) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(f), the notification requirements specified in § 257.106(f), and the Internet requirements specified in § 257.107(f).

§ 257.71 Liner design criteria for existing CCR surface impoundments.

(a)(1) No later than October 17, 2016, the owner or operator of an existing CCR surface impoundment must document whether or not such unit was constructed with any one of the following:

(i) A liner consisting of a minimum of two feet of compacted soil with a hydraulic conductivity of no more than 1×10^{-7} cm/sec;

(ii) A composite liner that meets the requirements of § 257.70(b); or

(iii) An alternative composite liner that meets the requirements of § 257.70(c).

(2) The hydraulic conductivity of the compacted soil must be determined using recognized and generally accepted methods.

(3) An existing CCR surface impoundment is considered to be an existing unlined CCR surface impoundment if either:

(i) The owner or operator of the CCR unit determines that the CCR unit is not constructed with a liner that meets the requirements of paragraphs (a)(1)(i), (ii), or (iii) of this section; or

(ii) The owner or operator of the CCR unit fails to document whether the CCR unit was constructed with a liner that meets the requirements of paragraphs (a)(1)(i), (ii), or (iii) of this section.

(4) All existing unlined CCR surface impoundments are subject to the requirements of § 257.101(a).

(b) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer attesting that the documentation as to whether a CCR unit meets the requirements of paragraph (a) of this section is accurate.

(c) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(f), the notification requirements specified in § 257.106(f), and the Internet requirements specified in § 257.107(f).

§ 257.72 Liner design criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment.

(a) New CCR surface impoundments and lateral expansions of existing and new CCR surface impoundments must

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be designed, constructed, operated, and maintained with either a composite liner or an alternative composite liner that meets the requirements of § 257.70(b) or (c).

(b) Any liner specified in this section must be installed to cover all surrounding earth likely to be in contact with CCR. Dikes shall not be constructed on top of the composite liner.

(c) Prior to construction of the CCR surface impoundment or any lateral expansion of a CCR surface impoundment, the owner or operator must obtain certification from a qualified professional engineer that the design of the composite liner or, if applicable, the design of an alternative composite liner complies with the requirements of this section.

(d) Upon completion, the owner or operator must obtain certification from a qualified professional engineer that the composite liner or if applicable, the alternative composite liner has been constructed in accordance with the requirements of this section.

(e) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(f), the notification requirements specified in § 257.106(f), and the Internet requirements specified in § 257.107(f).

§ 257.73 Structural integrity criteria for existing CCR surface impoundments.

(a) The requirements of paragraphs (a)(1) through (4) of this section apply to all existing CCR surface impoundments, except for those existing CCR surface impoundments that are incised CCR units. If an incised CCR surface impoundment is subsequently modified (*e.g.,* a dike is constructed) such that the CCR unit no longer meets the definition of an incised CCR unit, the CCR unit is subject to the requirements of paragraphs (a)(1) through (4) of this section.

(1) No later than, December 17, 2015, the owner or operator of the CCR unit must place on or immediately adjacent to the CCR unit a permanent identification marker, at least six feet high showing the identification number of the CCR unit, if one has been assigned by the state, the name associated with the CCR unit and the name of the owner or operator of the CCR unit.

(2) *Periodic hazard potential classification assessments.* (i) The owner or operator of the CCR unit must conduct initial and periodic hazard potential classification assessments of the CCR unit according to the timeframes specified in paragraph (f) of this section. The owner or operator must document the hazard potential classification of each CCR unit as either a high hazard potential CCR surface impoundment, a significant hazard potential CCR surface impoundment, or a low hazard potential CCR surface impoundment. The owner or operator must also document the basis for each hazard potential classification.

(ii) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial hazard potential classification and each subsequent periodic classification specified in paragraph (a)(2)(i) of this section was conducted in accordance with the requirements of this section.

(3) *Emergency Action Plan (EAP)*—(i) *Development of the plan.* No later than April 17, 2017, the owner or operator of a CCR unit determined to be either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment under paragraph (a)(2) of this section must prepare and maintain a written EAP. At a minimum, the EAP must:

(A) Define the events or circumstances involving the CCR unit that represent a safety emergency, along with a description of the procedures that will be followed to detect a safety emergency in a timely manner;

(B) Define responsible persons, their respective responsibilities, and notification procedures in the event of a safety emergency involving the CCR unit;

(C) Provide contact information of emergency responders;

(D) Include a map which delineates the downstream area which would be affected in the event of a CCR unit failure and a physical description of the CCR unit; and

(E) Include provisions for an annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders.

(ii) *Amendment of the plan.* (A) The owner or operator of a CCR unit subject to the requirements of paragraph (a)(3)(i) of this section may amend the written EAP at any time provided the revised plan is placed in the facility's operating record as required by § 257.105(f)(6). The owner or operator must amend the written EAP whenever there is a change in conditions that would substantially affect the EAP in effect.

(B) The written EAP must be evaluated, at a minimum, every five years to ensure the information required in paragraph (a)(3)(i) of this section is accurate. As necessary, the EAP must be updated and a revised EAP placed in the facility's operating record as required by § 257.105(f)(6).

(iii) *Changes in hazard potential classification.* (A) If the owner or operator of a CCR unit determines during a periodic hazard potential assessment that the CCR unit is no longer classified as either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment, then the owner or operator of the CCR unit is no longer subject to the requirement to prepare and maintain a written EAP beginning on the date the periodic hazard potential assessment documentation is placed in the facility's operating record as required by § 257.105(f)(5).

(B) If the owner or operator of a CCR unit classified as a low hazard potential CCR surface impoundment subsequently determines that the CCR unit is properly re-classified as either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment, then the owner or operator of the CCR unit must prepare a written EAP for the CCR unit as required by paragraph (a)(3)(i) of this section within six months of completing such periodic hazard potential assessment.

(iv) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the written EAP, and any subsequent amendment of the EAP, meets the requirements of paragraph (a)(3) of this section.

(v) *Activation of the EAP.* The EAP must be implemented once events or circumstances involving the CCR unit that represent a safety emergency are detected, including conditions identified during periodic structural stability assessments, annual inspections, and inspections by a qualified person.

(4) The CCR unit and surrounding areas must be designed, constructed, operated, and maintained with vegetated slopes of dikes not to exceed a height of 6 inches above the slope of the dike, except for slopes which are protected with an alternate form(s) of slope protection.

(b) The requirements of paragraphs (c) through (e) of this section apply to an owner or operator of an existing CCR surface impoundment that either:

(1) Has a height of five feet or more and a storage volume of 20 acre-feet or more; or

(2) Has a height of 20 feet or more.

(c)(1) No later than October 17, 2016, the owner or operator of the CCR unit must compile a history of construction, which shall contain, to the extent feasible, the information specified in

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paragraphs (c)(1)(i) through (xi) of this section.

(i) The name and address of the person(s) owning or operating the CCR unit; the name associated with the CCR unit; and the identification number of the CCR unit if one has been assigned by the state.

(ii) The location of the CCR unit identified on the most recent U.S. Geological Survey (USGS) 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(iii) A statement of the purpose for which the CCR unit is being used.

(iv) The name and size in acres of the watershed within which the CCR unit is located.

(v) A description of the physical and engineering properties of the foundation and abutment materials on which the CCR unit is constructed.

(vi) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR unit; the method of site preparation and construction of each zone of the CCR unit; and the approximate dates of construction of each successive stage of construction of the CCR unit.

(vii) At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit, detailed dimensional drawings of the CCR unit, including a plan view and cross sections of the length and width of the CCR unit, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation.

(viii) A description of the type, purpose, and location of existing instrumentation.

(ix) Area-capacity curves for the CCR unit.

(x) A description of each spillway and diversion design features and capacities and calculations used in their determination.

(xi) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR unit.

(xii) Any record or knowledge of structural instability of the CCR unit.

(2) *Changes to the history of construction.* If there is a significant change to any information compiled under paragraph (c)(1) of this section, the owner or operator of the CCR unit must update the relevant information and place it in the facility's operating record as required by § 257.105(f)(9).

(d) *Periodic structural stability assessments.* (1) The owner or operator of the CCR unit must conduct initial and periodic structural stability assessments and document whether the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR and CCR wastewater which can be impounded therein. The assessment must, at a minimum, document whether the CCR unit has been designed, constructed, operated, and maintained with:

(i) Stable foundations and abutments;

(ii) Adequate slope protection to protect against surface erosion, wave action, and adverse effects of sudden drawdown;

(iii) Dikes mechanically compacted to a density sufficient to withstand the range of loading conditions in the CCR unit;

(iv) Vegetated slopes of dikes and surrounding areas not to exceed a height of six inches above the slope of the dike, except for slopes which have an alternate form or forms of slope protection;

(v) A single spillway or a combination of spillways configured as specified in paragraph (d)(1)(v)(A) of this section. The combined capacity of all spillways must be designed, constructed, operated, and maintained to adequately manage flow during and following the peak discharge from the event specified in paragraph (d)(1)(v)(B) of this section.

(A) All spillways must be either:

(*1*) Of non-erodible construction and designed to carry sustained flows; or

(*2*) Earth- or grass-lined and designed to carry short-term, infrequent flows at non-erosive velocities where sustained flows are not expected.

(B) The combined capacity of all spillways must adequately manage flow during and following the peak discharge from a:

(*1*) Probable maximum flood (PMF) for a high hazard potential CCR surface impoundment; or

(*2*) 1000-year flood for a significant hazard potential CCR surface impoundment; or

(*3*) 100-year flood for a low hazard potential CCR surface impoundment.

(vi) Hydraulic structures underlying the base of the CCR unit or passing through the dike of the CCR unit that maintain structural integrity and are free of significant deterioration, deformation, distortion, bedding deficiencies, sedimentation, and debris which may negatively affect the operation of the hydraulic structure; and

(vii) For CCR units with downstream slopes which can be inundated by the pool of an adjacent water body, such as a river, stream or lake, downstream slopes that maintain structural stability during low pool of the adjacent water body or sudden drawdown of the adjacent water body.

(2) The periodic assessment described in paragraph (d)(1) of this section must identify any structural stability deficiencies associated with the CCR unit in addition to recommending corrective measures. If a deficiency or a release is identified during the periodic assessment, the owner or operator unit must remedy the deficiency or release as soon as feasible and prepare documentation detailing the corrective measures taken.

(3) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial assessment and each subsequent periodic assessment was conducted in accordance with the requirements of this section.

(e) *Periodic safety factor assessments.* (1) The owner or operator must conduct an initial and periodic safety factor assessments for each CCR unit and document whether the calculated factors of safety for each CCR unit achieve the minimum safety factors specified in paragraphs (e)(1)(i) through (iv) of this section for the critical cross section of the embankment. The critical cross section is the cross section anticipated to be the most susceptible of all cross sections to structural failure based on appropriate engineering considerations, including loading conditions. The safety factor assessments must be supported by appropriate engineering calculations.

(i) The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.50.

(ii) The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40.

(iii) The calculated seismic factor of safety must equal or exceed 1.00.

(iv) For dikes constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

(2) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating

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that the initial assessment and each subsequent periodic assessment specified in paragraph (e)(1) of this section meets the requirements of this section.

(f) *Timeframes for periodic assessments*—(1) *Initial assessments.* Except as provided by paragraph (f)(2) of this section, the owner or operator of the CCR unit must complete the initial assessments required by paragraphs (a)(2), (d), and (e) of this section no later than October 17, 2016. The owner or operator has completed an initial assessment when the owner or operator has placed the assessment required by paragraphs (a)(2), (d), and (e) of this section in the facility's operating record as required by § 257.105(f)(5), (10), and (12).

(2) *Use of a previously completed assessment(s) in lieu of the initial assessment(s).* The owner or operator of the CCR unit may elect to use a previously completed assessment to serve as the initial assessment required by paragraphs (a)(2), (d), and (e) of this section provided that the previously completed assessment(s):

(i) Was completed no earlier than 42 months prior to October 17, 2016; and

(ii) Meets the applicable requirements of paragraphs (a)(2), (d), and (e) of this section.

(3) *Frequency for conducting periodic assessments.* The owner or operator of the CCR unit must conduct and complete the assessments required by paragraphs (a)(2), (d), and (e) of this section every five years. The date of completing the initial assessment is the basis for establishing the deadline to complete the first subsequent assessment. If the owner or operator elects to use a previously completed assessment(s) in lieu of the initial assessment as provided by paragraph (f)(2) of this section, the date of the report for the previously completed assessment is the basis for establishing the deadline to complete the first subsequent assessment. The owner or operator may complete any required assessment prior to the required deadline provided the owner or operator places the completed assessment(s) into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing subsequent assessments is based on the date of completing the previous assessment. For purposes of this paragraph (f)(3), the owner or operator has completed an assessment when the relevant assessment(s) required by paragraphs (a)(2), (d), and (e) of this section has been placed in the facility's operating record as required by § 257.105(f)(5), (10), and (12).

(4) *Closure of the CCR unit.* An owner or operator of a CCR unit who either fails to complete a timely safety factor assessment or fails to demonstrate minimum safety factors as required by paragraph (e) of this section is subject to the requirements of § 257.101(b)(2).

(g) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(f), the notification requirements specified in § 257.106(f), and the internet requirements specified in § 257.107(f).

§ 257.74 Structural integrity criteria for new CCR surface impoundments and any lateral expansion of a CCR surface impoundment.

(a) The requirements of paragraphs (a)(1) through (4) of this section apply to all new CCR surface impoundments and any lateral expansion of a CCR surface impoundment, except for those new CCR surface impoundments that are incised CCR units. If an incised CCR surface impoundment is subsequently modified (*e.g.,* a dike is constructed) such that the CCR unit no longer meets the definition of an incised CCR unit, the CCR unit is subject to the requirements of paragraphs (a)(1) through (4) of this section.

(1) No later than the initial receipt of CCR, the owner or operator of the CCR unit must place on or immediately adjacent to the CCR unit a permanent identification marker, at least six feet high showing the identification number of the CCR unit, if one has been assigned by the state, the name associated with the CCR unit and the name of the owner or operator of the CCR unit.

(2) *Periodic hazard potential classification assessments.* (i) The owner or operator of the CCR unit must conduct initial and periodic hazard potential classification assessments of the CCR unit according to the timeframes specified in paragraph (f) of this section. The owner or operator must document the hazard potential classification of each CCR unit as either a high hazard potential CCR surface impoundment, a significant hazard potential CCR surface impoundment, or a low hazard potential CCR surface impoundment. The owner or operator must also document the basis for each hazard potential classification.

(ii) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial hazard potential classification and each subsequent periodic classification specified in paragraph (a)(2)(i) of this section was conducted in accordance with the requirements of this section.

(3) *Emergency Action Plan (EAP)*—(i) *Development of the plan.* Prior to the initial receipt of CCR in the CCR unit, the owner or operator of a CCR unit determined to be either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment under paragraph (a)(2) of this section must prepare and maintain a written EAP. At a minimum, the EAP must:

(A) Define the events or circumstances involving the CCR unit that represent a safety emergency, along with a description of the procedures that will be followed to detect a safety emergency in a timely manner;

(B) Define responsible persons, their respective responsibilities, and notification procedures in the event of a safety emergency involving the CCR unit;

(C) Provide contact information of emergency responders;

(D) Include a map which delineates the downstream area which would be affected in the event of a CCR unit failure and a physical description of the CCR unit; and

(E) Include provisions for an annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders.

(ii) *Amendment of the plan.* (A) The owner or operator of a CCR unit subject to the requirements of paragraph (a)(3)(i) of this section may amend the written EAP at any time provided the revised plan is placed in the facility's operating record as required by § 257.105(f)(6). The owner or operator must amend the written EAP whenever there is a change in conditions that would substantially affect the EAP in effect.

(B) The written EAP must be evaluated, at a minimum, every five years to ensure the information required in paragraph (a)(3)(i) of this section is accurate. As necessary, the EAP must be updated and a revised EAP placed in the facility's operating record as required by § 257.105(f)(6).

(iii) *Changes in hazard potential classification.* (A) If the owner or operator of a CCR unit determines during a periodic hazard potential assessment that the CCR unit is no longer classified as either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment, then the owner or operator of the CCR unit is no longer subject to the requirement to prepare and maintain a written EAP beginning on the date the periodic hazard potential assessment documentation is

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placed in the facility's operating record as required by § 257.105(f)(5).

(B) If the owner or operator of a CCR unit classified as a low hazard potential CCR surface impoundment subsequently determines that the CCR unit is properly re-classified as either a high hazard potential CCR surface impoundment or a significant hazard potential CCR surface impoundment, then the owner or operator of the CCR unit must prepare a written EAP for the CCR unit as required by paragraph (a)(3)(i) of this section within six months of completing such periodic hazard potential assessment.

(iv) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the written EAP, and any subsequent amendment of the EAP, meets the requirements of paragraph (a)(3) of this section.

(v) *Activation of the EAP.* The EAP must be implemented once events or circumstances involving the CCR unit that represent a safety emergency are detected, including conditions identified during periodic structural stability assessments, annual inspections, and inspections by a qualified person.

(4) The CCR unit and surrounding areas must be designed, constructed, operated, and maintained with vegetated slopes of dikes not to exceed a height of six inches above the slope of the dike, except for slopes which are protected with an alternate form(s) of slope protection.

(b) The requirements of paragraphs (c) through (e) of this section apply to an owner or operator of a new CCR surface impoundment and any lateral expansion of a CCR surface impoundment that either:

(1) Has a height of five feet or more and a storage volume of 20 acre-feet or more; or

(2) Has a height of 20 feet or more.

(c)(1) No later than the initial receipt of CCR in the CCR unit, the owner or operator unit must compile the design and construction plans for the CCR unit, which must include, to the extent feasible, the information specified in paragraphs (c)(1)(i) through (xi) of this section.

(i) The name and address of the person(s) owning or operating the CCR unit; the name associated with the CCR unit; and the identification number of the CCR unit if one has been assigned by the state.

(ii) The location of the CCR unit identified on the most recent U.S. Geological Survey (USGS) 7½ minute or 15 minute topographic quadrangle map, or a topographic map of equivalent scale if a USGS map is not available.

(iii) A statement of the purpose for which the CCR unit is being used.

(iv) The name and size in acres of the watershed within which the CCR unit is located.

(v) A description of the physical and engineering properties of the foundation and abutment materials on which the CCR unit is constructed.

(vi) A statement of the type, size, range, and physical and engineering properties of the materials used in constructing each zone or stage of the CCR unit; the method of site preparation and construction of each zone of the CCR unit; and the dates of construction of each successive stage of construction of the CCR unit.

(vii) At a scale that details engineering structures and appurtenances relevant to the design, construction, operation, and maintenance of the CCR unit, detailed dimensional drawings of the CCR unit, including a plan view and cross sections of the length and width of the CCR unit, showing all zones, foundation improvements, drainage provisions, spillways, diversion ditches, outlets, instrument locations, and slope protection, in addition to the normal operating pool surface elevation and the maximum pool surface elevation following peak discharge from the inflow design flood, the expected maximum depth of CCR within the CCR surface impoundment, and any identifiable natural or manmade features that could adversely affect operation of the CCR unit due to malfunction or mis-operation.

(viii) A description of the type, purpose, and location of existing instrumentation.

(ix) Area-capacity curves for the CCR unit.

(x) A description of each spillway and diversion design features and capacities and calculations used in their determination.

(xi) The construction specifications and provisions for surveillance, maintenance, and repair of the CCR unit.

(xii) Any record or knowledge of structural instability of the CCR unit.

(2) *Changes in the design and construction.* If there is a significant change to any information compiled under paragraph (c)(1) of this section, the owner or operator of the CCR unit must update the relevant information and place it in the facility's operating record as required by § 257.105(f)(13).

(d) *Periodic structural stability assessments.* (1) The owner or operator of the CCR unit must conduct initial and periodic structural stability assessments and document whether the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering practices for the maximum volume of CCR and CCR wastewater which can be impounded therein. The assessment must, at a minimum, document whether the CCR unit has been designed, constructed, operated, and maintained with:

(i) Stable foundations and abutments;

(ii) Adequate slope protection to protect against surface erosion, wave action, and adverse effects of sudden drawdown;

(iii) Dikes mechanically compacted to a density sufficient to withstand the range of loading conditions in the CCR unit;

(iv) Vegetated slopes of dikes and surrounding areas not to exceed a height of six inches above the slope of the dike, except for slopes which have an alternate form or forms of slope protection;

(v) A single spillway or a combination of spillways configured as specified in paragraph (d)(1)(v)(A) of this section. The combined capacity of all spillways must be designed, constructed, operated, and maintained to adequately manage flow during and following the peak discharge from the event specified in paragraph (d)(1)(v)(B) of this section.

(A) All spillways must be either:

(*1*) Of non-erodible construction and designed to carry sustained flows; or

(*2*) Earth- or grass-lined and designed to carry short-term, infrequent flows at non-erosive velocities where sustained flows are not expected.

(B) The combined capacity of all spillways must adequately manage flow during and following the peak discharge from a:

(*1*) Probable maximum flood (PMF) for a high hazard potential CCR surface impoundment; or

(*2*) 1000-year flood for a significant hazard potential CCR surface impoundment; or

(*3*) 100-year flood for a low hazard potential CCR surface impoundment.

(vi) Hydraulic structures underlying the base of the CCR unit or passing through the dike of the CCR unit that maintain structural integrity and are free of significant deterioration, deformation, distortion, bedding deficiencies, sedimentation, and debris which may negatively affect the operation of the hydraulic structure; and

(vii) For CCR units with downstream slopes which can be inundated by the pool of an adjacent water body, such as a river, stream or lake, downstream slopes that maintain structural stability

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during low pool of the adjacent water body or sudden drawdown of the adjacent water body.

(2) The periodic assessment described in paragraph (d)(1) of this section must identify any structural stability deficiencies associated with the CCR unit in addition to recommending corrective measures. If a deficiency or a release is identified during the periodic assessment, the owner or operator unit must remedy the deficiency or release as soon as feasible and prepare documentation detailing the corrective measures taken.

(3) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial assessment and each subsequent periodic assessment was conducted in accordance with the requirements of this section.

(e) *Periodic safety factor assessments.* (1) The owner or operator must conduct an initial and periodic safety factor assessments for each CCR unit and document whether the calculated factors of safety for each CCR unit achieve the minimum safety factors specified in paragraphs (e)(1)(i) through (v) of this section for the critical cross section of the embankment. The critical cross section is the cross section anticipated to be the most susceptible of all cross sections to structural failure based on appropriate engineering considerations, including loading conditions. The safety factor assessments must be supported by appropriate engineering calculations.

(i) The calculated static factor of safety under the end-of-construction loading condition must equal or exceed 1.30. The assessment of this loading condition is only required for the initial safety factor assessment and is not required for subsequent assessments.

(ii) The calculated static factor of safety under the long-term, maximum storage pool loading condition must equal or exceed 1.50.

(iii) The calculated static factor of safety under the maximum surcharge pool loading condition must equal or exceed 1.40.

(iv) The calculated seismic factor of safety must equal or exceed 1.00.

(v) For dikes constructed of soils that have susceptibility to liquefaction, the calculated liquefaction factor of safety must equal or exceed 1.20.

(2) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the initial assessment and each subsequent periodic assessment specified in paragraph (e)(1) of this section meets the requirements of this section.

(f) *Timeframes for periodic assessments*—(1) *Initial assessments.* Except as provided by paragraph (f)(2) of this section, the owner or operator of the CCR unit must complete the initial assessments required by paragraphs (a)(2), (d), and (e) of this section prior to the initial receipt of CCR in the unit. The owner or operator has completed an initial assessment when the owner or operator has placed the assessment required by paragraphs (a)(2), (d), and (e) of this section in the facility's operating record as required by § 257.105(f)(5), (10), and (12).

(2) *Frequency for conducting periodic assessments.* The owner or operator of the CCR unit must conduct and complete the assessments required by paragraphs (a)(2), (d), and (e) of this section every five years. The date of completing the initial assessment is the basis for establishing the deadline to complete the first subsequent assessment. The owner or operator may complete any required assessment prior to the required deadline provided the owner or operator places the completed assessment(s) into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing subsequent assessments is based on the date of completing the previous assessment. For purposes of this paragraph (f)(2), the owner or operator has completed an assessment when the relevant assessment(s) required by paragraphs (a)(2), (d), and (e) of this section has been placed in the facility's operating record as required by § 257.105(f)(5), (10), and (12).

(3) *Failure to document minimum safety factors during the initial assessment.* Until the date an owner or operator of a CCR unit documents that the calculated factors of safety achieve the minimum safety factors specified in paragraphs (e)(1)(i) through (v) of this section, the owner or operator is prohibited from placing CCR in such unit.

(4) *Closure of the CCR unit.* An owner or operator of a CCR unit who either fails to complete a timely periodic safety factor assessment or fails to demonstrate minimum safety factors as required by paragraph (e) of this section is subject to the requirements of § 257.101(c).

(g) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(f), the notification requirements specified in § 257.106(f), and the internet requirements specified in § 257.107(f).

Operating Criteria

§ 257.80 Air criteria.

(a) The owner or operator of a CCR landfill, CCR surface impoundment, or any lateral expansion of a CCR unit must adopt measures that will effectively minimize CCR from becoming airborne at the facility, including CCR fugitive dust originating from CCR units, roads, and other CCR management and material handling activities.

(b) *CCR fugitive dust control plan.* The owner or operator of the CCR unit must prepare and operate in accordance with a CCR fugitive dust control plan as specified in paragraphs (b)(1) through (7) of this section. This requirement applies in addition to, not in place of, any applicable standards under the Occupational Safety and Health Act.

(1) The CCR fugitive dust control plan must identify and describe the CCR fugitive dust control measures the owner or operator will use to minimize CCR from becoming airborne at the facility. The owner or operator must select, and include in the CCR fugitive dust control plan, the CCR fugitive dust control measures that are most appropriate for site conditions, along with an explanation of how the measures selected are applicable and appropriate for site conditions. Examples of control measures that may be appropriate include: Locating CCR inside an enclosure or partial enclosure; operating a water spray or fogging system; reducing fall distances at material drop points; using wind barriers, compaction, or vegetative covers; establishing and enforcing reduced vehicle speed limits; paving and sweeping roads; covering trucks transporting CCR; reducing or halting operations during high wind events; or applying a daily cover.

(2) If the owner or operator operates a CCR landfill or any lateral expansion of a CCR landfill, the CCR fugitive dust control plan must include procedures to emplace CCR as conditioned CCR. Conditioned CCR means wetting CCR with water to a moisture content that will prevent wind dispersal, but will not result in free liquids. In lieu of water, CCR conditioning may be accomplished with an appropriate chemical dust suppression agent.

(3) The CCR fugitive dust control plan must include procedures to log citizen complaints received by the owner or operator involving CCR fugitive dust events at the facility.

(4) The CCR fugitive dust control plan must include a description of the procedures the owner or operator will

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follow to periodically assess the effectiveness of the control plan.

(5) The owner or operator of a CCR unit must prepare an initial CCR fugitive dust control plan for the facility no later than October 19, 2015, or by initial receipt of CCR in any CCR unit at the facility if the owner or operator becomes subject to this subpart after October 19, 2015. The owner or operator has completed the initial CCR fugitive dust control plan when the plan has been placed in the facility's operating record as required by § 257.105(g)(1).

(6) *Amendment of the plan.* The owner or operator of a CCR unit subject to the requirements of this section may amend the written CCR fugitive dust control plan at any time provided the revised plan is placed in the facility's operating record as required by § 257.105(g)(1). The owner or operator must amend the written plan whenever there is a change in conditions that would substantially affect the written plan in effect, such as the construction and operation of a new CCR unit.

(7) The owner or operator must obtain a certification from a qualified professional engineer that the initial CCR fugitive dust control plan, or any subsequent amendment of it, meets the requirements of this section.

(c) *Annual CCR fugitive dust control report.* The owner or operator of a CCR unit must prepare an annual CCR fugitive dust control report that includes a description of the actions taken by the owner or operator to control CCR fugitive dust, a record of all citizen complaints, and a summary of any corrective measures taken. The initial annual report must be completed no later than 14 months after placing the initial CCR fugitive dust control plan in the facility's operating record. The deadline for completing a subsequent report is one year after the date of completing the previous report. For purposes of this paragraph (c), the owner or operator has completed the annual CCR fugitive dust control report when the plan has been placed in the facility's operating record as required by § 257.105(g)(2).

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(g), the notification requirements specified in § 257.106(g), and the internet requirements specified in § 257.107(g).

§ 257.81 Run-on and run-off controls for CCR landfills.

(a) The owner or operator of an existing or new CCR landfill or any lateral expansion of a CCR landfill must design, construct, operate, and maintain:

(1) A run-on control system to prevent flow onto the active portion of the CCR unit during the peak discharge from a 24-hour, 25-year storm; and

(2) A run-off control system from the active portion of the CCR unit to collect and control at least the water volume resulting from a 24-hour, 25-year storm.

(b) Run-off from the active portion of the CCR unit must be handled in accordance with the surface water requirements under § 257.3–3.

(c) *Run-on and run-off control system plan*—(1) *Content of the plan.* The owner or operator must prepare initial and periodic run-on and run-off control system plans for the CCR unit according to the timeframes specified in paragraphs (c)(3) and (4) of this section. These plans must document how the run-on and run-off control systems have been designed and constructed to meet the applicable requirements of this section. Each plan must be supported by appropriate engineering calculations. The owner or operator has completed the initial run-on and run-off control system plan when the plan has been placed in the facility's operating record as required by § 257.105(g)(3).

(2) *Amendment of the plan.* The owner or operator may amend the written run-on and run-off control system plan at any time provided the revised plan is placed in the facility's operating record as required by § 257.105(g)(3). The owner or operator must amend the written run-on and run-off control system plan whenever there is a change in conditions that would substantially affect the written plan in effect.

(3) *Timeframes for preparing the initial plan*—(i) *Existing CCR landfills.* The owner or operator of the CCR unit must prepare the initial run-on and run-off control system plan no later than October 17, 2016.

(ii) *New CCR landfills and any lateral expansion of a CCR landfill.* The owner or operator must prepare the initial run-on and run-off control system plan no later than the date of initial receipt of CCR in the CCR unit.

(4) *Frequency for revising the plan.* The owner or operator of the CCR unit must prepare periodic run-on and run-off control system plans required by paragraph (c)(1) of this section every five years. The date of completing the initial plan is the basis for establishing the deadline to complete the first subsequent plan. The owner or operator may complete any required plan prior to the required deadline provided the owner or operator places the completed plan into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing a subsequent plan is based on the date of completing the previous plan. For purposes of this paragraph (c)(4), the owner or operator has completed a periodic run-on and run-off control system plan when the plan has been placed in the facility's operating record as required by § 257.105(g)(3).

(5) The owner or operator must obtain a certification from a qualified professional engineer stating that the initial and periodic run-on and run-off control system plans meet the requirements of this section.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(g), the notification requirements specified in § 257.106(g), and the internet requirements specified in § 257.107(g).

§ 257.82 Hydrologic and hydraulic capacity requirements for CCR surface impoundments.

(a) The owner or operator of an existing or new CCR surface impoundment or any lateral expansion of a CCR surface impoundment must design, construct, operate, and maintain an inflow design flood control system as specified in paragraphs (a)(1) and (2) of this section.

(1) The inflow design flood control system must adequately manage flow into the CCR unit during and following the peak discharge of the inflow design flood specified in paragraph (a)(3) of this section.

(2) The inflow design flood control system must adequately manage flow from the CCR unit to collect and control the peak discharge resulting from the inflow design flood specified in paragraph (a)(3) of this section.

(3) The inflow design flood is:

(i) For a high hazard potential CCR surface impoundment, as determined under § 257.73(a)(2) or § 257.74(a)(2), the probable maximum flood;

(ii) For a significant hazard potential CCR surface impoundment, as determined under § 257.73(a)(2) or § 257.74(a)(2), the 1,000-year flood;

(iii) For a low hazard potential CCR surface impoundment, as determined under § 257.73(a)(2) or § 257.74(a)(2), the 100-year flood; or

(iv) For an incised CCR surface impoundment, the 25-year flood.

(b) Discharge from the CCR unit must be handled in accordance with the surface water requirements under § 257.3–3.

(c) *Inflow design flood control system plan*—(1) *Content of the plan.* The owner or operator must prepare initial

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and periodic inflow design flood control system plans for the CCR unit according to the timeframes specified in paragraphs (c)(3) and (4) of this section. These plans must document how the inflow design flood control system has been designed and constructed to meet the requirements of this section. Each plan must be supported by appropriate engineering calculations. The owner or operator of the CCR unit has completed the inflow design flood control system plan when the plan has been placed in the facility's operating record as required by § 257.105(g)(4).

(2) *Amendment of the plan.* The owner or operator of the CCR unit may amend the written inflow design flood control system plan at any time provided the revised plan is placed in the facility's operating record as required by § 257.105(g)(4). The owner or operator must amend the written inflow design flood control system plan whenever there is a change in conditions that would substantially affect the written plan in effect.

(3) *Timeframes for preparing the initial plan*—(i) *Existing CCR surface impoundments.* The owner or operator of the CCR unit must prepare the initial inflow design flood control system plan no later than October 17, 2016.

(ii) *New CCR surface impoundments and any lateral expansion of a CCR surface impoundment.* The owner or operator must prepare the initial inflow design flood control system plan no later than the date of initial receipt of CCR in the CCR unit.

(4) *Frequency for revising the plan.* The owner or operator must prepare periodic inflow design flood control system plans required by paragraph (c)(1) of this section every five years. The date of completing the initial plan is the basis for establishing the deadline to complete the first periodic plan. The owner or operator may complete any required plan prior to the required deadline provided the owner or operator places the completed plan into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing a subsequent plan is based on the date of completing the previous plan. For purposes of this paragraph (c)(4), the owner or operator has completed an inflow design flood control system plan when the plan has been placed in the facility's operating record as required by § 257.105(g)(4).

(5) The owner or operator must obtain a certification from a qualified professional engineer stating that the initial and periodic inflow design flood control system plans meet the requirements of this section.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(g), the notification requirements specified in § 257.106(g), and the internet requirements specified in § 257.107(g).

§ 257.83 Inspection requirements for CCR surface impoundments.

(a) *Inspections by a qualified person.* (1) All CCR surface impoundments and any lateral expansion of a CCR surface impoundment must be examined by a qualified person as follows:

(i) At intervals not exceeding seven days, inspect for any appearances of actual or potential structural weakness and other conditions which are disrupting or have the potential to disrupt the operation or safety of the CCR unit;

(ii) At intervals not exceeding seven days, inspect the discharge of all outlets of hydraulic structures which pass underneath the base of the surface impoundment or through the dike of the CCR unit for abnormal discoloration, flow or discharge of debris or sediment; and

(iii) At intervals not exceeding 30 days, monitor all CCR unit instrumentation.

(iv) The results of the inspection by a qualified person must be recorded in the facility's operating record as required by § 257.105(g)(5).

(2) *Timeframes for inspections by a qualified person*—(i) *Existing CCR surface impoundments.* The owner or operator of the CCR unit must initiate the inspections required under paragraph (a) of this section no later than October 19, 2015.

(ii) *New CCR surface impoundments and any lateral expansion of a CCR surface impoundment.* The owner or operator of the CCR unit must initiate the inspections required under paragraph (a) of this section upon initial receipt of CCR by the CCR unit.

(b) Annual i*nspections by a qualified professional engineer.* (1) If the existing or new CCR surface impoundment or any lateral expansion of the CCR surface impoundment is subject to the periodic structural stability assessment requirements under § 257.73(d) or § 257.74(d), the CCR unit must additionally be inspected on a periodic basis by a qualified professional engineer to ensure that the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering standards. The inspection must, at a minimum, include:

(i) A review of available information regarding the status and condition of the CCR unit, including, but not limited to, files available in the operating record (*e.g.,* CCR unit design and construction information required by §§ 257.73(c)(1) and 257.74(c)(1), previous periodic structural stability assessments required under §§ 257.73(d) and 257.74(d), the results of inspections by a qualified person, and results of previous annual inspections);

(ii) A visual inspection of the CCR unit to identify signs of distress or malfunction of the CCR unit and appurtenant structures; and

(iii) A visual inspection of any hydraulic structures underlying the base of the CCR unit or passing through the dike of the CCR unit for structural integrity and continued safe and reliable operation.

(2) *Inspection report.* The qualified professional engineer must prepare a report following each inspection that addresses the following:

(i) Any changes in geometry of the impounding structure since the previous annual inspection;

(ii) The location and type of existing instrumentation and the maximum recorded readings of each instrument since the previous annual inspection;

(iii) The approximate minimum, maximum, and present depth and elevation of the impounded water and CCR since the previous annual inspection;

(iv) The storage capacity of the impounding structure at the time of the inspection;

(v) The approximate volume of the impounded water and CCR at the time of the inspection;

(vi) Any appearances of an actual or potential structural weakness of the CCR unit, in addition to any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the CCR unit and appurtenant structures; and

(vii) Any other change(s) which may have affected the stability or operation of the impounding structure since the previous annual inspection.

(3) *Timeframes for conducting the initial inspection*—(i) *Existing CCR surface impoundments.* The owner or operator of the CCR unit must complete the initial inspection required by paragraphs (b)(1) and (2) of this section no later than January 18, 2016.

(ii) *New CCR surface impoundments and any lateral expansion of a CCR surface impoundment.* The owner or operator of the CCR unit must complete the initial annual inspection required by paragraphs (b)(1) and (2) of this section is completed no later than 14 months

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following the date of initial receipt of CCR in the CCR unit.

(4) *Frequency of inspections.* (i) Except as provided for in paragraph (b)(4)(ii) of this section, the owner or operator of the CCR unit must conduct the inspection required by paragraphs (b)(1) and (2) of this section on an annual basis. The date of completing the initial inspection report is the basis for establishing the deadline to complete the first subsequent inspection. Any required inspection may be conducted prior to the required deadline provided the owner or operator places the completed inspection report into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing subsequent inspection reports is based on the date of completing the previous inspection report. For purposes of this section, the owner or operator has completed an inspection when the inspection report has been placed in the facility's operating record as required by § 257.105(g)(6).

(ii) In any calendar year in which both the periodic inspection by a qualified professional engineer and the quinquennial (occurring every five years) structural stability assessment by a qualified professional engineer required by §§ 257.73(d) and 257.74(d) are required to be completed, the annual inspection is not required, provided the structural stability assessment is completed during the calendar year. If the annual inspection is not conducted in a year as provided by this paragraph (b)(4)(ii), the deadline for completing the next annual inspection is one year from the date of completing the quinquennial structural stability assessment.

(5) If a deficiency or release is identified during an inspection, the owner or operator must remedy the deficiency or release as soon as feasible and prepare documentation detailing the corrective measures taken.

(c) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(g), the notification requirements specified in § 257.106(g), and the internet requirements specified in § 257.107(g).

§ 257.84 Inspection requirements for CCR landfills.

(a) *Inspections by a qualified person.* (1) All CCR landfills and any lateral expansion of a CCR landfill must be examined by a qualified person as follows:

(i) At intervals not exceeding seven days, inspect for any appearances of actual or potential structural weakness and other conditions which are disrupting or have the potential to disrupt the operation or safety of the CCR unit; and

(ii) The results of the inspection by a qualified person must be recorded in the facility's operating record as required by § 257.105(g)(8).

(2) *Timeframes for inspections by a qualified person*—(i) *Existing CCR landfills.* The owner or operator of the CCR unit must initiate the inspections required under paragraph (a) of this section no later than October 19, 2015.

(ii) *New CCR landfills and any lateral expansion of a CCR landfill.* The owner or operator of the CCR unit must initiate the inspections required under paragraph (a) of this section upon initial receipt of CCR by the CCR unit.

(b) *Annual inspections by a qualified professional engineer.* (1) Existing and new CCR landfills and any lateral expansion of a CCR landfill must be inspected on a periodic basis by a qualified professional engineer to ensure that the design, construction, operation, and maintenance of the CCR unit is consistent with recognized and generally accepted good engineering standards. The inspection must, at a minimum, include:

(i) A review of available information regarding the status and condition of the CCR unit, including, but not limited to, files available in the operating record (*e.g.,* the results of inspections by a qualified person, and results of previous annual inspections); and

(ii) A visual inspection of the CCR unit to identify signs of distress or malfunction of the CCR unit.

(2) *Inspection report.* The qualified professional engineer must prepare a report following each inspection that addresses the following:

(i) Any changes in geometry of the structure since the previous annual inspection;

(ii) The approximate volume of CCR contained in the unit at the time of the inspection;

(iii) Any appearances of an actual or potential structural weakness of the CCR unit, in addition to any existing conditions that are disrupting or have the potential to disrupt the operation and safety of the CCR unit; and

(iv) Any other change(s) which may have affected the stability or operation of the CCR unit since the previous annual inspection.

(3) *Timeframes for conducting the initial inspection*—(i) *Existing CCR landfills.* The owner or operator of the CCR unit must complete the initial inspection required by paragraphs (b)(1) and (2) of this section no later than January 18, 2016.

(ii) *New CCR landfills and any lateral expansion of a CCR landfill.* The owner or operator of the CCR unit must complete the initial annual inspection required by paragraphs (b)(1) and (2) of this section no later than 14 months following the date of initial receipt of CCR in the CCR unit.

(4) *Frequency of inspections.* The owner or operator of the CCR unit must conduct the inspection required by paragraphs (b)(1) and (2) of this section on an annual basis. The date of completing the initial inspection report is the basis for establishing the deadline to complete the first subsequent inspection. Any required inspection may be conducted prior to the required deadline provided the owner or operator places the completed inspection report into the facility's operating record within a reasonable amount of time. In all cases, the deadline for completing subsequent inspection reports is based on the date of completing the previous inspection report. For purposes of this section, the owner or operator has completed an inspection when the inspection report has been placed in the facility's operating record as required by § 257.105(g)(9).

(5) If a deficiency or release is identified during an inspection, the owner or operator must remedy the deficiency or release as soon as feasible and prepare documentation detailing the corrective measures taken.

(c) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(g), the notification requirements specified in § 257.106(g), and the internet requirements specified in § 257.107(g).

Groundwater Monitoring and Corrective Action

§ 257.90 Applicability.

(a) Except as provided for in § 257.100 for inactive CCR surface impoundments, all CCR landfills, CCR surface impoundments, and lateral expansions of CCR units are subject to the groundwater monitoring and corrective action requirements under §§ 257.90 through 257.98.

(b) *Initial timeframes*—(1) *Existing CCR landfills and existing CCR surface impoundments.* No later than October 17, 2017, the owner or operator of the CCR unit must be in compliance with the following groundwater monitoring requirements:

(i) Install the groundwater monitoring system as required by § 257.91;

(ii) Develop the groundwater sampling and analysis program to include selection of the statistical

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procedures to be used for evaluating groundwater monitoring data as required by § 257.93;

(iii) Initiate the detection monitoring program to include obtaining a minimum of eight independent samples for each background and downgradient well as required by § 257.94(b); and

(iv) Begin evaluating the groundwater monitoring data for statistically significant increases over background levels for the constituents listed in appendix III of this part as required by § 257.94.

(2) *New CCR landfills, new CCR surface impoundments, and all lateral expansions of CCR units.* Prior to initial receipt of CCR by the CCR unit, the owner or operator must be in compliance with the groundwater monitoring requirements specified in paragraph (b)(1)(i) and (ii) of this section. In addition, the owner or operator of the CCR unit must initiate the detection monitoring program to include obtaining a minimum of eight independent samples for each background well as required by § 257.94(b).

(c) Once a groundwater monitoring system and groundwater monitoring program has been established at the CCR unit as required by this subpart, the owner or operator must conduct groundwater monitoring and, if necessary, corrective action throughout the active life and post-closure care period of the CCR unit.

(d) In the event of a release from a CCR unit, the owner or operator must immediately take all necessary measures to control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of contaminants into the environment. The owner or operator of the CCR unit must comply with all applicable requirements in §§ 257.96, 257.97, and 257.98.

(e) *Annual groundwater monitoring and corrective action report.* For existing CCR landfills and existing CCR surface impoundments, no later than January 31, 2018, and annually thereafter, the owner or operator must prepare an annual groundwater monitoring and corrective action report. For new CCR landfills, new CCR surface impoundments, and all lateral expansions of CCR units, the owner or operator must prepare the initial annual groundwater monitoring and corrective action report no later than January 31 of the year following the calendar year a groundwater monitoring system has been established for such CCR unit as required by this subpart, and annually thereafter. For the preceding calendar year, the annual report must document the status of the groundwater monitoring and corrective action program for the CCR unit, summarize key actions completed, describe any problems encountered, discuss actions to resolve the problems, and project key activities for the upcoming year. For purposes of this section, the owner or operator has prepared the annual report when the report is placed in the facility's operating record as required by § 257.105(h)(1). At a minimum, the annual groundwater monitoring and corrective action report must contain the following information, to the extent available:

(1) A map, aerial image, or diagram showing the CCR unit and all background (or upgradient) and downgradient monitoring wells, to include the well identification numbers, that are part of the groundwater monitoring program for the CCR unit;

(2) Identification of any monitoring wells that were installed or decommissioned during the preceding year, along with a narrative description of why those actions were taken;

(3) In addition to all the monitoring data obtained under §§ 257.90 through 257.98, a summary including the number of groundwater samples that were collected for analysis for each background and downgradient well, the dates the samples were collected, and whether the sample was required by the detection monitoring or assessment monitoring programs;

(4) A narrative discussion of any transition between monitoring programs (*e.g.,* the date and circumstances for transitioning from detection monitoring to assessment monitoring in addition to identifying the constituent(s) detected at a statistically significant increase over background levels); and

(5) Other information required to be included in the annual report as specified in §§ 257.90 through 257.98.

(f) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the internet requirements specified in § 257.107(h).

§ 257.91 Groundwater monitoring systems.

(a) *Performance standard.* The owner or operator of a CCR unit must install a groundwater monitoring system that consists of a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer that:

(1) Accurately represent the quality of background groundwater that has not been affected by leakage from a CCR unit. A determination of background quality may include sampling of wells that are not hydraulically upgradient of the CCR management area where:

(i) Hydrogeologic conditions do not allow the owner or operator of the CCR unit to determine what wells are hydraulically upgradient; or

(ii) Sampling at other wells will provide an indication of background groundwater quality that is as representative or more representative than that provided by the upgradient wells; and

(2) Accurately represent the quality of groundwater passing the waste boundary of the CCR unit. The downgradient monitoring system must be installed at the waste boundary that ensures detection of groundwater contamination in the uppermost aquifer. All potential contaminant pathways must be monitored.

(b) The number, spacing, and depths of monitoring systems shall be determined based upon site-specific technical information that must include thorough characterization of:

(1) Aquifer thickness, groundwater flow rate, groundwater flow direction including seasonal and temporal fluctuations in groundwater flow; and

(2) Saturated and unsaturated geologic units and fill materials overlying the uppermost aquifer, materials comprising the uppermost aquifer, and materials comprising the confining unit defining the lower boundary of the uppermost aquifer, including, but not limited to, thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities and effective porosities.

(c) The groundwater monitoring system must include the minimum number of monitoring wells necessary to meet the performance standards specified in paragraph (a) of this section, based on the site-specific information specified in paragraph (b) of this section. The groundwater monitoring system must contain:

(1) A minimum of one upgradient and three downgradient monitoring wells; and

(2) Additional monitoring wells as necessary to accurately represent the quality of background groundwater that has not been affected by leakage from the CCR unit and the quality of groundwater passing the waste boundary of the CCR unit.

(d) The owner or operator of multiple CCR units may install a multiunit groundwater monitoring system instead of separate groundwater monitoring systems for each CCR unit.

(1) The multiunit groundwater monitoring system must be equally as capable of detecting monitored constituents at the waste boundary of

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the CCR unit as the individual groundwater monitoring system specified in paragraphs (a) through (c) of this section for each CCR unit based on the following factors:

(i) Number, spacing, and orientation of each CCR unit;

(ii) Hydrogeologic setting;

(iii) Site history; and

(iv) Engineering design of the CCR unit.

(2) If the owner or operator elects to install a multiunit groundwater monitoring system, and if the multiunit system includes at least one existing unlined CCR surface impoundment as determined by § 257.71(a), and if at any time after October 19, 2015 the owner or operator determines in any sampling event that the concentrations of one or more constituents listed in appendix IV to this part are detected at statistically significant levels above the groundwater protection standard established under § 257.95(h) for the multiunit system, then all unlined CCR surface impoundments comprising the multiunit groundwater monitoring system are subject to the closure requirements under § 257.101(a) to retrofit or close.

(e) Monitoring wells must be cased in a manner that maintains the integrity of the monitoring well borehole. This casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of groundwater samples. The annular space (*i.e.,* the space between the borehole and well casing) above the sampling depth must be sealed to prevent contamination of samples and the groundwater.

(1) The owner or operator of the CCR unit must document and include in the operating record the design, installation, development, and decommissioning of any monitoring wells, piezometers and other measurement, sampling, and analytical devices. The qualified professional engineer must be given access to this documentation when completing the groundwater monitoring system certification required under paragraph (f) of this section.

(2) The monitoring wells, piezometers, and other measurement, sampling, and analytical devices must be operated and maintained so that they perform to the design specifications throughout the life of the monitoring program.

(f) The owner or operator must obtain a certification from a qualified professional engineer stating that the groundwater monitoring system has been designed and constructed to meet the requirements of this section. If the groundwater monitoring system includes the minimum number of monitoring wells specified in paragraph (c)(1) of this section, the certification must document the basis supporting this determination.

(g) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the internet requirements specified in § 257.107(h).

§ 257.92 [Reserved]

§ 257.93 Groundwater sampling and analysis requirements.

(a) The groundwater monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of groundwater quality at the background and downgradient wells required by § 257.91. The owner or operator of the CCR unit must develop a sampling and analysis program that includes procedures and techniques for:

(1) Sample collection;

(2) Sample preservation and shipment;

(3) Analytical procedures;

(4) Chain of custody control; and

(5) Quality assurance and quality control.

(b) The groundwater monitoring program must include sampling and analytical methods that are appropriate for groundwater sampling and that accurately measure hazardous constituents and other monitoring parameters in groundwater samples. For purposes of §§ 257.90 through 257.98, the term *constituent* refers to both hazardous constituents and other monitoring parameters listed in either appendix III or IV of this part.

(c) Groundwater elevations must be measured in each well immediately prior to purging, each time groundwater is sampled. The owner or operator of the CCR unit must determine the rate and direction of groundwater flow each time groundwater is sampled. Groundwater elevations in wells which monitor the same CCR management area must be measured within a period of time short enough to avoid temporal variations in groundwater flow which could preclude accurate determination of groundwater flow rate and direction.

(d) The owner or operator of the CCR unit must establish background groundwater quality in a hydraulically upgradient or background well(s) for each of the constituents required in the particular groundwater monitoring program that applies to the CCR unit as determined under § 257.94(a) or § 257.95(a). Background groundwater quality may be established at wells that are not located hydraulically upgradient from the CCR unit if it meets the requirements of § 257.91(a)(1).

(e) The number of samples collected when conducting detection monitoring and assessment monitoring (for both downgradient and background wells) must be consistent with the statistical procedures chosen under paragraph (f) of this section and the performance standards under paragraph (g) of this section. The sampling procedures shall be those specified under § 257.94(b) through (d) for detection monitoring, § 257.95(b) through (d) for assessment monitoring, and § 257.96(b) for corrective action.

(f) The owner or operator of the CCR unit must select one of the statistical methods specified in paragraphs (f)(1) through (5) of this section to be used in evaluating groundwater monitoring data for each specified constituent. The statistical test chosen shall be conducted separately for each constituent in each monitoring well.

(1) A parametric analysis of variance followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent.

(2) An analysis of variance based on ranks followed by multiple comparison procedures to identify statistically significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent.

(3) A tolerance or prediction interval procedure, in which an interval for each constituent is established from the distribution of the background data and the level of each constituent in each compliance well is compared to the upper tolerance or prediction limit.

(4) A control chart approach that gives control limits for each constituent.

(5) Another statistical test method that meets the performance standards of paragraph (g) of this section.

(6) The owner or operator of the CCR unit must obtain a certification from a qualified professional engineer stating that the selected statistical method is appropriate for evaluating the groundwater monitoring data for the CCR management area. The certification must include a narrative description of the statistical method selected to evaluate the groundwater monitoring data.

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(g) Any statistical method chosen under paragraph (f) of this section shall comply with the following performance standards, as appropriate, based on the statistical test method used:

(1) The statistical method used to evaluate groundwater monitoring data shall be appropriate for the distribution of constituents. Normal distributions of data values shall use parametric methods. Non-normal distributions shall use non-parametric methods. If the distribution of the constituents is shown by the owner or operator of the CCR unit to be inappropriate for a normal theory test, then the data must be transformed or a distribution-free (non-parametric) theory test must be used. If the distributions for the constituents differ, more than one statistical method may be needed.

(2) If an individual well comparison procedure is used to compare an individual compliance well constituent concentration with background constituent concentrations or a groundwater protection standard, the test shall be done at a Type I error level no less than 0.01 for each testing period. If a multiple comparison procedure is used, the Type I experiment wise error rate for each testing period shall be no less than 0.05; however, the Type I error of no less than 0.01 for individual well comparisons must be maintained. This performance standard does not apply to tolerance intervals, prediction intervals, or control charts.

(3) If a control chart approach is used to evaluate groundwater monitoring data, the specific type of control chart and its associated parameter values shall be such that this approach is at least as effective as any other approach in this section for evaluating groundwater data. The parameter values shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(4) If a tolerance interval or a predictional interval is used to evaluate groundwater monitoring data, the levels of confidence and, for tolerance intervals, the percentage of the population that the interval must contain, shall be such that this approach is at least as effective as any other approach in this section for evaluating groundwater data. These parameters shall be determined after considering the number of samples in the background data base, the data distribution, and the range of the concentration values for each constituent of concern.

(5) The statistical method must account for data below the limit of detection with one or more statistical procedures that shall at least as effective as any other approach in this section for evaluating groundwater data. Any practical quantitation limit that is used in the statistical method shall be the lowest concentration level that can be reliably achieved within specified limits of precision and accuracy during routine laboratory operating conditions that are available to the facility.

(6) If necessary, the statistical method must include procedures to control or correct for seasonal and spatial variability as well as temporal correlation in the data.

(h) The owner or operator of the CCR unit must determine whether or not there is a statistically significant increase over background values for each constituent required in the particular groundwater monitoring program that applies to the CCR unit, as determined under § 257.94(a) or § 257.95(a).

(1) In determining whether a statistically significant increase has occurred, the owner or operator must compare the groundwater quality of each constituent at each monitoring well designated pursuant to § 257.91(a)(2) or (d)(1) to the background value of that constituent, according to the statistical procedures and performance standards specified under paragraphs (f) and (g) of this section.

(2) Within 90 days after completing sampling and analysis, the owner or operator must determine whether there has been a statistically significant increase over background for any constituent at each monitoring well.

(i) The owner or operator must measure ''total recoverable metals'' concentrations in measuring groundwater quality. Measurement of total recoverable metals captures both the particulate fraction and dissolved fraction of metals in natural waters. Groundwater samples shall not be field-filtered prior to analysis.

(j) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the Internet requirements specified in § 257.107(h).

§ 257.94 Detection monitoring program.

(a) The owner or operator of a CCR unit must conduct detection monitoring at all groundwater monitoring wells consistent with this section. At a minimum, a detection monitoring program must include groundwater monitoring for all constituents listed in appendix III to this part.

(b) Except as provided in paragraph (d) of this section, the monitoring frequency for the constituents listed in appendix III to this part shall be at least semiannual during the active life of the CCR unit and the post-closure period. For existing CCR landfills and existing CCR surface impoundments, a minimum of eight independent samples from each background and downgradient well must be collected and analyzed for the constituents listed in appendix III and IV to this part no later than October 17, 2017. For new CCR landfills, new CCR surface impoundments, and all lateral expansions of CCR units, a minimum of eight independent samples for each background well must be collected and analyzed for the constituents listed in appendices III and IV to this part during the first six months of sampling.

(c) The number of samples collected and analyzed for each background well and downgradient well during subsequent semiannual sampling events must be consistent with § 257.93(e), and must account for any unique characteristics of the site, but must be at least one sample from each background and downgradient well.

(d) The owner or operator of a CCR unit may demonstrate the need for an alternative monitoring frequency for repeated sampling and analysis for constituents listed in appendix III to this part during the active life and the post-closure care period based on the availability of groundwater. If there is not adequate groundwater flow to sample wells semiannually, the alternative frequency shall be no less than annual. The need to vary monitoring frequency must be evaluated on a site-specific basis. The demonstration must be supported by, at a minimum, the information specified in paragraphs (d)(1) and (2) of this section.

(1) Information documenting that the need for less frequent sampling. The alternative frequency must be based on consideration of the following factors:

(i) Lithology of the aquifer and unsaturated zone;

(ii) Hydraulic conductivity of the aquifer and unsaturated zone; and

(iii) Groundwater flow rates.

(2) Information documenting that the alternative frequency will be no less effective in ensuring that any leakage from the CCR unit will be discovered within a timeframe that will not materially delay establishment of an assessment monitoring program.

(3) The owner or operator must obtain a certification from a qualified

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professional engineer stating that the demonstration for an alternative groundwater sampling and analysis frequency meets the requirements of this section. The owner or operator must include the demonstration providing the basis for the alternative monitoring frequency and the certification by a qualified professional engineer in the annual groundwater monitoring and corrective action report required by § 257.90(e).

(e) If the owner or operator of the CCR unit determines, pursuant to § 257.93(h) that there is a statistically significant increase over background levels for one or more of the constituents listed in appendix III to this part at any monitoring well at the waste boundary specified under § 257.91(a)(2), the owner or operator must:

(1) Except as provided for in paragraph (e)(2) of this section, within 90 days of detecting a statistically significant increase over background levels for any constituent, establish an assessment monitoring program meeting the requirements of § 257.95.

(2) The owner or operator may demonstrate that a source other than the CCR unit caused the statistically significant increase over background levels for a constituent or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. The owner or operator must complete the written demonstration within 90 days of detecting a statistically significant increase over background levels to include obtaining a certification from a qualified professional engineer verifying the accuracy of the information in the report. If a successful demonstration is completed within the 90-day period, the owner or operator of the CCR unit may continue with a detection monitoring program under this section. If a successful demonstration is not completed within the 90-day period, the owner or operator of the CCR unit must initiate an assessment monitoring program as required under § 257.95. The owner or operator must also include the demonstration in the annual groundwater monitoring and corrective action report required by § 257.90(e), in addition to the certification by a qualified professional engineer.

(3) The owner or operator of a CCR unit must prepare a notification stating that an assessment monitoring program has been established. The owner or operator has completed the notification when the notification is placed in the facility's operating record as required by § 257.105(h)(5).

(f) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the Internet requirements specified in § 257.107(h).

§ 257.95 Assessment monitoring program.

(a) Assessment monitoring is required whenever a statistically significant increase over background levels has been detected for one or more of the constituents listed in appendix III to this part.

(b) Within 90 days of triggering an assessment monitoring program, and annually thereafter, the owner or operator of the CCR unit must sample and analyze the groundwater for all constituents listed in appendix IV to this part. The number of samples collected and analyzed for each well during each sampling event must be consistent with § 257.93(e), and must account for any unique characteristics of the site, but must be at least one sample from each well.

(c) The owner or operator of a CCR unit may demonstrate the need for an alternative monitoring frequency for repeated sampling and analysis for constituents listed in appendix IV to this part during the active life and the post-closure care period based on the availability of groundwater. If there is not adequate groundwater flow to sample wells semiannually, the alternative frequency shall be no less than annual. The need to vary monitoring frequency must be evaluated on a site-specific basis. The demonstration must be supported by, at a minimum, the information specified in paragraphs (c)(1) and (2) of this section.

(1) Information documenting that the need for less frequent sampling. The alternative frequency must be based on consideration of the following factors:

(i) Lithology of the aquifer and unsaturated zone;

(ii) Hydraulic conductivity of the aquifer and unsaturated zone; and

(iii) Groundwater flow rates.

(2) Information documenting that the alternative frequency will be no less effective in ensuring that any leakage from the CCR unit will be discovered within a timeframe that will not materially delay the initiation of any necessary remediation measures.

(3) The owner or operator must obtain a certification from a qualified professional engineer stating that the demonstration for an alternative groundwater sampling and analysis frequency meets the requirements of this section. The owner or operator must include the demonstration providing the basis for the alternative monitoring frequency and the certification by a qualified professional engineer in the annual groundwater monitoring and corrective action report required by § 257.90(e).

(d) After obtaining the results from the initial and subsequent sampling events required in paragraph (b) of this section, the owner or operator must:

(1) Within 90 days of obtaining the results, and on at least a semiannual basis thereafter, resample all wells that were installed pursuant to the requirements of § 257.91, conduct analyses for all parameters in appendix III to this part and for those constituents in appendix IV to this part that are detected in response to paragraph (b) of this section, and record their concentrations in the facility operating record. The number of samples collected and analyzed for each background well and downgradient well during subsequent semiannual sampling events must be consistent with § 257.93(e), and must account for any unique characteristics of the site, but must be at least one sample from each background and downgradient well;

(2) Establish groundwater protection standards for all constituents detected pursuant to paragraph (b) or (d) of this section. The groundwater protection standards must be established in accordance with paragraph (h) of this section; and

(3) Include the recorded concentrations required by paragraph (d)(1) of this section, identify the background concentrations established under § 257.94(b), and identify the groundwater protection standards established under paragraph (d)(2) of this section in the annual groundwater monitoring and corrective action report required by § 257.90(e).

(e) If the concentrations of all constituents listed in appendices III and IV to this part are shown to be at or below background values, using the statistical procedures in § 257.93(g), for two consecutive sampling events, the owner or operator may return to detection monitoring of the CCR unit. The owner or operator must prepare a notification stating that detection monitoring is resuming for the CCR unit. The owner or operator has completed the notification when the notification is placed in the facility's operating record as required by § 257.105(h)(7).

(f) If the concentrations of any constituent in appendices III and IV to this part are above background values, but all concentrations are below the groundwater protection standard

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established under paragraph (h) of this section, using the statistical procedures in § 257.93(g), the owner or operator must continue assessment monitoring in accordance with this section.

(g) If one or more constituents in appendix IV to this part are detected at statistically significant levels above the groundwater protection standard established under paragraph (h) of this section in any sampling event, the owner or operator must prepare a notification identifying the constituents in appendix IV to this part that have exceeded the groundwater protection standard. The owner or operator has completed the notification when the notification is placed in the facility's operating record as required by § 257.105(h)(8). The owner or operator of the CCR unit also must:

(1) Characterize the nature and extent of the release and any relevant site conditions that may affect the remedy ultimately selected. The characterization must be sufficient to support a complete and accurate assessment of the corrective measures necessary to effectively clean up all releases from the CCR unit pursuant to § 257.96. Characterization of the release includes the following minimum measures:

(i) Install additional monitoring wells necessary to define the contaminant plume(s);

(ii) Collect data on the nature and estimated quantity of material released including specific information on the constituents listed in appendix IV of this part and the levels at which they are present in the material released;

(iii) Install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well in accordance with paragraph (d)(1) of this section; and

(iv) Sample all wells in accordance with paragraph (d)(1) of this section to characterize the nature and extent of the release.

(2) Notify all persons who own the land or reside on the land that directly overlies any part of the plume of contamination if contaminants have migrated off-site if indicated by sampling of wells in accordance with paragraph (g)(1) of this section. The owner or operator has completed the notifications when they are placed in the facility's operating record as required by § 257.105(h)(8).

(3) Within 90 days of finding that any of the constituents listed in appendix IV to this part have been detected at a statistically significant level exceeding the groundwater protection standards the owner or operator must either:

(i) Initiate an assessment of corrective measures as required by § 257.96; or

(ii) Demonstrate that a source other than the CCR unit caused the contamination, or that the statistically significant increase resulted from error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. Any such demonstration must be supported by a report that includes the factual or evidentiary basis for any conclusions and must be certified to be accurate by a qualified professional engineer. If a successful demonstration is made, the owner or operator must continue monitoring in accordance with the assessment monitoring program pursuant to this section, and may return to detection monitoring if the constituents in appendices III and IV to this part are at or below background as specified in paragraph (e) of this section. The owner or operator must also include the demonstration in the annual groundwater monitoring and corrective action report required by § 257.90(e), in addition to the certification by a qualified professional engineer.

(4) If a successful demonstration has not been made at the end of the 90 day period provided by paragraph (g)(3)(ii) of this section, the owner or operator of the CCR unit must initiate the assessment of corrective measures requirements under § 257.96.

(5) If an assessment of corrective measures is required under § 257.96 by either paragraph (g)(3)(i) or (g)(4) of this section, and if the CCR unit is an existing unlined CCR surface impoundment as determined by § 257.71(a), then the CCR unit is subject to the closure requirements under § 257.101(a) to retrofit or close. In addition, the owner or operator must prepare a notification stating that an assessment of corrective measures has been initiated.

(h) The owner or operator of the CCR unit must establish a groundwater protection standard for each constituent in appendix IV to this part detected in the groundwater. The groundwater protection standard shall be:

(1) For constituents for which a maximum contaminant level (MCL) has been established under §§ 141.62 and 141.66 of this title, the MCL for that constituent;

(2) For constituents for which an MCL has not been established, the background concentration for the constituent established from wells in accordance with § 257.91; or

(3) For constituents for which the background level is higher than the MCL identified under paragraph (h)(1) of this section, the background concentration.

(i) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the Internet requirements specified in § 257.107(h).

§ 257.96 Assessment of corrective measures.

(a) Within 90 days of finding that any constituent listed in appendix IV to this part has been detected at a statistically significant level exceeding the groundwater protection standard defined under § 257.95(h), or immediately upon detection of a release from a CCR unit, the owner or operator must initiate an assessment of corrective measures to prevent further releases, to remediate any releases and to restore affected area to original conditions. The assessment of corrective measures must be completed within 90 days, unless the owner or operator demonstrates the need for additional time to complete the assessment of corrective measures due to site-specific conditions or circumstances. The owner or operator must obtain a certification from a qualified professional engineer attesting that the demonstration is accurate. The 90-day deadline to complete the assessment of corrective measures may be extended for no longer than 60 days. The owner or operator must also include the demonstration in the annual groundwater monitoring and corrective action report required by § 257.90(e), in addition to the certification by a qualified professional engineer.

(b) The owner or operator of the CCR unit must continue to monitor groundwater in accordance with the assessment monitoring program as specified in § 257.95.

(c) The assessment under paragraph (a) of this section must include an analysis of the effectiveness of potential corrective measures in meeting all of the requirements and objectives of the remedy as described under § 257.97 addressing at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy;

(3) The institutional requirements, such as state or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

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(d) The owner or operator must place the completed assessment of corrective measures in the facility's operating record. The assessment has been completed when it is placed in the facility's operating record as required by § 257.105(h)(10).

(e) The owner or operator must discuss the results of the corrective measures assessment at least 30 days prior to the selection of remedy, in a public meeting with interested and affected parties.

(f) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the Internet requirements specified in § 257.107(h).

§ 257.97 Selection of remedy.

(a) Based on the results of the corrective measures assessment conducted under § 257.96, the owner or operator must, as soon as feasible, select a remedy that, at a minimum, meets the standards listed in paragraph (b) of this section. This requirement applies to, not in place of, any applicable standards under the Occupational Safety and Health Act. The owner or operator must prepare a semiannual report describing the progress in selecting and designing the remedy. Upon selection of a remedy, the owner or operator must prepare a final report describing the selected remedy and how it meets the standards specified in paragraph (b) of this section. The owner or operator must obtain a certification from a qualified professional engineer that the remedy selected meets the requirements of this section. The report has been completed when it is placed in the operating record as required by § 257.105(h)(12).

(b) Remedies must:

(1) Be protective of human health and the environment;

(2) Attain the groundwater protection standard as specified pursuant to § 257.95(h);

(3) Control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of constituents in appendix IV to this part into the environment;

(4) Remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, taking into account factors such as avoiding inappropriate disturbance of sensitive ecosystems;

(5) Comply with standards for management of wastes as specified in § 257.98(d).

(c) In selecting a remedy that meets the standards of paragraph (b) of this section, the owner or operator of the CCR unit shall consider the following evaluation factors:

(1) The long- and short-term effectiveness and protectiveness of the potential remedy(s), along with the degree of certainty that the remedy will prove successful based on consideration of the following:

(i) Magnitude of reduction of existing risks;

(ii) Magnitude of residual risks in terms of likelihood of further releases due to CCR remaining following implementation of a remedy;

(iii) The type and degree of long-term management required, including monitoring, operation, and maintenance;

(iv) Short-term risks that might be posed to the community or the environment during implementation of such a remedy, including potential threats to human health and the environment associated with excavation, transportation, and re-disposal of contaminant;

(v) Time until full protection is achieved;

(vi) Potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, re-disposal, or containment;

(vii) Long-term reliability of the engineering and institutional controls; and

(viii) Potential need for replacement of the remedy.

(2) The effectiveness of the remedy in controlling the source to reduce further releases based on consideration of the following factors:

(i) The extent to which containment practices will reduce further releases; and

(ii) The extent to which treatment technologies may be used.

(3) The ease or difficulty of implementing a potential remedy(s) based on consideration of the following types of factors:

(i) Degree of difficulty associated with constructing the technology;

(ii) Expected operational reliability of the technologies;

(iii) Need to coordinate with and obtain necessary approvals and permits from other agencies;

(iv) Availability of necessary equipment and specialists; and

(v) Available capacity and location of needed treatment, storage, and disposal services.

(4) The degree to which community concerns are addressed by a potential remedy(s).

(d) The owner or operator must specify as part of the selected remedy a schedule(s) for implementing and completing remedial activities. Such a schedule must require the completion of remedial activities within a reasonable period of time taking into consideration the factors set forth in paragraphs (d)(1) through (6) of this section. The owner or operator of the CCR unit must consider the following factors in determining the schedule of remedial activities:

(1) Extent and nature of contamination, as determined by the characterization required under § 257.95(g);

(2) Reasonable probabilities of remedial technologies in achieving compliance with the groundwater protection standards established under § 257.95(h) and other objectives of the remedy;

(3) Availability of treatment or disposal capacity for CCR managed during implementation of the remedy;

(4) Potential risks to human health and the environment from exposure to contamination prior to completion of the remedy;

(5) Resource value of the aquifer including:

(i) Current and future uses;

(ii) Proximity and withdrawal rate of users;

(iii) Groundwater quantity and quality;

(iv) The potential damage to wildlife, crops, vegetation, and physical structures caused by exposure to CCR constituents;

(v) The hydrogeologic characteristic of the facility and surrounding land; and

(vi) The availability of alternative water supplies; and

(6) Other relevant factors.

(e) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the Internet requirements specified in § 257.107(h).

§ 257.98 Implementation of the corrective action program.

(a) Within 90 days of selecting a remedy under § 257.97, the owner or operator must initiate remedial activities. Based on the schedule established under § 257.97(d) for implementation and completion of remedial activities the owner or operator must:

(1) Establish and implement a corrective action groundwater monitoring program that:

(i) At a minimum, meets the requirements of an assessment monitoring program under § 257.95;

(ii) Documents the effectiveness of the corrective action remedy; and

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(iii) Demonstrates compliance with the groundwater protection standard pursuant to paragraph (c) of this section.

(2) Implement the corrective action remedy selected under § 257.97; and

(3) Take any interim measures necessary to reduce the contaminants leaching from the CCR unit, and/or potential exposures to human or ecological receptors. Interim measures must, to the greatest extent feasible, be consistent with the objectives of and contribute to the performance of any remedy that may be required pursuant to § 257.97. The following factors must be considered by an owner or operator in determining whether interim measures are necessary:

(i) Time required to develop and implement a final remedy;

(ii) Actual or potential exposure of nearby populations or environmental receptors to any of the constituents listed in appendix IV of this part;

(iii) Actual or potential contamination of drinking water supplies or sensitive ecosystems;

(iv) Further degradation of the groundwater that may occur if remedial action is not initiated expeditiously;

(v) Weather conditions that may cause any of the constituents listed in appendix IV to this part to migrate or be released;

(vi) Potential for exposure to any of the constituents listed in appendix IV to this part as a result of an accident or failure of a container or handling system; and

(vii) Other situations that may pose threats to human health and the environment.

(b) If an owner or operator of the CCR unit, determines, at any time, that compliance with the requirements of § 257.97(b) is not being achieved through the remedy selected, the owner or operator must implement other methods or techniques that could feasibly achieve compliance with the requirements.

(c) Remedies selected pursuant to § 257.97 shall be considered complete when:

(1) The owner or operator of the CCR unit demonstrates compliance with the groundwater protection standards established under § 257.95(h) has been achieved at all points within the plume of contamination that lie beyond the groundwater monitoring well system established under § 257.91.

(2) Compliance with the groundwater protection standards established under § 257.95(h) has been achieved by demonstrating that concentrations of constituents listed in appendix IV to this part have not exceeded the groundwater protection standard(s) for a period of three consecutive years using the statistical procedures and performance standards in § 257.93(f) and (g).

(3) All actions required to complete the remedy have been satisfied.

(d) All CCR that are managed pursuant to a remedy required under § 257.97, or an interim measure required under paragraph (a)(3) of this section, shall be managed in a manner that complies with all applicable RCRA requirements.

(e) Upon completion of the remedy, the owner or operator must prepare a notification stating that the remedy has been completed. The owner or operator must obtain a certification from a qualified professional engineer attesting that the remedy has been completed in compliance with the requirements of paragraph (c) of this section. The report has been completed when it is placed in the operating record as required by § 257.105(h)(13).

(f) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(h), the notification requirements specified in § 257.106(h), and the internet requirements specified in § 257.107(h).

Closure and Post-Closure Care

§ 257.100 Inactive CCR surface impoundments.

(a) Except as provided by paragraph (b) of this section, inactive CCR surface impoundments are subject to all of the requirements of this subpart applicable to existing CCR surface impoundments.

(b) An owner or operator of an inactive CCR surface impoundment that completes closure of such CCR unit, and meets all of the requirements of either paragraphs (b)(1) through (4) of this section or paragraph (b)(5) of this section no later than April 17, 2018, is exempt from all other requirements of this subpart.

(1) *Closure by leaving CCR in place.* If the owner or operator of the inactive CCR surface impoundment elects to close the CCR surface impoundment by leaving CCR in place, the owner or operator must ensure that, at a minimum, the CCR unit is closed in a manner that will:

(i) Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;

(ii) Preclude the probability of future impoundment of water, sediment, or slurry;

(iii) Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system; and

(iv) Minimize the need for further maintenance of the CCR unit.

(2) The owner or operator of the inactive CCR surface impoundment must meet the requirements of paragraphs (b)(2)(i) and (ii) of this section prior to installing the final cover system required under paragraph (b)(3) of this section.

(i) Free liquids must be eliminated by removing liquid wastes or solidifying the remaining wastes and waste residues.

(ii) Remaining wastes must be stabilized sufficient to support the final cover system.

(3) The owner or operator must install a final cover system that is designed to minimize infiltration and erosion, and at a minimum, meets the requirements of paragraph (b)(3)(i) of this section, or the requirements of an alternative final cover system specified in paragraph (b)(3)(ii) of this section.

(i) The final cover system must be designed and constructed to meet the criteria specified in paragraphs (b)(3)(i)(A) through (D) of this section.

(A) The permeability of the final cover system must be less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} centimeters/second, whichever is less.

(B) The infiltration of liquids through the CCR unit must be minimized by the use of an infiltration layer that contains a minimum of 18 inches of earthen material.

(C) The erosion of the final cover system must be minimized by the use of an erosion layer that contains a minimum of six inches of earthen material that is capable of sustaining native plant growth.

(D) The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

(ii) The owner or operator may select an alternative final cover system design, provided the alternative final cover system is designed and constructed to meet the criteria in paragraphs (b)(3)(ii)(A) through (C) of this section.

(A) The design of the final cover system must include an infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs (b)(3)(i)(A) and (B) of this section.

(B) The design of the final cover system must include an erosion layer that provides equivalent protection from wind or water erosion as the erosion layer specified in paragraph (b)(3)(i)(C) of this section.

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(C) The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

(4) The owner or operator of the CCR surface impoundment must obtain a written certification from a qualified professional engineer stating that the design of the final cover system meets either the requirements of paragraphs (b)(3)(i) or (ii) of this section.

(5) *Closure through removal of CCR.* The owner or operator may alternatively elect to close an inactive CCR surface impoundment by removing and decontaminating all areas affected by releases from the CCR surface impoundment. CCR removal and decontamination of the CCR surface impoundment are complete when all CCR in the inactive CCR surface impoundment is removed, including the bottom liner of the CCR unit.

(6) The owner or operator of the CCR surface impoundment must obtain a written certification from a qualified professional engineer that closure of the CCR surface impoundment under either paragraphs (b)(1) through (4) or (b)(5) of this section is technically feasible within the timeframe in paragraph (b) of this section.

(7) If the owner or operator of the CCR surface impoundment fails to complete closure of the inactive CCR surface impoundment within the timeframe in paragraph (b) of this section, the CCR unit must comply with all of the requirements applicable to existing CCR surface impoundments under this subpart.

(c) *Required notices and progress reports.* An owner or operator of an inactive CCR surface impoundment that closes in accordance with paragraph (b) of this section must complete the notices and progress reports specified in paragraphs (c)(1) through (3) of this section.

(1) No later than December 17, 2015, the owner or operator must prepare and place in the facility's operating record a notification of intent to initiate closure of the CCR surface impoundment. The notification must state that the CCR surface impoundment is an inactive CCR surface impoundment closing under the requirements of paragraph (b) of this section. The notification must also include a narrative description of how the CCR surface impoundment will be closed, a schedule for completing closure activities, and the required certifications under paragraphs (b)(4) and (6) of this section, if applicable.

(2) The owner or operator must prepare periodic progress reports summarizing the progress of closure implementation, including a description of the actions completed to date, any problems encountered and a description of the actions taken to resolve the problems, and projected closure activities for the upcoming year. The annual progress reports must be completed according to the following schedule:

(i) The first annual progress report must be prepared no later than 13 months after completing the notification of intent to initiate closure required by paragraph (c)(1) of this section.

(ii) The second annual progress report must be prepared no later than 12 months after completing the first progress report required by paragraph (c)(2)(i) of this section.

(iii) The owner or operator has completed the progress reports specified in paragraph (c)(2) of this section when the reports are placed in the facility's operating record as required by § 257.105(i)(2).

(3) The owner or operator must prepare and place in the facility's operating record a notification of completion of closure of the CCR surface impoundment. The notification must be submitted within 60 days of completing closure of the CCR surface impoundment and must include a written certification from a qualified professional engineer stating that the CCR surface impoundment was closed in accordance with the requirements of either paragraph (b)(1) through (4) or (b)(5) of this section.

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(i), the notification requirements specified in § 257.106(i), and the internet requirements specified in § 257.107(i).

§ 257.101 Closure or retrofit of CCR units.

(a) The owner or operator of an existing unlined CCR surface impoundment, as determined under § 257.71(a), is subject to the requirements of paragraph (a)(1) of this section.

(1) Except as provided by paragraph (a)(3) of this section, if at any time after October 19, 2015 an owner or operator of an existing unlined CCR surface impoundment determines in any sampling event that the concentrations of one or more constituents listed in appendix IV to this part are detected at statistically significant levels above the groundwater protection standard established under § 257.95(h) for such CCR unit, within six months of making such determination, the owner or operator of the existing unlined CCR surface impoundment must cease placing CCR and non-CCR wastestreams into such CCR surface impoundment and either retrofit or close the CCR unit in accordance with the requirements of § 257.102.

(2) An owner or operator of an existing unlined CCR surface impoundment that closes in accordance with paragraph (a)(1) of this section must include a statement in the notification required under § 257.102(g) or (k)(5) that the CCR surface impoundment is closing or retrofitting under the requirements of paragraph (a)(1) of this section.

(3) The timeframe specified in paragraph (a)(1) of this section does not apply if the owner or operator complies with the alternative closure procedures specified in § 257.103.

(4) At any time after the initiation of closure under paragraph (a)(1) of this section, the owner or operator may cease closure activities and initiate a retrofit of the CCR unit in accordance with the requirements of § 257.102(k).

(b) The owner or operator of an existing CCR surface impoundment is subject to the requirements of paragraph (b)(1) of this section.

(1) Except as provided by paragraph (b)(4) of this section, within six months of determining that an existing CCR surface impoundment has not demonstrated compliance with any location standard specified in §§ 257.60(a), 257.61(a), 257.62(a), 257.63(a), and 257.64(a), the owner or operator of the CCR surface impoundment must cease placing CCR and non-CCR wastestreams into such CCR unit and close the CCR unit in accordance with the requirements of § 257.102.

(2) Within six months of either failing to complete the initial or any subsequent periodic safety factor assessment required by § 257.73(e) by the deadlines specified in § 257.73(f)(1) through (3) or failing to document that the calculated factors of safety for the existing CCR surface impoundment achieve the minimum safety factors specified in § 257.73(e)(1)(i) through (iv), the owner or operator of the CCR surface impoundment must cease placing CCR and non-CCR wastestreams into such CCR unit and close the CCR unit in accordance with the requirements of § 257.102.

(3) An owner or operator of an existing CCR surface impoundment that closes in accordance with paragraphs (b)(1) or (2) of this section must include a statement in the notification required under § 257.102(g) that the CCR surface impoundment is closing under the requirements of paragraphs (b)(1) or (2) of this section.

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(4) The timeframe specified in paragraph (b)(1) of this section does not apply if the owner or operator complies with the alternative closure procedures specified in § 257.103.

(c) The owner or operator of a new CCR surface impoundment is subject to the requirements of paragraph (c)(1) of this section.

(1) Within six months of either failing to complete the initial or any subsequent periodic safety factor assessment required by § 257.74(e) by the deadlines specified in § 257.74(f)(1) through (3) or failing to document that the calculated factors of safety for the new CCR surface impoundment achieve the minimum safety factors specified in § 257.74(e)(1)(i) through (v), the owner or operator of the CCR surface impoundment must cease placing CCR and non-CCR wastestreams into such CCR unit and close the CCR unit in accordance with the requirements of § 257.102.

(2) An owner or operator of an new CCR surface impoundment that closes in accordance with paragraph (c)(1) of this section must include a statement in the notification required under § 257.102(g) that the CCR surface impoundment is closing under the requirements of paragraph (c)(1) of this section.

(d) The owner or operator of an existing CCR landfill is subject to the requirements of paragraph (d)(1) of this section.

(1) Except as provided by paragraph (d)(3) of this section, within six months of determining that an existing CCR landfill has not demonstrated compliance with the location restriction for unstable areas specified in § 257.64(a), the owner or operator of the CCR unit must cease placing CCR and non-CCR waste streams into such CCR landfill and close the CCR unit in accordance with the requirements of § 257.102.

(2) An owner or operator of an existing CCR landfill that closes in accordance with paragraph (d)(1) of this section must include a statement in the notification required under § 257.102(g) that the CCR landfill is closing under the requirements of paragraph (d)(1) of this section.

(3) The timeframe specified in paragraph (d)(1) of this section does not apply if the owner or operator complies with the alternative closure procedures specified in § 257.103.

§ 257.102 Criteria for conducting the closure or retrofit of CCR units.

(a) Closure of a CCR landfill, CCR surface impoundment, or any lateral expansion of a CCR unit must be completed either by leaving the CCR in place and installing a final cover system or through removal of the CCR and decontamination of the CCR unit, as described in paragraphs (b) through (j) of this section. Retrofit of a CCR surface impoundment must be completed in accordance with the requirements in paragraph (k) of this section.

(b) *Written closure plan*—(1) *Content of the plan.* The owner or operator of a CCR unit must prepare a written closure plan that describes the steps necessary to close the CCR unit at any point during the active life of the CCR unit consistent with recognized and generally accepted good engineering practices. The written closure plan must include, at a minimum, the information specified in paragraphs (b)(1)(i) through (vi) of this section.

(i) A narrative description of how the CCR unit will be closed in accordance with this section.

(ii) If closure of the CCR unit will be accomplished through removal of CCR from the CCR unit, a description of the procedures to remove the CCR and decontaminate the CCR unit in accordance with paragraph (c) of this section.

(iii) If closure of the CCR unit will be accomplished by leaving CCR in place, a description of the final cover system, designed in accordance with paragraph (d) of this section, and the methods and procedures to be used to install the final cover. The closure plan must also discuss how the final cover system will achieve the performance standards specified in paragraph (d) of this section.

(iv) An estimate of the maximum inventory of CCR ever on-site over the active life of the CCR unit.

(v) An estimate of the largest area of the CCR unit ever requiring a final cover as required by paragraph (d) of this section at any time during the CCR unit's active life.

(vi) A schedule for completing all activities necessary to satisfy the closure criteria in this section, including an estimate of the year in which all closure activities for the CCR unit will be completed. The schedule should provide sufficient information to describe the sequential steps that will be taken to close the CCR unit, including identification of major milestones such as coordinating with and obtaining necessary approvals and permits from other agencies, the dewatering and stabilization phases of CCR surface impoundment closure, or installation of the final cover system, and the estimated timeframes to complete each step or phase of CCR unit closure. When preparing the written closure plan, if the owner or operator of a CCR unit estimates that the time required to complete closure will exceed the timeframes specified in paragraph (f)(1) of this section, the written closure plan must include the site-specific information, factors and considerations that would support any time extension sought under paragraph (f)(2) of this section.

(2) *Timeframes for preparing the initial written closure plan*—(i) *Existing CCR landfills and existing CCR surface impoundments.* No later than October 17, 2016, the owner or operator of the CCR unit must prepare an initial written closure plan consistent with the requirements specified in paragraph (b)(1) of this section.

(ii) *New CCR landfills and new CCR surface impoundments, and any lateral expansion of a CCR unit.* No later than the date of the initial receipt of CCR in the CCR unit, the owner or operator must prepare an initial written closure plan consistent with the requirements specified in paragraph (b)(1) of this section.

(iii) The owner or operator has completed the written closure plan when the plan, including the certification required by paragraph (b)(4) of this section, has been placed in the facility's operating record as required by § 257.105(i)(4).

(3) *Amendment of a written closure plan.* (i) The owner or operator may amend the initial or any subsequent written closure plan developed pursuant to paragraph (b)(1) of this section at any time.

(ii) The owner or operator must amend the written closure plan whenever:

(A) There is a change in the operation of the CCR unit that would substantially affect the written closure plan in effect; or

(B) Before or after closure activities have commenced, unanticipated events necessitate a revision of the written closure plan.

(iii) The owner or operator must amend the closure plan at least 60 days prior to a planned change in the operation of the facility or CCR unit, or no later than 60 days after an unanticipated event requires the need to revise an existing written closure plan. If a written closure plan is revised after closure activities have commenced for a CCR unit, the owner or operator must amend the current closure plan no later than 30 days following the triggering event.

(4) The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the initial and any amendment of

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the written closure plan meets the requirements of this section.

(c) *Closure by removal of CCR.* An owner or operator may elect to close a CCR unit by removing and decontaminating all areas affected by releases from the CCR unit. CCR removal and decontamination of the CCR unit are complete when constituent concentrations throughout the CCR unit and any areas affected by releases from the CCR unit have been removed and groundwater monitoring concentrations do not exceed the groundwater protection standard established pursuant to § 257.95(h) for constituents listed in appendix IV to this part.

(d) *Closure performance standard when leaving CCR in place*—(1) The owner or operator of a CCR unit must ensure that, at a minimum, the CCR unit is closed in a manner that will:

(i) Control, minimize or eliminate, to the maximum extent feasible, post-closure infiltration of liquids into the waste and releases of CCR, leachate, or contaminated run-off to the ground or surface waters or to the atmosphere;

(ii) Preclude the probability of future impoundment of water, sediment, or slurry;

(iii) Include measures that provide for major slope stability to prevent the sloughing or movement of the final cover system during the closure and post-closure care period;

(iv) Minimize the need for further maintenance of the CCR unit; and

(v) Be completed in the shortest amount of time consistent with recognized and generally accepted good engineering practices.

(2) *Drainage and stabilization of CCR surface impoundments.* The owner or operator of a CCR surface impoundment or any lateral expansion of a CCR surface impoundment must meet the requirements of paragraphs (d)(2)(i) and (ii) of this section prior to installing the final cover system required under paragraph (d)(3) of this section.

(i) Free liquids must be eliminated by removing liquid wastes or solidifying the remaining wastes and waste residues.

(ii) Remaining wastes must be stabilized sufficient to support the final cover system.

(3) *Final cover system.* If a CCR unit is closed by leaving CCR in place, the owner or operator must install a final cover system that is designed to minimize infiltration and erosion, and at a minimum, meets the requirements of paragraph (d)(3)(i) of this section, or the requirements of the alternative final cover system specified in paragraph (d)(3)(ii) of this section.

(i) The final cover system must be designed and constructed to meet the criteria in paragraphs (d)(3)(i)(A) through (D) of this section. The design of the final cover system must be included in the written closure plan required by paragraph (b) of this section.

(A) The permeability of the final cover system must be less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1×10^{-5} cm/sec, whichever is less.

(B) The infiltration of liquids through the closed CCR unit must be minimized by the use of an infiltration layer that contains a minimum of 18 inches of earthen material.

(C) The erosion of the final cover system must be minimized by the use of an erosion layer that contains a minimum of six inches of earthen material that is capable of sustaining native plant growth.

(D) The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

(ii) The owner or operator may select an alternative final cover system design, provided the alternative final cover system is designed and constructed to meet the criteria in paragraphs (f)(3)(ii)(A) through (D) of this section. The design of the final cover system must be included in the written closure plan required by paragraph (b) of this section.

(A) The design of the final cover system must include an infiltration layer that achieves an equivalent reduction in infiltration as the infiltration layer specified in paragraphs (d)(3)(i)(A) and (B) of this section.

(B) The design of the final cover system must include an erosion layer that provides equivalent protection from wind or water erosion as the erosion layer specified in paragraph (d)(3)(i)(C) of this section.

(C) The disruption of the integrity of the final cover system must be minimized through a design that accommodates settling and subsidence.

(iii) The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the design of the final cover system meets the requirements of this section.

(e) *Initiation of closure activities.* Except as provided for in paragraph (e)(4) of this section and § 257.103, the owner or operator of a CCR unit must commence closure of the CCR unit no later than the applicable timeframes specified in either paragraph (e)(1) or (2) of this section.

(1) The owner or operator must commence closure of the CCR unit no later than 30 days after the date on which the CCR unit either:

(i) Receives the known final receipt of waste, either CCR or any non-CCR waste stream; or

(ii) Removes the known final volume of CCR from the CCR unit for the purpose of beneficial use of CCR.

(2)(i) Except as provided by paragraph (e)(2)(ii) of this section, the owner or operator must commence closure of a CCR unit that has not received CCR or any non-CCR waste stream or is no longer removing CCR for the purpose of beneficial use within two years of the last receipt of waste or within two years of the last removal of CCR material for the purpose of beneficial use.

(ii) Notwithstanding paragraph (e)(2)(i) of this section, the owner or operator of the CCR unit may secure an additional two years to initiate closure of the idle unit provided the owner or operator provides written documentation that the CCR unit will continue to accept wastes or will start removing CCR for the purpose of beneficial use. The documentation must be supported by, at a minimum, the information specified in paragraphs (e)(2)(ii)(A) and (B) of this section. The owner or operator may obtain two-year extensions provided the owner or operator continues to be able to demonstrate that there is reasonable likelihood that the CCR unit will accept wastes in the foreseeable future or will remove CCR from the unit for the purpose of beneficial use. The owner or operator must place each completed demonstration, if more than one time extension is sought, in the facility's operating record as required by § 257.105(i)(5) prior to the end of any two-year period.

(A) Information documenting that the CCR unit has remaining storage or disposal capacity or that the CCR unit can have CCR removed for the purpose of beneficial use; and

(B) Information demonstrating that that there is a reasonable likelihood that the CCR unit will resume receiving CCR or non-CCR waste streams in the foreseeable future or that CCR can be removed for the purpose of beneficial use. The narrative must include a best estimate as to when the CCR unit will resume receiving CCR or non-CCR waste streams. The situations listed in paragraphs (e)(2)(ii)(B)(*1*) through (*4*) of this section are examples of situations that would support a determination that the CCR unit will resume receiving CCR or non-CCR waste streams in the foreseeable future.

(*1*) Normal plant operations include periods during which the CCR unit does not receive CCR or non-CCR waste

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streams, such as the alternating use of two or more CCR units whereby at any point in time one CCR unit is receiving CCR while CCR is being removed from a second CCR unit after its dewatering.

(*2*) The CCR unit is dedicated to a coal-fired boiler unit that is temporarily idled (*e.g.,* CCR is not being generated) and there is a reasonable likelihood that the coal-fired boiler will resume operations in the future.

(*3*) The CCR unit is dedicated to an operating coal-fired boiler (*i.e.,* CCR is being generated); however, no CCR are being placed in the CCR unit because the CCR are being entirely diverted to beneficial uses, but there is a reasonable likelihood that the CCR unit will again be used in the foreseeable future.

(*4*) The CCR unit currently receives only non-CCR waste streams and those non-CCR waste streams are not generated for an extended period of time, but there is a reasonable likelihood that the CCR unit will again receive non-CCR waste streams in the future.

(iii) In order to obtain additional time extension(s) to initiate closure of a CCR unit beyond the two years provided by paragraph (e)(2)(i) of this section, the owner or operator of the CCR unit must include with the demonstration required by paragraph (e)(2)(ii) of this section the following statement signed by the owner or operator or an authorized representative:

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this demonstration and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

(3) For purposes of this subpart, closure of the CCR unit has commenced if the owner or operator has ceased placing waste and completes any of the following actions or activities:

(i) Taken any steps necessary to implement the written closure plan required by paragraph (b) of this section;

(ii) Submitted a completed application for any required state or agency permit or permit modification; or

(iii) Taken any steps necessary to comply with any state or other agency standards that are a prerequisite, or are otherwise applicable, to initiating or completing the closure of a CCR unit.

(4) The timeframes specified in paragraphs (e)(1) and (2) of this section do not apply to any of the following owners or operators:

(i) An owner or operator of an inactive CCR surface impoundment closing the CCR unit as required by § 257.100(b);

(ii) An owner or operator of an existing unlined CCR surface impoundment closing the CCR unit as required by § 257.101(a);

(iii) An owner or operator of an existing CCR surface impoundment closing the CCR unit as required by § 257.101(b);

(iv) An owner or operator of a new CCR surface impoundment closing the CCR unit as required by § 257.101(c); or

(v) An owner or operator of an existing CCR landfill closing the CCR unit as required by § 257.101(d).

(f) *Completion of closure activities.* (1) Except as provided for in paragraph (f)(2) of this section, the owner or operator must complete closure of the CCR unit:

(i) For existing and new CCR landfills and any lateral expansion of a CCR landfill, within six months of commencing closure activities.

(ii) For existing and new CCR surface impoundments and any lateral expansion of a CCR surface impoundment, within five years of commencing closure activities.

(2)(i) *Extensions of closure timeframes.* The timeframes for completing closure of a CCR unit specified under paragraphs (f)(1) of this section may be extended if the owner or operator can demonstrate that it was not feasible to complete closure of the CCR unit within the required timeframes due to factors beyond the facility's control. If the owner or operator is seeking a time extension beyond the time specified in the written closure plan as required by paragraph (b)(1) of this section, the demonstration must include a narrative discussion providing the basis for additional time beyond that specified in the closure plan. The owner or operator must place each completed demonstration, if more than one time extension is sought, in the facility's operating record as required by § 257.105(i)(6) prior to the end of any two-year period. Factors that may support such a demonstration include:

(A) Complications stemming from the climate and weather, such as unusual amounts of precipitation or a significantly shortened construction season;

(B) Time required to dewater a surface impoundment due to the volume of CCR contained in the CCR unit or the characteristics of the CCR in the unit;

(C) The geology and terrain surrounding the CCR unit will affect the amount of material needed to close the CCR unit; or

(D) Time required or delays caused by the need to coordinate with and obtain necessary approvals and permits from a state or other agency.

(ii) *Maximum time extensions.* (A) CCR surface impoundments of 40 acres or smaller may extend the time to complete closure by no longer than two years.

(B) CCR surface impoundments larger than 40 acres may extend the timeframe to complete closure of the CCR unit multiple times, in two-year increments. For each two-year extension sought, the owner or operator must substantiate the factual circumstances demonstrating the need for the extension. No more than a total of five two-year extensions may be obtained for any CCR surface impoundment.

(C) CCR landfills may extend the timeframe to complete closure of the CCR unit multiple times, in one-year increments. For each one-year extension sought, the owner or operator must substantiate the factual circumstances demonstrating the need for the extension. No more than a total of two one-year extensions may be obtained for any CCR landfill.

(iii) In order to obtain additional time extension(s) to complete closure of a CCR unit beyond the times provided by paragraph (f)(1) of this section, the owner or operator of the CCR unit must include with the demonstration required by paragraph (f)(2)(i) of this section the following statement signed by the owner or operator or an authorized representative:

I certify under penalty of law that I have personally examined and am familiar with the information submitted in this demonstration and all attached documents, and that, based on my inquiry of those individuals immediately responsible for obtaining the information, I believe that the submitted information is true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment.

(3) Upon completion, the owner or operator of the CCR unit must obtain a certification from a qualified professional engineer verifying that closure has been completed in accordance with the closure plan specified in paragraph (b) of this section and the requirements of this section.

(g) No later than the date the owner or operator initiates closure of a CCR unit, the owner or operator must prepare a notification of intent to close a CCR unit. The notification must include the certification by a qualified professional engineer for the design of the final cover system as required by § 257.102(d)(3)(iii), if applicable. The

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owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(i)(7).

(h) Within 30 days of completion of closure of the CCR unit, the owner or operator must prepare a notification of closure of a CCR unit. The notification must include the certification by a qualified professional engineer as required by § 257.102(f)(3). The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(i)(8).

(i) *Deed notations.* (1) Except as provided by paragraph (i)(4) of this section, following closure of a CCR unit, the owner or operator must record a notation on the deed to the property, or some other instrument that is normally examined during title search.

(2) The notation on the deed must in perpetuity notify any potential purchaser of the property that:

(i) The land has been used as a CCR unit; and

(ii) Its use is restricted under the post-closure care requirements as provided by § 257.104(d)(1)(iii).

(3) Within 30 days of recording a notation on the deed to the property, the owner or operator must prepare a notification stating that the notation has been recorded. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(i)(9).

(4) An owner or operator that closes a CCR unit in accordance with paragraph (c) of this section is not subject to the requirements of paragraphs (i)(1) through (3) of this section.

(j) The owner or operator of the CCR unit must comply with the closure recordkeeping requirements specified in § 257.105(i), the closure notification requirements specified in § 257.106(i), and the closure Internet requirements specified in § 257.107(i).

(k) *Criteria to retrofit an existing CCR surface impoundment.* (1) To retrofit an existing CCR surface impoundment, the owner or operator must:

(i) First remove all CCR, including any contaminated soils and sediments from the CCR unit; and

(ii) Comply with the requirements in § 257.72.

(iii) A CCR surface impoundment undergoing a retrofit remains subject to all other requirements of this subpart, including the requirement to conduct any necessary corrective action.

(2) *Written retrofit plan*—(i) *Content of the plan.* The owner or operator must prepare a written retrofit plan that describes the steps necessary to retrofit the CCR unit consistent with recognized and generally accepted good engineering practices. The written retrofit plan must include, at a minimum, all of the following information:

(A) A narrative description of the specific measures that will be taken to retrofit the CCR unit in accordance with this section.

(B) A description of the procedures to remove all CCR and contaminated soils and sediments from the CCR unit.

(C) An estimate of the maximum amount of CCR that will be removed as part of the retrofit operation.

(D) An estimate of the largest area of the CCR unit that will be affected by the retrofit operation.

(E) A schedule for completing all activities necessary to satisfy the retrofit criteria in this section, including an estimate of the year in which retrofit activities of the CCR unit will be completed.

(ii) *Timeframes for preparing the initial written retrofit plan.* (A) No later than 60 days prior to date of initiating retrofit activities, the owner or operator must prepare an initial written retrofit plan consistent with the requirements specified in paragraph (k)(2) of this section. For purposes of this subpart, initiation of retrofit activities has commenced if the owner or operator has ceased placing waste in the unit and completes any of the following actions or activities:

(*1*) Taken any steps necessary to implement the written retrofit plan;

(*2*) Submitted a completed application for any required state or agency permit or permit modification; or

(*3*) Taken any steps necessary to comply with any state or other agency standards that are a prerequisite, or are otherwise applicable, to initiating or completing the retrofit of a CCR unit.

(B) The owner or operator has completed the written retrofit plan when the plan, including the certification required by paragraph (k)(2)(iv) of this section, has been placed in the facility's operating record as required by § 257.105(j)(1).

(iii) *Amendment of a written retrofit plan.* (A) The owner or operator may amend the initial or any subsequent written retrofit plan at any time.

(B) The owner or operator must amend the written retrofit plan whenever:

(*1*) There is a change in the operation of the CCR unit that would substantially affect the written retrofit plan in effect; or

(*2*) Before or after retrofit activities have commenced, unanticipated events necessitate a revision of the written retrofit plan.

(C) The owner or operator must amend the retrofit plan at least 60 days prior to a planned change in the operation of the facility or CCR unit, or no later than 60 days after an unanticipated event requires the revision of an existing written retrofit plan. If a written retrofit plan is revised after retrofit activities have commenced for a CCR unit, the owner or operator must amend the current retrofit plan no later than 30 days following the triggering event.

(iv) The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the activities outlined in the written retrofit plan, including any amendment of the plan, meet the requirements of this section.

(3) *Deadline for completion of activities related to the retrofit of a CCR unit.* Any CCR surface impoundment that is being retrofitted must complete all retrofit activities within the same time frames and procedures specified for the closure of a CCR surface impoundment in § 257.102(f) or, where applicable, § 257.103.

(4) Upon completion, the owner or operator must obtain a certification from a qualified professional engineer verifying that the retrofit activities have been completed in accordance with the retrofit plan specified in paragraph (k)(2) of this section and the requirements of this section.

(5) No later than the date the owner or operator initiates the retrofit of a CCR unit, the owner or operator must prepare a notification of intent to retrofit a CCR unit. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(j)(5).

(6) Within 30 days of completing the retrofit activities specified in paragraph (k)(1) of this section, the owner or operator must prepare a notification of completion of retrofit activities. The notification must include the certification by a qualified professional engineer as required by paragraph (k)(4) of this section. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(j)(6).

(7) At any time after the initiation of a CCR unit retrofit, the owner or operator may cease the retrofit and initiate closure of the CCR unit in accordance with the requirements of § 257.102.

(8) The owner or operator of the CCR unit must comply with the retrofit recordkeeping requirements specified in

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§ 257.105(j), the retrofit notification requirements specified in § 257.106(j), and the retrofit Internet requirements specified in § 257.107(j).

§ 257.103 Alternative closure requirements.

The owner or operator of a CCR landfill, CCR surface impoundment, or any lateral expansion of a CCR unit that is subject to closure pursuant to § 257.101(a), (b)(1), or (d) may continue to receive CCR in the unit provided the owner or operator meets the requirements of either paragraph (a) or (b) of this section.

(a)(1) *No alternative CCR disposal capacity.* Notwithstanding the provisions of § 257.101(a), (b)(1), or (d), a CCR unit may continue to receive CCR if the owner or operator of the CCR unit certifies that the CCR must continue to be managed in that CCR unit due to the absence of alternative disposal capacity both on-site and off-site of the facility. To qualify under this paragraph (a)(1), the owner or operator of the CCR unit must document that all of the following conditions have been met:

(i) No alternative disposal capacity is available on-site or off-site. An increase in costs or the inconvenience of existing capacity is not sufficient to support qualification under this section;

(ii) The owner or operator has made, and continues to make, efforts to obtain additional capacity. Qualification under this subsection lasts only as long as no alternative capacity is available. Once alternative capacity is identified, the owner or operator must arrange to use such capacity as soon as feasible;

(iii) The owner or operator must remain in compliance with all other requirements of this subpart, including the requirement to conduct any necessary corrective action; and

(iv) The owner or operator must prepare an annual progress report documenting the continued lack of alternative capacity and the progress towards the development of alternative CCR disposal capacity.

(2) Once alternative capacity is available, the CCR unit must cease receiving CCR and initiate closure following the timeframes in § 257.102(e) and (f).

(3) If no alternative capacity is identified within five years after the initial certification, the CCR unit must cease receiving CCR and close in accordance with the timeframes in § 257.102(e) and (f).

(b)(1) *Permanent cessation of a coal-fired boiler(s) by a date certain.* Notwithstanding the provisions of § 257.101(a), (b)(1), and (d), a CCR unit may continue to receive CCR if the owner or operator certifies that the facility will cease operation of the coal-fired boilers within the timeframes specified in paragraphs (b)(2) through (4) of this section, but in the interim period (prior to closure of the coal-fired boiler), the facility must continue to use the CCR unit due to the absence of alternative disposal capacity both on-site and off-site of the facility. To qualify under this paragraph (b)(1), the owner or operator of the CCR unit must document that all of the following conditions have been met:

(i) No alternative disposal capacity is available on-site or off-site. An increase in costs or the inconvenience of existing capacity is not sufficient to support qualification under this section.

(ii) The owner or operator must remain in compliance with all other requirements of this subpart, including the requirement to conduct any necessary corrective action; and

(iii) The owner or operator must prepare an annual progress report documenting the continued lack of alternative capacity and the progress towards the closure of the coal-fired boiler.

(2) For a CCR surface impoundment that is 40 acres or smaller, the coal-fired boiler must cease operation and the CCR surface impoundment must have completed closure no later than October 17, 2023.

(3) For a CCR surface impoundment that is larger than 40 acres, the coal-fired boiler must cease operation, and the CCR surface impoundment must complete closure no later than October 17, 2028.

(4) For a CCR landfill, the coal-fired boiler must cease operation, and the CCR landfill must complete closure no later than April 19, 2021.

(c) Required notices and progress reports. An owner or operator of a CCR unit that closes in accordance with paragraphs (a) or (b) of this section must complete the notices and progress reports specified in paragraphs (c)(1) through (3) of this section.

(1) Within six months of becoming subject to closure pursuant to § 257.101(a), (b)(1), or (d), the owner or operator must prepare and place in the facility's operating record a notification of intent to comply with the alternative closure requirements of this section. The notification must describe why the CCR unit qualifies for the alternative closure provisions under either paragraph (a) or (b) of this section, in addition to providing the documentation and certifications required by paragraph (a) or (b) of this section.

(2) The owner or operator must prepare the periodic progress reports required by paragraphs (a)(1)(iv) or (b)(1)(iii), in addition to describing any problems encountered and a description of the actions taken to resolve the problems. The annual progress reports must be completed according to the following schedule:

(i) The first annual progress report must be prepared no later than 13 months after completing the notification of intent to comply with the alternative closure requirements required by paragraph (c)(1) of this section.

(ii) The second annual progress report must be prepared no later than 12 months after completing the first annual progress report. Additional annual progress reports must be prepared within 12 months of completing the previous annual progress report.

(iii) The owner or operator has completed the progress reports specified in paragraph (c)(2) of this section when the reports are placed in the facility's operating record as required by § 257.105(i)(10).

(3) An owner or operator of a CCR unit must also prepare the notification of intent to close a CCR unit as required by § 257.102(g).

(d) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(i), the notification requirements specified in § 257.106(i), and the Internet requirements specified in § 257.107(i).

§ 257.104 Post-closure care requirements.

(a) *Applicability.* (1) Except as provided by either paragraph (a)(2) or (3) of this section, § 257.104 applies to the owners or operators of CCR landfills, CCR surface impoundments, and all lateral expansions of CCR units that are subject to the closure criteria under § 257.102.

(2) An owner or operator of a CCR unit that elects to close a CCR unit by removing CCR as provided by § 257.102(c) is not subject to the post-closure care criteria under this section.

(3) An owner or operator of an inactive CCR surface impoundment that elects to close a CCR unit pursuant to the requirements under § 257.100(b) is not subject to the post-closure care criteria under this section.

(b) *Post-closure care maintenance requirements.* Following closure of the CCR unit, the owner or operator must conduct post-closure care for the CCR unit, which must consist of at least the following:

(1) Maintaining the integrity and effectiveness of the final cover system, including making repairs to the final

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cover as necessary to correct the effects of settlement, subsidence, erosion, or other events, and preventing run-on and run-off from eroding or otherwise damaging the final cover;

(2) If the CCR unit is subject to the design criteria under § 257.70, maintaining the integrity and effectiveness of the leachate collection and removal system and operating the leachate collection and removal system in accordance with the requirements of § 257.70; and

(3) Maintaining the groundwater monitoring system and monitoring the groundwater in accordance with the requirements of §§ 257.90 through 257.98.

(c) *Post-closure care period.* (1) Except as provided by paragraph (c)(2) of this section, the owner or operator of the CCR unit must conduct post-closure care for 30 years.

(2) If at the end of the post-closure care period the owner or operator of the CCR unit is operating under assessment monitoring in accordance with § 257.95, the owner or operator must continue to conduct post-closure care until the owner or operator returns to detection monitoring in accordance with § 257.95.

(d) *Written post-closure plan*—(1) *Content of the plan.* The owner or operator of a CCR unit must prepare a written post-closure plan that includes, at a minimum, the information specified in paragraphs (d)(1)(i) through (iii) of this section.

(i) A description of the monitoring and maintenance activities required in paragraph (b) of this section for the CCR unit, and the frequency at which these activities will be performed;

(ii) The name, address, telephone number, and email address of the person or office to contact about the facility during the post-closure care period; and

(iii) A description of the planned uses of the property during the post-closure period. Post-closure use of the property shall not disturb the integrity of the final cover, liner(s), or any other component of the containment system, or the function of the monitoring systems unless necessary to comply with the requirements in this subpart. Any other disturbance is allowed if the owner or operator of the CCR unit demonstrates that disturbance of the final cover, liner, or other component of the containment system, including any removal of CCR, will not increase the potential threat to human health or the environment. The demonstration must be certified by a qualified professional engineer, and notification shall be provided to the State Director that the demonstration has been placed in the operating record and on the owners or operator's publicly accessible Internet site.

(2) *Deadline to prepare the initial written post-closure plan*—(i) *Existing CCR landfills and existing CCR surface impoundments.* No later than October 17, 2016, the owner or operator of the CCR unit must prepare an initial written post-closure plan consistent with the requirements specified in paragraph (d)(1) of this section.

(ii) *New CCR landfills, new CCR surface impoundments, and any lateral expansion of a CCR unit.* No later than the date of the initial receipt of CCR in the CCR unit, the owner or operator must prepare an initial written post-closure plan consistent with the requirements specified in paragraph (d)(1) of this section.

(iii) The owner or operator has completed the written post-closure plan when the plan, including the certification required by paragraph (d)(4) of this section, has been placed in the facility's operating record as required by § 257.105(i)(4).

(3) *Amendment of a written post-closure plan.* (i) The owner or operator may amend the initial or any subsequent written post-closure plan developed pursuant to paragraph (d)(1) of this section at any time.

(ii) The owner or operator must amend the written closure plan whenever:

(A) There is a change in the operation of the CCR unit that would substantially affect the written post-closure plan in effect; or

(B) After post-closure activities have commenced, unanticipated events necessitate a revision of the written post-closure plan.

(iii) The owner or operator must amend the written post-closure plan at least 60 days prior to a planned change in the operation of the facility or CCR unit, or no later than 60 days after an unanticipated event requires the need to revise an existing written post-closure plan. If a written post-closure plan is revised after post-closure activities have commenced for a CCR unit, the owner or operator must amend the written post-closure plan no later than 30 days following the triggering event.

(4) The owner or operator of the CCR unit must obtain a written certification from a qualified professional engineer that the initial and any amendment of the written post-closure plan meets the requirements of this section.

(e) *Notification of completion of post-closure care period.* No later than 60 days following the completion of the post-closure care period, the owner or operator of the CCR unit must prepare a notification verifying that post-closure care has been completed. The notification must include the certification by a qualified professional engineer verifying that post-closure care has been completed in accordance with the closure plan specified in paragraph (d) of this section and the requirements of this section. The owner or operator has completed the notification when it has been placed in the facility's operating record as required by § 257.105(i)(13).

(f) The owner or operator of the CCR unit must comply with the recordkeeping requirements specified in § 257.105(i), the notification requirements specified in § 257.106(i), and the Internet requirements specified in § 257.107(i).

Recordkeeping, Notification, and Posting of Information to the Internet

§ 257.105 Recordkeeping requirements.

(a) Each owner or operator of a CCR unit subject to the requirements of this subpart must maintain files of all information required by this section in a written operating record at their facility.

(b) Unless specified otherwise, each file must be retained for at least five years following the date of each occurrence, measurement, maintenance, corrective action, report, record, or study.

(c) An owner or operator of more than one CCR unit subject to the provisions of this subpart may comply with the requirements of this section in one recordkeeping system provided the system identifies each file by the name of each CCR unit. The files may be maintained on microfilm, on a computer, on computer disks, on a storage system accessible by a computer, on magnetic tape disks, or on microfiche.

(d) The owner or operator of a CCR unit must submit to the State Director and/or appropriate Tribal authority any demonstration or documentation required by this subpart, if requested, when such information is not otherwise available on the owner or operator's publicly accessible Internet site.

(e) *Location restrictions.* The owner or operator of a CCR unit subject to this subpart must place the demonstrations documenting whether or not the CCR unit is in compliance with the requirements under §§ 257.60(a), 257.61(a), 257.62(a), 257.63(a), and 257.64(a), as it becomes available, in the facility's operating record.

(f) *Design criteria.* The owner or operator of a CCR unit subject to this subpart must place the following

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information, as it becomes available, in the facility's operating record:

(1) The design and construction certifications as required by § 257.70(e) and (f).

(2) The documentation of liner type as required by § 257.71(a).

(3) The design and construction certifications as required by § 257.72(c) and (d).

(4) Documentation prepared by the owner or operator stating that the permanent identification marker was installed as required by §§ 257.73(a)(1) and 257.74(a)(1).

(5) The initial and periodic hazard potential classification assessments as required by §§ 257.73(a)(2) and 257.74(a)(2).

(6) The emergency action plan (EAP), and any amendment of the EAP, as required by §§ 257.73(a)(3) and 257.74(a)(3), except that only the most recent EAP must be maintained in the facility's operating record irrespective of the time requirement specified in paragraph (b) of this section.

(7) Documentation prepared by the owner or operator recording the annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders as required by §§ 257.73(a)(3)(i)(E) and 257.74(a)(3)(i)(E).

(8) Documentation prepared by the owner or operator recording all activations of the emergency action plan as required by §§ 257.73(a)(3)(v) and 257.74(a)(3)(v).

(9) The history of construction, and any revisions of it, as required by § 257.73(c), except that these files must be maintained until the CCR unit completes closure of the unit in accordance with § 257.102.

(10) The initial and periodic structural stability assessments as required by §§ 257.73(d) and 257.74(d).

(11) Documentation detailing the corrective measures taken to remedy the deficiency or release as required by §§ 257.73(d)(2) and 257.74(d)(2).

(12) The initial and periodic safety factor assessments as required by §§ 257.73(e) and 257.74(e).

(13) The design and construction plans, and any revisions of it, as required by § 257.74(c), except that these files must be maintained until the CCR unit completes closure of the unit in accordance with § 257.102.

(g) *Operating criteria.* The owner or operator of a CCR unit subject to this subpart must place the following information, as it becomes available, in the facility's operating record:

(1) The CCR fugitive dust control plan, and any subsequent amendment of the plan, required by § 257.80(b), except that only the most recent control plan must be maintained in the facility's operating record irrespective of the time requirement specified in paragraph (b) of this section.

(2) The annual CCR fugitive dust control report required by § 257.80(c).

(3) The initial and periodic run-on and run-off control system plans as required by § 257.81(c).

(4) The initial and periodic inflow design flood control system plan as required by § 257.82(c).

(5) Documentation recording the results of each inspection and instrumentation monitoring by a qualified person as required by § 257.83(a).

(6) The periodic inspection report as required by § 257.83(b)(2).

(7) Documentation detailing the corrective measures taken to remedy the deficiency or release as required by §§ 257.83(b)(5) and 257.84(b)(5).

(8) Documentation recording the results of the weekly inspection by a qualified person as required by § 257.84(a).

(9) The periodic inspection report as required by § 257.84(b)(2).

(h) *Groundwater monitoring and corrective action.* The owner or operator of a CCR unit subject to this subpart must place the following information, as it becomes available, in the facility's operating record:

(1) The annual groundwater monitoring and corrective action report as required by § 257.90(e).

(2) Documentation of the design, installation, development, and decommissioning of any monitoring wells, piezometers and other measurement, sampling, and analytical devices as required by § 257.91(e)(1).

(3) The groundwater monitoring system certification as required by § 257.91(f).

(4) The selection of a statistical method certification as required by § 257.93(f)(6).

(5) Within 30 days of establishing an assessment monitoring program, the notification as required by § 257.94(e)(3).

(6) The results of appendices III and IV to this part constituent concentrations as required by § 257.95(d)(1).

(7) Within 30 days of returning to a detection monitoring program, the notification as required by § 257.95(e).

(8) Within 30 days of detecting one or more constituents in appendix IV to this part at statistically significant levels above the groundwater protection standard, the notifications as required by § 257.95(g).

(9) Within 30 days of initiating the assessment of corrective measures requirements, the notification as required by § 257.95(g)(5).

(10) The completed assessment of corrective measures as required by § 257.96(d).

(11) Documentation prepared by the owner or operator recording the public meeting for the corrective measures assessment as required by § 257.96(e).

(12) The semiannual report describing the progress in selecting and designing the remedy and the selection of remedy report as required by § 257.97(a), except that the selection of remedy report must be maintained until the remedy has been completed.

(13) Within 30 days of completing the remedy, the notification as required by § 257.98(e).

(i) *Closure and post-closure care.* The owner or operator of a CCR unit subject to this subpart must place the following information, as it becomes available, in the facility's operating record:

(1) The notification of intent to initiate closure of the CCR unit as required by § 257.100(c)(1).

(2) The annual progress reports of closure implementation as required by § 257.100(c)(2)(i) and (ii).

(3) The notification of closure completion as required by § 257.100(c)(3).

(4) The written closure plan, and any amendment of the plan, as required by § 257.102(b), except that only the most recent closure plan must be maintained in the facility's operating record irrespective of the time requirement specified in paragraph (b) of this section.

(5) The written demonstration(s), including the certification required by § 257.102(e)(2)(iii), for a time extension for initiating closure as required by § 257.102(e)(2)(ii).

(6) The written demonstration(s), including the certification required by § 257.102(f)(2)(iii), for a time extension for completing closure as required by § 257.102(f)(2)(i).

(7) The notification of intent to close a CCR unit as required by § 257.102(g).

(8) The notification of completion of closure of a CCR unit as required by § 257.102(h).

(9) The notification recording a notation on the deed as required by § 257.102(i).

(10) The notification of intent to comply with the alternative closure requirements as required by § 257.103(c)(1).

(11) The annual progress reports under the alternative closure requirements as required by § 257.103(c)(2).

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(12) The written post-closure plan, and any amendment of the plan, as required by § 257.104(d), except that only the most recent closure plan must be maintained in the facility's operating record irrespective of the time requirement specified in paragraph (b) of this section.

(13) The notification of completion of post-closure care period as required by § 257.104(e).

(j) *Retrofit criteria.* The owner or operator of a CCR unit subject to this subpart must place the following information, as it becomes available, in the facility's operating record:

(1) The written retrofit plan, and any amendment of the plan, as required by § 257.102(k)(2), except that only the most recent retrofit plan must be maintained in the facility's operating record irrespective of the time requirement specified in paragraph (b) of this section.

(2) The notification of intent that the retrofit activities will proceed in accordance with the alternative procedures in § 257.103.

(3) The annual progress reports required under the alternative requirements as required by § 257.103.

(4) The written demonstration(s), including the certification in § 257.102(f)(2)(iii), for a time extension for completing retrofit activities as required by § 257.102(k)(3).

(5) The notification of intent to initiate retrofit of a CCR unit as required by § 257.102(k)(5).

(6) The notification of completion of retrofit activities as required by § 257.102(k)(6).

§ 257.106 Notification requirements.

(a) The notifications required under paragraphs (e) through (i) of this section must be sent to the relevant State Director and/or appropriate Tribal authority before the close of business on the day the notification is required to be completed. For purposes of this section, *before the close of business* means the notification must be postmarked or sent by electronic mail (email). If a notification deadline falls on a weekend or federal holiday, the notification deadline is automatically extended to the next business day.

(b) If any CCR unit is located in its entirety within Indian Country, the notifications of this section must be sent to the appropriate Tribal authority. If any CCR unit is located in part within Indian Country, the notifications of this section must be sent both to the appropriate State Director and Tribal authority.

(c) Notifications may be combined as long as the deadline requirement for each notification is met.

(d) Unless otherwise required in this section, the notifications specified in this section must be sent to the State Director and/or appropriate Tribal authority within 30 days of placing in the operating record the information required by § 257.105.

(e) *Location restrictions.* The owner or operator of a CCR unit subject to the requirements of this subpart must notify the State Director and/or appropriate Tribal authority that each demonstration specified under § 257.105(e) has been placed in the operating record and on the owner or operator's publicly accessible internet site.

(f) *Design criteria.* The owner or operator of a CCR unit subject to this subpart must notify the State Director and/or appropriate Tribal authority when information has been placed in the operating record and on the owner or operator's publicly accessible internet site. The owner or operator must:

(1) Within 60 days of commencing construction of a new CCR unit, provide notification of the availability of the design certification specified under § 257.105(f)(1) or (3). If the owner or operator of the CCR unit elects to install an alternative composite liner, the owner or operator must also submit to the State Director and/or appropriate Tribal authority a copy of the alternative composite liner design.

(2) No later than the date of initial receipt of CCR by a new CCR unit, provide notification of the availability of the construction certification specified under § 257.105(f)(1) or (3).

(3) Provide notification of the availability of the documentation of liner type specified under § 257.105(f)(2).

(4) Provide notification of the availability of the initial and periodic hazard potential classification assessments specified under § 257.105(f)(5).

(5) Provide notification of the availability of emergency action plan (EAP), and any revisions of the EAP, specified under § 257.105(f)(6).

(6) Provide notification of the availability of documentation prepared by the owner or operator recording the annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders specified under § 257.105(f)(7).

(7) Provide notification of documentation prepared by the owner or operator recording all activations of the emergency action plan specified under § 257.105(f)(8).

(8) Provide notification of the availability of the history of construction, and any revision of it, specified under § 257.105(f)(9).

(9) Provide notification of the availability of the initial and periodic structural stability assessments specified under § 257.105(f)(10).

(10) Provide notification of the availability of the documentation detailing the corrective measures taken to remedy the deficiency or release specified under § 257.105(f)(11).

(11) Provide notification of the availability of the initial and periodic safety factor assessments specified under § 257.105(f)(12).

(12) Provide notification of the availability of the design and construction plans, and any revision of them, specified under § 257.105(f)(13).

(g) *Operating criteria.* The owner or operator of a CCR unit subject to this subpart must notify the State Director and/or appropriate Tribal authority when information has been placed in the operating record and on the owner or operator's publicly accessible internet site. The owner or operator must:

(1) Provide notification of the availability of the CCR fugitive dust control plan, or any subsequent amendment of the plan, specified under § 257.105(g)(1).

(2) Provide notification of the availability of the annual CCR fugitive dust control report specified under § 257.105(g)(2).

(3) Provide notification of the availability of the initial and periodic run-on and run-off control system plans specified under § 257.105(g)(3).

(4) Provide notification of the availability of the initial and periodic inflow design flood control system plans specified under § 257.105(g)(4).

(5) Provide notification of the availability of the periodic inspection reports specified under § 257.105(g)(6).

(6) Provide notification of the availability of the documentation detailing the corrective measures taken to remedy the deficiency or release specified under § 257.105(g)(7).

(7) Provide notification of the availability of the periodic inspection reports specified under § 257.105(g)(9).

(h) *Groundwater monitoring and corrective action.* The owner or operator of a CCR unit subject to this subpart must notify the State Director and/or appropriate Tribal authority when information has been placed in the operating record and on the owner or operator's publicly accessible internet site. The owner or operator must:

(1) Provide notification of the availability of the annual groundwater

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monitoring and corrective action report specified under § 257.105(h)(1).

(2) Provide notification of the availability of the groundwater monitoring system certification specified under § 257.105(h)(3).

(3) Provide notification of the availability of the selection of a statistical method certification specified under § 257.105(h)(4).

(4) Provide notification that an assessment monitoring programs has been established specified under § 257.105(h)(5).

(5) Provide notification that the CCR unit is returning to a detection monitoring program specified under § 257.105(h)(7).

(6) Provide notification that one or more constituents in appendix IV to this part have been detected at statistically significant levels above the groundwater protection standard and the notifications to land owners specified under § 257.105(h)(8).

(7) Provide notification that an assessment of corrective measures has been initiated specified under § 257.105(h)(9).

(8) Provide notification of the availability of assessment of corrective measures specified under § 257.105(h)(10).

(9) Provide notification of the availability of the semiannual report describing the progress in selecting and designing the remedy and the selection of remedy report specified under § 257.105(h)(12).

(10) Provide notification of the completion of the remedy specified under § 257.105(h)(13).

(i) *Closure and post-closure care.* The owner or operator of a CCR unit subject to this subpart must notify the State Director and/or appropriate Tribal authority when information has been placed in the operating record and on the owner or operator's publicly accessible Internet site. The owner or operator must:

(1) Provide notification of the intent to initiate closure of the CCR unit specified under § 257.105(i)(1).

(2) Provide notification of the availability of the annual progress reports of closure implementation specified under § 257.105(i)(2).

(3) Provide notification of closure completion specified under § 257.105(i)(3).

(4) Provide notification of the availability of the written closure plan, and any amendment of the plan, specified under § 257.105(i)(4).

(5) Provide notification of the availability of the demonstration(s) for a time extension for initiating closure specified under § 257.105(i)(5).

(6) Provide notification of the availability of the demonstration(s) for a time extension for completing closure specified under § 257.105(i)(6).

(7) Provide notification of intent to close a CCR unit specified under § 257.105(i)(7).

(8) Provide notification of completion of closure of a CCR unit specified under § 257.105(i)(8).

(9) Provide notification of the deed notation as required by § 257.105(i)(9).

(10) Provide notification of intent to comply with the alternative closure requirements specified under § 257.105(i)(10).

(11) The annual progress reports under the alternative closure requirements as required by § 257.105(i)(11).

(12) Provide notification of the availability of the written post-closure plan, and any amendment of the plan, specified under § 257.105(i)(12).

(13) Provide notification of completion of post-closure care specified under § 257.105(i)(13).

(j) *Retrofit criteria.* The owner or operator of a CCR unit subject to this subpart must notify the State Director and/or appropriate Tribal authority when information has been placed in the operating record and on the owner or operator's publicly accessible Internet site. The owner or operator must:

(1) Provide notification of the availability of the written retrofit plan, and any amendment of the plan, specified under § 257.105(j)(1).

(2) Provide notification of intent to comply with the alternative retrofit requirements specified under § 257.105(j)(2).

(3) The annual progress reports under the alternative retrofit requirements as required by § 257.105(j)(3).

(4) Provide notification of the availability of the demonstration(s) for a time extension for completing retrofit activities specified under § 257.105(j)(4).

(5) Provide notification of intent to initiate retrofit of a CCR unit specified under § 257.105(j)(5).

(6) Provide notification of completion of retrofit activities specified under § 257.105(j)(6).

§ 257.107 Publicly accessible Internet site requirements.

(a) Each owner or operator of a CCR unit subject to the requirements of this subpart must maintain a publicly accessible Internet site (CCR Web site) containing the information specified in this section. The owner or operator's Web site must be titled ''CCR Rule Compliance Data and Information.''

(b) An owner or operator of more than one CCR unit subject to the provisions of this subpart may comply with the requirements of this section by using the same Internet site for multiple CCR units provided the CCR Web site clearly delineates information by the name or identification number of each unit.

(c) Unless otherwise required in this section, the information required to be posted to the CCR Web site must be made available to the public for at least five years following the date on which the information was first posted to the CCR Web site.

(d) Unless otherwise required in this section, the information must be posted to the CCR Web site within 30 days of placing the pertinent information required by § 257.105 in the operating record.

(e) *Location restrictions.* The owner or operator of a CCR unit subject to this subpart must place each demonstration specified under § 257.105(e) on the owner or operator's CCR Web site.

(f) *Design criteria.* The owner or operator of a CCR unit subject to this subpart must place the following information on the owner or operator's CCR Web site:

(1) Within 60 days of commencing construction of a new unit, the design certification specified under § 257.105(f)(1) or (3).

(2) No later than the date of initial receipt of CCR by a new CCR unit, the construction certification specified under § 257.105(f)(1) or (3).

(3) The documentation of liner type specified under § 257.105(f)(2).

(4) The initial and periodic hazard potential classification assessments specified under § 257.105(f)(5).

(5) The emergency action plan (EAP) specified under § 257.105(f)(6), except that only the most recent EAP must be maintained on the CCR Web site irrespective of the time requirement specified in paragraph (c) of this section.

(6) Documentation prepared by the owner or operator recording the annual face-to-face meeting or exercise between representatives of the owner or operator of the CCR unit and the local emergency responders specified under § 257.105(f)(7).

(7) Documentation prepared by the owner or operator recording any activation of the emergency action plan specified under § 257.105(f)(8).

(8) The history of construction, and any revisions of it, specified under § 257.105(f)(9).

(9) The initial and periodic structural stability assessments specified under § 257.105(f)(10).

(10) The documentation detailing the corrective measures taken to remedy the

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deficiency or release specified under § 257.105(f)(11).

(11) The initial and periodic safety factor assessments specified under § 257.105(f)(12).

(12) The design and construction plans, and any revisions of them, specified under § 257.105(f)(13).

(g) *Operating criteria.* The owner or operator of a CCR unit subject to this subpart must place the following information on the owner or operator's CCR Web site:

(1) The CCR fugitive dust control plan, or any subsequent amendment of the plan, specified under § 257.105(g)(1) except that only the most recent plan must be maintained on the CCR Web site irrespective of the time requirement specified in paragraph (c) of this section.

(2) The annual CCR fugitive dust control report specified under § 257.105(g)(2).

(3) The initial and periodic run-on and run-off control system plans specified under § 257.105(g)(3).

(4) The initial and periodic inflow design flood control system plans specified under § 257.105(g)(4).

(5) The periodic inspection reports specified under § 257.105(g)(6).

(6) The documentation detailing the corrective measures taken to remedy the deficiency or release specified under § 257.105(g)(7).

(7) The periodic inspection reports specified under § 257.105(g)(9).

(h) *Groundwater monitoring and corrective action.* The owner or operator of a CCR unit subject to this subpart must place the following information on the owner or operator's CCR Web site:

(1) The annual groundwater monitoring and corrective action report specified under § 257.105(h)(1).

(2) The groundwater monitoring system certification specified under § 257.105(h)(3).

(3) The selection of a statistical method certification specified under § 257.105(h)(4).

(4) The notification that an assessment monitoring programs has been established specified under § 257.105(h)(5).

(5) The notification that the CCR unit is returning to a detection monitoring program specified under § 257.105(h)(7).

(6) The notification that one or more constituents in appendix IV to this part have been detected at statistically significant levels above the groundwater protection standard and the notifications to land owners specified under § 257.105(h)(8).

(7) The notification that an assessment of corrective measures has been initiated specified under § 257.105(h)(9).

(8) The assessment of corrective measures specified under § 257.105(h)(10).

(9) The semiannual reports describing the progress in selecting and designing remedy and the selection of remedy report specified under § 257.105(h)(12), except that the selection of the remedy report must be maintained until the remedy has been completed.

(10) The notification that the remedy has been completed specified under § 257.105(h)(13).

(i) *Closure and post-closure care.* The owner or operator of a CCR unit subject to this subpart must place the following information on the owner or operator's CCR Web site:

(1) The notification of intent to initiate closure of the CCR unit specified under § 257.105(i)(1).

(2) The annual progress reports of closure implementation specified under § 257.105(i)(2).

(3) The notification of closure completion specified under § 257.105(i)(3).

(4) The written closure plan, and any amendment of the plan, specified under § 257.105(i)(4).

(5) The demonstration(s) for a time extension for initiating closure specified under § 257.105(i)(5).

(6) The demonstration(s) for a time extension for completing closure specified under § 257.105(i)(6).

(7) The notification of intent to close a CCR unit specified under § 257.105(i)(7).

(8) The notification of completion of closure of a CCR unit specified under § 257.105(i)(8).

(9) The notification recording a notation on the deed as required by § 257.105(i)(9).

(10) The notification of intent to comply with the alternative closure requirements as required by § 257.105(i)(10).

(11) The annual progress reports under the alternative closure requirements as required by § 257.105(i)(11).

(12) The written post-closure plan, and any amendment of the plan, specified under § 257.105(i)(12).

(13) The notification of completion of post-closure care specified under § 257.105(i)(13).

(j) *Retrofit criteria.* The owner or operator of a CCR unit subject to this subpart must place the following information on the owner or operator's CCR Web site:

(1) The written retrofit plan, and any amendment of the plan, specified under § 257.105(j)(1).

(2) The notification of intent to comply with the alternative retrofit requirements as required by § 257.105(j)(2).

(3) The annual progress reports under the alternative retrofit requirements as required by § 257.105(j)(3).

(4) The demonstration(s) for a time extension for completing retrofit activities specified under § 257.105(j)(4).

(5) The notification of intent to retrofit a CCR unit specified under § 257.105(j)(5).

(6) The notification of completion of retrofit activities specified under § 257.105(j)(6).

■ 5. Amend part 257 by adding ''Appendix III to Part 257'' and ''Appendix IV to Part 257'' to read as follows:

Appendix III to Part 257—Constituents for Detection Monitoring

Common name [1]
Boron
Calcium
Chloride
Fluoride
pH
Sulfate
Total Dissolved Solids (TDS)

[1] Common names are those widely used in government regulations, scientific publications, and commerce; synonyms exist for many chemicals.

Appendix IV to Part 257—Constituents for Assessment Monitoring

Common name [1]
Antimony
Arsenic
Barium
Beryllium
Cadmium
Chromium
Cobalt
Fluoride
Lead
Lithium
Mercury
Molybdenum
Selenium
Thallium
Radium 226 and 228 combined

[1] Common names are those widely used in government regulations, scientific publications, and commerce; synonyms exist for many chemicals.

PART 261—IDENTIFICATION AND LISTING OF HAZARDOUS WASTE

■ 6. The authority citation for part 261 continues to read as follows:

Authority: 42 U.S.C. 6905, 6912(a), 6921, 6922, 6924(y) and 6938.

■ 7. Section 261.4 is amended by revising paragraph (b)(4) to read as follows:

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§ 261.4 Exclusions.

* * * * *

(b) * * *

(4)(i) Fly ash waste, bottom ash waste, slag waste, and flue gas emission control waste generated primarily from the combustion of coal or other fossil fuels, except as provided by § 266.112 of this chapter for facilities that burn or process hazardous waste.

(ii) The following wastes generated primarily from processes that support the combustion of coal or other fossil fuels that are co-disposed with the wastes in paragraph (b)(4)(i) of this section, except as provided by § 266.112 of this chapter for facilities that burn or process hazardous waste:

(A) *Coal pile run-off.* For purposes of paragraph (b)(4) of this section, coal pile run-off means any precipitation that drains off coal piles.

(B) *Boiler cleaning solutions.* For purposes of paragraph (b)(4) of this section, boiler cleaning solutions means water solutions and chemical solutions used to clean the fire-side and water-side of the boiler.

(C) *Boiler blowdown.* For purposes of paragraph (b)(4) of this section, boiler blowdown means water purged from boilers used to generate steam.

(D) *Process water treatment and demineralizer regeneration wastes.* For purposes of paragraph (b)(4) of this section, process water treatment and demineralizer regeneration wastes means sludges, rinses, and spent resins generated from processes to remove dissolved gases, suspended solids, and dissolved chemical salts from combustion system process water.

(E) *Cooling tower blowdown.* For purposes of paragraph (b)(4) of this section, cooling tower blowdown means water purged from a closed cycle cooling system. Closed cycle cooling systems include cooling towers, cooling ponds, or spray canals.

(F) *Air heater and precipitator washes.* For purposes of paragraph (b)(4) of this section, air heater and precipitator washes means wastes from cleaning air preheaters and electrostatic precipitators.

(G) *Effluents from floor and yard drains and sumps.* For purposes of paragraph (b)(4) of this section, effluents from floor and yard drains and sumps means wastewaters, such as wash water, collected by or from floor drains, equipment drains, and sumps located inside the power plant building; and wastewaters, such as rain runoff, collected by yard drains and sumps located outside the power plant building.

(H) *Wastewater treatment sludges.* For purposes of paragraph (b)(4) of this section, wastewater treatment sludges refers to sludges generated from the treatment of wastewaters specified in paragraphs (b)(4)(ii)(A) through (F) of this section.

* * * * *

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Appendix 25

USEPA, Human and Ecological Risk Assessment of Coal Combustion Residuals, 2050-AE81 (December 2014) (Deposition Exhibit 17)

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HUMAN AND ECOLOGICAL RISK ASSESSMENT OF COAL COMBUSTION RESIDUALS

Final

December 2014

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Office of Resource Conservation and Recovery

Regulation Identifier Number: 2050-AE81

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AUTHORS AND REVIEWERS

The U.S. EPA Office of Solid Waste and Emergency Response, Office of Resource Conservation and Recovery was responsible for the preparation of this risk assessment. Jason Mills, Zubair Saleem and Taetaye Shimeles served as Work Assignment Managers for the current version of the document, providing overall direction and technical assistance, and is also a contributing author. Drafts of this document were prepared and edited by RTI International for EPA under contract number EP-W-09-004.

CONTRIBUTING AUTHORS

U.S. EPA

Richard Benware (Office of Solid Waste and Emergency Response)
Colette Hodes (Office of Solid Waste and Emergency Response)
Lee Hofmann (Office of Solid Waste and Emergency Response)
Jason Mills (Office of Solid Waste and Emergency Response)
Zubair Saleem (Office of Solid Waste and Emergency Response)
Taetaye Shimeles (Office of Solid Waste and Emergency Response)
Susan Thorneloe (Office of Research and Development)

RTI International
Linda Andrews
Steve Beaulieu
Jamie Cajka
Michael Lowry
Anne Lutes
Jennifer Redmon
Kristin Smith
Robert Truesdale
Donna Womack

Hydrogeologic, Inc.
Hua Chen
Varut Guvansen
Jan Kool
Ted Lillys

ARCADIS
Peter Kariher

Vanderbilt University
David Kosson
Andrew Garrabrants
Sohini Sarkar

Allison Geoscience Consultants, Inc.
Jerry Allison

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CONTRIBUTORS AND REVIEWERS

Office of the Administrator
Sharon Cooperstein
Robin Jenkins
Gregory Miller
William Nickerson
Sarah Rees

Office of Administration and Resources Management
Davy Simonson

Office of Air and Radiation
Jim Eddinger
Brian Fisher
Nick Hutson
Ellen Kurlansky
Scott Wilson

Office of Chemical Safety and Pollution Prevention
Thomas Groeneveld

Office of Enforcement and Compliance Assurance
Declan Hayes
Pete Raack

Office of Environmental Information
Velu Senthil

Office of General Counsel
Laurel Celeste

Office of Research and Development
Souhail Al-Abed
Jace Cuje
Chunming Su
Thabet Tolaymat

Office of Solid Waste and Emergency Response
Lynn Beasley
Frank Behan
Paul Cassidy
Gerain Cogliano
Betsy Devlin
Craig Dufficy
Elaine Eby
Stiven Foster
Patricia Gioffre
Greg Helms
Nick Hilosky
Stephen Hoffman
Barabara Hostage
Mary Jackson
Patrick Kelly
Richard Kinch
Alexander Livnat
Richard Mattick
Vernon Myers
Kathleen Raffaele
Bonnie Robinson
Elliot Ross
John Sager
William Schoenborn
Steve Souders

Office of Water
Alicea Jezebele
Phillip Flanders
Ronald Jordan
Robert Smith
William Swietlik
Joseph Tiago

Region 3
Andrea Barbieri
Rick Rogers

Region 4
Jon Johnston
Frank Ney
Steven Smith

Region 5
Jerri-Anne Garl
Susan Mooney
Carol Staniec

Region 6
Eric Adidas
Golam Mustafa
Frances Verhalen

Region 7
Belinda Holmes
Nicole Moran
Don Toensing

Region 8
Christina Cosentini
Kendra Morrison

Region 9
John Schofield

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PEER REVIEWERS

The 2010 Risk Assessment was reviewed by an external panel of experts. The panel was composed of the following individuals:

- Dr. Nicholas Basta, Ohio State University
- Dr. Charles Harvey, Massachusetts Institute of Technology
- Dr. William Hopkins, Virginia Polytechnic Institute and State University
- Dr. Kerry Rowe, Queens University
- Dr. Donna Vorhees, The Science Collaborative

Executive Summary

Purpose

The purpose of the risk assessment is to characterize the risks that may result from the current disposal practices for coal combustion residuals (CCRs) and provide a scientific basis for the development of regulations necessary to protect human health and the environment under the Resource Conservation and Recovery Act (RCRA).

Scope

CCR is a broad term used to refer to the byproducts that are generated either directly by coal combustion or as a result of applying certain pollution control devices to emissions from coal-fired combustion units. The distinct CCR categories identified in the rulemaking include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) materials. All coal-fired electric utility plants in the United States generate at least one of these wastes. These different CCR wastes may be generated separately or mixed together. Once generated, CCRs may be either beneficially used or disposed of in surface impoundments and landfills (collectively referred to as "waste management units" or "WMUs"). The regulatory scope of this rulemaking is limited to current disposal practices for CCRs generated by coal-fired electric utilities and independent power producers covered by the North American Industry Classification System (NAICS) code 221112. The scope of this risk assessment is limited accordingly. The United Stated Environmental Protection Agency (EPA) did not evaluate disposal of wastes other than CCRs, disposal of CCRs at off-site locations, WMUs that have ceased receiving waste, or historical disposal of CCRs by facilities that are no longer operating or not otherwise covered by NAICS code 221112.

Some coal-fired power plants conduct coal preparation activities prior to combustion. These activities may include, but are not limited to, coal handling by conveyor systems, coal washing for removing mineral matter, and coal "sizing" to reduce the average particle size of coal. The wastes generated from these coal preparation activities are collectively referred to as "coal refuse." However, some facilities are known to dispose of coal refuse together with CCRs because the chemical characteristics of the coal refuse can have a pronounced effect on the release of chemical constituents from CCRs, EPA also considered the codisposal of this additional waste stream (referred to as "ash and coal refuse") in the risk assessment.

Overview of Risk Assessment

EPA used mathematical models to determine the rate at which chemical constituents may be released from different WMUs, to predict the fate and transport of these constituents through the environment, and to estimate the resulting risks to human and ecological receptors. Modeling was conducted in a stepwise fashion, with more refined analyses used at each subsequent step. The findings at each of the analyses conducted for this risk assessment are summarized below.

Problem Formulation

EPA first developed conceptual models to illustrate a general layout of surface impoundments and landfills, the chemical constituents that may be released from these WMUs, the routes through which these constituents may migrate through environmental media, and the types of exposures that may result. These conceptual models were used as the basis for all subsequent data collection efforts. EPA first collected data on the coal-fired power plants and CCR WMUs located across the United States. EPA then collected regional and national data to characterize the environment and receptor population surrounding each WMU. The data assembled represent the most current and comprehensive information available to the Agency at the time this risk assessment was conducted. Using the data collected, EPA first conducted a simplified hazard identification to determine which constituents warranted further evaluation. At this stage, EPA considered the presence of a constituent in CCR waste, combined with the availability of at least one toxicity benchmark, sufficient evidence of hazard potential. **Table ES-1** presents a summary of the different chemical constituents retained as constituents of potential concern (COPCs) for further analysis.

Table ES-1. List of Chemical Constituents Evaluated in the CCR Risk Assessment

▪ Aluminum	▪ Cadmium	▪ Iron	▪ Molybdenum	▪ Strontium
▪ Ammonia	▪ Calcium	▪ Lanthanum	▪ Nickel	▪ Sulfate
▪ Antimony	▪ Chloride	▪ Lead	▪ Nitrate / Nitrite	▪ Sulfide
▪ Arsenic	▪ Chromium	▪ Lithium	▪ Selenium	▪ Thallium
▪ Barium	▪ Cobalt	▪ Magnesium	▪ Silicon	▪ Uranium
▪ Beryllium	▪ Copper	▪ Manganese	▪ Silver	▪ Vanadium
▪ Boron	▪ Fluoride	▪ Mercury	▪ Sodium	▪ Zinc

All risks identified in subsequent analyses were compared against risk criteria of cancer risk greater than 1×10^{-5} or a noncancer hazard quotient (HQ) greater than 1. EPA typically relies on a risk range to determine the point at which regulation is appropriate. EPA uses as an initial cancer risk "level of concern" a calculated risk level of 1×10^{-5} (one in one hundred thousand) or an HQ above 1.0 for any noncarcinogens. For example, waste streams for which the calculated high-end individual cancer-risk level is 1×10^{-5} or higher generally are considered candidates for regulation. Waste streams whose risks are calculated to be 1×10^{-4} or higher generally will be considered to pose a substantial present or potential hazard to human health and the environment and generally will be regulated. Waste streams for which these risks are calculated to be 1×10^{-6} or lower, and lower than 1.0 HQs or EQs for any noncarcinogens, generally will be considered not to pose a substantial present or potential hazard to human health and the environment and generally will not regulated. See 59 FR 66075–66077, December 22, 1994.

Screening Analysis

EPA conducted separate screening analyses for each exposure pathway to identify which COPCs are most likely to pose risk to receptors. The results of this screening generally do not provide a

precise characterization of individual risks that may occur, but rather identify those COPCs that are most likely to exceed risk criteria. In cases where well established, post-construction management practices ("controls") have been shown to minimize releases from WMUs, EPA considered exposures for both an uncontrolled and controlled management scenario.

This screening analysis identified potential risks to human and ecological receptors resulting from the releases of particulate matter and the chemical constituents contained therein through wind and run-off. Under an uncontrolled management scenario, risks to human receptors resulted from the inhalation of windblown particulates in ambient air and the ingestion of soil and animal products (i.e., meat and dairy), while risks to ecological receptors resulted from exposures to soil and sediment. Under a controlled management scenario, which consisted of fugitive dust controls and run-on/run-off controls, all risks associated with these exposure pathways decreased to below the criteria. Due to the conservative nature of the screening, there is a great deal of uncertainty surrounding the specific risks calculated for these exposure pathways. These risks represent a protective, but unlikely, combination of conditions that reflect at least an upper bound on potential exposures. Thus, the cumulative effect of these uncertainties results in an overestimation of nationwide risks to most or all receptors. Therefore, EPA makes no direct findings concerning the magnitude of the risks that may occur under either an uncontrolled or controlled management scenario, but concludes with a high degree of confidence that the reductions achievable with standard management practices are sufficient to be protective even under this conservative screening assessment. Based on these lines of evidence, EPA concluded that no further characterization was warranted for these exposure pathways.

These screening analyses identified potential risks to human and ecological receptors from leaching of chemical constituents from CCR waste into surrounding environmental media. Risks to human health resulted from ingestion of ground water and fish, while risks to ecological receptors resulted from exposure to surface water. There was no simple method to estimate the effect controls may have for these pathways. However, considerable dilution and attenuation may occur before COPCs reach downgradient private wells and surface water bodies. Therefore, EPA retained all of the COPCs found to be above risk criteria in ground water and surface water for further characterization. In addition, EPA used the uncontrolled screening results for the above ground sediment pathway as a conservative proxy for the ground water to surface water sediment pathway. As a result, sediment exposures of four COPCs were retained for further characterization. **Table ES-2** presents a summary of the chemical constituents retained as COPCs for each pathway.

Table ES-2. List of Chemical Constituents Retained for Probabilistic Analysis

Human Health		Ecological		
Ingestion of Ground Water	Ingestion of Fish	Surface Water Exposure		Sediment Exposure
▪ Antimony	▪ Arsenic	▪ Aluminum	▪ Iron	▪ Antimony
▪ Arsenic	▪ Cadmium	▪ Arsenic	▪ Lead	▪ Arsenic
▪ Boron	▪ Mercury	▪ Barium	▪ Molybdenum	▪ Silver
▪ Cadmium	▪ Selenium	▪ Beryllium	▪ Nickel	▪ Vanadium
▪ Cobalt	▪ Thallium	▪ Boron	▪ Selenium	
▪ Fluoride		▪ Cadmium	▪ Silver	
▪ Lead		▪ Chloride	▪ Vanadium	
▪ Lithium		▪ Chromium	▪ Zinc	
▪ Molybdenum		▪ Cobalt		
▪ Thallium		▪ Copper		

These screening analyses also identified potential risks to ecological receptors from direct exposure to impoundment wastewater. Unlike the other exposure pathways, no dilution or attenuation will occur within impoundment wastewater prior to ecological exposures. Thus, the direct exposures considered in the screening analysis provide a reasonable estimate of the relative magnitude of risks. Based on the screening analyses, EPA concluded that HQs for ecological receptors exceeded 1 for the following constituents (listed from highest to lowest potential): arsenic (100), barium (50), aluminum (30), boron (30), selenium (20), cadmium (10), vanadium (10), beryllium (2), chloride (2) and chromium (2). Because the screening analysis provides sufficient characterization of these exposures, this pathway was not carried forward for further analysis.

Probabilistic Analysis

EPA conducted a national-scale, probabilistic analysis to better characterize the potential risks to human and ecological receptors associated with leachate released from surface impoundments and landfills. The specific exposure routes evaluated for these releases were human ingestion of ground water used as a source of drinking water and fish caught from freshwater lakes or streams, as well as ecological contact with and ingestion of surface water and sediment. A combination of models was used to predict COPC fate and transport through the environment, receptor exposures, and the resulting risks. Site-specific data were used, supplemented by regional and national data sets, to capture the national variability of disposal practices, environmental conditions and receptor behavior. EPA modeled risks for both highly exposed individuals (90th percentile risks) and more moderately exposed individuals (50th percentile risks). In instances where the speciation of a COPC has been shown to greatly affect fate and transport, EPA modeled multiple species to provide a bounding on potential exposures.

Table ES-3 shows the 90th percentile human health risks to the most sensitive age cohorts for constituents that exceeded the risk criteria. Risks are presented for arsenic modeled entirely as two different species (III and V) to provide a bounding on potential risks. Values that exceed the selected risk criteria (cancer risk > 1×10^{-5} or noncancer HQ > 1) are shown in **bold**. No 90th percentile risks above ecological criteria were identified for either surface impoundment or landfills. No 50th percentile risks above human health or ecological criteria were identified for either surface impoundment or landfills.

Table ES-3. 90th Percentile Nationwide Probabilistic Risk Results

COPC	Ingestion of Ground Water	
	Surface Impoundments	Landfills
Cancer Risks		
Arsenic III	**2×10^{-4}**	5×10^{-6}
Arsenic V	1×10^{-5}	7×10^{-8}
Noncancer Risks		
Arsenic III	**5**	0.1
Arsenic V	0.4	< 0.01
Lithium	**2**	--[a]
Molybdenum	**2**	< 0.01

a) Leachate data were not available to model this COPC for landfills.

- **Surface Impoundments:** Ingestion of ground water was the only exposure pathway that resulted in risks above a cancer risk of 1×10^{-5} or noncancer HQ of 1. 90th percentile cancer risks above 1×10^{-5} were identified for arsenic III (2×10^{-4}). The 90th percentile noncancer risks above an HQ of 1 were identified for arsenic III (5), lithium (2) and molybdenum (2).
- **Landfills:** All 90th percentile cancer and noncancer risks were below human health criteria.

High-end risks identified for surface impoundments are consistently higher than those for landfills. These results are attributed to the higher infiltration rates through surface impoundments, which are driven by the hydraulic head of the ponded water. Median risks for both surface impoundments and landfills were substantially lower than both the high-end risks in this risk assessment and the median risks modeled in the 2010 Risk Assessment (U.S. EPA, 2010a). This decrease is attributed primarily to the interception of ground water by surface water bodies, which is accounted for in the revised risk assessment to provide a more accurate mass balance of constituent mass during transport. It is common for coal-fired utilities to be located near water bodies, which are used as a source of cooling water and conveyance of waste. As a result, in the majority of model iterations, the interception of ground water by surface water bodies resulted in negligible downstream well concentrations.

Based on the results of the probabilistic analysis, EPA concludes that leaching from CCR waste management units has the potential to pose risk to receptors. Arsenic, lithium and molybdenum are the chemical constituents found to pose the greatest risks from surface impoundments, while

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arsenic posed the greatest risks from landfills. Available toxicological profiles indicate that risks from arsenic ingestion are linked to an increased likelihood of cancer in the skin, liver, bladder and lungs, as well as nausea, vomiting, abnormal heart rhythm, and damage to blood vessels;[1] risks from lithium ingestion are linked to neurological and psychiatric effects, decreased thyroid function, renal effects, cardiovascular effects, skin eruptions, and gastrointestinal effects;[2] and risks from molybdenum ingestion are linked to higher levels of uric acid in the blood, gout-like symptoms, and anemia.[3]

Sensitivity and Uncertainty Analyses

The modeled probabilistic risks capture the range of current, nationwide CCR disposal practices. However, because of the broad scope of the analysis, there are a number of sources of variability and uncertainty present. Therefore, to confirm the results of the probabilistic analysis and to better understand whether any particular subset of disposal practices drives the risks identified, EPA conducted additional sensitivity and uncertainty analyses.

EPA reviewed the models used, as well as the data and assumptions input into these models, to better understand the sources of variability and uncertainty inherent in the probabilistic analysis. The Agency then qualitatively and, to the extent possible, quantitatively analyzed these sources to understand the potential effects each may have on the modeled risk results. During this review, specific attention was focused on the parameters shown to have the greatest influence on model results. As a further method of validation, EPA compared the results of the sensitivity and uncertainty analyses with proven and potential damage cases. Together these analyses and comparisons show that there is a high degree of confidence in the principal findings of the probabilistic analysis. However, the review of sensitive parameters revealed some specific disposal practices that may result in greater risks than identified in the probabilistic modeling.

Through these additional sensitivity and uncertainty analyses, which explored different subsets of national disposal practices, EPA identified the potential for higher risks than those identified in the broader, national analysis. In particular, consideration of different waste pH values showed higher risks for arsenic at more acidic and basic pH values, as well as additional risks for boron, cobalt, fluoride and mercury at these more extreme pH values. Consideration of specific liner types showed that ground water risks are driven by disposal in unlined units and, in particular, unlined surface impoundments. For these units, EPA identified higher risks for arsenic and molybdenum, as well as additional risks for thallium. Clay-lined units were found to pose lower risks than unlined units. Composite-lined units were found to be the most protective disposal practice, resulting in risks far below all criteria identified in this risk assessment.

[1] Profile for arsenic available online at: www.epa.gov/iris/subst/0278.htm and www.atsdr.cdc.gov/toxprofiles/tp2.pdf

[2] Profile for lithium available online at: hhpprtv.ornl.gov/issue_papers/Lithium.pdf

[3] Profile for molybdenum available online at: www.epa.gov/iris/subst/0425.htm

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Conclusions

Based on the analyses presented in this document, EPA concludes that current management practice of placing CCR waste in surface impoundments and landfills poses risks to human health and the environment within the range that OSWER typically regulates. On a national scale, surface impoundments presented higher risks than landfills. Risks to ecological receptors were identified from exposures to aluminum, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, selenium and vanadium through direct exposure to impoundment wastewater. Risks to residential receptors were identified primarily from exposures to arsenic and molybdenum in ground water used as a source of drinking water, but additional risks from boron, cadmium, cobalt, fluoride, mercury and thallium were identified for specific subsets of national disposal practices.

Sensitivity analyses on liner type indicate that disposal of CCR wastes in unlined surface impoundments and landfills presents the greatest risks to human health and the environment. As modeled, the national risks from clay-lined units are lower than those for unlined units, but such units can exceed risk criteria at individual sites. Composite liners were the only liner type modeled that effectively reduced risks from all pathways and constituents far below human health and ecological criteria in every sensitivity analysis conducted. Sensitivity analyses on waste type indicate that the acidic conditions that result from codisposal of CCR waste with coal refuse and the basic conditions that result from disposal of FGD waste result in higher risks from arsenic and other constituents than CCR waste disposed alone.

The risk results are consistent with the ground water damage cases compiled by EPA. These damage cases were primarily associated with unlined units and were most frequently associated with releases of arsenic. Recent surveys of the industry indicate the majority of newly constructed units are lined, and that that the practice of codisposal with coal refuse has declined. However, this risk assessment presents a static snapshot of current disposal practices. While newer units may be managed in a more protective manner, older units, which still comprise the majority of current units, continue to operate in a manner that poses risks to human health and the environment within the range that OSWER typically regulates.

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List of Abbreviations and Acronyms

3MRA	Multimedia, Multiple Exposure Pathway, Multiple Receptor Risk Assessment
ACI	Activated carbon injection
ADD	Average daily dose
AEGL	Acute Exposure Guideline Levels
AERMOD	American Meteorological Society/EPA Regulatory Model
ATSDR	Agency For Toxic Substances And Disease Registry
BCF	Bioconcentration factors
BTF	Biotransfer factors
CAIR	Clean Air Interstate Rule
CalEPA	California EPA
CAMR	Clean Air Mercury Rule
CASRN	Chemical Abstract Service Registry Number
CBI	Confidential Business Information
CCC	Criterion Continuous Concentration
CCR	Coal combustion residual
CIBO	Council of Industrial Boiler Owners
COMID	Common Identifier
CONUS-SOIL	Conterminous United States Multilayer Soil Characteristics
COPC	Constituent of Potential Concern
CSEFH	Child-Specific Exposure Factors Handbook
CSF	Cancer slope factor
CSFo	Oral cancer slope factor
DAF	Dilution attenuation factor
DBGS	Depth below ground surface
DOC	Dissolved organic carbon
DOE	U.S. Department Of Energy
DOM	Dissolved organic matter
DW	Drinking water
Eco-SSL	Ecological Soil Screening Levels
EFH	Exposure Factors Handbook
EIA	Energy Information Agency
ELG	Effluent Limitation Guidelines
EPA	U.S. Environmental Protection Agency
EPACMTP	EPA’s Composite Model for Leachate Migration with Transformation Products
EPRI	Electric Power Research Institute
ERL	Effects range low

ERPG	Emergency Response Planning Guidelines
ESP	Electrostatic precipitator
FBC	Fluidized-bed combustion
FCV	Final Chronic Value
FGD	Flue gas desulfurization
GIS	Geographic information system
GW	Ground water
HDPE	High-density polyethylene
HEAST	Health Effects Assessment Summary Tables
HEI	Highly exposed individual
HELP	Hydrologic Evaluation Of Landfill Performance
HFO	Hydrous ferric oxide
HGDB	Hydrogeologic Database
HHRAP	Human Health Risk Assessment Protocol
HQ	Hazard quotient
HSDB	Hazardous Substances Data Bank
ID	Identification
IDLH	Immediately Dangerous to Life or Health
IEM	Indirect Exposure Methodology
IEUBK	Integrated Exposure and Uptake Biokinetic model
IRIS	Integrated Risk Information System
IWAIR	Industrial Waste Air Model
IWEM	Industrial Waste Evaluation Model
K_d	Soil-water partition coefficient
L/S	Liquid-to-solid ratio
LADD	Lifetime average daily dose
LEAF	Leaching Evaluation Assessment Framework
LF	Landfill
LOAEL	Lowest observed adverse exposure level
MCL	Maximum Concentration Limit
MINTEQA2	Metal Speciation Equilibrium Model For Surface And Ground Water
MODHMS	MODFLOW-based Hydrologic Modeling System
MRL	Minimal Risk Level
MSW	Municipal solid waste
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NAWQP	National Ambient Water Quality Program
NED	National Elevation Data set

NHD	National Hydrography Data set
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No observed adverse exposure level
NODA	Notice of Data Availability
OSWER	Office of Solid Waste And Emergency Response
PM	Particulate matter
POM	Particulate organic matter
PPRTV	Provisional Peer-Reviewed Toxicity Values
RAGS	Risk Assessment Guidance For Superfund
RCRA	Resource Conservation And Recovery Act
REL	Reference Exposure Levels
RfC	Reference concentration
RfD	Reference dose
RME	Reasonable Maximum Exposure
RTC	Report To Congress
SAB	Science Advisory Board
SCV	Secondary Chronic Value
SD	Standard deviation
SI	Surface impoundment
SPLP	Synthetic Precipitation Leaching Procedure
SQuiRTs	Screening Quick Reference Tables
STATSGO	State Soil Geographic Database
STORET	Storage And Retrieval Data Warehouse
SW	Surface Water
TCLP	Toxicity Characteristic Leaching Procedure
TEEL	Temporary Emergency Exposure Limits
TEL	Threshold effect level
TL3	Trophic level 3
TL4	Trophic level 4
TSS	Total suspended solids
URF	Unit risk factors
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WBD	Watershed Boundary Data set
WMU	Waste management unit

1 Introduction

The U.S. Environmental Protection Agency (EPA or the Agency) has taken many steps toward characterizing the risks that may result from the current disposal practices for coal combustion residuals (CCRs) and developing the regulations necessary to protect human health and the environment under the Resource Conservation and Recovery Act (RCRA). A full timeline of the Agency's previous work on CCRs can be found on the EPA website.[4]

The revised risk assessment presented in this document builds on the two most recently completed analyses in that timeline, *Non-ground water Pathways, Human Health and Ecological Risk Analysis for Fossil Fuel Combustion Phase 2* (U.S. EPA, 1998) and *Human and Ecological Risk Assessment of Coal Combustion Wastes* (U.S. EPA, 2010a). Specifically, EPA has revised the 2010 Risk Assessment to incorporate new data and to address the comments received from both independent external peer reviewers and public commenters on the methodology, data sources and assumptions used by the Agency. The scope of the peer review was a draft of the 2010 Risk Assessment. The scope of public comments was a 2007 Notice of Data Availability (NODA), the 2010 Risk Assessment, and two subsequent NODAs in 2011 and 2013.[5] The Agency responses to these comments are available in separate documents for the peer review and the public in the docket for the final rule.

1.1 Purpose and Scope of the Risk Assessment

The purpose of this document is to characterize the risks associated with current CCR disposal practices to aid in the review and revision of the Agency's 2010 proposed rulemaking. To accomplish this, EPA characterized the current state of CCR disposal practices, identified the different releases that may occur from these waste management units (WMUs), and evaluated the resulting risks to human and ecological receptors. The regulatory scope of the rulemaking is limited to current disposal practices for CCRs generated by coal-fired electric utilities and independent power producers covered by the North American Industry Classification System (NAICS) code 221112. The scope of this risk assessment is limited accordingly. EPA did not evaluate disposal of wastes other than CCRs, disposal of CCRs at off-site locations, WMUs that have ceased receiving waste, or historical disposal of CCRs by facilities that are no longer operating or not otherwise covered by NAICS code 221112.

1.2 Overview of Risk Assessment Methodology

In total, this risk assessment is divided into seven main sections and eleven appendices. The main text summarizes the different data sources relied upon, analyses performed, model results and final Agency conclusions. The appendices provide a more detailed discussion of the data and models underlying the analyses summarized in the main text. The remainder of this section provides

[4] Available online at: www.epa.gov/osw/nonhaz/industrial/special/fossil/regs.htm

[5] Available online in docket numbers EPA-HQ-RCRA-2011-0392 and EPA-HQ-RCRA-2012-0028 at: www.regulations.gov

further information about the contents of each section and appendix, while **Figure 1-1** provides a decision flowchart followed throughout the risk assessment.

- **Section 2, Problem Formulation:** describes the conceptual models used to identify the potential exposure pathways associated with CCR WMUs, summarizes the sources of data available to characterize these exposure pathways, and presents the results of hazard identification used to identify an initial list of constituents of potential concern (COPCs) carried forward for further analysis.
- **Section 3, Screening Analysis:** describes the framework used to conduct a conservative screening analysis for human and ecological receptors. The results of this screening analysis are presented and used to identify pathways and constituents for further modeling.
- **Section 4, Probabilistic Analysis:** describes the probabilistic modeling used to (1) estimate the magnitude of COPC releases from CCR WMUs for all pathways not sufficiently characterized in the screening analysis, (2) model the fate and transport of constituents through environmental media, (3) calculate potential exposures for human and ecological receptors, and (4) estimate resulting risks to these receptors. The results of this analysis are presented as separate national estimates for impoundments and landfills.
- **Section 5, Sensitivity and Uncertainty Analyses:** describes the various sources of variability and uncertainty present in the risk assessment. To the extent possible, these sources are quantitatively and qualitatively characterized to identify the potential for higher or lower risks than those modeled in the probabilistic analysis.
- **Section 6, Final Risk Characterization:** synthesizes available information from all sections of the risk assessment to reach final conclusions about the risks that may result from current CCR disposal practices.
- **Section 7, References:** provides citations for all documents referenced throughout the text.

The first five appendices provide the underlying data used in the risk assessment. **Appendix A** describes the site-based data used to characterize CCR surface impoundments and landfills (e.g., geographic location, surface area, capacity, geometry, liner status). **Appendix B** describes the regional and national data used to characterize the environmental setting around each facility and WMU (e.g., meteorology, climate, soils, aquifers and water bodies). **Appendix C** describes the chemical constituents present in and released from different CCR wastes. **Appendix D** details the collection and prioritization of human exposure factors. **Appendix E** details the collection and prioritization of toxicity benchmarks for human and ecological receptors.

The next six appendices provide detailed information on the specific models and equations used in the various analyses. **Appendix F** provides models and data used to estimate COPC concentrations suspended in ambient air and deposited on downgradient plants. **Appendix G** provides the equations and data used to estimate the accumulation of COPCs within the food chain. **Appendix H** details the development of soil-water partitioning coefficients used to model COPC concentrations in ground water. **Appendix I** describes the development of the landfill source term. **Appendix J** provides the models and data used to estimate COPC concentrations in surface water

and sediment. **Appendix K** provides a summary of several of the sensitivity and uncertainty analyses performed.

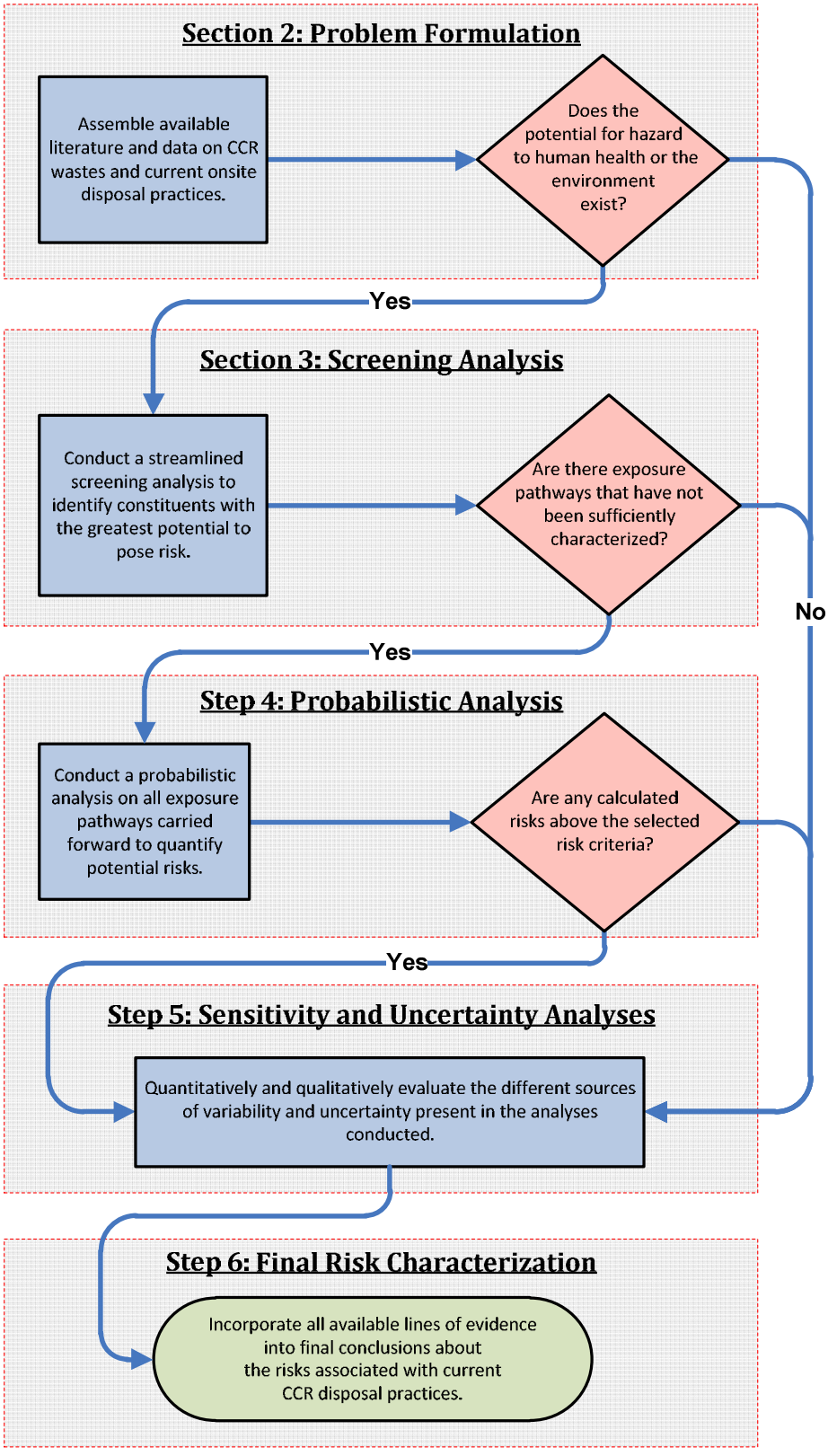

Figure 1-1. Decision flowchart for CCR risk assessment.

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2 Problem Formulation

This purpose of this section is to describe the development of the conceptual models that form the basis for the analysis of surface impoundments and landfills. This section also provides a summary of the data sources used to characterize coal-fired facilities, waste management practices, constituent releases and receptor behavior. Finally, this section includes a preliminary hazard identification to identify the COPCs to be carried forward for further analysis. This section is divided into the following subsections:

- **Section 2.1** provides an overview of the source and properties of each major type of CCR.
- **Section 2.2** provides the conceptual models developed for surface impoundments and landfills that identify each relevant release route, transport pathway, and receptor.
- **Section 2.3** summarizes the data sources incorporated into the risk analysis.
- **Section 2.4** provides the risk criteria used to evaluate risks throughout the assessment.
- **Section 2.5** identifies the potential hazards that warrant further evaluation.

2.1 Overview of Coal Combustion and Residuals

CCR is a broad term used to refer to the byproducts that are generated either directly by coal combustion or as a result of applying certain pollution control devices to emissions from coal-fired combustion units, with the resulting wastes destined for disposal. CCRs may be generated wet or dry; however, this composition may change after generation. Some CCRs are dewatered, while others are mixed with water to facilitate transport (i.e., sluiced). When multiple types of CCRs are generated at the same facility, mixing and codisposal may occur. The distinct CCR categories identified in the 2010 Proposed Rulemaking include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) materials:

- **Fly ash** is the fraction of combusted coal that becomes suspended in plant flue gases. It is a very fine, powdery material composed primarily of silica. Fly ash is removed from the plant exhaust gases primarily by electrostatic precipitators (ESPs) or baghouses that contain fabric filters. In facilities that use activated carbon injection (ACI) before fly ash collection, the fly ash waste stream will also contain the carbon, along with other mercury control wastes. However, where ACI occurs after fly ash collection, a separate waste stream may result.
- **Bottom ash** consists of ash particles that are too large to become entrained in the flue gas during combustion. It is coarse, with grain sizes that range from fine sand to fine gravel, and quite angular, with a porous surface structure. Bottom ash is collected from the furnace after it collides with and agglomerates to furnace walls or falls through open grates to an ash hopper beneath the furnace.
- **Boiler slag** is molten bottom ash that has been quenched with water. When the molten ash comes in contact with the water, it crystallizes, fractures and forms pellets that are hard with

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a smooth, glassy appearance. Boiler slag is collected from the base of either slag tap or cyclone type furnaces.

- **FGD materials** are produced through a process used to reduce sulfur dioxide (SO_2) emissions from the exhaust gas system of a coal-fired boiler. The physical nature of these materials varies from a wet sludge to a dry powdered material, depending on the pollution control technology, and the composition consists of sulfites, sulfates or a mixture thereof.

These different CCR wastes may be generated separately or mixed together. Even when generated separately, facilities often codispose of multiple waste types in a single WMU. **Figure 2-1** provides the layout of a hypothetical coal-fired plant. This simplified layout is intended to demonstrate some of the major pollution control technologies, waste streams and collection points associated with coal combustion. It is intended to be illustrative and does not capture all possible control technologies or plant layouts.

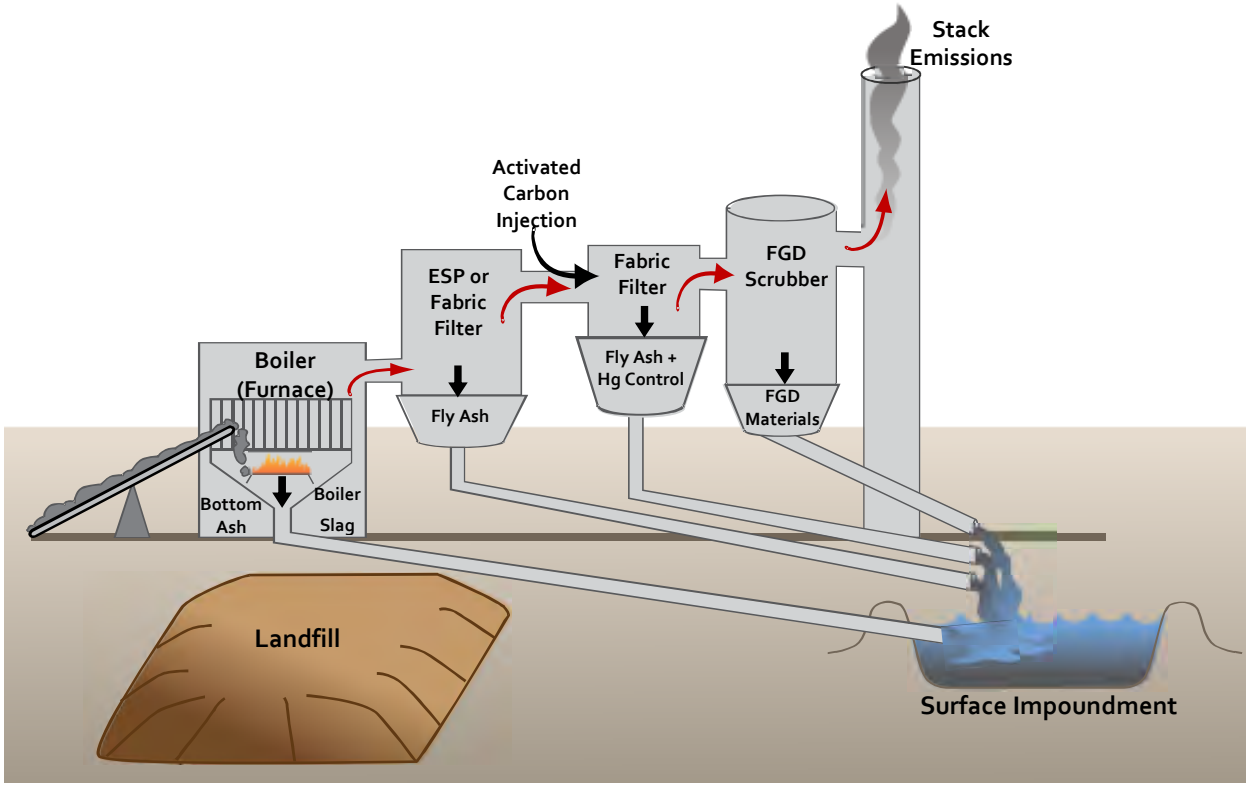

Figure 2-1. Generalized coal-fired power plant layout.

2.2 Conceptual Models

Once disposed in WMUs, the chemical constituents present in CCRs may be released to the surrounding environment. To evaluate the risks to human health and the environment that may result from these releases, EPA first developed conceptual models to specify the layout of surface impoundments and landfills, the types of releases that may occur from these WMUs, and the types of exposures that may result. These conceptual models were developed to represent generic WMU layouts and are not intended to reflect any specific facility or WMU. These conceptual models were used to form the basis for data collection and modeling efforts.

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Neither conceptual model includes direct, point source discharges to surface water. These types of releases are permitted under the National Pollutant Discharge Elimination System of the Clean Water Act and have been evaluated separately in the *Environmental Assessment for the Proposed Effluent Limitation Guidelines and Standards for the Steam Electric Power Generating Point Source Category* (U.S. EPA, 2013). The risk assessment for direct discharges was conducted in support of proposed effluent limitation guidelines (ELG) for the steam electric power generating point source category.[6] That assessment is under revision by EPA in response to the public comments received on the proposal and will be released in conjunction with the final ELG rule.

Surface water used as a source of potable water is not included in either conceptual model. Surface water is assumed to be routed through a municipal water treatment facility prior to consumption, reducing constituent levels present. Furthermore, neither conceptual model includes incidental ingestion of, inhalation of, or dermal contact with COPCs in surface water that may occur during swimming or other activities near a water body. For human receptors, it is assumed that these exposures are infrequent and small in comparison to similar exposures from ground water.

2.2.1 Surface Impoundment Conceptual Model

Surface impoundments are conceptualized as square units that are constructed anywhere from entirely above grade to entirely below ground surface. During operation, a surface impoundment receives waste sluiced from the facility. Over time, impoundment water may be lost to some combination of infiltration, evaporation, and controlled discharges to other impoundments and nearby water bodies, while the CCR solids either accumulate until the surface impoundment's capacity is reached or are periodically dredged for final disposition elsewhere. To reflect that the majority of impoundments are periodically dredged, the conceptual model assumes that dredging losses are balanced out by continued loading from the facility, resulting in a constant ponding depth over the operational life. It is assumed that all waste is removed from most units prior to closure (i.e., clean closure). However, in some instances, waste is left in place and the unit is closed and capped. Closed surface impoundments are assumed to behave the same as a closed landfill. **Figure 2-2** depicts a cross-section of the conceptual layout for operating impoundments.

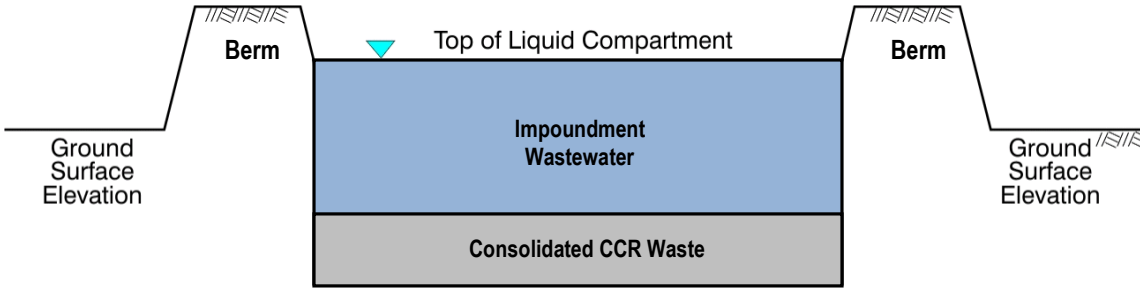

Figure 2-2. Cross-sectional view of generic surface impoundment site model.

Chemical constituents can be released from surface impoundments through the leaching of soluble constituents into the water that comes in contact with the CCRs and percolation of the resulting

[6] Available online in docket number EPA-HQ-OW-2009-0819 at: www.regulations.gov.

leachate into the subsurface soil and ground water. Constituents can then be transported underground through the ground water (GW) to downgradient drinking water (DW) wells (GW→DW pathway), where residents may be exposed through ingestion of contaminated drinking water, as well as dermal contact with and inhalation of constituents through bathing and showering in that water. Contaminated ground water may also discharge to surface water (SW) bodies (GW→SW pathway), where human receptors may be exposed through the ingestion of fish that live in the surface water body and ecological receptors may be exposed by living in or foraging in contaminated surface water or sediment. The CCR solids, along with any constituents contained within them, may also be released aboveground from operating impoundments through particulate matter disturbed by wind or runoff if the water level above the waste decreases. Additional aboveground exposures may result from ecological receptor contact with surface impoundment wastewater. **Figure 2-3** depicts the different exposure pathways considered for impoundments.

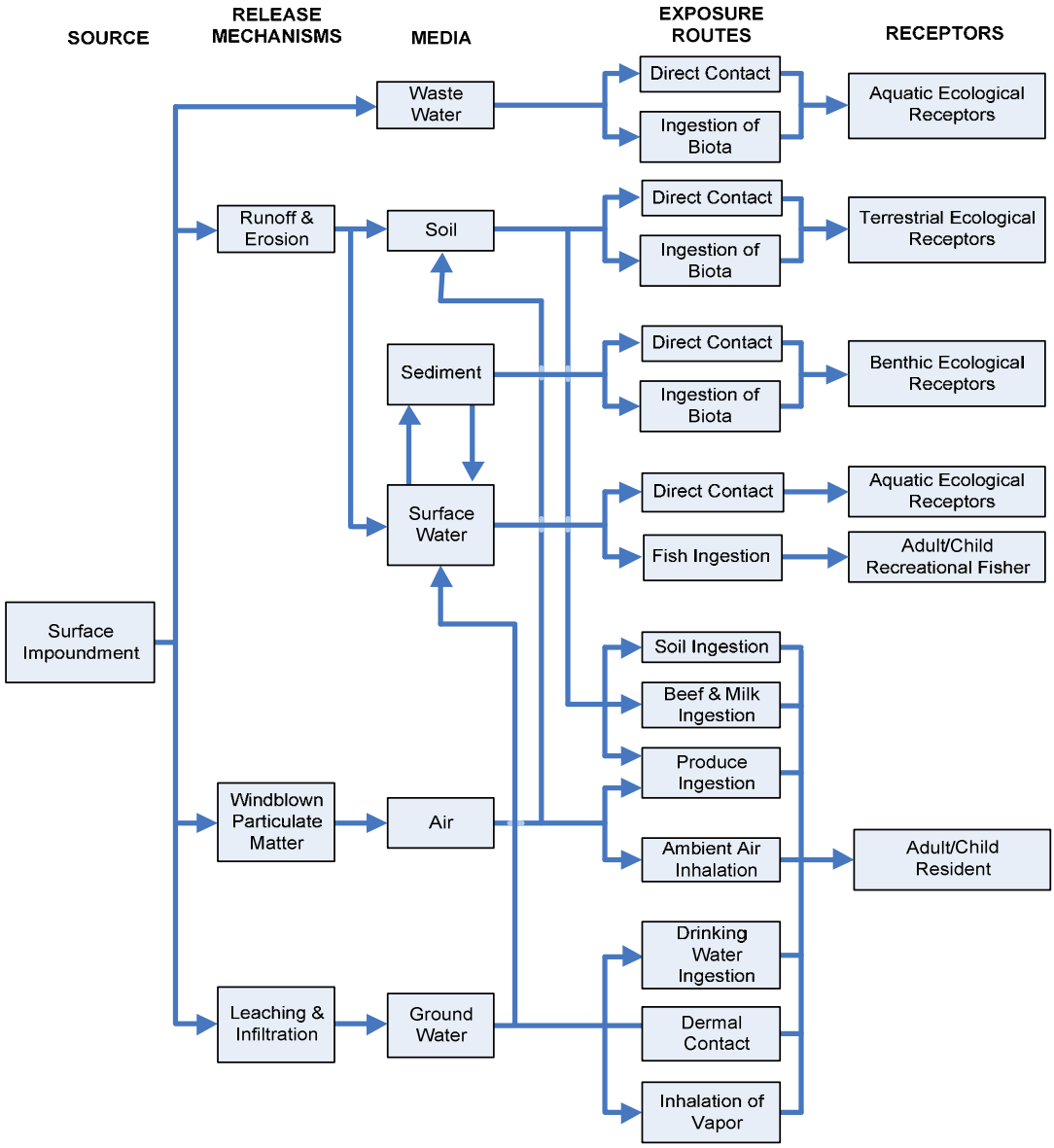

Figure 2-3. Surface impoundment conceptual exposure model.

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2.2.2 Landfill Conceptual Model

Landfills are conceptualized as square units that are constructed anywhere from entirely above grade to entirely below ground surface. During operation, landfills gradually accumulate CCRs in a smaller, active portion of the landfill, until the capacity is reached. During closure, waste is left in place and the entire landfill is capped. **Figure 2-4** depicts a cross-section of the conceptual layout for closed landfills.

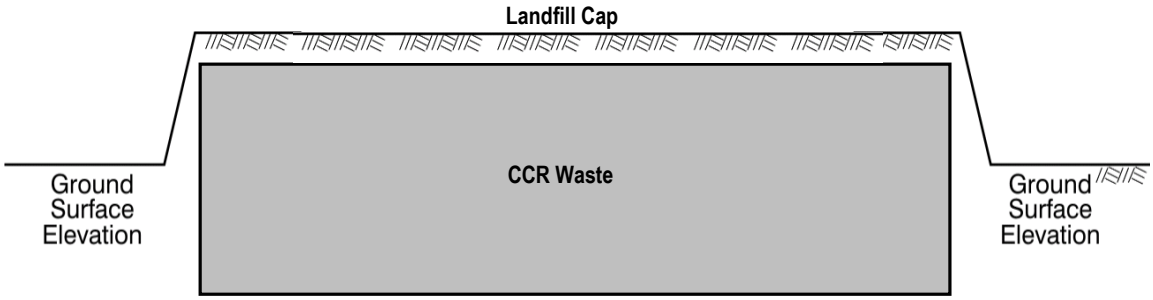

Figure 2-4. Cross-sectional view of generic landfill site model.

Chemical constituents can be released from landfills through leaching of soluble constituents into the water that comes in contact with the CCRs and percolation of the resulting leachate into subsurface soil and ground water. Constituents can then be transported underground through the ground water to downgradient drinking water wells, where residents may be exposed through ingestion of contaminated drinking water, as well as dermal contact with and inhalation of constituents through bathing and showering in that water. Contaminated ground water may also discharge to surface water bodies, where human receptors may be exposed through the ingestion of fish that live in the surface water body and ecological receptors may be exposed through living in or foraging in contaminated surface water or sediment. The CCR solids, along with any constituents contained within them, may also be released aboveground from operating landfills through particulate matter disturbed by wind; overland run-off; and mechanical disturbances, such as truck traffic, unloading operations, or spreading and compacting operations. These constituents are then transported downgradient where they may be directly inhaled by residents or settle out onto nearby soils and produce, where they may be ingested by ecological receptors or accumulated in crops and livestock that are subsequently ingested by residents. **Figure 2-5** depicts the different exposure pathways considered for landfills.

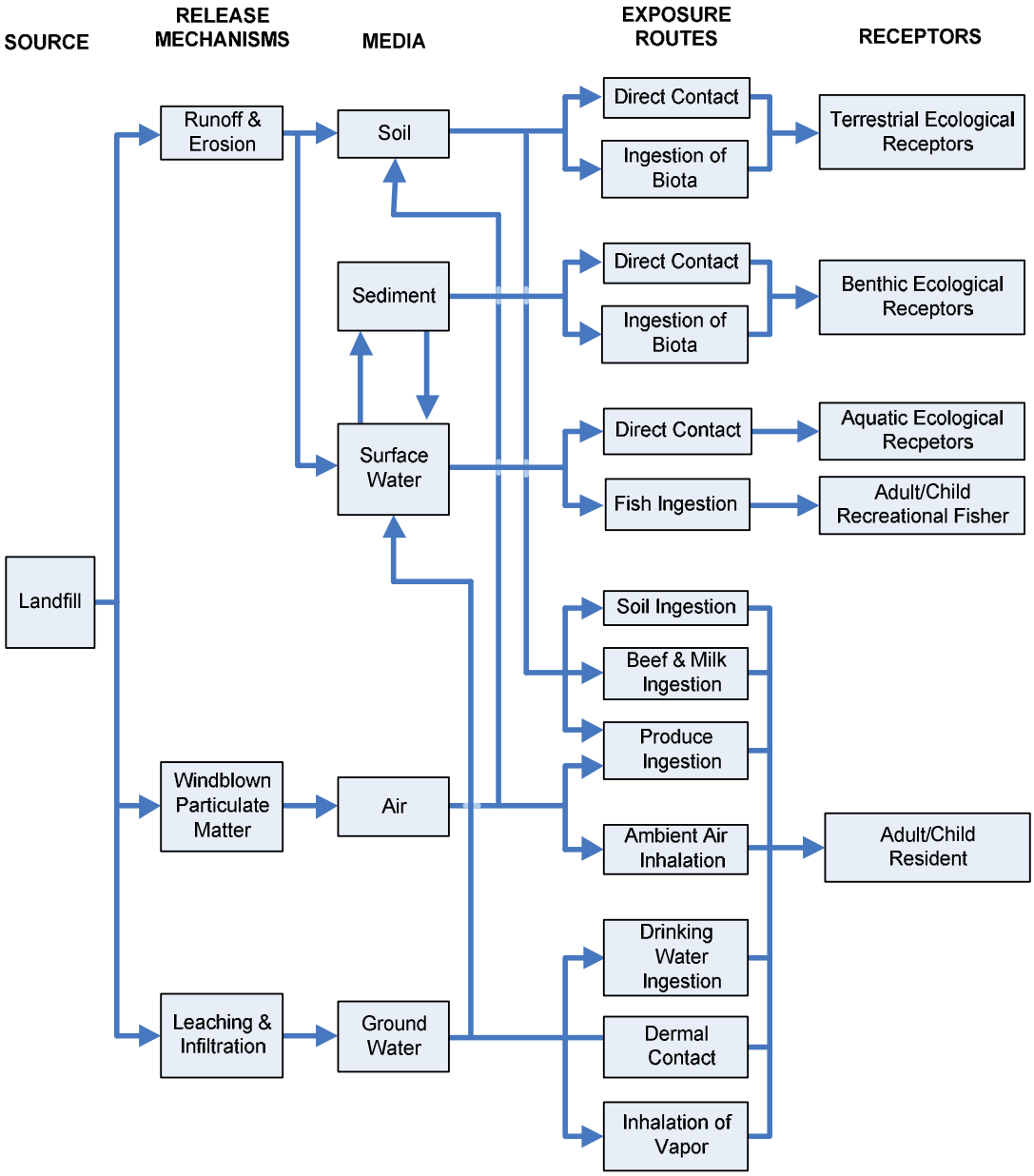

Figure 2-5. Landfill conceptual exposure model.

2.3 Data Collection

2.3.1 Facility and Waste Management Unit Data

EPA relied on the U.S. Department of Energy (DOE) Energy Information Agency (EIA) Database for information on the location, generating capacity and coal burned for each coal-fired utility power plant (hereafter referred to as "facilities"). The 2005 EIA Database used in the 2010 Risk Assessment reported a total of 495 facilities in operation, while the 2009 EIA database used in the revised risk assessment updated this number to 507 facilities. At the time that these data were collected, the 2009 EIA database was the most recent version available.

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Although the EIA Database provides information on the tons of CCRs generated annually, as well as their disposition (e.g., landfilled), it does not provide information on the characteristics of the WMUs where the disposed CCRs are managed. The 2010 Risk Assessment (U.S. EPA, 2010a) relied on a 1997 Electric Power Research Institute (EPRI) survey to characterize the type, size, design and location of CCR surface impoundments and landfills. However, two more-recent EPA surveys of on-site WMUs have since been completed:

- 2009 *Information Request Responses* [obtained under Section 104(e) of the Comprehensive Environmental Response, Compensation, and Liability Act][7] together with *Impoundment Assessment Reports*,[8] hereafter jointly referred to as "the 2009 EPA Survey"; and
- 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines, hereafter referred to as "the 2010 EPA Survey."[9]

The new data from these EPA surveys are hereafter collectively referred to as the "CCR WMU database." Although facilities and WMUs are constantly opening and closing, the CCR WMU database comprehensively covered all operating facilities at that time it was compiled. As a result, these surveys identified more than twice as many facilities with on-site disposal, as well as substantially more individual WMUs located at these facilities. Thus, the revised risk assessment provides a more complete snapshot of current disposal practices. **Table 2-1** shows the increase in coverage provided by the updated data sets.

Table 2-1. Number of On-site Surface Impoundments and Landfills Contained in the 1995 EPRI Survey and CCR WMU Database

Data Source	EIA Facilities	Facilities with On-site WMUs	Total On-site Impoundments	Total On-site Landfills
1995 EPRI Survey	495	181	96	108
CCR WMU Database	507	384	953	431

The CCR WMU database represents the most current and complete data on WMUs available and provides a significant increase in coverage of the relevant facilities. However, some data gaps remain in the CCR WMU database. Information on some parameters, such as WMU size, is missing for a subset of WMUs. To fill these data gaps, EPA probabilistically sampled from distributions compiled from the available data for other WMUs. Further information about the methods used to collect and analyze these data is provided in **Appendix A**, with the underlying raw data available in following attachments:

[7] Available online at: www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys/index.htm

[8] Additional impoundment assessment reports have been conducted since the model inputs were developed. Available online at: www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys2/index.htm

[9] Available online at: water.epa.gov/scitech/wastetech/guide/steam_index.cfm

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- **Attachment A-1** provides data collected for each facility geographic location, number of surface impoundments and landfills present, amount of coal burned and the associated coal use quartile.
- **Attachment A-2** provides the WMU-specific data used in the CCR risk assessment, including geographic locations, CCR type, dimensions, liner type and first year of operation for each of the surface impoundments and landfills modeled.

2.3.2 Environmental Parameters Data

EPA collected data on the surrounding environmental conditions with the aid of geographic information system (GIS) software. In the 2010 Risk Assessment, these data were selected based on the geographic location of each facility. The latitudes and longitudes reported in the EIA Database often represent a centroid or front gate location for each facility. However, WMUs can be located some distance away from the main facility. Therefore, where possible, the revised risk assessment used the newly available data from the CCR WMU database to identify the locations of individual WMUs, and only relied on facility locations when no WMU-specific data were available. The reported locations for both facilities and WMUs were then reviewed based on visual inspection of aerial photography using Google Earth and adjusted as appropriate.

EPA used the facility and WMU locations to identify site-specific data on soil type, hydrogeologic environment and distance to nearest water body. However, because uncertainty remained about the precise location for some units, EPA pulled data from a two-kilometer radius around the reported location to effectively capture local variability. Regional data were collected by assigning each facility to the nearest reference point in national databases, such as the Hydrologic Evaluation of Landfill Performance (HELP) model climate stations and the U.S. Geological Survey (USGS) hydrological regions. Whenever environmental parameters could not be linked based on location, EPA relied on national distributions. Further information about the methods used to collected and analyze these data is provided in **Appendix B**, with the data available in the following attachments:

- **Attachment B-1** provides the specific soil texture, pH and organic carbon content associated with each facility.
- **Attachment B-2** provides hydrogeologic environments.
- **Attachment B-3** provides climate center, precipitation rate and infiltration rate.
- **Attachment B-4** provides USGS Hydrologic Region; distance to nearest water body; and water body mean recharge, area, length, mean annual flow and mean annual velocity.

Figure 2-6 maps the coal-fired utilities within the contiguous United States for which on-site disposal of CCRs is known to take place. Although these facilities are concentrated in the eastern United States, they are located in nearly every state, in both urban and rural settings. One additional facility in Alaska, with a single on-site surface impoundment, is not shown on this figure. Because soil and hydrogeologic data were unavailable for Alaska, data on this one facility and surface impoundment were not incorporated in the revised risk assessment.

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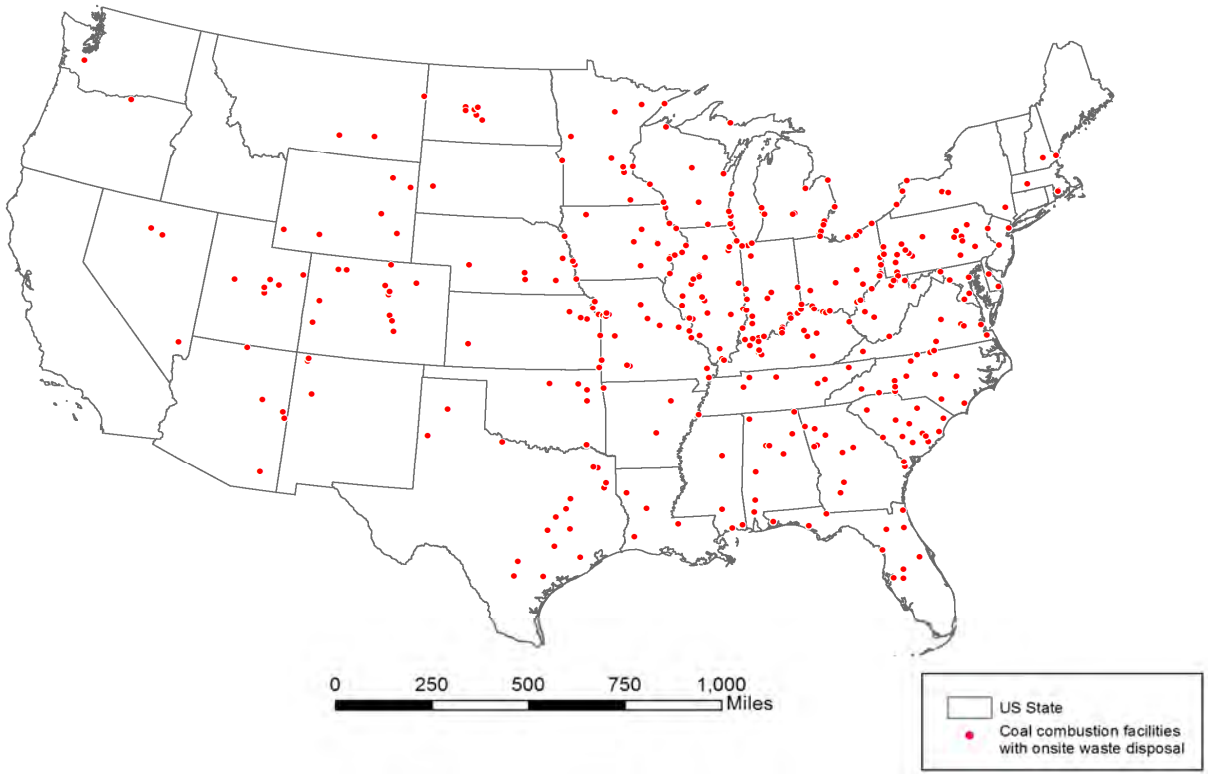

Figure 2-6. Coal-fired facilities in the conterminous United States with both on-site disposal and available soil and hydrogeological data.

2.3.3 Constituent Data

The revised risk assessment relies on a database that contains all of the constituent data collected since the 1998 Risk Assessment (U.S. EPA, 1998a,b), referred to as the "CCR constituent database." This database includes information on both the identity and concentrations of the different constituents that may be present in and released from different CCRs. EPA has continued to incorporate new data as it becomes available through public comment and Agency collection efforts. The available data comprise the most recent and complete data set available at the time of this assessment. Further information about this database is provided in **Appendix C**, with the data available in the following attachments:

- **Attachment C-1** provides a complete list of data sources in the updated database.
- **Attachment C-2** provides the surface impoundment pore water concentration data used to characterize leaching from these units.
- **Attachment C-3** provides the surface impoundment wastewater concentration data used to characterize surface water within these units.
- **Attachment C-4** provides the whole waste concentration data ("totals") used to characterize the mass of COPCs present in the CCR waste.
- **Attachment C-5** provides leachate data collected with EPA Leaching Evaluation Assessment Framework (LEAF) methods used to characterize landfills.

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2.3.4 Exposure Factors

EPA previously used data from the 1997 *Exposure Factors Handbook* (EFH) (U.S. EPA, 1997b,c,d) to characterize human exposure factors. In the revised risk assessment, EPA reviewed and incorporated the data and recommendations from the 2008 *Child-Specific Exposure Factor's Handbook* (CSEFH; U.S. EPA, 2008a), including the subdivision of child receptors into specific age cohorts. Because the 2008 CSEFH does not provide additional data for adult exposures, the data from the 1997 EFH were retained for these adult receptors. Where sufficient data were available, the percentiles and corresponding data points drawn from these two sources were used to develop a distribution in order to reflect the variability within the U.S. population. Otherwise, EPA relied on point values selected based on either the recommendations of the EFH/CSEFH or established Agency guidance.

The 2011 *Exposure Factors Handbook* (U.S. EPA, 2011) has been completed and updates some of the data from the 1997 EFH. During the finalization of this risk assessment, EPA released *OSWER Directive 9200.1-120* (U.S. EPA, 2014c). Although this document provides default exposure factors to use for point estimates, EPA is still in the process of updating the full distributions necessary for probabilistic analysis. Therefore, this risk assessment does not incorporate the data from the 2011 EFH. Further information about the methods used to collected and analyze these exposure data is provided in **Appendix D.**

2.3.5 Toxicity Benchmarks

Ingestion Benchmarks

For human health exposures from the ingestion of soil and water, EPA updated the chronic toxicity values used in the 2010 Risk Assessment. The benchmarks collected in this report reflect current toxicity data as of January 2012. Values were selected according to the hierarchy established in the 2003 *Office of Solid Waste and Emergency Response Directive 9285.7-53* (U.S. EPA, 2003f), which encourages the prioritization of toxicity values from sources that are current, transparent and publicly available, and that have been peer reviewed. During this update, two new benchmarks were identified: a noncancer benchmark for lanthanum was identified from the National Sanitation Foundation International and a cancer benchmark for chromium VI from the New Jersey Department of Environmental Protection (NJDEP). Benchmarks were drawn from the following sources:

- **Tier I:** EPA Integrated Risk Information System (IRIS).
- **Tier II:** Provisional Peer-Reviewed Toxicity Values for Superfund.
- **Tier III:** Agency for Toxic Substances and Disease Registry minimal risk levels, California Environmental Protection Agency (CalEPA) cancer potency factors, the International Toxicity Estimates for Risk database, NJDEP, and the EPA Health Effects Assessment Summary Table.

For lead, there is currently has no consensus on the development or identification of an effect threshold needed to develop benchmarks within these tiers. Therefore, the maximum contaminant level (MCL) was used as an alternative benchmark for approximating human health risk.

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Inhalation Benchmarks

EPA collected National Ambient Air Quality Standards (NAAQS) for evaluating inhalation of particulate matter (PM) and lead. Because the fugitive dust screening summarized in the 2010 Risk Assessment identified the potential for acute exposures to exceed these standards, EPA also collected acute inhalation toxicity values to evaluate additional constituents that may be sorbed to the particulate surface. Guidelines intended to protect against mild adverse health effects (e.g., respiratory irritation) were gathered. If these guidelines were not available, the severe effect guidelines were used with a safety factor of 10 to approximate a milder effect level, based on the recommendations in *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (U.S. EPA, 2005). All sources considered have either undergone peer review or were developed based on a peer-reviewed process. In addition, the reference exposure levels (RELs) and acute exposure guideline levels (AEGLs) have been made available for public review and comment. Benchmarks for inhalation were drawn from the following sources, listed in order of preference:

- CalEPA acute RELs,
- U.S. EPA AEGLs,
- American Industrial Hygiene Association emergency response planning guidelines ,
- U.S. DOE temporary emergency exposure limits, and
- National Institute for Occupational Safety and Health immediately dangerous to life or health divided by an uncertainty factor of 10.

Ecological Benchmarks

EPA updated the concentration-based benchmarks used in the 2010 Risk Assessment for ecological exposures that result from direct contact with and foraging in soil, surface water and sediment. These benchmarks are based on classes of receptors (e.g., invertebrates, mammals) and do not consider predator–prey interactions. Ecological benchmarks for the revised risk assessment were obtained from the following sources listed below in order of preference for each medium, with further information about each source provided in **Appendix E**:

- **Surface Water:** Criterion Continuous Concentrations developed under the EPA National Ambient Water Quality Program, Final Chronic Values implemented under the Great Lakes Water Quality Initiative, and Secondary Chronic Values presented in Suter and Tsao (1996).
- **Sediment:** Threshold Effect Level drawn from Buchman (2008) and Effects Range Low Levels drawn from various literature sources.
- **Soil:** Ecological Soil Screening Levels developed by multi-stakeholder workgroup led by EPA and Oak Ridge National Lab screening benchmarks developed for the U.S. DOE.

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2.4 Risk Criteria

One of the primary goals of this risk assessment is to identify the likelihood of adverse effects. An adverse effect is a broad term for any abnormal, harmful, or undesirable change that may results from chemical constituent exposures. These effects can be divided into two broad types: carcinogenic and noncarcinogenic. Carcinogenic effects are those that ultimately result in the occurrence of cancer somewhere in the individual. The likelihood of carcinogenic effects is expressed as the increased lifetime probability of cancer that results from an incremental exposure. Noncarcinogenic effects are those that result in adverse health effects other than cancer. The likelihood of noncarcinogenic effects is expressed as a ratio of the exposure level and the level below which no adverse effects are known or anticipated to occur. To evaluate adverse effects in this risk assessment, EPA used the following criteria:

- **Human Health Cancer Risk:** EPA considered excess lifetime cancer risks within the OSWER risk range of between a 1 in 1,000,000 (1×10^{-6}) and a 1 in 10,000 (1×10^{-4}) excess cancer risk. EPA has historically used a 1×10^{-5} excess cancer risk as the point of departure for RCRA hazardous waste listings (59 FR 66075). Thus, in determining whether to retain constituents for further analysis, EPA used a 1×10^{-5} excess lifetime cancer risk. Cancer risk represents the increased risk of developing cancer for members of the exposed population over their lifetime.
- **Human Health Noncancer Risk:** An HQ > 1 was selected, based on the recommendations of U.S. EPA (1989). An HQ represents the ratio of actual exposure and the highest exposure level at which no adverse health effects are likely to occur. An HQs > 1 indicates that an adverse effect may occur, with a higher HQ indicating a greater likelihood of occurrence. However, this ratio does not correspond to an exact probability of noncancer adverse effects for members of the exposed population.
- **Ecological Risk:** An HQ > 1 was selected to evaluate adverse effects to ecological receptors.

2.5 Hazard Identification

Hazard potential exists where a constituent is present and is either known or anticipated to cause adverse effects to human health or the environment. For purposes of this preliminary stage of the assessment, EPA considered the presence of a constituent with one or more toxicity benchmarks sufficient evidence of hazard potential. A review of available data identified a total of 34 constituents for which both concentration data and toxicity benchmarks were available. EPA retained each of these constituents for further evaluation as COPCs. The hazard identification results are shown in **Table 2-2**. Those constituents that had no toxicity value or concentration for a given pathway could not be carried forward for further quantitative analysis. Instead, these exposures are further discussed qualitatively as part of the uncertainty analyses in **Section 5**.

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Table 2-2. Hazard Identification Results

Constituent	CASRN	Human Health			Ecological		
		Chronic Oral	Acute Inhalation	Chronic Inhalation	Soil	Surface Water	Sediment
Aluminum	7429-90-5	✓	✓	✓	—	✓	—
Ammonia	7664-41-7	✓	—	—	—	—	—
Antimony	7440-36-0	✓	✓	✓	✓	✓	✓
Arsenic	7440-38-2	✓	✓	✓	✓	✓	✓
Barium	7440-39-3	✓	✓	—	✓	✓	✓
Beryllium	7440-41-7	✓	✓	✓	✓	✓	—
Boron	7440-42-8	✓	✓	—	✓	✓	—
Cadmium	7440-43-9	✓	✓	✓	✓	✓	✓
Calcium	7440-70-2	—	✓	—	—	—	—
Chloride	16887-00-6	—	✓	—	—	✓	—
Chromium	7440-47-3	✓	✓	✓	✓	✓	✓
Cobalt	7440-48-4	✓	✓	✓	✓	✓	—
Copper	7440-50-8	✓	✓	—	✓	✓	✓
Fluoride	16984-48-8	✓	✓	—	—	—	—
Iron	7439-89-6	✓	✓	—	—	✓	—
Lanthanum	7439-91-0	✓	✓	—	—	—	—
Lead	7439-92-1	✓	✓	—	✓	✓	✓
Lithium	7439-93-2	✓	—	—	—	—	—
Magnesium	7439-95-4	—	✓	—	—	—	—
Manganese	7439-96-5	✓	✓	✓	✓	✓	—
Mercury	7439-97-6	✓	✓	✓	✓	✓	✓
Molybdenum	7439-98-7	✓	✓	—	✓	✓	✓
Nickel	7440-02-0	✓	✓	✓	✓	✓	✓
Nitrate/Nitrite	14797-55-8/-65-0	✓	✓	—	—	—	—
Selenium	7782-49-2	✓	✓	✓	✓	✓	—
Silicon	7631-86-9	—	✓	—	—	—	—
Silicon	7631-86-9	—	✓	—	—	—	—
Silver	7440-22-4	✓	✓	—	✓	✓	✓
Sodium	7440-23-5	—	✓	—	—	—	—
Strontium	7440-24-6	✓	✓	—	—	—	—
Sulfate	14808-79-8	—	✓	—	—	—	—
Sulfide	18496-25-8	—	—	—	—	✓	—
Thallium	7440-28-0	✓	✓	—	—	✓	—
Uranium	7440-61-1	✓	✓	✓	—	—	—
Vanadium	7440-62-2	✓	✓	✓	✓	✓	✓
Zinc	7440-66-6	✓	✓	—	✓	✓	✓

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3 Screening Analysis

EPA conducted a screening analysis for each of the exposure pathways identified in the conceptual models developed in **Section 2**. Consistent with the regional screening tables used in the Superfund program, EPA screened risks using children and adult age cohorts, but not infants. The results of this screening are not intended to provide a precise characterization of individual risks that may occur, but rather to identify those COPCs that are most likely to pose risk. Because this screening analysis is deterministic, it does not account for site-based variability. Based on the results of this screening, EPA determined which pathways and associated COPCs to retain for further characterization with more refined, probabilistic modeling summarized in **Section 4**. The discussion of the screening analysis is divided into the following sections:

- **Section 3.1** discusses the development of source concentrations used to characterize releases from WMUs in the screening.
- **Section 3.2** provides an overview of the screening for exposures through ambient air that result from transport of CCR waste by wind.
- **Section 3.3** provides an overview of the screening for exposures through soil, sediment, produce and livestock that result from transport of CCR waste by wind and overland run-off.
- **Section 3.4** provides an overview of the screening for exposures through ground water, surface water, and fish that result from transport of leachate through ground water.
- **Section 3.5** summarizes the results and conclusions of the screening and identifies the COPCs and exposure pathways retained for further probabilistic modeling.

3.1 Waste Source Concentrations

EPA used the data contained in the CCR constituent database (**Appendix C**) as the basis for calculating COPC concentrations present in and released from surface impoundments and landfills. These data have been collected over time from many facilities and are intended to capture national variability. EPA calculated 90th percentile concentrations to represent high-end releases from WMUs. Prior to calculation, all available data were processed to minimize bias, as described below. The resulting 90th percentile values are presented in **Table 3-1** at the end of this subsection.

- **Treatment of Nondetects:** Nondetect measurements represent constituent concentrations below the capability of an analytical methodology to differentiate from background noise and do not provide definitive evidence that a constituent is or is not present. However, nondetect measurements do indicate that the constituents are not present at concentrations above the detection limit. Thus, eliminating nondetects outright will unduly bias the remaining, truncated data set toward the higher, detected values. The revised risk assessment replaced nondetect values with half of the reported detection limit according to the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (U.S. EPA, 1989) and *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (U.S. EPA, 1991).

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- **Data for Mercury.** With the exception of mercury, EPA used all available data in the CCR constituent database to characterize exposures. The majority of mercury data measured prior to 2010 had high detection limits and a large proportion of nondetects. Newer data made available to the Agency since the 2010 Risk Assessment (U.S. EPA, 2010a) were measured using newer methods with significantly lower detection limits. In many cases, the mercury concentrations detected with the new methods were less than half the older detection limits. Because use of the older mercury data has the potential to introduce a large bias into the analysis, EPA chose to use only the post-2010 mercury data in the revised risk assessment. These data contain few nondetects and are more likely to accurately represent the mercury concentrations present in and released from CCR WMUs.
- **Development of Waste Types:** Given the large size of the WMUs and the generally basic nature of CCR leachate, it is possible that leachate could alter the subsurface geochemistry that governs the migration of inorganic constituents. Therefore, a statistical analysis of the concentrations of major ions (e.g., calcium, sulfate, hydrogen ions) in the pore water was conducted to identify distinct waste types (**Appendix H**). These waste types are considered separately to better capture the behavior of COPCs released from these wastes in the subsurface environment. The three distinct waste types considered in this analysis are:
  - **Ash and Coal Refuse:** Includes any CCR that is codisposed with coal refuse, which is waste coal produced from coal handling, crushing and sizing operations. This waste type is characterized by a low to moderate pH (1.7–8.2) and high levels of sulfate, iron and manganese.
  - **FGD Wastes:** Includes any type of wet or dry FGD waste when disposed in dedicated monofills. This waste type is characterized by a moderate to high pH (8.7–11.3) and high levels of calcium, sulfate, sodium and chlorine.
  - **Combined Ash:** Includes any CCRs other than those listed above (e.g., fly ash, bottom ash, boiler slag) either monofilled or in combination with each other. Due to the variability in disposal practices, this waste type is characterized by a broad range in pH (3.9–12.3), sulfate and calcium levels.
- **Site Quartiles:** Some sample sites in the CCR constituent database have many data points, while others have only a few. Thus, the available data would tend to bias concentrations toward those sites where more samples were collected. To avoid this, EPA developed quartiles of the COPC concentrations for each site. This approach provides equal weighting to each site while also retaining some of the intrasite variability that would be lost through the use of a single summary statistic for each site, such as an average. To develop the site quartiles, EPA first separated the data at each site into the different waste types reported at that site. This was done because combining the data for the different waste types into a single set of quartiles for a site might bias concentrations toward the most sampled waste types. Where only one sample was available for a waste type at a sample site, all of the quartiles were set to this value to ensure equal weighting. For the purposes of this screening, all

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quartiles developed were then combined into a single distribution representing all sites and all waste types, from which a 90th percentile concentration was drawn.

Table 3-1. 90th Percentile Concentrations Used for Screening Analysis

Constituent	Impoundment Pore Water (mg/L)	Impoundment Wastewater (mg/L)	Whole Waste (mg/kg)
Aluminum	12.3	2.3	91,500
Ammonia	5.1	–	–
Antimony	0.04	0.02	47.0
Arsenic	0.78	0.13	106
Barium	0.21	0.43	1,103
Beryllium	0.001	0.001	18.3
Boron	97.8	36.2	388
Cadmium	0.06	0.003	3.8
Calcium	592	577	114,750
Chloride	2,023	345	384
Chromium	0.2	0.03	153
Cobalt	0.05	0.02	65.9
Copper	0.13	0.01	226
Fluoride	21.3	–	25
Iron	11.9	0.04	42,426
Lanthanum	–	–	58.6
Lead	0.10	0.0006	75.3
Lithium	0.45	1.99	–
Magnesium	174	1,990	17,550
Manganese	1.8	0.56	413
Mercury	0.000007	0.00003	1.1
Molybdenum	7.1	0.42	31.0
Nickel	0.3	0.07	199
Nitrate	13.7	–	0.25
Nitrite	5.0	–	–
Potassium	221	40	9,622
Selenium	0.32	0.10	18.2
Silicon	19.0	12.7	262,700
Silver	0.005	0.0001	11.1
Sodium	3,288	743	3,557

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Table 3-1. 90th Percentile Concentrations Used for Screening Analysis

Constituent	Impoundment Pore Water (mg/L)	Impoundment Wastewater (mg/L)	Whole Waste (mg/kg)
Strontium	9.1	4.3	891
Sulfate	4,398	10,400	9,630
Sulfide	–	–	26.2
Sulfur	3,842	–	36,000
Thallium	0.003	0.009	33.9
Uranium	0.01	0.004	5.0
Vanadium	0.52	0.23	562
Zinc	0.19	0.06	269

These 90th percentile values represent the concentrations present in and released from CCR wastes. Impoundment pore water is the water present within interstitial spaces of the settled CCRs. Impoundment wastewater is the free water ponded on top of the settled CCR waste. Whole waste represents the concentrations present within CCRs at the time of generation. However, most receptors will not come in direct contact with CCR wastes. Instead, receptors are exposed to environmental media, such as air; soil and water, that have been contaminated by releases from these wastes. To estimate the concentrations that may be present in these environmental media, EPA used conservative assumptions to account for fate and transport of COPCs through the environment. The calculation of these media-specific exposure concentrations are discussed in the following subsections.

3.2 Ambient Air Screening

This subsection summarizes the screening for exposure pathways associated with two management scenarios: uncontrolled and controlled releases. Uncontrolled releases occur when no action is taken to reduce particulate emissions. Controlled releases occur when management practices are put in place to minimize the rate of particulates emissions. The controls considered in this analysis include wetting and/or the use of surfactants.[10] Yet, even with the best available management practices, some emissions may still occur. Relevant exposure pathways include human inhalation of particulate matter and any COPCs contained therein. The greatest source of these pathways are landfills during operation, as water cover for impoundments and postclosure cap for landfills will limit the release of particulate matter. Therefore, EPA screened these pathways for landfills and the results were also used to identify any COPCs for surface impoundments.

[10] Surfactants refer to compounds that lower the surface tension (or interfacial tension) between a liquid and a solid, and can increase the effectiveness of water as a dust control mechanism.

3.2.1 Exposure Concentrations

EPA used the 90th percentile whole waste concentrations presented in **Table 3-1** to estimate exposures to ambient air. However, these whole waste concentrations represent the mass of COPCs present within CCR wastes. To translate the concentrations in CCR waste to those in ambient air, EPA conducted modeling in two phases with the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) and the corresponding screening model, AERSCREEN. Unitized particulate emission rates of 1 g/s and 1 µg/s-m^2 were used as inputs for AERSCREEN and AERMOD, respectively, to calculate a set of unitized dispersion factors. The purpose of these unitized factors was to allow for quick and easy scaling of the model results and to minimize the number of model runs required. Further discussion of this approach and the inputs used to run and scale these models is provided in **Appendix F**.

EPA first used AERSCREEN to calculate maximum unitized dispersion factors that could occur over one hour with weather data from a number of climate stations. This 1-hour averaging time was chosen as the most appropriate value to represent short-term exposures. AERSCREEN also calculates maximum air concentrations for other averaging times (i.e., 3-hour, 8-hour, 24-hour, annual) by scaling the 1-hour concentration. However, for area sources such as landfills, the screening model uses a scaling factor of 1 for these longer averaging times, which results in overly conservative long-term concentrations that are equal to the 1-hour concentration. Instead, a second phase of modeling was conducted with AERMOD to calculate unitized dispersion factors for 24-hour, monthly and annual averaging times. To minimize the resources required, EPA conducted a single AERMOD model run using five years of weather data from the climate station associated with the 90th percentile unitized dispersion factor from AERSCREEN. For both models, EPA selected the modeled unitized dispersion factors from the distance that resulted in the highest value and scaled each using **Equation 3-1**:

(3-1) $$C_{air} = \frac{E \cdot DF \cdot C_{waste}}{A \cdot \left(10^9 \frac{\mu g}{kg}\right)}$$

Where:

C_{air} = Air concentration of constituent (mg/m^3),
E = Aggregate emission rate (g/s),
DF = Unitized dispersion factor (µg/m^3 per g/m^2-s),
C_{waste} = 90th percentile constituent-specific whole waste concentration (mg/kg),
A = Active area of landfill (m^2).

Emission rates were calculated for particles 10 micrometers in diameter or smaller (PM_{10}), and were separately scaled for the fraction of PM_{10} that are 2.5 micrometers in diameter or smaller ($PM_{2.5}$). These are the particles most likely pass through the nose and throat and enter the lungs, dramatically increasing the risk of adverse health effects. Emission rates were calculated for four specific sources: wind erosion, vehicular activity, loading/unloading and spreading/compaction using equations from *AP-42: Compilation of Air Pollutant Emission Factors* (U.S. EPA, 1985a) and *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*

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(U.S. EPA, 1985b). To capture the variability of national meteorological conditions, emission estimates were developed for a range of active landfill sizes with data from more than 40 meteorological stations that represent locations throughout the conterminous United States where CCR disposal in landfills are known to occur. Each of these emission rates was developed for both uncontrolled and controlled management scenarios. For each set of conditions evaluated, EPA summed the contributions from the four sources together to obtain an aggregate PM_{10} emission rate (E_{10}) and an aggregate $PM_{2.5}$ emission rate ($E_{2.5}$).

AERSCREEN and AERMOD results were scaled using every combination of PM_{10} emission rates, whole waste concentrations from **Table 3-1**, and active landfill sizes drawn from EPA surveys to obtain COPC concentrations in ambient air. A second scaling was conducted without the whole waste concentration data, to obtain PM_{10} and $PM_{2.5}$ concentrations in ambient air. From each of these sets of calculations, EPA selected the highest air concentrations from each management scenario for comparison in the screening.

3.2.2 Air Risks

EPA used the calculated air concentrations of particulates and COPCs to estimate risks for human receptors. EPA considered human health risks from inhalation of particulates and the COPCs contained on or in those particulates. Because air concentrations can vary considerably over time, EPA considered multiple averaging times to screen both short-term (i.e., acute) and long-tem (i.e., chronic) exposures.

Acute Human Inhalation Risks

Acute human health risks associated with the inhalation of COPCs present in ambient air were evaluated using concentration-based benchmarks (**Appendix E**). These benchmarks represent air concentrations below which no acute adverse effects are known or anticipated to occur for short exposure durations. Acute risks were evaluated by comparing these benchmarks to the maximum 1-hour concentrations calculated with AERSCREEN. The resulting noncancer risks were calculated using **Equation 3-2**:

(3-2) $$HQ_A = \frac{C_{air}}{RfC_A}$$

Where:

HQ_A = Acute hazard quotient (unitless)
C_{air} = 1-hour air concentration (mg/m^3)
RfC_A = Acute reference concentration (mg/m^3)

Table 3-2 presents these screening results for acute health risks resulting from inhalation of the COPCs from airborne particulates. These conservative results are presented for each COPC under both the controlled and uncontrolled management scenarios. Values found to be above the selected risk criteria (i.e., an $HQ_A > 1$) are shown in **bold**.

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Table 3-2. Screening Results for Acute Human Health Risks Resulting from the Inhalation of Ambient Air

COPC	Management Scenario	
	Uncontrolled	Controlled
Aluminum	0.1	0.03
Antimony	< 0.01	< 0.01
Arsenic	**2**	0.5
Barium	< 0.01	< 0.01
Beryllium	0.02	< 0.01
Boron	< 0.01	< 0.01
Cadmium	< 0.01	< 0.01
Calcium	0.01	< 0.01
Chloride	< 0.01	< 0.01
Chromium	< 0.01	< 0.01
Cobalt	< 0.01	< 0.01
Copper	< 0.01	< 0.01
Fluoride	< 0.01	< 0.01
Iron	0.02	0.01
Lanthanum	< 0.01	< 0.01
Lead	< 0.01	< 0.01
Magnesium	0.01	< 0.01
Manganese	< 0.01	< 0.01
Mercury (elemental)	< 0.01	< 0.01
Molybdenum	< 0.01	< 0.01
Nickel	0.1	0.03
Nitrate/Nitrite	< 0.01	< 0.01
Potassium	0.2	0.05
Selenium	< 0.01	< 0.01
Silicon	0.02	< 0.01
Silver	< 0.01	< 0.01
Sodium	< 0.01	< 0.01
Strontium	< 0.01	< 0.01
Sulfate	< 0.01	< 0.01
Thallium	< 0.01	< 0.01
Uranium	< 0.01	< 0.01
Vanadium	< 0.01	< 0.01
Zinc	< 0.01	< 0.01

Noncancer risks above the risk criteria were identified for arsenic by a factor of 2 under the uncontrolled management scenario, but decreased below risk criteria when fugitive dust controls were considered. All other COPCs were below the risk criteria under the uncontrolled management scenario, and were over an order of magnitude below the criteria for the controlled management scenario.

Chronic Human Inhalation Risks

Chronic human health risks associated with the inhalation of COPCs present in ambient air were evaluated using concentration-based benchmarks. These benchmarks represent air concentrations below which no adverse effects are known or anticipated to occur over a lifetime of chronic exposure. Chronic risks were evaluated by comparing these benchmarks to the maximum annual concentrations calculated with AERMOD. Cancer risks were calculated using **Equation 3-3**:

(3-3) $$\text{Risk}_{\text{Inhal}} = C_{air} \cdot \text{URF}_{\text{inhal}} \cdot 1{,}000 \left(\frac{\mu g}{mg}\right)$$

Where:

$\text{Risk}_{\text{Inhal}}$ = Individual cancer risk from inhalation of contaminants (unitless)
C_{air} = Annual air concentration (mg/m^3)
$\text{URF}_{\text{inhal}}$ = Inhalation unit risk factor (per $\mu g/m^3$)

While noncancer HQs were calculated using **Equation 3-4**:

(3-4) $$HQ_C = \frac{C_{air}}{RfC_C}$$

Where:

HQ_C = Chronic hazard quotient (unitless)
C_{air} = Annual air concentration (mg/m^3)
RfC_C = Chronic reference concentration (mg/m^3).

Table 3-3 presents the screening results for both cancer and noncancer risks. Where benchmarks were available for multiple species of a constituent, the most conservative was used in the screening calculations. These conservative results are presented for each COPC under controlled and uncontrolled management scenarios. No values were found to be above either the cancer or noncancer criteria for either scenario.

Table 3-3. Screening Results for Chronic Human Health Risks Resulting from Inhalation of Ambient Air

COPC	Management Scenario	
	Uncontrolled	Controlled
Carcinogenic Risks		
Arsenic	2×10^{-6}	7×10^{-7}
Beryllium	2×10^{-7}	7×10^{-8}
Cadmium	4×10^{-8}	1×10^{-8}
Chromium	9×10^{-6}	3×10^{-6}
Cobalt	3×10^{-6}	9×10^{-7}

(continued)

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Table 3-3. Screening Results for Chronic Human Health Risks Resulting from Inhalation of Ambient Air

COPC	Management Scenario	
	Uncontrolled	Controlled
Noncarcinogenic Risks		
Aluminum	0.6	0.2
Antimony	< 0.01	< 0.01
Arsenic	0.2	0.07
Beryllium	0.03	0.01
Cadmium	0.01	< 0.01
Chromium	0.05	0.02
Cobalt	0.4	0.1
Manganese	0.3	0.09
Mercury	< 0.01	< 0.01
Nickel	0.08	0.02
Selenium	< 0.01	< 0.01
Sulfide	< 0.01	< 0.01
Uranium	< 0.01	< 0.01
Vanadium	0.2	0.06

National Ambient Air Quality Standards

NAAQS are concentration-based regulatory limits developed for several priority pollutants by EPA. These benchmarks represent air concentrations protective of public health, including sensitive populations, such as asthmatics, children and the elderly. NAAQS exceedances were evaluated by comparing these benchmarks to the concentrations calculated with AERMOD for the available averaging time closest to that specified by the NAAQS standards. Annual concentrations were used for PM_{10} while both annual and 24-hour concentrations were used for $PM_{2.5}$. The specified averaging time for lead is a rolling 3-month average, which is not an available output from either AERSCREEN or AERMOD. Instead, lead concentrations were evaluated using a more protective monthly average concentration. The HQs were calculated using **Equation 3-5**:

$$\textbf{(3-5)} \quad \text{Ratio} = \frac{C_{air}}{NAAQS}$$

Where:

Ratio = Exposure ratio (unitless)
C_{air} = 24-hour/monthly/annual air concentration (mg/m^3)
NAAQS = National ambient air quality standard (mg/m^3).

Table 3-4 presents the screening results for both NAAQS standards. These conservative results are presented for each COPC under both the controlled and uncontrolled management scenarios. Values found to be above the selected risk criteria (i.e., a ratio > 1) are shown in **bold**.

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Table 3-4. Screening Results for NAAQS

COPC	Averaging Time	Management Scenario	
		Uncontrolled	Controlled
PM_{10}	24-hour	0.4	0.1
$PM_{2.5}$	Annual	0.5	0.3
$PM_{2.5}$	24-hour	**2**	1
Lead	Monthly	0.03	0.02

An air concentration above the NAAQS for 24-hr $PM_{2.5}$ by a factor of 2 was identified under an uncontrolled management scenario, but decreased below relevant NAAQS when fugitive dust controls were considered.

3.3 Soil, Sediment, Plant and Animal Screening

This section summarizes the screening for all exposure pathways that result from aboveground transport of COPCs to downgradient soil and sediment. Aboveground transport occurs through windblown dust and particulates suspended in overland run-off. Two management scenarios are considered: uncontrolled and controlled releases. Uncontrolled releases occur when no action is taken to control particulate releases. Controlled releases occur when there is active management of CCR waste to minimize the rate of particulates emissions. These management practices include the use of wetting and surfactants to reduce windblown dust, and run-on/run-off controls to collect or otherwise control run-off from all rainfall events less than the maximum storm predicted for each 25-year interval in the area.

Relevant human exposure pathways include incidental ingestion of contaminated soils, as well as ingestion of any crops or livestock raised on contaminated soils. Relevant ecological exposures include direct contact with and ingestion of contaminated soils and sediment, as well as ingestion of any biota living around contaminated soil and sediment. Sediment exposures were screened through this pathway under the assumption that overland transport would contribute substantially higher loadings to downgradient water bodies than subsurface transport through ground water. Each of these exposure pathways are primarily associated with landfills during operation, as the constant water cover in impoundments and the postclosure cap in landfills will limit the transport of particulates by wind and overland run-off.

3.3.1 Exposure Concentrations

EPA used the 90th percentile whole waste concentrations listed in **Table 3-1** to estimate exposures to soil, sediment, produce and animal products. However, these whole waste concentrations represent the total mass of COPCs present in CCR wastes. To translate the concentrations in CCR waste to those in soil, sediment, produce and livestock, additional calculations were necessary.

Soil and Sediment Concentrations

EPA used dilution attenuation factors (DAFs) to estimate the COPC concentrations that may accumulate in downgradient soils and sediments under the uncontrolled management scenario. A DAF is a ratio of the initial constituent concentration at the point of release to the final constituent concentration at the point of exposure. EPA identified an appropriate DAF for the uncontrolled management scenario from the 1998 Risk Assessment (U.S. EPA, 1998a), which considered unmitigated transport of CCR waste from uncovered CCR landfills by wind and overland runoff. **Figure 3-1** plots the DAFs for each modeled constituent against the corresponding soil–water partition coefficient (K_d). K_d values are a measure of the tendency of a constituent to distribute between the solid and liquid phases. A strong inverse relationship can be seen between the DAFs and the K_d values for the COPCs. This is because the constituents most likely to leach out (i.e., those with low K_d values) will not accumulate in surficial soils to the same degree as those least likely to leach out (i.e., those with high K_d values).

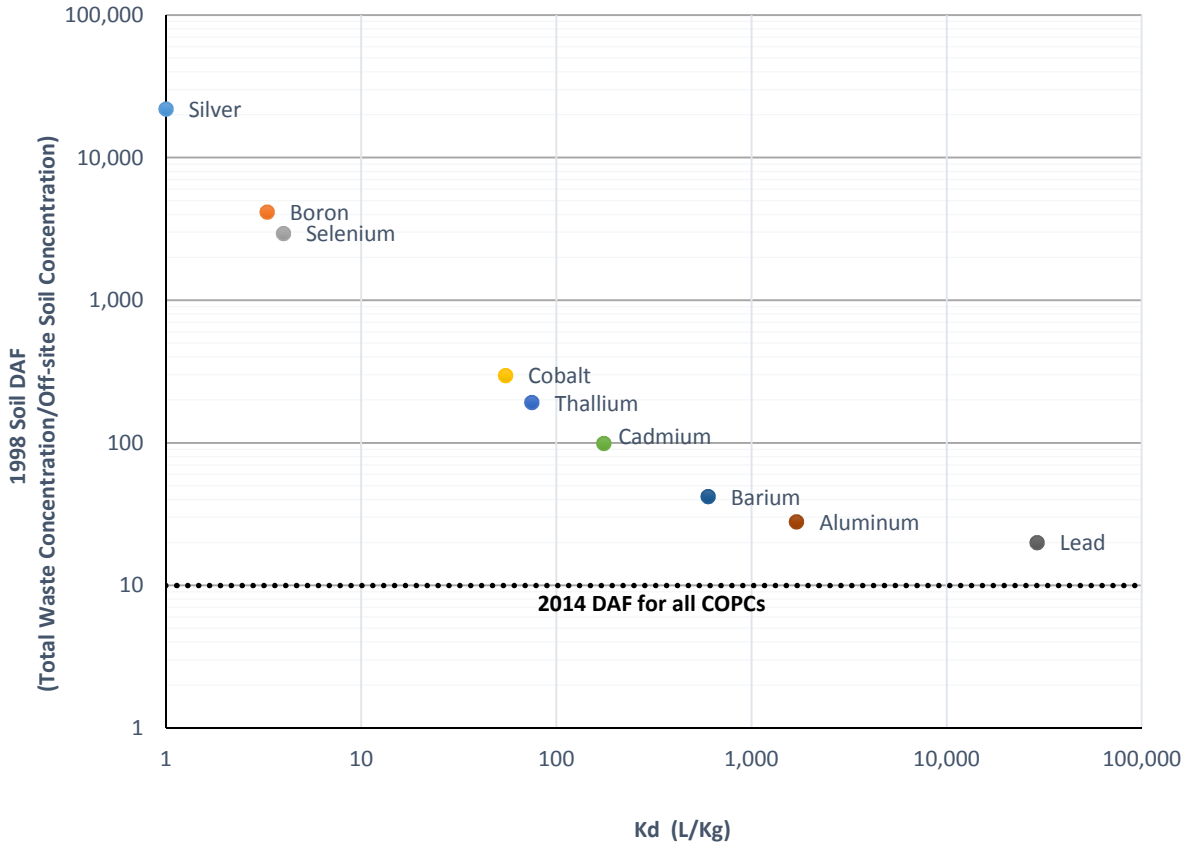

Figure 3-1. Dilution-attenuation factors as a function of K_d values as modeled in the 1998 risk assessment (adapted from U.S. EPA, 1998a).

For ease of calculation and to ensure that potential exposures were not underestimated, the revised risk assessment applied a single DAF of 10 to all COPCs for the uncontrolled management scenario. The selected DAF is below the lowest value identified in U.S. EPA (1998a) for lead, which had the highest K_d value of any COPC modeled. EPA divided the 90th percentile whole

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waste concentrations by the DAF of 10 to generate downgradient concentrations used to screen exposures to both soil and sediment for the uncontrolled management scenario.

For the controlled management scenario, run-on and run-off controls for landfills require collection and control of all run-off up to that of a 24-hour, 25-year event. These controls would essentially eliminate all off-site migration through overland run-off on an annual basis. Thus, EPA assumed that run-off was negligible. Instead, soil and sediment concentrations were calculated assuming that transport resulted only from the deposition of windblown particulates onto soil. EPA calculated a total deposition rate onto soils with **Equation 3-6**:

(3-6) $$D_p = \left[\frac{E_{10} \cdot C_{waste}}{A \cdot \left(10^6 \frac{mg}{kg}\right)}\right] \cdot \left[D_{ydp} + D_{wdp}\right]$$

Where:

D_p = Deposition rate (g/m^2-yr)
E_{10} = PM_{10} emission rate (g/s)
C_{waste} = 90th percentile constituent-specific whole waste concentration (mg/kg)
A = Active landfill area (m^2)
D_{ydp} = Unitized dry deposition rate (g/m^2-yr per g/m^2-s)
D_{wdp} = Unitized wet deposition rate (g/m^2-yr per g/m^2-s).

The unitized dry and wet deposition rates are outputs generated by AERMOD during the model runs conducted to screen ambient air concentrations. Thus, all inputs were the same. Further detail on the inputs used for AERMOD is provided in **Appendix F**. The soil and sediment concentrations that result from deposition under the controlled management scenario were calculated using the conservative assumption that the deposition of particulates occurs continuously without any losses over the course of 10 years, consistent with an average exposure duration for adults. The settled particulates are uniformly mixed within the first centimeter of topsoil and surface sediment, which has a fixed density of 1,300 kg/m^3.

Concentrations in Produce

COPCs present in the soil can be drawn into plants through the root systems and consumed along with the edible portion of the plant. Plants may also become contaminated from windblown particulates that settle out on the plant surface. Both root uptake and air deposition may happen simultaneously, and thus, the resulting exposures are assumed to be additive. However, air deposition will not contribute to exposures for some produce categories because the plants have protective outer layers that are discarded prior to consumption. **Table 3-5** provides a breakdown of the different types of plants considered. Some of these plant categories (i.e., silage, forage) are considered as feed for cattle raised as a source of beef and milk for human consumption.

Table 3-5. Potential Routes of Contamination for Different Plant Types

Produce/Plant Category	Example	Root Uptake	Air Deposition
Exposed Fruits	Strawberry	✓	✓
Exposed Vegetables	Lettuce	✓	✓
Silage	Alfalfa	✓	✓
Forage	Grass	✓	✓
Protected Fruit	Watermelon	✓	–
Protected Vegetables	Onion	✓	–
Grains	Wheat	✓	–
Root Vegetables	Carrot	✓	–

The degree to which COPCs are taken up from the soil by different plants varies. To represent these differences, EPA used bioconcentration factors (BCFs) drawn from the available literature for each of the eight plant types listed above. BCFs provide information on the amount of uptake and accumulation of a substance from soil and are expressed as a concentration in the plant per unit of concentration in the soil. The COPC concentration in the edible portion of the plant was calculated by multiplying the concentration in the soil by the appropriate BCF. The resulting concentrations are in terms of dry weight, but human consumption data are available on a wet weight basis. Therefore, the calculated dry weight concentrations were multiplied by a water adjustment factor to scale to wet weight. The specific equations, BCFs and other inputs used for this pathway are presented in **Appendix G**.

In addition to soil uptake, several plant types also accumulate particulates on exposed surfaces from air deposition. The deposition to soils in **Equation 3-6** was adjusted to account for the fraction of deposition that will not adhere to the plant surface, resulting in **Equation 3-7**:

(3-7) $$D_p = \left[\frac{E_{10} \cdot C_{waste}}{A \cdot \left(10^6 \frac{mg}{kg}\right)}\right] \cdot \left[D_{ydp} + \left(F_w \cdot D_{wdp}\right)\right]$$

Where:

D_p = Deposition rate (g/m^2-yr)
E_{10} = PM_{10} emission rate (g/s)
C_{waste} = 90th percentile constituent-specific whole waste concentration (mg/kg)
A = Active landfill area (m^2)
D_{ydp} = Unitized dry deposition rate (g/m^2-yr per g/m^2-s)
D_{wdp} = Unitized wet deposition rate (g/m^2-yr per g/m^2-s)
F_w = Fraction of wet deposition adhering to plant surface (unitless).

As with deposition onto soil, the unitized dry and wet dry deposition rates are outputs generated by AERMOD during the model runs conducted to screen ambient air concentrations. Thus, all weather data, active landfill area, emission rates and other inputs were the same. **Appendix G**

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provides the plant-specific parameters (i.e., F_w) used in this equation, as well as the other equations used to convert the deposition rate into a concentration for aboveground produce.

Concentrations in Livestock

COPCs may concentrate in livestock through the ingestion of contaminated soil and feedstock. To represent this accumulation, EPA used biotransfer factors (BTFs) drawn from the available literature. BTFs provide information on the amount of accumulation of a chemical compound in animal products (e.g., beef, milk) based on the rate of consumption of feed and soil. The COPC concentrations in beef and milk were calculated for uncontrolled and controlled management scenarios by multiplying the mass of contaminant consumed each day by the appropriate BTF. The mass consumed was calculated by multiplying the quantity of feed or soil consumed by the concentration in the feed or soil and then summed across the types of feed plus soil. For both the uncontrolled and controlled management scenarios, EPA assumed all feedstock consumed by cattle were grown on contaminated soils, and that any soil consumed while foraging was also contaminated. The specific equations and BTFs used are presented in **Appendix G.**

3.3.2 Receptor Risks

EPA used the COPC concentrations calculated for each environmental media to estimate risks for human and ecological receptors under both uncontrolled and controlled management scenarios. EPA considered human health risks from ingestion of media from around home-based farm and ecological risks from ingestion of and direct contact with media. All pathways were evaluated for adverse effects resulting from chronic exposures. Generally, adverse effects from chronic exposures occur at lower media concentrations than acute exposures. Therefore, the constant, high-end concentrations used to screen chronic exposures will also be protective of acute exposures.

Human Health Risk from Ingestion

Human health risks associated with ingestion are evaluated using dose-based benchmarks. In order to translate the calculated exposure concentrations for each medium into risks, EPA first had to characterize the potential receptors. This was done for each receptor cohort by calculating an average daily dose (ADD), which is the intake rate averaged over specified exposure duration and expressed as a daily dose per unit of body weight. For noncancer risks, the dose was averaged on an annual basis using **Equation 3-8**.

(3-8) $$ADD = \sum_{i=s}^{n} \left[\frac{I_i \cdot ED_i}{ED_{total}} \right]$$

Where:

ADD = Average daily dose (mg/kg-day)
I_i = Intake for receptor age cohort i (mg/kg-day) (calculated in **Appendix G**)
ED_i = Exposure duration of age cohort i (yr) (cannot exceed length of age cohort)
ED_{total} = Total exposure duration (yr).

For cancer risks, the dose averaged over the lifetime of the individual using **Equation 3-9**, resulting in a lifetime average daily dose (LADD).

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(3-9) $$\text{LADD} = \sum_{i=s}^{n} \left[\frac{\text{ADD} \cdot \text{ED}_i \cdot \text{EF}_i}{\text{AT} \cdot \left(365 \frac{\text{days}}{\text{year}}\right)} \right]$$

Where:

LADD = Lifetime average daily dose (mg/kg-day)
EF_i = Exposure frequency for age cohort i (day/yr)
AT = Averaging time (yr).

To calculate these dose rates, EPA used central tendency exposure factors. These factors were chosen to balance some of the conservatism present elsewhere in the screening. Exposures were considered separately for receptors starting in seven different age cohorts (i.e., 1 to < 2 yrs, 2 to < 3 yrs, 3 to < 6 yrs, 6 to < 11 yrs, 11 to < 16 yrs, 16 to < 21 yrs, and > 21 yrs). Since some exposure factors were specific to an age cohort, exposure calculations aged receptors from the beginning of the specified cohort through subsequent cohorts until the full exposure duration had been reached.

ADD and LADD were calculated on a COPC-specific basis for each age cohort. The calculated doses were compared to human health benchmarks for noncancer and cancer effects, respectively. A reference dose (RfD), which is an estimate of a daily exposure that is likely to be without appreciable risk, was used to estimate HQs for noncancer effects. These HQs were calculated using **Equation 3-10**.

(3-10) $$\text{HQ}_C = \frac{\text{ADD}}{\text{RfD}}$$

Where:

HQ_C = Noncancer risk from ingestion (unitless)
RfD = Reference dose (mg/kg-day).

A cancer slope factor (CSF), which is an upper-bound estimate of the increased human cancer risk from a lifetime of daily exposure, was used to estimate cancer risks. These cancer risks were calculated using **Equation 3-11**.

(3-11) $$\text{Risk}_{\text{Ing}} = \text{LADD} \cdot \text{CSF}_{\text{oral}}$$

Where:

$Risk_{Ing}$ = Cancer risk from ingestion (unitless)
CSF_{oral} = Oral cancer slope factor (risk per mg/kg-day)

Table 3-6 presents the screening results for human exposures to soil, produce, and animal products. Where benchmarks were available for multiple species of a constituent, the most conservative was used in the screening calculations. Results are presented for both the controlled and uncontrolled management scenarios. For both scenarios, these conservative results are based on the most sensitive age cohorts for cancer risks and noncancer risks. For cancer risks, this was 1 to < 2-year-olds for soil ingestion and adults for produce, beef, and milk ingestion. For noncancer risks, this was 1 to < 2-year-olds for all pathways. Results are presented under both the controlled

and uncontrolled management scenarios. Values found to be above the selected risk criteria (i.e., an HQ > 1) are shown in **bold**.

Table 3-6. Screening Results for Human Health Risks Resulting from Soil, Produce, Beef and Milk Ingestion

COPC	Uncontrolled				Controlled			
	Soil	Produce	Beef	Milk	Soil	Produce	Beef	Milk
Cancer Effects								
Arsenic	7×10^{-6}	9×10^{-6}	6×10^{-6}	2×10^{-6}	6×10^{-8}	8×10^{-7}	3×10^{-7}	7×10^{-8}
Chromium	3×10^{-6}	7×10^{-7}	4×10^{-6}	9×10^{-6}	3×10^{-8}	4×10^{-7}	3×10^{-7}	8×10^{-7}
Noncancer Effects								
Aluminum	0.06	0.02	0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Antimony	0.08	0.9	0.07	0.1	< 0.01	0.01	< 0.01	< 0.01
Arsenic	0.2	0.1	0.1	0.05	< 0.01	0.01	< 0.01	< 0.01
Barium	< 0.01	0.03	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Beryllium	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Boron	< 0.01	0.6	0.02	0.5	< 0.01	0.01	< 0.01	< 0.01
Cadmium	< 0.01	0.05	< 0.01	0.06	< 0.01	< 0.01	< 0.01	< 0.01
Chromium	0.03	< 0.01	0.02	0.08	< 0.01	< 0.01	< 0.01	< 0.01
Cobalt	0.1	0.3	0.6	0.8	< 0.01	< 0.01	0.03	0.05
Copper	0.01	0.7	0.2	0.6	< 0.01	< 0.01	< 0.01	< 0.01
Fluoride	< 0.01	< 0.01	–	–	< 0.01	< 0.01	–	–
Iron	0.04	< 0.01	0.1	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Lanthanum	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Manganese	< 0.01	0.03	< 0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01
Mercury	< 0.01	0.05	0.1	0.6	< 0.01	< 0.01	< 0.01	< 0.01
Molybdenum	< 0.01	0.08	0.03	0.1	< 0.01	< 0.01	< 0.01	< 0.01
Nickel	< 0.01	0.06	< 0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01
Nitrate/Nitrite	< 0.01	< 0.01	–	–	< 0.01	< 0.01	–	–
Selenium	< 0.01	0.01	< 0.01	0.03	< 0.01	< 0.01	< 0.01	< 0.01
Silver	< 0.01	0.04	< 0.01	0.7	< 0.01	< 0.01	< 0.01	0.01
Strontium	< 0.01	0.1	< 0.01	0.2	< 0.01	< 0.01	< 0.01	< 0.01
Thallium	**2**	0.6	**10**	**8**	0.03	0.09	0.8	0.6
Uranium	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Vanadium	0.04	0.03	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Zinc	< 0.01	0.08	0.07	0.1	< 0.01	< 0.01	< 0.01	< 0.01

– Indicates that no BCF or BTF was available

All cancer risks fell below human health risk criteria under both uncontrolled and controlled scenarios. Noncancer risks were identified above human health criteria for thallium in soil (2), beef (10) and milk (8) under the uncontrolled management scenario. When management controls were considered, all human health risks fell below the risk range.

Ecological Risk

Ecological risks from direct contact with and ingestion of environmental media were evaluated using concentration-based benchmarks (**Appendix E**). These benchmarks, which represent concentrations below which no adverse effects are known or anticipated to occur, were used to estimate HQs using **Equation 3-12**.

(3-12) $$HQ = \frac{C_{soil}}{Eco_{soil}} \text{ or } \frac{C_{sed}}{Eco_{sed}}$$

Where:

C_{soil} = Soil concentration (mg/kg)
C_{sed} = Sediment concentration (mg/kg)
Eco_{soil} = Ecological soil benchmark (mg/kg)
Eco_{sed} = Ecological sediment benchmark (mg/kg).

Table 3-7 presents the screening results for ecological exposures to soil and sediment. Where benchmarks were available for multiple species of a constituent, the most conservative was used in the screening calculations. Results are presented for both the controlled and uncontrolled management scenarios. For both scenarios, these conservative results are based on the most sensitive receptors, specified by the toxicity benchmarks. Values that exceed the selected risk criteria (i.e., HQ > 1) are shown in **bold**.

Table 3-7. Screening Results for Ecological Risks Resulting from Soil and Sediment Exposures

COPC	Uncontrolled		Controlled	
	Soil	Sediment	Soil	Sediment
Antimony	**20**	**2**	0.1	< 0.01
Arsenic	0.6	**2**	< 0.01	< 0.01
Barium	0.3	0.6	< 0.01	< 0.01
Beryllium	0.1	–	< 0.01	–
Boron	**80**	–	0.6	–
Cadmium	1	0.7	< 0.01	< 0.01
Chromium	0.6	0.4	< 0.01	< 0.01
Cobalt	0.5	–	< 0.01	–
Copper	0.8	0.6	< 0.01	< 0.01
Lead	0.7	0.2	< 0.01	< 0.01
Manganese	0.2	–	< 0.01	–
Mercury	1	0.6	< 0.01	< 0.01
Molybdenum	0.1	0.1	< 0.01	< 0.01
Nickel	0.5	1	0.01	< 0.01
Selenium	**3**	–	0.03	–
Silver	0.3	**2**	< 0.01	< 0.01
Vanadium	**7**	**3**	0.1	< 0.01
Zinc	0.6	0.2	< 0.01	< 0.01

– Indicates that no benchmark was available for these receptors

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Ecological soil risks above an HQ of 1 were identified were identified for the following constituents: boron (80) antimony (20) vanadium (7) and selenium (3). Ecological sediment risks were also identified above an HQ of 1 for the following constituents: vanadium (3), antimony (2), arsenic (2) and silver (2). When fugitive dust and run-off controls were considered, all ecological risks fell below the ecological risk criteria.

3.4 Ground Water, Surface Water, Wastewater and Fish Screening

This section summarizes the screening for all exposure pathways that result from leaching of COPCs into water. These exposure pathways are associated with both landfills and surface impoundments as a result of rainfall and/or wastewater percolating through the WMU. Relevant pathways include ecological exposures to impoundment wastewater, ecological exposure to downgradient surface waters, human consumption of ground water and fish, and human dermal and inhalation exposure through bathing and showering. While these pathways may be present for both impoundments and landfills, the 2010 Risk Assessment demonstrated that risks from surface impoundments are consistently higher than those from landfills. Therefore, EPA screened these pathways for surface impoundments and the results also were used to identify COPCs for landfills.

3.4.1 Exposure Concentrations

EPA used the 90th percentile concentrations for impoundment pore water and wastewater listed in **Table 3-1** to estimate exposures to ground water, surface water, wastewater and fish. Impoundment wastewater concentrations were used to screen exposures for ecological receptors that live in and around surface impoundments. These concentrations were collected from the surface water within surface impoundments after CCR solids settled out. Since wastewater concentrations are representative of the environment that these ecological receptors would inhabit, the measured concentrations were used directly in the screening. Impoundment pore water concentrations were used to screen human exposures to ground water and fish, as well as exposures for ecological receptors that live in and around downgradient surface water bodies. Pore water concentrations were collected from the interstitial water between waste particles at the bottom of the surface impoundment. These concentrations are representative of leachate released from impoundments to downgradient receptor wells and surface water bodies.

Dilution Attenuation Factors

DAFs were used to conservatively account for the reduction in concentrations that would occur during subsurface transport between a WMU and a downgradient water body. The 2010 Risk Assessment yielded a 10th percentile DAF of approximately 2 across all modeled constituents. For ease of calculation and to ensure that potential exposures were not underestimated, the revised risk assessment applied a single DAF of 1 to all water pathways. This DAF is equivalent to direct exposure to pore water. The 90th percentile pore water concentrations were divided by the selected DAF to generate exposure concentrations.

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Bioconcentration in Fish

The fish caught and consumed by recreational fishers and their families were assumed to be exposed to undiluted pore water. EPA assumed that all of the fish consumed by receptors originated from the third trophic level (TL3) and fourth trophic level (TL4). TL3 consists of carnivores that eat herbivores or secondary consumers such as invertebrates and plankton (e.g., carp, smelt, perch, catfish, sucker, bullhead, sauger), while TL4 consists of carnivores that eat other carnivores (e.g., salmon, trout, walleye, bass). While specific fish may not fit entirely into one category, EPA chose conservative categorizations for these fish to remain protective of human health. Because the degree of bioconcentration may differ between these two trophic levels, the Agency used separate BCFs for these two trophic levels, when available. For BCFs and the equations used to calculate fish concentrations, see **Appendix G**.

3.4.2 Ground Water, Surface Water, Wastewater and Fish Risks

EPA used the calculated concentrations in the different media to calculate risks for human and ecological receptors. EPA considered human health risks from ingestion of ground water and fish, as well as dermal contact with ground water and inhalation of volatilized COPCs. EPA considered ecological risks from ingestion of and direct contact with impoundment wastewater and downgradient surface water. All pathways were evaluated for adverse effects resulting from chronic exposures. Generally, adverse effects from chronic exposures occur at lower media concentrations than acute exposures. Therefore, the constant, high-end concentrations used to screen chronic exposures will also be protective of acute exposures.

Chronic Human Ingestion Risks

Human health risks associated with ingestion were evaluated using dose-based benchmarks. In order to translate the calculated exposure concentrations for each media into risks, EPA first had to characterize the potential receptors. For most COPCs, this was done for each receptor cohort by calculating either a noncancer ADD using **Equation 3-8** or a cancer LADD using **Equation 3-9**. The calculated ADD and LADD were then used to calculate HQs using **Equation 3-10** and cancer risks using **Equation 3-11**, respectively. In contrast, lead risks were characterized by comparing the ground water concentrations directly to the concentration-based MCL because no dose-based benchmark is currently available. This was done using **Equation 3-13**.

(3-13) $$\text{Ratio} = \frac{C_{DW}}{MCL}$$

Where:

Ratio = Exposure Ratio (unitless)
C_{DW} = Drinking water concentration (mg/L)
MCL = Maximum contaminant level (mg/L).

Table 3-8 presents the screening results for chronic exposures to ground water and fish. Where benchmarks were available for multiple species of a constituent, the most conservative was used in the screening calculations. For both scenarios, these conservative results are based on the most

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sensitive age cohorts for cancer risks (adults) and noncancer risks (children ages 1 to < 2). Values that exceed the selected criteria (i.e., a cancer risk > 1×10^{-5} or an HQ > 1) are shown in **bold**.

Table 3-8. Screening Results for Human Health Risks Resulting from Ground Water and Fish Ingestion

COPC	Ground Water Ingestion	Fish Ingestion
Cancer Effects		
Arsenic	**3×10^{-3}**	**4×10^{-5}**
Chromium	**3×10^{-4}**	5×10^{-7}
Noncancer Effect		
Aluminum	0.2	0.06
Ammonia	0.1	–
Antimony	**2**	< 0.01
Arsenic	**50**	1
Barium	0.02	0.02
Beryllium	0.01	< 0.01
Boron	**10**	–
Cadmium	**2**	**2**
Chromium	1	< 0.01
Cobalt	**3**	–
Copper	0.2	< 0.01
Fluoride	**7**	0.1
Iron	0.3	0.04
Lead	**7**	–
Lithium	**4**	–
Manganese	0.8	< 0.01
Mercury	< 0.01	**7**
Molybdenum	**30**	0.7
Nickel	0.3	< 0.01
Nitrate/Nitrite	0.2	–
Selenium	1	**10**
Silver	0.02	–
Strontium	0.3	0.02
Thallium	**6**	**4**
Uranium	0.08	0.02
Vanadium	1	0.2
Zinc	0.01	0.03

–Indicates no BCF was available

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Ingestion of ground water resulted in risks above the human health criteria. Cancer risks above 1×10^{-5} were identified for arsenic (3×10^{-3}) and chromium VI (3×10^{-4}). Noncancer risks above an HQ of 1 were identified were identified for: arsenic (50), molybdenum (30), boron (10), fluoride (7), lead (7) thallium (6), lithium (4), cobalt (3), antimony (2) and cadmium (2).

Ingestion of fish resulted in risks above the human health criteria. Cancer risks above 1×10^{-5} were identified for arsenic (4×10^{-5}). Noncancer risks above an HQ of 1 were identified were identified for: selenium (10), mercury (7), thallium (4) and cadmium (2).

Human Health Risks from Inhalation

In addition to dermal exposure during showering and bathing, receptors may also be exposed to volatile COPCs present in the ground water through inhalation of any vapors released. The elevated temperature and physical disturbance of water as it is forced through faucets and showerheads for baths and showers may facilitate the volatilization of COPCs. The extent to which a constituent will volatilize from shower water depends on a number of factors, including chemical properties, the water temperature, the type of shower nozzle, and the duration of showering. Elemental mercury is the only COPC identified that may volatilize to any appreciable degree under the relevant range of household conditions. Based on an estimate of air concentrations calculated by multiplying the 90th percentile mercury pore water concentration by the Andelman volatilization factor of 0.5 L/m^3 (U.S. EPA, 1991), this exposure pathway resulted in an HQ below the risk criteria using **Equation 3-4**. Therefore, this pathway was not retained for further evaluation.

Human Health Risks from Dermal Contact

Human receptors may be exposed to COPC concentrations in ground water through prolonged dermal contact with contaminated water during showering or bathing. EPA screened these dermal exposures based on the recommendations in *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual* (*Part E, Supplemental Guidance for Dermal Risk Assessment*) (U.S. EPA, 2004), which recommends that dermal exposure should be retained for evaluation if the dermal exposure is greater than 10 percent of oral exposure. Prior performing the calculations, EPA reviewed the literature to ensure the use of the most appropriate values. Based the *Public Health Goals for Chemicals in Drinking Water: Hexavalent Chromium (Cr VI)* (CalEPA, 2011), the dermal permeability coefficient (K_p) was updated to 7×10^{-6} cm/hr and gastrointestinal absorption updated to 1% for Chromium VI. Values provided by RAGS Part E were used for all other constituents. Using the process demonstrated in Exhibit B-4 of RAGS Part E, EPA determined that a screening assessment should be conducted for barium, beryllium, cadmium, chromium III, manganese, mercury (divalent), silver, vanadium, and zinc.[11]

Risk calculations were performed for a showering adult, identified in RAGS Part E as the most highly exposed receptor, using *Inorganic Chemicals in Water* spreadsheet provided in U.S. EPA (2004). The spreadsheet was updated to reflect residential exposure assumptions consistent with

[11] Because gastrointestinal adsorption of zinc is listed as highly variable, a conservative value of 1% was used for the purposes of this screening.

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the ingestion screening (see **Appendix D**). **Table 3-9** Results are presented for each COPC under controlled and uncontrolled management scenarios. No values were found to be above noncancer criteria.

Table 3-9. Screening Results for Human Health Risks Resulting from Dermal Contact

COPC	Dermal Contact
Noncancer Risks	
Barium	< 0.01
Beryllium	< 0.01
Cadmium	0.7
Chromium	< 0.01
Manganese	0.09
Mercury	< 0.01
Silver	< 0.01
Vanadium	0.3
Zinc	0.2

Ecological Risk

Ecological risks associated with direct contact with and ingestion of environmental media were evaluated using concentration-based benchmarks. These benchmarks, which represent media concentrations below which no adverse effects are known or anticipated to occur for the species, were used to estimate HQs using **Equation 3-13**.

(3-13) $$HQ = \frac{C_{sw}}{Eco_{water}} \text{ or } \frac{C_{ww}}{Eco_{water}}$$

Where:

HQ = Hazard quotient (unitless)
C_{sw} = Surface water concentration (mg/L)
C_{ww} = Wastewater concentration (mg/L)
Eco_{water} = Ecological water benchmarks (mg/L).

Table 3-10 presents the screening results for direct ecological exposures to surface water and impoundment wastewater. Where benchmarks were available for multiple species of a constituent, the most conservative was used in the screening calculations. These results are based on the most sensitive receptors for each COPC, specified by the selected toxicity benchmark. Values that exceed the selected risk criteria (i.e., an HQ > 1) are shown in **bold**.

Table 3-10. Screening Result for Ecological Risks Resulting from Surface Water and Impoundment Water Exposure

COPC	Surface Water	Impoundment Wastewater
Aluminum	**100**	**30**
Antimony	1	0.7
Arsenic	**100**	**20**
Barium	**50**	**100**
Beryllium	**2**	**2**
Boron	**100**	**30**
Cadmium	**200**	**10**
Chloride	**9**	**2**
Chromium	**20**	**2**
Cobalt	**2**	0.8
Copper	**10**	1
Iron	**10**	0.05
Lead	**40**	0.2
Mercury	0.4	< 0.01
Molybdenum	**20**	1
Nickel	**6**	1
Selenium	**60**	**20**
Silver	**10**	0.3
Thallium	0.3	0.7
Vanadium	**30**	**10**
Zinc	**2**	0.5

Direct contact with and ingestion of surface water resulted in risks above ecological criteria. Ecological risks above an HQ of 1 were identified were identified for, listed from highest to lowest: cadmium (200), aluminum (100), arsenic (100), boron (100), selenium (60), barium (50), lead (40), vanadium (30), chromium III (20), molybdenum (20), copper (10), iron (10), silver (10), chloride (9), nickel (6), beryllium (2), cobalt (2) and zinc (2).

Direct contact with and ingestion of impoundment wastewater resulted in risks above ecological criteria. Ecological risks above an HQ of 1 were identified were identified for, listed from highest to lowest: arsenic (100), barium (50), aluminum (30), boron (30), selenium (20), cadmium (10), vanadium (10), beryllium (2), chloride (2) and chromium (2).

3.5 Screening Analysis Conclusions

EPA conducted this screening analysis to determine which COPCs are most likely to pose risk to receptors for each of the exposure pathways identified in **Section 2**. Based on the results of this

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conservative screening, EPA determined which pathways to retain for further characterization with more refined, probabilistic modeling discussed in **Section 4**. The following subsection summarizes the results of the different screening analyses and the Agency's conclusions.

3.5.1 Ambient Air Conclusions

EPA calculated ambient air concentrations that result from windblown dust from landfills under uncontrolled and controlled management scenarios. Risks were estimated for based on short-term (i.e., acute) and long-term (i.e., chronic) exposures. Under the uncontrolled management scenario, concentrations of arsenic were found to pose acute risks and $PM_{2.5}$ was found to exceed the 24-hour NAAQS. However, all risks fell below selected criteria under the controlled management scenario. Based on these results, EPA did not retain exposures to ambient air for further analysis. Even with the conservative assumptions used here, risks fell below selected criteria when dust controls were considered. Thus, these screening results are sufficient to characterize high-end risks for this pathway, and the controls required by the rule are considered protective.

3.5.2 Soil, Sediment, Produce and Animal Product Conclusions

EPA calculated downgradient soil, sediment, produce, beef and milk concentrations that result from windblown dust and run-off from landfills under uncontrolled and controlled management scenarios. Under the uncontrolled management scenario, thallium was found to pose human health risks for multiple pathways, while multiple constituents were found to pose ecological risks for soil and sediment. However, all risks fell below selected criteria under the controlled management scenario. Based on these results, EPA did not retain these aboveground pathways for further analysis. Even with the conservative assumptions used here, risks fell below all benchmarks when fugitive dust and run-on/run-off controls were considered. Thus, these screening results are sufficient to characterize high-end risks for this pathway, and the controls required by the rule are considered protective.

Although aboveground transport of CCR waste was not retained for further analysis, the sediment screening was used as a more conservative estimate of sediment concentrations than may occur due belowground transport of leachate from CCR waste water. Thus, these results were used to identify COPCs for subsurface transport through ground water. As a result, EPA retained antimony, arsenic, silver and vanadium for further characterization through the ground water to surface water sediment pathway.

3.5.3 Ground Water, Surface Water, Wastewater and Fish Conclusions

These conservative screening analyses identified potential risks to human and ecological receptors from leaching of chemical constituents from CCR waste into surrounding environmental media. Risks to human health resulted from ingestion of ground water and fish, while risks to ecological receptors resulted from exposure to surface water. While EPA did not consider the various controls that may mitigate these releases, considerable dilution and attenuation may occur before COPCs reach downgradient private wells and surface water bodies. Nevertheless, EPA retained all of the COPCs found to be above risk criteria in ground water and surface water for further

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characterization in the probabilistic analysis. A summary of the COPCs retained for ground water, surface water, and sediment is presented in **Table 3-11**.

Table 3-11. Summary of the Exposure Pathways and COPCs Carried Forward for Probabilistic Analysis

COPC	Human Health		Ecological	
	Ground Water Ingestion	Fish Ingestion	Surface Water	Sediment
Carcinogenic Effects				
Arsenic	✓	✓	–	–
Chromium	✓	–	–	–
Noncarcinogenic Effects				
Aluminum	–	–	✓	–
Ammonia	–	–	–	–
Antimony	✓	–	–	✓
Arsenic	✓	–	✓	✓
Barium	–	–	✓	–
Beryllium	–	–	✓	–
Boron	✓	–	✓	–
Cadmium	✓	✓	✓	–
Chloride	–	–	✓	–
Chromium	–	–	✓	–
Cobalt	✓	–	✓	–
Copper	–	–	✓	–
Fluoride	✓	–	–	–
Iron	–	–	✓	–
Lead	✓	–	✓	–
Lithium	✓		–	–
Manganese	–	–	–	–
Mercury	–	✓	–	–
Molybdenum	✓	–	✓	–
Nickel	–	–	✓	–
Nitrate/Nitrite	–	–	–	–
Selenium	–	✓	✓	–
Silver	–	–	✓	✓
Strontium	–	–	–	–
Thallium	✓	✓	–	–
Uranium	–	–	–	–
Vanadium	–	–	✓	✓
Zinc	–	–	✓	–

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These screening analyses also identified potential risks to ecological receptors from direct exposures to impoundment wastewater. Unlike the other exposure pathways, no dilution or attenuation will occur within impoundment wastewater prior to ecological exposures. Because of this, the screening analysis provides sufficient characterization of these exposures. Based on these results, EPA concludes that there is the potential for risks to ecological receptors from aluminum, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, selenium and vanadium based on direct contact with surface impoundment wastewater. Therefore, this exposure pathway was not carried forward for further analysis, but is discussed in the risk characterization.

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4 Probabilistic Analysis

The screening analysis presented in **Section 3** identified the potential for risks to human health and the environment through multiple exposure pathways. This screening provided adequate characterization of the risks associated with several of the evaluated pathways. However, due to the conservative nature of the screening, additional characterization of human ingestion of ground water and fish, as well as ecological contact with and ingestion of surface water and sediment, were necessary to support a robust set of conclusions about current CCR disposal practices. The Agency conducted this further analysis using a probabilistic, site-based approach that combined site-specific data with regional and national data. This section describes the overarching analytical framework, as well as the specific models and inputs used within this framework to predict the fate and transport of COPCs through subsurface soils and ground water. The discussion of the probabilistic analysis is divided into the following sections:

- **Section 4.1:** Outlines the probabilistic modeling framework used by EPA to quantify the potential risks to human and ecological receptors that result from WMU leaching.
- **Section 4.2:** Details the selection of modeled leachate concentrations.
- **Section 4.3:** Details the selection of modeled leaching durations.
- **Section 4.4:** Details the selection of modeled infiltration rates.
- **Section 4.5:** Details the selection of modeled depth of WMUs below ground surface.
- **Section 4.6:** Details the selection of modeled receptor locations.
- **Section 4.7:** Provides an overview of subsurface transport modeling used to calculate exposures resulting from drinking water ingestion (human health).
- **Section 4.8:** Provides an overview of the surface water models used to calculate exposures resulting from ingestion of fish (human health) and direct contact with both surface water and sediment (ecological).
- **Section 4.9:** Provides an overview of the exposure and risk models used to quantify the risks associated with calculated exposure concentrations.
- **Section 4.10**: Presents the modeled probabilistic risks results.

4.1 General Analytical Framework

Ground water fate and transport modeling was conducted with the EPA Composite Model for Leachate Migration with Transformation Products (EPACMTP) (U.S. EPA, 1996a, 1997a, 2003a,b,c). EPACMTP consists of two coupled modules: a one-dimensional module that simulates infiltration and dissolved constituent transport through unsaturated soils in the vadose zone and a three-dimensional module that simulates transport through ground water. EPACMTP models ground water concentrations present at a specified location (such as a private well or a stream) as

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a function of time. The outputs from EPACMTP were fed into additional models that calculate surface water concentrations, sediment concentrations, receptor exposure rates, and receptor risks.

The probabilistic framework used in this risk assessment is a Monte Carlo analysis, which is a statistical technique where a quantity (in this case, risk) is calculated through repeated simulations using values selected probabilistically from an assigned parameter distribution for each model run (or iteration). The results approximate the range of possible outcomes and the likelihood of each outcome. This framework includes a separate data preparation loop and calculation loop. The data preparation loop created a single file that contained all of the input data necessary for every iteration of EPACMTP and the other models. In this file, approximately 100 entries were created for each WMU, with each entry representing the data for a distinct model iteration. EPA selected this number of entries to effectively sample the variability of each site. Where site-specific data were known for a WMU, a fixed value was assigned to all entries for that unit and held constant for each model iteration. Otherwise, a distribution was assigned based on available site, regional or national data sources, and a different value was probabilistically sampled during each model iteration. **Table 4-1** provides a list of the different data included in this file.

Table 4-1. Summary of Parameters in the Probabilistic Analysis

Description	Resolution	Fixed or Variable*	Source
WMU Type	Site-Based	Fixed	Appendix A
Waste Type	Site-Based	Fixed	
WMU Dimensions	Site-Based	Fixed	
WMU Depth Below Ground Surface	Site-Based	Variable	
Impoundment Ponding Depth	Site-Based	Variable	
Sediment Depth	Single Value	Fixed	
Liner Type	Site-Based	Fixed	
Clay-lined Hydraulic Conductivity	Single Value	Fixed	
Thickness Of Clay Liner	Single Value	Fixed	
Water Body Type	Site-Based	Variable	Appendix B
Distance To Water Body	Site-Based	Variable	
Water Body Dimensions	Site-Based	Fixed	
Water Velocity	Site-Based	Fixed	
Base flow per unit length	Site-Based	Fixed	
Stream annual flow mixing volume	Regional	Fixed	
Lake annual flow mixing volume	Regional	Variable	
Total Suspended Solids	Regional	Variable	
Surface Water Temperature	Regional	Fixed	
Aquifer Temperature	Regional	Fixed	
Water pH	Regional	Variable	

(continued)

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Table 4-1. Summary of Parameters in the Probabilistic Analysis

Description	Resolution	Fixed or Variable*	Source
Climate Center	Regional	Fixed	Appendix B
Mean annual wind speed	Regional	Fixed	
Soil Type	Regional	Variable	
Natural Organic Matter in Soil	Regional	Variable	
Soil pH	Regional	Variable	
Hydrogeological Environment	Regional	Variable	
Leachable Mass	Site-Based	Variable	Appendix C
Leachate Concentration	Site-Based	Variable	
Leachate pH	Site-Based	Variable	
Exposure Averaging Time	Single Value	Fixed	Appendix D
Exposure Frequency	Single Value	Fixed	
Fraction of Drinking Water from Well	Single Value	Fixed	
Fraction of Ingested Fish Contaminated	Single Value	Fixed	
Fraction of Fish in Tropic Levels 3 and 4	Single Value	Fixed	
Water Ingestion Rate	National	Variable	
Fish Ingestion Rate	National	Variable	
Body Weight	National	Variable	
Exposure Duration	National	Variable	
Ecological Surface Water Benchmark	National	Fixed	Appendix E
Ecological Sediment Benchmark	National	Fixed	
Human Cancer Slope Factor	National	Fixed	
Human Noncancer Reference Dose	National	Fixed	
Fish Bioconcentration Factors	Single Value	Fixed	Appendix G
Landfill Leaching Duration	Site-Based	Variable	Appendix I
Bed Sediment Particle Concentration	Single Value	Fixed	Appendix J
Bed Sediment Porosity	Single Value	Fixed	
Depth of Upper Benthic Layer	Single Value	Fixed	
Bed Sediment K_d Value	National	Variable	
Suspended Sediment K_d Value	National	Variable	

* In some cases, variables listed as "fixed" were not known for a subset of WMUs, and were probabilistically selected instead.

Once the data preparation loop was complete, the generated data file was fed into the calculation loop. Each calculation loop consisted of numerous model iterations, one for each entry in the data file. In total, approximately 100,000 model iterations were conducted for all WMUs, which forms the basis for the probabilistic risk results presented in this section. Each model iteration pulled a different set of values from the data files based on the assigned probability distributions. **Figure 4-1** shows the looping structure of the Monte Carlo framework used in this risk assessment.

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The majority of the site, regional or national data used in the probabilistic analyses could be applied directly to the models in the probabilistic framework as collected. However, in certain instances, it was necessary to account for additional considerations to appropriately reflect the conditions present in surface impoundments and landfills. The following subsections describe the various considerations involved in the selection and application of these inputs to the modeling framework.

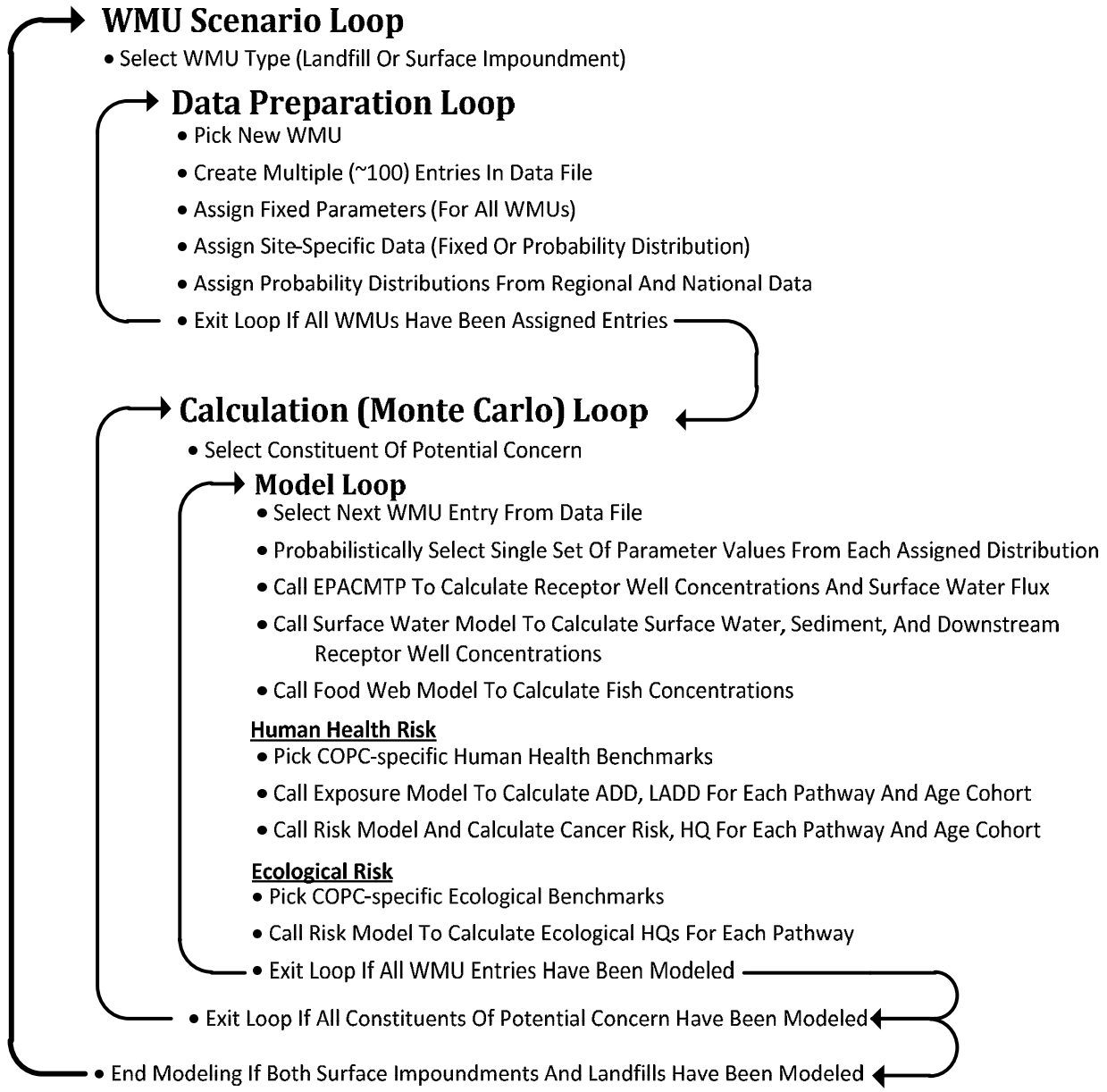

Figure 4-1. Looping structure of the CCR probabilistic modeling framework.

4.2 Source Leachate Concentrations

The following subsection summarizes the approach used to assign leachate concentrations to each WMU within the probabilistic framework. Over time, EPA has compiled a great deal of leachate data, collected and analyzed through different methods. While all of these data represent leaching

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from CCR waste, some better reflect the specific environmental conditions present at surface impoundments and landfills. Therefore, to make the best use of the available data, EPA used different data sets to characterize leachate from surface impoundments (**Section 4.2.1**) and landfills (**Section 4.2.2**).

4.2.1 Surface Impoundments

Similar to the screening analysis described in **Section 3**, EPA relied on pore water concentrations to characterize leaching from impoundments. These concentrations are collected from the interstitial water between waste particles in surface impoundments as it occurs in the field, and best reflect leachate as it is released into underlying soils. Within the CCR constituent database, some facilities have more than one sample site. Some of these sample sites have many data points, while others have only a few. Similarly, some of the waste types (i.e., combined ash, ash and coal refuse, and FGD waste) disposed at these sites may have more data points than others. Thus, combining all of the available data into a single distribution would bias the modeled concentrations toward individual facilities, sites, and waste types with more samples. To avoid this, EPA developed quartiles from the pore water data available for each waste type at each sample site. Where only one sample was available for a waste type or a sample site, all of the quartiles were set equal to that one value. This approach provides equal weighting while also retaining some intra-site variability that would have been lost through the use of a single summary statistic, such as an average.

Unlike the screening analysis, the quartiles were combined into three separate probability distributions, one for each waste type. During the data preparation loop, a fixed waste type was assigned to each surface impoundment if known from survey data. In the absence of site-specific data, a probability distribution was assigned based on the prevalence of waste types known to be present in other surface impoundments. From the assigned waste type, the data preparation loop assigned a waste-specific probability distribution for the pore water concentration of each COPC. During the calculation loop, the models probabilistically sampled from the assigned concentration distribution for every entry in the data file. The selected concentration was held constant for the entire duration of leaching.

4.2.2 Landfills

To characterize leaching from landfills, EPA collected samples of CCR waste from over 30 facilities that reflect the range of coal rank burned and likely air pollution control technology configurations at the time of this risk assessment. The leaching behavior of these samples was characterized with the SW-846 LEAF methods. These methods, described in greater detail in **Appendix C**, provide information on the leaching behavior of each sample under a range of environmental conditions. Because of this information available for each sample, it was not necessary to combine these samples into separate waste types to capture the variability of potential behavior in the subsurface environment.

During the data preparation loop, a single pH distribution that ranged between 2.8 and 12.8 was assigned to all landfill entries based on nationwide field measurements (U.S. EPA, 2009a). The

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data preparation loop also assigned a specific waste sample to each landfill entry, with an equal probability assigned to each sample. During the calculation loop, the models probabilistically sampled the assigned pH distribution during each model iteration. This pH was used to identify the pH-specific leachate concentration measured with LEAF Method 1313. The modeled leachate concentration was calculated in one of two ways, based on the type of leaching behavior exhibited by the waste sample at that pH (discussed further in **Appendix I**):

- **Solubility-Controlled Leaching** occurs when the total COPC mass available to be released from the waste is greater than the maximum amount that can be dissolved in the mass of water present. Because the solubility limit is reached at the higher liquid-to-solid ratio (L/S ratio) of 10:1 used in Method 1313, it will also be reached at the lower L/S ratio of around 1:2 typical of landfills. Thus, the concentrations measured with Method 1313 accurately reflect solubility-controlled leaching from landfills and the measured concentration was used for the model iteration.
- **Washout-Controlled Leaching** occurs when the total COPC mass available to be released from the waste is less than or equal to the maximum amount that can be dissolved in the mass of water present. Because the solubility limit is not reached for the higher L/S ratio of 10:1 used in Method 1313, the water concentration will increase as the L/S ratio decreases until the solubility limit is reached. Thus, washout-controlled leaching from landfills will be higher than the concentrations measured with Method 1313. To account for the difference in L/S ratios between Method 1313 and landfills, the measured Method 1313 concentration was multiplied by a factor of 20. This calculated concentration was used for the model iteration.

4.3 Leaching Duration

The following subsection summarizes the approach used to assign leaching durations to each WMU within the probabilistic framework. Leaching duration is the length of time that a WMU releases leachate into underlying soils. Because the aim of this probabilistic analysis is to provide an accurate estimate of peak concentrations, the leaching duration of interest for a WMU may not be the same as the total leaching duration. The duration of interest differs for surface impoundments and landfills because of the distinct leaching behavior of the two WMUs during operation and postclosure. Therefore, EPA used different data to characterize the leaching duration for surface impoundments (**Section 4.3.1**) and landfills (**Section 4.3.2**).

4.3.1 Surface Impoundments

Most surface impoundments are known to be periodically dredged. Since this dredging would remove any potential source postclosure, only the operational phase of a surface impoundment was modeled. The highest releases from surface impoundments are anticipated to occur during operational life due to the presence of a large hydraulic head that will drive infiltration rates. As a result, the length of the operating life was a key parameter for this analysis. Data on impoundment operating life were drawn from EPRI (1997a). A total of 86 of the 116 surveyed impoundments provided both an opening date and projected closure date, from which EPA calculated the expected operating life. No projected closure date was provided for the other 30 surface impoundments.

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Figure 4-2 shows the distribution of the calculated operating lives, along with a separate bar representing units with no reported closure date.

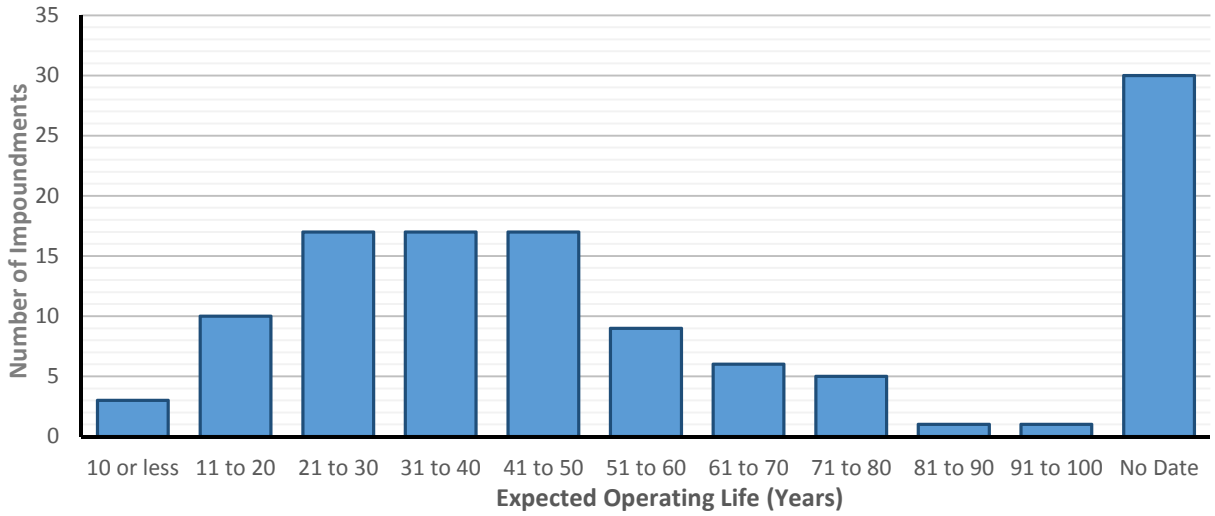

Figure 4-2. Distribution of operating life for surface impoundments from EPRI (1997a).

The calculated 50th percentile impoundment operating period was 40 years, while the 95th percentile value was 75 years. More recent information available in the CCR WMU database corroborates the distribution of expected operating life, and shows that many impoundments are currently approaching 40 years of age. At the same time, the EIA reported a large decrease in wet handling between 2009 and 2012 and many facilities have publicly announced plans to close surface impoundments.[12] Due to the uncertainty in operational lifetime for nearly a quarter of these units, and the potential for extended operational life through dredging, EPA selected a 95th percentile value of 75 years was assigned to all surface impoundments during the data preparation loop.

4.3.2 Landfills

Leaching from landfills was assumed to start at closure when the unit is filled to capacity with CCR waste. This point was chosen because EPACMTP requires a fixed WMU size, and the size at closure represents the largest possible footprint. Postclosure landfills were modeled as a finite source because the buried waste is not replenished as it leaches. For all COPCs except arsenic, leaching was idealized as a single, constant source that continued until the total available mass of a COPC had been depleted. For these COPCs, the total available mass was estimated as the maximum mass released at any pH over the range of 2.8 and 12.8 measured with Method 1313. The exact leaching duration varied between model iterations based on the modeled leachate concentration, total available mass and the leaching rate.

[12] Wilson, Mark. 2009. "Coal ash disposal varies from company to company." Evansville Courier & Press. October 24. Available online at: www.courierpress.com/lifestyle/health-and-fitness/coal-ash-disposal-varies-from-company-to-company

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For arsenic, the available data collected with the LEAF methods have demonstrated that the leaching of arsenic can be limited through oxidation by and complexation with calcium. As a result, the duration of arsenic leaching from CCRs is better represented by accounting for the presence of calcium. Arsenic leaching from landfills was modeled as having one of the following two relationships with dissolved calcium concentrations as a function of the cumulative L/S ratio (discussed further in **Appendix I**):

- **Case 1, Low Calcium Concentration (≤ 5,000 mg/kg):** Arsenic leaching begins at an initial concentration defined by the LEAF Method 1313 data and is held constant until the total available mass is depleted.
- **Case 2, High Calcium Concentration (> 5,000 mg/kg):** Arsenic leaching begins at an initial concentration defined by the LEAF Method 1313 data and is held constant until all of the free arsenic has been depleted. Empirical data available in LEACHXS Lite have shown that this generally occurs when the cumulative amount of water that has infiltrated through the ash relative to the mass of waste present approaches a ratio of 1. A typical landfill may take around a hundred years of leaching to reach this cumulative L/S ratio. At this point, further arsenic leaching is inhibited by the calcium present and effectively ceases until the time at which around 90 percent of the available calcium has been leached away. Arsenic then begins to leach again at the previous concentration until all remaining available arsenic is depleted.

4.4 Infiltration Rate

The following subsection summarizes the approach used to assign infiltration rates to each WMU within the probabilistic framework. Infiltration is the process through which water migrates through WMUs and enters the subsurface environment. The rate at which water can pass through a WMU is limited primarily by the hydraulic conductivity of the liner (if any) present. The 2009/2010 EPA Surveys contained information on the type of liner at different WMUs. Based on the descriptions of liners reported in survey responses, each surface impoundment and landfill was assigned one of three modeled liner types: no liner, clay liner or composite liner. These three liner types are the conceptual liner scenarios developed in support of EPA's Industrial Subtitle D Guidance (U.S. EPA, 2006b), and are described as follows:

- **No Liner Scenario:** Waste is placed directly on local soils, either on grade or excavated to some design depth and without a leachate collection system. At closure, two feet of native soil cover, the minimum required by Subtitle D regulations, is installed and assumed to support vegetation.
- **Clay Liner Scenario:** Waste is placed on a three-foot compacted clay liner that is installed over local soils without a leachate collection system, either on grade or excavated to some design depth. At closure, a three-foot clay cover is installed and covered with one foot of loam to support vegetation and drainage.
- **Composite Liner Scenario:** Waste is placed on a liner system that consists of a plastic liner (e.g., high-density polyethylene membrane) underlain by either a natural or geosynthetic clay

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liner. A leachate collection system is assumed to exist between the waste and the liner system. At closure, a three-foot clay cover (graded and otherwise designed to prevent ponding) or functional equivalent is assumed to be installed and covered with a one foot of loam to support vegetation and drainage.

During the data preparation loop, liner types were assigned to each WMU where known from survey data. In cases where available survey data indicated that a WMU was lined, but did not specify the type of liner, a clay or composite liner was selected probabilistically based on the relative prevalence of those liner types. In cases where neither the presence nor absence of a liner was specified in the available survey data, one of these three types was probabilistically assigned to that WMU based on the prevalence of liner types reported for other surface impoundments or landfills, as appropriate. During the Monte Carlo loop, EPACMTP used the assigned liner type, together with the assigned WMU type and local climate data to calculate an infiltration rate, as described in Appendix A of the EPACMTP background document (U.S. EPA, 2003b).

4.5 Depth Below Grade

The following subsection summarizes the approach used to assign a depth below grade to each WMU within the probabilistic framework. Depth below grade represents the total depth that a given WMU extends below the ground surface. This parameter was used during model iterations to determine the distance from the bottom of the WMU to the ground water table. EPA used the following two data sources to characterize this parameter for both surface impoundments and landfills:

- A collection of site-characterization reports published by EPRI (EPRI 1991; 1992; 1994a,b; 1996a,b; and 1997b-k); and
- A Council of Industrial Boiler Owners (CIBO) voluntary survey (CIBO, 1997).

The EPRI/CIBO reports provide diagrams of the layout of different WMUs that EPA used to determine the total depth that each extended below ground. These data were used to compile distributions that were probabilistically sampled during each model iteration. Because the designs of surface impoundments and landfills differ, separate distributions were developed for each. The selected value was constrained to be no deeper than the water table present in that model iteration. During a given model iteration, if the resulting depth below grade resulted in a unit below the ground water table, a new value was selected until the unit fell at or above the water table.

Figure 4-3 below displays the distributions of the data collected for surface impoundments. EPRI and CIBO provided data on a total of 16 surface impoundments. These reported depths tended to be mostly or entirely below-grade. The measured depths below grade at these 16 facilities were used to create an empirical distribution that was sampled during each model iteration.

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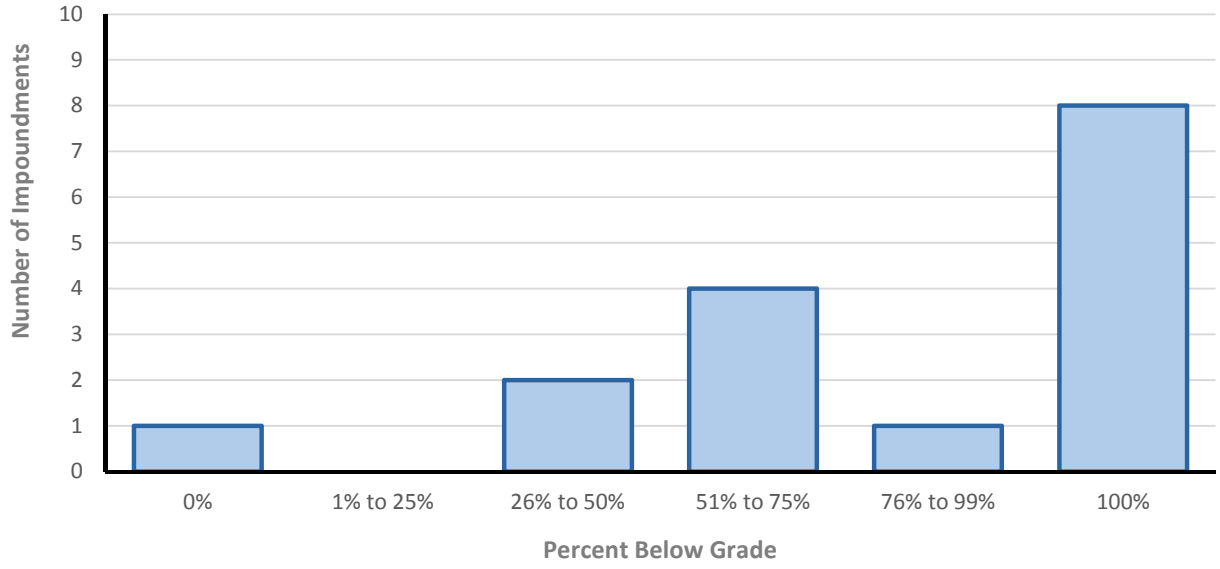

Figure 4-3. Distribution of below-grade geometry for surface impoundments from EPRI/CIBO reports.

Figure 4-4 below displays the distributions of the data collected from landfills. EPRI and CIBO provided data on a total of eight landfills. The depths reported ranged from entirely below-grade to entirely above-grade. Due to the symmetry of the available data and the relatively small available data set, EPA assumed that the percentage below-grade was uniformly distributed over the probabilistic analysis. Thus, a random value for percentage below grade between 0 and 100 percent was probabilistically sampled for each model iteration.

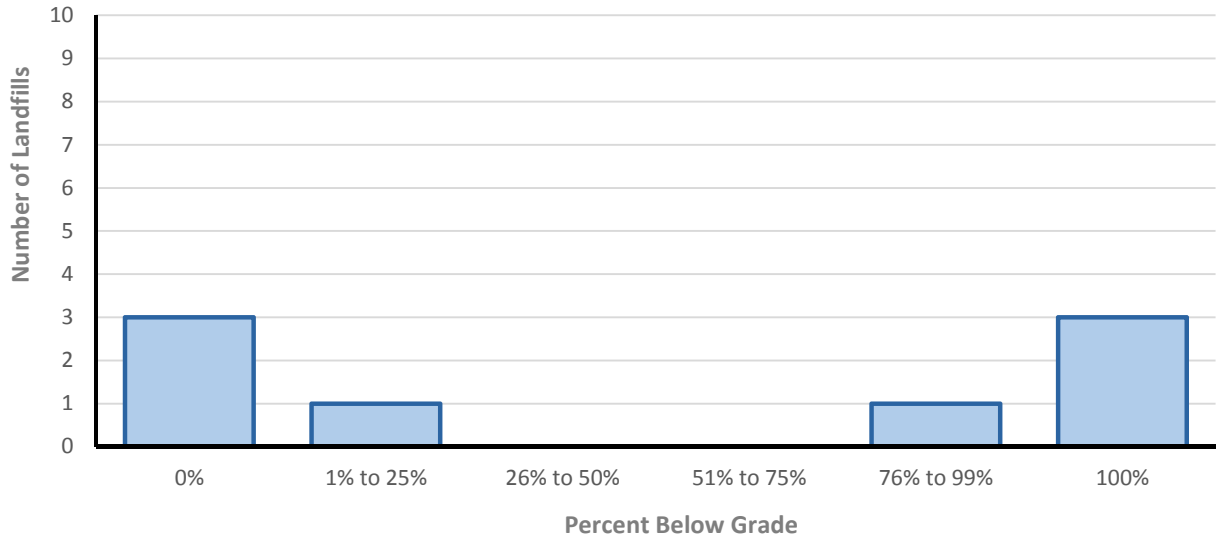

Figure 4-4. Distribution of below-grade geometry for landfills from EPRI/CIBO reports.

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4.6 Receptor Location

The following section summarizes the approach used to assign receptor locations to each WMU within the probabilistic framework. After the characteristics of the WMU have been selected, a receptor location was identified. The receptor location is the geographic location of residential drinking water wells or surface water bodies relative to the WMU. To capture the highly exposed individual (HEI), receptor wells and surface water bodies were placed probabilistically within the areal extent of the ground water plume, as estimated from the modeled WMU size and soil properties selected for that model iteration. **Figure 4-5** shows a schematic of how residential well drinking water intakes and surface water bodies were defined by the model. This figure is intended to be illustrative and does not capture all possible receptor well and water body locations.

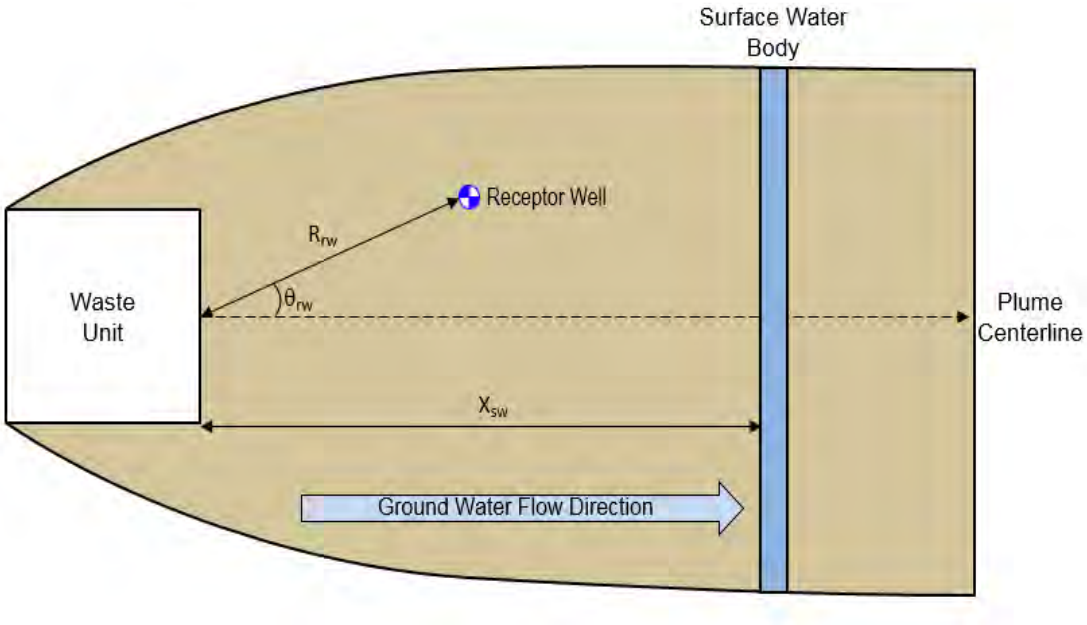

Figure 4-5. Aerial view of conceptual model for receptor location.

For wells, a radial distance (R_{rw}) from the downgradient edge of the WMU was probabilistically selected from a nationwide distribution developed by EPA based on known WMU locations and predicted household locations that incorporate 2000 Census data. The angle offset from plume centerline (θ_{rw}) was then selected from a uniform distribution ranging from 0 to 90 degrees. If the selected receptor well fell within the maximum boundary of the plume, then that well location was used. Otherwise, new values for R_{rw} and θ_{rw} were generated until the well fell within the plume. Once located, the depth of the well intake point was based on a uniform distribution ranging from the top of the water table to either the full saturated thickness of the aquifer or ten meters, whichever was less. This constraint is further discussed in U.S. EPA (2003b).

For surface water bodies, the straight-line distance (X_{sw}) from the downgradient edge of the WMU to the nearest surface water body was probabilistically selected from a nationwide distribution developed by EPA using GIS. The GIS tool used the geographic locations of the WMU and surrounding water bodies, along with topographical data, to determine the shortest flow path to nearby water bodies.

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4.7 Subsurface Transport

The following subsection provides an overview of the subsurface modeling conducted with EPACMTP. This model consists of two coupled modules that address subsurface transport through unsaturated and saturated zones. These modules treat soils as a uniform, porous medium and do not account for preferential pathways or facilitated transport. In the unsaturated zone, the flow of water is driven primarily by gravity. Therefore, flow is modeled entirely in the vertical direction, with negligible lateral (i.e., sideways) migration. This assumption can be made because the scale of lateral migration due to dispersion will be orders of magnitude less than the scale of vertical migration through WMU footprints (U.S. EPA, 2003b). In the saturated zone, EPACMTP assumes that the movement of COPCs is driven primarily by the ground water advection. Flow in the saturated zone is controlled primarily by the hydraulic conductivity of the aquifer and the regional hydraulic gradient. However, the flow may be altered both by mounding underneath the WMU from high volumes of leachate, which enhances the spreading of the constituent plume in all directions, and by uncontaminated recharge from precipitation that falls around the WMU, which increases mixing in the vertical direction. In addition to advection, EPACMTP also accounts for the mixing of ground water due to dispersion, which occurs to some degree in all directions.

During transport through both the unsaturated and saturated zones, COPCs may sorb to the surrounding soils. This process is represented by K_d. For most inorganics, K_d values are strongly dependent on the concentration present in leachate, with the K_d values generally decreasing with higher concentrations. For most COPCs[13], the K_d values used in this analysis were drawn from COPC-specific distributions of K_d values versus leachate concentrations, also known as sorption isotherms. EPA selected nonlinear isotherms as the most representative of changes in sorption as leachate concentrations decrease during transport through soil and ground water. CCR-specific nonlinear sorption isotherms were generated by Metal Speciation Equilibrium Model for Surface and Ground Water (MINTEQA2) (U.S. EPA, 2001) for this risk assessment based on CCR leachate chemistry. The development of these isotherms is described in detail in **Appendix H**.

- **Surface Impoundments.** To select K_d values for surface impoundments, one of the three waste types was probabilistically assigned to the surface impoundment at the start of each model iteration. A pore water sample was then selected based on the selected waste type to provide leachate pH.[14] Where pH data were not available for a particular waste sample, a value was probabilistically selected from the empirical distribution of pH data available for that waste type. Iron oxide, natural organic matter and leachate ionic strength were then probabilistically selected based on the selected waste type. These data were used together with COPC concentrations to identify isotherms for that model iteration. The pore water concentrations exiting the surface impoundment were used to select K_d values for the

[13] A single (constant) soil K_d value from Baes et al. (1984) was used for iron and both chloride and lithium were modeled as conservative tracers (Eriksson and Kunakasem, 1969) by setting the K_d values to 0 because data were not available to determine valid ranges or distributions for these three COPCs.

[14] No leachate data were available for antimony, beryllium, lithium, and thallium in ash and coal refuse.

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unsaturated zone module, while the soil pore water concentrations at the boundary of the unsaturated and saturated zones were used to select K_d values for the saturated zone module.

- **Landfills.** Because of inherent differences between the pore water samples used for surface impoundments and the LEAF data used for landfills, MINTEQA2 isotherms were selected somewhat differently for landfills. During the sampling conducted to develop the LEAF data set, EPA determined that the range and variability of waste pH was best represented by a single leachate pH distribution across all waste types (U.S. EPA, 2009a). To accommodate this single pH distribution, all other waste data, such as iron oxide, were drawn from the same distributions developed for the combined ash waste type. To select a MINTEQA2 isotherm for each model iteration, a leachate pH was randomly selected from the distribution. Based on the pH, iron oxide, natural organic matter and leachate ionic strength were probabilistically selected from the distributions. These data were used together with COPC concentrations to identify isotherms for that model iteration. The leachate concentrations exiting the landfill were used to select K_d values for the unsaturated zone module, while the soil pore water concentrations at the boundary of the unsaturated and saturated zones were used to select K_d values for the saturated zone module.

Constituents with low K_d values will have low retardation factors and may move at nearly the same velocity as the ground water. Constituents with high K_d values will have high retardation factors and may move much more slowly than ground water. The subsurface migration of some constituents may be very slow and it may take a substantial amount of time for the constituent plume to reach the downgradient receptors. As a result, the maximum concentration may not occur until thousands of years after the WMU has ceased operations. To prevent prohibitive model run times, while not missing significant risks to potential receptors, EPA ran the model until either the observed ground water concentration of a constituent at the receptor point peaked and then fell below a model-specified minimum concentration (10^{-16} mg/L), or the model had been run for a total duration of 10,000 years.

4.8 Surface Water Modeling

The following section provides an overview of the surface water modeling within the probabilistic framework. Downgradient surface water bodies can be impacted through the discharge of contaminated ground water. EPA first developed a separate surface water model used in conjunction with EPACMTP to calculate the fraction of the ground water plume that is intercepted by a surface water body (**Section 4.8.1**). Next, an equilibrium partitioning model, which calculated the steady-state into water and sediment (**Section 4.8.2**), and a precipitation model specifically for aluminum, which partitioned based on the maximum amount that may be dissolved in a water body (**Section 4.8.3)** were used to calculate the equilibrium COPC concentrations present in surface water and sediments. Finally, a food web model was used to calculate the COPC concentrations in fish (**Section 4.8.4**). Further discussion of each of these models and the associated inputs is presented in **Appendix J**.

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4.8.1 Interception by Water Body

EPACMTP outputs COPC concentrations at a downgradient receptor location as a function of time. A separate surface water model used these ground water concentrations, together with the velocity of both the ground water and surface water, to calculate a mass flux of ground water into a water body. To do so, the following simplifying assumptions were required:

- The direction of regional ground water flow is perpendicular to the water body;
- The water body intercepts the entire width of the ground water plume;
- The water body receives flow from the ground water year-round;
- Lakes always intercept the entire vertical extent of the ground water plume;
- Smaller streams may only partially penetrate the shallow aquifer, allowing some or all of the mass in the contaminated ground water to be transferred to the surface water;
- If the average annual stream flow in a reach was less than the rate of ground water flow, all of the stream flow is assumed to originate from ground water discharge, and the total COPC concentration in the stream is equal to the concentration in ground water;
- There is instantaneous mixing in the stream, resulting in full and homogenous mixing of the ground water with the surface water in the stream segment.

EPACMTP is not designed to account for the mass loss calculated by other models. Instead, EPACMTP first calculated well concentrations as though water bodies were not present. A second model adjusted these well concentrations to account for surface water interception. If the entire ground water plume was intercepted, the model revised the well concentration to zero. If some of the ground water plume was not intercepted and continued to migrate toward the receptor well, then the model used the rate of discharge into the water body to iteratively solve the ground water fate and transport equations used by EPACMTP and calculate a new well concentration by translating the mass lost to the water body into additional dilution and dispersion in ground water.

4.8.2 Equilibrium Partitioning Model

A steady-state equilibrium-partitioning model was used to determine the relative amounts of each COPC entering a water body that would remain dissolved in the water and that would sorb to sediments. This model was adapted from the EPA Indirect Exposure Methodology (U.S. EPA, 1998b) and Human Health Risk Assessment Protocol (U.S. EPA, 2005k), and was used for all constituents except aluminum (see **Section 4.8.3**). With this model, COPC loading rates (mass/time) were first divided by the water body flow rates (volume/time) to yield an overall water body concentration. The model then used partitioning coefficients to divide the mass of each COPC entering the water body into the separate fractions dissolved in the water column, sorbed onto suspended solids, sorbed onto sediment particles at the bottom of the water body, and dissolved in pore water in the sediment layer. This risk assessment does not account for potential COPC losses due to burial.

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4.8.3 Aluminum Precipitation Model

A separate model was used to identify the concentration of aluminum in surface water bodies. Unlike the other constituents modeled, the maximum concentration of aluminum that can be present in natural waters can be limited by solubility as a result of changes in the prevailing environmental conditions (e.g., pH) between ground water and a surface water body. Therefore, a precipitation model from MINTEQA2 was used to calculate aluminum concentrations in place of the equilibrium-partitioning model used for other COPCs. The maximum soluble aluminum concentration was calculated as a function of pH for a simplified surface water body using relationships drawn from the literature (Stumm and Morgan, 1996; Drever, 1988). The common aluminum mineral gibbsite (aluminum hydroxide) was assumed to be the solid phase for all precipitant, and the upper bound on dissolved water concentrations was assumed to be the highest solubility limit reported for each pH value. The precipitation model initially calculated the aluminum concentration in the surface water column by assuming that all aluminum entering the water body was dissolved. If this concentration exceeded the maximum soluble concentration based on the pH of the water body, the dissolved concentration was capped and all excess aluminum precipitated out as the mineral gibbsite to the benthic sediment layer.

4.8.4 Aquatic Food Web Model

An aquatic food web model was used to estimate the COPC concentrations in fish. The model uses COPC concentrations dissolved in the water column and sorbed to suspended solids to calculate the resulting concentration in fish tissue based on BCFs that account for both sources. The Agency considered exposures to TL3 and TL4 fish separately because the degree of bioconcentration may differ between these two trophic levels. TL3 consists of carnivores (i.e., carp, smelt, perch, catfish, sucker, bullhead, sauger) that eat herbivores or secondary consumers, while TL4 consists of carnivores (i.e., salmon, trout, walleye, bass) that eat other carnivores. Together, these two trophic levels are assumed to comprise all of the fish consumed by receptors.

4.9 Exposure and Risk

Each model iteration generated COPC concentrations at a specified location (receptor well or water body) as a function of time. For every model iteration, the maximum (i.e., peak) concentration at each time step was identified. Next, the single year of highest concentration across all modeled time steps was identified. Finally, a time-weighted exposure concentration was calculated by averaging the peak concentrations for each COPC at each time step over the specified exposure duration, centered around the year of highest concentration. For the GW→DW pathway, HEI exposures were calculated using a probability distribution of exposure durations that ranged anywhere from one to fifty years, based on the amount of time spent at a given residence. For the GW→SW pathway, HEI exposures were calculated based on the same distribution. Due to uncertainties about the ecological exposure durations, these exposures were based on the single year of highest concentration. In cases where the ground water concentration was found to still be increasing after 10,000 years, EPACMTP stopped modeling and used the ground water concentration at that final year to estimate exposures for all receptors.

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Risks were calculated using the same equations as the screening analysis in **Section 3**. However, to the extent that data were available, full probability distributions were used to characterize each of the human exposure factors (See **Appendix D**). The risks calculated for each model iteration were aggregated into separate probability distributions for the different combinations of WMU, exposure pathway, and receptor type. From these distributions, EPA selected high-end and median risk estimates to characterize the range of risks posed to human health and the environment from current CCR disposal practices. For the purposes of this risk assessment, EPA defined high-end risk based on the recommendations of the *Guidance for Risk Characterization* (U.S. EPA, 1995) as the 90th percentile of risks to the exposed population generated by the Monte Carlo simulation. These risks were compared to the selected risk criteria of cancer risks > 1×10^{-5} and HQs > 1.

4.10 Probabilistic Risk Analysis Results

EPA modeled the full universe of facilities, landfills and impoundments discussed throughout this document. However, after modeling was completed, a number of facilities, surface impoundments and landfills were discovered to be outside the scope of the rule for one of the following reasons:

- The facility was no longer a coal-fired electric utility according to the 2012 EIA database;
- The landfill or surface impoundment was found to be inactive or retired; or
- The surface impoundment was not designed to accumulate CCRs (e.g., cooling water ponds).

In total, 218 surface impoundments and 122 landfills that were modeled met these criteria, and were filtered from the results. A column denoting whether or not a WMU was excluded can be found in **Attachment A-2**. For the remaining impoundments, risks are presented for all COPCs found to exceed risk criteria in the screening analysis in **Section 3**. Because the 2010 Risk Assessment (U.S. EPA, 2010) demonstrated that risks from surface impoundments are consistently higher than those from landfills, these impoundment results were used as a secondary screening to identify COPCs to be modeled for landfills. To ensure that this approach did not underestimate risks, landfill modeling included all COPCs found to exceed risk criteria for any subset of surface impoundments during subsequent sensitivity analyses discussed in **Section 5**.

4.10.1 Human Health Risk Results

90th percentile risks for human receptors are presented in **Table 4-2**. These risks represent all of the modeled impoundments and landfills subject to the rulemaking. Both cancer and noncancer risks are presented for the highest exposed receptor group. For drinking water ingestion, the highest cancer risks were for adults (Ages > 21 years), while the highest noncancer risks were for infants (Age < 1 year). For fish ingestion, the highest cancer and noncancer risks were for children (Ages 1 to < 2 years). Values that exceed the selected risk criteria (i.e., cancer risk > $1x10^{-5}$ or HQ > 1) are shown in **bold**.

Table 4-2. 90th Percentile Nationwide Risk Results for Human Health

COPC	Surface Impoundments		Landfills	
	Drinking Water Ingestion	Fish Ingestion	Drinking Water Ingestion	Fish Ingestion
Carcinogenic Effects				
Arsenic III	**2×10^{-4}**	2×10^{-7}	5×10^{-6}	–
Arsenic V	1×10^{-5}	5×10^{-9}	7×10^{-8}	–
Chromium VI	6×10^{-7}	–	7×10^{-8}	–
Noncarcinogenic Effects				
Arsenic III	**5**	–	0.1	–
Arsenic V	0.4	–	< 0.01	–
Boron	0.6	–	< 0.01	–
Cadmium	0.04	< 0.01	–	–
Cobalt	0.01	–	< 0.01	–
Fluoride	0.2	–	– [a]	–
Lead	< 0.01	–	–	–
Lithium	**2**	–	– [b]	–
Mercury	–	0.02	–	0.01
Molybdenum	**2**	–	< 0.01	–
Selenium IV	–	< 0.01	–	–
Selenium VI	–	0.05	–	–
Thallium	0.9	0.04	0.08	–

– Constituent was not modeled for this pathway

a) Fluoride was found to slightly exceed risk criteria during one sensitivity analyses conducted for surface impoundments; however, Method 1313 data were not available to model this COPC for landfills.

b) Lithium was found to slightly exceed risk criteria in the probabilistic analysis for surface impoundments; however, Method 1313 data were not available in the literature to model this COPC for landfills.

For impoundments, the 90th percentile risks associated with ingestion of ground water were above cancer and noncancer criteria for arsenic III (risk = 2×10^{-4}, HQ = 5) and noncancer criteria for both lithium (HQ = 2) and molybdenum (HQ = 2). No risks above the human health criteria were identified for ingestion of fish. For landfills, no risks above the human health criteria were identified for any pathway. Consistent with the findings of the 2010 Risk Assessment, risks from landfills are consistently lower than those from surface impoundments. 50th percentile risks were also calculated for both surface impoundments and landfills, but are not shown because risks fell below all criteria.

4.10.2 Ecological Risk Results

90th percentile risks for ecological receptors are presented in **Table 4-3**. These risks represent all of the modeled impoundments and landfills subject to the rulemaking. For all surface water and sediment risks, the sensitive ecological receptor is defined by the available benchmarks.

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Table 4-3. 90th Percentile Nationwide Risk Results for Ecological Receptors

COPC	Surface Impoundments		Landfills	
	Surface Water	Sediment	Surface Water	Sediment
Aluminum	< 0.01	–	–	–
Antimony	–	0.06	–	–
Arsenic III	0.02	0.1	–	0.02
Arsenic V	< 0.01	< 0.01	< 0.01	–
Barium	< 0.01	–	–	–
Beryllium	< 0.01	–	–	–
Boron	0.3	–	< 0.01	–
Cadmium	0.1	–	–	–
Chloride	0.03	–	–	–
Chromium III	< 0.01	–	–	–
Chromium VI	< 0.01	–	–	–
Cobalt	< 0.01	–	–	–
Copper	< 0.01	–	–	–
Iron	< 0.01	–	–	–
Lead	< 0.01	–	–	–
Molybdenum	0.09	–	–	–
Nickel	< 0.01	–	–	–
Selenium IV	< 0.01	–	–	–
Selenium VI	0.1	–	–	–
Silver	0.06	0.02	–	–
Vanadium	< 0.01	< 0.01	–	–
Zinc	< 0.01	–	–	–

– Constituent was not modeled for this pathway

No 90th percentile risks above the ecological criteria were identified for either surface water or sediment for either surface impoundments or landfills. 50th percentile risks were also calculated for both surface impoundments and landfills, but are not shown because all fell well below the selected risk criteria.

4.10.3 Summary of Probabilistic Analysis

EPA conducted the probabilistic analysis described in this section to better characterize the potential risks to human and ecological receptors associated with leaching from WMUs to ground water. The potential exposure routes identified for this pathway were human ingestion of ground water and fish and ecological contact with and ingestion of surface water and sediment. To evaluate each of these exposure routes, the probabilistic analysis combined site-specific data with regional and national data to conduct a total of approximately 100,000 model iterations per COPC that

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capture the full range and frequency of disposal practices known to occur. These iterations form the basis for the risk results.

The modeling results showed 90th percentile risks above the human health criteria from surface impoundments. Human health exposures from the ingestion of ground water resulted in the highest risks, with a cancer risk of 2×10^{-4} and noncancer HQ of 5 for arsenic III and a noncancer HQ of 2 for molybdenum. Human health exposures from ingestion of fish, as well as all ecological exposures fell below risk criteria. All 90th percentile risks for landfills also fell below these thresholds.

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5 Sensitivity and Uncertainty Analyses

The probabilistic analysis presented in **Section 4** identified the potential for risks to human health through the ingestion of ground water that results from leaching of arsenic and molybdenum from surface impoundments. These risks reflect the full range of current, nationwide CCR disposal practices and, because of this broad scope, there are numerous sources of uncertainty present within the probabilistic analysis. To better understand the effect of these uncertainties on the modeled risks and to determine if any particular subset of disposal practices drive the risks identified, EPA conducted additional sensitivity and uncertainty analyses. The purpose of this section is to describe the results of these additional analyses, to identify the model parameters with the greatest potential to influence calculated risks and, to characterize the potential effects of these parameters on the principal results of the probabilistic analysis. This discussion is divided into the following subsections:

- **Section 5.1** provides an overview of the major sources of uncertainty in the probabilistic analysis, as well as a qualitative and, where possible, quantitative characterization of each.
- **Section 5.2** presents a summary of the sensitivity analysis conducted in support of the 2010 Risk Assessment (U.S. EPA, 2010a) and compares the sensitive parameters identified with the findings of the revised sensitivity and uncertainty analyses;
- **Section 5.3** compares trends in the characteristics of proven and potential damage cases with the findings of the revised sensitivity and uncertainty analyses;
- **Section 5.4** summarizes the results for the revised sensitivity and uncertainty analyses, as well as for the comparisons of these results with the previous sensitivity analysis and the proven and potential damage cases.

5.1 Variability, Data Uncertainty and Model Error

Uncertainty exists to some degree in any quantitative evaluation, and it may bias the calculated results higher or lower than actual values. It is important to understand both the direction and magnitude of uncertainties present in a risk assessment. The direction of uncertainty is the tendency for that uncertainty to push a predicted value higher or lower than the actual value, while the magnitude of uncertainty is the extent to which that uncertainty may push a predicted value away from the true value. Characterizing these uncertainties helps to ensure that the overall conclusions of the evaluation would not change with the consideration of additional information. There are three primary causes of uncertainty:

- Variability is the extent to which characteristics of environmental systems are heterogeneous, and is reflected in the parameter distributions used as inputs for the models. Although variability can be better captured by collecting additional data, it cannot be eliminated and must be treated explicitly in the assessment.

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- Data uncertainty is a description of the imperfection in knowledge of the true value of a particular parameter. Uncertainty is generally reducible through additional research and information-gathering.
- Model error occurs because models and their mathematical expressions are simplifications of reality that are used to approximate real-world conditions, processes and their relationships. These assumptions are sometimes necessary to solve complex mathematical equations or to fill gaps in available knowledge. However, the simplification of complex systems may misrepresent real-world conditions to an unknown degree.

The uncertainties identified in the probabilistic analysis were managed to the extent practicable to minimize potential effects on the model results. Variability was addressed to the extent possible by compiling available data into probabilistic distributions for each parameter. Uncertainty about the exact range or distribution of a parameter was addressed through the use of estimated point values or distributions intended to appropriately bound the true range, biased toward protection of human health and the environment. **Table 5-1** lists the general categories of uncertainties identified, along with the different portions of the document text where these topics are discussed.

Table 5-1. Summary of the Categories of Uncertainty Present in the Probabilistic Analysis and the Discussion Locations within the Risk Assessment Text

Uncertainty	Location of Original Discussion	Location of Corresponding Uncertainty Discussion
CCR WMU Database	Section 2 and Appendix A	Section 5.1.1
Environmental Parameters	Section 2 and Appendix B	Section 5.1.2
CCR Constituent Database	Section 2 and Appendix C	Section 5.1.3
Human Exposure Factors	Section 2 and Appendix D	Section 5.1.4
Human Health & Ecological Benchmarks	Section 2 and Appendix E	Section 5.1.5
Bioconcentration Factors	Section 3 and Appendix G	Section 5.1.6
WMU Source Term Models	Section 4 and Appendix I	Section 5.1.7
MINTAQA2 Isotherm Model	Section 4 and Appendix H	Section 5.1.8
EPACMTP Ground Water Model	Section 4 and Appendix I	Section 5.1.9
Surface Water Model	Section 4 and Appendix J	Section 5.1.10
Risk Models	Section 4	Section 5.1.11

5.1.1 CCR WMU Database

The CCR WMU database was populated with data from two EPA surveys conducted in 2009 and 2010. These surveys provide data on a total of 952 surface impoundments and 431 landfills at 383 facilities out of the known universe of 507 facilities that burn coal and dispose of the resulting waste on-site. The inclusion of data from these surveys greatly increased the information available on the characteristics of WMUs. The total number of facilities and WMUs will fluctuate over time. However, the CCR WMU database provides broad representation of operating facilities at the time

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it was compiled. Some gaps do exist in the database as a result of survey design, erroneous or unclear responses, and claims of confidential business information. These gaps were filled probabilistically, based on the distributions of available data. As discussed below, because the available data are far more representative sample than previously available and cover a large proportion of existing facilities, it is unlikely that this represent a major source of uncertainty.

Geographic Location Data

When locations were known for a specific WMU, the probabilistic analysis held this parameter constant for all model iterations associated with that unit. Because many of the environmental parameters used in the models were selected based on geographic location, the location does influence the analysis. Specific geographic coordinate locations were known for 67 percent of surface impoundments and for 81 percent of landfills. In cases where locations were not known, the location of the facility front gate or centroid reported in the 2009 EIA were used to place these units as close to actual locations as possible. In addition, where possible, the locations were verified by reviewing geo-referenced aerial photographs in GIS. While there is still some uncertainty associated with exact locations for a portion of WMUs in the full data set, the influence on results is anticipated to be small given the regional-scale resolution of most environmental data.

WMU Dimension Data

When area, thickness, or capacity was known for a specific WMU, the probabilistic analysis held these parameters constant for all model iterations associated with that unit. When no data were available or reported values were found to be unrealistic, these data gaps were filled during each model iteration by sampling probabilistically from the distributions developed from WMUs with data (see **Appendix A**). Area measurements were known for 92 percent of the surface impoundments and for 39 percent of landfills.

The full distribution of known area measurements for both surface impoundments and landfills were divided into separate distributions based on the annual amount of coal burnt (or "coal use"), available in the 2009 EIA database. First, the coal use reported for every facility was compiled into a single distribution and then divided into quartile ranges. The area measurements for the surface impoundments and landfills present at each facility in a coal use quartile range were combined into a total of four new area distributions. Where area measurements were unknown for a given unit, a fixed area distribution was assigned and probabilistically sampled based on the coal use reported for the corresponding facility. This approach ensured that the larger area measurements for large WMUs were not inadvertently assigned to smaller facilities. This coal use quartile-based probabilistic sampling may over- or underestimate dimensions for individual model iterations. However, the aggregate results reflect a national distribution with the best available data. As a result, this approach is unlikely to introduce much additional uncertainty.

Liner Data

When liner types were known for a specific WMU, the probabilistic analysis held these parameters constant for all model iterations associated with that unit. Specific liner types were known for 64 percent of surface impoundments and for 53 percent of landfills. When no data were available on

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liner type, this data gap was filled during each model iteration by sampling probabilistically from the distribution developed from WMUs with data. In cases where survey responses indicated the presence of a liner, but did not specify the type (additional 5 percent of surface impoundments and 34 percent of landfills), each model iteration sampled probabilistically from the distribution developed from WMUs with liners. This probabilistic sampling may not accurately represent liner type for specific WMUs, but the aggregate results likely reflect the larger national distribution due to the high proportion of known liner types. Thus, this approach is unlikely to result in much additional uncertainty.

Liner Assignment

The three liner types modeled in the probabilistic analysis are unlined, clay-lined and composite-lined. Although a number of different liner configurations were reported in the 2009/2010 EPA surveys, each was modeled as one of these three types. WMUs reported as lined with CCR waste, concrete, asphalt or other nonstandard liner materials were categorized as unlined because of the high likelihood cracks that would eliminate the effectiveness of the liner without constant maintenance. WMUs reported as lined with some form of natural or synthetic clay were categorized as clay-lined. WMUs reported as lined with some form of composite or flexible membrane liner were categorized as composite-lined. These three liner types were assigned because site-specific information on the effective hydraulic conductivities in the field were not readily available. Even if this type of data were available, the hydraulic conductivity of these liners as designed or currently measured may not capture higher leakage rates that result from cracks and tears that develop over time without proper monitoring and corrective action. The binning of reported liners into the three modeled categories is believed to best represent the range of liner behavior and introduce a small amount of uncertainty into the probabilistic analysis.

Liner Prevalence

A recent 2006 study conducted jointly by EPA and DOE (U.S. DOE, 2006) found that liners are more likely to be present in newly constructed WMUs and new expansions of existing WMUs. Between 1994 and 2004, 100 percent of the new impoundments (out of 20) and 97 percent of the new landfills (out of 42) included in the study contained some type of liner. **Table 5-2** provides a full comparison of the liner information in the CCR WMU database.

Table 5-2. Number and Percentages of WMUs with Different Liner Types Constructed Before and After 2000

Liner Type	Surface Impoundments						Landfills					
	Pre-2000		Post-2000		Unknown Date		Pre-2000		Post-2000		Unknown Date	
Total	**952**						**431**					
Unlined	371	(48%)	7	(12%)	28	(24%)	154	(52%)	12	(20%)	7	(10%)
Lined	198	(25%)	38	(63%)	16	(14%)	140	(47%)	48	(80%)	13	(17%)
Unknown	207	(27%)	15	(25%)	72	(62%)	3	(1%)	0	(0%)	54	(73%)

Note: Counts are derived by start year using the 2009/2010 EPA surveys. Some WMUs did not contain start years (unknown date column), while others may contain start years but not liner type information (unknown row).

Even though most of the recently constructed surface impoundments and landfills are lined in some fashion, the majority of units currently in operation remain unlined. Because this risk assessment evaluated current waste management practices, it does not examine the potential for future changes in liner types. However, because the majority of units in operation are unlined, EPA did consider the extent to which these units drive the modeled risks presented in **Section 4**. This sensitivity analysis was conducted by filtering the full distribution of risks into three separate distributions, one for each liner type, for surface impoundments and for landfills.

Table 5-3 shows the 90th percentile human and ecological risks separated out for unlined, clay-lined and composite-lined surface impoundments. Risks are presented for each constituent modeled in the probabilistic analysis that was also above risk criteria in this sensitivity analysis. Arsenic V risks are provided even where below criteria to provide a bound on arsenic speciation. Values that exceed the risk criteria (i.e., cancer risk > $1x10^{-5}$ or HQ > 1) are shown in **bold**.

Table 5-3. 90th Percentile Risk Exceedances by Liner Type: Surface Impoundments

COPC	Liner Type	Percent of Iterations	Human Health		Ecological	
			GW→DW Tap Water Ingestion	GW→SW Fish Ingestion	GW→SW Surface Water	GW→SW Sediment
Cancer Risk						
Arsenic III	Unlined	65%	**3×10^{-4}**	7×10^{-7}	—	—
	Clay Lined	18%	7×10^{-6}	2×10^{-9}	—	—
	Composite Lined	17%	$< 1 \times 10^{-10}$	$< 1 \times 10^{-10}$	—	—
Arsenic V	Unlined	65%	**4×10^{-5}**	3×10^{-8}	—	—
	Clay Lined	18%	1×10^{-7}	$< 1 \times 10^{-10}$	—	—
	Composite Lined	17%	$< 1 \times 10^{-10}$	$< 1 \times 10^{-10}$	—	—
Noncancer Risk						
Arsenic III	Unlined	65%	**8**	—	0.06	0.4
	Clay Lined	18%	0.2	—	< 0.01	< 0.01
	Composite Lined	17%	< 0.01	—	< 0.01	< 0.01
Arsenic V	Unlined	65%	1	—	0.06	0.02
	Clay Lined	18%	< 0.01	—	< 0.01	< 0.01
	Composite Lined	17%	< 0.01	—	< 0.01	< 0.01
Lithium	Unlined	65%	**3**	—	—	—
	Clay Lined	18%	**2**	—	—	—
	Composite Lined	17%	< 0.01	—	—	—
Molybdenum	Unlined	65%	**4**	—	0.2	—
	Clay Lined	18%	0.1	—	< 0.01	—
	Composite Lined	17%	< 0.01	—	< 0.01	—
Thallium	Unlined	65%	**2**	0.1	—	—
	Clay Lined	18%	0.02	< 0.01	—	—
	Composite Lined	17%	< 0.01	< 0.01	—	—

As seen in the table above, unlined units present the greatest risks. These unlined units result in cancer risks above 1×10^{-5} for arsenic III (3×10^{-4}) and arsenic V (4×10^{-5}), as well as noncancer risks above an HQ of 1 for arsenic III (8), molybdenum (4) and thallium (2). In many cases, due to the prevalence of unlined units, the risks for these units alone are similar to those for all units in the full-scale probabilistic modeling (**Section 4**). Clay-lined units present risks lower than unlined units, with noncancer risks above an HQ of 1 for lithium (2). Composite-lined units present risks far below all relevant risk criteria for all constituents.

Table 5-4 shows the 90th percentile human and ecological risks separated out for unlined, clay-lined and composite-lined landfills. Risks are presented for each constituent modeled in the probabilistic analysis that was also above risk criteria in this sensitivity analysis. In some instances, arsenic V risks are provided even where below criteria to provide a complete bounding on arsenic speciation. Values that exceed the selected risk criteria (i.e., cancer risk > $1x10^{-5}$) are shown in **bold**. No noncancer risks above human health criteria were identified.

Table 5-4. 90th Percentile Risk Exceedances by Liner Type: Landfills

COPC	Liner Type	Percent of Iterations	Human Health	
			GW→DW Tap Water Ingestion	GW→SW Fish Ingestion
Cancer				
Arsenic III	Unlined	42%	**2×10^{-5}**	—
	Clay Lined	25%	1×10^{-5}	—
	Composite Lined	33%	$< 1 \times 10^{-10}$	—
Arsenic V	Unlined	42%	1×10^{-6}	—
	Clay Lined	25%	3×10^{-7}	—
	Composite Lined	33%	$< 1 \times 10^{-10}$	—

Similar to surface impoundments, unlined landfills present the greatest risks. Unlined landfills result in cancer risks above 1×10^{-5} for arsenic III (2×10^{-5}). Clay-lined landfills present risks lower than unlined units and composite-lined units present risks far below all relevant risk criteria.

Impoundment Waste Type Assignment:

Waste pH is the primary factor used to determine appropriate K_d values, which dictate the rate at which COPCs move through the subsurface environment. EPA identified insufficient data to develop a national pH distribution for wastes disposed in surface impoundments. Instead, this risk assessment divided the available data into discrete waste types that reflect similar leachate pH conditions and ion concentrations. The modeled waste types include combined ash, ash and coal refuse, and FGD waste. When the type of CCR type disposed in an impoundment was known, the analysis assigned a fixed waste type based on the CCRs disposed for all model iterations. CCR types were known for 97 percent of the impoundments. When no data were available on the CCR type disposed in a unit, this data gap was filled during each model iteration by sampling probabilistically from the distribution of known waste types for other WMUs. This probabilistic sampling may over- or under-estimate leachate concentrations for individual model iterations.

However, given that waste types are known for the vast majority of units, this uncertainty is likely to have a negligible impact on the modeled national-scale risks.

Landfill Waste Type Assignment

Waste pH is the primary factor used to determine appropriate K_d values, which determine the rate at which COPCs move through the subsurface environment. Unlike for surface impoundments, a representative national distribution of pH values was available for landfills. This information was drawn from a nation-wide distribution of CCR waste pH compiled as part of U.S. EPA (2009a). **Figure 5-1** provides a graph of this pH distribution for landfills. Because a representative distribution was available for landfills, the segregation of different waste types was not needed to identify appropriate K_d ranges for each unit.

The pH of CCR wastes as managed range from around 3 to 13. Although the total pH range is wide, the majority of wastes are more basic, with a median value between 10 and 11. CCR wastes managed with coal refuse can be substantially more acidic, which accounts for some of the distribution far below a pH of 7. Similarly, FGD materials can be very basic, which accounts for some of the distribution above a pH of 11. Because this pH distribution provides the full range and relative frequency for different waste pH, treatment of CCRs disposed in landfills as a single waste type still captures the possible variations in K_d values. Thus, this introduces minimal uncertainty.

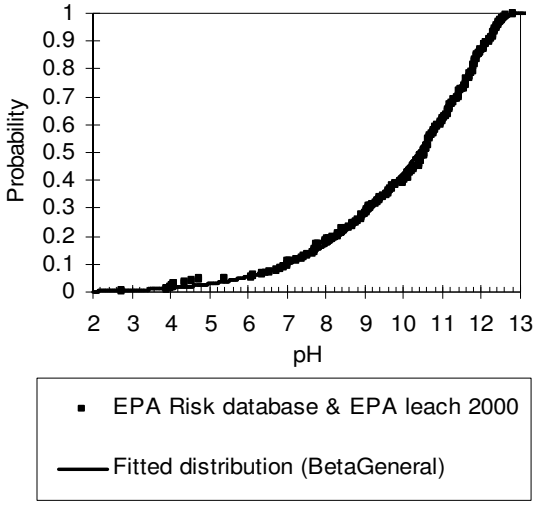

Figure 5-1. Measured landfill CCR waste pH values [Adapted from U.S. EPA (2009a)].

Waste Type Prevalence

A survey conducted by EPRI in 1995 showed that 34 percent of unlined landfills and 68 percent of unlined surface impoundments actively managed CCR wastes with coal refuse. However, the more recent 2009/2010 EPA surveys indicate that this management practice has declined significantly to around five percent of current units. At present, EPA has no data on trends in the generation of FGD waste. Because this risk assessment evaluated current waste management practices, it does not examine the potential for future shifts in the relative amounts of different waste types disposed. Yet, waste pH has been shown to be a key factor in leachate concentrations and these two waste types are more likely to have an extreme pH. Therefore, EPA did consider the extent to which management of these different waste types may drive the probabilistic risks presented in **Section 4**.

For surface impoundments, this sensitivity analysis was conducted by filtering the full distribution of risks into three separate distributions, one for each waste type. **Table 5-5** shows the 90th percentile human and ecological risks separated out for combined ash, ash and coal refuse, and FGD wastes. Risks are presented for each constituent modeled in the probabilistic analysis that was also above risk criteria in this sensitivity analysis. Values that exceed the risk criteria (i.e., cancer risk > 1×10^{-5} or HQ > 1) are shown in **bold**.

Table 5-5. 90th Percentile Risk Exceedances by Waste Type: Surface Impoundments

Constituent	Waste Type	Percent of Iterations	Human Health		Ecological	
			GW→DW Tap Water Ingestion	GW→SW Fish Ingestion	GW→SW Surface Water	GW→SW Sediment
Cancer Risks						
Arsenic III	Combined Ash	85%	**2×10^{-4}**	2×10^{-7}	—	—
	Ash & Coal Refuse	5%	**1×10^{-3}**	1×10^{-6}	—	—
	FGD Waste	10%	**2×10^{-4}**	2×10^{-7}	—	—
Arsenic V	Combined Ash	85%	1×10^{-5}	3×10^{-9}	—	—
	Ash & Coal Refuse	5%	**4×10^{-4}**	3×10^{-7}	—	—
	FGD Waste	10%	**2×10^{-5}**	1×10^{-8}	—	—
Noncancer Risks						
Arsenic III	Combined Ash	85%	**4**	—	0.02	0.1
	Ash & Coal Refuse	5%	**26**	—	0.1	0.8
	FGD Waste	10%	**5**	—	0.02	0.1
Arsenic V	Combined Ash	85%	0.3	—	< 0.01	< 0.01
	Ash & Coal Refuse	5%	**14**	—	0.7	0.2
	FGD Waste	10%	0.5	—	0.03	< 0.01
Boron	Combined Ash	85%	0.6	—	0.3	—
	Ash & Coal Refuse	5%	0.2	—	0.3	—
	FGD Waste	10%	**2**	—	**5**	—
Cadmium	Combined Ash	85%	0.03	< 0.01	0.1	—
	Ash & Coal Refuse	5%	0.6	0.04	**3**	—
	FGD Waste	10%	0.06	< 0.01	0.2	—
Cobalt	Combined Ash	85%	0.01	—	< 0.01	—
	Ash & Coal Refuse	5%	**13**	—	0.05	—
	FGD Waste	10%	0.02	—	< 0.01	—
Fluoride	Combined Ash	85%	0.1	—	—	—
	Ash & Coal Refuse	5%	0.2	—	—	—
	FGD Waste	10%	**2**	—	—	—
Lithium	Combined Ash	89%	**3**	—	—	—
	Ash & Coal Refuse	—	—[a]	—	—	—
	FGD Waste	11%	0.4	—	—	—
Mercury	Combined Ash	85%	—	0.02	—	—
	Ash & Coal Refuse	5%	—	**5**	—	—
	FGD Waste	10%	—	< 0.01	—	—
Molybdenum	Combined Ash	85%	**2**	—	0.1	—
	Ash & Coal Refuse	5%	1	—	0.1	—
	FGD Waste	10%	1	—	0.03	—

a) Leachate data were not available to model ash & coal refuse.

Disposal of combined ash resulted in risks very similar to those identified in the full probabilistic modeling because this waste type comprised the majority of model iterations. Codisposal of ash

and coal refuse resulted in risks for select constituents higher than for combined ash and above human health and ecological criteria. Cancer risks above 1×10^{-5} were identified for arsenic III (1×10^{-3}) and arsenic V (4×10^{-4}) from ingestion of ground water. Noncancer risks above an HQ of 1 were identified for arsenic III (26), arsenic V (14), and cobalt (13) from ingestion of ground water; for mercury (5) from fish ingestion; and for cadmium (3) from ecological exposure to surface water. Disposal of FGD waste also resulted in higher risks for select constituents than for combined ash. Cancer risks above 1×10^{-5} were identified for arsenic III (2×10^{-4}) and arsenic V (2×10^{-5}) from ingestion of ground water. Noncancer risks above an HQ of 1 were found for arsenic III (5), boron (2) and fluoride (2) from ingestion of ground water.

For landfills, this sensitivity analysis was conducted by filtering the full risk distribution into discrete pH ranges. Since it was the main risk driver for landfills, this sensitivity analyses was conducted for arsenic (both III and V). **Table 5-6** shows the 90th percentile human and ecological risks separated out for the target pH ranges specified by Method 1313 (U.S. EPA, 2012d). No risks were found to be above either the cancer or noncancer criteria. (i.e., cancer risk > 1×10^{-5} or HQ > 1).

Table 5-6. 90th Percentile Ground Water Ingestion Risk Exceedances by Waste pH: Landfills

pH Range	Percent of Iterations*	Cancer		Noncancer	
		As (III)	As (V)	As (III)	As (V)
3.5 – 4.5	1%	5×10^{-6}	4×10^{-6}	0.2	0.2
5.0 – 6.0	3%	3×10^{-6}	7×10^{-7}	0.1	0.02
6.5 – 7.5	6%	4×10^{-6}	$< 1 \times 10^{-10}$	0.1	< 0.01
7.5 – 8.5	9%	5×10^{-6}	$< 1 \times 10^{-10}$	0.2	< 0.01
8.5 – 9.5	13%	4×10^{-6}	2×10^{-10}	0.1	< 0.01
10.0 – 11.0	20%	4×10^{-6}	3×10^{-9}	0.1	< 0.01
11.5 – 12.5	22%	5×10^{-6}	8×10^{-7}	0.1	0.03
12.5 – 13.5	4%	1×10^{-5}	6×10^{-6}	0.2	0.1

* The pH ranges reflect specific ranges specified by Method 1313 for reference. Because the pH distribution is not continuous, the percentage of runs does not add up to exactly 100%.

Exclusion of FBC Waste Type

In addition to the waste types modeled in this risk assessment, EPA also identified fluidized-bed combustion (FBC) wastes as a distinct waste type. The 2010 Risk Assessment modeled the FBC waste type separately for landfills, but not surface impoundments, because of the lack of impoundment pore water data available. This modeling showed that the risks associated with disposal of FBC waste in landfills were lower than those for other CCR waste types and below all risk criteria. Given these results and the lack of additional leachate data available since 2010, EPA did not re-evaluate FBC wastes in the revised risk assessment. Disposal of FBC as a monofill is only known to occur at two facilities. Given the rarity of this waste type and the lower risks modeled, exclusion of FBC waste from the revised risk assessment is unlikely to have an appreciable impact on modeled national-scale risks.

Below-Grade Geometry

The WMU depth below grade was used along with depth to water table to calculate the distance from the bottom of the WMU to ground water (the "depth to ground water" used in the unsaturated zone transport model). A data set drawn from an EPRI 1997 survey was utilized to generate the distribution of WMU depths below grade. The 2009/2010 EPA surveys indicate the potential for a larger proportion of surface impoundments to have above-grade construction, and fewer impoundments that are mostly or entirely below grade than modeled. This difference could result in greater depths to ground water associated with the 2009/2010 EPA survey data when compared with the EPRI 1997 data used in the risk assessment. EPA conducted a sensitivity analysis to assess the extent to which depth to ground water changes the risk results. For this analysis, depths were broken out into quartiles and model results were filtered into the four corresponding bins. Results are presented in **Table 5-7**. The 90th percentile results for the middle two quartiles, which make up the inner-quartile range, were the same for all constituents, and are reported as a single value. Values that exceed the risk criteria (i.e., cancer risk > 1×10^{-5} or HQ > 1) are shown in **bold**.

Table 5-7. 90th Percentile Ground Water Ingestion Risk Exceedances by Depth to Ground Water: Surface Impoundments

COPC	Depth to Ground Water Quartiles			
	Full Range of Depths	Lower Quartile (≤ 0.95 m)	Inner-Quartile (0.95 to ≤ 19 m)	Upper Quartile (> 19 m)
Cancer Risks				
Arsenic III	**2×10^{-4}**	**3×10^{-4}**	**1×10^{-4}**	**7×10^{-5}**
Arsenic V	1×10^{-5}	**2×10^{-5}**	1×10^{-5}	4×10^{-6}
Noncancer Risks				
Arsenic III	**5**	**6**	**4**	**2**
Arsenic V	0.4	0.6	0.3	0.1
Lithium	**2**	**2**	**2**	**3**
Molybdenum	**2**	**3**	**2**	1

While data from the 2009 EPA survey for surface impoundments indicates that a greater number of units may be constructed above grade, the focus of many of these surveys was on above-grade impoundments at risk of structural failure. Therefore, these data may be biased toward units with a greater fraction of the unit above the water table. Conversely, it is known from reported damage cases that some CCR WMUs come in direct contact with the water table for at least part of the year. The probabilistic analysis limited the depth of every WMU to the boundary of the water table because EPACMTP is not designed to solve for leaching from within the water table. Furthermore, EPACMTP considers the annualized transport of constituents. Modeling WMUs below the water table would effectively treat WMUs as submerged year-round, which is often not realistic given seasonally fluctuating water tables. Thus, the probabilistic analysis may over- or underestimate risk on a case-by-case basis. The exact magnitude of this uncertainty is unknown. However, even with greater depths to ground water, risks above cancer and noncancer criteria were still identified.

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Given that there is potential for both higher and lower risks than modeled, this uncertainty is unlikely to have an appreciable effect on the principal findings of the probabilistic analysis.

Pollution Control Technology

Because this risk assessment evaluated current management practices, it did not examine the potential for future changes in air pollution technologies to alter the composition of CCR wastes. However, it has been established that mercury pollution controls can affect both the mercury content and the general leaching behavior of ash (U.S. EPA, 2006a, 2008b, 2009a). Therefore, EPA considered the extent to which these mercury-control wastes may drive the modeled risks presented in **Section 4**. This sensitivity analysis was conducted by filtering the full risk results for the subset of fly ash samples generated by facilities with ACI. These samples were collected from a total of five different facilities with the ACI system turned on and off. This comparison allows a consistent frame of reference to judge the effect of ACI on releases from fly ash. **Table 5-8** shows a comparison of 90th percentile risk results for these samples. The table presents results for arsenic because it is the primary risk driver and mercury because public commenters raised concerns about the potential for new pollution control technologies to result in higher releases of this constituent.

Table 5-8. Comparison of 90th Percentile Landfill Risks for Facilities with Activated Carbon Injection (ACI) Turned On and Off

Constituent	ACI Status	Percent of Iterations per COPC	Human Health		Ecological	
			GW→DW Tap Water Ingestion	GW→SW Fish Ingestion	GW→SW Surface Water	GW→SW Sediment
Cancer Risks						
Arsenic III	Turned On	9%	8×10^{-6}	—	—	—
	Turned Off	9%	1×10^{-5}	—	—	—
Arsenic V	Turned On	9%	6×10^{-8}	—	—	—
	Turned Off	9%	8×10^{-8}	—	—	—
Noncancer Risks						
Arsenic III	Turned On	9%	0.2	< 0.01	< 0.01	0.04
	Turned Off	9%	0.2	< 0.01	< 0.01	0.03
Arsenic V	Turned On	9%	< 0.01	< 0.01	< 0.01	< 0.01
	Turned Off	9%	< 0.01	< 0.01	< 0.01	< 0.01
Mercury	Turned On	9%	< 0.01	< 0.01	< 0.01	< 0.01
	Turned Off	9%	< 0.01	0.01	< 0.01	< 0.01

There is some difference in landfill risks modeled for ashes generated with and without ACI. In some instances, risks actually decreased slightly with the addition of activated carbon. Yet, the observed decreases were small enough that they may be an artifact of the relatively small number of model iterations conducted for these wastes. Based on the data available, the variations in risk observed would not alter the principal findings of the risk assessment that current disposal practices pose risks within the range where OSWER typically regulates. However, EPA draws no

conclusions about the exact effects of changing pollution control technologies (including ACI) on future risks.

Summary

A summary of the different uncertainties associated with the CCR WMU database, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-9**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. However, the sensitivity analyses conducted for specific liner types and specific waste pH identified subsets of disposal practices that result in appreciably higher risks than identified in the full probabilistic modeling.

Table 5-9. Likely Effect on Modeled Risks from CCR WMU Database Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
Geographic Location Data		●	
WMU Dimension Data		●	
Liner Data		●	
Liner Assignment		●	
Liner Prevalence			●
Impoundment Waste Type Assignment		●	
Landfill Waste Type Assignment			
Waste Type Prevalence			●
Exclusion of FBC Waste Type		●	
Below-Grade Geometry		●	
Pollution Control Technology		●	

5.1.2 Environmental Parameters

This risk assessment characterized the environmental conditions that may influence the fate and transport of constituents in the environment using region-specific data collected around each WMU or facility, based on the availability of geographic data. As discussed in **Section 5.1.1** above, some uncertainty exists with respect to the locations of WMUs which were derived from the 2009 EIA facility centroids. This section discusses how the variability and uncertainty associated with each location-based parameter were addressed.

Soil Data

For soil data, variability was accounted for through a probabilistic sampling of all soil types that fall within the WMU footprint (where available) or a two-kilometer radius around the facility centroid. The soil types were drawn from national databases that provide a regional resolution for these soil types. The use of these soil data sets have been thoroughly peer-reviewed and documented as part of the development and implementation of EPACMTP (see **Section 5.1.9**). In

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instances where the exact location of a WMU was not known, EPA addressed this uncertainty by collecting information on the different soil types present within a two kilometer radius around the centroid of the facility. The different soil types were sampled probabilistically during each model iteration based on relative prevalence at a given WMU. This approach effectively captures regional variability. Even though soil properties can be highly variable, the regional averaging of these parameters is believed to provide a good resolution for the transport distances considered in the probabilistic analysis. Therefore, the uncertainty introduced by the use of these data is believed to be minimal.

Aquifer Data

EPA assessed risks that result from contamination of surficial aquifers. For each WMU, the hydrogeologic environment of the surficial aquifer was assigned based on the geology and soil megatextures identified beneath the WMUs (see **Appendix B**). In instances where the exact location of a WMU was not known, EPA addressed this uncertainty by collecting information on the different hydrogeologic environments present within a two kilometer radius around the centroid of the facility. These environments were sampled probabilistically based on relative prevalence at a given WMU during each model iteration. The EPACMTP parameters with the largest impact on results are aquifer hydraulic conductivity and gradient. These parameters were selected from a database that contains regional aquifer properties across the conterminous United States. Even though aquifer properties can be highly variable, these regional data are believed to provide a good resolution for the transport distances considered in the probabilistic analysis. Therefore, the uncertainty introduced by the use of these data is believed to be minimal.

Ground Water Flow Direction and Water Body Selection

EPA used a raindrop tool to identify the nearest surface water body and to assign a ground water flow direction and distance (see **Appendix B**). The raindrop tool estimates the direction of overland run-off based on topographic elevations and is therefore an indirect representation of ground water flow. EPA received multiple public comments on the Agency's use of the tool, pointing to site-specific factors that may lead to alternate ground water flow directions, including:

- Localized ground water mounding;
- Ground water flow parallel to the surface water body;
- Water bodies that lose water to underlying aquifers for some or all of the year;
- Seasonal variations in the water table height and flow directions; and
- Anthropogenic influences, such as nearby ground water pumping.

EPA agrees that the direction of ground water flow can differ from the direction of the surface topographic gradient. However, without external stresses (e.g., pumping) or unique hydrogeologic conditions, ground water flow directions will generally mimic surface topographic gradients. Accurate characterization of ground water flow conditions at specific WMUs would require extensive site-specific spatial and temporal hydrogeologic data collection and analysis. Such effort was not feasible in support of this annualized, national-scale analysis. The method adopted by the

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Agency incorporated potential variability by allowing multiple transport pathways from each WMU with multiple nearby surface water bodies potentially receiving ground water (e.g., if the WMU was surrounded by more than one water body). In this way, a range of potential transport distances and receiving water bodies for each WMU were incorporated into the probabilistic analysis. The assumption of a straight-line ground water flow direction may overestimate risks in some model iterations due to the decreased sorption and dispersion from shorter than actual transport distances. However, the approach may also underestimate risks for other model iterations if the actual flow of ground water to surface water is more direct than suggested by topographic gradients. Overall, this uncertainty is anticipated to have a minimal effect on calculated risks. For GW→DW pathways, a stream that fully intercepts ground water will do so regardless of the exact distance from the WMU, resulting in a negligible well concentration. The high-end ground water risks for these pathways will be driven by model iterations where no surface water interception occurs. For GW→SW pathways, many plants are located very close to the water body due to the use of water in facility operations. The high-end surface water risks for these pathways will be driven by the WMUs directly adjacent to the water bodies, and any variations in the already short transport distances will have minimal impact on modeled risks.

Water Body Flow Rate

One of the most sensitive parameters identified for the GW→SW pathways was the surface water flow rate. In this risk assessment, EPA used average annual flow rates to estimate surface water risks. These rates are considerably higher than the low flow rates used in the 2010 Risk Assessment. Public commenters pointed out that average annual flows may not represent the typical flow of a water body because of lower median and low flow rate conditions that occur over most of the year. One specific example provided by commenters is Lick Creek in Indiana. **Table 5-10** presents the flow rate data provided by the commenters for this water body.

Table 5-10. Example Flow Rate Data for Lick Creek, Indiana

Annual Flow Rates			Ratios	
Average Annual	Median	Low	Average / Median	Average / Low
21 ft^3/s	7 ft^3/s	< 1 ft^3/s	3	> 20

As seen in the table above, the average flow rate is three times higher than the median flow rate, and over twenty times higher than the low flow rate. For this water body, and similarly behaving ones, the use of an average annual flow represents a stage of the river that occurs less than half of the year. Thus, use of an annual average value could overestimate the volume of water present in the water body and, consequently, the dilution of ground water concentrations entering the water body at certain times throughout the year. However, both EPACMTP and the surface water model used in this risk assessment consider fate and transport in yearly time steps. Therefore, EPA considered how best to reflect seasonal fluctuations when developing annualized inputs for these models.

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Ground water and surface water are interconnected. Just as the surface water flow rates vary throughout the year, hydraulic gradients are also subject to change in response to precipitation rates, among other factors (Sophocleous, 2002). Precipitation rates, ground water flow, and many other annual variables used in this risk assessment may all vary seasonally. Thus, varying one (i.e., surface water flow rates) but not the others would not capture actual interactions. Periods of naturally low ground water (e.g., drought) that also lead to low flow rates would be accompanied by decreased flux from the ground water to surface water, or could even transition to a net losing water body, as shown in **Figure 5-2**. Thus, while the use of average annual flow rates may overstate the volume of water passing through a water body for some portion of the year, this is the most appropriate flow rate in light of the annual increments used for all other variables.

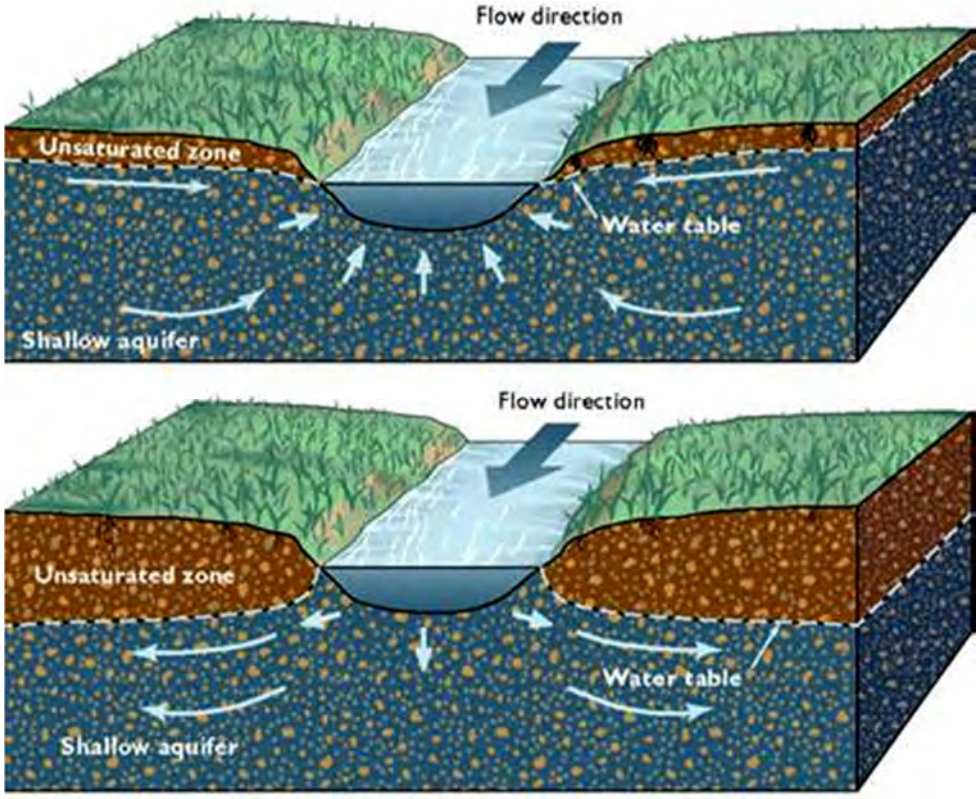

Figure 5-2. Interaction of ground water and surface water flow [reproduced from Winter et al., 1998).

Climate Data Selection

Climate regions were developed for this risk assessment to represent climate patterns within specified geographic regions. Data were collected for each WMU from the closest climate data center within each region that best matched the precipitation reported at that facility location. To the extent that actual climate data (e.g., precipitation rates) from a climate data center does not reflect the conditions at a specific WMU location, there is the potential to either overestimate or underestimate climate data on an annual basis. However, because EPA matched each unit with the most representative center, the potential effect of this uncertainty on modeled risks is likely to be small.

Climate Change

The climate data used in this risk assessment was collected for a period from 1961 through 1990. Therefore, some uncertainty is introduced because any potential effects from climate change that have occurred since 1990 are not reflected in this data set. The National Climate Assessment Report documents region-specific changes in rainfall, temperature and episodic rainfall events over recent decades (Melillo et al., 2014). This may result in an increase or decrease in risk on a case-by-case basis. The potential effect of this uncertainty on modeled risks is unknown.

Distance to Nearest Ground Water Receptor

EPA used a probability distribution to characterize the distance to nearest ground water receptor for surface impoundments created from combining U.S. Census data with the locations of a total of 729 impoundments drawn from the 2009 EPA survey. This distribution was compiled and incorporated into the analysis before data on an additional 223 impoundments from the 2010 EPA survey were processed and available for use. Much of the data on the additional surface impoundments were incorporated into the probabilistic analysis through further model iterations; however, due to the time intensive nature of the process to link receptor and WMU location, the distribution of distances to nearest receptor was not updated at that time. To characterize the uncertainty associated with the use of a distribution based on a subset of 729 surface impoundments, EPA later generated a revised probability distribution based on all 952 surface impoundments. **Figure 5-3** compares this combined nearest-receptor distribution with both the distribution used for modeling, as well as the distribution utilized in the 2010 Risk Assessment, which was based on receptor distances from municipal solid waste landfills.

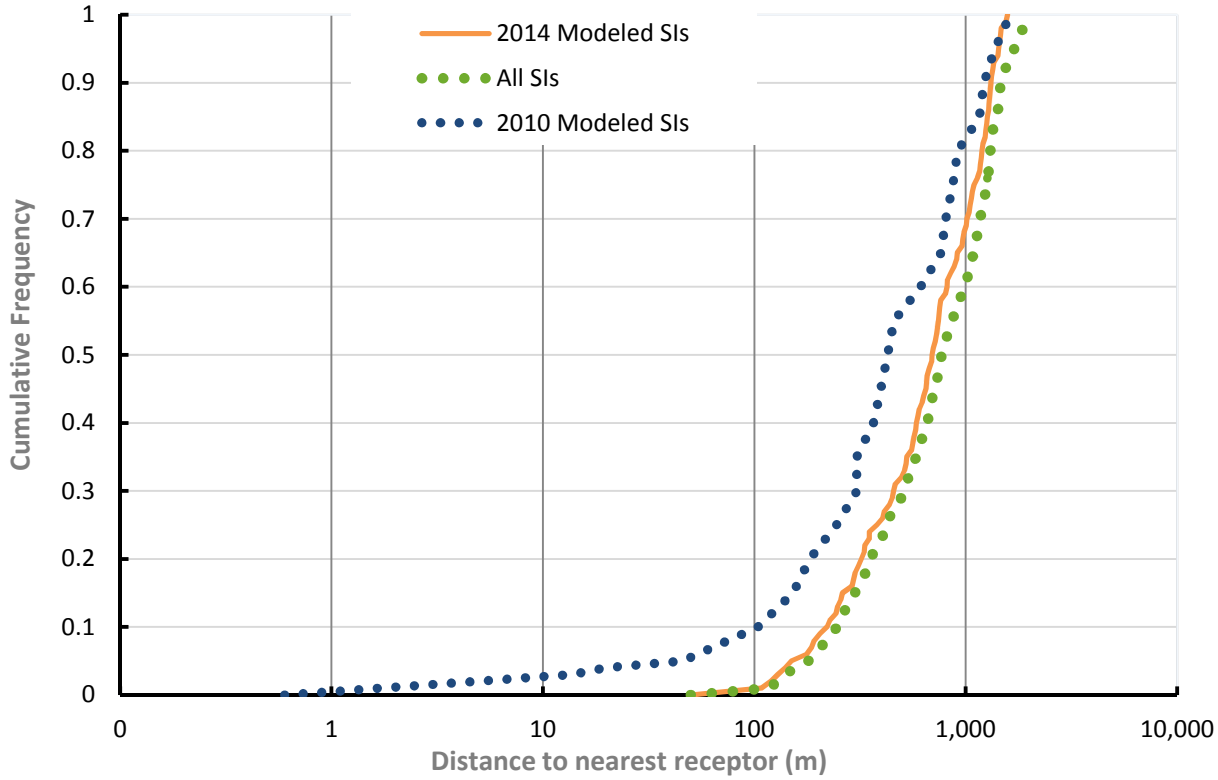

Figure 5-3. Distance to nearest ground water receptor distribution among data sets.

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As seen in the figure above, the combined surface impoundment data set results in slightly greater distances to ground water receptors. It also shows that the distribution for 729 impoundments used in the revised risk assessment is far more similar to the distribution of all 952 impoundments than to the distances used previously in the 2010 Risk Assessment. Given the small difference between the distributions for the 729 and all 952 surface impoundments, the potential impact of this uncertainty on the modeled risks is negligible.

Summary

A summary of the different uncertainties associated with environmental parameter data, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-11**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with climate change. The Agency relied on the best data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate risk results is uncertain.

Table 5-11. Likely Effect on Risk from Environmental Parameter Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
Soil Data		●	
Aquifer Data		●	
Ground Water Flow Direction & Water Body Selection		●	
Water Body Flow Rate		●	
Climate Data Selection		●	
Climate Change	●		
Distance to Nearest Residential Receptor		●	

5.1.3 CCR Constituent Database

Where possible, EPA used government sources and peer-reviewed primary literature for input data. EPA also preferentially used sources where the test methods and quality assurance/quality control protocols were well documented. Although additional data were made available through public comments received since the 2010 proposed rulemaking, there are relatively few data points available for some constituents (e.g., mercury). As a result, there is some uncertainty regarding how well these data reflect the range of CCR waste types.

Representativeness

Pore water data were determined to be the most representative data available for impoundments because these data are field-measured concentrations of leachate present at the bottom of these WMUs. In instances where the risks identified for surface impoundments are based on a limited

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data set, uncertainty exists with respect to the representativeness of the results. Of the modeled constituents found to be near or above risk criteria, thallium was the single one with a limited data set. Thallium had a total of 38 pore water samples from 14 distinct sample sites. In contrast, arsenic, boron, cadmium, fluoride, molybdenum and selenium had a much greater number of measurements (~ 200) from a greater number of sample sites (~ 30). While the more limited data set for thallium adds some uncertainty for this one constituent, it will not impact the principal results of the probabilistic analysis based on other risk drivers with more robust data sets.

Nondetects

The CCR constituent database contains a large number of nondetect data for some constituents. For each of these data points, EPA substituted half the reported detection limit. Because the evaluation relied on a value halfway between zero and the detection limit, the true value is equally likely to be higher or lower than the value assigned. Typically, the upper percentile risks calculated in the probabilistic assessment are associated with higher, detectable, concentrations rather than nondetects. Unless nondetect data account for a high percentage of the total data set or the detected values fall near the detection limit, the specific treatment of nondetect values has little effect on the upper percentile risks relied upon in this risk assessment.

Table 5-12 lists the constituents for which 50 percent or more of site data for impoundment wastewater were nondetects. These constituents are beryllium, lead, iron and silver. Beryllium is the only constituent that both failed the screening and has a high percentage of sites with nondetects (73 percent). All other constituents that failed the screening for this exposure pathway have nondetect percentages less than 25 percent. This introduces considerable uncertainty for beryllium. However, given the risks identified for multiple other constituents with well-defined data, these uncertainties do not change the ultimate conclusions that direct contact with impoundment wastewater has the potential to pose risk to ecological receptors.

Table 5-12. Review of Nondetects for Impoundment Wastewater

Constituent	Individual Nondetect Measurements		Sample Sites with All Nondetects	
	Total Count	Percent	Total Count	Percent
Silver	26	100%	11	100%
Beryllium	26	81%	11	73%
Iron	26	58%	11	64%
Lead	26	69%	11	55%

Table 5-13 lists the constituents for which 50 percent or more of site data for impoundment pore water were nondetects. These constituents are beryllium, chromium and silver. None of these constituents were found near risk criteria in the full probabilistic analysis; however, chromium did fall above a risk of 1×10^{-5} in the sensitivity analysis for waste types for both ash and coal waste (3×10^{-5}) and FGD waste (4×10^{-5}). Therefore, there is the potential for somewhat higher risks associated with chromium risks. However, because high-end risks are likely associated with the

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50 percent of higher, detected chromium concentrations, any increase is likely to be small. Of the constituents that posed risks in the full probabilistic analysis, arsenic and molybdenum have nondetect percentages of 19% and 36%, respectively. These relatively low nondetect percentages result in low uncertainty for these results. Therefore, the uncertainties associated with pore water are unlikely to change the ultimate conclusions that ingestion of ground water has the potential to pose risk to human receptors.

Table 5-13. Review of Nondetects for Impoundment Pore Water

Constituent	Individual Nondetect Measurements		Sample Sites with All Nondetects	
	Total Count	Percent	Total Count	Percent
Beryllium	38	97%	14	93%
Silver	76	95%	20	85%
Chromium	194	71%	30	50%

Table 5-14 lists the constituents for which 50 percent or more of site data for whole waste were nondetects. These constituents are nitrate, thallium and uranium. Thallium was the single constituent that failed the uncontrolled soil exposures for human health screening based on whole waste concentration; however, all risks fell below criteria based on consideration of dust and run-off controls. Because high-end risks are likely associated with the 45 percent of higher, detected thallium concentrations, any increase is likely to be small. Thus, the treatment of nondetects does not add significant uncertainty to these data.

Table 5-14. Review of Nondetects for Whole Waste

Constituent	Individual Nondetect Measurements		Sample Sites with All Nondetects	
	Total Count	Percent	Total Count	Percent
Nitrate	2	100%	2	100%
Uranium	9	100%	1	100%
Thallium	55	55%	18	50%

The LEAF data used in this analysis originated from CCR concentration data collected from CCR management operations that were selected to represent the range of coal-fired power plants, control technologies, and coal types in current use across the United States (U.S. EPA, 2009a). U.S. EPA (2006a, 2008b and 2009a) all contained data with low detection limits. Thus, for landfill leachate, nondetect percentages were very low (less than 1%) for most constituents, and still low for mercury (25%). Thus, the treatment of nondetects does not add significant uncertainty to these data.

Site Quartiles

This risk assessment divided pore water and whole waste constituent concentration data into quartiles (i.e., 25th, 50th, 75th) for each sample site and waste type. Compared to the site averages used in the 2010 Risk Assessment, this approach better captures the variability at each sample site. **Table 5-15** below shows the 2010 site averaged pore water distribution and 2014 site quartile

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distributions for arsenic. The ash waste type used previously in the 2010 Risk Assessment was separated into the combined ash waste type and the FGD waste type.

Table 5-15. Comparison of Arsenic Pore Water Concentrations Resulting from Data Processing: 2010 Averages versus 2014 Quartiles

Waste Type Name	Year	Data Treatment	Arsenic Pore Water Concentration Percentile (mg/L)				
			25th	50th	75th	90th	95th
Conventional Ash	2010	Average	0.02	0.07	0.29	1.0	1.3
Combined Ash	2014	Quartile	0.04	0.07	0.16	0.26	0.49
FGD Waste	2014	Quartile	0.02	0.21	0.80	2.86	6.41
Codisposed Ash	2010	Average	0.02	0.02	0.12	0.63	0.63
Ash & Coal Refuse	2014	Quartile	0.01	0.18	0.53	3.41	7.85

In general, the median and low-end concentrations changed very little as a result of the use of quartiles. Decreases in the combined ash arsenic concentrations in high-end percentiles are attributed to the separation of FGD waste data. The considerable increase ash and coal refuse arsenic concentrations in high-end percentiles is attributed to better characterization of intra-site variability. While some uncertainty remains because the quartile approach does not fully capture extreme values at some sites, these individual samples are reflected in the quartiles without assigning an undue weight to what may be an outlier within the larger site by using an empirical distribution. Because the use of quartiles provides much better resolution on the variability of pore water concentrations, EPA believes the uncertainty associated with this approach is minimal.

Summary

A summary of the different uncertainties associated with constituent data, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-16**. The uncertainties identified are unlikely to have an appreciable impact on the principal risk results.

Table 5-16. Likely Effect on Risk from Constituent Data Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Unknown	Low	High
Representativeness		●	
Nondetect Data		●	
Site Quartiles		●	

5.1.4 Human Exposure Factors

This risk assessment relied on the 1997 *EFH* (U.S. EPA, 1997b,c,d) and the 2008 *CSEFH* (U.S. EPA, 2008a) for information on human exposure factors for the U.S. population. EPA's evaluation criteria included peer-review status, reproducibility, pertinence to the United States, currency, adequacy of the data collection period, validity of the approach, representativeness of the

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population, characterization of the variability, lack of bias in study design, and measurement error. The data contained in these documents were used throughout this risk assessment to establish distributions for each exposure parameter and receptor. Both documents have undergone extensive external peer review.

2011 Exposure Factor Updates

The 2011 *Exposure Factors Handbook* (U.S. EPA, 2011b) has been completed and updates some of the data from the 1997 EFH. During the finalization of this risk assessment, EPA released OSWER Directive 9200.1-120 (U.S. EPA, 2014c). While this document provides default exposure factors to use for point estimates, EPA is still in the process of updating the full distributions necessary for probabilistic risk assessment. Therefore, this risk assessment does not incorporate the data from the 2011 EFH. The adult water consumption rates provided in the U.S. EPA (2011b) are somewhat lower than those found in the 1997 *EFH*, while adult body weights are somewhat higher. All other exposure factors used in the CCR risk assessment remained the same between the 1997 and 2011 Handbooks. As a result, risks for the drinking water ingestion and fish ingestion pathways may be slightly overestimated.

Drinking Water Ingestion Rate

Drinking water ingestion rate data for infants that consume formula (birth to < 1 month, 1 to < 3 months, 3 to < 6 months, and 6 to < 12 months) are available from the *CSEFH* (U.S. EPA, 2008a). As drinking water concentrations are provided by the model as annual averages, the consumption rate data were averaged to estimate a full year of exposure. The distribution of infant drinking water ingestion rates used in this analysis reflects sampling from percentiles averaged across all infant age ranges. The sample size associated with each age range was used to calculate a weighted average for each percentile. The data were weighted by sample size because the small sample sizes did not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (Life Sciences Research Office, 1995) for percentiles in several subcohorts. The resulting average percentiles were sampled to develop the infant drinking water distribution. As noted by the CSEFH, some of the reported sample sizes did not meet minimum requirements. These small sample sizes for certain infant subcohorts introduce some amount of uncertainty to the modeled risk results. Because infants were found to be the most sensitive age cohort for some exposure pathways, EPA conducted a sensitivity analysis comparing the drinking water risks for the infant cohort with those for other age cohorts to determine the potential magnitude of this uncertainty. **Table 5-17** provides the results of this comparison for each constituent that was modeled in the probabilistic analysis and that was above risk criteria in this sensitivity analysis for one or more age cohorts. Arsenic V risks are provided even where below criteria to provide a complete bounding on arsenic speciation. Values that exceed the risk criteria (i.e., cancer risk > $1x10^{-5}$ or HQ > 1) are shown in **bold**.

Table 5-17. 90th Percentile Human Health Risk Results for Surface Impoundment GW→DW Pathway by Age Cohort

COPC	Age Cohorts							
	Infant	1 to < 2	2 to < 3	3 to < 6	6 to < 11	11 to < 16	16 to < 21	Adult
Cancer								
Arsenic III	**1×10^{-4}**	**1×10^{-4}**	**9×10^{-5}**	**8×10^{-5}**	**8×10^{-5}**	**8×10^{-5}**	**8×10^{-5}**	**2×10^{-4}**
Arsenic V	1×10^{-5}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	1×10^{-5}
Noncancer								
Arsenic III	**5**	**3**	**3**	**3**	**2**	**2**	**2**	**3**
Arsenic V	0.4	0.2	0.2	0.2	0.2	0.1	0.1	0.2
Lithium	**2**	1	1	1	1	0.8	0.9	1
Molybdenum	**2**	1	1	1	0.8	0.7	0.8	1

As seen in the table above, the infant cancer risks for arsenic are slightly less than the adult cancer risks. Because infants were not the most sensitive receptors for these exposures, the magnitude of uncertainty introduced by the small sample sizes of the infant exposure factors is minimal. Infants are the most sensitive receptor for noncancer risks. However, the infant risk estimates are no more than a factor of two higher than the values modeled for other cohorts. In addition, exceedances of the arsenic risk criteria were identified for all age cohorts. Because the infant exposures are not the most sensitive age group for cancer risks and noncancer risks do no differ substantially across age groups, any uncertainty associated with the infant drinking water ingestions rates will have minimal impact on the final conclusions of the risk assessment.

Human Fish Consumption

Data on site-specific fish consumption rates were not available for use in this analysis. Instead, fish consumption rates were drawn from a study of Maine anglers that fished from streams, rivers, and ponds. This study was one of four recommended freshwater angler studies in the 1997 *Exposure Factors Handbook*. This evaluation selected the Maine data based on the completeness of the data set and because it agrees most closely with a separate U.S. Department of Agriculture (USDA) study of national fish consumption (USDA, 1992). However, applying Maine angler consumption rates to other parts of the country may under- or overestimate exposures on a case-by-case basis. For example, subsistence fishers were not evaluated, as the wide variety of possible consumption rates makes evaluation more appropriate at a site-specific level, rather than the national assessment conducted here. Additionally, data were available only for adult anglers. Because age-specific data for children were not available, all child cohorts were assumed to consume the same amount of fish as the adult cohort. This issue introduces uncertainty into the analysis, and likely results in an overestimate of risks from fish consumption among child cohorts. Furthermore, all fish consumed by both adult and child receptors is assumed to be contaminated. This assumption will also overestimate risks from contaminated fish consumption. The magnitude

of these overestimations are unknown; however, given that all risks associated with the fish ingestion pathway fell at least an order of magnitude below risk criteria, the potential for this overestimation to alter the conclusions of the probabilistic analysis is negligible.

Bioavailability

A host of different environmental factors such as the pH, particle size, moisture, and redox potential of the environment influence bioavailability. The individual receptor's age, sex, nutritional state, and physiological state also affect bioavailability (U.S. EPA, 2007a). For the purposes of this analysis, the model conservatively assumed that all forms of a constituent were equally bioavailable. For example, although U.S. EPA (2012b) recommends the use of a default bioavailability rate of 60 percent for arsenic in soils, EPA assumed 100 percent bioavailability in this risk assessment. Therefore, the actual exposures that may occur in the field will tend to be overestimated, making this a high-end assumption that will tend to overestimate risk. That magnitude of these overestimations are unknown; however, given that all risks associated with the soil, produce, beef, and milk ingestion screened out under a controlled management scenario, the potential for this overestimation to alter the conclusions of the probabilistic analysis is negligible.

Noncorrelation of Exposure Factors

While exposure factors were selected for specific age groups, the distributions for each exposure factor were not correlated with each other within each of these age groups. Instead, for each modeling run, each exposure factor was selected from its age-group-based distribution independently. Insufficient data are currently available to correlate these variables. This introduces some uncertainty into the evaluation because some combinations of exposure factors, such as a high fish consumption rate combined with small body weight, while possible, are unlikely. Therefore, this remains an uncertainty in the analysis that may under- or overestimate exposures for individual model iterations. The magnitude and direction of this uncertainty are unknown.

Consumption of Wildlife/Game

Neither the screening analysis nor the full-scale CCR risk assessment considered ingestion of game, which may pose non-negligible risks if humans consume wildlife contaminated by CCR constituents. Results of the screening analysis (**Section 3.5.2**) of the revised risk assessment show that consumption of contaminated beef and dairy from cows that consume contaminated soil and produce grown in contaminated soil may pose risks to human health for thallium. **Table 5-18** provides a comparison of the per capita intake rates for beef, dairy and game.

Table 5-18. Comparison of Per Capita Beef, Dairy & Wild Game Consumption Rates

Food	Percent of Population	Percentile (g/kg-day)								
		1st	5th	10th	25th	50th	75th	90th	95th	99th
Beef	91%	0	0	0.06	0.27	0.63	1.2	1.8	2.3	3.5
Dairy	97%	0	0.16	0.40	1.4	3.6	8.2	18.7	29.7	72.2
Game	1.2%	0	0	0	0	0	0	0	0	0.1

Rounded values drawn from EFH (U.S. EPA, 1997c) Tables 11-2, 11-3, and 11-6

Although EPA did not collect biotransfer factors for deer and other game, the following considerations make this pathway less of a concern than the beef and dairy pathways evaluated. First, only 1.2 percent of the population consumes game species. Second, the table also shows that the consumption rates for game species are typically orders of magnitude below the consumption rates of beef and dairy. Finally, beef and dairy cattle are assumed to get 100 percent of their diet from contaminated soil, forage, silage, and grains, whereas game species would forage throughout their natural habitat range, with direct ingestion of CCRs the only exposure pathway available. Thus, EPA does not consider the exclusion of this pathway to be a significant uncertainty nationally.

Summary

A summary of the different uncertainties associated with human exposure factors, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-19**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with the correlation of exposure factors. The Agency relied on the best data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate risk results is uncertain.

Table 5-19. Likely Effect on Risk from Human Exposure Factor Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
2011 Exposure Factor Updates		●	
Drinking Water Ingestion Rate		●	
Human Fish Consumption		●	
Bioavailability		●	
Noncorrelation of Exposure Factors	●		
Consumption of Wildlife/Game		●	

5.1.5 Human Health and Ecological Benchmarks

Use of Chronic Human Health Benchmarks for Less Than Lifetime Exposures

The uncertainties generally associated with human health benchmarks are discussed in detail in EPA's *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005) and the IRIS website (U.S. EPA, 2012a). EPA defines the RfD as "an estimate of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects during a lifetime." The CSF is an upperbound estimate of the human cancer risk per mg of chemical per kg body weight per day. Because calculated exposures were often less than lifetime, some uncertainty was introduced in the noncancer hazard and cancer risk estimates, though the magnitude and direction of this uncertainty is unknown.

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Use of MCL for Lead

For lead, EPA has no consensus on the development of an RfD or CSFo because of the difficulty associated with identifying an effect threshold needed to develop these benchmarks. Therefore, the MCL for drinking water was used as an alternative method of approximating human health risk. To ensure that risks were not underestimated, EPA separately considered lead exposures with the Integrated Exposure and Uptake Biokinetic (IEUBK) model (U.S. EPA, 2010b) to predict blood lead levels that may result from CCR disposal. The conservative exposure concentrations developed in **Section 3** for soil, fish, and drinking water were used to evaluate lead through separate IEUBK model runs. The methodology and default parameters EPA used are described in detail in the IEUBK *User's Guide* (U.S. EPA, 2007b). With the exception of drinking water, the estimated screening blood levels were below the current CDC target blood level of 5 μg/dL. However, lead was already retained for the GW→DW pathway because screening lead concentrations exceeded the MCL. The national-scale probabilistic modeling conducted in **Section 4** showed that lead concentrations fell several orders of magnitude below risk criteria based on the MCL. Thus, consideration of a lower blood lead level with IEUBK may have resulted in somewhat higher risks, these results would not have changed the findings of the risk assessment for this constituent.

Use of Proxy Benchmarks

Chemical-specific health benchmarks were used for all constituents assessed in the analyses. However, the RfD for fluoride was based on fluorine and the RfD for thallium was based on thallium chloride. The use of these surrogate data provides the best estimate of potential risks available, but may over- or underestimate risks to an unknown degree. However, because risks were identified for other constituents, this uncertainty is unlikely to affect the final conclusions of the risk assessment.

Ecological Benchmarks

Ecological benchmarks were obtained for CCR constituents when available and compared with the modeled media concentrations (e.g., surface water, sediment) to estimate the HQs used to characterize ecological risk. These benchmarks represent the best available estimates of receptor responses based "no effects" (NOAEL) or "lowest effects" (LOAEL) study data. In some scenarios, these benchmarks may be represent species not actually present in the field. In others, these benchmarks may not capture the most sensitive possible receptor at every site or for each constituent. While some benchmarks have factors of safety included to account for these or other uncertainties, there remains is the potential for the ecological benchmarks used to underestimate risks for the specific species and communities that live in surface waters impacted by CCR WMUs. The magnitude of this uncertainty is unknown. Consideration of any additional sensitive species not captured by the current benchmarks may result in some additional constituents above risk criteria in the probabilistic analysis. EPA notes that these some of these ecological risks are reflected in damage cases. However, this site-specific uncertainty is unlikely to affect the final, national conclusions of the risk assessment.

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Constituents with No Benchmarks

Constituents with no human health or ecological benchmarks could not be quantitatively evaluated in either the screening or full-scale modeling. Only three constituents (carbon, phosphate and potassium) for which constituent data were available did not have corresponding toxicity values for any pathway. However, most of these constituents are known to be essential human nutrients that are likely to be harmful only at very high doses. Other constituents have toxicity values available for some, but not all, exposure pathways evaluated. In these cases, the potential risks to receptors in these media could not be quantified. In particular, ecological benchmarks for chronic effects on amphibians are not available for many constituents. The absence of a toxicity value is not necessarily equivalent to the absence of risk. These constituents may pose pathway-specific risks or may influence either the fate and transport or toxicity of another constituent, resulting in an underestimation of rusk. The magnitude of this underestimation is unknown. However, because risks were identified for the available benchmarks, it is unlikely that this uncertainty would affect the final conclusions of the risk assessment.

Summary

A summary of the different uncertainties associated with toxicity benchmarks, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-20**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with the use of chronic benchmarks for less than lifetime exposures and the use of proxy benchmarks. The Agency relied on the best data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate risk results is uncertain.

Table 5-20. Likely Effect on Modeled Risk from Human Health and Ecological Benchmark Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
Use of Chronic Human Health Benchmarks for Less Than Lifetime Exposures	●		
Use of MCL for Lead		●	
Use of Proxy Human Health Benchmarks		●	
Ecological Benchmarks		●	
Constituents with No Benchmarks		●	

5.1.6 Bioconcentration Factors

Human exposures to constituents from fish consumption were calculated using BCFs for TL3 and TL4 freshwater fish to estimate the accumulation of constituents from surrounding environmental media into fish tissue. **Appendix G** lists the BCFs used in this risk assessment, as well as the literature sources from which they were drawn. BCFs are developed by dividing measured constituent concentrations in aquatic biota by total surface water constituent concentrations. In the

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revised risk assessment, the evaluation only used BCFs empirically measured from laboratory or field studies of TL3 and TL4 fish, rather than values estimated from physical or chemical properties [e.g., octanol-water partition coefficient (K_{ow})]. There are several sources of uncertainty associated with the models used to estimate BCFs for aquatic biota:

- Error may originate from the relatively short exposure timeframe used in a study compared to lifetime exposure (Arnot and Gobas, 2006; and CalEPA, 2012);
- Laboratory-prepared water may have constant and unrealistically high concentrations (Arnot and Gobas, 2006; and CalEPA, 2012);
- Radiolabeled compounds may be used without adequate correction for the parent signal (Arnot and Gobas, 2006; and CalEPA, 2012);
- Imprecise analytical methods may be used to analyze samples (Arnot and Gobas, 2006; and CalEPA, 2012);
- BCFs may be based on whole-body concentrations for fish which include organs and muscle tissues, rather than just the edible portion of the fish (du Preez et al., 1993);
- BCFs may be measured from juvenile fish, whereas metal concentrations in tissues decrease as fish size or weight increases (Liao et al., 2003, as cited by CalEPA, 2012);
- BCFs are based only on concentrations in environmental media, whereas consumption of sediment-dwelling invertebrates by bottom-dwelling fish species may also contribute to metal uptake by these fish (CalEPA, 2012); and
- BCFs may be collected for a particular species of fish that may or may not be present at the sites modeled in this risk assessment.

Significantly more research has been conducted for mercury than for other constituents. This mercury-specific data allowed EPA to address some of the concerns above (e.g., consumption of sediment-dwelling invertebrates) through the use of a bioaccumulation factor for methylmercury that takes into account accumulation in the entire food chain rather than just the water column. However, for the reasons stated above, reliance on BCFs to estimate fish exposure may overestimate or underestimate the actual accumulation of inorganics in fish tissue.

Summary

A summary of the different uncertainties associated with bioconcentration, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-21**. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with the use of bioconcentration factors. The Agency relied on the best data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate risk results is uncertain.

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Table 5-21. Likely Effect on Modeled Risk from Toxicity Benchmark Uncertainties

Uncertainty	Likely Effect on Risk		
	Uncertain	Low	High
Bioconcentration Factor	•		

5.1.7 WMU Source Term Models

Scaling of Washout Constituent Concentrations

Leaching profiles of washout phase constituents are characterized by an initial high-concentration pulse of 20 times the Method 1313 equilibrium concentration followed by a lower concentration pulse that continues until the leachable content is depleted. The use of a factor of 20 is supported by field data, as seen in U.S. EPA (2014b). However, in some cases, preferential flow or other considerations may result in concentrations only 10 times the Method 1313 equilibrium concentration. Therefore, this is unlikely to result in a significant uncertainty to the analysis.

Constant Leachate Concentrations

The nonlinear fate and transport solution used for inorganic constituents in the unsaturated zone module of EPACMTP requires constituent concentrations leached from the bottom of WMUs to remain constant for the entire duration of leaching (U.S. EPA, 2003b). However, empirical evidence reported in U.S. EPA (2009a) indicates that constituents can exhibit a leaching profile that changes over time. EPA conducted a sensitivity analysis to estimate the potential magnitude of error introduced by modeling a single, high-concentration pulse for washout constituents. This analysis, presented in **Appendix I**, found that there was a negligible (< 1 percent) difference in the peak time-averaged drinking water concentrations using a single, high-concentration pulse until depletion, or two pulses representing a high concentration followed by a low-concentration pulse until depletion. Although a leaching profile that changes over time may be more realistic, the simplified leaching profile used by the model provides very good approximations for peak ground water concentrations overall, and thus has a minimal effect on the risk results.

Surface Impoundment Leaching Duration

Leaching from surface impoundments was modeled based on the assumption that these units are periodically dredged during operation, resulting in a constant source that is continuously replenished. To reflect this assumption, the leachable mass was set equal to the total constituent mass in EPACMTP. This indirectly accounted for the constant source because an operating time of 75 years for impoundments is not enough to deplete the entire constituent mass present in CCR waste. After this timeframe, the model assumed clean closure of impoundments. EPA received public comments that indicated this approach is not consistent with the current practice of closing with wastes in place at some surface impoundments.

EPA considered the potential impact of postclosure releases through a sensitivity analysis (see **Appendix K**). This sensitivity analysis modeled closed surface impoundments equivalent to closed landfills, with the full constituent mass still available to leach without replacement. The results of this comparison show that releases from surface impoundments drop dramatically after

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closure, even with waste in place. This is because the large hydraulic head present during operation forces leachate into the underlying soils at a faster rate, resulting in higher releases to ground water than can occur postclosure. Based on these findings, EPA concluded that the assumption of clean closure has a negligible effect on modeled risks.

Landfill Leachable Content

It is likely that there may be some insoluble or otherwise unleachable constituent mass that remains bound within any waste. To account for the presence of this recalcitrant fraction, EPA used empirically derived estimates of the leachable mass of each constituent based on data collected using SW-846 Method 1313. However, long-term leachate studies have shown that short-term test methods may underestimate the total mass of constituents that can leach over longer periods of time (U.S. EPA, 2009a). For example, additional mass may become available as the physical matrix of the waste degrades over time.

EPA conducted a sensitivity analysis to provide a bound on the effects that the availability of this additional mass could have on modeled risks. In this sensitivity analysis, the Agency reran EPACMTP for landfills the same as in the full probabilistic analysis, except with the total constituent mass used in place of the leachable mass. This was done for 62 out of 69 CCR wastes sampled with Method 1313 for which data on total constituent mass were available. Since it was the only constituent to exceed any risk criteria in other sensitivity analyses conducted for landfills, arsenic (both III and V) was modeled for this analysis.

The use of total constituent mass resulted in an increase in arsenic III by a factor of less than 2, and an increase in arsenic V by a factor of 3 or less. These increases are not sufficient to push the modeled probabilistic risks above either cancer or noncancer criteria for either species. Furthermore, even if the total mass present in CCR waste were available to leach, it is unlikely that this mass would be released as a continuous pulse or at the same rate as early releases. Therefore, given that this conservative bound on releases modeled with total mass did not appreciably increase risks, the impact of this uncertainty on the modeled risks is negligible.

Closed Landfill Source Term

Landfills were only modeled postclosure because the nonlinear sorption isotherms used by EPACMTP require the infiltration rate to be held constant. The landfill source model assumes that the full footprint of the landfill is filled to capacity at the start of modeling, and that a cap no less permeable than the soil or liner underlying the WMU is present to avoid accumulation of water within the landfill. However, during operation, only a portion of the landfill will actively receive CCR wastes at any given time. The active portion of a landfill would be exposed directly to the elements. While the cap modeled on the closed landfill will limit infiltration, the filled capacity will overestimate the initial loadings into ground water. Because these uncertainties affect the results in opposite directions, the ultimate effect on risks is uncertain.

CCR Compaction

The landfill source model does not consider further compaction of CCR waste that may occur over time as a result of anthropogenic activities, gravity or infiltrating water. This decrease in space

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between the particulates can reduce hydraulic conductivity and inhibit water infiltration. However, no data on either the rate or degree to which these processes may occur were identified. As a result, the current full-scale modeling approach will likely overestimate long-term infiltration rates to some degree. However, the magnitude of this overestimation is unknown.

Clay Liner Thickness

Limited data are available on exact liner thickness of clay-lined WMUs. The probabilistic analysis assigned a fixed liner thickness of three feet for all units. There may be a wider range of thicknesses used in practice, with a minimum of two feet specified in Industrial Subtitle D Guidance (U.S. EPA, 2006b). EPA conducted a sensitivity analysis to provide a bound on the effects that different liner thickness may have on modeled risks. In this sensitivity analysis, the Agency reran EPACMTP for clay-lined surface impoundments the same as in the full probabilistic analysis, except with a fixed liner thickness of two feet for all units. Arsenic (both III and V) and boron were modeled in this sensitivity analysis to represent constituents with the highest risks and the fastest travel times, respectively. **Table 5-22** provides a comparison of the modeled risks for clay-lined surface impoundments modeled with a three-foot and two-foot liner.

Table 5-22. Comparison of 90th Percentile Ground Water Ingestion Risks for Clay-Lined Impoundments with Two- and Three-Foot Thick Liners

COPC	3-Foot Liner	2-Foot Liner	Ratio
Cancer Risks			
Arsenic III	6×10^{-6}	2×10^{-5}	3.3
Arsenic V	1×10^{-7}	4×10^{-7}	4.0
Noncancer Risks			
Arsenic III	0.2	0.6	3.0
Arsenic V	< 0.01	0.01	2.5
Boron	0.02	0.06	3.0

Risks from two-foot clay liners were up to four times higher than the risks from three-foot liners. This increase is sufficient to push arsenic III, which was already within the OSWER risk range, slightly above a cancer risk of 1×10^{-5}. Thus, the presence of a thinner liner than modeled in the full probabilistic analysis could lead to increased risks for clay-lined surface impoundments and landfills than modeled in the probabilistic analysis. Conversely, the presence of a thicker liner would result in lower risks than those modeled. The sensitivity analysis results for a two-foot thick liners at all units represents a conservative bound on potential risks. Thus, to the extent that clay-lined units in the field differ from those modeled, there is the potential for higher risks above cancer criteria. Without more detailed information on the actual thickness of liners present each WMU, the ultimate direction and magnitude of this uncertainty is uncertain.

Clay Liner Performance

This risk assessment assumed that compacted clay liners were designed and installed to be three feet thick and achieve a hydraulic conductivity of 1×10^{-7} cm/sec, consistent with the Industrial

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Subtitle D Guidance (U.S. EPA, 2006b). Peer reviewers and public commenters noted that clay liners designed to meet a 1×10^{-7} cm/sec hydraulic conductivity may perform differently in practice due to compaction, thixotropy and other factors. Moo-Young et al. (2004) investigated several clay-lined surface impoundments and landfills designed to a 1×10^{-7} cm/sec hydraulic conductivity. This study found clay-lined impoundments to have field hydraulic conductivities ranging from 3.0×10^{-6} to 3.2×10^{-5} cm/sec and clay-lined landfills have field hydraulic conductivities ranging from 2.0×10^{-9} to 4.4×10^{-8} cm/sec. Given the relatively small sample size, EPA draws no conclusions about actual range of hydraulic conductivities that may occur in the field or the tendency of different WMUs to perform better or worse than designed. However, these data do indicate that the assumption of a fixed hydraulic conductivity of 1×10^{-7} cm/sec could under- or overestimate risks on a case-by-case basis.

Composite Liner Leakage Rates

The composite liner leakage rates used in the probabilistic analysis were originally developed and peer-reviewed as part of the Industrial Waste Management Evaluation Model (U.S. EPA, 2002a). EPA excluded measurements for composite liners with a compacted clay layer from the distribution. This exclusion was based on the assumption that significant volumes of water can be released from clay due to consolidation from mechanical compaction from the weight of overlying waste. Several researchers have compared the chemical composition of leachate versus leak detection system water and concluded that a significant fraction of the water released is due to consolidation of the clay liner, rather than leachate from the overlying waste (Bonaparte et al., 2002; Bergstrom et al., 1993; Gross et al., 1990; Workman, 1993; Feeney and Maxson, 1993). Although clay liners have been shown to release consolidation water, the fraction of leakage attributable to consolidation has not been well quantified to date. These data were excluded due to the absence of consensus on an approach to determine the difference between consolidation flow and liner leakage. EPA conducted a sensitivity analysis as part of the 2010 Risk Assessment to provide a bound on the effects that different leakage rates may have on modeled risks. In this sensitivity analysis, the Agency reran EPACMTP for composite-lined landfills the same as in the full probabilistic analysis, except with all composite liner leakage rates. **Figure 5-4** compares the resulting distribution of DAFs for landfill runs with arsenic.

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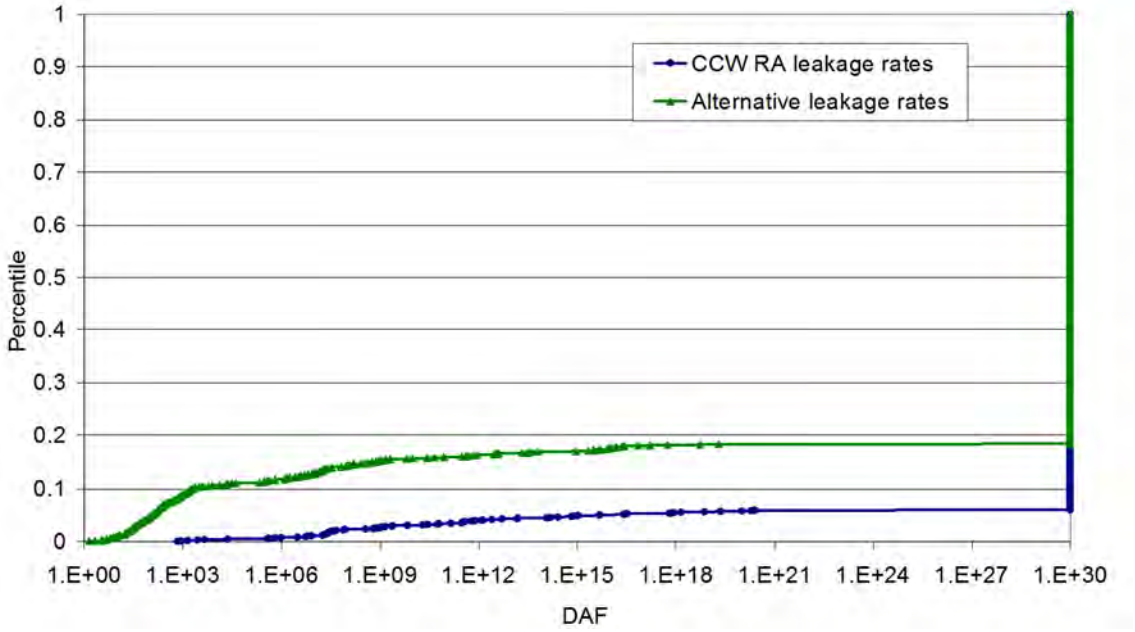

Figure 5-4. DAF Comparison for different leakage rates (landfills, arsenic).

In the figure above, the dramatic increase at a DAF of 1×10^{30} represents simulations where the constituent did not reach the receptor within the modeled timeframe. As anticipated, the use of higher infiltration rates for compacted clay layer units resulted in lower dilution and attenuation and a greater fraction of model iterations where the constituents reach the receptor well. Although use of all liner leakage rates would increase risks modeled for composite-lined facilities, the magnitude of the increase would not alter the finding that risks from composite-lined landfills are far lower risks than unlined and clay-lined landfills. Therefore, given that this conservative bound on releases from composite-lined releases would not appreciably increase risks, the potential impact of this uncertainty on the modeled risks is negligible.

Cap Degradation

For both unlined and clay-lined landfills, EPA used HELP Model–derived infiltration rates. These infiltration rates assume that the cap placed on top of the landfill at closure will remain intact for the duration of the probabilistic analysis, which extends up to a maximum of 10,000 years. Peer reviewers pointed out that the hydraulic conductivity of a clay cap may increase by orders of magnitude due to desiccation resulting from natural temperature cycles. In the near term, landfill caps will be maintained through periodic inspection and maintenance, but may degrade in the future without proper maintenance (Suter et al., 1993). However, predictions about the management and resulting performance of landfill caps centuries or more into the future would be speculative. To the extent that the performance of the cap does decrease over time, the modeled infiltration rates may underestimate infiltration into the landfill. However, since high-end risks will occur in on a shorter timeframe, the impact of this uncertainty on risk results is anticipated to be small.

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Summary

A summary of the different uncertainties associated with source term models, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-23**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with modeling landfills postclosure or variations in clay-liner design and performance. The Agency relied on the best data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate risk results is uncertain.

Table 5-23. Likely Effect on Risk from Source Term Model Uncertainties

Uncertainty	Potential to Affect Probabilistic Risk Results		
	Uncertain	Low	High
Scaling of Washout Constituent Concentrations		●	
Constant Leachate Concentrations		●	
Surface Impoundment Leachate Duration		●	
Landfill Leachable Content		●	
Closed Landfill Source Term	●		
CCR Compaction		●	
Clay Liner Thickness	●		
Clay Liner Performance	●		
Composite Liner Leakage Rates		●	
Cap Degradation		●	

5.1.8 Isotherm Model

MINTEQA2

MINTEQA2 has a long history of both internal review by the EPA Science Advisory Board (SAB) and external peer review during model development and implementation over the past two decades. These reviews largely focused on the use of MINTEQA2 to generate metal sorption isotherms for EPACMTP. During the most recent review, peer reviewers found that the revisions made to the MINTEQA2 model to account for CCR wastes were appropriate, but suggested further improvements that could be made to address the basic environments that are characteristic of many CCRs (U.S. EPA, 2003e). The version of MINTEQA2 used in this risk assessment addressed these recommendations by developing sorption isotherms specific to the geochemical conditions encountered in CCR surface impoundments and landfills. Due to the extensive peer reviews conducted, EPA has a high level of confidence in the model. However, there are many assumptions inherent in the application of MINTEQA2 to the revised risk assessment. These assumptions and the resulting limitations, discussed in detail in **Appendix H**, include:

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- Site-specific data on the ground water chemistry was not available.
- The types and numbers of sorption sites modeled likely do not reflect the full range of sorption sites possible in nature.
- There was more limited data on the specific ion concentrations present in CCR leachate that may influence K_d values.
- The model did not account for the potential of redox to influence K_d values.
- Because each constituent was considered separately, the model did not account for potential competition between constituents for sorption sites.

Although the direction of the potential uncertainties are apparent for some of these uncertainties, it is difficult to quantify the magnitude of the resulting uncertainty. Thus, the direction and magnitude of this class of uncertainties is unknown.

Lithium

At the time the probabilistic analysis was conducted, sufficient information was not available to develop chemical-specific K_d values for lithium. MINTEQA2 could not be used because iron oxide is not an appropriate sorbent for this constituent. Available literature indicates that lithium does adsorb weakly to clay soils, resulting in low retardation (Fuentes, 1989). This has resulted in its use as a conservative environmental tracer in some studies (LeBlanc et al., 1991; Anghel et al. 2002). The current evaluation used a conservative K_d of 0 to estimate lithium fate and transport. This may result in an overestimation of downgradient exposures. Given the moderate exceedance of noncancer risk criteria observed, it is possible that accounting for this low amount of retardation in the environment may reduce national-scale risks below risk criteria. However, as demonstrated by identified damage cases, lithium risks may be present on a site-specific basis. Thus, this uncertainty is unlikely to alter the final conclusions of the risk assessment.

Summary

A summary of the different uncertainties associated with MINTEQA2, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-24**. There are multiple uncertainties associated with the implementation of MINTEQA2, many of which were associated with the absence of site-specific data. Given the broad, national scope of the risk assessment, the potential magnitude or direction of this uncertainty remains uncertain.

Table 5-24. Likely Effect on Risk from Isotherm Model Uncertainties

Uncertainty	Potential to Affect Probabilistic Risk Results		
	Unknown	Low	High
MINTAQA2	●		
Lithium		●	

5.1.9 EPACMTP Ground Water Modeling

EPA has used EPACMTP and its predecessors to conduct ground water risk assessments in support of numerous regulations for land disposal of hazardous and nonhazardous wastes. During this time, EPACMTP has undergone multiple rounds of internal and external review, including several by the EPA SAB. Each of these reviews has determined that the use of this model for developing national regulations and guidance is appropriate. Some of the reviews include the following:

- **1994:** Consultation with the SAB on the use of EPACMTP for determining DAFs for the EPA's Soil Screening Guidance (U.S. EPA, 1996c); and peer-reviewed publication of EPACMTP in the Journal of Constituent Hydrology (Kool et al., 1994);
- **1995:** In-depth SAB review on the use of EPACMTP in the proposed/draft 1995 Hazardous Waste Identification Rule (U.S. EPA, 1996b);
- **1999:** Peer review of the implementation of EPACMTP in the EPA's multimedia, multiple exposure pathway, multiple receptor risk assessment (3MRA) model (U.S. EPA, 1999); and
- **2003:** SAB review of the 3MRA implementation of EPACMTP (SAB, 2004).

These reviews verified that the mathematical formulation of the model is scientifically sound and the code executes properly. In addition, recommendations from these reviews have been incorporated, resulting in a number of improvements to the model. Due to the high level of review and comment that this model has received, EPA has a high confidence in the accuracy of the model. Thus, EPA limited the discussion of uncertainties associated with EPACMTP in this document to those that were raised through public comments or that arose from the specific handling of inputs in this risk assessment. For a further discussion of the uncertainties associated with EPACMTP, see U.S. EPA (2003b).

10,000 Year Time Frame

This risk assessment assumed a constant hydrogeological environment and population distribution over the modeled timeframe. Peer reviewers and public commenters questioned the accuracy of using a maximum 10,000 year model duration. However, EPACMTP only ran to 10,000 years if a peak concentration had not been reached before that time. Arrival times for the peak well concentrations used to calculate ground water to drinking water risks for select CCR constituents (arsenic, boron, cobalt, selenium, and thallium) are plotted as cumulative distributions for surface impoundments and landfills in the figures in **Appendix K.** These constituents were selected both to capture those with the highest risks and highest mobility.

Tables 5-25 summarizes the time of travel results from the 2010 Risk Assessment sensitivity analysis by showing selected percentiles from these distributions for surface impoundments. For both unlined and clay-lined surface impoundments, the 10th percentile time to peak was less than 100 years for all constituents considered. The 50th percentile time to peak also remained under 100 years for multiple constituents, though the time for less mobile constituents increased appreciably. For composite-lined surface impoundments, even the faster time to peak approached 1,000 years. High-end risks will be associated with these lower percentile times. Thus, for unlined

and clay-lined surface impoundments, the uncertainties about future environmental settings have minimal impact on the peak risks. Uncertainties are much higher for composite-lined units. However, risks for these units were all well below all cancer and noncancer criteria. Therefore, use of a 10,000 year modeling timeframe adds a low uncertainty to the results of the probabilistic analysis.

Table 5-25. Years to Peak Well Concentration for Surface Impoundments by Liner Type

Percentile	Boron	Selenium VI	Arsenic III	Cobalt	Arsenic V	Selenium IV	Thallium
Unlined							
10th	70	70	70	71	73	76	—
50th	74	74	78	97	220	4,400	—
90th	110	110	170	970	6,500	> 10,000	—
Clay							
10th	75	75	75	86	95	81	—
50th	90	90	110	270	1,300	7,900	—
90th	150	150	340	3,100	10,000	>10,000	—
Composite							
10th	960	990	1,300	9,500	10,000	1,900	—
50th	4,400	4,600	8,600	>10,000	>10,000	>10,000	—
90th	10,000	10,000	>10,000	>10,000	>10,000	>10,000	—

Notes: Arrival times have been rounded to two significant digits.
A value of 10,000 means the concentration at the end of the maximum simulation time, 10,000 years, was the highest observed during the simulation. A value of >10,000 indicates that the constituent plume did not reach the receptor well during the modeled period.

Table 5-26 summarizes the time of travel results from the 2010 Risk Assessment sensitivity analysis by showing selected percentiles from these distributions for landfills. For both unlined and clay-lined landfills, the 10th percentile time to peak were all several hundred years. For both unlined and clay-lined landfills, the 50th percentile time to peak were all several thousand years. For all units, 90th percentile time to peak took more than 10,000 years to reach the receptor well for many constituents. Thus, for landfills, uncertainties about future environmental settings have much greater impact on peak risks than for surface impoundments. The potential magnitude of these uncertainties is unknown.

Table 5-26. Years to Peak Well Concentration for Landfills by Liner Type

Percentile	Boron	Selenium VI	Arsenic III	Thallium	Cobalt	Arsenic V	Selenium IV
Unlined							
10th	300	400	400	580	1,200	2,000	4,600
50th	2,000	2,600	2,800	2,300	7,800	9,700	10,000
90th	9,400	10,000	>10,000	9,700	>10,000	>10,000	>10,000
Clay							
10th	550	400	400	570	1,400	1,900	8,100
50th	5,600	5,100	4,000	4,300	10,000	10,000	>10,000
90th	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
Composite							
10th	9,600	9,000	10,000	>10,000	>10,000	>10,000	10,000
50th	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000
90th	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000	>10,000

Notes: Arrival times have been rounded to two significant digits.
A value of 10,000 means the concentration at the end of the maximum simulation time, 10,000 years, was the highest observed during the simulation. A value of >10,000 indicates that the constituent plume did not reach the receptor well during the modeled period.

The arrival times presented in these tables correspond to the arrival of the maximum estimated risks for each model run. However, for model runs where risk criteria were exceeded, the first exceedance may occur long before the maximum risks arrive.

Arsenic, Chromium, and Selenium Speciation

The speciation of arsenic, chromium and selenium can impact the mobility of these constituents in the environment, as well as the resulting toxicity to receptors. Arsenic can occur in either a +3 (arsenic III) or +5 (arsenic V) oxidation state, with arsenic III as the more mobile form. Chromium can occur in either a +3 (chromium III) or +6 (chromium VI) oxidation state, with chromium VI as the more mobile form. Selenium can occur in either a +4 (selenium IV) or +6 (selenium VI) oxidation state, with selenium VI as the more mobile form.

Although arsenic is generally thought to occur as arsenic III in leachate (Turner, 1981), evidence from damage cases suggests arsenic III can be converted to arsenic V during subsurface transport at some facilities (U.S. EPA, 2000a, 2003d; Lang and Schlictmann, 2004; Zillmer and Fauble, 2004). Similarly, although the dominant form of chromium leached from CCR wastes is chromium VI (Huggins et al., 1999; Stam et al., 2011), it is known to be converted to much less mobile chromium III form in ground water and soils (Palmer and Puls, 1994). However, the models used in this risk assessment do not consider changes to the speciation of metals during transport through the environment. To address this uncertainty, EPACMTP was run twice for both valence states of arsenic, chromium and selenium. The results from the two model runs bracket the full range of possible risks, given that there is likely some change in oxidation state during subsurface transport.

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As a result of changes in speciation during fate and transport, actual risks could fall anywhere in the range presented in each table, with arsenic III, chromium VI and selenium VI providing an upper bound and arsenic V, chromium III and selenium IV providing a lower bound. Both chromium and selenium fell below risk criteria for each species. For arsenic, arsenic III fell above risk criteria, while arsenic V fell just below a cancer risk of 1×10^{-5}. Because risks for both species fell mostly above or below criteria, this uncertainty has minimal effect on the results of the probabilistic analysis.

Aquifer pH

In the field, leachate plumes mix gradually with ground water over time through advection and diffusion. However, the probabilistic analysis assumed that leachate pH equilibrated with the ambient ground water on contact. Because the solubility of inorganic constituents can vary drastically with minor changes in pH (U.S. EPA, 2009b), EPA conducted a sensitivity analysis as part of the 2010 Risk Assessment to provide an upper bound on the potential effect this simplifying assumption may have on modeled risks. This sensitivity analysis consisted of an additional run of EPACMTP for landfills that assumed leachate does not mix with ground water at all, and that the pH of the plume is driven solely by the initial characteristics of the leachate. EPA chose to model the fate and transport of arsenic as both arsenic III and arsenic V for the following reasons:

- Arsenic is the constituent found to pose the greatest ground water risks for both surface impoundments and landfills.
- For the sorbents considered in this risk assessment, these arsenic species respond differently to changes in pH. For arsenic III, K_d values tend to decrease (i.e., increased mobility) as pH transitions from acidic to basic. For arsenic V, K_d values tend to increase (i.e., decreased mobility) as pH moves from acidic to neutral, and then decrease as the pH becomes more basic. Differences between K_d values for these species can be orders of magnitude.

The results from this model run were compared with the results of the full modeling conducted in 2010. **Table 5-27** summarizes the percent change in peak arsenic III and arsenic V well concentrations that results from modeling leachate pH as unchanged in the aquifer.

Table 5-27. Change in Peak Receptor Well Concentrations for CCR Waste Disposed in Landfills Assuming Leachate Does Not Mix in Aquifer

Percentile	Percent Decrease	
	Arsenic III	Arsenic V
10th	0.0 %	0.0 %
30th	0.9 %	0.0 %
50th	0.3 %	2.3 %
70th	0.2 %	58.0 %
90th	0.0 %	11.8 %

The modeled well concentrations of arsenic V are somewhat sensitive to changes in pH, while those of arsenic III are not at all. This is because, while K_d values for both arsenic III and V increase

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as the pH becomes more basic, the magnitude of the increase for arsenic V are much larger. As a result, while both species tend to sorb more at higher pH values, the effects are more pronounced for arsenic V. These results indicate that the assumption of complete equilibrium may slightly overestimate risks for constituents that behave similar to arsenic V. However, because the fate and transport of arsenic III is not sensitive to changes in pH, and because the predicted decrease in high-end arsenic V concentrations is minimal, this uncertainty will have no appreciable effect on the conclusions of the analysis.

Lateral Dispersion

EPACMTP simplifies flow in both the vadose zone (i.e., unsaturated soil) and in the aquifer. In the vadose zone, flow is modeled as vertical (one-dimensional) movement of infiltrating water flow. Since lateral migration is not modeled in the vadose zone, the concentration reaching the ground water table is somewhat higher than it may be in real-world conditions. Thus, this simplification may lead to an overestimation of risks. However, the magnitude of lateral dispersion in the vadose zone is typically relatively small, with a magnitude of one hundredth the vertical dispersivity as a reasonable first approximation (Simunek and van Genuchten, 2006), Because the areal extent of WMUs from which leachate occurs is orders of magnitude larger than the additional spreading that may occur in the vadose zone from lateral diffusion, the magnitude of this overestimation is likely to be small.

Preferential Flows

Ground water advection in the saturated zone is also modeled as a one-dimensional process in a homogeneous aquifer subject to surface infiltration and recharge. The flow direction is aligned with the regional flow direction. As the aquifer properties are regionally averaged, EPACMTP does not explicitly account for preferential pathways such as fractures and macropores. These assumptions could lead to either an overestimation of risk if actual flow paths direct flow away from receptors, or an underestimation of risk if preferential pathways lead to more streamlined transport than modeled. Without detailed, site-specific data on hydrogeologic conditions, the exact magnitude and direction of this uncertainty is unknown.

Ground Water Receptor Well Placement

Ground water wells were placed using a distribution of nearest wells described in **Appendix B**. Based on this distribution, wells were placed within approximately 1,600 meters for surface impoundments and 2,100 meters for landfills. However, it is possible that receptor wells may be located even further downgradient. EPA conducted a sensitivity analysis to examine the effect of not evaluating these further wells. First, EPA modeled arsenic as arsenic III in EPACMTP for wells at a variety of distances from surface impoundments and landfills. Wells were constrained to be within 5 m of the centerline of the plume where concentrations would be highest. EPA then calculated the percent of model runs where ground water concentrations exceeded the MCL for arsenic (10 µg/L). The results of the sensitivity analysis show that, while 2.2 percent of surface impoundment runs between 1,000 m and 1,500 meters exceeded the MCL, only 0.1 percent of model runs beyond 1,500 meters exceeded the MCL. Landfill model runs resulted in an even lower percent of MCL exceedances at both distances. The results of the sensitivity analysis show that

arsenic concentrations fall dramatically as the distance from the WMUs increases. This supports EPA's choice of a distribution of nearest receptor wells to represent a highly exposed individual, rather than considering even further distances. Thus, EPA finds that the placement of ground water receptor wells has a minimal effect on the highly exposed individual risks.

Ground Water Receptor Well Depth

Ground water receptor well concentrations were drawn from a single aquifer depth for each model iteration. Actual wells may be screened across an extended depth, resulting in capture of a combination of contaminated and pristine ground water. Sampling from a single depth may overestimate or underestimate risks on a case-by-case basis. However, given the size of the WMUs and the range receptors distances modeled in this analysis, the constituent plume within the first ten meters is expected to be fairly well mixed. Thus, the magnitude of this uncertainty is likely to be small.

Summary

A summary of the different uncertainties associated with the use of EPACMTP to model ground water transport, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-28**. The majority of uncertainties identified are unlikely to have an appreciable impact on the principal risk results. EPA was not able to characterize the potential magnitude or direction of the uncertainties associated with site-specific preferential flow in the subsurface. The Agency relied on the best regional data available at the time of the analysis; however, the potential of these uncertainties to overestimate or underestimate national risks remains uncertain.

Table 5-28. Likely Effect on Risk from EPACMTP Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
10,000 Year Time Frame		●	
Arsenic, Chromium and Selenium Speciation		●	
Aquifer pH		●	
Lateral Dispersion		●	
Preferential Flows	●		
Ground Water Receptor Well Placement		●	
Ground Water Receptor Well Depth		●	

5.1.10 Surface Water Fate and Transport Modeling

Surface Water Plume Interception

An EPACMTP post-processor was created to calculate the fraction of the ground water plume that is intercepted by a surface water body. This calculation assumes that ground water continues to flow in the same direction on the opposite side of the water body. In the field, ground water on both sides can flow toward the same water body. Overall, this uncertainty is anticipated to have a

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minimal effect on modeled risk results. For GW→DW exposure pathways, the high-end ground water risks for these pathways will be driven by model iterations where no surface water interception occurs. For GW→SW exposure pathways, the additional flow of uncontaminated ground water may result in further dilution of the constituent plume than predicted by the model and an overestimation of risks. Because this type of site-specific data is not available, the exact magnitude of this overestimation is unknown. However, given that the modeled risks for these pathways all fell below risk criteria, the potential for this overestimation to alter the results of the probabilistic analysis is negligible.

Equilibrium Partitioning

The equilibrium partitioning model used in the probabilistic analysis divided constituent loading rate (mass/time) by the water body flow rate (volume/time) to obtain an overall water body concentration. Following calculation of the constituent loading rates, the partitioning model determined the equilibrium constituent concentrations in each of the four compartments. As implemented in this analysis, the model does not account for losses that may result from burial. This is a conservative assumption that will overestimate risks to sediment receptors to some degree. However, given that all risks associated with sediment exposures fell at least an order of magnitude below risk criteria, the potential for this overestimation to alter the conclusions of the probabilistic analysis is negligible.

Summary

A summary of the different uncertainties associated with constituent data, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-29**. The uncertainties identified are unlikely to have an appreciable impact on the principal risk results.

Table 5-29. Likely Effect on Risk from Surface Water Model Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Unknown	Low	High
Surface Water Interception		●	
Equilibrium Partitioning		●	

5.1.11 Risk Models

Cumulative Pathways for Human Health Risk

This risk assessment considered the potential risks to human health from individual constituents and individual pathways. It is possible that individuals could be exposed to risks from drinking contaminated ground water, as well as eating contaminated fish from a local surface water body. However, it is unlikely that this will occur with any frequency in the real world for the following reasons:

- Only 27.5 million U.S. residents out of 312 million, or approximately 9 percent of the population, are recreational fishers (U.S. Census, 2012).

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- Of those who fish recreationally, approximately 49 percent eat at least some of the fish that are caught (Table 10-63, U.S. EPA, 2011).
- EPA assumes that the contaminated water bodies in this assessment are fishable, and that preferential fishing locations are not located nearby.
- On average, recreational fishers have been shown to travel between 35 to 41 miles to fish (Table 10-81 and Table 10-85, U.S. EPA, 2011). This provides a large area around a contaminated surface water body that individuals could come from to fish, and thus a smaller probability that they are also from an area within the contaminated ground water plume.
- If a fisher also resides within the ground water plume, approximately 15 percent of U.S. households rely on ground water as a source of potable water (U.S. EPA, 2002b).
- If the receptor lives close to the water body, there is a greater potential that the receptor well will be located downgradient from the water body, resulting in surface water interception of some or all constituent mass and lower drinking water risks than reported in this document.
- Were an individual exposed through both pathways, the different locations of the well and water body would result in different transit times until peak risks. Therefore, the cumulative exposure would be less than predicted by adding the risks reported in this document.

Because of the considerations listed above, EPA did not consider cumulative exposures from these pathways. This is a source of uncertainty that may result in an underestimation of risks to some individuals. However, given that risks were identified for individual COPCs and that these additional exposures will occur with a low frequency, the potential for any underestimation of risk to alter the principal results of the probabilistic analysis is small.

Cumulative COPCs for Human Health Risk

It is possible for an individual to be exposed to multiple constituents through a single pathway. This is a likely scenario because, as demonstrated by the available data, CCRs may leach multiple inorganic constituents. An individual COPC may interact with other constituents present, resulting in synergistic or antagonistic effects that exacerbate or diminish the health impacts predicted by evaluating each COPC independently. Where the potential for simultaneous exposure to multiple constituents exists, current EPA policy is to assume that the risks resulting from these exposures are additive (U.S. EPA, 2000b). However, the revised risk assessment did not consider additivity for the following reasons:

- The time to peak results presented earlier in this section indicate that while some constituents will migrate and reach peak concentrations in tens or hundreds of years, others may take thousands or tens of thousands of years. Thus, not all constituents will reach a receptor at the same time.
- Individual WMUs would not leach all constituents at the high-end concentrations considered in this risk assessment.
- EPACMTP is designed to use variable time steps to minimize computer processing time. These time steps are determined based on the rate of change of the modeled constituent

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concentration, with longer time steps used for slowly changing concentrations. To account for cumulative exposures, EPACMTP would need to undergo significant modifications to make the time steps the same for every constituent run so that risks from combined constituent concentrations could be modeled.

- The human health benchmarks used are based on the most sensitive adverse effect. Thus, the addition of constituent risks along the range of potentially affected organ systems would overestimate cumulative risks to less sensitive organ systems.

Because of the considerations listed above, EPA did not consider cumulative risk. This is a source of uncertainty that may result in an underestimation of risk. However, the probabilistic analysis identified individual constituents above risk criteria. Many of the other constituents modeled resulted in risks an order of magnitude or more below risk criteria. Thus, the consideration of additive risk, even with the high-end risks modeled in this risk assessment, is unlikely to alter the principal results of the probabilistic analysis.

Presence of Sensitive Ecological Receptors

Unlike for human receptors, where Census and other population statistics can be used to locate potential receptors with some accuracy, site-specific surveys are needed to confirm the presence of specific ecological receptors. In the absence of site-specific data, this risk assessment made the assumption of co-occurrence of sensitive ecological receptors and waste sites. However, the likelihood that sensitive receptors will be found downgradient from CCR WMUs is unknown. Nor is it known whether those areas support the type of habitat needed by these receptors. Therefore, this assumption may overestimate the potential risks to ecological receptors. The magnitude of this overestimation is unknown. However, given that the modeled risks for these receptors all fell below risk criteria, the potential for this overestimation to alter the results of the probabilistic analysis is negligible.

Ecological Receptor Diet

This analysis assumed that the entire diet of modeled receptors originates from the contaminated area downgradient of WMUs. This may be an appropriate assumption for plants and other relatively sedentary receptors. However, in the wild, many animals are opportunistic feeders with substantial variability in both the type of food items consumed and the geospatial patterns of feeding and foraging. Therefore, the actual proportion of wildlife receptors' diets that would be contaminated depends on a number of factors such as species foraging range, quality of food source, season, climate, and intra- or interspecies competition. Therefore, this assumption may overestimate the potential risks to some ecological receptors. The magnitude and frequency of this overestimation is unknown. However, given that the modeled risks for these receptors all fell below risk criteria, the potential for this overestimation to alter the results of the probabilistic analysis is negligible.

Indirect Ecological Effects

Indirect ecological effects (e.g., depletion of food resources) resulting from the on-site disposal of CCRs were not considered in the probabilistic analysis. Identifying the ways that impacts on food

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supply and habitat quality may adversely impact the overall health of ecological receptors is difficult, even for a site-specific evaluation, and is not currently possible on a national scale. However, for any given facility, the spatial scale of potential contamination would generally be a small fraction of the full home range for many species. In addition, many species are opportunistic feeders that will actively seek other food sources if those near the CCR facilities decline, regardless of the cause of this decline. Exclusion of these indirect effects may underestimate the potential risks to ecological receptors. The magnitude of this underestimation is unknown, but not anticipated to affect the final conclusions of the risk assessment.

Ecosystems and Ecological Receptors at Risk

One challenge in conducting a national risk assessment is representing all receptors and ecosystems at risk. In *Wastes from the Combustion of Coal by Electric Utility Power Plants - Report to Congress* (Exhibit 5-27; U.S. EPA, 1988), EPA noted that managed lands, critical habitats, or threatened and endangered species were located within a five kilometer radius of CCR WMUs at between 12 and 32 percent of facilities:

- **Managed Lands:** Because protected lands play a critical role in preserving plant and animal species, managed areas in the United States represent well recognized ecological values. Managed lands refer to a variety of lands designated by the federal government as worthy of protection, including National Wildlife Refuges, National Forests, Wilderness areas, and National Recreation areas.
- **Critical Habitats:** Critical habitats may be defined in a number of ways (e.g., presence of threatened species, fragmented habitat area). Wetlands are widely recognized as an important habitat serving critical ecological functions (e.g., maintenance of water quality). The U.S. Fish and Wildlife Service estimates that approximately 45 percent of the Nation's threatened and endangered species directly depend on aquatic and wetland habitats. Consequently, impacts of chemical stressors on wetland habitats may have high ecological (and societal) significance.
- **Threatened and Endangered Species:** A threatened species is one that "is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range." An endangered species is one that "is in danger of extinction throughout all or a significant portion of its range."

EPA did not consider impacts to managed lands and critical habitats for similar reasons as indirect ecological effects, as the necessary data on the negative impact on overall ecosystem health is difficult to quantify, even for a site-specific evaluation. Direct risks to threatened and endangered species were not explicitly evaluated as part of this risk assessment because of the lack of species-specific toxicity data. While these species were not explicitly considered, the ecological benchmarks used are based on the most sensitive receptors for which data are available, which are believed to be protective of the majority of species. In certain instances, exclusion of these effects to habitat and specific species may underestimate risks. The magnitude of this underestimation is unknown, but not anticipated to affect the final conclusions of the risk assessment.

Summary

A summary of the different uncertainties associated with the implementation of risk models, as well as the potential for each to affect the risks modeled in the probabilistic analysis is shown in **Table 5-30**. The uncertainties identified are unlikely to have an appreciable impact on the principal risk results.

Table 5-30. Likely Effect on Risk from Risk Model Uncertainties

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Unknown	Low	High
Cumulative Pathways for Human Health Risk		●	
Cumulative COPCs for Human Health Risk		●	
Presence of Sensitive Ecological Receptors		●	
Ecological Receptor Diet		●	
Indirect Ecological Effects		●	
Ecosystems and Ecological Receptors at Risk		●	

5.2 Results of the 2009 Sensitivity Analysis

The discussion of uncertainties in **Section 5.1** considered each uncertainty in isolation; however, the effects of these different sources can compound. In support of the 2010 Risk Assessment, EPA conducted a sensitivity analysis to determine the combination of parameters and associated uncertainties that have the greatest impact on calculated risks (U.S. EPA, 2009b). In this risk assessment, EPA used the results of the 2009 analysis to validate the findings of the revised sensitivity and uncertainty analyses. Although some of the data sources used in the revised risk assessment have changed, the type of inputs used by EPACMTP remained the same. Thus, for the purposes of understanding the sensitivities of the model, the results of this sensitivity analysis are still as relevant.

The 2009 sensitivity analysis used a response-surface regression method to derive a statistical model for ground water concentration (as the dependent variable) based on the input parameters from the probabilistic analysis (as independent variables). Concentration, rather than risk, was chosen as the dependent variable for the sensitivity analysis because the additional exposure factors used to calculate human health risk from environmental concentration (e.g., body weight) have well established, peer-reviewed distributions based on EPA policy. The outputs of the sensitivity analysis were goodness-of-fit values used to determine the relative importance of each input parameter. The most sensitive parameters identified are presented in **Table 5-31**.

Table 5-31. Parameters Identified in the 2009 Sensitivity Analysis

Pathway:	GW→DW Pathway		GW→SW Pathway
Constituents:	**All Constituents**	**Strongly Sorbing**	**All Constituents**
Sensitive Parameters	▪ Infiltration Rate ▪ Leachate Concentration ▪ Hydraulic Gradient ▪ Hydraulic Conductivity	▪ K_d Value ▪ Depth to Ground Water ▪ Distance to Receptor Well	▪ Infiltration Rate ▪ Leachate Concentration ▪ Water Body Flow Rate

As seen in the table above, the GW→DW exposure pathway had more input parameters that were highly sensitive (seven) than the GW→SW exposure pathways (three). The most sensitive parameters for the GW→DW pathways were parameters that impact flux (infiltration rate and leachate concentration) and ground water flow (hydraulic conductivity and gradient). When modeling strongly sorbing constituents, the K_d values and distance to receptor also become important. The most sensitive parameters for the GW→SW exposure pathways were parameters impacting flux (infiltration rate and leachate concentration) and the water body flow rate.

In the probabilistic analysis, risks were identified for the GW→DW exposure pathway. Further sensitivity and uncertainty analyses identified two input parameters with the greatest potential to affect the probabilistic risk results. These parameters align well with the findings of the 2009 sensitivity analysis:

- **Liner Type:** Liner type and design was shown to have one of the most significant effects on modeled risks. The higher hydraulic conductivity of unlined units resulted in the highest risks. Risks from clay-lined units were lower than unlined units, but still close to criteria. Thus, changes to the configuration of the liner, such as adjusting the thickness from three to two feet, has the potential to result in risks above the criteria. Composite liners, with the lowest hydraulic conductivity of any units, resulted in the lowest risks. This is consistent with the finding that infiltration rate is one of the most sensitive parameters, as the hydraulic conductivity of the liner is one of the major factors determining infiltration rate at each unit.
- **Waste pH:** Waste pH was shown to have a significant effect on risk. Multiple constituents presented higher risks when considered in WMUs managing ash and coal refuse at more acidic pHs or FGD wastes at more basic pHs. This is consistent with the finding that leachate concentrations and K values are two of the most sensitive parameters of the model, as pH is one of the driving factors for both parameters.

5.3 Field Comparisons

The comparison of model inputs and results to data collected in the field is a useful means of validation. As discussed previously, EPACMTP has been extensively reviewed and validated, but the specific set of inputs and assumptions applied to the model results in additional sources of

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uncertainty. EPA used two comparisons to assess whether the results of the probabilistic analysis accurately reflect with what may occur in the field. First, EPA examined the leachate data measured with LEAF methods and compared these concentrations to those measured in the field. Second, EPA examined the damage cases to identify the WMU types and constituents most frequently found at damage cases and compared these to the result of the sensitivity and uncertainty analyses.

Leachate Concentrations

EPA characterized leachate from surface impoundments using pore water data and leachate from landfills using LEAF data. Pore water data were collected from core samples both in and beneath surface impoundments. Since the cores take leachate directly from the field, these data are known to represent field conditions and no further comparison is necessary. For landfills, U.S. EPA (2014b) compared LEAF test methods to actual field leachate, both in Europe and the United States. In general, the report demonstrates that LEAF methods accurately capture the leachate characteristics found in the field. Properly accounting for both the pH of the waste in field conditions, as well as the liquid-to-solid ratio of the leachate and waste, was shown to result in lab results very close to those found in the corresponding field conditions.

Comparison of Results to Damage Cases

EPA reviewed the available data on both proven and potential damage cases and compared the findings with the results of the sensitivity and uncertainty analyses. Each damage case reflects a combination of site-specific conditions present at that site. This contrasts with the risk assessment, which is nationwide. Due to the differing nature of these two sources of information, a direct comparison would not be relevant. However, general characteristics and conclusions from the damage cases are relevant to support the findings of the risk assessment, and are discussed below.

The vast majority of damage cases were associated with unlined surface impoundments and landfills. No damage cases were identified for composite-lined units. This agrees well with the results of the sensitivity analyses, which showed that risks were significantly higher for unlined WMUs than for other units, and that risks for composite-lined units were far below all cancer and noncancer criteria.

Arsenic was by far the most common constituent associated with damage cases. Similarly, it was the constituent that exceeded the risk criteria in the most scenarios, and by the greatest magnitude. Other common constituents from the damage cases such as boron and cadmium also exceeded the criteria in the sensitivity analyses. Additional damage cases were identified for other constituents for which no risks were identified in the sensitivity analyses. There are a number of reasons why modeled ground water risks and damage cases do not perfectly align:

- **Different Benchmarks:** In some cases, state standards are more conservative than EPA standards. Other times, state standards exist for constituents where EPA has not yet established a benchmark.
- **Closer Monitoring Distances:** In many of the potential damage cases, ground water exceedances were discovered near the boundary of the WMU. The risk assessment

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considered further dilution and attenuation would occur between the WMU and potential ground water receptors. Thus, concentrations should be higher for all constituents in the damage cases than they would be at the modeled distances in the risk assessment. This is borne out by the fact that so many fewer proven damage cases exist, as these damage cases require, for example, off-site migration.

- **Disposal Practices:** Some damage cases occurred for disposal practices that could not be modeled in the risk assessment. For example, disposal below the water table. In this situation, the sorption that occurs in the unsaturated zone of the risk assessment model does not occur in the field. This and other site-specific risk factors could lead to additional contamination beyond what was modeled nationwide.

These differences between the modeled risks and site-specific damage cases provide examples of why a direct comparison of the risk assessment results to the damage cases is difficult. However, since the scenarios and constituents presenting the most risk are in general agreement, it still strengthens the results of the risk assessment.

5.4 Conclusions

In **Section 5.1**, the uncertainties were discussed in light of their ability to affect the risks of the full probabilistic analysis. Several of the uncertainties related to collecting data and filling data gaps, while the remaining uncertainties were a result of model development and use. **Table 5-32** presents the estimated effect of these uncertainties.

Table 5-32. Summary of Potential Effects of Uncertainty on Risk Results

Uncertainty	Potential to Affect Probabilistic Analysis Results		
	Uncertain	Low	High
CCR WMU Database	0	8	2
Environmental Parameters	1	6	0
CCR Constituent Database	0	3	0
Human Exposure Factors	1	5	0
Human Health and Ecological Benchmarks	2	3	0
Bioconcentration Factors	1	0	0
WMU Source Term Models	3	7	0
MINTAQA2 Isotherm Model	1	0	0
EPACMTP Ground Water Model	1	6	0
Surface Water Model	0	2	0
Risk Models	0	6	0
All Uncertainties	**10**	**46**	**2**

The majority of uncertainties identified (46) are expected to have a minimal effect on the principal results of the probabilistic analysis. EPA was unable to fully characterize the effects of several

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uncertainties (10). These uncertainties have the potential to underestimate or overestimate risks on a case-by-case basis. However, the Agency used the best available data sources to characterize these parameters and minimize potential influence of these uncertainties on modeled results. The remaining uncertainties (2), liner prevalence and waste type prevalence, had a strong influence on modeled results and resulted in appreciably higher risks when different subsets of national disposal practices were considered.

The 2009 sensitivity analysis discussed in **Section 5.2** identified the input parameters that have the greatest potential to influence the fate and transport of constituents. The two uncertainties found to have a high potential to affect modeled risks aligned well with sensitive parameters identified in the 2009 analysis.

Finally, as discussed in **Section 5.3**, EPA compared the risk assessment to field data and damage cases to validate the results. In general, leachate data were strongly corroborated by leachate concentrations observed in the field. The risk assessment results also generally agreed with the damage cases in that they both showed the same type of liners and constituents to cause the most risk to human health and the environment, and resulted in the same constituents exceeding the risk criteria most frequently. Where differences were observed, these were likely due to site-specific considerations that were not modeled in the risk assessment (e.g., placement of waste below the water table). As a result of these comparisons, and the analysis of the sensitivities and uncertainties of the model, EPA finds that the risk assessment provides a good representation of real-world, national-scale risks.

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6 Risk Characterization

The purpose of this document is to characterize the risks associated with current CCR disposal practices across the United States. To accomplish this task, EPA used mathematical models to estimate the rate at which chemical constituents are released from surface impoundments and landfills, the fate and transport of these constituents through the environment, and the potential risk of adverse effects to individual receptors within the exposed population. Modeling for each potential exposure pathway was conducted in a stepwise fashion, with more refined analyses used at each subsequent step until risks were sufficiently characterized. The purpose of this section is to summarize the analyses conducted and results obtained for each exposure pathway, provide further context for these results, and present the final Agency conclusions. This discussion is divided into the following subsections:

- **Section 6.1:** exposures to ambient air that result from the release of fugitive dust by wind.
- **Section 6.2:** exposures to soil, sediment, produce and animal products that result from the release of particulates by wind and overland run-off.
- **Section 6.3:** exposures to impoundment wastewater, ground water, surface water, and sediment that result from the release of leachate.

6.1 Exposure to Ambient Air

6.1.1 Problem Formulation

Many CCR wastes are composed of fine particulates that may become suspended in the air by the wind. These pathways are primarily associated with landfills during operation, as the postclosure cap for landfills and constant water cover for impoundments will limit the release of particulate matter. Although airborne releases may occur from surface impoundments if water levels decrease due to evaporation or other irregular events, EPA focused the analysis on landfills because of the potential for higher and more frequent releases. These particulates may be carried downwind, where the fine particulates and any chemical constituents contained therein may be inhaled by receptors. **Figures 6-1** depicts the potentially complete exposure pathways for these releases.

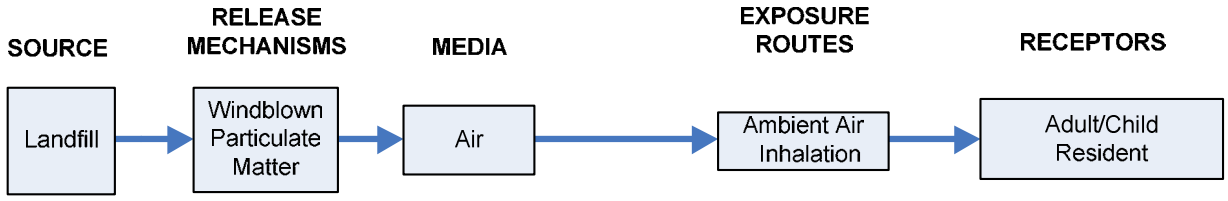

Figure 6-1. Conceptual model for ambient air exposures.

EPA first conducted a simplified hazard identification to identify the constituents that could be quantitatively evaluated. The confirmed presence of a constituent in CCR wastes, combined with the availability of at least one toxicity benchmark, was considered sufficient demonstration of

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hazard potential. Because air concentrations can vary considerably over time, EPA considered three sets of toxicity benchmarks to capture the range of potential exposures. The first are acute benchmarks, which represent short-term exposures. The second were chronic cancer and noncancer benchmarks, which represent long-term exposures. The third were NAAQS, which represent EPA-developed regulatory standards based on varying exposure durations. **Table 6-1** lists each of the constituents which both concentration data and toxicity benchmarks were available. Each of these constituents was retained as COPCs for further analysis.

Table 6-1. List of Constituents Evaluated for Ambient Air Exposures

COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)	
Aluminum	(A,C)	Antimony	(A,C)	Arsenic	(A,C)	Barium	(A)
Beryllium	(A,C)	Boron	(A)	Cadmium	(A,C)	Calcium	(A)
Chloride	(A)	Chromium	(A,C)	Cobalt	(A,C)	Copper	(A)
Fluoride	(A)	Iron	(A)	Lanthanum	(A)	Lead	(A,N)
Magnesium	(A)	Manganese	(A,C)	Mercury	(A,C)	Molybdenum	(A)
Nickel	(A,C)	Nitrate/Nitrite	(A)	Selenium	(A,C)	Silicon	(A)
Silver	(A)	Sodium	(A)	Strontium	(A)	Sulfate	(A)
Thallium	(A)	Uranium	(A,C)	Vanadium	(A,C)	Zinc	(A)
PM_{10}	(N)	$PM_{2.5}$	(N)				

A – Acute Toxicity Benchmark
C – Chronic Toxicity Benchmark
N – National Ambient Air Quality Standard.

6.1.2 Screening Analysis

The screening analysis was conducted using the steady-state plume models, AERSCREEN and AERMOD. These models were used to calculate the maximum air concentrations that may occur, averaged over the course of 1 hour, 24 hours, 1 month and 1 year. Each of these exposure durations was calculated for two management scenarios: uncontrolled and controlled releases. Uncontrolled releases occur when no action is taken to reduce particulate emissions, while controlled releases occur when management practices are put in place to minimize the rate of particulates emissions. Yet, even with the best available fugitive dust controls, some emissions may still occur. Therefore, EPA modeled these reduced releases based on available field data. The modeled air concentrations reflect a combination of multiple high-end parameters, including emission rate, landfill size, weather, distance to receptor and waste COPC concentration. EPA used these air concentrations, together with available toxicity benchmarks, to estimate the likelihood of adverse effects to downgradient receptors.

- **Acute Risks** were calculated based on the maximum 1-hour concentration. Risks above an HQ_A of 1 was identified for arsenic (2) under an uncontrolled management scenario, but decreased below risk criteria when fugitive dust controls were considered.

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- **Chronic Risks** were calculated based on the maximum annual concentration. All risks fell below the selected human health risk criteria under both a controlled and uncontrolled management scenario.
- **NAAQS** exceedances were calculated based on the available averaging time closest to that specified by the standards. An air concentration above the NAAQS for 24-hr $PM_{2.5}$ by a factor of 2 was identified under an uncontrolled management scenario, but decreased below risk criteria when fugitive dust controls were considered.

The screening analysis shows the potential for risks under an uncontrolled management scenario for acute arsenic exposure; chronic arsenic, cobalt and chromium VI exposures; and short-term $PM_{2.5}$ exposures. Due to the conservative nature of the screening, there is a great deal of uncertainty surrounding the calculated risks. The modeled ambient air concentrations represent a protective, but unlikely, combination of conditions that reflect at least an upper bound on potential exposures. Thus, the cumulative effect of these uncertainties results in an overestimation of potential risks to most or all receptors. Therefore, EPA makes no direct findings concerning the magnitude of the risks that may occur under either an uncontrolled or controlled management scenario, but concludes with a high degree of confidence that the reductions achievable with available management practices are sufficient to be protective even under this conservative screening assessment. Based on these lines of evidence, EPA concluded that no further characterization of is warranted.

6.2 Releases to Soil

6.2.1 Problem Formulation

Many CCR wastes are composed of fine particulates that may become suspended in the air by the wind or washed away overland by run-off and erosion. These pathways are primarily associated with landfills during operation, as the postclosure cap for landfills and constant water cover for impoundments will limit the release of particulate matter. Although these releases may occur from surface impoundments if water levels decrease due to evaporation, overtopping from extreme rainfall or other irregular events, EPA focused the analysis on landfills because of the potential for higher and more frequent releases. Released particulates may be carried downgradient, where COPCs may accumulate on top of soil, sediment and plant surfaces, as well as concentrate within plants and animals raised on contaminated soils. Receptors may be exposed through contact with or ingestion of the contaminated media. **Figures 6-2** depicts the potentially complete exposure pathways for these releases.

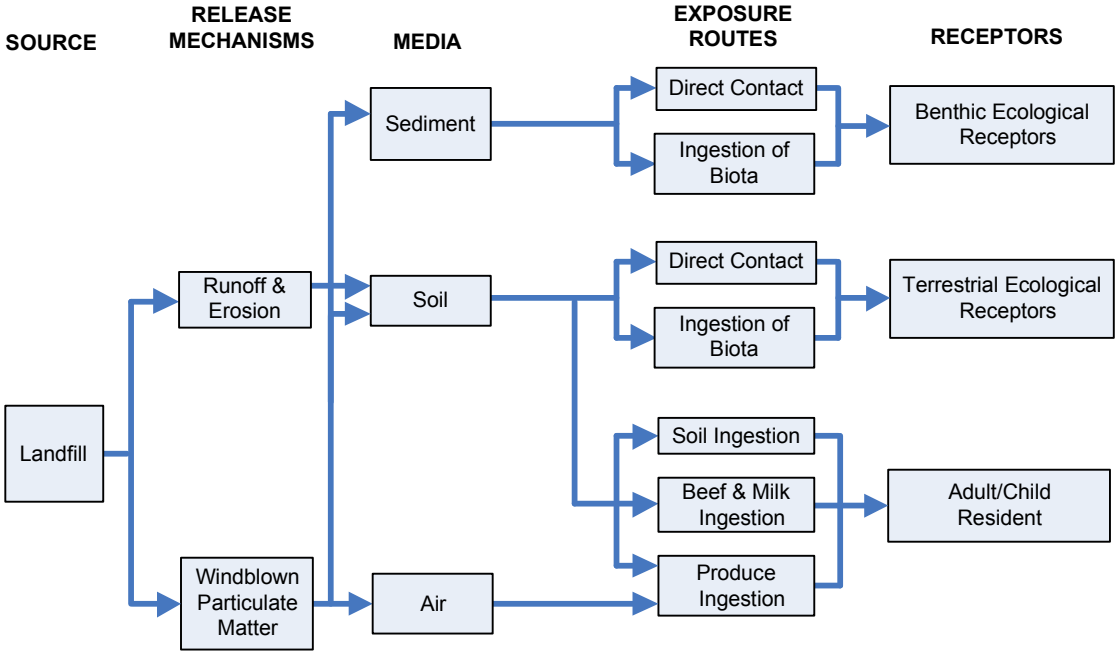

Figure 6-2. Conceptual model for soil exposures.

EPA first conducted a simplified hazard identification to identify the chemical constituents to be quantitatively evaluated. The confirmed presence of a constituent in CCR wastes, combined with the availability of at least one toxicity benchmark, was considered sufficient demonstration of hazard potential. EPA used chronic toxicity benchmarks to evaluate these exposures. Adverse effects from chronic exposures occur at lower concentrations than acute exposures. Therefore, the risks calculated for chronic exposures will also be protective of more acute exposures. **Table 6-2** lists each of the constituents for which both concentration data and toxicity benchmarks were available. Each of these constituents were retained as COPCs for further analysis.

Table 6-2. List of Constituents Evaluated for Soil, Sediment, Produce and Animal Product Exposures

COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)	
Aluminum	(N,E)	Antimony	(N,S,D)	Arsenic	(C,N,S,D)	Barium	(N,S,D)
Beryllium	(N,S)	Boron	(N,S)	Cadmium	(N,S,D)	Chromium	(C,N,S,D)
Cobalt	(N,S)	Copper	(N,S,D)	Fluoride	(N)	Iron	(N)
Lanthanum	(N)	Lead	(S,D)	Manganese	(N,S)	Mercury	(N,S,D)
Molybdenum	(N,S,D)	Nickel	(N,S,D)	Nitrate/Nitrite	(N)	Selenium	(N,S)
Silver	(N,S,D)	Strontium	(N)	Thallium	(N)	Uranium	(N)
Vanadium	(N,S,D)	Zinc	(N,S,D)				

C – Human Health Cancer Benchmark
N – Human Health Noncancer Benchmark
S – Ecological Soil Benchmark
D – Ecological Sediment Benchmark

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6.2.2 Screening Analysis

The screening analysis was conducted using a combination of a conservative DAF of 10 and deposition rates calculated with AERMOD. Exposures were calculated for two management scenarios: uncontrolled and controlled releases. Uncontrolled releases occur when no action is taken to reduce particulate emissions. Controlled releases occur when management practices are put in place to minimize the rate of particulates emissions. Yet, even with the best available management practices, some emissions may still occur. Therefore, EPA modeled these reduced releases based on available field data. The modeled media concentrations reflect a combination of multiple high-end parameters, including emission rate, landfill size, weather, distance to receptor and waste COPC concentration. EPA used the modeled media concentrations, together with available toxicity benchmarks, to estimate the likelihood of adverse effects.

- **Human Health Cancer Risks** all fell below the selected human health risk criteria under both a controlled and uncontrolled management scenario.
- **Human Health Noncancer Risks** above an HQ of 1 were identified under the uncontrolled scenario. Thallium risks were identified for exposures to soil (2), beef (10) and milk (8). When fugitive dust and run-off controls were considered, all cancer risks fell below the risk range.
- **Ecological Soil Risks** above relevant criteria were identified under the uncontrolled scenario. Ecological risks above an HQ of 1 were identified were identified for, listed from highest to lowest: boron (80) antimony (20) vanadium (7) and selenium (3). When fugitive dust and run-off controls were considered, all risks fell below the risk range.
- **Ecological Sediment Risks** above relevant criteria were identified under the uncontrolled scenario. Ecological risks above an HQ of 1 were identified were identified for, listed from highest to lowest: vanadium (3), antimony (2), arsenic (2) and silver (2). When fugitive dust and run-off controls were considered, all risks fell below the risk range.

The screening analysis shows the potential for risks to both human and ecological receptors under an uncontrolled management scenario. Risks to human health resulted from ingestion of arsenic, chromium and thallium present in soil, produce and animal products. Ecological risks resulted from antimony, boron, selenium and vanadium present in soils and antimony, arsenic, silver and vanadium present in sediments. Due to the conservative nature of the screening, there is a great deal of uncertainty surrounding the calculated risks. The modeled media concentrations represent a protective, but unlikely, combination of conditions that most likely reflects an upper bound on potential exposures. The cumulative effect of these uncertainties results in an overestimation of potential risks. Therefore, EPA makes no direct findings concerning the magnitude of the risks that may occur under either an uncontrolled or controlled management scenario, but concludes with a high degree of confidence that the reductions achievable with available management practices are sufficient to be protective even under this conservative screening assessment.

Based on these lines of evidence, EPA concluded that no further characterization of soil, produce, or animal products is warranted. Although sediment exposures also screened out under the

controlled management scenario, EPA did retain sediment for further characterization. The results of the uncontrolled exposure scenario were used as a conservative screen for risks that may occur from subsurface transport of COPCs through ground water to sediment.

6.3 Releases to Ground Water

6.3.1 Problem Formulation

When CCR wastes are disposed on the ground, it may result in leaching to ground water. Many of these pathways are associated with both surface impoundments and landfills. Once mixed with ground water, the COPCs may migrate downgradient to private wells where it is ingested by receptors, to water bodies were **Figures 6-3** depicts the potentially complete exposure pathways for these releases.

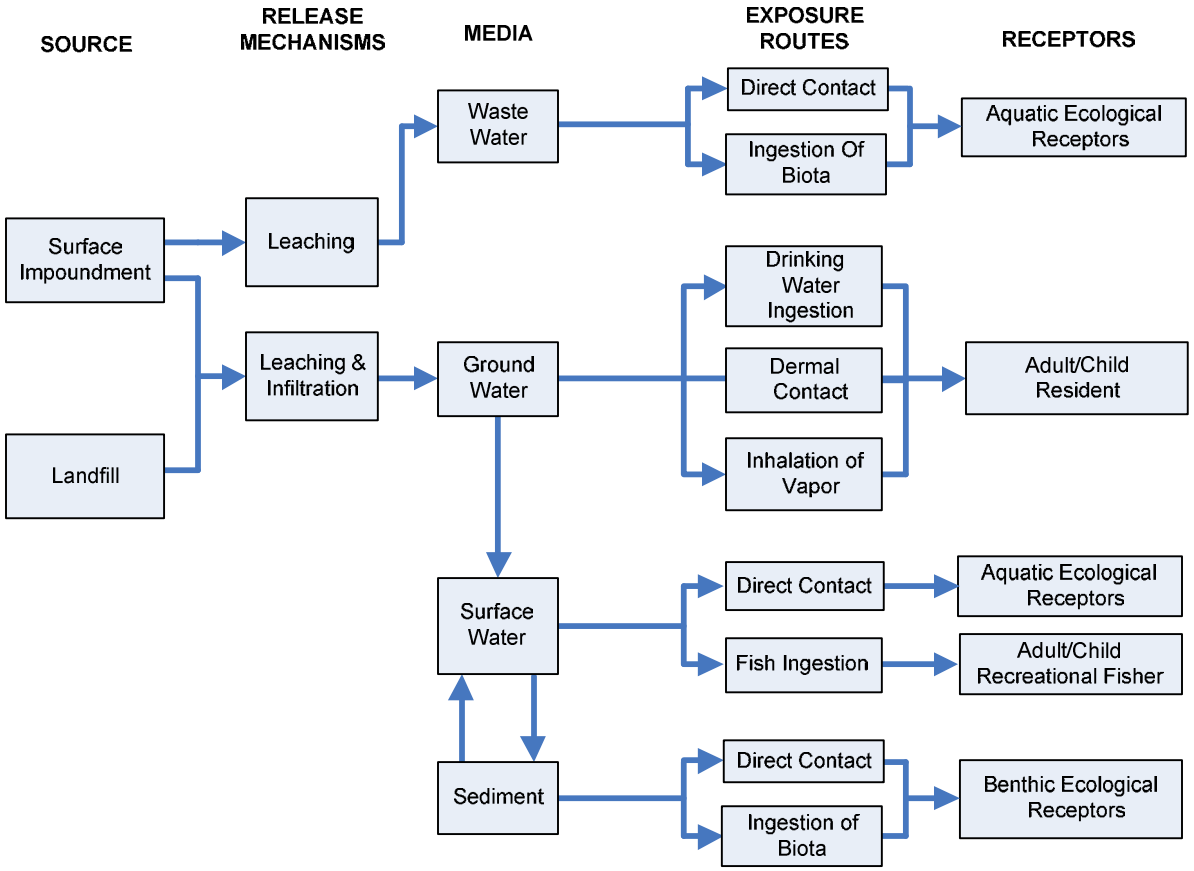

Figure 6-3. Conceptual model for ground water exposures.

EPA first conducted a simplified hazard identification to identify the constituents that could be quantitatively evaluated. The confirmed presence of a constituent in CCR wastes, combined with the availability of at least one toxicity benchmarks, was considered sufficient demonstration of hazard potential. EPA used chronic toxicity benchmarks to evaluate these exposures. Adverse effects from chronic exposures occur at lower concentrations than acute exposures. Therefore, the risks calculated for chronic exposures will also be protective of more acute exposures. **Table 6-3**

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lists each of the constituents for which both concentration data and toxicity benchmarks were available. Each of these constituents were retained as COPCs for further analysis.

Table 6-3. List of Constituents Evaluated for Ground Water, Surface Water and Wastewater Exposures

COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)		COPC (Benchmark)	
Aluminum	(N,E)	Ammonia	(N)	Antimony	(N,E)	Arsenic	(C,N,E)
Barium	(N,E)	Beryllium	(N,E)	Boron	(N,E)	Cadmium	(N,E)
Chloride	(E)	Chromium	(C,N,E)	Cobalt	(N,E)	Copper	(N,E)
Fluoride	(N)	Iron	(N,E)	Lanthanum	(N)	Lead	(M,E)
Lithium	(N)	Manganese	(N,E)	Mercury	(N,E)	Molybdenum	(N,E)
Nickel	(N,E)	Nitrate/Nitrite	(N)	Selenium	(N,E)	Silver	(N,E)
Strontium	(N)	Sulfide	(E)	Thallium	(N,E)	Uranium	(N)
Vanadium	(N,E)	Zinc	(N,E)				

C – Human Health Cancer Benchmark
N – Human Health Noncancer Benchmark
M – Maximum Contaminant Limit
E – Ecological Surface Water Benchmark

6.3.2 Screening Analysis

EPA used a conservative DAF of 1 to estimate the COPC concentrations that may be present in ground water, surface water and wastewater. The resulting exposure concentrations are equivalent to direct receptor exposures to undiluted CCR leachate. For these exposure pathways, EPA did not identify any post-construction management practices that could mitigate releases, so only one release scenario was considered. In addition, because the 2010 Risk Assessment (U.S. EPA, 2010a) previously demonstrated that risks from surface impoundments are consistently higher than those from landfills, EPA used the screening results for surface impoundments to also identify the initial set of COPCs for landfills. A summary of the modeled risks above relevant human health or ecological criteria is provided below:

- **Ground Water:** Ingestion of ground water resulted in risks above the human health criteria. Cancer risks above 1×10^{-5} were identified for arsenic (3×10^{-3}) and chromium VI (2×10^{-4}). Noncancer risks above an HQ of 1 were identified, from highest to lowest, for: arsenic (50), molybdenum (30), boron (10), fluoride (7), thallium (6), lithium (4), cobalt (3), antimony (2) and cadmium (2).
- **Surface Water:** Ingestion of fish resulted in risks above the human health criteria. Cancer risks above 1×10^{-5} were identified for arsenic (4×10^{-5}). Noncancer risks above an HQ of 1 were identified, from highest to lowest, for: selenium (10), mercury (7), thallium (4) and cadmium (2).
- **Surface Water:** Direct contact with and ingestion of surface water resulted in risks above ecological criteria. Ecological risks above an HQ of 1 were identified, from highest to lowest,

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for: cadmium (200), aluminum (100), arsenic (100), boron (100), selenium (60), barium (50), lead (40), vanadium (30), chromium III (20), molybdenum (20), copper (10), iron (10), silver (10), chloride (9), nickel (6), beryllium (2), cobalt (2) and zinc (2).

- **Wastewater:** Direct contact with and ingestion of impoundment wastewater resulted in risks above ecological criteria. Ecological risks above an HQ of 1 were identified, from highest to lowest, for: arsenic (100), barium (50), aluminum (30), boron (30), selenium (20), cadmium (10), vanadium (10), beryllium (2), chloride (2) and chromium (2).

Multiple COPCs resulted in risks above human health and ecological criteria. For these pathways, there were no post-construction management practices identified to mitigate releases. However, considerable dilution and attenuation may occur before leachate reaches downgradient private wells, surface water and sediments. Therefore, EPA retained all of the COPCs found to be above risk criteria in ground water and surface water for further characterization in the probabilistic analysis. In addition, EPA carried forward the COPCs identified in the sediment screening previously discussed in **Section 6.2.2**.

Unlike the other exposure pathways, there will be little to no dilution and attenuation that will occur in impoundment wastewater prior to ecological exposures. Because of this, the screening analysis conducted provides sufficient characterization of this exposure pathway. Therefore, EPA concludes that there is the potential for risks to ecological receptors from concentrations of aluminum, arsenic, barium, beryllium, boron, cadmium, chloride, chromium, selenium and vanadium in surface impoundment wastewater.

6.3.3 Probabilistic Analysis

EPA conducted national-scale, probabilistic modeling to better characterize the risks to human and ecological receptors associated with leachate released from surface impoundments and landfills. A combination of models were used to predict COPC fate and transport through the environment, receptor exposures, and the resulting risks. EPA used the most complete and current data sets available to run these models. Site-specific data were used, supplemented by regional and national data sets, to capture the national variability of disposal practices, environmental conditions and receptor behavior. EPA modeled risks for both highly exposed individuals (90th percentile risks) and moderately exposed individuals (50th percentile risks). A summary of the modeled risks above relevant human health or ecological criteria is provided below:

- **Surface Impoundments:** Ingestion of ground water was the only exposure pathway that resulted in risks above the relevant criteria. 90th percentile cancer risks above 1×10^{-5} were identified for arsenic III (2×10^{-4}). 90th percentile noncancer risks above an HQ of 1 were identified for arsenic III (5), lithium (2), and molybdenum (2).
- **Landfills:** 90th percentile cancer and noncancer risks were all below human health criteria.

High-end risks for surface impoundments are consistently higher than those for landfills. These results are attributed primarily to the higher infiltration rates through surface impoundments, which is controlled by the hydraulic head of ponded water. Median risks for both surface impoundments

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and landfills were substantially lower than both the high-end risks in this risk assessment and the median risks modeled in the 2010 Risk Assessment. This decrease is attributed primarily to the interception of ground water by surface water bodies, which is accounted for in the revised risk assessment to provide a more accurate mass balance of constituent mass during transport. It is common for coal-fired utilities to be located near water bodies, which are used as a source of cooling water and conveyance of waste. As a result, in the majority of model iterations, the interception of ground water by surface water bodies resulted in negligible downstream well concentrations.

The modeled probabilistic risks capture the range of current, nationwide CCR disposal practices. However, because of the broad scope of the analysis, there are a number of sources of variability and uncertainty present. Therefore, to confirm the results of the probabilistic analysis and to better understand whether any particular subset of disposal practices drives the risks identified, EPA retained each of the exposure pathways from the probabilistic analyses for additional sensitivity and uncertainty analyses.

6.3.4 Sensitivity and Uncertainty Analyses

EPA reviewed the models used, as well as all of the data and assumptions input into these models, to better understand the sources of variability and uncertainty inherent in the probabilistic analysis. The Agency then qualitatively and, where possible, quantitatively analyzed these sources to understand the potential effects each may have on the modeled risk results. During this review, specific attention was focused on the parameters shown to have the greatest influence on model results. The review found that, on the whole, the risk assessment results do not appear to be strongly biased toward overestimation or underestimation of risks, and there is a high degree of confidence in the principal findings of the probabilistic analysis. However, the review of sensitive parameters revealed some specific disposal practices that may result in greater risks than identified in the probabilistic modeling.

Two sensitive parameters are the leachate concentration and the subsurface K_d values. Both of these parameters are greatly influenced by the pH of the disposed waste. To explore the effect of pH on modeled risk results, EPA separated the full-scale national results into separate distributions to capture changes in risk at different pH values. Because of the very low 50th percentile risks identified in the probabilistic analyses, all risks presented are 90th percentile.

- **Surface Impoundments (low pH):** More acidic wastes, represented by the codisposal of ash and coal refuse (pH 1.7–8.2) resulted in risks above human health and ecological criteria. Cancer risks above 1×10^{-5} were identified for arsenic III (1×10^{-3}) and arsenic V (4×10^{-4}) from ingestion of ground water. Noncancer risks above an HQ of 1 were identified for arsenic III (26), arsenic V (14) and cobalt (13) from ingestion of ground water; for mercury (5) from fish ingestion; and for cadmium (3) from ecological exposure to surface water.
- **Surface Impoundments (high pH):** More basic wastes, represented by the disposal of FGD materials (pH 8.7–11.3) resulted in risks above human health criteria. Cancer risks above 1×10^{-5} were identified for arsenic III (2×10^{-4}) and arsenic V (2×10^{-5}) from ingestion of

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ground water. Noncancer risks above an HQ of 1 were identified for arsenic III (5), boron (2) and fluoride (2) from ingestion of ground water.

- **Landfills:** 90th percentile cancer and noncancer risks were all below human health criteria over the relevant pH range.

The results show that the potential for higher risks from disposal of CCRs under more acidic and basic conditions. Additional risks from surface impoundments were identified for boron, cobalt, fluoride and mercury. Given the smaller fraction of units that manage wastes at these pH values, there is greater uncertainty associated with these risks. However, damage cases were identified for all of these constituents except fluoride.

Another sensitive parameter is the rate at which leachate can infiltrate through the WMU and into underlying soils. This parameter is controlled primarily by the type of liner present. To explore the effect of liner type on modeled risk results, EPA divided full-scale national results for surface impoundments and landfills into three separate distributions, one for each liner type modeled. Because of the very low 50th percentile risks identified in the probabilistic analyses, all risks presented are 90th percentile.

- **Unlined Units** were found to present the greatest risks. Unlined impoundments result in cancer risks above 1×10^{-5} for arsenic III (3×10^{-4}) and arsenic V (4×10^{-5}), as well as noncancer risks above an HQ of 1 for arsenic III (8), molybdenum (4), lithium (3) and thallium (2). Unlined landfills result in cancer risks above 1×10^{-5} for arsenic III (2×10^{-5}).
- **Clay-lined Units** were found to present risks lower than unlined units. Clay-lined impoundments result in noncancer risks for lithium (2).
- **Composite-lined Units** were found to result in risks far below all relevant risk criteria.

As modeled, unlined units present the greatest risks to human health and the environment. There is a high degree of confidence in these modeled results. EPA modeled these units with site-based soil hydraulic conductivities selected based on geographic location. In addition, these findings are corroborated by field observations that show the vast majority of damage cases to be associated with unlined units. The hydraulic conductivity of clay liners is based on a single value specified by the EPA Industrial Subtitle D Guidance (U.S. EPA, 2006b). Therefore, to the extent that clay-lined units behave differently in the field; because of a different effective hydraulic conductivity, liner thickness, or other factors; the risk assessment may over- or underestimate risks from these units. The hydraulic conductivity of composite-lined units was based on a range of field-measured values. Given the very low risks associated with these units, the various uncertainties are unlikely to affect the modeled results.

Additional damage cases were identified for other constituents for which no risks were identified in these sensitivity analyses (e.g., beryllium, lead, selenium). There are a number of reasons why modeled ground water risks and damage cases do not perfectly align. EPA considered a range of distances to receptor wells, whereas damage cases for ground water are typically associated with monitoring wells near the WMU. Furthermore, some individual damage cases reflect site-specific

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disposal scenarios, such as placement of waste in contact with the water table, which could not be explicitly modeled. Therefore, EPA believes that these real-world risks validate those identified in the probabilistic and sensitivity analyses.

6.3.5 Conclusions

Based on the results of the probabilistic analysis, EPA concludes that leaching from CCR waste management units has the potential to pose risk to both human and ecological receptors. Arsenic, lithium and molybdenum are the chemical constituents found to pose the greatest risks from surface impoundments, while arsenic posed the greatest risks from landfills. Risks from arsenic ingestion are linked to an increase the risk of cancer in the skin, liver, bladder and lungs, as well as nausea, vomiting, abnormal heart rhythm, and damage to blood vessels. Risks from lithium ingestion are linked to neurological and psychiatric effects, decreased thyroid function, renal effects, cardiovascular effects, skin eruptions, and gastrointestinal effects. Risks from molybdenum ingestion are linked to higher levels of uric acid in the blood, gout-like symptoms, and anemia. EPA found that there is a high degree of confidence in underlying data for these modeled risks. In addition, these results are supported by damage cases. Arsenic is the constituent found most frequently in ground water damage cases and, while no MCL exists for lithium or molybdenum, exceedances of other criteria were identified for these two constituents in ground water damage cases.

Through additional sensitivity and uncertainty analyses that explored different subsets of disposal practices, EPA identified the potential for higher risks than those identified in the broader, national analysis. Consideration of different waste pH values showed higher risks for arsenic at more acidic and basic pH values, as well as additional risks for boron, cadmium, cobalt, fluoride and mercury at these more acidic and basic pHs. Consideration of specific liner types showed that ground water risks are driven by disposal in unlined units and, in particular, unlined surface impoundments. For these units, EPA identified higher risks for arsenic, lithium and molybdenum, as well as additional risks for thallium. Clay-lined units were found to pose risks that, while lower than unlined units, were still above the noncancer risk criteria for lithium. Consideration of uncertainties associated with the analysis of clay-lined units may result in somewhat lower or higher risks, which may decrease lithium risks below noncancer criteria, but may also result in additional constituents above cancer or noncancer risk criteria. Composite-lined units were found to be the most protective disposal practice, resulting in risks far below all criteria identified in this risk assessment.

The comparison of recent 2009/2010 EPA surveys with an older, 1995 EPRI survey indicates that the majority of newly constructed units are lined, and that that the practice of codisposal with coal refuse is declining. However, this risk assessment presents a static snapshot of current disposal practices. While newer units may be managed in a more protective manner, older units, which still comprise the majority of currently operating units, continue to operate in a manner that may pose risks to human health and the environment.

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Appendix A.

CCR Waste Management Unit Database

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A.1 Introduction

The U.S. Environmental Protection Agency (EPA or the Agency) relied on the U.S. Department of Energy (DOE) Energy Information Agency (EIA) Database for information on the location, generating capacity, and coal burned for each coal-fired utility power plant (hereafter referred to as "facilities"). The 2009 EIA database contained information on the tons of coal combustion residuals (CCRs) generated annually, as well as their disposition (e.g., landfilled) at 507 facilities. However, EIA does not provide information on the characteristics of the waste management units (WMUs) where the disposed CCRs are managed. For this information, two recent EPA surveys of on-site WMUs have since been completed:

- 2009 *Information Request Responses* [obtained under Section 104(e) of the Comprehensive Environmental Response, Compensation, and Liability Act][1] together with *Impoundment Assessment Reports*,[2] hereafter jointly referred to as "the 2009 EPA Survey"; and
- 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines, hereafter referred to as "the 2010 EPA Survey.[3]"

A.1.1 2009 EPA Information Request Letters and Impoundment Assessment Reports

Following the massive coal ash spill at the Tennessee Valley Authority's Kingston facility in December 2008, EPA took aggressive steps to assess surface impoundments and other WMUs that manage residuals from coal combustion and that contain free liquids. Beginning on March 9, 2009, EPA mailed information request letters to electric utilities and corporations that reported wet CCR disposal to EIA in 2005. These letters requested information on the location (latitude/longitude) of each surface impoundment, as well as the surface impoundment area, capacity, liner type, operating period and waste type managed.

The Agency also conducted site assessments at many of these impoundments using contractors with expertise in dam integrity. To ensure that surface impoundment data were as accurate as possible, the site assessment reports were reviewed by EPA for the same information requested in the information request letters. The data from these two sources included information on a total of 729 surface impoundments as of June 2011. These data were extracted for inputs in the revised risk assessment. Further impoundment assessment reports have been compiled since this time, but the data from these reports are not reflected in this analysis. However, the Agency has continued to update this information on its website.[4]

[1] Available online at: www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys/index.htm

[2] Additional impoundment assessment reports have been conducted since the model inputs were developed. Available online at: www.epa.gov/osw/nonhaz/industrial/special/fossil/surveys2/index.htm

[3] Available online at: water.epa.gov/scitech/wastetech/guide/steam_index.cfm

[4] Available online at: www.epa.gov/wastes/nonhaz/industrial/special/fossil/coalashletter.htm

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A.1.2 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines

In 2010, EPA distributed questionnaires to approximately 700 fossil- and nuclear-fueled steam electric power plants to support its proposed rule amending the effluent guidelines for the Steam Electric Power Generating category. The questionnaire requested information about many facets of facility operation, including surface impoundment and landfill operations. To reduce burden under the Paperwork Reduction Act (44 U.S.C. §3501 et seq.), the survey was comprised of nine sections (A through I), and EPA organized the respondents into four groups that completed different sections. Most coal-fired power plants received only Parts A through D, H and I of the survey. However, a statistically representative subset received all sections of the survey (Parts A through I).

The 2009 survey discussed above only contained surface impoundments information from facilities and companies that reported wet disposal to EIA in 2005. However, this survey captured both surface impoundment and landfill information from all facilities within the regulatory scope of the rulemaking. Thus, it accounted for both surface impoundments at facilities that did not report a wet disposal tonnage in EIA 2005 and landfills. Information included geographic location, dimensions (area, capacity and thickness), waste type, liner status and type, and operating period. These parameters were extracted from a database assembled to exclude data considered confidential business information (CBI). This database provided information on a total of 431 landfills and an additional 223 impoundments that had not been captured in the 2009 EPA survey.

A.2 Filling Data Gaps

The data from the surveys discussed above are hereafter collectively referred to as the CCR WMU database. Although facilities and WMUs are constantly opening and closing, the CCR WMU database identified all operating facilities at that time it was compiled. However, some data gaps still existed in the CCR WMU database, with information on some parameters (e.g., WMU size) missing for a subset of the WMUs. This occurred for four reasons. First, as part of its efforts to comply with the Paperwork Reduction Act, EPA sent different, incomplete versions of its 2010 survey to a number of facilities. Second, even when a facility received and answered all relevant questions, those facilities sometimes did not know the answer to some questions, or otherwise provided nonresponsive answers. Finally, even when a response was received, it was sometimes claimed as CBI. The data claimed as CBI that EPA was unable to successfully challenge by the time the data set was compiled for the analysis could not be presented in this document. Thus, to maintain the transparency of this report, EPA chose not to rely on it here.

To fill in data gaps, EPA first attempted to calculate the missing data for a WMU based on other available data for the same WMU. Where this was not possible, EPA filled in the gaps by drawing from a probability distribution created from surface impoundments and landfills with data. If the parameter in question was not anticipated to correlate to plant size (e.g., liner type), then EPA used the distributions developed for all impoundments or landfills. However, if the parameter in question may correlate to plant size (e.g., WMU size), EPA further divided the distributions into

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quartiles based on the amount of coal burnt at each facility to avoid unrealistic combinations (e.g., largest WMU size and smallest facility). EPA defined the quartiles based on the coal use reported in the 2009 EIA database. All of the WMUs associated with facilities within a quartile were aggregated to create a new distribution. EPA then drew from the distribution type located at facilities in the same coal use quartile.

A description of the gap-filling procedures for each parameter is included below. **Attachment A-1** provides a summary of the data collected for each facility on geographic location, number of surface impoundments and landfills present, amount of coal burned and the associated coal use quartile. **Attachment A-2** provides a summary of the WMU-specific data collected for the CCR risk assessment, including geographic locations, dimensions, waste type, and liner type. Missing data for individual facilities and WMUs are listed in the attachment as blank fields.

A.2.1 Geographic Location

Each WMU in the survey was matched with a specific electric utility facility in the U.S. Department of Energy's EIA Forms EIA-860 (Annual Electric Generator Report) and EIA-923 (Power Plant Operations Report) using the Office of the Regulatory Information System facility identification code assigned by the EIA. This was done to provide a complete data set of approximate WMU locations. The latitudes and longitudes reported in the EIA Database often represent a centroid or front-gate location for each facility. However, WMUs can be located some distance away from the main facility. Therefore, where possible, the revised risk assessment used the available data from the CCR WMU database to identify the specific locations of individual WMUs and only relied on facility locations when no WMU-specific data was available. The reported locations for both facilities and WMUs were then reviewed based on visual inspection of aerial photography using Google Earth and adjusted, as appropriate. Obtaining and checking the latitude and longitude centroid locations missing in the survey data allowed greater accuracy for collecting the WMU-specific environmental setting information described in **Appendix B**.

A.2.2 Dimensions

The CCR WMU database includes information on the total surface area and total volumetric waste capacity of most surface impoundments and landfills included in the survey. Because the final capacity of a WMU was not always known, the capacity at closure was preferred when multiple values were available, followed by constructed capacity and current capacity as the best estimates for surface impoundment or landfill volume. To impute data for facilities missing either area or capacity data, but not both, linear regression equations were developed based on WMUs with both area and capacity data. The final regression equations are shown in **Figures A-1** and **A-2** for surface impoundments[5] and **Figures A-3** and **A-4** for landfills. In each case, the standard error around the regression line was used during source data file preparation to randomly vary the area or capacity from iteration to iteration within the bounds defined by the standard error. In cases where neither area nor capacity data were available, an area and capacity pairing was

[5] At the time these regressions were developed, EPA had data on 729 surface impoundments from the 2009 survey.

probabilistically selected from available data for units in the same coal use quartile as the units with the missing data.

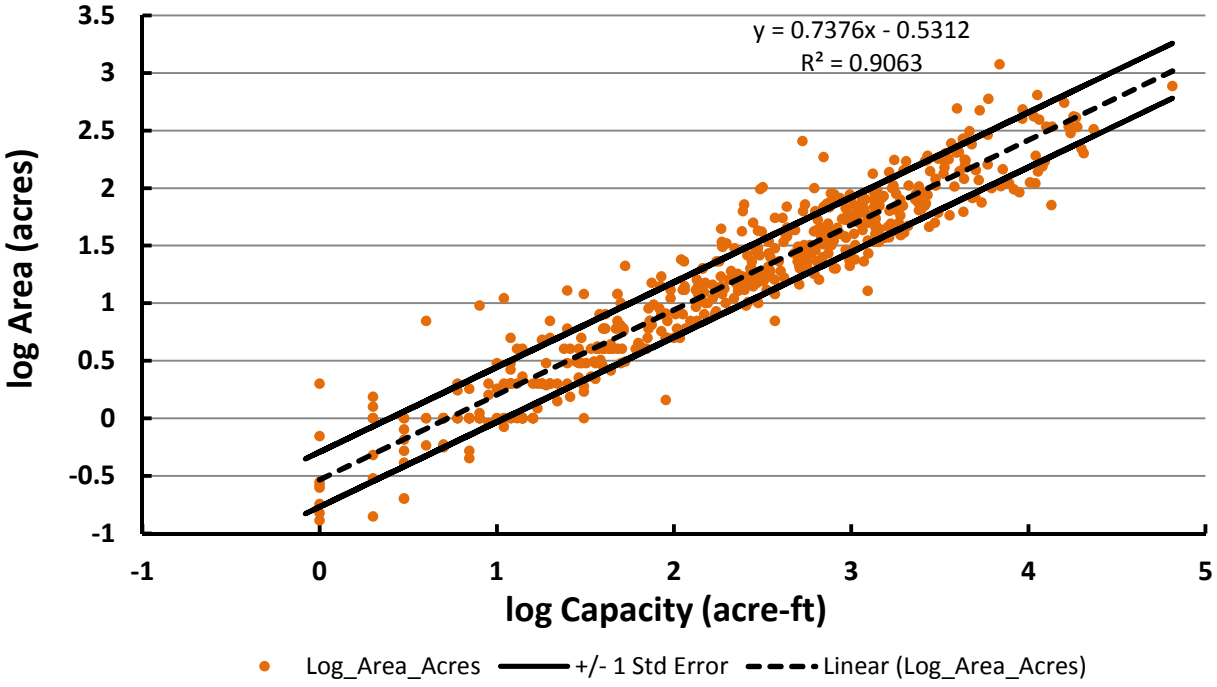

Figure A-1. Linear regression to impute surface impoundment area from capacity.

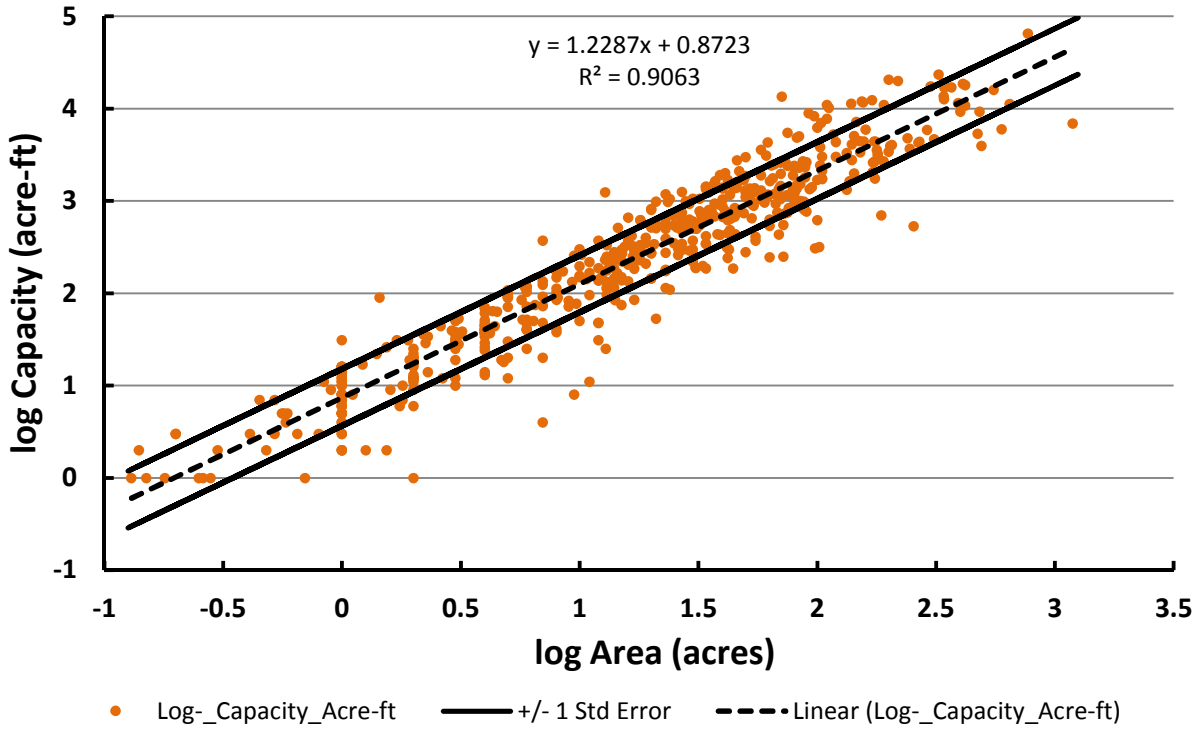

Figure A-2. Linear regression to impute surface impoundment capacity from area.

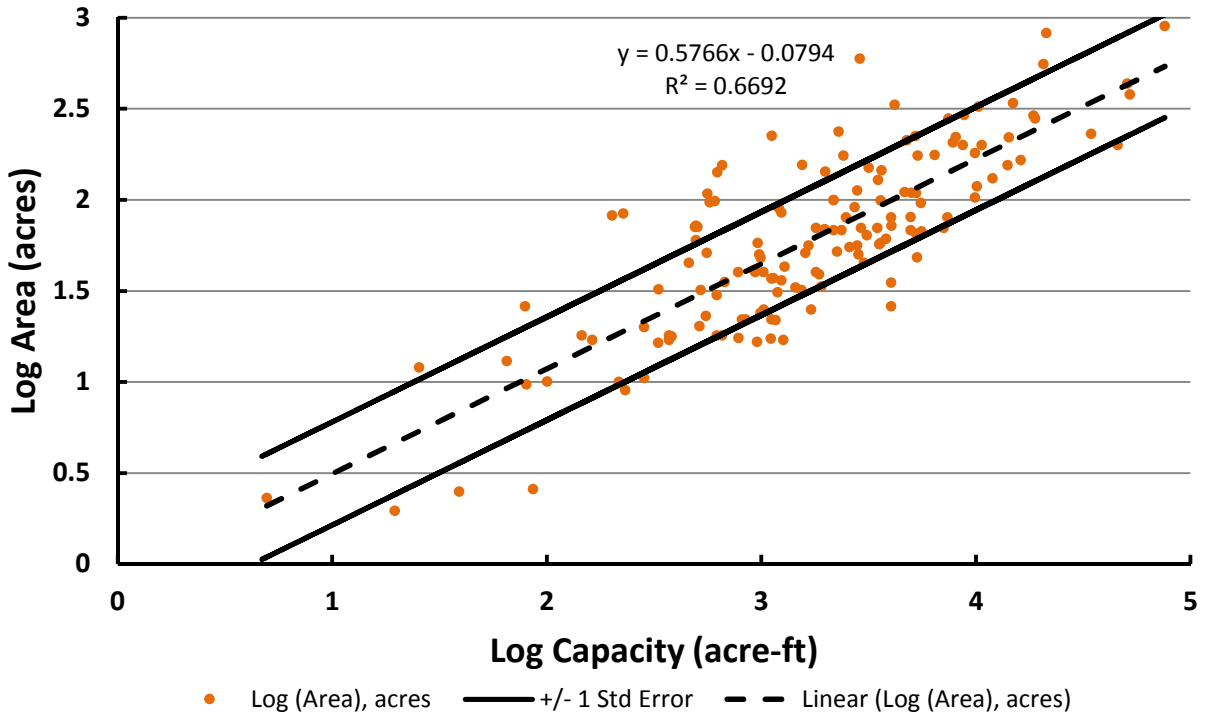

Figure A-3. Linear regression to impute landfill area from capacity.

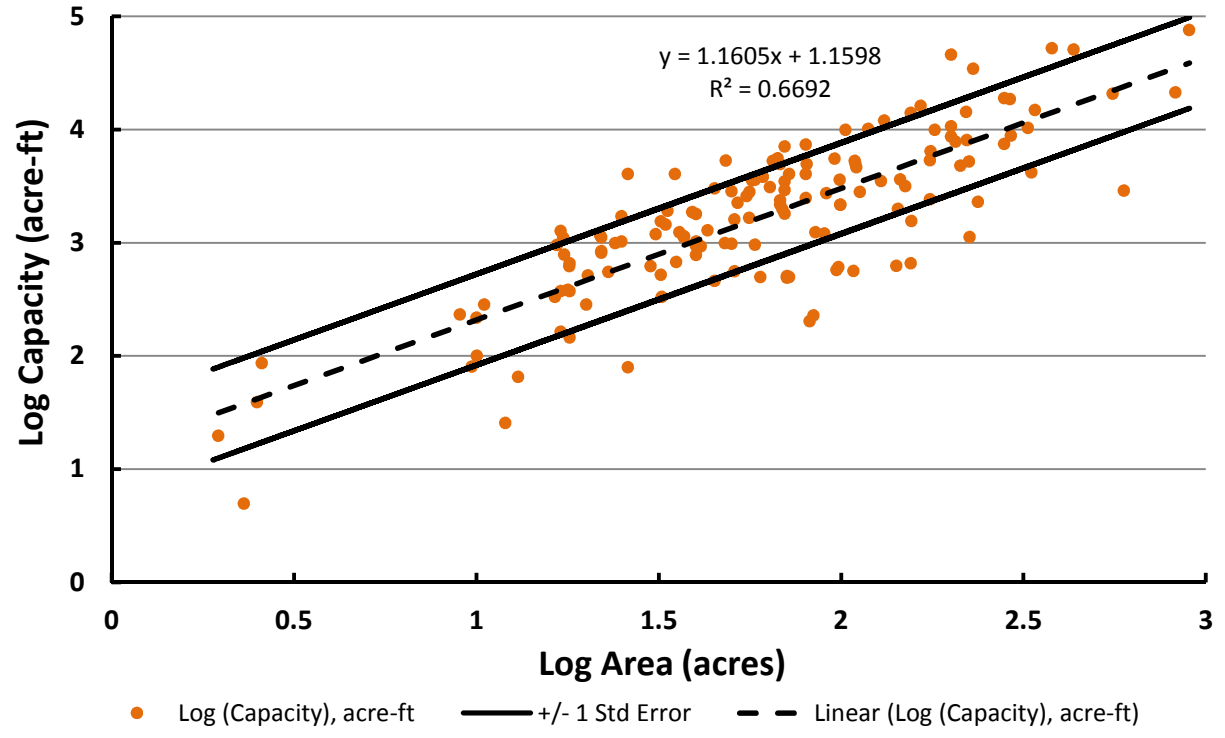

Figure A-4. Linear regression to impute landfill capacity from area.

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The survey data do not include total unit depth, so it was calculated from area and capacity. For WMUs with both area and capacity reported, an average depth was calculated by dividing capacity by area. Where either area or capacity was missing, the missing value was imputed using a linear regression of capacity and area combinations reported for other WMUs. The resulting depths were then checked against the depths calculated for WMUs with both capacity and area data. For landfills, depths were compared to the minimum and maximum calculated depths (2 and 240 feet). For surface impoundments, depths were compared to the 1st and 99th percentile of the calculated depths (2 and 91 feet). Where depths for WMUs with imputed area or capacity were outside of these constraints, the imputed area or capacity was discarded and replaced with a new selection based on probabilistic selection within the standard error bounds surrounding the regression line, and the depth recalculated. No range check was performed on depths calculated when both area and capacity were reported; thus, a few surface impoundment depth values fall outside the 2- to 91-foot range.

A.2.3 Waste Type

The CCR WMU database included information on the type of CCRs managed in the WMUs. Waste types are necessary to account for differences in soil-water partition coefficient due to, for example, differences in pH. Based on the types of CCRs reported, the WMUs were assigned to one of three waste types: combined ash, ash and coal refuse, and flue gas desulfurization (FGD) waste. The three model waste types that EPA assigned to each WMU were:

- **Ash and Coal Refuse**: Includes any CCR that is codisposed with coal refuse, which is waste coal produced from coal handling, crushing and sizing operations. This waste type is characterized by a low to moderate pH (1.7–8.2) and high levels of sulfate, iron and manganese.
- **FGD Wastes**: Includes any type of wet or dry FGD waste when disposed in dedicated monofills. This waste type is characterized by a moderate to high pH (8.7–11.3) and high levels of calcium, sulfate, sodium and chlorine.
- **Combined Ash**: Includes any CCRs other than those listed above (e.g., fly ash, bottom ash, boiler slag) either monofilled or in combination with each other. Due to the variability in disposal practices, this waste type is characterized by a broad range in pH (3.9–12.3), sulfate and calcium levels.

In cases where the CCRs were not specified, one of these three waste types was probabilistically assigned to that WMU during each model run based on the prevalence of each among WMUs with reported waste types. **Table A-1** shows the crosswalk used to match reported CCRs to the different waste types for modeling surface impoundments. For landfills all waste types were modeled as combined ash.

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Table A-1. Crosswalk Between Reported and Modeled Waste Type for Surface Impoundments

Reported CCRs	Model Waste Type
Fly ash(1,2)	Combined ash
Boiler slag(1), Slag(2)	
Bottom ash(1,2)	
Pozzolonic material(2)	
Any combination of FGD residues and other ash materials	
Flue gas emission control residuals(1)	FGD Waste
Gypsum(2)	
Ca sulfite(2)	
Dry FGD(2)	
Any of the above plus "Other" field containing coal refuse, such as pyrite(s), pyritic material, coal, coal fines, coal pile sludge, coal impurities, coal mill rejects, mill rejects, coal prep plant solids, coal pulverizer rejects, or coal refuse	Ash and coal refuse

1) Specified in 2009 Section 104(e) Information Request
2) Specified in 2010 Questionnaire for the Steam Electric Power Generating Effluent Guidelines

In addition to the waste types modeled in the revised risk assessment, EPA also identified FBC wastes as a distinct waste type. The 2010 Risk Assessment modeled the FBC waste type separately for landfills, but not surface impoundments, because of a lack of pore water data available at that time. This modeling showed that the risks associated with disposal of FBC waste in landfills were lower than those for other CCR waste types and below all risk criteria. Given these results and the lack of additional leachate data available since 2010, EPA did not re-evaluate FBC wastes in the revised risk assessment.

A.2.4 Liner Type

The CCR WMU database included information on the type of liner (if any) for the WMUs. Based on the type of liner reported, the WMUs were assigned to one of three liner types: an unlined (no liner) scenario, a compacted clay liner, and a composite liner that combines a plastic liner (e.g., high-density polyethylene membrane) over either geosynthetic or natural clays. These three liner types are the conceptual liner scenarios developed in support of EPA's *Guide for Industrial Waste Management* (U.S. EPA, 2002), and are described as follows:

- **No Liner Scenario:** Waste is placed directly on local soils, either on grade or excavated to some design depth and without a leachate collection system. At closure, two feet of native soil cover, the minimum required by Subtitle D regulations, is installed and assumed to support vegetation.
- **Clay Liner Scenario:** Waste is placed on a three-foot compacted clay liner that is installed over local soils without a leachate collection system, either on grade or excavated to some

design depth. At closure, a three-foot clay cover is installed and covered with one foot of loam to support vegetation and drainage.

- **Composite Liner Scenario:** Waste is placed on a liner system that consists of a plastic liner (e.g., high-density polyethylene membrane) underlain by either a natural or geosynthetic clay liner. A leachate collection system is assumed to exist between the waste and the liner system. At closure, a three-foot clay cover (graded and otherwise designed to prevent ponding) or functional equivalent is assumed to be installed and covered with one foot of loam to support vegetation and drainage.

In cases where the presence of a liner was not specified, one of these three scenarios was probabilistically assigned to that WMU during each model iteration based on the prevalence of these scenarios reported for impoundments or landfills. In cases where the survey indicated that a WMU was lined, but did not specify the type of liner, a clay or composite scenario was assigned probabilistically based on the prevalence of the different liner types reported for impoundments or landfills. **Table A-2** shows the crosswalk used to match these three conceptual liner scenarios to the different types reported in the CCR WMU database. The five impoundments lined with asphalt and 12 impoundments lined with concrete were treated as effectively unlined because these materials tend to crack, eliminating the effectiveness of the liner without regular maintenance. Thus, these materials are not considered to be adequate liners for regulated waste disposal facilities. The two "natural clay" lined impoundments were also considered to be unlined because they are unlikely to meet the design specifications of the clay-lined scenario.

Table A-2. Crosswalk Between Survey Data and CCR Source Model Liner Types for CCR Surface Impoundments and Landfills

Reported Survey Liner Type	Model Liner Description
Surface Impoundment Liners	
None	Unlined
Natural clay	
Asphalt	
Concrete	
Clay	Clay-Lined
Bentonite	
Composite	Composite-Lined
Flexible Membrane Liner	
Yes	Clay or Composite*
Confidential Business Information	Blank

(continued)

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Table A-2. Crosswalk Between Survey Data and CCR Source Model Liner Types for CCR Surface Impoundments and Landfills

Reported Survey Liner Type	Model Liner Description
Landfill Liners	
None	Unlined
Coal Combustion Residual	
Clay	Clay-Lined
Composite	Composite-Lined
Flexible Membrane Liner	
Yes	Clay or Composite*

*Randomly selected from these two options based on the frequency of occurrence of each type in the database for landfills.

A.3 References

U.S. EPA (Environmental Protection Agency). 2002. *Industrial Waste Management Evaluation Model (IWEM) Technical Background Document.* EPA 530-R-02-012. Office of Solid Waste, Washington, DC. August.

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Attachment A-1.
Plant Information

Attachment A-1. Plant Information

Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
6137	A. B. Brown Generating Station	Mount Vernon	Posey	IN	37.9053	-87.715	2	1	1,073,131	3
2535	AES Cayuga, LLC	Lansing	Tompkins	NY	42.6028	-76.6336	0	1	660,804	2
2527	AES Greenidge	Dresden	Yates	NY	42.6789	-76.9483	2	1	186,643	1
994	AES Petersburg	Petersburg	Pike	IN	38.5267	-87.2525	4	1	5,137,697	4
6082	AES Somerset LLC	Barker	Niagara	NY	43.3561	-78.6039	1	2	1,276,355	3
3942	Albright Power Station	Albright	Preston	WV	39.4883	-79.6367	2	2	161,122	1
1915	Allen S King	Bayport	Washington	MN	45.03	-92.7786	0	1	1,953,756	3
3393	Allen Steam Plant	Memphis	Shelby	TN	35.0742	-90.1492	2	0	2,836,020	4
4140	Alma	Alma	Buffalo	WI	44.302886	-91.912731	0	2	232,721	1
1122	Ames Electric Services Power Plant	Ames	--	IA	42.025244	-93.607994	1	0	238,410	1
6469	Antelope Valley Station	Beulah	Mercer	ND	47.37	-101.8353	2	2	5,785,560	4
160	Apache Station	Cochise	Cochise	AZ	32.061431	-109.894189	10	0	1,127,721	3
465	Arapahoe	Denver	Denver	CO	39.67	-105.0028	6	0	552,381	2
3178	Armstrong Power Station	Adrian	Armstrong	PA	40.9289	-79.4658	0	2	254,872	2
2076	Asbury	Asbury	Jasper	MO	37.361322	-94.589235	3	0	789,610	2
2706	Asheville Steam Electric Plant	Arden	Buncombe	NC	35.4714	-82.5431	2	0	949,209	2
2835	Ashtabula	Ashtabula Township	Ashtabula	OH	41.9083	-80.7667	1	0	305,324	2
1961	Austin Northeast	Austin	Mower	MN	43.701292	-92.962461	0	1	690	1
2836	Avon Lake	Avon Lake	Lorain	OH	41.504175	-82.055917	2	1	1,245,125	3
995	Bailly	Chesterton	Porter	IN	41.6433	-87.1225	6	2	1,146,280	3
889	Baldwin Energy Complex	Baldwin	Randolph	IL	38.205	-89.855	1	0	7,281,194	4
3	Barry	Bucks	Mobile	AL	31.0069	-88.0103	1	0	3,526,534	4
3982	Bay Front	Ashland	Ashland	WI	46.5869	-90.9017	2	2	99,729	1
2878	Bay Shore	Oregon	Lucas	OH	41.6925	-83.4375	1	1	1,005,669	3
8042	Belews Creek Steam Station	Belews Creek	Stokes	NC	36.2811	-80.0603	1	3	5,544,561	4
6034	Belle River	China Township	St Clair	MI	42.7748	-82.4945	1	1	5,239,679	4
3325	Ben French	Rapid City	Pennington	SD	44.0872	-103.2614	1	0	138,345	1
645	Big Bend	Apollo Beach	Hillsborough	FL	27.7944	-82.4036	8	1	3,730,004	4
3497	Big Brown	Fairfield	Freestone	TX	31.8206	-96.0561	4	4	5,598,198	4
6055	Big Cajun 2	New Roads	Pointe Coupee	LA	30.7261	-91.3669	3	1	7,622,197	4
1353	Big Sandy	Louisa	Lawrence	KY	38.169873	-82.618975	3	0	2,507,625	3
6098	Big Stone	Big Stone City	Grant	SD	45.3047	-96.5103	1	1	1,968,292	3
1904	Black Dog	Burnsville	Dakota	MN	44.8108	-93.2501	1	1	824,624	2
6106	Boardman	Boardman	Morrow	OR	45.6933	-119.8056	3	1	1,854,042	3
7790	Bonanza Power Plant	Vernal	Uintah	UT	40.0864	-109.2844	3	2	1,830,397	3
1893	Boswell Energy Center	Cohasset	Itasca	MN	47.2603	-93.6531	3	3	3,647,016	4
703	Bowen	Cartersville	Bartow	GA	34.1256	-84.9192	1	1	8,563,992	4
602	Brandon Shores	Baltimore	Anne Arundel	MD	39.180082	-76.5393	2	0	2,804,331	3
1619	Brayton Point	Somerset	Bristol	MA	41.7125	-71.1914	10	5	2,951,760	4
3796	Bremo Bluff	Bremo Bluff	Fluvanna	VA	37.7089	-78.2878	2	0	394,451	2
6094	Bruce Mansfield	Shippingport	Beaver	PA	40.6344	-80.42	5	0	6,803,553	4
2720	Buck	Salisbury	Rowan	NC	35.7133	-80.3767	3	0	203,504	1
3396	Bull Run	Clinton	Anderson	TN	36.0211	-84.1567	4	2	1,244,205	3
1104	Burlington	Burlington	Des Moines	IA	40.741617	-91.117447	5	0	764,035	2
676	C D McIntosh Jr	Lakeland	Polk	FL	28.0809	-81.9256	0	2	702,933	2
468	Cameo	Palisade	Mesa	CO	39.148759	-108.318221	2	0	242,481	1
3280	Canadys Steam	Canadys	Colleton	SC	33.0648	-80.623906	3	0	466,851	2
1363	Cane Run	Louisville	Jefferson	KY	38.1828	-85.8894	5	1	1,575,971	3
2708	Cape Fear Steam Electric Plant	Moncure	Chatham	NC	35.595	-79.0492	5	0	733,115	2
3644	Carbon Plant	Helper	Carbon	UT	39.7264	-110.8639	2	2	561,457	2
2828	Cardinal	Brilliant	Jefferson	OH	40.2522	-80.6486	2	1	4,477,802	4
1001	Cayuga	Cayuga	Vermillion	IN	39.9239	-87.4272	4	1	2,393,527	3
1571	Chalk Point LLC	Aquasco	Prince Georges	MD	38.5444	-76.6861	0	2	1,452,908	3
2169	Chamois Power Plant	Chamois	Osage	MO	38.6853	-91.7556	1	0	267,468	2
56	Charles R. Lowman	Leroy	Washington	AL	31.484791	-87.914365	4	1	1,400,093	3
469	Cherokee	Denver	Adams	CO	39.807872	-104.964447	6	0	1,533,203	3
3803	Chesapeake Energy Center	Chesapeake	Chesapeake	VA	36.7711	-76.3019	1	1	1,458,128	3
3797	Chesterfield	Chester	Chesterfield	VA	37.3822	-77.3833	2	0	3,299,383	4
8226	Cheswick Power Plant	Springdale	Allegheny	PA	40.538427	-79.790906	2	1	1,163,744	3
113	Cholla	Joseph City	Navajo	AZ	34.9414	-110.3003	2	1	3,934,490	4
2721	Cliffside	Cliffside	Cleveland	NC	35.22	-81.7594	3	0	1,327,943	3
983	Clifty Creek	Madison	Jefferson	IN	38.7383	-85.4192	2	2	4,352,443	4
3775	Clinch River	Cleveland	Russell	VA	36.9333	-82.1997	2	1	659,643	2
7213	Clover	Clover	Halifax	VA	36.869415	-78.704332	5	2	2,281,319	3
6030	Coal Creek	Underwood	McLean	ND	47.3789	-101.1572	2	6	8,037,582	4
861	Coffeen	Coffeen	Montgomery	IL	39.0586	-89.4031	2	1	2,582,575	3
47	Colbert	Tuscumbia	Colbert	AL	34.744214	-87.848825	3	1	1,437,063	3
6178	Coleto Creek	Fannin	Goliad	TX	28.7128	-97.2142	2	0	3,072,440	4
6076	Colstrip	Colstrip	Rosebud	MT	45.8844	-106.6139	8	0	8,344,993	4
10784	Colstrip Energy LP	Colstrip	Rosebud	MT	45.880278	-106.61333	0	2	242,424	1
8023	Columbia	Pardeville	Columbia	WI	43.4864	-89.4203	4	2	4,053,332	4
2123	Columbia	Columbia	Boone	MO	38.9658	-92.3175	1	0	41,364	1

Attachment A-1. Plant Information

Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
470	Comanche	Pueblo	Pueblo	CO	38.2081	-104.5747	5	1	2,869,801	4
3118	Conemaugh	New Florence	Indiana	PA	40.3842	-79.0611	5	2	4,546,143	4
2840	Conesville	Conesville	Coshocton	OH	40.1842	-81.8811	1	2	2,817,418	3
1710	Consumers Energy - J.H. Campbell	West Olive	Ottawa	MI	42.9103	-86.2036	1	4	5,175,189	4
1384	Cooper Station.	Somerset	Pulaski	KY	36.999267	-84.591617	0	1	685,149	2
7210	Cope	Cope	Orangeburg	SC	33.3642	-81.03	0	1	982,303	3
6177	Coronado Generating Station	St. Johns	Apache	AZ	34.5778	-109.2717	1	2	3,241,666	4
8222	Coyote	Beulah	Mercer	ND	47.2217	-101.8139	3	4	2,032,400	3
2549	CR Huntley Generating Station	Tonawanda	Erie	NY	42.97	-78.93	3	1	1,188,116	3
6021	Craig	Craig	Moffat	CO	40.4627	-107.5912	2	1	4,695,209	4
867	Crawford	Chicago	Cook	IL	41.8278	-87.7236	1	0	1,531,424	3
753	Crisp Plant	Warwick	Worth	GA	31.844713	-83.940655	1	0	37	1
641	Crist	Pensacola	Escambia	FL	30.5658	-87.2239	7	1	1,573,176	3
130	Cross	Pineville	Berkeley	SC	33.3692	-80.1119	3	4	5,716,190	4
628	Crystal River Power Plant	Crystal River	Citrus	FL	28.957539	-82.700478	0	1	4,749,124	4
3399	Cumberland	Cumberland City	Stewart	TN	36.3903	-87.6539	3	1	6,517,310	4
6823	D B Wilson	Centertown	Ohio	KY	37.45002	-87.07687	0	2	898,927	2
1702	D.E. Karn	Essexville	Bay	MI	43.645	-83.8414	2	1	1,422,822	3
1385	Dale Station	Winchester	Clark	KY	37.8807	-84.2634	3	0	389,154	2
963	Dallman	Springfield	Sangamon	IL	39.7547	-89.6008	1	2	1,045,347	3
2723	Dan River	Eden	Rockingham	NC	36.485975	-79.720814	3	0	84,887	1
2480	Danskammer Generating Station	Newburgh	Orange	NY	41.571403	-73.975069	0	1	843,688	2
4158	Dave Johnston Plant	Glenrock	Converse	WY	42.837966	-105.776594	8	1	3,572,403	4
996	Dean H Mitchell	Gary	Lake	IN	41.6394	-87.4069	8	0	-	1
663	Deerhaven Generating Station	Gainsville	Alachua	FL	29.7586	-82.3883	1	1	555,951	2
1572	Dickerson	Dickerson	Montgomery	MD	39.2086	-77.4644	0	1	949,178	2
51	Dolet Hills	Mansfield	De Soto	LA	32.0306	-93.5692	7	1	3,727,310	4
3317	Dolphus M Grainger	Conway	Horry	SC	33.8253	-79.0528	2	0	76,913	1
1046	Dubuque	Dubuque	Dubuque	IA	42.503036	-90.658408	1	0	108,348	1
6016	Duck Creek	Canton	Fulton	IL	40.4663	-89.9841	3	1	1,078,018	3
2554	Dunkirk Generating Plant	Dunkirk	Chautauqua	NY	42.4919	-79.3469	3	1	1,595,419	3
26	E. C. Gaston	Wilsonville	Shelby	AL	33.244063	-86.457147	1	0	3,299,127	4
1355	E.W. Brown	Harrodsburg	Mercer	KY	37.7889	-84.7139	2	0	1,092,651	3
991	Eagle Valley	Martinsville	Morgan	IN	39.484911	-86.418192	5	0	548,714	2
1217	Earl F Wisdom	Spencer	Clay	IA	43.1606	-95.2569	0	1	2,615	1
6018	East Bend Station	Rabbit Hash	Boone	KY	38.9031	-84.8511	3	1	1,913,481	3
2837	Eastlake	Eastlake	Lake	OH	41.6713	-81.4432	1	1	2,548,374	3
856	ED Edwards	Bartonville	Peoria	IL	40.5958	-89.6631	3	0	2,869,904	4
4050	Edgewater	Sheboygan	Sheboygan	WI	43.7181	-87.7092	6	2	2,472,707	3
1004	Edwardsport	Edwardsport	Knox	IN	38.8067	-87.2472	2	1	35,077	1
1374	Elmer Smith Station	Owensboro	Daviess	KY	37.795285	-87.059517	4	0	1,197,428	3
3098	Elrama Power Plant	Elrama	Washington	PA	40.253219	-79.917297	4	1	173,581	1
1832	Erickson Station	Lansing	Eaton	MI	42.6919	-84.6572	1	0	580,153	2
87	Escalante	Prewitt	McKinley	NM	35.4159	-108.082	5	1	1,097,758	3
1012	F. B. Culley	Newburgh	Warrick	IN	37.91	-87.3267	2	0	775,722	2
1218	Fair Station	Muscatine	Muscatine	IA	41.457127	-90.823729	2	1	117,062	1
6179	Fayette Power Project	La Grange	Fayette	TX	29.9172	-96.7506	2	1	6,964,482	4
886	Fisk	Chicago	Cook	IL	41.8508	-87.6533	3	0	1,001,069	3
6138	Flint Creek	Gentry	Benton	AR	36.2561	-94.5241	2	1	1,751,468	3
3943	Fort Martin Power Station	Maidsville	Monongalia	WV	39.7107	-79.9275	2	2	1,884,600	3
10343	Foster Wheeler Mt Carmel Cogen	MARION HEIGHTS	Northumberland	PA	40.8092	-76.4539	0	1	470,797	2
2442	Four Corners	Fruitland	San Juan	NM	36.69	-108.4814	5	2	8,826,370	4
1043	Frank E. Ratts	Petersburg	Pike	IN	38.5183	-87.2722	8	0	731,704	2
2718	G G Allen	Belmont	Gaston	NC	35.1897	-81.0122	3	1	1,513,392	3
7	Gadsden	Gadsden	Etowah	AL	34.012872	-85.97065	1	0	133,915	1
3403	Gallatin	Gallatin	Sumner	TN	36.3156	-86.4006	3	0	3,886,195	4
8102	General James M. Gavin	Cheshire	Gallia	OH	38.9347	-82.1158	2	1	7,984,101	4
4143	Genoa	Genoa	Vernon	WI	43.5592	-91.2333	0	2	984,696	3
1091	George Neal North	Sergeant Bluff	Woodbury	IA	42.324274	-96.379052	3	5	3,779,259	4
7343	George Neal South	Salix	Woodbury	IA	42.3022	-96.3622	1	1	2,431,599	3
6077	Gerald Gentleman	Sutherland	Lincoln	NE	41.081192	-101.141087	0	1	6,011,209	4
1356	Ghent	Ghent	Carroll	KY	38.7497	-85.035	5	0	5,331,887	4
6136	Gibbons Creek Steam Electric Station	Anderson	Grimes	TX	30.6167	-96.0778	4	2	2,057,295	3
6113	Gibson	Owensville	Gibson	IN	38.3722	-87.7661	6	2	8,691,426	4
3776	Glen Lyn	Glen Lyn	Giles	VA	37.370314	-80.863778	2	1	187,903	1
8	Gorgas	Parrish	Walker	AL	33.6446	-87.2003	2	1	2,251,490	3
1825	Grand Haven City of J.B. Sims	Grand Haven	Ottawa	MI	43.069233	-86.233953	2	0	156,699	1
10151	Grant Town Power Plant	GrantTown	Marion	WV	39.5611	-80.1642	5	3	590,673	2
165	GRDA	Chouteau	Mayes	OK	36.1906	-95.2889	1	1	4,506,123	4
1357	Green River	Central City	Muhlenberg	KY	37.3636	-87.1214	5	0	303,105	2
10	Greene County	Forkland	Greene	AL	32.6017	-87.7811	1	0	1,014,259	3

Attachment A-1. Plant Information

Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
6041	H L Spurlock Station	Maysville	Mason	KY	38.7	-83.8175	1	1	3,567,030	4
2709	H.F. Lee Plant	Goldsboro	Wayne	NC	35.379904	-78.087722	5	0	823,583	2
708	Hammond	Rome	Floyd	GA	34.2533	-85.3456	4	1	1,507,985	3
1731	Harbor Beach Power Plant	Harbor Beach	Huron	MI	43.851856	-82.643811	1	0	70,624	1
990	Harding Street	Indianapolis	Marion	IN	39.7119	-86.1975	5	0	1,783,189	3
709	Harllee Branch	Milledgeville	Putnam	GA	33.1942	-83.2994	5	0	2,604,594	3
6193	Harrington	Amarillo	Potter	TX	35.2972	-101.7475	0	2	4,336,723	4
3944	Harrison Power Station	Haywood	Harrison	WV	39.384521	-80.332908	1	1	4,153,187	4
3179	Hatfield's Ferry Power Station	Masontown	Greene	PA	39.856043	-79.92796	5	1	3,886,391	4
891	Havana	Havana	Mason	IL	40.2797	-90.0775	2	0	1,345,638	3
2079	Hawthorn	Kansas City	Jackson	MO	39.130668	-94.477876	1	1	2,442,255	3
525	Hayden	Hayden	Routt	CO	40.487247	-107.185218	6	2	1,516,188	3
3251	HB Robinson / Darlington Electric Power Plant	Hartsville	Darlington	SC	34.4017	-80.1589	1	0	408,053	2
892	Hennepin Power Station	Hennepin	Putnam	IL	41.3028	-89.315	1	1	1,246,097	3
1382	HMP&L Station Two Henderson	Robards	Henderson	KY	37.6472	-87.5028	2	1	751,395	2
108	HOLCOMB	HOLCOMB	Finney	KS	37.9306	-100.9725	0	1	1,636,686	3
3122	Homer City Station	Homer City	Indiana	PA	40.5142	-79.1969	14	3	4,572,113	4
1943	Hoot Lake	Fergus Falls	Otter Tail	MN	46.29	-96.0428	0	7	370,078	2
10771	Hopewell	Hopewell	Hopewell City	VA	37.297747	-77.282104	1	0	51,795	1
6772	Hugo	Fort Towson	Choctaw	OK	34.0158	-95.3206	4	1	2,011,996	3
3176	Hunlock Power Station	Hunlock Creek	Luzerne	PA	41.2033	-76.0683	2	0	194,691	1
6165	Hunter Plant	Castle Dale	Emery	UT	39.173597	-111.029432	1	1	4,428,980	4
8069	Huntington Plant	Huntington	Emery	UT	39.379164	-111.078356	2	3	2,743,739	3
863	Hutsonville	Hutsonville	Crawford	IL	39.1333	-87.6597	4	0	349,618	2
6065	Iatan	Weston	Platte	MO	39.447967	-94.979744	1	1	2,313,427	3
6641	Independence	Newark	Independence	AR	35.6733	-91.4083	0	1	6,820,983	4
2132	Independence Power & Light - Blue Valley Station	Independence	Jackson	MO	39.0919	-94.3261	3	0	95,597	1
594	Indian River Generating Station	Dagsboro	Sussex	DE	38.585411	-75.234872	2	2	1,085,100	3
6481	Intermountain Power Project	Delta	Millard	UT	39.5108	-112.5792	6	0	5,943,436	4
7097	J K Spruce	San Antonio	Bexar	TX	29.3064	-98.3203	6	1	2,149,348	3
2850	J M Stuart	Aberdeen	Adams	OH	38.6361	-83.6939	6	2	6,749,846	4
6181	J T Deely	San Antonio	Bexar	TX	29.3072	-98.3228	6	2	2,770,903	3
1720	J.C. Weadock	Essexville	Bay	MI	43.643903	-83.841217	4	1	934,487	2
1723	J.R Whiting	Erie	Monroe	MI	41.7917	-83.4486	4	2	1,017,083	3
710	Jack McDonough	Smyrna	Cobb	GA	33.8244	-84.475	4	1	865,958	2
2049	Jack Watson	Gulfport	Harrison	MS	30.4392	-89.0264	1	1	1,300,445	3
1830	James De Young	Holland	Ottawa	MI	42.7956	-86.1133	1	1	119,322	1
6002	James H. Miller Jr.	Quinton	Jefferson	AL	33.6319	-87.0597	1	0	12,161,264	4
2161	James River Power Station	Springfield	Greene	MO	37.1086	-93.2592	1	1	806,629	2
2187	JE Corette Plant	Billings	Yellowstone	MT	45.7747	-108.4803	2	1	694,842	2
3319	Jefferies	Moncks Corner	Berkeley	SC	33.2422	-79.9875	2	0	99,857	1
6068	Jeffrey Energy Center	St Marys	Pottawatomie	KS	39.287164	-96.118144	3	2	8,638,976	4
8066	Jim Bridger Plant Units 1-4	Point of Rocks	Sweetwater	WY	41.738008	-108.786719	2	1	8,344,833	4
3935	John E. Amos	Winfield	Putnam	WV	38.4731	-81.8233	2	2	5,498,720	4
4271	John P. Madgett	Alma	Buffalo	WI	44.3022	-91.9142	0	2	1,499,381	3
3405	John Sevier	Rogersville	Hawkins	TN	36.3767	-82.9639	2	1	1,536,343	3
3406	Johnsonville	New Johnsonville	Humphreys	TN	36.0278	-87.9861	2	2	2,452,565	3
384	Joliet 29	Joliet	Will	IL	41.4947	-88.125	1	1	3,790,190	4
874	Joliet 9	Joliet	Will	IL	41.4931	-88.1153	2	0	811,962	2
887	Joppa Steam	Joppa	Massac	IL	37.2103	-88.8606	1	1	4,383,292	4
3947	Kammer	Moundsville	Marshall	WV	39.8464	-80.8189	1	0	852,381	2
3936	Kanawha River	Glasgow	Kanawha	WV	38.2056	-81.4211	1	0	699,984	2
1381	Kenneth C Coleman	Hawesville	Hancock	KY	37.9628	-86.7917	3	0	1,278,540	3
3136	Keystone	Shelocta	Armstrong	PA	40.6604	-79.3411	11	3	3,992,921	4
6031	Killen Station	Manchester	Adams	OH	38.6903	-83.4803	2	0	1,864,977	3
876	Kincaid Generation LLC	Kincaid	Christian	IL	39.591472	-89.496897	1	1	4,224,227	4
3407	Kingston	Harriman	Roane	TN	35.8992	-84.5194	2	0	989,568	3
733	Kraft	Port Wentworth	Chatham	GA	32.1486	-81.1458	1	1	422,035	2
2876	Kyger Creek	Cheshire	Gallia	OH	38.9161	-82.1281	2	1	3,602,671	4
2713	L.V. Sutton Electric Plant	Wilmington	New Hanover	NC	34.2831	-77.9867	2	0	1,097,862	3
1241	La Cygne	La Cygne	Linn	KS	38.348094	-94.644683	2	1	5,718,291	4
2103	Labadie	Labadie	Franklin	MO	38.561429	-90.837277	2	0	10,122,717	4
2098	Lake Road	St. Joseph	Buchanan	MO	39.723933	-94.877747	2	1	404,999	2
2838	Lake Shore	Cleveland	Cuyahoga	OH	41.535458	-81.641633	1	0	182,014	1
964	Lakeside	Springfield	Sangamon	IL	39.7539	-89.6011	1	0	1,480	1
1047	Lansing	Lansing	Allamakee	IA	43.336125	-91.166833	2	2	862,048	2
643	Lansing Smith	Southport	Bay	FL	30.2689	-85.7003	1	1	652,366	2
6204	Laramie River Station	Wheatland	Platte	WY	42.1103	-104.8828	2	1	7,132,436	4
1891	Laskin Energy Center	Hoyt Lakes	St Louis	MN	47.5306	-92.1619	2	0	354,312	2
1250	Lawrence Energy Center	Lawrence	Douglas	KS	39.0078	-95.2681	4	3	2,058,823	3

Attachment A-1. Plant Information

Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
2817	Leland Olds	Stanton	Mercer	ND	47.2819	-101.3194	3	2	3,412,913	4
6089	Lewis & Clark	Sidney	Richland	MT	47.678875	-104.157014	5	3	307,772	2
298	Limestone	Jewett	Limestone	TX	31.423386	-96.251653	9	1	8,508,363	4
2240	Lon Wright	Freemont	Dodge	NE	41.4275	-96.4619	0	1	279,452	2
6664	Louisa	Muscatine	Louisa	IA	41.3153	-91.0936	2	1	2,964,296	4
976	Marion Generating Station	Marion	Williamson	IL	37.6206	-88.955	12	1	1,064,499	3
2727	Marshall	Terrell	Catawba	NC	35.5975	-80.9658	1	2	4,776,946	4
492	Martin Drake	Colorado Springs	El Paso	CO	38.8244	-104.8331	4	1	968,628	3
6146	Martin Lake	Tatum	Rusk	TX	32.2597	-94.5703	4	5	13,195,519	4
6250	Mayo Electric Generating Facility	Roxboro	Person	NC	36.5278	-78.8917	1	0	1,778,603	3
6124	McIntosh	Rincon	Effingham	GA	32.3558	-81.1683	1	0	-	1
3287	McMeekin	Columbia	Lexington	SC	34.0533	-81.2178	0	1	382,435	2
2104	Meramec	St. Louis	St Louis	MO	38.4017	-90.3358	5	0	3,250,555	4
864	Meredosia	Meredosia	Morgan	IL	39.8194	-90.5647	2	0	329,623	2
6213	Merom	Sullivan	Sullivan	IN	39.0694	-87.5108	1	2	3,549,562	4
2364	Merrimack Station	Bow	Merrimack	NH	43.1411	-71.4692	2	1	956,935	3
2832	Miami Fort	North Bend	Hamilton	OH	39.1131	-84.8031	2	2	3,579,522	4
997	Michigan City	Michigan City	La Porte	IN	41.7203	-86.9097	6	0	1,156,086	3
1364	Mill Creek	Louisville	Jefferson	KY	38.0531	-85.91	5	3	4,748,412	4
2823	Milton R. Young Station	Center	Oliver	ND	47.0664	-101.2139	4	5	4,124,626	4
2171	Missouri City	Missouri City	Clay	MO	39.23196	-94.307989	1	0	12,865	1
3948	Mitchell	Moundsville	Marshall	WV	39.8297	-80.8153	2	0	3,678,634	4
727	Mitchell	Albany	Dougherty	GA	31.4442	-84.135456	3	0	9,734	1
3181	Mitchell Power Station	Courtney	Washington	PA	39.8297	-80.8153	0	2	373,494	2
1048	ML Kapp	Clinton	Clinton	IA	41.807941	-90.234369	4	0	515,844	2
1733	Monroe Power Plant	Monroe	Monroe	MI	41.8917	-83.3461	2	0	9,261,743	4
6147	Monticello	Mt. Pleasant	Titus	TX	33.0917	-95.0417	4	3	10,757,329	4
2080	Montrose	Clinton	Henry	MO	38.3108	-93.9331	3	1	2,068,649	3
1573	Morgantown Generating Plant	Newburg	Charles	MD	38.3592	-76.9767	0	2	2,500,524	3
1606	Mount Tom	Holyoke	Hampden	MA	42.2814	-72.6053	3	1	248,386	2
6264	Mountaineer	New Haven	Mason	WV	38.9794	-81.9344	1	1	3,727,529	4
3954	Mt. Storm	Mt. Storm	Grant	WV	39.2014	-79.2667	0	4	3,991,565	4
1167	Muscatine #1	Muscatine	Muscatine	IA	41.391592	-91.05636	1	1	873,871	2
2872	Muskingum River	Waterford	Washington	OH	39.5908	-81.6797	4	0	2,869,762	4
2952	Muskogee	Fort Gibson	Muskogee	OK	35.7617	-95.2847	3	0	5,139,684	4
4162	Naughton Plant	Kemmerer	Lincoln	WY	41.7572	-110.5986	4	1	2,491,422	3
4941	Navajo Generating Station	Page	Coconino	AZ	36.90422	-111.388906	0	1	7,530,160	4
6064	Nearman Creek	Kansas City	Wyandotte	KS	39.1714	-94.6958	1	2	905,954	2
6096	Nebraska City	Nebraska City	Otoe	NE	40.6215	-95.7765	2	2	4,282,248	4
4054	Nelson Dewey	Cassville	Grant	WI	42.7247	-91.0058	2	1	484,540	2
3138	New Castle Plant	West Pittsburg	Lawrence	PA	40.9383	-80.3683	2	1	292,388	2
2167	New Madrid	Marston	New Madrid	MO	36.5147	-89.5617	4	1	4,266,998	4
6017	Newton	Newton	Jasper	IL	38.9361	-88.2778	2	2	4,604,471	4
2291	North Omaha	Omaha	Douglas	NE	41.33	-95.9467	3	2	1,872,463	3
8224	North Valmy	Valmy	Humboldt	NV	40.880608	-117.152216	0	1	1,705,618	3
2963	Northeastern	Oologah	Rogers	OK	36.4317	-95.7008	1	1	4,083,677	4
667	Northside Generating Station	JACKSONVILLE	Duval	FL	30.430967	-81.550775	0	1	131,582	1
10030	NRG Energy Center Dover	Dover	Kent	DE	39.1467	-75.5461	1	0	47,581	1
527	Nucla	Nucla	Montrose	CO	38.2386	-108.5072	1	1	370,948	2
2848	O H Hutchings	Miamisburg	Montgomery	OH	39.6094	-84.2931	3	0	50,479	1
6180	Oak Grove	Franklin	Robertson	TX	31.182054	-96.487494	1	3	2,590,468	3
127	Oklaunion	Vernon	Wilbarger	TX	34.0825	-99.1753	3	1	1,800,551	3
4151	Osage	Osage	Weston	WY	43.970041	-104.411635	2	2	247,093	1
1831	Otto E. Eckert Station	Lansing	Ingham	MI	42.7183	-84.5586	1	0	618,929	2
6254	Ottumwa	Ottumwa	Wapello	IA	41.0961	-92.5556	4	1	2,487,180	3
1378	Paradise	Drakesboro	Muhlenberg	KY	37.2608	-86.9783	3	0	6,331,623	4
6248	Pawnee	Brush	Morgan	CO	40.2217	-103.6803	7	1	1,324,186	3
6238	Pearl Station	Pearl	Pike	IL	39.4489	-90.6142	1	0	26,057	1
3938	Philip Sporn	New Haven	Mason	WV	38.9669	-81.9231	2	1	1,074,116	3
2843	Picway	Lockbourne	Pickaway	OH	39.7933	-83.0097	1	0	61,270	1
7902	Pirkey	Hallsville	Harrison	TX	32.4607	-94.4852	6	1	2,939,060	4
59	Platte	Grand Island	Hall	NE	40.855508	-98.348199	0	2	390,640	2
6170	Pleasant Prairie	Pleasant Prairie	Kenosha	WI	42.5381	-87.9033	0	1	4,761,560	4
6004	Pleasants Power Station	Willow Island	Pleasants	WV	39.3668	-81.2944	1	1	2,404,993	3
7242	Polk	Mulberry	--	FL	27.7286	-81.9897	0	1	508,207	2
3113	Portland	Mt. Bethel	Northampton	PA	40.91	-75.0789	3	4	899,978	2
879	Powerton	Pekin	Tazewell	IL	40.5408	-89.6786	7	0	5,813,360	4
3140	PPL Brunner Island	Mt. Wolf	York	PA	40.094914	-76.696786	3	1	3,364,135	4
3149	PPL Montour	Washingtonville	Montour	PA	41.071444	-76.666849	5	2	3,750,432	4
1073	Prairie Creek	Cedar Rapids	Linn	IA	41.9378	-91.639641	10	0	59,034	1
1769	Presque Isle	Marquette	Marquette	MI	46.578947	-87.395044	0	3	1,572,482	3
2403	PSEG Hudson Generating Station	Jersey City	Hudson	NJ	40.7478	-74.0719	2	1	796,708	2

Attachment A-1. Plant Information

Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
2408	PSEG Mercer Generating Station	Mercer	Mercer	NJ	40.1797	-74.7325	2	1	553,756	2
4072	Pulliam	Green Bay	Brown	WI	44.5397	-88.0083	1	1	945,855	2
1295	Quindaro	Kansas City	Wyandotte	KS	39.150759	-94.636563	0	1	683,410	2
6639	R D Green	Robards	Webster	KY	37.6467	-87.5006	1	1	1,176,462	3
2864	R. E. Burger	Shadyside	Belmont	OH	39.9094	-80.7608	2	1	328,250	2
1008	R. Gallagher	New Albany	Floyd	IN	38.2636	-85.8381	2	9	839,443	2
1570	R. Paul Smith Power Station	Williamsport	Washington	MD	39.595039	-77.826792	2	1	64,727	1
2790	R.M. Heskett Station	Mandan	Morton	ND	46.8669	-100.8839	0	2	536,721	2
6085	R.M. Schahfer	Wheatfield	Jasper	IN	41.2175	-87.0239	7	1	4,834,326	4
6761	Rawhide	Wellington	Larimer	CO	40.8611	-105.0206	2	2	1,333,960	3
8219	Ray D Nixon	Fountain	El Paso	CO	38.6306	-104.7056	1	1	959,694	3
55076	Red Hills Generating Facility	Ackerman	Choctaw	MS	33.3761	-89.2183	1	1	3,744,477	4
2324	Reid Gardner	Moapa	Clark	NV	36.655704	-114.632408	8	1	1,477,313	3
1740	River Rouge Power Plant	River Rouge	Wayne	MI	42.2733	-83.1131	1	0	1,719,332	3
2732	Riverbend	Mt. Holly	Gaston	NC	35.36	-80.9742	2	0	222,209	1
1081	Riverside	Bettendorf	Scott	IA	41.540506	-90.44815	2	0	464,395	2
1927	Riverside	Minneapolis	Hennepin	MN	45.0203	-93.2753	1	0	-	1
1239	Riverton	Riverton	Cherokee	KS	37.0719	-94.6986	1	0	245,628	1
3945	Rivesville Power Station	Rivesville	Marion	WV	39.5314	-80.113	4	2	10,415	1
6166	Rockport	Rockport	Spencer	IN	37.9256	-87.0372	1	1	10,265,905	4
6190	Rodemacher	Lena	Rapides	LA	31.395	-92.7167	3	0	2,089,934	3
2712	Roxboro Steam Electric Plant	Semora	Person	NC	36.4833	-79.0731	4	1	6,262,948	4
1393	RS Nelson	Westlake	Calcasieu	LA	30.287587	-93.29391	2	2	2,282,209	3
6155	Rush Island	Festus	Jefferson	MO	38.1306	-90.2625	1	1	4,826,892	4
2451	San Juan	Waterflow	San Juan	NM	36.8006	-108.4386	1	0	6,588,396	4
6183	San Miguel	Christine	Atascosa	TX	28.704903	-98.476883	3	2	3,303,265	4
6648	Sandow No 4	Rockdale	Milam	TX	30.5642	-97.0639	1	5	4,027,601	4
6257	Scherer	Juliette	Monroe	GA	33.0583	-83.8072	2	0	14,030,288	4
2367	SCHILLER	Portsmouth	Rockingham	NH	43.0978	-70.7842	0	1	250,999	2
642	Scholz	Sneads	Jackson	FL	30.669158	-84.8875	3	0	3,621	1
136	Seminole Generating Station	Palatka	Putnam	FL	29.733848	-81.632368	0	1	2,916,317	4
1379	Shawnee	West Paducah	McCracken	KY	37.1517	-88.775	2	2	4,090,940	4
3131	Shawville	Shawville	Clearfield	PA	41.067	-78.3656	4	2	974,359	3
2277	Sheldon Station	Hallam	Lancaster	NE	40.5589	-96.7842	1	4	1,020,516	3
6090	Sherburne County	Becker	Sherburne	MN	45.3792	-93.8958	6	1	9,171,628	4
2094	Sibley	Sibley	Jackson	MO	39.1778	-94.1861	2	1	1,648,794	3
6768	Sikeston Power Station	Sikeston	Scott	MO	36.8786	-89.6169	2	0	1,096,237	3
2107	Sioux	West Alton	St Charles	MO	38.915429	-90.291115	2	0	3,142,617	4
1058	Sixth Street	Cedar Rapids	Linn	IA	41.984207	-91.667517	4	0	--	--
1613	Somerset Station	Somerset	Bristol	MA	41.737	-71.146	4	0	58,047	1
6095	Sooner	Red Rock	Noble	OK	36.45	-97.0531	2	0	3,877,889	4
6061	South Mississippi El Pwr Assn	Purvis	Lamar	MS	31.2194	-89.3933	2	3	823,757	2
4041	South Oak Creek	Oak Creek	Milwaukee	WI	42.8457	-87.8294	0	3	2,565,605	3
6195	Southwest Power Station	Springfield	Greene	MO	37.1519	-93.3892	2	2	699,635	2
8223	Springerville	Springerville	Apache	AZ	34.3186	-109.1636	1	1	4,854,606	4
1743	St Clair Power Plant	East China Township	St Clair	MI	42.7625	-82.4722	1	0	3,751,842	4
207	St Johns River Power Park	Jacksonville	Duval	FL	30.4311	-81.5508	0	3	3,733,618	4
2824	Stanton	Stanton	Mercer	ND	47.2872	-101.3314	3	3	663,440	2
564	Stanton Energy Center	Orlando	Orange	FL	28.4836	-81.1686	0	1	2,381,605	3
1131	Streeter Station	Cedar Falls	Black Hawk	IA	42.526822	-92.440176	0	1	14,253	1
3152	Sunbury Generation LP	Shamokin Dam	Snyder	PA	40.8361	-76.825	1	0	613,993	2
50951	Sunnyside Cogen Associates	Sunnyside	Carbon	UT	39.546486	-110.391153	0	1	417,241	2
1077	Sutherland	Marshalltown	Marshall	IA	42.0472	-92.857721	3	2	292,568	2
10075	Taconite Harbor Energy Center	Schroeder	Cook	MN	47.5314	-90.9111	0	3	664,576	2
988	Tanners Creek	Lawrenceburg	Dearborn	IN	39.0831	-84.8581	5	1	1,358,323	3
1252	Tecumseh Energy Center	Tecumseh	Shawnee	KS	39.054072	-95.568775	2	3	894,924	2
2168	Thomas Hill	Clifton Hill	Randolph	MO	39.5531	-92.6392	6	1	4,356,018	4
3115	Titus	Birdsboro	Berks	PA	40.3061	-75.9081	0	4	424,803	2
6194	Tolk	Sudan	Lamb	TX	34.1847	-102.5686	0	1	4,080,504	4
3845	TransAlta Centralia Generation	Centralia	Lewis	WA	46.755636	-122.857583	0	1	4,974,233	4
1745	Trenton Channel Power Plant	Trenton	Wayne	MI	42.1236	-83.1811	1	1	2,012,466	3
6071	Trimble Co.	Bedford	Trimble	KY	38.5847	-85.4117	1	0	1,409,667	3
56224	TS Power Plant	Dunphy	Eureka	NV	40.708739	-116.529021	0	1	638,633	2
7030	Twin Oaks Power One	Bremond	Robertson	TX	31.0928	-96.6933	0	1	1,712,108	3
1361	Tyrone	Versailles	Woodford	KY	38.047838	-84.848337	2	0	12,091	1
3295	Urquhart	Beech Island	Aiken	SC	33.435	-81.9111	3	1	151,533	1
4042	Valley	Milwaukee	Milwaukee	WI	43.0303	-87.925	0	4	611,825	2
477	Valmont	Boulder	Boulder	CO	40.0195	-105.202	3	2	536,002	2
897	Vermilion	Oakwood	Vermilion	IL	40.1781	-87.7481	2	1	433,469	2
6073	Victor J. Daniel Jr	Moss Point	Jackson	MS	30.5335	-88.5574	1	4	2,554,163	3
6019	W H Zimmer	Moscow	Clermont	OH	38.8689	-84.2286	1	1	3,044,248	4
3470	W. A. Parish	Thompsons	Fort Bend	TX	29.4828	-95.6311	8	1	11,517,217	4

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Oris Code	Plant Name	City	County	State	Latitude	Longitude	# of SIs	# of LFs	Coal Use (short tons)	Coal Use Quartile
2866	W. H. Sammis	Stratton	Jefferson	OH	40.5308	-80.6311	2	1	4,200,741	4
3264	W. S. Lee	Belton	Anderson	SC	34.6022	-82.435	2	0	196,442	1
2716	W.H. Weatherspoon Plant	Lumberton	Robeson	NC	34.5889	-78.975	1	0	143,957	1
1010	Wabash River	West Terre Haute	Vigo	IN	39.53	-87.4247	4	0	1,609,012	3
2830	Walter C Beckjord	New Richmond	Clermont	OH	38.9917	-84.2972	4	2	2,310,221	3
1082	Walter Scott Jr. Energy Center	Council Bluffs	Pottawattamie	IA	41.18	-95.8408	2	1	6,577,427	4
6052	Wansley	Carrollton	Heard	GA	33.4112	-85.0341	1	0	2,905,006	4
6705	Warrick Power Plant	Newburgh	Warrick	IN	37.915	-87.3319	1	0	2,223,793	3
3297	Wateree	Eastover	Richland	SC	33.8264	-80.6218	2	1	1,331,447	3
883	Waukegan	Waukegan	Lake	IL	42.3833	-87.8133	2	0	2,568,340	3
6139	Welsh	Pittsburg	Titus	TX	33.054539	-94.840542	3	1	6,615,744	4
4078	Weston	Rothschild	Marathon	WI	44.8606	-89.6553	6	2	3,314,523	4
60	Whelan Energy Center Unit 1 (WEC1)	Hastings	Adams	NE	40.5806	-98.3106	1	0	326,208	2
6009	White Bluff	Redfield	Jefferson	AR	34.4236	-92.1392	0	1	6,421,536	4
1040	Whitewater Valley	Richmond	Wayne	IN	39.8028	-84.8953	5	0	105,300	1
4057	WI Power & Light Co -Rock River Generating	Beloit	Rock	WI	42.583275	-89.035401	4	0	--	--
50	Widows Creek	Stevenson	Jackson	AL	34.8825	-85.7547	12	0	2,263,802	3
884	Will County	Romeoville	Will	IL	41.634093	-88.062381	1	0	3,118,919	4
3298	Williams	Goose Creek	Berkeley	SC	33.0163	-79.9285	0	2	1,452,860	3
3946	Willow Island	Willow Island	Pleasants	WV	39.3672	-81.3006	0	1	58,263	1
6249	Winyah	Georgetown	Georgetown	SC	33.329692	-79.357933	6	1	2,452,036	3
898	Wood River	Alton	Madison	IL	38.863454	-90.134001	2	0	1,988,950	3
50611	WPS Westwood Generation, LLC	Tremont	Schuylkill	PA	40.618731	-76.450706	0	1	408,017	2
6101	Wyodak Plant	Gillette	Campbell	WY	44.28795	-105.385236	1	1	2,005,001	3
728	Yates	Newnan	Coweta	GA	33.4622	-84.8986	8	2	1,875,227	3
3809	Yorktown	Yorktown	York	VA	37.2144	-76.4611	1	1	681,147	2

Attachment A-2.
WMU Information

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6137	A. B. Brown Generating Station	88	SI	Lower Ash Pond	37.90488889	-101.8346944	53	930	17.54716981	Ash & Coal Refuse	None	--
6137	A. B. Brown Generating Station	1163	LF	FGD Lanfill	37.91361111	-87.70916667	176	6421.487603	36.48572502	Combined Ash	Yes	--
6137	A. B. Brown Generating Station	89	SI	Upper Ash Pond	37.9	-87.7	103	2417	23.46601942	Combined Ash	None	--
2535	AES Cayuga, LLC	1102	LF	Ash Site Landfill	42.60871111	-76.61863056	--	--	--	Combined Ash	Yes	--
2527	AES Greenidge	1286	SI	Lookwood Sedimentation/naturalization Basin	42.67595833	-76.96069167	1.75151515	5.919421488	3.379600503	Combined Ash	Clay	--
2527	AES Greenidge	1101	LF	AES Lockwood	42.6813	-76.948687	--	--	--	Combined Ash	Yes	--
2527	AES Greenidge	1285	SI	Bottom Ash Pond C-Pond	42.68086667	-76.94438056	2.61707989	13.08539945	5	Combined Ash	None	--
994	AES Petersburg	431	SI	Pond A - Discharge	38.53353611	-87.24662778	5	108	21.6	Combined Ash	None	--
994	AES Petersburg	432	SI	Pond B	38.53639722	-87.24515833	35	1240	35.42857143	Combined Ash	None	Excluded
994	AES Petersburg	430	SI	Pond A - Active	38.53194444	-87.24491944	67	930	13.88059701	Combined Ash	None	--
994	AES Petersburg	433	SI	Pond C	38.53921667	-87.24106944	30	1054	35.13333333	Combined Ash	None	Excluded
994	AES Petersburg	989	LF	RWS Type III	38.53035278	-87.23888056	118.5	10103.30579	85.25996443	Combined Ash	Yes	--
6082	AES Somerset LLC	1287	SI	Sludge Basin	43.352783	-78.605356	2.181	--	--	FGD Waste	Yes	--
6082	AES Somerset LLC	1106	LF	SWDA 1	43.359	-78.58375	84	227.2727273	2.705627706	Combined Ash	Clay	Excluded
6082	AES Somerset LLC	1105	LF	SWDA 2	43.35161111	-78.58358333	82	202.020202	2.463661	Combined Ash	Composite	--
3942	Albright Power Station	1385	SI	North Lagoon	39.49	-79.64083333	1.02846648	9.794811754	9.523705357	Combined Ash	Clay	--
3942	Albright Power Station	1386	SI	South Lagoon	39.486978	-79.635108	1.13406795	9.821297062	8.660236842	Combined Ash	Clay	--
3942	Albright Power Station	931	LF	Active CCB Landfill	39.48676944	-79.60292778	45	3006.198347	66.80440771	Combined Ash	None	--
3942	Albright Power Station	930	LF	Closed CCB Landfill	39.49138889	-79.60263333	70	1797.520661	25.67886659	Combined Ash	None	Excluded
1915	Allen S King	927	LF	AS King Ash Disposal Facility	45.03444444	-92.79916667	--	--	--	Combined Ash	Yes	--
3393	Allen Steam Plant	119	SI	East Ash Stilling Pond	--	--	23	180	7.826086957	Combined Ash	--	--
3393	Allen Steam Plant	120	SI	East Ash Disposal	--	--	70	1100	15.71428571	Combined Ash	--	--
4140	Alma	993	LF	--	--	--	85	1239.669422	14.58434614	Combined Ash	--	--
4140	Alma	994	LF	--	--	--	--	--	--	Combined Ash	--	Excluded
1122	Ames Electric Services Power Plant	1202	SI	Ash Pond	42.028175	-93.59932778	4.14	--	--	Ash & Coal Refuse	Yes	--
6469	Antelope Valley Station	212	SI	Spray Drier Ash Water Make-Up Pond	47.373	-101.8346944	3.1	28	9.032258065	Combined Ash	Composite	Excluded
6469	Antelope Valley Station	923	LF	SP-025	47.38347	-101.82575	63.8	3099.173554	48.57638799	Combined Ash	Clay	--
6469	Antelope Valley Station	922	LF	SP-160	47.38922222	-101.81725	102.7	9917.355372	96.56626458	Combined Ash	Clay	--
6469	Antelope Valley Station	213	SI	Decant Pond (Temporary Pond)	--	--	3	19	6.333333333	Combined Ash	Clay	Excluded
160	Apache Station	299	SI	Scrubber Sludge Pond 1	32.07277778	-109.9127778	41.7	314	7.529976019	Combined Ash	Composite	--
160	Apache Station	297	SI	Scrubber Sludge Pond 2	32.07666667	-109.9127778	42	446	10.61904762	Combined Ash	Composite	--
160	Apache Station	295	SI	Evaporation Pond	32.07416667	-109.9083333	80	--	--	Combined Ash	Composite	--
160	Apache Station	296	SI	Ash Pond 3	32.07611111	-109.905	32.6	720	22.08588957	Combined Ash	Composite	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
160	Apache Station	294	SI	Ash Pond 2	32.07222222	-109.9044444	32.6	720	22.08588957	Combined Ash	Composite	--
160	Apache Station	298	SI	Ash Pond 4	32.07589722	-109.9019528	32.6	693	21.25766871	Combined Ash	Composite	--
160	Apache Station	293	SI	Ash Pond 1	32.07222222	-109.9011111	32.6	717	21.99386503	Combined Ash	Composite	--
160	Apache Station	287	SI	Low Volume Wastewater Pond	--	--	42	618	14.71428571	Combined Ash	--	--
160	Apache Station	288	SI	Evaporation 1	--	--	--	823	--	Combined Ash	Composite	--
160	Apache Station	292	SI	Cooling Tower Blowdown Pond	--	--	--	7	--	Combined Ash	--	--
465	Arapahoe	310	SI	Ash Pump Pond	--	--	--	4	--	Combined Ash	--	--
465	Arapahoe	311	SI	Discharge Pond	--	--	1	7	7	Combined Ash	--	Excluded
465	Arapahoe	312	SI	North Storm Water/Process Water Pond	--	--	1	8	8	Combined Ash	--	Excluded
465	Arapahoe	313	SI	South Storm Water/Process Water Pond	--	--	1	14	14	Combined Ash	--	Excluded
465	Arapahoe	314	SI	South Ash Pond	--	--	1	14	14	Combined Ash	--	--
465	Arapahoe	315	SI	Emergency Pond	--	--	2	12	6	Combined Ash	--	Excluded
3178	Armstrong Power Station	926	LF	Closed Ash Site	40.915954	-79.47162	--	--	--	Combined Ash	None	Excluded
3178	Armstrong Power Station	921	LF	Active Ash Site	40.92222222	-79.47083333	--	--	--	Combined Ash	Yes	--
2076	Asbury	598	SI	Upper Pond	37.35972222	-94.58555556	17.6	--	--	--	None	--
2076	Asbury	597	SI	Lower Pond	37.36055556	-94.58166667	63	--	--	Combined Ash	None	--
2076	Asbury	596	SI	Ash Impoundment	--	--	92	--	--	Combined Ash	--	--
2706	Asheville Steam Electric Plant	649	SI	1964 Pond	35.4675	-82.54805556	45	1380	30.66666667	Combined Ash	Composite	--
2706	Asheville Steam Electric Plant	650	SI	1982 Pond	35.46472222	-82.54416667	46	1400	30.43478261	Combined Ash	None	--
2835	Ashtabula	1263	SI	Combined Treatment Basin	41.90833333	-80.7625	0.40174472	2.0087236	5	Combined Ash	None	--
1961	Austin Northeast	958	LF	Coal Ash Monofill	43.69878611	-92.96217222	--	--	--	Combined Ash	None	Excluded
2836	Avon Lake	1175	SI	Primary Ash Settling Basin	41.50531111	-82.05285	0.09022039	1.082644628	12	Combined Ash	None	--
2836	Avon Lake	1176	SI	Secondary Ash Settling Basin	41.50551667	-82.05202778	0.09022039	1.082644628	12	Combined Ash	None	--
2836	Avon Lake	975	LF	--	--	--	--	--	--	Combined Ash	--	--
995	Bailly	434	SI	Forebay	41.644381	-87.125098	0.14	2	14.28571429	Combined Ash	--	Excluded
995	Bailly	439	SI	Bottom Ash Pond	41.638356	-87.121326	1	2	2	Combined Ash	--	--
995	Bailly	436	SI	Primary 1	41.638387	-87.118974	6	41	6.833333333	Combined Ash	--	--
995	Bailly	437	SI	Primary 2	41.638357	-87.115771	6	47	7.833333333	Combined Ash	--	--
995	Bailly	438	SI	Secondary 2	41.638375	-87.11335	3	30	10	Combined Ash	--	--
995	Bailly	435	SI	Secondary 1	41.637988	-87.111999	2	18	9	Combined Ash	--	--
995	Bailly	939	LF	BGS South Landfill	41.63619167	-87.102575	--	--	--	Combined Ash	None	Excluded

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
995	Bailly	952	LF	BGS North Landfill	41.63854167	-87.102575	--	--	--	Combined Ash	None	Excluded
889	Baldwin Energy Complex	391	SI	Ash Pond System	38.19286	-89.867555	492	3957	8.042682927	Combined Ash	--	--
3	Barry	252	SI	Barry Ash Pond	--	--	597	5965	9.991624791	Combined Ash	None	--
3982	Bay Front	946	LF	Woodfield	46.52152778	-90.93394444	10	216.9421489	21.69421489	Combined Ash	Yes	--
3982	Bay Front	945	LF	Deer Creek	46.47444444	-90.92805556	--	--	--	Combined Ash	None	Excluded
3982	Bay Front	162	SI	Polishing Pond	46.585243	-90.902906	0.41	3	7.317073171	Combined Ash	--	--
3982	Bay Front	163	SI	Surge Basin	46.585471	-90.902568	0.15	1	6.666666667	Combined Ash	--	--
2878	Bay Shore	1326	SI	Bottom Ash Pond	41.69611111	-83.43833333	0.99862259	5.492424242	5.5	Combined Ash	None	--
2878	Bay Shore	977	LF	--	--	--	85	--	--	Combined Ash	--	--
8042	Belews Creek Steam Station	1009	LF	Closed Pine Hall Road Landfill	36.28277778	-80.07861111	68	--	--	Combined Ash	None	Excluded
8042	Belews Creek Steam Station	243	SI	Active Ash Pond	36.296519	-80.075439	342	12654	37	Combined Ash	None	--
8042	Belews Creek Steam Station	1079	LF	Craig Road Ash Landfill	36.26888889	-80.0675	31	1190.96281	38.41815516	Combined Ash	Composite	--
8042	Belews Creek Steam Station	1010	LF	FGD Residual Landfill	36.27444444	-80.05666667	24	991.7355372	41.32231405	Combined Ash	Composite	--
6034	Belle River	1035	LF	Range Road	42.792242	-82.506315	--	--	--	Combined Ash	Yes	--
6034	Belle River	33	SI	Pond	--	--	--	--	--	Combined Ash	--	--
3325	Ben French	1379	SI	Ash Pond	44.08916667	-103.2641667	0.31955923	0.764876033	2.393534483	Combined Ash	Clay	--
645	Big Bend	347	SI	South Bottom Ash Pond	27.79111111	-82.39888889	6	--	--	Combined Ash	Composite	--
645	Big Bend	345	SI	North Bottom Ash	27.79166667	-82.39888889	5.7	--	--	Combined Ash	Composite	--
645	Big Bend	1164	LF	FGD Storage Area	27.78388889	-82.39638889	--	--	--	Combined Ash	None	--
645	Big Bend	343	SI	South Economizer Ash Pond	27.79083333	-82.395	6	--	--	Ash & Coal Refuse	Composite	--
645	Big Bend	344	SI	North Economizer Ash Pond	27.79166667	-82.395	5.5	--	--	Ash & Coal Refuse	Composite	--
645	Big Bend	342	SI	North Recycle Pond	--	--	3	--	--	FGD Waste	--	--
645	Big Bend	346	SI	Longterm Flyash Pond	--	--	12	--	--	Combined Ash	--	--
645	Big Bend	348	SI	Settling Pond	--	--	1	--	--	FGD Waste	--	--
645	Big Bend	349	SI	South Recycle Pond	--	--	9	--	--	FGD Waste	--	--
3497	Big Brown	784	LF	Class 3 bottom ash landfill Area B	31.81666667	-96.0725	1.96	19.6	10	Combined Ash	None	Excluded
3497	Big Brown	1179	SI	Bottom Ash Pond(s)	31.82	-96.06472222	19.2837466	227.3428834	11.78935238	Combined Ash	Clay	--
3497	Big Brown	1178	SI	Operating Pond	31.82805556	-96.05972222	14.6923783	229.135124	15.59550938	Combined Ash	Clay	Excluded
3497	Big Brown	776	LF	Class 3 bottom ash landfill Area A	31.829465	-96.054781	10.029	100.2899908	9.999999084	Combined Ash	None	Excluded
3497	Big Brown	790	LF	Ash Disposal Area 1	31.82944444	-96.05472222	128.595	3499.999587	27.21722918	Combined Ash	Clay	Excluded
3497	Big Brown	1177	SI	Lignite Retention Pond	31.82416667	-96.04972222	15.5	66.22651515	4.272678397	Combined Ash	Yes	Excluded
3497	Big Brown	1180	SI	Settling Pond	31.82444444	-96.04527778	0.51652893	5.155716253	9.981466667	Combined Ash	Yes	--
3497	Big Brown	791	LF	Ash Disposal Area 2	31.83555556	-96.04166667	331.993	4183.8843	12.60232686	Combined Ash	Clay	--
6055	Big Cajun 2	815	LF	Fly Ash	30.725	-91.38972222	175	2417.355372	13.81345927	Combined Ash	Clay	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6055	Big Cajun 2	36	SI	Bottom Ash Unit	--	--	66	1188	18	Combined Ash	Clay	--
6055	Big Cajun 2	37	SI	Fly Ash Unit	--	--	175	1750	10	Combined Ash	Clay	--
6055	Big Cajun 2	38	SI	Water Treatment Unit	--	--	32	585	18.28125	Combined Ash	Clay	--
1353	Big Sandy	521	SI	Horseford Run Dam	38.18666667	-82.6325	176	--	--	Combined Ash	Clay	--
1353	Big Sandy	523	SI	Fly Ash	38.186667	-82.6325	97	8302	85.58762887	Combined Ash	--	--
1353	Big Sandy	522	SI	Bottom Ash Complex	38.17111111	-82.62194444	6	40	6.666666667	Combined Ash	None	--
6098	Big Stone	1261	SI	Ash Pond	45.30001389	-96.51001944	2.1	21	10	Combined Ash	None	--
6098	Big Stone	814	LF	Ash Disposal Site	45.30443889	-96.49121667	109.4	5008.264463	45.77938266	Combined Ash	None	--
1904	Black Dog	799	LF	Ash Storage Area	44.82048056	-93.23732778	96	5539.026446	57.69819215	Combined Ash	None	Excluded
1904	Black Dog	593	SI	Settling Ponds 1-4	--	--	17	218	12.82352941	Combined Ash	None	--
6106	Boardman	1339	SI	Carty	45.701206	-119.809153	1450	38000	26.20689655	Combined Ash	None	Excluded
6106	Boardman	1341	SI	-999	45.701206	-119.809153	10.28	--	--	Combined Ash	Yes	Excluded
6106	Boardman	1340	SI	Settling Pond	45.691617	-119.806178	1.26262626	17.21763085	13.63636364	Combined Ash	None	Excluded
6106	Boardman	746	LF	Ash Pit	45.67916667	-119.7816667	240	--	--	Combined Ash	None	--
7790	Bonanza Power Plant	1207	SI	Emergency Holding Pond 1 (EHP-1)	40.08825	-109.513461	0.91827365	11.01928375	12	FGD Waste	Clay	--
7790	Bonanza Power Plant	735	LF	Bottom Ash	40.30555556	-109.45	50	977.0431589	19.54086318	Combined Ash	None	--
7790	Bonanza Power Plant	1208	SI	Emergency Holding Pond 2 (EHP-2)	40.08222222	-109.2802778	6.50505051	65.05050505	10	FGD Waste	None	--
7790	Bonanza Power Plant	1209	SI	Emergency Holding Pond 3 (EHP-3)	40.08361111	-109.28	4.93572084	68.87052342	13.95348837	FGD Waste	None	--
7790	Bonanza Power Plant	737	LF	Fly ash/Scrubber sludge	40.21138889	-109.2725	25	1709.825528	68.39302112	Combined Ash	None	--
1893	Boswell Energy Center	862	LF	SE Units 1,2 and 3 Dry Fly Ash Landfill	47.27277778	-93.67916667	110	4648.760331	42.26145755	Combined Ash	None	--
1893	Boswell Energy Center	591	SI	Inactive Bottom Ash Pond	47.26361111	-93.67083333	200	3413	17.065	Combined Ash	Clay	Excluded
1893	Boswell Energy Center	590	SI	Complex: Pond 3, 4, and Bottom Ash Pond	47.26972222	-93.66777778	645	11236	17.42015504	Combined Ash	Clay	--
1893	Boswell Energy Center	853	LF	Industrial Solid Waste Landfill	47.26194444	-93.66722222	336	--	--	Combined Ash	None	--
1893	Boswell Energy Center	796	LF	Hibbing Ash Cell	47.26305556	-93.66694444	20	--	--	Combined Ash	None	Excluded
1893	Boswell Energy Center	592	SI	Wastewater Treatment Plant Pond	47.25944444	-93.64972222	1.6	9	5.625	Combined Ash	Clay	--
703	Bowen	1103	LF	CCB Disposal Facility	34.13722222	-84.90222222	51.01	556.8415289	10.9163209	Combined Ash	Yes	--
703	Bowen	350	SI	Ash Pond	--	--	245	3676	15.00408163	Combined Ash	Clay	--
602	Brandon Shores	1289	SI	01 Lagoon	39.18444444	-76.53666667	0.66574839	4.017447199	6.034482759	Combined Ash	Composite	--
602	Brandon Shores	1290	SI	02 Lagoon	39.18444444	-76.53666667	0.66574839	4.017447199	6.034482759	Combined Ash	Composite	--
1619	Brayton Point	731	LF	Cells 1 - 8	41.71835083	-71.193638	--	--	--	Combined Ash	Yes	Excluded
1619	Brayton Point	1191	SI	EQ Basin	41.71312889	-71.19279833	0.40495868	3.682667585	9.09393424	Combined Ash	None	Excluded
1619	Brayton Point	1187	SI	Recycle	41.71313283	-71.19277083	1.81	--	--	Combined Ash	None	Excluded
1619	Brayton Point	1188	SI	Basin 1	41.716621	-71.191151	1.81	--	--	Combined Ash	Yes	Excluded
1619	Brayton Point	1189	SI	Basin 2	41.718367	-71.190972	1.81	--	--	Combined Ash	Yes	Excluded
1619	Brayton Point	824	LF	Cell 9	41.720545	-71.19089083	--	--	--	Combined Ash	Yes	Excluded

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Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
1619	Brayton Point	800	LF	Cell 1A	41.717322	-71.19035483	--	--	--	Combined Ash	Yes	Excluded
1619	Brayton Point	1190	SI	Basin 3	41.71997783	-71.189987	1.81	--	--	Combined Ash	None	Excluded
1619	Brayton Point	1194	SI	Basin A	41.712899	-71.18957183	0.48209366	2.838751148	5.888380952	Combined Ash	Composite	--
1619	Brayton Point	1193	SI	52 Basin	41.717186	-71.188797	1.68044077	14.35009183	8.539480874	Combined Ash	Composite	Excluded
1619	Brayton Point	1192	SI	51 Basin	41.71805556	-71.18833333	1.65748393	14.35009183	8.657756233	Combined Ash	Composite	Excluded
1619	Brayton Point	1195	SI	Basin B	41.712879	-71.18825983	0.73461892	6.137764004	8.35503125	Combined Ash	Composite	--
1619	Brayton Point	1196	SI	Basin C	41.71323683	-71.18783383	0.73461892	6.137764004	8.35503125	Combined Ash	Composite	--
1619	Brayton Point	761	LF	Cell 10	41.71899483	-71.18704483	--	--	--	Combined Ash	Yes	--
1619	Brayton Point	760	LF	Cell 10A	41.718431	-71.18656183	--	--	--	Combined Ash	Yes	Excluded
3796	Bremo Bluff	148	SI	West Ash Pond	37.71111111	-78.29222222	17	290	17.05882353	Combined Ash	None	--
3796	Bremo Bluff	149	SI	North Ash Pond	37.70805556	-78.27833333	62	4300	69.35483871	Combined Ash	None	--
6094	Bruce Mansfield	79	SI	Little Blue Run Dam	40.62781667	-80.51291667	770	65000	84.41558442	Combined Ash	None	--
6094	Bruce Mansfield	75	SI	North LDS Pond (N-LDS)	40.63643333	-80.41331111	3.2	38.5	12.03125	Combined Ash	None	--
6094	Bruce Mansfield	78	SI	South LDS Pond (S-LDS)	40.63603611	-80.41256667	3.1	35.3	11.38709677	Combined Ash	None	--
6094	Bruce Mansfield	76	SI	West HDS Pond (W-HPDS)	40.63459444	-80.41128333	2.9	39.5	13.62068966	Combined Ash	None	--
6094	Bruce Mansfield	77	SI	East HDS (Decommissioned in 2003) (Add this unit to DB)	--	--	--	--	--	--	None	--
2720	Buck	672	SI	Additional Primary Cell Basin	35.70431667	-80.37264167	73.5	2645	35.98639456	Combined Ash	None	--
2720	Buck	671	SI	Old Primary Cell	35.70537778	-80.36640833	46	1610	35	Combined Ash	None	--
2720	Buck	673	SI	Secondary Pond	35.70982222	-80.36273611	14.5	510	35.17241379	Combined Ash	None	--
3396	Bull Run	889	LF	East/West Dredge Cell	36.006672	-84.14839	--	--	--	Combined Ash	None	Excluded
3396	Bull Run	890	LF	Fly Ash Stack	36.02506667	-84.14698889	--	--	--	Combined Ash	None	--
3396	Bull Run	121	SI	Bottom Ash Disposal Area 1	--	--	32	543	16.96875	Combined Ash	--	--
3396	Bull Run	122	SI	Fly Ash Pond & Stilling Basin Area 2	--	--	49	1674	34.16326531	Combined Ash	--	--
3396	Bull Run	123	SI	Gypsum Disposal Area 2A	--	--	42	1700	40.47619048	Combined Ash	--	--
3396	Bull Run	124	SI	Dry Fly Ash Disposal Area	--	--	50	2975	59.5	Combined Ash	--	--
1104	Burlington	507	SI	Ash Seal & Storm Water Pond	--	--	4	68	17	Combined Ash	None	Excluded
1104	Burlington	508	SI	Upper Ash Pond	--	--	13	133	10.23076923	Combined Ash	None	--
1104	Burlington	509	SI	Economizer Ash Pond	--	--	11	166	15.09090909	Combined Ash	None	--
1104	Burlington	510	SI	Lower Ash Pond	--	--	23	114	4.956521739	Combined Ash	None	--
1104	Burlington	511	SI	Main Ash Pond	--	--	17	85	5	Combined Ash	None	--
676	C D McIntosh Jr	885	LF	Northeast Landfill	28.08472222	-81.91722222	17.3	1106.97888	63.98721848	Combined Ash	None	Excluded
676	C D McIntosh Jr	888	LF	Landfill (active)	28.08333333	-81.91666667	48.3	5311.753903	109.9742009	Combined Ash	None	--
468	Cameo	316	SI	Process Water Retention Pond	--	--	--	2	--	Combined Ash	--	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
468	Cameo	317	SI	Ash Silo Storm Water Retention Pond	--	--	--	1	--	Combined Ash	--	Excluded
3280	Canadys Steam	107	SI	Inactive Ash Pond	33.07416667	-80.62194444	80	1000	12.5	Combined Ash	None	--
3280	Canadys Steam	108	SI	Polishing Pond	33.075	-80.61722222	3.5	--	--	--	None	--
3280	Canadys Steam	109	SI	Ash Pond	33.07083333	-80.61527778	95	1407	14.81052632	Combined Ash	None	--
1363	Cane Run	869	LF	Cane Run Special Waste Landfill	38.175	-85.89444444	--	--	--	Combined Ash	None	--
1363	Cane Run	538	SI	Main Ash Pond/E-Pond	38.1775	-85.8875	40	868	21.7	Combined Ash	None	--
1363	Cane Run	541	SI	Dead Storage Pond	38.18345556	-85.88604167	5	--	--	FGD Waste	None	--
1363	Cane Run	540	SI	Basin Pond	38.18305556	-85.88472222	5	--	--	FGD Waste	None	--
1363	Cane Run	539	SI	Clearwell Pond	--	--	1	--	--	FGD Waste	--	--
1363	Cane Run	542	SI	Emergency Pond	--	--	2	--	--	FGD Waste	--	--
2708	Cape Fear Steam Electric Plant	654	SI	1956 Ash Pond	35.59709167	-79.05053333	--	--	--	Combined Ash	None	Excluded
2708	Cape Fear Steam Electric Plant	652	SI	1963 Ash Pond	35.58801667	-79.05015	--	--	--	Combined Ash	None	Excluded
2708	Cape Fear Steam Electric Plant	655	SI	1970 Ash Pond	35.582975	-79.04858333	50	--	--	Combined Ash	None	Excluded
2708	Cape Fear Steam Electric Plant	651	SI	1978 Ash Pond	35.58784167	-79.04622222	43	1161	27	Combined Ash	None	--
2708	Cape Fear Steam Electric Plant	653	SI	1985 Ash Pond	35.59012778	-79.04109444	65	1764	27.13846154	Combined Ash	None	--
3644	Carbon Plant	905	LF	Original Landfill	39.71293056	-110.8653556	--	--	--	Combined Ash	None	Excluded
3644	Carbon Plant	1387	SI	South Settling Pond	39.72472222	-110.8638889	1.12759412	14.40082645	12.77128548	Combined Ash	None	--
3644	Carbon Plant	1388	SI	North Settling Pond	39.72472222	-110.8638889	0.55151515	2.829017447	5.12953713	Combined Ash	None	--
3644	Carbon Plant	876	LF	Ash Landfill	39.708785	-110.861003	11.7739066	--	--	Combined Ash	None	--
2828	Cardinal	694	SI	Bottom Ash Complex	40.237992	-80.659561	19	350	18.42105263	Combined Ash	None	--
2828	Cardinal	899	LF	FAR 1 Residual Waste Landfill	40.27202634	-80.65446374	--	--	--	Combined Ash	Yes	--
2828	Cardinal	693	SI	Fly Ash Reservoir 2	40.266333	-80.646583	139	11350	81.65467626	Combined Ash	None	--
1001	Cayuga	838	LF	Cayuga RWS 1 Landfill	39.91472222	-87.43388889	80	7376.28942	92.20361775	Combined Ash	Composite	--
1001	Cayuga	454	SI	Lined Ash Disposal Pond - Cell #1	39.91916667	-87.42388889	40	1400	35	Combined Ash	Composite	--
1001	Cayuga	457	SI	Ash Disposal Area #1	39.91472222	-87.42083333	26	260	10	Combined Ash	None	--
1001	Cayuga	455	SI	Primary Ash Settling Basin	39.91416667	-87.41666667	15	225	15	Combined Ash	None	--
1001	Cayuga	456	SI	Secondary Ash Settling Basin	39.91361111	-87.41416667	3	36	12	Combined Ash	None	--
1571	Chalk Point LLC	836	LF	brandywine	38.70583333	-76.80277778	596	2872.31405	4.819318875	Combined Ash	Yes	--
1571	Chalk Point LLC	1104	LF	controlled storage area	38.559166	-76.688333	--	--	--	Combined Ash	Yes	--
2169	Chamois Power Plant	1288	SI	Ash Pond #002	38.68194444	-91.75861111	2.75482094	24.79338843	9	Combined Ash	None	--
56	Charles R. Lowman	273	SI	Units 2-3 Pond	31.48694444	-87.91611111	29	629	21.68965517	Combined Ash	None	--
56	Charles R. Lowman	270	SI	Scrubber Waste Pond	31.48972222	-87.91416667	36	760	21.11111111	FGD Waste	None	--
56	Charles R. Lowman	272	SI	#1 Bottom Ash Pond	31.485	-87.91305556	16.5	330	20	Combined Ash	None	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
56	Charles R. Lowman	271	SI	Process Waste Pond	31.49166667	-87.91222222	6	--	--	Combined Ash	None	--
56	Charles R. Lowman	900	LF	--	--	--	--	--	--	Combined Ash	--	--
469	Cherokee	318	SI	Center Ash Pond	--	--	1	10	10	Combined Ash	--	--
469	Cherokee	319	SI	West Polishing Pond	--	--	1	16	16	Combined Ash	--	--
469	Cherokee	320	SI	West Ash Pond	--	--	--	8	--	Combined Ash	--	--
469	Cherokee	321	SI	Emergency Spill Pond	--	--	--	5	--	--	--	--
469	Cherokee	322	SI	East Ash Pond	--	--	--	8	--	Combined Ash	--	--
469	Cherokee	323	SI	East Polishing Pond	--	--	1	16	16	Combined Ash	--	--
3803	Chesapeake Energy Center	152	SI	Bottom Ash/Sedimentation Pond	36.76205833	-76.30375	9.7	77	7.93814433	Combined Ash	None	--
3803	Chesapeake Energy Center	865	LF	ash landfill	36.76444444	-76.3025	--	--	--	Combined Ash	Yes	--
3797	Chesterfield	150	SI	Lower (Old) Ash Pond	37.37277778	-77.38055556	49	740	15.10204082	Combined Ash	None	--
3797	Chesterfield	151	SI	Upper (New) Ash Pond	37.37277778	-77.36472222	112	10240	91.42857143	Combined Ash	None	--
8226	Cheswick Power Plant	1099	LF	Lefever	40.581433	-79.832236	--	--	--	Combined Ash	Yes	--
8226	Cheswick Power Plant	1165	SI	Bottom Ash Emergency Pond	40.54361111	-79.79416667	0.57392103	4.965794307	8.6524	Combined Ash	Clay	--
8226	Cheswick Power Plant	1166	SI	Bottom Ash Recycle Pond	40.54444444	-79.79416667	0.65206612	3.208425161	4.920398535	Combined Ash	Clay	--
113	Cholla	280	SI	Bottom Ash Pond	34.955225	-110.2884306	80	2300	28.75	Combined Ash	None	--
113	Cholla	863	LF	Bottom Ash Monofill	34.96388889	-110.2861111	--	--	--	Combined Ash	None	--
113	Cholla	279	SI	Fly Ash Pond	34.93276389	-110.2648361	420	18000	42.85714286	Combined Ash	None	--
2721	Cliffside	675	SI	Active Ash Pond	35.21333333	-81.74972222	84	5025	59.82142857	Combined Ash	None	--
2721	Cliffside	674	SI	Retired Unit 1-4 Basin	--	--	14	--	--	Combined Ash	--	Excluded
2721	Cliffside	676	SI	Retired Unit 5 Basin	--	--	46	--	--	Combined Ash	--	Excluded
983	Clifty Creek	848	LF	Type I Fly Ash Landfill	38.733774	-85.437397	--	--	--	Combined Ash	Yes	--
983	Clifty Creek	847	LF	Type III Fly Ash Landfill	38.73565	-85.434455	--	--	--	Combined Ash	None	--
983	Clifty Creek	414	SI	South Fly Ash Runoff Pond Site 16	38.73379722	-85.43019722	40	--	--	Combined Ash	None	--
983	Clifty Creek	413	SI	West Bottom Ash Pond Site 16 (Regn 5)	38.74023611	-85.41523611	58	3600	62.06896552	Combined Ash	None	--
3775	Clinch River	849	LF	Clinch River Industrial Waste Landfill, Permit 223	36.924744	-82.203874	--	--	--	Combined Ash	Yes	--
3775	Clinch River	144	SI	Bottom Ash Pond 1A/1B	36.93722222	-82.19752778	12.8	1240	96.875	Combined Ash	None	--
3775	Clinch River	145	SI	Bottom Ash Pond 2	36.9385	-82.19083333	--	1332	--	Combined Ash	None	Excluded
7213	Clover	851	LF	Stage 1&2	36.87027778	-78.72083333	33	1441.115702	43.6701728	Combined Ash	Composite	Excluded
7213	Clover	850	LF	Stage 3	36.869618	-78.720416	80.5	4958.677686	61.59848057	Combined Ash	Composite	--
7213	Clover	1280	SI	North Sludge	36.87	-78.70166667	1.80153811	4.304132231	2.389143039	FGD Waste	Composite	--
7213	Clover	1281	SI	South Sludge	36.87	-78.70166667	1.80153811	10.76033058	5.972857598	FGD Waste	Composite	--
7213	Clover	1283	SI	Leachate 1	36.87194444	-78.69777778	38.22	--	--	Combined Ash	Yes	Excluded
7213	Clover	1284	SI	Leachate 2	36.87194444	-78.69777778	38.22	--	--	Combined Ash	Yes	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
7213	Clover	1282	SI	Coal/Limestone	36.86861111	-78.69444444	38.22	--	--	Ash & Coal Refuse	Yes	Excluded
6030	Coal Creek	854	LF	Section 26	47.44116472	-101.2160697	--	--	--	Combined Ash	Yes	--
6030	Coal Creek	868	LF	Section 31	47.42348333	-101.1640528	--	--	--	Combined Ash	Yes	Excluded
6030	Coal Creek	855	LF	Section 5	47.41005833	-101.1603578	--	--	--	Combined Ash	None	Excluded
6030	Coal Creek	1119	LF	Section 32	47.42028056	-101.1581611	220	14256.1983	64.80090136	Combined Ash	Yes	--
6030	Coal Creek	29	SI	Ash Pond 91	47.37609	-101.143559	72	249	3.458333333	Combined Ash	--	--
6030	Coal Creek	857	LF	SW Section 16	47.37834778	-101.1317489	--	--	--	Combined Ash	Yes	Excluded
6030	Coal Creek	30	SI	Upstream Raise/Ash Pond 92/SW Section 16	47.380215	-101.129303	90	769	8.544444444	Combined Ash	--	--
6030	Coal Creek	852	LF	SE Section 16	47.37575556	-101.1258111	70	2913.22314	41.61747343	Combined Ash	Yes	--
861	Coffeen	846	LF	Landfill	39.06930556	-89.40025	--	--	--	Combined Ash	Yes	--
861	Coffeen	380	SI	Gypsum Management Facility Recycle Pond	39.06624722	-89.39559722	17	243	14.29411765	FGD Waste	Composite	--
861	Coffeen	379	SI	Recycle Pond	39.05831667	-89.39442222	23	500	21.73913043	Combined Ash	None	Excluded
47	Colbert	859	LF	#5 Dry Stack (fly ash)	34.73305556	-87.83408333	--	--	--	Combined Ash	None	--
47	Colbert	258	SI	Disposal Area 5 Basin	--	--	12	372	31	Combined Ash	--	--
47	Colbert	259	SI	Disposal Area 5	--	--	75	5455	72.73333333	Combined Ash	--	--
47	Colbert	260	SI	Ash Pond 4	--	--	52	1364	26.23076923	Combined Ash	--	--
6178	Coleto Creek	182	SI	Primary Ash Pond	28.72472222	-97.20916667	190	2700	14.21052632	Combined Ash	Clay	--
6178	Coleto Creek	181	SI	Secondary Settling Pond	28.72861111	-97.20638889	10	300	30	Combined Ash	Clay	--
6076	Colstrip	49	SI	Units 1 & 2 Stage Two Evaporation Ponds (STEP)	45.9055	-106.6442222	176	4370	24.82954545	Combined Ash	Composite	--
6076	Colstrip	50	SI	Units 1 & 2 A Pond	45.87916667	-106.6188889	14	245	17.5	Combined Ash	None	--
6076	Colstrip	52	SI	Units 1 & 2 Bottom Ash Pond	45.88138889	-106.61875	7	73	10.42857143	Combined Ash	Composite	--
6076	Colstrip	51	SI	Units 3 & 4 Effluent Holding Pond (EHP)	45.87027778	-106.5482222	367	17000	46.32152589	Combined Ash	None	--
6076	Colstrip	46	SI	Units 3 & 4 Scrubber Drain Collection Pond	--	--	6	72	12	Combined Ash	--	Excluded
6076	Colstrip	47	SI	Units 3 & 4 Bottom Ash Pond	--	--	8	38	4.75	Combined Ash	--	--
6076	Colstrip	48	SI	Units 1 & 2 B Fly Ash Pond	--	--	10	196	19.6	Combined Ash	--	--
6076	Colstrip	53	SI	Units 3 & 4 Scrubber Wash Tray Pond	--	--	8	85	10.625	Combined Ash	--	Excluded
10784	Colstrip Energy LP	860	LF	CELP	45.97886111	-106.6635	--	--	--	Combined Ash	None	--
10784	Colstrip Energy LP	861	LF	CELP	45.97533333	-106.6594444	--	--	--	Combined Ash	None	Excluded
2123	Columbia	1213	SI	Ash Settling Pond	38.96584333	-92.31849028	8.5	45	5.294117647	Combined Ash	None	--
8023	Columbia	1136	LF	Ash Pond Disposal Facility	43.48969444	-89.42175	--	--	--	Combined Ash	None	Excluded
8023	Columbia	1135	LF	Dry Ash Disposal Facility	43.48727778	-89.41205556	--	--	--	Combined Ash	Yes	--
8023	Columbia	239	SI	Landfill Storm Water Pond	--	--	11	11	1	Combined Ash	Composite	Excluded
8023	Columbia	240	SI	Secondary Ash Pond	--	--	16	204	12.75	Combined Ash	None	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
8023	Columbia	241	SI	Polishing Pond	--	--	1	5	5	Combined Ash	None	--
8023	Columbia	242	SI	Primary Ash Pond	--	--	9	72	8	Combined Ash	None	--
470	Comanche	1137	LF	Comanche ADF	38.20170556	-104.5825083	280	18882.02479	67.43580283	Combined Ash	None	--
470	Comanche	324	SI	Ash Pond #2	--	--	2	12	6	FGD Waste	--	--
470	Comanche	325	SI	Polishing Pond (#4)	--	--	2	12	6	Combined Ash	--	--
470	Comanche	326	SI	Ash Pond #3	--	--	2	12	6	Combined Ash	--	--
470	Comanche	327	SI	Ash Pond #1	--	--	2	12	6	FGD Waste	--	--
470	Comanche	328	SI	Ash Disposal Facility (ADF) Stormwater Retention Pond	--	--	1	8	8	Combined Ash	--	--
3118	Conemaugh	1138	LF	Stage I	40.41111111	-79.07166667	--	--	--	Combined Ash	None	Excluded
3118	Conemaugh	864	LF	Stage II	40.40666667	-79.07027778	434	50826.44628	117.1116274	Combined Ash	Yes	--
3118	Conemaugh	1338	SI	Bottom Ash Final Settling Pond - D	40.38277778	-79.06333333	0.83677686	6.198347107	7.407407407	Combined Ash	Clay	--
3118	Conemaugh	1337	SI	Bottom Ash Final Settling Pond - C	40.38305556	-79.06333333	0.83677686	6.198347107	7.407407407	Combined Ash	Clay	--
3118	Conemaugh	1336	SI	Bottom Ash Final Settling Pond - B	40.38361111	-79.06333333	0.83677686	6.198347107	7.407407407	Combined Ash	Clay	--
3118	Conemaugh	1335	SI	Bottom Ash Sluice Recycle Pond - A	40.38388889	-79.06333333	0.83677686	6.198347107	7.407407407	Combined Ash	Clay	--
3118	Conemaugh	1334	SI	Cooling Tower Desilting Basin	40.38555556	-79.05777778	9.524	--	--	Combined Ash	Yes	Excluded
2840	Conesville	701	SI	Ash Pond Complex	40.18833333	-81.86972222	82	865	10.54878049	Combined Ash	None	--
2840	Conesville	1005	LF	--	--	--	52	2252.066116	43.30896376	Combined Ash	Composite	--
2840	Conesville	1006	LF	--	--	--	50	2835.743802	56.71487603	Combined Ash	--	Excluded
1710	Consumers Energy - J.H. Campbell	572	SI	EPRI 4	--	--	267	4276.859504	16.01820039	Ash & Coal Refuse	--	Excluded
1710	Consumers Energy - J.H. Campbell	967	LF	--	--	--	17.96	620.298967	34.5378044	Combined Ash	Composite	--
1710	Consumers Energy - J.H. Campbell	985	LF	--	--	--	18	657.1338843	36.50743802	Combined Ash	Composite	--
1710	Consumers Energy - J.H. Campbell	998	LF	--	--	--	17.4	783.1828512	45.01050869	Combined Ash	Composite	--
1710	Consumers Energy - J.H. Campbell	999	LF	--	--	--	17	1266.432645	74.49603792	Combined Ash	Composite	--
1384	Cooper Station.	973	LF	--	--	--	--	--	--	Combined Ash	--	--
7210	Cope	866	LF	Cope Landfill	33.37005556	-81.04075	340	14876.03306	43.75303841	Combined Ash	None	--
6177	Coronado Generating Station	180	SI	Evaporation Pond/Dam	34.55833333	-109.2952778	290	5900	20.34482759	Combined Ash	None	--
6177	Coronado Generating Station	867	LF	Ash Disposal	34.54766667	-109.28325	230	34435.26171	149.7185292	Combined Ash	None	--
6177	Coronado Generating Station	835	LF	N/A	--	--	--	--	--	Combined Ash	--	Excluded
8222	Coyote	250	SI	Ash Pond	47.218595	-101.814109	4	40	10	Combined Ash	--	--
8222	Coyote	248	SI	Nelson Pond	47.217021	-101.80979	5	92	18.4	Combined Ash	--	--

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8222	Coyote	249	SI	Sluice Pond	47.217006	-101.805935	1	5	5	Combined Ash	--	--
8222	Coyote	826	LF	Black Pit	47.22230278	-101.7959417	43	1285.53719	29.89621372	Combined Ash	Clay	Excluded
8222	Coyote	833	LF	Blue Pit	47.21148889	-101.7883222	224	5224.416322	23.32328715	Combined Ash	Clay	--
8222	Coyote	825	LF	Green Pit	47.22711667	-101.7874778	98.3	607.4380165	6.179430484	Combined Ash	Clay	Excluded
8222	Coyote	856	LF	Purple Pit	47.22349722	-101.7578444	155.7	1548.370064	9.944573309	Combined Ash	None	--
2549	CR Huntley Generating Station	1100	LF	Huntley Ash Landfill	42.98833333	-78.92805556	--	--	--	Combined Ash	Yes	--
2549	CR Huntley Generating Station	645	SI	North Equalization Basin	42.96678611	-78.92686111	2	9	4.5	Combined Ash	--	--
2549	CR Huntley Generating Station	644	SI	South Equalization Basin	42.966509	-78.926638	2	6	3	Combined Ash	--	--
2549	CR Huntley Generating Station	643	SI	South Settling Pond System	42.96695	-78.925467	7	48	6.857142857	Combined Ash	--	--
6021	Craig	27	SI	Concentrator Decant Basin #1	--	--	--	1	--	Combined Ash	--	Excluded
6021	Craig	28	SI	Concentrator Decant Basin #2	--	--	--	1	--	FGD Waste	--	Excluded
6021	Craig	974	LF	--	--	--	18	--	--	Combined Ash	Clay	Excluded
867	Crawford	387	SI	EPRI 2	--	--	--	--	--	--	--	Excluded
753	Crisp Plant	1265	SI	Crisp Plant	31.84490556	-83.94425	6.82	--	--	Combined Ash	None	--
641	Crist	1276	SI	Interim Landfill Pond	30.568	-87.23752778	2.24517906	8.980716253	4	Combined Ash	None	--
641	Crist	1139	LF	Ash Landfill	30.56383333	-87.23536111	68	2364.554637	34.77286231	Combined Ash	Yes	--
641	Crist	1275	SI	Ash Landfill Pond	30.568	-87.23527778	2.68365473	40.25482094	15	Combined Ash	None	Excluded
641	Crist	1278	SI	Gypsum Area 1 SedimentationPond	30.57	-87.2325	4.75206612	95.04132231	20	FGD Waste	Composite	Excluded
641	Crist	1277	SI	Gypsum Area 1 Cell 2	30.56833333	-87.232	15.610652	402.5799128	25.78879559	FGD Waste	Composite	--
641	Crist	1279	SI	Gypsum Area 1 Return Water Pond	30.56888889	-87.23055556	3.52157943	52.82369146	15	FGD Waste	Composite	Excluded
641	Crist	1273	SI	Governor's Island Ash Pond	30.56413056	-87.22170556	13.51	--	--	Ash & Coal Refuse	None	Excluded
641	Crist	1274	SI	Ash Pond	30.56216667	-87.22011111	16.3	240.9142562	14.78001572	Ash & Coal Refuse	None	--
130	Cross	827	LF	Poz-O-Tec	33.38416667	-80.1175	91	2727.272727	29.97002997	Combined Ash	None	--
130	Cross	285	SI	Gypsum Pond	33.36791667	-80.10877778	1	6	6	FGD Waste	Clay	--
130	Cross	284	SI	Bottom Ash 1	33.37088889	-80.10466667	12.8	230	17.96875	Combined Ash	Clay	--
130	Cross	286	SI	Bottom Ash 2	33.37361111	-80.10072222	79	1158	14.65822785	Combined Ash	Clay	--
130	Cross	828	LF	-999	--	--	--	--	--	Combined Ash	--	--
130	Cross	829	LF	-999	--	--	--	--	--	Combined Ash	--	--
130	Cross	830	LF	-999	--	--	--	--	--	Combined Ash	--	--
628	Crystal River Power Plant	831	LF	Landfill-1	28.96666667	-82.68722222	--	--	--	Combined Ash	None	--
3399	Cumberland	125	SI	Gypsum Storage Area (North/South)	--	--	170	12397	72.92352941	FGD Waste	--	--
3399	Cumberland	126	SI	Dry Ash Stack	--	--	110	7810	71	Combined Ash	--	--
3399	Cumberland	127	SI	Ash Pond	--	--	50	1240	24.8	Combined Ash	--	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
3399	Cumberland	978	LF	--	--	--	--	--	--	Combined Ash	--	--
6823	D B Wilson	845	LF	Phase II Landfill	37.46083333	-87.08888889	--	--	--	Combined Ash	None	--
6823	D B Wilson	832	LF	Phase I Landfill	37.46027778	-87.085	--	--	--	Combined Ash	None	--
1702	D.E. Karn	571	SI	DE Karn 1 and 2 Solid Waste Disposal Area	43.64583333	-83.8325	--	--	--	--	None	--
1702	D.E. Karn	570	SI	Pond A	--	--	174	4423	25.41954023	Combined Ash	None	--
1702	D.E. Karn	1004	LF	--	--	--	40	1022.727273	25.56818182	Combined Ash	--	--
1385	Dale Station	558	SI	Dale Ash Pond #3	37.885	-84.26333333	1.6	--	--	Combined Ash	--	--
1385	Dale Station	560	SI	Dale Ash Pond #2	37.88388889	-84.26222222	8	112	14	Combined Ash	None	--
1385	Dale Station	559	SI	Dale Ash Pond #4	37.87777778	-84.26166667	10.7	143	13.36448598	Combined Ash	None	--
963	Dallman	399	SI	Dallman Ash Pond	39.76722222	-89.6	34	682	20.05882353	Combined Ash	None	--
963	Dallman	834	LF	Unit 2	39.769459	-89.597701	22	1115.702479	50.71374906	Combined Ash	Yes	--
963	Dallman	823	LF	Unit 1	39.766279	-89.596662	--	--	--	Combined Ash	None	Excluded
2723	Dan River	678	SI	Primary Pond	36.489167	-79.716111	27	477	17.66666667	Combined Ash	None	Excluded
2723	Dan River	679	SI	Dry Storage Basin, Dredge Pond Dike	36.48946389	-79.71566944	--	--	--	--	--	Excluded
2723	Dan River	677	SI	Secondary Pond	36.491944	-79.713056	12	187	15.58333333	Combined Ash	None	Excluded
2480	Danskammer Generating Station	1140	LF	Danskammer Solid Waste Management Facility	41.57666667	-73.96944444	21.8	1167.84045	53.57066284	Combined Ash	Composite	Excluded
4158	Dave Johnston Plant	4	SI	Blowdown Canal	42.84222222	-105.7805556	1	3	3	Combined Ash	None	Excluded
4158	Dave Johnston Plant	5	SI	4B Ash Pond	42.84222222	-105.7805556	20	145	7.25	Combined Ash	Composite	--
4158	Dave Johnston Plant	6	SI	4A Ash Pond	42.84222222	-105.7805556	20	145	7.25	Combined Ash	Composite	--
4158	Dave Johnston Plant	7	SI	1A Ash Pond	42.84222222	-105.7805556	13	115	8.846153846	Combined Ash	Composite	Excluded
4158	Dave Johnston Plant	8	SI	4 Clear Pond	42.84222222	-105.7805556	6.4	50	7.8125	Combined Ash	None	--
4158	Dave Johnston Plant	9	SI	1B Clear Pond	42.84222222	-105.7805556	2	20	10	Combined Ash	None	--
4158	Dave Johnston Plant	10	SI	1B Ash Pond	42.84222222	-105.7805556	13	112	8.615384615	Combined Ash	Composite	--
4158	Dave Johnston Plant	11	SI	1A Clear Pond	42.84222222	-105.7805556	2	16	8	Combined Ash	None	--
4158	Dave Johnston Plant	837	LF	Dave Johnston Plant Industrial Landfill	42.84611111	-105.7630556	555	20661.15702	37.22730995	Combined Ash	None	--
996	Dean H Mitchell	446	SI	Secondary 2	41.638407	-87.410366	0.48	2	4.166666667	Combined Ash	--	Excluded
996	Dean H Mitchell	445	SI	Secondary 1	41.64043	-87.406511	0.52	3	5.769230769	Combined Ash	--	Excluded
996	Dean H Mitchell	443	SI	Primary 2	41.639964	-87.406162	1.7	31	18.23529412	Combined Ash	--	Excluded
996	Dean H Mitchell	444	SI	Primary 3	41.639408	-87.405385	1.9	31	16.31578947	Combined Ash	--	Excluded
996	Dean H Mitchell	447	SI	Primary 4	41.638818	-87.403168	2.3	34	14.7826087	Combined Ash	--	Excluded
996	Dean H Mitchell	442	SI	Primary 1	41.634588	-87.395399	1.4	22	15.71428571	Combined Ash	--	Excluded
996	Dean H Mitchell	440	SI	Bottom Ash Complex	--	--	--	--	--	Combined Ash	None	Excluded
996	Dean H Mitchell	441	SI	Fly Ash Pond	--	--	--	--	--	Combined Ash	None	Excluded
663	Deerhaven Generating Station	1141	LF	Fly Ash Landfill	29.764712	-82.397978	--	--	--	Combined Ash	Yes	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
663	Deerhaven Generating Station	1331	SI	CoolingTowerBlowdown&BottomAshPond	29.76472222	-82.39222222	2.81221304	52.8953168	18.80914286	Combined Ash	None	--
1572	Dickerson	839	LF	Westland Ash Storage Site	39.19222222	-77.4575	206	7809.917355	37.91222017	Combined Ash	Yes	--
51	Dolet Hills	265	SI	Surge Pond No. 1	32.02997222	-93.57208333	2.25	29	12.88888889	Combined Ash	Clay	--
51	Dolet Hills	840	LF	Flyash/FGD Landfill	32.0125	-93.57083333	109	5268.595041	48.33573432	Combined Ash	Yes	--
51	Dolet Hills	269	SI	Auxiliary Surge Pond	32.02963889	-93.57052778	1.54	2	1.298701299	Combined Ash	Clay	--
51	Dolet Hills	267	SI	Surge Pond No. 2	32.02875	-93.56772222	4.8	18	3.75	Combined Ash	Clay	--
51	Dolet Hills	263	SI	Landfill Storm Water/Leachate	32.02041667	-93.56661111	1.32	--	--	Combined Ash	Clay	--
51	Dolet Hills	264	SI	Ash Basin No. 1	32.03044444	-93.56211111	30	578	19.26666667	Combined Ash	Clay	--
51	Dolet Hills	266	SI	Secondary Basin	32.03277778	-93.56208333	6.5	75	11.53846154	Combined Ash	None	--
51	Dolet Hills	268	SI	Ash Basin No. 2	32.0355	-93.56080556	31	501	16.16129032	Combined Ash	Clay	--
3317	Dolphus M Grainger	116	SI	Ash Pond 1	33.82709722	-79.04948889	42.5	298	7.011764706	Combined Ash	None	Excluded
3317	Dolphus M Grainger	115	SI	Ash Pond 2	33.82227778	-79.04708611	39	429	11	Combined Ash	None	Excluded
1046	Dubuque	476	SI	Ash Channel	--	--	--	10	--	Combined Ash	--	--
6016	Duck Creek	842	LF	Landfill	40.52027778	-89.98833333	169	--	--	Combined Ash	Composite	--
6016	Duck Creek	18	SI	Recycle Pond	--	--	--	--	--	--	Clay	--
6016	Duck Creek	19	SI	Ash Pond 1	--	--	58	1900	32.75862069	Combined Ash	None	Excluded
6016	Duck Creek	20	SI	Ash Pond 2	--	--	85	1000	11.76470588	Combined Ash	None	Excluded
2554	Dunkirk Generating Plant	843	LF	SWMF	42.497091	-79.305372	55.96	1660	29.66404575	Combined Ash	Composite	--
2554	Dunkirk Generating Plant	646	SI	Northwest Pump House	--	--	--	--	--	Combined Ash	--	Excluded
2554	Dunkirk Generating Plant	647	SI	Equalization Basin	--	--	--	2	--	Combined Ash	--	--
2554	Dunkirk Generating Plant	648	SI	Settling Pond System	--	--	2	12	6	Combined Ash	--	--
26	E. C. Gaston	257	SI	Ash Pond Dam	--	--	339	18888	55.71681416	Combined Ash	None	--
1355	E.W. Brown	524	SI	Ash Pond	37.7875	-84.71888889	75.12	--	--	Combined Ash	Composite	--
1355	E.W. Brown	525	SI	Auxiliary Pond	37.78109167	-84.71879167	25.7	515	20.03891051	Combined Ash	Composite	--
991	Eagle Valley	426	SI	C Pond	39.48408611	-86.42719444	8	102	12.75	Combined Ash	None	--
991	Eagle Valley	428	SI	B Pond	39.48254167	-86.42694444	13	177	13.61538462	Combined Ash	None	--
991	Eagle Valley	427	SI	A Pond	39.48098611	-86.42684444	19	400	21.05263158	Combined Ash	None	--
991	Eagle Valley	425	SI	E Pond	39.48441944	-86.4231	4	45	11.25	Combined Ash	None	Excluded
991	Eagle Valley	429	SI	D Pond	39.48308889	-86.42246389	16	370	23.125	Combined Ash	None	--
1217	Earl F Wisdom	844	LF	Ash Landfill	43.16133333	-95.25288889	--	--	--	Combined Ash	None	--
6018	East Bend Station	24	SI	East Bend Station Unit 1	38.90194444	-84.84111111	53.4	1277	23.91385768	Combined Ash	None	--
6018	East Bend Station	879	LF	East Landfill	38.90916667	-84.84027778	--	--	--	Combined Ash	Yes	--
6018	East Bend Station	23	SI	FGD Pond East	--	--	4	51	12.75	FGD Waste	--	--
6018	East Bend Station	25	SI	FGD Pond West	--	--	4	45	11.25	FGD Waste	--	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2837	Eastlake	1262	SI	Combined Treatment Basin	41.67305556	-81.44305556	0.58539945	2.869605142	4.901960784	Combined Ash	None	--
2837	Eastlake	914	LF	North Park	--	--	--	--	--	Combined Ash	Yes	--
856	ED Edwards	378	SI	Pond 2 - Ash Pond Settling	40.59277778	-89.66722222	32	--	--	Combined Ash	None	--
856	ED Edwards	377	SI	Pond 3 - Clarification Pond	40.58972222	-89.66527778	23	--	--	Combined Ash	None	--
856	ED Edwards	376	SI	Ash Pond	--	--	89	1800	20.2247191	Combined Ash	None	--
4050	Edgewater	858	LF	I-43 ADF	43.69333333	-87.76416667	25	1026.260331	41.05041322	Combined Ash	Yes	--
4050	Edgewater	894	LF	Edgewater 1-4 Closed ADF	43.71138889	-87.71305556	--	--	--	Combined Ash	None	Excluded
4050	Edgewater	168	SI	B Pond	43.710917	-87.711869	1.93	19	9.844559585	Combined Ash	--	--
4050	Edgewater	165	SI	A Ponds (Two)	43.712168	-87.711684	4.4	44	10	Combined Ash	--	--
4050	Edgewater	164	SI	C Pond	43.71111	-87.711003	0.65	3	4.615384615	Combined Ash	--	--
4050	Edgewater	166	SI	I43 Coal Combustion landfill Contact Pond	43.717171	-87.710875	1.11	8	7.207207207	Combined Ash	--	Excluded
4050	Edgewater	169	SI	F Pond	43.710195	-87.704069	0.9	9	10	Combined Ash	--	--
4050	Edgewater	167	SI	Slag Pond	43.709357	-87.703924	1.8	10	5.555555556	Combined Ash	--	--
1004	Edwardsport	459	SI	Primary Ash Pond	38.80080556	-87.24330556	8	170	21.25	Combined Ash	None	--
1004	Edwardsport	458	SI	Secondary Ash Pond	38.80072222	-87.24302778	1	7	7	Combined Ash	None	--
1004	Edwardsport	971	LF	--	--	--	--	--	--	Combined Ash	--	--
1374	Elmer Smith Station	1234	SI	Pond #1	37.79491667	-87.06419444	1.60697888	24.1046832	15	Combined Ash	None	--
1374	Elmer Smith Station	1235	SI	Pond #2	37.79344444	-87.06313889	13.7741047	24.79338843	1.8	Combined Ash	None	--
1374	Elmer Smith Station	1237	SI	FGD Scrubber Purge basin	37.79722222	-87.06145	0.13774105	0.20661157	1.5	FGD Waste	None	--
1374	Elmer Smith Station	1236	SI	FGD Emergency Pond	37.79572222	-87.05869444	0.68870523	8.26446281	12	FGD Waste	Composite	--
3098	Elrama Power Plant	1342	SI	Ash Settling Pond 1	40.25333333	-79.92027778	2.13269054	29.34421488	13.7592465	Combined Ash	Yes	--
3098	Elrama Power Plant	1343	SI	Ash Settling Pond 2	40.25388889	-79.92027778	2.224	--	--	Combined Ash	Yes	--
3098	Elrama Power Plant	1344	SI	Ash Polishing Pond 4	40.25472222	-79.92027778	0.3902663	6.634527089	17	Combined Ash	Yes	--
3098	Elrama Power Plant	1345	SI	Scrubber Emergency Pond 5	40.25527778	-79.91972222	0.20661157	3.512396694	17	FGD Waste	Yes	Excluded
3098	Elrama Power Plant	895	LF	Fern Valley	40.28111111	-79.88972222	--	--	--	Combined Ash	Yes	Excluded
1832	Erickson Station	587	SI	Unit 1	42.687523	-84.653971	33	198	6	Combined Ash	--	--
87	Escalante	274	SI	Management Units 3 & 4 Bottom Ash	--	--	13	96	7.384615385	Combined Ash	--	--
87	Escalante	276	SI	Evaporation Pond 1a + 1b	--	--	2.3	14	6.086956522	FGD Waste	--	--
87	Escalante	277	SI	Emergency Scrubber Pond	--	--	0.8	3	3.75	FGD Waste	--	--
87	Escalante	278	SI	Evaporation Ponds 2-5	--	--	--	--	--	--	--	--
87	Escalante	275	SI	N/A	--	--	--	--	--	--	--	Excluded
87	Escalante	992	LF	--	--	--	97	573.9210285	5.916711634	Combined Ash	Clay	--
1012	F. B. Culley	466	SI	West Ash Pond	37.91198222	-87.32948472	18	620	34.44444444	Combined Ash	None	Excluded
1012	F. B. Culley	467	SI	East Pond	37.90922778	-87.32296111	7	372	53.14285714	Combined Ash	None	--
1218	Fair Station	896	LF	CIPCO landfill	41.46194444	-90.85888889	--	--	--	Combined Ash	Yes	Excluded

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
1218	Fair Station	1184	SI	#2 ash pond	41.45833333	-90.825	1.20523416	13.25757576	11	Combined Ash	Clay	Excluded
1218	Fair Station	1183	SI	#1 ash pond	41.45833333	-90.82444444	2.26280992	24.89090909	11	Combined Ash	Clay	Excluded
6179	Fayette Power Project	183	SI	Management Unit 009	29.90944444	-96.75111111	30	600	20	Combined Ash	Clay	--
6179	Fayette Power Project	184	SI	Management Unit 002	29.91472222	-96.74055556	84	2293	27.29761905	Combined Ash	Clay	--
6179	Fayette Power Project	897	LF	CCB Landfill	--	--	23	552	24	Combined Ash	Yes	--
886	Fisk	1238	SI	Dewatering Pad	41.84916667	-87.65666667	0.25482094	0.126262626	0.495495495	Ash & Coal Refuse	None	Excluded
886	Fisk	1239	SI	Dewatering Bin Sump	41.84888889	-87.65638889	0.09182736	0.183654729	2	Ash & Coal Refuse	None	Excluded
886	Fisk	1240	SI	Equalization Basin (Flume)	41.84861111	-87.65472222	0.04820937	0.482093664	10	Ash & Coal Refuse	None	Excluded
6138	Flint Creek	898	LF	Ash landfill	36.259077	-94.514209	40	934.8657025	23.37164256	Combined Ash	Yes	--
6138	Flint Creek	173	SI	Secondary Bottom Ash Pond	--	--	4	24	6	Ash & Coal Refuse	--	--
6138	Flint Creek	174	SI	Primary Bottom Ash Pond	--	--	43	484	11.25581395	Ash & Coal Refuse	--	--
3943	Fort Martin Power Station	1143	LF	Gypsum Phase I Landfill	39.717275	-79.95	99.5	2169.421489	21.80323104	Combined Ash	Yes	--
3943	Fort Martin Power Station	1142	LF	Ash Landfill	39.71277778	-79.9425	99.5	2169.421489	21.80323104	Combined Ash	None	--
3943	Fort Martin Power Station	1181	SI	Wastewater Treatment Lagoon 1	39.709222	-79.930731	1.26262626	10.19283747	8.072727273	Combined Ash	None	Excluded
3943	Fort Martin Power Station	1182	SI	Wastewater Treatment Lagoon 2	39.709222	-79.930731	1.26262626	10.19283747	8.072727273	Combined Ash	None	Excluded
10343	Foster Wheeler Mt Carmel Cogen	901	LF	-999	--	--	--	--	--	Combined Ash	--	--
2442	Four Corners	638	SI	Low Volume Waste Water System Decant Cells	36.6831	-108.5124	45.1	435	9.645232816	Combined Ash	--	--
2442	Four Corners	915	LF	Dry Flyash Disposal Area	36.68583333	-108.5080556	--	--	--	Combined Ash	Yes	--
2442	Four Corners	639	SI	Lined Ash Impoundment	36.6849	-108.5066	75	2399	31.98666667	Combined Ash	Composite	--
2442	Four Corners	903	LF	Plant Disposal (Gridded)	36.68833333	-108.5063889	--	--	--	Combined Ash	None	--
2442	Four Corners	640	SI	Lined Water Impoundment	--	--	45	435	9.666666667	FGD Waste	Composite	--
2442	Four Corners	641	SI	Low Volume Waste Water Pond	--	--	14	137	9.785714286	Combined Ash	--	--
2442	Four Corners	642	SI	Upper Retention Sump	--	--	1	11	11	FGD Waste	--	--
1043	Frank E. Ratts	469	SI	Pond 4	38.51630556	-87.27	25	--	--	Combined Ash	--	--
1043	Frank E. Ratts	470	SI	Pond 3	38.51636111	-87.26682778	10	--	--	Combined Ash	--	--
1043	Frank E. Ratts	475	SI	Pond 2	38.51716667	-87.26455556	10	--	--	Combined Ash	--	--
1043	Frank E. Ratts	472	SI	Pond 1	38.51955556	-87.26347222	6	--	--	Combined Ash	None	--
1043	Frank E. Ratts	468	SI	Fly Ash Pond 3	--	--	25	--	--	Combined Ash	None	--
1043	Frank E. Ratts	471	SI	Bottom Ash Pond	--	--	6	40	6.666666667	Combined Ash	None	--
1043	Frank E. Ratts	473	SI	Fly Ash Pond 2	--	--	16	--	--	Combined Ash	None	--
1043	Frank E. Ratts	474	SI	Fly Ash Pond 1	--	--	10	--	--	Combined Ash	None	--
2718	G G Allen	670	SI	Active Ash Basin	35.17741389	-81.01114722	160	5915	36.96875	Combined Ash	None	--
2718	G G Allen	668	SI	North Dike - Active Ash Basin	35.18098611	-81.01024722	--	--	--	Combined Ash	None	--

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Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2718	G G Allen	892	LF	Ash/Gypsum Landfill	35.18388889	-81.01	--	--	--	Combined Ash	Yes	--
2718	G G Allen	669	SI	East Dike - Active Ash Basin	35.17736944	-81.00711944	--	--	--	Combined Ash	None	--
7	Gadsden	253	SI	Ash Pond (NID #1428)	--	--	68	753	11.07352941	Combined Ash	--	--
3403	Gallatin	128	SI	Bottom Ash Pond A	--	--	269	4390	16.3197026	Combined Ash	--	--
3403	Gallatin	129	SI	Fly Ash Pond E	--	--	157	4401	28.03184713	Combined Ash	--	--
3403	Gallatin	130	SI	Stilling Pond B, C, D	--	--	55	372	6.763636364	Combined Ash	--	--
8102	General James M. Gavin	246	SI	Stingy Run Ash Disposal Pond	38.96430833	-82.14427222	324.5	23365	72.00308166	Ash & Coal Refuse	None	--
8102	General James M. Gavin	1144	LF	FGD Landfill	38.95555556	-82.14111111	225	1118.204775	4.969799	Combined Ash	Composite	--
8102	General James M. Gavin	247	SI	Bottom Ash Pond	38.93055556	-82.12083333	85	1530	18	Ash & Coal Refuse	None	--
4143	Genoa	1007	LF	--	--	--	--	--	--	Combined Ash	--	Excluded
4143	Genoa	1131	LF	--	--	--	100	--	--	Combined Ash	--	--
1091	George Neal North	909	LF	Neal North Landfill West	42.31888889	-96.37055556	--	--	--	Combined Ash	None	Excluded
1091	George Neal North	910	LF	Neal North Landfill East	42.31944444	-96.36638889	--	--	--	Combined Ash	None	Excluded
1091	George Neal North	906	LF	Neal North Landfill Active	42.31555556	-96.36611111	200	--	--	Combined Ash	Yes	--
1091	George Neal North	907	LF	--	--	--	--	--	--	Combined Ash	--	--
1091	George Neal North	908	LF	--	--	--	--	--	--	Combined Ash	--	--
1091	George Neal North	504	SI	Surface Impoundment 1	--	--	12	137	11.41666667	Combined Ash	None	--
1091	George Neal North	505	SI	Surface Impoundment 3	--	--	76	837	11.01315789	Combined Ash	None	--
1091	George Neal North	506	SI	Surface Impoundment 2	--	--	27	296	10.96296296	Combined Ash	None	--
7343	George Neal South	1332	SI	Air Heater Wash Pond	42.29722222	-96.35888889	2.8238292	16.94297521	6	Combined Ash	Composite	Excluded
7343	George Neal South	911	LF	Neal 4 Landfill	42.29916667	-96.34722222	32	521.546281	16.29832128	Combined Ash	None	--
6077	Gerald Gentleman	912	LF	Fossil Fuels Combustion Ash Landfill	41.07222222	-101.1497222	--	--	--	Combined Ash	Yes	--
1356	Ghent	528	SI	Gypsum Stacking Facility	38.75166667	-85.02777778	46	2758	59.95652174	FGD Waste	None	--
1356	Ghent	527	SI	Ash Treatment Basin #1	38.74861111	-85.02722222	120	4339	36.15833333	Combined Ash	None	--
1356	Ghent	529	SI	Ash Treatment Basin #2	38.73972222	-85.02305556	146	7190	49.24657534	Combined Ash	None	--
1356	Ghent	526	SI	Secondary Ash Treatment Basin	--	--	4	--	--	Combined Ash	--	--
1356	Ghent	530	SI	Gypsum Stack Surge/Reclaim Pond	--	--	8	--	--	FGD Waste	Clay	--
6136	Gibbons Creek Steam Electric Station	913	LF	Site A	30.63444444	-96.09305556	--	--	--	Combined Ash	Yes	--
6136	Gibbons Creek Steam Electric Station	1244	SI	Scrubber Sludge Pond	30.61136111	-96.07977778	7.64038108	122.0256198	15.97114313	FGD Waste	Composite	--
6136	Gibbons Creek Steam Electric Station	1241	SI	Ash Pond A	30.61680556	-96.07602778	10.617539	212.3507805	20	Combined Ash	Clay	--
6136	Gibbons Creek Steam Electric Station	1242	SI	Ash Pond B	30.61680556	-96.07602778	10.617539	212.3507805	20	Combined Ash	Clay	--
6136	Gibbons Creek Steam Electric Station	1243	SI	Ash Pond C	30.61680556	-96.07602778	10.617539	212.3507805	20	Combined Ash	Clay	--
6136	Gibbons Creek Steam Electric Station	881	LF	Site F	30.63833333	-96.06666667	--	--	--	Combined Ash	Yes	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6113	Gibson	902	LF	S Aggregate Landfill (26-06)	38.33638889	-87.78444444	378	52189.51871	138.0675098	Combined Ash	Composite	--
6113	Gibson	86	SI	North Settling Basin	38.37916667	-87.76333333	15	150	10	--	None	--
6113	Gibson	84	SI	North Ash Pond	38.37722222	-87.75805556	25	350	14	Combined Ash	None	--
6113	Gibson	904	LF	Aggregate Landfill (26-02)	38.37222222	-87.75194444	131.3	11968.00413	91.15006955	Combined Ash	Composite	--
6113	Gibson	83	SI	East Pond #2	38.37666667	-87.74277778	105	1733	16.5047619	Combined Ash	None	--
6113	Gibson	82	SI	East Settling Basin	38.37166667	-87.74083333	45	743	16.51111111	--	None	--
6113	Gibson	85	SI	East Pond #3	38.3825	-87.73972222	133	3325	25	Combined Ash	None	--
6113	Gibson	81	SI	East Pond #1	38.37666667	-87.73722222	105	1733	16.5047619	Combined Ash	None	--
3776	Glen Lyn	146	SI	Auxiliary Fly Ash Pond	37.37855556	-80.87558333	44.3	185	4.176072235	Combined Ash	None	--
3776	Glen Lyn	870	LF	Glen Lyn Industrial Waste Landfill, Permit 222	37.37805556	-80.875	--	--	--	Combined Ash	Yes	--
3776	Glen Lyn	147	SI	Bottom Ash Pond	37.37261111	-80.86544444	1.44	90	62.5	Combined Ash	None	--
8	Gorgas	254	SI	Gypsum Storage Facility	33.655278	-87.217222	21	983	46.80952381	FGD Waste	Composite	--
8	Gorgas	255	SI	Ash Pond (NID #1198) Rattlesnake Dam	33.639722	-87.185556	420	10750	25.5952381	Combined Ash	None	--
8	Gorgas	963	LF	--	--	--	--	--	--	Combined Ash	--	--
1825	Grand Haven City of J.B. Sims	1309	SI	West Ash Pond	43.07180556	-86.23280556	0.29660239	2.076216713	7	Combined Ash	Clay	--
1825	Grand Haven City of J.B. Sims	1310	SI	East Ash Pond	43.07180556	-86.23280556	0.29660239	2.076216713	7	Combined Ash	Clay	--
10151	Grant Town Power Plant	873	LF	Farmington	39.50555556	-80.25111111	--	--	--	Combined Ash	None	--
10151	Grant Town Power Plant	872	LF	Barrackville	39.501641	-80.179709	--	--	--	Combined Ash	None	--
10151	Grant Town Power Plant	871	LF	Grant Town	39.5575	-80.16972222	--	--	--	Combined Ash	None	--
10151	Grant Town Power Plant	1168	SI	Pond 3	39.5584	-80.16638889	1.83654729	14.69237833	8	Combined Ash	None	--
10151	Grant Town Power Plant	1167	SI	Pond 10	39.55972222	-80.16611111	0.12626263	1.01010101	8	Combined Ash	None	--
10151	Grant Town Power Plant	1170	SI	Sedimentation Pond 5	39.56305556	-80.16583333	0.17217631	1.377410468	8	Combined Ash	None	--
10151	Grant Town Power Plant	1169	SI	Sedimentation Pond 9	39.56	-80.16555556	0.54407713	4.35261708	8	Combined Ash	None	--
10151	Grant Town Power Plant	1171	SI	Sedimentation Pond 6	39.5625	-80.16527778	0.03673095	0.293847567	8	Combined Ash	None	--
165	GRDA	1210	SI	SS1	36.18555556	-95.29194444	0.05034435	0.528673095	10.50113999	FGD Waste	None	--
165	GRDA	874	LF	ash landfill	36.18555556	-95.28833333	--	--	--	Combined Ash	Yes	--
1357	Green River	531	SI	Main Ash Pond	37.36974722	-87.12181667	32	775	24.21875	Combined Ash	None	--
1357	Green River	532	SI	Former Ash Pond	37.36556944	-87.11969444	6	--	--	Combined Ash	None	--
1357	Green River	533	SI	Ash Pond Number 2	37.36809444	-87.11804167	23	--	--	Combined Ash	None	--
1357	Green River	534	SI	Finishing Pond Number 3	37.04961944	-87.11576667	2	--	--	Combined Ash	None	--
1357	Green River	535	SI	Scrubber Pond	37.36812778	-87.11523056	10	150	15	FGD Waste	None	--
10	Greene County	256	SI	Ash Pond	--	--	474	5331	11.24683544	Combined Ash	None	--
6041	H L Spurlock Station	34	SI	Spurlock Ash Pond	38.70044883	-83.80169383	61.4	1085	17.67100977	Combined Ash	Clay	--
6041	H L Spurlock Station	972	LF	--	--	--	33.42	1907.73905	57.08375373	Combined Ash	Clay	--
2709	H.F. Lee Plant	658	SI	Ash Pond 1	35.38168333	-78.10723611	33	--	--	Combined Ash	None	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2709	H.F. Lee Plant	656	SI	Ash Pond 3	35.37596944	-78.10719722	85	--	--	Combined Ash	None	Excluded
2709	H.F. Lee Plant	657	SI	Ash Pond 2	35.38053056	-78.1038	53	--	--	Combined Ash	None	Excluded
2709	H.F. Lee Plant	659	SI	Active Ash Pond	35.3791	-78.069	143	1980	13.84615385	Combined Ash	None	--
2709	H.F. Lee Plant	660	SI	1980 Pond	--	--	--	--	--	Combined Ash	--	--
708	Hammond	1145	LF	Huffaker CCB	34.296139	-85.30457	--	--	--	Combined Ash	Yes	--
708	Hammond	351	SI	Ash Pond 2	--	--	21	509	24.23809524	Combined Ash	None	--
708	Hammond	352	SI	Ash Pond 1	--	--	35	800	22.85714286	Combined Ash	None	--
708	Hammond	353	SI	Ash Pond 4	--	--	54	1242	23	Combined Ash	None	--
708	Hammond	354	SI	Ash Pond 3	--	--	25	687	27.48	Combined Ash	None	Excluded
1731	Harbor Beach Power Plant	581	SI	Pond	--	--	--	--	--	Combined Ash	--	--
990	Harding Street	420	SI	Pond 2	39.706656	-86.202417	30	505	16.83333333	Combined Ash	None	--
990	Harding Street	423	SI	Pond 1	39.708192	-86.199089	7	92	13.14285714	Combined Ash	None	--
990	Harding Street	422	SI	Ponds 2A/2B	39.70665	-86.197319	4	43	10.75	Combined Ash	None	--
990	Harding Street	424	SI	Pond 3	39.707464	-86.196203	9.5	8	0.842105263	Combined Ash	None	--
990	Harding Street	421	SI	Pond 4	39.7042	-86.194464	26	304	11.69230769	Combined Ash	None	--
709	Harllee Branch	355	SI	Ash Pond E	33.204167	-83.326389	311	4665	15	Ash & Coal Refuse	None	--
709	Harllee Branch	358	SI	Ash Pond D	33.1869	-83.3055	45	675	15	Ash & Coal Refuse	None	--
709	Harllee Branch	359	SI	Ash Pond C	33.1869	-83.3055	70	1050	15	Ash & Coal Refuse	None	--
709	Harllee Branch	357	SI	Ash Pond B	33.1915	-83.3033	75	750	10	Ash & Coal Refuse	None	--
709	Harllee Branch	356	SI	A	--	--	1	14	14	Ash & Coal Refuse	--	Excluded
6193	Harrington	878	LF	001	35.305659	-101.754015	--	--	--	Combined Ash	Yes	--
6193	Harrington	877	LF	117	35.30305556	-101.7508333	--	--	--	Combined Ash	Yes	--
3944	Harrison Power Station	891	LF	CCB Landfill	39.40444444	-80.33222222	200	45862.80992	229.3140496	Combined Ash	Clay	--
3944	Harrison Power Station	158	SI	EPRI 6	--	--	300	17355.3719	57.85123967	Combined Ash	--	Excluded
3179	Hatfield's Ferry Power Station	880	LF	Ash Disposal Site	39.851828	-79.945337	32	1542.235537	48.19486054	Combined Ash	None	--
3179	Hatfield's Ferry Power Station	1217	SI	Limestone Runoff Basin	39.86000556	-79.93233611	1.464	--	--	FGD Waste	Yes	Excluded
3179	Hatfield's Ferry Power Station	1218	SI	Gypsum Runoff Basin	39.86061667	-79.9311	1.464	--	--	FGD Waste	Yes	Excluded
3179	Hatfield's Ferry Power Station	1216	SI	West Lagoon	39.86256111	-79.93094444	1.51515152	15.3454775	10.12801515	Combined Ash	None	--
3179	Hatfield's Ferry Power Station	1215	SI	East Lagoon	39.86278333	-79.93034722	1.51515152	15.3454775	10.12801515	Combined Ash	None	--
3179	Hatfield's Ferry Power Station	1219	SI	Gypsum Storage Area Basin	39.86116111	-79.93009444	1.464	--	--	FGD Waste	Yes	Excluded
891	Havana	392	SI	North Ash Pond System	40.27676389	-90.07905278	6	25	4.166666667	Combined Ash	--	--
891	Havana	393	SI	East Ash Pond	40.2801	-90.07119722	90	2625	29.16666667	Combined Ash	Composite	--
2079	Hawthorn	599	SI	Scrubber Waste Settling Pond	--	--	1	2	2	FGD Waste	--	--
2079	Hawthorn	962	LF	--	--	--	--	--	--	Combined Ash	--	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
525	Hayden	1146	LF	Hayden Coal Ash Disposal Facility	40.47387222	-107.1611361	--	--	--	Combined Ash	None	--
525	Hayden	882	LF	Ash Disposal Facility	40.45109722	-107.1319972	--	--	--	Combined Ash	None	Excluded
525	Hayden	332	SI	Intermediate Quality Pond	--	--	20	274	13.7	Combined Ash	--	--
525	Hayden	333	SI	High Quality Skimmer Pond	--	--	1	6	6	Combined Ash	--	Excluded
525	Hayden	334	SI	High Quality Pond	--	--	4	40	10	Combined Ash	--	Excluded
525	Hayden	335	SI	Fly Ash Decant Basin	--	--	--	--	--	Combined Ash	--	--
525	Hayden	336	SI	Common Wet Ash Settling Basin	--	--	--	--	--	Combined Ash	--	--
525	Hayden	337	SI	Ash Disposal Facility (ADF) Contact Storm Water Pond	--	--	1	4	4	Combined Ash	--	--
3251	HB Robinson / Darlington Electric Power Plant	104	SI	Pond	34.41411111	-80.16222222	55	410	7.454545455	Combined Ash	None	--
892	Hennepin Power Station	394	SI	Ash Pond System (2 cells)	41.300222	-89.323988	21	563	26.80952381	Combined Ash	--	--
892	Hennepin Power Station	883	LF	-999	--	--	--	--	--	Combined Ash	Yes	--
1382	HMP&L Station Two Henderson	556	SI	Ash Pond No. 0855	37.647739	-87.505317	12.4	--	--	Combined Ash	None	--
1382	HMP&L Station Two Henderson	557	SI	Green Ash Pond	37.64612	-87.501376	21.3	--	--	Combined Ash	None	--
1382	HMP&L Station Two Henderson	984	LF	--	--	--	--	--	--	Combined Ash	--	--
108	HOLCOMB	1147	LF	HCF	37.945852	-100.965669	8	--	--	Combined Ash	None	--
3122	Homer City Station	725	SI	Coal Refuse Disposal Site - Leachate Pump Pond	40.518625	-79.212578	0.26	1	3.846153846	Combined Ash	--	Excluded
3122	Homer City Station	719	SI	Ash Disposal Site - Polishing Pond	40.518299	-79.212487	0.13	--	--	Combined Ash	--	--
3122	Homer City Station	92	SI	Coal Refuse Disposal Site - Small Sediment Trap	40.518566	-79.212215	0.18	1	5.555555556	Combined Ash	--	Excluded
3122	Homer City Station	884	LF	Ash Disposal Site	40.52638889	-79.21194444	145	3629.209711	25.02903249	Combined Ash	None	--
3122	Homer City Station	721	SI	Ash Disposal Site - Stormwater Surge Pond	40.526794	-79.20486	1.22	17	13.93442623	Combined Ash	--	Excluded
3122	Homer City Station	723	SI	Ash Disposal Site - Treatment Pond #2	40.516075	-79.199559	0.28	1	3.571428571	Combined Ash	--	--
3122	Homer City Station	90	SI	Coal Refuse Disposal Site - Stage I & II Pond	40.520906	-79.19929	1	13	13	Combined Ash	--	--
3122	Homer City Station	724	SI	Ash Disposal Site - Treatment Pond #1	40.515623	-79.199137	0.25	1	4	Combined Ash	--	--
3122	Homer City Station	726	SI	Ash Recycle Pond #2	40.514744	-79.198884	0.59	5	8.474576271	Combined Ash	--	--
3122	Homer City Station	722	SI	Ash Recycle Pond #1	40.514863	-79.198504	0.58	4	6.896551724	Combined Ash	--	--
3122	Homer City Station	91	SI	Ash Recycle Pond #4	40.513697	-79.198352	0.56	5	8.928571429	Combined Ash	--	--

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3122	Homer City Station	727	SI	Ash Recycle Pond #3	40.51378	-79.197979	0.57	5	8.771929825	Combined Ash	--	--
3122	Homer City Station	720	SI	Coal Refuse Disposal Site - Storage Pond #2	40.509042	-79.197338	0.84	11	13.0952381	Combined Ash	--	--
3122	Homer City Station	886	LF	Emergency Strike Landfill	40.5175	-79.18888889	27	--	--	Combined Ash	None	Excluded
3122	Homer City Station	1134	LF	Coal Refuse Disposal Site	40.52777778	-79.18888889	165	16178.12213	98.04922503	Combined Ash	Composite	--
3122	Homer City Station	729	SI	Coal Refuse Disposal Site - Storage Pond #1	40.521757	-79.188655	1.26	2	1.587301587	Combined Ash	--	--
3122	Homer City Station	728	SI	Coal Refuse Disposal Site - Stage III & IV Pond	40.522143	-79.186773	1.54	26	16.88311688	Combined Ash	--	--
1943	Hoot Lake	1148	LF	Area 4	46.289375	-96.0384	--	--	--	Combined Ash	None	Excluded
1943	Hoot Lake	1158	LF	Area 1	46.28971389	-96.03636944	--	--	--	Combined Ash	None	Excluded
1943	Hoot Lake	1157	LF	Area 2	46.29038333	-96.0339	--	--	--	Combined Ash	None	Excluded
1943	Hoot Lake	1159	LF	IL002-Phase 1	46.28746667	-96.03198056	--	--	--	Combined Ash	Yes	--
1943	Hoot Lake	1160	LF	IL001-II	46.28780278	-96.03071667	--	--	--	Combined Ash	None	--
1943	Hoot Lake	887	LF	IL001-I	46.28873611	-96.030075	72	495.8677686	6.887052342	Combined Ash	None	--
1943	Hoot Lake	1156	LF	Area 3	46.29062	-96.013039	--	--	--	Combined Ash	None	Excluded
10771	Hopewell	1362	SI	Coal Pile Runoff Pond	37.298131	-77.284872	0.78739669	9.448760331	12	Ash & Coal Refuse	Composite	--
6772	Hugo	755	LF	Fly Ash Landfill	34.008487	-95.32962872	35.3	675.3991736	19.13312106	Combined Ash	Clay	--
6772	Hugo	230	SI	South Bottom Ash	34.00915278	-95.316675	34	344	10.11764706	Combined Ash	Clay	--
6772	Hugo	229	SI	North Bottom Ash Unit	34.01064722	-95.31594444	34	344	10.11764706	Combined Ash	Clay	--
6772	Hugo	231	SI	North Fly Ash	--	--	18	332	18.44444444	Combined Ash	Clay	--
6772	Hugo	232	SI	South Fly Ash Unit	--	--	18	332	18.44444444	Combined Ash	Clay	--
3176	Hunlock Power Station	103	SI	West Basin (005)	41.200563	-76.072583	5	90	18	Combined Ash	--	Excluded
3176	Hunlock Power Station	102	SI	East Basin (003)	41.199839	-76.072148	5	90	18	Combined Ash	--	Excluded
6165	Hunter Plant	756	LF	FGD Cell	39.00262778	-111.0102056	280	7438.016529	26.56434475	Combined Ash	None	--
6165	Hunter Plant	1258	SI	Landfill FGD Cell	39.15262778	-111.0102056	104.1	--	--	Combined Ash	Yes	Excluded
8069	Huntington Plant	757	LF	class III-b Industrial Waste Landfill	39.36940833	-111.0823778	70	7066.115703	100.94451	Combined Ash	None	--
8069	Huntington Plant	1364	SI	Scrubber Pond	39.37793333	-111.0813056	1.03305785	4	3.872	FGD Waste	Composite	--
8069	Huntington Plant	759	LF	Old Landfill	39.36836111	-111.0802111	--	--	--	Combined Ash	None	Excluded
8069	Huntington Plant	1363	SI	Lacey's lake	39.37630833	-111.0784278	1	4	4	Combined Ash	None	Excluded
8069	Huntington Plant	758	LF	Conditionally Exempt Combustion Waste Landfill	39.36466389	-111.0718639	--	--	--	Combined Ash	None	--
863	Hutsonville	383	SI	Ash Pond B	39.129551	-87.659345	4	70	17.5	Combined Ash	--	Excluded
863	Hutsonville	381	SI	Bottom Ash Pond	39.133223	-87.658424	1	6	6	Combined Ash	--	Excluded
863	Hutsonville	382	SI	Ash Pond C	39.131165	-87.658387	2	20	10	Combined Ash	--	Excluded
863	Hutsonville	384	SI	Ash Pond A	39.130078	-87.656369	14	250	17.85714286	Combined Ash	--	Excluded
6065	Iatan	1154	LF	Utility Waste Landfill	39.44972222	-94.96388889	--	--	--	Combined Ash	Yes	--
6065	Iatan	40	SI	Ash Pond	--	--	89	2328	26.15730337	Combined Ash	--	Excluded

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Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6641	Independence	1153	LF	ISES Landfill	35.679507	-91.391202	221	8069.008264	36.51134961	Combined Ash	Clay	--
2132	Independence Power & Light - Blue Valley Station	618	SI	Bottom Ash Pond	39.09584722	-94.32355278	9.3	133	14.30107527	Combined Ash	None	--
2132	Independence Power & Light - Blue Valley Station	617	SI	South Fly Ash Pond	39.09617222	-94.322075	15.1	271	17.94701987	Combined Ash	None	Excluded
2132	Independence Power & Light - Blue Valley Station	616	SI	North Fly Ash Pond	39.09873056	-94.32163611	16.8	252	15	Combined Ash	None	--
594	Indian River Generating Station	775	LF	Burton Island Landfill	38.585207	-75.241928	--	--	--	Combined Ash	None	Excluded
594	Indian River Generating Station	762	LF	Solid Waste Landfill	38.579359	-75.232033	--	--	--	Combined Ash	Yes	--
594	Indian River Generating Station	339	SI	Sedimentation Pond	--	--	--	--	--	Combined Ash	--	--
594	Indian River Generating Station	340	SI	Ash Silo Area Sump System	--	--	--	--	--	Combined Ash	--	Excluded
6481	Intermountain Power Project	214	SI	Settling Basin	--	--	14	145	10.35714286	FGD Waste	Composite	--
6481	Intermountain Power Project	215	SI	Ash Water Recycle	--	--	27	590	21.85185185	Combined Ash	Composite	--
6481	Intermountain Power Project	216	SI	Land Fill Run-Off	--	--	5	30	6	--	Composite	--
6481	Intermountain Power Project	217	SI	Evaporation Ponds (6 Ponds)	--	--	180	3225	17.91666667	FGD Waste	Composite	--
6481	Intermountain Power Project	218	SI	Bottom Ash Basin	--	--	105	3000	28.57142857	Combined Ash	Composite	--
6481	Intermountain Power Project	219	SI	Wastewater Holding Basin	--	--	53	650	12.26415094	FGD Waste	Composite	--
7097	J K Spruce	1369	SI	NOR 001a	29.32041667	-98.31666667	2.006	--	--	Combined Ash	Yes	Excluded
7097	J K Spruce	1368	SI	NOR 001	29.31905556	-98.31597222	2.006	--	--	Combined Ash	Yes	Excluded
7097	J K Spruce	1372	SI	SRH	29.323975	-98.31481944	1.60697888	9.400826446	5.85	FGD Waste	Composite	--
7097	J K Spruce	1373	SI	NOR (021)	29.33138889	-98.31477778	4.98852158	47.28191001	9.478140819	Combined Ash	Composite	--
7097	J K Spruce	1370	SI	NOR 002	29.32005556	-98.31452778	2.006	--	--	Combined Ash	Yes	Excluded
7097	J K Spruce	1371	SI	NOR 008	29.31813889	-98.31416667	2.006	--	--	Combined Ash	Yes	Excluded
7097	J K Spruce	753	LF	Landfill (NOR 010)	29.32397222	-98.31369444	--	--	--	Combined Ash	Yes	--
2850	J M Stuart	706	SI	Ash Pond No. 5	38.64138889	-83.70388889	34	1426	41.94117647	Combined Ash	None	Excluded
2850	J M Stuart	711	SI	Ash Pond No. 10	38.63944444	-83.685	29	930	32.06896552	Combined Ash	Clay	--
2850	J M Stuart	710	SI	Ash Pond No. 3A	38.63416667	-83.68361111	50	1302	26.04	Combined Ash	Clay	--
2850	J M Stuart	767	LF	Landfill 11	38.637	-83.67811111	--	--	--	Combined Ash	Yes	--
2850	J M Stuart	708	SI	Pond #7A	38.631111	-83.678056	3	38	12.66666667	--	--	Excluded
2850	J M Stuart	709	SI	Ash Pond No. 7	38.63111111	-83.67805556	37	1550	41.89189189	Combined Ash	Clay	Excluded
2850	J M Stuart	707	SI	Ash Pond No. 6	38.63277778	-83.67611111	37	1550	41.89189189	Combined Ash	Clay	Excluded
2850	J M Stuart	766	LF	Landfill 9	38.63433333	-83.66205556	--	--	--	Combined Ash	Yes	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6181	J T Deely	1295	SI	bottom ash	29.30684444	-98.32140278	6.68503214	54.19306703	8.106627747	Combined Ash	None	--
6181	J T Deely	1296	SI	bottom ash	29.30891667	-98.31782222	6.28099174	50.27892562	8.004934211	Combined Ash	None	--
6181	J T Deely	1292	SI	NOR 001a	29.32041667	-98.31666667	2.006	--	--	Combined Ash	Yes	Excluded
6181	J T Deely	1291	SI	NOR 001	29.31905556	-98.31597222	2.006	--	--	Combined Ash	Yes	Excluded
6181	J T Deely	768	LF	JTD / Evaporation Pond #021	29.323972	-98.3148	--	--	--	Combined Ash	Yes	--
6181	J T Deely	1293	SI	NOR 002	29.32005556	-98.31452778	2.006	--	--	Combined Ash	Yes	Excluded
6181	J T Deely	1294	SI	NOR 008	29.31813889	-98.31416667	2.006	--	--	Combined Ash	Yes	Excluded
6181	J T Deely	1002	LF	--	--	--	--	--	--	Combined Ash	--	--
1720	J.C. Weadock	573	SI	J.C. Weadock Fly Ash Dam	--	--	--	--	--	--	Clay	--
1720	J.C. Weadock	574	SI	East 7 & 8 Ponds	--	--	136	--	--	Combined Ash	--	--
1720	J.C. Weadock	575	SI	West A - E Ponds	--	--	156	--	--	Combined Ash	--	--
1720	J.C. Weadock	576	SI	Weadock Landfill Embankment	--	--	--	--	--	--	Clay	--
1720	J.C. Weadock	1003	LF	--	--	--	--	--	--	Combined Ash	--	--
1723	J.R Whiting	577	SI	Ponds 3-5	--	--	82	1489	18.15853659	Combined Ash	--	--
1723	J.R Whiting	578	SI	Pond 1	--	--	8	148	18.5	Combined Ash	None	--
1723	J.R Whiting	579	SI	Pond 2	--	--	7	135	19.28571429	Combined Ash	None	--
1723	J.R Whiting	580	SI	Pond 6	--	--	32	1054	32.9375	Combined Ash	None	--
1723	J.R Whiting	965	LF	--	--	--	11.87	--	--	Combined Ash	--	Excluded
1723	J.R Whiting	1000	LF	--	--	--	5.44	--	--	Combined Ash	--	Excluded
710	Jack McDonough	360	SI	Ash Pond 4	--	--	41	1996	48.68292683	Combined Ash	None	--
710	Jack McDonough	361	SI	Ash Pond 3	--	--	23	642	27.91304348	Combined Ash	None	--
710	Jack McDonough	362	SI	Ash Pond 1	--	--	25	546	21.84	Combined Ash	None	Excluded
710	Jack McDonough	363	SI	Ash Pond 2	--	--	6	118	19.66666667	Combined Ash	None	--
710	Jack McDonough	968	LF	--	--	--	--	--	--	Combined Ash	--	--
2049	Jack Watson	769	LF	Dry Ash Monofill	30.43333333	-89.02611111	--	--	--	Combined Ash	Yes	--
2049	Jack Watson	595	SI	Ash Pond	--	--	102	317	3.107843137	Combined Ash	None	--
1830	James De Young	1333	SI	Ash Settling Ponds	42.79388889	-86.11361111	1.49219467	6.014692378	4.030769231	Combined Ash	None	--
1830	James De Young	770	LF	Zeeland Township Landfill	42.78944444	-85.91888889	--	--	--	Combined Ash	None	--
6002	James H. Miller Jr.	16	SI	Ash Pond (NID #1101)	--	--	341	13606	39.90029326	Combined Ash	--	--
2161	James River Power Station	771	LF	Ash Landfill	37.10277778	-93.26805556	17	163.0165289	9.589207584	Combined Ash	Composite	--
2161	James River Power Station	619	SI	Pond	--	--	--	--	--	Combined Ash	--	--
2187	JE Corette Plant	764	LF	Fly Ash Landfill	45.78	-108.4825	--	--	--	Combined Ash	None	Excluded
2187	JE Corette Plant	1249	SI	Bottom Ash Pond #1	45.78194444	-108.4811111	2.48	--	--	Combined Ash	None	--
2187	JE Corette Plant	1250	SI	Bottom Ash Pond #2	45.78305556	-108.4808333	2.48	--	--	Combined Ash	None	--
3319	Jefferies	117	SI	Ash Pond B	33.31872222	-79.35136111	63	245	3.888888889	Combined Ash	None	--
3319	Jefferies	118	SI	Ash Pond A	33.325525	-79.34736111	88	982	11.15909091	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6068	Jeffrey Energy Center	41	SI	Bottom Ash Pond Dam	39.28223333	-96.14759167	72	550	7.638888889	Combined Ash	None	--
6068	Jeffrey Energy Center	42	SI	Bottom Ash Lake Dam	39.24375	-96.14678611	120	3000	25	Combined Ash	None	--
6068	Jeffrey Energy Center	772	LF	Fly Ash Landfill	39.28722222	-96.14333333	--	--	--	Combined Ash	None	--
6068	Jeffrey Energy Center	773	LF	Gypsum Landfill	39.27916667	-96.13916667	--	--	--	Combined Ash	None	--
6068	Jeffrey Energy Center	43	SI	Bottom Ash Settling Pond	39.2667	-96.13587778	53	988	18.64150943	Combined Ash	--	--
8066	Jim Bridger Plant Units 1-4	244	SI	FGD Pond #1	41.75380556	-108.8074444	93	1340	14.40860215	Combined Ash	Clay	Excluded
8066	Jim Bridger Plant Units 1-4	774	LF	Landfill	41.77012778	-108.7938111	180.5	9899.051963	54.84239315	Combined Ash	None	--
8066	Jim Bridger Plant Units 1-4	245	SI	FGD Pond #2	41.75688889	-108.7879167	392	11534	29.42346939	Combined Ash	None	--
3935	John E. Amos	742	LF	Quarrier Landfill	38.509045	-81.868582	200	8677.68595	43.38842975	Combined Ash	Yes	--
3935	John E. Amos	740	LF	John E Amos FGD Landfill	38.485988	-81.856277	--	--	--	Combined Ash	Yes	--
3935	John E. Amos	153	SI	Fly Ash Pond	--	--	175	2687	15.35428571	Combined Ash	None	--
3935	John E. Amos	154	SI	Bottom Ash Complex	--	--	30	220	7.333333333	Combined Ash	None	--
4271	John P. Madgett	990	LF	--	--	--	--	--	--	Combined Ash	--	--
4271	John P. Madgett	991	LF	--	--	--	--	--	--	Combined Ash	--	Excluded
3405	John Sevier	763	LF	Dry Fly Ash Stack	36.372825	-82.974115	90	1206.148804	13.40165338	Combined Ash	Composite	--
3405	John Sevier	131	SI	Dry Ash Stack	--	--	84	2355	28.03571429	Combined Ash	--	--
3405	John Sevier	132	SI	Bottom Ash Pond	--	--	41	744	18.14634146	Combined Ash	--	--
3406	Johnsonville	732	LF	DuPont Dredge Cell	36.03440278	-87.97888889	20.2	514.4628099	25.46845594	Combined Ash	None	--
3406	Johnsonville	733	LF	South Rail Loop	36.02591667	-87.9775	22	814	37	Combined Ash	Clay	Excluded
3406	Johnsonville	133	SI	Ash Disposal Area 2	--	--	87	2702	31.05747126	Combined Ash	--	--
3406	Johnsonville	291	SI	DuPont Road Dredge Cell	--	--	22	--	--	--	None	--
384	Joliet 29	309	SI	EPRI 1	--	--	63.1	627.2727273	9.940930702	Ash & Coal Refuse	--	Excluded
384	Joliet 29	1098	LF	--	--	--	--	--	--	Combined Ash	--	--
874	Joliet 9	1328	SI	Lower Quarry	41.49416667	-88.10694444	1.60491276	27.28351699	17	Combined Ash	None	--
874	Joliet 9	1327	SI	Upper Quarry	41.49472222	-88.10638889	42.2038567	2887.066116	68.40763708	Combined Ash	None	--
887	Joppa Steam	390	SI	Ash Pond	37.21527778	-88.85	103	3833	37.21359223	Ash & Coal Refuse	None	--
887	Joppa Steam	734	LF	-999	--	--	--	--	--	Combined Ash	Yes	--
3947	Kammer	159	SI	Boiler Slag Pond	--	--	2	22	11	Combined Ash	--	--
3936	Kanawha River	155	SI	Bottom Ash Complex	--	--	6	116	19.33333333	Combined Ash	--	--
1381	Kenneth C Coleman	553	SI	Active Ash Pond A	37.96666667	-86.79580556	23	1180	51.30434783	Combined Ash	None	--
1381	Kenneth C Coleman	555	SI	Inactive Ash Pond C	37.95661111	-86.79488889	19.5	--	--	Combined Ash	None	--
1381	Kenneth C Coleman	554	SI	New Ash Pond	--	--	64	2417	37.765625	Combined Ash	--	--
3136	Keystone	1307	SI	Bottom Ash Settling Pond (C)	40.864258	-79.499139	0.73415978	4.296740129	5.852595372	Combined Ash	Clay	--
3136	Keystone	1306	SI	Bottom Ash Settling Pond (B)	40.864847	-79.497442	0.73415978	4.296740129	5.852595372	Combined Ash	Clay	--
3136	Keystone	1305	SI	Bottom Ash Settling Pond (A)	40.864306	-79.495056	0.73415978	3.837603306	5.227204503	Combined Ash	Clay	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
3136	Keystone	1301	SI	Low Volume Waste Inlet Pond (A)	40.76202222	-79.46743056	7.508	--	--	Combined Ash	Yes	Excluded
3136	Keystone	1302	SI	Low Volume Waste Inlet Pond (B)	40.761903	-79.466419	7.508	--	--	Combined Ash	Yes	Excluded
3136	Keystone	1303	SI	Low Volume Waste Outlet Pond (A)	40.765825	-79.465603	7.508	--	--	Combined Ash	Yes	Excluded
3136	Keystone	1304	SI	Low Volume Waste Outlet Pond (B)	40.766278	-79.465044	7.508	--	--	FGD Waste	Yes	Excluded
3136	Keystone	736	LF	Original Ash Site	40.66025	-79.35361111	--	--	--	Combined Ash	None	Excluded
3136	Keystone	1297	SI	Bottom Ash Thermal Pond	40.66408056	-79.351125	7.11662075	128.5583104	18.06451613	Combined Ash	Composite	--
3136	Keystone	1300	SI	East Valley Ash Site Storm Water Pond (B)	40.66461944	-79.34950556	7.508	--	--	Combined Ash	Yes	--
3136	Keystone	1299	SI	East Valley Ash Site Storm Water Pond (A)	40.66524167	-79.34615278	7.508	--	--	Combined Ash	Yes	--
3136	Keystone	1298	SI	West Valley Ash Site Contact Stormwater / Leachate Pond	40.66516944	-79.34444167	7.508	--	--	Combined Ash	Yes	Excluded
3136	Keystone	1151	LF	West Valley Ash Site	40.67577778	-79.33927778	--	--	--	Combined Ash	Yes	--
3136	Keystone	1152	LF	East Valley Ash Site	40.67580556	-79.33494444	155	14047.38843	90.62831245	Combined Ash	Yes	--
6031	Killen Station	32	SI	Bottom Ash Pond	38.689341	-83.471246	39	1903	48.79487179	Combined Ash	--	--
6031	Killen Station	31	SI	Fly Ash Pond	38.683126	-83.467549	191	11004	57.61256545	Combined Ash	--	--
876	Kincaid Generation LLC	388	SI	Slag Field	39.59563889	-89.49238889	178	3560	20	Combined Ash	None	--
876	Kincaid Generation LLC	969	LF	--	--	--	--	--	--	Combined Ash	--	--
3407	Kingston	134	SI	Stilling Pond	--	--	29	290	10	Combined Ash	--	--
3407	Kingston	135	SI	Main Ash Pond	--	--	92	8907	96.81521739	Combined Ash	--	--
733	Kraft	1150	LF	Grumman Road Dry Ash Monofill	32.14027778	-81.18361111	--	--	--	Combined Ash	None	--
733	Kraft	375	SI	Ash Pond	--	--	8	41	5.125	Ash & Coal Refuse	--	--
2876	Kyger Creek	738	LF	Type III landfill	38.92361111	-82.16472222	--	--	--	Combined Ash	Yes	--
2876	Kyger Creek	716	SI	Bottom Ash Pond	38.91027778	-82.13277778	34	1435	42.20588235	Combined Ash	None	--
2876	Kyger Creek	717	SI	South Fly Ash Pond	38.91888889	-82.13055556	66	2500	37.87878788	Combined Ash	None	--
2713	L.V. Sutton Electric Plant	665	SI	1971 Pond	34.29591944	-77.9899	53	921	17.37735849	Combined Ash	None	--
2713	L.V. Sutton Electric Plant	666	SI	1984 Pond	34.29224722	-77.98971389	82	1364	16.63414634	Combined Ash	Clay	--
1241	La Cygne	739	LF	Utility Waste Landfill	38.35722222	-94.62777778	--	--	--	Combined Ash	Yes	--
1241	La Cygne	513	SI	Scrubber Sludge Ponds	--	--	483	9298	19.2505176	Combined Ash	Clay	--
1241	La Cygne	514	SI	Bottom Ash Settling Pond	--	--	2	12	6	Combined Ash	Clay	--
2103	Labadie	607	SI	Bottom Ash Pond	--	--	154	12000	77.92207792	Combined Ash	None	--
2103	Labadie	608	SI	Fly Ash Pond	--	--	79	1900	24.05063291	Combined Ash	Composite	--
2098	Lake Road	752	LF	Fly Ash Landfill	39.71777778	-94.88666667	9.7	80.34894399	8.283396287	Combined Ash	Clay	Excluded
2098	Lake Road	605	SI	Slag/Coal Pile Run-off Pond	39.72277778	-94.87861111	1.8	7	3.888888889	Combined Ash	None	Excluded
2098	Lake Road	606	SI	Settling Pond	--	--	1	5	5	Combined Ash	--	--

Electronic Filing: Received, Clerk's Office 07/01/2024

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2838	Lake Shore	1270	SI	Combined Treatment Basin	41.53333333	-81.64166667	0.50505051	2.525252525	5	Combined Ash	None	--
964	Lakeside	400	SI	Lakeside Ash Pond	39.76305556	-89.59722222	37	680	18.37837838	Combined Ash	None	Excluded
1047	Lansing	730	LF	Closed Ash Disposal Facility	43.329578	-91.16616	--	--	--	Combined Ash	None	Excluded
1047	Lansing	741	LF	Active Ash Disposal Facility	43.328369	-91.163119	--	--	--	Combined Ash	None	--
1047	Lansing	477	SI	Lower Ash Pond	--	--	--	2	--	Combined Ash	None	--
1047	Lansing	478	SI	Main Ash Pond	--	--	15	294	19.6	Combined Ash	None	--
643	Lansing Smith	743	LF	Ash Landfill	30.26802778	-85.68436111	--	--	--	Combined Ash	Yes	--
643	Lansing Smith	341	SI	Ash Pond	--	--	172	2611	15.18023256	Combined Ash	None	--
6204	Laramie River Station	744	LF	Landfill	42.11333333	-104.9022222	--	--	--	Combined Ash	None	--
6204	Laramie River Station	188	SI	Bottom Ash Ponds 1 & 2 (BAP1 & BAP2)	42.108251	-104.89733	105	2111	20.1047619	Combined Ash	Composite	--
6204	Laramie River Station	189	SI	Emergency Holding Pond	42.117535	-104.882691	54.1	916	16.93160813	FGD Waste	Composite	--
1891	Laskin Energy Center	588	SI	Cells A, B, C & D (retired)	--	--	73	730	10	Combined Ash	None	Excluded
1891	Laskin Energy Center	589	SI	Cell E	--	--	23	174	7.565217391	Combined Ash	Composite	--
1250	Lawrence Energy Center	745	LF	Landfill 600	39.005	-95.27333333	825	21260.3306	25.7700977	Combined Ash	None	--
1250	Lawrence Energy Center	747	LF	Landfill 0333	39.00611111	-95.26277778	30	619.834711	20.66115703	Combined Ash	None	Excluded
1250	Lawrence Energy Center	1149	LF	Landfill 0847	39.004994	-95.259549	22	842.975207	38.31705486	Combined Ash	Yes	--
1250	Lawrence Energy Center	515	SI	Area 4	--	--	14	185	13.21428571	Combined Ash	None	--
1250	Lawrence Energy Center	516	SI	Area 1	--	--	5	71	14.2	Combined Ash	None	--
1250	Lawrence Energy Center	517	SI	Area 3	--	--	18	273	15.16666667	Combined Ash	Clay	--
1250	Lawrence Energy Center	518	SI	Area 2	--	--	10	155	15.5	Combined Ash	None	--
2817	Leland Olds	749	LF	SP-143	47.24605833	-101.3635333	20	283.884298	14.1942149	Combined Ash	Yes	--
2817	Leland Olds	683	SI	Ash Pond #1	47.28069444	-101.3181944	27	744	27.55555556	Combined Ash	None	--
2817	Leland Olds	684	SI	Ash Pond #2	47.28069444	-101.3181944	38	924	24.31578947	Combined Ash	None	--
2817	Leland Olds	685	SI	Ash Pond #3	47.28069444	-101.3181944	3	12	4	Combined Ash	None	--
2817	Leland Olds	748	LF	SP-038	47.27644722	-101.3107889	37	1115.70248	30.15412108	Combined Ash	None	--
6089	Lewis & Clark	750	LF	Savage Mine	47.47905556	-104.4383611	--	--	--	Combined Ash	None	--
6089	Lewis & Clark	1374	SI	West Scrubber Pond Cell 1	47.68016667	-104.1579167	1.33149679	11.47842057	8.620689655	Combined Ash	Clay	--
6089	Lewis & Clark	1375	SI	West Scrubber Pond Cell 2	47.67975	-104.1572222	0.42699725	2.089072544	4.892473118	Combined Ash	Clay	--
6089	Lewis & Clark	1377	SI	East Scrubber Pond Cell 2	47.67975	-104.1572222	0.42699725	2.089072544	4.892473118	Combined Ash	Clay	--
6089	Lewis & Clark	1376	SI	East Scrubber Pond Cell 1	47.67936111	-104.1563889	1.33149679	11.47842057	8.620689655	Combined Ash	Clay	--
6089	Lewis & Clark	751	LF	Scrubber Sludge	47.68258333	-104.1521111	--	--	--	Combined Ash	None	Excluded
6089	Lewis & Clark	1378	SI	Ash Pond 1	47.68144444	-104.1517222	15.1905418	182.2773186	11.9993955	Combined Ash	Composite	--
6089	Lewis & Clark	786	LF	-999	--	--	--	--	--	Combined Ash	None	Excluded
298	Limestone	300	SI	ST 18	31.41888889	-96.25638611	--	--	--	--	Clay	Excluded
298	Limestone	308	SI	DSDA Unit No. 003	31.41888889	-96.25638611	20.84	--	--	Combined Ash	Clay	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
298	Limestone	821	LF	Class II Landfill	31.43277778	-96.24138889	--	--	--	Combined Ash	Yes	--
298	Limestone	301	SI	FGD Emergency Pond E	--	--	1	31	31	FGD Waste	--	--
298	Limestone	302	SI	ST-10 Pump	--	--	--	1	--	Combined Ash	--	Excluded
298	Limestone	303	SI	ST-9 Pump	--	--	--	--	--	Combined Ash	--	Excluded
298	Limestone	304	SI	Bottom Ash Cooling Pond	--	--	3	50	16.66666667	Combined Ash	--	--
298	Limestone	305	SI	Dewatered Sludge Disposal Area	--	--	3	25	8.333333333	FGD Waste	--	Excluded
298	Limestone	306	SI	Stormwater Pond A	--	--	1	14	14	--	--	Excluded
298	Limestone	307	SI	Stormwater Pond B	--	--	1	14	14	--	--	Excluded
2240	Lon Wright	765	LF	Ash Monofill	--	--	--	105.3719008	--	Combined Ash	Yes	--
6664	Louisa	801	LF	CCR Landfill	41.33361111	-91.09555556	26	79.2271809	3.047199265	Combined Ash	None	--
6664	Louisa	223	SI	Bottom Ash Pond	41.48055556	-90.81611111	42	--	--	Ash & Coal Refuse	Clay	--
6664	Louisa	222	SI	Louisa Surface Impoundment	--	--	42	242	5.761904762	Combined Ash	Clay	--
976	Marion Generating Station	402	SI	Pond A-1	37.622483	-88.959618	32	--	--	Combined Ash	--	--
976	Marion Generating Station	401	SI	Fly Ash Disposal Pond	37.623085	-88.958022	45	--	--	Combined Ash	--	--
976	Marion Generating Station	411	SI	South Fly Ash Pond	37.614852	-88.957672	103	--	--	Combined Ash	--	--
976	Marion Generating Station	410	SI	Pond 4	37.622813	-88.955435	55	--	--	Combined Ash	--	--
976	Marion Generating Station	412	SI	Pond 2	37.623314	-88.953918	15	--	--	Combined Ash	--	--
976	Marion Generating Station	405	SI	Pond 1	37.62245	-88.953884	9	--	--	Combined Ash	--	--
976	Marion Generating Station	802	LF	1990555005	37.62472222	-88.95288889	143	1983.47107	13.87042706	Combined Ash	None	--
976	Marion Generating Station	409	SI	Pond S-3	37.62583	-88.952365	20	--	--	Combined Ash	--	--
976	Marion Generating Station	406	SI	Pond S-1	37.623553	-88.95221	71	--	--	Combined Ash	--	--
976	Marion Generating Station	408	SI	Pond S-2	37.625837	-88.951926	25	--	--	Combined Ash	--	--
976	Marion Generating Station	404	SI	Pond S-6	37.62782	-88.951541	16	--	--	Combined Ash	--	--
976	Marion Generating Station	403	SI	Pond 3	37.624879	-88.95028	20	--	--	Combined Ash	--	--
976	Marion Generating Station	407	SI	Pond 3A	37.624139	-88.949876	20	--	--	Combined Ash	--	--
2727	Marshall	803	LF	FGD Residue Landfill	35.60361111	-80.97833333	18	145.3512397	8.075068871	Combined Ash	Composite	--
2727	Marshall	804	LF	Ash Landfill	35.61611111	-80.96861111	58	3595.041322	61.98347107	Combined Ash	None	Excluded
2727	Marshall	680	SI	Active Ash Pond	35.605944	-80.959917	1188	6885	5.795454545	Combined Ash	None	--
492	Martin Drake	1254	SI	Drake Equalization Basin	38.82385	-104.8330528	0.03859045	0.491046832	12.72456871	Combined Ash	None	--
492	Martin Drake	1253	SI	Drake W. Bottom Ash Basin	38.82361111	-104.833025	0.0530303	0.265151515	5	Combined Ash	None	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
492	Martin Drake	1252	SI	Drake E. Bottom Ash Basin	38.82361944	-104.8328833	0.05050505	0.265151515	5.25	Combined Ash	None	--
492	Martin Drake	1251	SI	Drake Cooling Tower 4	38.82458333	-104.8326583	0.07889118	0.394444444	4.999854503	Combined Ash	None	--
492	Martin Drake	805	LF	-999	--	--	--	--	--	Combined Ash	None	--
6146	Martin Lake	822	LF	PDP #2	32.26124167	-94.58276111	--	--	--	Combined Ash	Yes	Excluded
6146	Martin Lake	810	LF	PDP #3	32.25926944	-94.58261944	--	--	--	Combined Ash	Yes	Excluded
6146	Martin Lake	808	LF	PDP #1	32.26230556	-94.5823	--	--	--	Combined Ash	Yes	Excluded
6146	Martin Lake	1226	SI	Permanent Disposal Pond #4	32.25824444	-94.57884444	15.339876	347.107438	22.62778638	Combined Ash	Composite	--
6146	Martin Lake	1225	SI	East Bottom Ash Pond	32.26187778	-94.56365278	14.5798898	306.177686	21	Combined Ash	None	--
6146	Martin Lake	1224	SI	West Bottom Ash Pond	32.26071667	-94.56348889	14.5798898	306.177686	21	Combined Ash	Composite	--
6146	Martin Lake	1223	SI	ESP	32.26076944	-94.56153889	12.0999082	211.0130854	17.43923031	FGD Waste	Composite	--
6146	Martin Lake	807	LF	Caney Branch	32.243539	-94.540761	--	--	--	Combined Ash	Yes	Excluded
6146	Martin Lake	806	LF	A-1 ash disposal	32.22916944	-94.52399167	290	18595.04132	64.12083214	Combined Ash	Yes	--
6250	Mayo Electric Generating Facility	204	SI	1982 Pond	36.5378	-78.8931	140	4100	29.28571429	Combined Ash	None	--
6124	McIntosh	87	SI	Ash Pond	--	--	27	342	12.66666667	Ash & Coal Refuse	--	--
3287	McMeekin	1155	LF	Ash Landfill	34.04633333	-81.21327778	--	--	--	Combined Ash	None	--
2104	Meramec	609	SI	Bottom Ash Pond (3)	--	--	14	280	20	Combined Ash	None	--
2104	Meramec	610	SI	Fly Ash Pond #494 (Pond 7), Fly Ash Pond #495 (Pond 8), Fly Ash Pond #490 (Pond 9), and Fly Ash Pond #491 (Pond 10)	--	--	--	--	--	Combined Ash	None	Excluded
2104	Meramec	611	SI	Old Fly Ash Pond	--	--	18	300	16.66666667	Combined Ash	Composite	--
2104	Meramec	612	SI	New Fly Ash Pond	--	--	14	230	16.42857143	Combined Ash	Composite	--
2104	Meramec	613	SI	Retention Pond	--	--	1	10	10	Combined Ash	None	Excluded
864	Meredosia	385	SI	Fly Ash Pond	--	--	186	700	3.76344086	Combined Ash	None	Excluded
864	Meredosia	386	SI	Bottom Ash Pond	--	--	34	186	5.470588235	Combined Ash	None	Excluded
6213	Merom	812	LF	Area 2	39.06638889	-87.50027778	65	5268.595041	81.05530833	Combined Ash	Yes	--
6213	Merom	813	LF	Area 1	39.07472222	-87.50027778	--	--	--	Combined Ash	None	Excluded
6213	Merom	190	SI	All	--	--	--	--	--	Combined Ash	--	Excluded
2364	Merrimack Station	754	LF	Coal Ash Landfill	43.13497222	-71.4765	--	--	--	Combined Ash	Yes	--
2364	Merrimack Station	1319	SI	WWT #3 Slag Sluice Settling Area	43.14125	-71.47186111	0.64538567	0.529476584	0.820403372	Combined Ash	None	--
2364	Merrimack Station	1320	SI	Waste Treatment #4 Slag Settling Pond	43.13983333	-71.47016667	1.73576676	10.0674472	5.8	Combined Ash	None	--
2832	Miami Fort	700	SI	Ash Basin B	39.11194444	-84.81277778	20	515	25.75	Ash & Coal Refuse	None	--
2832	Miami Fort	699	SI	Ash Basin A	39.1125	-84.81	20	803	40.15	Ash & Coal Refuse	None	--
2832	Miami Fort	1121	LF	Miamiview Road Ash Landfill	39.15388889	-84.78888889	--	--	--	Combined Ash	Yes	Excluded
2832	Miami Fort	1109	LF	Lawrenceberg Road Ash Landfill	--	--	80	2479.338843	30.99173554	Combined Ash	Yes	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
997	Michigan City	451	SI	Primary 2	41.716443	-86.915613	2.6	44	16.92307692	Combined Ash	--	--
997	Michigan City	450	SI	Secondary 2	41.71739	-86.914924	0.2	3	15	Combined Ash	--	--
997	Michigan City	453	SI	Primary 1	41.71814	-86.914534	2.2	36	16.36363636	Combined Ash	--	--
997	Michigan City	452	SI	Secondary 1	41.718947	-86.913976	0.2	3	15	Combined Ash	--	--
997	Michigan City	448	SI	Final Settling Pond	41.720692	-86.913242	5.7	85	14.9122807	Combined Ash	--	--
997	Michigan City	449	SI	Bottom Ash Area	41.719552	-86.912839	0.7	1	1.428571429	Combined Ash	--	--
1364	Mill Creek	543	SI	Ash Pond	33.204167	-85.909242	43	--	--	Combined Ash	None	--
1364	Mill Creek	817	LF	Mill Creek Special Waste Landfill-Site A	38.04222222	-85.90888889	--	--	--	Combined Ash	None	--
1364	Mill Creek	819	LF	Mill Creek Special Waste Landfill-Site B	38.05083333	-85.90555556	--	--	--	Combined Ash	None	--
1364	Mill Creek	818	LF	Mill Creek Special Waste Landfill-Site C	38.04444444	-85.90472222	--	--	--	Combined Ash	Yes	--
1364	Mill Creek	544	SI	Emergency Pond	--	--	1	--	--	FGD Waste	--	--
1364	Mill Creek	545	SI	Dead Storage Pond	--	--	2	--	--	FGD Waste	--	--
1364	Mill Creek	546	SI	Construction Run Off Pond	--	--	3	--	--	FGD Waste	--	--
1364	Mill Creek	547	SI	Clearwell Pond	--	--	2	--	--	FGD Waste	--	--
2823	Milton R. Young Station	777	LF	IT-197	47.07111111	-101.3134528	--	--	--	Combined Ash	None	Excluded
2823	Milton R. Young Station	788	LF	IT-205 Section 3	47.06308333	-101.3125278	--	--	--	Combined Ash	None	--
2823	Milton R. Young Station	809	LF	IT-068	47.07941389	-101.2864889	--	--	--	Combined Ash	None	Excluded
2823	Milton R. Young Station	811	LF	Horseshoe Pit	47.07838889	-101.2733833	--	--	--	Combined Ash	None	Excluded
2823	Milton R. Young Station	820	LF	Cell 1 30 Year Ponds	47.05989	-101.22055	80	4028.92562	50.36157025	Combined Ash	Yes	--
2823	Milton R. Young Station	686	SI	Cell 1	--	--	--	--	--	Combined Ash	Clay	--
2823	Milton R. Young Station	687	SI	Unit 1 Alternative Bottom Ash Pond	--	--	2	25	12.5	Combined Ash	Clay	--
2823	Milton R. Young Station	688	SI	30 Year Ponds (Cell 2)	--	--	27	1252	46.37037037	Combined Ash	Clay	--
2823	Milton R. Young Station	689	SI	Horseshoe Pit Evaporation Pond	--	--	4	34	8.5	Combined Ash	--	--
2171	Missouri City	1257	SI	Ash Pond	39.23212222	-94.30763611	0.331	--	--	Combined Ash	None	--
3948	Mitchell	160	SI	Bottom Ash Complex	39.825	-80.815556	10.2	262	25.68627451	Combined Ash	Composite	--
3948	Mitchell	161	SI	Fly Ash Pond	39.823611	-80.815	71	13500	190.1408451	Ash & Coal Refuse	--	--
727	Mitchell	364	SI	Ash Pond A	--	--	4	61	15.25	Combined Ash	None	--
727	Mitchell	365	SI	Ash Pond 2	--	--	43	644	14.97674419	Combined Ash	None	--
727	Mitchell	366	SI	Ash Pond 1	--	--	44	659	14.97727273	Combined Ash	None	--
3181	Mitchell Power Station	779	LF	Inactive coal combustion byproduct disposal site	40.226871	-79.978892	--	--	--	Combined Ash	None	Excluded
3181	Mitchell Power Station	778	LF	Active Coal Combustion byproduct disposal site	40.22611111	-79.97888889	70	3471.07438	49.58677686	Combined Ash	None	--
1048	ML Kapp	479	SI	Main Ash Secondary Settling Pond	--	--	2	1	0.5	Combined Ash	None	--
1048	ML Kapp	480	SI	Emergency Ash Primary Settling Pond	--	--	1	3	3	Combined Ash	None	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
1048	ML Kapp	481	SI	Emergency Ash Secondary Settling Pond	--	--	1	2	2	Combined Ash	None	--
1048	ML Kapp	482	SI	Main Ash Primary Settling Pond	--	--	7	4	0.571428571	Combined Ash	None	--
1733	Monroe Power Plant	582	SI	Fly Ash Basin	41.88416667	-83.37527778	410.576	18595	45.29003157	Combined Ash	none	--
1733	Monroe Power Plant	583	SI	Bottom Ash Basin	--	--	100	620	6.2	Combined Ash	--	--
6147	Monticello	781	LF	G Area	33.14444444	-95.03805556	--	--	--	Combined Ash	Yes	--
6147	Monticello	1204	SI	West Decant Basin(s)	33.08489722	-95.03458056	0.88699311	15.96434803	17.99827732	Combined Ash	Composite	Excluded
6147	Monticello	1203	SI	East Decant Basin(s)	33.08515	-95.03393056	0.88705234	15.96434803	17.99707557	Combined Ash	None	Excluded
6147	Monticello	1205	SI	Bottom Ash Pond(s)	33.08775556	-95.03381111	20.2298439	293.6139118	14.51389904	Combined Ash	None	--
6147	Monticello	1206	SI	New Operating Scrubber Pond 2	33.08592778	-95.03345556	1	12.00325987	12.00325987	FGD Waste	Composite	Excluded
6147	Monticello	782	LF	A Area	33.09211111	-95.02919444	--	--	--	Combined Ash	None	Excluded
6147	Monticello	780	LF	B Area	--	--	--	--	--	Combined Ash	None	--
2080	Montrose	783	LF	Utility Waste Landfill	38.31138889	-93.94388889	--	--	--	Combined Ash	Yes	--
2080	Montrose	601	SI	South Ash Pond	38.31053889	-93.93953611	2.7	--	--	Combined Ash	--	--
2080	Montrose	600	SI	North Ash Pond	38.31093889	-93.93916667	1.65	--	--	Combined Ash	--	--
2080	Montrose	602	SI	Ash Settling Pond	--	--	4	13	3.25	Combined Ash	--	--
1573	Morgantown Generating Plant	1108	LF	Controlled Storage	38.36138889	-76.96944444	212	4772.727273	22.51286449	Combined Ash	Yes	--
1573	Morgantown Generating Plant	785	LF	Faulkner Ash Site	38.439064	-76.961462	--	--	--	Combined Ash	Yes	--
1606	Mount Tom	563	SI	Equalization Tank	42.278607	-72.60317	0.014	--	--	Combined Ash	--	Excluded
1606	Mount Tom	798	LF	Former Bottom Ash Basin "A"	42.276003	-72.602229	--	--	--	Combined Ash	None	Excluded
1606	Mount Tom	564	SI	Special Basin	--	--	1	7	7	Combined Ash	--	Excluded
1606	Mount Tom	565	SI	Bottom Ash Basin	--	--	2	18	9	Combined Ash	--	Excluded
6264	Mountaineer	787	LF	Little Broad Run Landfill	38.94666667	-81.95166667	325	10289.2562	31.65924984	Combined Ash	Composite	--
6264	Mountaineer	211	SI	Bottom Ash Complex	38.97	-81.936667	29	508	17.51724138	Combined Ash	Clay	--
3954	Mt. Storm	1112	LF	Closed Ash Mtn	39.19111111	-79.29027778	54	--	--	Combined Ash	Clay	Excluded
3954	Mt. Storm	1110	LF	Phase B Landfill	39.18555556	-79.28388889	155	656.5656566	4.235907462	Combined Ash	None	--
3954	Mt. Storm	1111	LF	Phase A Landfill (ASH)	39.196095	-79.282034	71	505.0505051	7.113387395	Combined Ash	Clay	--
3954	Mt. Storm	789	LF	Phase A Landfill (FGD)	39.196262	-79.276722	71	491.2764004	6.919385921	Combined Ash	Composite	--
1167	Muscatine #1	792	LF	Coal Combustion Residue Landfill	41.38	-91.20722222	36	1239.669422	34.43526171	Combined Ash	Yes	--
1167	Muscatine #1	1361	SI	coal pile runoff pond	41.38861111	-91.05805556	0.45913682	4.591368228	10	Ash & Coal Refuse	Clay	Excluded
2872	Muskingum River	712	SI	Unit 1-4 Bottom Ash Pond Dam	39.58362778	-81.68921111	5	100	20	Combined Ash	None	--
2872	Muskingum River	714	SI	Middle Fly Ash Pond	39.58166667	-81.68833333	40	1370	34.25	Combined Ash	None	--
2872	Muskingum River	715	SI	Lower Fly Ash Dam	39.58583333	-81.68833333	16	660	41.25	Combined Ash	None	--
2872	Muskingum River	713	SI	Upper Fly Ash Pond	39.575	-81.685	116.8	5250	44.94863014	Combined Ash	None	--
2952	Muskogee	1174	SI	T01	35.76555556	-95.29222222	23.14	--	--	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2952	Muskogee	1173	SI	F03	35.75361111	-95.29027778	0.44977043	--	--	Combined Ash	None	--
2952	Muskogee	1172	SI	F01	35.76388889	-95.28111111	17.5298439	--	--	Combined Ash	Clay	--
4162	Naughton Plant	15	SI	FGD Pond #1	41.767492	-110.595608	40	1038	25.95	Combined Ash	Composite	--
4162	Naughton Plant	14	SI	South Ash Pond	41.748486	-110.594661	206	4057	19.69417476	Combined Ash	None	--
4162	Naughton Plant	13	SI	North Ash Pond	41.761525	-110.588586	151.5	3370	22.24422442	Combined Ash	None	--
4162	Naughton Plant	12	SI	FGD Pond #2	41.766639	-110.586917	40	671	16.775	Combined Ash	Composite	--
4162	Naughton Plant	980	LF	--	--	--	--	--	--	Combined Ash	--	--
4941	Navajo Generating Station	793	LF	Ash Disposal Area	36.90861111	-111.3569444	--	--	--	Combined Ash	None	--
6064	Nearman Creek	795	LF	Fly Ash Dry Deposition Area	39.10694444	-94.71773889	--	--	--	Combined Ash	None	--
6064	Nearman Creek	794	LF	Bottom Ash Pond	39.174112	-94.692221	--	--	--	Combined Ash	Yes	--
6064	Nearman Creek	39	SI	N/A	--	--	7	124	17.71428571	Combined Ash	Clay	--
6096	Nebraska City	797	LF	NC2 Landfill Cell 1	40.62561111	-95.78605556	--	--	--	Combined Ash	Yes	--
6096	Nebraska City	943	LF	NC1 landfill	40.61922222	-95.78602778	17	371.9008265	21.8765192	Combined Ash	None	--
6096	Nebraska City	1271	SI	Bottom Ash Pond 1	40.625103	-95.774172	11.359045	96.7637741	8.518654002	Combined Ash	None	--
6096	Nebraska City	1272	SI	Bottom Ash Pond 2	40.625103	-95.774172	12.2520661	111.1042241	9.06820311	Combined Ash	None	--
4054	Nelson Dewey	170	SI	WPDES Pond	42.725581	-91.013559	4	26	6.5	Combined Ash	--	Excluded
4054	Nelson Dewey	893	LF	Ash Disposal Facility	42.72680556	-91.01277778	17.8	381.818182	21.45045966	Combined Ash	None	Excluded
4054	Nelson Dewey	171	SI	Slag Pond	42.725413	-91.008642	5	20	4	Combined Ash	--	--
3138	New Castle Plant	1350	SI	South Bottom Ash Pond	40.94	-80.37138889	0.72084481	5.766758494	8	Combined Ash	None	--
3138	New Castle Plant	1349	SI	North Bottom Ash Pond	40.941817	-80.368153	2.0087236	16.0697888	8	Combined Ash	None	--
3138	New Castle Plant	941	LF	Fly Ash Landfill	40.94555556	-80.36805556	57	3548.347107	62.25170364	Combined Ash	Composite	--
2167	New Madrid	1032	LF	UCW landfill	36.48964306	-89.58599806	--	--	--	Combined Ash	Yes	--
2167	New Madrid	622	SI	Ash Pond 1	36.50611111	-89.57388889	31	570	18.38709677	Combined Ash	None	--
2167	New Madrid	621	SI	Slag Pond 2	36.51444444	-89.55944444	4	14	3.5	Combined Ash	None	--
2167	New Madrid	620	SI	Ash Pond 2	36.50166667	-89.5575	79	1351	17.10126582	Combined Ash	Composite	--
2167	New Madrid	623	SI	Slag Pond 1	36.5075	-89.55666667	62	1137	18.33870968	Combined Ash	None	--
6017	Newton	1034	LF	Landfill Phase I	38.93305556	-88.295	--	--	--	Combined Ash	None	Excluded
6017	Newton	1033	LF	Landfill Phase II	38.93083333	-88.29194444	309	--	--	Combined Ash	Yes	--
6017	Newton	21	SI	Secondary Ash Pond	38.92195556	-88.29063889	9	83	9.222222222	Combined Ash	None	--
6017	Newton	22	SI	Primary Ash Pond	38.92836667	-88.28351389	400	9250	23.125	Combined Ash	None	--
2291	North Omaha	1113	LF	North Omaha Ash Landfill	41.33294444	-95.95097778	13	65.08264463	5.006357279	Combined Ash	None	--
2291	North Omaha	1036	LF	North Omaha Ash Landfill closed area	41.32966667	-95.9505	--	--	--	Combined Ash	Yes	Excluded
2291	North Omaha	1222	SI	Coal Pile Runoff pond	41.33008333	-95.94894444	2.298	--	--	Ash & Coal Refuse	None	Excluded
2291	North Omaha	1220	SI	West Ash Pond (IAW-3A)	41.33063889	-95.94569444	15.9894399	14.66023875	0.916870065	Combined Ash	Composite	--
2291	North Omaha	1221	SI	East Ash Pond (IAW-3B)	41.33063889	-95.94569444	11.5909091	10.6359045	0.917607447	Combined Ash	Composite	--
8224	North Valmy	1037	LF	U1, U2 & U3 Ash Landfill	40.89145278	-117.1504278	--	--	--	Combined Ash	None	--
2963	Northeastern	1038	LF	Fly Ash Landfill	36.41583333	-95.69833333	69	1974.291322	28.61291771	Combined Ash	Yes	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2963	Northeastern	718	SI	Bottom Ash Pond	--	--	69	700	10.14492754	Combined Ash	Clay	--
667	Northside Generating Station	1039	LF	Outdoor pile 1	30.42694444	-81.55666667	--	--	--	Combined Ash	Yes	--
10030	NRG Energy Center Dover	251	SI	Waste Water Pond	--	--	--	--	--	Combined Ash	--	--
527	Nucla	338	SI	Coal/Ash Settling Basin	--	--	--	--	--	Combined Ash	--	--
527	Nucla	964	LF	--	--	--	41.2	929.7520665	22.56679773	Combined Ash	--	--
2848	O H Hutchings	705	SI	West Primary Settling Pond	39.61163056	-84.29494167	7.88	--	--	Combined Ash	None	--
2848	O H Hutchings	703	SI	Secondary Settling Pond	39.613175	-84.29474722	1.75	6	3.428571429	Combined Ash	None	--
2848	O H Hutchings	704	SI	East Primary Settling Pond	39.61177778	-84.29355556	5.4	--	--	Combined Ash	None	--
6180	Oak Grove	1040	LF	Ash Landfill 1	31.17544167	-96.49919167	--	--	--	Combined Ash	Yes	--
6180	Oak Grove	1185	SI	FGD-A	31.18421944	-96.49215278	9.43526171	144.2470156	15.28807786	Combined Ash	Clay	--
6180	Oak Grove	1042	LF	-999	--	--	--	--	--	Combined Ash	None	--
6180	Oak Grove	1054	LF	-999	--	--	--	--	--	Combined Ash	None	--
127	Oklaunion	281	SI	Wastewater Evaporation Pond 6	34.07999722	-99.17916667	58	1044	18	Combined Ash	Clay	--
127	Oklaunion	282	SI	Sludge Pond	--	--	23	565	24.56521739	FGD Waste	--	--
127	Oklaunion	283	SI	Pond #23	--	--	13	333	25.61538462	Combined Ash	--	--
127	Oklaunion	841	LF	--	--	--	--	--	--	Combined Ash	Composite	--
4151	Osage	1044	LF	Historic Ash Dam	43.971173	-104.40813	--	--	--	Combined Ash	None	Excluded
4151	Osage	1031	LF	Old Ash Dam	43.96988889	-104.4077778	--	--	--	Combined Ash	None	Excluded
4151	Osage	1267	SI	West Dam	43.96516667	-104.4068056	45	--	--	Combined Ash	None	Excluded
4151	Osage	1266	SI	East Dam	43.96483333	-104.40625	2.671	--	--	Combined Ash	Clay	Excluded
1831	Otto E. Eckert Station	586	SI	EPRI 5	--	--	151	4462.809917	29.55503257	Combined Ash	--	Excluded
6254	Ottumwa	1045	LF	Ottumwa Midland Landfill	41.07772222	-92.45022222	--	--	--	Combined Ash	Yes	--
6254	Ottumwa	205	SI	Monofill Leachate Retention Pond	--	--	--	1	--	Combined Ash	--	Excluded
6254	Ottumwa	206	SI	Monofill Storm Water Retention Pond	--	--	2	18	9	--	--	Excluded
6254	Ottumwa	207	SI	Main Ash Pond	--	--	18	229	12.72222222	Combined Ash	None	--
6254	Ottumwa	208	SI	Zero Liquid Discharge Pond	--	--	17	319	18.76470588	Combined Ash	None	Excluded
1378	Paradise	548	SI	Fly Ash Extension Area Pond	--	--	203	3935	19.38423645	Combined Ash	--	--
1378	Paradise	549	SI	Scrubber Sludge Complex	--	--	255	532	2.08627451	Combined Ash	--	--
1378	Paradise	550	SI	Slag Areas 2A & 2B	--	--	27	600	22.22222222	Combined Ash	--	Excluded
6248	Pawnee	1046	LF	Pawnee Station Landfill	40.20954167	-103.6840472	--	--	--	Combined Ash	None	--
6248	Pawnee	191	SI	Evaporative Pond C	--	--	11	96	8.727272727	Combined Ash	--	--
6248	Pawnee	192	SI	Intermediate Quality (IQ) Water Pond	--	--	4	48	12	Combined Ash	--	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6248	Pawnee	193	SI	New Bottom Ash Water Recovery Pond	--	--	6	52	8.666666667	Combined Ash	--	--
6248	Pawnee	194	SI	Ash Disposal Facility (ADF)	--	--	34	1349	39.67647059	Combined Ash	--	--
6248	Pawnee	195	SI	Ash Water Recovery Pond	--	--	1	5	5	Combined Ash	--	Excluded
6248	Pawnee	196	SI	Evaporative Pond B	--	--	15	138	9.2	Combined Ash	--	--
6248	Pawnee	197	SI	Bottom Ash Disposal Pond	--	--	13	250	19.23076923	Combined Ash	--	Excluded
6238	Pearl Station	1211	SI	AP	39.44888889	-90.61555556	12.7988981	127.9889807	10	Combined Ash	None	--
3938	Philip Sporn	157	SI	Unit 5 (Fly Ash Pond)	38.97361111	-81.93777778	70.3	1965	27.95163585	Combined Ash	None	--
3938	Philip Sporn	156	SI	Bottom Ash Pond	38.96888889	-81.92888889	9.5	256	26.94736842	Ash & Coal Refuse	None	--
3938	Philip Sporn	979	LF	--	--	--	--	--	--	Combined Ash	--	--
2843	Picway	702	SI	[blank]	39.792655	-83.007777	23	275	11.95652174	--	--	--
7902	Pirkey	236	SI	Scrubber Sludg Landfill Runoff Pond	32.45136111	-94.49844444	12.88	25	1.940993789	FGD Waste	None	Excluded
7902	Pirkey	233	SI	West Bottom Ash Pond	32.46736111	-94.49172222	30.85	188	6.094003241	Combined Ash	None	--
7902	Pirkey	235	SI	Secondary Bottom Ash Pond	32.46538889	-94.48772222	2.65	12	4.528301887	Combined Ash	None	--
7902	Pirkey	237	SI	Surge Pond	32.46297222	-94.48741667	4.7	19	4.042553191	FGD Waste	None	Excluded
7902	Pirkey	234	SI	East Bottom Ash Pond	32.46705556	-94.48675	30.85	188	6.094003241	Combined Ash	None	--
7902	Pirkey	238	SI	Auxilliary Surge Pond	32.46447222	-94.48580556	4.3	64	14.88372093	FGD Waste	None	--
7902	Pirkey	1132	LF	--	--	--	--	--	--	Combined Ash	Composite	--
59	Platte	1047	LF	Ash Disposal Phase II	40.85487778	-98.35371667	--	--	--	Combined Ash	None	--
59	Platte	1048	LF	Ash Disposal Phase I	40.85370833	-98.35303611	--	--	--	Combined Ash	None	Excluded
6170	Pleasant Prairie	1049	LF	Pleasant Prairie	42.56166667	-87.90111111	26	4028.92562	154.9586777	Combined Ash	Yes	--
6004	Pleasants Power Station	1050	LF	McElroy's Run	39.36819	-81.271275	--	--	--	Combined Ash	Yes	--
6004	Pleasants Power Station	17	SI	McElroy's Run Embankment	39.36666667	-81.27083333	219	20000	91.32420091	Combined Ash	None	--
7242	Polk	1051	LF	Slag Pile	27.72611111	-81.99138889	--	--	--	Combined Ash	Yes	--
3113	Portland	1020	LF	Quarry 1	40.87027778	-75.20027778	2.3	4.958448118	2.155847008	Combined Ash	None	Excluded
3113	Portland	1052	LF	Bangor Landfill	40.87194444	-75.19833333	16.6	954.5454545	57.50273823	Combined Ash	Composite	--
3113	Portland	1043	LF	Quarry 2 & 3	40.87027778	-75.19805556	12	25.45454545	2.121212121	Combined Ash	None	Excluded
3113	Portland	1201	SI	West Sedimentation Basin	40.90611111	-75.07777778	0.89990817	3.130257117	3.478418367	Combined Ash	None	--
3113	Portland	1200	SI	East Sedimentation Basin	40.90611111	-75.0775	0.89990817	3.130257117	3.478418367	Combined Ash	None	--
3113	Portland	1199	SI	IWT Sedimentation Basin	40.90638889	-75.0775	1.48	--	--	Combined Ash	Yes	Excluded
3113	Portland	1041	LF	-999	--	--	--	--	--	Combined Ash	None	Excluded
879	Powerton	1228	SI	East Yard Runoff Basin	40.53916667	-89.68027778	8.38	--	--	Combined Ash	None	Excluded
879	Powerton	1231	SI	Metal Cleaning Basin	40.54472222	-89.67777778	1.91000918	16.52892562	8.653846154	Combined Ash	None	Excluded
879	Powerton	1229	SI	Secondary Ash Settling Basin	40.54638889	-89.6775	1.78145087	23.15886134	13	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
879	Powerton	1227	SI	Ash Surge Basin	40.54638889	-89.67638889	8.14049587	113.9669421	14	Combined Ash	None	--
879	Powerton	1230	SI	Ash Bypass Basin	40.54194444	-89.67611111	0.90679522	6.081267218	6.706329114	Combined Ash	None	--
879	Powerton	1233	SI	Limestone Runoff Basin	40.545	-89.675	8.38	--	--	Combined Ash	Yes	Excluded
879	Powerton	1232	SI	41	40.54722222	-89.67416667	12.855831	51.42332415	4	Combined Ash	None	Excluded
3140	PPL Brunner Island	1114	LF	Disposal Area 8	40.08666667	-76.68833333	--	--	--	Combined Ash	Yes	--
3140	PPL Brunner Island	95	SI	Ash Basin No.6	40.086838	-76.688102	70	2600	37.14285714	Combined Ash	--	--
3140	PPL Brunner Island	93	SI	Industrial Waste Treatment Basin	40.078064	-76.680176	7	20	2.857142857	--	--	Excluded
3140	PPL Brunner Island	94	SI	Equalizatipond	40.07666	-76.678687	1	5	5	Combined Ash	--	--
3149	PPL Montour	1115	LF	Ash Area No. 3	41.06305556	-76.66111111	--	--	--	Combined Ash	Yes	--
3149	PPL Montour	1011	LF	Ash Area No. 2	41.06416667	-76.65138889	--	--	--	Combined Ash	--	Excluded
3149	PPL Montour	96	SI	Silo Runoff Pond	--	--	--	1	--	Combined Ash	--	Excluded
3149	PPL Montour	97	SI	Ash Area 3 Leachate Runoff Basin	--	--	2	11	5.5	Combined Ash	--	Excluded
3149	PPL Montour	98	SI	Detention Basin	--	--	21	53	2.523809524	--	--	Excluded
3149	PPL Montour	99	SI	Stormwater Basin	--	--	2	13	6.5	--	--	Excluded
3149	PPL Montour	100	SI	Ash Basin No. 1	--	--	143	5070	35.45454545	Combined Ash	--	--
1073	Prairie Creek	487	SI	Ash Pond #10	--	--	--	1	--	Combined Ash	--	--
1073	Prairie Creek	488	SI	Ash Pond #5	--	--	1	12	12	Combined Ash	--	--
1073	Prairie Creek	489	SI	Ash Pond #6	--	--	1	14	14	Combined Ash	--	--
1073	Prairie Creek	490	SI	Ash Pond #7	--	--	--	1	--	Combined Ash	--	--
1073	Prairie Creek	491	SI	Ash Pond #3	--	--	1	7	7	Combined Ash	--	--
1073	Prairie Creek	492	SI	Ash Pond #2	--	--	1	8	8	Combined Ash	--	--
1073	Prairie Creek	493	SI	Ash Pond #4	--	--	1	8	8	Combined Ash	--	--
1073	Prairie Creek	494	SI	Ash Pond #1	--	--	--	4	--	Combined Ash	--	--
1073	Prairie Creek	495	SI	Ash Pond #8 - Plant Drains	--	--	--	--	--	Combined Ash	--	--
1073	Prairie Creek	496	SI	Ash Pond #9 - Dumper Building	--	--	--	1	--	Combined Ash	--	--
1769	Presque Isle	1014	LF	Presque Isle Power Plant Ash Landfill #2	46.587834	-87.476013	--	--	--	Combined Ash	Yes	Excluded
1769	Presque Isle	1012	LF	Presque Isle Power Plant Ash Landfill #3	46.584725	-87.473626	292	8801.652893	30.14264689	Combined Ash	Yes	--
1769	Presque Isle	1013	LF	Presque Isle Power Plant Ash Landfill #1	46.587875	-87.469134	--	--	--	Combined Ash	None	Excluded
2403	PSEG Hudson Generating Station	1015	LF	Landfill 1	40.754374	-74.079108	--	--	--	Combined Ash	None	--
2403	PSEG Hudson Generating Station	1352	SI	South Pond	40.755306	-74.078844	4.233	59.13682277	13.97042825	Combined Ash	Clay	Excluded
2403	PSEG Hudson Generating Station	1351	SI	North Pond	40.75180556	-74.07522222	4.306	52.93847567	12.29411883	Combined Ash	Clay	Excluded
2408	PSEG Mercer Generating Station	1197	SI	South Pond	40.18036111	-74.72963889	0.854	--	--	Combined Ash	None	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
2408	PSEG Mercer Generating Station	1198	SI	North Pond	40.17874444	-74.72816667	0.854	--	--	Combined Ash	None	Excluded
2408	PSEG Mercer Generating Station	1016	LF	Landfill 1	40.18225	-74.71694444	--	--	--	Combined Ash	None	--
4072	Pulliam	1017	LF	Pulliam Landfill	44.54388889	-88.01666667	--	--	--	Combined Ash	None	Excluded
4072	Pulliam	1212	SI	Pulliam Waste Water Pond	44.54388889	-88.01305556	0.12454086	1.930394858	15.50009217	Ash & Coal Refuse	None	--
1295	Quindaro	1030	LF	Quindaro Ash Landfill	39.14894444	-94.64483333	--	--	--	Combined Ash	Yes	--
6639	R D Green	1019	LF	Green Station Landfill	37.63416667	-87.50444444	--	--	--	Combined Ash	None	--
6639	R D Green	220	SI	Ash Pond Dam #0980	37.63438889	-87.50400278	21.3	--	--	Combined Ash	None	--
2864	R. E. Burger	1381	SI	Bottom Ash Pond	39.91289722	-80.76889444	3.44352617	40.17447199	11.66666667	Combined Ash	None	Excluded
2864	R. E. Burger	1380	SI	Fly Ash Pond	39.910125	-80.76314444	9.50413223	109.0449954	11.47342995	Combined Ash	None	Excluded
2864	R. E. Burger	976	LF	--	--	--	--	--	--	Combined Ash	--	Excluded
1008	R. Gallagher	460	SI	Ash Pond A	38.25655833	-85.84235	37	936	25.2972973	Combined Ash	None	--
1008	R. Gallagher	461	SI	Secondary Ash Pond	38.25681111	-85.83926389	4.5	63	14	Combined Ash	None	--
1008	R. Gallagher	1023	LF	N/A	--	--	--	--	--	Combined Ash	--	--
1008	R. Gallagher	1024	LF	N/A	--	--	--	--	--	Combined Ash	--	--
1008	R. Gallagher	1025	LF	N/A	--	--	--	--	--	Combined Ash	--	--
1008	R. Gallagher	1026	LF	N/A	--	--	--	--	--	Combined Ash	--	--
1008	R. Gallagher	1027	LF	N/A	--	--	--	--	--	Combined Ash	--	Excluded
1008	R. Gallagher	1029	LF	N/A	--	--	--	--	--	Combined Ash	--	Excluded
1008	R. Gallagher	1053	LF	N/A	--	--	--	--	--	Combined Ash	--	Excluded
1008	R. Gallagher	1056	LF	N/A	--	--	--	--	--	Combined Ash	--	Excluded
1008	R. Gallagher	1001	LF	--	--	--	--	--	--	Combined Ash	--	--
1570	R. Paul Smith Power Station	1083	LF	CCB Landfill	39.58972222	-77.83666667	--	--	--	Combined Ash	Yes	--
1570	R. Paul Smith Power Station	562	SI	Ash Pond #4	39.58741944	-77.83118611	11	218	19.81818182	Combined Ash	Composite	--
1570	R. Paul Smith Power Station	561	SI	Ash Pond #3	39.59195556	-77.83095	6	104	17.33333333	Combined Ash	None	--
2790	R.M. Heskett Station	1080	LF	Ash Disposal Site	46.867451	-100.897253	58	960.7438017	16.5645483	Combined Ash	Yes	--
2790	R.M. Heskett Station	1081	LF	Old Ash Landfill	46.87	-100.8902778	--	--	--	Combined Ash	None	Excluded
6085	R.M. Schahfer	68	SI	Gypsum Storage (Units 14&15)A	41.21004722	-87.02274722	45	--	--	FGD Waste	None	--
6085	R.M. Schahfer	54	SI	Waste Disposal Area	41.20505	-87.02237778	75	1165	15.53333333	Combined Ash	None	Excluded
6085	R.M. Schahfer	56	SI	Material Storage Runoff Basin	41.21239444	-87.01941389	12	48	4	FGD Waste	None	--
6085	R.M. Schahfer	58	SI	Gypsum Storage (Units 14&15)B	41.20936944	-87.01741944	9.5	--	--	FGD Waste	None	--
6085	R.M. Schahfer	55	SI	Recycle Basin	41.20560556	-87.01729722	30	372	12.4	Combined Ash	None	--
6085	R.M. Schahfer	67	SI	Metal Cleaning Waste Basin	41.21192222	-87.01636389	12	48	4	FGD Waste	None	--
6085	R.M. Schahfer	57	SI	FGD Landfill Stormwater Runoff Pond	41.21859722	-87.00565556	5	12	2.4	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6085	R.M. Schahfer	1082	LF	RMSGS Landfill	41.21458333	-87.00162778	200	10661.15703	53.30578513	Combined Ash	Yes	--
6761	Rawhide	1086	LF	CCR Monofill	40.87283333	-105.0426944	150	3162.194674	21.08129783	Combined Ash	None	--
6761	Rawhide	225	SI	North Bottom Ash Transfer Pond	--	--	4	37	9.25	Combined Ash	--	--
6761	Rawhide	226	SI	South Bottom Ash Transfer Pond	--	--	4	37	9.25	Combined Ash	--	--
6761	Rawhide	996	LF	--	--	--	--	--	--	Combined Ash	--	--
8219	Ray D Nixon	1087	LF	Clear Spring Ranch Ash Landfill	38.60823	-104.7132283	--	--	--	Combined Ash	None	--
8219	Ray D Nixon	1255	SI	Nixon Equalization Basin	38.62931167	-104.6996264	3.71271809	40.9884068	11.03999975	Combined Ash	None	Excluded
55076	Red Hills Generating Facility	1256	SI	AMU Basin	33.3825	-89.21888889	2.62	--	--	Combined Ash	Yes	--
55076	Red Hills Generating Facility	1088	LF	AMU	33.37972222	-89.21583333	--	--	--	Combined Ash	Yes	--
2324	Reid Gardner	637	SI	Pond C2	36.65886111	-114.6510806	8.5	173	20.35294118	FGD Waste	Composite	Excluded
2324	Reid Gardner	632	SI	Pond C1	36.65701111	-114.649775	14	115	8.214285714	FGD Waste	Composite	Excluded
2324	Reid Gardner	631	SI	Pond B3	36.65356389	-114.649225	8.1	90	11.11111111	FGD Waste	Composite	--
2324	Reid Gardner	630	SI	Pond B2	36.65486111	-114.6482694	12.4	148	11.93548387	FGD Waste	Composite	--
2324	Reid Gardner	634	SI	Pond B1	36.65599444	-114.6467972	13.4	193	14.40298507	FGD Waste	Composite	--
2324	Reid Gardner	635	SI	Pond E2	36.65433889	-114.6403417	14.4	165	11.45833333	FGD Waste	Composite	--
2324	Reid Gardner	636	SI	Pond E1	36.65317778	-114.6386806	5.9	115	19.49152542	FGD Waste	Composite	--
2324	Reid Gardner	633	SI	Pond F	36.65478333	-114.6377	4	37	9.25	FGD Waste	Composite	--
2324	Reid Gardner	1090	LF	Landfill	--	--	112.5	2801.652893	24.90358127	Combined Ash	None	--
1740	River Rouge Power Plant	1186	SI	bottom ash pond	42.27247778	-83.11265556	1.83654729	18.36547291	10	Combined Ash	None	--
2732	Riverbend	682	SI	Primary Ash Disposal Pond	35.36520278	-80.96329444	37.2	1640	44.08602151	Combined Ash	None	--
2732	Riverbend	681	SI	Secondary Pond	35.36810556	-80.96187778	23.5	980	41.70212766	Combined Ash	None	--
1081	Riverside	501	SI	South Ash Pond	41.53555556	-90.45166667	12	140	11.66666667	Combined Ash	None	--
1081	Riverside	500	SI	North Ash Pond	41.54416667	-90.44611111	14.1	84	5.957446809	Combined Ash	None	--
1927	Riverside	594	SI	Triangle Pond	--	--	--	2	--	Combined Ash	--	Excluded
1239	Riverton	512	SI	Industrial Landfill-East and West Ponds	37.06895278	-94.70081389	28	992	35.42857143	Combined Ash	None	--
3945	Rivesville Power Station	1358	SI	Bottom ash basin	39.530214	-80.115744	0.4323	--	--	Combined Ash	None	--
3945	Rivesville Power Station	1356	SI	Lagoon 1	39.53027778	-80.11527778	0.46717172	4.671717172	10	Combined Ash	Yes	Excluded
3945	Rivesville Power Station	1355	SI	Lagoon 2	39.53055556	-80.11444444	0.40174472	4.017447199	10	Combined Ash	Yes	Excluded
3945	Rivesville Power Station	1095	LF	Closed ash site	39.53888889	-80.09916667	60	495.8677686	8.26446281	Combined Ash	None	Excluded
3945	Rivesville Power Station	1116	LF	Ash disposal	39.5392	-80.094436	40	780.5325987	19.51331497	Combined Ash	None	--
3945	Rivesville Power Station	1357	SI	Disposal Site Sedimentation Pond	39.54	-80.09055556	0.59917355	3.379935721	5.640996169	Combined Ash	Clay	Excluded
6166	Rockport	179	SI	Bottom Ash Complex	37.91877222	-87.03744444	137	1640	11.97080292	Combined Ash	None	--
6166	Rockport	1097	LF	Rockport Plant Ash Landfill	--	--	--	--	--	Combined Ash	Yes	--
6190	Rodemacher	186	SI	Fly Ash Pond	31.39273056	-92.704125	42	670	15.95238095	Combined Ash	Clay	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6190	Rodemacher	187	SI	Bottom Ash Pond	31.39666667	-92.70138889	43	641	14.90697674	Combined Ash	Clay	--
6190	Rodemacher	185	SI	Leachate Pond	31.39035833	-92.70029722	8	--	--	Combined Ash	Composite	--
2712	Roxboro Steam Electric Plant	661	SI	FGD Flush Pond	36.47371944	-79.07788611	3.1	53	17.09677419	FGD Waste	Composite	--
2712	Roxboro Steam Electric Plant	664	SI	FGD Settling Pond	36.46875	-79.07121111	16.6	420	25.30120482	FGD Waste	Composite	--
2712	Roxboro Steam Electric Plant	1096	LF	Fly ash landfill	36.47888889	-79.06166667	55	2581.61157	46.93839219	Combined Ash	None	--
2712	Roxboro Steam Electric Plant	662	SI	West Ash Pond Dam & Dikes 1, 2,,& 4	36.51852222	-79.022475	2400	--	--	Combined Ash	--	--
2712	Roxboro Steam Electric Plant	663	SI	Ash Pond	--	--	240	4800	20	Combined Ash	None	--
1393	RS Nelson	1330	SI	Coal Ash Settling Pond Unit 6	30.28611111	-93.30166667	11.4784206	60.83562902	5.3	Ash & Coal Refuse	Composite	Excluded
1393	RS Nelson	1085	LF	Unit 6 Coal Ash	30.27666667	-93.29833333	--	--	--	Combined Ash	Yes	--
1393	RS Nelson	1329	SI	CFB Ash Landfill Retention Basin	30.27805556	-93.28722222	2.47546488	11.96787649	4.834597577	Combined Ash	Composite	Excluded
1393	RS Nelson	1084	LF	CFB Ash Landfill	30.2775	-93.28694444	--	--	--	Combined Ash	Yes	--
6155	Rush Island	1091	LF	-999	--	--	--	--	--	Combined Ash	None	Excluded
6155	Rush Island	178	SI	Ash Pond	--	--	104	7000	67.30769231	Combined Ash	None	--
2451	San Juan	1308	SI	Solids Waste Pit	36.79915833	-108.4354222	21.293	--	--	FGD Waste	Yes	Excluded
6183	San Miguel	1094	LF	Mine Pits	28.64166667	-98.48972222	--	--	--	Combined Ash	Yes	--
6183	San Miguel	1093	LF	Emergency Ash Pit	28.68027778	-98.48333333	--	--	--	Combined Ash	Yes	Excluded
6183	San Miguel	1366	SI	Ash Water Transport Pond 1B	28.69944444	-98.47527778	13	216	16.61538462	Combined Ash	Clay	--
6183	San Miguel	1367	SI	Ash Water Transport Pond 1A	28.70027778	-98.47527778	12.7704316	216	16.91407205	Combined Ash	Clay	--
6183	San Miguel	1365	SI	Equalization Pond	28.70138889	-98.46777778	25	410	16.4	FGD Waste	Clay	Excluded
6648	Sandow No 4	1067	LF	Bottom Ash Fines	30.5401	-97.07942	51	1606.97888	31.5093898	Combined Ash	None	--
6648	Sandow No 4	1065	LF	Class II Landfill	30.54527778	-97.07883333	45	459.136823	10.20304051	Combined Ash	None	--
6648	Sandow No 4	1092	LF	B Pit	30.54713889	-97.07233333	56	2800.734619	50.01311819	Combined Ash	Clay	--
6648	Sandow No 4	1089	LF	Comb Slag-Bot Ash Landfills	30.56044444	-97.06358333	237	2295.684114	9.68643086	Combined Ash	None	--
6648	Sandow No 4	1057	LF	-999	--	--	--	--	--	Combined Ash	--	Excluded
6648	Sandow No 4	221	SI	EPRI 8	--	--	45	837.9997934	18.62221763	Ash & Coal Refuse	--	--
6257	Scherer	209	SI	Settlement-Recycle Pond	--	--	--	--	--	--	None	--
6257	Scherer	210	SI	Ash Pond	--	--	553	15955	28.8517179	Ash & Coal Refuse	None	--
2367	SCHILLER	1058	LF	Closed Landfill	43.093	-70.78186111	--	--	--	Combined Ash	None	Excluded
642	Scholz	1348	SI	Lower Pond	30.66897222	-84.89230556	11.2	168	15	Ash & Coal Refuse	None	--
642	Scholz	1347	SI	Middle Pond	30.66911111	-84.89086111	9.7	145.5	15	Ash & Coal Refuse	None	--
642	Scholz	1346	SI	Upper Pond	30.66983333	-84.89033333	10.9	375.8088843	34.47787929	Ash & Coal Refuse	None	--
136	Seminole Generating Station	1059	LF	FGD Landfill	29.74237778	-81.62952778	--	--	--	Combined Ash	Yes	--
1379	Shawnee	1060	LF	AFBC Fly Ash &	37.144521	-88.780926	2.5	39.02662994	15.61065197	Combined Ash	None	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
1379	Shawnee	1061	LF	-999	--	--	--	--	--	Combined Ash	--	--
1379	Shawnee	551	SI	Ash Pond	--	--	180	3099	17.21666667	Combined Ash	--	--
1379	Shawnee	552	SI	Consolidated Waste Dry Stack	--	--	200	20575	102.875	Combined Ash	--	--
3131	Shawville	1248	SI	Pond B	41.06063889	-78.37491667	1.61193756	12.21303949	7.576620713	Combined Ash	Composite	--
3131	Shawville	1246	SI	Pond 2	41.06258333	-78.37202778	1.212	--	--	Combined Ash	None	Excluded
3131	Shawville	1247	SI	Pond A	41.06258333	-78.37202778	1.66083563	12.64921947	7.616177812	Combined Ash	Composite	--
3131	Shawville	1245	SI	Pond 1	41.06377778	-78.37033333	1.212	--	--	Combined Ash	None	Excluded
3131	Shawville	1063	LF	Original	41.057479	-78.366463	--	--	--	Combined Ash	None	Excluded
3131	Shawville	1062	LF	Current	41.05841	-78.363989	68	4958.677686	72.92173068	Combined Ash	Yes	--
2277	Sheldon Station	1064	LF	Ash Landfill No. 4	40.555094	-96.793041	9	232.4380165	25.82644628	Combined Ash	Yes	--
2277	Sheldon Station	1066	LF	Ash Landfill No. 2	40.55583333	-96.78833333	--	--	--	Combined Ash	None	Excluded
2277	Sheldon Station	1360	SI	PROCESS POND	40.56111111	-96.78805556	2.14150597	19.52167126	9.115861241	Combined Ash	Clay	Excluded
2277	Sheldon Station	1078	LF	Ash Landfill No. 3	40.55277778	-96.7875	--	--	--	Combined Ash	Yes	Excluded
2277	Sheldon Station	1055	LF	Ash Landfill No. 1	40.56527778	-96.78722222	--	--	--	Combined Ash	None	Excluded
6090	Sherburne County	1068	LF	Landfill	45.38972222	-93.90555556	--	--	--	Combined Ash	Yes	--
6090	Sherburne County	69	SI	Bottom Ash Pond	45.37458333	-93.89047222	18	620	34.44444444	Combined Ash	Clay	--
6090	Sherburne County	70	SI	Pond No. 1	45.37111111	-93.89011111	61	3099	50.80327869	Combined Ash	Clay	--
6090	Sherburne County	71	SI	Pond No. 2	45.36963889	-93.884	100	6198	61.98	Combined Ash	Clay	--
6090	Sherburne County	73	SI	Pond 3 N	45.37172222	-93.87838889	50	1860	37.2	Combined Ash	Composite	--
6090	Sherburne County	72	SI	Recycle Basin	--	--	7	--	--	Combined Ash	--	--
6090	Sherburne County	74	SI	Unit No. 3 Dry Ash Landfill Basin	--	--	3	--	--	Combined Ash	--	--
2094	Sibley	1069	LF	Utility Waste Landfill	39.17222222	-94.16333333	--	--	--	Combined Ash	Yes	--
2094	Sibley	603	SI	Slag Settling Pond	--	--	1	--	--	Combined Ash	None	--
2094	Sibley	604	SI	Fly Ash Settling Pond	--	--	15	224	14.93333333	Combined Ash	Clay	--
6768	Sikeston Power Station	227	SI	Fly Ash Pond	36.88083333	-89.61472222	30	560	18.66666667	Combined Ash	Clay	--
6768	Sikeston Power Station	228	SI	Bottom Ash Pond	36.8775	-89.61388889	54	891	16.5	Combined Ash	Clay	--
2107	Sioux	614	SI	Fly Ash Pond	--	--	60	960	16	Combined Ash	Composite	--
2107	Sioux	615	SI	Bottom Ash Pond	--	--	47	2100	44.68085106	Combined Ash	None	--
1058	Sixth Street	486	SI	Ash Pond 1	41.98642	-91.663308	0.45	7	15.55555556	Combined Ash	--	Excluded
1058	Sixth Street	483	SI	Ash Pond 2	41.98679	-91.662879	0.52	7	13.46153846	Combined Ash	--	Excluded
1058	Sixth Street	485	SI	Ash Pond 4	41.98631	-91.662258	3	32	10.66666667	Combined Ash	--	Excluded
1058	Sixth Street	484	SI	Ash Pond 3	41.987194	-91.661573	4	40	10	Combined Ash	--	Excluded
1613	Somerset Station	566	SI	North Lift Pit	--	--	--	--	--	Combined Ash	--	Excluded
1613	Somerset Station	567	SI	South Pond	--	--	--	2	--	Combined Ash	--	Excluded
1613	Somerset Station	568	SI	Coal Pile Run-Off Sump	--	--	--	--	--	Combined Ash	--	Excluded
1613	Somerset Station	569	SI	Equalization Basin	--	--	--	--	--	Combined Ash	--	Excluded
6095	Sooner	1260	SI	F07	36.45611111	-97.04583333	2.5	7.800022957	3.120009183	Combined Ash	Clay	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6095	Sooner	1259	SI	F04	36.46555556	-97.04305556	21	124.0005601	5.904788578	Combined Ash	Clay	--
6061	South Mississippi El Pwr Assn	1021	LF	West Active Landfill	31.21277778	-89.39944444	--	--	--	Combined Ash	--	--
6061	South Mississippi El Pwr Assn	1022	LF	Cells 1-6	31.20916667	-89.39833333	--	--	--	Combined Ash	Yes	--
6061	South Mississippi El Pwr Assn	1008	LF	East Inactive Landfill	31.21111111	-89.39777778	--	--	--	Combined Ash	--	--
6061	South Mississippi El Pwr Assn	1353	SI	Scrubber Supply Pond	31.21277778	-89.39555556	29.33	--	--	FGD Waste	Yes	--
6061	South Mississippi El Pwr Assn	1354	SI	Emergency Dump Pond	31.21527778	-89.39555556	29.33	--	--	FGD Waste	Yes	--
4041	South Oak Creek	1072	LF	Oak Creek South Ash Landfill	42.84580556	-87.84716667	--	--	--	Combined Ash	None	Excluded
4041	South Oak Creek	1070	LF	Caledonia Ash Landfill	42.83869444	-87.84177778	175	5361.57025	30.63754429	Combined Ash	Yes	--
4041	South Oak Creek	1071	LF	Oak Creek North Ash Landfill	42.85277778	-87.83872222	--	--	--	Combined Ash	None	Excluded
6195	Southwest Power Station	1074	LF	Demonstration	37.14555556	-93.38694444	--	--	--	Combined Ash	None	Excluded
6195	Southwest Power Station	1269	SI	West Ash Pond	37.1475	-93.38555556	5	--	--	Combined Ash	Clay	--
6195	Southwest Power Station	1268	SI	East Ash Pond	37.14777778	-93.38472222	3	--	--	Combined Ash	Clay	--
6195	Southwest Power Station	1073	LF	Landfill active	37.14805556	-93.38083333	--	--	--	Combined Ash	None	--
8223	Springerville	1384	SI	Process Water Collection pond	34.319558	-109.160581	0.61310836	2.301652893	3.754071966	Combined Ash	None	Excluded
8223	Springerville	1075	LF	Ash LandFill	34.311956	-109.155852	900	75757.57576	84.17508418	Combined Ash	None	--
1743	St Clair Power Plant	584	SI	Pond	--	--	--	--	--	Combined Ash	--	--
207	St Johns River Power Park	1076	LF	Area 2	30.43916667	-81.55222222	40	1794.600551	44.86501377	Combined Ash	None	--
207	St Johns River Power Park	1018	LF	Area 1	30.43833333	-81.54583333	72	4037.667585	56.07871646	Combined Ash	None	Excluded
207	St Johns River Power Park	1077	LF	Area B	30.443508	-81.538978	35	4032	115.2	Combined Ash	None	--
2824	Stanton	997	LF	Old Ash Landfill	47.24444444	-101.3377778	108	561.5702479	5.199724518	Combined Ash	Yes	Excluded
2824	Stanton	937	LF	Fly Ash Landfill	47.2425	-101.3344444	37.1	1137.396694	30.65759284	Combined Ash	Clay	--
2824	Stanton	940	LF	Bottom Ash Landfill	47.28277778	-101.3333333	10.5	283.8842975	27.03659976	Combined Ash	Clay	--
2824	Stanton	692	SI	South Bottom Ash Pond/Cell 2	47.281834	-101.331463	4	40	10	Combined Ash	--	Excluded
2824	Stanton	691	SI	North Bottom Ash Pond/Cell	47.283774	-101.33139	4	37	9.25	Combined Ash	--	--
2824	Stanton	690	SI	Middle Bottom Ash Pond/Retention Cell	47.28279	-101.331359	3	38	12.66666667	Combined Ash	--	--
564	Stanton Energy Center	942	LF	CWSA	28.48138889	-81.18027778	312	--	--	Combined Ash	None	--
1131	Streeter Station	1028	LF	Leversee Road	42.544536	-92.420248	--	--	--	Combined Ash	None	--
3152	Sunbury Generation LP	101	SI	Residual Waste Ash Basin No. 1	40.83027778	-76.83472222	62	1139	18.37096774	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
50951	Sunnyside Cogen Associates	944	LF	Sunnyside Ash Landfill - Landfill 1	39.53888889	-110.4105556	--	--	--	Combined Ash	None	--
1077	Sutherland	499	SI	Unit 3 Initial Settling Pond	42.047092	-92.85607	0.13	1	7.692307692	Combined Ash	--	--
1077	Sutherland	498	SI	Unit 1 & 2 Initial Settling Pond	42.047729	-92.855957	0.3	2	6.666666667	Combined Ash	--	--
1077	Sutherland	497	SI	Main Ash Settling Pond	42.047192	-92.854642	5.75	52	9.043478261	Combined Ash	--	--
1077	Sutherland	1117	LF	Marshalltown West	42.0686	-92.843121	17	--	--	Combined Ash	None	Excluded
1077	Sutherland	1118	LF	Marshalltown East	42.068625	-92.836794	2.58	86.46694215	33.51431866	Combined Ash	Clay	Excluded
10075	Taconite Harbor Energy Center	948	LF	Cell 2	47.53688389	-90.95482778	--	--	--	Combined Ash	Yes	--
10075	Taconite Harbor Energy Center	961	LF	Cell 3	47.536917	-90.954561	--	--	--	Combined Ash	Yes	--
10075	Taconite Harbor Energy Center	947	LF	Cell 1	47.53689083	-90.95415556	--	--	--	Combined Ash	Yes	--
988	Tanners Creek	418	SI	Fly Ash Pond - Clear Pond and Original (Lower Pond) Dike	39.07356944	-84.88386111	12	--	--	Combined Ash	Composite	--
988	Tanners Creek	417	SI	Fly Ash Pond - Upper Pond	39.07691667	-84.88013611	47.7	--	--	Combined Ash	None	--
988	Tanners Creek	419	SI	Fly Ash Pond	39.076917	-84.880136	60	1076	17.93333333	Combined Ash	Composite	--
988	Tanners Creek	950	LF	Ash Landfill	39.07527778	-84.875	--	--	--	Combined Ash	Yes	--
988	Tanners Creek	416	SI	Bottom Ash Complex	39.077375	-84.86681111	63.3	1645	25.98736177	Combined Ash	None	--
988	Tanners Creek	415	SI	Boiler Slag Pond (U-4)	--	--	20	820	41	Combined Ash	--	--
1252	Tecumseh Energy Center	519	SI	Area 2	39.05311111	-95.57283333	1	12	12	Combined Ash	None	--
1252	Tecumseh Energy Center	520	SI	Area 1	39.05219444	-95.57238889	2	20	10	Combined Ash	None	--
1252	Tecumseh Energy Center	1120	LF	Old Landfill	39.05583333	-95.56277778	--	--	--	Combined Ash	None	Excluded
1252	Tecumseh Energy Center	1133	LF	Landfill 322	39.04805556	-95.5625	32.2	331.6115702	10.29849597	Combined Ash	None	--
1252	Tecumseh Energy Center	995	LF	--	--	--	4.12	--	--	Combined Ash	--	--
2168	Thomas Hill	953	LF	MO-717502	39.53902583	-92.64948111	--	--	--	Combined Ash	None	--
2168	Thomas Hill	624	SI	Ash Pond Cell 2 - Middle	39.54277778	-92.63805556	12	31	2.583333333	Combined Ash	None	--
2168	Thomas Hill	627	SI	Ash Pond Slag Dewatering	39.54277778	-92.63805556	3	10	3.333333333	Combined Ash	None	--
2168	Thomas Hill	625	SI	Ash Pond Cell 1 - Upper	--	--	7	--	--	Combined Ash	--	--
2168	Thomas Hill	626	SI	Ash -3 Landfill	--	--	24	1050	43.75	--	--	--
2168	Thomas Hill	628	SI	Ash - 2 Landfill	--	--	44	1446	32.86363636	Combined Ash	--	--
2168	Thomas Hill	629	SI	Ash Pond Cell 3 - Lowest	--	--	10	50	5	Combined Ash	--	--
3115	Titus	955	LF	Old Ash Site (Flyash)	40.31472222	-75.91694444	--	--	--	Combined Ash	None	Excluded
3115	Titus	956	LF	Old Ash Site (Bottom Ash)	40.30944444	-75.91083333	--	--	--	Combined Ash	None	Excluded
3115	Titus	957	LF	Eyler Station Ash Site	40.31111111	-75.91083333	--	--	--	Combined Ash	None	Excluded
3115	Titus	954	LF	Beagle Club Ash Disposal Site	40.30583333	-75.90361111	39	1859.504132	47.67959313	Combined Ash	None	--
6194	Tolk	1161	LF	116	34.200988	-102.569056	--	--	--	Combined Ash	None	--

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
3845	TransAlta Centralia Generation	959	LF	Limited Purpose Landfill	46.75694444	-122.8166667	--	--	--	Combined Ash	Yes	--
1745	Trenton Channel Power Plant	960	LF	Sibley Quarry	42.16305556	-83.17472222	--	--	--	Combined Ash	None	--
1745	Trenton Channel Power Plant	585	SI	Pond	--	--	--	--	--	Combined Ash	--	--
6071	Trimble Co.	44	SI	Coal Combustion Waste Pond	38.59333333	-85.41777778	82	4841	59.03658537	Combined Ash	Clay	--
56224	TS Power Plant	816	LF	--	--	--	--	--	--	Combined Ash	--	--
7030	Twin Oaks Power One	928	LF	Ash Landfill	31.097149	-96.684213	61	3807.317975	62.41504877	Combined Ash	Yes	--
1361	Tyrone	537	SI	Ash Pond	38.04972222	-84.84527778	13	--	--	Combined Ash	None	--
1361	Tyrone	536	SI	Secondary Ash Pond	38.05138889	-84.84361111	1.2	--	--	Combined Ash	None	--
3295	Urquhart	1107	LF	Urquhart Landfill 1	33.429539	-81.91508	--	--	--	Combined Ash	None	--
3295	Urquhart	111	SI	Ash Pond	33.43527778	-81.91166667	9	--	--	Combined Ash	None	--
3295	Urquhart	110	SI	Ash Pond 1	--	--	1	11	11	Combined Ash	--	--
3295	Urquhart	112	SI	Ash Pond 2	--	--	1	7	7	Combined Ash	--	--
4042	Valley	920	LF	System Control Center Ash Landfill	43.05555556	-88.21694444	--	--	--	Combined Ash	Yes	Excluded
4042	Valley	919	LF	Highway 59 Ash Landfill	43.01222222	-88.19583333	--	--	--	Combined Ash	None	Excluded
4042	Valley	918	LF	Highway 32 Ash Landfill	43.342715	-87.915031	--	--	--	Combined Ash	Yes	--
4042	Valley	949	LF	Caledonia Ash Landfill	42.83861111	-87.84166667	16.4	330.9917355	20.1824229	Combined Ash	Yes	--
477	Valmont	1122	LF	Valmont Station ADF	40.028601	-105.203106	--	--	--	Combined Ash	None	--
477	Valmont	1123	LF	Closed Valmont Station ADF	40.03193056	-105.1951417	--	--	--	Combined Ash	None	Excluded
477	Valmont	329	SI	West Ash Settling Pond	--	--	1	16	16	Combined Ash	--	--
477	Valmont	330	SI	East Ash Settling Pond	--	--	1	16	16	Combined Ash	--	--
477	Valmont	331	SI	Coal Pile Stormwater Runoff Pond	--	--	--	--	--	Combined Ash	--	Excluded
897	Vermilion	395	SI	North Ash Pond System	40.18636944	-87.74571944	80	2400	30	Combined Ash	None	Excluded
897	Vermilion	396	SI	New East Ash Pond System	40.17841944	-87.73732222	20.6	340	16.50485437	Combined Ash	None	Excluded
897	Vermilion	970	LF	--	--	--	--	--	--	Combined Ash	--	Excluded
6073	Victor J. Daniel Jr	924	LF	CAMU - Central Ash Mngt. Unit	30.54972222	-88.56111111	--	--	--	Combined Ash	Yes	--
6073	Victor J. Daniel Jr	1124	LF	NAMU - North Ash Mngt. Unit	30.54305556	-88.55833333	49.2016308	--	--	Combined Ash	Yes	--
6073	Victor J. Daniel Jr	925	LF	-999	--	--	--	--	--	Combined Ash	--	Excluded
6073	Victor J. Daniel Jr	938	LF	-999	--	--	--	--	--	Combined Ash	--	Excluded
6073	Victor J. Daniel Jr	45	SI	EPRI 7	--	--	20.0387942	--	--	Ash & Coal Refuse	--	--
6019	W H Zimmer	26	SI	Wastewater Pond Complex	38.878405	-84.22883	15	75	5	FGD Waste	Clay	--
6019	W H Zimmer	929	LF	Class III Residual	38.85611111	-84.16777778	--	--	--	Combined Ash	Yes	--
3470	W. A. Parish	1125	LF	WAP Landfill	29.50888889	-95.62805556	28.6832221	--	--	Combined Ash	Yes	--
3470	W. A. Parish	136	SI	Air Preheater Pond	--	--	1	4	4	Combined Ash	--	Excluded

Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
3470	W. A. Parish	137	SI	Unit 5 Bottom Ash Overflow Basin	--	--	--	--	--	Combined Ash	--	--
3470	W. A. Parish	138	SI	Flue Gas Desulfurization Emergency Pond (E-Pond)	--	--	--	2	--	FGD Waste	--	--
3470	W. A. Parish	139	SI	Unit 8 Bottom Ash Overflow Basin	--	--	--	--	--	Combined Ash	--	--
3470	W. A. Parish	140	SI	Unit 7/8 Dewatering Bin Basin	--	--	--	--	--	Combined Ash	--	Excluded
3470	W. A. Parish	141	SI	Unit 7 Bottom Ash Overflow Basin	--	--	--	--	--	Combined Ash	--	--
3470	W. A. Parish	142	SI	Coal Pile Run Off Pond	--	--	24	110	4.583333333	Combined Ash	--	Excluded
3470	W. A. Parish	143	SI	Unit 6 Bottom Ash Overflow Basin	--	--	--	--	--	Combined Ash	--	--
2866	W. H. Sammis	916	LF	Hollow Rock	40.51166667	-80.68	141.6	624.0128558	4.406870451	Combined Ash	Composite	--
2866	W. H. Sammis	1383	SI	South Ash Pond	40.52722222	-80.63027778	4.61432507	64.60055096	14	Combined Ash	None	--
2866	W. H. Sammis	1382	SI	North Ash Pond	40.52805556	-80.63027778	5.09641873	71.16620753	13.96396396	Combined Ash	None	--
3264	W. S. Lee	105	SI	Secondary Ash Pond	34.60424722	-82.44513056	23	391	17	Combined Ash	None	--
3264	W. S. Lee	106	SI	Primary Active Ash Pond	34.60294167	-82.44166667	41	779	19	Combined Ash	None	--
2716	W.H. Weatherspoon Plant	667	SI	Ash Pond	34.59083333	-78.97	54.5	1375	25.2293578	Combined Ash	None	Excluded
1010	Wabash River	462	SI	South Ash Pond	39.51	-87.425	70	1450	20.71428571	Combined Ash	Composite	--
1010	Wabash River	465	SI	Primary Ash Pond Cell A	39.518056	-87.421389	69	1350	19.56521739	Combined Ash	None	--
1010	Wabash River	464	SI	Primary Ash Pond Cell B	39.51805556	-87.42138889	21	530	25.23809524	Combined Ash	None	--
1010	Wabash River	463	SI	Secondary Ash Pond	39.515	-87.42111111	7	73	10.42857143	Combined Ash	None	--
2830	Walter C Beckjord	698	SI	Ash Pond A	38.99916667	-84.29833333	83.2	--	--	Combined Ash	None	Excluded
2830	Walter C Beckjord	697	SI	Ash Pond B	38.99472222	-84.29527778	50	280	5.6	Combined Ash	None	--
2830	Walter C Beckjord	696	SI	Ash Pond C	38.98583333	-84.29416667	45	1400	31.11111111	Combined Ash	None	--
2830	Walter C Beckjord	695	SI	Ash Pond C ext.	38.97777778	-84.29305556	58	1300	22.4137931	Combined Ash	None	Excluded
2830	Walter C Beckjord	1127	LF	Beckjord Ash Landfill	39.003333	-84.281388	126	--	--	Combined Ash	None	Excluded
2830	Walter C Beckjord	1126	LF	Pond Run Ash Disposal	38.995	-84.27916667	99	3595.041322	36.31354871	Combined Ash	Clay	--
1082	Walter Scott Jr. Energy Center	932	LF	Monofill	41.1622	-95.83461111	66.9	5578.512397	83.38583553	Combined Ash	Composite	--
1082	Walter Scott Jr. Energy Center	502	SI	North Surface Impoundment	--	--	171	2046	11.96491228	Combined Ash	None	--
1082	Walter Scott Jr. Energy Center	503	SI	South Surface Impoundment	--	--	133	1326	9.969924812	Combined Ash	None	--
6052	Wansley	35	SI	Ash Pond	--	--	343	16920	49.32944606	Ash & Coal Refuse	None	--
6705	Warrick Power Plant	224	SI	EPRI 9	--	--	140	2789.256198	19.92325856	Ash & Coal Refuse	--	--
3297	Wateree	933	LF	Wateree	33.824072	-80.63195	--	--	--	Combined Ash	Yes	--
3297	Wateree	114	SI	Ash Pond No. 1	33.82061111	-80.62081944	80	1200	15	Combined Ash	None	--
3297	Wateree	113	SI	Ash Pond No. 2	33.81611111	-80.61638889	80	1200	15	Combined Ash	None	--
883	Waukegan	1311	SI	East Ash Pond	42.37888889	-87.81444444	10	110	11	Ash & Coal Refuse	Composite	--
883	Waukegan	1312	SI	West Ash Pond	42.37888889	-87.81444444	10.1	111.1	11	Ash & Coal Refuse	Composite	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
6139	Welsh	177	SI	Primary Ash Pond	33.04975	-94.84635833	98.1	307	3.129459735	Combined Ash	None	--
6139	Welsh	934	LF	Ash landfill	33.04794444	-94.84608333	--	--	--	Combined Ash	None	--
6139	Welsh	175	SI	Active Bottom Ash Storage	33.04425833	-94.84401389	20	270	13.5	Combined Ash	Composite	--
6139	Welsh	176	SI	Secondary Ash Pond	33.04848611	-94.84154444	4.2	37	8.80952381	Combined Ash	None	--
4078	Weston	1318	SI	Tertiary BAT W3&4	44.85388889	-89.65805556	1.04196511	4.784022039	4.59134573	Combined Ash	Clay	--
4078	Weston	936	LF	Weston Onsite Ash Landfill #2879	44.85611111	-89.65611111	--	--	--	Combined Ash	None	Excluded
4078	Weston	1317	SI	South Secondary BAT W3&4	44.85361111	-89.655	2.95748393	14.08613407	4.762877635	Combined Ash	Clay	--
4078	Weston	1316	SI	North Secondary BAT W3&4	44.85444444	-89.655	2.83133609	13.60479798	4.805080554	Combined Ash	Clay	--
4078	Weston	1314	SI	North Primary BAT W3&4	44.85416667	-89.65388889	0.19338843	0.096694215	0.5	Combined Ash	Clay	--
4078	Weston	1315	SI	South Primary BAT W3&4	44.85361111	-89.65361111	0.18728191	0.093640955	0.5	Combined Ash	Clay	--
4078	Weston	1313	SI	W1&2 Seepage Basin	44.86277778	-89.6525	6.51551882	38.99609734	5.985110071	Combined Ash	None	--
4078	Weston	935	LF	Weston Ash - Legner	44.72361111	-89.63694444	18	371.9008265	20.66115703	Combined Ash	Yes	--
60	Whelan Energy Center Unit 1 (WEC1)	1214	SI	Ash Pond	40.578403	-98.313878	22.9568411	183.6547291	8	Combined Ash	Yes	--
6009	White Bluff	1128	LF	Ash Landfill	34.41694444	-92.14888889	--	--	--	Combined Ash	Yes	--
1040	Whitewater Valley	1323	SI	Aux Settling Pond A3	39.804328	-84.896458	0.168	--	--	Combined Ash	None	Excluded
1040	Whitewater Valley	1321	SI	Aux Settling Pond A1	39.803906	-84.896317	0.259	--	--	Combined Ash	None	Excluded
1040	Whitewater Valley	1324	SI	Aux Settling Pond A4	39.803561	-84.896272	0.235	--	--	Combined Ash	None	Excluded
1040	Whitewater Valley	1325	SI	Bottom Ash Sluicing Pond	39.803561	-84.896272	0.18939394	1.147842057	6.060606061	Combined Ash	None	--
1040	Whitewater Valley	1322	SI	Aux Settling Pond A2	39.804125	-84.896206	0.17	--	--	Combined Ash	None	Excluded
4057	WI Power & Light Co -Rock River Generating	2	SI	Slag Pond	42.577814	-89.031436	3	29	9.666666667	Combined Ash	--	--
4057	WI Power & Light Co -Rock River Generating	3	SI	WPDES Pond 2	42.576967	-89.03059	1	14	14	Combined Ash	--	--
4057	WI Power & Light Co -Rock River Generating	1	SI	WPDES Pond 1	42.577944	-89.030346	2	17	8.5	Combined Ash	--	--
4057	WI Power & Light Co -Rock River Generating	172	SI	Final WPDES Pond	42.580952	-89.030247	4	29	7.25	Combined Ash	--	--
50	Widows Creek	59	SI	Bottom Ash Stack	--	--	32	--	--	Combined Ash	None	--
50	Widows Creek	60	SI	Dredge Cell	--	--	116	--	--	Combined Ash	None	--
50	Widows Creek	61	SI	Gypsum Stack Pond 1	--	--	10	--	--	FGD Waste	None	--
50	Widows Creek	62	SI	Gypsum Stack Pond 2A	--	--	12	--	--	FGD Waste	None	--
50	Widows Creek	63	SI	Gypsum Stack Pond 2B	--	--	14	--	--	FGD Waste	None	--
50	Widows Creek	64	SI	Gypsum Stack Pond 3	--	--	59	--	--	FGD Waste	None	--
50	Widows Creek	65	SI	Gypsum Stack Stilling Pond	--	--	9	--	--	FGD Waste	None	--
50	Widows Creek	66	SI	Pump Pond	--	--	0.25	--	--	FGD Waste	None	--
50	Widows Creek	261	SI	Ash Pond	--	--	156	11709	75.05769231	Combined Ash	--	--
50	Widows Creek	262	SI	Gypsum Stack (Wet Stacking Area)	--	--	110	10961	99.64545455	Combined Ash	--	--

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Attachment A-2. WMU Information

Oris Code	Plant Name	WMU ID	WMU Type	Unit Name	Latitude	Longitude	WMU Area (acres)	WMU Capacity (acre-ft)	WMU Depth (ft)	WMU Waste Type	WMU Liner Type	Shown in Results?
50	Widows Creek	289	SI	Red Water Pond	--	--	32	--	--	Combined Ash	None	--
50	Widows Creek	290	SI	Upper/Lower Stilling Pond	--	--	8	--	--	FGD Waste	None	--
884	Will County	389	SI	EPRI 3	--	--	--	--	--	--	--	Excluded
3298	Williams	1130	LF	Hwy 17A	33.14988889	-80.05594444	--	--	--	Combined Ash	Yes	--
3298	Williams	1129	LF	Hwy 52	33.11430556	-80.04661111	--	--	--	Combined Ash	Yes	--
3946	Willow Island	917	LF	-999	--	--	--	--	--	Combined Ash	Yes	--
6249	Winyah	199	SI	West Ash Pond	33.33189167	-79.37042778	62	1178	19	Combined Ash	None	--
6249	Winyah	198	SI	Unit 3 & 4 Slurry Pond	33.33744722	-79.36841111	100	1700	17	FGD Waste	None	--
6249	Winyah	200	SI	South Ash Pond	33.32435278	-79.35452222	61	1129	18.50819672	Combined Ash	None	--
6249	Winyah	202	SI	Ash Pond B	33.31872222	-79.35136111	63	537	8.523809524	Combined Ash	None	--
6249	Winyah	203	SI	Unit 2 Slurry Pond	33.33065	-79.35086667	34	416	12.23529412	FGD Waste	None	--
6249	Winyah	201	SI	Ash Pond A	33.325525	-79.34736111	88	807	9.170454545	Combined Ash	None	--
6249	Winyah	982	LF	--	--	--	--	--	--	Combined Ash	--	--
898	Wood River	398	SI	West Ash Pond (2 cells) Cells 2E and 3	38.86955278	-90.14046111	19	210	11.05263158	Combined Ash	Clay	--
898	Wood River	397	SI	East Ash Pond (2 cells)	38.86821944	-90.13142778	38	435	11.44736842	Combined Ash	Composite	--
50611	WPS Westwood Generation, LLC	951	LF	Closed Ash Landfill	40.62305556	-76.45194444	--	--	--	Combined Ash	Yes	Excluded
6101	Wyodak Plant	80	SI	Wyodak	44.28888889	-105.3911111	15.5	320	20.64516129	Combined Ash	None	--
6101	Wyodak Plant	981	LF	--	--	--	68	2169.421489	31.90325718	Combined Ash	--	--
728	Yates	987	LF	Gypsum Solid Waste Facility	33.46638889	-84.9	--	--	--	Combined Ash	Yes	--
728	Yates	986	LF	R-6 Ash Monofill	33.453585	-84.895905	--	--	--	Combined Ash	None	--
728	Yates	367	SI	Ash Pond 3	--	--	69	434	6.289855072	Combined Ash	None	--
728	Yates	368	SI	Pond B	--	--	6	--	--	Combined Ash	None	Excluded
728	Yates	369	SI	Ash Pond 1	--	--	17	184	10.82352941	Combined Ash	None	--
728	Yates	370	SI	Ash Pond 2	--	--	50	1103	22.06	Combined Ash	None	--
728	Yates	371	SI	B' Pond	--	--	30	298	9.933333333	Combined Ash	None	--
728	Yates	372	SI	Gypsum Solid Waste Facility	--	--	16	135	8.4375	FGD Waste	Composite	--
728	Yates	373	SI	Pond A	--	--	19	--	--	Combined Ash	None	Excluded
728	Yates	374	SI	Pond C	--	--	12	--	--	Combined Ash	None	Excluded
3809	Yorktown	1359	SI	Finger Ponds	37.21638889	-76.45777778	4.775	--	--	Combined Ash	Yes	Excluded
3809	Yorktown	988	LF	Ash Landfill	37.215975	-76.442493	48	991.7355372	20.66115702	Combined Ash	Clay	--

Appendix B.

Environmental Parameter Data

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B.1 Introduction

The U.S. Environmental Protection Agency (EPA or the Agency) used the facility and waste management unit (WMU) locations discussed in **Appendix A** to identify site-specific data on soil type, hydrogeologic environment, climate and nearby surface water bodies. Where possible, environmental data were collected using geographic information system (GIS) software to associate geographic coordinates for each WMU to site-specific and region-specific data. However, because uncertainty remained about the precise location for some units, EPA pulled data from a two-kilometer radius around the facility centroid to effectively capture local variability. Regional data were collected by assigning each facility to the nearest reference point in national databases, such as the Hydrologic Evaluation of Landfill Performance (HELP) model climate stations and the U.S. Geological Survey (USGS) hydrological regions. Whenever environmental parameters could not be linked based on location, EPA relied on national distributions.

Information about the methods used to collected and analyze these data is provided below. **Attachment B-1** provides the specific soil texture, pH and organic carbon content associated with each facility. **Attachment B-2** provides hydrogeologic environments. **Attachment B-3** provides climate center, precipitation rate and infiltration rate. **Attachment B-4** provides USGS Hydrologic Region; distance to nearest water body; and water body mean recharge, area, length, mean annual flow and mean annual velocity.

B.2 Soil Data

The ground water model used in the revised risk assessment, EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP), requires the properties of the entire soil column to model leachate transport through both the unsaturated (vadose) and saturated (ground water table) zones. Soil data were collected using either the reported WMU location and footprint or, where WMU locations were not available, a two-kilometer radius around each facility centroid.

B.2.1 Data Sources

The primary data source for soil properties was the State Soil Geographic (STATSGO) database. STATSGO is a repository of nationwide soil properties compiled primarily by the U.S. Department of Agriculture (USDA) from county soil survey data (USDA, 1994). STATSGO includes 1:250,000-scale GIS coverage that delineates the conterminous United States into map units and an associated database that contains soil data for each map unit. The map units that overlap with either the WMU footprint or two-kilometer radius surrounding a facility, as appropriate, were used to spatially represent soils in the database. USSOILS (Schwarz and Alexander, 1995) and Conterminous United States Multilayer Soil Characteristics (CONUS-SOIL) (Miller and White, 1998) are simplified compilations of STATSGO data which were used to collect soil properties.

- **USSOILS.** The USSOILS data set averages STATSGO data vertically over the entire soil column for each map unit (Schwarz and Alexander, 1995). USSOILS aggregates the STATSGO layer and component information up to the level of a map unit by depth-

averaging median properties within a component over the entire soil column and then area-averaging component values across a map unit.[1]

- **CONUS-SOIL.** The CONUS-SOIL soil data set was compiled by the Earth System Science Center in the College of Earth and Mineral Sciences at Pennsylvania State University (Miller and White, 1998). CONUS contains STATSGO soil properties averaged to 11 standard layer depths from the STATSGO layers to a total depth of 2.5 m. Within each STATSGO map unit and CONUS standard layer, soil properties either represent the predominant property (as with soil texture) or are area-weighted averages of STATSGO component values.[2]

B.2.2 Methodology

EPA first collected soil pH and organic matter data from USSOILS and soil texture data from CONUS-SOIL for each map unit. Soil texture data were used to provide nationally correlated bulk density, saturated water content, saturated hydraulic conductivity, and the van Genuchten soil moisture retention parameters (alpha and beta) based on Carsel and Parrish (1988) and Carsel et al. (1988). GIS software was then used to overlay the WMU footprint or the two-kilometer radius onto the STATSGO map to determine which STATSGO map units fell within these boundaries. Using these overlays, EPA calculated the percent of that bounded area that fell within each map unit. These percentages were used to allow probabilistic sampling of the soil texture, pH, and organic matter data for each WMU.

Table B-1. Soil Texture Crosswalk

STATSGO SCS Soil Texture	EPACMTP Soil Megatexture
Sand	Sandy Loam
Loamy Sand	
Sandy Loam	
Silt Loam	Silt Loam
Silt	
Loam	
Sandy Clay Loam	
Clay Loam	
Silty Clay Loam	Silty Clay Loam
Sandy Clay	
Silty Clay	
Clay	

SCS = Soil Conservation Service

Table B-1 shows the crosswalk that was used to assign the SCS textures to the EPACMTP megatextures. Soil data used for modeling is presented in **Attachment B-1**. STATSGO soils are classified into 12 Soil Conservation Service (SCS) soil textures, but EPACMTP uses three soil megatextures to represent the variability of hydrologic soil properties. Therefore, each STATSGO soil texture was crosswalked in a database to the EPACMTP megatexture with the most similar hydrogeologic properties. When merging these soil texture entries, EPA aggregated the percentages of map units that fell within the same megatexture and averaged both the pH and organic matter proportionally.

[1] Metadata on USSOILS are available online at: water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml

[2] Additional information on CONUS is available online at: www.soilinfo.psu.edu/index.cgi?soil_data&conus

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B.3 Hydrogeologic Environment Data

Each facility modeled in this analysis was assigned one or more hydrogeologic environment(s) from EPA's Hydrogeologic Database (HGDB) in order to characterize four subsurface parameters required by EPACMTP: depth to ground water, aquifer thickness, hydraulic gradient, and saturated hydraulic conductivity. The HGDB was developed by the American Petroleum Institute (Newell et al., 1989; 1990) to specify correlated empirical probability distributions of these four parameters for the 12 distinct hydrogeologic environments described in Newell et al. (1990). To assign the HGDB distributions to the CCR WMUs modeled in this assessment, EPA first developed a national geographic coverage of the 12 hydrogeologic environments, and then used GIS software to overlay the CCR WMU locations and dimensions, and assign the hydrogeologic environments to each WMU.

B.3.1 Data Sources

EPACMTP uses the HGDB for national and regional analyses. Therefore, it was necessary to assign each facility to one or more hydrogeologic environments corresponding to the HGDB data set. Given the national scale of the risk assessment, only national data sets were used to delineate hydrogeologic environments, defined by an approximate 1:7,500,000 map scale. The following individual map layers were combined using GIS software to develop a single map layer for assigning the 12 hydrogeologic environments across the United States:

- **Shallowest principal aquifers** from *Principal Aquifers of the Conterminous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands* [USGS map file: aquifrp025]. 1:2,500,000 map scale, was used as the base layer in the assessment and to delineate several of the 12 hydrogeologic environments.
- **Alluvial and glacial aquifers** from *Aquifers of Alluvial and Glacial Origin* [USGS map file: alvaqfp025]. 1:2,500,000 map scale, was used to represent alluvial and glacial aquifers for the 22 states north of the southernmost line of glaciation. Note that the alluvial aquifers in this coverage are identical to those in the Hunt (1979) surficial geology layer below.
- **Surficial geology** of the conterminous United States was taken from:
  - *Surficial Geology of the Conterminous United States* [map file: geol75m]. 1:7,500,000 map scale, provided by Hunt (1979), these data was used to characterize shallow soil lithology and alluvial aquifers.
  - *The Surficial Deposits and Materials in the Eastern and Central United States (East of 102 degrees West Longitude)* [map file: sfgeoep020]. 1:1,000,00 map scale, includes the line of maximum glacial advance and represents surficial materials that have accumulated or formed during the past two million years, including residual soils, alluvium, and glacial deposits.
- **Karst aquifers** from *Engineering Aspects of Karst* [map file: karst0p075], 1:7,500,000-map scale, showing karst and pseudokarst (i.e., karst-like terrain produced by processes other than the dissolution of rocks) across the United States.

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- **Bedrock geology** from *Generalized Geologic Map of the United States* [map file: geolgyp075], 1:7,500,00 map scale, showing the bedrock geology at or near land surface (i.e., beneath surficial soils, alluvium and glacial deposits).
- **STATSGO soils,** 1:250,000 map scale, from the digital map and attribute data for soils described in **Section B.2**.

As described below, these data layers were used to develop a national GIS hydrogeologic environment layer for assigning an aquifer type to a point or area of interest.

B.3.2 Methodology

To create the hydrogeologic environment layer, each individual data layer described above was obtained as a GIS shapefile and processed as needed to ensure that coordinate systems matched and the layers could be overlain. **Table B-2** describes how the polygons comprising the 12 hydrogeologic environments were developed in the GIS using these layers.

Table B-2. GIS Procedures for Assembling National Coverage of Hydrogeologic Environments [map file name in square brackets].

Hydrogeologic Environment		Description
1)	Metamorphic and igneous rock	Select polygons where ROCK_NAME = "igneous and metamorphic-rock aquifers" from the principal aquifer layer [aquifrp025] AND "igneous" or "metamorphic" polygons from the bedrock geology layer [geolgyp075] AND polygons from the Hunt (1979) surficial geology layer [geol75m] derived from or directly overlaying igneous or metamorphic rock.
2)	Bedded sedimentary rock	Select polygons where the ROCK_NAME = "sandstone and carbonate-rock aquifers" OR AQ_NAME was "Other rocks" from the principal aquifer layer [aquifrp025] AND "sedimentary" polygons from the bedrock geology layer [geolgyp075].
3)	Till over sedimentary rock	Select polygons that had a surficial geology [geol75m] = "mg: deposits of mountain glaciers", "tg: till or ground moraine" "ts: ice-laid deposits, like tg but mostly sand and silt", OR "ts/K,T: thin ice-laid deposits, like ts but thin and discontinuous. . ..", AND overlaying "sedimentary" polygons from the bedrock geology layer [geolgyp075].
4)	Sand and gravel	Select polygons where AQ_NAME = "other rocks" OR "high plains aquifer" from the principal aquifer layer [aquifrp025] AND sand and gravel related names in SURFICIALG from the Hunt (1979) surficial geology layer [geol75m] (SURFICIALG contained many different types of sand and gravel deposits).
5)	Alluvial valleys, basins and fans	Select polygons where AQ_NAME = "Unconsolidated sand and gravel aquifers" from the principal aquifer layer [aquifrp025] name OR surficial geology type (SURFICIALG) was either "fg: fan gravels" or "fs: fan sands" in the Hunt (1979) surficial geology layer [geol75m].

(continued)

Table B-2. GIS Procedures for Assembling National Coverage of Hydrogeologic Environments [map file name in square brackets].

Hydrogeologic Environment		Description
6)	River valleys and floodplains with overbank deposits	Select polygons where SURFICIALG = "al: floodplain and alluvium gravel terraces" in Hunt (1979) surficial geology layer [geol75m] AND STATSGO soils with < 50% sand AND a low permeability (< 0.0147 inches per hour).
7)	River valleys and floodplains without overbank deposits	Select polygons where SURFICIALG = "al: floodplain and alluvium gravel terraces" in Hunt (1979) surficial geology layer [geol75m] AND STATSGO soils that do NOT have < 50% sand AND a low permeability (< 0.0147 inches per hour).
8)	Outwash	Select polygons where ORIGIN_AGE = "glaciofluvial (outwash) deposits" in the Surficial Deposits and Materials layer [sfgeomean020] AND where SURFICIALG = anything but "ts: ice-laid deposits, like tg but mostly sand and silt" in the Hunt (1979) surficial geology layer [geol75m].
9)	Till and till over outwash	Select polygons from Hunt (1979) surficial geology layer [geol75,] that were not already classified hydrogeologic environment 8 AND where SURFICIALG = "w: gravel, sand and clay deposited by glacial streams adjacent to or downstream from temporary ice fronts" OR "ts: ice-laid deposits, like tg but mostly sand and silt" OR "tg: till, or ground moraine".
10)	Unconsolidated and semi-consolidated shallow aquifers	Select polygons where AQ_NAME = "coastal lowlands aquifer system," "Mississippi embayment aquifer system," "Northern Atlantic Coastal Plain aquifer system," "Southeast Coastal Plain aquifer system," "Texas coastal uplands aquifer system," or "surficial aquifer system." from the principal aquifers layer [aquifrp025].
11)	Coastal beach	Select polygons where SURFICIALG = "si: sea islands" from the Hunt (1979) surficial geology layer [geol75m].
12)	Solution limestone	Select polygons where ROCK_NAME contains "carbonate-rock aquifers," "sandstone and carbonate-rock aquifers", "unconsolidated sand and gravel aquifers," OR "sandstone aquifers" from the principal aquifer layer [aquifrp025] AND, for the last two only, are defined as areas of karst in the Engineering Aspects of Karst layer [karst0p075]

B.3.3 Data Processing

One or more of the 12 hydrogeological environments was assigned to each WMU footprint or two-kilometer region surrounding a facility, as appropriate, and the percentages of each assigned environment within the data collection area was determined and included with the assignments. When there was more than one environment assigned to a WMU (in cases where the assignment or location was uncertain), the hydrogeological environment was varied probabilistically based on these percentages during each Monte Carlo iteration for a particular WMU. **Table B-3** summarizes these assignments, showing the number of CCR facilities, surface impoundments and landfills for each hydrogeologic environment sent to EPACMTP.

Table B-3. Number of Facilities and WMUs in Each Hydrogeologic Environment

Hydrogeologic Environment		Facilities (2-km radius)	Impoundments (Boundary)	Landfills (Boundary)
1)	Metamorphic and igneous	20	46	19
2)	Bedded sedimentary rock	85	198	93
3)	Till over sedimentary rock	18	48	28
4)	Sand and gravel	47	94	43
5)	Alluvial basins valleys and fans	7	27	5
6)	River valleys and floodplains with overbank deposits	141	335	86
7)	River valleys and floodplains without overbank deposits	119	259	70
8)	Outwash	17	44	16
9)	Till and till over outwash	16	31	13
10)	Unconsolidated and semi-consolidated shallow aquifers	43	100	64
11)	Coastal beaches	2	0	4
12)	Solution limestone	42	92	34

Once the hydrogeologic environments were assigned, a preprocessing run of EPACMTP was conducted to construct a set of randomly generated but correlated hydrogeologic parameter values (i.e., depth to ground water, aquifer thickness, hydraulic gradient, and saturated hydraulic conductivity) for each occurrence of the hydrogeologic environments in the source data files. Missing values in the HGDB data set were filled using correlations during EPACMTP execution, as described in U.S. EPA (1997).

B.4 Climate Data

EPACMTP uses the climate station, along with soil texture, to select both the HELP-modeled infiltration rates in the landfill source model and the recharge rates to use in EPACMTP. Thus, the CCR risk assessment selected HELP meteorological (or climate) stations for each CCR disposal site to collect the climatic data necessary for fate and transport modeling.

To assign the EPACMTP/HELP climate centers to each facility, GIS software was used to determine the three climate centers closest to the facility and to get the long-term (1961–1990) annual average precipitation rate at each facility from a USGS coverage for the contiguous U.S.

(www.nationalatlas.gov; **Figure B-1**). The long-term average precipitation for each of the three closest EPACMTP climate centers was then compared with the precipitation for each facility location to select the climate station with the closest precipitation to the facility. **Attachment B-3** lists the climate center assigned to each CCR disposal facility along with the five-year average precipitation and HELP soil-specific infiltration/recharge rates for each station.

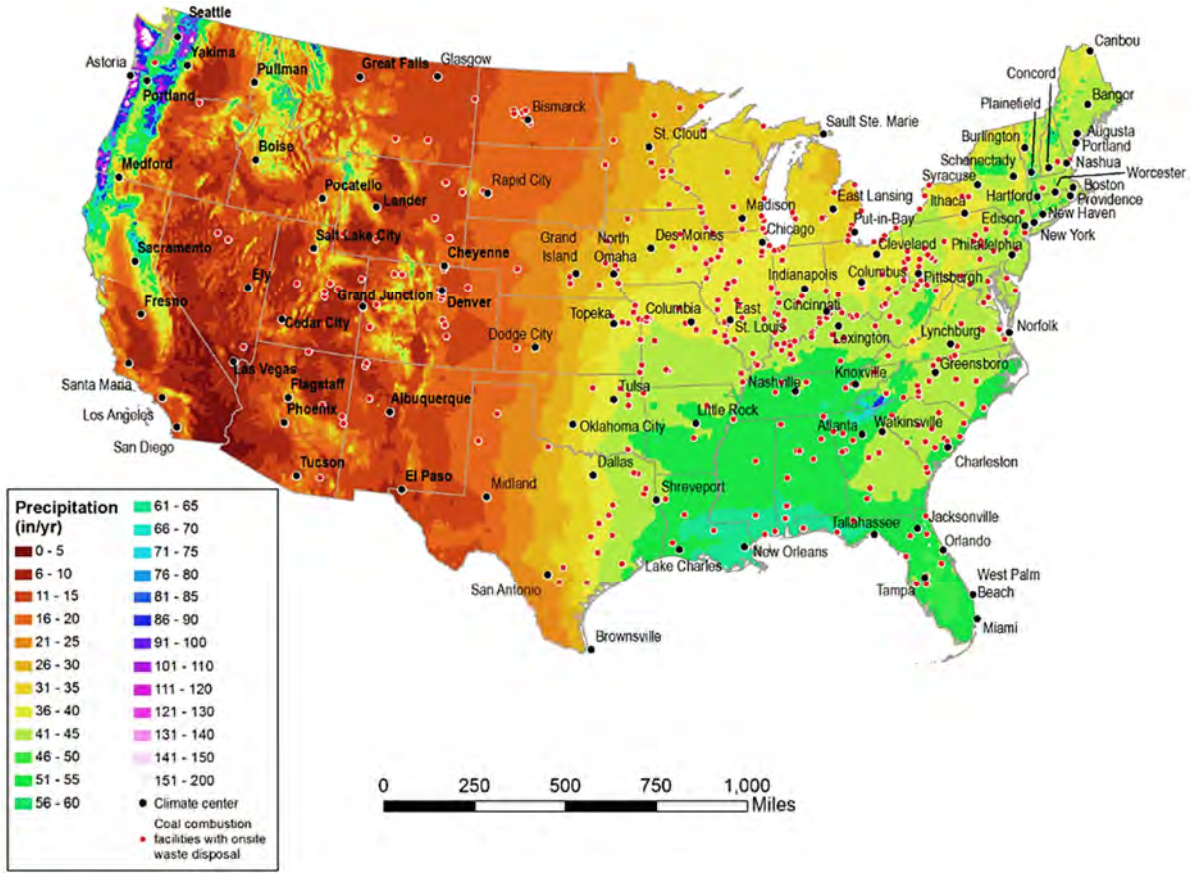

Figure B-1. EPACMTP climate centers, precipitation ranges and CCR disposal facilities.

B.5 Surface Water Data

The surface water model used in the revised risk assessment requires information on the water body type (stream or lake), flow conditions, dimensions and water quality for each surface water body. Data were collected on a site-based, regional or national basis depending on the specific parameter and data availability. Collection methods are discussed in the following subsections.

B.5.1 Data Sources

Data on surface water body characteristics and distances was necessary to calculate the fraction of the ground water plume intercepted by surface water bodies, as well as the resulting constituent concentrations in the surface water. Water body data were collected based on WMU location data, and consisted of the following sources:

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- **NHDplus.** NHDplus is a geospatial, hydrologic framework data set that integrates the features of the National Hydrography Dataset (NHD), the Watershed Boundary Dataset (WBD), and the National Elevation Dataset (NED).[3] The NHD represents the drainage network with features such as rivers, streams, canals, lakes, ponds, coastline, dams and stream gauges. The WBD represents drainage basins as enclosed areas in eight different size categories. Both these data sets represent surface waters at a nominal scale of 1:24,000, and use an integer value as a common identifier (COMID) that uniquely identifies the occurrence of each NHD feature. The NED provides basic elevation information for earth science studies and mapping applications in the United States.
- **STORET.** The STORET (STOrage and RETrieval) Data Warehouse is EPA's repository of the water quality monitoring data including total suspended solids (TSS), surface water temperatures, and surface water pH. These data were collected by water resource management groups across the country including states, tribes, watershed groups, other federal agencies, volunteer groups and universities.[4]

B.5.2 Selection of Nearest Water Body

Prior to collecting data on surface water bodies, EPA identified the nearest water bodies and associated ComIDs for each WMU. This was done for the purpose of evaluating ground water flow direction for discharge into a surface water body. EPA notes that topography often controls general shallow ground water flow. Thus, EPA used surface topography as a proxy for the direction of ground water flow in the shallow aquifers modeled in the revised risk assessment. The NHD*Plus* Flow Direction Grid (U.S. EPA and USGS, 2007) provided the foundation for evaluating the probable topographical course of overland runoff. EPA utilized an application of this grid, known as the "Raindrop Tool," to trace the downhill path a hypothetical raindrop is likely to follow as it flows overland until it intersects with the nearest surface water body, as defined by NHD features.[5]

This tool is useful for evaluating the path of a raindrop from a single point. However, WMUs were often large enough that different points within a given WMU may result in runoff to different surface water bodies. Thus, water bodies and ComIDs were identified in the following steps:

- The area of the WMU was idealized as a circle centered at the WMU longitude/latitude.
- Eight points were placed around the circumference of each WMU at equally spaced angles of 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°.
- For each of the eight points, the Raindrop Tool selected the surface water body/ComID pair to which the runoff discharged. Each of the eight starting points were assigned an equal probability of occurrence.

[3] Further detail on NHDPlus is available online at: www.horizon-systems.com/nhdplus/

[4] Additional information on STORET is available online at: www.epa.gov/storet/

[5] Further discussion is available online at: www.epa.gov/waters/doc/rad/raindrop.html

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- Where multiple points discharged to the same water body/ComID pair, the probabilities for that pair were aggregated.

For each surface water body/ComID pair identified, EPA collected the waterbody type, mean recharge rate, area, length, mean annual flow, and mean annual velocity from the NHDPlus.

Example results of this process are illustrated in **Figure B-2**. The dashed red lines represent the modeled raindrop pathlines, while the straight black lines represent the corresponding shortest straight-line distances from the WMUs to the surface water body. In cases where the projected rain drop flow path overlapped with the WMU footprint, an adjusted distance from where the straight-line distance exited the WMU footprint to the surface water body was used. In cases where the surface water body overlapped with the interior WMU footprint as a result of the idealized boundary, the distance from the water body to the WMU boundary was taken as representative. EPA notes that, since the actual boundary of the WMU already falls so close to the surface water body, the short distances resulting from this approach are believed to be representative. In addition to flow lines, the NHDPlus maintains a data set of polygons that represent larger water bodies, such as lakes and wide rivers. In some cases, the NHDPlus flow lines are located within the middle of the water body, while the polygon outlines the perimeter of the water body. In these cases, the distances to the NHDPlus polygons were used.

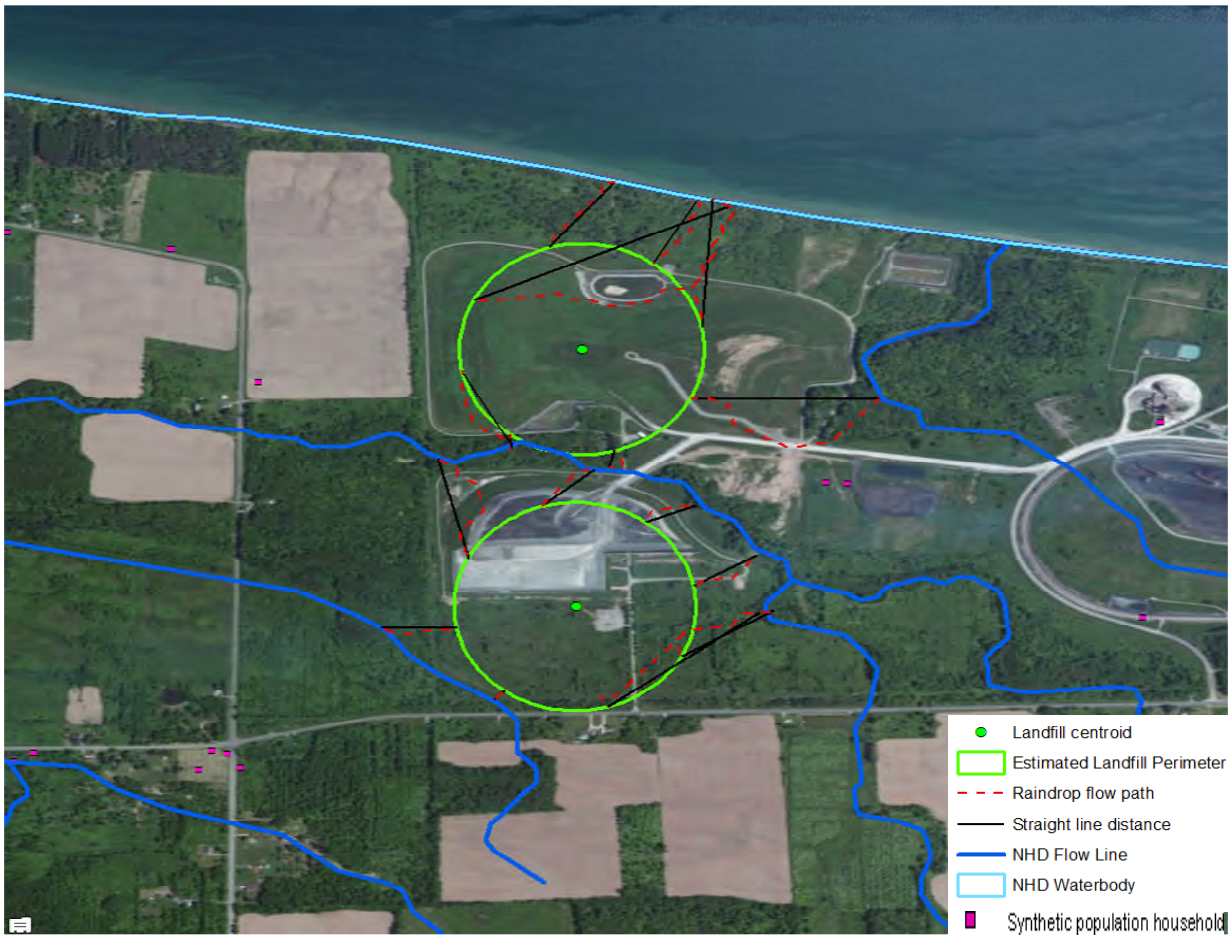

Figure B-2. Examples of surface water body identification results.

Some WMUs did not have location data to permit identification of the nearest water bodies. These units were probabilistically assigned distances and water bodies during the Monte Carlo analysis based on the distributions developed from data available for other impoundments or landfills. The resulting probability distributions are shown in **Figure B-3**. To minimize the potential for outliers at small distances to be selected for facilities without location data, minimum values were set at the first percentile for both surface impoundments (9.3 m) and landfills (19 m).

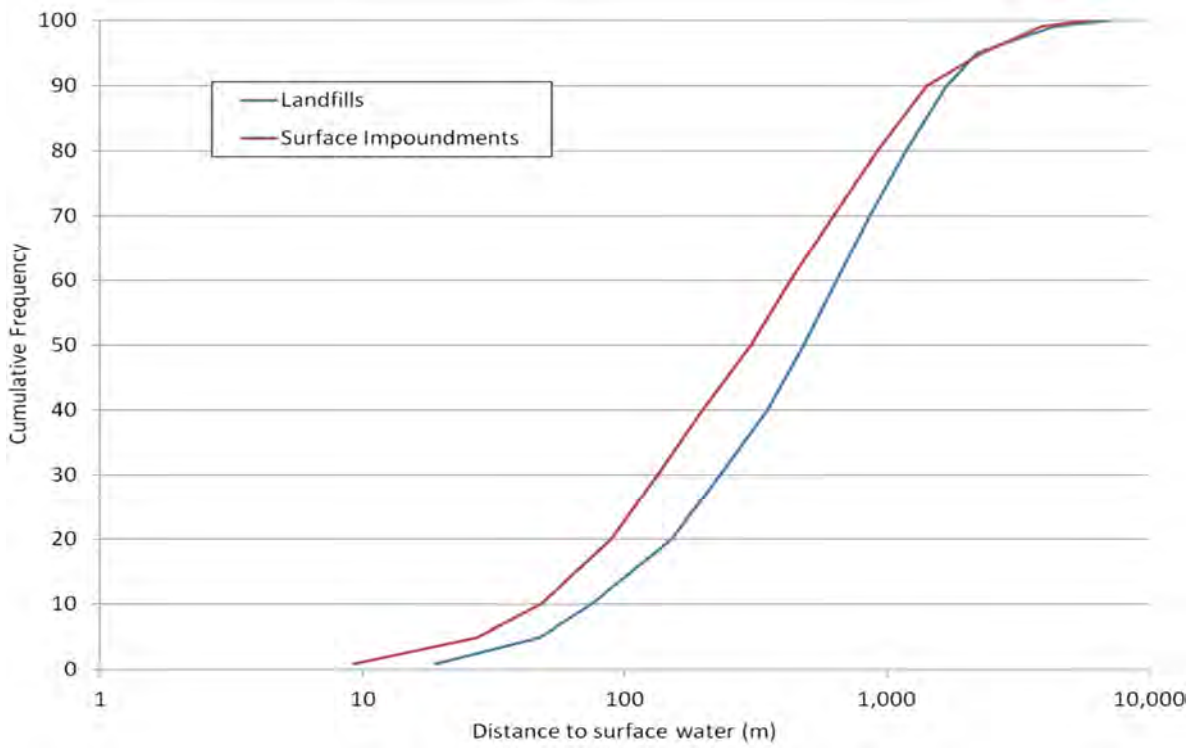

Figure B-3. Cumulative probability distributions for distance to surface water bodies.

B.5.3 Water Body Type

While there are several water body types in NHDplus, EPA only identified surface water models for streams and lakes. Thus, each of the NHDplus water body types needed to be designated as either a stream or a lake. Streams and rivers were designated as streams due to their measurable flow rates, while all other types were designated as lakes due to their negligible flow rates. **Table B-4** lists the NHDplus water body types identified near CCR WMUs and facilities, along with a crosswalk to the stream or lake designation assigned to that type.

Table B-4. NHDplus Water Body Types Assigned to CCR Disposal Facilities

NHDplus Water Body Type	Reach Model Type	Number of CCR Facilities	Surface Impoundments	Landfills
Connector	Stream	3	4	2
CanalDitch		11	11	6
ArtificialPath		173	372	148
Stream/River		264	540	416
Reservoir	Lake	3	2	2
Playa		2	11	0
Coastline		24	51	15
Lake/Pond		82	183	79

Stream Flow Conditions and Dimensions

NHDplus includes estimates of the mean annual stream flow rates for all flowing reaches, as well as the velocities that correspond to these mean flows. Stream dimensions were calculated from the NHDplus flow data as follows. First, the length of the modeled stream segment was set equal to the width of the ground water plume as it enters the water body, which was determined by EPACMTP. The stream width was then derived from the flow rate using an equation derived from empirical data by Kocher and Sartor (1997):

(B-1) $$W = 5.1867Q^{0.4559}$$

Where:

W = Stream width (L); and
Q = Mean annual stream flow rate (L^3/T)

The water column depth was then derived using the continuity equation, which assumes that a stream's flow rate is equal to the product of its cross-sectional area occupied by flow and mean flow velocity:

(B-2) $$Q = Av$$

Where:

A = Cross-sectional area occupied by flow (L^2); and
v = Mean annual stream flow velocity (L/T)

Rearranging and solving for water column depth (with dwc = A/W):

(B-3) $$dwc = \frac{Q}{vW}$$

Where:

dwc = Water column depth (L)

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Lake Flow Conditions and Dimensions

Exact areas and depths were not readily available for many of the lakes located near facilities from either NHDplus or other sources. In addition, some facilities were located on very large water bodies (e.g., the Great Lakes) where applying the simple steady-state, single-compartment model used in this analysis to the entire water body would not be appropriate because contamination would be localized to a specific portion of that water body. Thus, a single, small lake (or model lake) was used to represent all lake water body types assigned to the CCR disposal facility. This was considered appropriate because it captures the impact of localized effects through a conservative approximation of much larger lakes. The model lake chosen was Shipman City Lake in Illinois, which is a well characterized 13-acre lake previously selected by EPA as the index reservoir for modeling drinking water exposures to pesticides (Jones et al., 1998). The parameter values for Shipman City Lake are shown in **Equation B-4**.

(B-4) $$V = \frac{A(dwc)}{HRT}$$

where:

V = Annual flow mixing volume (L3/T);
A = Area (13 acres);
dwc = Water column depth (9 ft); and
HRT = Hydraulic residence time [1 month (min), 6 months (mean), 24 months (max)].

B.5.4 Stream and Lake Water Quality Data

EPA's STORET system is the largest single source of water quality data in the country, containing over 275 million analyses performed on more than 45 million samples collected from 800,000 stations across the United States between the years of 1960 and 1998. Data on raw surface water temperature, TSS and pH were collected from the legacy STORET database based on the assigned USGS hydrologic region for use in the surface water model. However, the STORET website states:

> *"The EPA does not change or filter incoming data. This means that when pulling data out of the Warehouse, users must be aware that they are responsible for screening the data for their use."*[6]

EPA notes that there is a high degree of variability in the data due to differences in quality assurance/quality control testing , bias towards samples collected at site locations known to have contamination problems, and bias towards samples collected during critical periods (e.g., summer low flows). To account for these factors, EPA used the STORET data as discussed below.

Surface Water Temperature

Median surface water temperatures were collected for each hydrologic region and assigned to each facility centroid using GIS. Median values were selected in order to capture an appropriate annualized value while minimizing the impact of variability. These temperatures are provided for

[6] Available online at: www.epa.gov/storet/about.html

each hydrologic region in **Table B-5**, as well as the number of modeled facilities and WMUs assigned to each region.

Table B-5. Regional Surface Water Temperatures: CCR Disposal Facilities

Hydrologic Region	Median Surface Water Temperature (°C)	Number of CCR Facilities	Number of CCR Surface Impoundments	Number of CCR Landfills
1	14	5	19	8
2	16	25	36	32
3	21	60	130	51
4	14	36	71	40
5	17	81	244	87
6	18	8	29	7
7	15	51	119	38
8	20	5	13	4
9	10	1	0	7
10	13	49	118	78
11	17	22	50	21
12	21	15	56	30
13	16	1	5	1
14	9	14	31	18
15	17	5	22	5
16	9	3	6	2
17	11[a]	2	3	2

Data source: Legacy STORET database.

[a] Legacy STORET data were not available for Hydrologic Region 17 at the time of this CCR data collection effort. A median temperature of 11 was assigned to be representative of the cooler surface water temperatures anticipated in the mountainous Pacific northwest region.

Total Suspended Solids

Median annual TSS values were collected for each hydrologic region and assigned to each facility centroid using GIS. Medians were selected in order to capture an appropriate annualized value while minimizing the impact of variability. Data were collected separately for streams and lakes because the latter grouping tends to have lower TSS levels as a result of reduced sediment disturbance from moving water.

Minimum, maximum and weighted geometric means of these collected values were used to define log triangular distributions regionally for streams, but only nationally for lakes due to more limited data. The triangular distribution was selected because it is typically used to describe a population for which there is only limited sample data, but there is sufficient knowledge to determine that the

distribution is modal, rather than uniform, as was the case here. Geometric means weighted by the annual number of measurements were used because the actual distribution around the median is unknown. Once developed, these distributions were sampled during the preparation of the input data files. **Table B-6** provides the TSS values used to define the distribution for each region, along with the number of the modeled facilities assigned to that region.

Table B-6. Surface Water Total Suspended Solids (TSS) Distributions

Hydrologic Region	Number of CCR Facilities	Number of Samples	Number of Annual Median Values	Annual Median TSS (log-triangular distribution)		
				Minimum	Maximum	Weighted Geometric Mean
1	5	9,007	33	3.2	40	8
2	25	47,202	38	10	316	32
3	54	43,395	36	6.3	79	25
4	21	29,577	37	6.3	794	25
5	77	39,900	38	4	100	25
6	5	4,137	28	5	316	16
7	49	34,494	37	32	1,585	63
8	4	46,231	38	50	316	158
9	1	3,254	35	13	3,162	32
10	49	62,791	38	10	398	126
11	21	48,969	38	25	794	200
12	12	7,280	35	40	1,995	79
13	1	13,974	37	32	79,433	200
14	13	26,699	38	16	5,012	158
15	4	9,162	37	20	19,953	200
16	3	19,965	33	4	2,512	16
17	2	173,136	37	2	316	6
Lakes	109	4,360	99	1	398	25

Data source: Legacy STORET database.

Note: Because both lakes and streams can be modeled for the same facility, the total count of facilities in this table exceeds 383.

Surface Water pH

Median annual pH values were collected for each hydrologic region and assigned to each facility centroid using GIS. Median values were selected in order to capture an appropriate annualized value while minimizing the impact of variability. Because pH data are already log scale, the minimum, maximum and weighted averages of these collected values were used to define triangular distributions for each hydrologic region. The triangular distribution was selected

because it is typically used to describe a population for which there is only limited sample data, but there is sufficient knowledge to determine that the distribution is modal, rather than uniform, as was the case here. Once developed, these distributions were sampled during the preparation of the input data files. **Table B-7** provides the pH values used to define the distribution for each region, along with the number of the modeled facilities assigned to that region.

Table B-7. Regional Surface Water pH Distributions

Hydrologic Region	Number of CCR Facilities	Number of Samples	Number of Annual Median Values	Annual Median pH (triangular distribution)		
				Minimum	Maximum	Weighted Average
1	5	232,025	38	5.9	7.7	6.5
2	25	447,166	39	7.2	7.6	7.4
3	60	1,595,237	39	6.3	7.2	7.0
4	36	335,261	39	7.6	8.2	8.1
5	81	684,235	41	3.5	7.5	7.2
6	8	382,915	39	6.3	7.7	7.2
7	51	234,589	39	7.6	8.1	7.9
8	5	171,643	39	6.9	7.8	7.1
9	1	23,038	38	7.5	8.4	7.9
10	49	269,570	39	7.6	8.2	8.0
11	22	311,768	39	7.4	8.1	7.8
12	15	178,990	39	7.0	7.9	7.8
13	1	35,355	39	7.0	8.1	8.0
14	14	77,041	39	7.9	8.3	8.1
15	5	75,145	38	7.7	8.3	8.0
16	3	68,581	38	7.5	8.3	8.0
17	2	293,909	39	6.9	8.0	7.5

Data source: Legacy STORET database

B.6 National Drinking Water Well Distribution

Residents that use ground water from private wells as a source of potable water may be exposed to COPCs through the GW→DW pathway. Therefore, the location of these wells relative to the surface impoundments and landfills is an important parameter for the risk assessment. Since the human population is not evenly distributed across the landscape, EPA used synthetic population data to place each household and its occupants as discrete points. Synthetic populations are a

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representation of households and individual residents in a given area based on methods to identify realistic locations.

Synthesized households and residents are placed to match the population distribution estimated by the LandScan USA 90-meter gridded population data set (Bhaduri, 2007), which distributes the U.S. population across a grid of 90-meter square cells using a combination of satellite imagery and other geographic data layers, including 2000 Census boundaries. The placement of synthesized households is constrained to match the population within a given 2000 Census block. Once a set of households is selected for a particular 90-meter grid cell, they are placed randomly within that 90-meter area. As a result, LandScan USA provides estimates of household locations at a finer resolution than is available from the 2000 Census data alone.

Figure B-4 provides an example CCR landfill and the corresponding synthetic household placement. The WMU centroid and estimated perimeter are shown, as well as a series of dashed-line buffers spaced at 0.2-mile (~ 300 meters) intervals from the WMU perimeter up to one mile away for an idea of scale. Synthetic population households are shown primarily along roadways. Although the household locations do not necessarily coincide with actual house locations, their locations are representative of typical dwelling location distributions as can be seen in the figure.

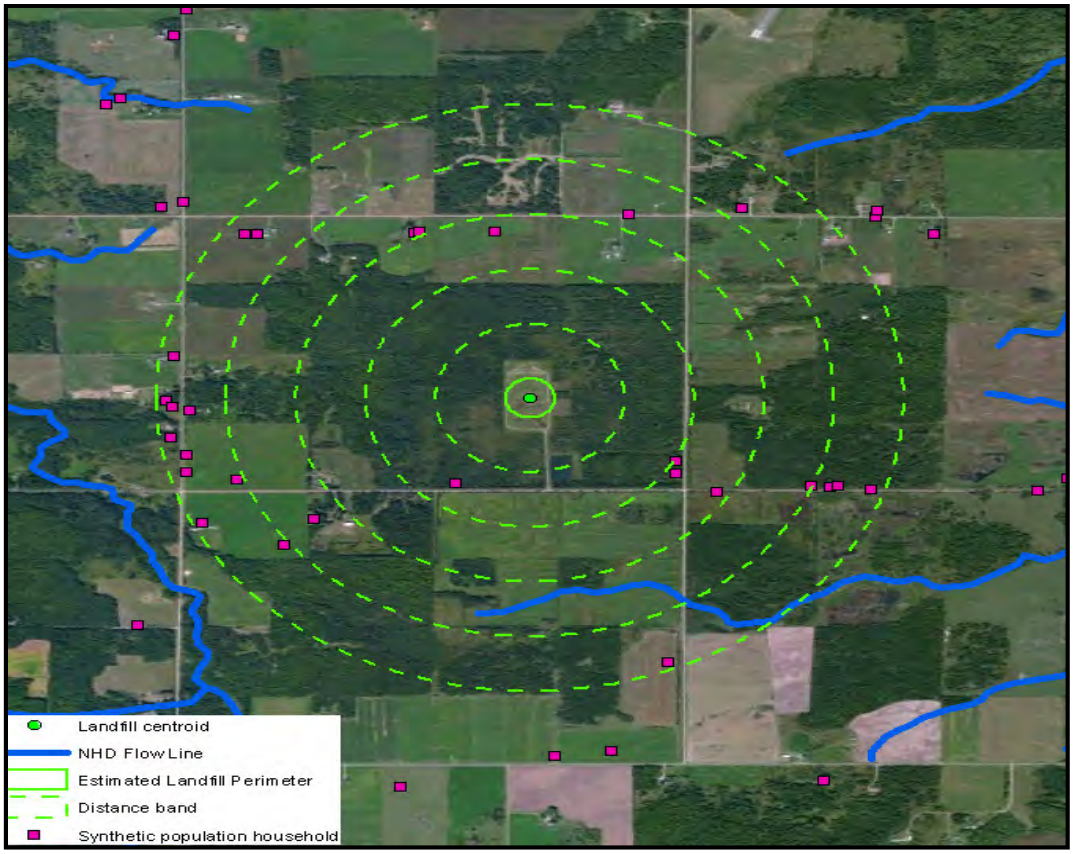

Figure B-4. Synthetic population locations in the vicinity of an example CCR landfill.

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The GW→DW pathway considers residential exposure from the use of well water as a source of potable water. The revised risk assessment considered potential risks to highly exposed individuals, which are hypothetical receptors that represent an upper bound of the range of realistic exposures that may occur within the modeled population. Therefore, a GIS algorithm was applied to identify the nearest household from the edge of the WMU. Since houses were randomly placed within a 90 m grid, aerial photographs were visually inspected for all distances less than 150 m (approximately 1.5 grid lengths) to ensure that the location assigned aligned with the location of an actual residence. The associated receptor distances were corrected as necessary.

Figure B-5 shows the cumulative probability distributions for the distance to nearest receptors for CCR impoundments and landfills. Also included for comparison are the well distances used in the 2010 Risk Assessment, which were drawn from an earlier survey of municipal solid waste landfills (U.S. EPA, 1988). As these comparisons indicate, the three distributions are similar, but residents tend to be located somewhat further away from CCR WMUs. Among the CCR WMUs, residents tend to live closer to landfills (minimum of 20 m) than surface impoundments (minimum of 50 m), though much of the distinction between the two disappears at greater distances.

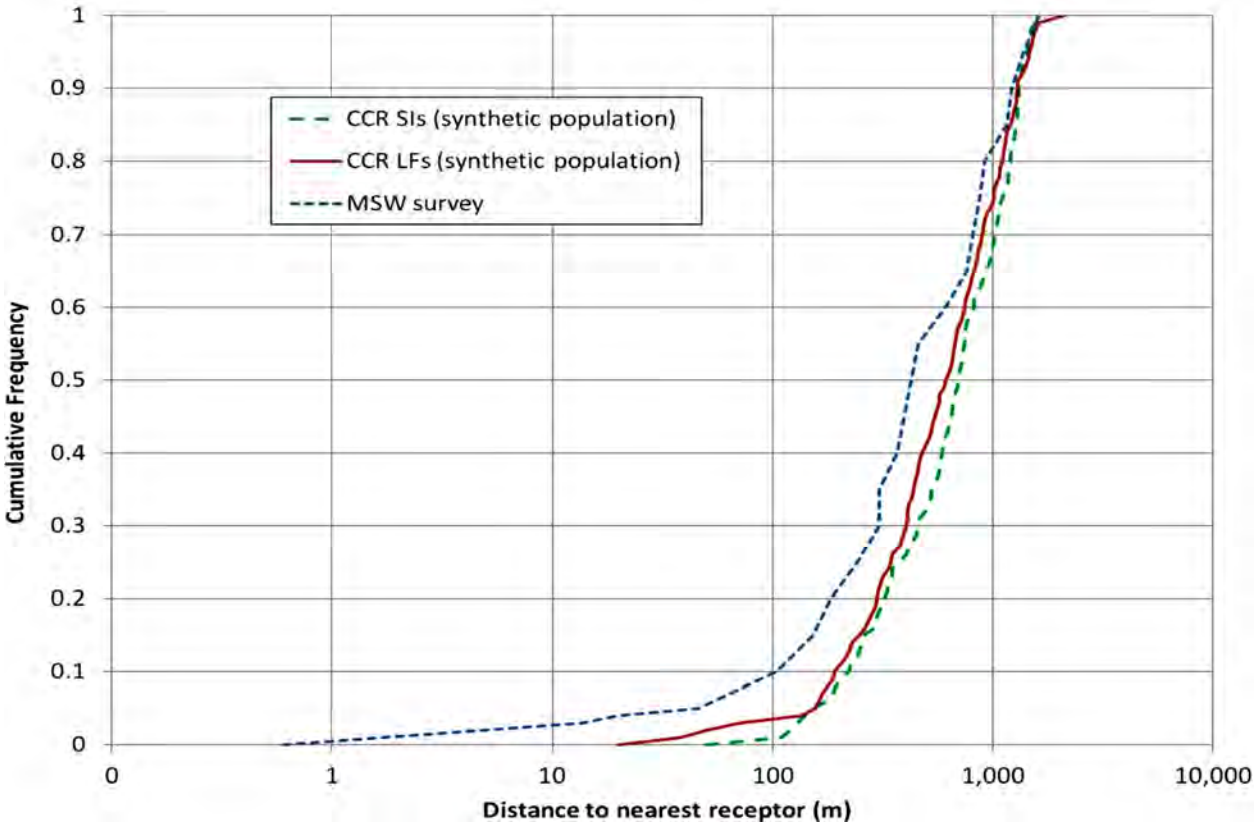

Figure B-5. Cumulative probability distributions for the distance to nearest receptor.

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Attachment B-1.

Soil Data

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6137	A. B. Brown Generating Station	88	SI	100	SLT	7.9	0.4
6137	A. B. Brown Generating Station	89	SI	100	SCL	6.0	0.3
6137	A. B. Brown Generating Station	1163	LF	100	SCL	6.0	0.3
2535	AES Cayuga, LLC	1102	LF	100	SLT	7.1	1
2527	AES Greenidge	1101	LF	100	SLT	7.1	1
2527	AES Greenidge	1285	SI	100	SLT	7.1	1
2527	AES Greenidge	1286	SI	100	SLT	7.1	1
994	AES Petersburg	430	SI	100	SLT	6.7	0.98
994	AES Petersburg	431	SI	100	SLT	6.8	1
994	AES Petersburg	432	SI	100	SLT	6.8	1
994	AES Petersburg	433	SI	89	SLT	6.8	1
994	AES Petersburg	433	SI	11	SNL	6.4	0.6
994	AES Petersburg	989	LF	73	SLT	5.5	0.39
994	AES Petersburg	989	LF	27	SNL	6.4	0.6
6082	AES Somerset LLC	1105	LF	100	SLT	7.1	1
6082	AES Somerset LLC	1106	LF	100	SLT	7.1	1
6082	AES Somerset LLC	1287	SI	100	SLT	7.1	1
3942	Albright Power Station	930	LF	100	SLT	4.6	0.4
3942	Albright Power Station	931	LF	100	SLT	4.6	0.4
3942	Albright Power Station	1385	SI	100	SLT	4.6	0.4
3942	Albright Power Station	1386	SI	100	SLT	4.6	0.4
1915	Allen S King	927	LF	100	SNL	6.1	1.6
3393	Allen Steam Plant	119	SI	42	SCL	7.0	0.5
3393	Allen Steam Plant	119	SI	58	SLT	7.1	0.4
3393	Allen Steam Plant	120	SI	42	SCL	7.0	0.5
3393	Allen Steam Plant	120	SI	58	SLT	7.1	0.4
4140	Alma	993	LF	100	SLT	7.2	1.6
4140	Alma	994	LF	100	SLT	7.2	1.6
1122	Ames Electric Services Power Plant	1202	SI	100	SLT	7.0	2.4
6469	Antelope Valley Station	212	SI	100	SLT	7.7	1.4
6469	Antelope Valley Station	213	SI	100	SLT	7.6	1.2
6469	Antelope Valley Station	922	LF	100	SLT	7.6	1.1
6469	Antelope Valley Station	923	LF	100	SLT	7.6	1.2
160	Apache Station	287	SI	100	SCL	9.0	0.1
160	Apache Station	288	SI	100	SCL	9.0	0.1
160	Apache Station	292	SI	100	SCL	9.0	0.1
160	Apache Station	293	SI	100	SCL	9.0	0.1
160	Apache Station	294	SI	100	SCL	9.0	0.1
160	Apache Station	295	SI	100	SCL	9.0	0.1

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
160	Apache Station	296	SI	100	SCL	9.0	0.1
160	Apache Station	297	SI	100	SCL	9.0	0.1
160	Apache Station	298	SI	100	SCL	9.0	0.1
160	Apache Station	299	SI	100	SCL	9.0	0.1
465	Arapahoe	310	SI	47	SLT	7.5	0.3
465	Arapahoe	310	SI	53	SNL	7.3	0.4
465	Arapahoe	311	SI	47	SLT	7.5	0.3
465	Arapahoe	311	SI	53	SNL	7.3	0.4
465	Arapahoe	312	SI	47	SLT	7.5	0.3
465	Arapahoe	312	SI	53	SNL	7.3	0.4
465	Arapahoe	313	SI	47	SLT	7.5	0.3
465	Arapahoe	313	SI	53	SNL	7.3	0.4
465	Arapahoe	314	SI	47	SLT	7.5	0.3
465	Arapahoe	314	SI	53	SNL	7.3	0.4
465	Arapahoe	315	SI	47	SLT	7.5	0.3
465	Arapahoe	315	SI	53	SNL	7.3	0.4
3178	Armstrong Power Station	921	LF	100	SLT	5.0	0.6
3178	Armstrong Power Station	926	LF	100	SLT	5.0	0.6
2076	Asbury	596	SI	100	SLT	6.1	0.3
2076	Asbury	597	SI	100	SLT	6.1	0.3
2076	Asbury	598	SI	100	SLT	6.1	0.3
2706	Asheville Steam Electric Plant	649	SI	100	SLT	5.1	0.77
2706	Asheville Steam Electric Plant	650	SI	100	SLT	5.1	0.7
2835	Ashtabula	1263	SI	100	SNL	6.0	0.3
1961	Austin Northeast	958	LF	100	SLT	6.6	1.2
2836	Avon Lake	975	LF	100	SCL	5.3	1.00
2836	Avon Lake	1175	SI	100	SCL	5.0	1.1
2836	Avon Lake	1176	SI	100	SCL	5.0	1.1
995	Bailly	434	SI	100	SNL	6.2	0.4
995	Bailly	435	SI	100	SNL	6.2	0.4
995	Bailly	436	SI	100	SNL	6.2	0.4
995	Bailly	437	SI	100	SNL	6.2	0.4
995	Bailly	438	SI	100	SNL	6.2	0.4
995	Bailly	439	SI	100	SNL	6.2	0.4
995	Bailly	939	LF	100	SNL	6.2	0.4
995	Bailly	952	LF	100	SNL	6.2	0.4
889	Baldwin Energy Complex	391	SI	14	SCL	6.4	0.6
889	Baldwin Energy Complex	391	SI	86	SLT	5.5	0.4
3	Barry	252	SI	100	SCL	4.9	0.6
3982	Bay Front	162	SI	100	SCL	7.0	2
3982	Bay Front	163	SI	100	SCL	7.0	2

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3982	Bay Front	945	LF	100	SCL	7.0	2
3982	Bay Front	946	LF	100	SCL	7.0	2
2878	Bay Shore	977	LF	100	SCL	7.1	0.7
2878	Bay Shore	1326	SI	100	SCL	7.1	0.7
8042	Belews Creek Steam Station	243	SI	100	SCL	5.1	0.36
8042	Belews Creek Steam Station	1009	LF	100	SCL	5.3	0.3
8042	Belews Creek Steam Station	1010	LF	100	SCL	5.3	0.3
8042	Belews Creek Steam Station	1079	LF	100	SCL	5.3	0.3
6034	Belle River	33	SI	100	SCL	7.0	0.6
6034	Belle River	1035	LF	100	SCL	7.0	0.6
3325	Ben French	1379	SI	100	SLT	7.9	0.4
645	Big Bend	342	SI	100	SNL	5.5	0.45
645	Big Bend	343	SI	100	SNL	5.6	0.7
645	Big Bend	344	SI	100	SNL	5.6	0.7
645	Big Bend	345	SI	100	SNL	5.6	0.66
645	Big Bend	346	SI	100	SNL	5.5	0.45
645	Big Bend	347	SI	100	SNL	5.6	0.68
645	Big Bend	348	SI	100	SNL	5.5	0.45
645	Big Bend	349	SI	100	SNL	5.5	0.45
645	Big Bend	1164	LF	100	SNL	5.6	0.7
3497	Big Brown	776	LF	100	SLT	6.2	0.7
3497	Big Brown	784	LF	100	SLT	6.2	0.7
3497	Big Brown	790	LF	100	SLT	6.2	0.7
3497	Big Brown	791	LF	100	SLT	6.2	0.7
3497	Big Brown	1177	SI	100	SLT	6.2	0.7
3497	Big Brown	1178	SI	100	SLT	6.2	0.7
3497	Big Brown	1179	SI	100	SLT	6.2	0.7
3497	Big Brown	1180	SI	100	SLT	6.2	0.7
6055	Big Cajun 2	36	SI	100	SCL	7.1	0.80
6055	Big Cajun 2	37	SI	100	SCL	7.1	0.80
6055	Big Cajun 2	38	SI	100	SCL	7.1	0.80
6055	Big Cajun 2	815	LF	100	SCL	7.0	0.65
1353	Big Sandy	521	SI	14	SCL	5.9	0.2
1353	Big Sandy	521	SI	86	SNL	4.9	0.8
1353	Big Sandy	522	SI	100	SCL	5.9	0.6
1353	Big Sandy	523	SI	2	SCL	5.9	0.2
1353	Big Sandy	523	SI	98	SNL	4.9	0.8
6098	Big Stone	814	LF	100	SNL	7.6	1.2
6098	Big Stone	1261	SI	100	SNL	7.6	1.2

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1904	Black Dog	593	SI	86	SLT	7.2	1.6
1904	Black Dog	593	SI	14	SNL	6.9	2.4
1904	Black Dog	799	LF	100	SLT	7.3	1.7
6106	Boardman	746	LF	100	SNL	8.0	0.37
6106	Boardman	1339	SI	100	SNL	7.7	0.3
6106	Boardman	1340	SI	100	SNL	7.7	0.3
6106	Boardman	1341	SI	100	SNL	7.7	0.3
7790	Bonanza Power Plant	735	LF	100	SLT	8.6	0.6
7790	Bonanza Power Plant	737	LF	100	SLT	8.4	0.1
7790	Bonanza Power Plant	1207	SI	100	SLT	8.6	0.1
7790	Bonanza Power Plant	1208	SI	100	SLT	8.6	0.1
7790	Bonanza Power Plant	1209	SI	100	SLT	8.6	0.1
1893	Boswell Energy Center	590	SI	100	SNL	6.1	10
1893	Boswell Energy Center	591	SI	100	SNL	6.1	6.1
1893	Boswell Energy Center	592	SI	100	SNL	6.1	5.9
1893	Boswell Energy Center	796	LF	100	SNL	6.1	5.9
1893	Boswell Energy Center	853	LF	100	SNL	6.1	5.9
1893	Boswell Energy Center	862	LF	100	SNL	6.1	13.3
703	Bowen	350	SI	100	SLT	5.0	0.4
703	Bowen	1103	LF	100	SLT	5.0	0.4
602	Brandon Shores	1289	SI	100	SCL	4.6	0.4
602	Brandon Shores	1290	SI	100	SCL	4.6	0.4
1619	Brayton Point	731	LF	100	SNL	5.3	0.2
1619	Brayton Point	760	LF	11	SLT	5.2	2.3
1619	Brayton Point	760	LF	89	SNL	5.3	0.2
1619	Brayton Point	761	LF	8	SLT	5.2	2.3
1619	Brayton Point	761	LF	92	SNL	5.3	0.2
1619	Brayton Point	800	LF	100	SNL	5.3	0.2
1619	Brayton Point	824	LF	100	SNL	5.3	0.2
1619	Brayton Point	1187	SI	100	SNL	5.3	0.2
1619	Brayton Point	1188	SI	100	SNL	5.3	0.2
1619	Brayton Point	1189	SI	100	SNL	5.3	0.2
1619	Brayton Point	1190	SI	100	SNL	5.3	0.2
1619	Brayton Point	1191	SI	100	SNL	5.3	0.2
1619	Brayton Point	1192	SI	100	SNL	5.3	0.2
1619	Brayton Point	1193	SI	100	SNL	5.3	0.2
1619	Brayton Point	1194	SI	100	SNL	5.3	0.2
1619	Brayton Point	1195	SI	100	SNL	5.3	0.2
1619	Brayton Point	1196	SI	100	SNL	5.3	0.2
3796	Bremo Bluff	148	SI	93	SCL	5.1	0.3
3796	Bremo Bluff	148	SI	7	SLT	5.6	1
3796	Bremo Bluff	149	SI	95	SCL	5.1	0.3
3796	Bremo Bluff	149	SI	5	SLT	5.6	1

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6094	Bruce Mansfield	75	SI	100	SLT	5.2	0.3
6094	Bruce Mansfield	76	SI	100	SLT	4.7	0.5
6094	Bruce Mansfield	77	SI	100	SLT	5.0	0.39
6094	Bruce Mansfield	78	SI	100	SLT	5.2	0.31
6094	Bruce Mansfield	79	SI	100	SLT	4.8	0.48
2720	Buck	671	SI	100	SCL	5.3	0.3
2720	Buck	672	SI	100	SCL	5.3	0.3
2720	Buck	673	SI	100	SCL	5.3	0.3
3396	Bull Run	121	SI	89	SCL	5.4	0.40
3396	Bull Run	121	SI	11	SNL	5.1	0.5
3396	Bull Run	122	SI	89	SCL	5.4	0.40
3396	Bull Run	122	SI	11	SNL	5.1	0.5
3396	Bull Run	123	SI	89	SCL	5.4	0.40
3396	Bull Run	123	SI	11	SNL	5.1	0.5
3396	Bull Run	124	SI	89	SCL	5.4	0.40
3396	Bull Run	124	SI	11	SNL	5.1	0.5
3396	Bull Run	889	LF	100	SCL	6.5	0.3
3396	Bull Run	890	LF	100	SCL	5.5	0.6
1104	Burlington	507	SI	100	SCL	6.3	2.4
1104	Burlington	508	SI	100	SCL	6.3	2.4
1104	Burlington	509	SI	100	SCL	6.3	2.4
1104	Burlington	510	SI	100	SCL	6.3	2.4
1104	Burlington	511	SI	100	SCL	6.3	2.4
676	C D McIntosh Jr	885	LF	100	SNL	5.2	0.40
676	C D McIntosh Jr	888	LF	100	SNL	6.0	0.35
468	Cameo	316	SI	11	SLT	8.1	0.1
468	Cameo	316	SI	89	SNL	8.3	0.2
468	Cameo	317	SI	11	SLT	8.1	0.1
468	Cameo	317	SI	89	SNL	8.3	0.2
3280	Canadys Steam	107	SI	100	SNL	5.3	0.9
3280	Canadys Steam	108	SI	100	SNL	5.3	0.9
3280	Canadys Steam	109	SI	100	SNL	5.3	0.9
1363	Cane Run	538	SI	100	SCL	5.9	0.5
1363	Cane Run	539	SI	98	SCL	5.9	0.58
1363	Cane Run	539	SI	2	SLT	5.1	0.4
1363	Cane Run	540	SI	100	SCL	5.9	0.5
1363	Cane Run	541	SI	100	SCL	5.9	0.5
1363	Cane Run	542	SI	98	SCL	5.9	0.58
1363	Cane Run	542	SI	2	SLT	5.1	0.4
1363	Cane Run	869	LF	100	SCL	5.9	0.5
2708	Cape Fear Steam Electric Plant	651	SI	100	SLT	5.8	1

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2708	Cape Fear Steam Electric Plant	652	SI	69	SCL	4.9	0.35
2708	Cape Fear Steam Electric Plant	652	SI	31	SLT	5.8	1
2708	Cape Fear Steam Electric Plant	653	SI	95	SCL	4.9	0.3
2708	Cape Fear Steam Electric Plant	653	SI	5	SLT	5.8	1
2708	Cape Fear Steam Electric Plant	654	SI	69	SCL	4.9	0.35
2708	Cape Fear Steam Electric Plant	654	SI	31	SLT	5.8	1
2708	Cape Fear Steam Electric Plant	655	SI	100	SLT	5.8	1
3644	Carbon Plant	876	LF	100	SLT	7.8	0.3
3644	Carbon Plant	905	LF	100	SLT	7.8	0.3
3644	Carbon Plant	1387	SI	100	SLT	7.8	0.3
3644	Carbon Plant	1388	SI	100	SLT	7.8	0.3
2828	Cardinal	693	SI	100	SCL	5.9	0.5
2828	Cardinal	694	SI	100	SCL	5.9	0.5
2828	Cardinal	899	LF	100	SCL	6.1	0.44
1001	Cayuga	454	SI	100	SLT	7.1	1.9
1001	Cayuga	455	SI	100	SLT	7.1	1.9
1001	Cayuga	456	SI	100	SLT	7.1	1.9
1001	Cayuga	457	SI	100	SLT	7.1	1.9
1001	Cayuga	838	LF	100	SNL	6.5	2
1571	Chalk Point LLC	836	LF	100	SNL	4.8	0.4
1571	Chalk Point LLC	1104	LF	100	SNL	4.7	0.9
2169	Chamois Power Plant	1288	SI	100	SLT	7.7	0.8
56	Charles R. Lowman	270	SI	100	SLT	5.1	0.2
56	Charles R. Lowman	271	SI	100	SLT	5.1	0.2
56	Charles R. Lowman	272	SI	100	SLT	5.1	0.2
56	Charles R. Lowman	273	SI	100	SLT	5.1	0.2
56	Charles R. Lowman	900	LF	44	SCL	5.0	0.3
56	Charles R. Lowman	900	LF	56	SLT	5.1	0.2
469	Cherokee	318	SI	4	SCL	8.2	0.4
469	Cherokee	318	SI	29	SLT	7.8	0.7
469	Cherokee	318	SI	67	SNL	7.3	0.4
469	Cherokee	319	SI	4	SCL	8.2	0.4
469	Cherokee	319	SI	29	SLT	7.8	0.7
469	Cherokee	319	SI	67	SNL	7.3	0.4
469	Cherokee	320	SI	4	SCL	8.2	0.4
469	Cherokee	320	SI	29	SLT	7.8	0.7

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
469	Cherokee	320	SI	67	SNL	7.3	0.4
469	Cherokee	321	SI	4	SCL	8.2	0.4
469	Cherokee	321	SI	29	SLT	7.8	0.7
469	Cherokee	321	SI	67	SNL	7.3	0.4
469	Cherokee	322	SI	4	SCL	8.2	0.4
469	Cherokee	322	SI	29	SLT	7.8	0.7
469	Cherokee	322	SI	67	SNL	7.3	0.4
469	Cherokee	323	SI	4	SCL	8.2	0.4
469	Cherokee	323	SI	29	SLT	7.8	0.7
469	Cherokee	323	SI	67	SNL	7.3	0.4
3803	Chesapeake Energy Center	152	SI	100	SNL	6.4	5.3
3803	Chesapeake Energy Center	865	LF	100	SNL	6.4	5.3
3797	Chesterfield	150	SI	100	SNL	5.2	0.1
3797	Chesterfield	151	SI	100	SNL	5.2	0.1
8226	Cheswick Power Plant	1099	LF	100	SLT	5.1	0.5
8226	Cheswick Power Plant	1165	SI	100	SLT	5.2	0.3
8226	Cheswick Power Plant	1166	SI	100	SLT	5.2	0.3
113	Cholla	279	SI	100	SLT	8.1	0.20
113	Cholla	280	SI	100	SLT	7.9	0
113	Cholla	863	LF	100	SLT	7.9	0
2721	Cliffside	674	SI	100	SCL	5.3	0.3
2721	Cliffside	675	SI	100	SCL	5.3	0.3
2721	Cliffside	676	SI	100	SCL	5.3	0.3
983	Clifty Creek	413	SI	4	SCL	6.5	0.4
983	Clifty Creek	413	SI	96	SLT	6.5	0.6
983	Clifty Creek	414	SI	100	SCL	6.5	0.4
983	Clifty Creek	847	LF	100	SCL	6.5	0.4
983	Clifty Creek	848	LF	100	SCL	6.5	0.4
3775	Clinch River	144	SI	100	SCL	4.7	0.4
3775	Clinch River	145	SI	100	SCL	4.7	0.4
3775	Clinch River	849	LF	100	SCL	4.7	0.4
7213	Clover	850	LF	100	SCL	4.9	0.4
7213	Clover	851	LF	100	SCL	4.9	0.4
7213	Clover	1280	SI	100	SCL	5.2	0.2
7213	Clover	1281	SI	100	SCL	5.2	0.2
7213	Clover	1282	SI	47	SCL	5.2	0.2
7213	Clover	1282	SI	53	SLT	5.6	1
7213	Clover	1283	SI	88	SCL	5.2	0.2
7213	Clover	1283	SI	12	SLT	5.6	1
7213	Clover	1284	SI	88	SCL	5.2	0.2
7213	Clover	1284	SI	12	SLT	5.6	1
6030	Coal Creek	29	SI	16	SLT	7.6	1.5
6030	Coal Creek	29	SI	84	SNL	7.7	1

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6030	Coal Creek	30	SI	100	SNL	7.7	1
6030	Coal Creek	852	LF	100	SNL	7.7	1
6030	Coal Creek	854	LF	100	SLT	7.6	1.5
6030	Coal Creek	855	LF	100	SLT	7.6	1.5
6030	Coal Creek	857	LF	100	SNL	7.7	1
6030	Coal Creek	868	LF	100	SLT	7.6	1.5
6030	Coal Creek	1119	LF	100	SLT	7.6	1.5
861	Coffeen	379	SI	100	SLT	5.5	0.4
861	Coffeen	380	SI	100	SCL	6.3	0.6
861	Coffeen	846	LF	83	SCL	6.3	0.6
861	Coffeen	846	LF	17	SLT	5.5	0.4
47	Colbert	258	SI	100	SCL	5.3	0.30
47	Colbert	259	SI	100	SCL	5.3	0.30
47	Colbert	260	SI	100	SCL	5.3	0.30
47	Colbert	859	LF	100	SCL	5.2	0.2
6178	Coleto Creek	181	SI	100	SCL	7.5	0.6
6178	Coleto Creek	182	SI	100	SCL	7.5	0.6
6076	Colstrip	46	SI	100	SLT	8.2	0.41
6076	Colstrip	47	SI	100	SLT	8.2	0.41
6076	Colstrip	48	SI	100	SLT	8.2	0.41
6076	Colstrip	49	SI	100	SLT	8.2	0.5
6076	Colstrip	50	SI	100	SLT	8.2	0.4
6076	Colstrip	51	SI	100	SLT	8.2	0.5
6076	Colstrip	52	SI	100	SLT	8.2	0.4
6076	Colstrip	53	SI	100	SLT	8.2	0.41
10784	Colstrip Energy LP	860	LF	100	SLT	8.2	0.40
10784	Colstrip Energy LP	861	LF	100	SLT	8.2	0.40
8023	Columbia	239	SI	40	SLT	7.2	4.7
8023	Columbia	239	SI	60	SNL	6.9	2.7
8023	Columbia	240	SI	40	SLT	7.2	4.7
8023	Columbia	240	SI	60	SNL	6.9	2.7
8023	Columbia	241	SI	40	SLT	7.2	4.7
8023	Columbia	241	SI	60	SNL	6.9	2.7
8023	Columbia	242	SI	40	SLT	7.2	4.7
8023	Columbia	242	SI	60	SNL	6.9	2.7
8023	Columbia	1135	LF	100	SLT	7.2	4.7
8023	Columbia	1136	LF	100	SNL	6.9	2.7
2123	Columbia	1213	SI	36	SCL	6.0	0.5
2123	Columbia	1213	SI	64	SLT	5.9	0.5
470	Comanche	324	SI	87	SLT	8.1	0.52
470	Comanche	324	SI	13	SNL	8.1	0.3
470	Comanche	325	SI	87	SLT	8.1	0.52
470	Comanche	325	SI	13	SNL	8.1	0.3

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
470	Comanche	326	SI	87	SLT	8.1	0.52
470	Comanche	326	SI	13	SNL	8.1	0.3
470	Comanche	327	SI	87	SLT	8.1	0.52
470	Comanche	327	SI	13	SNL	8.1	0.3
470	Comanche	328	SI	87	SLT	8.1	0.52
470	Comanche	328	SI	13	SNL	8.1	0.3
470	Comanche	1137	LF	100	SLT	8.2	0.4
3118	Conemaugh	864	LF	100	SLT	4.8	0.5
3118	Conemaugh	1138	LF	100	SLT	4.8	0.5
3118	Conemaugh	1334	SI	100	SLT	5.0	0.6
3118	Conemaugh	1335	SI	100	SLT	5.0	0.6
3118	Conemaugh	1336	SI	100	SLT	5.0	0.6
3118	Conemaugh	1337	SI	100	SLT	5.0	0.6
3118	Conemaugh	1338	SI	100	SLT	5.0	0.6
2840	Conesville	701	SI	100	SLT	5.6	0.38
2840	Conesville	1005	LF	100	SLT	5.8	0.3
2840	Conesville	1006	LF	100	SLT	5.8	0.3
1710	Consumers Energy - J.H. Campbell	572	SI	100	SNL	5.9	0.7
1710	Consumers Energy - J.H. Campbell	967	LF	100	SNL	5.9	0.7
1710	Consumers Energy - J.H. Campbell	985	LF	100	SNL	5.9	0.7
1710	Consumers Energy - J.H. Campbell	998	LF	100	SNL	5.9	0.7
1710	Consumers Energy - J.H. Campbell	999	LF	100	SNL	5.9	0.7
1384	Cooper Station.	973	LF	100	SCL	6.0	0.50
7210	Cope	866	LF	100	SLT	5.3	1.6
6177	Coronado Generating Station	180	SI	67	SLT	8.3	0.4
6177	Coronado Generating Station	180	SI	33	SNL	7.9	0.2
6177	Coronado Generating Station	835	LF	100	SNL	7.9	0.2
6177	Coronado Generating Station	867	LF	100	SNL	7.9	0.2
8222	Coyote	248	SI	100	SLT	7.6	0.9
8222	Coyote	249	SI	100	SLT	7.6	0.9
8222	Coyote	250	SI	100	SLT	7.6	0.9
8222	Coyote	825	LF	100	SLT	7.6	0.9
8222	Coyote	826	LF	100	SLT	7.6	0.9
8222	Coyote	833	LF	100	SLT	7.6	0.9

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
8222	Coyote	856	LF	100	SLT	7.6	0.9
2549	CR Huntley Generating Station	643	SI	100	SNL	6.7	0.3
2549	CR Huntley Generating Station	644	SI	100	SNL	6.7	0.3
2549	CR Huntley Generating Station	645	SI	100	SNL	6.7	0.3
2549	CR Huntley Generating Station	1100	LF	100	SNL	6.7	0.3
6021	Craig	27	SI	100	SLT	8.0	0.5
6021	Craig	28	SI	100	SLT	8.0	0.5
6021	Craig	974	LF	100	SLT	8.0	0.5
867	Crawford	387	SI	100	SNL	6.8	0.60
753	Crisp Plant	1265	SI	50	SLT	5.0	0.3
753	Crisp Plant	1265	SI	50	SNL	6.1	1.2
641	Crist	1139	LF	100	SLT	5.0	0.4
641	Crist	1273	SI	100	SLT	5.1	0.59
641	Crist	1274	SI	100	SLT	5.2	0.67
641	Crist	1275	SI	100	SLT	5.0	0.4
641	Crist	1276	SI	100	SLT	5.0	0.4
641	Crist	1277	SI	100	SLT	5.0	0.4
641	Crist	1278	SI	100	SLT	5.0	0.4
641	Crist	1279	SI	100	SLT	5.0	0.4
130	Cross	284	SI	100	SLT	4.8	0.7
130	Cross	285	SI	100	SLT	4.8	0.7
130	Cross	286	SI	100	SLT	4.8	0.7
130	Cross	827	LF	100	SLT	4.8	0.7
130	Cross	828	LF	100	SLT	4.8	0.7
130	Cross	829	LF	100	SLT	4.8	0.7
130	Cross	830	LF	100	SLT	4.8	0.7
628	Crystal River Power Plant	831	LF	100	SNL	6.1	0.5
3399	Cumberland	125	SI	12	SCL	5.1	0.4
3399	Cumberland	125	SI	88	SLT	5.8	0.60
3399	Cumberland	126	SI	12	SCL	5.1	0.4
3399	Cumberland	126	SI	88	SLT	5.8	0.60
3399	Cumberland	127	SI	12	SCL	5.1	0.4
3399	Cumberland	127	SI	88	SLT	5.8	0.60
3399	Cumberland	978	LF	12	SCL	5.1	0.4
3399	Cumberland	978	LF	88	SLT	5.8	0.60
6823	D B Wilson	832	LF	100	SLT	5.2	0.6
6823	D B Wilson	845	LF	100	SLT	5.2	0.6
1702	D.E. Karn	570	SI	95	SLT	7.9	1
1702	D.E. Karn	570	SI	5	SNL	6.3	1.1

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1702	D.E. Karn	571	SI	100	SLT	7.9	1
1702	D.E. Karn	1004	LF	100	SLT	7.9	1
1385	Dale Station	558	SI	100	SCL	6.4	0.6
1385	Dale Station	559	SI	100	SCL	6.4	0.6
1385	Dale Station	560	SI	100	SCL	6.4	0.6
963	Dallman	399	SI	100	SLT	7.1	1.9
963	Dallman	823	LF	100	SLT	7.1	1.9
963	Dallman	834	LF	100	SLT	7.1	1.9
2723	Dan River	677	SI	100	SCL	5.0	0.4
2723	Dan River	678	SI	100	SCL	5.0	0.4
2723	Dan River	679	SI	100	SCL	5.0	0.39
2480	Danskammer Generating Station	1140	LF	100	SLT	6.7	1.1
4158	Dave Johnston Plant	4	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	5	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	6	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	7	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	8	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	9	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	10	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	11	SI	100	SLT	8.2	0.3
4158	Dave Johnston Plant	837	LF	100	SLT	8.2	0.31
996	Dean H Mitchell	440	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	441	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	442	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	443	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	444	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	445	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	446	SI	100	SNL	6.2	0.4
996	Dean H Mitchell	447	SI	100	SNL	6.2	0.4
663	Deerhaven Generating Station	1141	LF	100	SNL	5.6	0.7
663	Deerhaven Generating Station	1331	SI	100	SNL	5.6	0.7
1572	Dickerson	839	LF	100	SLT	5.1	0.6
51	Dolet Hills	263	SI	100	SCL	4.7	0.9
51	Dolet Hills	264	SI	100	SCL	4.7	0.9
51	Dolet Hills	265	SI	100	SCL	5.1	0.71
51	Dolet Hills	266	SI	100	SCL	4.7	0.9
51	Dolet Hills	267	SI	100	SCL	4.7	0.9
51	Dolet Hills	268	SI	100	SCL	4.7	0.9
51	Dolet Hills	269	SI	100	SCL	4.7	0.9
51	Dolet Hills	840	LF	100	SCL	4.7	0.9

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3317	Dolphus M Grainger	115	SI	100	SNL	6.1	0.8
3317	Dolphus M Grainger	116	SI	100	SNL	6.1	0.8
1046	Dubuque	476	SI	32	SCL	6.2	0.65
1046	Dubuque	476	SI	68	SLT	6.8	1.3
6016	Duck Creek	18	SI	48	SCL	7.7	0.6
6016	Duck Creek	18	SI	52	SLT	5.9	0.5
6016	Duck Creek	19	SI	48	SCL	7.7	0.6
6016	Duck Creek	19	SI	52	SLT	5.9	0.5
6016	Duck Creek	20	SI	48	SCL	7.7	0.6
6016	Duck Creek	20	SI	52	SLT	5.9	0.5
6016	Duck Creek	842	LF	100	SCL	6.2	0.44
2554	Dunkirk Generating Plant	646	SI	10	SLT	7.1	1
2554	Dunkirk Generating Plant	646	SI	90	SNL	6.7	0.3
2554	Dunkirk Generating Plant	647	SI	10	SLT	7.1	1
2554	Dunkirk Generating Plant	647	SI	90	SNL	6.7	0.3
2554	Dunkirk Generating Plant	648	SI	10	SLT	7.1	1
2554	Dunkirk Generating Plant	648	SI	90	SNL	6.7	0.3
2554	Dunkirk Generating Plant	843	LF	98	SLT	7.1	1
2554	Dunkirk Generating Plant	843	LF	2	SNL	6.7	0.3
26	E. C. Gaston	257	SI	51	SCL	4.9	0.29
26	E. C. Gaston	257	SI	49	SLT	5.1	0.36
1355	E.W. Brown	524	SI	100	SCL	6.6	1.1
1355	E.W. Brown	525	SI	100	SCL	6.6	1.1
991	Eagle Valley	425	SI	100	SLT	7.1	1.9
991	Eagle Valley	426	SI	100	SLT	7.1	1.9
991	Eagle Valley	427	SI	100	SLT	7.1	1.9
991	Eagle Valley	428	SI	100	SLT	7.1	1.9
991	Eagle Valley	429	SI	100	SLT	6.9	1.8
1217	Earl F Wisdom	844	LF	100	SCL	7.1	2.9
6018	East Bend Station	23	SI	80	SCL	6.2	0.47
6018	East Bend Station	23	SI	20	SLT	6.5	0.6
6018	East Bend Station	24	SI	100	SCL	6.0	0.5
6018	East Bend Station	25	SI	80	SCL	6.2	0.47
6018	East Bend Station	25	SI	20	SLT	6.5	0.6
6018	East Bend Station	879	LF	100	SCL	6.0	0.5
2837	Eastlake	914	LF	100	SNL	6.0	0.3
2837	Eastlake	1262	SI	100	SNL	6.0	0.3
856	ED Edwards	376	SI	74	SCL	6.6	1.3
856	ED Edwards	376	SI	20	SLT	5.9	0.5
856	ED Edwards	376	SI	5	SNL	6.5	1
856	ED Edwards	377	SI	100	SCL	6.8	1.6
856	ED Edwards	378	SI	100	SCL	6.8	1.6
4050	Edgewater	164	SI	100	SNL	6.2	0.4

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
4050	Edgewater	165	SI	100	SNL	6.2	0.4
4050	Edgewater	166	SI	100	SNL	6.2	0.4
4050	Edgewater	167	SI	100	SNL	6.2	0.4
4050	Edgewater	168	SI	100	SNL	6.2	0.4
4050	Edgewater	169	SI	100	SNL	6.2	0.4
4050	Edgewater	858	LF	100	SCL	7.3	4.6
4050	Edgewater	894	LF	100	SNL	6.2	0.4
1004	Edwardsport	458	SI	100	SLT	6.8	1
1004	Edwardsport	459	SI	100	SLT	6.8	1
1004	Edwardsport	971	LF	18	SCL	6.0	0.3
1004	Edwardsport	971	LF	77	SLT	6.2	0.70
1004	Edwardsport	971	LF	5	SNL	6.7	1.3
1374	Elmer Smith Station	1234	SI	100	SCL	5.8	0.5
1374	Elmer Smith Station	1235	SI	100	SCL	5.8	0.5
1374	Elmer Smith Station	1236	SI	100	SCL	5.8	0.5
1374	Elmer Smith Station	1237	SI	100	SCL	5.8	0.5
3098	Elrama Power Plant	895	LF	38	SLT	5.2	0.3
3098	Elrama Power Plant	895	LF	62	SNL	5.5	0.2
3098	Elrama Power Plant	1342	SI	100	SLT	5.6	0.5
3098	Elrama Power Plant	1343	SI	100	SLT	5.6	0.5
3098	Elrama Power Plant	1344	SI	100	SLT	5.6	0.5
3098	Elrama Power Plant	1345	SI	100	SLT	5.5	0.5
1832	Erickson Station	587	SI	100	SLT	7.2	2.1
87	Escalante	274	SI	5	SLT	8.1	0.2
87	Escalante	274	SI	95	SNL	7.8	0.2
87	Escalante	275	SI	5	SLT	8.1	0.2
87	Escalante	275	SI	95	SNL	7.8	0.2
87	Escalante	276	SI	5	SLT	8.1	0.2
87	Escalante	276	SI	95	SNL	7.8	0.2
87	Escalante	277	SI	5	SLT	8.1	0.2
87	Escalante	277	SI	95	SNL	7.8	0.2
87	Escalante	278	SI	5	SLT	8.1	0.2
87	Escalante	278	SI	95	SNL	7.8	0.2
87	Escalante	992	LF	100	SNL	7.8	0.2
1012	F. B. Culley	466	SI	1	SCL	6.0	0.3
1012	F. B. Culley	466	SI	99	SLT	6.5	0.6
1012	F. B. Culley	467	SI	100	SLT	6.5	0.6
1218	Fair Station	896	LF	100	SCL	6.0	0.6
1218	Fair Station	1183	SI	100	SCL	6.4	2.8
1218	Fair Station	1184	SI	100	SCL	6.4	2.8
6179	Fayette Power Project	183	SI	100	SCL	7.9	3
6179	Fayette Power Project	184	SI	100	SCL	7.9	3
6179	Fayette Power Project	897	LF	100	SCL	7.9	3

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
886	Fisk	1238	SI	100	SNL	6.8	0.6
886	Fisk	1239	SI	100	SNL	6.8	0.6
886	Fisk	1240	SI	100	SNL	6.8	0.6
6138	Flint Creek	173	SI	100	SCL	5.0	0.5
6138	Flint Creek	174	SI	100	SCL	5.0	0.5
6138	Flint Creek	898	LF	100	SCL	5.1	0.5
3943	Fort Martin Power Station	1142	LF	100	SLT	5.6	0.5
3943	Fort Martin Power Station	1143	LF	100	SLT	5.6	0.42
3943	Fort Martin Power Station	1181	SI	100	SCL	5.3	0.5
3943	Fort Martin Power Station	1182	SI	100	SCL	5.3	0.5
10343	Foster Wheeler Mt Carmel Cogen	901	LF	100	SLT	5.6	0.4
2442	Four Corners	638	SI	100	SLT	8.3	0.2
2442	Four Corners	639	SI	100	SLT	8.3	0.2
2442	Four Corners	640	SI	100	SLT	8.3	0.2
2442	Four Corners	641	SI	100	SLT	8.3	0.2
2442	Four Corners	642	SI	100	SLT	8.3	0.2
2442	Four Corners	903	LF	100	SLT	8.3	0.2
2442	Four Corners	915	LF	100	SLT	8.3	0.2
1043	Frank E. Ratts	468	SI	34	SCL	6.0	0.3
1043	Frank E. Ratts	468	SI	58	SLT	6.4	0.79
1043	Frank E. Ratts	468	SI	8	SNL	6.4	0.6
1043	Frank E. Ratts	469	SI	100	SLT	6.8	1
1043	Frank E. Ratts	470	SI	100	SLT	6.7	0.96
1043	Frank E. Ratts	471	SI	34	SCL	6.0	0.3
1043	Frank E. Ratts	471	SI	58	SLT	6.4	0.79
1043	Frank E. Ratts	471	SI	8	SNL	6.4	0.6
1043	Frank E. Ratts	472	SI	100	SLT	6.4	0.84
1043	Frank E. Ratts	473	SI	34	SCL	6.0	0.3
1043	Frank E. Ratts	473	SI	58	SLT	6.4	0.79
1043	Frank E. Ratts	473	SI	8	SNL	6.4	0.6
1043	Frank E. Ratts	474	SI	34	SCL	6.0	0.3
1043	Frank E. Ratts	474	SI	58	SLT	6.4	0.79
1043	Frank E. Ratts	474	SI	8	SNL	6.4	0.6
1043	Frank E. Ratts	475	SI	100	SLT	5.9	0.57
2718	G G Allen	668	SI	100	SCL	5.3	0.3
2718	G G Allen	669	SI	100	SCL	5.3	0.3
2718	G G Allen	670	SI	100	SCL	5.3	0.3
2718	G G Allen	892	LF	100	SCL	5.3	0.3
7	Gadsden	253	SI	24	SCL	5.0	0.3
7	Gadsden	253	SI	76	SLT	5.2	0.46
7	Gadsden	253	SI	0	SNL	4.7	0.4
3403	Gallatin	128	SI	48	SCL	6.0	0.6

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3403	Gallatin	128	SI	52	SLT	5.3	0.8
3403	Gallatin	129	SI	48	SCL	6.0	0.6
3403	Gallatin	129	SI	52	SLT	5.3	0.8
3403	Gallatin	130	SI	48	SCL	6.0	0.6
3403	Gallatin	130	SI	52	SLT	5.3	0.8
8102	General James M. Gavin	246	SI	100	SNL	5.1	0.3
8102	General James M. Gavin	247	SI	100	SCL	5.7	0.6
8102	General James M. Gavin	1144	LF	100	SNL	5.1	0.3
4143	Genoa	1007	LF	100	SLT	6.8	1.4
4143	Genoa	1131	LF	100	SLT	6.8	1.4
1091	George Neal North	504	SI	100	SLT	7.9	0.8
1091	George Neal North	505	SI	100	SLT	7.9	0.8
1091	George Neal North	506	SI	100	SLT	7.9	0.8
1091	George Neal North	906	LF	100	SLT	7.9	0.8
1091	George Neal North	907	LF	100	SLT	7.9	0.8
1091	George Neal North	908	LF	100	SLT	7.9	0.8
1091	George Neal North	909	LF	100	SLT	7.9	0.8
1091	George Neal North	910	LF	100	SLT	7.9	0.8
7343	George Neal South	911	LF	100	SLT	7.9	0.8
7343	George Neal South	1332	SI	100	SLT	7.9	0.8
6077	Gerald Gentleman	912	LF	100	SLT	7.3	0.6
1356	Ghent	526	SI	60	SCL	6.4	0.81
1356	Ghent	526	SI	40	SLT	6.5	0.6
1356	Ghent	527	SI	100	SCL	6.0	0.5
1356	Ghent	528	SI	100	SCL	6.0	0.5
1356	Ghent	529	SI	100	SCL	7.1	1.3
1356	Ghent	530	SI	60	SCL	6.4	0.81
1356	Ghent	530	SI	40	SLT	6.5	0.6
6136	Gibbons Creek Steam Electric Station	881	LF	100	SCL	5.4	0.6
6136	Gibbons Creek Steam Electric Station	913	LF	100	SCL	5.4	0.6
6136	Gibbons Creek Steam Electric Station	1241	SI	100	SCL	5.4	0.6
6136	Gibbons Creek Steam Electric Station	1242	SI	100	SCL	5.4	0.6
6136	Gibbons Creek Steam Electric Station	1243	SI	100	SCL	5.4	0.6
6136	Gibbons Creek Steam Electric Station	1244	SI	100	SCL	5.4	0.6
6113	Gibson	81	SI	100	SCL	6.6	0.8
6113	Gibson	82	SI	100	SCL	6.6	0.8
6113	Gibson	83	SI	82	SCL	6.6	0.8

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6113	Gibson	83	SI	18	SLT	6.8	1
6113	Gibson	84	SI	100	SLT	6.8	1
6113	Gibson	85	SI	100	SCL	6.6	0.8
6113	Gibson	86	SI	100	SLT	6.8	1
6113	Gibson	902	LF	62	SCL	6.6	0.8
6113	Gibson	902	LF	38	SLT	6.8	1
6113	Gibson	904	LF	100	SLT	6.8	1
3776	Glen Lyn	146	SI	100	SCL	5.1	0.6
3776	Glen Lyn	147	SI	100	SCL	5.1	0.6
3776	Glen Lyn	870	LF	100	SCL	5.1	0.6
8	Gorgas	254	SI	100	SLT	5.1	0.3
8	Gorgas	255	SI	100	SLT	5.1	0.3
8	Gorgas	963	LF	100	SLT	5.1	0.3
1825	Grand Haven City of J.B. Sims	1309	SI	100	SNL	5.9	0.7
1825	Grand Haven City of J.B. Sims	1310	SI	100	SNL	5.9	0.7
10151	Grant Town Power Plant	871	LF	100	SCL	5.3	0.5
10151	Grant Town Power Plant	872	LF	100	SCL	5.3	0.5
10151	Grant Town Power Plant	873	LF	100	SCL	5.3	0.5
10151	Grant Town Power Plant	1167	SI	100	SCL	5.3	0.5
10151	Grant Town Power Plant	1168	SI	100	SCL	5.3	0.5
10151	Grant Town Power Plant	1169	SI	100	SCL	5.3	0.5
10151	Grant Town Power Plant	1170	SI	100	SCL	5.3	0.5
10151	Grant Town Power Plant	1171	SI	100	SCL	5.3	0.5
165	GRDA	874	LF	100	SCL	4.9	0.5
165	GRDA	1210	SI	100	SCL	4.9	0.5
1357	Green River	531	SI	100	SLT	5.2	0.6
1357	Green River	532	SI	56	SCL	6.5	0.6
1357	Green River	532	SI	44	SLT	5.2	0.6
1357	Green River	533	SI	40	SCL	6.5	0.6
1357	Green River	533	SI	60	SLT	5.2	0.6
1357	Green River	534	SI	100	SLT	5.2	0.6
1357	Green River	535	SI	100	SCL	6.5	0.6
10	Greene County	256	SI	100	SLT	5.0	0.2
6041	H L Spurlock Station	34	SI	100	SCL	5.9	0.5
6041	H L Spurlock Station	972	LF	100	SCL	5.9	0.5
2709	H.F. Lee Plant	656	SI	100	SCL	5.0	0.5
2709	H.F. Lee Plant	657	SI	85	SCL	5.0	0.5
2709	H.F. Lee Plant	657	SI	15	SLT	4.7	0.5
2709	H.F. Lee Plant	658	SI	92	SCL	5.0	0.5
2709	H.F. Lee Plant	658	SI	8	SLT	4.7	0.5
2709	H.F. Lee Plant	659	SI	41	SCL	5.0	0.5

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2709	H.F. Lee Plant	659	SI	59	SLT	5.8	1
2709	H.F. Lee Plant	660	SI	46	SCL	5.0	0.5
2709	H.F. Lee Plant	660	SI	30	SLT	5.7	0.93
2709	H.F. Lee Plant	660	SI	24	SNL	4.9	0.4
708	Hammond	351	SI	89	SCL	5.1	0.4
708	Hammond	351	SI	11	SNL	5.1	0.4
708	Hammond	352	SI	89	SCL	5.1	0.4
708	Hammond	352	SI	11	SNL	5.1	0.4
708	Hammond	353	SI	89	SCL	5.1	0.4
708	Hammond	353	SI	11	SNL	5.1	0.4
708	Hammond	354	SI	89	SCL	5.1	0.4
708	Hammond	354	SI	11	SNL	5.1	0.4
708	Hammond	1145	LF	100	SCL	5.0	0.4
1731	Harbor Beach Power Plant	581	SI	38	SLT	7.8	0.4
1731	Harbor Beach Power Plant	581	SI	62	SNL	6.3	1.1
990	Harding Street	420	SI	100	SLT	7.1	1.9
990	Harding Street	421	SI	100	SLT	7.1	1.9
990	Harding Street	422	SI	100	SLT	7.1	1.9
990	Harding Street	423	SI	100	SLT	7.1	1.9
990	Harding Street	424	SI	100	SLT	7.1	1.9
709	Harllee Branch	355	SI	100	SNL	5.1	0.2
709	Harllee Branch	356	SI	45	SCL	5.3	0.3
709	Harllee Branch	356	SI	55	SNL	5.1	0.2
709	Harllee Branch	357	SI	21	SCL	5.3	0.3
709	Harllee Branch	357	SI	79	SNL	5.1	0.2
709	Harllee Branch	358	SI	99	SCL	5.3	0.3
709	Harllee Branch	358	SI	1	SNL	5.1	0.2
709	Harllee Branch	359	SI	94	SCL	5.3	0.3
709	Harllee Branch	359	SI	6	SNL	5.1	0.2
6193	Harrington	877	LF	100	SLT	8.1	0.7
6193	Harrington	878	LF	100	SLT	8.1	0.85
3944	Harrison Power Station	158	SI	53	SCL	5.3	0.5
3944	Harrison Power Station	158	SI	47	SLT	5.1	0.4
3944	Harrison Power Station	891	LF	100	SCL	5.3	0.5
3179	Hatfield's Ferry Power Station	880	LF	100	SCL	5.8	0.4
3179	Hatfield's Ferry Power Station	1215	SI	100	SLT	5.6	0.5
3179	Hatfield's Ferry Power Station	1216	SI	100	SLT	5.6	0.5
3179	Hatfield's Ferry Power Station	1217	SI	100	SLT	5.6	0.5

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3179	Hatfield's Ferry Power Station	1218	SI	100	SLT	5.6	0.5
3179	Hatfield's Ferry Power Station	1219	SI	100	SLT	5.6	0.5
891	Havana	392	SI	100	SCL	6.8	1.6
891	Havana	393	SI	15	SCL	6.8	1.6
891	Havana	393	SI	85	SNL	6.0	0.4
2079	Hawthorn	599	SI	100	SLT	7.7	0.9
2079	Hawthorn	962	LF	100	SLT	7.7	0.9
525	Hayden	332	SI	100	SLT	7.7	0.9
525	Hayden	333	SI	100	SLT	7.7	0.9
525	Hayden	334	SI	100	SLT	7.7	0.9
525	Hayden	335	SI	100	SLT	7.7	0.9
525	Hayden	336	SI	100	SLT	7.7	0.9
525	Hayden	337	SI	100	SLT	7.7	0.9
525	Hayden	882	LF	100	SNL	7.1	1
525	Hayden	1146	LF	100	SLT	7.7	0.9
3251	HB Robinson / Darlington Electric Power Plant	104	SI	100	SNL	5.2	0.4
892	Hennepin Power Station	394	SI	100	SLT	7.1	1.9
892	Hennepin Power Station	883	LF	100	SLT	7.1	1.9
1382	HMP&L Station Two Henderson	556	SI	100	SLT	5.3	0.3
1382	HMP&L Station Two Henderson	557	SI	100	SLT	5.3	0.3
1382	HMP&L Station Two Henderson	984	LF	39	SCL	6.5	0.6
1382	HMP&L Station Two Henderson	984	LF	61	SLT	5.3	0.33
108	HOLCOMB	1147	LF	100	SNL	7.3	0.1
3122	Homer City Station	90	SI	100	SLT	4.8	0.5
3122	Homer City Station	91	SI	100	SLT	4.8	0.5
3122	Homer City Station	92	SI	100	SLT	4.8	0.5
3122	Homer City Station	719	SI	100	SLT	4.8	0.5
3122	Homer City Station	720	SI	100	SLT	4.8	0.5
3122	Homer City Station	721	SI	100	SLT	4.8	0.5
3122	Homer City Station	722	SI	100	SLT	4.8	0.5
3122	Homer City Station	723	SI	100	SLT	4.8	0.5
3122	Homer City Station	724	SI	100	SLT	4.8	0.5
3122	Homer City Station	725	SI	100	SLT	4.8	0.5
3122	Homer City Station	726	SI	100	SLT	4.8	0.5
3122	Homer City Station	727	SI	100	SLT	4.8	0.5
3122	Homer City Station	728	SI	100	SLT	4.8	0.5

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3122	Homer City Station	729	SI	100	SLT	4.8	0.5
3122	Homer City Station	884	LF	100	SLT	4.8	0.5
3122	Homer City Station	886	LF	100	SLT	4.9	0.53
3122	Homer City Station	1134	LF	100	SLT	4.8	0.50
1943	Hoot Lake	887	LF	100	SNL	7.5	2.5
1943	Hoot Lake	1148	LF	100	SNL	7.4	3.3
1943	Hoot Lake	1156	LF	100	SNL	7.4	3.3
1943	Hoot Lake	1157	LF	100	SNL	7.4	3.3
1943	Hoot Lake	1158	LF	100	SNL	7.4	3.3
1943	Hoot Lake	1159	LF	100	SNL	7.6	1.6
1943	Hoot Lake	1160	LF	100	SNL	7.5	1.8
10771	Hopewell	1362	SI	100	SLT	4.9	0.5
6772	Hugo	229	SI	100	SCL	7.4	1.4
6772	Hugo	230	SI	100	SCL	7.4	1.4
6772	Hugo	231	SI	100	SCL	7.3	1.4
6772	Hugo	232	SI	100	SCL	7.3	1.4
6772	Hugo	755	LF	100	SCL	7.4	1.4
3176	Hunlock Power Station	102	SI	100	SLT	5.4	0.6
3176	Hunlock Power Station	103	SI	100	SLT	5.4	0.6
6165	Hunter Plant	756	LF	100	SNL	8.3	0.3
6165	Hunter Plant	1258	SI	100	SCL	8.2	0.5
8069	Huntington Plant	757	LF	100	SLT	8.3	0.38
8069	Huntington Plant	758	LF	100	SLT	8.4	0.4
8069	Huntington Plant	759	LF	100	SLT	8.4	0.4
8069	Huntington Plant	1363	SI	100	SLT	8.4	0.4
8069	Huntington Plant	1364	SI	100	SLT	8.4	0.4
863	Hutsonville	381	SI	100	SLT	7.1	1.9
863	Hutsonville	382	SI	100	SLT	7.1	1.9
863	Hutsonville	383	SI	100	SLT	7.1	1.9
863	Hutsonville	384	SI	100	SLT	7.1	1.9
6065	Iatan	40	SI	100	SLT	7.7	0.90
6065	Iatan	1154	LF	100	SLT	7.7	0.9
6641	Independence	1153	LF	56	SCL	6.4	0.6
6641	Independence	1153	LF	44	SLT	6.2	0.6
2132	Independence Power & Light - Blue Valley Station	616	SI	100	SLT	6.4	1
2132	Independence Power & Light - Blue Valley Station	617	SI	100	SLT	6.4	1
2132	Independence Power & Light - Blue Valley Station	618	SI	100	SLT	6.4	1
594	Indian River Generating Station	339	SI	100	SNL	4.6	0.6

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
594	Indian River Generating Station	340	SI	100	SNL	4.6	0.6
594	Indian River Generating Station	762	LF	100	SNL	4.6	0.6
594	Indian River Generating Station	775	LF	100	SNL	4.6	0.6
6481	Intermountain Power Project	214	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	214	SI	65	SNL	8.7	0.4
6481	Intermountain Power Project	215	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	215	SI	65	SNL	8.7	0.4
6481	Intermountain Power Project	216	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	216	SI	65	SNL	8.7	0.4
6481	Intermountain Power Project	217	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	217	SI	65	SNL	8.7	0.4
6481	Intermountain Power Project	218	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	218	SI	65	SNL	8.7	0.4
6481	Intermountain Power Project	219	SI	35	SCL	8.8	0.5
6481	Intermountain Power Project	219	SI	65	SNL	8.7	0.4
7097	J K Spruce	753	LF	100	SCL	6.7	0.5
7097	J K Spruce	1368	SI	100	SCL	6.7	0.5
7097	J K Spruce	1369	SI	100	SCL	6.7	0.5
7097	J K Spruce	1370	SI	100	SCL	6.7	0.5
7097	J K Spruce	1371	SI	100	SCL	6.7	0.5
7097	J K Spruce	1372	SI	100	SCL	6.7	0.5
7097	J K Spruce	1373	SI	100	SCL	6.7	0.5
2850	J M Stuart	706	SI	100	SCL	5.7	0.6
2850	J M Stuart	707	SI	100	SCL	5.7	0.6
2850	J M Stuart	708	SI	100	SCL	5.7	0.6
2850	J M Stuart	709	SI	100	SCL	5.7	0.6
2850	J M Stuart	710	SI	100	SCL	5.7	0.6
2850	J M Stuart	711	SI	100	SCL	5.7	0.6

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2850	J M Stuart	766	LF	100	SCL	5.7	0.6
2850	J M Stuart	767	LF	100	SCL	5.7	0.6
6181	J T Deely	768	LF	100	SCL	6.7	0.5
6181	J T Deely	1002	LF	100	SCL	6.7	0.5
6181	J T Deely	1291	SI	100	SCL	6.7	0.5
6181	J T Deely	1292	SI	100	SCL	6.7	0.5
6181	J T Deely	1293	SI	100	SCL	6.7	0.5
6181	J T Deely	1294	SI	100	SCL	6.7	0.5
6181	J T Deely	1295	SI	100	SCL	6.7	0.5
6181	J T Deely	1296	SI	100	SCL	6.7	0.5
1720	J.C. Weadock	573	SI	96	SLT	7.9	1
1720	J.C. Weadock	573	SI	4	SNL	6.3	1.1
1720	J.C. Weadock	574	SI	96	SLT	7.9	1
1720	J.C. Weadock	574	SI	4	SNL	6.3	1.1
1720	J.C. Weadock	575	SI	96	SLT	7.9	1
1720	J.C. Weadock	575	SI	4	SNL	6.3	1.1
1720	J.C. Weadock	576	SI	96	SLT	7.9	1
1720	J.C. Weadock	576	SI	4	SNL	6.3	1.1
1720	J.C. Weadock	1003	LF	100	SLT	7.9	1
1723	J.R Whiting	577	SI	100	SCL	7.1	0.9
1723	J.R Whiting	578	SI	100	SCL	7.1	0.9
1723	J.R Whiting	579	SI	100	SCL	7.1	0.9
1723	J.R Whiting	580	SI	100	SCL	7.1	0.9
1723	J.R Whiting	965	LF	100	SCL	7.1	0.9
1723	J.R Whiting	1000	LF	100	SCL	7.1	0.9
710	Jack McDonough	360	SI	100	SNL	5.3	0.1
710	Jack McDonough	361	SI	100	SNL	5.3	0.1
710	Jack McDonough	362	SI	100	SNL	5.3	0.1
710	Jack McDonough	363	SI	100	SNL	5.3	0.1
710	Jack McDonough	968	LF	100	SNL	5.3	0.1
2049	Jack Watson	595	SI	100	SLT	4.9	1.4
2049	Jack Watson	769	LF	100	SLT	4.7	1.9
1830	James De Young	770	LF	100	SCL	6.9	2.5
1830	James De Young	1333	SI	100	SNL	5.9	0.7
6002	James H. Miller Jr.	16	SI	100	SLT	5.1	0.3
2161	James River Power Station	619	SI	74	SCL	5.2	0.42
2161	James River Power Station	619	SI	26	SLT	6.2	0.8
2161	James River Power Station	771	LF	4	SCL	5.1	0.4
2161	James River Power Station	771	LF	96	SLT	6.2	0.8
2187	JE Corette Plant	764	LF	100	SLT	8.0	0.7
2187	JE Corette Plant	1249	SI	100	SLT	8.0	0.7
2187	JE Corette Plant	1250	SI	100	SLT	8.0	0.7
3319	Jefferies	117	SI	100	SLT	5.4	0.68

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3319	Jefferies	118	SI	100	SLT	5.4	0.68
6068	Jeffrey Energy Center	41	SI	100	SCL	7.2	2.1
6068	Jeffrey Energy Center	42	SI	100	SCL	7.2	2.1
6068	Jeffrey Energy Center	43	SI	100	SCL	7.2	2.1
6068	Jeffrey Energy Center	772	LF	100	SCL	7.2	2.1
6068	Jeffrey Energy Center	773	LF	100	SCL	7.2	2.1
8066	Jim Bridger Plant Units 1-4	244	SI	100	SNL	8.3	0.2
8066	Jim Bridger Plant Units 1-4	245	SI	100	SNL	8.3	0.2
8066	Jim Bridger Plant Units 1-4	774	LF	100	SNL	8.3	0.2
3935	John E. Amos	153	SI	100	SLT	6.0	0.46
3935	John E. Amos	154	SI	100	SLT	6.0	0.46
3935	John E. Amos	740	LF	100	SLT	5.3	0.4
3935	John E. Amos	742	LF	100	SLT	5.3	0.4
4271	John P. Madgett	990	LF	100	SLT	7.2	1.6
4271	John P. Madgett	991	LF	100	SLT	7.2	1.6
3405	John Sevier	131	SI	11	SCL	5.1	0.2
3405	John Sevier	131	SI	89	SLT	6.0	0.5
3405	John Sevier	132	SI	11	SCL	5.1	0.2
3405	John Sevier	132	SI	89	SLT	6.0	0.5
3405	John Sevier	763	LF	100	SLT	6.4	0.5
3406	Johnsonville	133	SI	2	SCL	4.9	0.5
3406	Johnsonville	133	SI	98	SLT	5.2	0.40
3406	Johnsonville	291	SI	2	SCL	4.9	0.5
3406	Johnsonville	291	SI	98	SLT	5.2	0.40
3406	Johnsonville	732	LF	100	SLT	5.2	0.4
3406	Johnsonville	733	LF	100	SLT	5.2	0.4
384	Joliet 29	309	SI	13	SCL	7.1	1.4
384	Joliet 29	309	SI	87	SLT	6.9	1.7
384	Joliet 29	1098	LF	13	SCL	7.1	1.4
384	Joliet 29	1098	LF	87	SLT	6.9	1.7
874	Joliet 9	1327	SI	100	SLT	6.9	1.9
874	Joliet 9	1328	SI	100	SLT	6.9	1.9
887	Joppa Steam	390	SI	100	SLT	5.2	0.3
887	Joppa Steam	734	LF	100	SLT	5.2	0.3
3947	Kammer	159	SI	35	SCL	5.5	0.55
3947	Kammer	159	SI	65	SLT	5.7	0.41
3936	Kanawha River	155	SI	100	SNL	5.1	0.40
1381	Kenneth C Coleman	553	SI	100	SCL	5.8	0.5
1381	Kenneth C Coleman	554	SI	95	SCL	5.9	0.53
1381	Kenneth C Coleman	554	SI	5	SLT	5.4	0.4
1381	Kenneth C Coleman	555	SI	100	SCL	5.8	0.5
3136	Keystone	736	LF	100	SLT	5.0	0.6
3136	Keystone	1151	LF	100	SLT	4.9	0.7

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
3136	Keystone	1152	LF	100	SLT	5.0	0.65
3136	Keystone	1297	SI	100	SLT	5.0	0.63
3136	Keystone	1298	SI	100	SLT	5.0	0.6
3136	Keystone	1299	SI	100	SLT	5.0	0.61
3136	Keystone	1300	SI	100	SLT	5.0	0.64
3136	Keystone	1301	SI	100	SLT	4.7	0.64
3136	Keystone	1302	SI	100	SLT	4.6	0.61
3136	Keystone	1303	SI	100	SLT	4.9	0.7
3136	Keystone	1304	SI	100	SLT	4.9	0.7
3136	Keystone	1305	SI	100	SLT	5.0	0.6
3136	Keystone	1306	SI	100	SLT	5.0	0.6
3136	Keystone	1307	SI	100	SLT	5.0	0.6
6031	Killen Station	31	SI	100	SCL	5.7	0.6
6031	Killen Station	32	SI	100	SCL	5.7	0.6
876	Kincaid Generation LLC	388	SI	100	SCL	6.6	1.3
876	Kincaid Generation LLC	969	LF	100	SCL	6.6	1.3
3407	Kingston	134	SI	54	SCL	5.2	0.3
3407	Kingston	134	SI	19	SLT	5.1	0.3
3407	Kingston	134	SI	27	SNL	5.1	0.5
3407	Kingston	135	SI	54	SCL	5.2	0.3
3407	Kingston	135	SI	19	SLT	5.1	0.3
3407	Kingston	135	SI	27	SNL	5.1	0.5
733	Kraft	375	SI	43	SLT	5.1	1
733	Kraft	375	SI	57	SNL	7.2	7.1
733	Kraft	1150	LF	100	SNL	5.3	1.1
2876	Kyger Creek	716	SI	100	SCL	5.7	0.6
2876	Kyger Creek	717	SI	100	SCL	5.7	0.6
2876	Kyger Creek	738	LF	100	SNL	5.1	0.3
2713	L.V. Sutton Electric Plant	665	SI	16	SLT	5.3	1.7
2713	L.V. Sutton Electric Plant	665	SI	84	SNL	5.4	1
2713	L.V. Sutton Electric Plant	666	SI	48	SLT	5.3	1.7
2713	L.V. Sutton Electric Plant	666	SI	52	SNL	5.4	1
1241	La Cygne	513	SI	100	SCL	6.4	0.98
1241	La Cygne	514	SI	100	SCL	6.4	0.98
1241	La Cygne	739	LF	100	SCL	6.3	1
2103	Labadie	607	SI	5	SCL	6.1	0.57
2103	Labadie	607	SI	95	SLT	7.7	0.8
2103	Labadie	608	SI	5	SCL	6.1	0.57
2103	Labadie	608	SI	95	SLT	7.7	0.8
2098	Lake Road	605	SI	100	SLT	7.7	0.9
2098	Lake Road	606	SI	100	SLT	7.6	0.91
2098	Lake Road	752	LF	100	SLT	7.7	0.9
2838	Lake Shore	1270	SI	100	SNL	6.3	0.2

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
964	Lakeside	400	SI	8	SCL	5.8	0.4
964	Lakeside	400	SI	92	SLT	7.1	1.9
1047	Lansing	477	SI	100	SLT	6.7	0.88
1047	Lansing	478	SI	100	SLT	6.7	0.88
1047	Lansing	730	LF	100	SLT	6.7	0.7
1047	Lansing	741	LF	100	SLT	6.7	0.7
643	Lansing Smith	341	SI	100	SNL	4.9	3.4
643	Lansing Smith	743	LF	100	SNL	4.9	3.3
6204	Laramie River Station	188	SI	100	SLT	7.9	0.4
6204	Laramie River Station	189	SI	100	SLT	7.9	0.4
6204	Laramie River Station	744	LF	100	SLT	7.9	0.4
1891	Laskin Energy Center	588	SI	0	SCL	6.3	11.5
1891	Laskin Energy Center	588	SI	100	SNL	5.8	13
1891	Laskin Energy Center	589	SI	0	SCL	6.3	11.5
1891	Laskin Energy Center	589	SI	100	SNL	5.8	13
1250	Lawrence Energy Center	515	SI	44	SCL	6.6	1.3
1250	Lawrence Energy Center	515	SI	56	SLT	7.3	1.3
1250	Lawrence Energy Center	516	SI	44	SCL	6.6	1.3
1250	Lawrence Energy Center	516	SI	56	SLT	7.3	1.3
1250	Lawrence Energy Center	517	SI	44	SCL	6.6	1.3
1250	Lawrence Energy Center	517	SI	56	SLT	7.3	1.3
1250	Lawrence Energy Center	518	SI	44	SCL	6.6	1.3
1250	Lawrence Energy Center	518	SI	56	SLT	7.3	1.3
1250	Lawrence Energy Center	745	LF	44	SCL	6.6	1
1250	Lawrence Energy Center	745	LF	56	SLT	7.3	1.3
1250	Lawrence Energy Center	747	LF	48	SCL	6.6	1
1250	Lawrence Energy Center	747	LF	52	SLT	7.3	1.3
1250	Lawrence Energy Center	1149	LF	83	SCL	6.6	1
1250	Lawrence Energy Center	1149	LF	17	SLT	7.3	1.3
2817	Leland Olds	683	SI	100	SCL	7.8	0.2
2817	Leland Olds	684	SI	100	SCL	7.8	0.2
2817	Leland Olds	685	SI	100	SCL	7.8	0.2
2817	Leland Olds	748	LF	98	SCL	7.8	0.2
2817	Leland Olds	748	LF	2	SLT	7.8	0.9
2817	Leland Olds	749	LF	100	SLT	7.8	0.9
6089	Lewis & Clark	750	LF	100	SLT	8.0	0.8
6089	Lewis & Clark	751	LF	100	SLT	8.0	0.45
6089	Lewis & Clark	786	LF	100	SLT	7.9	0.54
6089	Lewis & Clark	1374	SI	100	SLT	7.9	0.6
6089	Lewis & Clark	1375	SI	100	SLT	7.9	0.6
6089	Lewis & Clark	1376	SI	100	SLT	7.9	0.6
6089	Lewis & Clark	1377	SI	100	SLT	7.9	0.6
6089	Lewis & Clark	1378	SI	100	SLT	8.0	0.34

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
298	Limestone	300	SI	100	SLT	6.2	0.70
298	Limestone	301	SI	100	SLT	6.2	0.70
298	Limestone	302	SI	100	SLT	6.2	0.70
298	Limestone	303	SI	100	SLT	6.2	0.70
298	Limestone	304	SI	100	SLT	6.2	0.70
298	Limestone	305	SI	100	SLT	6.2	0.70
298	Limestone	306	SI	100	SLT	6.2	0.70
298	Limestone	307	SI	100	SLT	6.2	0.70
298	Limestone	308	SI	100	SLT	6.2	0.7
298	Limestone	821	LF	100	SLT	6.2	0.7
2240	Lon Wright	765	LF	100	SCL	7.8	1.3
6664	Louisa	222	SI	37	SCL	6.4	2.8
6664	Louisa	222	SI	63	SNL	6.3	1
6664	Louisa	223	SI	100	SCL	6.0	0.6
6664	Louisa	801	LF	100	SNL	6.3	1
976	Marion Generating Station	401	SI	50	SCL	5.0	0.4
976	Marion Generating Station	401	SI	50	SLT	5.2	0.3
976	Marion Generating Station	402	SI	34	SCL	5.0	0.4
976	Marion Generating Station	402	SI	66	SLT	5.2	0.30
976	Marion Generating Station	403	SI	100	SCL	5.0	0.4
976	Marion Generating Station	404	SI	100	SCL	5.0	0.4
976	Marion Generating Station	405	SI	18	SCL	5.0	0.4
976	Marion Generating Station	405	SI	82	SLT	5.2	0.3
976	Marion Generating Station	406	SI	77	SCL	5.0	0.4
976	Marion Generating Station	406	SI	23	SLT	5.2	0.3
976	Marion Generating Station	407	SI	100	SCL	5.0	0.4
976	Marion Generating Station	408	SI	100	SCL	5.0	0.4
976	Marion Generating Station	409	SI	100	SCL	5.0	0.4
976	Marion Generating Station	410	SI	42	SCL	5.0	0.4
976	Marion Generating Station	410	SI	58	SLT	5.2	0.3
976	Marion Generating Station	411	SI	100	SLT	5.2	0.3
976	Marion Generating Station	412	SI	66	SCL	5.0	0.4
976	Marion Generating Station	412	SI	34	SLT	5.2	0.3
976	Marion Generating Station	802	LF	100	SCL	5.0	0.4
2727	Marshall	680	SI	100	SCL	5.3	0.3
2727	Marshall	803	LF	100	SCL	5.3	0.3
2727	Marshall	804	LF	100	SCL	5.3	0.3
492	Martin Drake	805	LF	100	SNL	6.9	0.9
492	Martin Drake	1251	SI	100	SNL	6.9	0.9
492	Martin Drake	1252	SI	100	SNL	6.9	0.9
492	Martin Drake	1253	SI	100	SNL	6.9	0.9
492	Martin Drake	1254	SI	100	SNL	6.9	0.9
6146	Martin Lake	806	LF	100	SNL	5.1	0.6

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6146	Martin Lake	807	LF	100	SNL	5.1	0.6
6146	Martin Lake	808	LF	100	SCL	5.1	0.6
6146	Martin Lake	810	LF	100	SCL	5.1	0.6
6146	Martin Lake	822	LF	100	SCL	5.1	0.6
6146	Martin Lake	1223	SI	100	SCL	5.1	0.6
6146	Martin Lake	1224	SI	100	SCL	5.1	0.6
6146	Martin Lake	1225	SI	100	SCL	5.1	0.6
6146	Martin Lake	1226	SI	100	SCL	5.1	0.6
6250	Mayo Electric Generating Facility	204	SI	100	SNL	6.1	0.3
6124	McIntosh	87	SI	56	SCL	5.4	2.5
6124	McIntosh	87	SI	44	SNL	4.9	1.9
3287	McMeekin	1155	LF	100	SCL	5.0	0.3
2104	Meramec	609	SI	63	SCL	6.4	0.93
2104	Meramec	609	SI	37	SLT	6.4	1
2104	Meramec	610	SI	63	SCL	6.4	0.93
2104	Meramec	610	SI	37	SLT	6.4	1
2104	Meramec	611	SI	63	SCL	6.4	0.93
2104	Meramec	611	SI	37	SLT	6.4	1
2104	Meramec	612	SI	63	SCL	6.4	0.93
2104	Meramec	612	SI	37	SLT	6.4	1
2104	Meramec	613	SI	63	SCL	6.4	0.93
2104	Meramec	613	SI	37	SLT	6.4	1
864	Meredosia	385	SI	48	SCL	6.8	1.6
864	Meredosia	385	SI	52	SNL	6.0	0.4
864	Meredosia	386	SI	48	SCL	6.8	1.6
864	Meredosia	386	SI	52	SNL	6.0	0.4
6213	Merom	190	SI	64	SCL	5.6	0.4
6213	Merom	190	SI	36	SLT	5.5	0.4
6213	Merom	812	LF	100	SLT	5.5	0.4
6213	Merom	813	LF	100	SLT	5.5	0.4
2364	Merrimack Station	754	LF	100	SNL	5.1	3
2364	Merrimack Station	1319	SI	100	SNL	5.3	0.5
2364	Merrimack Station	1320	SI	100	SNL	5.3	0.5
2832	Miami Fort	699	SI	100	SLT	7.1	1.9
2832	Miami Fort	700	SI	100	SLT	7.1	1.9
2832	Miami Fort	1109	LF	100	SLT	7.1	1.9
2832	Miami Fort	1121	LF	99	SCL	6.5	0.4
2832	Miami Fort	1121	LF	1	SLT	7.1	1.9
997	Michigan City	448	SI	100	SNL	6.2	0.4
997	Michigan City	449	SI	100	SNL	6.2	0.4
997	Michigan City	450	SI	100	SNL	6.2	0.4
997	Michigan City	451	SI	100	SNL	6.2	0.4

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
997	Michigan City	452	SI	100	SNL	6.2	0.4
997	Michigan City	453	SI	100	SNL	6.2	0.4
1364	Mill Creek	543	SI	100	SCL	5.2	0.3
1364	Mill Creek	544	SI	85	SCL	6.0	0.67
1364	Mill Creek	544	SI	15	SLT	6.5	0.6
1364	Mill Creek	545	SI	85	SCL	6.0	0.67
1364	Mill Creek	545	SI	15	SLT	6.5	0.6
1364	Mill Creek	546	SI	85	SCL	6.0	0.67
1364	Mill Creek	546	SI	15	SLT	6.5	0.6
1364	Mill Creek	547	SI	85	SCL	6.0	0.67
1364	Mill Creek	547	SI	15	SLT	6.5	0.6
1364	Mill Creek	817	LF	100	SCL	5.9	0.5
1364	Mill Creek	818	LF	100	SCL	5.9	0.5
1364	Mill Creek	819	LF	100	SCL	5.9	0.5
2823	Milton R. Young Station	686	SI	100	SLT	7.7	0.92
2823	Milton R. Young Station	687	SI	100	SLT	7.7	0.92
2823	Milton R. Young Station	688	SI	100	SLT	7.7	0.92
2823	Milton R. Young Station	689	SI	100	SLT	7.7	0.92
2823	Milton R. Young Station	777	LF	100	SLT	7.6	0.9
2823	Milton R. Young Station	788	LF	100	SLT	7.6	0.9
2823	Milton R. Young Station	809	LF	100	SLT	7.6	0.9
2823	Milton R. Young Station	811	LF	100	SLT	7.7	0.9
2823	Milton R. Young Station	820	LF	100	SLT	7.8	0.9
2171	Missouri City	1257	SI	100	SLT	7.7	0.9
3948	Mitchell	160	SI	6	SCL	5.3	0.5
3948	Mitchell	160	SI	94	SLT	6.2	0.4
3948	Mitchell	161	SI	36	SCL	5.3	0.5
3948	Mitchell	161	SI	64	SLT	6.2	0.4
727	Mitchell	364	SI	100	SLT	5.2	0.37
727	Mitchell	365	SI	100	SLT	5.2	0.37
727	Mitchell	366	SI	100	SLT	5.2	0.37
3181	Mitchell Power Station	778	LF	100	SLT	5.6	0.5
3181	Mitchell Power Station	779	LF	100	SLT	5.6	0.5
1048	ML Kapp	479	SI	70	SCL	6.4	1.8
1048	ML Kapp	479	SI	30	SLT	6.8	1.4
1048	ML Kapp	480	SI	70	SCL	6.4	1.8
1048	ML Kapp	480	SI	30	SLT	6.8	1.4
1048	ML Kapp	481	SI	70	SCL	6.4	1.8
1048	ML Kapp	481	SI	30	SLT	6.8	1.4
1048	ML Kapp	482	SI	70	SCL	6.4	1.8
1048	ML Kapp	482	SI	30	SLT	6.8	1.4
1733	Monroe Power Plant	582	SI	100	SCL	7.1	0.9
1733	Monroe Power Plant	583	SI	8	SCL	7.1	0.9

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1733	Monroe Power Plant	583	SI	92	SLT	7.1	0.6
6147	Monticello	780	LF	100	SCL	5.6	0.6
6147	Monticello	781	LF	100	SCL	5.6	0.6
6147	Monticello	782	LF	100	SCL	5.6	0.6
6147	Monticello	1203	SI	100	SCL	5.6	0.6
6147	Monticello	1204	SI	100	SCL	5.6	0.6
6147	Monticello	1205	SI	100	SCL	5.6	0.6
6147	Monticello	1206	SI	100	SCL	5.6	0.6
2080	Montrose	600	SI	100	SCL	6.4	1
2080	Montrose	601	SI	100	SCL	6.4	1
2080	Montrose	602	SI	100	SCL	6.4	1
2080	Montrose	783	LF	100	SCL	6.4	1
1573	Morgantown Generating Plant	785	LF	100	SNL	4.8	0.4
1573	Morgantown Generating Plant	1108	LF	100	SNL	4.6	0.7
1606	Mount Tom	563	SI	100	SLT	5.0	0
1606	Mount Tom	564	SI	74	SLT	5.4	0.22
1606	Mount Tom	564	SI	26	SNL	5.0	0.9
1606	Mount Tom	565	SI	74	SLT	5.4	0.22
1606	Mount Tom	565	SI	26	SNL	5.0	0.9
1606	Mount Tom	798	LF	100	SLT	5.0	0
6264	Mountaineer	211	SI	100	SLT	6.0	0.4
6264	Mountaineer	787	LF	100	SLT	5.3	0.4
3954	Mt. Storm	789	LF	100	SLT	4.6	0.4
3954	Mt. Storm	1110	LF	94	SLT	4.6	0.4
3954	Mt. Storm	1110	LF	6	SNL	4.5	0.5
3954	Mt. Storm	1111	LF	100	SLT	4.6	0.4
3954	Mt. Storm	1112	LF	100	SNL	4.5	0.5
1167	Muscatine #1	792	LF	100	SCL	6.3	1.6
1167	Muscatine #1	1361	SI	100	SNL	6.3	1
2872	Muskingum River	712	SI	100	SCL	6.0	0.4
2872	Muskingum River	713	SI	100	SCL	6.0	0.2
2872	Muskingum River	714	SI	100	SCL	6.0	0.32
2872	Muskingum River	715	SI	100	SCL	6.0	0.4
2952	Muskogee	1172	SI	100	SLT	7.3	0.5
2952	Muskogee	1173	SI	100	SLT	7.3	0.5
2952	Muskogee	1174	SI	100	SLT	7.3	0.5
4162	Naughton Plant	12	SI	100	SLT	8.2	0.5
4162	Naughton Plant	13	SI	100	SLT	8.2	0.5
4162	Naughton Plant	14	SI	100	SLT	8.2	0.5
4162	Naughton Plant	15	SI	100	SLT	8.2	0.5
4162	Naughton Plant	980	LF	100	SLT	8.2	0.5

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
4941	Navajo Generating Station	793	LF	100	SNL	8.0	0.5
6064	Nearman Creek	39	SI	100	SLT	7.3	0.94
6064	Nearman Creek	794	LF	100	SLT	7.7	0.9
6064	Nearman Creek	795	LF	100	SLT	6.5	1.0
6096	Nebraska City	797	LF	100	SLT	7.9	0.8
6096	Nebraska City	943	LF	100	SLT	7.9	0.8
6096	Nebraska City	1271	SI	100	SLT	7.9	0.8
6096	Nebraska City	1272	SI	100	SLT	7.9	0.8
4054	Nelson Dewey	170	SI	100	SLT	6.8	1.4
4054	Nelson Dewey	171	SI	100	SLT	6.8	1.4
4054	Nelson Dewey	893	LF	100	SLT	6.8	1.4
3138	New Castle Plant	941	LF	100	SLT	6.2	0.6
3138	New Castle Plant	1349	SI	100	SLT	6.2	0.6
3138	New Castle Plant	1350	SI	100	SLT	6.2	0.6
2167	New Madrid	620	SI	80	SCL	6.9	0.4
2167	New Madrid	620	SI	20	SNL	5.9	0.6
2167	New Madrid	621	SI	100	SCL	6.9	0.4
2167	New Madrid	622	SI	99	SLT	6.2	0.6
2167	New Madrid	622	SI	1	SNL	5.9	0.6
2167	New Madrid	623	SI	97	SCL	6.9	0.4
2167	New Madrid	623	SI	3	SNL	5.9	0.6
2167	New Madrid	1032	LF	100	SLT	6.2	0.6
6017	Newton	21	SI	100	SLT	5.3	0.5
6017	Newton	22	SI	100	SLT	5.3	0.5
6017	Newton	1033	LF	100	SLT	5.3	0.5
6017	Newton	1034	LF	100	SLT	5.3	0.5
2291	North Omaha	1036	LF	100	SLT	7.9	0.8
2291	North Omaha	1113	LF	100	SLT	7.9	0.8
2291	North Omaha	1220	SI	100	SLT	7.9	0.8
2291	North Omaha	1221	SI	100	SLT	7.9	0.8
2291	North Omaha	1222	SI	100	SLT	7.9	0.8
8224	North Valmy	1037	LF	100	SNL	8.6	0.3
2963	Northeastern	718	SI	100	SCL	6.8	1.1
2963	Northeastern	1038	LF	100	SCL	6.5	1.0
667	Northside Generating Station	1039	LF	100	SNL	5.6	0.6
10030	NRG Energy Center Dover	251	SI	100	SLT	4.6	0.5
527	Nucla	338	SI	36	SLT	8.1	0.1
527	Nucla	338	SI	64	SNL	8.0	0.5
527	Nucla	964	LF	36	SLT	8.1	0.1
527	Nucla	964	LF	64	SNL	8.0	0.5
2848	O H Hutchings	703	SI	100	SLT	7.1	1.9
2848	O H Hutchings	704	SI	100	SLT	7.1	1.9

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2848	O H Hutchings	705	SI	100	SLT	7.1	1.9
6180	Oak Grove	1040	LF	100	SLT	6.2	0.7
6180	Oak Grove	1042	LF	100	SLT	6.2	0.7
6180	Oak Grove	1054	LF	100	SLT	6.2	0.7
6180	Oak Grove	1185	SI	100	SLT	6.2	0.7
127	Oklaunion	281	SI	100	SLT	8.0	0.2
127	Oklaunion	282	SI	100	SLT	8.0	0.2
127	Oklaunion	283	SI	100	SLT	8.0	0.2
127	Oklaunion	841	LF	100	SLT	8.0	0.2
4151	Osage	1031	LF	100	SCL	6.0	0.3
4151	Osage	1044	LF	100	SCL	6.0	0.3
4151	Osage	1266	SI	100	SCL	6.0	0.3
4151	Osage	1267	SI	100	SCL	6.0	0.3
1831	Otto E. Eckert Station	586	SI	100	SNL	6.9	1
6254	Ottumwa	205	SI	6	SCL	5.9	0.64
6254	Ottumwa	205	SI	94	SLT	6.2	1.2
6254	Ottumwa	206	SI	6	SCL	5.9	0.64
6254	Ottumwa	206	SI	94	SLT	6.2	1.2
6254	Ottumwa	207	SI	6	SCL	5.9	0.64
6254	Ottumwa	207	SI	94	SLT	6.2	1.2
6254	Ottumwa	208	SI	6	SCL	5.9	0.64
6254	Ottumwa	208	SI	94	SLT	6.2	1.2
6254	Ottumwa	1045	LF	79	SCL	6.0	0.73
6254	Ottumwa	1045	LF	21	SLT	6.0	0.7
1378	Paradise	548	SI	100	SLT	6.1	0.47
1378	Paradise	549	SI	100	SLT	6.1	0.47
1378	Paradise	550	SI	100	SLT	6.1	0.47
6248	Pawnee	191	SI	100	SNL	7.5	0.41
6248	Pawnee	192	SI	100	SNL	7.5	0.41
6248	Pawnee	193	SI	100	SNL	7.5	0.41
6248	Pawnee	194	SI	100	SNL	7.5	0.41
6248	Pawnee	195	SI	100	SNL	7.5	0.41
6248	Pawnee	196	SI	100	SNL	7.5	0.41
6248	Pawnee	197	SI	100	SNL	7.5	0.41
6248	Pawnee	1046	LF	100	SNL	7.3	0.3
6238	Pearl Station	1211	SI	100	SCL	6.8	1.6
3938	Philip Sporn	156	SI	100	SLT	6.0	0.4
3938	Philip Sporn	157	SI	100	SLT	6.0	0.4
3938	Philip Sporn	979	LF	24	SCL	5.5	0.27
3938	Philip Sporn	979	LF	57	SLT	6.0	0.4
3938	Philip Sporn	979	LF	19	SNL	5.4	0.3
2843	Picway	702	SI	100	SLT	7.1	0.6
7902	Pirkey	233	SI	100	SLT	4.9	0.6

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
7902	Pirkey	234	SI	100	SLT	4.9	0.6
7902	Pirkey	235	SI	100	SLT	4.9	0.6
7902	Pirkey	236	SI	100	SLT	4.9	0.6
7902	Pirkey	237	SI	100	SLT	4.9	0.6
7902	Pirkey	238	SI	100	SLT	4.9	0.6
7902	Pirkey	1132	LF	100	SLT	4.9	0.6
59	Platte	1047	LF	100	SNL	6.6	0.4
59	Platte	1048	LF	100	SNL	6.6	0.4
6170	Pleasant Prairie	1049	LF	100	SCL	7.3	10.3
6004	Pleasants Power Station	17	SI	100	SLT	5.3	0.4
6004	Pleasants Power Station	1050	LF	100	SLT	5.3	0.4
7242	Polk	1051	LF	100	SNL	5.6	0.7
3113	Portland	1020	LF	100	SNL	5.3	0.5
3113	Portland	1041	LF	100	SNL	6.2	0.3
3113	Portland	1043	LF	100	SNL	5.3	0.5
3113	Portland	1052	LF	100	SNL	5.3	0.5
3113	Portland	1199	SI	100	SNL	6.2	0.3
3113	Portland	1200	SI	100	SNL	6.2	0.3
3113	Portland	1201	SI	100	SNL	6.2	0.3
879	Powerton	1227	SI	100	SNL	6.5	1
879	Powerton	1228	SI	100	SNL	6.5	1
879	Powerton	1229	SI	100	SNL	6.5	1
879	Powerton	1230	SI	100	SNL	6.5	1
879	Powerton	1231	SI	100	SNL	6.5	1
879	Powerton	1232	SI	100	SNL	6.5	1
879	Powerton	1233	SI	100	SNL	6.5	1
3140	PPL Brunner Island	93	SI	100	SLT	5.1	0.5
3140	PPL Brunner Island	94	SI	100	SLT	5.1	0.5
3140	PPL Brunner Island	95	SI	100	SLT	5.1	0.5
3140	PPL Brunner Island	1114	LF	100	SLT	5.1	0.5
3149	PPL Montour	96	SI	7	SCL	6.0	0.5
3149	PPL Montour	96	SI	93	SLT	5.3	0.53
3149	PPL Montour	97	SI	7	SCL	6.0	0.5
3149	PPL Montour	97	SI	93	SLT	5.3	0.53
3149	PPL Montour	98	SI	7	SCL	6.0	0.5
3149	PPL Montour	98	SI	93	SLT	5.3	0.53
3149	PPL Montour	99	SI	7	SCL	6.0	0.5
3149	PPL Montour	99	SI	93	SLT	5.3	0.53
3149	PPL Montour	100	SI	7	SCL	6.0	0.5
3149	PPL Montour	100	SI	93	SLT	5.3	0.53
3149	PPL Montour	1011	LF	100	SLT	5.4	0.56
3149	PPL Montour	1115	LF	100	SLT	5.2	0.5
1073	Prairie Creek	487	SI	100	SCL	6.4	1.9

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1073	Prairie Creek	488	SI	100	SCL	6.4	1.9
1073	Prairie Creek	489	SI	100	SCL	6.4	1.9
1073	Prairie Creek	490	SI	100	SCL	6.4	1.9
1073	Prairie Creek	491	SI	100	SCL	6.4	1.9
1073	Prairie Creek	492	SI	100	SCL	6.4	1.9
1073	Prairie Creek	493	SI	100	SCL	6.4	1.9
1073	Prairie Creek	494	SI	100	SCL	6.4	1.9
1073	Prairie Creek	495	SI	100	SCL	6.4	1.9
1073	Prairie Creek	496	SI	100	SCL	6.4	1.9
1769	Presque Isle	1012	LF	100	SNL	5.5	2.4
1769	Presque Isle	1013	LF	100	SNL	5.5	2.4
1769	Presque Isle	1014	LF	100	SNL	5.5	2.4
2403	PSEG Hudson Generating Station	1015	LF	100	SLT	6.2	7.1
2403	PSEG Hudson Generating Station	1351	SI	100	SLT	6.2	7.1
2403	PSEG Hudson Generating Station	1352	SI	100	SLT	6.2	7.1
2408	PSEG Mercer Generating Station	1016	LF	100	SNL	4.9	7.1
2408	PSEG Mercer Generating Station	1197	SI	100	SNL	4.9	7.1
2408	PSEG Mercer Generating Station	1198	SI	100	SNL	4.9	7.1
4072	Pulliam	1017	LF	100	SCL	7.3	4.6
4072	Pulliam	1212	SI	100	SCL	7.3	4.6
1295	Quindaro	1030	LF	100	SLT	6.6	0.99
6639	R D Green	220	SI	100	SLT	5.3	0.3
6639	R D Green	1019	LF	8	SCL	6.5	0.6
6639	R D Green	1019	LF	92	SLT	5.3	0.3
2864	R. E. Burger	976	LF	68	SCL	5.5	0.54
2864	R. E. Burger	976	LF	32	SLT	6.2	0.4
2864	R. E. Burger	1380	SI	100	SCL	5.7	0.6
2864	R. E. Burger	1381	SI	100	SCL	5.7	0.6
1008	R. Gallagher	460	SI	100	SCL	5.9	0.6
1008	R. Gallagher	461	SI	100	SCL	5.9	0.6
1008	R. Gallagher	1001	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1023	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1024	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1025	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1026	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1027	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1029	LF	100	SCL	5.9	0.6

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1008	R. Gallagher	1053	LF	100	SCL	5.9	0.6
1008	R. Gallagher	1056	LF	100	SCL	5.9	0.6
1570	R. Paul Smith Power Station	561	SI	100	SLT	5.2	0.8
1570	R. Paul Smith Power Station	562	SI	100	SLT	5.2	0.8
1570	R. Paul Smith Power Station	1083	LF	100	SLT	5.2	0.8
2790	R.M. Heskett Station	1080	LF	100	SNL	7.7	1
2790	R.M. Heskett Station	1081	LF	100	SNL	7.7	1
6085	R.M. Schahfer	54	SI	100	SNL	7.0	0.80
6085	R.M. Schahfer	55	SI	100	SNL	6.9	0.75
6085	R.M. Schahfer	56	SI	100	SNL	6.8	0.68
6085	R.M. Schahfer	57	SI	100	SNL	6.8	9.3
6085	R.M. Schahfer	58	SI	100	SNL	7.0	0.79
6085	R.M. Schahfer	67	SI	100	SNL	6.2	0.4
6085	R.M. Schahfer	68	SI	100	SNL	7.0	0.8
6085	R.M. Schahfer	1082	LF	100	SNL	6.8	9.3
6761	Rawhide	225	SI	100	SLT	8.0	0.4
6761	Rawhide	226	SI	100	SLT	8.0	0.4
6761	Rawhide	996	LF	100	SLT	8.0	0.4
6761	Rawhide	1086	LF	100	SLT	8.0	0.4
8219	Ray D Nixon	1087	LF	100	SLT	8.0	0.6
8219	Ray D Nixon	1255	SI	100	SLT	8.0	0.6
55076	Red Hills Generating Facility	1088	LF	100	SLT	5.0	0.2
55076	Red Hills Generating Facility	1256	SI	100	SLT	5.0	0.2
2324	Reid Gardner	630	SI	100	SLT	8.3	0.3
2324	Reid Gardner	631	SI	100	SLT	8.3	0.3
2324	Reid Gardner	632	SI	100	SLT	8.3	0.3
2324	Reid Gardner	633	SI	100	SLT	8.3	0.3
2324	Reid Gardner	634	SI	100	SLT	8.3	0.3
2324	Reid Gardner	635	SI	100	SLT	8.3	0.3
2324	Reid Gardner	636	SI	100	SLT	8.3	0.3
2324	Reid Gardner	637	SI	100	SLT	8.3	0.3
2324	Reid Gardner	1090	LF	100	SLT	8.3	0.3
1740	River Rouge Power Plant	1186	SI	100	SLT	6.8	0.8
2732	Riverbend	681	SI	100	SCL	5.3	0.3
2732	Riverbend	682	SI	100	SCL	5.3	0.3
1081	Riverside	500	SI	100	SCL	6.4	2.8
1081	Riverside	501	SI	100	SCL	6.4	2.8
1927	Riverside	594	SI	32	SLT	6.8	5.3

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1927	Riverside	594	SI	68	SNL	6.4	1.3
1239	Riverton	512	SI	100	SLT	6.2	0.8
3945	Rivesville Power Station	1095	LF	100	SCL	5.3	0.5
3945	Rivesville Power Station	1116	LF	100	SCL	5.3	0.5
3945	Rivesville Power Station	1355	SI	100	SLT	5.1	0.4
3945	Rivesville Power Station	1356	SI	100	SLT	5.1	0.4
3945	Rivesville Power Station	1357	SI	100	SCL	5.3	0.5
3945	Rivesville Power Station	1358	SI	100	SLT	5.1	0.4
6166	Rockport	179	SI	100	SCL	5.9	0.6
6166	Rockport	1097	LF	100	SCL	5.9	0.6
6190	Rodemacher	185	SI	16	SCL	7.4	1
6190	Rodemacher	185	SI	84	SLT	7.8	0.8
6190	Rodemacher	186	SI	100	SCL	7.4	1
6190	Rodemacher	187	SI	100	SCL	7.4	1
6190	Rodemacher	187	SI	0	SLT	5.1	0.3
2712	Roxboro Steam Electric Plant	661	SI	100	SNL	5.8	0.3
2712	Roxboro Steam Electric Plant	662	SI	100	SNL	5.9	0.28
2712	Roxboro Steam Electric Plant	663	SI	4	SCL	5.1	0.2
2712	Roxboro Steam Electric Plant	663	SI	96	SNL	5.8	0.29
2712	Roxboro Steam Electric Plant	664	SI	100	SNL	5.8	0.3
2712	Roxboro Steam Electric Plant	1096	LF	100	SNL	5.8	0.3
1393	RS Nelson	1084	LF	100	SCL	5.6	0.7
1393	RS Nelson	1085	LF	100	SCL	5.6	0.7
1393	RS Nelson	1329	SI	100	SCL	5.6	0.7
1393	RS Nelson	1330	SI	100	SCL	6.2	2.4
6155	Rush Island	178	SI	42	SCL	5.8	0.73
6155	Rush Island	178	SI	58	SLT	7.0	0.68
6155	Rush Island	1091	LF	100	SLT	5.6	0.4
2451	San Juan	1308	SI	100	SLT	8.4	0
6183	San Miguel	1093	LF	100	SCL	7.8	1.1
6183	San Miguel	1094	LF	100	SCL	7.8	1.1
6183	San Miguel	1365	SI	0	SCL	7.8	1.1
6183	San Miguel	1365	SI	100	SLT	7.5	0.9
6183	San Miguel	1366	SI	100	SLT	7.5	0.9
6183	San Miguel	1367	SI	100	SLT	7.5	0.9
6648	Sandow No 4	221	SI	100	SLT	6.5	0.41
6648	Sandow No 4	1057	LF	100	SLT	6.2	0.7

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6648	Sandow No 4	1065	LF	100	SLT	6.9	0.02
6648	Sandow No 4	1067	LF	100	SLT	6.9	0
6648	Sandow No 4	1089	LF	100	SLT	6.6	0.27
6648	Sandow No 4	1092	LF	100	SLT	6.9	0
6257	Scherer	209	SI	16	SCL	5.3	0.3
6257	Scherer	209	SI	84	SNL	5.2	0.2
6257	Scherer	210	SI	16	SCL	5.3	0.3
6257	Scherer	210	SI	84	SNL	5.2	0.2
2367	SCHILLER	1058	LF	100	SNL	5.5	0.5
642	Scholz	1346	SI	71	SLT	5.1	0.3
642	Scholz	1346	SI	29	SNL	5.0	0.4
642	Scholz	1347	SI	56	SLT	5.1	0.3
642	Scholz	1347	SI	44	SNL	5.0	0.4
642	Scholz	1348	SI	83	SLT	5.1	0.3
642	Scholz	1348	SI	17	SNL	5.0	0.4
136	Seminole Generating Station	1059	LF	100	SNL	5.0	0.2
1379	Shawnee	551	SI	100	SLT	6.0	0.53
1379	Shawnee	552	SI	100	SLT	6.0	0.53
1379	Shawnee	1060	LF	100	SLT	5.4	0.4
1379	Shawnee	1061	LF	100	SLT	6.7	0.7
3131	Shawville	1062	LF	100	SLT	4.5	0.6
3131	Shawville	1063	LF	100	SLT	4.5	0.6
3131	Shawville	1245	SI	100	SLT	4.5	0.6
3131	Shawville	1246	SI	100	SLT	4.5	0.6
3131	Shawville	1247	SI	100	SLT	4.5	0.6
3131	Shawville	1248	SI	100	SLT	4.5	0.6
2277	Sheldon Station	1055	LF	65	SCL	6.7	0.4
2277	Sheldon Station	1055	LF	35	SLT	7.2	1.3
2277	Sheldon Station	1064	LF	100	SLT	7.2	1.3
2277	Sheldon Station	1066	LF	78	SCL	6.7	0.4
2277	Sheldon Station	1066	LF	22	SLT	7.2	1.3
2277	Sheldon Station	1078	LF	100	SCL	6.7	0.4
2277	Sheldon Station	1360	SI	61	SCL	6.7	0.4
2277	Sheldon Station	1360	SI	39	SLT	7.2	1.3
6090	Sherburne County	69	SI	100	SNL	6.4	1.3
6090	Sherburne County	70	SI	100	SNL	6.4	1.3
6090	Sherburne County	71	SI	100	SNL	6.4	1.3
6090	Sherburne County	72	SI	100	SNL	6.4	1.3
6090	Sherburne County	73	SI	100	SNL	6.4	1.3
6090	Sherburne County	74	SI	100	SNL	6.4	1.3
6090	Sherburne County	1068	LF	100	SNL	6.4	1.3
2094	Sibley	603	SI	100	SLT	6.7	0.98

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2094	Sibley	604	SI	100	SLT	6.7	0.98
2094	Sibley	1069	LF	100	SLT	6.4	1
6768	Sikeston Power Station	227	SI	4	SLT	6.7	0.7
6768	Sikeston Power Station	227	SI	96	SNL	6.0	0.4
6768	Sikeston Power Station	228	SI	100	SNL	6.0	0.4
2107	Sioux	614	SI	46	SCL	5.7	1.1
2107	Sioux	614	SI	54	SLT	7.7	0.8
2107	Sioux	615	SI	46	SCL	5.7	1.1
2107	Sioux	615	SI	54	SLT	7.7	0.8
1058	Sixth Street	483	SI	100	SCL	6.4	2.8
1058	Sixth Street	484	SI	90	SCL	6.4	2.8
1058	Sixth Street	484	SI	10	SLT	6.7	2.1
1058	Sixth Street	485	SI	100	SCL	6.4	2.8
1058	Sixth Street	486	SI	100	SCL	6.4	2.8
1613	Somerset Station	566	SI	21	SLT	5.2	2.3
1613	Somerset Station	566	SI	79	SNL	5.3	0.23
1613	Somerset Station	567	SI	21	SLT	5.2	2.3
1613	Somerset Station	567	SI	79	SNL	5.3	0.23
1613	Somerset Station	568	SI	21	SLT	5.2	2.3
1613	Somerset Station	568	SI	79	SNL	5.3	0.23
1613	Somerset Station	569	SI	21	SLT	5.2	2.3
1613	Somerset Station	569	SI	79	SNL	5.3	0.23
6095	Sooner	1259	SI	100	SLT	7.0	0.8
6095	Sooner	1260	SI	100	SCL	7.4	0.8
6061	South Mississippi El Pwr Assn	1008	LF	100	SNL	5.0	0.30
6061	South Mississippi El Pwr Assn	1021	LF	100	SNL	5.0	0.3
6061	South Mississippi El Pwr Assn	1022	LF	100	SNL	5.0	0.24
6061	South Mississippi El Pwr Assn	1353	SI	100	SNL	5.0	0.3
6061	South Mississippi El Pwr Assn	1354	SI	100	SNL	5.0	0.3
4041	South Oak Creek	1070	LF	100	SCL	6.9	4.3
4041	South Oak Creek	1071	LF	100	SCL	6.9	4.3
4041	South Oak Creek	1072	LF	100	SCL	6.9	4.3
6195	Southwest Power Station	1073	LF	100	SCL	5.5	0.47
6195	Southwest Power Station	1074	LF	100	SCL	5.6	0.5
6195	Southwest Power Station	1268	SI	100	SCL	5.6	0.5
6195	Southwest Power Station	1269	SI	100	SCL	5.6	0.5
8223	Springerville	1075	LF	100	SNL	7.9	0.2
8223	Springerville	1384	SI	100	SNL	7.9	0.2

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1743	St Clair Power Plant	584	SI	100	SCL	7.0	0.6
207	St Johns River Power Park	1018	LF	100	SNL	5.1	0.86
207	St Johns River Power Park	1076	LF	100	SNL	5.0	0.89
207	St Johns River Power Park	1077	LF	100	SNL	5.0	0.9
2824	Stanton	690	SI	1	SCL	7.8	0.2
2824	Stanton	690	SI	99	SLT	7.8	0.9
2824	Stanton	691	SI	83	SCL	7.8	0.2
2824	Stanton	691	SI	17	SLT	7.8	0.9
2824	Stanton	692	SI	100	SLT	7.8	0.9
2824	Stanton	937	LF	100	SLT	7.8	0.9
2824	Stanton	940	LF	100	SLT	7.8	0.9
2824	Stanton	997	LF	100	SLT	7.8	0.9
564	Stanton Energy Center	942	LF	100	SNL	5.2	0.4
1131	Streeter Station	1028	LF	100	SLT	6.3	2.4
3152	Sunbury Generation LP	101	SI	100	SLT	5.4	0.6
50951	Sunnyside Cogen Associates	944	LF	100	SLT	8.5	0.1
1077	Sutherland	497	SI	100	SCL	6.4	2.8
1077	Sutherland	498	SI	100	SCL	6.4	2.8
1077	Sutherland	499	SI	100	SCL	6.4	2.8
1077	Sutherland	1117	LF	100	SCL	6.3	2.2
1077	Sutherland	1118	LF	100	SCL	6.3	1.6
10075	Taconite Harbor Energy Center	947	LF	100	SLT	5.8	4.1
10075	Taconite Harbor Energy Center	948	LF	100	SLT	5.8	4.1
10075	Taconite Harbor Energy Center	961	LF	100	SLT	5.8	4.1
988	Tanners Creek	415	SI	51	SCL	6.3	0.48
988	Tanners Creek	415	SI	49	SLT	6.5	0.6
988	Tanners Creek	416	SI	100	SLT	6.5	0.6
988	Tanners Creek	417	SI	100	SLT	6.5	0.6
988	Tanners Creek	418	SI	100	SLT	6.5	0.6
988	Tanners Creek	419	SI	100	SLT	6.5	0.6
988	Tanners Creek	950	LF	100	SLT	6.5	0.6
1252	Tecumseh Energy Center	519	SI	100	SLT	7.3	1.3
1252	Tecumseh Energy Center	520	SI	100	SLT	7.3	1.3
1252	Tecumseh Energy Center	995	LF	100	SLT	7.3	1.3
1252	Tecumseh Energy Center	1120	LF	100	SLT	7.3	1.3
1252	Tecumseh Energy Center	1133	LF	100	SCL	6.3	1
2168	Thomas Hill	624	SI	100	SLT	5.9	0.5
2168	Thomas Hill	625	SI	100	SLT	5.9	0.61
2168	Thomas Hill	626	SI	100	SLT	5.9	0.61

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
2168	Thomas Hill	627	SI	100	SLT	5.9	0.5
2168	Thomas Hill	628	SI	100	SLT	5.9	0.61
2168	Thomas Hill	629	SI	100	SLT	5.9	0.61
2168	Thomas Hill	953	LF	100	SLT	6.1	1.3
3115	Titus	954	LF	100	SLT	5.7	0.5
3115	Titus	955	LF	100	SLT	5.8	0.5
3115	Titus	956	LF	100	SLT	5.8	0.5
3115	Titus	957	LF	100	SLT	5.8	0.5
6194	Tolk	1161	LF	100	SNL	7.5	0.1
3845	TransAlta Centralia Generation	959	LF	100	SLT	6.1	1.5
1745	Trenton Channel Power Plant	585	SI	100	SCL	7.1	0.7
1745	Trenton Channel Power Plant	960	LF	100	SCL	7.1	0.7
6071	Trimble Co.	44	SI	100	SCL	6.2	0.63
56224	TS Power Plant	816	LF	18	SCL	7.7	0.3
56224	TS Power Plant	816	LF	82	SLT	8.7	0.48
7030	Twin Oaks Power One	928	LF	100	SLT	6.2	0.7
1361	Tyrone	536	SI	100	SCL	6.6	1.1
1361	Tyrone	537	SI	100	SCL	6.6	1.1
3295	Urquhart	110	SI	100	SLT	5.4	1.0
3295	Urquhart	111	SI	100	SLT	5.5	1.2
3295	Urquhart	112	SI	100	SLT	5.4	1.0
3295	Urquhart	1107	LF	100	SLT	5.5	1.2
4042	Valley	918	LF	100	SCL	7.3	4.6
4042	Valley	919	LF	100	SLT	7.3	2.2
4042	Valley	920	LF	100	SLT	7.3	2.2
4042	Valley	949	LF	100	SCL	6.9	4.3
477	Valmont	329	SI	100	SNL	7.8	0.58
477	Valmont	330	SI	100	SNL	7.8	0.58
477	Valmont	331	SI	100	SNL	7.8	0.58
477	Valmont	1122	LF	100	SNL	7.8	0.6
477	Valmont	1123	LF	100	SNL	7.8	0.6
897	Vermilion	395	SI	13	SCL	6.9	4.3
897	Vermilion	395	SI	87	SLT	7.1	1.9
897	Vermilion	396	SI	100	SLT	7.1	1.9
897	Vermilion	970	LF	75	SCL	7.0	3.7
897	Vermilion	970	LF	25	SLT	7.1	1.9
6073	Victor J. Daniel Jr	45	SI	70	SCL	4.6	2.1
6073	Victor J. Daniel Jr	45	SI	30	SLT	4.9	1.1
6073	Victor J. Daniel Jr	924	LF	66	SCL	4.6	0.8
6073	Victor J. Daniel Jr	924	LF	34	SLT	4.9	1.1

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
6073	Victor J. Daniel Jr	925	LF	100	SLT	4.9	1.1
6073	Victor J. Daniel Jr	938	LF	100	SLT	4.9	1.1
6073	Victor J. Daniel Jr	1124	LF	7	SCL	4.6	0.8
6073	Victor J. Daniel Jr	1124	LF	93	SLT	4.9	1.1
6019	W H Zimmer	26	SI	100	SLT	6.6	0.4
6019	W H Zimmer	929	LF	67	SCL	6.5	0.4
6019	W H Zimmer	929	LF	33	SLT	6.1	0.3
3470	W. A. Parish	136	SI	100	SCL	7.0	1.2
3470	W. A. Parish	137	SI	100	SCL	7.0	1.2
3470	W. A. Parish	138	SI	100	SCL	7.0	1.2
3470	W. A. Parish	139	SI	100	SCL	7.0	1.2
3470	W. A. Parish	140	SI	100	SCL	7.0	1.2
3470	W. A. Parish	141	SI	100	SCL	7.0	1.2
3470	W. A. Parish	142	SI	100	SCL	7.0	1.2
3470	W. A. Parish	143	SI	100	SCL	7.0	1.2
3470	W. A. Parish	1125	LF	100	SCL	7.9	1.6
2866	W. H. Sammis	916	LF	100	SCL	6.2	0.4
2866	W. H. Sammis	1382	SI	100	SLT	4.9	0.7
2866	W. H. Sammis	1383	SI	100	SLT	4.9	0.7
3264	W. S. Lee	105	SI	100	SCL	5.2	0.22
3264	W. S. Lee	106	SI	100	SCL	5.3	0.30
2716	W.H. Weatherspoon Plant	667	SI	100	SLT	4.8	0.66
1010	Wabash River	462	SI	100	SLT	7.1	1.9
1010	Wabash River	463	SI	100	SLT	7.1	1.9
1010	Wabash River	464	SI	100	SLT	7.1	1.9
1010	Wabash River	465	SI	100	SLT	7.1	1.9
2830	Walter C Beckjord	695	SI	100	SLT	6.6	0.4
2830	Walter C Beckjord	696	SI	100	SLT	6.6	0.4
2830	Walter C Beckjord	697	SI	100	SLT	6.6	0.4
2830	Walter C Beckjord	698	SI	100	SLT	6.6	0.4
2830	Walter C Beckjord	1126	LF	100	SCL	6.5	0.4
2830	Walter C Beckjord	1127	LF	100	SCL	6.5	0.4
1082	Walter Scott Jr. Energy Center	502	SI	17	SCL	7.4	1.4
1082	Walter Scott Jr. Energy Center	502	SI	83	SLT	7.9	0.8
1082	Walter Scott Jr. Energy Center	503	SI	17	SCL	7.4	1.4
1082	Walter Scott Jr. Energy Center	503	SI	83	SLT	7.9	0.8
1082	Walter Scott Jr. Energy Center	932	LF	58	SCL	7.4	1.4

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
1082	Walter Scott Jr. Energy Center	932	LF	42	SLT	7.9	0.8
6052	Wansley	35	SI	62	SCL	5.3	0.3
6052	Wansley	35	SI	33	SLT	5.6	0.7
6052	Wansley	35	SI	6	SNL	5.1	0.2
6705	Warrick Power Plant	224	SI	22	SCL	6.0	0.3
6705	Warrick Power Plant	224	SI	78	SLT	6.4	0.65
3297	Wateree	113	SI	100	SCL	5.4	2.5
3297	Wateree	114	SI	94	SCL	5.3	2.4
3297	Wateree	114	SI	6	SLT	4.8	0.3
3297	Wateree	933	LF	100	SLT	4.8	0.3
883	Waukegan	1311	SI	100	SNL	6.2	0.4
883	Waukegan	1312	SI	100	SNL	6.2	0.4
6139	Welsh	175	SI	100	SLT	4.9	0.6
6139	Welsh	176	SI	100	SLT	4.9	0.6
6139	Welsh	177	SI	100	SLT	4.9	0.6
6139	Welsh	934	LF	100	SLT	4.9	0.6
4078	Weston	935	LF	100	SLT	5.6	2.9
4078	Weston	936	LF	100	SNL	6.1	3
4078	Weston	1313	SI	100	SNL	6.1	3
4078	Weston	1314	SI	100	SNL	6.1	3
4078	Weston	1315	SI	100	SNL	6.1	3
4078	Weston	1316	SI	100	SNL	6.1	3
4078	Weston	1317	SI	100	SNL	6.1	3
4078	Weston	1318	SI	100	SNL	6.1	3
60	Whelan Energy Center Unit 1 (WEC1)	1214	SI	100	SCL	6.9	1.1
6009	White Bluff	1128	LF	100	SCL	4.8	0.7
1040	Whitewater Valley	1321	SI	100	SLT	7.0	0.5
1040	Whitewater Valley	1322	SI	100	SLT	7.0	0.5
1040	Whitewater Valley	1323	SI	100	SLT	7.0	0.5
1040	Whitewater Valley	1324	SI	100	SLT	7.0	0.5
1040	Whitewater Valley	1325	SI	100	SLT	7.0	0.5
4057	WI Power & Light Co -Rock River Generating	1	SI	100	SLT	7.0	1.3
4057	WI Power & Light Co -Rock River Generating	2	SI	100	SLT	7.0	1.3
4057	WI Power & Light Co -Rock River Generating	3	SI	100	SLT	7.0	1.3
4057	WI Power & Light Co -Rock River Generating	172	SI	100	SLT	7.0	1.3
50	Widows Creek	59	SI	100	SCL	5.7	0.57
50	Widows Creek	60	SI	100	SCL	5.7	0.57

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
50	Widows Creek	61	SI	100	SCL	5.7	0.57
50	Widows Creek	62	SI	100	SCL	5.7	0.57
50	Widows Creek	63	SI	100	SCL	5.7	0.57
50	Widows Creek	64	SI	100	SCL	5.7	0.57
50	Widows Creek	65	SI	100	SCL	5.7	0.57
50	Widows Creek	66	SI	100	SCL	5.7	0.57
50	Widows Creek	261	SI	100	SCL	5.7	0.57
50	Widows Creek	262	SI	100	SCL	5.7	0.57
50	Widows Creek	289	SI	100	SCL	5.7	0.57
50	Widows Creek	290	SI	100	SCL	5.7	0.57
884	Will County	389	SI	33	SCL	6.9	4.3
884	Will County	389	SI	67	SLT	6.9	1.9
3298	Williams	1129	LF	100	SCL	4.9	1.1
3298	Williams	1130	LF	100	SLT	5.1	0.6
3946	Willow Island	917	LF	100	SLT	6.2	0.4
6249	Winyah	198	SI	3	SCL	4.9	1.1
6249	Winyah	198	SI	97	SLT	5.1	0.6
6249	Winyah	199	SI	66	SCL	4.9	1.1
6249	Winyah	199	SI	34	SLT	5.1	0.6
6249	Winyah	200	SI	100	SLT	5.1	0.6
6249	Winyah	201	SI	35	SLT	5.1	0.6
6249	Winyah	201	SI	65	SNL	5.3	1.3
6249	Winyah	202	SI	0	SCL	4.9	1.1
6249	Winyah	202	SI	55	SLT	5.1	0.6
6249	Winyah	202	SI	45	SNL	5.3	1.3
6249	Winyah	203	SI	100	SLT	5.1	0.6
6249	Winyah	982	LF	27	SCL	4.9	1.1
6249	Winyah	982	LF	50	SLT	5.1	0.6
6249	Winyah	982	LF	23	SNL	5.3	1.3
898	Wood River	397	SI	100	SCL	6.8	1.6
898	Wood River	398	SI	60	SCL	6.8	1.6
898	Wood River	398	SI	40	SLT	6.4	1.2
50611	WPS Westwood Generation, LLC	951	LF	100	SLT	5.6	0.4
6101	Wyodak Plant	80	SI	100	SNL	7.9	0.4
6101	Wyodak Plant	981	LF	100	SNL	7.9	0.4
728	Yates	367	SI	27	SCL	5.3	0.3
728	Yates	367	SI	34	SLT	5.6	0.7
728	Yates	367	SI	39	SNL	5.1	0.2
728	Yates	368	SI	27	SCL	5.3	0.3
728	Yates	368	SI	34	SLT	5.6	0.7
728	Yates	368	SI	39	SNL	5.1	0.2
728	Yates	369	SI	27	SCL	5.3	0.3

Attachment B-1. Soil Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percent Comp-osition	Mega-texture Code	Average pH	Average % Organic Material
728	Yates	369	SI	34	SLT	5.6	0.7
728	Yates	369	SI	39	SNL	5.1	0.2
728	Yates	370	SI	27	SCL	5.3	0.3
728	Yates	370	SI	34	SLT	5.6	0.7
728	Yates	370	SI	39	SNL	5.1	0.2
728	Yates	371	SI	27	SCL	5.3	0.3
728	Yates	371	SI	34	SLT	5.6	0.7
728	Yates	371	SI	39	SNL	5.1	0.2
728	Yates	372	SI	27	SCL	5.3	0.3
728	Yates	372	SI	34	SLT	5.6	0.7
728	Yates	372	SI	39	SNL	5.1	0.2
728	Yates	373	SI	27	SCL	5.3	0.3
728	Yates	373	SI	34	SLT	5.6	0.7
728	Yates	373	SI	39	SNL	5.1	0.2
728	Yates	374	SI	27	SCL	5.3	0.3
728	Yates	374	SI	34	SLT	5.6	0.7
728	Yates	374	SI	39	SNL	5.1	0.2
728	Yates	986	LF	86	SCL	5.3	0.3
728	Yates	986	LF	14	SNL	5.1	0.2
728	Yates	987	LF	46	SLT	5.6	0.7
728	Yates	987	LF	54	SNL	5.1	0.2
3809	Yorktown	988	LF	100	SCL	4.7	0.7
3809	Yorktown	1359	SI	100	SCL	4.7	0.7

Attachment B-2.
Hydrogeologic Data

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6137	A. B. Brown Generating Station	88	SI	100	4	Sand and Gravel
6137	A. B. Brown Generating Station	89	SI	10	2	Bedded Sedimentary Rock
6137	A. B. Brown Generating Station	89	SI	44	4	Sand and Gravel
6137	A. B. Brown Generating Station	89	SI	46	8	Outwash
6137	A. B. Brown Generating Station	1163	LF	100	4	Sand and Gravel
2535	AES Cayuga, LLC	1102	LF	100	4	Sand and Gravel
2527	AES Greenidge	1101	LF	100	12	Solution Limestone
2527	AES Greenidge	1285	SI	100	12	Solution Limestone
2527	AES Greenidge	1286	SI	100	12	Solution Limestone
994	AES Petersburg	430	SI	100	2	Bedded Sedimentary Rock
994	AES Petersburg	431	SI	100	2	Bedded Sedimentary Rock
994	AES Petersburg	432	SI	100	2	Bedded Sedimentary Rock
994	AES Petersburg	433	SI	100	2	Bedded Sedimentary Rock
994	AES Petersburg	989	LF	100	2	Bedded Sedimentary Rock
6082	AES Somerset LLC	1105	LF	100	4	Sand and Gravel
6082	AES Somerset LLC	1106	LF	100	4	Sand and Gravel
6082	AES Somerset LLC	1287	SI	100	4	Sand and Gravel
3942	Albright Power Station	930	LF	100	2	Bedded Sedimentary Rock
3942	Albright Power Station	931	LF	100	2	Bedded Sedimentary Rock
3942	Albright Power Station	1385	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3942	Albright Power Station	1386	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1915	Allen S King	927	LF	54	2	Bedded Sedimentary Rock
1915	Allen S King	927	LF	46	9	Till and Till Over Outwash
3393	Allen Steam Plant	119	SI	35	6	River Valleys and Floodplains With Overbank Deposits
3393	Allen Steam Plant	119	SI	65	7	River Valleys and Floodplains Without Overbank Deposits
3393	Allen Steam Plant	120	SI	35	6	River Valleys and Floodplains With Overbank Deposits
3393	Allen Steam Plant	120	SI	65	7	River Valleys and Floodplains Without Overbank Deposits
4140	Alma	993	LF	100	6	River Valleys and Floodplains With Overbank Deposits
4140	Alma	994	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1122	Ames Electric Services Power Plant	1202	SI	100	9	Till and Till Over Outwash
6469	Antelope Valley Station	212	SI	100	3	Till Over Sedimentary Rock
6469	Antelope Valley Station	213	SI	100	3	Till Over Sedimentary Rock
6469	Antelope Valley Station	922	LF	100	3	Till Over Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6469	Antelope Valley Station	923	LF	100	3	Till Over Sedimentary Rock
160	Apache Station	287	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	288	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	292	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	293	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	294	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	295	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	296	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	297	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	298	SI	100	5	Alluvial Basins Valleys and Fans
160	Apache Station	299	SI	100	5	Alluvial Basins Valleys and Fans
465	Arapahoe	310	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	310	SI	32	6	River Valleys and Floodplains With Overbank Deposits
465	Arapahoe	310	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
465	Arapahoe	311	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	311	SI	32	6	River Valleys and Floodplains With Overbank Deposits
465	Arapahoe	311	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
465	Arapahoe	312	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	312	SI	32	6	River Valleys and Floodplains With Overbank Deposits
465	Arapahoe	312	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
465	Arapahoe	313	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	313	SI	32	6	River Valleys and Floodplains With Overbank Deposits
465	Arapahoe	313	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
465	Arapahoe	314	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	314	SI	32	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
465	Arapahoe	314	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
465	Arapahoe	315	SI	15	2	Bedded Sedimentary Rock
465	Arapahoe	315	SI	32	6	River Valleys and Floodplains With Overbank Deposits
465	Arapahoe	315	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
3178	Armstrong Power Station	921	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3178	Armstrong Power Station	926	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2076	Asbury	596	SI	100	4	Sand and Gravel
2076	Asbury	597	SI	100	4	Sand and Gravel
2076	Asbury	598	SI	100	4	Sand and Gravel
2706	Asheville Steam Electric Plant	649	SI	100	1	Metamorphic and Igneous
2706	Asheville Steam Electric Plant	650	SI	100	1	Metamorphic and Igneous
2835	Ashtabula	1263	SI	100	4	Sand and Gravel
1961	Austin Northeast	958	LF	85	12	Solution Limestone
1961	Austin Northeast	958	LF	15	8	Outwash
2836	Avon Lake	975	LF	100	4	Sand and Gravel
2836	Avon Lake	1175	SI	100	4	Sand and Gravel
2836	Avon Lake	1176	SI	100	4	Sand and Gravel
995	Bailly	434	SI	53	3	Till Over Sedimentary Rock
995	Bailly	434	SI	47	9	Till and Till Over Outwash
995	Bailly	435	SI	100	3	Till Over Sedimentary Rock
995	Bailly	436	SI	100	3	Till Over Sedimentary Rock
995	Bailly	437	SI	100	3	Till Over Sedimentary Rock
995	Bailly	438	SI	100	3	Till Over Sedimentary Rock
995	Bailly	439	SI	100	3	Till Over Sedimentary Rock
995	Bailly	939	LF	100	3	Till Over Sedimentary Rock
995	Bailly	952	LF	100	3	Till Over Sedimentary Rock
889	Baldwin Energy Complex	391	SI	94	6	River Valleys and Floodplains With Overbank Deposits
889	Baldwin Energy Complex	391	SI	1	7	River Valleys and Floodplains Without Overbank Deposits
889	Baldwin Energy Complex	391	SI	5	8	Outwash
3	Barry	252	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3982	Bay Front	162	SI	100	2	Bedded Sedimentary Rock
3982	Bay Front	163	SI	100	2	Bedded Sedimentary Rock
3982	Bay Front	945	LF	100	4	Sand and Gravel
3982	Bay Front	946	LF	100	4	Sand and Gravel
2878	Bay Shore	977	LF	100	12	Solution Limestone
2878	Bay Shore	1326	SI	100	12	Solution Limestone
8042	Belews Creek Steam Station	243	SI	88	1	Metamorphic and Igneous

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
8042	Belews Creek Steam Station	243	SI	12	2	Bedded Sedimentary Rock
8042	Belews Creek Steam Station	1009	LF	100	1	Metamorphic and Igneous
8042	Belews Creek Steam Station	1010	LF	100	1	Metamorphic and Igneous
8042	Belews Creek Steam Station	1079	LF	100	1	Metamorphic and Igneous
6034	Belle River	33	SI	100	4	Sand and Gravel
6034	Belle River	1035	LF	100	4	Sand and Gravel
3325	Ben French	1379	SI	100	12	Solution Limestone
645	Big Bend	342	SI	100	12	Solution Limestone
645	Big Bend	343	SI	100	12	Solution Limestone
645	Big Bend	344	SI	100	12	Solution Limestone
645	Big Bend	345	SI	100	12	Solution Limestone
645	Big Bend	346	SI	100	12	Solution Limestone
645	Big Bend	347	SI	100	12	Solution Limestone
645	Big Bend	348	SI	100	12	Solution Limestone
645	Big Bend	349	SI	100	12	Solution Limestone
645	Big Bend	1164	LF	100	12	Solution Limestone
3497	Big Brown	776	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	784	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	790	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	791	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	1177	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	1178	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	1179	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3497	Big Brown	1180	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6055	Big Cajun 2	36	SI	82	6	River Valleys and Floodplains With Overbank Deposits
6055	Big Cajun 2	36	SI	18	7	River Valleys and Floodplains Without Overbank Deposits
6055	Big Cajun 2	37	SI	82	6	River Valleys and Floodplains With Overbank Deposits
6055	Big Cajun 2	37	SI	18	7	River Valleys and Floodplains Without Overbank Deposits
6055	Big Cajun 2	38	SI	82	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6055	Big Cajun 2	38	SI	18	7	River Valleys and Floodplains Without Overbank Deposits
6055	Big Cajun 2	815	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1353	Big Sandy	521	SI	14	6	River Valleys and Floodplains With Overbank Deposits
1353	Big Sandy	521	SI	86	7	River Valleys and Floodplains Without Overbank Deposits
1353	Big Sandy	522	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1353	Big Sandy	523	SI	2	6	River Valleys and Floodplains With Overbank Deposits
1353	Big Sandy	523	SI	98	7	River Valleys and Floodplains Without Overbank Deposits
6098	Big Stone	814	LF	100	9	Till and Till Over Outwash
6098	Big Stone	1261	SI	100	9	Till and Till Over Outwash
1904	Black Dog	593	SI	52	2	Bedded Sedimentary Rock
1904	Black Dog	593	SI	48	8	Outwash
1904	Black Dog	799	LF	11	2	Bedded Sedimentary Rock
1904	Black Dog	799	LF	89	8	Outwash
6106	Boardman	746	LF	100	5	Alluvial Basins Valleys and Fans
6106	Boardman	1339	SI	100	5	Alluvial Basins Valleys and Fans
6106	Boardman	1340	SI	100	5	Alluvial Basins Valleys and Fans
6106	Boardman	1341	SI	100	5	Alluvial Basins Valleys and Fans
7790	Bonanza Power Plant	735	LF	74	6	River Valleys and Floodplains With Overbank Deposits
7790	Bonanza Power Plant	735	LF	26	7	River Valleys and Floodplains Without Overbank Deposits
7790	Bonanza Power Plant	737	LF	100	5	Alluvial Basins Valleys and Fans
7790	Bonanza Power Plant	1207	SI	100	2	Bedded Sedimentary Rock
7790	Bonanza Power Plant	1208	SI	100	2	Bedded Sedimentary Rock
7790	Bonanza Power Plant	1209	SI	100	2	Bedded Sedimentary Rock
1893	Boswell Energy Center	590	SI	100	1	Metamorphic and Igneous
1893	Boswell Energy Center	591	SI	100	1	Metamorphic and Igneous
1893	Boswell Energy Center	592	SI	100	1	Metamorphic and Igneous
1893	Boswell Energy Center	796	LF	100	1	Metamorphic and Igneous
1893	Boswell Energy Center	853	LF	100	1	Metamorphic and Igneous
1893	Boswell Energy Center	862	LF	100	1	Metamorphic and Igneous
703	Bowen	350	SI	100	12	Solution Limestone
703	Bowen	1103	LF	100	12	Solution Limestone

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
602	Brandon Shores	1289	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
602	Brandon Shores	1290	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1619	Brayton Point	731	LF	100	3	Till Over Sedimentary Rock
1619	Brayton Point	760	LF	100	3	Till Over Sedimentary Rock
1619	Brayton Point	761	LF	100	3	Till Over Sedimentary Rock
1619	Brayton Point	800	LF	100	3	Till Over Sedimentary Rock
1619	Brayton Point	824	LF	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1187	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1188	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1189	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1190	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1191	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1192	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1193	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1194	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1195	SI	100	3	Till Over Sedimentary Rock
1619	Brayton Point	1196	SI	100	3	Till Over Sedimentary Rock
3796	Bremo Bluff	148	SI	7	6	River Valleys and Floodplains With Overbank Deposits
3796	Bremo Bluff	148	SI	93	7	River Valleys and Floodplains Without Overbank Deposits
3796	Bremo Bluff	149	SI	5	6	River Valleys and Floodplains With Overbank Deposits
3796	Bremo Bluff	149	SI	95	7	River Valleys and Floodplains Without Overbank Deposits
6094	Bruce Mansfield	75	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6094	Bruce Mansfield	76	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6094	Bruce Mansfield	77	SI	24	2	Bedded Sedimentary Rock
6094	Bruce Mansfield	77	SI	69	6	River Valleys and Floodplains With Overbank Deposits
6094	Bruce Mansfield	77	SI	7	7	River Valleys and Floodplains Without Overbank Deposits
6094	Bruce Mansfield	78	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6094	Bruce Mansfield	79	SI	1	2	Bedded Sedimentary Rock
6094	Bruce Mansfield	79	SI	99	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6094	Bruce Mansfield	79	SI	0	7	River Valleys and Floodplains Without Overbank Deposits
2720	Buck	671	SI	100	1	Metamorphic and Igneous
2720	Buck	672	SI	100	1	Metamorphic and Igneous
2720	Buck	673	SI	100	1	Metamorphic and Igneous
3396	Bull Run	121	SI	78	2	Bedded Sedimentary Rock
3396	Bull Run	121	SI	11	6	River Valleys and Floodplains With Overbank Deposits
3396	Bull Run	121	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
3396	Bull Run	122	SI	78	2	Bedded Sedimentary Rock
3396	Bull Run	122	SI	11	6	River Valleys and Floodplains With Overbank Deposits
3396	Bull Run	122	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
3396	Bull Run	123	SI	78	2	Bedded Sedimentary Rock
3396	Bull Run	123	SI	11	6	River Valleys and Floodplains With Overbank Deposits
3396	Bull Run	123	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
3396	Bull Run	124	SI	78	2	Bedded Sedimentary Rock
3396	Bull Run	124	SI	11	6	River Valleys and Floodplains With Overbank Deposits
3396	Bull Run	124	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
3396	Bull Run	889	LF	100	2	Bedded Sedimentary Rock
3396	Bull Run	890	LF	100	2	Bedded Sedimentary Rock
1104	Burlington	507	SI	56	6	River Valleys and Floodplains With Overbank Deposits
1104	Burlington	507	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
1104	Burlington	508	SI	56	6	River Valleys and Floodplains With Overbank Deposits
1104	Burlington	508	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
1104	Burlington	509	SI	56	6	River Valleys and Floodplains With Overbank Deposits
1104	Burlington	509	SI	44	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1104	Burlington	510	SI	56	6	River Valleys and Floodplains With Overbank Deposits
1104	Burlington	510	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
1104	Burlington	511	SI	56	6	River Valleys and Floodplains With Overbank Deposits
1104	Burlington	511	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
676	C D McIntosh Jr	885	LF	100	4	Sand and Gravel
676	C D McIntosh Jr	888	LF	100	4	Sand and Gravel
468	Cameo	316	SI	8	2	Bedded Sedimentary Rock
468	Cameo	316	SI	11	6	River Valleys and Floodplains With Overbank Deposits
468	Cameo	316	SI	81	7	River Valleys and Floodplains Without Overbank Deposits
468	Cameo	317	SI	8	2	Bedded Sedimentary Rock
468	Cameo	317	SI	11	6	River Valleys and Floodplains With Overbank Deposits
468	Cameo	317	SI	81	7	River Valleys and Floodplains Without Overbank Deposits
3280	Canadys Steam	107	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3280	Canadys Steam	108	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3280	Canadys Steam	109	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1363	Cane Run	538	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1363	Cane Run	539	SI	60	6	River Valleys and Floodplains With Overbank Deposits
1363	Cane Run	539	SI	40	7	River Valleys and Floodplains Without Overbank Deposits
1363	Cane Run	540	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1363	Cane Run	541	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1363	Cane Run	542	SI	60	6	River Valleys and Floodplains With Overbank Deposits
1363	Cane Run	542	SI	40	7	River Valleys and Floodplains Without Overbank Deposits
1363	Cane Run	869	LF	89	6	River Valleys and Floodplains With Overbank Deposits
1363	Cane Run	869	LF	11	7	River Valleys and Floodplains Without Overbank Deposits
2708	Cape Fear Steam Electric Plant	651	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2708	Cape Fear Steam Electric Plant	652	SI	18	1	Metamorphic and Igneous
2708	Cape Fear Steam Electric Plant	652	SI	68	6	River Valleys and Floodplains With Overbank Deposits
2708	Cape Fear Steam Electric Plant	652	SI	14	7	River Valleys and Floodplains Without Overbank Deposits
2708	Cape Fear Steam Electric Plant	653	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2708	Cape Fear Steam Electric Plant	654	SI	18	1	Metamorphic and Igneous
2708	Cape Fear Steam Electric Plant	654	SI	68	6	River Valleys and Floodplains With Overbank Deposits
2708	Cape Fear Steam Electric Plant	654	SI	14	7	River Valleys and Floodplains Without Overbank Deposits
2708	Cape Fear Steam Electric Plant	655	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3644	Carbon Plant	876	LF	100	2	Bedded Sedimentary Rock
3644	Carbon Plant	905	LF	100	2	Bedded Sedimentary Rock
3644	Carbon Plant	1387	SI	100	2	Bedded Sedimentary Rock
3644	Carbon Plant	1388	SI	100	2	Bedded Sedimentary Rock
2828	Cardinal	693	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2828	Cardinal	694	SI	93	6	River Valleys and Floodplains With Overbank Deposits
2828	Cardinal	694	SI	7	7	River Valleys and Floodplains Without Overbank Deposits
2828	Cardinal	899	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1001	Cayuga	454	SI	99	8	Outwash

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1001	Cayuga	454	SI	1	9	Till and Till Over Outwash
1001	Cayuga	455	SI	100	8	Outwash
1001	Cayuga	456	SI	100	8	Outwash
1001	Cayuga	457	SI	100	8	Outwash
1001	Cayuga	838	LF	100	8	Outwash
1571	Chalk Point LLC	836	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1571	Chalk Point LLC	1104	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2169	Chamois Power Plant	1288	SI	100	6	River Valleys and Floodplains With Overbank Deposits
56	Charles R. Lowman	270	SI	57	10	Unconsolidated and Semiconsolidated Shallow Aquifers
56	Charles R. Lowman	270	SI	43	7	River Valleys and Floodplains Without Overbank Deposits
56	Charles R. Lowman	271	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
56	Charles R. Lowman	272	SI	22	10	Unconsolidated and Semiconsolidated Shallow Aquifers
56	Charles R. Lowman	272	SI	78	7	River Valleys and Floodplains Without Overbank Deposits
56	Charles R. Lowman	273	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
56	Charles R. Lowman	900	LF	44	10	Unconsolidated and Semiconsolidated Shallow Aquifers
56	Charles R. Lowman	900	LF	8	6	River Valleys and Floodplains With Overbank Deposits
56	Charles R. Lowman	900	LF	48	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	318	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	318	SI	27	6	River Valleys and Floodplains With Overbank Deposits
469	Cherokee	318	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	319	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	319	SI	27	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
469	Cherokee	319	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	320	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	320	SI	27	6	River Valleys and Floodplains With Overbank Deposits
469	Cherokee	320	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	321	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	321	SI	27	6	River Valleys and Floodplains With Overbank Deposits
469	Cherokee	321	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	322	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	322	SI	27	6	River Valleys and Floodplains With Overbank Deposits
469	Cherokee	322	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
469	Cherokee	323	SI	22	2	Bedded Sedimentary Rock
469	Cherokee	323	SI	27	6	River Valleys and Floodplains With Overbank Deposits
469	Cherokee	323	SI	51	7	River Valleys and Floodplains Without Overbank Deposits
3803	Chesapeake Energy Center	152	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3803	Chesapeake Energy Center	865	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3797	Chesterfield	150	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3797	Chesterfield	151	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8226	Cheswick Power Plant	1099	LF	100	2	Bedded Sedimentary Rock
8226	Cheswick Power Plant	1165	SI	100	6	River Valleys and Floodplains With Overbank Deposits
8226	Cheswick Power Plant	1166	SI	100	6	River Valleys and Floodplains With Overbank Deposits
113	Cholla	279	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
113	Cholla	280	SI	100	6	River Valleys and Floodplains With Overbank Deposits
113	Cholla	863	LF	56	2	Bedded Sedimentary Rock
113	Cholla	863	LF	44	6	River Valleys and Floodplains With Overbank Deposits
2721	Cliffside	674	SI	100	1	Metamorphic and Igneous
2721	Cliffside	675	SI	100	1	Metamorphic and Igneous
2721	Cliffside	676	SI	100	1	Metamorphic and Igneous
983	Clifty Creek	413	SI	100	6	River Valleys and Floodplains With Overbank Deposits
983	Clifty Creek	414	SI	100	6	River Valleys and Floodplains With Overbank Deposits
983	Clifty Creek	847	LF	100	6	River Valleys and Floodplains With Overbank Deposits
983	Clifty Creek	848	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3775	Clinch River	144	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3775	Clinch River	145	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3775	Clinch River	849	LF	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	850	LF	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	851	LF	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	1280	SI	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	1281	SI	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	1282	SI	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	1283	SI	100	6	River Valleys and Floodplains With Overbank Deposits
7213	Clover	1284	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6030	Coal Creek	29	SI	100	3	Till Over Sedimentary Rock
6030	Coal Creek	30	SI	100	3	Till Over Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6030	Coal Creek	852	LF	100	3	Till Over Sedimentary Rock
6030	Coal Creek	854	LF	100	3	Till Over Sedimentary Rock
6030	Coal Creek	855	LF	100	3	Till Over Sedimentary Rock
6030	Coal Creek	857	LF	100	3	Till Over Sedimentary Rock
6030	Coal Creek	868	LF	100	3	Till Over Sedimentary Rock
6030	Coal Creek	1119	LF	100	3	Till Over Sedimentary Rock
861	Coffeen	379	SI	100	4	Sand and Gravel
861	Coffeen	380	SI	100	4	Sand and Gravel
861	Coffeen	846	LF	100	4	Sand and Gravel
47	Colbert	258	SI	1	12	Solution Limestone
47	Colbert	258	SI	65	6	River Valleys and Floodplains With Overbank Deposits
47	Colbert	258	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
47	Colbert	259	SI	1	12	Solution Limestone
47	Colbert	259	SI	65	6	River Valleys and Floodplains With Overbank Deposits
47	Colbert	259	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
47	Colbert	260	SI	1	12	Solution Limestone
47	Colbert	260	SI	65	6	River Valleys and Floodplains With Overbank Deposits
47	Colbert	260	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
47	Colbert	859	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6178	Coleto Creek	181	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6178	Coleto Creek	182	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6076	Colstrip	46	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	47	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	48	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	49	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	50	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	51	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	52	SI	100	2	Bedded Sedimentary Rock
6076	Colstrip	53	SI	100	2	Bedded Sedimentary Rock
10784	Colstrip Energy LP	860	LF	100	2	Bedded Sedimentary Rock
10784	Colstrip Energy LP	861	LF	100	2	Bedded Sedimentary Rock
8023	Columbia	239	SI	100	2	Bedded Sedimentary Rock
8023	Columbia	240	SI	100	2	Bedded Sedimentary Rock
8023	Columbia	241	SI	100	2	Bedded Sedimentary Rock
8023	Columbia	242	SI	100	2	Bedded Sedimentary Rock
8023	Columbia	1135	LF	100	2	Bedded Sedimentary Rock
8023	Columbia	1136	LF	100	2	Bedded Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2123	Columbia	1213	SI	31	12	Solution Limestone
2123	Columbia	1213	SI	69	4	Sand and Gravel
470	Comanche	324	SI	92	2	Bedded Sedimentary Rock
470	Comanche	324	SI	8	6	River Valleys and Floodplains With Overbank Deposits
470	Comanche	325	SI	92	2	Bedded Sedimentary Rock
470	Comanche	325	SI	8	6	River Valleys and Floodplains With Overbank Deposits
470	Comanche	326	SI	92	2	Bedded Sedimentary Rock
470	Comanche	326	SI	8	6	River Valleys and Floodplains With Overbank Deposits
470	Comanche	327	SI	92	2	Bedded Sedimentary Rock
470	Comanche	327	SI	8	6	River Valleys and Floodplains With Overbank Deposits
470	Comanche	328	SI	92	2	Bedded Sedimentary Rock
470	Comanche	328	SI	8	6	River Valleys and Floodplains With Overbank Deposits
470	Comanche	1137	LF	100	2	Bedded Sedimentary Rock
3118	Conemaugh	864	LF	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1138	LF	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1334	SI	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1335	SI	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1336	SI	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1337	SI	100	2	Bedded Sedimentary Rock
3118	Conemaugh	1338	SI	100	2	Bedded Sedimentary Rock
2840	Conesville	701	SI	15	6	River Valleys and Floodplains With Overbank Deposits
2840	Conesville	701	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
2840	Conesville	1005	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2840	Conesville	1006	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1710	Consumers Energy - J.H. Campbell	572	SI	100	4	Sand and Gravel
1710	Consumers Energy - J.H. Campbell	967	LF	100	4	Sand and Gravel
1710	Consumers Energy - J.H. Campbell	985	LF	100	4	Sand and Gravel
1710	Consumers Energy - J.H. Campbell	998	LF	100	4	Sand and Gravel
1710	Consumers Energy - J.H. Campbell	999	LF	100	4	Sand and Gravel
1384	Cooper Station.	973	LF	89	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1384	Cooper Station.	973	LF	11	7	River Valleys and Floodplains Without Overbank Deposits
7210	Cope	866	LF	46	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7210	Cope	866	LF	54	7	River Valleys and Floodplains Without Overbank Deposits
6177	Coronado Generating Station	180	SI	100	2	Bedded Sedimentary Rock
6177	Coronado Generating Station	835	LF	100	2	Bedded Sedimentary Rock
6177	Coronado Generating Station	867	LF	100	2	Bedded Sedimentary Rock
8222	Coyote	248	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	249	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	250	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	825	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	826	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	833	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
8222	Coyote	856	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2549	CR Huntley Generating Station	643	SI	100	12	Solution Limestone
2549	CR Huntley Generating Station	644	SI	100	12	Solution Limestone
2549	CR Huntley Generating Station	645	SI	100	12	Solution Limestone
2549	CR Huntley Generating Station	1100	LF	100	4	Sand and Gravel
6021	Craig	27	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6021	Craig	28	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6021	Craig	974	LF	100	6	River Valleys and Floodplains With Overbank Deposits
867	Crawford	387	SI	100	12	Solution Limestone
753	Crisp Plant	1265	SI	100	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
641	Crist	1139	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1273	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1274	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1275	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1276	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1277	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1278	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
641	Crist	1279	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
130	Cross	284	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	285	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	286	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	827	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	828	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	829	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
130	Cross	830	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
628	Crystal River Power Plant	831	LF	100	12	Solution Limestone
3399	Cumberland	125	SI	79	6	River Valleys and Floodplains With Overbank Deposits
3399	Cumberland	125	SI	21	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3399	Cumberland	126	SI	79	6	River Valleys and Floodplains With Overbank Deposits
3399	Cumberland	126	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
3399	Cumberland	127	SI	79	6	River Valleys and Floodplains With Overbank Deposits
3399	Cumberland	127	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
3399	Cumberland	978	LF	79	6	River Valleys and Floodplains With Overbank Deposits
3399	Cumberland	978	LF	21	7	River Valleys and Floodplains Without Overbank Deposits
6823	D B Wilson	832	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6823	D B Wilson	845	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1702	D.E. Karn	570	SI	100	2	Bedded Sedimentary Rock
1702	D.E. Karn	571	SI	100	2	Bedded Sedimentary Rock
1702	D.E. Karn	1004	LF	100	2	Bedded Sedimentary Rock
1385	Dale Station	558	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1385	Dale Station	559	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1385	Dale Station	560	SI	100	6	River Valleys and Floodplains With Overbank Deposits
963	Dallman	399	SI	100	4	Sand and Gravel
963	Dallman	823	LF	100	4	Sand and Gravel
963	Dallman	834	LF	100	4	Sand and Gravel
2723	Dan River	677	SI	100	2	Bedded Sedimentary Rock
2723	Dan River	678	SI	100	2	Bedded Sedimentary Rock
2723	Dan River	679	SI	100	2	Bedded Sedimentary Rock
2480	Danskammer Generating Station	1140	LF	100	12	Solution Limestone
4158	Dave Johnston Plant	4	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	5	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	6	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
4158	Dave Johnston Plant	7	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	8	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	9	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	10	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	11	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	837	LF	93	6	River Valleys and Floodplains With Overbank Deposits
4158	Dave Johnston Plant	837	LF	7	7	River Valleys and Floodplains Without Overbank Deposits
996	Dean H Mitchell	440	SI	100	12	Solution Limestone
996	Dean H Mitchell	441	SI	100	12	Solution Limestone
996	Dean H Mitchell	442	SI	100	12	Solution Limestone
996	Dean H Mitchell	443	SI	100	12	Solution Limestone
996	Dean H Mitchell	444	SI	100	12	Solution Limestone
996	Dean H Mitchell	445	SI	100	12	Solution Limestone
996	Dean H Mitchell	446	SI	100	12	Solution Limestone
996	Dean H Mitchell	447	SI	100	12	Solution Limestone
663	Deerhaven Generating Station	1141	LF	100	4	Sand and Gravel
663	Deerhaven Generating Station	1331	SI	100	4	Sand and Gravel
1572	Dickerson	839	LF	47	12	Solution Limestone
1572	Dickerson	839	LF	53	6	River Valleys and Floodplains With Overbank Deposits
51	Dolet Hills	263	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	264	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	265	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	266	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	267	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
51	Dolet Hills	268	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	269	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
51	Dolet Hills	840	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3317	Dolphus M Grainger	115	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3317	Dolphus M Grainger	116	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1046	Dubuque	476	SI	36	6	River Valleys and Floodplains With Overbank Deposits
1046	Dubuque	476	SI	64	7	River Valleys and Floodplains Without Overbank Deposits
6016	Duck Creek	18	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6016	Duck Creek	19	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6016	Duck Creek	20	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6016	Duck Creek	842	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2554	Dunkirk Generating Plant	646	SI	100	4	Sand and Gravel
2554	Dunkirk Generating Plant	647	SI	100	4	Sand and Gravel
2554	Dunkirk Generating Plant	648	SI	100	4	Sand and Gravel
2554	Dunkirk Generating Plant	843	LF	100	4	Sand and Gravel
26	E. C. Gaston	257	SI	93	6	River Valleys and Floodplains With Overbank Deposits
26	E. C. Gaston	257	SI	7	7	River Valleys and Floodplains Without Overbank Deposits
1355	E.W. Brown	524	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1355	E.W. Brown	525	SI	100	6	River Valleys and Floodplains With Overbank Deposits
991	Eagle Valley	425	SI	100	4	Sand and Gravel
991	Eagle Valley	426	SI	100	4	Sand and Gravel
991	Eagle Valley	427	SI	100	4	Sand and Gravel
991	Eagle Valley	428	SI	100	4	Sand and Gravel
991	Eagle Valley	429	SI	100	4	Sand and Gravel

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1217	Earl F Wisdom	844	LF	100	2	Bedded Sedimentary Rock
6018	East Bend Station	23	SI	47	6	River Valleys and Floodplains With Overbank Deposits
6018	East Bend Station	23	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
6018	East Bend Station	24	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6018	East Bend Station	25	SI	47	6	River Valleys and Floodplains With Overbank Deposits
6018	East Bend Station	25	SI	53	7	River Valleys and Floodplains Without Overbank Deposits
6018	East Bend Station	879	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2837	Eastlake	914	LF	100	4	Sand and Gravel
2837	Eastlake	1262	SI	100	4	Sand and Gravel
856	ED Edwards	376	SI	95	6	River Valleys and Floodplains With Overbank Deposits
856	ED Edwards	376	SI	4	7	River Valleys and Floodplains Without Overbank Deposits
856	ED Edwards	376	SI	2	8	Outwash
856	ED Edwards	377	SI	100	6	River Valleys and Floodplains With Overbank Deposits
856	ED Edwards	378	SI	100	6	River Valleys and Floodplains With Overbank Deposits
4050	Edgewater	164	SI	100	12	Solution Limestone
4050	Edgewater	165	SI	100	12	Solution Limestone
4050	Edgewater	166	SI	100	12	Solution Limestone
4050	Edgewater	167	SI	100	12	Solution Limestone
4050	Edgewater	168	SI	100	12	Solution Limestone
4050	Edgewater	169	SI	100	12	Solution Limestone
4050	Edgewater	858	LF	100	12	Solution Limestone
4050	Edgewater	894	LF	100	12	Solution Limestone
1004	Edwardsport	458	SI	100	2	Bedded Sedimentary Rock
1004	Edwardsport	459	SI	100	2	Bedded Sedimentary Rock
1004	Edwardsport	971	LF	100	2	Bedded Sedimentary Rock
1374	Elmer Smith Station	1234	SI	100	8	Outwash
1374	Elmer Smith Station	1235	SI	100	8	Outwash
1374	Elmer Smith Station	1236	SI	100	8	Outwash
1374	Elmer Smith Station	1237	SI	100	8	Outwash
3098	Elrama Power Plant	895	LF	38	6	River Valleys and Floodplains With Overbank Deposits
3098	Elrama Power Plant	895	LF	62	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3098	Elrama Power Plant	1342	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3098	Elrama Power Plant	1343	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3098	Elrama Power Plant	1344	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3098	Elrama Power Plant	1345	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1832	Erickson Station	587	SI	100	2	Bedded Sedimentary Rock
87	Escalante	274	SI	100	2	Bedded Sedimentary Rock
87	Escalante	275	SI	100	2	Bedded Sedimentary Rock
87	Escalante	276	SI	100	2	Bedded Sedimentary Rock
87	Escalante	277	SI	100	2	Bedded Sedimentary Rock
87	Escalante	278	SI	100	2	Bedded Sedimentary Rock
87	Escalante	992	LF	100	2	Bedded Sedimentary Rock
1012	F. B. Culley	466	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1012	F. B. Culley	467	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1218	Fair Station	896	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1218	Fair Station	1183	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1218	Fair Station	1184	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6179	Fayette Power Project	183	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6179	Fayette Power Project	184	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6179	Fayette Power Project	897	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
886	Fisk	1238	SI	100	12	Solution Limestone
886	Fisk	1239	SI	100	12	Solution Limestone
886	Fisk	1240	SI	100	12	Solution Limestone
6138	Flint Creek	173	SI	100	12	Solution Limestone
6138	Flint Creek	174	SI	100	12	Solution Limestone
6138	Flint Creek	898	LF	100	12	Solution Limestone
3943	Fort Martin Power Station	1142	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3943	Fort Martin Power Station	1143	LF	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3943	Fort Martin Power Station	1181	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3943	Fort Martin Power Station	1182	SI	100	6	River Valleys and Floodplains With Overbank Deposits
10343	Foster Wheeler Mt Carmel Cogen	901	LF	100	2	Bedded Sedimentary Rock
2442	Four Corners	638	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	639	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	640	SI	2	2	Bedded Sedimentary Rock
2442	Four Corners	640	SI	98	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	641	SI	2	2	Bedded Sedimentary Rock
2442	Four Corners	641	SI	98	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	642	SI	2	2	Bedded Sedimentary Rock
2442	Four Corners	642	SI	98	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	903	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2442	Four Corners	915	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1043	Frank E. Ratts	468	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	469	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	470	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	471	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	472	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	473	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	474	SI	100	2	Bedded Sedimentary Rock
1043	Frank E. Ratts	475	SI	100	2	Bedded Sedimentary Rock
2718	G G Allen	668	SI	100	1	Metamorphic and Igneous
2718	G G Allen	669	SI	100	1	Metamorphic and Igneous
2718	G G Allen	670	SI	100	1	Metamorphic and Igneous
2718	G G Allen	892	LF	100	1	Metamorphic and Igneous
7	Gadsden	253	SI	100	12	Solution Limestone
3403	Gallatin	128	SI	65	6	River Valleys and Floodplains With Overbank Deposits
3403	Gallatin	128	SI	35	7	River Valleys and Floodplains Without Overbank Deposits
3403	Gallatin	129	SI	65	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3403	Gallatin	129	SI	35	7	River Valleys and Floodplains Without Overbank Deposits
3403	Gallatin	130	SI	65	6	River Valleys and Floodplains With Overbank Deposits
3403	Gallatin	130	SI	35	7	River Valleys and Floodplains Without Overbank Deposits
8102	General James M. Gavin	246	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8102	General James M. Gavin	247	SI	100	6	River Valleys and Floodplains With Overbank Deposits
8102	General James M. Gavin	1144	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
4143	Genoa	1007	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
4143	Genoa	1131	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	504	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	505	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	506	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	906	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	907	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	908	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	909	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1091	George Neal North	910	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
7343	George Neal South	911	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
7343	George Neal South	1332	SI	100	7	River Valleys and Floodplains Without Overbank Deposits

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6077	Gerald Gentleman	912	LF	100	4	Sand and Gravel
1356	Ghent	526	SI	55	6	River Valleys and Floodplains With Overbank Deposits
1356	Ghent	526	SI	45	7	River Valleys and Floodplains Without Overbank Deposits
1356	Ghent	527	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1356	Ghent	528	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1356	Ghent	529	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1356	Ghent	530	SI	55	6	River Valleys and Floodplains With Overbank Deposits
1356	Ghent	530	SI	45	7	River Valleys and Floodplains Without Overbank Deposits
6136	Gibbons Creek Steam Electric Station	881	LF	100	4	Sand and Gravel
6136	Gibbons Creek Steam Electric Station	913	LF	100	4	Sand and Gravel
6136	Gibbons Creek Steam Electric Station	1241	SI	100	4	Sand and Gravel
6136	Gibbons Creek Steam Electric Station	1242	SI	100	4	Sand and Gravel
6136	Gibbons Creek Steam Electric Station	1243	SI	100	4	Sand and Gravel
6136	Gibbons Creek Steam Electric Station	1244	SI	100	4	Sand and Gravel
6113	Gibson	81	SI	11	2	Bedded Sedimentary Rock
6113	Gibson	81	SI	89	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	82	SI	8	2	Bedded Sedimentary Rock
6113	Gibson	82	SI	92	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	83	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	84	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	85	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	86	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6113	Gibson	902	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6113	Gibson	904	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3776	Glen Lyn	146	SI	70	6	River Valleys and Floodplains With Overbank Deposits
3776	Glen Lyn	146	SI	30	7	River Valleys and Floodplains Without Overbank Deposits
3776	Glen Lyn	147	SI	82	6	River Valleys and Floodplains With Overbank Deposits
3776	Glen Lyn	147	SI	18	7	River Valleys and Floodplains Without Overbank Deposits
3776	Glen Lyn	870	LF	78	6	River Valleys and Floodplains With Overbank Deposits
3776	Glen Lyn	870	LF	22	7	River Valleys and Floodplains Without Overbank Deposits
8	Gorgas	254	SI	100	6	River Valleys and Floodplains With Overbank Deposits
8	Gorgas	255	SI	88	6	River Valleys and Floodplains With Overbank Deposits
8	Gorgas	255	SI	12	7	River Valleys and Floodplains Without Overbank Deposits
8	Gorgas	963	LF	94	6	River Valleys and Floodplains With Overbank Deposits
8	Gorgas	963	LF	6	7	River Valleys and Floodplains Without Overbank Deposits
1825	Grand Haven City of J.B. Sims	1309	SI	100	2	Bedded Sedimentary Rock
1825	Grand Haven City of J.B. Sims	1310	SI	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	871	LF	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	872	LF	100	6	River Valleys and Floodplains With Overbank Deposits
10151	Grant Town Power Plant	873	LF	34	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	873	LF	66	6	River Valleys and Floodplains With Overbank Deposits
10151	Grant Town Power Plant	1167	SI	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	1168	SI	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	1169	SI	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	1170	SI	100	2	Bedded Sedimentary Rock
10151	Grant Town Power Plant	1171	SI	100	2	Bedded Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
165	GRDA	874	LF	100	6	River Valleys and Floodplains With Overbank Deposits
165	GRDA	1210	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1357	Green River	531	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1357	Green River	532	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1357	Green River	533	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1357	Green River	534	SI	100	2	Bedded Sedimentary Rock
1357	Green River	535	SI	100	6	River Valleys and Floodplains With Overbank Deposits
10	Greene County	256	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6041	H L Spurlock Station	34	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6041	H L Spurlock Station	972	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2709	H.F. Lee Plant	656	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2709	H.F. Lee Plant	657	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2709	H.F. Lee Plant	658	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2709	H.F. Lee Plant	659	SI	59	6	River Valleys and Floodplains With Overbank Deposits
2709	H.F. Lee Plant	659	SI	41	7	River Valleys and Floodplains Without Overbank Deposits
2709	H.F. Lee Plant	660	SI	5	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2709	H.F. Lee Plant	660	SI	26	6	River Valleys and Floodplains With Overbank Deposits
2709	H.F. Lee Plant	660	SI	70	7	River Valleys and Floodplains Without Overbank Deposits
708	Hammond	351	SI	100	2	Bedded Sedimentary Rock
708	Hammond	352	SI	100	2	Bedded Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
708	Hammond	353	SI	100	2	Bedded Sedimentary Rock
708	Hammond	354	SI	100	2	Bedded Sedimentary Rock
708	Hammond	1145	LF	100	2	Bedded Sedimentary Rock
1731	Harbor Beach Power Plant	581	SI	100	4	Sand and Gravel
990	Harding Street	420	SI	100	3	Till Over Sedimentary Rock
990	Harding Street	421	SI	100	3	Till Over Sedimentary Rock
990	Harding Street	422	SI	100	3	Till Over Sedimentary Rock
990	Harding Street	423	SI	100	3	Till Over Sedimentary Rock
990	Harding Street	424	SI	100	3	Till Over Sedimentary Rock
709	Harllee Branch	355	SI	100	6	River Valleys and Floodplains With Overbank Deposits
709	Harllee Branch	356	SI	43	6	River Valleys and Floodplains With Overbank Deposits
709	Harllee Branch	356	SI	57	7	River Valleys and Floodplains Without Overbank Deposits
709	Harllee Branch	357	SI	79	6	River Valleys and Floodplains With Overbank Deposits
709	Harllee Branch	357	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
709	Harllee Branch	358	SI	1	6	River Valleys and Floodplains With Overbank Deposits
709	Harllee Branch	358	SI	99	7	River Valleys and Floodplains Without Overbank Deposits
709	Harllee Branch	359	SI	6	6	River Valleys and Floodplains With Overbank Deposits
709	Harllee Branch	359	SI	94	7	River Valleys and Floodplains Without Overbank Deposits
6193	Harrington	877	LF	100	4	Sand and Gravel
6193	Harrington	878	LF	100	4	Sand and Gravel
3944	Harrison Power Station	158	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3944	Harrison Power Station	891	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3179	Hatfield's Ferry Power Station	880	LF	16	2	Bedded Sedimentary Rock
3179	Hatfield's Ferry Power Station	880	LF	84	6	River Valleys and Floodplains With Overbank Deposits
3179	Hatfield's Ferry Power Station	1215	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3179	Hatfield's Ferry Power Station	1216	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3179	Hatfield's Ferry Power Station	1217	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3179	Hatfield's Ferry Power Station	1218	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3179	Hatfield's Ferry Power Station	1219	SI	100	6	River Valleys and Floodplains With Overbank Deposits
891	Havana	392	SI	100	6	River Valleys and Floodplains With Overbank Deposits
891	Havana	393	SI	15	6	River Valleys and Floodplains With Overbank Deposits
891	Havana	393	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
2079	Hawthorn	599	SI	87	6	River Valleys and Floodplains With Overbank Deposits
2079	Hawthorn	599	SI	13	7	River Valleys and Floodplains Without Overbank Deposits
2079	Hawthorn	962	LF	87	6	River Valleys and Floodplains With Overbank Deposits
2079	Hawthorn	962	LF	13	7	River Valleys and Floodplains Without Overbank Deposits
525	Hayden	332	SI	1	2	Bedded Sedimentary Rock
525	Hayden	332	SI	99	6	River Valleys and Floodplains With Overbank Deposits
525	Hayden	333	SI	1	2	Bedded Sedimentary Rock
525	Hayden	333	SI	99	6	River Valleys and Floodplains With Overbank Deposits
525	Hayden	334	SI	1	2	Bedded Sedimentary Rock
525	Hayden	334	SI	99	6	River Valleys and Floodplains With Overbank Deposits
525	Hayden	335	SI	1	2	Bedded Sedimentary Rock
525	Hayden	335	SI	99	6	River Valleys and Floodplains With Overbank Deposits
525	Hayden	336	SI	1	2	Bedded Sedimentary Rock
525	Hayden	336	SI	99	6	River Valleys and Floodplains With Overbank Deposits
525	Hayden	337	SI	1	2	Bedded Sedimentary Rock
525	Hayden	337	SI	99	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
525	Hayden	882	LF	100	2	Bedded Sedimentary Rock
525	Hayden	1146	LF	12	2	Bedded Sedimentary Rock
525	Hayden	1146	LF	88	6	River Valleys and Floodplains With Overbank Deposits
3251	HB Robinson / Darlington Electric Power Plant	104	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
892	Hennepin Power Station	394	SI	100	4	Sand and Gravel
892	Hennepin Power Station	883	LF	100	4	Sand and Gravel
1382	HMP&L Station Two Henderson	556	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1382	HMP&L Station Two Henderson	557	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1382	HMP&L Station Two Henderson	984	LF	100	6	River Valleys and Floodplains With Overbank Deposits
108	HOLCOMB	1147	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
3122	Homer City Station	90	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	91	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	92	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	719	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	720	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	721	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	722	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	723	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	724	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	725	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	726	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	727	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	728	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	729	SI	100	2	Bedded Sedimentary Rock
3122	Homer City Station	884	LF	100	2	Bedded Sedimentary Rock
3122	Homer City Station	886	LF	100	2	Bedded Sedimentary Rock
3122	Homer City Station	1134	LF	100	2	Bedded Sedimentary Rock
1943	Hoot Lake	887	LF	100	9	Till and Till Over Outwash
1943	Hoot Lake	1148	LF	100	9	Till and Till Over Outwash
1943	Hoot Lake	1156	LF	79	1	Metamorphic and Igneous
1943	Hoot Lake	1156	LF	21	9	Till and Till Over Outwash
1943	Hoot Lake	1157	LF	100	9	Till and Till Over Outwash
1943	Hoot Lake	1158	LF	100	9	Till and Till Over Outwash
1943	Hoot Lake	1159	LF	100	9	Till and Till Over Outwash
1943	Hoot Lake	1160	LF	100	9	Till and Till Over Outwash
10771	Hopewell	1362	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6772	Hugo	229	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6772	Hugo	230	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6772	Hugo	231	SI	4	12	Solution Limestone
6772	Hugo	231	SI	2	2	Bedded Sedimentary Rock
6772	Hugo	231	SI	95	6	River Valleys and Floodplains With Overbank Deposits
6772	Hugo	232	SI	4	12	Solution Limestone
6772	Hugo	232	SI	2	2	Bedded Sedimentary Rock
6772	Hugo	232	SI	95	6	River Valleys and Floodplains With Overbank Deposits
6772	Hugo	755	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3176	Hunlock Power Station	102	SI	100	2	Bedded Sedimentary Rock
3176	Hunlock Power Station	103	SI	100	2	Bedded Sedimentary Rock
6165	Hunter Plant	756	LF	100	2	Bedded Sedimentary Rock
6165	Hunter Plant	1258	SI	100	2	Bedded Sedimentary Rock
8069	Huntington Plant	757	LF	100	2	Bedded Sedimentary Rock
8069	Huntington Plant	758	LF	100	2	Bedded Sedimentary Rock
8069	Huntington Plant	759	LF	100	2	Bedded Sedimentary Rock
8069	Huntington Plant	1363	SI	100	2	Bedded Sedimentary Rock
8069	Huntington Plant	1364	SI	100	2	Bedded Sedimentary Rock
863	Hutsonville	381	SI	100	9	Till and Till Over Outwash
863	Hutsonville	382	SI	100	9	Till and Till Over Outwash
863	Hutsonville	383	SI	100	9	Till and Till Over Outwash
863	Hutsonville	384	SI	100	9	Till and Till Over Outwash
6065	Iatan	40	SI	87	6	River Valleys and Floodplains With Overbank Deposits
6065	Iatan	40	SI	13	7	River Valleys and Floodplains Without Overbank Deposits
6065	Iatan	1154	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6641	Independence	1153	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2132	Independence Power & Light - Blue Valley Station	616	SI	100	4	Sand and Gravel
2132	Independence Power & Light - Blue Valley Station	617	SI	100	4	Sand and Gravel
2132	Independence Power & Light - Blue Valley Station	618	SI	100	4	Sand and Gravel
594	Indian River Generating Station	339	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
594	Indian River Generating Station	340	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
594	Indian River Generating Station	762	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
594	Indian River Generating Station	775	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6481	Intermountain Power Project	214	SI	100	5	Alluvial Basins Valleys and Fans
6481	Intermountain Power Project	215	SI	100	5	Alluvial Basins Valleys and Fans
6481	Intermountain Power Project	216	SI	100	5	Alluvial Basins Valleys and Fans
6481	Intermountain Power Project	217	SI	100	5	Alluvial Basins Valleys and Fans
6481	Intermountain Power Project	218	SI	100	5	Alluvial Basins Valleys and Fans
6481	Intermountain Power Project	219	SI	100	5	Alluvial Basins Valleys and Fans
7097	J K Spruce	753	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1368	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1369	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1370	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1371	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1372	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7097	J K Spruce	1373	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2850	J M Stuart	706	SI	85	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	706	SI	15	7	River Valleys and Floodplains Without Overbank Deposits
2850	J M Stuart	707	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	708	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	709	SI	81	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2850	J M Stuart	709	SI	19	7	River Valleys and Floodplains Without Overbank Deposits
2850	J M Stuart	710	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	710	SI	0	7	River Valleys and Floodplains Without Overbank Deposits
2850	J M Stuart	711	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	766	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2850	J M Stuart	767	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6181	J T Deely	768	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1002	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1291	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1292	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1293	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1294	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1295	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6181	J T Deely	1296	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1720	J.C. Weadock	573	SI	100	2	Bedded Sedimentary Rock
1720	J.C. Weadock	574	SI	100	2	Bedded Sedimentary Rock
1720	J.C. Weadock	575	SI	100	2	Bedded Sedimentary Rock
1720	J.C. Weadock	576	SI	100	2	Bedded Sedimentary Rock
1720	J.C. Weadock	1003	LF	100	2	Bedded Sedimentary Rock
1723	J.R Whiting	577	SI	100	12	Solution Limestone
1723	J.R Whiting	578	SI	100	12	Solution Limestone
1723	J.R Whiting	579	SI	100	12	Solution Limestone
1723	J.R Whiting	580	SI	100	12	Solution Limestone
1723	J.R Whiting	965	LF	100	12	Solution Limestone
1723	J.R Whiting	1000	LF	100	12	Solution Limestone
710	Jack McDonough	360	SI	100	1	Metamorphic and Igneous
710	Jack McDonough	361	SI	100	1	Metamorphic and Igneous

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
710	Jack McDonough	362	SI	100	1	Metamorphic and Igneous
710	Jack McDonough	363	SI	100	1	Metamorphic and Igneous
710	Jack McDonough	968	LF	100	1	Metamorphic and Igneous
2049	Jack Watson	595	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2049	Jack Watson	769	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1830	James De Young	770	LF	100	3	Till Over Sedimentary Rock
1830	James De Young	1333	SI	100	4	Sand and Gravel
6002	James H. Miller Jr.	16	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2161	James River Power Station	619	SI	100	12	Solution Limestone
2161	James River Power Station	771	LF	100	12	Solution Limestone
2187	JE Corette Plant	764	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2187	JE Corette Plant	1249	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2187	JE Corette Plant	1250	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3319	Jefferies	117	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3319	Jefferies	118	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6068	Jeffrey Energy Center	41	SI	100	4	Sand and Gravel
6068	Jeffrey Energy Center	42	SI	100	4	Sand and Gravel
6068	Jeffrey Energy Center	43	SI	100	4	Sand and Gravel
6068	Jeffrey Energy Center	772	LF	100	4	Sand and Gravel
6068	Jeffrey Energy Center	773	LF	100	4	Sand and Gravel
8066	Jim Bridger Plant Units 1-4	244	SI	100	2	Bedded Sedimentary Rock
8066	Jim Bridger Plant Units 1-4	245	SI	100	2	Bedded Sedimentary Rock
8066	Jim Bridger Plant Units 1-4	774	LF	100	2	Bedded Sedimentary Rock
3935	John E. Amos	153	SI	16	2	Bedded Sedimentary Rock
3935	John E. Amos	153	SI	74	6	River Valleys and Floodplains With Overbank Deposits
3935	John E. Amos	153	SI	10	7	River Valleys and Floodplains Without Overbank Deposits
3935	John E. Amos	154	SI	16	2	Bedded Sedimentary Rock
3935	John E. Amos	154	SI	74	6	River Valleys and Floodplains With Overbank Deposits
3935	John E. Amos	154	SI	10	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3935	John E. Amos	740	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3935	John E. Amos	742	LF	100	6	River Valleys and Floodplains With Overbank Deposits
4271	John P. Madgett	990	LF	100	6	River Valleys and Floodplains With Overbank Deposits
4271	John P. Madgett	991	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3405	John Sevier	131	SI	58	12	Solution Limestone
3405	John Sevier	131	SI	34	6	River Valleys and Floodplains With Overbank Deposits
3405	John Sevier	131	SI	9	7	River Valleys and Floodplains Without Overbank Deposits
3405	John Sevier	132	SI	58	12	Solution Limestone
3405	John Sevier	132	SI	34	6	River Valleys and Floodplains With Overbank Deposits
3405	John Sevier	132	SI	9	7	River Valleys and Floodplains Without Overbank Deposits
3405	John Sevier	763	LF	91	12	Solution Limestone
3405	John Sevier	763	LF	9	7	River Valleys and Floodplains Without Overbank Deposits
3406	Johnsonville	133	SI	16	4	Sand and Gravel
3406	Johnsonville	133	SI	2	6	River Valleys and Floodplains With Overbank Deposits
3406	Johnsonville	133	SI	82	7	River Valleys and Floodplains Without Overbank Deposits
3406	Johnsonville	291	SI	16	4	Sand and Gravel
3406	Johnsonville	291	SI	2	6	River Valleys and Floodplains With Overbank Deposits
3406	Johnsonville	291	SI	82	7	River Valleys and Floodplains Without Overbank Deposits
3406	Johnsonville	732	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
3406	Johnsonville	733	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
384	Joliet 29	309	SI	100	12	Solution Limestone
384	Joliet 29	1098	LF	100	12	Solution Limestone
874	Joliet 9	1327	SI	100	12	Solution Limestone
874	Joliet 9	1328	SI	100	12	Solution Limestone

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
887	Joppa Steam	390	SI	100	6	River Valleys and Floodplains With Overbank Deposits
887	Joppa Steam	734	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3947	Kammer	159	SI	88	6	River Valleys and Floodplains With Overbank Deposits
3947	Kammer	159	SI	12	7	River Valleys and Floodplains Without Overbank Deposits
3936	Kanawha River	155	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1381	Kenneth C Coleman	553	SI	2	6	River Valleys and Floodplains With Overbank Deposits
1381	Kenneth C Coleman	553	SI	98	8	Outwash
1381	Kenneth C Coleman	554	SI	1	2	Bedded Sedimentary Rock
1381	Kenneth C Coleman	554	SI	9	4	Sand and Gravel
1381	Kenneth C Coleman	554	SI	9	6	River Valleys and Floodplains With Overbank Deposits
1381	Kenneth C Coleman	554	SI	31	7	River Valleys and Floodplains Without Overbank Deposits
1381	Kenneth C Coleman	554	SI	50	8	Outwash
1381	Kenneth C Coleman	555	SI	100	8	Outwash
3136	Keystone	736	LF	100	2	Bedded Sedimentary Rock
3136	Keystone	1151	LF	100	2	Bedded Sedimentary Rock
3136	Keystone	1152	LF	100	2	Bedded Sedimentary Rock
3136	Keystone	1297	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1298	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1299	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1300	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1301	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1302	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1303	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1304	SI	100	2	Bedded Sedimentary Rock
3136	Keystone	1305	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3136	Keystone	1306	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3136	Keystone	1307	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6031	Killen Station	31	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6031	Killen Station	32	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
876	Kincaid Generation LLC	388	SI	100	4	Sand and Gravel
876	Kincaid Generation LLC	969	LF	3	2	Bedded Sedimentary Rock
876	Kincaid Generation LLC	969	LF	97	4	Sand and Gravel
3407	Kingston	134	SI	44	6	River Valleys and Floodplains With Overbank Deposits
3407	Kingston	134	SI	56	7	River Valleys and Floodplains Without Overbank Deposits
3407	Kingston	135	SI	44	6	River Valleys and Floodplains With Overbank Deposits
3407	Kingston	135	SI	56	7	River Valleys and Floodplains Without Overbank Deposits
733	Kraft	375	SI	48	6	River Valleys and Floodplains With Overbank Deposits
733	Kraft	375	SI	52	7	River Valleys and Floodplains Without Overbank Deposits
733	Kraft	1150	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2876	Kyger Creek	716	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2876	Kyger Creek	717	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2876	Kyger Creek	738	LF	67	2	Bedded Sedimentary Rock
2876	Kyger Creek	738	LF	33	7	River Valleys and Floodplains Without Overbank Deposits
2713	L.V. Sutton Electric Plant	665	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2713	L.V. Sutton Electric Plant	666	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1241	La Cygne	513	SI	100	4	Sand and Gravel
1241	La Cygne	514	SI	100	4	Sand and Gravel
1241	La Cygne	739	LF	100	4	Sand and Gravel
2103	Labadie	607	SI	88	6	River Valleys and Floodplains With Overbank Deposits
2103	Labadie	607	SI	12	7	River Valleys and Floodplains Without Overbank Deposits
2103	Labadie	608	SI	88	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2103	Labadie	608	SI	12	7	River Valleys and Floodplains Without Overbank Deposits
2098	Lake Road	605	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2098	Lake Road	606	SI	7	2	Bedded Sedimentary Rock
2098	Lake Road	606	SI	84	6	River Valleys and Floodplains With Overbank Deposits
2098	Lake Road	606	SI	9	7	River Valleys and Floodplains Without Overbank Deposits
2098	Lake Road	752	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2838	Lake Shore	1270	SI	100	4	Sand and Gravel
964	Lakeside	400	SI	100	4	Sand and Gravel
1047	Lansing	477	SI	43	2	Bedded Sedimentary Rock
1047	Lansing	477	SI	11	6	River Valleys and Floodplains With Overbank Deposits
1047	Lansing	477	SI	46	7	River Valleys and Floodplains Without Overbank Deposits
1047	Lansing	478	SI	43	2	Bedded Sedimentary Rock
1047	Lansing	478	SI	11	6	River Valleys and Floodplains With Overbank Deposits
1047	Lansing	478	SI	46	7	River Valleys and Floodplains Without Overbank Deposits
1047	Lansing	730	LF	100	2	Bedded Sedimentary Rock
1047	Lansing	741	LF	100	2	Bedded Sedimentary Rock
643	Lansing Smith	341	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
643	Lansing Smith	743	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6204	Laramie River Station	188	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6204	Laramie River Station	189	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6204	Laramie River Station	744	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1891	Laskin Energy Center	588	SI	100	3	Till Over Sedimentary Rock
1891	Laskin Energy Center	589	SI	100	3	Till Over Sedimentary Rock
1250	Lawrence Energy Center	515	SI	16	4	Sand and Gravel

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1250	Lawrence Energy Center	515	SI	84	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	516	SI	16	4	Sand and Gravel
1250	Lawrence Energy Center	516	SI	84	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	517	SI	16	4	Sand and Gravel
1250	Lawrence Energy Center	517	SI	84	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	518	SI	16	4	Sand and Gravel
1250	Lawrence Energy Center	518	SI	84	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	745	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	747	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1250	Lawrence Energy Center	1149	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2817	Leland Olds	683	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2817	Leland Olds	684	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2817	Leland Olds	685	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2817	Leland Olds	748	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2817	Leland Olds	749	LF	100	3	Till Over Sedimentary Rock
6089	Lewis & Clark	750	LF	100	3	Till Over Sedimentary Rock
6089	Lewis & Clark	751	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6089	Lewis & Clark	786	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6089	Lewis & Clark	1374	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6089	Lewis & Clark	1375	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6089	Lewis & Clark	1376	SI	100	7	River Valleys and Floodplains Without Overbank Deposits

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6089	Lewis & Clark	1377	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6089	Lewis & Clark	1378	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
298	Limestone	300	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	301	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	302	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	303	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	304	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	305	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	306	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	307	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	308	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
298	Limestone	821	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2240	Lon Wright	765	LF	100	2	Bedded Sedimentary Rock
6664	Louisa	222	SI	30	6	River Valleys and Floodplains With Overbank Deposits
6664	Louisa	222	SI	70	7	River Valleys and Floodplains Without Overbank Deposits
6664	Louisa	223	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6664	Louisa	801	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
976	Marion Generating Station	401	SI	100	4	Sand and Gravel
976	Marion Generating Station	402	SI	100	4	Sand and Gravel
976	Marion Generating Station	403	SI	100	4	Sand and Gravel
976	Marion Generating Station	404	SI	100	4	Sand and Gravel
976	Marion Generating Station	405	SI	100	4	Sand and Gravel

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
976	Marion Generating Station	406	SI	100	4	Sand and Gravel
976	Marion Generating Station	407	SI	100	4	Sand and Gravel
976	Marion Generating Station	408	SI	100	4	Sand and Gravel
976	Marion Generating Station	409	SI	100	4	Sand and Gravel
976	Marion Generating Station	410	SI	100	4	Sand and Gravel
976	Marion Generating Station	411	SI	100	4	Sand and Gravel
976	Marion Generating Station	412	SI	100	4	Sand and Gravel
976	Marion Generating Station	802	LF	100	4	Sand and Gravel
2727	Marshall	680	SI	100	1	Metamorphic and Igneous
2727	Marshall	803	LF	100	1	Metamorphic and Igneous
2727	Marshall	804	LF	100	1	Metamorphic and Igneous
492	Martin Drake	805	LF	100	2	Bedded Sedimentary Rock
492	Martin Drake	1251	SI	100	2	Bedded Sedimentary Rock
492	Martin Drake	1252	SI	100	2	Bedded Sedimentary Rock
492	Martin Drake	1253	SI	100	2	Bedded Sedimentary Rock
492	Martin Drake	1254	SI	100	2	Bedded Sedimentary Rock
6146	Martin Lake	806	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	807	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	808	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	810	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	822	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	1223	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	1224	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	1225	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6146	Martin Lake	1226	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6250	Mayo Electric Generating Facility	204	SI	100	1	Metamorphic and Igneous
6124	McIntosh	87	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3287	McMeekin	1155	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2104	Meramec	609	SI	77	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2104	Meramec	609	SI	23	7	River Valleys and Floodplains Without Overbank Deposits
2104	Meramec	610	SI	77	6	River Valleys and Floodplains With Overbank Deposits
2104	Meramec	610	SI	23	7	River Valleys and Floodplains Without Overbank Deposits
2104	Meramec	611	SI	77	6	River Valleys and Floodplains With Overbank Deposits
2104	Meramec	611	SI	23	7	River Valleys and Floodplains Without Overbank Deposits
2104	Meramec	612	SI	77	6	River Valleys and Floodplains With Overbank Deposits
2104	Meramec	612	SI	23	7	River Valleys and Floodplains Without Overbank Deposits
2104	Meramec	613	SI	77	6	River Valleys and Floodplains With Overbank Deposits
2104	Meramec	613	SI	23	7	River Valleys and Floodplains Without Overbank Deposits
864	Meredosia	385	SI	48	6	River Valleys and Floodplains With Overbank Deposits
864	Meredosia	385	SI	52	7	River Valleys and Floodplains Without Overbank Deposits
864	Meredosia	386	SI	48	6	River Valleys and Floodplains With Overbank Deposits
864	Meredosia	386	SI	52	7	River Valleys and Floodplains Without Overbank Deposits
6213	Merom	190	SI	100	2	Bedded Sedimentary Rock
6213	Merom	812	LF	100	2	Bedded Sedimentary Rock
6213	Merom	813	LF	100	2	Bedded Sedimentary Rock
2364	Merrimack Station	754	LF	100	9	Till and Till Over Outwash
2364	Merrimack Station	1319	SI	32	3	Till Over Sedimentary Rock
2364	Merrimack Station	1319	SI	68	9	Till and Till Over Outwash
2364	Merrimack Station	1320	SI	96	3	Till Over Sedimentary Rock
2364	Merrimack Station	1320	SI	4	9	Till and Till Over Outwash
2832	Miami Fort	699	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2832	Miami Fort	700	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2832	Miami Fort	1109	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2832	Miami Fort	1121	LF	100	6	River Valleys and Floodplains With Overbank Deposits
997	Michigan City	448	SI	90	3	Till Over Sedimentary Rock
997	Michigan City	448	SI	10	9	Till and Till Over Outwash
997	Michigan City	449	SI	100	3	Till Over Sedimentary Rock
997	Michigan City	450	SI	100	3	Till Over Sedimentary Rock
997	Michigan City	451	SI	98	3	Till Over Sedimentary Rock
997	Michigan City	451	SI	2	9	Till and Till Over Outwash
997	Michigan City	452	SI	100	3	Till Over Sedimentary Rock
997	Michigan City	453	SI	100	3	Till Over Sedimentary Rock
1364	Mill Creek	543	SI	100	1	Metamorphic and Igneous
1364	Mill Creek	544	SI	40	2	Bedded Sedimentary Rock
1364	Mill Creek	544	SI	48	6	River Valleys and Floodplains With Overbank Deposits
1364	Mill Creek	544	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
1364	Mill Creek	545	SI	40	2	Bedded Sedimentary Rock
1364	Mill Creek	545	SI	48	6	River Valleys and Floodplains With Overbank Deposits
1364	Mill Creek	545	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
1364	Mill Creek	546	SI	40	2	Bedded Sedimentary Rock
1364	Mill Creek	546	SI	48	6	River Valleys and Floodplains With Overbank Deposits
1364	Mill Creek	546	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
1364	Mill Creek	547	SI	40	2	Bedded Sedimentary Rock
1364	Mill Creek	547	SI	48	6	River Valleys and Floodplains With Overbank Deposits
1364	Mill Creek	547	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
1364	Mill Creek	817	LF	100	2	Bedded Sedimentary Rock
1364	Mill Creek	817	LF	0	6	River Valleys and Floodplains With Overbank Deposits
1364	Mill Creek	818	LF	100	2	Bedded Sedimentary Rock
1364	Mill Creek	819	LF	88	2	Bedded Sedimentary Rock
1364	Mill Creek	819	LF	12	6	River Valleys and Floodplains With Overbank Deposits
2823	Milton R. Young Station	686	SI	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	687	SI	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	688	SI	100	3	Till Over Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2823	Milton R. Young Station	689	SI	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	777	LF	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	788	LF	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	809	LF	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	811	LF	100	3	Till Over Sedimentary Rock
2823	Milton R. Young Station	820	LF	100	3	Till Over Sedimentary Rock
2171	Missouri City	1257	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3948	Mitchell	160	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3948	Mitchell	161	SI	100	6	River Valleys and Floodplains With Overbank Deposits
727	Mitchell	364	SI	56	12	Solution Limestone
727	Mitchell	364	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
727	Mitchell	365	SI	56	12	Solution Limestone
727	Mitchell	365	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
727	Mitchell	366	SI	56	12	Solution Limestone
727	Mitchell	366	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
3181	Mitchell Power Station	778	LF	100	2	Bedded Sedimentary Rock
3181	Mitchell Power Station	779	LF	100	2	Bedded Sedimentary Rock
1048	ML Kapp	479	SI	28	6	River Valleys and Floodplains With Overbank Deposits
1048	ML Kapp	479	SI	72	7	River Valleys and Floodplains Without Overbank Deposits
1048	ML Kapp	479	SI	0	8	Outwash
1048	ML Kapp	480	SI	28	6	River Valleys and Floodplains With Overbank Deposits
1048	ML Kapp	480	SI	72	7	River Valleys and Floodplains Without Overbank Deposits
1048	ML Kapp	480	SI	0	8	Outwash
1048	ML Kapp	481	SI	28	6	River Valleys and Floodplains With Overbank Deposits
1048	ML Kapp	481	SI	72	7	River Valleys and Floodplains Without Overbank Deposits
1048	ML Kapp	481	SI	0	8	Outwash
1048	ML Kapp	482	SI	28	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1048	ML Kapp	482	SI	72	7	River Valleys and Floodplains Without Overbank Deposits
1048	ML Kapp	482	SI	0	8	Outwash
1733	Monroe Power Plant	582	SI	100	12	Solution Limestone
1733	Monroe Power Plant	583	SI	100	12	Solution Limestone
6147	Monticello	780	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	781	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	782	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	1203	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	1204	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	1205	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6147	Monticello	1206	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2080	Montrose	600	SI	100	4	Sand and Gravel
2080	Montrose	601	SI	100	4	Sand and Gravel
2080	Montrose	602	SI	39	2	Bedded Sedimentary Rock
2080	Montrose	602	SI	47	4	Sand and Gravel
2080	Montrose	602	SI	14	6	River Valleys and Floodplains With Overbank Deposits
2080	Montrose	602	SI	0	7	River Valleys and Floodplains Without Overbank Deposits
2080	Montrose	783	LF	100	4	Sand and Gravel
1573	Morgantown Generating Plant	785	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1573	Morgantown Generating Plant	1108	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1606	Mount Tom	563	SI	100	2	Bedded Sedimentary Rock
1606	Mount Tom	564	SI	100	2	Bedded Sedimentary Rock
1606	Mount Tom	565	SI	100	2	Bedded Sedimentary Rock
1606	Mount Tom	798	LF	100	2	Bedded Sedimentary Rock
6264	Mountaineer	211	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6264	Mountaineer	787	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3954	Mt. Storm	789	LF	100	2	Bedded Sedimentary Rock

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3954	Mt. Storm	1110	LF	100	2	Bedded Sedimentary Rock
3954	Mt. Storm	1111	LF	100	2	Bedded Sedimentary Rock
3954	Mt. Storm	1112	LF	100	2	Bedded Sedimentary Rock
1167	Muscatine #1	792	LF	100	12	Solution Limestone
1167	Muscatine #1	1361	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2872	Muskingum River	712	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2872	Muskingum River	713	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2872	Muskingum River	714	SI	41	6	River Valleys and Floodplains With Overbank Deposits
2872	Muskingum River	714	SI	59	7	River Valleys and Floodplains Without Overbank Deposits
2872	Muskingum River	715	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2952	Muskogee	1172	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2952	Muskogee	1173	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2952	Muskogee	1174	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
4162	Naughton Plant	12	SI	100	2	Bedded Sedimentary Rock
4162	Naughton Plant	13	SI	100	2	Bedded Sedimentary Rock
4162	Naughton Plant	14	SI	100	2	Bedded Sedimentary Rock
4162	Naughton Plant	15	SI	100	2	Bedded Sedimentary Rock
4162	Naughton Plant	980	LF	97	2	Bedded Sedimentary Rock
4162	Naughton Plant	980	LF	3	6	River Valleys and Floodplains With Overbank Deposits
4941	Navajo Generating Station	793	LF	100	2	Bedded Sedimentary Rock
6064	Nearman Creek	39	SI	89	6	River Valleys and Floodplains With Overbank Deposits
6064	Nearman Creek	39	SI	11	7	River Valleys and Floodplains Without Overbank Deposits
6064	Nearman Creek	794	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6064	Nearman Creek	795	LF	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6096	Nebraska City	797	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6096	Nebraska City	943	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6096	Nebraska City	1271	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
6096	Nebraska City	1272	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
4054	Nelson Dewey	170	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
4054	Nelson Dewey	171	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
4054	Nelson Dewey	893	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
3138	New Castle Plant	941	LF	100	2	Bedded Sedimentary Rock
3138	New Castle Plant	1349	SI	100	2	Bedded Sedimentary Rock
3138	New Castle Plant	1350	SI	100	2	Bedded Sedimentary Rock
2167	New Madrid	620	SI	80	6	River Valleys and Floodplains With Overbank Deposits
2167	New Madrid	620	SI	20	7	River Valleys and Floodplains Without Overbank Deposits
2167	New Madrid	621	SI	34	6	River Valleys and Floodplains With Overbank Deposits
2167	New Madrid	621	SI	66	7	River Valleys and Floodplains Without Overbank Deposits
2167	New Madrid	622	SI	99	6	River Valleys and Floodplains With Overbank Deposits
2167	New Madrid	622	SI	1	7	River Valleys and Floodplains Without Overbank Deposits
2167	New Madrid	623	SI	90	6	River Valleys and Floodplains With Overbank Deposits
2167	New Madrid	623	SI	10	7	River Valleys and Floodplains Without Overbank Deposits
2167	New Madrid	1032	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6017	Newton	21	SI	100	2	Bedded Sedimentary Rock
6017	Newton	22	SI	100	2	Bedded Sedimentary Rock
6017	Newton	1033	LF	100	2	Bedded Sedimentary Rock

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6017	Newton	1034	LF	100	2	Bedded Sedimentary Rock
2291	North Omaha	1036	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2291	North Omaha	1113	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2291	North Omaha	1220	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2291	North Omaha	1221	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
2291	North Omaha	1222	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
8224	North Valmy	1037	LF	100	5	Alluvial Basins Valleys and Fans
2963	Northeastern	718	SI	21	4	Sand and Gravel
2963	Northeastern	718	SI	79	6	River Valleys and Floodplains With Overbank Deposits
2963	Northeastern	718	SI	0	7	River Valleys and Floodplains Without Overbank Deposits
2963	Northeastern	1038	LF	100	6	River Valleys and Floodplains With Overbank Deposits
667	Northside Generating Station	1039	LF	100	11	Coastal Beaches
10030	NRG Energy Center Dover	251	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
527	Nucla	338	SI	100	2	Bedded Sedimentary Rock
527	Nucla	964	LF	100	2	Bedded Sedimentary Rock
2848	O H Hutchings	703	SI	100	9	Till and Till Over Outwash
2848	O H Hutchings	704	SI	100	9	Till and Till Over Outwash
2848	O H Hutchings	705	SI	100	9	Till and Till Over Outwash
6180	Oak Grove	1040	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6180	Oak Grove	1042	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6180	Oak Grove	1054	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6180	Oak Grove	1185	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
127	Oklaunion	281	SI	100	2	Bedded Sedimentary Rock
127	Oklaunion	282	SI	100	2	Bedded Sedimentary Rock
127	Oklaunion	283	SI	100	2	Bedded Sedimentary Rock
127	Oklaunion	841	LF	100	2	Bedded Sedimentary Rock
4151	Osage	1031	LF	100	12	Solution Limestone

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
4151	Osage	1044	LF	100	12	Solution Limestone
4151	Osage	1266	SI	100	12	Solution Limestone
4151	Osage	1267	SI	100	12	Solution Limestone
1831	Otto E. Eckert Station	586	SI	100	2	Bedded Sedimentary Rock
6254	Ottumwa	205	SI	50	12	Solution Limestone
6254	Ottumwa	205	SI	23	2	Bedded Sedimentary Rock
6254	Ottumwa	205	SI	26	6	River Valleys and Floodplains With Overbank Deposits
6254	Ottumwa	206	SI	50	12	Solution Limestone
6254	Ottumwa	206	SI	23	2	Bedded Sedimentary Rock
6254	Ottumwa	206	SI	26	6	River Valleys and Floodplains With Overbank Deposits
6254	Ottumwa	207	SI	50	12	Solution Limestone
6254	Ottumwa	207	SI	23	2	Bedded Sedimentary Rock
6254	Ottumwa	207	SI	26	6	River Valleys and Floodplains With Overbank Deposits
6254	Ottumwa	208	SI	50	12	Solution Limestone
6254	Ottumwa	208	SI	23	2	Bedded Sedimentary Rock
6254	Ottumwa	208	SI	26	6	River Valleys and Floodplains With Overbank Deposits
6254	Ottumwa	1045	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1378	Paradise	548	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1378	Paradise	549	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1378	Paradise	550	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6248	Pawnee	191	SI	100	4	Sand and Gravel
6248	Pawnee	192	SI	100	4	Sand and Gravel
6248	Pawnee	193	SI	100	4	Sand and Gravel
6248	Pawnee	194	SI	100	4	Sand and Gravel
6248	Pawnee	195	SI	100	4	Sand and Gravel
6248	Pawnee	196	SI	100	4	Sand and Gravel
6248	Pawnee	197	SI	100	4	Sand and Gravel
6248	Pawnee	1046	LF	100	4	Sand and Gravel
6238	Pearl Station	1211	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3938	Philip Sporn	156	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3938	Philip Sporn	157	SI	100	7	River Valleys and Floodplains Without Overbank Deposits

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3938	Philip Sporn	979	LF	24	6	River Valleys and Floodplains With Overbank Deposits
3938	Philip Sporn	979	LF	76	7	River Valleys and Floodplains Without Overbank Deposits
2843	Picway	702	SI	100	3	Till Over Sedimentary Rock
7902	Pirkey	233	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	234	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	235	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	236	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	237	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	238	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
7902	Pirkey	1132	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
59	Platte	1047	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
59	Platte	1048	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6170	Pleasant Prairie	1049	LF	100	12	Solution Limestone
6004	Pleasants Power Station	17	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6004	Pleasants Power Station	1050	LF	100	6	River Valleys and Floodplains With Overbank Deposits
7242	Polk	1051	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3113	Portland	1020	LF	100	2	Bedded Sedimentary Rock
3113	Portland	1041	LF	100	2	Bedded Sedimentary Rock
3113	Portland	1043	LF	100	2	Bedded Sedimentary Rock
3113	Portland	1052	LF	100	2	Bedded Sedimentary Rock
3113	Portland	1199	SI	100	2	Bedded Sedimentary Rock
3113	Portland	1200	SI	100	2	Bedded Sedimentary Rock
3113	Portland	1201	SI	100	2	Bedded Sedimentary Rock
879	Powerton	1227	SI	96	4	Sand and Gravel

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ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
879	Powerton	1227	SI	4	7	River Valleys and Floodplains Without Overbank Deposits
879	Powerton	1228	SI	100	4	Sand and Gravel
879	Powerton	1229	SI	71	4	Sand and Gravel
879	Powerton	1229	SI	29	7	River Valleys and Floodplains Without Overbank Deposits
879	Powerton	1230	SI	100	4	Sand and Gravel
879	Powerton	1231	SI	100	4	Sand and Gravel
879	Powerton	1232	SI	100	4	Sand and Gravel
879	Powerton	1233	SI	100	4	Sand and Gravel
3140	PPL Brunner Island	93	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3140	PPL Brunner Island	94	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3140	PPL Brunner Island	95	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3140	PPL Brunner Island	1114	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3149	PPL Montour	96	SI	100	12	Solution Limestone
3149	PPL Montour	97	SI	100	12	Solution Limestone
3149	PPL Montour	98	SI	100	12	Solution Limestone
3149	PPL Montour	99	SI	100	12	Solution Limestone
3149	PPL Montour	100	SI	100	12	Solution Limestone
3149	PPL Montour	1011	LF	100	12	Solution Limestone
3149	PPL Montour	1115	LF	100	12	Solution Limestone
1073	Prairie Creek	487	SI	35	12	Solution Limestone
1073	Prairie Creek	487	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	487	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	488	SI	35	12	Solution Limestone
1073	Prairie Creek	488	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	488	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	489	SI	35	12	Solution Limestone
1073	Prairie Creek	489	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	489	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	490	SI	35	12	Solution Limestone

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1073	Prairie Creek	490	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	490	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	491	SI	35	12	Solution Limestone
1073	Prairie Creek	491	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	491	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	492	SI	35	12	Solution Limestone
1073	Prairie Creek	492	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	492	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	493	SI	35	12	Solution Limestone
1073	Prairie Creek	493	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	493	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	494	SI	35	12	Solution Limestone
1073	Prairie Creek	494	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	494	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	495	SI	35	12	Solution Limestone
1073	Prairie Creek	495	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	495	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1073	Prairie Creek	496	SI	35	12	Solution Limestone
1073	Prairie Creek	496	SI	45	6	River Valleys and Floodplains With Overbank Deposits
1073	Prairie Creek	496	SI	21	7	River Valleys and Floodplains Without Overbank Deposits
1769	Presque Isle	1012	LF	100	1	Metamorphic and Igneous
1769	Presque Isle	1013	LF	100	1	Metamorphic and Igneous
1769	Presque Isle	1014	LF	100	1	Metamorphic and Igneous
2403	PSEG Hudson Generating Station	1015	LF	100	3	Till Over Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
2403	PSEG Hudson Generating Station	1351	SI	100	3	Till Over Sedimentary Rock
2403	PSEG Hudson Generating Station	1352	SI	100	3	Till Over Sedimentary Rock
2408	PSEG Mercer Generating Station	1016	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2408	PSEG Mercer Generating Station	1197	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2408	PSEG Mercer Generating Station	1198	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
4072	Pulliam	1017	LF	100	2	Bedded Sedimentary Rock
4072	Pulliam	1212	SI	100	2	Bedded Sedimentary Rock
1295	Quindaro	1030	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6639	R D Green	220	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6639	R D Green	1019	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2864	R. E. Burger	976	LF	90	6	River Valleys and Floodplains With Overbank Deposits
2864	R. E. Burger	976	LF	10	7	River Valleys and Floodplains Without Overbank Deposits
2864	R. E. Burger	1380	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2864	R. E. Burger	1381	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1008	R. Gallagher	460	SI	100	8	Outwash
1008	R. Gallagher	461	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	461	SI	66	8	Outwash
1008	R. Gallagher	1001	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1001	LF	60	8	Outwash
1008	R. Gallagher	1023	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1023	LF	60	8	Outwash
1008	R. Gallagher	1024	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1024	LF	60	8	Outwash

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1008	R. Gallagher	1025	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1025	LF	60	8	Outwash
1008	R. Gallagher	1026	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1026	LF	60	8	Outwash
1008	R. Gallagher	1027	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1027	LF	60	8	Outwash
1008	R. Gallagher	1029	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1029	LF	60	8	Outwash
1008	R. Gallagher	1053	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1053	LF	60	8	Outwash
1008	R. Gallagher	1056	LF	40	7	River Valleys and Floodplains Without Overbank Deposits
1008	R. Gallagher	1056	LF	60	8	Outwash
1570	R. Paul Smith Power Station	561	SI	81	6	River Valleys and Floodplains With Overbank Deposits
1570	R. Paul Smith Power Station	561	SI	19	7	River Valleys and Floodplains Without Overbank Deposits
1570	R. Paul Smith Power Station	562	SI	83	6	River Valleys and Floodplains With Overbank Deposits
1570	R. Paul Smith Power Station	562	SI	17	7	River Valleys and Floodplains Without Overbank Deposits
1570	R. Paul Smith Power Station	1083	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2790	R.M. Heskett Station	1080	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
2790	R.M. Heskett Station	1081	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
6085	R.M. Schahfer	54	SI	100	8	Outwash
6085	R.M. Schahfer	55	SI	100	8	Outwash
6085	R.M. Schahfer	56	SI	100	8	Outwash
6085	R.M. Schahfer	57	SI	100	8	Outwash
6085	R.M. Schahfer	58	SI	100	8	Outwash
6085	R.M. Schahfer	67	SI	100	8	Outwash
6085	R.M. Schahfer	68	SI	100	8	Outwash
6085	R.M. Schahfer	1082	LF	100	8	Outwash
6761	Rawhide	225	SI	100	2	Bedded Sedimentary Rock
6761	Rawhide	226	SI	100	2	Bedded Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6761	Rawhide	996	LF	100	2	Bedded Sedimentary Rock
6761	Rawhide	1086	LF	100	2	Bedded Sedimentary Rock
8219	Ray D Nixon	1087	LF	100	2	Bedded Sedimentary Rock
8219	Ray D Nixon	1255	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
55076	Red Hills Generating Facility	1088	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
55076	Red Hills Generating Facility	1256	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
2324	Reid Gardner	630	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	631	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	632	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	633	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	634	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	635	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	636	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	637	SI	100	5	Alluvial Basins Valleys and Fans
2324	Reid Gardner	1090	LF	100	5	Alluvial Basins Valleys and Fans
1740	River Rouge Power Plant	1186	SI	100	12	Solution Limestone
2732	Riverbend	681	SI	100	1	Metamorphic and Igneous
2732	Riverbend	682	SI	100	1	Metamorphic and Igneous
1081	Riverside	500	SI	84	6	River Valleys and Floodplains With Overbank Deposits
1081	Riverside	500	SI	16	7	River Valleys and Floodplains Without Overbank Deposits
1081	Riverside	501	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1927	Riverside	594	SI	93	2	Bedded Sedimentary Rock
1927	Riverside	594	SI	7	8	Outwash
1239	Riverton	512	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3945	Rivesville Power Station	1095	LF	100	6	River Valleys and Floodplains With Overbank Deposits
3945	Rivesville Power Station	1116	LF	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3945	Rivesville Power Station	1355	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3945	Rivesville Power Station	1356	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3945	Rivesville Power Station	1357	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3945	Rivesville Power Station	1358	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6166	Rockport	179	SI	100	8	Outwash
6166	Rockport	1097	LF	100	8	Outwash
6190	Rodemacher	185	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6190	Rodemacher	186	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6190	Rodemacher	187	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6190	Rodemacher	187	SI	0	7	River Valleys and Floodplains Without Overbank Deposits
2712	Roxboro Steam Electric Plant	661	SI	100	1	Metamorphic and Igneous
2712	Roxboro Steam Electric Plant	662	SI	100	1	Metamorphic and Igneous
2712	Roxboro Steam Electric Plant	663	SI	100	1	Metamorphic and Igneous
2712	Roxboro Steam Electric Plant	664	SI	100	1	Metamorphic and Igneous
2712	Roxboro Steam Electric Plant	1096	LF	100	1	Metamorphic and Igneous
1393	RS Nelson	1084	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1393	RS Nelson	1085	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1393	RS Nelson	1329	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1393	RS Nelson	1330	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6155	Rush Island	178	SI	63	6	River Valleys and Floodplains With Overbank Deposits
6155	Rush Island	178	SI	37	7	River Valleys and Floodplains Without Overbank Deposits
6155	Rush Island	1091	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2451	San Juan	1308	SI	100	2	Bedded Sedimentary Rock
6183	San Miguel	1093	LF	100	2	Bedded Sedimentary Rock

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6183	San Miguel	1094	LF	100	2	Bedded Sedimentary Rock
6183	San Miguel	1365	SI	100	2	Bedded Sedimentary Rock
6183	San Miguel	1366	SI	100	2	Bedded Sedimentary Rock
6183	San Miguel	1367	SI	100	2	Bedded Sedimentary Rock
6648	Sandow No 4	221	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6648	Sandow No 4	1057	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6648	Sandow No 4	1065	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6648	Sandow No 4	1067	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6648	Sandow No 4	1089	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6648	Sandow No 4	1092	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6257	Scherer	209	SI	100	1	Metamorphic and Igneous
6257	Scherer	210	SI	100	1	Metamorphic and Igneous
2367	SCHILLER	1058	LF	86	3	Till Over Sedimentary Rock
2367	SCHILLER	1058	LF	14	9	Till and Till Over Outwash
642	Scholz	1346	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
642	Scholz	1347	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
642	Scholz	1348	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
136	Seminole Generating Station	1059	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1379	Shawnee	551	SI	38	6	River Valleys and Floodplains With Overbank Deposits
1379	Shawnee	551	SI	62	7	River Valleys and Floodplains Without Overbank Deposits
1379	Shawnee	552	SI	38	6	River Valleys and Floodplains With Overbank Deposits
1379	Shawnee	552	SI	62	7	River Valleys and Floodplains Without Overbank Deposits
1379	Shawnee	1060	LF	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1379	Shawnee	1061	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
3131	Shawville	1062	LF	100	2	Bedded Sedimentary Rock
3131	Shawville	1063	LF	100	2	Bedded Sedimentary Rock
3131	Shawville	1245	SI	100	2	Bedded Sedimentary Rock
3131	Shawville	1246	SI	100	2	Bedded Sedimentary Rock
3131	Shawville	1247	SI	100	2	Bedded Sedimentary Rock
3131	Shawville	1248	SI	100	2	Bedded Sedimentary Rock
2277	Sheldon Station	1055	LF	100	4	Sand and Gravel
2277	Sheldon Station	1064	LF	100	4	Sand and Gravel
2277	Sheldon Station	1066	LF	100	4	Sand and Gravel
2277	Sheldon Station	1078	LF	100	4	Sand and Gravel
2277	Sheldon Station	1360	SI	100	4	Sand and Gravel
6090	Sherburne County	69	SI	100	8	Outwash
6090	Sherburne County	70	SI	100	8	Outwash
6090	Sherburne County	71	SI	100	8	Outwash
6090	Sherburne County	72	SI	74	8	Outwash
6090	Sherburne County	72	SI	26	9	Till and Till Over Outwash
6090	Sherburne County	73	SI	100	8	Outwash
6090	Sherburne County	74	SI	74	8	Outwash
6090	Sherburne County	74	SI	26	9	Till and Till Over Outwash
6090	Sherburne County	1068	LF	100	8	Outwash
2094	Sibley	603	SI	87	6	River Valleys and Floodplains With Overbank Deposits
2094	Sibley	603	SI	13	7	River Valleys and Floodplains Without Overbank Deposits
2094	Sibley	604	SI	87	6	River Valleys and Floodplains With Overbank Deposits
2094	Sibley	604	SI	13	7	River Valleys and Floodplains Without Overbank Deposits
2094	Sibley	1069	LF	100	6	River Valleys and Floodplains With Overbank Deposits
6768	Sikeston Power Station	227	SI	100	8	Outwash
6768	Sikeston Power Station	228	SI	100	8	Outwash
2107	Sioux	614	SI	66	6	River Valleys and Floodplains With Overbank Deposits
2107	Sioux	614	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
2107	Sioux	615	SI	66	6	River Valleys and Floodplains With Overbank Deposits
2107	Sioux	615	SI	34	7	River Valleys and Floodplains Without Overbank Deposits
1058	Sixth Street	483	SI	100	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1058	Sixth Street	484	SI	90	6	River Valleys and Floodplains With Overbank Deposits
1058	Sixth Street	484	SI	10	7	River Valleys and Floodplains Without Overbank Deposits
1058	Sixth Street	485	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1058	Sixth Street	486	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1613	Somerset Station	566	SI	15	1	Metamorphic and Igneous
1613	Somerset Station	566	SI	84	3	Till Over Sedimentary Rock
1613	Somerset Station	566	SI	1	9	Till and Till Over Outwash
1613	Somerset Station	567	SI	15	1	Metamorphic and Igneous
1613	Somerset Station	567	SI	84	3	Till Over Sedimentary Rock
1613	Somerset Station	567	SI	1	9	Till and Till Over Outwash
1613	Somerset Station	568	SI	15	1	Metamorphic and Igneous
1613	Somerset Station	568	SI	84	3	Till Over Sedimentary Rock
1613	Somerset Station	568	SI	1	9	Till and Till Over Outwash
1613	Somerset Station	569	SI	15	1	Metamorphic and Igneous
1613	Somerset Station	569	SI	84	3	Till Over Sedimentary Rock
1613	Somerset Station	569	SI	1	9	Till and Till Over Outwash
6095	Sooner	1259	SI	1	4	Sand and Gravel
6095	Sooner	1259	SI	99	6	River Valleys and Floodplains With Overbank Deposits
6095	Sooner	1260	SI	100	4	Sand and Gravel
6061	South Mississippi El Pwr Assn	1008	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6061	South Mississippi El Pwr Assn	1021	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6061	South Mississippi El Pwr Assn	1022	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6061	South Mississippi El Pwr Assn	1353	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6061	South Mississippi El Pwr Assn	1354	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
4041	South Oak Creek	1070	LF	100	12	Solution Limestone
4041	South Oak Creek	1071	LF	100	12	Solution Limestone
4041	South Oak Creek	1072	LF	100	12	Solution Limestone
6195	Southwest Power Station	1073	LF	100	12	Solution Limestone
6195	Southwest Power Station	1074	LF	100	12	Solution Limestone
6195	Southwest Power Station	1268	SI	100	12	Solution Limestone
6195	Southwest Power Station	1269	SI	100	12	Solution Limestone
8223	Springerville	1075	LF	100	2	Bedded Sedimentary Rock
8223	Springerville	1384	SI	100	2	Bedded Sedimentary Rock
1743	St Clair Power Plant	584	SI	100	4	Sand and Gravel
207	St Johns River Power Park	1018	LF	100	11	Coastal Beaches

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
207	St Johns River Power Park	1076	LF	100	11	Coastal Beaches
207	St Johns River Power Park	1077	LF	100	11	Coastal Beaches
2824	Stanton	690	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2824	Stanton	691	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2824	Stanton	692	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2824	Stanton	937	LF	100	3	Till Over Sedimentary Rock
2824	Stanton	940	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2824	Stanton	997	LF	100	3	Till Over Sedimentary Rock
564	Stanton Energy Center	942	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1131	Streeter Station	1028	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
3152	Sunbury Generation LP	101	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
50951	Sunnyside Cogen Associates	944	LF	100	2	Bedded Sedimentary Rock
1077	Sutherland	497	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1077	Sutherland	498	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1077	Sutherland	499	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1077	Sutherland	1117	LF	100	12	Solution Limestone
1077	Sutherland	1118	LF	100	12	Solution Limestone
10075	Taconite Harbor Energy Center	947	LF	100	1	Metamorphic and Igneous
10075	Taconite Harbor Energy Center	948	LF	100	1	Metamorphic and Igneous
10075	Taconite Harbor Energy Center	961	LF	100	1	Metamorphic and Igneous
988	Tanners Creek	415	SI	68	6	River Valleys and Floodplains With Overbank Deposits
988	Tanners Creek	415	SI	32	7	River Valleys and Floodplains Without Overbank Deposits
988	Tanners Creek	416	SI	75	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
988	Tanners Creek	416	SI	25	7	River Valleys and Floodplains Without Overbank Deposits
988	Tanners Creek	417	SI	100	6	River Valleys and Floodplains With Overbank Deposits
988	Tanners Creek	418	SI	100	6	River Valleys and Floodplains With Overbank Deposits
988	Tanners Creek	419	SI	100	6	River Valleys and Floodplains With Overbank Deposits
988	Tanners Creek	950	LF	100	6	River Valleys and Floodplains With Overbank Deposits
988	Tanners Creek	950	LF	0	7	River Valleys and Floodplains Without Overbank Deposits
1252	Tecumseh Energy Center	519	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1252	Tecumseh Energy Center	520	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
1252	Tecumseh Energy Center	995	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1252	Tecumseh Energy Center	1120	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
1252	Tecumseh Energy Center	1133	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2168	Thomas Hill	624	SI	100	2	Bedded Sedimentary Rock
2168	Thomas Hill	625	SI	94	2	Bedded Sedimentary Rock
2168	Thomas Hill	625	SI	6	4	Sand and Gravel
2168	Thomas Hill	626	SI	94	2	Bedded Sedimentary Rock
2168	Thomas Hill	626	SI	6	4	Sand and Gravel
2168	Thomas Hill	627	SI	100	2	Bedded Sedimentary Rock
2168	Thomas Hill	628	SI	94	2	Bedded Sedimentary Rock
2168	Thomas Hill	628	SI	6	4	Sand and Gravel
2168	Thomas Hill	629	SI	94	2	Bedded Sedimentary Rock
2168	Thomas Hill	629	SI	6	4	Sand and Gravel
2168	Thomas Hill	953	LF	100	2	Bedded Sedimentary Rock
3115	Titus	954	LF	100	2	Bedded Sedimentary Rock
3115	Titus	955	LF	100	2	Bedded Sedimentary Rock
3115	Titus	956	LF	100	2	Bedded Sedimentary Rock
3115	Titus	957	LF	100	2	Bedded Sedimentary Rock
6194	Tolk	1161	LF	100	4	Sand and Gravel
3845	TransAlta Centralia Generation	959	LF	100	2	Bedded Sedimentary Rock
1745	Trenton Channel Power Plant	585	SI	100	12	Solution Limestone
1745	Trenton Channel Power Plant	960	LF	100	12	Solution Limestone

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6071	Trimble Co.	44	SI	16	6	River Valleys and Floodplains With Overbank Deposits
6071	Trimble Co.	44	SI	84	7	River Valleys and Floodplains Without Overbank Deposits
56224	TS Power Plant	816	LF	1	5	Alluvial Basins Valleys and Fans
56224	TS Power Plant	816	LF	99	6	River Valleys and Floodplains With Overbank Deposits
7030	Twin Oaks Power One	928	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
1361	Tyrone	536	SI	100	6	River Valleys and Floodplains With Overbank Deposits
1361	Tyrone	537	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3295	Urquhart	110	SI	75	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3295	Urquhart	110	SI	25	7	River Valleys and Floodplains Without Overbank Deposits
3295	Urquhart	111	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3295	Urquhart	112	SI	75	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3295	Urquhart	112	SI	25	7	River Valleys and Floodplains Without Overbank Deposits
3295	Urquhart	1107	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
4042	Valley	918	LF	100	12	Solution Limestone
4042	Valley	919	LF	100	12	Solution Limestone
4042	Valley	920	LF	100	12	Solution Limestone
4042	Valley	949	LF	100	12	Solution Limestone
477	Valmont	329	SI	100	2	Bedded Sedimentary Rock
477	Valmont	330	SI	100	2	Bedded Sedimentary Rock
477	Valmont	331	SI	100	2	Bedded Sedimentary Rock
477	Valmont	1122	LF	100	2	Bedded Sedimentary Rock
477	Valmont	1123	LF	100	2	Bedded Sedimentary Rock
897	Vermilion	395	SI	100	3	Till Over Sedimentary Rock
897	Vermilion	396	SI	100	3	Till Over Sedimentary Rock
897	Vermilion	970	LF	100	3	Till Over Sedimentary Rock
6073	Victor J. Daniel Jr	45	SI	84	10	Unconsolidated and Semiconsolidated Shallow Aquifers

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6073	Victor J. Daniel Jr	45	SI	16	6	River Valleys and Floodplains With Overbank Deposits
6073	Victor J. Daniel Jr	924	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6073	Victor J. Daniel Jr	925	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6073	Victor J. Daniel Jr	938	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6073	Victor J. Daniel Jr	1124	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6019	W H Zimmer	26	SI	100	6	River Valleys and Floodplains With Overbank Deposits
6019	W H Zimmer	929	LF	100	4	Sand and Gravel
3470	W. A. Parish	136	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	136	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	136	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	137	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	137	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	137	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	138	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	138	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	138	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	139	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	139	SI	64	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
3470	W. A. Parish	139	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	140	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	140	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	140	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	141	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	141	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	141	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	142	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	142	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	142	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	143	SI	0	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3470	W. A. Parish	143	SI	64	6	River Valleys and Floodplains With Overbank Deposits
3470	W. A. Parish	143	SI	36	7	River Valleys and Floodplains Without Overbank Deposits
3470	W. A. Parish	1125	LF	100	6	River Valleys and Floodplains With Overbank Deposits
2866	W. H. Sammis	916	LF	100	2	Bedded Sedimentary Rock
2866	W. H. Sammis	1382	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2866	W. H. Sammis	1383	SI	100	6	River Valleys and Floodplains With Overbank Deposits
3264	W. S. Lee	105	SI	100	1	Metamorphic and Igneous
3264	W. S. Lee	106	SI	100	1	Metamorphic and Igneous
2716	W.H. Weatherspoon Plant	667	SI	100	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
1010	Wabash River	462	SI	100	9	Till and Till Over Outwash
1010	Wabash River	463	SI	100	9	Till and Till Over Outwash
1010	Wabash River	464	SI	100	9	Till and Till Over Outwash
1010	Wabash River	465	SI	100	9	Till and Till Over Outwash
2830	Walter C Beckjord	695	SI	100	6	River Valleys and Floodplains With Overbank Deposits
2830	Walter C Beckjord	696	SI	88	4	Sand and Gravel
2830	Walter C Beckjord	696	SI	12	6	River Valleys and Floodplains With Overbank Deposits
2830	Walter C Beckjord	697	SI	100	4	Sand and Gravel
2830	Walter C Beckjord	698	SI	100	4	Sand and Gravel
2830	Walter C Beckjord	1126	LF	100	4	Sand and Gravel
2830	Walter C Beckjord	1127	LF	100	4	Sand and Gravel
1082	Walter Scott Jr. Energy Center	502	SI	60	4	Sand and Gravel
1082	Walter Scott Jr. Energy Center	502	SI	40	7	River Valleys and Floodplains Without Overbank Deposits
1082	Walter Scott Jr. Energy Center	503	SI	60	4	Sand and Gravel
1082	Walter Scott Jr. Energy Center	503	SI	40	7	River Valleys and Floodplains Without Overbank Deposits
1082	Walter Scott Jr. Energy Center	932	LF	100	4	Sand and Gravel
6052	Wansley	35	SI	6	6	River Valleys and Floodplains With Overbank Deposits
6052	Wansley	35	SI	94	7	River Valleys and Floodplains Without Overbank Deposits
6705	Warrick Power Plant	224	SI	21	4	Sand and Gravel
6705	Warrick Power Plant	224	SI	49	6	River Valleys and Floodplains With Overbank Deposits
6705	Warrick Power Plant	224	SI	16	7	River Valleys and Floodplains Without Overbank Deposits
6705	Warrick Power Plant	224	SI	15	8	Outwash
3297	Wateree	113	SI	100	7	River Valleys and Floodplains Without Overbank Deposits
3297	Wateree	114	SI	7	6	River Valleys and Floodplains With Overbank Deposits
3297	Wateree	114	SI	93	7	River Valleys and Floodplains Without Overbank Deposits
3297	Wateree	933	LF	100	7	River Valleys and Floodplains Without Overbank Deposits
883	Waukegan	1311	SI	100	12	Solution Limestone
883	Waukegan	1312	SI	100	12	Solution Limestone
6139	Welsh	175	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
6139	Welsh	176	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6139	Welsh	177	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6139	Welsh	934	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
4078	Weston	935	LF	100	9	Till and Till Over Outwash
4078	Weston	936	LF	12	8	Outwash
4078	Weston	936	LF	88	9	Till and Till Over Outwash
4078	Weston	1313	SI	100	9	Till and Till Over Outwash
4078	Weston	1314	SI	100	8	Outwash
4078	Weston	1315	SI	100	8	Outwash
4078	Weston	1316	SI	93	8	Outwash
4078	Weston	1316	SI	7	9	Till and Till Over Outwash
4078	Weston	1317	SI	100	8	Outwash
4078	Weston	1318	SI	100	8	Outwash
60	Whelan Energy Center Unit 1 (WEC1)	1214	SI	100	12	Solution Limestone
6009	White Bluff	1128	LF	100	6	River Valleys and Floodplains With Overbank Deposits
1040	Whitewater Valley	1321	SI	100	12	Solution Limestone
1040	Whitewater Valley	1322	SI	100	12	Solution Limestone
1040	Whitewater Valley	1323	SI	100	12	Solution Limestone
1040	Whitewater Valley	1324	SI	100	12	Solution Limestone
1040	Whitewater Valley	1325	SI	100	12	Solution Limestone
4057	WI Power & Light Co -Rock River Generating	1	SI	100	9	Till and Till Over Outwash
4057	WI Power & Light Co -Rock River Generating	2	SI	100	9	Till and Till Over Outwash
4057	WI Power & Light Co -Rock River Generating	3	SI	100	9	Till and Till Over Outwash
4057	WI Power & Light Co -Rock River Generating	172	SI	100	9	Till and Till Over Outwash
50	Widows Creek	59	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	59	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	60	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	60	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	61	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	61	SI	85	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
50	Widows Creek	62	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	62	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	63	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	63	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	64	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	64	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	65	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	65	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	66	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	66	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	261	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	261	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	262	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	262	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	289	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	289	SI	85	7	River Valleys and Floodplains Without Overbank Deposits
50	Widows Creek	290	SI	15	6	River Valleys and Floodplains With Overbank Deposits
50	Widows Creek	290	SI	85	7	River Valleys and Floodplains Without Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
884	Will County	389	SI	100	12	Solution Limestone
3298	Williams	1129	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3298	Williams	1130	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3946	Willow Island	917	LF	70	6	River Valleys and Floodplains With Overbank Deposits
3946	Willow Island	917	LF	30	7	River Valleys and Floodplains Without Overbank Deposits
6249	Winyah	198	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	199	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	200	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	201	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	202	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	203	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
6249	Winyah	982	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
898	Wood River	397	SI	100	6	River Valleys and Floodplains With Overbank Deposits
898	Wood River	398	SI	100	6	River Valleys and Floodplains With Overbank Deposits
50611	WPS Westwood Generation, LLC	951	LF	100	2	Bedded Sedimentary Rock
6101	Wyodak Plant	80	SI	100	2	Bedded Sedimentary Rock
6101	Wyodak Plant	981	LF	100	2	Bedded Sedimentary Rock
728	Yates	367	SI	46	1	Metamorphic and Igneous
728	Yates	367	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	367	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	368	SI	46	1	Metamorphic and Igneous

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
728	Yates	368	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	368	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	369	SI	46	1	Metamorphic and Igneous
728	Yates	369	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	369	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	370	SI	46	1	Metamorphic and Igneous
728	Yates	370	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	370	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	371	SI	46	1	Metamorphic and Igneous
728	Yates	371	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	371	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	372	SI	46	1	Metamorphic and Igneous
728	Yates	372	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	372	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	373	SI	46	1	Metamorphic and Igneous
728	Yates	373	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	373	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	374	SI	46	1	Metamorphic and Igneous
728	Yates	374	SI	10	6	River Valleys and Floodplains With Overbank Deposits
728	Yates	374	SI	44	7	River Valleys and Floodplains Without Overbank Deposits
728	Yates	986	LF	100	1	Metamorphic and Igneous
728	Yates	987	LF	54	6	River Valleys and Floodplains With Overbank Deposits

Attachment B-2. Hydrogeologic Data

ORIS Code	ORIS Plant Name	WMU ID	Unit Type	Percentage	HE Code	Hydrogeologic Environment (HE) Description
728	Yates	987	LF	46	7	River Valleys and Floodplains Without Overbank Deposits
3809	Yorktown	988	LF	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers
3809	Yorktown	1359	SI	100	10	Unconsolidated and Semiconsolidated Shallow Aquifers

Attachment B-3.

Climate Data

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
6137	A. B. Brown Generating Station	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
2535	AES Cayuga, LLC	Ithaca, NY	40.2	0.168	0.214	0.139	Williamsport-Lycoming	3.4
2527	AES Greenidge	Ithaca, NY	40.2	0.168	0.214	0.139	Williamsport-Lycoming	3.4
994	AES Petersburg	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
6082	AES Somerset LLC	Ithaca, NY	40.2	0.168	0.214	0.139	Cleveland	4.7
3942	Albright Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
1915	Allen S King	Des Moines, IA	33.1	0.114	0.164	0.116	Minneapolis	4.7
3393	Allen Steam Plant	Nashville, TN	54.8	0.467	0.540	0.377	Meridian	2.8
4140	Alma	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
1122	Ames Electric Services Power Plant	Des Moines, IA	33.1	0.114	0.164	0.116	Waterloo	4.7
6469	Antelope Valley Station	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
160	Apache Station	Tucson, AZ	10.1	0.000	0.000	0.001	Phoenix	2.8
465	Arapahoe	Cheyenne, WY	11.2	0.001	0.001	0.009	Denver	3.9
3178	Armstrong Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Williamsport-Lycoming	3.4
2076	Asbury	Tulsa, OK	30.4	0.069	0.101	0.047	Tulsa	4.6
2706	Asheville Steam Electric Plant	Watkinsville, GA	42.7	0.289	0.356	0.233	Asheville	3.3
2835	Ashtabula	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7
1961	Austin Northeast	Des Moines, IA	33.1	0.114	0.164	0.116	Minneapolis	4.7
2836	Avon Lake	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7
995	Bailly	Chicago, IL	34.1	0.080	0.114	0.062	Muskegon	4.8
889	Baldwin Energy Complex	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
3	Barry	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
3982	Bay Front	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
2878	Bay Shore	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
8042	Belews Creek Steam Station	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
6034	Belle River	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
3325	Ben French	Rapid City, SD	15.4	0.001	0.007	0.003	Casper	5.7
645	Big Bend	Tampa, FL	38.2	0.066	0.103	0.048	Tampa	3.7
3497	Big Brown	Shreveport, LA	44.2	0.230	0.294	0.184	Dallas	4.8
6055	Big Cajun 2	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
1353	Big Sandy	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
6098	Big Stone	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
1904	Black Dog	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
6106	Boardman	Pullman, WA	12.1	0.007	0.013	0.008	Spokane	4
7790	Bonanza Power Plant	Grand Junction, CO	7.2	0.000	0.000	0.000	Salt Lake City	4
1893	Boswell Energy Center	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
703	Bowen	Atlanta, GA	49.5	0.342	0.399	0.282	Atlanta	4.1
602	Brandon Shores	Philadelphia, PA	43.7	0.201	0.261	0.164	Philadelphia	4.3
1619	Brayton Point	Providence, RI	46.7	0.213	0.286	0.175	Hartford	3.8
3796	Bremo Bluff	Lynchburg, VA	44.7	0.308	0.361	0.257	Raleigh-Durham	3.4
6094	Bruce Mansfield	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
2720	Buck	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
3396	Bull Run	Knoxville, TN	48.1	0.411	0.446	0.354	Bristol	2.4
1104	Burlington	Columbia, MO	37.1	0.153	0.199	0.122	Waterloo	4.7
676	C D McIntosh Jr	Tampa, FL	38.2	0.066	0.103	0.048	Tampa	3.7
468	Cameo	Grand Junction, CO	7.2	0.000	0.000	0.000	Denver	3.9
3280	Canadys Steam	Watkinsville, GA	42.7	0.289	0.356	0.233	Charleston, SC	3.9
1363	Cane Run	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
2708	Cape Fear Steam Electric Plant	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
3644	Carbon Plant	Grand Junction, CO	7.2	0.000	0.000	0.000	Salt Lake City	4
2828	Cardinal	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
1001	Cayuga	Cincinnati, OH	40.6	0.155	0.221	0.154	Waterloo	4.7
1571	Chalk Point LLC	Norfolk, VA	44.4	0.312	0.000	0.269	Philadelphia	4.3

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
2169	Chamois Power Plant	Columbia, MO	37.1	0.153	0.199	0.122	St Louis	4.3
56	Charles R. Lowman	New Orleans, LA	70.1	0.589	0.745	0.450	Meridian	2.8
469	Cherokee	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
3803	Chesapeake Energy Center	Norfolk, VA	44.4	0.312	0.000	0.269	Norfolk	4.7
3797	Chesterfield	Norfolk, VA	44.4	0.312	0.000	0.269	Norfolk	4.7
8226	Cheswick Power Plant	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
113	Cholla	Albuquerque, NM	8.4	0.000	0.000	0.000	Las Vegas	4.1
2721	Cliffside	Knoxville, TN	48.1	0.411	0.446	0.354	Raleigh-Durham	3.4
983	Clifty Creek	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
3775	Clinch River	Greensboro, NC	45.4	0.326	0.390	0.271	Bristol	2.4
7213	Clover	Lynchburg, VA	44.7	0.308	0.361	0.257	Raleigh-Durham	3.4
6030	Coal Creek	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
861	Coffeen	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
47	Colbert	Nashville, TN	54.8	0.467	0.540	0.377	Meridian	2.8
6178	Coleto Creek	San Antonio, TX	33.3	0.110	0.165	0.082	Houston	3.4
6076	Colstrip	Rapid City, SD	15.4	0.001	0.007	0.003	Bismarck	4.6
10784	Colstrip Energy LP	Rapid City, SD	15.4	0.001	0.007	0.003	Bismarck	4.6
2123	Columbia	Columbia, MO	37.1	0.153	0.199	0.122	St Louis	4.3
8023	Columbia	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
470	Comanche	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
3118	Conemaugh	Pittsburgh, PA	38.1	0.089	0.131	0.079	Williamsport-Lycoming	3.4
2840	Conesville	Cleveland, OH	36.7	0.078	0.121	0.082	Dayton	4.5
1710	Consumers Energy - J.H. Campbell	East Lansing, MI	30.0	0.109	0.145	0.110	Muskegon	4.8
1384	Cooper Station.	Knoxville, TN	48.1	0.411	0.446	0.354	Huntington	2.9
7210	Cope	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
6177	Coronado Generating Station	Albuquerque, NM	8.4	0.000	0.000	0.000	Albuquerque	4
8222	Coyote	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
2549	CR Huntley Generating Station	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
6021	Craig	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
867	Crawford	Chicago, IL	34.1	0.080	0.114	0.062	Chicago	4.6
753	Crisp Plant	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
641	Crist	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
130	Cross	Watkinsville, GA	42.7	0.289	0.356	0.233	Charleston, SC	3.9
628	Crystal River Power Plant	Jacksonville, FL	46.4	0.151	0.211	0.110	Tampa	3.7
3399	Cumberland	Nashville, TN	54.8	0.467	0.540	0.377	Nashville	3.6
6823	D B Wilson	Lexington, KY	50.8	0.329	0.397	0.270	Nashville	3.6
1702	D.E. Karn	East Lansing, MI	30.0	0.109	0.145	0.110	Detroit	4.6
1385	Dale Station	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
963	Dallman	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
2723	Dan River	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
2480	Danskammer Generating Station	New York, NY	44.8	0.244	0.294	0.197	Hartford	3.8
4158	Dave Johnston Plant	Lander, WY	12.3	0.003	0.005	0.009	Casper	5.7
996	Dean H Mitchell	Chicago, IL	34.1	0.080	0.114	0.062	Chicago	4.6
663	Deerhaven Generating Station	Jacksonville, FL	46.4	0.151	0.211	0.110	Charleston, SC	3.9
1572	Dickerson	Philadelphia, PA	43.7	0.201	0.261	0.164	Harrisburg	3.4
51	Dolet Hills	Shreveport, LA	44.2	0.230	0.294	0.184	Shreveport	3.7
3317	Dolphus M Grainger	Charleston, SC	48.3	0.261	0.329	0.212	Charleston, SC	3.9
1046	Dubuque	Madison, WI	32.1	0.091	0.140	0.069	Waterloo	4.7
6016	Duck Creek	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
2554	Dunkirk Generating Plant	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7
26	E. C. Gaston	Atlanta, GA	49.5	0.342	0.399	0.282	Meridian	2.8
1355	E.W. Brown	Lexington, KY	50.8	0.329	0.397	0.270	Nashville	3.6
991	Eagle Valley	Cincinnati, OH	40.6	0.155	0.221	0.154	Dayton	4.5
1217	Earl F Wisdom	Grand Island, NE	22.2	0.044	0.063	0.032	Waterloo	4.7
6018	East Bend Station	Cincinnati, OH	40.6	0.155	0.221	0.154	Huntington	2.9
2837	Eastlake	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7
856	ED Edwards	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
4050	Edgewater	Madison, WI	32.1	0.091	0.140	0.069	Chicago	4.6

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
1004	Edwardsport	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
1374	Elmer Smith Station	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
3098	Elrama Power Plant	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
1832	Erickson Station	East Lansing, MI	30.0	0.109	0.145	0.110	Detroit	4.6
87	Escalante	Albuquerque, NM	8.4	0.000	0.000	0.000	Albuquerque	4
1012	F. B. Culley	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
1218	Fair Station	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
6179	Fayette Power Project	Dallas, TX	31.1	0.060	0.107	0.053	Austin	4
886	Fisk	Chicago, IL	34.1	0.080	0.114	0.062	Chicago	4.6
6138	Flint Creek	Little Rock, AR	51.2	0.353	0.434	0.282	Tulsa	4.6
3943	Fort Martin Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
10343	Foster Wheeler Mt Carmel Cogen	Philadelphia, PA	43.7	0.201	0.261	0.164	Harrisburg	3.4
2442	Four Corners	Albuquerque, NM	8.4	0.000	0.000	0.000	Albuquerque	4
1043	Frank E. Ratts	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
2718	G G Allen	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
7	Gadsden	Atlanta, GA	49.5	0.342	0.399	0.282	Meridian	2.8
3403	Gallatin	Nashville, TN	54.8	0.467	0.540	0.377	Nashville	3.6
8102	General James M. Gavin	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
4143	Genoa	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
1091	George Neal North	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
7343	George Neal South	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
6077	Gerald Gentleman	Cheyenne, WY	11.2	0.001	0.001	0.009	Grand Island	5.3
1356	Ghent	Cincinnati, OH	40.6	0.155	0.221	0.154	Huntington	2.9
6136	Gibbons Creek Steam Electric Station	Shreveport, LA	44.2	0.230	0.294	0.184	Austin	4
6113	Gibson	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
3776	Glen Lyn	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
8	Gorgas	Nashville, TN	54.8	0.467	0.540	0.377	Meridian	2.8
1825	Grand Haven City of J.B. Sims	East Lansing, MI	30.0	0.109	0.145	0.110	Muskegon	4.8

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
10151	Grant Town Power Plant	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
165	GRDA	Little Rock, AR	51.2	0.353	0.434	0.282	Tulsa	4.6
1357	Green River	Lexington, KY	50.8	0.329	0.397	0.270	Nashville	3.6
10	Greene County	Atlanta, GA	49.5	0.342	0.399	0.282	Meridian	2.8
6041	H L Spurlock Station	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
2709	H.F. Lee Plant	Greensboro, NC	45.4	0.326	0.390	0.271	Norfolk	4.7
708	Hammond	Atlanta, GA	49.5	0.342	0.399	0.282	Bristol	2.4
1731	Harbor Beach Power Plant	East Lansing, MI	30.0	0.109	0.145	0.110	Detroit	4.6
990	Harding Street	Indianapolis, IN	40.3	0.130	0.186	0.106	Dayton	4.5
709	Harllee Branch	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
6193	Harrington	Midland, TX	16.3	0.018	0.025	0.014	Amarillo	6.1
3944	Harrison Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
3179	Hatfield's Ferry Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
891	Havana	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
2079	Hawthorn	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
525	Hayden	Cheyenne, WY	11.2	0.001	0.001	0.009	Denver	3.9
3251	HB Robinson / Darlington Electric Power Plant	Greensboro, NC	45.4	0.326	0.390	0.271	Macon	3.3
892	Hennepin Power Station	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
1382	HMP&L Station Two Henderson	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
108	HOLCOMB	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
3122	Homer City Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Williamsport-Lycoming	3.4
1943	Hoot Lake	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
10771	Hopewell	Norfolk, VA	44.4	0.312	0.000	0.269	Norfolk	4.7
6772	Hugo	Shreveport, LA	44.2	0.230	0.294	0.184	Dallas	4.8
3176	Hunlock Power Station	Ithaca, NY	40.2	0.168	0.214	0.139	Williamsport-Lycoming	3.4
6165	Hunter Plant	Grand Junction, CO	7.2	0.000	0.000	0.000	Salt Lake City	4

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
8069	Huntington Plant	Grand Junction, CO	7.2	0.000	0.000	0.000	Salt Lake City	4
863	Hutsonville	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
6065	Iatan	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
6641	Independence	Little Rock, AR	51.2	0.353	0.434	0.282	Little Rock	3.5
2132	Independence Power & Light - Blue Valley Station	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
594	Indian River Generating Station	Philadelphia, PA	43.7	0.201	0.261	0.164	Philadelphia	4.3
6481	Intermountain Power Project	Cedar City, UT	9.8	0.000	0.001	0.000	Salt Lake City	4
7097	J K Spruce	San Antonio, TX	33.3	0.110	0.165	0.082	Austin	4
2850	J M Stuart	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
6181	J T Deely	San Antonio, TX	33.3	0.110	0.165	0.082	Austin	4
1720	J.C. Weadock	East Lansing, MI	30.0	0.109	0.145	0.110	Detroit	4.6
1723	J.R Whiting	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
710	Jack McDonough	Atlanta, GA	49.5	0.342	0.399	0.282	Atlanta	4.1
2049	Jack Watson	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
1830	James De Young	Chicago, IL	34.1	0.080	0.114	0.062	Muskegon	4.8
6002	James H. Miller Jr.	Nashville, TN	54.8	0.467	0.540	0.377	Meridian	2.8
2161	James River Power Station	Little Rock, AR	51.2	0.353	0.434	0.282	Tulsa	4.6
2187	JE Corette Plant	Great Falls, MT	17.9	0.004	0.007	0.007	Billings	5
3319	Jefferies	Charleston, SC	48.3	0.261	0.329	0.212	Charleston, SC	3.9
6068	Jeffrey Energy Center	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
8066	Jim Bridger Plant Units 1-4	Lander, WY	12.3	0.003	0.005	0.009	Salt Lake City	4
3935	John E. Amos	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
4271	John P. Madgett	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
3405	John Sevier	Lexington, KY	50.8	0.329	0.397	0.270	Bristol	2.4
3406	Johnsonville	Nashville, TN	54.8	0.467	0.540	0.377	Nashville	3.6
384	Joliet 29	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
874	Joliet 9	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
887	Joppa Steam	East St. Louis, IL	36.2	0.144	0.168	0.070	Nashville	3.6

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3947	Kammer	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
3936	Kanawha River	Lynchburg, VA	44.7	0.308	0.361	0.257	Huntington	2.9
1381	Kenneth C Coleman	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
3136	Keystone	Pittsburgh, PA	38.1	0.089	0.131	0.079	Williamsport-Lycoming	3.4
6031	Killen Station	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
876	Kincaid Generation LLC	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
3407	Kingston	Knoxville, TN	48.1	0.411	0.446	0.354	Bristol	2.4
733	Kraft	Watkinsville, GA	42.7	0.289	0.356	0.233	Charleston, SC	3.9
2876	Kyger Creek	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
2713	L.V. Sutton Electric Plant	Charleston, SC	48.3	0.261	0.329	0.212	Norfolk	4.7
1241	La Cygne	Topeka, KS	32.2	0.105	0.148	0.076	Tulsa	4.6
2103	Labadie	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
2098	Lake Road	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
2838	Lake Shore	Cleveland, OH	36.7	0.078	0.121	0.082	Cleveland	4.7
964	Lakeside	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
1047	Lansing	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
643	Lansing Smith	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
6204	Laramie River Station	Denver, CO	13.0	0.001	0.001	0.004	Casper	5.7
1891	Laskin Energy Center	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
1250	Lawrence Energy Center	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
2817	Leland Olds	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
6089	Lewis & Clark	Great Falls, MT	17.9	0.004	0.007	0.007	Bismarck	4.6
298	Limestone	Dallas, TX	31.1	0.060	0.107	0.053	Dallas	4.8
2240	Lon Wright	North Omaha, NE	27.5	0.067	0.080	0.054	Grand Island	5.3
6664	Louisa	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
976	Marion Generating Station	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
2727	Marshall	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
492	Martin Drake	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
6146	Martin Lake	Shreveport, LA	44.2	0.230	0.294	0.184	Shreveport	3.7

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6250	Mayo Electric Generating Facility	Lynchburg, VA	44.7	0.308	0.361	0.257	Raleigh-Durham	3.4
6124	McIntosh	Watkinsville, GA	42.7	0.289	0.356	0.233	Charleston, SC	3.9
3287	McMeekin	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
2104	Meramec	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
864	Meredosia	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7
6213	Merom	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
2364	Merrimack Station	Nashua, NH	49.4	0.227	0.281	0.194	Portland, ME	3.9
2832	Miami Fort	Cincinnati, OH	40.6	0.155	0.221	0.154	Huntington	2.9
997	Michigan City	Chicago, IL	34.1	0.080	0.114	0.062	Muskegon	4.8
1364	Mill Creek	Lexington, KY	50.8	0.329	0.397	0.270	St Louis	4.3
2823	Milton R. Young Station	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
2171	Missouri City	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
727	Mitchell	Tallahassee, FL	68.4	0.591	0.731	0.456	Macon	3.3
3948	Mitchell	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
3181	Mitchell Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
1048	ML Kapp	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
1733	Monroe Power Plant	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
6147	Monticello	Shreveport, LA	44.2	0.230	0.294	0.184	Shreveport	3.7
2080	Montrose	Columbia, MO	37.1	0.153	0.199	0.122	Tulsa	4.6
1573	Morgantown Generating Plant	Norfolk, VA	44.4	0.312	0.000	0.269	Philadelphia	4.3
1606	Mount Tom	Worcester, MA	46.5	0.202	0.259	0.170	Hartford	3.8
6264	Mountaineer	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
3954	Mt. Storm	Lynchburg, VA	44.7	0.308	0.361	0.257	Huntington	2.9
1167	Muscatine #1	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
2872	Muskingum River	Columbus, OH	36.1	0.077	0.116	0.066	Huntington	2.9
2952	Muskogee	Little Rock, AR	51.2	0.353	0.434	0.282	Tulsa	4.6
4162	Naughton Plant	Lander, WY	12.3	0.003	0.005	0.009	Salt Lake City	4
4941	Navajo Generating Station	Cedar City, UT	9.8	0.000	0.001	0.000	Las Vegas	4.1
6064	Nearman Creek	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
6096	Nebraska City	North Omaha, NE	27.5	0.067	0.080	0.054	Grand Island	5.3

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4054	Nelson Dewey	Madison, WI	32.1	0.091	0.140	0.069	Waterloo	4.7
3138	New Castle Plant	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
2167	New Madrid	Little Rock, AR	51.2	0.353	0.434	0.282	Nashville	3.6
6017	Newton	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
2291	North Omaha	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
8224	North Valmy	Ely, NV	8.8	0.000	0.000	0.000	Winnemucca	3.6
2963	Northeastern	Tulsa, OK	30.4	0.069	0.101	0.047	Tulsa	4.6
667	Northside Generating Station	Jacksonville, FL	46.4	0.151	0.211	0.110	Charleston, SC	3.9
10030	NRG Energy Center Dover	Philadelphia, PA	43.7	0.201	0.261	0.164	Philadelphia	4.3
527	Nucla	Grand Junction, CO	7.2	0.000	0.000	0.000	Denver	3.9
2848	O H Hutchings	Columbus, OH	36.1	0.077	0.116	0.066	Dayton	4.5
6180	Oak Grove	Dallas, TX	31.1	0.060	0.107	0.053	Dallas	4.8
127	Oklaunion	Oklahoma City, OK	30.4	0.061	0.094	0.039	Amarillo	6.1
4151	Osage	Lander, WY	12.3	0.003	0.005	0.009	Casper	5.7
1831	Otto E. Eckert Station	East Lansing, MI	30.0	0.109	0.145	0.110	Detroit	4.6
6254	Ottumwa	Columbia, MO	37.1	0.153	0.199	0.122	Waterloo	4.7
1378	Paradise	Lexington, KY	50.8	0.329	0.397	0.270	Nashville	3.6
6248	Pawnee	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
6238	Pearl Station	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
3938	Philip Sporn	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
2843	Picway	Columbus, OH	36.1	0.077	0.116	0.066	Dayton	4.5
7902	Pirkey	Shreveport, LA	44.2	0.230	0.294	0.184	Shreveport	3.7
59	Platte	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
6170	Pleasant Prairie	Madison, WI	32.1	0.091	0.140	0.069	Chicago	4.6
6004	Pleasants Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
7242	Polk	Tampa, FL	38.2	0.066	0.103	0.048	Tampa	3.7
3113	Portland	New York, NY	44.8	0.244	0.294	0.197	Harrisburg	3.4
879	Powerton	East St. Louis, IL	36.2	0.144	0.168	0.070	Waterloo	4.7

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
3140	PPL Brunner Island	Philadelphia, PA	43.7	0.201	0.261	0.164	Harrisburg	3.4
3149	PPL Montour	Philadelphia, PA	43.7	0.201	0.261	0.164	Williamsport-Lycoming	3.4
1073	Prairie Creek	Des Moines, IA	33.1	0.114	0.164	0.116	Waterloo	4.7
1769	Presque Isle	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
2403	PSEG Hudson Generating Station	New York, NY	44.8	0.244	0.294	0.197	Philadelphia	4.3
2408	PSEG Mercer Generating Station	Philadelphia, PA	43.7	0.201	0.261	0.164	Philadelphia	4.3
4072	Pulliam	Sault Ste. Marie, MI	35.2	0.165	0.210	0.144	Chicago	4.6
1295	Quindaro	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
6639	R D Green	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
2864	R. E. Burger	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
1008	R. Gallagher	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
1570	R. Paul Smith Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Harrisburg	3.4
2790	R.M. Heskett Station	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
6085	R.M. Schahfer	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
6761	Rawhide	Denver, CO	13.0	0.001	0.001	0.004	Denver	3.9
8219	Ray D Nixon	Cheyenne, WY	11.2	0.001	0.001	0.009	Denver	3.9
55076	Red Hills Generating Facility	Nashville, TN	54.8	0.467	0.540	0.377	Meridian	2.8
2324	Reid Gardner	Las Vegas, NV	5.3	0.000	0.000	0.002	Las Vegas	4.1
1740	River Rouge Power Plant	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
2732	Riverbend	Greensboro, NC	45.4	0.326	0.390	0.271	Raleigh-Durham	3.4
1081	Riverside	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
1927	Riverside	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
1239	Riverton	Tulsa, OK	30.4	0.069	0.101	0.047	Tulsa	4.6
3945	Rivesville Power Station	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
6166	Rockport	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
6190	Rodemacher	Lake Charles, LA	52.2	0.365	0.464	0.282	Shreveport	3.7
2712	Roxboro Steam Electric Plant	Lynchburg, VA	44.7	0.308	0.361	0.257	Raleigh-Durham	3.4
1393	RS Nelson	Lake Charles, LA	52.2	0.365	0.464	0.282	Lake Charles	3.8

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
6155	Rush Island	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
2451	San Juan	Albuquerque, NM	8.4	0.000	0.000	0.000	Albuquerque	4
6183	San Miguel	San Antonio, TX	33.3	0.110	0.165	0.082	Austin	4
6648	Sandow No 4	Dallas, TX	31.1	0.060	0.107	0.053	Austin	4
6257	Scherer	Watkinsville, GA	42.7	0.289	0.356	0.233	Atlanta	4.1
2367	SCHILLER	Nashua, NH	49.4	0.227	0.281	0.194	Portland, ME	3.9
642	Scholz	Tallahassee, FL	68.4	0.591	0.731	0.456	Tampa	3.7
136	Seminole Generating Station	Jacksonville, FL	46.4	0.151	0.211	0.110	Charleston, SC	3.9
1379	Shawnee	East St. Louis, IL	36.2	0.144	0.168	0.070	Nashville	3.6
3131	Shawville	Syracuse, NY	48.0	0.255	0.325	0.212	Williamsport-Lycoming	3.4
2277	Sheldon Station	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
6090	Sherburne County	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
2094	Sibley	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
6768	Sikeston Power Station	Little Rock, AR	51.2	0.353	0.434	0.282	Nashville	3.6
2107	Sioux	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
1058	Sixth Street	Chicago, IL	34.1	0.080	0.114	0.062	Waterloo	4.7
1613	Somerset Station	Providence, RI	46.7	0.213	0.286	0.175	Hartford	3.8
6095	Sooner	Oklahoma City, OK	30.4	0.061	0.094	0.039	Tulsa	4.6
6061	South Mississippi El Pwr Assn	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
4041	South Oak Creek	Madison, WI	32.1	0.091	0.140	0.069	Chicago	4.6
6195	Southwest Power Station	Little Rock, AR	51.2	0.353	0.434	0.282	Tulsa	4.6
8223	Springerville	Albuquerque, NM	8.4	0.000	0.000	0.000	Albuquerque	4
1743	St Clair Power Plant	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
207	St Johns River Power Park	Jacksonville, FL	46.4	0.151	0.211	0.110	Charleston, SC	3.9
2824	Stanton	Bismarck, ND	15.8	0.024	0.030	0.020	Bismarck	4.6
564	Stanton Energy Center	Orlando, FL	44.6	0.102	0.170	0.081	Charleston, SC	3.9
1131	Streeter Station	Des Moines, IA	33.1	0.114	0.164	0.116	Waterloo	4.7

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
3152	Sunbury Generation LP	Philadelphia, PA	43.7	0.201	0.261	0.164	Williamsport-Lycoming	3.4
50951	Sunnyside Cogen Associates	Grand Junction, CO	7.2	0.000	0.000	0.000	Salt Lake City	4
1077	Sutherland	Des Moines, IA	33.1	0.114	0.164	0.116	Waterloo	4.7
10075	Taconite Harbor Energy Center	St. Cloud, MN	25.8	0.060	0.083	0.055	Minneapolis	4.7
988	Tanners Creek	Cincinnati, OH	40.6	0.155	0.221	0.154	Huntington	2.9
1252	Tecumseh Energy Center	Topeka, KS	32.2	0.105	0.148	0.076	Grand Island	5.3
2168	Thomas Hill	Columbia, MO	37.1	0.153	0.199	0.122	St Louis	4.3
3115	Titus	Philadelphia, PA	43.7	0.201	0.261	0.164	Harrisburg	3.4
6194	Tolk	Midland, TX	16.3	0.018	0.025	0.014	Amarillo	6.1
3845	TransAlta Centralia Generation	PortlandO, OR	34.7	0.417	0.439	0.393	Seattle	4
1745	Trenton Channel Power Plant	Put-in-Bay, OH	36.1	0.051	0.100	0.050	Detroit	4.6
6071	Trimble Co.	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
56224	TS Power Plant	Ely, NV	8.8	0.000	0.000	0.000	Winnemucca	3.6
7030	Twin Oaks Power One	Dallas, TX	31.1	0.060	0.107	0.053	Dallas	4.8
1361	Tyrone	Lexington, KY	50.8	0.329	0.397	0.270	Nashville	3.6
3295	Urquhart	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
4042	Valley	Madison, WI	32.1	0.091	0.140	0.069	Chicago	4.6
477	Valmont	Cheyenne, WY	11.2	0.001	0.001	0.009	Denver	3.9
897	Vermilion	Indianapolis, IN	40.3	0.130	0.186	0.106	Waterloo	4.7
6073	Victor J. Daniel Jr	New Orleans, LA	70.1	0.589	0.745	0.450	New Orleans	3.7
6019	W H Zimmer	Lexington, KY	50.8	0.329	0.397	0.270	Huntington	2.9
3470	W. A. Parish	Shreveport, LA	44.2	0.230	0.294	0.184	Houston	3.4
2866	W. H. Sammis	Pittsburgh, PA	38.1	0.089	0.131	0.079	Dayton	4.5
3264	W. S. Lee	Atlanta, GA	49.5	0.342	0.399	0.282	Atlanta	4.1
2716	W.H. Weatherspoon Plant	Greensboro, NC	45.4	0.326	0.390	0.271	Norfolk	4.7
1010	Wabash River	Cincinnati, OH	40.6	0.155	0.221	0.154	Waterloo	4.7
2830	Walter C Beckjord	Cincinnati, OH	40.6	0.155	0.221	0.154	Huntington	2.9
1082	Walter Scott Jr. Energy Center	North Omaha, NE	27.5	0.067	0.080	0.054	Grand Island	5.3

Attachment B-3. Climate Data

Oris Code	ORIS Plant Name	EPACMTP Climate Center	Precip 5-yr Avg (in/yr)	Recharge Rate Silty Loam	Recharge Rate Sandy Loam	Recharge Rate SiltyClay Loam	IWAIR Met Station	Mean Annual Windspeed (m/s)
6052	Wansley	Atlanta, GA	49.5	0.342	0.399	0.282	Atlanta	4.1
6705	Warrick Power Plant	Cincinnati, OH	40.6	0.155	0.221	0.154	St Louis	4.3
3297	Wateree	Watkinsville, GA	42.7	0.289	0.356	0.233	Macon	3.3
883	Waukegan	Madison, WI	32.1	0.091	0.140	0.069	Chicago	4.6
6139	Welsh	Shreveport, LA	44.2	0.230	0.294	0.184	Shreveport	3.7
4078	Weston	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
60	Whelan Energy Center Unit 1 (WEC1)	Grand Island, NE	22.2	0.044	0.063	0.032	Grand Island	5.3
6009	White Bluff	Little Rock, AR	51.2	0.353	0.434	0.282	Little Rock	3.5
1040	Whitewater Valley	Indianapolis, IN	40.3	0.130	0.186	0.106	Dayton	4.5
4057	WI Power & Light Co -Rock River Generating	Madison, WI	32.1	0.091	0.140	0.069	Minneapolis	4.7
50	Widows Creek	Nashville, TN	54.8	0.467	0.540	0.377	Bristol	2.4
884	Will County	Chicago, IL	34.1	0.080	0.114	0.062	Chicago	4.6
3298	Williams	Charleston, SC	48.3	0.261	0.329	0.212	Charleston, SC	3.9
3946	Willow Island	Pittsburgh, PA	38.1	0.089	0.131	0.079	Huntington	2.9
6249	Winyah	Charleston, SC	48.3	0.261	0.329	0.212	Charleston, SC	3.9
898	Wood River	East St. Louis, IL	36.2	0.144	0.168	0.070	St Louis	4.3
50611	WPS Westwood Generation, LLC	Philadelphia, PA	43.7	0.201	0.261	0.164	Harrisburg	3.4
6101	Wyodak Plant	Rapid City, SD	15.4	0.001	0.007	0.003	Casper	5.7
728	Yates	Atlanta, GA	49.5	0.342	0.399	0.282	Atlanta	4.1
3809	Yorktown	Norfolk, VA	44.4	0.312	0.000	0.269	Norfolk	4.7

Attachment B-4.
Water Body Data

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6137	A. B. Brown Generating Station	88	SI	21250406		36	100	StreamRiver	2	10.2	4.561	0.25	0.81
6137	A. B. Brown Generating Station	89	SI	10157689	Ohio River	88	100	ArtificialPath	66.5	5.3	3.145	146,613	3.9
6137	A. B. Brown Generating Station	1163	LF	10157317		1225	63	StreamRiver	66	3.9	2.475	1.8	0.82
6137	A. B. Brown Generating Station	1163	LF	10157551	Bayou Creek	1514	13	StreamRiver	66.9	43.9	10.931	24	0.81
6137	A. B. Brown Generating Station	1163	LF	10157737		191	25	LakePond	66	0.9	1.281	0.34	0.60
2535	AES Cayuga, LLC	1102	LF	21978623		71	29	StreamRiver	224	7.0	6.422	3.7	0.99
2535	AES Cayuga, LLC	1102	LF	21980363	Cayuga Lake	1447	71	LakePond	215.6	3.4	2.614	5.5	0.61
2527	AES Greenidge	1101	LF	21980257	Seneca Lake	33	100	LakePond	144.1	2.3	1.352	277	0.79
2527	AES Greenidge	1285	SI	21980257	Seneca Lake	339	100	LakePond	144.1	2.3	1.352	277	0.79
2527	AES Greenidge	1286	SI	21978203	Keuka Lake Outlet	452	100	StreamRiver	141.8	1.0	1.418	275	1.9
994	AES Petersburg	430	SI	18470878	Lick Creek	124	100	StreamRiver	96	6.9	2.401	4.6	0.78
994	AES Petersburg	431	SI	18470878	Lick Creek	438	100	StreamRiver	96	6.9	2.401	4.6	0.78
994	AES Petersburg	432	SI	18470878	Lick Creek	665	100	StreamRiver	96	6.9	2.401	4.6	0.78
994	AES Petersburg	433	SI	18470878	Lick Creek	1087	100	StreamRiver	96	6.9	2.401	4.6	0.78
994	AES Petersburg	989	LF	18446060	East Fork White River	1303	13	ArtificialPath	96	2.8	1.901	6,796	2.1
994	AES Petersburg	989	LF	18470878	Lick Creek	391	88	StreamRiver	96	6.9	2.401	4.6	0.78
6082	AES Somerset LLC	1105	LF	15559445	Fish Creek	115	50	StreamRiver	118	2.6	2.187	8.4	0.85
6082	AES Somerset LLC	1105	LF	15559465		35	25	StreamRiver	118	2.6	2.187	0.40	0.58
6082	AES Somerset LLC	1105	LF	15559543		234	25	StreamRiver	118	2.6	2.187	1.4	0.68
6082	AES Somerset LLC	1106	LF	15559445	Fish Creek	48	29	StreamRiver	118	2.6	2.187	8.4	0.85
6082	AES Somerset LLC	1106	LF	15559505		379	14	StreamRiver	118	2.2	1.363	1.3	0.71
6082	AES Somerset LLC	1106	LF	15561361	Ontario, Lake	221	57	Coastline	118	2.6	2.187		
6082	AES Somerset LLC	1287	SI	15559451		295	63	StreamRiver	118	2.2	1.363	0.44	0.65
6082	AES Somerset LLC	1287	SI	15559505		158	38	StreamRiver	118	2.2	1.363	1.3	0.71
3942	Albright Power Station	930	LF	3774457	Daugherty Run	731	100	StreamRiver	268.7	6.8	3.049	21	1.3
3942	Albright Power Station	931	LF	3774457	Daugherty Run	906	100	StreamRiver	268.7	6.8	3.049	21	1.3
3942	Albright Power Station	1385	SI	3775649	Cheat River	12	100	ArtificialPath	255.2	3.0	1.973	2,330	2.2
3942	Albright Power Station	1386	SI	3775651	Cheat River	13	100	ArtificialPath	259.6	1.9	1.006	2,306	1.1
1915	Allen S King	927	LF	2649096		942	100	StreamRiver	83	19.0	2.882	4.3	0.93
3393	Allen Steam Plant	119	SI	7474836				LakePond	110.7	15.7	4.673	275	1.0
3393	Allen Steam Plant	120	SI	7474836				LakePond	110.7	15.7	4.673	275	1.0
4140	Alma	993	LF	2118222				ArtificialPath	92.1	1.8	1.336	27,963	2.8

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
4140	Alma	994	LF	2118222				ArtificialPath	92.1	1.8	1.336	27,963	2.8
1122	Ames Electric Services Power Plant	1202	SI	6979020	South Skunk River	357	100	StreamRiver	58.2	6.4	3.532	169	1.4
6469	Antelope Valley Station	212	SI	16248553		171	100	StreamRiver	3	27.1	6.218	0.047	0.79
6469	Antelope Valley Station	213	SI	16248553				StreamRiver	3	27.1	6.218	0.047	0.79
6469	Antelope Valley Station	922	LF	16248507		21	40	StreamRiver	3.2	8.1	5.536	0.014	0.67
6469	Antelope Valley Station	922	LF	16248553		2184	60	StreamRiver	3	27.1	6.218	0.047	0.79
6469	Antelope Valley Station	923	LF	16248553		1351	100	StreamRiver	3	27.1	6.218	0.047	0.79
160	Apache Station	287	SI	21263023				Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	288	SI	21263023				Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	292	SI	21263023				Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	293	SI	21263023		2162	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	294	SI	21263023		2379	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	295	SI	21263023		2395	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	296	SI	21263023		2132	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	297	SI	21263023		2682	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	298	SI	21263023		1926	100	Playa	4.8	2055.9	14.545	66	1.1
160	Apache Station	299	SI	21263023		2909	100	Playa	4.8	2055.9	14.545	66	1.1
465	Arapahoe	310	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
465	Arapahoe	311	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
465	Arapahoe	312	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
465	Arapahoe	313	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
465	Arapahoe	314	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
465	Arapahoe	315	SI	194423				StreamRiver	21.5	5.7	1.3	1,392	2.4
3178	Armstrong Power Station	921	LF	4740193		113	33	StreamRiver	205	1.4	2.253	0.93	0.83
3178	Armstrong Power Station	921	LF	4742105	Allegheny River	114	50	ArtificialPath	206.8	0.3	0.279	15,341	2.4
3178	Armstrong Power Station	921	LF	4742115	Allegheny River	252	17	ArtificialPath	203.1	5.5	3.297	15,347	1.5
3178	Armstrong Power Station	926	LF	4742115	Allegheny River	277	100	ArtificialPath	203.1	5.5	3.297	15,347	1.5
2076	Asbury	596	SI	7589885				StreamRiver	90	5.3	4.771	1.6	0.67

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2076	Asbury	597	SI	7589885	Blackberry Creek	75	33	StreamRiver	90	5.3	4.771	1.6	0.67
2076	Asbury	597	SI	7589977	Blackberry Creek	137	67	StreamRiver	92.2	15.6	5.763	7.0	0.85
2076	Asbury	598	SI	7589885	Blackberry Creek	300	50	StreamRiver	90	5.3	4.771	1.6	0.67
2076	Asbury	598	SI	7589977	Blackberry Creek	563	50	StreamRiver	92.2	15.6	5.763	7.0	0.85
2706	Asheville Steam Electric Plant	649	SI	22165396	French Broad River	36	100	ArtificialPath	436.7	3.3	1.961	1,417	2.0
2706	Asheville Steam Electric Plant	650	SI	22165396	French Broad River	97	100	ArtificialPath	436.7	3.3	1.961	1,417	2.0
2835	Ashtabula	1263	SI	9842358	Erie, Lake	356	100	Coastline	119	3.3	6.095		
1961	Austin Northeast	958	LF	7014355	Cedar River	10	100	StreamRiver	88.3	6.1	3.637	87	1.2
2836	Avon Lake	975	LF	28125104				Coastline	72.3	11.5	4.879		
2836	Avon Lake	1175	SI	28125104		80	100	Coastline	72.3	11.5	4.879		
2836	Avon Lake	1176	SI	28125104		68	100	Coastline	72.3	11.5	4.879		
995	Bailly	434	SI	3398586		25	100	Coastline	159	7.8	13.701		
995	Bailly	435	SI	3398156		3870	100	StreamRiver	161.8	6.7	0.766	2.7	0.47
995	Bailly	436	SI	3398156		3378	100	StreamRiver	161.8	6.7	0.766	2.7	0.47
995	Bailly	437	SI	3398156		3611	63	StreamRiver	161.8	6.7	0.766	2.7	0.47
995	Bailly	437	SI	3398586		974	38	Coastline	159	7.8	13.701		
995	Bailly	438	SI	3398156		3786	63	StreamRiver	161.8	6.7	0.766	2.7	0.47
995	Bailly	438	SI	3398586		1130	38	Coastline	159	7.8	13.701		
995	Bailly	439	SI	3398156		3276	100	StreamRiver	161.8	6.7	0.766	2.7	0.47
995	Bailly	939	LF	3398444	Dunes Creek	2195	100	StreamRiver	173.9	10.5	3.006	4.3	0.74
995	Bailly	952	LF	3398444	Dunes Creek	2060	100	StreamRiver	173.9	10.5	3.006	4.3	0.74
889	Baldwin Energy Complex	391	SI	13892052		25	100	StreamRiver	31.9	0.6	1.012	0.86	0.73
3	Barry	252	SI	18520589				StreamRiver	288.8	1.0	1.352	49	0.79
3982	Bay Front	162	SI	1797315	Superior, Lake	31	100	Coastline	220.1	6.3	9.68		
3982	Bay Front	163	SI	1797315	Superior, Lake	36	100	Coastline	220.1	6.3	9.68		
3982	Bay Front	945	LF	1814535	Rock Creek	343	63	StreamRiver	233.1	3.3	5.16	1.4	0.75
3982	Bay Front	945	LF	1814545		549	13	StreamRiver	232.9	1.7	4.204	0.67	0.69
3982	Bay Front	945	LF	1814559		513	25	StreamRiver	231.7	1.0	2.287	0.42	0.65
3982	Bay Front	946	LF	1797055		1397	100	StreamRiver	222.3	4.8	3.999	5.5	0.89
2878	Bay Shore	977	LF	30726962				Coastline	88.8	6.9	9.271		
2878	Bay Shore	1326	SI	30726962		128	100	Coastline	88.8	6.9	9.271		

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
8042	Belews Creek Steam Station	243	SI	8679473	Dan River	247	88	StreamRiver	187.1	12.9	6.58	581	1.4
8042	Belews Creek Steam Station	243	SI	8679535		956	13	StreamRiver	186.9	2.0	2.44	0.91	0.78
8042	Belews Creek Steam Station	1009	LF	8679473	Dan River	2046	50	StreamRiver	187.1	12.9	6.58	581	1.4
8042	Belews Creek Steam Station	1009	LF	8679535		178	25	StreamRiver	186.9	2.0	2.44	0.91	0.78
8042	Belews Creek Steam Station	1009	LF	8680029	West Belews Creek	601	25	LakePond	186.1	3.8	1.994	15	0.65
8042	Belews Creek Steam Station	1010	LF	8679999	Belews Lake	1941	25	LakePond	182.9	15.8	3.821	82	1.2
8042	Belews Creek Steam Station	1010	LF	8680025	Belews Lake	300	25	LakePond	178.6	1.2	1.098	66	1.0
8042	Belews Creek Steam Station	1010	LF	8680029	West Belews Creek	465	50	LakePond	186.1	3.8	1.994	15	0.65
8042	Belews Creek Steam Station	1079	LF	8680027	Belews Lake	199	38	LakePond	184.3	1.0	1.397	16	0.91
8042	Belews Creek Steam Station	1079	LF	8680029	West Belews Creek	109	63	LakePond	186.1	3.8	1.994	15	0.65
6034	Belle River	33	SI	13195966				StreamRiver	69.2	6.3	2.636	1.9	0.68
6034	Belle River	1035	LF	13195770		733	13	StreamRiver	68.1	3.6	3.889	3.1	0.77
6034	Belle River	1035	LF	13195966		1393	88	StreamRiver	69.2	6.3	2.636	1.9	0.68
3325	Ben French	1379	SI	17533087		180	100	StreamRiver	30.5	1.4	1.324	0.040	0.68
645	Big Bend	342	SI	16919198				Coastline	126	0.3	2.737		
645	Big Bend	343	SI	16918212		20	100	StreamRiver	128.8	5.2	1.635	2.2	0.69
645	Big Bend	344	SI	16918212		26	100	StreamRiver	128.8	5.2	1.635	2.2	0.69
645	Big Bend	345	SI	16918212		37	100	StreamRiver	128.8	5.2	1.635	2.2	0.69
645	Big Bend	346	SI	16919198				Coastline	126	0.3	2.737		
645	Big Bend	347	SI	16918212		16	100	StreamRiver	128.8	5.2	1.635	2.2	0.69
645	Big Bend	348	SI	16919198				Coastline	126	0.3	2.737		
645	Big Bend	349	SI	16919198				Coastline	126	0.3	2.737		
645	Big Bend	1164	LF	16918212		585	50	StreamRiver	128.8	5.2	1.635	2.2	0.69
645	Big Bend	1164	LF	16918614		212	50	StreamRiver	127	1.8	2.239	0.75	0.58
3497	Big Brown	776	LF	1454945	Bear Creek	1158	100	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	784	LF	1455469	Fairfield Lake	514	100	LakePond	24	4.7	1.319	2.7	0.48
3497	Big Brown	790	LF	1454945	Bear Creek	865	100	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	791	LF	1454921	Tehuacana Creek	1857	75	StreamRiver	26.6	14.1	6.398	206	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3497	Big Brown	791	LF	1454945	Bear Creek	1038	25	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	1177	SI	1454945	Bear Creek	1881	25	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	1177	SI	1455407	Fairfield Lake	335	75	LakePond	24	3.2	1.997	19	1.2
3497	Big Brown	1178	SI	1454945	Bear Creek	355	100	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	1179	SI	1454945	Bear Creek	976	38	StreamRiver	24	12.0	5.823	2.8	0.83
3497	Big Brown	1179	SI	1455469	Fairfield Lake	242	63	LakePond	24	4.7	1.319	2.7	0.48
3497	Big Brown	1180	SI	1455407	Fairfield Lake	58	100	LakePond	24	3.2	1.997	19	1.2
6055	Big Cajun 2	36	SI	18714658				StreamRiver	121.7	31.9	3.946	30	0.63
6055	Big Cajun 2	37	SI	18714658				StreamRiver	121.7	31.9	3.946	30	0.63
6055	Big Cajun 2	38	SI	18714658				StreamRiver	121.7	31.9	3.946	30	0.63
6055	Big Cajun 2	815	LF	18714658	Patin Dyke Slough	68	100	StreamRiver	121.7	31.9	3.946	30	0.63
1353	Big Sandy	521	SI	908539	Blaine Creek	98	67	StreamRiver	99	4.0	3.035	326	1.3
1353	Big Sandy	521	SI	909005		353	33	Reservoir	99	1.1	1.206	1.1	0.63
1353	Big Sandy	522	SI	909015	Big Sandy River	75	100	ArtificialPath	99.2	16.8	7.427	5,111	2.0
1353	Big Sandy	523	SI	908507	Blaine Creek	45	67	StreamRiver	99	7.3	4.679	323	1.4
1353	Big Sandy	523	SI	908539	Blaine Creek	272	33	StreamRiver	99	4.0	3.035	326	1.3
6098	Big Stone	814	LF	4085588	Whetstone River	1885	100	StreamRiver	8.7	14.7	6.339	53	1.4
6098	Big Stone	1261	SI	4084392		1065	25	StreamRiver	8	8.7	3.009	0.46	0.75
6098	Big Stone	1261	SI	4085588	Whetstone River	890	75	StreamRiver	8.7	14.7	6.339	53	1.4
1904	Black Dog	593	SI	2387042				ArtificialPath	73.6	15.0	5.192	3,499	1.7
1904	Black Dog	799	LF	2387042	Minnesota River	28	67	ArtificialPath	73.6	15.0	5.192	3,499	1.7
1904	Black Dog	799	LF	2387356		78	33	LakePond	73.5	6.5	0.778	0.98	0.41
6106	Boardman	746	LF	24233486		1286	38	StreamRiver	11.4	12.0	5.768	1.4	0.97
6106	Boardman	746	LF	24235620		1618	63	StreamRiver	11.2	36.6	8.78	1.6	0.92
6106	Boardman	1339	SI	24235618		4646	100	StreamRiver	11	22.6	5.997	2.9	1.0
6106	Boardman	1340	SI	24235618		1046	100	StreamRiver	11	22.6	5.997	2.9	1.0
6106	Boardman	1341	SI	24235618		5841	13	StreamRiver	11	22.6	5.997	2.9	1.0
6106	Boardman	1341	SI	24235620		5594	25	StreamRiver	11.2	36.6	8.78	1.6	0.92
6106	Boardman	1341	SI	24235792		7548	63	ArtificialPath	11	115.4	0.43	30	0.74
7790	Bonanza Power Plant	735	LF	1372922		37	57	StreamRiver	11	1.2	1.685	0.022	0.50
7790	Bonanza Power Plant	735	LF	1374446	Green River	54	43	ArtificialPath	11	1.7	1.507	7,722	2.2
7790	Bonanza Power Plant	737	LF	1373564		19	38	StreamRiver	12	1.8	4.033	0.032	0.68
7790	Bonanza Power Plant	737	LF	1373600		178	25	StreamRiver	12	2.5	3.431	0.046	0.73
7790	Bonanza Power Plant	737	LF	5305188		1416	38	StreamRiver	12	2.9	2.079	0.051	0.70
7790	Bonanza Power Plant	1207	SI	5306592		95	100	StreamRiver	13	1.8	3.794	1.4	0.96

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
7790	Bonanza Power Plant	1208	SI	5305828		34	100	StreamRiver	13.2	0.7	1.937	0.15	0.70
7790	Bonanza Power Plant	1209	SI	5305828		2	100	StreamRiver	13.2	0.7	1.937	0.15	0.70
1893	Boswell Energy Center	590	SI	22326305		323	63	StreamRiver	92.6	16.5	2.293	3.5	0.79
1893	Boswell Energy Center	590	SI	22326521		59	25	LakePond	92.5	2.3	1.893	4.0	0.51
1893	Boswell Energy Center	590	SI	22326529		747	13	LakePond	93.1	6.3	2.591	1,550	1.6
1893	Boswell Energy Center	591	SI	22326521		54	63	LakePond	92.5	2.3	1.893	4.0	0.51
1893	Boswell Energy Center	591	SI	22326529		123	38	LakePond	93.1	6.3	2.591	1,550	1.6
1893	Boswell Energy Center	592	SI	22326523		319	100	LakePond	92	0.2	0.447	1,599	1.6
1893	Boswell Energy Center	796	LF	22326521		221	100	LakePond	92.5	2.3	1.893	4.0	0.51
1893	Boswell Energy Center	853	LF	22326521		7	67	LakePond	92.5	2.3	1.893	4.0	0.51
1893	Boswell Energy Center	853	LF	22326529		43	33	LakePond	93.1	6.3	2.591	1,550	1.6
1893	Boswell Energy Center	862	LF	22326305		1931	100	StreamRiver	92.6	16.5	2.293	3.5	0.79
703	Bowen	350	SI	6499098				ArtificialPath	264	12.9	5.814	2,598	2.0
703	Bowen	1103	LF	6499098	Etowah River	296	100	ArtificialPath	264	12.9	5.814	2,598	2.0
602	Brandon Shores	1289	SI	11690244		617	100	ArtificialPath	168.9	2.8	2.561	2.7	0.57
602	Brandon Shores	1290	SI	11690244		617	100	ArtificialPath	168.9	2.8	2.561	2.7	0.57
1619	Brayton Point	731	LF	6130309		20	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	760	LF	6130309		203	63	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	760	LF	6130319	Taunton River	1005	38	ArtificialPath	361.5	11.3	4.667	969	0.87
1619	Brayton Point	761	LF	6130309		134	63	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	761	LF	6130319	Taunton River	1072	38	ArtificialPath	361.5	11.3	4.667	969	0.87
1619	Brayton Point	800	LF	6130309		39	75	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	800	LF	6130319	Taunton River	1185	25	ArtificialPath	361.5	11.3	4.667	969	0.87
1619	Brayton Point	824	LF	6130309		65	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1187	SI	6130309		52	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1188	SI	6130309		54	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1189	SI	6130309		175	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1190	SI	6130309		220	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1191	SI	6130309		77	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1192	SI	6130309		254	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1193	SI	6130309		159	100	ArtificialPath	360.8	3.0	2.458	12	0.64
1619	Brayton Point	1194	SI	6130319	Taunton River	1048	100	ArtificialPath	361.5	11.3	4.667	969	0.87
1619	Brayton Point	1195	SI	6130319	Taunton River	948	100	ArtificialPath	361.5	11.3	4.667	969	0.87
1619	Brayton Point	1196	SI	6130319	Taunton River	952	100	ArtificialPath	361.5	11.3	4.667	969	0.87
3796	Bremo Bluff	148	SI	8545789	Holman Creek	94	17	StreamRiver	164	1.3	2.024	4.3	0.87
3796	Bremo Bluff	148	SI	8545819	Holman Creek	30	33	StreamRiver	163.8	1.0	0.373	5.8	0.54
3796	Bremo Bluff	148	SI	8548181	James River	70	33	ArtificialPath	164	0.5	0.624	5,608	2.0
3796	Bremo Bluff	148	SI	8557867	James River	36	17	ArtificialPath	164	0.1	0.284	5,625	2.0
3796	Bremo Bluff	149	SI	8545819	Holman Creek	692	63	StreamRiver	163.8	1.0	0.373	5.8	0.54

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3796	Bremo Bluff	149	SI	8548185	James River	205	38	ArtificialPath	163.2	1.9	1.829	5,631	2.0
6094	Bruce Mansfield	75	SI	3819803	Haden Run	344	50	StreamRiver	137.8	2.1	2.035	2.5	0.92
6094	Bruce Mansfield	75	SI	3821085	Ohio River	285	50	ArtificialPath	134.8	3.3	1.75	39,266	2.9
6094	Bruce Mansfield	76	SI	3819803	Haden Run	171	100	StreamRiver	137.8	2.1	2.035	2.5	0.92
6094	Bruce Mansfield	77	SI	3821085				ArtificialPath	134.8	3.3	1.75	39,266	2.9
6094	Bruce Mansfield	78	SI	3819803	Haden Run	275	100	StreamRiver	137.8	2.1	2.035	2.5	0.92
6094	Bruce Mansfield	79	SI	3820879	Mill Creek	192	50	StreamRiver	136.8	5.0	5.158	14	1.1
6094	Bruce Mansfield	79	SI	3821105	Mill Creek	45	25	ArtificialPath	133	0.1	0.276	17	0.66
6094	Bruce Mansfield	79	SI	3821113	Ohio River	359	25	ArtificialPath	135	3.0	1.365	39,859	2.9
2720	Buck	671	SI	9223641	Yadkin River	566	63	LakePond	163.1	3.7	1.95	4,292	1.9
2720	Buck	671	SI	9223657		959	38	LakePond	162.9	2.3	0.557	2.9	0.48
2720	Buck	672	SI	9223657		442	100	LakePond	162.9	2.3	0.557	2.9	0.48
2720	Buck	673	SI	9223641	Yadkin River	140	100	LakePond	163.1	3.7	1.95	4,292	1.9
3396	Bull Run	121	SI	22124076				StreamRiver	270.8	2.1	1.998	4.7	0.78
3396	Bull Run	122	SI	22124076				StreamRiver	270.8	2.1	1.998	4.7	0.78
3396	Bull Run	123	SI	22124076				StreamRiver	270.8	2.1	1.998	4.7	0.78
3396	Bull Run	124	SI	22124076				StreamRiver	270.8	2.1	1.998	4.7	0.78
3396	Bull Run	889	LF	14643321	Clinch River	59	50	LakePond	270.5	4.5	2.839	213	1.0
3396	Bull Run	889	LF	14643323	Clinch River	535	50	LakePond	271.8	2.5	1.802	4,628	1.9
3396	Bull Run	890	LF	22124042		167	17	StreamRiver	271.3	1.7	2.232	1.3	0.79
3396	Bull Run	890	LF	22124076	Worthington Branch	16	83	StreamRiver	270.8	2.1	1.998	4.7	0.78
1104	Burlington	507	SI	6966239				ArtificialPath	71	7.0	2.87	62,652	3.3
1104	Burlington	508	SI	6966239				ArtificialPath	71	7.0	2.87	62,652	3.3
1104	Burlington	509	SI	6966239				ArtificialPath	71	7.0	2.87	62,652	3.3
1104	Burlington	510	SI	6966239				ArtificialPath	71	7.0	2.87	62,652	3.3
1104	Burlington	511	SI	6966239				ArtificialPath	71	7.0	2.87	62,652	3.3
676	C D McIntosh Jr	885	LF	16794835	Saddle Creek	2678	100	StreamRiver	129	164.6	5.003	58	0.96
676	C D McIntosh Jr	888	LF	16794835	Saddle Creek	2422	100	StreamRiver	129	164.6	5.003	58	0.96
468	Cameo	316	SI	3178228				StreamRiver	43.1	0.3	0.263	0.79	0.91
468	Cameo	317	SI	3178228				StreamRiver	43.1	0.3	0.263	0.79	0.91
3280	Canadys Steam	107	SI	9614169	Edisto River	635	13	StreamRiver	196	0.7	1.336	2,219	1.7
3280	Canadys Steam	107	SI	9614527	Edisto River	113	63	StreamRiver	197.6	3.8	3.3	2,219	1.8
3280	Canadys Steam	107	SI	9614577	Edisto River	1008	25	StreamRiver	196.7	26.4	5.15	2,239	1.7
3280	Canadys Steam	108	SI	9614577	Edisto River	1064	100	StreamRiver	196.7	26.4	5.15	2,239	1.7
3280	Canadys Steam	109	SI	9614169	Edisto River	321	25	StreamRiver	196	0.7	1.336	2,219	1.7
3280	Canadys Steam	109	SI	9614577	Edisto River	261	75	StreamRiver	196.7	26.4	5.15	2,239	1.7
1363	Cane Run	538	SI	10163768	Mill Creek Cutoff	677	13	StreamRiver	111.3	6.9	3.556	40	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1363	Cane Run	538	SI	10163770	Mill Creek	2052	13	StreamRiver	112	1.5	0.622	0.71	0.62
1363	Cane Run	538	SI	10163782	Mill Creek	2202	75	StreamRiver	112.2	11.5	7.616	6.2	0.67
1363	Cane Run	539	SI	10163768				StreamRiver	111.3	6.9	3.556	40	1.1
1363	Cane Run	540	SI	10163768	Mill Creek Cutoff	127	100	StreamRiver	111.3	6.9	3.556	40	1.1
1363	Cane Run	541	SI	10163768	Mill Creek Cutoff	125	100	StreamRiver	111.3	6.9	3.556	40	1.1
1363	Cane Run	542	SI	10163768				StreamRiver	111.3	6.9	3.556	40	1.1
1363	Cane Run	869	LF	10163782	Mill Creek	2077	43	StreamRiver	112.2	11.5	7.616	6.2	0.67
1363	Cane Run	869	LF	10164018	Ohio River	13	57	ArtificialPath	111.9	1.3	1.817	123,554	3.7
2708	Cape Fear Steam Electric Plant	651	SI	8844487		121	40	StreamRiver	110.3	3.8	3.116	1.7	0.58
2708	Cape Fear Steam Electric Plant	651	SI	8844727	Cape Fear River	227	40	ArtificialPath	106.8	1.0	1.527	3,146	1.8
2708	Cape Fear Steam Electric Plant	651	SI	8844733	Cape Fear River	411	20	ArtificialPath	111	0.9	1.11	3,154	1.8
2708	Cape Fear Steam Electric Plant	652	SI	8844487		284	33	StreamRiver	110.3	3.8	3.116	1.7	0.58
2708	Cape Fear Steam Electric Plant	652	SI	8844727	Cape Fear River	25	67	ArtificialPath	106.8	1.0	1.527	3,146	1.8
2708	Cape Fear Steam Electric Plant	653	SI	8844487		62	88	StreamRiver	110.3	3.8	3.116	1.7	0.58
2708	Cape Fear Steam Electric Plant	653	SI	8897286	Shaddox Creek	504	13	StreamRiver	104.5	4.0	3.309	14	0.88
2708	Cape Fear Steam Electric Plant	654	SI	8844727	Cape Fear River	92	17	ArtificialPath	106.8	1.0	1.527	3,146	1.8
2708	Cape Fear Steam Electric Plant	654	SI	8897286	Shaddox Creek	45	67	StreamRiver	104.5	4.0	3.309	14	0.88
2708	Cape Fear Steam Electric Plant	654	SI	8898150	Haw River	26	17	ArtificialPath	103.8	0.1	0.373	1,602	1.6
2708	Cape Fear Steam Electric Plant	655	SI	8844727	Cape Fear River	83	25	ArtificialPath	106.8	1.0	1.527	3,146	1.8
2708	Cape Fear Steam Electric Plant	655	SI	8844733	Cape Fear River	110	75	ArtificialPath	111	0.9	1.11	3,154	1.8
3644	Carbon Plant	876	LF	3907885		3	100	StreamRiver	13.3	6.5	4.244	0.15	0.93
3644	Carbon Plant	905	LF	3907877	Price River	155	100	StreamRiver	13.7	3.5	2.347	225	2.0
3644	Carbon Plant	1387	SI	3907877	Price River	91	100	StreamRiver	13.7	3.5	2.347	225	2.0
3644	Carbon Plant	1388	SI	3907877	Price River	101	100	StreamRiver	13.7	3.5	2.347	225	2.0
2828	Cardinal	693	SI	19451557	Riddles Run	52	75	StreamRiver	156.8	2.1	2.148	2.6	0.91

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2828	Cardinal	693	SI	19453103	Ohio River	911	25	ArtificialPath	153.3	11.2	2.976	40,860	3.0
2828	Cardinal	694	SI	19451565	Salt Run	678	20	StreamRiver	157	1.4	0.964	6.8	1.0
2828	Cardinal	694	SI	19453117	Ohio River	33	80	ArtificialPath	157.5	6.6	3.078	40,873	3.0
2828	Cardinal	899	LF	19451557	Riddles Run	342	100	StreamRiver	156.8	2.1	2.148	2.6	0.91
1001	Cayuga	454	SI	10209979	Wabash River	481	100	ArtificialPath	100.2	20.2	9.504	9,307	2.2
1001	Cayuga	455	SI	10209979	Wabash River	283	100	ArtificialPath	100.2	20.2	9.504	9,307	2.2
1001	Cayuga	456	SI	10209979	Wabash River	191	100	ArtificialPath	100.2	20.2	9.504	9,307	2.2
1001	Cayuga	457	SI	10209979	Wabash River	514	100	ArtificialPath	100.2	20.2	9.504	9,307	2.2
1001	Cayuga	838	LF	10208939		1145	25	StreamRiver	99.6	6.5	3.806	3.4	0.85
1001	Cayuga	838	LF	10209979	Wabash River	1656	75	ArtificialPath	100.2	20.2	9.504	9,307	2.2
1571	Chalk Point LLC	836	LF	11908022	Mataponi Creek	53	75	StreamRiver	155.9	10.1	3.969	4.7	0.85
1571	Chalk Point LLC	836	LF	11908042	Rock Creek	1028	25	StreamRiver	159.8	5.1	3.531	2.4	0.81
1571	Chalk Point LLC	1104	LF	11908782	Swanson Creek	1759	50	ArtificialPath	179	4.9	2.171	34	0.75
1571	Chalk Point LLC	1104	LF	11908816	Patuxent River	285	50	ArtificialPath	179.4	5.0	2.986	813	1.4
2169	Chamois Power Plant	1288	SI	5159567		39	33	StreamRiver	24	0.1	0.077	2.2	0.47
2169	Chamois Power Plant	1288	SI	5159635	Dooling Creek	38	33	StreamRiver	24	2.2	3.422	2.2	0.77
2169	Chamois Power Plant	1288	SI	5160215		20	33	StreamRiver	24	1.0	1.768	0.061	0.60
56	Charles R. Lowman	270	SI	21642176	Tombigbee River	366	13	ArtificialPath	199.8	2.3	3.261	28,775	2.8
56	Charles R. Lowman	270	SI	21642548		1148	88	Connector	198.5	1.6	1.163	9.7	0.62
56	Charles R. Lowman	271	SI	21642176	Tombigbee River	297	25	ArtificialPath	199.8	2.3	3.261	28,775	2.8
56	Charles R. Lowman	271	SI	21642548		1220	75	Connector	198.5	1.6	1.163	9.7	0.62
56	Charles R. Lowman	272	SI	21642176	Tombigbee River	115	75	ArtificialPath	199.8	2.3	3.261	28,775	2.8
56	Charles R. Lowman	272	SI	21642548		1729	25	Connector	198.5	1.6	1.163	9.7	0.62
56	Charles R. Lowman	273	SI	21641264		1246	13	StreamRiver	200.9	4.2	3.246	2.6	0.63
56	Charles R. Lowman	273	SI	21642548		1360	88	Connector	198.5	1.6	1.163	9.7	0.62
56	Charles R. Lowman	900	LF	21642176				ArtificialPath	199.8	2.3	3.261	28,775	2.8
469	Cherokee	318	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
469	Cherokee	319	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
469	Cherokee	320	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
469	Cherokee	321	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
469	Cherokee	322	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
469	Cherokee	323	SI	229709				StreamRiver	18.9	23.5	3.109	1,505	2.4
3803	Chesapeake Energy Center	152	SI	10054854		26	50	ArtificialPath	152.9	1.3	1.092	61	0.84

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3803	Chesapeake Energy Center	152	SI	10055988		39	50	Reservoir	156.2	0.1	0.343	0.31	0.57
3803	Chesapeake Energy Center	865	LF	10055726	Southern Branch Elizabeth River	89	33	ArtificialPath	159	0.5	1.003	97	0.92
3803	Chesapeake Energy Center	865	LF	10055988		93	17	Reservoir	156.2	0.1	0.343	0.31	0.57
3803	Chesapeake Energy Center	865	LF	10055992		22	50	LakePond	158.8	0.7	0.237	0.27	0.32
3797	Chesterfield	150	SI	10067647		5	100	LakePond	158	7.3	1.114	2.7	0.47
3797	Chesterfield	151	SI	10067405	James River	151	43	ArtificialPath	159	2.2	1.906	7,627	2.1
3797	Chesterfield	151	SI	10072915		17	57	ArtificialPath	158.9	3.4	2.033	4.2	0.51
8226	Cheswick Power Plant	1099	LF	11049576	Little Deer Creek	217	100	StreamRiver	162.5	2.2	1.983	16	1.0
8226	Cheswick Power Plant	1165	SI	11049676	Tawney Run	5	100	StreamRiver	158.8	2.6	2.618	3.7	0.90
8226	Cheswick Power Plant	1166	SI	11049676	Tawney Run	3	100	StreamRiver	158.8	2.6	2.618	3.7	0.90
113	Cholla	279	SI	21746307		27	50	CanalDitch	7	4.1	3.921	0.67	0.64
113	Cholla	279	SI	21746347		420	50	CanalDitch	7	4.5	3.01	0.34	0.65
113	Cholla	280	SI	21746275		217	100	StreamRiver	7	3.1	2.615	0.10	0.77
113	Cholla	863	LF	21746245		679	100	StreamRiver	7	4.3	2.719	0.016	0.66
2721	Cliffside	674	SI	12035539				ArtificialPath	271.2	0.5	0.71	1,461	2.1
2721	Cliffside	675	SI	12034795	Suck Creek	101	67	StreamRiver	271	10.3	6.814	24	1.1
2721	Cliffside	675	SI	12035537	Broad River	240	17	ArtificialPath	279	0.2	0.451	1,485	1.5
2721	Cliffside	675	SI	12035809		80	17	LakePond	276	0.4	0.413	0.27	0.64
2721	Cliffside	676	SI	12035539				ArtificialPath	271.2	0.5	0.71	1,461	2.1
983	Clifty Creek	413	SI	10161792	Crooked Creek	35	100	StreamRiver	59.3	24.6	8.802	12	1.1
983	Clifty Creek	414	SI	10161794	Big Clifty Creek	273	88	StreamRiver	59.4	5.1	3.282	14	1.1
983	Clifty Creek	414	SI	10161934	Ohio River	17	13	ArtificialPath	60	16.3	5.415	122,540	3.7
983	Clifty Creek	847	LF	10161794	Big Clifty Creek	668	50	StreamRiver	59.4	5.1	3.282	14	1.1
983	Clifty Creek	847	LF	10161934	Ohio River	1243	50	ArtificialPath	60	16.3	5.415	122,540	3.7
983	Clifty Creek	848	LF	10161794	Big Clifty Creek	909	25	StreamRiver	59.4	5.1	3.282	14	1.1
983	Clifty Creek	848	LF	10161934	Ohio River	935	75	ArtificialPath	60	16.3	5.415	122,540	3.7
3775	Clinch River	144	SI	14638941	Dumps Creek	33	75	StreamRiver	195.1	2.2	1.566	36	0.97
3775	Clinch River	144	SI	14640413	Clinch River	61	25	ArtificialPath	197.8	0.7	1.651	820	1.6
3775	Clinch River	145	SI	14638941	Dumps Creek	73	100	StreamRiver	195.1	2.2	1.566	36	0.97
3775	Clinch River	849	LF	14640413	Clinch River	130	29	ArtificialPath	197.8	0.7	1.651	820	1.6
3775	Clinch River	849	LF	14640417	Clinch River	69	71	ArtificialPath	199.1	1.3	1.963	823	1.4
7213	Clover	850	LF	8651510	Black Walnut Creek	383	100	StreamRiver	115	2.4	1.134	8.0	0.84

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
7213	Clover	851	LF	8651510	Black Walnut Creek	407	100	StreamRiver	115	2.4	1.134	8.0	0.84
7213	Clover	1280	SI	8653052		459	63	LakePond	116	0.2	0.299	0.39	0.65
7213	Clover	1280	SI	8653054	Roanoke River	758	13	ArtificialPath	116	0.7	0.905	2,965	1.8
7213	Clover	1280	SI	8653058		332	25	LakePond	116	0.5	0.703	1.1	0.79
7213	Clover	1281	SI	8653052		459	63	LakePond	116	0.2	0.299	0.39	0.65
7213	Clover	1281	SI	8653054	Roanoke River	758	13	ArtificialPath	116	0.7	0.905	2,965	1.8
7213	Clover	1281	SI	8653058		332	25	LakePond	116	0.5	0.703	1.1	0.79
7213	Clover	1282	SI	8651532		31	14	StreamRiver	116	0.1	0.208	1.1	0.41
7213	Clover	1282	SI	8653054	Roanoke River	11	71	ArtificialPath	116	0.7	0.905	2,965	1.8
7213	Clover	1282	SI	8653058		7	14	LakePond	116	0.5	0.703	1.1	0.79
7213	Clover	1283	SI	8653052		51	38	LakePond	116	0.2	0.299	0.39	0.65
7213	Clover	1283	SI	8653054	Roanoke River	207	63	ArtificialPath	116	0.7	0.905	2,965	1.8
7213	Clover	1284	SI	8653052		51	38	LakePond	116	0.2	0.299	0.39	0.65
7213	Clover	1284	SI	8653054	Roanoke River	207	63	ArtificialPath	116	0.7	0.905	2,965	1.8
6030	Coal Creek	29	SI	14518483		4497	13	StreamRiver	4	6.5	2.255	0.0058	0.49
6030	Coal Creek	29	SI	14518523		4418	88	StreamRiver	4	6.2	2.234	0.0056	0.62
6030	Coal Creek	30	SI	14518523		4934	100	StreamRiver	4	6.2	2.234	0.0056	0.62
6030	Coal Creek	852	LF	14518523		4854	100	StreamRiver	4	6.2	2.234	0.0056	0.62
6030	Coal Creek	854	LF	14518385		1910	25	StreamRiver	4	7.9	2.161	0.0071	0.63
6030	Coal Creek	854	LF	14518389		270	75	StreamRiver	4	4.2	2.35	0.0038	0.59
6030	Coal Creek	855	LF	14518439		609	25	StreamRiver	4	2.0	1.606	0.0018	0.46
6030	Coal Creek	855	LF	14518483		6656	75	StreamRiver	4	6.5	2.255	0.0058	0.49
6030	Coal Creek	857	LF	14518523		4878	100	StreamRiver	4	6.2	2.234	0.0056	0.62
6030	Coal Creek	868	LF	14518407		26	100	StreamRiver	4	5.4	4.198	0.0049	0.60
6030	Coal Creek	1119	LF	14518407		398	100	StreamRiver	4	5.4	4.198	0.0049	0.60
861	Coffeen	379	SI	13881662		284	13	StreamRiver	30	2.4	2.472	0.79	0.68
861	Coffeen	379	SI	13882010		124	88	LakePond	29	2.4	2.783	1.6	0.59
861	Coffeen	380	SI	13881662		127	100	StreamRiver	30	2.4	2.472	0.79	0.68
861	Coffeen	846	LF	13881662		499	50	StreamRiver	30	2.4	2.472	0.79	0.68
861	Coffeen	846	LF	13882002		546	50	LakePond	29.6	4.5	1.961	9.9	0.75
47	Colbert	258	SI	19623794				LakePond	276.1	4.0	5.396	60,949	3.2
47	Colbert	259	SI	19623794				LakePond	276.1	4.0	5.396	60,949	3.2
47	Colbert	260	SI	19623794				LakePond	276.1	4.0	5.396	60,949	3.2
47	Colbert	859	LF	19581379	Cane Creek	888	50	StreamRiver	270.8	8.2	5.692	88	0.89
47	Colbert	859	LF	19623794	White Lake (historical)	545	50	LakePond	276.1	4.0	5.396	60,949	3.2
6178	Coleto Creek	181	SI	1639289	Coleto Creek Cooling Pond	44	100	LakePond	13.2	4.9	2.869	1.6	0.54

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6178	Coleto Creek	182	SI	1639289	Coleto Creek Cooling Pond	0	100	LakePond	13.2	4.9	2.869	1.6	0.54
6076	Colstrip	46	SI	13262665				StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	47	SI	13262665				StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	48	SI	13262665				StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	49	SI	13262665	East Fork Armells Creek	165	100	StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	50	SI	13262665	East Fork Armells Creek	166	100	StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	51	SI	13236335	Cow Creek	46	100	StreamRiver	10.7	12.0	1.867	0.29	0.80
6076	Colstrip	52	SI	13262665	East Fork Armells Creek	71	100	StreamRiver	9.5	30.6	11.221	0.98	0.97
6076	Colstrip	53	SI	13262665				StreamRiver	9.5	30.6	11.221	0.98	0.97
10784	Colstrip Energy LP	860	LF	13262539	East Fork Armells Creek	835	100	StreamRiver	9	6.3	4.522	6.5	1.1
10784	Colstrip Energy LP	861	LF	13262539	East Fork Armells Creek	720	63	StreamRiver	9	6.3	4.522	6.5	1.1
10784	Colstrip Energy LP	861	LF	13262549	Corral Creek	145	38	StreamRiver	9	5.2	4.706	0.39	0.85
8023	Columbia	239	SI	13633689				StreamRiver	127.7	9.0	4.583	3.7	0.71
8023	Columbia	240	SI	13633689				StreamRiver	127.7	9.0	4.583	3.7	0.71
8023	Columbia	241	SI	13633689				StreamRiver	127.7	9.0	4.583	3.7	0.71
8023	Columbia	242	SI	13633689				StreamRiver	127.7	9.0	4.583	3.7	0.71
8023	Columbia	1135	LF	13631823		461	13	StreamRiver	128.8	0.7	1.019	0.17	0.30
8023	Columbia	1135	LF	13633689		894	88	StreamRiver	127.7	9.0	4.583	3.7	0.71
8023	Columbia	1136	LF	13631785	Duck Creek	516	63	StreamRiver	129	0.6	0.462	0.84	0.39
8023	Columbia	1136	LF	13633653	Duck Creek	411	25	StreamRiver	129.3	2.5	1.845	0.62	0.37
8023	Columbia	1136	LF	13633689		1345	13	StreamRiver	127.7	9.0	4.583	3.7	0.71
2123	Columbia	1213	SI	5161861		220	100	StreamRiver	20	2.2	1.36	0.030	0.66
470	Comanche	324	SI	951449				StreamRiver	8.9	12.5	6.802	93	1.6
470	Comanche	325	SI	951449				StreamRiver	8.9	12.5	6.802	93	1.6
470	Comanche	326	SI	951449				StreamRiver	8.9	12.5	6.802	93	1.6
470	Comanche	327	SI	951449				StreamRiver	8.9	12.5	6.802	93	1.6
470	Comanche	328	SI	951449				StreamRiver	8.9	12.5	6.802	93	1.6
470	Comanche	1137	LF	951449	Saint Charles River	942	100	StreamRiver	8.9	12.5	6.802	93	1.6
3118	Conemaugh	864	LF	4754190		6	50	StreamRiver	259	3.1	2.288	2.1	0.89
3118	Conemaugh	864	LF	4754214		383	50	StreamRiver	257.3	4.2	2.809	2.9	0.95
3118	Conemaugh	1138	LF	4754190		36	100	StreamRiver	259	3.1	2.288	2.1	0.89

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3118	Conemaugh	1334	SI	4754980	Conemaugh River	14	100	ArtificialPath	260.4	3.6	2.327	1,311	1.5
3118	Conemaugh	1335	SI	4754980	Conemaugh River	469	88	ArtificialPath	260.4	3.6	2.327	1,311	1.5
3118	Conemaugh	1335	SI	4754982	Conemaugh River	496	13	ArtificialPath	259	1.0	1.279	1,326	1.5
3118	Conemaugh	1336	SI	4754980	Conemaugh River	435	100	ArtificialPath	260.4	3.6	2.327	1,311	1.5
3118	Conemaugh	1337	SI	4754980	Conemaugh River	373	100	ArtificialPath	260.4	3.6	2.327	1,311	1.5
3118	Conemaugh	1338	SI	4754980	Conemaugh River	342	100	ArtificialPath	260.4	3.6	2.327	1,311	1.5
2840	Conesville	701	SI	15379411	Muskingum River	815	100	ArtificialPath	131.5	18.1	6.036	4,329	2.3
2840	Conesville	1005	LF	15379411				ArtificialPath	131.5	18.1	6.036	4,329	2.3
2840	Conesville	1006	LF	15379411				ArtificialPath	131.5	18.1	6.036	4,329	2.3
1710	Consumers Energy - J.H. Campbell	572	SI	9017399				StreamRiver	245.1	3.7	1.794	66	0.86
1710	Consumers Energy - J.H. Campbell	967	LF	9017399				StreamRiver	245.1	3.7	1.794	66	0.86
1710	Consumers Energy - J.H. Campbell	985	LF	9017399				StreamRiver	245.1	3.7	1.794	66	0.86
1710	Consumers Energy - J.H. Campbell	998	LF	9017399				StreamRiver	245.1	3.7	1.794	66	0.86
1710	Consumers Energy - J.H. Campbell	999	LF	9017399				StreamRiver	245.1	3.7	1.794	66	0.86
1384	Cooper Station.	973	LF	3575676				LakePond	170.6	8.2	5.023	5,416	2.0
7210	Cope	866	LF	10553480	Roberts Swamp	74	100	StreamRiver	262	15.6	5.246	45	1.0
6177	Coronado Generating Station	180	SI	19895815		59	100	StreamRiver	10	11.9	7.041	0.056	0.74
6177	Coronado Generating Station	835	LF	19895759				StreamRiver	10	84.6	18.462	10	1.5
6177	Coronado Generating Station	867	LF	19895815		1604	60	StreamRiver	10	11.9	7.041	0.056	0.74
6177	Coronado Generating Station	867	LF	19896013		313	40	StreamRiver	10	8.4	6.608	0.010	0.68
8222	Coyote	248	SI	16249845		251	100	StreamRiver	4.4	12.5	8.055	0.022	0.71
8222	Coyote	249	SI	16249845		95	100	StreamRiver	4.4	12.5	8.055	0.022	0.71

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
8222	Coyote	250	SI	16249845		474	100	StreamRiver	4.4	12.5	8.055	0.022	0.71
8222	Coyote	825	LF	16249845		29	100	StreamRiver	4.4	12.5	8.055	0.022	0.71
8222	Coyote	826	LF	16249845		181	100	StreamRiver	4.4	12.5	8.055	0.022	0.71
8222	Coyote	833	LF	16249845		474	63	StreamRiver	4.4	12.5	8.055	0.022	0.71
8222	Coyote	833	LF	16249849		351	38	StreamRiver	5	2.6	2.8	0.0046	0.62
8222	Coyote	856	LF	16249841		326	25	StreamRiver	4	1.4	2.086	0.0024	0.58
8222	Coyote	856	LF	16249845		1544	75	StreamRiver	4.4	12.5	8.055	0.022	0.71
2549	CR Huntley Generating Station	643	SI	15569803	Niagara River	20	100	ArtificialPath	170	1.0	0.505	28	0.72
2549	CR Huntley Generating Station	644	SI	15569803	Niagara River	36	100	ArtificialPath	170	1.0	0.505	28	0.72
2549	CR Huntley Generating Station	645	SI	15569803	Niagara River	57	100	ArtificialPath	170	1.0	0.505	28	0.72
2549	CR Huntley Generating Station	1100	LF	15568803		603	38	StreamRiver	164	4.7	1.874	0.96	0.66
2549	CR Huntley Generating Station	1100	LF	15569791	Niagara River	765	50	ArtificialPath	172	21.7	3.244	39	0.80
2549	CR Huntley Generating Station	1100	LF	15569797	Niagara River	1149	13	ArtificialPath	172	21.7	3.244	31	0.66
6021	Craig	27	SI	1356794				LakePond	22.1	1.0	0.47	0.36	0.74
6021	Craig	28	SI	1356794				LakePond	22.1	1.0	0.47	0.36	0.74
6021	Craig	974	LF	1356794				LakePond	22.1	1.0	0.47	0.36	0.74
867	Crawford	387	SI	14786229				ArtificialPath	109.6	131.5	5.928	203	1.1
753	Crisp Plant	1265	SI	6445762	Flint River	224	100	ArtificialPath	207.9	6.0	3.338	4,758	2.6
641	Crist	1139	LF	448392	Clear Creek	524	100	StreamRiver	436.7	17.4	6.123	13	0.95
641	Crist	1273	SI	450574	Clear Creek	42	38	ArtificialPath	438.2	1.3	1.737	15	0.63
641	Crist	1273	SI	450576	Clear Creek	50	63	ArtificialPath	440	0.1	0.116	15	0.63
641	Crist	1274	SI	448630	Escambia River	56	33	ArtificialPath	440.1	1.4	1.565	6,840	2.1
641	Crist	1274	SI	448632	Thompson Bayou	77	33	ArtificialPath	442.5	4.9	2.313	20	1.0
641	Crist	1274	SI	450574	Clear Creek	263	17	ArtificialPath	438.2	1.3	1.737	15	0.63
641	Crist	1274	SI	450576	Clear Creek	318	17	ArtificialPath	440	0.1	0.116	15	0.63
641	Crist	1275	SI	448392	Clear Creek	380	100	StreamRiver	436.7	17.4	6.123	13	0.95
641	Crist	1276	SI	448392	Clear Creek	229	100	StreamRiver	436.7	17.4	6.123	13	0.95
641	Crist	1277	SI	448392	Clear Creek	569	38	StreamRiver	436.7	17.4	6.123	13	0.95
641	Crist	1277	SI	450574	Clear Creek	248	63	ArtificialPath	438.2	1.3	1.737	15	0.63
641	Crist	1278	SI	448392	Clear Creek	334	13	StreamRiver	436.7	17.4	6.123	13	0.95
641	Crist	1278	SI	450574	Clear Creek	174	88	ArtificialPath	438.2	1.3	1.737	15	0.63
641	Crist	1279	SI	450574	Clear Creek	115	100	ArtificialPath	438.2	1.3	1.737	15	0.63

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
130	Cross	284	SI	9644979	Lake Moultrie	1469	100	ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	285	SI	9644979	Lake Moultrie	1060	100	ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	286	SI	9644979	Lake Moultrie	1748	88	ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	286	SI	9644981	Lake Moultrie	121	13	LakePond	179	0.0	0.033	60	0.83
130	Cross	827	LF	9644979	Lake Moultrie	1973	75	ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	827	LF	9644981	Lake Moultrie	2818	25	LakePond	179	0.0	0.033	60	0.83
130	Cross	828	LF	9644979				ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	829	LF	9644979				ArtificialPath	178.4	38.6	5.022	60	0.85
130	Cross	830	LF	9644979				ArtificialPath	178.4	38.6	5.022	60	0.85
628	Crystal River Power Plant	831	LF	16928218	Gulf of Mexico	1250	100	Coastline	121.6	5.9	1.024		
3399	Cumberland	125	SI	11884358				StreamRiver	191.3	2.0	1.81	80	0.87
3399	Cumberland	126	SI	11884358				StreamRiver	191.3	2.0	1.81	80	0.87
3399	Cumberland	127	SI	11884358				StreamRiver	191.3	2.0	1.81	80	0.87
3399	Cumberland	978	LF	11884358				StreamRiver	191.3	2.0	1.81	80	0.87
6823	D B Wilson	832	LF	11629499		1360	75	StreamRiver	105.9	11.5	4.61	6.3	0.75
6823	D B Wilson	832	LF	11629523		1134	13	StreamRiver	106	2.0	2.606	1.1	0.71
6823	D B Wilson	832	LF	11629529		765	13	StreamRiver	106	2.0	1.524	1.1	0.64
6823	D B Wilson	845	LF	11629499		1553	50	StreamRiver	105.9	11.5	4.61	6.3	0.75
6823	D B Wilson	845	LF	11629523		238	50	StreamRiver	106	2.0	2.606	1.1	0.71
1702	D.E. Karn	570	SI	12928873				Coastline	72	2.0	4.496		
1702	D.E. Karn	571	SI	12928873	Saginaw Bay	106	100	Coastline	72	2.0	4.496		
1702	D.E. Karn	1004	LF	12928873				Coastline	72	2.0	4.496		
1385	Dale Station	558	SI	1827714	Kentucky River	18	100	ArtificialPath	122.8	4.0	1.478	5,597	2.0
1385	Dale Station	559	SI	1827730	Kentucky River	14	100	ArtificialPath	123	5.2	3.322	5,508	1.8
1385	Dale Station	560	SI	1827714	Kentucky River	78	100	ArtificialPath	122.8	4.0	1.478	5,597	2.0
963	Dallman	399	SI	13564568	Sugar Creek	81	63	StreamRiver	63	0.5	0.954	183	1.4
963	Dallman	399	SI	13564578	Sugar Creek	44	38	StreamRiver	63	1.3	1.05	180	1.5
963	Dallman	823	LF	13564568	Sugar Creek	268	50	StreamRiver	63	0.5	0.954	183	1.4
963	Dallman	823	LF	13564576		245	38	StreamRiver	63	2.4	2.435	0.62	0.68
963	Dallman	823	LF	13564578	Sugar Creek	335	13	StreamRiver	63	1.3	1.05	180	1.5
963	Dallman	834	LF	13564568	Sugar Creek	35	75	StreamRiver	63	0.5	0.954	183	1.4
963	Dallman	834	LF	13564576		215	25	StreamRiver	63	2.4	2.435	0.62	0.68
2723	Dan River	677	SI	8677721	Dan River	2	100	ArtificialPath	170.5	8.4	1.912	2,001	1.6
2723	Dan River	678	SI	8677721	Dan River	1	100	ArtificialPath	170.5	8.4	1.912	2,001	1.6
2723	Dan River	679	SI	8677721	Dan River	20	100	ArtificialPath	170.5	8.4	1.912	2,001	1.6
2480	Danskammer Generating Station	1140	LF	6212808	Hudson River	300	100	ArtificialPath	273.4	7.2	2.609	22,244	2.6
4158	Dave Johnston Plant	4	SI	22109291	Sand Creek	749	100	StreamRiver	9	15.4	8.207	2.9	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
4158	Dave Johnston Plant	5	SI	22109291	Sand Creek	619	75	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	5	SI	22109491	North Platte River	626	25	LakePond	10	1.9	1.315	6,033	2.1
4158	Dave Johnston Plant	6	SI	22109291	Sand Creek	619	75	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	6	SI	22109491	North Platte River	626	25	LakePond	10	1.9	1.315	6,033	2.1
4158	Dave Johnston Plant	7	SI	22109291	Sand Creek	651	75	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	7	SI	22109491	North Platte River	655	25	LakePond	10	1.9	1.315	6,033	2.1
4158	Dave Johnston Plant	8	SI	22109291	Sand Creek	692	100	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	9	SI	22109291	Sand Creek	734	100	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	10	SI	22109291	Sand Creek	651	75	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	10	SI	22109491	North Platte River	655	25	LakePond	10	1.9	1.315	6,033	2.1
4158	Dave Johnston Plant	11	SI	22109291	Sand Creek	734	100	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	837	LF	22109291	Sand Creek	307	25	StreamRiver	9	15.4	8.207	2.9	1.1
4158	Dave Johnston Plant	837	LF	22109475	North Platte River	558	75	ArtificialPath	9.6	32.3	6.533	6,045	2.9
996	Dean H Mitchell	440	SI	3398598				Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	441	SI	3398598				Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	442	SI	3398598		107	100	Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	443	SI	3398598		92	100	Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	444	SI	3398598		112	100	Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	445	SI	3398598		99	100	Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	446	SI	3398598		598	100	Coastline	117.6	15.7	20.517		
996	Dean H Mitchell	447	SI	3398598		61	100	Coastline	117.6	15.7	20.517		
663	Deerhaven Generating Station	1141	LF	2161584		2491	13	StreamRiver	115.1	16.3	6.467	5.2	0.85
663	Deerhaven Generating Station	1141	LF	2161594		629	38	StreamRiver	114.7	2.8	2.264	0.88	0.73
663	Deerhaven Generating Station	1141	LF	2161866	Turkey Creek	1912	50	StreamRiver	106	15.9	5.544	5.1	0.87
663	Deerhaven Generating Station	1331	SI	2161866	Turkey Creek	2453	100	StreamRiver	106	15.9	5.544	5.1	0.87
1572	Dickerson	839	LF	4505898		209	80	StreamRiver	163	2.6	0.971	2.7	0.88
1572	Dickerson	839	LF	4505932		122	20	StreamRiver	166.5	3.0	2.229	1.2	0.81
51	Dolet Hills	263	SI	8342665	Mundy Bayou	2190	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	264	SI	8342665	Mundy Bayou	1951	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	265	SI	8342665	Mundy Bayou	1027	100	StreamRiver	48	27.2	10.148	12	0.93

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
51	Dolet Hills	266	SI	8342665	Mundy Bayou	1801	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	267	SI	8342665	Mundy Bayou	1417	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	268	SI	8342665	Mundy Bayou	1489	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	269	SI	8342665	Mundy Bayou	1182	100	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	840	LF	8342665	Mundy Bayou	2512	63	StreamRiver	48	27.2	10.148	12	0.93
51	Dolet Hills	840	LF	8342675	Fraigeson Creek	554	38	StreamRiver	42	5.3	2.804	1.5	0.80
3317	Dolphus M Grainger	115	SI	9071958	Waccamaw River	123	100	ArtificialPath	163.9	4.8	2.786	1,536	1.6
3317	Dolphus M Grainger	116	SI	9071944		357	20	LakePond	163.6	2.9	1.535	1.2	0.41
3317	Dolphus M Grainger	116	SI	9071958	Waccamaw River	9	80	ArtificialPath	163.9	4.8	2.786	1,536	1.6
1046	Dubuque	476	SI	13357548				ArtificialPath	124	3.9	0.97	44,809	3.1
6016	Duck Creek	18	SI	13606866				LakePond	89.6	34.2	2.847	8.9	0.99
6016	Duck Creek	19	SI	13606866				LakePond	89.6	34.2	2.847	8.9	0.99
6016	Duck Creek	20	SI	13606866				LakePond	89.6	34.2	2.847	8.9	0.99
6016	Duck Creek	842	LF	13606302		1264	50	LakePond	88	0.3	0.33	0.073	0.26
6016	Duck Creek	842	LF	13606412	Buckheart Creek	49	50	StreamRiver	91.7	7.3	2.505	3.8	0.87
2554	Dunkirk Generating Plant	646	SI	9840316				Coastline	212	0.7	2.17		
2554	Dunkirk Generating Plant	647	SI	9840316				Coastline	212	0.7	2.17		
2554	Dunkirk Generating Plant	648	SI	9840316				Coastline	212	0.7	2.17		
2554	Dunkirk Generating Plant	843	LF	9840306	Erie, Lake	1087	100	Coastline	213.9	3.2	0.374		
26	E. C. Gaston	257	SI	22273418				LakePond	198.9	1.8	1.645	15,076	2.4
1355	E.W. Brown	524	SI	1827810	Herrington Lake	100	100	LakePond	112.4	0.7	0.768	0.76	0.65
1355	E.W. Brown	525	SI	1827810	Herrington Lake	327	100	LakePond	112.4	0.7	0.768	0.76	0.65
991	Eagle Valley	425	SI	18477247	White River	204	50	StreamRiver	83.8	3.3	2.817	2,402	2.2
991	Eagle Valley	425	SI	18477265	White River	1296	50	StreamRiver	84.2	7.2	1.511	2,430	1.7
991	Eagle Valley	426	SI	18477247	White River	194	50	StreamRiver	83.8	3.3	2.817	2,402	2.2
991	Eagle Valley	426	SI	18477265	White River	970	50	StreamRiver	84.2	7.2	1.511	2,430	1.7
991	Eagle Valley	427	SI	18477265	White River	760	100	StreamRiver	84.2	7.2	1.511	2,430	1.7
991	Eagle Valley	428	SI	18477265	White River	848	100	StreamRiver	84.2	7.2	1.511	2,430	1.7
991	Eagle Valley	429	SI	18477247	White River	307	13	StreamRiver	83.8	3.3	2.817	2,402	2.2

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
991	Eagle Valley	429	SI	18477265	White River	1239	88	StreamRiver	84.2	7.2	1.511	2,430	1.7
1217	Earl F Wisdom	844	LF	14621206	Stony Creek	51	100	StreamRiver	51.1	36.4	11.252	8.9	1.0
6018	East Bend Station	23	SI	3407479				ArtificialPath	57.5	10.1	3.572	112,068	3.7
6018	East Bend Station	24	SI	3407479	Ohio River	7	100	ArtificialPath	57.5	10.1	3.572	112,068	3.7
6018	East Bend Station	25	SI	3407479				ArtificialPath	57.5	10.1	3.572	112,068	3.7
6018	East Bend Station	879	LF	3407135	Lick Creek	318	38	StreamRiver	61.8	14.6	7.033	6.3	0.93
6018	East Bend Station	879	LF	3407479	Ohio River	961	63	ArtificialPath	57.5	10.1	3.572	112,068	3.7
2837	Eastlake	914	LF	28123876				Coastline	132.4	19.4	7.628		
2837	Eastlake	1262	SI	28123876		40	100	Coastline	132.4	19.4	7.628		
856	ED Edwards	376	SI	13605656				StreamRiver	75.2	2.3	1.028	0.57	0.37
856	ED Edwards	377	SI	13605656		27	88	StreamRiver	75.2	2.3	1.028	0.57	0.37
856	ED Edwards	377	SI	13606204	Illinois River	280	13	ArtificialPath	74.4	3.0	4.616	10,239	2.3
856	ED Edwards	378	SI	13605656		52	75	StreamRiver	75.2	2.3	1.028	0.57	0.37
856	ED Edwards	378	SI	13606204	Illinois River	325	25	ArtificialPath	74.4	3.0	4.616	10,239	2.3
4050	Edgewater	164	SI	12175600		419	100	StreamRiver	104.6	4.1	2.588	2.3	0.78
4050	Edgewater	165	SI	12175600		361	88	StreamRiver	104.6	4.1	2.588	2.3	0.78
4050	Edgewater	165	SI	12176006		627	13	Coastline	105	2.8	4.96		
4050	Edgewater	166	SI	12175600		958	100	StreamRiver	104.6	4.1	2.588	2.3	0.78
4050	Edgewater	167	SI	12176006		23	100	Coastline	105	2.8	4.96		
4050	Edgewater	168	SI	12175600		290	100	StreamRiver	104.6	4.1	2.588	2.3	0.78
4050	Edgewater	169	SI	12176006		4	100	Coastline	105	2.8	4.96		
4050	Edgewater	858	LF	12175618	Weedons Creek	918	50	StreamRiver	101.9	3.7	2.175	4.7	0.84
4050	Edgewater	858	LF	12175636	Weedons Creek	1121	50	StreamRiver	102	2.8	1.45	0.70	0.56
4050	Edgewater	894	LF	12175600		41	100	StreamRiver	104.6	4.1	2.588	2.3	0.78
1004	Edwardsport	458	SI	18471000	White River	131	100	ArtificialPath	93	16.8	9.517	5,153	1.7
1004	Edwardsport	459	SI	18471000	White River	83	100	ArtificialPath	93	16.8	9.517	5,153	1.7
1004	Edwardsport	971	LF	18471000				ArtificialPath	93	16.8	9.517	5,153	1.7
1374	Elmer Smith Station	1234	SI	10110377	Ohio River	2	100	ArtificialPath	103.3	22.8	9.88	131,885	3.8
1374	Elmer Smith Station	1235	SI	10110377	Ohio River	86	100	ArtificialPath	103.3	22.8	9.88	131,885	3.8
1374	Elmer Smith Station	1236	SI	10110377	Ohio River	381	100	ArtificialPath	103.3	22.8	9.88	131,885	3.8
1374	Elmer Smith Station	1237	SI	10110377	Ohio River	100	100	ArtificialPath	103.3	22.8	9.88	131,885	3.8
3098	Elrama Power Plant	895	LF	3785889	Monongahela River	140	88	ArtificialPath	153	1.4	0.943	10,419	2.2
3098	Elrama Power Plant	895	LF	3785893	Monongahela River	286	13	ArtificialPath	152.3	4.4	1.815	10,410	2.2
3098	Elrama Power Plant	1342	SI	3785905	Monongahela River	321	100	ArtificialPath	149.5	3.2	1.277	10,394	2.8

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3098	Elrama Power Plant	1343	SI	3785905	Monongahela River	376	100	ArtificialPath	149.5	3.2	1.277	10,394	2.8
3098	Elrama Power Plant	1344	SI	3785905	Monongahela River	491	100	ArtificialPath	149.5	3.2	1.277	10,394	2.8
3098	Elrama Power Plant	1345	SI	3785905	Monongahela River	558	100	ArtificialPath	149.5	3.2	1.277	10,394	2.8
1832	Erickson Station	587	SI	12241814		499	100	StreamRiver	108	7.5	3.232	1.6	0.75
87	Escalante	274	SI	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
87	Escalante	275	SI	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
87	Escalante	276	SI	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
87	Escalante	277	SI	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
87	Escalante	278	SI	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
87	Escalante	992	LF	17771165				StreamRiver	9	10.0	6.024	0.19	0.80
1012	F. B. Culley	466	SI	10110339	Ohio River	3	100	ArtificialPath	89	11.0	4.03	132,544	2.2
1012	F. B. Culley	467	SI	10110269		10	63	StreamRiver	97.3	9.2	7.937	559	1.3
1012	F. B. Culley	467	SI	10110337		60	38	ArtificialPath	92.6	0.3	0.554	559	1.3
1218	Fair Station	896	LF	14805213	Pine Creek	21	100	StreamRiver	79	6.9	4.51	25	1.1
1218	Fair Station	1183	SI	14805943	Mississippi River	119	100	ArtificialPath	79	0.5	0.711	54,904	3.2
1218	Fair Station	1184	SI	14805943	Mississippi River	125	100	ArtificialPath	79	0.5	0.711	54,904	3.2
6179	Fayette Power Project	183	SI	5791766	Cedar Creek	827	100	StreamRiver	15.8	35.8	10.694	4.5	0.91
6179	Fayette Power Project	184	SI	5791766	Cedar Creek	99	100	StreamRiver	15.8	35.8	10.694	4.5	0.91
6179	Fayette Power Project	897	LF	5791766				StreamRiver	15.8	35.8	10.694	4.5	0.91
886	Fisk	1238	SI	14789961	Chicago Sanitary And Ship Canal	9	100	ArtificialPath	112	25.6	5.83	165	1.0
886	Fisk	1239	SI	14789961	Chicago Sanitary And Ship Canal	1	100	ArtificialPath	112	25.6	5.83	165	1.0
886	Fisk	1240	SI	14789961	Chicago Sanitary And Ship Canal	9	100	ArtificialPath	112	25.6	5.83	165	1.0
6138	Flint Creek	173	SI	399464				StreamRiver	137	4.8	4.08	1.3	0.77
6138	Flint Creek	174	SI	399464				StreamRiver	137	4.8	4.08	1.3	0.77
6138	Flint Creek	898	LF	399464		50	100	StreamRiver	137	4.8	4.08	1.3	0.77
3943	Fort Martin Power Station	1142	LF	3768484		260	50	StreamRiver	160.4	3.3	3.197	2.5	0.83

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3943	Fort Martin Power Station	1142	LF	3768832	Monongahela River	654	50	ArtificialPath	162.6	7.5	4.138	5,343	1.1
3943	Fort Martin Power Station	1143	LF	3768476	Crooked Run	90	100	StreamRiver	159.7	2.3	1.753	5.6	0.70
3943	Fort Martin Power Station	1181	SI	3768832	Monongahela River	35	100	ArtificialPath	162.6	7.5	4.138	5,343	1.1
3943	Fort Martin Power Station	1182	SI	3768832	Monongahela River	35	100	ArtificialPath	162.6	7.5	4.138	5,343	1.1
10343	Foster Wheeler Mt Carmel Cogen	901	LF	4517604				StreamRiver	267.2	30.8	7.184	20	1.1
2442	Four Corners	638	SI	16967534	Chaco River	661	100	StreamRiver	11	4.0	1.933	295	2.2
2442	Four Corners	639	SI	16967534	Chaco River	1142	100	StreamRiver	11	4.0	1.933	295	2.2
2442	Four Corners	640	SI	16968628				StreamRiver	11	22.1	0.57	0.36	0.80
2442	Four Corners	641	SI	16968628				StreamRiver	11	22.1	0.57	0.36	0.80
2442	Four Corners	642	SI	16968628				StreamRiver	11	22.1	0.57	0.36	0.80
2442	Four Corners	903	LF	16967534	Chaco River	1565	63	StreamRiver	11	4.0	1.933	295	2.2
2442	Four Corners	903	LF	16968630		76	38	StreamRiver	11	1.4	2.403	0.022	0.64
2442	Four Corners	915	LF	16967534	Chaco River	1139	100	StreamRiver	11	4.0	1.933	295	2.2
1043	Frank E. Ratts	468	SI	18472136				ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	469	SI	18472136	White River	228	100	ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	470	SI	18472136	White River	360	100	ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	471	SI	18472136				ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	472	SI	18472136	White River	237	100	ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	473	SI	18472136				ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	474	SI	18472136				ArtificialPath	96.4	7.0	2.717	12,422	2.4
1043	Frank E. Ratts	475	SI	18472136	White River	381	100	ArtificialPath	96.4	7.0	2.717	12,422	2.4
2718	G G Allen	668	SI	9756896	Catawba River	223	100	LakePond	123.8	12.9	5.276	3,884	1.8
2718	G G Allen	669	SI	9756896	Catawba River	18	100	LakePond	123.8	12.9	5.276	3,884	1.8
2718	G G Allen	670	SI	9756896	Catawba River	84	100	LakePond	123.8	12.9	5.276	3,884	1.8
2718	G G Allen	892	LF	9756896	Catawba River	163	100	LakePond	123.8	12.9	5.276	3,884	1.8
7	Gadsden	253	SI	22199835				ArtificialPath	246	2.7	3.254	10,374	2.3
3403	Gallatin	128	SI	18415917				LakePond	137.8	42.5	11.478	18,812	2.5
3403	Gallatin	129	SI	18415917				LakePond	137.8	42.5	11.478	18,812	2.5
3403	Gallatin	130	SI	18415917				LakePond	137.8	42.5	11.478	18,812	2.5
8102	General James M. Gavin	246	SI	19443209		155	25	StreamRiver	103	1.3	1.26	0.53	0.72
8102	General James M. Gavin	246	SI	19443217		187	25	StreamRiver	103	0.4	0.708	0.71	0.67

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
8102	General James M. Gavin	246	SI	19443421	Stingy Run	96	50	StreamRiver	103	0.9	1.959	1.9	0.73
8102	General James M. Gavin	247	SI	19443293	Kyger Creek	460	63	StreamRiver	106.4	6.1	3.804	26	0.90
8102	General James M. Gavin	247	SI	19443465	Ohio River	553	13	ArtificialPath	106.9	3.9	3.277	59,443	3.2
8102	General James M. Gavin	247	SI	19443471	Ohio River	139	25	ArtificialPath	107.9	6.3	3.367	59,450	3.2
8102	General James M. Gavin	1144	LF	19443209		637	40	StreamRiver	103	1.3	1.26	0.53	0.72
8102	General James M. Gavin	1144	LF	19443249	Turkey Run	696	60	StreamRiver	104.3	4.3	3.652	1.8	0.83
4143	Genoa	1007	LF	13208374				ArtificialPath	145.4	1.9	2.556	32,842	2.9
4143	Genoa	1131	LF	13208374				ArtificialPath	145.4	1.9	2.556	32,842	2.9
1091	George Neal North	504	SI	17244416				ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	505	SI	17244416				ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	506	SI	17244416				ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	906	LF	17244030		1893	38	StreamRiver	30.5	34.3	1.424	0.13	0.31
1091	George Neal North	906	LF	17244416	Missouri River	8	63	ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	907	LF	17244416				ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	908	LF	17244416				ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	909	LF	17244416	Missouri River	15	100	ArtificialPath	28.5	31.9	6.467	46,038	3.5
1091	George Neal North	910	LF	17244416	Missouri River	343	100	ArtificialPath	28.5	31.9	6.467	46,038	3.5
7343	George Neal South	911	LF	17244030		221	100	StreamRiver	30.5	34.3	1.424	0.13	0.31
7343	George Neal South	1332	SI	17244416	Missouri River	659	100	ArtificialPath	28.5	31.9	6.467	46,038	3.5
6077	Gerald Gentleman	912	LF	17432276		39	100	StreamRiver	14.5	160.9	5.16	1.4	0.46
1356	Ghent	526	SI	3408285				ArtificialPath	56	4.1	2.236	112,376	3.7
1356	Ghent	527	SI	3408285	Ohio River	165	100	ArtificialPath	56	4.1	2.236	112,376	3.7
1356	Ghent	528	SI	3408281	Ohio River	7	29	ArtificialPath	56	0.1	0.212	112,374	4.1
1356	Ghent	528	SI	3408285	Ohio River	51	71	ArtificialPath	56	4.1	2.236	112,376	3.7
1356	Ghent	529	SI	3408201	Black Creek	824	100	StreamRiver	56	7.0	3.389	2.7	0.92
1356	Ghent	530	SI	3408285				ArtificialPath	56	4.1	2.236	112,376	3.7
6136	Gibbons Creek Steam Electric Station	881	LF	5577597	Plum Creek	1260	50	StreamRiver	19.9	12.1	8.059	2.4	0.78
6136	Gibbons Creek Steam Electric Station	881	LF	5577627	Hog Creek	830	50	StreamRiver	18.7	9.3	5.079	6.9	0.73
6136	Gibbons Creek Steam Electric Station	913	LF	5577621		171	13	StreamRiver	19.1	2.8	2.038	0.55	0.70

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6136	Gibbons Creek Steam Electric Station	913	LF	5577627	Hog Creek	423	88	StreamRiver	18.7	9.3	5.079	6.9	0.73
6136	Gibbons Creek Steam Electric Station	1241	SI	5577643	Gibbons Creek	740	100	StreamRiver	18.6	1.8	1.182	30	1.2
6136	Gibbons Creek Steam Electric Station	1242	SI	5577643	Gibbons Creek	740	100	StreamRiver	18.6	1.8	1.182	30	1.2
6136	Gibbons Creek Steam Electric Station	1243	SI	5577643	Gibbons Creek	740	100	StreamRiver	18.6	1.8	1.182	30	1.2
6136	Gibbons Creek Steam Electric Station	1244	SI	5577653	Big Branch	303	75	StreamRiver	19.5	4.0	2.998	1.0	0.72
6136	Gibbons Creek Steam Electric Station	1244	SI	5578305	Carlos Lake	445	25	LakePond	20	0.7	0.326	1.2	0.41
6113	Gibson	81	SI	10381539		569	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
6113	Gibson	82	SI	10381539		290	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
6113	Gibson	83	SI	10381539		20	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
6113	Gibson	84	SI	10381539		2449	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
6113	Gibson	85	SI	10381539		220	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
6113	Gibson	86	SI	10382059	Wabash River	255	100	ArtificialPath	71.8	2.9	3.354	28,710	2.2
6113	Gibson	902	LF	10381975		40	40	CanalDitch	69.6	6.5	5.035	2.0	0.61
6113	Gibson	902	LF	10381977	Coffee Bayou	193	60	StreamRiver	70.5	21.6	9.114	45	1.0
6113	Gibson	904	LF	10381539		109	100	StreamRiver	73.9	15.2	5.831	4.7	0.61
3776	Glen Lyn	146	SI	6908685	New River	61	100	ArtificialPath	169	3.0	2.602	5,294	2.3
3776	Glen Lyn	147	SI	6907783	East River	113	38	StreamRiver	172.5	9.8	5.516	97	1.4
3776	Glen Lyn	147	SI	6908699	New River	39	63	ArtificialPath	170.8	3.8	0.827	5,186	2.0
3776	Glen Lyn	870	LF	6908685	New River	59	100	ArtificialPath	169	3.0	2.602	5,294	2.3
8	Gorgas	254	SI	18592152	Mulberry Fork	681	100	LakePond	231.3	12.2	10.193	3,543	1.8
8	Gorgas	255	SI	18592136	Mulberry Fork	86	50	LakePond	235.3	0.5	1.123	3,510	1.8
8	Gorgas	255	SI	18592152	Mulberry Fork	661	50	LakePond	231.3	12.2	10.193	3,543	1.8
8	Gorgas	963	LF	18591860				StreamRiver	231.6	5.3	3.953	25	0.83
1825	Grand Haven City of J.B. Sims	1309	SI	9005799	Grand River	418	100	ArtificialPath	251	11.7	4.315	3,605	1.5
1825	Grand Haven City of J.B. Sims	1310	SI	9005799	Grand River	418	100	ArtificialPath	251	11.7	4.315	3,605	1.5
10151	Grant Town Power Plant	871	LF	3769488	Paw Paw Creek	63	100	StreamRiver	142.2	6.1	3.947	59	1.2
10151	Grant Town Power Plant	872	LF	3769696	Moody Run	259	29	StreamRiver	141.2	0.9	1.297	2.8	0.85
10151	Grant Town Power Plant	872	LF	3771470	Buffalo Creek	41	57	StreamRiver	140.3	0.6	0.827	227	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
10151	Grant Town Power Plant	872	LF	3771476	Buffalo Creek	339	14	Connector	141	0.0	0.067	227	1.1
10151	Grant Town Power Plant	873	LF	3769768	Buffalo Creek	391	100	StreamRiver	142.1	7.3	3.549	195	1.0
10151	Grant Town Power Plant	1167	SI	3769488	Paw Paw Creek	751	100	StreamRiver	142.2	6.1	3.947	59	1.2
10151	Grant Town Power Plant	1168	SI	3769488	Paw Paw Creek	567	100	StreamRiver	142.2	6.1	3.947	59	1.2
10151	Grant Town Power Plant	1169	SI	3769488	Paw Paw Creek	779	100	StreamRiver	142.2	6.1	3.947	59	1.2
10151	Grant Town Power Plant	1170	SI	3769488	Paw Paw Creek	1148	100	StreamRiver	142.2	6.1	3.947	59	1.2
10151	Grant Town Power Plant	1171	SI	3769488	Paw Paw Creek	1044	100	StreamRiver	142.2	6.1	3.947	59	1.2
165	GRDA	874	LF	21773139	Chouteau Creek	1381	100	ArtificialPath	40	22.4	6.481	64	0.81
165	GRDA	1210	SI	21773139	Chouteau Creek	1575	100	ArtificialPath	40	22.4	6.481	64	0.81
1357	Green River	531	SI	11629601		555	13	StreamRiver	100	1.1	1.646	0.61	0.71
1357	Green River	531	SI	11630665	Green River	450	88	ArtificialPath	100	2.7	2.491	9,266	2.2
1357	Green River	532	SI	11630665	Green River	66	100	ArtificialPath	100	2.7	2.491	9,266	2.2
1357	Green River	533	SI	11630665	Green River	176	100	ArtificialPath	100	2.7	2.491	9,266	2.2
1357	Green River	534	SI	11630375		177	63	StreamRiver	143	2.0	1.789	1.9	0.83
1357	Green River	534	SI	11630393		208	38	StreamRiver	145.8	1.4	1.51	0.78	0.74
1357	Green River	535	SI	11629611		106	38	StreamRiver	100	0.5	0.829	1.1	0.65
1357	Green River	535	SI	11630665	Green River	143	63	ArtificialPath	100	2.7	2.491	9,266	2.2
10	Greene County	256	SI	18211194				LakePond	140.8	9.4	4.374	10,380	2.3
6041	H L Spurlock Station	34	SI	1922018	Ohio River	89	100	ArtificialPath	68	7.0	4.62	98,763	3.6
6041	H L Spurlock Station	972	LF	1922018				ArtificialPath	68	7.0	4.62	98,763	3.6
2709	H.F. Lee Plant	656	SI	8790567	Halfmile Branch	30	57	StreamRiver	158.4	8.3	2.364	4.2	0.80
2709	H.F. Lee Plant	656	SI	11239877	Neuse River	115	43	StreamRiver	159.7	1.9	1.63	2,009	1.8
2709	H.F. Lee Plant	657	SI	8790567	Halfmile Branch	60	43	StreamRiver	158.4	8.3	2.364	4.2	0.80
2709	H.F. Lee Plant	657	SI	11239863	Neuse River	93	57	StreamRiver	159.4	0.8	0.994	2,014	1.7
2709	H.F. Lee Plant	658	SI	8790567	Halfmile Branch	21	86	StreamRiver	158.4	8.3	2.364	4.2	0.80
2709	H.F. Lee Plant	658	SI	11239863	Neuse River	757	14	StreamRiver	159.4	0.8	0.994	2,014	1.7
2709	H.F. Lee Plant	659	SI	11239873		1217	33	StreamRiver	157.2	1.8	1.708	0.68	0.51

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2709	H.F. Lee Plant	659	SI	11239875	Neuse River	56	67	StreamRiver	157.3	6.2	7.423	2,032	1.3
2709	H.F. Lee Plant	660	SI	11239875				StreamRiver	157.3	6.2	7.423	2,032	1.3
708	Hammond	351	SI	15821397				StreamRiver	244.9	1.0	0.739	26	0.83
708	Hammond	352	SI	15821397				StreamRiver	244.9	1.0	0.739	26	0.83
708	Hammond	353	SI	15821397				StreamRiver	244.9	1.0	0.739	26	0.83
708	Hammond	354	SI	15821397				StreamRiver	244.9	1.0	0.739	26	0.83
708	Hammond	1145	LF	15821107	Smith Creek	117	50	StreamRiver	252.7	1.5	1.406	1.5	0.73
708	Hammond	1145	LF	15821109		19	50	StreamRiver	256.6	1.9	3.311	1.2	0.85
1731	Harbor Beach Power Plant	581	SI	12919103				Coastline	67	0.4	1.427		
990	Harding Street	420	SI	18476899	White River	104	100	ArtificialPath	76.5	20.4	4.325	1,869	1.9
990	Harding Street	421	SI	18476899	White River	590	100	ArtificialPath	76.5	20.4	4.325	1,869	1.9
990	Harding Street	422	SI	18476493		161	88	StreamRiver	80.2	18.9	10.144	22	1.0
990	Harding Street	422	SI	18476899	White River	429	13	ArtificialPath	76.5	20.4	4.325	1,869	1.9
990	Harding Street	423	SI	18476493		13	100	StreamRiver	80.2	18.9	10.144	22	1.0
990	Harding Street	424	SI	18476493		29	100	StreamRiver	80.2	18.9	10.144	22	1.0
709	Harllee Branch	355	SI	1056813		160	33	StreamRiver	174.9	1.2	1.657	0.59	0.67
709	Harllee Branch	355	SI	1056825	Beaverdam Creek	384	33	StreamRiver	174	0.6	0.783	3.3	0.78
709	Harllee Branch	355	SI	1056829		21	33	StreamRiver	174.2	3.1	1.497	2.1	0.77
709	Harllee Branch	356	SI	1057729				LakePond	170.2	2.7	2.464	921	1.4
709	Harllee Branch	357	SI	1057729	Little River	256	50	LakePond	170.2	2.7	2.464	921	1.4
709	Harllee Branch	357	SI	1057741	Little River	231	50	LakePond	173.1	10.7	3.682	918	0.96
709	Harllee Branch	358	SI	1057741	Little River	41	100	LakePond	173.1	10.7	3.682	918	0.96
709	Harllee Branch	359	SI	1057741	Little River	5	100	LakePond	173.1	10.7	3.682	918	0.96
6193	Harrington	877	LF	19983982		238	100	StreamRiver	5	39.4	5.199	0.49	0.91
6193	Harrington	878	LF	19983982		23	100	StreamRiver	5	39.4	5.199	0.49	0.91
3944	Harrison Power Station	158	SI	3715706				StreamRiver	140.4	2.3	2.527	1,431	2.1
3944	Harrison Power Station	891	LF	3715680	Robinson Run	378	100	StreamRiver	139.9	11.4	6.605	9.7	0.98
3179	Hatfield's Ferry Power Station	880	LF	3787587	Little Whiteley Creek	638	100	StreamRiver	150.3	7.6	3.892	14	1.1
3179	Hatfield's Ferry Power Station	1215	SI	3787587	Little Whiteley Creek	49	100	StreamRiver	150.3	7.6	3.892	14	1.1
3179	Hatfield's Ferry Power Station	1216	SI	3787587	Little Whiteley Creek	25	100	StreamRiver	150.3	7.6	3.892	14	1.1
3179	Hatfield's Ferry Power Station	1217	SI	3787587	Little Whiteley Creek	43	100	StreamRiver	150.3	7.6	3.892	14	1.1
3179	Hatfield's Ferry Power Station	1218	SI	3787587	Little Whiteley Creek	58	100	StreamRiver	150.3	7.6	3.892	14	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3179	Hatfield's Ferry Power Station	1219	SI	3787587	Little Whiteley Creek	34	100	StreamRiver	150.3	7.6	3.892	14	1.1
891	Havana	392	SI	13608610	Illinois River	271	100	ArtificialPath	98.7	8.7	5.527	12,540	2.4
891	Havana	393	SI	13608610	Illinois River	349	100	ArtificialPath	98.7	8.7	5.527	12,540	2.4
2079	Hawthorn	599	SI	4391195				StreamRiver	47	45.7	9.406	82	1.1
2079	Hawthorn	962	LF	4391195				StreamRiver	47	45.7	9.406	82	1.1
525	Hayden	332	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	333	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	334	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	335	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	336	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	337	SI	120299630				StreamRiver	24.7	4.3	4.247	0.23	0.33
525	Hayden	882	LF	1355212	Grassy Creek	680	100	StreamRiver	29.4	4.4	0.962	5.8	1.0
525	Hayden	1146	LF	120299723	Sage Creek	229	88	StreamRiver	26.4	5.1	3.487	11	1.5
525	Hayden	1146	LF	120299725	Grassy Creek	489	13	StreamRiver	27.2	3.3	3.603	8.6	1.6
3251	HB Robinson / Darlington Electric Power Plant	104	SI	9176570		149	100	StreamRiver	239.8	0.1	0.392	0.85	0.71
892	Hennepin Power Station	394	SI	14837739	Illinois River	6	50	ArtificialPath	75	5.8	5.035	9,133	2.0
892	Hennepin Power Station	394	SI	14837757	Illinois River	232	50	ArtificialPath	75	3.5	1.557	9,137	2.2
892	Hennepin Power Station	883	LF	14837739				ArtificialPath	75	5.8	5.035	9,133	2.0
1382	HMP&L Station Two Henderson	556	SI	11617207	Grane Creek	1185	100	StreamRiver	84.1	16.3	6.565	9.4	0.90
1382	HMP&L Station Two Henderson	557	SI	11617207	Grane Creek	1495	13	StreamRiver	84.1	16.3	6.565	9.4	0.90
1382	HMP&L Station Two Henderson	557	SI	11617335	Green River	171	88	ArtificialPath	83.8	11.1	6.149	12,480	2.3
1382	HMP&L Station Two Henderson	984	LF	11617207				StreamRiver	84.1	16.3	6.565	9.4	0.90
108	HOLCOMB	1147	LF	21251510		4032	100	StreamRiver	2.1	10.0	2.77	0.12	0.63
3122	Homer City Station	90	SI	4752220		537	100	StreamRiver	243.2	3.6	3.492	2.5	0.87
3122	Homer City Station	91	SI	4752280		1284	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	92	SI	4752260		25	100	StreamRiver	242	2.7	1.332	1.8	0.82
3122	Homer City Station	719	SI	4752260		6	100	StreamRiver	242	2.7	1.332	1.8	0.82
3122	Homer City Station	720	SI	4752280		848	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	721	SI	4752220		447	100	StreamRiver	243.2	3.6	3.492	2.5	0.87

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3122	Homer City Station	722	SI	4752280		1428	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	723	SI	4752280		1633	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	724	SI	4752280		1573	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	725	SI	4752260		15	100	StreamRiver	242	2.7	1.332	1.8	0.82
3122	Homer City Station	726	SI	4752280		1406	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	727	SI	4752280		1276	100	StreamRiver	248.1	2.6	1.512	1.8	0.87
3122	Homer City Station	728	SI	4752220		6	100	StreamRiver	243.2	3.6	3.492	2.5	0.87
3122	Homer City Station	729	SI	4752220		22	100	StreamRiver	243.2	3.6	3.492	2.5	0.87
3122	Homer City Station	884	LF	4752220		696	13	StreamRiver	243.2	3.6	3.492	2.5	0.87
3122	Homer City Station	884	LF	4752250	Muddy Run	804	25	StreamRiver	239.5	6.2	3.004	7.9	0.93
3122	Homer City Station	884	LF	4752260		313	63	StreamRiver	242	2.7	1.332	1.8	0.82
3122	Homer City Station	886	LF	4752220		211	63	StreamRiver	243.2	3.6	3.492	2.5	0.87
3122	Homer City Station	886	LF	4752244	Cherry Run	457	38	StreamRiver	249	1.0	1.488	28	1.0
3122	Homer City Station	1134	LF	4752176		380	38	StreamRiver	238.1	4.7	3.577	3.2	0.89
3122	Homer City Station	1134	LF	4752220		209	63	StreamRiver	243.2	3.6	3.492	2.5	0.87
1943	Hoot Lake	887	LF	6657971		114	100	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1148	LF	6657951	Otter Tail River	128	33	StreamRiver	31.9	0.2	0.523	258	2.6
1943	Hoot Lake	1148	LF	6657971		94	33	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1148	LF	6658359	Wright Lake	109	33	LakePond	32	0.9	1.391	258	1.9
1943	Hoot Lake	1156	LF	6657971		154	63	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1156	LF	6659311		1960	38	StreamRiver	35.5	25.2	8.409	6.8	0.58
1943	Hoot Lake	1157	LF	6657971		48	50	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1157	LF	6658359	Wright Lake	68	50	LakePond	32	0.9	1.391	258	1.9
1943	Hoot Lake	1158	LF	6657971		22	75	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1158	LF	6658359	Wright Lake	155	25	LakePond	32	0.9	1.391	258	1.9
1943	Hoot Lake	1159	LF	6657971		22	100	StreamRiver	32.1	3.6	4.426	0.34	0.63
1943	Hoot Lake	1160	LF	6657971		35	100	StreamRiver	32.1	3.6	4.426	0.34	0.63
10771	Hopewell	1362	SI	10067517	James River	1996	100	ArtificialPath	161.1	7.1	3.305	9,218	2.2
6772	Hugo	229	SI	592548	Bird Creek	281	100	StreamRiver	45.1	9.9	4.384	9.1	0.92
6772	Hugo	230	SI	592548	Bird Creek	319	100	StreamRiver	45.1	9.9	4.384	9.1	0.92
6772	Hugo	231	SI	592548				StreamRiver	45.1	9.9	4.384	9.1	0.92
6772	Hugo	232	SI	592548				StreamRiver	45.1	9.9	4.384	9.1	0.92
6772	Hugo	755	LF	592548	Bird Creek	1562	38	StreamRiver	45.1	9.9	4.384	9.1	0.92
6772	Hugo	755	LF	593644	Bird Creek	2191	38	StreamRiver	45	2.7	0.604	10	0.94
6772	Hugo	755	LF	593682	Kiamichi River	3132	25	StreamRiver	44.2	18.0	6.629	2,069	1.7
3176	Hunlock Power Station	102	SI	2603121	Susquehanna River	3	100	ArtificialPath	246.7	14.7	9.45	14,712	2.5
3176	Hunlock Power Station	103	SI	2603121	Susquehanna River	76	100	ArtificialPath	246.7	14.7	9.45	14,712	2.5

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6165	Hunter Plant	756	LF	4876935		2340	13	StreamRiver	24.7	4.0	0.909	0.10	0.79
6165	Hunter Plant	756	LF	4876945		1190	25	StreamRiver	24.9	2.7	1.736	0.024	0.66
6165	Hunter Plant	756	LF	4878793		293	63	StreamRiver	22.6	8.5	3.963	0.074	0.79
6165	Hunter Plant	1258	SI	4876749		89	50	StreamRiver	35.4	5.2	4.458	0.045	0.70
6165	Hunter Plant	1258	SI	4877929		910	50	StreamRiver	34	5.1	2.612	0.095	0.74
8069	Huntington Plant	757	LF	4876411	Huntington Creek	1031	100	StreamRiver	60.6	9.3	4.198	72	1.8
8069	Huntington Plant	758	LF	4876411	Huntington Creek	1041	100	StreamRiver	60.6	9.3	4.198	72	1.8
8069	Huntington Plant	759	LF	4876411	Huntington Creek	1057	100	StreamRiver	60.6	9.3	4.198	72	1.8
8069	Huntington Plant	1363	SI	4876411	Huntington Creek	534	100	StreamRiver	60.6	9.3	4.198	72	1.8
8069	Huntington Plant	1364	SI	4876411	Huntington Creek	743	100	StreamRiver	60.6	9.3	4.198	72	1.8
863	Hutsonville	381	SI	10286344	Wabash River	19	100	ArtificialPath	76	5.5	3.144	12,016	2.4
863	Hutsonville	382	SI	10285974	Raccoon Creek	610	13	StreamRiver	75.4	20.8	6.42	36	1.0
863	Hutsonville	382	SI	10286344	Wabash River	145	88	ArtificialPath	76	5.5	3.144	12,016	2.4
863	Hutsonville	383	SI	10285974	Raccoon Creek	684	38	StreamRiver	75.4	20.8	6.42	36	1.0
863	Hutsonville	383	SI	10286344	Wabash River	310	63	ArtificialPath	76	5.5	3.144	12,016	2.4
863	Hutsonville	384	SI	10286344	Wabash River	42	100	ArtificialPath	76	5.5	3.144	12,016	2.4
6065	Iatan	40	SI	2254745				StreamRiver	46	4.3	4.141	2.5	0.64
6065	Iatan	1154	LF	2254745		260	13	StreamRiver	46	4.3	4.141	2.5	0.64
6065	Iatan	1154	LF	2254749		519	88	StreamRiver	46	5.3	2.685	0.053	0.56
6641	Independence	1153	LF	7550633		69	20	StreamRiver	113	2.6	1.941	0.85	0.48
6641	Independence	1153	LF	11832646		745	80	StreamRiver	113	0.8	1.32	1.4	0.43
2132	Independence Power & Light - Blue Valley Station	616	SI	4390505		934	100	StreamRiver	51.4	4.6	2.874	0.19	0.73
2132	Independence Power & Light - Blue Valley Station	617	SI	4390505		1181	100	StreamRiver	51.4	4.6	2.874	0.19	0.73
2132	Independence Power & Light - Blue Valley Station	618	SI	4390505		1345	100	StreamRiver	51.4	4.6	2.874	0.19	0.73
594	Indian River Generating Station	339	SI	8409145				ArtificialPath	320	1.2	1.671	119	0.95
594	Indian River Generating Station	340	SI	8409145				ArtificialPath	320	1.2	1.671	119	0.95

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
594	Indian River Generating Station	762	LF	8409145	Indian River	89	100	ArtificialPath	320	1.2	1.671	119	0.95
594	Indian River Generating Station	775	LF	8409147	Indian River	77	88	ArtificialPath	331.4	3.4	1.42	118	0.95
594	Indian River Generating Station	775	LF	8409159	Indian River	452	13	ArtificialPath	331.4	3.4	1.42	103	0.92
6481	Intermountain Power Project	214	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
6481	Intermountain Power Project	215	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
6481	Intermountain Power Project	216	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
6481	Intermountain Power Project	217	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
6481	Intermountain Power Project	218	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
6481	Intermountain Power Project	219	SI	1197680				StreamRiver	14.6	89.8	6.688	0.72	0.41
7097	J K Spruce	753	LF	10840882	Calaveras Lake	293	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1368	SI	10840882	Calaveras Lake	819	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1369	SI	10840882	Calaveras Lake	844	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1370	SI	10840882	Calaveras Lake	654	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1371	SI	10840882	Calaveras Lake	347	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1372	SI	10840882	Calaveras Lake	621	100	LakePond	14.9	20.6	7.798	26	0.74
7097	J K Spruce	1373	SI	10840882	Calaveras Lake	894	100	LakePond	14.9	20.6	7.798	26	0.74
2850	J M Stuart	706	SI	1920658	Threemile Creek	44	29	StreamRiver	70.7	0.6	0.545	7.3	0.56
2850	J M Stuart	706	SI	1920666	Threemile Creek	74	43	StreamRiver	71.2	3.4	3.016	6.2	0.91
2850	J M Stuart	706	SI	1922204	Ohio River	219	29	ArtificialPath	72	0.5	0.708	98,702	3.6
2850	J M Stuart	707	SI	1920740	Buzzardroost Creek	210	50	StreamRiver	73	3.0	2.9	1.4	0.85
2850	J M Stuart	707	SI	1922224	Ohio River	158	50	ArtificialPath	72	4.3	2.962	98,699	3.6
2850	J M Stuart	708	SI	1922224	Ohio River	89	100	ArtificialPath	72	4.3	2.962	98,699	3.6
2850	J M Stuart	709	SI	1922224	Ohio River	15	100	ArtificialPath	72	4.3	2.962	98,699	3.6
2850	J M Stuart	710	SI	1922224	Ohio River	41	100	ArtificialPath	72	4.3	2.962	98,699	3.6
2850	J M Stuart	711	SI	1920666	Threemile Creek	76	38	StreamRiver	71.2	3.4	3.016	6.2	0.91

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2850	J M Stuart	711	SI	1920740	Buzzardroost Creek	1018	13	StreamRiver	73	3.0	2.9	1.4	0.85
2850	J M Stuart	711	SI	1922224	Ohio River	563	50	ArtificialPath	72	4.3	2.962	98,699	3.6
2850	J M Stuart	766	LF	1920716	Elk Run	742	13	StreamRiver	75.9	0.7	0.645	1.9	0.74
2850	J M Stuart	766	LF	1920740	Buzzardroost Creek	408	38	StreamRiver	73	3.0	2.9	1.4	0.85
2850	J M Stuart	766	LF	1922226	Ohio River	434	50	ArtificialPath	75.7	1.2	1.023	98,620	3.6
2850	J M Stuart	767	LF	1920740	Buzzardroost Creek	315	75	StreamRiver	73	3.0	2.9	1.4	0.85
2850	J M Stuart	767	LF	1922224	Ohio River	564	25	ArtificialPath	72	4.3	2.962	98,699	3.6
6181	J T Deely	768	LF	10840882	Calaveras Lake	401	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1002	LF	10840882				LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1291	SI	10840882	Calaveras Lake	819	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1292	SI	10840882	Calaveras Lake	844	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1293	SI	10840882	Calaveras Lake	654	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1294	SI	10840882	Calaveras Lake	347	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1295	SI	10840882	Calaveras Lake	353	100	LakePond	14.9	20.6	7.798	26	0.74
6181	J T Deely	1296	SI	10840882	Calaveras Lake	290	100	LakePond	14.9	20.6	7.798	26	0.74
1720	J.C. Weadock	573	SI	12928873				Coastline	72	2.0	4.496		
1720	J.C. Weadock	574	SI	12928873				Coastline	72	2.0	4.496		
1720	J.C. Weadock	575	SI	12928873				Coastline	72	2.0	4.496		
1720	J.C. Weadock	576	SI	12928873				Coastline	72	2.0	4.496		
1720	J.C. Weadock	1003	LF	12928873				Coastline	72	2.0	4.496		
1723	J.R Whiting	577	SI	25769231				Coastline	95	2.9	17.625		
1723	J.R Whiting	578	SI	25769231				Coastline	95	2.9	17.625		
1723	J.R Whiting	579	SI	25769231				Coastline	95	2.9	17.625		
1723	J.R Whiting	580	SI	25769231				Coastline	95	2.9	17.625		
1723	J.R Whiting	965	LF	25769231				Coastline	95	2.9	17.625		
1723	J.R Whiting	1000	LF	25769231				Coastline	95	2.9	17.625		
710	Jack McDonough	360	SI	3286334				ArtificialPath	236.4	9.3	2.507	3,781	1.8
710	Jack McDonough	361	SI	3286334				ArtificialPath	236.4	9.3	2.507	3,781	1.8
710	Jack McDonough	362	SI	3286334				ArtificialPath	236.4	9.3	2.507	3,781	1.8
710	Jack McDonough	363	SI	3286334				ArtificialPath	236.4	9.3	2.507	3,781	1.8
710	Jack McDonough	968	LF	3286334				ArtificialPath	236.4	9.3	2.507	3,781	1.8
2049	Jack Watson	595	SI	18076850				CanalDitch	243.4	1.6	1.07	1.0	0.39
2049	Jack Watson	769	LF	18076850		37	57	CanalDitch	243.4	1.6	1.07	1.0	0.39
2049	Jack Watson	769	LF	18077068		788	43	ArtificialPath	247.3	5.1	4.454	3.3	0.49
1830	James De Young	770	LF	9017139		600	63	StreamRiver	222.2	5.5	4.861	1.7	0.75
1830	James De Young	770	LF	9017145		86	38	StreamRiver	221.9	3.1	4.632	0.98	0.72

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1830	James De Young	1333	SI	9017853	Macatawa, Lake	140	100	LakePond	235.9	15.6	3.908	109	0.94
6002	James H. Miller Jr.	16	SI	18567309				StreamRiver	287.9	15.2	10.511	173	1.2
2161	James River Power Station	619	SI	7608061				LakePond	103.8	2.6	0.83	232	1.7
2161	James River Power Station	771	LF	7607387	James River	286	25	StreamRiver	104	0.6	0.778	233	1.1
2161	James River Power Station	771	LF	7608001	James River	156	75	StreamRiver	104	1.0	1.355	233	1.4
2187	JE Corette Plant	764	LF	4342872		66	67	StreamRiver	65.4	33.3	5.094	0.81	0.78
2187	JE Corette Plant	764	LF	4343546	Yellowstone River	52	33	ArtificialPath	64.2	0.2	0.48	9,675	2.3
2187	JE Corette Plant	1249	SI	4343546	Yellowstone River	20	100	ArtificialPath	64.2	0.2	0.48	9,675	2.3
2187	JE Corette Plant	1250	SI	4342872		143	20	StreamRiver	65.4	33.3	5.094	0.81	0.78
2187	JE Corette Plant	1250	SI	4343004	Yellowstone River	7	40	ArtificialPath	64	0.0	0.062	9,675	2.3
2187	JE Corette Plant	1250	SI	4343546	Yellowstone River	8	40	ArtificialPath	64.2	0.2	0.48	9,675	2.3
3319	Jefferies	117	SI	11565234		76	33	StreamRiver	171.9	1.0	1.446	0.40	0.54
3319	Jefferies	117	SI	11566154		76	33	LakePond	170.2	1.2	2.977	3.9	0.50
3319	Jefferies	117	SI	11566156		22	33	LakePond	172	1.1	1.607	0.86	0.39
3319	Jefferies	118	SI	11565204		107	40	CanalDitch	169.2	0.6	0.953	4.2	0.51
3319	Jefferies	118	SI	11565234		212	40	StreamRiver	171.9	1.0	1.446	0.40	0.54
3319	Jefferies	118	SI	11566154		158	20	LakePond	170.2	1.2	2.977	3.9	0.50
6068	Jeffrey Energy Center	41	SI	3644400		76	100	LakePond	35	2.5	1.392	0.56	0.66
6068	Jeffrey Energy Center	42	SI	3643012		123	100	StreamRiver	35	7.6	6.861	0.41	0.74
6068	Jeffrey Energy Center	43	SI	3644572		31	100	LakePond	35	1.4	1.108	0.29	0.58
6068	Jeffrey Energy Center	772	LF	3644400		37	100	LakePond	35	2.5	1.392	0.56	0.66
6068	Jeffrey Energy Center	773	LF	3644400		92	100	LakePond	35	2.5	1.392	0.56	0.66
8066	Jim Bridger Plant Units 1-4	244	SI	3388381		20	100	StreamRiver	11	7.1	6.533	0.12	0.80
8066	Jim Bridger Plant Units 1-4	245	SI	3387697		226	33	StreamRiver	11	2.6	2.445	2.7	0.92
8066	Jim Bridger Plant Units 1-4	245	SI	3388445	Jim Bridger Project Evaporation Pond	88	33	LakePond	11	1.0	0.54	1.4	0.76

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
8066	Jim Bridger Plant Units 1-4	245	SI	3388465		28	33	Playa	11	0.1	0.319	1.4	0.87
8066	Jim Bridger Plant Units 1-4	774	LF	3387677		345	63	StreamRiver	11	3.2	2.276	1.3	1.0
8066	Jim Bridger Plant Units 1-4	774	LF	3387679		272	25	StreamRiver	11	5.2	2.734	0.65	0.89
8066	Jim Bridger Plant Units 1-4	774	LF	3388445	Jim Bridger Project Evaporation Pond	480	13	LakePond	11	1.0	0.54	1.4	0.76
3935	John E. Amos	153	SI	19315422				ArtificialPath	131.5	2.1	1.283	18,953	2.4
3935	John E. Amos	154	SI	19315422				ArtificialPath	131.5	2.1	1.283	18,953	2.4
3935	John E. Amos	740	LF	19314852		444	100	StreamRiver	124.3	5.8	3.446	4.3	0.89
3935	John E. Amos	742	LF	19314054		54	100	StreamRiver	120.5	3.0	1.905	1.6	0.81
4271	John P. Madgett	990	LF	2118222				ArtificialPath	92.1	1.8	1.336	27,963	2.8
4271	John P. Madgett	991	LF	2118222				ArtificialPath	92.1	1.8	1.336	27,963	2.8
3405	John Sevier	131	SI	22178442				LakePond	164.6	2.6	1.657	4,980	1.3
3405	John Sevier	132	SI	22178442				LakePond	164.6	2.6	1.657	4,980	1.3
3405	John Sevier	763	LF	22178184		50	50	StreamRiver	166.9	3.1	1.789	1.8	0.77
3405	John Sevier	763	LF	22178442		76	50	LakePond	164.6	2.6	1.657	4,980	1.3
3406	Johnsonville	133	SI	10582213				LakePond	189.9	6.1	1.25	73,013	3.3
3406	Johnsonville	291	SI	10582213				LakePond	189.9	6.1	1.25	73,013	3.3
3406	Johnsonville	732	LF	10579813		2058	100	LakePond	189.7	3.0	0.633	3.1	0.48
3406	Johnsonville	733	LF	10582213		2665	100	LakePond	189.9	6.1	1.25	73,013	3.3
384	Joliet 29	309	SI	14788089				ArtificialPath	101.4	9.1	4.652	1,019	1.5
384	Joliet 29	1098	LF	14788089				ArtificialPath	101.4	9.1	4.652	1,019	1.5
874	Joliet 9	1327	SI	14788089	Des Plaines River	43	100	ArtificialPath	101.4	9.1	4.652	1,019	1.5
874	Joliet 9	1328	SI	14788089	Des Plaines River	437	100	ArtificialPath	101.4	9.1	4.652	1,019	1.5
887	Joppa Steam	390	SI	1838869		34	25	StreamRiver	61	0.8	1.57	0.36	0.66
887	Joppa Steam	390	SI	1839963	Ohio River	954	75	ArtificialPath	61.2	9.1	2.863	287,115	4.4
887	Joppa Steam	734	LF	1839963				ArtificialPath	61.2	9.1	2.863	287,115	4.4
3947	Kammer	159	SI	19455337				ArtificialPath	141.5	2.5	1.894	42,109	3.0
3936	Kanawha River	155	SI	6925319				ArtificialPath	185.9	8.6	4.288	13,724	2.4
1381	Kenneth C Coleman	553	SI	10109049		242	50	StreamRiver	119.7	1.7	3.211	3.6	0.68
1381	Kenneth C Coleman	553	SI	10109549	Ohio River	236	50	ArtificialPath	121	19.6	9.095	130,878	3.8
1381	Kenneth C Coleman	554	SI	10109549				ArtificialPath	121	19.6	9.095	130,878	3.8
1381	Kenneth C Coleman	555	SI	10109087		200	100	StreamRiver	120.7	4.3	2.367	2.6	0.52

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3136	Keystone	736	LF	4741479		140	25	StreamRiver	208.8	1.0	1.065	7.8	0.97
3136	Keystone	736	LF	4741511		109	38	StreamRiver	207	1.3	1.94	0.83	0.77
3136	Keystone	736	LF	4741521	Crooked Creek	343	13	StreamRiver	203	0.2	0.547	335	1.6
3136	Keystone	736	LF	4742313		74	25	LakePond	203.5	0.3	0.642	8.0	0.71
3136	Keystone	1151	LF	4741419		395	33	StreamRiver	210.2	2.6	2.543	1.7	0.81
3136	Keystone	1151	LF	4741433	Plum Creek	888	50	StreamRiver	210.4	2.0	1.306	136	0.96
3136	Keystone	1151	LF	4741471		66	17	StreamRiver	210	0.9	1.777	0.58	0.73
3136	Keystone	1152	LF	4741433	Plum Creek	401	75	StreamRiver	210.4	2.0	1.306	136	0.96
3136	Keystone	1152	LF	4741471		172	25	StreamRiver	210	0.9	1.777	0.58	0.73
3136	Keystone	1297	SI	4741479		6	100	StreamRiver	208.8	1.0	1.065	7.8	0.97
3136	Keystone	1298	SI	4741479		375	100	StreamRiver	208.8	1.0	1.065	7.8	0.97
3136	Keystone	1299	SI	4741479		236	100	StreamRiver	208.8	1.0	1.065	7.8	0.97
3136	Keystone	1300	SI	4741479		6	100	StreamRiver	208.8	1.0	1.065	7.8	0.97
3136	Keystone	1301	SI	4741053	Garretts Run	54	100	StreamRiver	200.3	2.2	1.739	1.5	0.81
3136	Keystone	1302	SI	4741053	Garretts Run	33	100	StreamRiver	200.3	2.2	1.739	1.5	0.81
3136	Keystone	1303	SI	4741031	Garretts Run	539	38	StreamRiver	200	0.8	1.082	2.0	0.77
3136	Keystone	1303	SI	4741053	Garretts Run	375	63	StreamRiver	200.3	2.2	1.739	1.5	0.81
3136	Keystone	1304	SI	4741031	Garretts Run	610	25	StreamRiver	200	0.8	1.082	2.0	0.77
3136	Keystone	1304	SI	4741053	Garretts Run	419	75	StreamRiver	200.3	2.2	1.739	1.5	0.81
3136	Keystone	1305	SI	4742139	Allegheny River	554	100	ArtificialPath	200	0.8	0.987	15,444	2.4
3136	Keystone	1306	SI	4741753		190	100	StreamRiver	200	3.3	3.15	2.5	0.91
3136	Keystone	1307	SI	4741753		66	100	StreamRiver	200	3.3	3.15	2.5	0.91
6031	Killen Station	31	SI	1921950	Ohio River	238	50	ArtificialPath	80.8	1.3	1.582	98,562	3.6
6031	Killen Station	31	SI	1921988	Ohio River	167	50	ArtificialPath	84	4.8	2.075	98,553	3.6
6031	Killen Station	32	SI	1920376	Spring Run	631	100	StreamRiver	84	0.0	0.201	0.0021	0.16
876	Kincaid Generation LLC	388	SI	13565478	Sangchris Lake	156	43	LakePond	49	1.2	0.962	20	0.69
876	Kincaid Generation LLC	388	SI	13565484	Sangchris Lake	55	43	LakePond	49.1	9.0	5.117	6.9	0.71
876	Kincaid Generation LLC	388	SI	13565486	Sangchris Lake	36	14	LakePond	49	1.2	0.951	5.0	0.53
876	Kincaid Generation LLC	969	LF	13565486				LakePond	49	1.2	0.951	5.0	0.53
3407	Kingston	134	SI	22125770				LakePond	252	2.1	0.779	5.4	0.53
3407	Kingston	135	SI	22125770				LakePond	252	2.1	0.779	5.4	0.53
733	Kraft	375	SI	20107245				ArtificialPath	119	4.9	3.406	53	0.64
733	Kraft	1150	LF	20106909	Saint Augustine Creek	3473	38	StreamRiver	119.6	33.3	9.191	49	0.98
733	Kraft	1150	LF	20107243	Savannah River	2226	63	ArtificialPath	118.6	45.5	7.722	15,010	2.4
2876	Kyger Creek	716	SI	19443313	Kyger Creek	64	71	StreamRiver	108	1.2	1.71	33	0.75
2876	Kyger Creek	716	SI	19443471	Ohio River	3	29	ArtificialPath	107.9	6.3	3.367	59,450	3.2

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2876	Kyger Creek	717	SI	19443313	Kyger Creek	165	63	StreamRiver	108	1.2	1.71	33	0.75
2876	Kyger Creek	717	SI	19443471	Ohio River	279	38	ArtificialPath	107.9	6.3	3.367	59,450	3.2
2876	Kyger Creek	738	LF	19443295	Little Kyger Creek	774	88	StreamRiver	106.3	8.4	4.619	6.3	0.87
2876	Kyger Creek	738	LF	19443299	Little Campaign Creek	1054	13	StreamRiver	106.8	1.5	1.23	2.6	0.79
2713	L.V. Sutton Electric Plant	665	SI	8834990	Cape Fear River	1283	100	ArtificialPath	256.8	28.0	11.105	7,616	2.1
2713	L.V. Sutton Electric Plant	666	SI	8832596	Cape Fear River	530	25	ArtificialPath	258	0.7	1.075	7,630	2.1
2713	L.V. Sutton Electric Plant	666	SI	8834990	Cape Fear River	919	75	ArtificialPath	256.8	28.0	11.105	7,616	2.1
1241	La Cygne	513	SI	2998084				LakePond	32	6.2	2.221	12	0.64
1241	La Cygne	514	SI	2998084				LakePond	32	6.2	2.221	12	0.64
1241	La Cygne	739	LF	2996362		239	25	StreamRiver	32	3.1	2.792	0.038	0.63
1241	La Cygne	739	LF	2998084	La Cygnes Lake	1190	75	LakePond	32	6.2	2.221	12	0.64
2103	Labadie	607	SI	6009846				StreamRiver	57.3	6.3	2.399	0.092	0.72
2103	Labadie	608	SI	6009846				StreamRiver	57.3	6.3	2.399	0.092	0.72
2098	Lake Road	605	SI	2252949	Missouri River	425	100	ArtificialPath	41.9	114.2	13.223	61,092	3.4
2098	Lake Road	606	SI	2252949				ArtificialPath	41.9	114.2	13.223	61,092	3.4
2098	Lake Road	752	LF	2252747	Contrary Creek	1332	38	CanalDitch	43.9	26.2	9.576	15	0.92
2098	Lake Road	752	LF	2252949	Missouri River	638	63	ArtificialPath	41.9	114.2	13.223	61,092	3.4
2838	Lake Shore	1270	SI	28123868		246	100	Coastline	135.1	109.4	23.697		
964	Lakeside	400	SI	13564568	Sugar Creek	629	50	StreamRiver	63	0.5	0.954	183	1.4
964	Lakeside	400	SI	13564578	Sugar Creek	67	25	StreamRiver	63	1.3	1.05	180	1.5
964	Lakeside	400	SI	13565430	Lake Springfield	25	25	LakePond	59.8	6.2	2.311	180	1.5
1047	Lansing	477	SI	13211666				ArtificialPath	136	0.7	1.105	33,701	2.4
1047	Lansing	478	SI	13211666				ArtificialPath	136	0.7	1.105	33,701	2.4
1047	Lansing	730	LF	13210258		46	100	StreamRiver	134.1	1.5	1.214	2.7	0.83
1047	Lansing	741	LF	13210286		38	100	StreamRiver	136	1.5	1.381	1.1	0.86
643	Lansing Smith	341	SI	2178625				StreamRiver	646.4	1.8	1.236	28	0.80
643	Lansing Smith	743	LF	2179431	Saint Andrew Bay	213	100	Coastline	640.6	2.6	2.871		
6204	Laramie River Station	188	SI	17483575	Laramie River	1714	100	StreamRiver	12	18.1	3.609	2,035	2.3
6204	Laramie River Station	189	SI	17483575	Laramie River	506	50	StreamRiver	12	18.1	3.609	2,035	2.3
6204	Laramie River Station	189	SI	17483589	Laramie River	930	50	StreamRiver	12	8.6	3.327	2,037	2.0
6204	Laramie River Station	744	LF	17483575	Laramie River	1425	75	StreamRiver	12	18.1	3.609	2,035	2.3

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6204	Laramie River Station	744	LF	17483631		558	25	StreamRiver	12	7.1	4.935	27	1.3
1891	Laskin Energy Center	588	SI	1767116				LakePond	140	1.3	1.82	0.50	0.35
1891	Laskin Energy Center	589	SI	1767116				LakePond	140	1.3	1.82	0.50	0.35
1250	Lawrence Energy Center	515	SI	3729567				ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	516	SI	3729567				ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	517	SI	3729567				ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	518	SI	3729567				ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	745	LF	3729357		26	17	StreamRiver	35.1	1.2	1.316	0.061	0.65
1250	Lawrence Energy Center	745	LF	3729559	Kansas River	44	17	ArtificialPath	36	3.8	4.346	2,606	1.9
1250	Lawrence Energy Center	745	LF	3729567	Kansas River	455	17	ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	745	LF	3731689		175	33	StreamRiver	35	1.9	1.337	0.050	0.66
1250	Lawrence Energy Center	745	LF	3733255		914	17	StreamRiver	36.2	2.2	1.924	0.021	0.57
1250	Lawrence Energy Center	747	LF	3729567	Kansas River	72	100	ArtificialPath	36.9	3.0	2.917	2,611	2.4
1250	Lawrence Energy Center	1149	LF	3729567	Kansas River	122	100	ArtificialPath	36.9	3.0	2.917	2,611	2.4
2817	Leland Olds	683	SI	14519643	Missouri River	330	100	ArtificialPath	4	2.8	2.781	43,597	3.3
2817	Leland Olds	684	SI	14519643	Missouri River	106	100	ArtificialPath	4	2.8	2.781	43,597	3.3
2817	Leland Olds	685	SI	14519643	Missouri River	690	100	ArtificialPath	4	2.8	2.781	43,597	3.3
2817	Leland Olds	748	LF	14518609		352	25	CanalDitch	4	1.4	1.633	0.025	0.23
2817	Leland Olds	748	LF	14519643	Missouri River	761	75	ArtificialPath	4	2.8	2.781	43,597	3.3
2817	Leland Olds	749	LF	14519461	Alderin Creek	429	75	StreamRiver	4.1	6.5	5.777	0.0058	0.65
2817	Leland Olds	749	LF	14519463		496	25	StreamRiver	4.6	5.8	4.154	0.035	0.80
6089	Lewis & Clark	750	LF	21874629	Peabody Coulee	128	100	StreamRiver	5	14.0	8.038	0.019	0.73
6089	Lewis & Clark	751	LF	21870815	Lone Tree Creek	1379	13	StreamRiver	5	29.4	7.069	1.2	1.0
6089	Lewis & Clark	751	LF	21871785	Yellowstone River	6	88	ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	786	LF	21871785				ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	1374	SI	21871785	Yellowstone River	238	100	ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	1375	SI	21871785	Yellowstone River	178	100	ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	1376	SI	21871785	Yellowstone River	91	100	ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	1377	SI	21871785	Yellowstone River	178	100	ArtificialPath	4.9	33.2	4.922	22,379	3.5
6089	Lewis & Clark	1378	SI	21871785	Yellowstone River	17	100	ArtificialPath	4.9	33.2	4.922	22,379	3.5
298	Limestone	300	SI	5575475	Lambs Creek	1886	50	StreamRiver	21	4.2	2.28	11	0.82

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
298	Limestone	300	SI	5576035	Lynn Creek	572	50	StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	301	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	302	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	303	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	304	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	305	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	306	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	307	SI	5576035				StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	308	SI	5575475	Lambs Creek	1883	50	StreamRiver	21	4.2	2.28	11	0.82
298	Limestone	308	SI	5576035	Lynn Creek	569	50	StreamRiver	21.6	12.8	7.431	2.6	0.84
298	Limestone	821	LF	5576035	Lynn Creek	307	100	StreamRiver	21.6	12.8	7.431	2.6	0.84
2240	Lon Wright	765	LF	17264353				CanalDitch	40.1	11.8	7.316	0.68	0.67
6664	Louisa	222	SI	14807047				ArtificialPath	75.1	2.5	2.24	55,000	3.2
6664	Louisa	223	SI	14805067		931	14	StreamRiver	80.3	4.7	2.908	1.1	0.79
6664	Louisa	223	SI	14805109		55	57	StreamRiver	79	1.2	0.8	0.30	0.71
6664	Louisa	223	SI	14805139		693	29	StreamRiver	79	1.3	1.555	0.53	0.73
6664	Louisa	801	LF	14806993		1267	100	StreamRiver	75.6	35.6	7.177	8.6	0.59
976	Marion Generating Station	401	SI	10147935	Lake of Egypt	377	100	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	402	SI	10147091	Little Saline Creek	10	88	StreamRiver	49.1	3.0	2.629	11	0.95
976	Marion Generating Station	402	SI	10147935	Lake of Egypt	517	13	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	403	SI	10147055	South Fork Saline River	1	100	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	404	SI	10147055	South Fork Saline River	69	100	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	405	SI	10147935	Lake of Egypt	147	100	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	406	SI	10147055	South Fork Saline River	41	50	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	406	SI	10147935	Lake of Egypt	50	50	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	407	SI	10147055	South Fork Saline River	26	100	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	408	SI	10147055	South Fork Saline River	8	43	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	408	SI	10147091	Little Saline Creek	67	29	StreamRiver	49.1	3.0	2.629	11	0.95

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
976	Marion Generating Station	408	SI	10147935	Lake of Egypt	315	29	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	409	SI	10147055	South Fork Saline River	71	50	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	409	SI	10147091	Little Saline Creek	69	38	StreamRiver	49.1	3.0	2.629	11	0.95
976	Marion Generating Station	409	SI	10147935	Lake of Egypt	349	13	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	410	SI	10147091	Little Saline Creek	11	38	StreamRiver	49.1	3.0	2.629	11	0.95
976	Marion Generating Station	410	SI	10147935	Lake of Egypt	162	63	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	411	SI	10147091	Little Saline Creek	759	25	StreamRiver	49.1	3.0	2.629	11	0.95
976	Marion Generating Station	411	SI	10147935	Lake of Egypt	127	75	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	412	SI	10147935	Lake of Egypt	183	100	LakePond	49.6	5.8	1.804	31	1.2
976	Marion Generating Station	802	LF	10147055	South Fork Saline River	72	20	StreamRiver	49	0.4	1.283	32	1.2
976	Marion Generating Station	802	LF	10147091	Little Saline Creek	33	20	StreamRiver	49.1	3.0	2.629	11	0.95
976	Marion Generating Station	802	LF	10147935	Lake of Egypt	27	60	LakePond	49.6	5.8	1.804	31	1.2
2727	Marshall	680	SI	9751108	Lake Norman	34	67	LakePond	202	14.8	4.317	3,088	1.5
2727	Marshall	680	SI	9751144	Lake Norman	158	33	LakePond	196.4	15.0	6.197	3,112	1.8
2727	Marshall	803	LF	9750934	Beaverdam Creek	241	25	StreamRiver	201.5	0.9	0.987	0.65	0.69
2727	Marshall	803	LF	9751108	Lake Norman	1704	75	LakePond	202	14.8	4.317	3,088	1.5
2727	Marshall	804	LF	9751108	Lake Norman	1325	100	LakePond	202	14.8	4.317	3,088	1.5
492	Martin Drake	805	LF	1529727				StreamRiver	11	0.5	0.721	179	1.9
492	Martin Drake	1251	SI	1529727	Fountain Creek	168	100	StreamRiver	11	0.5	0.721	179	1.9
492	Martin Drake	1252	SI	1529727	Fountain Creek	179	100	StreamRiver	11	0.5	0.721	179	1.9
492	Martin Drake	1253	SI	1529727	Fountain Creek	164	100	StreamRiver	11	0.5	0.721	179	1.9
492	Martin Drake	1254	SI	1529727	Fountain Creek	159	100	StreamRiver	11	0.5	0.721	179	1.9
6146	Martin Lake	806	LF	5279038	Caney Branch	1330	13	StreamRiver	53.5	2.6	1.269	1.4	0.70
6146	Martin Lake	806	LF	5279582	Caney Creek	1303	38	StreamRiver	49.6	21.1	7.207	7.3	0.89
6146	Martin Lake	806	LF	5279746	Martin Lake	1898	13	LakePond	54.8	7.6	2.618	3.6	0.50
6146	Martin Lake	806	LF	5279840	Caney Creek	1217	38	LakePond	49.6	3.9	0.175	1.1	0.75

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6146	Martin Lake	807	LF	5279038	Caney Branch	55	100	StreamRiver	53.5	2.6	1.269	1.4	0.70
6146	Martin Lake	808	LF	5279740	Martin Lake	228	63	LakePond	66.9	28.7	4.214	10	0.70
6146	Martin Lake	808	LF	5279756	Martin Lake	1197	38	LakePond	58.7	12.5	5.061	81	0.89
6146	Martin Lake	810	LF	5279756	Martin Lake	869	100	LakePond	58.7	12.5	5.061	81	0.89
6146	Martin Lake	822	LF	5279740	Martin Lake	392	38	LakePond	66.9	28.7	4.214	10	0.70
6146	Martin Lake	822	LF	5279756	Martin Lake	1075	63	LakePond	58.7	12.5	5.061	81	0.89
6146	Martin Lake	1223	SI	5279740	Martin Lake	100	67	LakePond	66.9	28.7	4.214	10	0.70
6146	Martin Lake	1223	SI	5279756	Martin Lake	47	33	LakePond	58.7	12.5	5.061	81	0.89
6146	Martin Lake	1224	SI	5279740	Martin Lake	146	75	LakePond	66.9	28.7	4.214	10	0.70
6146	Martin Lake	1224	SI	5279756	Martin Lake	147	25	LakePond	58.7	12.5	5.061	81	0.89
6146	Martin Lake	1225	SI	5279740	Martin Lake	48	100	LakePond	66.9	28.7	4.214	10	0.70
6146	Martin Lake	1226	SI	5279756	Martin Lake	670	100	LakePond	58.7	12.5	5.061	81	0.89
6250	Mayo Electric Generating Facility	204	SI	8693539	Crutchfield Branch	22	100	StreamRiver	95.8	3.5	2.356	1.7	0.85
6124	McIntosh	87	SI	20107091				ArtificialPath	131.6	1.0	0.753	14,801	2.4
3287	McMeekin	1155	LF	9869858	Saluda River	266	100	ArtificialPath	211.4	10.7	3.386	3,480	1.8
2104	Meramec	609	SI	3629071				ArtificialPath	51.8	7.9	3.831	173,379	4.2
2104	Meramec	610	SI	3629071				ArtificialPath	51.8	7.9	3.831	173,379	4.2
2104	Meramec	611	SI	3629071				ArtificialPath	51.8	7.9	3.831	173,379	4.2
2104	Meramec	612	SI	3629071				ArtificialPath	51.8	7.9	3.831	173,379	4.2
2104	Meramec	613	SI	3629071				ArtificialPath	51.8	7.9	3.831	173,379	4.2
864	Meredosia	385	SI	3598258				ArtificialPath	40.3	7.7	6.926	17,544	2.6
864	Meredosia	386	SI	3598258				ArtificialPath	40.3	7.7	6.926	17,544	2.6
6213	Merom	190	SI	10286370				LakePond	80	24.6	4.535	24	0.92
6213	Merom	812	LF	10286196	Little Turtle Creek	2493	50	StreamRiver	79.7	18.5	8.824	7.1	0.85
6213	Merom	812	LF	10286370	Turtle Creek	1565	50	LakePond	80	24.6	4.535	24	0.92
6213	Merom	813	LF	10286370	Turtle Creek	2195	100	LakePond	80	24.6	4.535	24	0.92
2364	Merrimack Station	754	LF	6740568	Bow Bog Brook	528	13	StreamRiver	254	1.5	3.296	14	0.95
2364	Merrimack Station	754	LF	6742050	Merrimack River	884	63	ArtificialPath	254.4	3.4	1.03	4,730	1.7
2364	Merrimack Station	754	LF	6742472	Merrimack River	523	25	ArtificialPath	254	2.7	2.145	4,728	1.9
2364	Merrimack Station	1319	SI	6742472	Merrimack River	376	100	ArtificialPath	254	2.7	2.145	4,728	1.9
2364	Merrimack Station	1320	SI	6742472	Merrimack River	164	100	ArtificialPath	254	2.7	2.145	4,728	1.9
2832	Miami Fort	699	SI	3406069	Ohio River	141	13	ArtificialPath	70	0.4	0.614	106,377	3.6
2832	Miami Fort	699	SI	3410051	Ohio River	150	63	ArtificialPath	70	2.0	1.259	106,372	3.6

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2832	Miami Fort	699	SI	3886058	Great Miami River	212	25	ArtificialPath	70	0.7	1.031	4,970	2.4
2832	Miami Fort	700	SI	3406069	Ohio River	123	13	ArtificialPath	70	0.4	0.614	106,377	3.6
2832	Miami Fort	700	SI	3886058	Great Miami River	84	88	ArtificialPath	70	0.7	1.031	4,970	2.4
2832	Miami Fort	1109	LF	3410051				ArtificialPath	70	2.0	1.259	106,372	3.6
2832	Miami Fort	1121	LF	3886028	Great Miami River	207	13	ArtificialPath	69	1.0	0.805	4,954	2.0
2832	Miami Fort	1121	LF	3886034	Great Miami River	40	88	ArtificialPath	69.3	0.8	0.576	4,954	2.0
997	Michigan City	448	SI	3397270		9	100	Coastline	205.6	2.1	2.365		
997	Michigan City	449	SI	3397270		145	100	Coastline	205.6	2.1	2.365		
997	Michigan City	450	SI	3397270		100	100	Coastline	205.6	2.1	2.365		
997	Michigan City	451	SI	3397270		35	100	Coastline	205.6	2.1	2.365		
997	Michigan City	452	SI	3397270		86	100	Coastline	205.6	2.1	2.365		
997	Michigan City	453	SI	3397270		26	100	Coastline	205.6	2.1	2.365		
1364	Mill Creek	543	SI	22034711		23	100	StreamRiver	270.4	6.7	4.644	3.8	0.93
1364	Mill Creek	544	SI	10163798				StreamRiver	111.6	7.6	6.297	19	0.95
1364	Mill Creek	545	SI	10163798				StreamRiver	111.6	7.6	6.297	19	0.95
1364	Mill Creek	546	SI	10163798				StreamRiver	111.6	7.6	6.297	19	0.95
1364	Mill Creek	547	SI	10163798				StreamRiver	111.6	7.6	6.297	19	0.95
1364	Mill Creek	817	LF	10164038	Ohio River	176	100	ArtificialPath	114.8	8.5	6.832	123,620	3.7
1364	Mill Creek	818	LF	10164038	Ohio River	907	63	ArtificialPath	114.8	8.5	6.832	123,620	3.7
1364	Mill Creek	818	LF	10264556	Pond Creek	1475	38	StreamRiver	114.5	5.8	2.98	123	1.1
1364	Mill Creek	819	LF	10163798	Mill Creek	1487	38	StreamRiver	111.6	7.6	6.297	19	0.95
1364	Mill Creek	819	LF	10164038	Ohio River	686	50	ArtificialPath	114.8	8.5	6.832	123,620	3.7
1364	Mill Creek	819	LF	10264556	Pond Creek	2393	13	StreamRiver	114.5	5.8	2.98	123	1.1
2823	Milton R. Young Station	686	SI	14519747				LakePond	5	0.9	0.671	1.8	0.87
2823	Milton R. Young Station	687	SI	14519747				LakePond	5	0.9	0.671	1.8	0.87
2823	Milton R. Young Station	688	SI	14519747				LakePond	5	0.9	0.671	1.8	0.87
2823	Milton R. Young Station	689	SI	14519747				LakePond	5	0.9	0.671	1.8	0.87
2823	Milton R. Young Station	777	LF	14519097		1021	100	StreamRiver	5	5.7	2.767	0.0051	0.62
2823	Milton R. Young Station	788	LF	14519203		1806	100	StreamRiver	5	3.9	1.753	0.14	0.63
2823	Milton R. Young Station	809	LF	14519143		361	100	StreamRiver	5	4.1	2.726	0.0037	0.60
2823	Milton R. Young Station	811	LF	14519065	Square Butte Creek	2604	38	StreamRiver	4.6	4.4	1.149	0.88	0.84
2823	Milton R. Young Station	811	LF	14519143		774	25	StreamRiver	5	4.1	2.726	0.0037	0.60
2823	Milton R. Young Station	811	LF	14519165		2011	38	StreamRiver	5	3.0	2.146	0.40	0.84
2823	Milton R. Young Station	820	LF	14519125		565	25	StreamRiver	5	0.6	1.214	0.66	0.41

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2823	Milton R. Young Station	820	LF	14519219		547	38	StreamRiver	5	3.7	3.662	0.0033	0.61
2823	Milton R. Young Station	820	LF	14519747	Nelson Lake	675	38	LakePond	5	0.9	0.671	1.8	0.87
2171	Missouri City	1257	SI	4391111	Rose Branch	144	100	StreamRiver	45.9	7.5	5.977	0.10	0.73
3948	Mitchell	160	SI	19455355	Ohio River	170	100	ArtificialPath	136.5	5.0	2.617	42,118	3.0
3948	Mitchell	161	SI	19455355	Ohio River	3	100	ArtificialPath	136.5	5.0	2.617	42,118	3.0
727	Mitchell	364	SI	902770057				ArtificialPath	205.3	28.2	7.846	6,739	2.0
727	Mitchell	365	SI	902770057				ArtificialPath	205.3	28.2	7.846	6,739	2.0
727	Mitchell	366	SI	902770057				ArtificialPath	205.3	28.2	7.846	6,739	2.0
3181	Mitchell Power Station	778	LF	3785375	Froman Run	883	38	StreamRiver	145.3	4.1	2.957	3.8	0.92
3181	Mitchell Power Station	778	LF	3785919	Monongahela River	362	63	ArtificialPath	147.5	3.3	2.14	10,381	2.2
3181	Mitchell Power Station	779	LF	3785361	Huston Run	701	13	StreamRiver	146.5	2.1	1.728	1.3	0.88
3181	Mitchell Power Station	779	LF	3785375	Froman Run	1088	13	StreamRiver	145.3	4.1	2.957	3.8	0.92
3181	Mitchell Power Station	779	LF	3785919	Monongahela River	340	75	ArtificialPath	147.5	3.3	2.14	10,381	2.2
1048	ML Kapp	479	SI	14804357				ArtificialPath	104	2.6	2.109	29	0.74
1048	ML Kapp	480	SI	14804357				ArtificialPath	104	2.6	2.109	29	0.74
1048	ML Kapp	481	SI	14804357				ArtificialPath	104	2.6	2.109	29	0.74
1048	ML Kapp	482	SI	14804357				ArtificialPath	104	2.6	2.109	29	0.74
1733	Monroe Power Plant	582	SI	13167364	Davis Drain	409	13	StreamRiver	92	2.8	3.315	0.77	0.63
1733	Monroe Power Plant	582	SI	25769197		58	88	Coastline	93.8	3.9	6.272		
1733	Monroe Power Plant	583	SI	25769309				Coastline	93.2	2.5	11.147		
6147	Monticello	780	LF	1010606				LakePond	54	11.5	5.155	24	0.71
6147	Monticello	781	LF	1009014	Tankersley Creek	3741	63	StreamRiver	56.3	35.9	10.783	26	0.99
6147	Monticello	781	LF	1010484	Dragoo Creek	1811	38	StreamRiver	48.8	12.4	6.592	4.0	0.83
6147	Monticello	782	LF	1010610	Monticello Reservoir	541	100	LakePond	57.6	43.0	3.018	173	1.0
6147	Monticello	1203	SI	1010610	Monticello Reservoir	645	100	LakePond	57.6	43.0	3.018	173	1.0
6147	Monticello	1204	SI	1010610	Monticello Reservoir	618	100	LakePond	57.6	43.0	3.018	173	1.0
6147	Monticello	1205	SI	1010610	Monticello Reservoir	796	100	LakePond	57.6	43.0	3.018	173	1.0
6147	Monticello	1206	SI	1010610	Monticello Reservoir	729	100	LakePond	57.6	43.0	3.018	173	1.0
2080	Montrose	600	SI	2334415	Montrose Lake	149	100	LakePond	38.1	2.8	2.085	25	0.74
2080	Montrose	601	SI	2334415	Montrose Lake	113	100	LakePond	38.1	2.8	2.085	25	0.74
2080	Montrose	602	SI	2333733				StreamRiver	39.8	1.8	2.65	0.024	0.58

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2080	Montrose	783	LF	2334415	Montrose Lake	139	100	LakePond	38.1	2.8	2.085	25	0.74
1573	Morgantown Generating Plant	785	LF	4530667		1385	13	StreamRiver	165	0.5	0.886	1.7	0.44
1573	Morgantown Generating Plant	785	LF	4531757	Scar Branch	50	50	StreamRiver	165	3.3	3.707	1.5	0.79
1573	Morgantown Generating Plant	785	LF	4531763	Bowling Creek	128	38	StreamRiver	165.1	1.4	2.193	0.61	0.68
1573	Morgantown Generating Plant	1108	LF	4530805		960	13	StreamRiver	159.9	6.7	1.291	3.1	0.48
1573	Morgantown Generating Plant	1108	LF	4530855		20	63	StreamRiver	171	5.8	4.441	2.1	0.72
1573	Morgantown Generating Plant	1108	LF	4532017		400	25	ArtificialPath	163	4.4	1.809	5.4	0.53
1606	Mount Tom	563	SI	6782121	Connecticut River	68	100	ArtificialPath	308.4	0.7	0.869	14,863	2.4
1606	Mount Tom	564	SI	6782113				ArtificialPath	308.7	2.1	1.471	14,861	2.4
1606	Mount Tom	565	SI	6782113				ArtificialPath	308.7	2.1	1.471	14,861	2.4
1606	Mount Tom	798	LF	6781171		117	20	StreamRiver	303.7	3.3	1.534	4.1	0.88
1606	Mount Tom	798	LF	6782121	Connecticut River	53	60	ArtificialPath	308.4	0.7	0.869	14,863	2.4
1606	Mount Tom	798	LF	6782123		23	20	ArtificialPath	307	0.0	0.156	4.2	0.90
6264	Mountaineer	211	SI	19441555	Little Broad Run	63	88	StreamRiver	100	5.3	5.431	2.9	0.80
6264	Mountaineer	211	SI	19442931	Ohio River	676	13	ArtificialPath	100	4.0	3.01	59,204	3.2
6264	Mountaineer	787	LF	19441577	Little Broad Run	162	20	StreamRiver	100	1.6	1.485	0.66	0.72
6264	Mountaineer	787	LF	19441623	Broad Run	1077	40	StreamRiver	100	9.4	6.254	6.7	0.85
6264	Mountaineer	787	LF	19441625		661	40	StreamRiver	100	0.9	0.673	0.39	0.72
3954	Mt. Storm	789	LF	14366062	Mount Storm Lake	545	100	LakePond	270.5	8.1	3.263	34	0.80
3954	Mt. Storm	1110	LF	14365768	Morgan Run	484	38	StreamRiver	269.7	3.8	2.569	1.8	0.93
3954	Mt. Storm	1110	LF	14366062	Mount Storm Lake	1095	38	LakePond	270.5	8.1	3.263	34	0.80
3954	Mt. Storm	1110	LF	14366064	Mount Storm Lake	839	25	LakePond	264.5	1.4	1.436	24	0.59
3954	Mt. Storm	1111	LF	14366062	Mount Storm Lake	1049	100	LakePond	270.5	8.1	3.263	34	0.80
3954	Mt. Storm	1112	LF	3775537	Beaver Creek	739	13	StreamRiver	277.3	6.4	3.832	5.6	0.94
3954	Mt. Storm	1112	LF	14365710	Fourmile Run	382	50	StreamRiver	280.6	3.1	2.633	1.4	0.91

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3954	Mt. Storm	1112	LF	14365768	Morgan Run	1089	13	StreamRiver	269.7	3.8	2.569	1.8	0.93
3954	Mt. Storm	1112	LF	14366062	Mount Storm Lake	1930	25	LakePond	270.5	8.1	3.263	34	0.80
1167	Muscatine #1	792	LF	17557513		8	100	StreamRiver	70.2	3.3	2.812	0.80	0.74
1167	Muscatine #1	1361	SI	14806993		6124	100	StreamRiver	75.6	35.6	7.177	8.6	0.59
2872	Muskingum River	712	SI	15383195	Muskingum River	456	100	ArtificialPath	113.2	1.5	1.026	7,195	2.1
2872	Muskingum River	713	SI	15382427	Hayward Run	632	25	StreamRiver	108.8	3.3	1.96	1.4	0.80
2872	Muskingum River	713	SI	15383195	Muskingum River	1131	13	ArtificialPath	113.2	1.5	1.026	7,195	2.1
2872	Muskingum River	713	SI	15383255	Muskingum River	860	63	ArtificialPath	108.7	4.3	2.734	7,291	2.1
2872	Muskingum River	714	SI	15383195	Muskingum River	525	100	ArtificialPath	113.2	1.5	1.026	7,195	2.1
2872	Muskingum River	715	SI	15383195	Muskingum River	264	100	ArtificialPath	113.2	1.5	1.026	7,195	2.1
2952	Muskogee	1172	SI	381680	Arkansas River	1461	50	ArtificialPath	56.7	2.9	1.297	26,553	2.8
2952	Muskogee	1172	SI	381842		58	50	LakePond	57	0.9	1.002	0.34	0.33
2952	Muskogee	1173	SI	380530		89	100	StreamRiver	57	0.8	1.503	0.63	0.61
2952	Muskogee	1174	SI	381680	Arkansas River	426	100	ArtificialPath	56.7	2.9	1.297	26,553	2.8
4162	Naughton Plant	12	SI	3266034		108	88	StreamRiver	92.5	4.6	4.411	0.043	0.67
4162	Naughton Plant	12	SI	3266082		254	13	LakePond	86	0.0	0.166	0.031	0.68
4162	Naughton Plant	13	SI	3265276		38	50	StreamRiver	82.8	0.4	0.554	0.32	0.77
4162	Naughton Plant	13	SI	3266034		394	25	StreamRiver	92.5	4.6	4.411	0.043	0.67
4162	Naughton Plant	13	SI	3266084		26	25	LakePond	91.8	1.0	0.531	0.23	0.74
4162	Naughton Plant	14	SI	3265282		280	100	StreamRiver	75.7	4.6	3.156	0.36	0.74
4162	Naughton Plant	15	SI	3266084		590	100	LakePond	91.8	1.0	0.531	0.23	0.74
4162	Naughton Plant	980	LF	24712403				LakePond	84.1	1.7	0.39	0.32	0.70
4941	Navajo Generating Station	793	LF	3528413		679	100	StreamRiver	14	28.5	14.877	0.17	0.93
6064	Nearman Creek	39	SI	2255187				StreamRiver	47	2.6	2.305	0.052	0.66
6064	Nearman Creek	794	LF	2255187	Nearman Creek	57	38	StreamRiver	47	2.6	2.305	0.052	0.66
6064	Nearman Creek	794	LF	2255471	Missouri River	2459	63	ArtificialPath	47	6.1	1.645	62,045	3.2
6064	Nearman Creek	795	LF	3727463		432	25	StreamRiver	49	2.7	2.516	0.93	0.82
6064	Nearman Creek	795	LF	3727473	Muncie Creek	350	75	StreamRiver	49	2.9	3.05	0.58	0.74
6096	Nebraska City	797	LF	7312135	Fourmile Creek	475	38	StreamRiver	41.4	10.7	5.325	2.7	0.81
6096	Nebraska City	797	LF	7312407		767	63	LakePond	41	1.7	0.475	0.25	0.32
6096	Nebraska City	943	LF	7312407		568	100	LakePond	41	1.7	0.475	0.25	0.32
6096	Nebraska City	1271	SI	7312385	Missouri River	192	100	ArtificialPath	41	4.6	3.805	58,958	3.0

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6096	Nebraska City	1272	SI	7312385	Missouri River	194	100	ArtificialPath	41	4.6	3.805	58,958	3.0
4054	Nelson Dewey	170	SI	13326790		105	100	ArtificialPath	119	1.1	1.07	7.4	0.57
4054	Nelson Dewey	171	SI	13326790		244	100	ArtificialPath	119	1.1	1.07	7.4	0.57
4054	Nelson Dewey	893	LF	13326790		187	100	ArtificialPath	119	1.1	1.07	7.4	0.57
3138	New Castle Plant	941	LF	19463874	McKee Run	400	100	StreamRiver	146.8	5.1	2.186	9.8	1.1
3138	New Castle Plant	1349	SI	19463874	McKee Run	185	100	StreamRiver	146.8	5.1	2.186	9.8	1.1
3138	New Castle Plant	1350	SI	19464182	Beaver River	17	100	ArtificialPath	146	0.2	0.662	2,559	2.3
2167	New Madrid	620	SI	7469410	Mississippi River	959	25	ArtificialPath	181.6	19.3	6.293	573,662	5.2
2167	New Madrid	620	SI	7470334	Point Pleasant Chute	3116	75	LakePond	177.8	17.9	2.74	10	0.75
2167	New Madrid	621	SI	7469410	Mississippi River	6	100	ArtificialPath	181.6	19.3	6.293	573,662	5.2
2167	New Madrid	622	SI	760280		171	88	StreamRiver	182.9	8.9	1.674	4.1	0.67
2167	New Madrid	622	SI	7469410	Mississippi River	1488	13	ArtificialPath	181.6	19.3	6.293	573,662	5.2
2167	New Madrid	623	SI	7469410	Mississippi River	31	43	ArtificialPath	181.6	19.3	6.293	573,662	5.2
2167	New Madrid	623	SI	7470334	Point Pleasant Chute	3773	57	LakePond	177.8	17.9	2.74	10	0.75
2167	New Madrid	1032	LF	762036		120	100	StreamRiver	181.8	0.6	1.058	0.28	0.55
6017	Newton	21	SI	10435494		72	100	LakePond	35	6.3	4.093	21	0.67
6017	Newton	22	SI	10435490		75	40	LakePond	37.7	14.1	5.767	19	0.72
6017	Newton	22	SI	10435492		1	20	LakePond	35	0.0	0.276	0.52	0.65
6017	Newton	22	SI	10435496		342	40	LakePond	34.8	10.5	6.462	13	0.57
6017	Newton	1033	LF	10435496		114	83	LakePond	34.8	10.5	6.462	13	0.57
6017	Newton	1033	LF	10435536		69	17	LakePond	35	1.6	0.939	0.50	0.49
6017	Newton	1034	LF	10435496		515	100	LakePond	34.8	10.5	6.462	13	0.57
2291	North Omaha	1036	LF	17219446	Missouri River	177	100	ArtificialPath	53.5	18.4	3.316	46,968	3.0
2291	North Omaha	1113	LF	17219446	Missouri River	71	100	ArtificialPath	53.5	18.4	3.316	46,968	3.0
2291	North Omaha	1220	SI	17219446	Missouri River	53	100	ArtificialPath	53.5	18.4	3.316	46,968	3.0
2291	North Omaha	1221	SI	17219446	Missouri River	15	100	ArtificialPath	53.5	18.4	3.316	46,968	3.0
2291	North Omaha	1222	SI	17219446	Missouri River	268	100	ArtificialPath	53.5	18.4	3.316	46,968	3.0
8224	North Valmy	1037	LF	11202824	Humboldt River	979	100	StreamRiver	12	7.7	3.828	2,800	2.4
2963	Northeastern	718	SI	832872				StreamRiver	22	66.8	14.196	30	1.0
2963	Northeastern	1038	LF	833360	Verdigris River	48	100	StreamRiver	22	4.4	2.513	2,288	3.0
667	Northside Generating Station	1039	LF	16658019	San Carlos Creek	128	50	StreamRiver	126.2	1.6	0.767	0.62	0.37

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
667	Northside Generating Station	1039	LF	16659871	San Carlos Creek	1057	50	ArtificialPath	126.1	1.3	0.211	2.4	0.53
10030	NRG Energy Center Dover	251	SI	8074674				StreamRiver	260.3	2.3	1.776	1.1	0.66
527	Nucla	338	SI	18375940				StreamRiver	11.8	8.8	4.975	330	2.1
527	Nucla	964	LF	18375940				StreamRiver	11.8	8.8	4.975	330	2.1
2848	O H Hutchings	703	SI	3883754	Great Miami River	30	100	ArtificialPath	121.8	4.5	2.654	2,347	1.7
2848	O H Hutchings	704	SI	3883754	Great Miami River	21	100	ArtificialPath	121.8	4.5	2.654	2,347	1.7
2848	O H Hutchings	705	SI	3883754	Great Miami River	111	100	ArtificialPath	121.8	4.5	2.654	2,347	1.7
6180	Oak Grove	1040	LF	5575759		281	75	StreamRiver	12.6	6.3	2.344	1.3	0.76
6180	Oak Grove	1040	LF	5576197	Oliver Branch	961	25	LakePond	13	0.8	0.485	1.3	0.74
6180	Oak Grove	1042	LF	5575759				StreamRiver	12.6	6.3	2.344	1.3	0.76
6180	Oak Grove	1054	LF	5575759				StreamRiver	12.6	6.3	2.344	1.3	0.76
6180	Oak Grove	1185	SI	5576195	Herds Branch	468	38	LakePond	13	1.2	1.186	3.2	0.49
6180	Oak Grove	1185	SI	5576197	Oliver Branch	346	63	LakePond	13	0.8	0.485	1.3	0.74
127	Oklaunion	281	SI	13727077	Boggy Creek	70	50	StreamRiver	3	1.2	1.475	0.076	0.62
127	Oklaunion	281	SI	13727091	Boggy Creek	1207	38	StreamRiver	3	6.0	3.319	0.52	0.69
127	Oklaunion	281	SI	13728375	Boggy Creek	23	13	LakePond	3	0.1	0.103	0.079	0.28
127	Oklaunion	282	SI	13727091				StreamRiver	3	6.0	3.319	0.52	0.69
127	Oklaunion	283	SI	13727091				StreamRiver	3	6.0	3.319	0.52	0.69
127	Oklaunion	841	LF	13727091				StreamRiver	3	6.0	3.319	0.52	0.69
4151	Osage	1031	LF	9386901		22	100	StreamRiver	14.8	1.1	1.999	0.12	0.67
4151	Osage	1044	LF	9386901		56	100	StreamRiver	14.8	1.1	1.999	0.12	0.67
4151	Osage	1266	SI	9386901		35	100	StreamRiver	14.8	1.1	1.999	0.12	0.67
4151	Osage	1267	SI	9386901		136	100	StreamRiver	14.8	1.1	1.999	0.12	0.67
1831	Otto E. Eckert Station	586	SI	12241730				StreamRiver	99	0.9	1.792	442	1.8
6254	Ottumwa	205	SI	4994571				StreamRiver	40	4.7	4.828	33	1.1
6254	Ottumwa	206	SI	4994571				StreamRiver	40	4.7	4.828	33	1.1
6254	Ottumwa	207	SI	4994571				StreamRiver	40	4.7	4.828	33	1.1
6254	Ottumwa	208	SI	4994571				StreamRiver	40	4.7	4.828	33	1.1
6254	Ottumwa	1045	LF	4994605		373	63	StreamRiver	41	2.5	1.774	0.58	0.76
6254	Ottumwa	1045	LF	4994609		90	38	StreamRiver	42.3	1.1	1.664	0.24	0.68
1378	Paradise	548	SI	11628855				ArtificialPath	115.2	5.8	4.113	8,970	2.2
1378	Paradise	549	SI	11628855				ArtificialPath	115.2	5.8	4.113	8,970	2.2
1378	Paradise	550	SI	11628855				ArtificialPath	115.2	5.8	4.113	8,970	2.2
6248	Pawnee	191	SI	215051				StreamRiver	10	117.9	11.707	44	1.5

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6248	Pawnee	192	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	193	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	194	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	195	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	196	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	197	SI	215051				StreamRiver	10	117.9	11.707	44	1.5
6248	Pawnee	1046	LF	3561528	Badger Creek	611	100	StreamRiver	10	19.4	14.16	59	1.4
6238	Pearl Station	1211	SI	3601022	Illinois River	143	100	ArtificialPath	38	1.3	1.615	18,247	2.6
3938	Philip Sporn	156	SI	19442931	Ohio River	284	100	ArtificialPath	100	4.0	3.01	59,204	3.2
3938	Philip Sporn	157	SI	19441555	Little Broad Run	74	50	StreamRiver	100	5.3	5.431	2.9	0.80
3938	Philip Sporn	157	SI	19442931	Ohio River	449	50	ArtificialPath	100	4.0	3.01	59,204	3.2
3938	Philip Sporn	979	LF	19442931				ArtificialPath	100	4.0	3.01	59,204	3.2
2843	Picway	702	SI	5218205	Scioto River	89	100	ArtificialPath	96	2.0	1.526	1,915	1.6
7902	Pirkey	233	SI	5279492	Hatley Creek	2397	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	234	SI	5279492	Hatley Creek	2804	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	235	SI	5279492	Hatley Creek	2828	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	236	SI	5279492	Hatley Creek	1388	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	237	SI	5279492	Hatley Creek	2751	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	238	SI	5279492	Hatley Creek	2915	100	StreamRiver	66.7	45.2	13.335	27	1.0
7902	Pirkey	1132	LF	5278680				StreamRiver	65	0.0	0.062	0.084	0.27
59	Platte	1047	LF	7265233		55	100	StreamRiver	14.5	6.1	7.884	0.012	0.56
59	Platte	1048	LF	7265233		214	100	StreamRiver	14.5	6.1	7.884	0.012	0.56
6170	Pleasant Prairie	1049	LF	14783669		143	100	StreamRiver	89.3	4.3	2.753	1.2	0.64
6004	Pleasants Power Station	17	SI	15433660	McElroys Run	113	67	StreamRiver	87.8	4.6	4.474	2.5	0.85
6004	Pleasants Power Station	17	SI	15434036	Forest City Lake	1483	17	LakePond	87.3	2.3	1.085	38	0.76
6004	Pleasants Power Station	17	SI	15434040	Ohio River	735	17	ArtificialPath	87.5	2.2	2.502	43,994	3.0
6004	Pleasants Power Station	1050	LF	15433660	McElroys Run	210	88	StreamRiver	87.8	4.6	4.474	2.5	0.85
6004	Pleasants Power Station	1050	LF	15434040	Ohio River	794	13	ArtificialPath	87.5	2.2	2.502	43,994	3.0
7242	Polk	1051	LF	16801745	Little Payne Creek	636	100	StreamRiver	139.7	34.9	6.028	12	0.79
3113	Portland	1020	LF	2587865	Martins Creek	516	100	StreamRiver	316.8	15.4	6.508	32	1.2
3113	Portland	1041	LF	2588325				ArtificialPath	309.8	3.5	2.543	8,342	2.8
3113	Portland	1043	LF	2587865	Martins Creek	599	100	StreamRiver	316.8	15.4	6.508	32	1.2

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3113	Portland	1052	LF	2587865	Martins Creek	678	100	StreamRiver	316.8	15.4	6.508	32	1.2
3113	Portland	1199	SI	2588325	Delaware River	48	100	ArtificialPath	309.8	3.5	2.543	8,342	2.8
3113	Portland	1200	SI	2588325	Delaware River	55	100	ArtificialPath	309.8	3.5	2.543	8,342	2.8
3113	Portland	1201	SI	2588325	Delaware River	78	100	ArtificialPath	309.8	3.5	2.543	8,342	2.8
879	Powerton	1227	SI	13605832		95	63	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1227	SI	13605926	Lost Creek	225	38	StreamRiver	77.4	9.9	5.442	16	1.0
879	Powerton	1228	SI	13605832		373	100	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1229	SI	13605832		33	100	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1230	SI	13605832		183	75	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1230	SI	13605926	Lost Creek	185	25	StreamRiver	77.4	9.9	5.442	16	1.0
879	Powerton	1231	SI	13605832		12	100	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1232	SI	13605832		251	17	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1232	SI	13605926	Lost Creek	70	83	StreamRiver	77.4	9.9	5.442	16	1.0
879	Powerton	1233	SI	13605832		195	25	StreamRiver	78.8	1.1	0.925	0.27	0.53
879	Powerton	1233	SI	13605926	Lost Creek	57	75	StreamRiver	77.4	9.9	5.442	16	1.0
3140	PPL Brunner Island	93	SI	4721375		100	75	StreamRiver	230.4	0.6	0.852	6.9	0.76
3140	PPL Brunner Island	93	SI	4722219		68	25	ArtificialPath	231.4	0.5	1.022	7.1	0.80
3140	PPL Brunner Island	94	SI	4721375		99	100	StreamRiver	230.4	0.6	0.852	6.9	0.76
3140	PPL Brunner Island	95	SI	4721427	Hartman Run	83	43	StreamRiver	226	4.3	4.589	6.1	0.93
3140	PPL Brunner Island	95	SI	4722211	Susquehanna River	7	57	ArtificialPath	231.9	9.2	3.642	37,472	2.9
3140	PPL Brunner Island	1114	LF	4721427	Hartman Run	122	38	StreamRiver	226	4.3	4.589	6.1	0.93
3140	PPL Brunner Island	1114	LF	4722211	Susquehanna River	95	63	ArtificialPath	231.9	9.2	3.642	37,472	2.9
3149	PPL Montour	96	SI	8151995				StreamRiver	216.8	3.2	2.792	28	0.94
3149	PPL Montour	97	SI	8151995				StreamRiver	216.8	3.2	2.792	28	0.94
3149	PPL Montour	98	SI	8151995				StreamRiver	216.8	3.2	2.792	28	0.94
3149	PPL Montour	99	SI	8151995				StreamRiver	216.8	3.2	2.792	28	0.94
3149	PPL Montour	100	SI	8151995				StreamRiver	216.8	3.2	2.792	28	0.94
3149	PPL Montour	1011	LF	8152033		9	100	StreamRiver	221.6	2.9	1.939	2.7	0.68
3149	PPL Montour	1115	LF	8152033		465	100	StreamRiver	221.6	2.9	1.939	2.7	0.68
1073	Prairie Creek	487	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	488	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	489	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	490	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	491	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	492	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	493	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	494	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1073	Prairie Creek	495	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1073	Prairie Creek	496	SI	22477477				StreamRiver	72	5.7	3.096	109	1.1
1769	Presque Isle	1012	LF	12025972		453	13	StreamRiver	276.2	0.4	0.884	163	1.0
1769	Presque Isle	1012	LF	12026272	Compeau Creek	186	88	StreamRiver	275.9	18.4	9.277	8.1	0.57
1769	Presque Isle	1013	LF	12026272	Compeau Creek	62	100	StreamRiver	275.9	18.4	9.277	8.1	0.57
1769	Presque Isle	1014	LF	12026272	Compeau Creek	141	100	StreamRiver	275.9	18.4	9.277	8.1	0.57
2403	PSEG Hudson Generating Station	1015	LF	6250804		58	33	StreamRiver	220	6.5	3.41	5.9	0.70
2403	PSEG Hudson Generating Station	1015	LF	6251356	Hackensack River	50	33	ArtificialPath	214	2.6	1.839	358	1.2
2403	PSEG Hudson Generating Station	1015	LF	6254202		35	33	ArtificialPath	212.5	0.1	0.3	6.0	0.54
2403	PSEG Hudson Generating Station	1351	SI	6250804		8	100	StreamRiver	220	6.5	3.41	5.9	0.70
2403	PSEG Hudson Generating Station	1352	SI	6250804		125	38	StreamRiver	220	6.5	3.41	5.9	0.70
2403	PSEG Hudson Generating Station	1352	SI	6254202		256	63	ArtificialPath	212.5	0.1	0.3	6.0	0.54
2408	PSEG Mercer Generating Station	1016	LF	4480871		166	50	StreamRiver	231.9	0.3	0.539	2.0	0.44
2408	PSEG Mercer Generating Station	1016	LF	4481751	Crosswicks Creek	222	25	ArtificialPath	236	1.3	0.892	201	1.3
2408	PSEG Mercer Generating Station	1016	LF	4481951		12	25	LakePond	232.1	0.4	0.858	2.2	0.67
2408	PSEG Mercer Generating Station	1197	SI	4480891		83	100	CanalDitch	229.2	1.5	1.956	0.91	0.39
2408	PSEG Mercer Generating Station	1198	SI	4480891		135	100	CanalDitch	229.2	1.5	1.956	0.91	0.39
4072	Pulliam	1017	LF	6802232	Green Bay	115	25	Coastline	113	1.2	1.517		
4072	Pulliam	1017	LF	6802234	Green Bay	45	75	Coastline	113	0.3	0.685		
4072	Pulliam	1212	SI	6802234	Green Bay	115	100	Coastline	113	0.3	0.685		
1295	Quindaro	1030	LF	2255479	Missouri River	79	100	ArtificialPath	47	11.1	4.257	62,047	4.7
6639	R D Green	220	SI	11617021	Groves Creek	611	25	StreamRiver	84	0.9	1.184	41	1.1
6639	R D Green	220	SI	11617335	Green River	148	75	ArtificialPath	83.8	11.1	6.149	12,480	2.3
6639	R D Green	1019	LF	11617021	Groves Creek	437	50	StreamRiver	84	0.9	1.184	41	1.1
6639	R D Green	1019	LF	11617335	Green River	144	50	ArtificialPath	83.8	11.1	6.149	12,480	2.3

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2864	R. E. Burger	976	LF	19455275				ArtificialPath	141.5	0.0	0.124	41,857	3.0
2864	R. E. Burger	1380	SI	19455277	Ohio River	34	100	ArtificialPath	143.9	4.3	2.693	41,859	3.0
2864	R. E. Burger	1381	SI	19455277	Ohio River	248	100	ArtificialPath	143.9	4.3	2.693	41,859	3.0
1008	R. Gallagher	460	SI	10163876		41	100	StreamRiver	109.6	3.4	3.554	1.6	0.62
1008	R. Gallagher	461	SI	10163876		406	50	StreamRiver	109.6	3.4	3.554	1.6	0.62
1008	R. Gallagher	461	SI	10164012	Ohio River	13	50	ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1001	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1023	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1024	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1025	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1026	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1027	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1029	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1053	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1008	R. Gallagher	1056	LF	10164012				ArtificialPath	109.7	37.5	5.704	123,503	3.7
1570	R. Paul Smith Power Station	561	SI	5891920	Potomac River	22	100	ArtificialPath	199.2	5.1	2.205	6,633	2.1
1570	R. Paul Smith Power Station	562	SI	5891920	Potomac River	5	100	ArtificialPath	199.2	5.1	2.205	6,633	2.1
1570	R. Paul Smith Power Station	1083	LF	5891548		304	25	StreamRiver	199.9	2.8	2.628	1.0	0.79
1570	R. Paul Smith Power Station	1083	LF	5891920	Potomac River	373	75	ArtificialPath	199.2	5.1	2.205	6,633	2.1
2790	R.M. Heskett Station	1080	LF	14523377	Rock Haven Creek	51	100	StreamRiver	5	7.1	4.211	0.0063	0.66
2790	R.M. Heskett Station	1081	LF	14523377	Rock Haven Creek	30	83	StreamRiver	5	7.1	4.211	0.0063	0.66
2790	R.M. Heskett Station	1081	LF	14523603	Rock Haven Creek	313	17	ArtificialPath	5	0.2	0.495	0.011	0.22
6085	R.M. Schahfer	54	SI	13436733		82	100	StreamRiver	157.2	0.4	0.453	15	0.64
6085	R.M. Schahfer	55	SI	13436733		631	100	StreamRiver	157.2	0.4	0.453	15	0.64
6085	R.M. Schahfer	56	SI	13436723		583	100	StreamRiver	151.4	42.1	3.1	28	0.90
6085	R.M. Schahfer	57	SI	13434629	Kankakee River	33	100	StreamRiver	170.1	31.7	2.012	1,127	1.5
6085	R.M. Schahfer	58	SI	13436723		759	100	StreamRiver	151.4	42.1	3.1	28	0.90
6085	R.M. Schahfer	67	SI	13434629	Kankakee River	849	25	StreamRiver	170.1	31.7	2.012	1,127	1.5
6085	R.M. Schahfer	67	SI	13436723		824	75	StreamRiver	151.4	42.1	3.1	28	0.90
6085	R.M. Schahfer	68	SI	13436723		168	75	StreamRiver	151.4	42.1	3.1	28	0.90
6085	R.M. Schahfer	68	SI	13436733		431	25	StreamRiver	157.2	0.4	0.453	15	0.64
6085	R.M. Schahfer	1082	LF	13434629	Kankakee River	91	100	StreamRiver	170.1	31.7	2.012	1,127	1.5

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6761	Rawhide	225	SI	2898303				StreamRiver	13	2.9	4.417	1.1	0.96
6761	Rawhide	226	SI	2898303				StreamRiver	13	2.9	4.417	1.1	0.96
6761	Rawhide	996	LF	2898303				StreamRiver	13	2.9	4.417	1.1	0.96
6761	Rawhide	1086	LF	2898203		175	50	StreamRiver	13	1.5	2.801	0.032	0.63
6761	Rawhide	1086	LF	2898315		10	50	StreamRiver	13	4.8	4.998	0.11	0.71
8219	Ray D Nixon	1087	LF	1530503		31	50	StreamRiver	9.4	3.2	3.059	0.53	0.75
8219	Ray D Nixon	1087	LF	1531245		28	50	StreamRiver	9.3	3.7	4.761	2.4	0.93
8219	Ray D Nixon	1255	SI	1530449	Little Fountain Creek	45	100	StreamRiver	9.7	0.8	1.156	23	1.3
55076	Red Hills Generating Facility	1088	LF	15778976		723	13	StreamRiver	120	1.7	2.277	0.89	0.68
55076	Red Hills Generating Facility	1088	LF	19221367		97	88	StreamRiver	120	2.3	2.501	1.2	0.74
55076	Red Hills Generating Facility	1256	SI	19221367		20	100	StreamRiver	120	2.3	2.501	1.2	0.74
2324	Reid Gardner	630	SI	20624280		178	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	631	SI	20624280		370	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	632	SI	20624280		89	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	633	SI	20624280		27	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	634	SI	20624280		13	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	635	SI	20624280		50	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	636	SI	20624280		200	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	637	SI	20624280		99	100	StreamRiver	4	70.0	13.352	193	2.2
2324	Reid Gardner	1090	LF	20624280				StreamRiver	4	70.0	13.352	193	2.2
1740	River Rouge Power Plant	1186	SI	10850250	Detroit River	117	100	ArtificialPath	82.5	11.0	5.711	2,097	1.7
2732	Riverbend	681	SI	9755520	Catawba River	99	100	LakePond	143.4	4.4	3.335	3,383	1.8
2732	Riverbend	682	SI	9755520	Catawba River	291	75	LakePond	143.4	4.4	3.335	3,383	1.8
2732	Riverbend	682	SI	9755522	Catawba River	234	25	ArtificialPath	148.4	8.6	3.788	3,380	1.8
1081	Riverside	500	SI	14803985	Crow Creek	221	17	StreamRiver	92.3	1.6	1.281	12	1.0
1081	Riverside	500	SI	14804491	Crow Creek	36	33	ArtificialPath	91.4	0.4	0.663	12	0.89
1081	Riverside	500	SI	14804493	Mississippi River	32	50	ArtificialPath	91	2.3	1.371	48,707	3.2
1081	Riverside	501	SI	14804493	Mississippi River	45	100	ArtificialPath	91	2.3	1.371	48,707	3.2
1927	Riverside	594	SI	1100714				ArtificialPath	73	9.2	3.784	8,935	2.6
1239	Riverton	512	SI	7591065	Lowell Reservoir	4	75	LakePond	103.5	4.3	1.851	1,384	1.5
1239	Riverton	512	SI	7591153		442	25	LakePond	102.7	0.8	0.247	0.27	0.46

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3945	Rivesville Power Station	1095	LF	3769538	Parker Run	162	100	StreamRiver	150	4.1	2.923	3.1	0.89
3945	Rivesville Power Station	1116	LF	3769538	Parker Run	683	38	StreamRiver	150	4.1	2.923	3.1	0.89
3945	Rivesville Power Station	1116	LF	3769820	Monongahela River	561	63	ArtificialPath	149.9	9.6	5.956	4,888	1.9
3945	Rivesville Power Station	1355	SI	3769828	Monongahela River	60	100	ArtificialPath	150	1.3	1.195	4,816	2.2
3945	Rivesville Power Station	1356	SI	3769828	Monongahela River	62	100	ArtificialPath	150	1.3	1.195	4,816	2.2
3945	Rivesville Power Station	1357	SI	3769820	Monongahela River	379	100	ArtificialPath	149.9	9.6	5.956	4,888	1.9
3945	Rivesville Power Station	1358	SI	3769542	Pharaoh Run	143	13	StreamRiver	150	4.5	3.55	6.7	0.96
3945	Rivesville Power Station	1358	SI	3769828	Monongahela River	75	88	ArtificialPath	150	1.3	1.195	4,816	2.2
6166	Rockport	179	SI	10110119		388	13	StreamRiver	114	3.6	3.783	2.2	0.56
6166	Rockport	179	SI	10110131		2420	88	StreamRiver	117.5	4.1	2.312	32	1.1
6166	Rockport	1097	LF	10110119				StreamRiver	114	3.6	3.783	2.2	0.56
6190	Rodemacher	185	SI	19918814	Jean De Jean Bayou	90	100	StreamRiver	164.1	2.5	4.824	96	0.91
6190	Rodemacher	186	SI	19918814	Jean De Jean Bayou	24	100	StreamRiver	164.1	2.5	4.824	96	0.91
6190	Rodemacher	187	SI	19919248	Red River	415	33	ArtificialPath	162.8	2.1	2.65	31,015	2.9
6190	Rodemacher	187	SI	19919336		7	67	LakePond	163.5	1.1	0.906	0.49	0.52
2712	Roxboro Steam Electric Plant	661	SI	8701445	Hyco Lake	43	100	LakePond	98.1	3.8	3.522	4.6	0.71
2712	Roxboro Steam Electric Plant	662	SI	8693605	Ghent Creek	409	50	StreamRiver	92.9	1.8	2.543	6.1	0.86
2712	Roxboro Steam Electric Plant	662	SI	8696103	Ghent Creek	174	50	StreamRiver	95.2	3.2	2.037	5.5	0.75
2712	Roxboro Steam Electric Plant	663	SI	8701445				LakePond	98.1	3.8	3.522	4.6	0.71
2712	Roxboro Steam Electric Plant	664	SI	8701445	Hyco Lake	9	100	LakePond	98.1	3.8	3.522	4.6	0.71
2712	Roxboro Steam Electric Plant	1096	LF	8701437	Hyco Lake	999	100	LakePond	97.7	6.2	1.241	167	1.0
1393	RS Nelson	1084	LF	3709730	Verdine, Bayou	106	63	StreamRiver	99.9	8.0	3.08	4.2	0.64

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1393	RS Nelson	1084	LF	15075536	West Fork Calcasieu River	1698	38	ArtificialPath	100	5.5	2.87	943	1.4
1393	RS Nelson	1085	LF	3709730	Verdine, Bayou	310	88	StreamRiver	99.9	8.0	3.08	4.2	0.64
1393	RS Nelson	1085	LF	15075546	Houston River	1195	13	StreamRiver	99.7	18.1	13.086	484	0.82
1393	RS Nelson	1329	SI	15075536	West Fork Calcasieu River	1878	100	ArtificialPath	100	5.5	2.87	943	1.4
1393	RS Nelson	1330	SI	15075546	Houston River	268	100	StreamRiver	99.7	18.1	13.086	484	0.82
6155	Rush Island	178	SI	3629181				ArtificialPath	55	2.1	2.057	176,931	4.2
6155	Rush Island	1091	LF	3629181				ArtificialPath	55	2.1	2.057	176,931	4.2
2451	San Juan	1308	SI	17001804	Westwater Arroyo	404	50	StreamRiver	12	1.6	1.045	1.4	0.99
2451	San Juan	1308	SI	17001806		54	50	StreamRiver	12	1.1	2.423	0.016	0.62
6183	San Miguel	1093	LF	10828296		643	100	StreamRiver	6	5.3	3.651	0.52	0.72
6183	San Miguel	1094	LF	10671315		84	100	StreamRiver	6	2.6	1.689	0.15	0.64
6183	San Miguel	1365	SI	10828244		23	50	StreamRiver	6.9	2.5	1.967	2.5	0.83
6183	San Miguel	1365	SI	10828254		96	25	StreamRiver	6.4	2.6	3.669	1.6	0.76
6183	San Miguel	1365	SI	10828730	Souse Creek	59	25	LakePond	6	0.0	0.061	1.1	0.42
6183	San Miguel	1366	SI	10828642	Souse Creek	187	100	StreamRiver	6.1	10.3	6.166	1.1	0.79
6183	San Miguel	1367	SI	10828642	Souse Creek	280	100	StreamRiver	6.1	10.3	6.166	1.1	0.79
6648	Sandow No 4	221	SI	5566231				StreamRiver	29	2.6	0.559	0.23	0.72
6648	Sandow No 4	1057	LF	5566231				StreamRiver	29	2.6	0.559	0.23	0.72
6648	Sandow No 4	1065	LF	5566241	East Yegua Creek	657	100	StreamRiver	28	11.0	3.813	0.97	0.84
6648	Sandow No 4	1067	LF	5566241	East Yegua Creek	1217	100	StreamRiver	28	11.0	3.813	0.97	0.84
6648	Sandow No 4	1089	LF	5566231		1471	38	StreamRiver	29	2.6	0.559	0.23	0.72
6648	Sandow No 4	1089	LF	5566241	East Yegua Creek	292	25	StreamRiver	28	11.0	3.813	0.97	0.84
6648	Sandow No 4	1089	LF	5566547	East Yegua Creek	46	38	LakePond	28.3	1.1	0.992	1.1	0.73
6648	Sandow No 4	1092	LF	5566241	East Yegua Creek	551	100	StreamRiver	28	11.0	3.813	0.97	0.84
6257	Scherer	209	SI	6336802				LakePond	177	0.1	0.183	0.97	0.69
6257	Scherer	210	SI	6336802				LakePond	177	0.1	0.183	0.97	0.69
2367	SCHILLER	1058	LF	5845176		272	20	StreamRiver	267.1	8.8	3.414	1.3	0.67
2367	SCHILLER	1058	LF	5846414	Piscataqua River	21	80	ArtificialPath	268.2	3.4	2.169	1,484	1.5
642	Scholz	1346	SI	902800005	Apalachicola River	437	100	ArtificialPath	285.6	49.1	4.702	24,243	2.7

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
642	Scholz	1347	SI	902800005	Apalachicola River	416	100	ArtificialPath	285.6	49.1	4.702	24,243	2.7
642	Scholz	1348	SI	902800005	Apalachicola River	502	100	ArtificialPath	285.6	49.1	4.702	24,243	2.7
136	Seminole Generating Station	1059	LF	16664705		1860	100	StreamRiver	128.9	9.6	2.022	3.9	0.65
1379	Shawnee	551	SI	1840007				ArtificialPath	63.4	8.5	3.795	287,058	4.4
1379	Shawnee	552	SI	1840007				ArtificialPath	63.4	8.5	3.795	287,058	4.4
1379	Shawnee	1060	LF	1839881	Little Bayou Creek	635	100	StreamRiver	65.4	16.6	6.749	12	0.88
1379	Shawnee	1061	LF	1840007				ArtificialPath	63.4	8.5	3.795	287,058	4.4
3131	Shawville	1062	LF	4672489	West Branch Susquehanna River	580	13	ArtificialPath	257.8	0.9	1.196	1,482	1.4
3131	Shawville	1062	LF	4672491	Bloody Run	831	13	ArtificialPath	259	0.0	0.041	1.3	0.82
3131	Shawville	1062	LF	4672501	West Branch Susquehanna River	698	50	ArtificialPath	253.3	3.6	2.668	1,551	1.7
3131	Shawville	1062	LF	4672505	West Branch Susquehanna River	649	25	ArtificialPath	254.8	1.8	1.48	1,480	1.8
3131	Shawville	1063	LF	4672489	West Branch Susquehanna River	626	13	ArtificialPath	257.8	0.9	1.196	1,482	1.4
3131	Shawville	1063	LF	4672501	West Branch Susquehanna River	934	25	ArtificialPath	253.3	3.6	2.668	1,551	1.7
3131	Shawville	1063	LF	4672505	West Branch Susquehanna River	523	63	ArtificialPath	254.8	1.8	1.48	1,480	1.8
3131	Shawville	1245	SI	4672489	West Branch Susquehanna River	7	100	ArtificialPath	257.8	0.9	1.196	1,482	1.4
3131	Shawville	1246	SI	4672505	West Branch Susquehanna River	15	100	ArtificialPath	254.8	1.8	1.48	1,480	1.8
3131	Shawville	1247	SI	4672505	West Branch Susquehanna River	7	100	ArtificialPath	254.8	1.8	1.48	1,480	1.8

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3131	Shawville	1248	SI	4672505	West Branch Susquehanna River	16	100	ArtificialPath	254.8	1.8	1.48	1,480	1.8
2277	Sheldon Station	1055	LF	17405763		494	88	StreamRiver	30.8	7.6	3.275	0.28	0.76
2277	Sheldon Station	1055	LF	17405987	Salt Creek Reservoir 13-A	268	13	LakePond	30.5	2.1	0.369	0.23	0.32
2277	Sheldon Station	1064	LF	17405763		810	38	StreamRiver	30.8	7.6	3.275	0.28	0.76
2277	Sheldon Station	1064	LF	17405987	Salt Creek Reservoir 13-A	313	63	LakePond	30.5	2.1	0.369	0.23	0.32
2277	Sheldon Station	1066	LF	17405987	Salt Creek Reservoir 13-A	124	100	LakePond	30.5	2.1	0.369	0.23	0.32
2277	Sheldon Station	1078	LF	17405987	Salt Creek Reservoir 13-A	436	100	LakePond	30.5	2.1	0.369	0.23	0.32
2277	Sheldon Station	1360	SI	17405987	Salt Creek Reservoir 13-A	188	100	LakePond	30.5	2.1	0.369	0.23	0.32
6090	Sherburne County	69	SI	2723115	Mississippi River	779	100	ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	70	SI	2723115	Mississippi River	323	100	ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	71	SI	2723115	Mississippi River	354	100	ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	72	SI	2723115				ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	73	SI	2723115	Mississippi River	920	63	ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	73	SI	2723123	Mississippi River	1221	38	ArtificialPath	72.5	13.6	1.374	6,730	2.1
6090	Sherburne County	74	SI	2723115				ArtificialPath	72	20.7	5.526	6,727	2.2
6090	Sherburne County	1068	LF	2723105	Mississippi River	833	100	ArtificialPath	72.3	17.3	2.25	6,724	2.8
2094	Sibley	603	SI	4391311				ArtificialPath	45.7	21.9	2.416	65,158	3.5
2094	Sibley	604	SI	4391311				ArtificialPath	45.7	21.9	2.416	65,158	3.5
2094	Sibley	1069	LF	4391319	Missouri River	112	100	ArtificialPath	45.1	3.1	2.545	65,158	3.5
6768	Sikeston Power Station	227	SI	758572		131	100	StreamRiver	136.2	5.8	2.624	2.7	0.67
6768	Sikeston Power Station	228	SI	758572		194	63	StreamRiver	136.2	5.8	2.624	2.7	0.67
6768	Sikeston Power Station	228	SI	758654	Ash Slough Ditch	897	38	CanalDitch	150.2	7.4	4.378	29	0.84
2107	Sioux	614	SI	880570				LakePond	39.2	2.5	1.584	0.71	0.38
2107	Sioux	615	SI	880570				LakePond	39.2	2.5	1.584	0.71	0.38

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1058	Sixth Street	483	SI	22477721	West Fork Cedar River	773	100	ArtificialPath	71.7	29.8	1.009	3,062	1.8
1058	Sixth Street	484	SI	22477721	West Fork Cedar River	838	100	ArtificialPath	71.7	29.8	1.009	3,062	1.8
1058	Sixth Street	485	SI	22477721	West Fork Cedar River	776	100	ArtificialPath	71.7	29.8	1.009	3,062	1.8
1058	Sixth Street	486	SI	22477721	West Fork Cedar River	733	100	ArtificialPath	71.7	29.8	1.009	3,062	1.8
1613	Somerset Station	566	SI	6130213				ArtificialPath	352.7	1.8	1.296	957	1.1
1613	Somerset Station	567	SI	6130213				ArtificialPath	352.7	1.8	1.296	957	1.1
1613	Somerset Station	568	SI	6130213				ArtificialPath	352.7	1.8	1.296	957	1.1
1613	Somerset Station	569	SI	6130213				ArtificialPath	352.7	1.8	1.296	957	1.1
6095	Sooner	1259	SI	20970046	Cat Creek	1680	63	StreamRiver	14	4.6	4.105	0.52	0.71
6095	Sooner	1259	SI	20970180	Coon Creek	1641	38	StreamRiver	16.7	11.6	9.029	1.3	0.79
6095	Sooner	1260	SI	20970156		883	100	StreamRiver	15.6	6.2	4.364	0.70	0.75
6061	South Mississippi El Pwr Assn	1008	LF	18104286	Spring Creek	571	13	StreamRiver	216.1	2.2	2.993	1.3	0.73
6061	South Mississippi El Pwr Assn	1008	LF	18104316	Black Creek	118	88	StreamRiver	217	3.5	2.641	230	1.4
6061	South Mississippi El Pwr Assn	1021	LF	18104286	Spring Creek	331	38	StreamRiver	216.1	2.2	2.993	1.3	0.73
6061	South Mississippi El Pwr Assn	1021	LF	18104316	Black Creek	278	63	StreamRiver	217	3.5	2.641	230	1.4
6061	South Mississippi El Pwr Assn	1022	LF	18104316	Black Creek	101	100	StreamRiver	217	3.5	2.641	230	1.4
6061	South Mississippi El Pwr Assn	1353	SI	18104286	Spring Creek	788	13	StreamRiver	216.1	2.2	2.993	1.3	0.73
6061	South Mississippi El Pwr Assn	1353	SI	18104316	Black Creek	554	88	StreamRiver	217	3.5	2.641	230	1.4
6061	South Mississippi El Pwr Assn	1354	SI	18104316	Black Creek	801	100	StreamRiver	217	3.5	2.641	230	1.4
4041	South Oak Creek	1070	LF	12169039		941	63	StreamRiver	76	4.0	2.427	0.95	0.77
4041	South Oak Creek	1070	LF	12169263		877	38	StreamRiver	77.8	6.5	3.303	1.5	0.67
4041	South Oak Creek	1071	LF	12169329		166	100	Coastline	75.5	9.3	7.337		
4041	South Oak Creek	1072	LF	12169263		899	100	StreamRiver	77.8	6.5	3.303	1.5	0.67
6195	Southwest Power Station	1073	LF	7607249	Wilsons Creek	201	50	StreamRiver	101.6	0.7	0.954	48	1.1
6195	Southwest Power Station	1073	LF	7607261	Wilsons Creek	563	50	StreamRiver	103	1.4	0.829	50	1.2

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
6195	Southwest Power Station	1074	LF	7607261	Wilsons Creek	805	63	StreamRiver	103	1.4	0.829	50	1.2
6195	Southwest Power Station	1074	LF	7607293		795	38	StreamRiver	104.5	3.6	2.656	1.1	0.78
6195	Southwest Power Station	1268	SI	7607261	Wilsons Creek	958	100	StreamRiver	103	1.4	0.829	50	1.2
6195	Southwest Power Station	1269	SI	7607261	Wilsons Creek	974	100	StreamRiver	103	1.4	0.829	50	1.2
8223	Springerville	1075	LF	20584624		893	50	StreamRiver	11	10.7	7.975	0.020	0.76
8223	Springerville	1075	LF	21762216		659	17	StreamRiver	11	11.6	3.809	0.014	0.68
8223	Springerville	1075	LF	21762258		146	33	StreamRiver	11	13.9	11.778	0.087	0.86
8223	Springerville	1384	SI	20584624		83	100	StreamRiver	11	10.7	7.975	0.020	0.76
1743	St Clair Power Plant	584	SI	13196020				ArtificialPath	69.1	13.0	13.448	721	1.4
207	St Johns River Power Park	1018	LF	16659333		59	100	StreamRiver	125.3	1.3	1.375	0.51	0.58
207	St Johns River Power Park	1076	LF	16659333		662	50	StreamRiver	125.3	1.3	1.375	0.51	0.58
207	St Johns River Power Park	1076	LF	16659871	San Carlos Creek	2410	50	ArtificialPath	126.1	1.3	0.211	2.4	0.53
207	St Johns River Power Park	1077	LF	16659331		201	50	StreamRiver	124.5	1.1	0.799	0.45	0.52
207	St Johns River Power Park	1077	LF	16659685		1305	50	ArtificialPath	124.2	1.2	0.675	0.51	0.35
2824	Stanton	690	SI	14519595	Missouri River	530	100	ArtificialPath	4	1.8	2.578	43,597	3.7
2824	Stanton	691	SI	14519595	Missouri River	400	100	ArtificialPath	4	1.8	2.578	43,597	3.7
2824	Stanton	692	SI	14519595	Missouri River	614	100	ArtificialPath	4	1.8	2.578	43,597	3.7
2824	Stanton	937	LF	14518731		456	38	StreamRiver	4.7	9.4	7.089	0.0084	0.67
2824	Stanton	937	LF	14519463		875	63	StreamRiver	4.6	5.8	4.154	0.035	0.80
2824	Stanton	940	LF	14519605		18	100	Reservoir	4	0.4	0.415	0.040	0.25
2824	Stanton	997	LF	14519463		556	100	StreamRiver	4.6	5.8	4.154	0.035	0.80
564	Stanton Energy Center	942	LF	10997353		2879	38	StreamRiver	134.3	14.8	2.531	5.3	0.79
564	Stanton Energy Center	942	LF	11008205	Cowpen Branch	2995	13	StreamRiver	142.8	10.9	1.347	3.9	0.77
564	Stanton Energy Center	942	LF	11008233		6449	25	StreamRiver	141.4	8.5	1.796	3.0	0.71
564	Stanton Energy Center	942	LF	11009165	Hart Branch	2609	25	StreamRiver	144.4	4.0	1.786	1.4	0.70
1131	Streeter Station	1028	LF	22472175	West Fork Cedar River	1334	100	ArtificialPath	81.4	26.5	4.878	2,184	1.9
3152	Sunbury Generation LP	101	SI	4517358	Rolling Green Run	90	100	StreamRiver	240.7	4.7	5.233	2.6	0.88

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
50951	Sunnyside Cogen Associates	944	LF	3908507	Grassy Trail Creek	40	100	StreamRiver	11.7	4.6	5.375	12	1.4
1077	Sutherland	497	SI	17538901	Iowa River	959	50	StreamRiver	73.1	4.7	3.928	805	1.7
1077	Sutherland	497	SI	17538959		959	50	StreamRiver	72.3	3.1	0.834	0.64	0.69
1077	Sutherland	498	SI	17538901	Iowa River	1148	88	StreamRiver	73.1	4.7	3.928	805	1.7
1077	Sutherland	498	SI	17538959		1082	13	StreamRiver	72.3	3.1	0.834	0.64	0.69
1077	Sutherland	499	SI	17538959		999	100	StreamRiver	72.3	3.1	0.834	0.64	0.69
1077	Sutherland	1117	LF	17538831	Nickolson Creek	85	100	StreamRiver	73.6	4.4	3.191	2.8	0.83
1077	Sutherland	1118	LF	17538831	Nickolson Creek	202	100	StreamRiver	73.6	4.4	3.191	2.8	0.83
10075	Taconite Harbor Energy Center	947	LF	4798258		178	100	StreamRiver	170.9	3.3	3.122	16	1.1
10075	Taconite Harbor Energy Center	948	LF	4798258		162	100	StreamRiver	170.9	3.3	3.122	16	1.1
10075	Taconite Harbor Energy Center	961	LF	4798258		170	100	StreamRiver	170.9	3.3	3.122	16	1.1
988	Tanners Creek	415	SI	3406123				ArtificialPath	70.4	1.8	1.929	111,358	3.6
988	Tanners Creek	416	SI	3405453	Tanners Creek	32	20	StreamRiver	70	0.2	0.355	107	0.93
988	Tanners Creek	416	SI	3406123	Ohio River	116	20	ArtificialPath	70.4	1.8	1.929	111,358	3.6
988	Tanners Creek	416	SI	3406125	Tanners Creek	23	60	ArtificialPath	70.1	0.3	0.569	107	0.93
988	Tanners Creek	417	SI	3405491		29	86	StreamRiver	70.2	1.9	2.174	0.74	0.76
988	Tanners Creek	417	SI	3406133	Ohio River	354	14	ArtificialPath	70.5	3.0	1.551	111,466	3.6
988	Tanners Creek	418	SI	3405491		33	100	StreamRiver	70.2	1.9	2.174	0.74	0.76
988	Tanners Creek	419	SI	3405491		21	86	StreamRiver	70.2	1.9	2.174	0.74	0.76
988	Tanners Creek	419	SI	3406133	Ohio River	324	14	ArtificialPath	70.5	3.0	1.551	111,466	3.6
988	Tanners Creek	950	LF	3405491		579	43	StreamRiver	70.2	1.9	2.174	0.74	0.76
988	Tanners Creek	950	LF	3406125	Tanners Creek	108	14	ArtificialPath	70.1	0.3	0.569	107	0.93
988	Tanners Creek	950	LF	3406133	Ohio River	11	43	ArtificialPath	70.5	3.0	1.551	111,466	3.6
1252	Tecumseh Energy Center	519	SI	3646684	Tecumseh Creek	6	100	StreamRiver	36.5	11.1	8.699	3.3	0.89
1252	Tecumseh Energy Center	520	SI	3646684	Tecumseh Creek	37	100	StreamRiver	36.5	11.1	8.699	3.3	0.89
1252	Tecumseh Energy Center	995	LF	3646866				ArtificialPath	38	0.1	0.41	2,337	1.8
1252	Tecumseh Energy Center	1120	LF	3646298		4	33	StreamRiver	38	0.6	1.595	0.11	0.64
1252	Tecumseh Energy Center	1120	LF	3646856	Kansas River	74	67	ArtificialPath	38	0.8	1.171	2,338	2.9

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1252	Tecumseh Energy Center	1133	LF	3646298		47	100	StreamRiver	38	0.6	1.595	0.11	0.64
2168	Thomas Hill	624	SI	4461386	Middle Fork Little Chariton River	551	100	StreamRiver	38.3	7.2	3.155	48	1.1
2168	Thomas Hill	625	SI	4461582				LakePond	38.8	13.3	3.318	47	1.3
2168	Thomas Hill	626	SI	4461582				LakePond	38.8	13.3	3.318	47	1.3
2168	Thomas Hill	627	SI	4461386	Middle Fork Little Chariton River	636	100	StreamRiver	38.3	7.2	3.155	48	1.1
2168	Thomas Hill	628	SI	4461582				LakePond	38.8	13.3	3.318	47	1.3
2168	Thomas Hill	629	SI	4461582				LakePond	38.8	13.3	3.318	47	1.3
2168	Thomas Hill	953	LF	4461386	Middle Fork Little Chariton River	108	100	StreamRiver	38.3	7.2	3.155	48	1.1
3115	Titus	954	LF	4782753	Schuylkill River	21	100	ArtificialPath	300.1	8.7	6.204	1,353	2.0
3115	Titus	955	LF	4782323	Schuylkill River	77	50	ArtificialPath	297	11.8	3.234	1,331	1.5
3115	Titus	955	LF	4782753	Schuylkill River	842	50	ArtificialPath	300.1	8.7	6.204	1,353	2.0
3115	Titus	956	LF	4782753	Schuylkill River	139	100	ArtificialPath	300.1	8.7	6.204	1,353	2.0
3115	Titus	957	LF	4782753	Schuylkill River	135	100	ArtificialPath	300.1	8.7	6.204	1,353	2.0
6194	Tolk	1161	LF	13475965	Blackwater Draw	4296	100	Connector	2.2	598.2	13.555	36	1.5
3845	TransAlta Centralia Generation	959	LF	23850959	Hanaford Creek	395	38	StreamRiver	775.4	2.5	2.052	73	1.1
3845	TransAlta Centralia Generation	959	LF	23850961	Hanaford Creek	322	25	StreamRiver	824.4	8.7	6.586	59	1.1
3845	TransAlta Centralia Generation	959	LF	23851493	Packwood Creek	1185	38	StreamRiver	781	1.4	1.073	32	1.0
1745	Trenton Channel Power Plant	585	SI	10850286				ArtificialPath	88.1	1.4	0.872	2,144	1.7
1745	Trenton Channel Power Plant	960	LF	10849980	Huntington Creek	1127	63	StreamRiver	82.7	13.4	4.012	3.6	0.71
1745	Trenton Channel Power Plant	960	LF	10850316		878	38	ArtificialPath	87.7	4.3	1.85	2,142	1.7
6071	Trimble Co.	44	SI	10161564		437	63	StreamRiver	68.9	6.9	3.43	3.3	0.97
6071	Trimble Co.	44	SI	10161570	Corn Creek	623	38	StreamRiver	71.5	0.7	0.448	37	0.91
56224	TS Power Plant	816	LF	11206810				StreamRiver	12	18.7	10.928	2,438	2.2
7030	Twin Oaks Power One	928	LF	5555198	Bee Branch	123	100	StreamRiver	19.9	19.3	10.858	2.9	0.83
1361	Tyrone	536	SI	1825620	Kentucky River	49	100	ArtificialPath	108.8	7.5	3.874	7,293	2.2

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
1361	Tyrone	537	SI	1825620	Kentucky River	37	100	ArtificialPath	108.8	7.5	3.874	7,293	2.2
3295	Urquhart	110	SI	22724031				ArtificialPath	268	2.6	2.197	11,843	1.6
3295	Urquhart	111	SI	22724031	Savannah River	43	100	ArtificialPath	268	2.6	2.197	11,843	1.6
3295	Urquhart	112	SI	22724031				ArtificialPath	268	2.6	2.197	11,843	1.6
3295	Urquhart	1107	LF	22724031	Savannah River	26	100	ArtificialPath	268	2.6	2.197	11,843	1.6
4042	Valley	918	LF	12162414		827	100	StreamRiver	95	23.0	8.195	5.0	0.80
4042	Valley	919	LF	14767328	Fox River	2125	75	StreamRiver	86.8	5.2	1.028	74	1.1
4042	Valley	919	LF	14767352		1309	25	StreamRiver	83.8	1.7	0.842	1.6	0.79
4042	Valley	920	LF	14767308		40	100	StreamRiver	82.7	5.4	3.093	1.3	0.76
4042	Valley	949	LF	12169039		1133	100	StreamRiver	76	4.0	2.427	0.95	0.77
477	Valmont	329	SI	2889816				LakePond	29.1	3.9	3.048	173	1.0
477	Valmont	330	SI	2889816				LakePond	29.1	3.9	3.048	173	1.0
477	Valmont	331	SI	2889816				LakePond	29.1	3.9	3.048	173	1.0
477	Valmont	1122	LF	2889270		725	14	StreamRiver	31	0.6	0.989	0.33	0.58
477	Valmont	1122	LF	2889298		1932	29	StreamRiver	28.7	6.6	5.134	174	1.7
477	Valmont	1122	LF	2889816	Hillcrest Reservoir	15	57	LakePond	29.1	3.9	3.048	173	1.0
477	Valmont	1123	LF	2889298		1147	63	StreamRiver	28.7	6.6	5.134	174	1.7
477	Valmont	1123	LF	2889816	Hillcrest Reservoir	4	38	LakePond	29.1	3.9	3.048	173	1.0
897	Vermilion	395	SI	10080952	Middle Fork Vermilion River	84	100	StreamRiver	85	12.8	8.3	335	1.5
897	Vermilion	396	SI	10080952	Middle Fork Vermilion River	80	100	StreamRiver	85	12.8	8.3	335	1.5
897	Vermilion	970	LF	10080988				LakePond	85	1.6	1.93	1.1	0.69
6073	Victor J. Daniel Jr	45	SI	18094759				StreamRiver	268.9	18.8	3.31	13	0.62
6073	Victor J. Daniel Jr	924	LF	18120652		847	100	StreamRiver	261.1	3.3	2.639	3.1	0.58
6073	Victor J. Daniel Jr	925	LF	18094759				StreamRiver	268.9	18.8	3.31	13	0.62
6073	Victor J. Daniel Jr	938	LF	18094759				StreamRiver	268.9	18.8	3.31	13	0.62
6073	Victor J. Daniel Jr	1124	LF	18094759		124	50	StreamRiver	268.9	18.8	3.31	13	0.62
6073	Victor J. Daniel Jr	1124	LF	18120652		1991	13	StreamRiver	261.1	3.3	2.639	3.1	0.58
6073	Victor J. Daniel Jr	1124	LF	18120712		676	38	StreamRiver	265.5	4.1	2.007	2.9	0.67
6019	W H Zimmer	26	SI	1922898	Ohio River	94	100	ArtificialPath	59.6	4.6	2.331	99,680	3.6
6019	W H Zimmer	929	LF	1922624	Little Indian Creek	1362	100	StreamRiver	61.9	12.3	7.396	6.1	0.98
3470	W. A. Parish	136	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	137	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
3470	W. A. Parish	138	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	139	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	140	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	141	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	142	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	143	SI	3126488				LakePond	49.8	19.7	6.332	11	0.75
3470	W. A. Parish	1125	LF	3123354	Dry Bayou	199	75	StreamRiver	50.3	6.7	3.241	1.2	0.63
3470	W. A. Parish	1125	LF	3123360		328	25	StreamRiver	53.6	5.8	4.598	2.6	0.66
2866	W. H. Sammis	916	LF	3820585	Carter Run	170	38	StreamRiver	138.2	3.2	2.295	1.4	0.86
2866	W. H. Sammis	916	LF	3820671	Hollow Rock Run	570	25	StreamRiver	138.2	3.6	2.504	4.4	0.97
2866	W. H. Sammis	916	LF	3820723	Hollow Rock Run	403	38	StreamRiver	140.4	6.7	2.478	2.8	0.87
2866	W. H. Sammis	1382	SI	3821343	Ohio River	62	100	ArtificialPath	139.6	9.2	2.225	40,225	3.2
2866	W. H. Sammis	1383	SI	3821343	Ohio River	102	75	ArtificialPath	139.6	9.2	2.225	40,225	3.2
2866	W. H. Sammis	1383	SI	3821351	Ohio River	287	25	ArtificialPath	141.5	4.0	1.808	40,227	3.0
3264	W. S. Lee	105	SI	9867770		17	100	StreamRiver	295	0.0	0.192	0.25	0.73
3264	W. S. Lee	106	SI	9867770		59	25	StreamRiver	295	0.0	0.192	0.25	0.73
3264	W. S. Lee	106	SI	9867774		26	25	StreamRiver	295	0.0	0.185	0.24	0.72
3264	W. S. Lee	106	SI	9868670		43	25	LakePond	295.3	0.3	0.333	0.25	0.66
3264	W. S. Lee	106	SI	9868678	Saluda River	339	25	ArtificialPath	292.7	1.9	1.519	607	1.9
2716	W.H. Weatherspoon Plant	667	SI	9127156		583	13	StreamRiver	223.1	0.2	0.281	0.12	0.49
2716	W.H. Weatherspoon Plant	667	SI	9128006	Jacob Swamp	320	88	StreamRiver	222.6	3.4	3.167	10	0.79
1010	Wabash River	462	SI	10283910	Wabash River	622	83	ArtificialPath	96.1	6.2	1.799	11,390	2.3
1010	Wabash River	462	SI	10286204	Wabash River	817	17	ArtificialPath	95.6	4.9	1.23	11,391	2.3
1010	Wabash River	463	SI	10283906	Wabash River	289	100	ArtificialPath	95.5	5.1	2.676	11,382	2.9
1010	Wabash River	464	SI	10283906	Wabash River	82	100	ArtificialPath	95.5	5.1	2.676	11,382	2.9
1010	Wabash River	465	SI	10283906	Wabash River	91	100	ArtificialPath	95.5	5.1	2.676	11,382	2.9
2830	Walter C Beckjord	695	SI	1922510	Pond Run	167	86	StreamRiver	65	5.1	2.891	2.9	0.90
2830	Walter C Beckjord	695	SI	1922876	Ohio River	3	14	ArtificialPath	65	1.0	1.147	99,825	3.6
2830	Walter C Beckjord	696	SI	1922510	Pond Run	19	33	StreamRiver	65	5.1	2.891	2.9	0.90
2830	Walter C Beckjord	696	SI	1922872	Ohio River	74	33	ArtificialPath	65	4.0	2.053	99,830	3.6
2830	Walter C Beckjord	696	SI	1922874	Pond Run	144	33	ArtificialPath	65	0.1	0.314	2.9	0.48
2830	Walter C Beckjord	697	SI	1922872	Ohio River	53	100	ArtificialPath	65	4.0	2.053	99,830	3.6
2830	Walter C Beckjord	698	SI	1918228	Ohio River	124	20	ArtificialPath	65	0.2	0.387	99,830	3.6
2830	Walter C Beckjord	698	SI	1922872	Ohio River	71	80	ArtificialPath	65	4.0	2.053	99,830	3.6
2830	Walter C Beckjord	1126	LF	1922510	Pond Run	63	100	StreamRiver	65	5.1	2.891	2.9	0.90

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
2830	Walter C Beckjord	1127	LF	1918114	Tenmile Creek	495	63	StreamRiver	65	5.9	4.531	15	0.98
2830	Walter C Beckjord	1127	LF	1922510	Pond Run	1001	38	StreamRiver	65	5.1	2.891	2.9	0.90
1082	Walter Scott Jr. Energy Center	502	SI	17219106				CanalDitch	53.7	0.3	0.516	38	0.80
1082	Walter Scott Jr. Energy Center	503	SI	17219106				CanalDitch	53.7	0.3	0.516	38	0.80
1082	Walter Scott Jr. Energy Center	932	LF	17219100		1861	50	CanalDitch	52.8	4.9	1.627	2.5	0.74
1082	Walter Scott Jr. Energy Center	932	LF	17219200		1171	50	StreamRiver	52	6.0	4.956	0.033	0.55
6052	Wansley	35	SI	3291908				ArtificialPath	266.1	3.8	2.064	5,214	2.0
6705	Warrick Power Plant	224	SI	10110339				ArtificialPath	89	11.0	4.03	132,544	2.2
3297	Wateree	113	SI	9721753	Wateree River	2	100	ArtificialPath	216.2	6.3	3.062	8,073	2.2
3297	Wateree	114	SI	9721507		322	25	StreamRiver	217.1	2.8	2.977	1.2	0.72
3297	Wateree	114	SI	9721753	Wateree River	70	75	ArtificialPath	216.2	6.3	3.062	8,073	2.2
3297	Wateree	933	LF	9721507		15	50	StreamRiver	217.1	2.8	2.977	1.2	0.72
3297	Wateree	933	LF	9721753	Wateree River	1129	50	ArtificialPath	216.2	6.3	3.062	8,073	2.2
883	Waukegan	1311	SI	12170763		220	100	Coastline	88.1	10.8	5.042		
883	Waukegan	1312	SI	12170763		219	100	Coastline	88.1	10.8	5.042		
6139	Welsh	175	SI	1009152	Swauano Creek	868	100	StreamRiver	76.6	8.5	7.689	19	0.96
6139	Welsh	176	SI	1009160	Welsh Reservoir	462	100	LakePond	75.7	8.2	2.431	16	0.66
6139	Welsh	177	SI	1009152	Swauano Creek	1346	13	StreamRiver	76.6	8.5	7.689	19	0.96
6139	Welsh	177	SI	1009160	Welsh Reservoir	645	88	LakePond	75.7	8.2	2.431	16	0.66
6139	Welsh	934	LF	1009152	Swauano Creek	1172	38	StreamRiver	76.6	8.5	7.689	19	0.96
6139	Welsh	934	LF	1009160	Welsh Reservoir	704	63	LakePond	75.7	8.2	2.431	16	0.66
4078	Weston	935	LF	14731726	Johnson Creek	792	100	StreamRiver	150.7	3.7	2.451	23	0.95
4078	Weston	936	LF	14732378	Wisconsin River	72	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
4078	Weston	1313	SI	14732378	Wisconsin River	10	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
4078	Weston	1314	SI	14732378	Wisconsin River	656	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
4078	Weston	1315	SI	14732378	Wisconsin River	670	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
4078	Weston	1316	SI	14732378	Wisconsin River	380	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
4078	Weston	1317	SI	14732378	Wisconsin River	473	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
4078	Weston	1318	SI	14732378	Wisconsin River	218	100	ArtificialPath	140.8	6.3	3.668	3,564	1.9
60	Whelan Energy Center Unit 1 (WEC1)	1214	SI	18758724		2141	100	StreamRiver	19.4	5.5	3.717	0.050	0.63
6009	White Bluff	1128	LF	22850711		367	25	StreamRiver	119	2.4	3.827	0.91	0.72
6009	White Bluff	1128	LF	22850721	Lipscomb Branch	323	25	StreamRiver	119	1.6	1.847	0.61	0.66
6009	White Bluff	1128	LF	22851451	Surge Pond	921	50	LakePond	119	1.5	0.502	2.2	0.75
1040	Whitewater Valley	1321	SI	3922369	East Fork Whitewater River	1486	100	StreamRiver	119	11.5	5.936	124	1.4
1040	Whitewater Valley	1322	SI	3922369	East Fork Whitewater River	1510	100	StreamRiver	119	11.5	5.936	124	1.4
1040	Whitewater Valley	1323	SI	3922369	East Fork Whitewater River	1506	100	StreamRiver	119	11.5	5.936	124	1.4
1040	Whitewater Valley	1324	SI	3922369	East Fork Whitewater River	1469	100	StreamRiver	119	11.5	5.936	124	1.4
1040	Whitewater Valley	1325	SI	3922369	East Fork Whitewater River	1471	100	StreamRiver	119	11.5	5.936	124	1.4
4057	WI Power & Light Co -Rock River Generating	1	SI	13297306	Rock River	2	100	ArtificialPath	123.8	33.5	4.925	1,493	1.6
4057	WI Power & Light Co -Rock River Generating	2	SI	13297306	Rock River	59	100	ArtificialPath	123.8	33.5	4.925	1,493	1.6
4057	WI Power & Light Co -Rock River Generating	3	SI	13297306	Rock River	3	100	ArtificialPath	123.8	33.5	4.925	1,493	1.6
4057	WI Power & Light Co -Rock River Generating	172	SI	13297306	Rock River	58	100	ArtificialPath	123.8	33.5	4.925	1,493	1.6
50	Widows Creek	59	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	60	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	61	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	62	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	63	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	64	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
50	Widows Creek	65	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	66	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	261	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	262	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	289	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
50	Widows Creek	290	SI	19646344				LakePond	254.7	0.9	1.097	46,353	3.0
884	Will County	389	SI	14787485				ArtificialPath	116.2	2.5	6.427	342	1.2
3298	Williams	1129	LF	9644721		709	100	StreamRiver	179	5.3	3.391	1.9	0.44
3298	Williams	1130	LF	9644711	Molly Branch	74	63	StreamRiver	179	1.1	1.289	0.58	0.65
3298	Williams	1130	LF	9644713	Stony Branch	215	38	StreamRiver	179	2.1	1.944	0.75	0.69
3946	Willow Island	917	LF	15438238				ArtificialPath	90.6	0.1	0.139	44,013	3.0
6249	Winyah	198	SI	11565178		113	50	StreamRiver	171.7	1.8	1.718	0.75	0.38
6249	Winyah	198	SI	11565200	Pennyroyal Creek	66	50	StreamRiver	172	1.0	1.165	7.1	0.56
6249	Winyah	199	SI	11565200	Pennyroyal Creek	148	75	StreamRiver	172	1.0	1.165	7.1	0.56
6249	Winyah	199	SI	11565228	Pennyroyal Creek	60	25	StreamRiver	172	1.6	1.429	5.1	0.53
6249	Winyah	200	SI	11565228	Pennyroyal Creek	700	50	StreamRiver	172	1.6	1.429	5.1	0.53
6249	Winyah	200	SI	11565234		45	50	StreamRiver	171.9	1.0	1.446	0.40	0.54
6249	Winyah	201	SI	11565204		107	40	CanalDitch	169.2	0.6	0.953	4.2	0.51
6249	Winyah	201	SI	11565234		212	40	StreamRiver	171.9	1.0	1.446	0.40	0.54
6249	Winyah	201	SI	11566154		158	20	LakePond	170.2	1.2	2.977	3.9	0.50
6249	Winyah	202	SI	11565234		76	33	StreamRiver	171.9	1.0	1.446	0.40	0.54
6249	Winyah	202	SI	11566154		76	33	LakePond	170.2	1.2	2.977	3.9	0.50
6249	Winyah	202	SI	11566156		22	33	LakePond	172	1.1	1.607	0.86	0.39
6249	Winyah	203	SI	11565204		26	100	CanalDitch	169.2	0.6	0.953	4.2	0.51
6249	Winyah	982	LF	11565228				StreamRiver	172	1.6	1.429	5.1	0.53
898	Wood River	397	SI	879884		217	88	StreamRiver	37	5.1	2.435	1.5	0.68
898	Wood River	397	SI	879898	Wood River	157	13	StreamRiver	37	0.3	1.326	92	0.98
898	Wood River	398	SI	879892		495	100	StreamRiver	37	0.7	0.239	0.62	0.48
50611	WPS Westwood Generation, LLC	951	LF	4707642	Good Spring Creek	208	33	StreamRiver	320.7	20.0	9.297	11	1.1
50611	WPS Westwood Generation, LLC	951	LF	4707680	Lower Rausch Creek	17	67	StreamRiver	328	10.5	6.365	5.8	1.0
6101	Wyodak Plant	80	SI	10902255	Donkey Creek	356	100	StreamRiver	9.2	29.5	4.496	0.42	0.90
6101	Wyodak Plant	981	LF	10902255				StreamRiver	9.2	29.5	4.496	0.42	0.90
728	Yates	367	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72

Attachment B-4. Waterbody Data

Oris Code	ORIS Plant Name	WMU ID	Unit Type	COMID	Nearest Waterbody Name (if available)	Minimum Distance to Waterbody (m)	Percent-age	Waterbody Type	Mean Recharge (mm/yr)	Area (km^2)	Length (km)	Mean Annual Flow (cfs)	Mean Annual Velocity (fps)
728	Yates	368	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	369	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	370	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	371	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	372	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	373	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	374	SI	3288658				StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	986	LF	3288658		108	67	StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	986	LF	3288684		188	33	StreamRiver	254.5	0.9	0.814	1.7	0.75
728	Yates	987	LF	3288658		431	25	StreamRiver	255.1	2.1	1.429	3.1	0.72
728	Yates	987	LF	3290264	Chattahoochee River	590	50	ArtificialPath	257	2.0	0.729	5,008	1.9
728	Yates	987	LF	3290268	Chattahoochee River	567	25	ArtificialPath	256.3	2.5	1.696	5,011	1.6
3809	Yorktown	988	LF	9897200	West Branch Wormley Creek	376	25	ArtificialPath	182	5.6	2.495	6.2	0.55
3809	Yorktown	988	LF	9897296		1579	75	Coastline	182	3.0	3.071		
3809	Yorktown	1359	SI	9897200	West Branch Wormley Creek	135	100	ArtificialPath	182	5.6	2.495	6.2	0.55

Appendix C.

Constituent Data

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C.1 CCR Constituent Database

This risk assessment addresses metallic and other inorganic constituents identified as constituents of potential concern (COPCs) in coal combustion residuals (CCRs). The CCR constituent database contains data collected over a series of CCR-related regulatory activities from 1998 through 2010, as follows:

- CCR and CCR leachate data used in the 1998 Risk Assessment (U.S. EPA, 1998a,b) and documented in the 1999 Report to Congress ("1999 RTC") (U.S. EPA, 1999);
- Data submitted to EPA through public comments on the 1999 RTC;
- Data submitted to EPA through public comments on the 2000 Regulatory Determination;
- Data submitted to and collected by EPA after the close of the public comment period for the 2000 Regulatory Determination;
- Data submitted to EPA through public comments on the 2010 Proposed CCR Rule;
- Data developed by EPA's Office of Research and Development using the Leaching Evaluation Assessment Framework (LEAF) test methods (U.S. EPA, 2009); and

Attachment C-1 provides a complete list of the data sources contained in the updated 2014 database that were considered in this risk assessment. The data in the CCR constituent database characterizes the concentrations of COPCs present in and released from CCRs. In addition to COPC concentrations, this database also provides information, as available, on the coal burned at the facility and the type of CCR(s) analyzed. The CCR constituent database includes CCRs generated from the major coal ranks: bituminous, sub-bituminous, and, to a lesser degree, lignite and anthracite. In some cases, the coal rank associated with samples in the database is not specified, partly because many facilities mix coals from different sources over time based on a number of factors, such as fuel cost and the need to reduce sulfur levels. The CCR constituent database also includes data on all major types of CCRs, which include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) waste. Similar to coal type, many of the available samples reflect the practice of codisposal, such as fly ash with bottom ash or CCRs with coal refuse. Thus, the CCR constituent database provides a snapshot of current management practices across a broad cross-section of the regulated universe, with a large number of samples collected from sites in 30 states. **Table C-1** lists the data evaluated in this risk assessment, along with the number of sites representing each waste type in the CCR constituent database.

Table C-1. Waste Types in the 2014 CCR Database

CCR Type	Number of Sites by Waste Type		
	Impoundment Wastewater	Impoundment Pore Water	Total Waste
Combined Ash	9	18	67
Ash and Coal Refuse	0	5	1
FGD Waste	2	7	6

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C.2 Intra-site Variability

The 2010 Risk Assessment (U.S. EPA, 2010) averaged all of the samples collected at each site for each constituent and waste stream (impoundment surface water, impoundment pore water and whole waste) to create a single concentration for each site, constituent, and waste stream. EPA initially chose this approach in order to avoid the potential to bias the evaluation results toward sites with more samples. However, that approach was found to not adequately account for intra-site variability. Therefore, in the revised risk assessment, EPA relied on a quartile approach to retain more of the intra-site variability lost through the use of site averages. To develop the site quartiles, EPA first separated the data for each site, constituent, and waste stream by waste type (i.e., combined ash, ash and coal waste, FGD waste). Combining the data for the different waste types into a single set of quartiles for a site might bias concentrations toward the most sampled waste types. Therefore, quartiles were calculated for each waste type at each sample site for each waste stream and constituent. Where only one sample was available for a waste type at a sample site, all of the quartiles were set to this value to ensure equal weighting.

Nondetect analytical results were included using a value of half the reported detection limit. For the screening analysis, the 90th percentile of these quartiles across all sites and waste streams was calculated and used. For the full-scale probabilistic analysis, the Monte Carlo simulation sampled from the site-specific quartiles for each constituent and waste stream. **Attachments C-2** through **C-4** provides the quartiles used (sampled) in the full-scale CCR risk assessment by waste type/WMU scenario for CCR impoundment wastewater, pore water and whole waste, respectively. **Attachment C-5** provides a list of the constituents that have concentration data and notes which types of concentration are available (pore water, impoundment wastewater or whole waste).

C.3 LEAF Data

For surface impoundments, the revised risk assessment applied the data from the CCR constituent database in the same way as the 2010 Risk Assessment. For landfills, the 2010 Risk Assessment relied on a hierarchy of dissolved concentration data, ranging from field leachate data to toxicity characteristic leaching procedure. Since that time, new data have been made available through a series of EPA reports (U.S. EPA 2006, 2008, 2009) that examined the effects of coal rank and changes in air pollution control technologies on CCR leaching behavior. The leaching test methods used to evaluate leaching behavior are from the EPA SW-846 LEAF methods. The interlaboratory validation for these methods are described in U.S. EPA (2012a,b), while Kosson et al. (2002) provides the detailed test methodology for Methods SR02 and SR03.[1] These data were collected with three of the LEAF test methods, specifically SW-846 Methods 1313, 1314 and 1316. The data from these three methods were used together to develop the source term to characterize leaching from landfills considering geographically distributed, site-specific conditions and uncertainties to form a set of disposal scenarios that were used in the risk assessment. All three of these methods are briefly summarized in the following text.

[1] Methods SR02 and SR03 are predecessor methods to SW-846 Methods 1313 and 1316.

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C.3.1 Summary of LEAF Methods Used

Method 1313: Liquid-Solid Partitioning as a Function of Eluate pH using a Parallel Batch Extraction Procedure

Method 1313 is a leaching test designed to estimate constituent concentrations in eluate as a function of pH. This procedure consists of nine separate parallel batch extractions, which involve placing a given mass of ash in a container with a specific volume of eluent to achieve a L/S ratio of 10 mL/g-dry. Each eluent is buffered using a dilute acid or base to achieve different target pH values ranging between 2.8 and 13. One of these values is the natural pH of the material (also referred to as "own pH"), which is achieved by allowing the material to equilibrate with deionized water. The extraction contact time ranges somewhere between 24 and 72 hours, based on the grain size of the material "as tested." This may be distinct from the grain size of the material "as received," because particle size reduction or air drying may be required either to improve handling and to achieve equilibrium between the liquid eluent and solid sample within a reasonable extraction timeframe. Solid and liquid phases are separated by either vacuum- or pressure-assisted filtration and prepared for chemical analysis. The measured eluate concentrations are plotted as a function of final pH for each batch. Eluate concentrations may be interpolated between these measured concentrations to provide a uniform basis for comparison, as the final measured eluate pH values are likely to differ marginally from the target values. The data collected with Method 1313 were used to characterize the leaching behavior of different CCRs as a function of pH and total leachable content. **Figure C-1** compares example concentration profiles for four constituents as a function of pH for three duplicate samples of the same ash (Sample ID: EaFA). For this waste, the arsenic (As) leachate concentrations ranged over about two orders of magnitude, with peak concentrations at the highest and lowest pH, and a minimum concentration at a pH of approximately 5.6. Chromium (Cr) concentrations varied by over four orders of magnitude across the same range, with a minimum at a pH of 5.6, while molybdenum (Mo) and calcium (Ca) ranging over a little more than an order of magnitude. Additional information on this subject can be found at U.S. EPA (2009).

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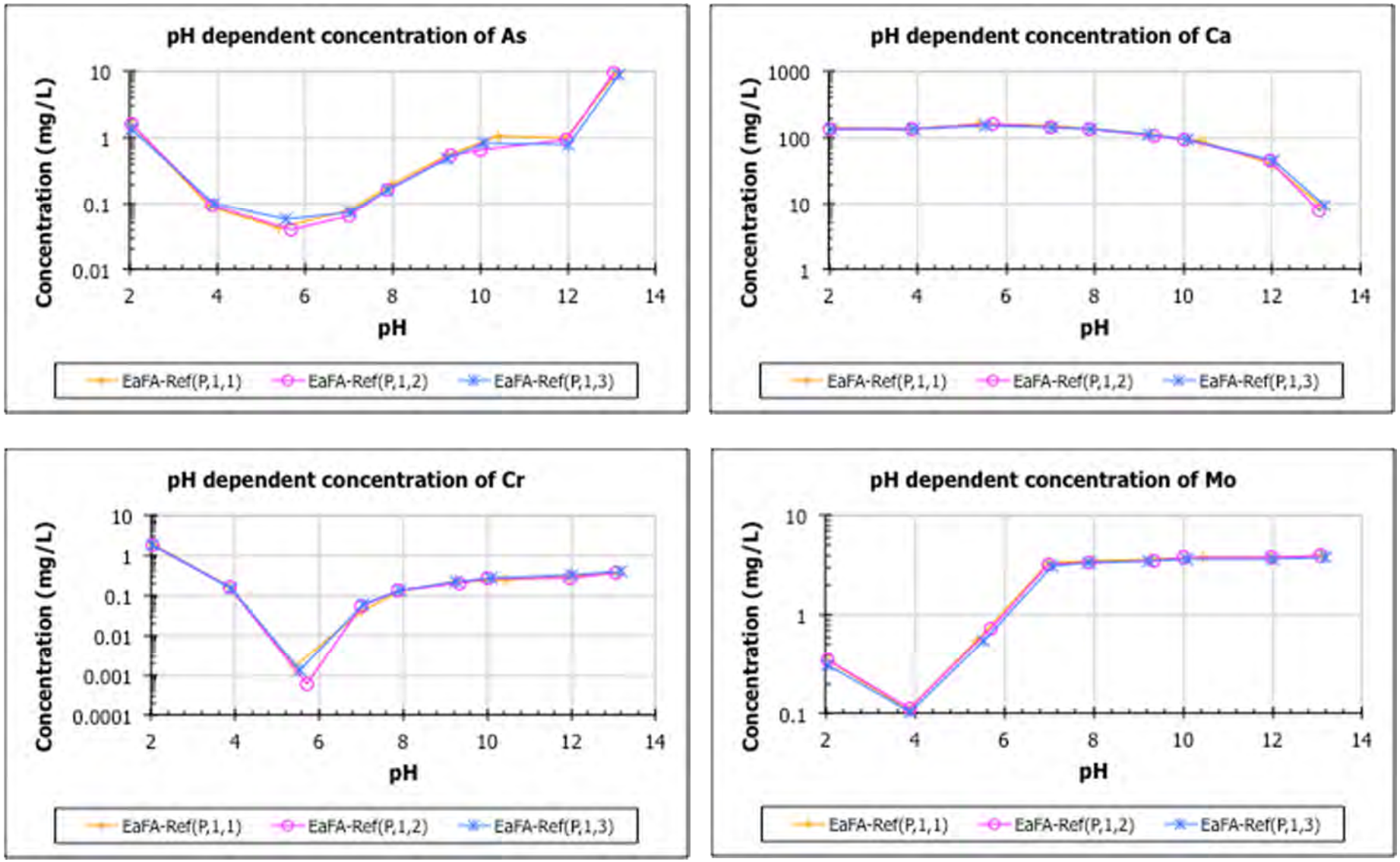

Figure C-1. Example eluate concentrations as a function of pH as obtained from Method 1313 on coal fly ash sample EaFA (Adapted from data in U.S. EPA, 2012a).

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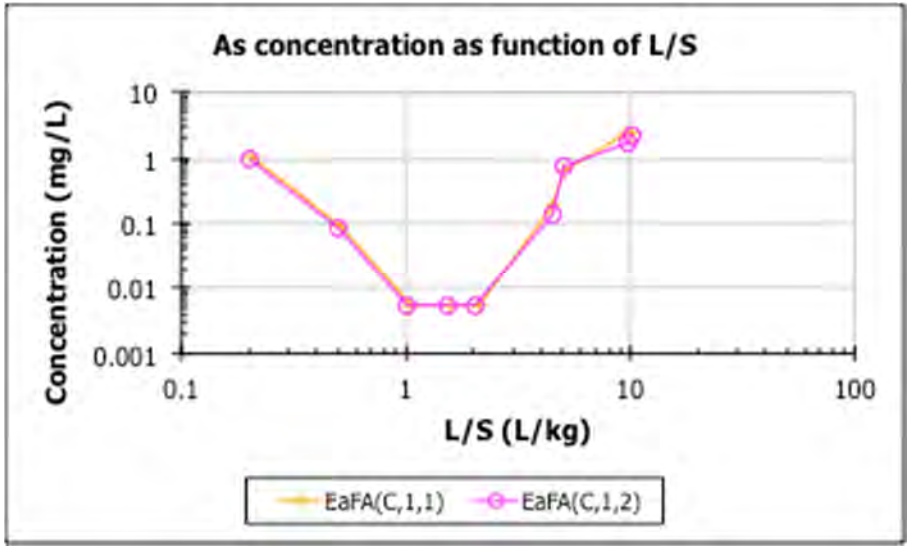
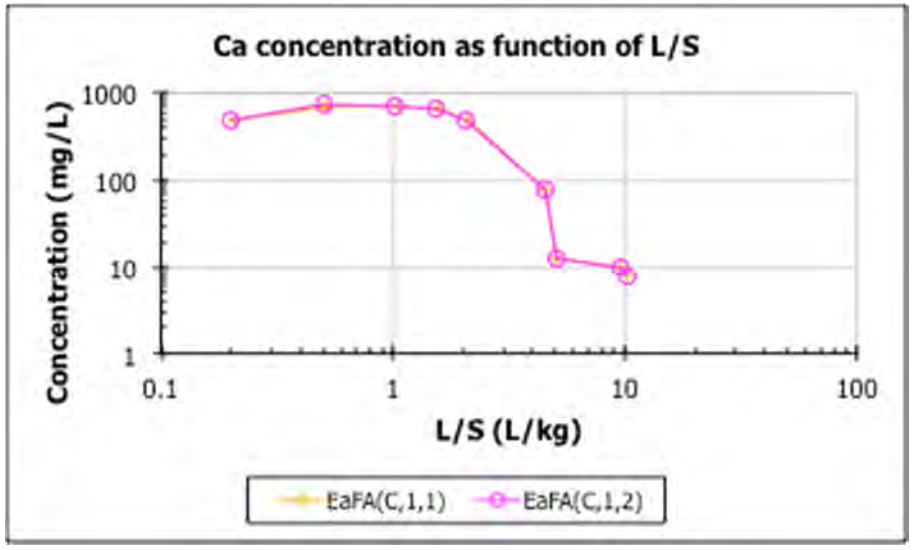
Method 1314: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio (L/S) for Constituents in Solid Materials Using an Up-Flow Percolation Column Procedure

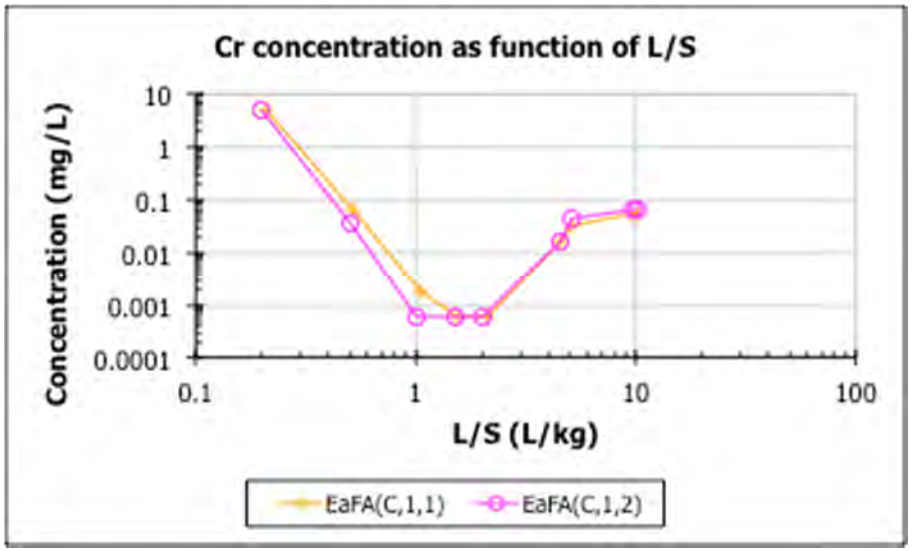
Method 1314 is a leaching test designed to estimate constituent concentrations in eluate as a function of the cumulative L/S ratio. This procedure consists of five separate, parallel upflow percolation columns, which involves percolating deionized water through a given mass of moderately compacted ash against the force of gravity. The upflow percolation is intended to minimize air entrainment and preferential flow channeling. The flow rate is maintained at a level corresponding to in an increase of the L/S ratio between 0.5 and 1.0 mL/g-day in order to increase the likelihood of local equilibrium developing between the liquid eluate and solid ash. Samples are collected each time a specified cumulative L/S ratio has been reached. For the purposes of chemical speciation modeling, the entire eluent volume up to 10 mL/g of dry sample is collected in nine specific aliquots of varying volume. The data collected with Method 1314 were used together with those from Method 1316 to verify that the application of the Method 1313 data, which is collected at a single (10 mL/g) L/S ratio, provides a conservative estimate for peak leachate concentrations. **Figure C-2** shows example results of eluate concentrations as a function of the L/S ratio. Both arsenic and chromium show highest concentrations at the lowest and highest L/S ratio tested, while calcium and molybdenum leachate concentrations peak at just less than an L/S of 1 mL/g (L/kg).

Method 1316: Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio using a Parallel Batch Extraction Procedure

Method 1316 is a leaching test designed to estimate constituent concentrations in eluate as a function of L/S ratio. This procedure consists of five separate parallel batch extractions, which involve placing a given mass of ash in a container with a specific volume of eluent. Each batch is set to a different, constant L/S ratio ranging between 0.5 and 10 mL/g-day. Particle size reduction of the solid material may be required in order to facilitate the approach to liquid-solid equilibrium. The extraction contact time ranges somewhere between 24 and 72 hours, based on the grain size of the material "as tested." This may be distinct from the grain size of the material "as received," because particle size reduction or air drying may be required either to improve handling and to achieve equilibrium between the liquid eluent and solid sample within a reasonable extraction timeframe. Solid and liquid phases are separated by either vacuum- or pressure-assisted filtration and prepared for chemical analysis. The measured eluate concentrations are plotted as a function of L/S ratio. This method provides data on the changes in equilibrium chemistry (i.e., ionic strength, constituent concentrations) as the L/S ratio value approaches values found within the solid phase pore solution. The data collected with Method 1316 were used together with those from Method 1314 to verify that the application of the Method 1313 data, which is collected at a single L/S ratio, provides a conservative estimate for peak leachate concentrations. **Figure C-3** shows example results of eluate concentrations as a function of the L/S ratio as obtained from parallel batch extractions using Method 1316.







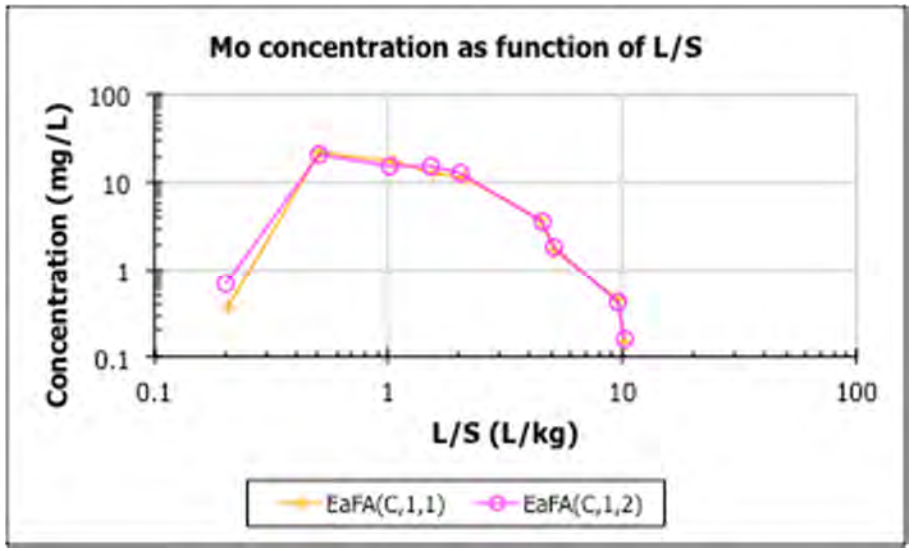


Figure C-2. Eluate concentrations as a function of L/S ratio as obtained from Method 1314 applied to coal fly ash sample EaFA (Adapted from data in U.S. EPA, 2012a).

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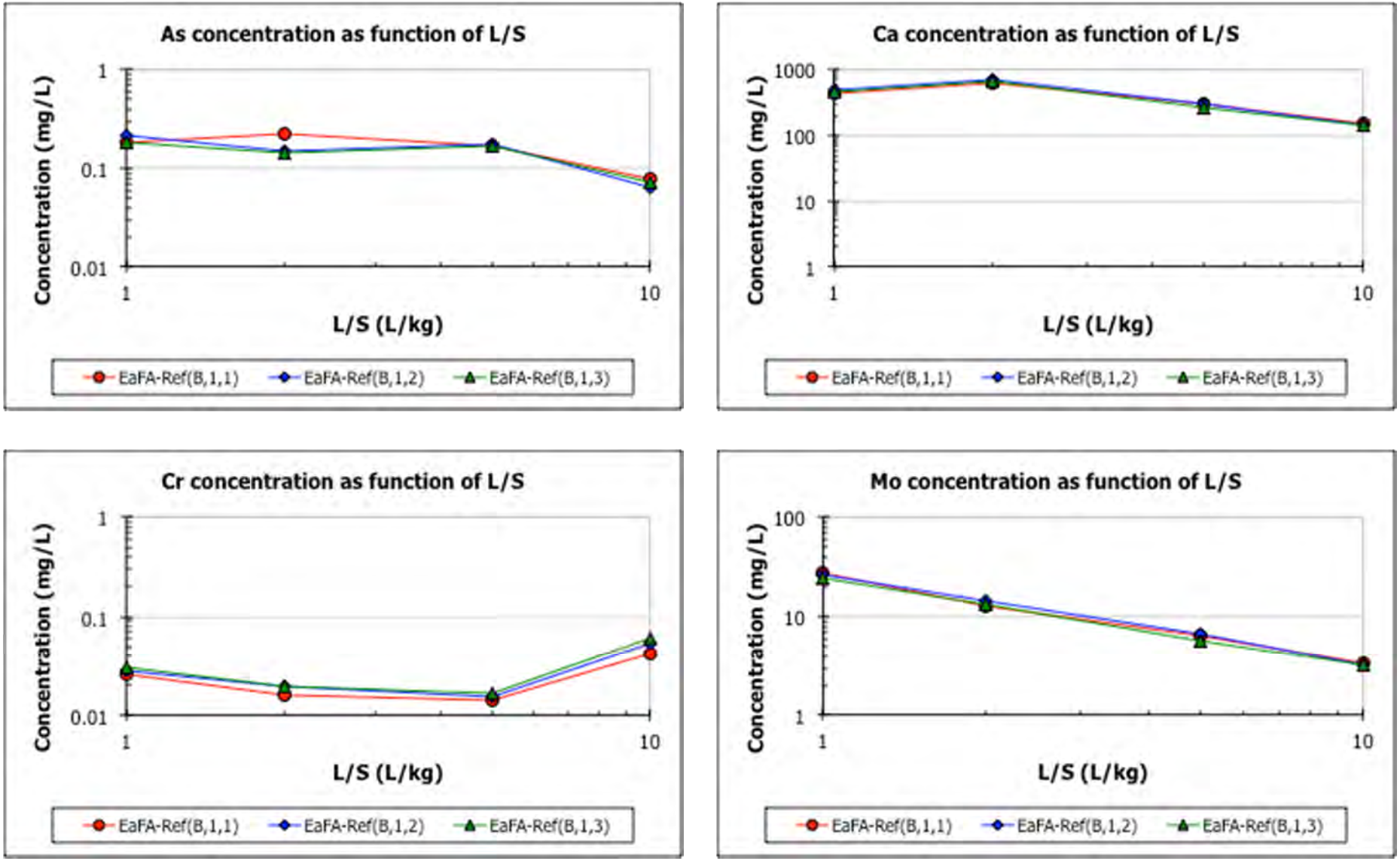

Figure C-3. Eluate concentrations as a function of L/S ratio as obtained from Method 1316 applied to coal fly ash sample EaFA (Adapted from data in U.S. EPA, 2012a).

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C.3.2 Constituent Leaching Behavior

The leaching behavior of constituents, as defined by the Method 1313 data, can be divided into the following categories: washout-controlled and solubility-controlled. A single constituent may alternate between the two categories over the relevant pH range (e.g. some constituents may be washout-controlled at a low pH and solubility-controlled at a high pH, while other constituents display the opposite behavior). In addition, this behavior profile is not constant for a constituent across all CCR types. A given constituent may fall entirely into the washout-controlled zone when leached from ash generated by one combination of coal type and pollution control technology, but enter the solubility-controlled zone when leached from ash generated by a different combination. With these considerations in mind, the two leaching categories are briefly described below.

The washout-controlled zone is characterized by the quick dissolution and release of the more soluble species (e.g., sodium, potassium) from the ash into the pore water. In Method 1313 data, this behavior is characterized by a generally constant leachate concentration over a pH range. **Figure C-4** shows an example of an ash (Sample ID: AaFA) for which boron falls in the washout-controlled zone over the entire pH range evaluated and leachate concentrations are almost constant.

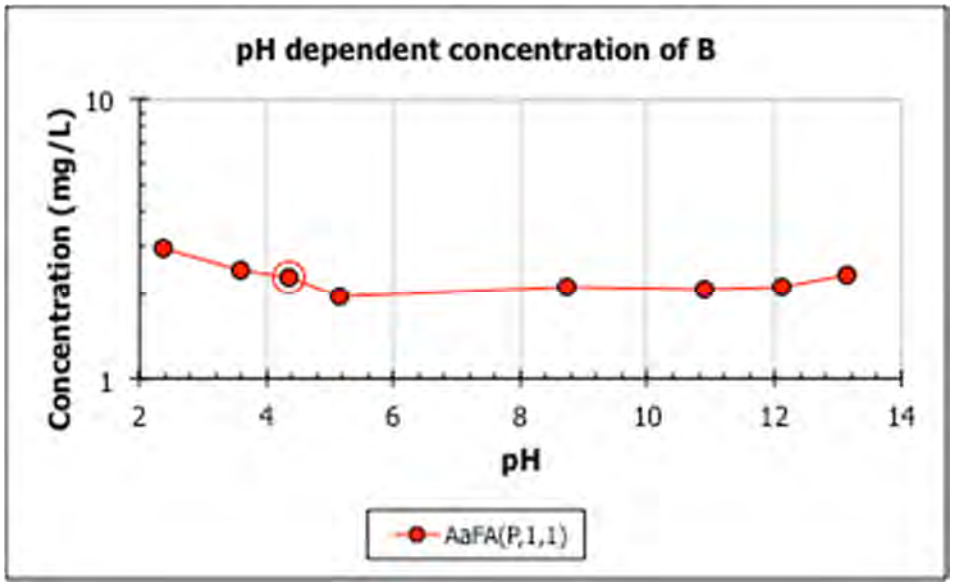

Figure C-4. Example of a washout-controlled species over the full experimental pH domain for sample AaFA (Adapted from data in U.S. EPA, 2009).

The solubility-controlled zone is characterized by a slower release of less soluble species (e.g., calcium, aluminum) where the leachate concentration is controlled by solubility of the species at a specific pH value. In Method 1313 data, this is characterized by variable leachate concentrations over the pH range. **Figure C-5** shows an example of an ash (Sample ID: AaFA) for which chromium falls within the solubility-controlled zone over the entire pH range. Note that concentrations vary by almost two orders of magnitude over the pH range evaluated.

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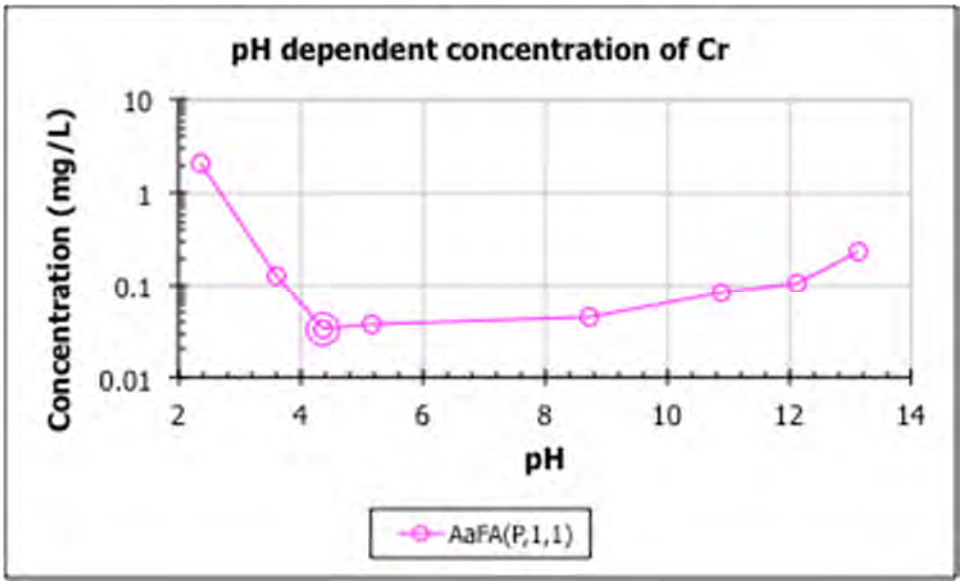

Figure C-5. Example of a solubility-controlled species over the full experimental pH domain for sample AaFA (Adapted from data in U.S. EPA, 2009).

In some cases, a constituent may be washout-controlled over one part of the pH range and solubility-controlled over another. **Figure C-6** shows an example of an ash (Sample ID: AFA) for which boron is washout-controlled, with an almost constant leachate concentration for pH values less than eight, and solubility-controlled for pH values above eight.

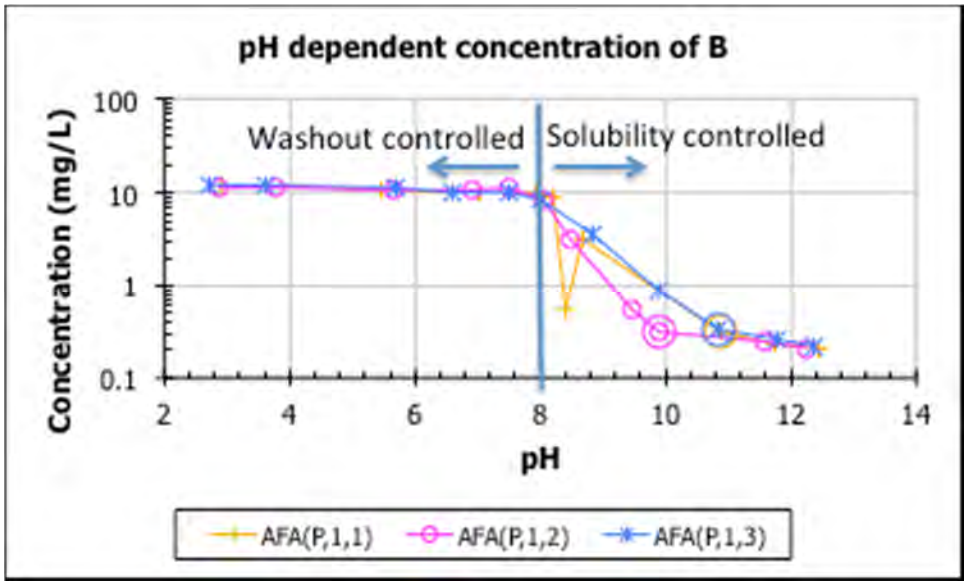

Figure C-6. Example of a part washout- and part solubility-controlled species triplicate measurements of sample AaFA (Adapted from data in U.S. EPA, 2009).

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C.3.3 Data Preparation

During the waste sampling and LEAF analysis conducted to develop constituent concentrations for landfills, EPA determined that the range and variability of different waste chemistry was best represented by a single pH distribution for all waste types (U.S. EPA, 2009). Even though on a single distribution, it still effectively captures the different waste types. For example, low pH conditions were used to represent codisposal of CCR with coal refuse.

To accommodate this single distribution within the CCR Metal Speciation Equilibrium Model for Surface and Ground Water (MINTEQA2) modeling construct, the waste types for landfills were modeled using a single combined ash isotherm, and risk results were evaluated across all landfill waste types. To select a MINTEQA2 isotherm for each iteration of the Monte Carlo analysis for landfills, a leachate pH was randomly selected from the distribution, a combined ash waste type was assumed, and aquifer type was assigned based on the location of the landfill being modeled (see **Appendix B, Section B.3)**. Iron oxide, natural organic matter, and leachate ionic strength were then randomly selected based on the combined ash waste type to identify the unsaturated and saturated zone isotherms to be used for a particular model run. How these data were prepared for and used by EPA's Composite Model For Leachate Migration With Transformation Products (EPACMTP) is described in **Appendix I**.

The LEAF-generated landfill leachate data were consolidated into a single data set for the revised risk assessment. The Method 1313 data were organized into a series of tables, each containing the data collected for each ash sample, as described in U.S. EPA (2009). The landfill leachate data tables also included a measured availability (in mg/kg) for each constituent and waste that was used by the EPACMTP landfill model to provide a limit in the constituent mass that can be leached from a particular CCR waste at a particular leachate concentration. **Attachment C-7** provides each of these generated tables. Availability data, by constituent, are at the bottom of each table.

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Attachment C-1.
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Attachment C-2.

Quartile Data for CCR Impoundment Porewater

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
13115B	Combined ash	Aluminum	mg/L	0.075	0.075	0.0775	TRUE
14093	Fly Ash	Aluminum	mg/L	0.1575	0.3	0.415	TRUE
22346	Other	Aluminum	mg/L	0.011	0.021	0.031	TRUE
23223B	FGD waste	Aluminum	mg/L	0.68	0.75	0.82	TRUE
25410A	Combined ash	Aluminum	mg/L	44.4	44.4	44.4	TRUE
25410B	Fly Ash	Aluminum	mg/L	0.075	0.075	0.075	TRUE
33104	Fly Ash	Aluminum	mg/L	1.0185	1.979	2.9395	TRUE
33106	Fly Ash	Aluminum	mg/L	0.01	0.014	0.0145	TRUE
35015B	Fly Ash	Aluminum	mg/L	0.1525	0.165	0.1775	TRUE
40109	Fly Ash	Aluminum	mg/L	5.2825	8.555	11.8275	TRUE
43035	Combined ash	Aluminum	mg/L	5.6725	5.755	5.8375	TRUE
49003A	Fly Ash	Aluminum	mg/L	0.04875	0.0655	0.0825	TRUE
AP	Combined ash	Aluminum	mg/L	0.125	0.358	0.819	TRUE
BR	Ash & coal waste	Aluminum	mg/L	1.7	11.55	51.975	TRUE
C	Combined ash	Aluminum	mg/L	2.9	3.9	5.6	TRUE
CADK	FGD waste	Aluminum	mg/L	0.1625	0.165	0.1675	TRUE
CASJ	FGD waste	Aluminum	mg/L	0.054	0.15	0.15	TRUE
CATT	FGD waste	Aluminum	mg/L	0.275	0.28	0.285	TRUE
CL	Ash & coal waste	Aluminum	mg/L	0.22925	1.05125	3.78375	TRUE
CY	FGD waste	Aluminum	mg/L	4.2075	7.055	8.945	TRUE
FC	Ash & coal waste	Aluminum	mg/L	9.3725	10.5	13.45	TRUE
HA	Ash & coal waste	Aluminum	mg/L	0.65	0.65	0.65	TRUE
HA	Combined ash	Aluminum	mg/L	0.12875	0.28975	1.043	TRUE
L	Combined ash	Aluminum	mg/L	0.015	0.015	0.015	TRUE
MO	Ash & coal waste	Aluminum	mg/L	0.41	0.5775	352.375	TRUE
MO	Bottom ash	Aluminum	mg/L	0.2185	0.31525	1.6789375	TRUE
NA	Na FGD Sludge	Aluminum	mg/L	0.3	0.3	2.5	TRUE
OK	Bottom ash	Aluminum	mg/L	0.606125	0.92925	1.252375	TRUE
OK	Fly ash	Aluminum	mg/L	22.4025	42.11	66.8925	TRUE
SX	Bottom ash	Aluminum	mg/L	0.081792425	0.25028275	0.334547025	TRUE
SX	Fly ash	Aluminum	mg/L	8.06025	12.1525	12.36875	TRUE
AP	Combined ash	Ammonia	mg/L	0.05	0.05	0.05	TRUE
C	Combined ash	Ammonia	mg/L	1.4	2.55	3.2	TRUE
CL	Ash & coal waste	Ammonia	mg/L	0.29	0.55	0.88	TRUE
MO	Ash & coal waste	Ammonia	mg/L	1.135	3.69	6.3875	TRUE
MO	Bottom ash	Ammonia	mg/L	0.27	0.49	0.6	TRUE
SX	Bottom ash	Ammonia	mg/L	0.16	4.805	6.115	TRUE
13115B	Combined ash	Antimony	mg/L	0.0011	0.0016	0.0025	TRUE
14093	Fly Ash	Antimony	mg/L	0.00135	0.002	0.00435	TRUE
22346	Other	Antimony	mg/L	0.0003125	0.000575	0.0008375	TRUE
23223B	FGD waste	Antimony	mg/L	0.001225	0.00175	0.002275	TRUE
25410A	Combined ash	Antimony	mg/L	0.0024	0.0024	0.0024	TRUE
25410B	Fly Ash	Antimony	mg/L	0.0013	0.0013	0.0013	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
33104	Fly Ash	Antimony	mg/L	0.002575	0.00445	0.006325	TRUE
33106	Fly Ash	Antimony	mg/L	0.00135	0.0024	0.0035	TRUE
35015B	Fly Ash	Antimony	mg/L	0.003275	0.00385	0.004425	TRUE
40109	Fly Ash	Antimony	mg/L	0.00555	0.0085	0.01145	TRUE
43035	Combined ash	Antimony	mg/L	0.00025	0.0003	0.00035	TRUE
49003A	Fly Ash	Antimony	mg/L	0.02465	0.04495	0.05865	TRUE
AP	Combined ash	Antimony	mg/L	0.01	0.01	0.01	TRUE
C	Combined ash	Antimony	mg/L	0.05	0.05	0.1	TRUE
13115B	Combined ash	Arsenic	mg/L	0.022	0.023	0.0415	TRUE
14093	Fly Ash	Arsenic	mg/L	0.0925	0.163	0.2005	TRUE
22346	Other	Arsenic	mg/L	0.256	0.413	0.57	TRUE
23223B	FGD waste	Arsenic	mg/L	0.01775	0.0185	0.01925	TRUE
25410A	Combined ash	Arsenic	mg/L	0.069	0.069	0.069	TRUE
25410B	Fly Ash	Arsenic	mg/L	0.072	0.072	0.072	TRUE
33104	Fly Ash	Arsenic	mg/L	0.3915	0.721	1.0505	TRUE
33106	Fly Ash	Arsenic	mg/L	0.049	0.056	0.0895	TRUE
35015B	Fly Ash	Arsenic	mg/L	0.0875	0.132	0.1765	TRUE
40109	Fly Ash	Arsenic	mg/L	0.19275	0.2215	0.25025	TRUE
43035	Combined ash	Arsenic	mg/L	0.0055	0.0058	0.0061	TRUE
49003A	Fly Ash	Arsenic	mg/L	0.0825	0.148	0.2	TRUE
AP	Combined ash	Arsenic	mg/L	0.0325	0.041	0.059	TRUE
BR	Ash & coal waste	Arsenic	mg/L	0.004	0.022	0.9765	TRUE
C	Combined ash	Arsenic	mg/L	0.072	0.091	0.11	TRUE
CADK	FGD waste	Arsenic	mg/L	0.00625	0.0075	0.00875	TRUE
CASJ	FGD waste	Arsenic	mg/L	1.81725	2.855	6.41	TRUE
CATT	FGD waste	Arsenic	mg/L	0.139	0.206	0.273	TRUE
CL	Ash & coal waste	Arsenic	mg/L	0.082584687	0.404963334	0.66338875	TRUE
CY	FGD waste	Arsenic	mg/L	0.06405	0.0748	0.20825	TRUE
FC	Ash & coal waste	Arsenic	mg/L	0.0025	0.0025	0.0025	TRUE
HA	Ash & coal waste	Arsenic	mg/L	0.18	0.18	0.18	TRUE
HA	Combined ash	Arsenic	mg/L	0.005821	0.01933	0.1081	TRUE
MO	Ash & coal waste	Arsenic	mg/L	0.182282849	5.03	14.42148508	TRUE
MO	Bottom ash	Arsenic	mg/L	0.0025	0.0055785	0.014373468	TRUE
NA	Na FGD Sludge	Arsenic	mg/L	0.8	0.8	10	TRUE
O	FGD waste	Arsenic	mg/L	0.18025	0.3438	0.3438	TRUE
OK	Bottom ash	Arsenic	mg/L	0.025	0.025	0.025	TRUE
OK	Fly ash	Arsenic	mg/L	0.056195	0.0568	0.073125	TRUE
SX	Bottom ash	Arsenic	mg/L	0.008688875	0.02661935	0.105585375	TRUE
SX	Fly ash	Arsenic	mg/L	0.00836	0.0111	0.015	TRUE
13115B	Combined ash	Arsenic (III)	mg/L	0.00005	0.00005	0.000235	TRUE
14093	Fly Ash	Arsenic (III)	mg/L	0.0028	0.0037	0.05035	TRUE
22346	Other	Arsenic (III)	mg/L	0.024875	0.04025	0.055625	TRUE
23223B	FGD waste	Arsenic (III)	mg/L	0.0008125	0.000875	0.0009375	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
25410A	Combined ash	Arsenic (III)	mg/L	0.0003	0.0003	0.0003	TRUE
25410B	Fly Ash	Arsenic (III)	mg/L	0.00088	0.00088	0.00088	TRUE
33104	Fly Ash	Arsenic (III)	mg/L	0.214825	0.42955	0.644275	TRUE
33106	Fly Ash	Arsenic (III)	mg/L	0.00085	0.0014	0.002	TRUE
35015B	Fly Ash	Arsenic (III)	mg/L	0.052875	0.10225	0.151625	TRUE
40109	Fly Ash	Arsenic (III)	mg/L	0.04425	0.0655	0.08675	TRUE
43035	Combined ash	Arsenic (III)	mg/L	0.0000625	0.000075	0.0000875	TRUE
49003A	Fly Ash	Arsenic (III)	mg/L	0.000575	0.00077	0.0011175	TRUE
13115B	Combined ash	Arsenic (V)	mg/L	0.00605	0.0069	0.02045	TRUE
14093	Fly Ash	Arsenic (V)	mg/L	0.033125	0.066	0.076	TRUE
22346	Other	Arsenic (V)	mg/L	0.21175	0.3195	0.42725	TRUE
23223B	FGD waste	Arsenic (V)	mg/L	0.0004375	0.000625	0.0008125	TRUE
25410A	Combined ash	Arsenic (V)	mg/L	0.025	0.025	0.025	TRUE
25410B	Fly Ash	Arsenic (V)	mg/L	0.047	0.047	0.047	TRUE
33104	Fly Ash	Arsenic (V)	mg/L	0.1575	0.278	0.3985	TRUE
33106	Fly Ash	Arsenic (V)	mg/L	0.0435	0.053	0.053	TRUE
35015B	Fly Ash	Arsenic (V)	mg/L	0.02525	0.0265	0.02775	TRUE
40109	Fly Ash	Arsenic (V)	mg/L	0.026275	0.04485	0.063425	TRUE
43035	Combined ash	Arsenic (V)	mg/L	0.0037	0.0038	0.0039	TRUE
49003A	Fly Ash	Arsenic (V)	mg/L	0.0935	0.1535	0.19375	TRUE
13115B	Combined ash	rsenic, othe	mg/L	0.000085	0.00014	0.000185	TRUE
14093	Fly Ash	rsenic, othe	mg/L	0.000225	0.0003	0.00058	TRUE
23223B	FGD waste	rsenic, othe	mg/L	0.0003625	0.000575	0.0007875	TRUE
25410A	Combined ash	rsenic, othe	mg/L	0.0003	0.0003	0.0003	TRUE
25410B	Fly Ash	rsenic, othe	mg/L	0.00005	0.00005	0.00005	TRUE
35015B	Fly Ash	rsenic, othe	mg/L	0.000435	0.00052	0.000605	TRUE
40109	Fly Ash	rsenic, othe	mg/L	0.0007	0.0007	0.0007	TRUE
43035	Combined ash	rsenic, othe	mg/L	0.0000625	0.000075	0.0000875	TRUE
49003A	Fly Ash	rsenic, othe	mg/L	0.000125	0.00015	0.000155	TRUE
13115B	Combined ash	Barium	mg/L	0.07	0.08	0.09	TRUE
14093	Fly Ash	Barium	mg/L	0.0275	0.04	0.04	TRUE
22346	Other	Barium	mg/L	0.1184	0.1376	0.1568	TRUE
23223B	FGD waste	Barium	mg/L	0.02375	0.0325	0.04125	TRUE
25410A	Combined ash	Barium	mg/L	0.14	0.14	0.14	TRUE
25410B	Fly Ash	Barium	mg/L	0.08	0.08	0.08	TRUE
33104	Fly Ash	Barium	mg/L	0.202	0.21	0.218	TRUE
33106	Fly Ash	Barium	mg/L	0.101	0.125	0.147	TRUE
35015B	Fly Ash	Barium	mg/L	0.065	0.07	0.075	TRUE
40109	Fly Ash	Barium	mg/L	0.12775	0.1685	0.20925	TRUE
43035	Combined ash	Barium	mg/L	0.043	0.05	0.057	TRUE
49003A	Fly Ash	Barium	mg/L	0.09425	0.1075	0.1425	TRUE
AP	Combined ash	Barium	mg/L	0.0435	0.057	0.084	TRUE
BR	Ash & coal waste	Barium	mg/L	0.05	0.05	0.05	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
C	Combined ash	Barium	mg/L	0.06	0.079	0.19	TRUE
CADK	FGD waste	Barium	mg/L	0.02	0.02	0.02	TRUE
CASJ	FGD waste	Barium	mg/L	0.01	0.013	0.014	TRUE
CATT	FGD waste	Barium	mg/L	0.0825	0.085	0.0875	TRUE
CL	Ash & coal waste	Barium	mg/L	0.222633542	0.298316875	0.400052188	TRUE
CY	FGD waste	Barium	mg/L	0.121475	0.151	0.20925	TRUE
FC	Ash & coal waste	Barium	mg/L	0.11375	0.1315	0.1785	TRUE
HA	Ash & coal waste	Barium	mg/L	0.11	0.11	0.11	TRUE
HA	Combined ash	Barium	mg/L	0.08743	0.1761	0.2501	TRUE
L	Combined ash	Barium	mg/L	0.001	0.001	0.001	TRUE
MO	Ash & coal waste	Barium	mg/L	0.015126777	0.024100382	0.050431993	TRUE
MO	Bottom ash	Barium	mg/L	0.013491368	0.019940978	0.022872989	TRUE
NA	Na FGD Sludge	Barium	mg/L	0.02	0.14	0.25	TRUE
OK	Bottom ash	Barium	mg/L	0.10633	0.13262	0.15891	TRUE
OK	Fly ash	Barium	mg/L	0.087405	0.1958	0.22505	TRUE
SX	Bottom ash	Barium	mg/L	0.052247125	0.0673179	0.079726375	TRUE
SX	Fly ash	Barium	mg/L	0.0857	0.0947	0.0989	TRUE
13115B	Combined ash	Beryllium	mg/L	0.0004	0.0004	0.00045	TRUE
14093	Fly Ash	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
22346	Other	Beryllium	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
25410A	Combined ash	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
25410B	Fly Ash	Beryllium	mg/L	0.0004	0.0004	0.0004	TRUE
33104	Fly Ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
33106	Fly Ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
35015B	Fly Ash	Beryllium	mg/L	0.0004	0.0004	0.0004	TRUE
40109	Fly Ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
43035	Combined ash	Beryllium	mg/L	0.000125	0.00015	0.000175	TRUE
49003A	Fly Ash	Beryllium	mg/L	0.0001	0.00025	0.0004	TRUE
AP	Combined ash	Beryllium	mg/L	0.0062	0.0062	0.0062	TRUE
C	Combined ash	Beryllium	mg/L	0.001	0.001	0.001	TRUE
13115B	Combined ash	Boron	mg/L	14.325	26.3	34.5	TRUE
14093	Fly Ash	Boron	mg/L	74.15	93.4	102.7	TRUE
22346	Other	Boron	mg/L	1.91	2.71	3.51	TRUE
23223B	FGD waste	Boron	mg/L	57.125	65.25	73.375	TRUE
25410A	Combined ash	Boron	mg/L	109	109	109	TRUE
25410B	Fly Ash	Boron	mg/L	24.2	24.2	24.2	TRUE
33104	Fly Ash	Boron	mg/L	1.0205	1.547	2.0735	TRUE
33106	Fly Ash	Boron	mg/L	1.0785	1.24	1.315	TRUE
35015B	Fly Ash	Boron	mg/L	4.3625	5.445	6.5275	TRUE
40109	Fly Ash	Boron	mg/L	5.3075	5.995	6.6825	TRUE
43035	Combined ash	Boron	mg/L	3.275	3.48	3.685	TRUE
49003A	Fly Ash	Boron	mg/L	0.91075	1.2055	1.6025	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
AP	Combined ash	Boron	mg/L	4.679	9.665	14.563	TRUE
BR	Ash & coal waste	Boron	mg/L	0.65	3.85	6.7	TRUE
C	Combined ash	Boron	mg/L	4.4	8.55	13.7	TRUE
CADK	FGD waste	Boron	mg/L	55.825	60.05	64.275	TRUE
CASJ	FGD waste	Boron	mg/L	18	18.1	29	TRUE
CATT	FGD waste	Boron	mg/L	102.25	110.5	118.75	TRUE
CL	Ash & coal waste	Boron	mg/L	0.5011875	0.78275	1.365	TRUE
CY	FGD waste	Boron	mg/L	0.025	0.025	0.025	TRUE
FC	Ash & coal waste	Boron	mg/L	0.155	0.35	1.3425	TRUE
HA	Ash & coal waste	Boron	mg/L	1.7	1.7	1.7	TRUE
HA	Combined ash	Boron	mg/L	0.544375	0.76825	2.393	TRUE
L	Combined ash	Boron	mg/L	0.61	0.62	0.63	TRUE
MO	Ash & coal waste	Boron	mg/L	0.77175	3.903333333	24.55	TRUE
MO	Bottom ash	Boron	mg/L	0.0341875	0.069	0.1323125	TRUE
NA	Na FGD Sludge	Boron	mg/L	123.5	170	492.5	TRUE
O	FGD waste	Boron	mg/L	4.895	8.71	8.71	TRUE
OK	Bottom ash	Boron	mg/L	2.0513125	3.966375	5.8814375	TRUE
OK	Fly ash	Boron	mg/L	1.5318125	2.626	4.1864375	TRUE
SX	Bottom ash	Boron	mg/L	0.5600625	38.575	72.89166667	TRUE
SX	Fly ash	Boron	mg/L	15.49	19.26375	20.5875	TRUE
AP	Combined ash	Bromide	mg/L	0.9175	1.285	2.18	FALSE
CADK	FGD waste	Bromide	mg/L	1.175	2.05	2.925	FALSE
CASJ	FGD waste	Bromide	mg/L	0.05	0.05	0.05	FALSE
CATT	FGD waste	Bromide	mg/L	48.325	50.75	53.175	FALSE
CL	Ash & coal waste	Bromide	mg/L	0.05225	0.078	0.0955	FALSE
CY	FGD waste	Bromide	mg/L	0.25	0.32	0.4175	FALSE
FC	Ash & coal waste	Bromide	mg/L	0.1	0.1	0.1	FALSE
HA	Combined ash	Bromide	mg/L	0.05	0.203	0.441	FALSE
MO	Ash & coal waste	Bromide	mg/L	0.25	0.5	2.5	FALSE
MO	Bottom ash	Bromide	mg/L	0.0425	0.05	0.08375	FALSE
NA	Na FGD Sludge	Bromide	mg/L	517	742	2750	FALSE
OK	Bottom ash	Bromide	mg/L	2.86575	3.1465	3.42725	FALSE
OK	Fly ash	Bromide	mg/L	10.384	13.003	16.5565	FALSE
SX	Bottom ash	Bromide	mg/L	0.08425	0.179	0.318	FALSE
SX	Fly ash	Bromide	mg/L	0.5	0.918	1.696	FALSE
13115B	Combined ash	Cadmium	mg/L	0.00095	0.0015	0.005	TRUE
14093	Fly Ash	Cadmium	mg/L	0.00095	0.0015	0.01135	TRUE
22346	Other	Cadmium	mg/L	0.00025	0.0004	0.00055	TRUE
23223B	FGD waste	Cadmium	mg/L	0.011925	0.01205	0.012175	TRUE
25410A	Combined ash	Cadmium	mg/L	0.0647	0.0647	0.0647	TRUE
25410B	Fly Ash	Cadmium	mg/L	0.014	0.014	0.014	TRUE
33104	Fly Ash	Cadmium	mg/L	0.000375	0.00045	0.000525	TRUE
33106	Fly Ash	Cadmium	mg/L	0.00265	0.0041	0.00435	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
35015B	Fly Ash	Cadmium	mg/L	0.0002375	0.000325	0.0004125	TRUE
40109	Fly Ash	Cadmium	mg/L	0.001175	0.00155	0.001925	TRUE
43035	Combined ash	Cadmium	mg/L	0.001275	0.00155	0.001825	TRUE
49003A	Fly Ash	Cadmium	mg/L	0.00115	0.0013	0.00245	TRUE
AP	Combined ash	Cadmium	mg/L	0.000725	0.001125	0.00125	TRUE
BR	Ash & coal waste	Cadmium	mg/L	0.05	0.075	0.375	TRUE
C	Combined ash	Cadmium	mg/L	0.0025	0.0025	0.0025	TRUE
CADK	FGD waste	Cadmium	mg/L	0.001	0.001	0.001	TRUE
CASJ	FGD waste	Cadmium	mg/L	0.009	0.02	0.02	TRUE
CATT	FGD waste	Cadmium	mg/L	0.0015	0.002	0.0025	TRUE
CL	Ash & coal waste	Cadmium	mg/L	0.00125	0.00125	0.00125	TRUE
CY	FGD waste	Cadmium	mg/L	0.00125	0.00125	0.0040625	TRUE
FC	Ash & coal waste	Cadmium	mg/L	0.00125	0.00125	0.00125	TRUE
HA	Ash & coal waste	Cadmium	mg/L	0.0025	0.0025	0.0025	TRUE
HA	Combined ash	Cadmium	mg/L	0.00125	0.00125	0.00125	TRUE
L	Combined ash	Cadmium	mg/L	0.001	0.001	0.001	TRUE
MO	Ash & coal waste	Cadmium	mg/L	0.013536534	0.075	0.092407083	TRUE
MO	Bottom ash	Cadmium	mg/L	0.00125	0.00125	0.00125	TRUE
NA	Na FGD Sludge	Cadmium	mg/L	0.25	0.25	0.25	TRUE
OK	Bottom ash	Cadmium	mg/L	0.0125	0.0125	0.0125	TRUE
OK	Fly ash	Cadmium	mg/L	0.006875	0.0125	0.0125	TRUE
SX	Bottom ash	Cadmium	mg/L	0.00125	0.01433105	0.032575025	TRUE
SX	Fly ash	Cadmium	mg/L	0.00602	0.00752	0.00909	TRUE
13115B	Combined ash	Calcium	mg/L	261	291	296.5	TRUE
14093	Fly Ash	Calcium	mg/L	587.5	591	636	TRUE
22346	Other	Calcium	mg/L	97.725	100.15	102.575	TRUE
23223B	FGD waste	Calcium	mg/L	533.75	543.5	553.25	TRUE
25410A	Combined ash	Calcium	mg/L	15	15	15	TRUE
25410B	Fly Ash	Calcium	mg/L	529	529	529	TRUE
33104	Fly Ash	Calcium	mg/L	60.45	65.8	71.15	TRUE
33106	Fly Ash	Calcium	mg/L	40.7	45.3	45.55	TRUE
35015B	Fly Ash	Calcium	mg/L	415.25	498.5	581.75	TRUE
40109	Fly Ash	Calcium	mg/L	61.175	63.95	66.725	TRUE
43035	Combined ash	Calcium	mg/L	4.1875	7.125	10.0625	TRUE
49003A	Fly Ash	Calcium	mg/L	48.75	51	59.5	TRUE
AP	Combined ash	Calcium	mg/L	158.9	343	524.8	TRUE
BR	Ash & coal waste	Calcium	mg/L	480.5	496	534.25	TRUE
C	Combined ash	Calcium	mg/L	76.525	144	156.5	TRUE
CADK	FGD waste	Calcium	mg/L	751.5	766	780.5	TRUE
CASJ	FGD waste	Calcium	mg/L	590	594	619	TRUE
CATT	FGD waste	Calcium	mg/L	834.25	873.5	912.75	TRUE
CL	Ash & coal waste	Calcium	mg/L	34.60958334	57.35125	91.99	TRUE
CY	FGD waste	Calcium	mg/L	28.425	38.55	76.225	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
FC	Ash & coal waste	Calcium	mg/L	28.9	76.35	101.275	TRUE
HA	Ash & coal waste	Calcium	mg/L	80	80	80	TRUE
HA	Combined ash	Calcium	mg/L	41.82	77.84	93.43	TRUE
L	Combined ash	Calcium	mg/L	406.775	471.85	536.925	TRUE
MO	Ash & coal waste	Calcium	mg/L	483.6875	541.9	574.2125	TRUE
MO	Bottom ash	Calcium	mg/L	93.25125	104.8566667	116.7833334	TRUE
NA	Na FGD Sludge	Calcium	mg/L	15.5	22	38	TRUE
O	FGD waste	Calcium	mg/L	543	592	592	TRUE
OK	Bottom ash	Calcium	mg/L	361.90625	440.3375	518.76875	TRUE
OK	Fly ash	Calcium	mg/L	37.86875	46.125	68.3825	TRUE
SX	Bottom ash	Calcium	mg/L	42.16708334	357.35	555.5	TRUE
SX	Fly ash	Calcium	mg/L	132.475	138.85	198.6375	TRUE
13115B	Combined ash	Chloride	mg/L	37.3	45.4	54.4	TRUE
14093	Fly Ash	Chloride	mg/L	18.15	27.3	30.05	TRUE
22346	Other	Chloride	mg/L	70.225	72.55	74.875	TRUE
23223B	FGD waste	Chloride	mg/L	421.25	471.5	521.75	TRUE
25410A	Combined ash	Chloride	mg/L	54.8	54.8	54.8	TRUE
25410B	Fly Ash	Chloride	mg/L	22.2	22.2	22.2	TRUE
33104	Fly Ash	Chloride	mg/L	9.275	11.45	13.625	TRUE
33106	Fly Ash	Chloride	mg/L	9.1	9.4	9.55	TRUE
35015B	Fly Ash	Chloride	mg/L	47.1	60.4	73.7	TRUE
40109	Fly Ash	Chloride	mg/L	7.725	7.85	7.975	TRUE
43035	Combined ash	Chloride	mg/L	33.875	36.75	39.625	TRUE
49003A	Fly Ash	Chloride	mg/L	16.85	18.8	21.8	TRUE
AP	Combined ash	Chloride	mg/L	131.4	262	326.65	TRUE
BR	Ash & coal waste	Chloride	mg/L	2.3025	3.555	5.09	TRUE
C	Combined ash	Chloride	mg/L	27.3	33	47	TRUE
CADK	FGD waste	Chloride	mg/L	460.5	603	745.5	TRUE
CASJ	FGD waste	Chloride	mg/L	4100	4220	4280	TRUE
CATT	FGD waste	Chloride	mg/L	738.25	791.5	844.75	TRUE
CL	Ash & coal waste	Chloride	mg/L	4.63625	6.183	6.95525	TRUE
CY	FGD waste	Chloride	mg/L	30.525	33.6	37.5	TRUE
FC	Ash & coal waste	Chloride	mg/L	13.25	14.85	17.125	TRUE
HA	Ash & coal waste	Chloride	mg/L	58	58	58	TRUE
HA	Combined ash	Chloride	mg/L	9.912	20.449	38.207	TRUE
L	Combined ash	Chloride	mg/L	19.13	24.07	29.01	TRUE
MO	Ash & coal waste	Chloride	mg/L	7.8725	20.245	27	TRUE
MO	Bottom ash	Chloride	mg/L	3.734	8.0155	16.515	TRUE
NA	Na FGD Sludge	Chloride	mg/L	5675	13400	52000	TRUE
O	FGD waste	Chloride	mg/L	1718	2023	2023	TRUE
OK	Bottom ash	Chloride	mg/L	1909.64025	1938.0885	1966.53675	TRUE
OK	Fly ash	Chloride	mg/L	10774.3275	12397.996	16202.1915	TRUE
SX	Bottom ash	Chloride	mg/L	17.00725	19.3245	22.68375	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
SX	Fly ash	Chloride	mg/L	29.371	36.057	39.896	TRUE
13115B	Combined ash	Chromium	mg/L	0.00025	0.00025	0.00025	TRUE
14093	Fly Ash	Chromium	mg/L	0.00025	0.00025	0.00025	TRUE
22346	Other	Chromium	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Chromium	mg/L	0.0006125	0.000975	0.0013375	TRUE
25410A	Combined ash	Chromium	mg/L	0.0038	0.0038	0.0038	TRUE
25410B	Fly Ash	Chromium	mg/L	0.00025	0.00025	0.00025	TRUE
33104	Fly Ash	Chromium	mg/L	0.00265	0.0051	0.00755	TRUE
33106	Fly Ash	Chromium	mg/L	0.0002	0.0002	0.0002	TRUE
35015B	Fly Ash	Chromium	mg/L	0.00025	0.00025	0.00025	TRUE
40109	Fly Ash	Chromium	mg/L	0.0002	0.0002	0.0002	TRUE
43035	Combined ash	Chromium	mg/L	0.045	0.066	0.087	TRUE
49003A	Fly Ash	Chromium	mg/L	0.0002125	0.00025	0.000265	TRUE
AP	Combined ash	Chromium	mg/L	0.0018	0.00459	0.020525	TRUE
BR	Ash & coal waste	Chromium	mg/L	0.05	0.05	0.05	TRUE
C	Combined ash	Chromium	mg/L	0.001	0.001	0.001	TRUE
CADK	FGD waste	Chromium	mg/L	0.1	0.1	0.1	TRUE
CASJ	FGD waste	Chromium	mg/L	0.1	0.1	0.5	TRUE
CATT	FGD waste	Chromium	mg/L	0.29	0.3	0.31	TRUE
CL	Ash & coal waste	Chromium	mg/L	0.00125	0.00125	0.00125	TRUE
CY	FGD waste	Chromium	mg/L	0.00125	0.00249	0.0059225	TRUE
FC	Ash & coal waste	Chromium	mg/L	0.00125	0.00125	0.00125	TRUE
HA	Ash & coal waste	Chromium	mg/L	0.005	0.005	0.005	TRUE
HA	Combined ash	Chromium	mg/L	0.00125	0.00125	0.00125	TRUE
L	Combined ash	Chromium	mg/L	0.005	0.005	0.005	TRUE
MO	Ash & coal waste	Chromium	mg/L	0.00125	0.223695848	0.68875	TRUE
MO	Bottom ash	Chromium	mg/L	0.00125	0.00125	0.00125	TRUE
NA	Na FGD Sludge	Chromium	mg/L	0.2	0.2	1	TRUE
O	FGD waste	Chromium	mg/L	0.012	0.012	0.012	TRUE
OK	Bottom ash	Chromium	mg/L	0.0125	0.0125	0.0125	TRUE
OK	Fly ash	Chromium	mg/L	0.0125	0.02927	0.034475	TRUE
SX	Bottom ash	Chromium	mg/L	0.00125	0.00125	0.00125	TRUE
SX	Fly ash	Chromium	mg/L	0.137	0.297	0.501	TRUE
22346	Other	hromium (II	mg/L	0.00001725	0.0000245	0.00003175	TRUE
23223B	FGD waste	hromium (II	mg/L	0.00005	0.00005	0.00005	TRUE
25410A	Combined ash	hromium (II	mg/L	0.00005	0.00005	0.00005	TRUE
33104	Fly Ash	hromium (II	mg/L	0.00044	0.00061	0.00078	TRUE
33106	Fly Ash	hromium (II	mg/L	0.000005	0.000005	0.000005	TRUE
40109	Fly Ash	hromium (II	mg/L	0.0000775	0.000105	0.0001325	TRUE
43035	Combined ash	hromium (II	mg/L	0.0014225	0.002315	0.0032075	TRUE
13115B	Combined ash	hromium (V	mg/L	0.0013	0.0013	0.0013	TRUE
14093	Fly Ash	hromium (V	mg/L	0.0006	0.0007	0.0013	TRUE
22346	Other	hromium (V	mg/L	0.000003	0.000003	0.000003	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
23223B	FGD waste	hromium (V	mg/L	0.0007625	0.001475	0.0021875	TRUE
25410A	Combined ash	hromium (V	mg/L	0.00025	0.00025	0.00025	TRUE
25410B	Fly Ash	hromium (V	mg/L	0.00005	0.00005	0.00005	TRUE
33104	Fly Ash	hromium (V	mg/L	0.00155375	0.0031025	0.00465125	TRUE
33106	Fly Ash	hromium (V	mg/L	0.000005	0.000005	0.000005	TRUE
35015B	Fly Ash	hromium (V	mg/L	0.00003125	0.0000375	0.00004375	TRUE
40109	Fly Ash	hromium (V	mg/L	0.00001975	0.0000345	0.00004925	TRUE
43035	Combined ash	hromium (V	mg/L	0.04975	0.0735	0.09725	TRUE
49003A	Fly Ash	hromium (V	mg/L	0.00008125	0.0001375	0.00019375	TRUE
13115B	Combined ash	Cobalt	mg/L	0.0005	0.0005	0.00125	TRUE
14093	Fly Ash	Cobalt	mg/L	0.0005	0.0005	0.00375	TRUE
22346	Other	Cobalt	mg/L	0.0003375	0.000495	0.0006525	TRUE
23223B	FGD waste	Cobalt	mg/L	0.001875	0.00325	0.004625	TRUE
25410A	Combined ash	Cobalt	mg/L	0.002	0.002	0.002	TRUE
25410B	Fly Ash	Cobalt	mg/L	0.0005	0.0005	0.0005	TRUE
33104	Fly Ash	Cobalt	mg/L	0.00015	0.0002	0.00025	TRUE
33106	Fly Ash	Cobalt	mg/L	0.0004	0.0007	0.0012	TRUE
35015B	Fly Ash	Cobalt	mg/L	0.000625	0.00075	0.000875	TRUE
40109	Fly Ash	Cobalt	mg/L	0.000125	0.00015	0.000175	TRUE
43035	Combined ash	Cobalt	mg/L	0.000065	0.00011	0.000155	TRUE
49003A	Fly Ash	Cobalt	mg/L	0.001445	0.00188	0.00284	TRUE
AP	Combined ash	Cobalt	mg/L	0.01	0.01	0.01	TRUE
BR	Ash & coal waste	Cobalt	mg/L	0.05	0.05	0.2225	TRUE
C	Combined ash	Cobalt	mg/L	0.005	0.005	0.005	TRUE
MO	Ash & coal waste	Cobalt	mg/L	0.155	1.7175	6.26125	TRUE
13115B	Combined ash	Copper	mg/L	0.006	0.007	0.021	TRUE
14093	Fly Ash	Copper	mg/L	0.0015	0.0015	0.0015	TRUE
22346	Other	Copper	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Copper	mg/L	0.0215	0.029	0.0365	TRUE
25410A	Combined ash	Copper	mg/L	0.021	0.021	0.021	TRUE
25410B	Fly Ash	Copper	mg/L	0.0015	0.0015	0.0015	TRUE
33104	Fly Ash	Copper	mg/L	0.00045	0.0007	0.00095	TRUE
33106	Fly Ash	Copper	mg/L	0.00035	0.0005	0.00075	TRUE
35015B	Fly Ash	Copper	mg/L	0.005125	0.00875	0.012375	TRUE
40109	Fly Ash	Copper	mg/L	0.00345	0.0051	0.00675	TRUE
43035	Combined ash	Copper	mg/L	0.00285	0.0033	0.00375	TRUE
49003A	Fly Ash	Copper	mg/L	0.0013	0.0038	0.0065	TRUE
AP	Combined ash	Copper	mg/L	0.005	0.005	0.005	TRUE
BR	Ash & coal waste	Copper	mg/L	0.05	0.1	0.6375	TRUE
C	Combined ash	Copper	mg/L	0.0005	0.0005	0.0005	TRUE
CADK	FGD waste	Copper	mg/L	0.03625	0.0475	0.05875	TRUE
CASJ	FGD waste	Copper	mg/L	0.02	0.02	0.125	TRUE
CATT	FGD waste	Copper	mg/L	0.125	0.125	0.125	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
CY	FGD waste	Copper	mg/L	0.054325	0.1085	0.20975	TRUE
FC	Ash & coal waste	Copper	mg/L	0.005	0.005	0.005	TRUE
HA	Ash & coal waste	Copper	mg/L	0.025	0.025	0.025	TRUE
HA	Combined ash	Copper	mg/L	0.005	0.01259	0.01706	TRUE
L	Combined ash	Copper	mg/L	0.0025	0.0025	0.0025	TRUE
MO	Ash & coal waste	Copper	mg/L	0.013778731	0.086168366	0.20363499	TRUE
MO	Bottom ash	Copper	mg/L	0.005	0.005	0.01307	TRUE
NA	Na FGD Sludge	Copper	mg/L	0.04	0.04	0.25	TRUE
OK	Bottom ash	Copper	mg/L	0.0799	0.1098	0.1397	TRUE
OK	Fly ash	Copper	mg/L	0.16695	0.2739	0.5153	TRUE
SX	Bottom ash	Copper	mg/L	0.005	0.005	0.01133445	TRUE
SX	Fly ash	Copper	mg/L	0.005	0.005	0.0104	TRUE
C	Combined ash	Organic Carl	mg/L	7.125	7.19	10.495	FALSE
CADK	FGD waste	Organic Carl	mg/L	45.35	55.6	65.85	FALSE
CASJ	FGD waste	Organic Carl	mg/L	51.7	59	90.4	FALSE
CATT	FGD waste	Organic Carl	mg/L	249.25	320.5	391.75	FALSE
CY	FGD waste	Organic Carl	mg/L	90.225	102.35	111.5	FALSE
FC	Ash & coal waste	Organic Carl	mg/L	2.015	3.725	5.8475	FALSE
HA	Combined ash	Organic Carl	mg/L	4.936707565	6.07919464	7.740028161	FALSE
MO	Ash & coal waste	Organic Carl	mg/L	4.199438087	7.1	16.72	FALSE
MO	Bottom ash	Organic Carl	mg/L	2.329383299	3.029477933	3.410523972	FALSE
NA	Na FGD Sludge	Organic Carl	mg/L	417	636	825	FALSE
OK	Bottom ash	Organic Carl	mg/L	22.66128815	22.66128815	22.66128815	FALSE
OK	Fly ash	Organic Carl	mg/L	47.93557138	51.16074497	73.13920452	FALSE
SX	Bottom ash	Organic Carl	mg/L	5.26756475	20.753413	32.318292	FALSE
SX	Fly ash	Organic Carl	mg/L	5.301197768	7.111551852	7.114545823	FALSE
SX	Bottom ash	rganic Carb	mg/L	5.90591625	22.1745605	33.76040725	FALSE
13115B	Combined ash	solved oxyg	%	2.9	2.9	2.9	FALSE
14093	Fly Ash	solved oxyg	%	4.5	5	5.25	FALSE
22346	Other	solved oxyg	%	31.175	34.35	37.525	FALSE
23223B	FGD waste	solved oxyg	%	0.225	0.25	0.275	FALSE
25410A	Combined ash	solved oxyg	%	2.9	2.9	2.9	FALSE
33104	Fly Ash	solved oxyg	%	44.75	51.6	58.45	FALSE
33106	Fly Ash	solved oxyg	%	30.55	33.5	34.25	FALSE
35015B	Fly Ash	solved oxyg	%	11.975	17.85	23.725	FALSE
40109	Fly Ash	solved oxyg	%	44.45	48.3	52.15	FALSE
43035	Combined ash	solved oxyg	%	18.575	24.05	29.525	FALSE
49003A	Fly Ash	solved oxyg	%	16.975	23	28.675	FALSE
AP	Combined ash	Ferric Iron	mg/L	0.03	0.03	0.03	FALSE
BR	Ash & coal waste	Ferric Iron	mg/L	1.9075	23.235	28.575	FALSE
L	Combined ash	Ferric Iron	mg/L	2.6	3.1	3.6	FALSE
MO	Ash & coal waste	Ferric Iron	mg/L	92.925	683.05	1040.09	FALSE
MO	Bottom ash	Ferric Iron	mg/L	0.8715	1.148	1.188	FALSE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
SX	Bottom ash	Ferric Iron	mg/L	0.0805	0.101	0.2125	FALSE
AP	Combined ash	Ferrous Iron	mg/L	0.035	0.035	0.035	FALSE
BR	Ash & coal waste	Ferrous Iron	mg/L	22.85	606.9	1439.75	FALSE
L	Combined ash	Ferrous Iron	mg/L	96.825	123.55	150.275	FALSE
MO	Ash & coal waste	Ferrous Iron	mg/L	643.0795	4382.885	17999	FALSE
MO	Bottom ash	Ferrous Iron	mg/L	7.057	11.781	14.72	FALSE
SX	Bottom ash	Ferrous Iron	mg/L	0.07	0.07	0.12375	FALSE
AP	Combined ash	Fluoride	mg/L	1.07	2.245	5.21	TRUE
C	Combined ash	Fluoride	mg/L	0.1	0.19	0.23	TRUE
CADK	FGD waste	Fluoride	mg/L	21.25	22.7	24.15	TRUE
CASJ	FGD waste	Fluoride	mg/L	10.47	12.55	15.75	TRUE
CATT	FGD waste	Fluoride	mg/L	6.455	6.49	6.525	TRUE
CL	Ash & coal waste	Fluoride	mg/L	0.37575	0.6205	0.854	TRUE
CY	FGD waste	Fluoride	mg/L	0.875	1.5	2	TRUE
FC	Ash & coal waste	Fluoride	mg/L	0.05	0.05	1.505	TRUE
HA	Combined ash	Fluoride	mg/L	0.05	0.095	0.14	TRUE
L	Combined ash	Fluoride	mg/L	0.3825	0.395	0.4075	TRUE
MO	Ash & coal waste	Fluoride	mg/L	0.1125	0.45	1	TRUE
MO	Bottom ash	Fluoride	mg/L	0.025	0.025	0.046	TRUE
NA	Na FGD Sludge	Fluoride	mg/L	337	376	404	TRUE
OK	Bottom ash	Fluoride	mg/L	0.25	0.25	0.25	TRUE
OK	Fly ash	Fluoride	mg/L	1.25	1.25	2.5	TRUE
SX	Bottom ash	Fluoride	mg/L	0.291	1.0595	1.466	TRUE
SX	Fly ash	Fluoride	mg/L	0.125	0.125	0.25	TRUE
C	Combined ash	nic Carbon,	mg/L	3.185	3.76	8.63	FALSE
CADK	FGD waste	nic Carbon,	mg/L	44.45	48.2	51.95	FALSE
CASJ	FGD waste	nic Carbon,	mg/L	12.8	14.1	33	FALSE
CATT	FGD waste	nic Carbon,	mg/L	3.2875	4.015	4.7425	FALSE
CY	FGD waste	nic Carbon,	mg/L	6.325	14.77	24.225	FALSE
FC	Ash & coal waste	nic Carbon,	mg/L	2.365	2.955	5.505	FALSE
HA	Combined ash	nic Carbon,	mg/L	3.775220912	40.1068722	44.58886074	FALSE
MO	Ash & coal waste	nic Carbon,	mg/L	1.135	8.135	20.57775997	FALSE
MO	Bottom ash	nic Carbon,	mg/L	12.67615104	16.83220219	17.53674564	FALSE
NA	Na FGD Sludge	nic Carbon,	mg/L	856.75	1114.5	1372.25	FALSE
OK	Bottom ash	nic Carbon,	mg/L	2.800281761	2.800281761	2.800281761	FALSE
OK	Fly ash	nic Carbon,	mg/L	1.678493618	1.722405184	2.148047972	FALSE
SX	Bottom ash	nic Carbon,	mg/L	5.00663275	9.952692	20.026531	FALSE
SX	Fly ash	nic Carbon,	mg/L	2.655525949	3.059711949	3.212404438	FALSE
SX	Bottom ash	ic Carbon, I	mg/L	6.59552225	11.0942695	21.23101175	FALSE
13115B	Combined ash	Iron	mg/L	0.025	0.025	1.6075	TRUE
14093	Fly Ash	Iron	mg/L	0.025	0.025	7.3625	TRUE
22346	Other	Iron	mg/L	6.4465	12.831	19.2155	TRUE
23223B	FGD waste	Iron	mg/L	0.31875	0.6125	0.90625	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
25410A	Combined ash	Iron	mg/L	1.53	1.53	1.53	TRUE
25410B	Fly Ash	Iron	mg/L	0.025	0.025	0.025	TRUE
33104	Fly Ash	Iron	mg/L	0.55525	1.0935	1.63175	TRUE
33106	Fly Ash	Iron	mg/L	0.9955	1.07	1.385	TRUE
35015B	Fly Ash	Iron	mg/L	0.025	0.025	0.025	TRUE
40109	Fly Ash	Iron	mg/L	0.0195	0.023	0.0265	TRUE
43035	Combined ash	Iron	mg/L	0.0125	0.0125	0.0125	TRUE
49003A	Fly Ash	Iron	mg/L	0.091625	0.21	0.31225	TRUE
AP	Combined ash	Iron	mg/L	0.036	0.0495	0.16525	TRUE
BR	Ash & coal waste	Iron	mg/L	31.525	610	1617.5	TRUE
C	Combined ash	Iron	mg/L	0.02	0.02	0.02	TRUE
CADK	FGD waste	Iron	mg/L	0.0125	0.015	0.0175	TRUE
CASJ	FGD waste	Iron	mg/L	0.025	0.025	0.125	TRUE
CATT	FGD waste	Iron	mg/L	0.02	0.02	0.02	TRUE
CL	Ash & coal waste	Iron	mg/L	0.025	0.025	0.212875	TRUE
CY	FGD waste	Iron	mg/L	0.19	0.445	1.045	TRUE
FC	Ash & coal waste	Iron	mg/L	0.0525	0.09	0.18	TRUE
HA	Ash & coal waste	Iron	mg/L	0.025	0.025	0.025	TRUE
HA	Combined ash	Iron	mg/L	0.025	0.025	0.07375	TRUE
MO	Ash & coal waste	Iron	mg/L	125.644375	2038.1	19170	TRUE
MO	Bottom ash	Iron	mg/L	8.04540625	17.7025	18.833125	TRUE
NA	Na FGD Sludge	Iron	mg/L	0.05	0.5	0.5	TRUE
O	FGD waste	Iron	mg/L	0.0566	0.0879	0.0879	TRUE
OK	Bottom ash	Iron	mg/L	0.0446875	0.064375	0.0840625	TRUE
OK	Fly ash	Iron	mg/L	0.025	0.025	0.047625	TRUE
SX	Bottom ash	Iron	mg/L	0.0484375	0.083725	0.2899375	TRUE
SX	Fly ash	Iron	mg/L	0.12475	0.4615	0.991	TRUE
13115B	Combined ash	Lead	mg/L	0.00025	0.0004	0.0004	TRUE
14093	Fly Ash	Lead	mg/L	0.0001	0.0001	0.0001	TRUE
22346	Other	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
23223B	FGD waste	Lead	mg/L	0.0011	0.0019	0.0027	TRUE
25410A	Combined ash	Lead	mg/L	0.0046	0.0046	0.0046	TRUE
25410B	Fly Ash	Lead	mg/L	0.0008	0.0008	0.0008	TRUE
33104	Fly Ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
33106	Fly Ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
35015B	Fly Ash	Lead	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Fly Ash	Lead	mg/L	0.0001625	0.000275	0.0003875	TRUE
43035	Combined ash	Lead	mg/L	0.00007	0.00007	0.00007	TRUE
49003A	Fly Ash	Lead	mg/L	0.00007	0.000085	0.0001	TRUE
AP	Combined ash	Lead	mg/L	0.00125	0.00125	0.00125	TRUE
C	Combined ash	Lead	mg/L	0.0015	0.0022	0.00305	TRUE
CADK	FGD waste	Lead	mg/L	0.1	0.1	0.1	TRUE
CASJ	FGD waste	Lead	mg/L	0.1	0.3	0.3	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
CATT	FGD waste	Lead	mg/L	0.21825	0.2275	0.23675	TRUE
CL	Ash & coal waste	Lead	mg/L	0.0025	0.0025	0.0025	TRUE
CY	FGD waste	Lead	mg/L	0.0025	0.0025	0.008125	TRUE
FC	Ash & coal waste	Lead	mg/L	0.0025	0.0025	0.0025	TRUE
HA	Ash & coal waste	Lead	mg/L	0.025	0.025	0.025	TRUE
HA	Combined ash	Lead	mg/L	0.0025	0.0025	0.0025	TRUE
MO	Ash & coal waste	Lead	mg/L	0.0025	0.0025	0.093	TRUE
MO	Bottom ash	Lead	mg/L	0.0025	0.0025	0.0025	TRUE
OK	Bottom ash	Lead	mg/L	0.025	0.025	0.025	TRUE
OK	Fly ash	Lead	mg/L	0.01375	0.025	0.025	TRUE
SX	Bottom ash	Lead	mg/L	0.0002351	0.0003696	0.0007448	TRUE
SX	Fly ash	Lead	mg/L	0.0025	0.0025	0.0025	TRUE
13115B	Combined ash	Lithium	mg/L	0.045	0.06	0.56	FALSE
14093	Fly Ash	Lithium	mg/L	0.09	0.1	0.105	FALSE
22346	Other	Lithium	mg/L	0.13525	0.1365	0.13775	FALSE
23223B	FGD waste	Lithium	mg/L	0.05	0.09	0.13	FALSE
25410A	Combined ash	Lithium	mg/L	0.06	0.06	0.06	FALSE
25410B	Fly Ash	Lithium	mg/L	0.05	0.05	0.05	FALSE
33104	Fly Ash	Lithium	mg/L	0.177	0.199	0.221	FALSE
33106	Fly Ash	Lithium	mg/L	0.0815	0.082	0.1035	FALSE
35015B	Fly Ash	Lithium	mg/L	0.1775	0.255	0.3325	FALSE
40109	Fly Ash	Lithium	mg/L	0.5695	0.578	0.5865	FALSE
43035	Combined ash	Lithium	mg/L	0.00925	0.0115	0.01375	FALSE
49003A	Fly Ash	Lithium	mg/L	0.17025	0.2485	0.31925	FALSE
13115B	Combined ash	Magnesium	mg/L	12	21	28.5	TRUE
14093	Fly Ash	Magnesium	mg/L	10	13	24.5	TRUE
22346	Other	Magnesium	mg/L	22.325	25.15	27.975	TRUE
23223B	FGD waste	Magnesium	mg/L	48.5	74	99.5	TRUE
25410A	Combined ash	Magnesium	mg/L	20	20	20	TRUE
25410B	Fly Ash	Magnesium	mg/L	7	7	7	TRUE
33104	Fly Ash	Magnesium	mg/L	1.325	2.54	3.755	TRUE
33106	Fly Ash	Magnesium	mg/L	4.845	6.61	6.76	TRUE
35015B	Fly Ash	Magnesium	mg/L	36	37	38	TRUE
40109	Fly Ash	Magnesium	mg/L	0.09	0.1	0.11	TRUE
43035	Combined ash	Magnesium	mg/L	0.025	0.025	0.025	TRUE
49003A	Fly Ash	Magnesium	mg/L	18.25	21	23.5	TRUE
AP	Combined ash	Magnesium	mg/L	4.2235	19.957	74.3665	TRUE
BR	Ash & coal waste	Magnesium	mg/L	13.4775	92	170	TRUE
C	Combined ash	Magnesium	mg/L	0.03	0.042	0.0865	TRUE
CADK	FGD waste	Magnesium	mg/L	303.5	329	354.5	TRUE
CASJ	FGD waste	Magnesium	mg/L	600	760	780	TRUE
CATT	FGD waste	Magnesium	mg/L	99.5	120	140.5	TRUE
CL	Ash & coal waste	Magnesium	mg/L	0.4920625	3.13	6.74	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
CY	FGD waste	Magnesium	mg/L	0.615	0.895	1.155	TRUE
FC	Ash & coal waste	Magnesium	mg/L	0.05	0.06	0.0775	TRUE
HA	Ash & coal waste	Magnesium	mg/L	5	5	5	TRUE
HA	Combined ash	Magnesium	mg/L	0.180375	5.44175	25.76125	TRUE
L	Combined ash	Magnesium	mg/L	17.85	18.87	19.89	TRUE
MO	Ash & coal waste	Magnesium	mg/L	47.40375	178	363.375	TRUE
MO	Bottom ash	Magnesium	mg/L	6.02790625	15.8325	18.0828125	TRUE
NA	Na FGD Sludge	Magnesium	mg/L	26.5	38	126	TRUE
O	FGD waste	Magnesium	mg/L	141	205	205	TRUE
OK	Bottom ash	Magnesium	mg/L	2.54325	4.7795	7.01575	TRUE
OK	Fly ash	Magnesium	mg/L	0.025	0.025	0.025	TRUE
SX	Bottom ash	Magnesium	mg/L	12.64166667	15.01666667	21.82916667	TRUE
SX	Fly ash	Magnesium	mg/L	0.714375	0.91225	2.949875	TRUE
13115B	Combined ash	Manganese	mg/L	0.002	0.002	2.086	TRUE
14093	Fly Ash	Manganese	mg/L	0.0235	0.025	1.2925	TRUE
22346	Other	Manganese	mg/L	0.115825	0.14055	0.165275	TRUE
23223B	FGD waste	Manganese	mg/L	0.26075	0.4085	0.55625	TRUE
25410A	Combined ash	Manganese	mg/L	0.008	0.008	0.008	TRUE
25410B	Fly Ash	Manganese	mg/L	0.052	0.052	0.052	TRUE
33104	Fly Ash	Manganese	mg/L	0.098825	0.19755	0.296275	TRUE
33106	Fly Ash	Manganese	mg/L	0.246	0.248	0.2545	TRUE
35015B	Fly Ash	Manganese	mg/L	0.098	0.155	0.212	TRUE
40109	Fly Ash	Manganese	mg/L	0.001775	0.00315	0.004525	TRUE
43035	Combined ash	Manganese	mg/L	0.000125	0.00015	0.000175	TRUE
49003A	Fly Ash	Manganese	mg/L	0.127	0.148	0.223	TRUE
AP	Combined ash	Manganese	mg/L	0.0045	0.0455	0.21975	TRUE
BR	Ash & coal waste	Manganese	mg/L	1.1	6.6	13.175	TRUE
C	Combined ash	Manganese	mg/L	0.005	0.005	0.005	TRUE
CADK	FGD waste	Manganese	mg/L	6.75	7.41	8.07	TRUE
CASJ	FGD waste	Manganese	mg/L	0.28	0.31	0.39	TRUE
CATT	FGD waste	Manganese	mg/L	0.105	0.16	0.215	TRUE
CL	Ash & coal waste	Manganese	mg/L	0.00125	0.00337045	0.099217063	TRUE
CY	FGD waste	Manganese	mg/L	0.00505	0.007465	0.0128775	TRUE
FC	Ash & coal waste	Manganese	mg/L	0.00125	0.00125	0.00125	TRUE
HA	Ash & coal waste	Manganese	mg/L	0.05	0.05	0.05	TRUE
HA	Combined ash	Manganese	mg/L	0.00125	0.00585	0.2501	TRUE
MO	Ash & coal waste	Manganese	mg/L	9.863572775	44.8	63.85	TRUE
MO	Bottom ash	Manganese	mg/L	0.650675	1.49234706	1.81367353	TRUE
NA	Na FGD Sludge	Manganese	mg/L	0.02	0.25	0.25	TRUE
OK	Bottom ash	Manganese	mg/L	0.0342	0.0559	0.0776	TRUE
OK	Fly ash	Manganese	mg/L	0.006875	0.0125	0.0125	TRUE
SX	Bottom ash	Manganese	mg/L	0.019177875	0.03458515	0.18725165	TRUE
SX	Fly ash	Manganese	mg/L	0.00125	0.00598	0.00737	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
22346	Other	Mercury	mg/L	3.325E-07	0.000000415	4.975E-07	TRUE
23223B	FGD waste	Mercury	mg/L	0.000002475	0.00000305	0.000003625	TRUE
35015B	Fly Ash	Mercury	mg/L	0.0000019	0.000003	0.0000041	TRUE
43035	Combined ash	Mercury	mg/L	0.0000064	0.0000074	0.0000084	TRUE
49003A	Fly Ash	Mercury	mg/L	0.0000014	0.0000014	0.0000014	TRUE
HA	Ash & coal waste	Mercury	mg/L	0.00025	0.00025	0.00025	TRUE
13115B	Combined ash	Molybdenum	mg/L	0.3	0.5	1.205	TRUE
14093	Fly Ash	Molybdenum	mg/L	0.42	0.74	3.385	TRUE
22346	Other	Molybdenum	mg/L	0.172	0.209	0.246	TRUE
23223B	FGD waste	Molybdenum	mg/L	15.6275	30.685	45.7425	TRUE
25410A	Combined ash	Molybdenum	mg/L	39.6	39.6	39.6	TRUE
25410B	Fly Ash	Molybdenum	mg/L	3.01	3.01	3.01	TRUE
33104	Fly Ash	Molybdenum	mg/L	0.1145	0.134	0.1535	TRUE
33106	Fly Ash	Molybdenum	mg/L	0.6735	1.06	1.085	TRUE
35015B	Fly Ash	Molybdenum	mg/L	0.1575	0.175	0.1925	TRUE
40109	Fly Ash	Molybdenum	mg/L	0.2745	0.303	0.3315	TRUE
43035	Combined ash	Molybdenum	mg/L	0.296	0.372	0.448	TRUE
49003A	Fly Ash	Molybdenum	mg/L	0.441	0.605	0.8525	TRUE
AP	Combined ash	Molybdenum	mg/L	0.18	0.365	0.557	TRUE
BR	Ash & coal waste	Molybdenum	mg/L	0.5	0.5	0.5	TRUE
C	Combined ash	Molybdenum	mg/L	0.46	0.53	0.74	TRUE
CADK	FGD waste	Molybdenum	mg/L	1.0725	1.165	1.2575	TRUE
CASJ	FGD waste	Molybdenum	mg/L	0.05	0.05	0.25	TRUE
CATT	FGD waste	Molybdenum	mg/L	0.4975	0.655	0.8125	TRUE
CL	Ash & coal waste	Molybdenum	mg/L	0.131375	0.342333334	0.570875	TRUE
CY	FGD waste	Molybdenum	mg/L	0.575	0.645	0.725	TRUE
FC	Ash & coal waste	Molybdenum	mg/L	0.25	0.25	0.25	TRUE
HA	Ash & coal waste	Molybdenum	mg/L	0.075	0.075	0.075	TRUE
HA	Combined ash	Molybdenum	mg/L	0.025	0.1475	0.153	TRUE
L	Combined ash	Molybdenum	mg/L	0.08625	0.1675	0.24875	TRUE
MO	Ash & coal waste	Molybdenum	mg/L	0.05	0.25	0.25	TRUE
MO	Bottom ash	Molybdenum	mg/L	0.25	0.25225	1.21815625	TRUE
NA	Na FGD Sludge	Molybdenum	mg/L	0.1	0.1	1	TRUE
O	FGD waste	Molybdenum	mg/L	0.0179	0.0179	0.0179	TRUE
OK	Bottom ash	Molybdenum	mg/L	0.2326875	0.269625	0.3065625	TRUE
OK	Fly ash	Molybdenum	mg/L	0.7425	0.8195	0.904625	TRUE
SX	Bottom ash	Molybdenum	mg/L	0.1643125	6.643333334	16.20833334	TRUE
SX	Fly ash	Molybdenum	mg/L	7.50225	9.25475	12.68125	TRUE
13115B	Combined ash	Nickel	mg/L	0.0075	0.008	0.009	TRUE
14093	Fly Ash	Nickel	mg/L	0.0045	0.005	0.01	TRUE
22346	Other	Nickel	mg/L	0.001375	0.00245	0.003525	TRUE
23223B	FGD waste	Nickel	mg/L	0.153	0.301	0.449	TRUE
25410A	Combined ash	Nickel	mg/L	0.128	0.128	0.128	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
25410B	Fly Ash	Nickel	mg/L	0.0015	0.0015	0.0015	TRUE
33104	Fly Ash	Nickel	mg/L	0.001225	0.00215	0.003075	TRUE
33106	Fly Ash	Nickel	mg/L	0.0033	0.0042	0.0057	TRUE
35015B	Fly Ash	Nickel	mg/L	0.00425	0.0055	0.00675	TRUE
40109	Fly Ash	Nickel	mg/L	0.0006	0.0009	0.0012	TRUE
43035	Combined ash	Nickel	mg/L	0.000475	0.00065	0.000825	TRUE
49003A	Fly Ash	Nickel	mg/L	0.00325	0.005	0.00675	TRUE
AP	Combined ash	Nickel	mg/L	0.016	0.039	0.051	TRUE
BR	Ash & coal waste	Nickel	mg/L	0.05	0.8	1.275	TRUE
C	Combined ash	Nickel	mg/L	0.01	0.028	0.04375	TRUE
CADK	FGD waste	Nickel	mg/L	0.1	0.1	0.1	TRUE
CASJ	FGD waste	Nickel	mg/L	0.1	0.3	0.3	TRUE
CATT	FGD waste	Nickel	mg/L	0.1	0.1	0.1	TRUE
CL	Ash & coal waste	Nickel	mg/L	0.0025	0.0025	0.0025	TRUE
CY	FGD waste	Nickel	mg/L	0.0803	0.095	0.2896	TRUE
FC	Ash & coal waste	Nickel	mg/L	0.0025	0.00575	0.0117	TRUE
HA	Combined ash	Nickel	mg/L	0.005076	0.005545	0.01094	TRUE
L	Combined ash	Nickel	mg/L	0.005	0.005	0.005	TRUE
MO	Ash & coal waste	Nickel	mg/L	0.421472482	5.6606893	14.21225123	TRUE
MO	Bottom ash	Nickel	mg/L	0.0136275	0.01733788	0.06515894	TRUE
NA	Na FGD Sludge	Nickel	mg/L	0.2	0.2	1.5	TRUE
O	FGD waste	Nickel	mg/L	0.0461	0.0461	0.0461	TRUE
OK	Bottom ash	Nickel	mg/L	0.03131	0.03762	0.04393	TRUE
OK	Fly ash	Nickel	mg/L	0.14345	0.2762	0.46435	TRUE
SX	Bottom ash	Nickel	mg/L	0.008434175	0.01259345	0.016400675	TRUE
SX	Fly ash	Nickel	mg/L	0.00552	0.00561	0.00985	TRUE
AP	Combined ash	trate nitrog	mg/L	0.025	0.05	0.19	TRUE
C	Combined ash	trate nitrog	mg/L	0.31	2.2	5.8	TRUE
CADK	FGD waste	trate nitrog	mg/L	6.5	11	15.5	TRUE
CASJ	FGD waste	trate nitrog	mg/L	0.125	0.125	4.5	TRUE
CL	Ash & coal waste	trate nitrog	mg/L	0.076	0.0995	0.13375	TRUE
CY	FGD waste	trate nitrog	mg/L	2.865	3.9	750.4225	TRUE
FC	Ash & coal waste	trate nitrog	mg/L	0.1	0.1	0.1	TRUE
HA	Combined ash	trate nitrog	mg/L	0.075	0.145	1.363	TRUE
MO	Ash & coal waste	trate nitrog	mg/L	0.20625	0.7	3.5	TRUE
MO	Bottom ash	trate nitrog	mg/L	0.075	0.075	0.09375	TRUE
NA	Na FGD Sludge	trate nitrog	mg/L	1310	1345	1372.5	TRUE
OK	Bottom ash	trate nitrog	mg/L	1.645	2.54	3.435	TRUE
OK	Fly ash	trate nitrog	mg/L	3.75	3.75	7.5	TRUE
SX	Bottom ash	trate nitrog	mg/L	0.0965	0.3465	1.367	TRUE
SX	Fly ash	trate nitrog	mg/L	0.598	0.75	0.75	TRUE
AP	Combined ash	trite nitrog	mg/L	0.075	0.075	0.15	TRUE
C	Combined ash	trite nitrog	mg/L	3.75	7.5	10.15	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
CADK	FGD waste	trite nitrog	mg/L	0.1025	0.135	0.1675	TRUE
CASJ	FGD waste	trite nitrog	mg/L	0.005	0.005	0.01	TRUE
CATT	FGD waste	trite nitrog	mg/L	0.01	0.01	0.01	TRUE
CL	Ash & coal waste	trite nitrog	mg/L	0.015	0.015	0.09775	TRUE
CY	FGD waste	trite nitrog	mg/L	0.25	0.375	1	TRUE
FC	Ash & coal waste	trite nitrog	mg/L	0.1	0.1	0.1	TRUE
HA	Combined ash	trite nitrog	mg/L	0.05	0.05	0.05	TRUE
MO	Ash & coal waste	trite nitrog	mg/L	0.375	1	2.5	TRUE
MO	Bottom ash	trite nitrog	mg/L	0.03	0.04	0.05	TRUE
NA	Na FGD Sludge	trite nitrog	mg/L	0.08	1.29	2.5	TRUE
O	FGD waste	trite nitrog	mg/L	461	461	461	TRUE
OK	Bottom ash	trite nitrog	mg/L	0.5	0.5	0.5	TRUE
OK	Fly ash	trite nitrog	mg/L	2.5	2.5	5	TRUE
SX	Bottom ash	trite nitrog	mg/L	0.01925	0.0545	0.1345	TRUE
SX	Fly ash	trite nitrog	mg/L	0.25	0.25	0.5	TRUE
CL	Ash & coal waste	Oxalate	mg/L	0.04	0.04	0.04	FALSE
SX	Bottom ash	Oxalate	mg/L	0.04	0.04	0.04	FALSE
13115B	Combined ash	n-reduction	mV	94	94	94	FALSE
14093	Fly Ash	n-reduction	mV	171	240	242.5	FALSE
22346	Other	n-reduction	mV	135	156	177	FALSE
23223B	FGD waste	n-reduction	mV	89.75	178.5	267.25	FALSE
25410A	Combined ash	n-reduction	mV	124	124	124	FALSE
33104	Fly Ash	n-reduction	mV	154	168	182	FALSE
33106	Fly Ash	n-reduction	mV	173.5	184	188	FALSE
35015B	Fly Ash	n-reduction	mV	46.25	133.5	220.75	FALSE
40109	Fly Ash	n-reduction	mV	211.25	211.5	211.75	FALSE
43035	Combined ash	n-reduction	mV	231	237	243	FALSE
49003A	Fly Ash	n-reduction	mV	228.25	238	255.5	FALSE
BR	Ash & coal waste	pH	pH	3.525	3.63	3.995	FALSE
MO	Ash & coal waste	pH	pH	2.005	3.4	3.68	FALSE
13115B	Combined ash	pH (field)	pH	7.4	7.4	7.4	FALSE
14093	Fly Ash	pH (field)	pH	8.75	9.3	9.35	FALSE
22346	Other	pH (field)	pH	7.0075	7.265	7.5225	FALSE
23223B	FGD waste	pH (field)	pH	6.75	7.3	7.85	FALSE
25410A	Combined ash	pH (field)	pH	11.7	11.7	11.7	FALSE
33104	Fly Ash	pH (field)	pH	8.175	9.1	10.025	FALSE
33106	Fly Ash	pH (field)	pH	7.01	7.04	7.045	FALSE
35015B	Fly Ash	pH (field)	pH	8.5	8.5	8.5	FALSE
40109	Fly Ash	pH (field)	pH	9.3375	9.755	10.1725	FALSE
43035	Combined ash	pH (field)	pH	11.7425	11.745	11.7475	FALSE
49003A	Fly Ash	pH (field)	pH	6.9975	7.37	7.78	FALSE
C	Combined ash	pH (field)	pH	11.2	11.3	11.7	FALSE
CL	Ash & coal waste	pH (field)	pH	9.355	9.79	10.235	FALSE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
HA	Combined ash	pH (field)	pH	7.44	7.97	10.32	FALSE
MO	Ash & coal waste	pH (field)	pH	2.78	3.755	5.6975	FALSE
MO	Bottom ash	pH (field)	pH	4.5225	5.85	6.12	FALSE
OK	Bottom ash	pH (field)	pH	10.84	10.84	10.84	FALSE
OK	Fly ash	pH (field)	pH	11.15	11.165	11.1975	FALSE
SX	Fly ash	pH (field)	pH	10.34	10.79	10.88	FALSE
AP	Combined ash	pH (lab)	pH	8.035	8.5	8.895	FALSE
CASJ	FGD waste	pH (lab)	pH	8.75	8.8	8.85	FALSE
CATT	FGD waste	pH (lab)	pH	9.265	9.3	9.335	FALSE
CL	Ash & coal waste	pH (lab)	pH	7.785	8.16	8.46	FALSE
CY	FGD waste	pH (lab)	pH	11.415	11.75	11.8725	FALSE
FC	Ash & coal waste	pH (lab)	pH	11.3525	11.485	11.605	FALSE
L	Combined ash	pH (lab)	pH	6.405	6.68	6.955	FALSE
MO	Ash & coal waste	pH (lab)	pH	6.855	6.91	8.255	FALSE
NA	Na FGD Sludge	pH (lab)	pH	4.25	5.4	6.275	FALSE
O	FGD waste	pH (lab)	pH	7.75	7.75	7.805	FALSE
OK	Bottom ash	pH (lab)	pH	10.84	10.84	10.84	FALSE
OK	Fly ash	pH (lab)	pH	11.025	11.16	11.19	FALSE
SX	Bottom ash	pH (lab)	pH	7.74375	8.212	8.60375	FALSE
AP	Combined ash	Phosphate	mg/L	0.175	0.175	0.325	FALSE
C	Combined ash	Phosphate	mg/L	0.025	0.057	0.088	FALSE
CADK	FGD waste	Phosphate	mg/L	0.05	0.05	0.05	FALSE
CASJ	FGD waste	Phosphate	mg/L	0.5	0.5	0.5	FALSE
CL	Ash & coal waste	Phosphate	mg/L	0.073	0.2135	0.47625	FALSE
CY	FGD waste	Phosphate	mg/L	0.25	0.4375	0.78125	FALSE
FC	Ash & coal waste	Phosphate	mg/L	0.125	0.125	0.125	FALSE
HA	Combined ash	Phosphate	mg/L	0.125	0.582	1.546	FALSE
MO	Ash & coal waste	Phosphate	mg/L	0.4375	1.425	5.55	FALSE
MO	Bottom ash	Phosphate	mg/L	0.125	0.1875	0.25	FALSE
NA	Na FGD Sludge	Phosphate	mg/L	2445	2580	2745	FALSE
OK	Bottom ash	Phosphate	mg/L	1.25	1.25	1.25	FALSE
OK	Fly ash	Phosphate	mg/L	6.25	6.25	12.5	FALSE
SX	Bottom ash	Phosphate	mg/L	0.045	0.045	0.12375	FALSE
SX	Fly ash	Phosphate	mg/L	0.625	0.625	1.25	FALSE
13115B	Combined ash	Potassium	mg/L	28.5	48	162.5	TRUE
14093	Fly Ash	Potassium	mg/L	18	26	50.5	TRUE
22346	Other	Potassium	mg/L	7.75	9.5	11.25	TRUE
23223B	FGD waste	Potassium	mg/L	35	50	65	TRUE
25410A	Combined ash	Potassium	mg/L	229	229	229	TRUE
25410B	Fly Ash	Potassium	mg/L	38	38	38	TRUE
33104	Fly Ash	Potassium	mg/L	7.2	8	8.8	TRUE
33106	Fly Ash	Potassium	mg/L	2.25	2.3	3.8	TRUE
35015B	Fly Ash	Potassium	mg/L	27.5	35	42.5	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
40109	Fly Ash	Potassium	mg/L	9.675	10.15	10.625	TRUE
43035	Combined ash	Potassium	mg/L	25	30	35	TRUE
49003A	Fly Ash	Potassium	mg/L	10.25	11	11	TRUE
AP	Combined ash	Potassium	mg/L	2.175	2.65	3.125	TRUE
BR	Ash & coal waste	Potassium	mg/L	8.95	30	70	TRUE
C	Combined ash	Potassium	mg/L	54.6	87.6	110	TRUE
CADK	FGD waste	Potassium	mg/L	200.725	353.15	505.575	TRUE
CASJ	FGD waste	Potassium	mg/L	200	220	280	TRUE
CATT	FGD waste	Potassium	mg/L	54.75	55.5	56.25	TRUE
CY	FGD waste	Potassium	mg/L	53.15	73.25	83.125	TRUE
FC	Ash & coal waste	Potassium	mg/L	8.265	12.095	43.35	TRUE
HA	Ash & coal waste	Potassium	mg/L	11	11	11	TRUE
HA	Combined ash	Potassium	mg/L	9.035	14.446	22.1725	TRUE
L	Combined ash	Potassium	mg/L	29.325	32.15	34.975	TRUE
MO	Ash & coal waste	Potassium	mg/L	15.055	34.45	44.95375	TRUE
MO	Bottom ash	Potassium	mg/L	3.0864375	5.1205	6.1205	TRUE
NA	Na FGD Sludge	Potassium	mg/L	420	636	940	TRUE
O	FGD waste	Potassium	mg/L	20.5	34	34	TRUE
OK	Bottom ash	Potassium	mg/L	12.9099375	21.919125	30.9283125	TRUE
OK	Fly ash	Potassium	mg/L	115.48	177.2	206.4625	TRUE
SX	Fly ash	Potassium	mg/L	93.3525	96.1425	109.4875	TRUE
SX	Bottom ash	geable Orga	mg/L	0.8806455	1.4025095	1.48405075	FALSE
AP	Combined ash	tential, EH (	mg/L	156	187.2	195	FALSE
C	Combined ash	tential, EH (	mg/L	87	167	284	FALSE
CASJ	FGD waste	tential, EH (	mg/L	-289	-280	-230	FALSE
CATT	FGD waste	tential, EH (	mg/L	-328.5	-289	-249.5	FALSE
CL	Ash & coal waste	tential, EH (	mg/L	181.65	247.85	290.425	FALSE
CY	FGD waste	tential, EH (	mg/L	48.5	128	142.25	FALSE
FC	Ash & coal waste	tential, EH (	mg/L	36.5	64.5	79	FALSE
HA	Combined ash	tential, EH (	mg/L	203	326.93	357.23	FALSE
L	Combined ash	tential, EH (	mg/L	-101	-29	43	FALSE
MO	Ash & coal waste	tential, EH (	mg/L	276.60625	395.5	519.825	FALSE
MO	Bottom ash	tential, EH (	mg/L	256.7	327.1	439.5	FALSE
NA	Na FGD Sludge	tential, EH (	mg/L	-58.25	-11.7	1.95	FALSE
O	FGD waste	tential, EH (	mg/L	204	293	293	FALSE
OK	Bottom ash	tential, EH (	mg/L	35.275	35.275	35.275	FALSE
OK	Fly ash	tential, EH (	mg/L	1.875	14.225	50.85	FALSE
SX	Bottom ash	tential, EH (	mg/L	204.61	230.955	246.32	FALSE
SX	Fly ash	tential, EH (	mg/L	71.7	74.03	117.93	FALSE
13115B	Combined ash	Selenium	mg/L	0.00485	0.0092	0.0156	TRUE
14093	Fly Ash	Selenium	mg/L	0.00104	0.0018	0.0025	TRUE
22346	Other	Selenium	mg/L	0.0002625	0.000365	0.0004675	TRUE
23223B	FGD waste	Selenium	mg/L	0.075025	0.14635	0.217675	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
25410A	Combined ash	Selenium	mg/L	0.193	0.193	0.193	TRUE
25410B	Fly Ash	Selenium	mg/L	0.0078	0.0078	0.0078	TRUE
33104	Fly Ash	Selenium	mg/L	0.031225	0.05815	0.085075	TRUE
33106	Fly Ash	Selenium	mg/L	0.00015	0.00017	0.001085	TRUE
35015B	Fly Ash	Selenium	mg/L	0.02075	0.0285	0.03625	TRUE
40109	Fly Ash	Selenium	mg/L	0.0034	0.0056	0.0078	TRUE
43035	Combined ash	Selenium	mg/L	0.112	0.135	0.158	TRUE
49003A	Fly Ash	Selenium	mg/L	0.00489275	0.01775	0.0925	TRUE
AP	Combined ash	Selenium	mg/L	0.00995	0.015	0.0575	TRUE
C	Combined ash	Selenium	mg/L	0.01325	0.017	0.0215	TRUE
CADK	FGD waste	Selenium	mg/L	0.0925	0.125	0.1575	TRUE
CASJ	FGD waste	Selenium	mg/L	0.23375	0.3615	0.5335	TRUE
CATT	FGD waste	Selenium	mg/L	0.9375	1.025	1.1125	TRUE
CL	Ash & coal waste	Selenium	mg/L	0.005	0.05648275	0.1203835	TRUE
CY	FGD waste	Selenium	mg/L	0.017725	0.06815	0.137	TRUE
FC	Ash & coal waste	Selenium	mg/L	0.01745	0.02185	0.0239	TRUE
HA	Ash & coal waste	Selenium	mg/L	0.0025	0.0025	0.0025	TRUE
HA	Combined ash	Selenium	mg/L	0.01	0.01	0.01	TRUE
MO	Ash & coal waste	Selenium	mg/L	0.005	0.035740303	0.10475	TRUE
MO	Bottom ash	Selenium	mg/L	0.005	0.005	0.005	TRUE
O	FGD waste	Selenium	mg/L	0.0022	0.0022	0.00325	TRUE
OK	Bottom ash	Selenium	mg/L	0.05	0.05	0.05	TRUE
OK	Fly ash	Selenium	mg/L	0.2929	0.3256	0.3922	TRUE
SX	Bottom ash	Selenium	mg/L	0.005	0.005	0.01512635	TRUE
SX	Fly ash	Selenium	mg/L	0.318	0.341	0.488	TRUE
13115B	Combined ash	elenium (IV	mg/L	0.000275	0.0005	0.00155	TRUE
14093	Fly Ash	elenium (IV	mg/L	0.00032	0.00059	0.000995	TRUE
22346	Other	elenium (IV	mg/L	0.000325	0.00055	0.000775	TRUE
23223B	FGD waste	elenium (IV	mg/L	0.0197875	0.039525	0.0592625	TRUE
25410A	Combined ash	elenium (IV	mg/L	0.101	0.101	0.101	TRUE
25410B	Fly Ash	elenium (IV	mg/L	0.0018	0.0018	0.0018	TRUE
33104	Fly Ash	elenium (IV	mg/L	0.02625	0.0475	0.06875	TRUE
33106	Fly Ash	elenium (IV	mg/L	0.000245	0.00025	0.001425	TRUE
35015B	Fly Ash	elenium (IV	mg/L	0.00744	0.01396	0.02048	TRUE
40109	Fly Ash	elenium (IV	mg/L	0.002425	0.00385	0.005275	TRUE
43035	Combined ash	elenium (IV	mg/L	0.01225	0.0125	0.01275	TRUE
49003A	Fly Ash	elenium (IV	mg/L	0.0040375	0.01215	0.0685	TRUE
13115B	Combined ash	elenium (VI	mg/L	0.00295	0.0058	0.0109	TRUE
14093	Fly Ash	elenium (VI	mg/L	0.000075	0.0001	0.0001	TRUE
22346	Other	elenium (VI	mg/L	0.0004875	0.000825	0.0011625	TRUE
23223B	FGD waste	elenium (VI	mg/L	0.0299525	0.059635	0.0893175	TRUE
25410A	Combined ash	elenium (VI	mg/L	0.014	0.014	0.014	TRUE
25410B	Fly Ash	elenium (VI	mg/L	0.0036	0.0036	0.0036	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
33104	Fly Ash	elenium (V	mg/L	0.0155	0.021	0.0265	TRUE
33106	Fly Ash	elenium (V	mg/L	0.00035	0.0005	0.0005	TRUE
35015B	Fly Ash	elenium (V	mg/L	0.007125	0.00875	0.010375	TRUE
40109	Fly Ash	elenium (V	mg/L	0.002	0.002	0.002	TRUE
43035	Combined ash	elenium (V	mg/L	0.1385	0.174	0.2095	TRUE
49003A	Fly Ash	elenium (V	mg/L	0.00045	0.001	0.001775	TRUE
43035	Combined ash	lenium, oth	mg/L	0.00015	0.00015	0.00015	FALSE
13115B	Combined ash	Silicon	mg/L	3.35	3.4	6.85	TRUE
14093	Fly Ash	Silicon	mg/L	1.5	1.5	10	TRUE
22346	Other	Silicon	mg/L	4.25	6.2	8.15	TRUE
23223B	FGD waste	Silicon	mg/L	2.925	5.45	7.975	TRUE
25410A	Combined ash	Silicon	mg/L	19	19	19	TRUE
25410B	Fly Ash	Silicon	mg/L	2.4	2.4	2.4	TRUE
33104	Fly Ash	Silicon	mg/L	7.9275	8.985	10.0425	TRUE
33106	Fly Ash	Silicon	mg/L	7.33	7.66	7.81	TRUE
35015B	Fly Ash	Silicon	mg/L	1.45	2.2	2.95	TRUE
40109	Fly Ash	Silicon	mg/L	1.245	1.46	1.675	TRUE
43035	Combined ash	Silicon	mg/L	9.6625	9.875	10.0875	TRUE
49003A	Fly Ash	Silicon	mg/L	3.26	4.4	7.05	TRUE
AP	Combined ash	Silicon	mg/L	1.535	3.19	5.84	TRUE
C	Combined ash	Silicon	mg/L	4.2	5.1	5.8	TRUE
CADK	FGD waste	Silicon	mg/L	11.175	11.25	11.325	TRUE
CASJ	FGD waste	Silicon	mg/L	9	10.3	10.8	TRUE
CATT	FGD waste	Silicon	mg/L	6.2125	6.595	6.9775	TRUE
CL	Ash & coal waste	Silicon	mg/L	2.707083333	3.94875	5.981666667	TRUE
CY	FGD waste	Silicon	mg/L	17.0775	21.15	23.6	TRUE
FC	Ash & coal waste	Silicon	mg/L	7.2575	10.955	21.65	TRUE
HA	Combined ash	Silicon	mg/L	1.83425	3.72025	5.53675	TRUE
L	Combined ash	Silicon	mg/L	10.355	11.73	13.105	TRUE
MO	Ash & coal waste	Silicon	mg/L	7.5415	17.1	52.86	TRUE
MO	Bottom ash	Silicon	mg/L	15.5253125	19.651875	21.893125	TRUE
NA	Na FGD Sludge	Silicon	mg/L	2.4	7	13.8	TRUE
OK	Bottom ash	Silicon	mg/L	16.33625	19.5275	22.71875	TRUE
OK	Fly ash	Silicon	mg/L	11.04125	11.9625	14.9675	TRUE
SX	Bottom ash	Silicon	mg/L	2.75875	6.62	9.40125	TRUE
SX	Fly ash	Silicon	mg/L	0.5	2.31175	5.5695	TRUE
13115B	Combined ash	Silver	mg/L	0.00045	0.0008	0.0014	TRUE
14093	Fly Ash	Silver	mg/L	0.0001	0.0001	0.00015	TRUE
22346	Other	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
25410A	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
25410B	Fly Ash	Silver	mg/L	0.0011	0.0011	0.0011	TRUE
33104	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
33106	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
35015B	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
43035	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
49003A	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
AP	Combined ash	Silver	mg/L	0.0025	0.0025	0.0025	TRUE
C	Combined ash	Silver	mg/L	0.005	0.005	0.005	TRUE
CY	FGD waste	Silver	mg/L	0.0005	0.0005	0.001625	TRUE
FC	Ash & coal waste	Silver	mg/L	0.00005	0.00005	0.00005	TRUE
HA	Ash & coal waste	Silver	mg/L	0.005	0.005	0.005	TRUE
HA	Combined ash	Silver	mg/L	0.0005	0.0005	0.0005	TRUE
OK	Bottom ash	Silver	mg/L	0.005	0.005	0.005	TRUE
OK	Fly ash	Silver	mg/L	0.00275	0.005	0.005	TRUE
SX	Fly ash	Silver	mg/L	0.0005	0.0005	0.0005	TRUE
13115B	Combined ash	Sodium	mg/L	55	57	64.5	TRUE
14093	Fly Ash	Sodium	mg/L	23.5	30	42.5	TRUE
22346	Other	Sodium	mg/L	44.25	50.5	56.75	TRUE
23223B	FGD waste	Sodium	mg/L	787	968	1149	TRUE
25410A	Combined ash	Sodium	mg/L	731	731	731	TRUE
25410B	Fly Ash	Sodium	mg/L	52	52	52	TRUE
33104	Fly Ash	Sodium	mg/L	9.975	10.45	10.925	TRUE
33106	Fly Ash	Sodium	mg/L	3.85	3.9	4.3	TRUE
35015B	Fly Ash	Sodium	mg/L	33.75	42.5	51.25	TRUE
40109	Fly Ash	Sodium	mg/L	5.9	6.2	6.5	TRUE
43035	Combined ash	Sodium	mg/L	458	523	588	TRUE
49003A	Fly Ash	Sodium	mg/L	26.25	29.5	31.5	TRUE
AP	Combined ash	Sodium	mg/L	195	200	205	TRUE
BR	Ash & coal waste	Sodium	mg/L	5.25	23	33.75	TRUE
C	Combined ash	Sodium	mg/L	39	42	115	TRUE
CADK	FGD waste	Sodium	mg/L	32.3	33.6	34.9	TRUE
CASJ	FGD waste	Sodium	mg/L	5960	6100	6270	TRUE
CATT	FGD waste	Sodium	mg/L	686.5	762	837.5	TRUE
CY	FGD waste	Sodium	mg/L	1843.25	2005	2062.5	TRUE
FC	Ash & coal waste	Sodium	mg/L	62.925	136	374.75	TRUE
HA	Ash & coal waste	Sodium	mg/L	53	53	53	TRUE
HA	Combined ash	Sodium	mg/L	13.5875	25.9475	60.095	TRUE
L	Combined ash	Sodium	mg/L	9.375	9.75	10.125	TRUE
MO	Ash & coal waste	Sodium	mg/L	12.65	19.2	25.385	TRUE
MO	Bottom ash	Sodium	mg/L	3.076916667	7.041583334	10.3523125	TRUE
NA	Na FGD Sludge	Sodium	mg/L	29650	64100	79500	TRUE
O	FGD waste	Sodium	mg/L	2325	2890	2991.5	TRUE
OK	Bottom ash	Sodium	mg/L	1286.875	1312.75	1338.625	TRUE
OK	Fly ash	Sodium	mg/L	7250	9266	11416.5	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
SX	Fly ash	Sodium	mg/L	282.2666667	317.0833333	319.6666667	TRUE
13115B	Combined ash	ductance @	mS/cm	1.6	1.6	1.6	FALSE
14093	Fly Ash	ductance @	mS/cm	2.65	2.7	2.8	FALSE
22346	Other	ductance @	mS/cm	0.96425	1.0015	1.03875	FALSE
23223B	FGD waste	ductance @	mS/cm	5.675	6.55	7.425	FALSE
25410A	Combined ash	ductance @	mS/cm	5.1	5.1	5.1	FALSE
33104	Fly Ash	ductance @	mS/cm	0.516	0.599	0.682	FALSE
33106	Fly Ash	ductance @	mS/cm	0.348	0.379	0.38	FALSE
35015B	Fly Ash	ductance @	mS/cm	2.1	2.4	2.7	FALSE
40109	Fly Ash	ductance @	mS/cm	0.498	0.528	0.558	FALSE
43035	Combined ash	ductance @	mS/cm	2.9325	3.295	3.6575	FALSE
49003A	Fly Ash	ductance @	mS/cm	0.63225	0.658	0.67975	FALSE
C	Combined ash	ductance @	mg/L	1159	1722	1821	FALSE
CL	Ash & coal waste	ductance @	mg/L	253.5	286	300.5	FALSE
HA	Combined ash	ductance @	mg/L	321.5	461	625.5	FALSE
MO	Ash & coal waste	ductance @	mg/L	3620.565929	14200	24300	FALSE
MO	Bottom ash	ductance @	mg/L	410.25	665.5	863.75	FALSE
SX	Fly ash	ductance @	mg/L	2160	2255	3549	FALSE
AP	Combined ash	nductance (	mg/L	3347.25	3966.5	5182.25	FALSE
CASJ	FGD waste	nductance (	mg/L	2.6775	2.705	2.7325	FALSE
CL	Ash & coal waste	nductance (	mg/L	345.5	533	710	FALSE
CY	FGD waste	nductance (	mg/L	8540	8540	8540	FALSE
FC	Ash & coal waste	nductance (	mg/L	1523.5	1864	4616.25	FALSE
OK	Bottom ash	nductance (	mg/L	11142.80327	11142.80327	11142.80327	FALSE
OK	Fly ash	nductance (	mg/L	41677.11925	44657.92752	59236.78978	FALSE
SX	Bottom ash	nductance (	mg/L	1440.75	2525	2800	FALSE
13115B	Combined ash	Strontium	mg/L	0.66	0.68	0.805	TRUE
14093	Fly Ash	Strontium	mg/L	1.755	2.25	2.695	TRUE
22346	Other	Strontium	mg/L	2.2725	2.355	2.4375	TRUE
23223B	FGD waste	Strontium	mg/L	15.4	15.9	16.4	TRUE
25410A	Combined ash	Strontium	mg/L	1.2	1.2	1.2	TRUE
25410B	Fly Ash	Strontium	mg/L	2.69	2.69	2.69	TRUE
33104	Fly Ash	Strontium	mg/L	1.2175	1.425	1.6325	TRUE
33106	Fly Ash	Strontium	mg/L	1.235	1.35	1.355	TRUE
35015B	Fly Ash	Strontium	mg/L	1.3625	1.735	2.1075	TRUE
40109	Fly Ash	Strontium	mg/L	5.265	5.38	5.495	TRUE
43035	Combined ash	Strontium	mg/L	0.94425	1.2395	1.53475	TRUE
49003A	Fly Ash	Strontium	mg/L	0.713	0.7505	1.07575	TRUE
AP	Combined ash	Strontium	mg/L	3.898	6.855	7.5	TRUE
BR	Ash & coal waste	Strontium	mg/L	7.2	7.8	9	TRUE
C	Combined ash	Strontium	mg/L	0.39	0.64	1.1	TRUE
CADK	FGD waste	Strontium	mg/L	6.92	7	7.08	TRUE
CASJ	FGD waste	Strontium	mg/L	6.85	9	11.2	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
CATT	FGD waste	Strontium	mg/L	15.45	16.1	16.75	TRUE
CL	Ash & coal waste	Strontium	mg/L	0.831375	1.731666667	2.8225	TRUE
CY	FGD waste	Strontium	mg/L	1.9675	3.34	6.455	TRUE
FC	Ash & coal waste	Strontium	mg/L	2.4675	2.9	3.6425	TRUE
HA	Ash & coal waste	Strontium	mg/L	2.1	2.1	2.1	TRUE
HA	Combined ash	Strontium	mg/L	0.64875	1.0155	5.56875	TRUE
L	Combined ash	Strontium	mg/L	2.0325	2.385	2.7375	TRUE
MO	Ash & coal waste	Strontium	mg/L	0.4	1.83025	2.81075	TRUE
MO	Bottom ash	Strontium	mg/L	0.31721875	0.4619375	0.53934375	TRUE
NA	Na FGD Sludge	Strontium	mg/L	0.7	0.86	2	TRUE
OK	Bottom ash	Strontium	mg/L	8.42703125	14.5834375	20.73984375	TRUE
OK	Fly ash	Strontium	mg/L	2.226541667	4.880625	9.105875	TRUE
SX	Bottom ash	Strontium	mg/L	0.26075	3.813333334	4.557916667	TRUE
SX	Fly ash	Strontium	mg/L	5.192	5.4515	6.624	TRUE
13115B	Combined ash	Sulfate	mg/L	574.5	810	1035	TRUE
14093	Fly Ash	Sulfate	mg/L	1510	1650	1675	TRUE
22346	Other	Sulfate	mg/L	180	225	270	TRUE
23223B	FGD waste	Sulfate	mg/L	2347.5	2615	2882.5	TRUE
25410A	Combined ash	Sulfate	mg/L	910	910	910	TRUE
25410B	Fly Ash	Sulfate	mg/L	1530	1530	1530	TRUE
33104	Fly Ash	Sulfate	mg/L	75	89	103	TRUE
33106	Fly Ash	Sulfate	mg/L	111	121	122	TRUE
35015B	Fly Ash	Sulfate	mg/L	1168.5	1389	1609.5	TRUE
40109	Fly Ash	Sulfate	mg/L	140	152	164	TRUE
43035	Combined ash	Sulfate	mg/L	660.25	813.5	966.75	TRUE
49003A	Fly Ash	Sulfate	mg/L	200.5	206.5	219.5	TRUE
AP	Combined ash	Sulfate	mg/L	833.5	1443	1765	TRUE
BR	Ash & coal waste	Sulfate	mg/L	1953.5	4404.5	5300.75	TRUE
C	Combined ash	Sulfate	mg/L	137.5	239	446.25	TRUE
CADK	FGD waste	Sulfate	mg/L	2072.5	2135	2197.5	TRUE
CASJ	FGD waste	Sulfate	mg/L	9260	10000	10700	TRUE
CATT	FGD waste	Sulfate	mg/L	1927.5	1965	2002.5	TRUE
CL	Ash & coal waste	Sulfate	mg/L	69.2195	93.672	139.3145	TRUE
CY	FGD waste	Sulfate	mg/L	3736.75	4040	4373.5	TRUE
FC	Ash & coal waste	Sulfate	mg/L	171	185	210	TRUE
HA	Ash & coal waste	Sulfate	mg/L	200	200	200	TRUE
HA	Combined ash	Sulfate	mg/L	55.145	107.353	297.187	TRUE
L	Combined ash	Sulfate	mg/L	1345.55	1412.8	1480.05	TRUE
MO	Ash & coal waste	Sulfate	mg/L	2106.025	15065.916	45435.009	TRUE
MO	Bottom ash	Sulfate	mg/L	287.7795	376.4425	411.002	TRUE
NA	Na FGD Sludge	Sulfate	mg/L	77025	120500	153500	TRUE
OK	Bottom ash	Sulfate	mg/L	1335.93025	1593.7315	1851.53275	TRUE
OK	Fly ash	Sulfate	mg/L	752.238	1027.231	1060.0815	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
SX	Bottom ash	Sulfate	mg/L	196.31	940.85	1530.96475	TRUE
SX	Fly ash	Sulfate	mg/L	936.377	958.914	2283.071	TRUE
AP	Combined ash	Sulfite	mg/L	2.5	2.5	10	FALSE
BR	Ash & coal waste	Sulfite	mg/L	0.395	0.5	0.5	FALSE
C	Combined ash	Sulfite	mg/L	0.2	0.2	0.2	FALSE
CADK	FGD waste	Sulfite	mg/L	1.4825	2.915	4.3475	FALSE
CASJ	FGD waste	Sulfite	mg/L	0.05	58.6	89.7	FALSE
CATT	FGD waste	Sulfite	mg/L	16.825	18.65	20.475	FALSE
CL	Ash & coal waste	Sulfite	mg/L	0.5	0.5	0.5	FALSE
CY	FGD waste	Sulfite	mg/L	2.1875	2.5	3.4375	FALSE
FC	Ash & coal waste	Sulfite	mg/L	0.125	0.125	0.30875	FALSE
HA	Combined ash	Sulfite	mg/L	0.125	0.125	0.125	FALSE
MO	Ash & coal waste	Sulfite	mg/L	2.1875	5	6.25	FALSE
MO	Bottom ash	Sulfite	mg/L	0.125	0.1875	0.625	FALSE
NA	Na FGD Sludge	Sulfite	mg/L	112	2085	4550	FALSE
OK	Bottom ash	Sulfite	mg/L	1.25	1.25	1.25	FALSE
OK	Fly ash	Sulfite	mg/L	6.25	6.25	12.5	FALSE
SX	Bottom ash	Sulfite	mg/L	0.75	2.5	5	FALSE
SX	Fly ash	Sulfite	mg/L	0.625	0.625	1.25	FALSE
AP	Combined ash	Sulfur	mg/L	330.54175	672.25	789.667	TRUE
CL	Ash & coal waste	Sulfur	mg/L	22.86666667	31.27083334	44.66666667	TRUE
CY	FGD waste	Sulfur	mg/L	1261.25	1372	1490.5	TRUE
FC	Ash & coal waste	Sulfur	mg/L	64.5	71.45	78.225	TRUE
HA	Combined ash	Sulfur	mg/L	17.53333333	34.9525	47.675	TRUE
MO	Ash & coal waste	Sulfur	mg/L	1129.246875	5742	17597.5	TRUE
MO	Bottom ash	Sulfur	mg/L	98.17	124.3	135.465625	TRUE
O	FGD waste	Sulfur	mg/L	3687	3997	4307	TRUE
OK	Bottom ash	Sulfur	mg/L	445.125	537.7	630.275	TRUE
OK	Fly ash	Sulfur	mg/L	236.675	344.2625	366.78125	TRUE
SX	Bottom ash	Sulfur	mg/L	68.99166668	323.9166667	520.2083334	TRUE
SX	Fly ash	Sulfur	mg/L	318.05	328.2625	754.425	TRUE
13115B	Combined ash	Temperatur	°C	18.3	18.3	18.3	FALSE
14093	Fly Ash	Temperatur	°C	20.9	21.3	21.95	FALSE
22346	Other	Temperatur	°C	19.275	19.35	19.425	FALSE
23223B	FGD waste	Temperatur	°C	19.925	22.25	24.575	FALSE
25410A	Combined ash	Temperatur	°C	30.6	30.6	30.6	FALSE
33104	Fly Ash	Temperatur	°C	27.95	28.3	28.65	FALSE
33106	Fly Ash	Temperatur	°C	22.35	22.7	23.45	FALSE
35015B	Fly Ash	Temperatur	°C	15.45	15.5	15.55	FALSE
40109	Fly Ash	Temperatur	°C	26.8	26.9	27	FALSE
43035	Combined ash	Temperatur	°C	16.4875	16.575	16.6625	FALSE
49003A	Fly Ash	Temperatur	°C	19.95	20.89	21.2425	FALSE
13115B	Combined ash	Thallium	mg/L	0.000175	0.00025	0.00025	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
14093	Fly Ash	Thallium	mg/L	0.00005	0.00005	0.000325	TRUE
22346	Other	Thallium	mg/L	0.0001375	0.000225	0.0003125	TRUE
23223B	FGD waste	Thallium	mg/L	0.0001	0.00015	0.0002	TRUE
25410A	Combined ash	Thallium	mg/L	0.0003	0.0003	0.0003	TRUE
25410B	Fly Ash	Thallium	mg/L	0.0031	0.0031	0.0031	TRUE
33104	Fly Ash	Thallium	mg/L	0.0002	0.0003	0.0004	TRUE
33106	Fly Ash	Thallium	mg/L	0.0001	0.0001	0.0001	TRUE
35015B	Fly Ash	Thallium	mg/L	0.0008875	0.001725	0.0025625	TRUE
40109	Fly Ash	Thallium	mg/L	0.000325	0.00035	0.000375	TRUE
43035	Combined ash	Thallium	mg/L	0.00005	0.00005	0.00005	TRUE
49003A	Fly Ash	Thallium	mg/L	0.000675	0.00105	0.00135	TRUE
AP	Combined ash	Thallium	mg/L	0.0025	0.0025	0.0025	TRUE
C	Combined ash	Thallium	mg/L	0.05	0.05	0.05	TRUE
AP	Combined ash	hiosulfate Ic	mg/L	0.225	0.225	1.43	FALSE
CADK	FGD waste	hiosulfate Ic	mg/L	0.51875	0.9125	1.30625	FALSE
CASJ	FGD waste	hiosulfate Ic	mg/L	0.125	0.125	22.5625	FALSE
CATT	FGD waste	hiosulfate Ic	mg/L	40.35	54.2	68.05	FALSE
CY	FGD waste	hiosulfate Ic	mg/L	0.21875	0.6715	2.2225	FALSE
FC	Ash & coal waste	hiosulfate Ic	mg/L	0.125	0.125	0.125	FALSE
HA	Combined ash	hiosulfate Ic	mg/L	0.125	0.125	0.125	FALSE
MO	Ash & coal waste	hiosulfate Ic	mg/L	0.18	0.18	0.9	FALSE
MO	Bottom ash	hiosulfate Ic	mg/L	0.18	0.18	0.18	FALSE
NA	Na FGD Sludge	hiosulfate Ic	mg/L	2150	4865	5007.5	FALSE
OK	Bottom ash	hiosulfate Ic	mg/L	1.8	1.8	1.8	FALSE
OK	Fly ash	hiosulfate Ic	mg/L	13.5	18	22.391	FALSE
SX	Fly ash	hiosulfate Ic	mg/L	0.9	0.9	1.8	FALSE
13115B	Combined ash	TOC	mg/L	17.85	21.5	22	FALSE
14093	Fly Ash	TOC	mg/L	2.9	3.9	5.1	FALSE
22346	Other	TOC	mg/L	0.10875	0.1725	0.23625	FALSE
23223B	FGD waste	TOC	mg/L	17.275	18.35	19.425	FALSE
25410A	Combined ash	TOC	mg/L	24	24	24	FALSE
25410B	Fly Ash	TOC	mg/L	16.6	16.6	16.6	FALSE
33104	Fly Ash	TOC	mg/L	0.045	0.045	0.045	FALSE
33106	Fly Ash	TOC	mg/L	0.045	0.045	0.045	FALSE
35015B	Fly Ash	TOC	mg/L	3.125	5.75	8.375	FALSE
40109	Fly Ash	TOC	mg/L	0.725	0.75	0.775	FALSE
43035	Combined ash	TOC	mg/L	6.475	6.95	7.425	FALSE
49003A	Fly Ash	TOC	mg/L	1.35	1.6	1.9	FALSE
C	Combined ash	TOC	mg/L	12.05	12.4	20.2	FALSE
SX	Bottom ash	TOC	mg/L	27.602878	33.9537765	38.94643075	FALSE
13115B	Combined ash	inorganic c	mg/L	2.71	2.94	58.97	FALSE
14093	Fly Ash	inorganic c	mg/L	9.3	16.6	25.85	FALSE
22346	Other	inorganic c	mg/L	30.575	40.55	50.525	FALSE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
23223B	FGD waste	inorganic c	mg/L	2.475	2.55	2.625	FALSE
25410A	Combined ash	inorganic c	mg/L	5.6	5.6	5.6	FALSE
25410B	Fly Ash	inorganic c	mg/L	11.3	11.3	11.3	FALSE
33104	Fly Ash	inorganic c	mg/L	12.56	21.14	29.72	FALSE
33106	Fly Ash	inorganic c	mg/L	8.53	10.4	10.45	FALSE
35015B	Fly Ash	inorganic c	mg/L	3.7475	5.965	8.1825	FALSE
40109	Fly Ash	inorganic c	mg/L	3.715	4.13	4.545	FALSE
43035	Combined ash	inorganic c	mg/L	6.275	6.65	7.025	FALSE
49003A	Fly Ash	inorganic c	mg/L	12.6575	15.45	19.35	FALSE
13115B	Combined ash	Uranium	mg/L	0.0004	0.0007	0.00265	TRUE
14093	Fly Ash	Uranium	mg/L	0.00145	0.0018	0.00255	TRUE
22346	Other	Uranium	mg/L	0.0081325	0.014355	0.0205775	TRUE
23223B	FGD waste	Uranium	mg/L	0.00025	0.0004	0.00055	TRUE
25410A	Combined ash	Uranium	mg/L	0.0007	0.0007	0.0007	TRUE
25410B	Fly Ash	Uranium	mg/L	0.0125	0.0125	0.0125	TRUE
33104	Fly Ash	Uranium	mg/L	0.0003875	0.000725	0.0010625	TRUE
33106	Fly Ash	Uranium	mg/L	0.000075	0.0001	0.00015	TRUE
35015B	Fly Ash	Uranium	mg/L	0.002825	0.00365	0.004475	TRUE
40109	Fly Ash	Uranium	mg/L	0.0005	0.0009	0.0013	TRUE
43035	Combined ash	Uranium	mg/L	0.00001	0.00001	0.00001	TRUE
49003A	Fly Ash	Uranium	mg/L	0.002075	0.005305	0.0211325	TRUE
AP	Combined ash	Uranium 23	mg/L	0.0072	0.0072	0.0072	FALSE
13115B	Combined ash	Vanadium	mg/L	0.0235	0.041	0.1235	TRUE
14093	Fly Ash	Vanadium	mg/L	0.02	0.036	0.1155	TRUE
22346	Other	Vanadium	mg/L	0.003175	0.00595	0.008725	TRUE
23223B	FGD waste	Vanadium	mg/L	0.0045	0.008	0.0115	TRUE
25410A	Combined ash	Vanadium	mg/L	1.23	1.23	1.23	TRUE
25410B	Fly Ash	Vanadium	mg/L	0.011	0.011	0.011	TRUE
33104	Fly Ash	Vanadium	mg/L	0.048425	0.09125	0.134075	TRUE
33106	Fly Ash	Vanadium	mg/L	0.00475	0.0069	0.01035	TRUE
35015B	Fly Ash	Vanadium	mg/L	0.0075	0.011	0.0145	TRUE
40109	Fly Ash	Vanadium	mg/L	0.2354	0.4084	0.5814	TRUE
43035	Combined ash	Vanadium	mg/L	0.1505	0.179	0.2075	TRUE
49003A	Fly Ash	Vanadium	mg/L	0.17405	0.3095	0.40825	TRUE
AP	Combined ash	Vanadium	mg/L	0.0245	0.063	0.104	TRUE
C	Combined ash	Vanadium	mg/L	0.295	0.37	0.5625	TRUE
CADK	FGD waste	Vanadium	mg/L	0.0195	0.022	0.0245	TRUE
CASJ	FGD waste	Vanadium	mg/L	0.04	0.05	0.05	TRUE
CATT	FGD waste	Vanadium	mg/L	0.02225	0.0235	0.02475	TRUE
CL	Ash & coal waste	Vanadium	mg/L	0.007971675	0.1095205	0.302844688	TRUE
CY	FGD waste	Vanadium	mg/L	0.2685	0.3805	0.658	TRUE
FC	Ash & coal waste	Vanadium	mg/L	0.069875	0.1	0.13375	TRUE
HA	Combined ash	Vanadium	mg/L	0.00921	0.04591	0.1941	TRUE

Attachment C-2. Quartile Data for CCR Impoundment Porewater

Site	New WasteType	Analyte	Units	25th %ile	50th %ile	75th %ile	Risk
MO	Ash & coal waste	Vanadium	mg/L	0.029925673	0.720771658	0.948465304	TRUE
MO	Bottom ash	Vanadium	mg/L	0.00125	0.00125	0.00125	TRUE
NA	Na FGD Sludge	Vanadium	mg/L	0.1	0.1	0.5	TRUE
O	FGD waste	Vanadium	mg/L	0.01195	0.0189	0.0189	TRUE
OK	Bottom ash	Vanadium	mg/L	0.10023	0.13822	0.17621	TRUE
OK	Fly ash	Vanadium	mg/L	0.24685	0.2794	0.3255	TRUE
SX	Bottom ash	Vanadium	mg/L	0.005928175	0.02463615	0.05692185	TRUE
SX	Fly ash	Vanadium	mg/L	0.267	0.288	0.54	TRUE
13115B	Combined ash	Zinc	mg/L	0.00475	0.007	0.0115	TRUE
14093	Fly Ash	Zinc	mg/L	0.026	0.04	0.0425	TRUE
22346	Other	Zinc	mg/L	0.001125	0.00125	0.001375	TRUE
23223B	FGD waste	Zinc	mg/L	0.007625	0.01275	0.017875	TRUE
25410A	Combined ash	Zinc	mg/L	0.13	0.13	0.13	TRUE
25410B	Fly Ash	Zinc	mg/L	0.025	0.025	0.025	TRUE
33104	Fly Ash	Zinc	mg/L	0.0015	0.0015	0.0015	TRUE
33106	Fly Ash	Zinc	mg/L	0.0015	0.0015	0.0015	TRUE
35015B	Fly Ash	Zinc	mg/L	0.03225	0.0515	0.07075	TRUE
40109	Fly Ash	Zinc	mg/L	0.00255	0.0036	0.00465	TRUE
43035	Combined ash	Zinc	mg/L	0.001	0.001	0.001	TRUE
49003A	Fly Ash	Zinc	mg/L	0.00475	0.006	0.00725	TRUE
AP	Combined ash	Zinc	mg/L	0.0072	0.0125	0.0125	TRUE
BR	Ash & coal waste	Zinc	mg/L	0.11	0.25	1.025	TRUE
C	Combined ash	Zinc	mg/L	0.01	0.029	0.048	TRUE
CADK	FGD waste	Zinc	mg/L	0.1	0.1	0.1	TRUE
CASJ	FGD waste	Zinc	mg/L	0.1	0.1	0.125	TRUE
CATT	FGD waste	Zinc	mg/L	0.21	0.21	0.21	TRUE
CL	Ash & coal waste	Zinc	mg/L	0.0125	0.0125	0.0125	TRUE
CY	FGD waste	Zinc	mg/L	0.09425	0.1122	0.13175	TRUE
FC	Ash & coal waste	Zinc	mg/L	0.0125	0.0125	0.0125	TRUE
HA	Combined ash	Zinc	mg/L	0.03215	0.04411	0.06253	TRUE
L	Combined ash	Zinc	mg/L	0.12	0.12	0.12	TRUE
MO	Ash & coal waste	Zinc	mg/L	0.05	2.1573	27.85	TRUE
MO	Bottom ash	Zinc	mg/L	0.0228	0.0829	0.1224425	TRUE
NA	Na FGD Sludge	Zinc	mg/L	0.2	0.2	1	TRUE
O	FGD waste	Zinc	mg/L	0.02405	0.0378	0.0378	TRUE
OK	Bottom ash	Zinc	mg/L	0.125	0.125	0.125	TRUE
OK	Fly ash	Zinc	mg/L	0.06875	0.125	0.125	TRUE
SX	Bottom ash	Zinc	mg/L	0.0125	0.0125	0.02940415	TRUE
SX	Fly ash	Zinc	mg/L	0.0714	0.0778	0.0929	TRUE

Attachment C-3.

Quartile Data for CCR Impoundment Surface Water

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
13115A	Combined ash	Aluminum	mg/L	1.0275	1.325	1.6225	TRUE
13115A	Fly Ash	Aluminum	mg/L	4.19	4.19	4.19	TRUE
22346	Other	Aluminum	mg/L	1.08	1.08	1.08	TRUE
22347	Fly Ash	Aluminum	mg/L	2.03	2.03	2.03	TRUE
23223B	FGD waste	Aluminum	mg/L	0.19	0.19	0.19	TRUE
25410A	Combined ash	Aluminum	mg/L	0.1	0.1	0.1	TRUE
33104	Combined ash	Aluminum	mg/L	0.13875	0.2485	0.35825	TRUE
33104	Fly Ash	Aluminum	mg/L	2.31	2.31	2.31	TRUE
33106	Combined ash	Aluminum	mg/L	0.014	0.014	0.014	TRUE
33106	Fly Ash	Aluminum	mg/L	0.107	0.148	1.939	TRUE
34186B	FGD waste	Aluminum	mg/L	0.20025	0.3695	0.53875	TRUE
35015B	Combined ash	Aluminum	mg/L	0.0165	0.018	0.023	TRUE
40109	Combined ash	Aluminum	mg/L	0.17225	0.2335	0.29475	TRUE
40109	Fly Ash	Aluminum	mg/L	2.15	2.15	2.15	TRUE
49003A	Fly Ash	Aluminum	mg/L	0.023	0.0325	0.04	TRUE
13115A	Combined ash	Antimony	mg/L	0.0005	0.0005	0.0005	TRUE
13115A	Fly Ash	Antimony	mg/L	0.0006	0.0006	0.0006	TRUE
22346	Other	Antimony	mg/L	0.0011	0.0011	0.0011	TRUE
22347	Fly Ash	Antimony	mg/L	0.0029	0.0029	0.0029	TRUE
23223B	FGD waste	Antimony	mg/L	0.0046	0.0046	0.0046	TRUE
25410A	Combined ash	Antimony	mg/L	0.0014	0.0014	0.0014	TRUE
33104	Combined ash	Antimony	mg/L	0.008075	0.00855	0.009025	TRUE
33104	Fly Ash	Antimony	mg/L	0.0274	0.0274	0.0274	TRUE
33106	Combined ash	Antimony	mg/L	0.0071	0.0071	0.0071	TRUE
33106	Fly Ash	Antimony	mg/L	0.0113	0.0139	0.01585	TRUE
34186B	FGD waste	Antimony	mg/L	0.012625	0.01585	0.019075	TRUE
35015B	Combined ash	Antimony	mg/L	0.0028	0.0031	0.00345	TRUE
40109	Combined ash	Antimony	mg/L	0.00575	0.0059	0.00605	TRUE
40109	Fly Ash	Antimony	mg/L	0.0059	0.0059	0.0059	TRUE
49003A	Fly Ash	Antimony	mg/L	0.020525	0.0221	0.0237	TRUE
13115A	Combined ash	Arsenic	mg/L	0.004125	0.00415	0.004175	TRUE
13115A	Fly Ash	Arsenic	mg/L	0.0051	0.0051	0.0051	TRUE
22346	Other	Arsenic	mg/L	0.023	0.023	0.023	TRUE
22347	Fly Ash	Arsenic	mg/L	0.0062	0.0062	0.0062	TRUE
23223B	FGD waste	Arsenic	mg/L	0.029	0.029	0.029	TRUE
25410A	Combined ash	Arsenic	mg/L	0.024	0.024	0.024	TRUE
33104	Combined ash	Arsenic	mg/L	0.11075	0.1215	0.13225	TRUE
33104	Fly Ash	Arsenic	mg/L	0.178	0.178	0.178	TRUE
33106	Combined ash	Arsenic	mg/L	0.0054	0.0054	0.0054	TRUE
33106	Fly Ash	Arsenic	mg/L	0.01455	0.024	0.0495	TRUE
34186B	FGD waste	Arsenic	mg/L	0.08075	0.1305	0.18025	TRUE
35015B	Combined ash	Arsenic	mg/L	0.0275	0.03	0.0355	TRUE
40109	Combined ash	Arsenic	mg/L	0.10525	0.1115	0.11775	TRUE
40109	Fly Ash	Arsenic	mg/L	0.038	0.038	0.038	TRUE
49003A	Fly Ash	Arsenic	mg/L	0.008275	0.00965	0.011	TRUE
13115A	Combined ash	Arsenic (III)	mg/L	0.00091	0.00094	0.00097	TRUE
13115A	Fly Ash	Arsenic (III)	mg/L	0.00057	0.00057	0.00057	TRUE
22346	Other	Arsenic (III)	mg/L	0.00021	0.00021	0.00021	TRUE
22347	Fly Ash	Arsenic (III)	mg/L	0.00023	0.00023	0.00023	TRUE
23223B	FGD waste	Arsenic (III)	mg/L	0.003	0.003	0.003	TRUE
25410A	Combined ash	Arsenic (III)	mg/L	0.0003	0.0003	0.0003	TRUE
33104	Combined ash	Arsenic (III)	mg/L	0.0001	0.0001	0.0001	TRUE
33104	Fly Ash	Arsenic (III)	mg/L	0.0002	0.0002	0.0002	TRUE
33106	Combined ash	Arsenic (III)	mg/L	0.00002	0.00002	0.00002	TRUE
33106	Fly Ash	Arsenic (III)	mg/L	0.0000375	0.00005	0.00022	TRUE
34186B	FGD waste	Arsenic (III)	mg/L	0.0499625	0.098975	0.1479875	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
35015B	Combined ash	Arsenic (III)	mg/L	0.0003425	0.00066	0.00883	TRUE
40109	Combined ash	Arsenic (III)	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Fly Ash	Arsenic (III)	mg/L	0.0007	0.0007	0.0007	TRUE
49003A	Fly Ash	Arsenic (III)	mg/L	0.002575	0.00705	0.0115	TRUE
13115A	Combined ash	Arsenic (V)	mg/L	0.0001625	0.000285	0.0004075	TRUE
13115A	Fly Ash	Arsenic (V)	mg/L	0.00004	0.00004	0.00004	TRUE
22346	Other	Arsenic (V)	mg/L	0.015	0.015	0.015	TRUE
22347	Fly Ash	Arsenic (V)	mg/L	0.0024	0.0024	0.0024	TRUE
23223B	FGD waste	Arsenic (V)	mg/L	0.005	0.005	0.005	TRUE
25410A	Combined ash	Arsenic (V)	mg/L	0.024	0.024	0.024	TRUE
33104	Combined ash	Arsenic (V)	mg/L	0.1045	0.115	0.1255	TRUE
33104	Fly Ash	Arsenic (V)	mg/L	0.15	0.15	0.15	TRUE
33106	Combined ash	Arsenic (V)	mg/L	0.0023	0.0023	0.0023	TRUE
33106	Fly Ash	Arsenic (V)	mg/L	0.01075	0.019	0.0235	TRUE
34186B	FGD waste	Arsenic (V)	mg/L	0.02375	0.0325	0.04125	TRUE
35015B	Combined ash	Arsenic (V)	mg/L	0.024	0.031	0.038	TRUE
40109	Combined ash	Arsenic (V)	mg/L	0.1015	0.11	0.1185	TRUE
40109	Fly Ash	Arsenic (V)	mg/L	0.015	0.015	0.015	TRUE
49003A	Fly Ash	Arsenic (V)	mg/L	0.0004675	0.002895	0.005825	TRUE
13115A	Combined ash	Arsenic, other	mg/L	0.00008925	0.0001095	0.00012975	TRUE
13115A	Fly Ash	Arsenic, other	mg/L	0.00003	0.00003	0.00003	TRUE
23223B	FGD waste	Arsenic, other	mg/L	0.003	0.003	0.003	TRUE
25410A	Combined ash	Arsenic, other	mg/L	0.0003	0.0003	0.0003	TRUE
33106	Combined ash	Arsenic, other	mg/L	0.00002	0.00002	0.00002	TRUE
34186B	FGD waste	Arsenic, other	mg/L	0.001025	0.00195	0.002875	TRUE
35015B	Combined ash	Arsenic, other	mg/L	0.000112	0.00015	0.00022	TRUE
49003A	Fly Ash	Arsenic, other	mg/L	0.00002875	0.0000565	0.00008725	TRUE
13115A	Combined ash	Barium	mg/L	0.16	0.18	0.2	TRUE
13115A	Fly Ash	Barium	mg/L	0.35	0.35	0.35	TRUE
22346	Other	Barium	mg/L	0.434	0.434	0.434	TRUE
22347	Fly Ash	Barium	mg/L	0.294	0.294	0.294	TRUE
23223B	FGD waste	Barium	mg/L	0.09	0.09	0.09	TRUE
25410A	Combined ash	Barium	mg/L	0.35	0.35	0.35	TRUE
33104	Combined ash	Barium	mg/L	0.132	0.14	0.148	TRUE
33104	Fly Ash	Barium	mg/L	0.319	0.319	0.319	TRUE
33106	Combined ash	Barium	mg/L	0.195	0.195	0.195	TRUE
33106	Fly Ash	Barium	mg/L	0.103	0.131	0.1555	TRUE
34186B	FGD waste	Barium	mg/L	0.09575	0.1165	0.13725	TRUE
35015B	Combined ash	Barium	mg/L	0.134	0.15	0.155	TRUE
40109	Combined ash	Barium	mg/L	0.17375	0.1765	0.17925	TRUE
40109	Fly Ash	Barium	mg/L	0.545	0.545	0.545	TRUE
49003A	Fly Ash	Barium	mg/L	0.18075	0.186	0.19	TRUE
13115A	Combined ash	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
13115A	Fly Ash	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
22346	Other	Beryllium	mg/L	0.0001	0.0001	0.0001	TRUE
22347	Fly Ash	Beryllium	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
25410A	Combined ash	Beryllium	mg/L	0.0005	0.0005	0.0005	TRUE
33104	Combined ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
33104	Fly Ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
33106	Combined ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
33106	Fly Ash	Beryllium	mg/L	0.0012	0.0016	0.0051	TRUE
34186B	FGD waste	Beryllium	mg/L	0.000325	0.00055	0.000775	TRUE
35015B	Combined ash	Beryllium	mg/L	0.0001	0.0001	0.00025	TRUE
40109	Combined ash	Beryllium	mg/L	0.0002	0.0002	0.0002	TRUE
40109	Fly Ash	Beryllium	mg/L	0.0052	0.0052	0.0052	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
49003A	Fly Ash	Beryllium	mg/L	0.0001	0.00025	0.0004	TRUE
13115A	Combined ash	Boron	mg/L	0.74	0.78	0.82	TRUE
13115A	Fly Ash	Boron	mg/L	0.47	0.47	0.47	TRUE
22346	Other	Boron	mg/L	0.442	0.442	0.442	TRUE
22347	Fly Ash	Boron	mg/L	1.02	1.02	1.02	TRUE
23223B	FGD waste	Boron	mg/L	98.5	98.5	98.5	TRUE
25410A	Combined ash	Boron	mg/L	3.89	3.89	3.89	TRUE
33104	Combined ash	Boron	mg/L	0.213	0.219	0.225	TRUE
33104	Fly Ash	Boron	mg/L	0.476	0.476	0.476	TRUE
33106	Combined ash	Boron	mg/L	0.265	0.265	0.265	TRUE
33106	Fly Ash	Boron	mg/L	0.4275	0.429	0.6335	TRUE
34186B	FGD waste	Boron	mg/L	32.65	38.5	44.35	TRUE
35015B	Combined ash	Boron	mg/L	1.95	2.2	2.205	TRUE
40109	Combined ash	Boron	mg/L	0.31275	0.3255	0.33825	TRUE
40109	Fly Ash	Boron	mg/L	0.272	0.272	0.272	TRUE
49003A	Fly Ash	Boron	mg/L	0.4275	0.437	0.4455	TRUE
13115A	Combined ash	Cadmium	mg/L	0.00015	0.00015	0.00015	TRUE
13115A	Fly Ash	Cadmium	mg/L	0.00015	0.00015	0.00015	TRUE
22346	Other	Cadmium	mg/L	0.0001	0.0001	0.0001	TRUE
22347	Fly Ash	Cadmium	mg/L	0.0003	0.0003	0.0003	TRUE
23223B	FGD waste	Cadmium	mg/L	0.0042	0.0042	0.0042	TRUE
25410A	Combined ash	Cadmium	mg/L	0.001	0.001	0.001	TRUE
33104	Combined ash	Cadmium	mg/L	0.00015	0.0002	0.00025	TRUE
33104	Fly Ash	Cadmium	mg/L	0.0006	0.0006	0.0006	TRUE
33106	Combined ash	Cadmium	mg/L	0.0005	0.0005	0.0005	TRUE
33106	Fly Ash	Cadmium	mg/L	0.001	0.0013	0.0016	TRUE
34186B	FGD waste	Cadmium	mg/L	0.002025	0.00355	0.005075	TRUE
35015B	Combined ash	Cadmium	mg/L	0.0009	0.0012	0.0013	TRUE
40109	Combined ash	Cadmium	mg/L	0.000175	0.00025	0.000325	TRUE
40109	Fly Ash	Cadmium	mg/L	0.0024	0.0024	0.0024	TRUE
49003A	Fly Ash	Cadmium	mg/L	0.001475	0.0018	0.002	TRUE
13115A	Combined ash	Calcium	mg/L	43.75	44.5	45.25	TRUE
13115A	Fly Ash	Calcium	mg/L	81	81	81	TRUE
22346	Other	Calcium	mg/L	79.1	79.1	79.1	TRUE
22347	Fly Ash	Calcium	mg/L	34.4	34.4	34.4	TRUE
23223B	FGD waste	Calcium	mg/L	577	577	577	TRUE
25410A	Combined ash	Calcium	mg/L	255	255	255	TRUE
33104	Combined ash	Calcium	mg/L	20.75	22.5	24.25	TRUE
33104	Fly Ash	Calcium	mg/L	58.1	58.1	58.1	TRUE
33106	Combined ash	Calcium	mg/L	13.2	13.2	13.2	TRUE
33106	Fly Ash	Calcium	mg/L	13.9	15.4	17.65	TRUE
34186B	FGD waste	Calcium	mg/L	577.5	585	592.5	TRUE
35015B	Combined ash	Calcium	mg/L	122	123	123.5	TRUE
40109	Combined ash	Calcium	mg/L	16.8	16.8	16.8	TRUE
40109	Fly Ash	Calcium	mg/L	14.4	14.4	14.4	TRUE
49003A	Fly Ash	Calcium	mg/L	41.75	43	43.5	TRUE
13115A	Combined ash	Chloride	mg/L	72.975	73.95	74.925	TRUE
13115A	Fly Ash	Chloride	mg/L	84.8	84.8	84.8	TRUE
22346	Other	Chloride	mg/L	72	72	72	TRUE
22347	Fly Ash	Chloride	mg/L	68.4	68.4	68.4	TRUE
23223B	FGD waste	Chloride	mg/L	345	345	345	TRUE
25410A	Combined ash	Chloride	mg/L	25.3	25.3	25.3	TRUE
33104	Combined ash	Chloride	mg/L	8.5	9.7	10.9	TRUE
33104	Fly Ash	Chloride	mg/L	5	5	5	TRUE
33106	Combined ash	Chloride	mg/L	9.8	9.8	9.8	TRUE
33106	Fly Ash	Chloride	mg/L	8.4	9.7	9.75	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
34186B	FGD waste	Chloride	mg/L	1392.5	1705	2017.5	TRUE
35015B	Combined ash	Chloride	mg/L	60.35	64.8	65.5	TRUE
40109	Combined ash	Chloride	mg/L	4.775	5.05	5.325	TRUE
40109	Fly Ash	Chloride	mg/L	5.3	5.3	5.3	TRUE
49003A	Fly Ash	Chloride	mg/L	16.875	17.35	17.825	TRUE
13115A	Combined ash	Chromium	mg/L	0.001195	0.00173	0.002265	TRUE
13115A	Fly Ash	Chromium	mg/L	0.00096	0.00096	0.00096	TRUE
22346	Other	Chromium	mg/L	0.025	0.025	0.025	TRUE
22347	Fly Ash	Chromium	mg/L	0.02	0.02	0.02	TRUE
23223B	FGD waste	Chromium	mg/L	0.053	0.053	0.053	TRUE
25410A	Combined ash	Chromium	mg/L	0.013	0.013	0.013	TRUE
33104	Combined ash	Chromium	mg/L	0.003725	0.00425	0.004775	TRUE
33104	Fly Ash	Chromium	mg/L	0.022	0.022	0.022	TRUE
33106	Combined ash	Chromium	mg/L	0.0002	0.0002	0.0002	TRUE
33106	Fly Ash	Chromium	mg/L	0.0002	0.0002	0.0146	TRUE
34186B	FGD waste	Chromium	mg/L	0.0004	0.0006	0.0008	TRUE
35015B	Combined ash	Chromium	mg/L	0.000165	0.00023	0.000815	TRUE
40109	Combined ash	Chromium	mg/L	0.0021	0.0023	0.0025	TRUE
40109	Fly Ash	Chromium	mg/L	0.011	0.011	0.011	TRUE
49003A	Fly Ash	Chromium	mg/L	0.00107	0.0013	0.001575	TRUE
13115A	Combined ash	Chromium (III)	mg/L	0.00002	0.00002	0.00002	TRUE
13115A	Fly Ash	Chromium (III)	mg/L	0.00005	0.00005	0.00005	TRUE
22346	Other	Chromium (III)	mg/L	0.0012	0.0012	0.0012	TRUE
22347	Fly Ash	Chromium (III)	mg/L	0.0024	0.0024	0.0024	TRUE
23223B	FGD waste	Chromium (III)	mg/L	0.0013	0.0013	0.0013	TRUE
25410A	Combined ash	Chromium (III)	mg/L	0.0002	0.0002	0.0002	TRUE
33104	Combined ash	Chromium (III)	mg/L	0.0005025	0.000545	0.0005875	TRUE
33104	Fly Ash	Chromium (III)	mg/L	0.000044	0.000044	0.000044	TRUE
33106	Combined ash	Chromium (III)	mg/L	0.000074	0.000074	0.000074	TRUE
33106	Fly Ash	Chromium (III)	mg/L	0.00021	0.00025	0.013125	TRUE
35015B	Combined ash	Chromium (III)	mg/L	0.00005	0.00005	0.00005	TRUE
40109	Combined ash	Chromium (III)	mg/L	0.00028325	0.0005555	0.00082775	TRUE
40109	Fly Ash	Chromium (III)	mg/L	0.0099	0.0099	0.0099	TRUE
49003A	Fly Ash	Chromium (III)	mg/L	0.00002	0.00018	0.000355	TRUE
13115A	Combined ash	Chromium (VI)	mg/L	0.00071875	0.0014125	0.00210625	TRUE
13115A	Fly Ash	Chromium (VI)	mg/L	0.0009	0.0009	0.0009	TRUE
22346	Other	Chromium (VI)	mg/L	0.023	0.023	0.023	TRUE
22347	Fly Ash	Chromium (VI)	mg/L	0.015	0.015	0.015	TRUE
23223B	FGD waste	Chromium (VI)	mg/L	0.047	0.047	0.047	TRUE
25410A	Combined ash	Chromium (VI)	mg/L	0.013	0.013	0.013	TRUE
33104	Combined ash	Chromium (VI)	mg/L	0.003575	0.00415	0.004725	TRUE
33104	Fly Ash	Chromium (VI)	mg/L	0.023	0.023	0.023	TRUE
33106	Combined ash	Chromium (VI)	mg/L	0.000005	0.000005	0.000005	TRUE
33106	Fly Ash	Chromium (VI)	mg/L	0.000017	0.000029	0.0000395	TRUE
35015B	Combined ash	Chromium (VI)	mg/L	0.000025	0.000025	0.000025	TRUE
40109	Combined ash	Chromium (VI)	mg/L	0.0006325	0.000855	0.0010775	TRUE
40109	Fly Ash	Chromium (VI)	mg/L	0.000025	0.000025	0.000025	TRUE
49003A	Fly Ash	Chromium (VI)	mg/L	0.0002555	0.000605	0.0009	TRUE
13115A	Combined ash	Cobalt	mg/L	0.0005	0.0005	0.0005	TRUE
13115A	Fly Ash	Cobalt	mg/L	0.001	0.001	0.001	TRUE
22346	Other	Cobalt	mg/L	0.0008	0.0008	0.0008	TRUE
22347	Fly Ash	Cobalt	mg/L	0.00053	0.00053	0.00053	TRUE
23223B	FGD waste	Cobalt	mg/L	0.078	0.078	0.078	TRUE
25410A	Combined ash	Cobalt	mg/L	0.003	0.003	0.003	TRUE
33104	Combined ash	Cobalt	mg/L	0.0004	0.0007	0.001	TRUE
33104	Fly Ash	Cobalt	mg/L	0.0001	0.0001	0.0001	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
33106	Combined ash	Cobalt	mg/L	0.0052	0.0052	0.0052	TRUE
33106	Fly Ash	Cobalt	mg/L	0.0101	0.0115	0.01655	TRUE
34186B	FGD waste	Cobalt	mg/L	0.0033175	0.006545	0.0097725	TRUE
35015B	Combined ash	Cobalt	mg/L	0.00229	0.003	0.00338	TRUE
40109	Combined ash	Cobalt	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Fly Ash	Cobalt	mg/L	0.0189	0.0189	0.0189	TRUE
49003A	Fly Ash	Cobalt	mg/L	0.007125	0.007575	0.008	TRUE
13115A	Combined ash	Copper	mg/L	0.00825	0.0095	0.01075	TRUE
13115A	Fly Ash	Copper	mg/L	0.008	0.008	0.008	TRUE
22346	Other	Copper	mg/L	0.0038	0.0038	0.0038	TRUE
22347	Fly Ash	Copper	mg/L	0.0021	0.0021	0.0021	TRUE
23223B	FGD waste	Copper	mg/L	0.007	0.007	0.007	TRUE
25410A	Combined ash	Copper	mg/L	0.0015	0.0015	0.0015	TRUE
33104	Combined ash	Copper	mg/L	0.000975	0.00125	0.001525	TRUE
33104	Fly Ash	Copper	mg/L	0.0005	0.0005	0.0005	TRUE
33106	Combined ash	Copper	mg/L	0.0019	0.0019	0.0019	TRUE
33106	Fly Ash	Copper	mg/L	0.01035	0.012	0.082	TRUE
34186B	FGD waste	Copper	mg/L	0.0008	0.0012	0.0016	TRUE
35015B	Combined ash	Copper	mg/L	0.0022	0.0025	0.01325	TRUE
40109	Combined ash	Copper	mg/L	0.001475	0.00165	0.001825	TRUE
40109	Fly Ash	Copper	mg/L	0.452	0.452	0.452	TRUE
49003A	Fly Ash	Copper	mg/L	0.006375	0.0084	0.00905	TRUE
13115A	Combined ash	Dissolved oxygen	%	2.325	3.05	3.775	FALSE
13115A	Fly Ash	Dissolved oxygen	%	3.4	3.4	3.4	FALSE
22346	Other	Dissolved oxygen	%	65.1	65.1	65.1	FALSE
22347	Fly Ash	Dissolved oxygen	%	100	100	100	FALSE
23223B	FGD waste	Dissolved oxygen	%	0.3	0.3	0.3	FALSE
25410A	Combined ash	Dissolved oxygen	%	3.7	3.7	3.7	FALSE
33104	Combined ash	Dissolved oxygen	%	64.6	65.7	66.8	FALSE
33104	Fly Ash	Dissolved oxygen	%	67.7	67.7	67.7	FALSE
33106	Combined ash	Dissolved oxygen	%	77.6	77.6	77.6	FALSE
33106	Fly Ash	Dissolved oxygen	%	71.8	75.7	79.9	FALSE
34186B	FGD waste	Dissolved oxygen	%	10.5	19	27.5	FALSE
35015B	Combined ash	Dissolved oxygen	%	47.6	80.7	101.75	FALSE
40109	Combined ash	Dissolved oxygen	%	108.175	127.15	146.125	FALSE
40109	Fly Ash	Dissolved oxygen	%	82.4	82.4	82.4	FALSE
49003A	Fly Ash	Dissolved oxygen	%	34.925	63.05	89.85	FALSE
13115A	Combined ash	Iron	mg/L	0.025	0.025	0.025	TRUE
13115A	Fly Ash	Iron	mg/L	0.025	0.025	0.025	TRUE
22346	Other	Iron	mg/L	0.0015	0.0015	0.0015	TRUE
22347	Fly Ash	Iron	mg/L	0.0015	0.0015	0.0015	TRUE
23223B	FGD waste	Iron	mg/L	0.025	0.025	0.025	TRUE
25410A	Combined ash	Iron	mg/L	0.025	0.025	0.025	TRUE
33104	Combined ash	Iron	mg/L	0.008625	0.01475	0.020875	TRUE
33104	Fly Ash	Iron	mg/L	0.013	0.013	0.013	TRUE
33106	Combined ash	Iron	mg/L	0.007	0.007	0.007	TRUE
33106	Fly Ash	Iron	mg/L	0.012	0.018	0.37	TRUE
34186B	FGD waste	Iron	mg/L	0.016625	0.02855	0.040475	TRUE
35015B	Combined ash	Iron	mg/L	0.0065	0.0065	0.01575	TRUE
40109	Combined ash	Iron	mg/L	0.011	0.016	0.021	TRUE
40109	Fly Ash	Iron	mg/L	3.24	3.24	3.24	TRUE
49003A	Fly Ash	Iron	mg/L	0.0065	0.01575	0.025	TRUE
13115A	Combined ash	Lead	mg/L	0.0001	0.0001	0.0001	TRUE
13115A	Fly Ash	Lead	mg/L	0.00021	0.00021	0.00021	TRUE
22346	Other	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
22347	Fly Ash	Lead	mg/L	0.0002	0.0002	0.0002	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
23223B	FGD waste	Lead	mg/L	0.0001	0.0001	0.0001	TRUE
25410A	Combined ash	Lead	mg/L	0.0001	0.0001	0.0001	TRUE
33104	Combined ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
33104	Fly Ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
33106	Combined ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
33106	Fly Ash	Lead	mg/L	0.0002	0.0002	0.00105	TRUE
34186B	FGD waste	Lead	mg/L	0.00035	0.0005	0.00065	TRUE
35015B	Combined ash	Lead	mg/L	0.00007	0.00007	0.000085	TRUE
40109	Combined ash	Lead	mg/L	0.00005	0.00005	0.00005	TRUE
40109	Fly Ash	Lead	mg/L	0.008	0.008	0.008	TRUE
49003A	Fly Ash	Lead	mg/L	0.00007	0.000085	0.0001	TRUE
13115A	Combined ash	Lithium	mg/L	0.01	0.01	0.01	FALSE
13115A	Fly Ash	Lithium	mg/L	0.01	0.01	0.01	FALSE
22346	Other	Lithium	mg/L	0.06	0.06	0.06	FALSE
22347	Fly Ash	Lithium	mg/L	0.027	0.027	0.027	FALSE
23223B	FGD waste	Lithium	mg/L	2.72	2.72	2.72	FALSE
25410A	Combined ash	Lithium	mg/L	0.1	0.1	0.1	FALSE
33104	Combined ash	Lithium	mg/L	0.145	0.15	0.155	FALSE
33104	Fly Ash	Lithium	mg/L	0.43	0.43	0.43	FALSE
33106	Combined ash	Lithium	mg/L	0.099	0.099	0.099	FALSE
33106	Fly Ash	Lithium	mg/L	0.1625	0.179	0.209	FALSE
34186B	FGD waste	Lithium	mg/L	1.635	2.22	2.805	FALSE
35015B	Combined ash	Lithium	mg/L	0.201	0.24	0.2465	FALSE
40109	Combined ash	Lithium	mg/L	0.2735	0.28	0.2865	FALSE
40109	Fly Ash	Lithium	mg/L	0.52	0.52	0.52	FALSE
49003A	Fly Ash	Lithium	mg/L	0.3165	0.319	0.33	FALSE
13115A	Combined ash	Magnesium	mg/L	21.5	22	22.5	TRUE
13115A	Fly Ash	Magnesium	mg/L	28	28	28	TRUE
22346	Other	Magnesium	mg/L	19.1	19.1	19.1	TRUE
22347	Fly Ash	Magnesium	mg/L	12.6	12.6	12.6	TRUE
23223B	FGD waste	Magnesium	mg/L	1990	1990	1990	TRUE
25410A	Combined ash	Magnesium	mg/L	33	33	33	TRUE
33104	Combined ash	Magnesium	mg/L	1.875	1.97	2.065	TRUE
33104	Fly Ash	Magnesium	mg/L	1.49	1.49	1.49	TRUE
33106	Combined ash	Magnesium	mg/L	2.53	2.53	2.53	TRUE
33106	Fly Ash	Magnesium	mg/L	2.32	2.58	2.62	TRUE
34186B	FGD waste	Magnesium	mg/L	2202.5	3405	4607.5	TRUE
35015B	Combined ash	Magnesium	mg/L	58.5	67	69.5	TRUE
40109	Combined ash	Magnesium	mg/L	1.41	1.45	1.49	TRUE
40109	Fly Ash	Magnesium	mg/L	1.81	1.81	1.81	TRUE
49003A	Fly Ash	Magnesium	mg/L	14	15	16.25	TRUE
13115A	Combined ash	Manganese	mg/L	0.002	0.002	0.002	TRUE
13115A	Fly Ash	Manganese	mg/L	0.014	0.014	0.014	TRUE
22346	Other	Manganese	mg/L	0.002	0.002	0.002	TRUE
22347	Fly Ash	Manganese	mg/L	0.001	0.001	0.001	TRUE
23223B	FGD waste	Manganese	mg/L	0.564	0.564	0.564	TRUE
25410A	Combined ash	Manganese	mg/L	0.002	0.002	0.002	TRUE
33104	Combined ash	Manganese	mg/L	0.0058	0.0112	0.0166	TRUE
33104	Fly Ash	Manganese	mg/L	0.0001	0.0001	0.0001	TRUE
33106	Combined ash	Manganese	mg/L	0.0794	0.0794	0.0794	TRUE
33106	Fly Ash	Manganese	mg/L	0.0601	0.0775	0.0818	TRUE
34186B	FGD waste	Manganese	mg/L	0.64725	0.8215	0.99575	TRUE
35015B	Combined ash	Manganese	mg/L	0.0758	0.092	0.1235	TRUE
40109	Combined ash	Manganese	mg/L	0.00085	0.0011	0.00135	TRUE
40109	Fly Ash	Manganese	mg/L	0.113	0.113	0.113	TRUE
49003A	Fly Ash	Manganese	mg/L	0.059	0.08165	0.104	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
22346	Other	Mercury	mg/L	0.0000059	0.0000059	0.0000059	TRUE
22347	Fly Ash	Mercury	mg/L	0.0000021	0.0000021	0.0000021	TRUE
23223B	FGD waste	Mercury	mg/L	0.000028	0.000028	0.000028	TRUE
35015B	Combined ash	Mercury	mg/L	0.0000014	0.0000014	0.0000014	TRUE
49003A	Fly Ash	Mercury	mg/L	5.35E-07	0.00000069	8.45E-07	TRUE
13115A	Combined ash	Molybdenum	mg/L	0.03125	0.0475	0.06375	TRUE
13115A	Fly Ash	Molybdenum	mg/L	0.015	0.015	0.015	TRUE
22346	Other	Molybdenum	mg/L	0.0219	0.0219	0.0219	TRUE
22347	Fly Ash	Molybdenum	mg/L	0.0277	0.0277	0.0277	TRUE
23223B	FGD waste	Molybdenum	mg/L	0.32	0.32	0.32	TRUE
25410A	Combined ash	Molybdenum	mg/L	0.42	0.42	0.42	TRUE
33104	Combined ash	Molybdenum	mg/L	0.06525	0.0695	0.07375	TRUE
33104	Fly Ash	Molybdenum	mg/L	0.217	0.217	0.217	TRUE
33106	Combined ash	Molybdenum	mg/L	0.06	0.06	0.06	TRUE
33106	Fly Ash	Molybdenum	mg/L	0.0445	0.054	0.0905	TRUE
34186B	FGD waste	Molybdenum	mg/L	0.453	0.742	1.031	TRUE
35015B	Combined ash	Molybdenum	mg/L	0.10435	0.12	0.1255	TRUE
40109	Combined ash	Molybdenum	mg/L	0.06225	0.0625	0.06275	TRUE
40109	Fly Ash	Molybdenum	mg/L	0.008	0.008	0.008	TRUE
49003A	Fly Ash	Molybdenum	mg/L	0.339	0.37	0.4025	TRUE
13115A	Combined ash	Nickel	mg/L	0.00425	0.0045	0.00475	TRUE
13115A	Fly Ash	Nickel	mg/L	0.007	0.007	0.007	TRUE
22346	Other	Nickel	mg/L	0.0036	0.0036	0.0036	TRUE
22347	Fly Ash	Nickel	mg/L	0.0044	0.0044	0.0044	TRUE
23223B	FGD waste	Nickel	mg/L	0.463	0.463	0.463	TRUE
25410A	Combined ash	Nickel	mg/L	0.016	0.016	0.016	TRUE
33104	Combined ash	Nickel	mg/L	0.0018	0.003	0.0042	TRUE
33104	Fly Ash	Nickel	mg/L	0.0009	0.0009	0.0009	TRUE
33106	Combined ash	Nickel	mg/L	0.0136	0.0136	0.0136	TRUE
33106	Fly Ash	Nickel	mg/L	0.03225	0.0378	0.05485	TRUE
34186B	FGD waste	Nickel	mg/L	0.040725	0.07815	0.115575	TRUE
35015B	Combined ash	Nickel	mg/L	0.0115	0.015	0.016	TRUE
40109	Combined ash	Nickel	mg/L	0.00185	0.002	0.00215	TRUE
40109	Fly Ash	Nickel	mg/L	0.0582	0.0582	0.0582	TRUE
49003A	Fly Ash	Nickel	mg/L	0.014	0.0165	0.0195	TRUE
13115A	Combined ash	Oxidation-reduction potential	mV	292.5	296	299.5	FALSE
13115A	Fly Ash	Oxidation-reduction potential	mV	296	296	296	FALSE
22346	Other	Oxidation-reduction potential	mV	241	241	241	FALSE
22347	Fly Ash	Oxidation-reduction potential	mV	217	217	217	FALSE
23223B	FGD waste	Oxidation-reduction potential	mV	342	342	342	FALSE
25410A	Combined ash	Oxidation-reduction potential	mV	339	339	339	FALSE
33104	Combined ash	Oxidation-reduction potential	mV	220.75	221.5	222.25	FALSE
33104	Fly Ash	Oxidation-reduction potential	mV	214	214	214	FALSE
33106	Combined ash	Oxidation-reduction potential	mV	290	290	290	FALSE
33106	Fly Ash	Oxidation-reduction potential	mV	284	285	336.5	FALSE
34186B	FGD waste	Oxidation-reduction potential	mV	240.25	250.5	260.75	FALSE
35015B	Combined ash	Oxidation-reduction potential	mV	248.5	257	276	FALSE
40109	Combined ash	Oxidation-reduction potential	mV	409	409	409	FALSE
40109	Fly Ash	Oxidation-reduction potential	mV	387	387	387	FALSE
49003A	Fly Ash	Oxidation-reduction potential	mV	282	298	310	FALSE
13115A	Combined ash	pH (field)	pH	8.825	8.85	8.875	FALSE
13115A	Fly Ash	pH (field)	pH	8	8	8	FALSE
22346	Other	pH (field)	pH	8.64	8.64	8.64	FALSE
22347	Fly Ash	pH (field)	pH	9.36	9.36	9.36	FALSE
23223B	FGD waste	pH (field)	pH	7.4	7.4	7.4	FALSE
25410A	Combined ash	pH (field)	pH	9.3	9.3	9.3	FALSE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
33104	Combined ash	pH (field)	pH	7.905	8.24	8.575	FALSE
33104	Fly Ash	pH (field)	pH	10.12	10.12	10.12	FALSE
33106	Combined ash	pH (field)	pH	5.97	5.97	5.97	FALSE
33106	Fly Ash	pH (field)	pH	5.025	5.79	5.88	FALSE
34186B	FGD waste	pH (field)	pH	7.37	7.91	8.45	FALSE
35015B	Combined ash	pH (field)	pH	7.7	7.8	8.2	FALSE
40109	Combined ash	pH (field)	pH	8.005	8.35	8.695	FALSE
40109	Fly Ash	pH (field)	pH	4.35	4.35	4.35	FALSE
49003A	Fly Ash	pH (field)	pH	7.175	7.24	7.3125	FALSE
13115A	Combined ash	Potassium	mg/L	6.5	7	7.5	TRUE
13115A	Fly Ash	Potassium	mg/L	6	6	6	TRUE
22346	Other	Potassium	mg/L	5	5	5	TRUE
22347	Fly Ash	Potassium	mg/L	4	4	4	TRUE
23223B	FGD waste	Potassium	mg/L	40	40	40	TRUE
25410A	Combined ash	Potassium	mg/L	20	20	20	TRUE
33104	Combined ash	Potassium	mg/L	3.95	4.3	4.65	TRUE
33104	Fly Ash	Potassium	mg/L	9.4	9.4	9.4	TRUE
33106	Combined ash	Potassium	mg/L	4	4	4	TRUE
33106	Fly Ash	Potassium	mg/L	5.1	5.2	6.1	TRUE
34186B	FGD waste	Potassium	mg/L	410	440	470	TRUE
35015B	Combined ash	Potassium	mg/L	9.5	10	11.5	TRUE
40109	Combined ash	Potassium	mg/L	5.95	6.1	6.25	TRUE
40109	Fly Ash	Potassium	mg/L	13.6	13.6	13.6	TRUE
49003A	Fly Ash	Potassium	mg/L	9	9	9.25	TRUE
13115A	Combined ash	Selenium	mg/L	0.002425	0.00245	0.002475	TRUE
13115A	Fly Ash	Selenium	mg/L	0.0018	0.0018	0.0018	TRUE
22346	Other	Selenium	mg/L	0.019	0.019	0.019	TRUE
22347	Fly Ash	Selenium	mg/L	0.013	0.013	0.013	TRUE
23223B	FGD waste	Selenium	mg/L	2.36	2.36	2.36	TRUE
25410A	Combined ash	Selenium	mg/L	0.022	0.022	0.022	TRUE
33104	Combined ash	Selenium	mg/L	0.03075	0.0325	0.03425	TRUE
33104	Fly Ash	Selenium	mg/L	0.103	0.103	0.103	TRUE
33106	Combined ash	Selenium	mg/L	0.01	0.01	0.01	TRUE
33106	Fly Ash	Selenium	mg/L	0.019	0.024	0.0335	TRUE
34186B	FGD waste	Selenium	mg/L	0.046125	0.08375	0.121375	TRUE
35015B	Combined ash	Selenium	mg/L	0.018	0.018	0.023	TRUE
40109	Combined ash	Selenium	mg/L	0.00245	0.0025	0.00255	TRUE
40109	Fly Ash	Selenium	mg/L	0.00045	0.00045	0.00045	TRUE
49003A	Fly Ash	Selenium	mg/L	0.03175	0.0335	0.03525	TRUE
13115A	Combined ash	Selenium (IV)	mg/L	0.00042	0.00058	0.00074	TRUE
13115A	Fly Ash	Selenium (IV)	mg/L	0.00014	0.00014	0.00014	TRUE
22346	Other	Selenium (IV)	mg/L	0.018	0.018	0.018	TRUE
22347	Fly Ash	Selenium (IV)	mg/L	0.0087	0.0087	0.0087	TRUE
23223B	FGD waste	Selenium (IV)	mg/L	0.001	0.001	0.001	TRUE
25410A	Combined ash	Selenium (IV)	mg/L	0.015	0.015	0.015	TRUE
33104	Combined ash	Selenium (IV)	mg/L	0.03	0.031	0.032	TRUE
33104	Fly Ash	Selenium (IV)	mg/L	0.097	0.097	0.097	TRUE
33106	Combined ash	Selenium (IV)	mg/L	0.0083	0.0083	0.0083	TRUE
33106	Fly Ash	Selenium (IV)	mg/L	0.0155	0.02	0.0295	TRUE
34186B	FGD waste	Selenium (IV)	mg/L	0.001	0.001	0.001	TRUE
35015B	Combined ash	Selenium (IV)	mg/L	0.0155	0.018	0.0205	TRUE
40109	Combined ash	Selenium (IV)	mg/L	0.002125	0.00225	0.002375	TRUE
40109	Fly Ash	Selenium (IV)	mg/L	0.00025	0.00025	0.00025	TRUE
49003A	Fly Ash	Selenium (IV)	mg/L	0.02	0.025	0.03025	TRUE
13115A	Combined ash	Selenium (VI)	mg/L	0.0008675	0.000945	0.0010225	TRUE
13115A	Fly Ash	Selenium (VI)	mg/L	0.0013	0.0013	0.0013	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
22346	Other	Selenium (VI)	mg/L	0.00026	0.00026	0.00026	TRUE
22347	Fly Ash	Selenium (VI)	mg/L	0.0015	0.0015	0.0015	TRUE
23223B	FGD waste	Selenium (VI)	mg/L	1.66	1.66	1.66	TRUE
25410A	Combined ash	Selenium (VI)	mg/L	0.0034	0.0034	0.0034	TRUE
33104	Combined ash	Selenium (VI)	mg/L	0.001775	0.00185	0.001925	TRUE
33104	Fly Ash	Selenium (VI)	mg/L	0.002	0.002	0.002	TRUE
33106	Combined ash	Selenium (VI)	mg/L	0.00064	0.00064	0.00064	TRUE
33106	Fly Ash	Selenium (VI)	mg/L	0.0011	0.0017	0.0018	TRUE
34186B	FGD waste	Selenium (VI)	mg/L	0.0055	0.009	0.0125	TRUE
35015B	Combined ash	Selenium (VI)	mg/L	0.001025	0.0013	0.0015	TRUE
40109	Combined ash	Selenium (VI)	mg/L	0.0005	0.0005	0.0005	TRUE
40109	Fly Ash	Selenium (VI)	mg/L	0.0005	0.0005	0.0005	TRUE
49003A	Fly Ash	Selenium (VI)	mg/L	0.0022	0.00265	0.00315	TRUE
34186B	FGD waste	Selenium, other	mg/L	0.0135	0.026	0.0385	FALSE
13115A	Combined ash	Silicon	mg/L	2.4	2.6	2.8	TRUE
13115A	Fly Ash	Silicon	mg/L	3.4	3.4	3.4	TRUE
22346	Other	Silicon	mg/L	4.21	4.21	4.21	TRUE
22347	Fly Ash	Silicon	mg/L	1.05	1.05	1.05	TRUE
23223B	FGD waste	Silicon	mg/L	12.7	12.7	12.7	TRUE
25410A	Combined ash	Silicon	mg/L	8.8	8.8	8.8	TRUE
33104	Combined ash	Silicon	mg/L	7.255	7.32	7.385	TRUE
33104	Fly Ash	Silicon	mg/L	4.76	4.76	4.76	TRUE
33106	Combined ash	Silicon	mg/L	4.67	4.67	4.67	TRUE
33106	Fly Ash	Silicon	mg/L	4.715	4.73	5.255	TRUE
34186B	FGD waste	Silicon	mg/L	13.06	23.84	34.62	TRUE
35015B	Combined ash	Silicon	mg/L	3.29	3.71	4.555	TRUE
40109	Combined ash	Silicon	mg/L	5.0375	5.065	5.0925	TRUE
40109	Fly Ash	Silicon	mg/L	5.84	5.84	5.84	TRUE
49003A	Fly Ash	Silicon	mg/L	2.95	3.135	3.375	TRUE
13115A	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
13115A	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
22346	Other	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
22347	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
23223B	FGD waste	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
25410A	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
33104	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
33104	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
33106	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
33106	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
34186B	FGD waste	Silver	mg/L	0.0002	0.0003	0.0004	TRUE
35015B	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Combined ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
40109	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
49003A	Fly Ash	Silver	mg/L	0.0001	0.0001	0.0001	TRUE
13115A	Combined ash	Sodium	mg/L	53.25	53.5	53.75	TRUE
13115A	Fly Ash	Sodium	mg/L	56	56	56	TRUE
22346	Other	Sodium	mg/L	68	68	68	TRUE
22347	Fly Ash	Sodium	mg/L	45	45	45	TRUE
23223B	FGD waste	Sodium	mg/L	743	743	743	TRUE
25410A	Combined ash	Sodium	mg/L	60	60	60	TRUE
33104	Combined ash	Sodium	mg/L	7.2	8.4	9.6	TRUE
33104	Fly Ash	Sodium	mg/L	7.3	7.3	7.3	TRUE
33106	Combined ash	Sodium	mg/L	7	7	7	TRUE
33106	Fly Ash	Sodium	mg/L	8.4	8.5	8.55	TRUE
34186B	FGD waste	Sodium	mg/L	3610	3950	4290	TRUE
35015B	Combined ash	Sodium	mg/L	34	36	36	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
40109	Combined ash	Sodium	mg/L	8.2	8.3	8.4	TRUE
40109	Fly Ash	Sodium	mg/L	11.8	11.8	11.8	TRUE
49003A	Fly Ash	Sodium	mg/L	31.75	37	42.25	TRUE
13115A	Combined ash	Specific conductance @ 25C (field	mS/cm	0.7	0.7	0.7	FALSE
13115A	Fly Ash	Specific conductance @ 25C (field	mS/cm	1	1	1	FALSE
22346	Other	Specific conductance @ 25C (field	mS/cm	0.911	0.911	0.911	FALSE
22347	Fly Ash	Specific conductance @ 25C (field	mS/cm	0.547	0.547	0.547	FALSE
23223B	FGD waste	Specific conductance @ 25C (field	mS/cm	13	13	13	FALSE
25410A	Combined ash	Specific conductance @ 25C (field	mS/cm	1.6	1.6	1.6	FALSE
33104	Combined ash	Specific conductance @ 25C (field	mS/cm	0.1975	0.213	0.2285	FALSE
33104	Fly Ash	Specific conductance @ 25C (field	mS/cm	0.455	0.455	0.455	FALSE
33106	Combined ash	Specific conductance @ 25C (field	mS/cm	0.174	0.174	0.174	FALSE
33106	Fly Ash	Specific conductance @ 25C (field	mS/cm	0.1935	0.209	0.251	FALSE
34186B	FGD waste	Specific conductance @ 25C (field	mS/cm	20.6725	22.495	24.3175	FALSE
35015B	Combined ash	Specific conductance @ 25C (field	mS/cm	1.1595	1.319	1.3335	FALSE
40109	Combined ash	Specific conductance @ 25C (field	mS/cm	0.1905	0.192	0.1935	FALSE
40109	Fly Ash	Specific conductance @ 25C (field	mS/cm	0.287	0.287	0.287	FALSE
49003A	Fly Ash	Specific conductance @ 25C (field	mS/cm	0.56625	0.5835	0.6	FALSE
13115A	Combined ash	Strontium	mg/L	0.5775	0.625	0.6725	TRUE
13115A	Fly Ash	Strontium	mg/L	0.58	0.58	0.58	TRUE
22346	Other	Strontium	mg/L	0.828	0.828	0.828	TRUE
22347	Fly Ash	Strontium	mg/L	1.01	1.01	1.01	TRUE
23223B	FGD waste	Strontium	mg/L	11.7	11.7	11.7	TRUE
25410A	Combined ash	Strontium	mg/L	4.3	4.3	4.3	TRUE
33104	Combined ash	Strontium	mg/L	0.2785	0.299	0.3195	TRUE
33104	Fly Ash	Strontium	mg/L	0.478	0.478	0.478	TRUE
33106	Combined ash	Strontium	mg/L	0.209	0.209	0.209	TRUE
33106	Fly Ash	Strontium	mg/L	0.2085	0.247	0.2595	TRUE
34186B	FGD waste	Strontium	mg/L	2.87	4.24	5.61	TRUE
35015B	Combined ash	Strontium	mg/L	0.4125	0.465	0.486	TRUE
40109	Combined ash	Strontium	mg/L	0.5455	0.546	0.5465	TRUE
40109	Fly Ash	Strontium	mg/L	0.806	0.806	0.806	TRUE
49003A	Fly Ash	Strontium	mg/L	0.40375	0.408	0.41575	TRUE
13115A	Combined ash	Sulfate	mg/L	101.3	111.2	121.1	TRUE
13115A	Fly Ash	Sulfate	mg/L	124	124	124	TRUE
22346	Other	Sulfate	mg/L	174	174	174	TRUE
22347	Fly Ash	Sulfate	mg/L	92.8	92.8	92.8	TRUE
23223B	FGD waste	Sulfate	mg/L	10400	10400	10400	TRUE
25410A	Combined ash	Sulfate	mg/L	782	782	782	TRUE
33104	Combined ash	Sulfate	mg/L	46.25	47.5	48.75	TRUE
33104	Fly Ash	Sulfate	mg/L	150	150	150	TRUE
33106	Combined ash	Sulfate	mg/L	53	53	53	TRUE
33106	Fly Ash	Sulfate	mg/L	63.5	70	90.5	TRUE
34186B	FGD waste	Sulfate	mg/L	15275	20350	25425	TRUE
35015B	Combined ash	Sulfate	mg/L	413.5	441	451.5	TRUE
40109	Combined ash	Sulfate	mg/L	52.75	53.5	54.25	TRUE
40109	Fly Ash	Sulfate	mg/L	111	111	111	TRUE
49003A	Fly Ash	Sulfate	mg/L	165.25	191.5	217.5	TRUE
13115A	Combined ash	Temperature	°C	29.625	29.65	29.675	FALSE
13115A	Fly Ash	Temperature	°C	35.5	35.5	35.5	FALSE
22346	Other	Temperature	°C	30.2	30.2	30.2	FALSE
22347	Fly Ash	Temperature	°C	25.9	25.9	25.9	FALSE
23223B	FGD waste	Temperature	°C	25.6	25.6	25.6	FALSE
25410A	Combined ash	Temperature	°C	31.7	31.7	31.7	FALSE
33104	Combined ash	Temperature	°C	28.125	28.55	28.975	FALSE
33104	Fly Ash	Temperature	°C	30	30	30	FALSE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
33106	Combined ash	Temperature	°C	25.8	25.8	25.8	FALSE
33106	Fly Ash	Temperature	°C	30.7	32	32	FALSE
34186B	FGD waste	Temperature	°C	12.25	14.56	16.87	FALSE
35015B	Combined ash	Temperature	°C	12.19	13.9	14.275	FALSE
40109	Combined ash	Temperature	°C	29.175	29.85	30.525	FALSE
40109	Fly Ash	Temperature	°C	26.5	26.5	26.5	FALSE
49003A	Fly Ash	Temperature	°C	15.875	18.8	21.75	FALSE
13115A	Combined ash	Thallium	mg/L	0.00005	0.00005	0.00005	TRUE
13115A	Fly Ash	Thallium	mg/L	0.00005	0.00005	0.00005	TRUE
22346	Other	Thallium	mg/L	0.0005	0.0005	0.0005	TRUE
22347	Fly Ash	Thallium	mg/L	0.00005	0.00005	0.00005	TRUE
23223B	FGD waste	Thallium	mg/L	0.0029	0.0029	0.0029	TRUE
25410A	Combined ash	Thallium	mg/L	0.0025	0.0025	0.0025	TRUE
33104	Combined ash	Thallium	mg/L	0.00055	0.0007	0.00085	TRUE
33104	Fly Ash	Thallium	mg/L	0.0003	0.0003	0.0003	TRUE
33106	Combined ash	Thallium	mg/L	0.0007	0.0007	0.0007	TRUE
33106	Fly Ash	Thallium	mg/L	0.00115	0.0016	0.0029	TRUE
34186B	FGD waste	Thallium	mg/L	0.0001	0.00015	0.0002	TRUE
35015B	Combined ash	Thallium	mg/L	0.0105	0.0142	0.0159	TRUE
40109	Combined ash	Thallium	mg/L	0.000925	0.00095	0.000975	TRUE
40109	Fly Ash	Thallium	mg/L	0.0063	0.0063	0.0063	TRUE
49003A	Fly Ash	Thallium	mg/L	0.007525	0.0098	0.012075	TRUE
13115A	Combined ash	TOC	mg/L	1.975	3.55	5.125	FALSE
13115A	Fly Ash	TOC	mg/L	6	6	6	FALSE
22346	Other	TOC	mg/L	2.6	2.6	2.6	FALSE
22347	Fly Ash	TOC	mg/L	4.7	4.7	4.7	FALSE
23223B	FGD waste	TOC	mg/L	9.9	9.9	9.9	FALSE
25410A	Combined ash	TOC	mg/L	5.3	5.3	5.3	FALSE
33104	Combined ash	TOC	mg/L	0.045	0.045	0.045	FALSE
33104	Fly Ash	TOC	mg/L	0.045	0.045	0.045	FALSE
33106	Combined ash	TOC	mg/L	0.045	0.045	0.045	FALSE
33106	Fly Ash	TOC	mg/L	0.045	0.045	0.045	FALSE
34186B	FGD waste	TOC	mg/L	37.35	41.6	45.85	FALSE
35015B	Combined ash	TOC	mg/L	2.25	3.9	4	FALSE
40109	Combined ash	TOC	mg/L	0.045	0.045	0.045	FALSE
40109	Fly Ash	TOC	mg/L	0.045	0.045	0.045	FALSE
49003A	Fly Ash	TOC	mg/L	0.8	1.15	1.425	FALSE
13115A	Combined ash	Total inorganic carbon	mg/L	23	23.6	24.2	FALSE
13115A	Fly Ash	Total inorganic carbon	mg/L	48.7	48.7	48.7	FALSE
22346	Other	Total inorganic carbon	mg/L	35.9	35.9	35.9	FALSE
22347	Fly Ash	Total inorganic carbon	mg/L	11.9	11.9	11.9	FALSE
23223B	FGD waste	Total inorganic carbon	mg/L	1.7	1.7	1.7	FALSE
25410A	Combined ash	Total inorganic carbon	mg/L	15.4	15.4	15.4	FALSE
33104	Combined ash	Total inorganic carbon	mg/L	6.89	7.74	8.59	FALSE
33104	Fly Ash	Total inorganic carbon	mg/L	3.92	3.92	3.92	FALSE
33106	Combined ash	Total inorganic carbon	mg/L	2.18	2.18	2.18	FALSE
33106	Fly Ash	Total inorganic carbon	mg/L	0.89	1.03	1.52	FALSE
34186B	FGD waste	Total inorganic carbon	mg/L	3.3575	4.865	6.3725	FALSE
35015B	Combined ash	Total inorganic carbon	mg/L	16.05	19.2	20.4	FALSE
40109	Combined ash	Total inorganic carbon	mg/L	5.3075	5.545	5.7825	FALSE
40109	Fly Ash	Total inorganic carbon	mg/L	0.92	0.92	0.92	FALSE
49003A	Fly Ash	Total inorganic carbon	mg/L	1.4375	2.025	2.4825	FALSE
13115A	Combined ash	Uranium	mg/L	0.001125	0.00115	0.001175	TRUE
13115A	Fly Ash	Uranium	mg/L	0.0012	0.0012	0.0012	TRUE
22346	Other	Uranium	mg/L	0.00266	0.00266	0.00266	TRUE
22347	Fly Ash	Uranium	mg/L	0.00123	0.00123	0.00123	TRUE

Attachment C-3. Quartile Data for CCR Impoundment Surface Water

Site	New_WasteType	Analyte	Units	25th	50th	75th	Risk
23223B	FGD waste	Uranium	mg/L	0.0007	0.0007	0.0007	TRUE
25410A	Combined ash	Uranium	mg/L	0.0037	0.0037	0.0037	TRUE
33104	Combined ash	Uranium	mg/L	0.000775	0.00125	0.001725	TRUE
33104	Fly Ash	Uranium	mg/L	0.0007	0.0007	0.0007	TRUE
33106	Combined ash	Uranium	mg/L	0.00005	0.00005	0.00005	TRUE
33106	Fly Ash	Uranium	mg/L	0.00005	0.00005	0.000275	TRUE
34186B	FGD waste	Uranium	mg/L	0.0088525	0.011235	0.0136175	TRUE
35015B	Combined ash	Uranium	mg/L	0.001375	0.00175	0.001885	TRUE
40109	Combined ash	Uranium	mg/L	0.000675	0.00085	0.001025	TRUE
40109	Fly Ash	Uranium	mg/L	0.001	0.001	0.001	TRUE
49003A	Fly Ash	Uranium	mg/L	0.0001	0.000125	0.000155	TRUE
13115A	Combined ash	Vanadium	mg/L	0.01625	0.0165	0.01675	TRUE
13115A	Fly Ash	Vanadium	mg/L	0.01	0.01	0.01	TRUE
22346	Other	Vanadium	mg/L	0.103	0.103	0.103	TRUE
22347	Fly Ash	Vanadium	mg/L	0.0493	0.0493	0.0493	TRUE
23223B	FGD waste	Vanadium	mg/L	0.018	0.018	0.018	TRUE
25410A	Combined ash	Vanadium	mg/L	0.55	0.55	0.55	TRUE
33104	Combined ash	Vanadium	mg/L	0.06925	0.0772	0.08515	TRUE
33104	Fly Ash	Vanadium	mg/L	0.2296	0.2296	0.2296	TRUE
33106	Combined ash	Vanadium	mg/L	0.0056	0.0056	0.0056	TRUE
33106	Fly Ash	Vanadium	mg/L	0.0226	0.0356	0.0532	TRUE
34186B	FGD waste	Vanadium	mg/L	0.0271	0.0524	0.0777	TRUE
35015B	Combined ash	Vanadium	mg/L	0.00515	0.0065	0.00925	TRUE
40109	Combined ash	Vanadium	mg/L	0.032075	0.03285	0.033625	TRUE
40109	Fly Ash	Vanadium	mg/L	0.0047	0.0047	0.0047	TRUE
49003A	Fly Ash	Vanadium	mg/L	0.054125	0.05865	0.06475	TRUE
13115A	Combined ash	Zinc	mg/L	0.00875	0.0095	0.01025	TRUE
13115A	Fly Ash	Zinc	mg/L	0.009	0.009	0.009	TRUE
22346	Other	Zinc	mg/L	0.001	0.001	0.001	TRUE
22347	Fly Ash	Zinc	mg/L	0.003	0.003	0.003	TRUE
23223B	FGD waste	Zinc	mg/L	0.034	0.034	0.034	TRUE
25410A	Combined ash	Zinc	mg/L	0.0025	0.0025	0.0025	TRUE
33104	Combined ash	Zinc	mg/L	0.0015	0.0015	0.0015	TRUE
33104	Fly Ash	Zinc	mg/L	0.0015	0.0015	0.0015	TRUE
33106	Combined ash	Zinc	mg/L	0.0183	0.0183	0.0183	TRUE
33106	Fly Ash	Zinc	mg/L	0.04685	0.0581	0.06925	TRUE
34186B	FGD waste	Zinc	mg/L	0.01775	0.0345	0.05125	TRUE
35015B	Combined ash	Zinc	mg/L	0.006	0.011	0.013	TRUE
40109	Combined ash	Zinc	mg/L	0.002125	0.00275	0.003375	TRUE
40109	Fly Ash	Zinc	mg/L	0.0746	0.0746	0.0746	TRUE
49003A	Fly Ash	Zinc	mg/L	0.01375	0.015	0.01725	TRUE

Attachment C-4.

Quartile Data for CCR Whole Waste

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Harrim 3019	Ash (NOS)	Acid Neutr. Potential	ppm	16.7	16.7	16.7	FALSE
Harrim 3019	Bottom ash	Acid Neutr. Potential	ppm	396.75	398.5	400.25	FALSE
Harrim 3019	Fly ash	Acid Neutr. Potential	ppm	170.75	198	246.7	FALSE
Tracy Vein Slope	Ash (NOS)	Acid Neutr. Potential	ppm	290	290	290	FALSE
Tracy Vein Slope	FBC	Acid Neutr. Potential	ppm	555000	555000	555000	FALSE
City Mine	FBC	Aluminum	ppm	89379	101000	101500	TRUE
Philadelphia Girard	Ash (NOS)	Aluminum	ppm	21870	21870	21870	TRUE
Cleveland	Fly ash	Aluminum	ppm	25.7	25.7	25.7	TRUE
CLSM	Combined ash	Aluminum	ppm	90472.3	90472.3	90472.3	TRUE
CLSM	FBC	Aluminum	ppm	11708.3	11708.3	11708.3	TRUE
Emerald Anthracite	Ash (NOS)	Aluminum	ppm	25981.95	28890	30842.5	TRUE
Freeport Mine	FGD waste	Aluminum	ppm	877	877	877	TRUE
Gale	Ash (NOS)	Aluminum	ppm	13630	13630	13630	TRUE
Girard Estate	Ash (NOS)	Aluminum	ppm	10900	10900	10900	TRUE
HA	Ash & coal waste	Aluminum	ppm	4500	5300	6650	TRUE
Harrim 3019	Bottom ash	Aluminum	ppm	30287.5	34475	38662.5	TRUE
Harrim 3019	Fly ash	Aluminum	ppm	28700	39050	60750	TRUE
an Coal Corporatio	Ash (NOS)	Aluminum	ppm	7515	12750	19552.5	TRUE
an Coal Corporatio	Bottom ash	Aluminum	ppm	2242.5	3720	9290	TRUE
an Coal Corporatio	Fly ash	Aluminum	ppm	63980	77960	91940	TRUE
Coal Corporation 5	Ash (NOS)	Aluminum	ppm	17800	17800	17800	TRUE
Coal Corporation 5	Bottom ash	Aluminum	ppm	22825	35250	47675	TRUE
Coal Corporation 5	Fly ash	Aluminum	ppm	41200	53200	65200	TRUE
ddo Highland Coal (	Ash (NOS)	Aluminum	ppm	5170	8330	19400	TRUE
ddo Highland Coal (	Bottom ash	Aluminum	ppm	17900	17900	17900	TRUE
Knickerbocker Pit	FBC	Aluminum	ppm	22025	23075	28357.5	TRUE
gh Coal and Naviga	Ash (NOS)	Aluminum	ppm	20100	22200	22700	TRUE
ttle Sandy #10 Min	Combined ash	Aluminum	ppm	5435	6100	6250	TRUE
ttle Sandy #10 Min	FGD waste	Aluminum	ppm	3000	3200	3590	TRUE
Martins Creek	Bottom ash	Aluminum	ppm	100600	104000	125901	TRUE
Martins Creek	Fly ash	Aluminum	ppm	110342	118000	125471	TRUE
McCloskey Site	FBC	Aluminum	ppm	19300	27450	35600	TRUE
McKay Site	FBC	Aluminum	ppm	22500	30000	37500	TRUE
Miller Creek Mine	Bottom ash	Aluminum	ppm	3038	7195.39	8360	TRUE
Miller Creek Mine	Combined ash	Aluminum	ppm	1385.25	2453	8020.75	TRUE
Miller Creek Mine	Fly ash	Aluminum	ppm	8580	10000	10590	TRUE
N & L Coal Co.	Ash (NOS)	Aluminum	ppm	17275	115190	146850	TRUE
N & L Coal Co.-2	Ash (NOS)	Aluminum	ppm	17200	122000	131000	TRUE
o. 1 Contracting Co	Ash (NOS)	Aluminum	ppm	24075	25050	26025	TRUE
el Supply Company	Ash (NOS)	Aluminum	ppm	18400	23400	24500	TRUE
el Supply Company	Ash (NOS)	Aluminum	ppm	17200	24100	29429.4	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
el Supply Company	Ash (NOS)	Aluminum	ppm	17850	22300	26750	TRUE
rthampton400002	Ash (NOS)	Aluminum	ppm	24500	24500	24500	TRUE
heast Energy Com	Ash (NOS)	Aluminum	ppm	11683.75	15950	20125	TRUE
heast Energy Com	Bottom ash	Aluminum	ppm	1600	1600	1600	TRUE
heast Energy Com	Fly ash	Aluminum	ppm	8800	8800	8800	TRUE
eastern Power Cor	Ash (NOS)	Aluminum	ppm	16950	18400	22650	TRUE
eastern Power Cor	Bottom ash	Aluminum	ppm	9950	12000	15000	TRUE
eastern Power Cor	Fly ash	Aluminum	ppm	19330	22400	28700	TRUE
Nucla	FBC	Aluminum	ppm	102075	110050	118025	TRUE
Nucla2	FBC	Aluminum	ppm	95000	97000	103500	TRUE
Oak Creek	Bottom ash	Aluminum	ppm	95220	95220	95220	TRUE
Pacton Corp	Ash (NOS)	Aluminum	ppm	27500	27500	27500	TRUE
Pacton Corp	Bottom ash	Aluminum	ppm	10000	10000	10000	TRUE
Pacton Corp	Fly ash	Aluminum	ppm	25912.5	70200	132150	TRUE
Pagnotti Coal Co.	Ash (NOS)	Aluminum	ppm	22900	32275	37287.5	TRUE
Pagnotti Coal Co.	Bottom ash	Aluminum	ppm	8000	8000	8000	TRUE
Pagnotti Coal Co.	Fly ash	Aluminum	ppm	41250	42500	43750	TRUE
Panther Creek	FBC	Aluminum	ppm	25728.75	27595	31700	TRUE
Pleasant Prairie	Bottom ash	Aluminum	ppm	50784	50784	50784	TRUE
Porter Associates	Ash (NOS)	Aluminum	ppm	7275	10500	14700	TRUE
Porter Associates	Bottom ash	Aluminum	ppm	3642.5	8300	19950	TRUE
ylkill Reclamation (	Ash (NOS)	Aluminum	ppm	1270	1270	1270	TRUE
Shawnee	FBC	Aluminum	ppm	16200	39800	62000	TRUE
Silverton	Ash (NOS)	Aluminum	ppm	15250	16870	18490	TRUE
ehanna Coal Comp	Ash (NOS)	Aluminum	ppm	19125	25100	30975	TRUE
hanna Coal Compa	Ash (NOS)	Aluminum	ppm	24375	35050	36500	TRUE
SW	Bottom ash	Aluminum	ppm	133000	139000	145000	TRUE
SW	Fly ash	Aluminum	ppm	117000	124000	141000	TRUE
Tracy Vein Slope	Ash (NOS)	Aluminum	ppm	9047.5	12825	16400	TRUE
Tracy Vein Slope	Bottom ash	Aluminum	ppm	7677.5	8025	8372.5	TRUE
Tracy Vein Slope	FBC	Aluminum	ppm	7240	7240	7240	TRUE
Universal	Combined ash	Aluminum	ppm	4600	5770	8400	TRUE
wood Energy Prop	Ash (NOS)	Aluminum	ppm	10639.75	16250	18452.5	TRUE
Wheelabrator	FBC	Aluminum	ppm	16575	20430	22512.5	TRUE
12	FBC	Aluminum	ppm	32600	35700	46700	TRUE
14	FBC	Aluminum	ppm	25200	25200	25200	TRUE
17	FBC	Aluminum	ppm	35100	46946	60984	TRUE
18	FBC	Aluminum	ppm	20123	29532	29895	TRUE
19	FBC	Aluminum	ppm	3910	3910	3910	TRUE
2	FBC	Aluminum	ppm	9	14.5	20	TRUE
20	FBC	Aluminum	ppm	25890	31090	36176	TRUE
21	FBC	Aluminum	ppm	527.175	13500	27045	TRUE
26	FBC	Aluminum	ppm	15800	15800	15800	TRUE
27	FBC	Aluminum	ppm	66029	66029	66029	TRUE
28	FBC	Aluminum	ppm	11292.5	41925	50087.5	TRUE
29	FBC	Aluminum	ppm	5904.45	16719.55	27490.33	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
30	FBC	Aluminum	ppm	10174.43	22367.8	34243.95	TRUE
31	FBC	Aluminum	ppm	26218.75	29437.5	32656.25	TRUE
38	FBC	Aluminum	ppm	18318.75	21025	25912.5	TRUE
39	FBC	Aluminum	ppm	73825	78850	83875	TRUE
4	FBC	Aluminum	ppm	11029.55	14435	16255	TRUE
6	FBC	Aluminum	ppm	35573.25	42736.5	49899.75	TRUE
7	FBC	Aluminum	ppm	24729.99	24729.99	24729.99	TRUE
8	FBC	Aluminum	ppm	39000	39000	39000	TRUE
A/C Fuels Company	Ash (NOS)	Aluminum	ppm	19400	19400	19400	TRUE
B-D Mining Co.	Ash (NOS)	Aluminum	ppm	21817.5	27950	30968.45	TRUE
B-D Mining Co.	Bottom ash	Aluminum	ppm	26651	34698	51294.25	TRUE
B-D Mining Co.	Fly ash	Aluminum	ppm	32755	40702.5	54691.25	TRUE
Deer Ridge Mine	Fly ash	Aluminum	ppm	1787.5	2278.68	114250	TRUE
DPC	Bottom ash	Aluminum	ppm	2630	2630	2630	TRUE
DPC	Fly ash	Aluminum	ppm	10400	10400	10400	TRUE
ern Analytical, ID: 5	Slag	Aluminum	ppm	18000	18000	18000	TRUE
City Mine	FBC	Antimony	ppm	2.5	2.5	2.5	TRUE
CLSM	Combined ash	Antimony	ppm	7.9	7.9	7.9	TRUE
CLSM	FBC	Antimony	ppm	2.9	2.9	2.9	TRUE
Emerald Anthracite	Ash (NOS)	Antimony	ppm	75.59	81.18	84.09	TRUE
Freeport Mine	FGD waste	Antimony	ppm	10	10	10	TRUE
Gale	Ash (NOS)	Antimony	ppm	3	3	3	TRUE
Harrim 3019	Bottom ash	Antimony	ppm	1775	1775	1775	TRUE
Harrim 3019	Fly ash	Antimony	ppm	20	33.5	377.75	TRUE
an Coal Corporatio	Ash (NOS)	Antimony	ppm	2.31	6.41	12.625	TRUE
an Coal Corporatio	Bottom ash	Antimony	ppm	1.04425	2.7	6.27	TRUE
an Coal Corporatio	Fly ash	Antimony	ppm	1370	1370	1370	TRUE
Coal Corporation 5	Ash (NOS)	Antimony	ppm	47	47	47	TRUE
Coal Corporation 5	Bottom ash	Antimony	ppm	12.5	15	17.5	TRUE
Coal Corporation 5	Fly ash	Antimony	ppm	12.5	15	17.5	TRUE
ddo Highland Coal (	Ash (NOS)	Antimony	ppm	5.4	10	10	TRUE
ddo Highland Coal (	Bottom ash	Antimony	ppm	35	35	35	TRUE
Knickerbocker Pit	FBC	Antimony	ppm	27.5	32	48.7675	TRUE
gh Coal and Naviga	Ash (NOS)	Antimony	ppm	20	20	20	TRUE
LIMB Site	Ash (NOS)	Antimony	ppm	25	25	25	TRUE
Martins Creek	Bottom ash	Antimony	ppm	5	5	12	TRUE
Martins Creek	Fly ash	Antimony	ppm	5	5	5	TRUE
McKay Site	FBC	Antimony	ppm	2.5	2.5	2.5	TRUE
N & L Coal Co.	Ash (NOS)	Antimony	ppm	4	87.4	123.75	TRUE
N & L Coal Co.-2	Ash (NOS)	Antimony	ppm	10	10	40.225	TRUE
o. 1 Contracting Co	Ash (NOS)	Antimony	ppm	0.8	1.2	1.6	TRUE
uel Supply Company	Ash (NOS)	Antimony	ppm	20	20	20	TRUE
uel Supply Company	Ash (NOS)	Antimony	ppm	13.75	17.5	21.25	TRUE
uel Supply Company	Ash (NOS)	Antimony	ppm	30.5	41	51.5	TRUE
orthampton400002	Ash (NOS)	Antimony	ppm	20	20	20	TRUE
heast Energy Com	Ash (NOS)	Antimony	ppm	10	10	12.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
heast Energy Com	Bottom ash	Antimony	ppm	0.5	0.5	0.5	TRUE
heast Energy Com	Fly ash	Antimony	ppm	0.4	0.4	0.4	TRUE
eastern Power Cor	Bottom ash	Antimony	ppm	0.2155	0.4345	1.44375	TRUE
eastern Power Cor	Fly ash	Antimony	ppm	0.373	0.851	3.48	TRUE
Nucla	FBC	Antimony	ppm	24	24	24	TRUE
Nucla2	FBC	Antimony	ppm	29	40	60	TRUE
aceAnalytical (201(	Slag	Antimony	ppm	0.245	0.245	0.245	TRUE
Pacton Corp	Ash (NOS)	Antimony	ppm	44	44	44	TRUE
Pacton Corp	Bottom ash	Antimony	ppm	33	33	33	TRUE
Pacton Corp	Fly ash	Antimony	ppm	12	38	45	TRUE
Pagnotti Coal Co.	Ash (NOS)	Antimony	ppm	37.5	37.5	37.5	TRUE
Pagnotti Coal Co.	Fly ash	Antimony	ppm	0.21	0.21	0.21	TRUE
Panther Creek	FBC	Antimony	ppm	2.4	4.78	67	TRUE
Porter Associates	Ash (NOS)	Antimony	ppm	5.6	10	22	TRUE
Porter Associates	Bottom ash	Antimony	ppm	10	10	32	TRUE
Shawnee	FBC	Antimony	ppm	12	13	18	TRUE
ehanna Coal Comp	Ash (NOS)	Antimony	ppm	17.5	41.5	67.25	TRUE
hanna Coal Compa	Ash (NOS)	Antimony	ppm	24	38	52	TRUE
Tracy Vein Slope	Ash (NOS)	Antimony	ppm	7.4725	8.035	33.785	TRUE
Tracy Vein Slope	Bottom ash	Antimony	ppm	6.13	6.2	6.27	TRUE
USGS	Fly ash	Antimony	ppm	4.05	4.9	9.6	TRUE
wood Energy Prop	Ash (NOS)	Antimony	ppm	0.65675	2.515	7.8875	TRUE
Wheelabrator	FBC	Antimony	ppm	2.4325	15.39	35.75	TRUE
Xcel/MSI	Fly ash	Antimony	ppm	2.475	2.6	3.7	TRUE
Zhang et al. (2001)	Fly Ash	Antimony	ppm	9	12	16	TRUE
1	FBC	Antimony	ppm	40.86	40.86	40.86	TRUE
10	FBC	Antimony	ppm	15.625	18.75	21.875	TRUE
12	FBC	Antimony	ppm	5	21	25	TRUE
14	FBC	Antimony	ppm	5	5	5	TRUE
17	FBC	Antimony	ppm	0.955	4.55	21.15	TRUE
18	FBC	Antimony	ppm	3.5	5	6.5	TRUE
19	FBC	Antimony	ppm	6.25	6.25	6.25	TRUE
2	FBC	Antimony	ppm	2.858	2.858	2.858	TRUE
20	FBC	Antimony	ppm	28.75	38	52	TRUE
21	FBC	Antimony	ppm	0.25	0.25	0.4375	TRUE
26	FBC	Antimony	ppm	2.5	4.875	8.5625	TRUE
27	FBC	Antimony	ppm	9	9	9	TRUE
28	FBC	Antimony	ppm	46	114	553.25	TRUE
29	FBC	Antimony	ppm	0.125	0.125	0.125	TRUE
3	FBC	Antimony	ppm	12.5	12.5	12.5	TRUE
30	FBC	Antimony	ppm	5	30	62.4125	TRUE
31	FBC	Antimony	ppm	2.54875	5.0325	7.51625	TRUE
38	FBC	Antimony	ppm	0.025	0.375	10.75	TRUE
39	FBC	Antimony	ppm	1	1	1	TRUE
4	FBC	Antimony	ppm	11.425	28	39.391	TRUE
5	FBC	Antimony	ppm	2.5	2.5	2.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
6	FBC	Antimony	ppm	10.625	16.25	21.875	TRUE
8	FBC	Antimony	ppm	1.25	1.25	1.25	TRUE
A/C Fuels Company	Ash (NOS)	Antimony	ppm	1	1	1	TRUE
B-D Mining Co.	Ash (NOS)	Antimony	ppm	21.25	36	63	TRUE
B-D Mining Co.	Bottom ash	Antimony	ppm	23.125	28.5	53.75	TRUE
B-D Mining Co.	Fly ash	Antimony	ppm	37.5	40.5	48.75	TRUE
DPC	Bottom ash	Antimony	ppm	0.18	0.18	0.18	TRUE
DPC	Fly ash	Antimony	ppm	0.77	0.77	0.77	TRUE
ern Analytical, ID: 5	Slag	Antimony	ppm	0.25	0.25	0.25	TRUE
Bowen	Fly ash	Arsenic	ppm	68	68	68	TRUE
CAER	Bottom ash	Arsenic	ppm	23.235	35.91	50.55	TRUE
CAER	FGD waste	Arsenic	ppm	5.02	5.02	5.02	TRUE
CAER	Fly ash	Arsenic	ppm	75.47	111.7	133.28	TRUE
Cardinal	Fly ash	Arsenic	ppm	108.25	131.5	154.75	TRUE
City Mine	FBC	Arsenic	ppm	26	27	28.5	TRUE
Philadelphia Girard	Ash (NOS)	Arsenic	ppm	39.18	39.18	39.18	TRUE
Cleveland	Fly ash	Arsenic	ppm	0.047	0.047	0.047	TRUE
Emerald Anthracite	Ash (NOS)	Arsenic	ppm	15.8575	28.33	36.575	TRUE
EORDC	FGD waste	Arsenic	ppm	54	54	54	TRUE
Fleming	FBC	Arsenic	ppm	75	75	75	TRUE
Freeport Mine	FGD waste	Arsenic	ppm	3.2	3.2	3.2	TRUE
Gale	Ash (NOS)	Arsenic	ppm	51.5	51.5	51.5	TRUE
Girard Estate	Ash (NOS)	Arsenic	ppm	11	11	11	TRUE
HA	Ash & coal waste	Arsenic	ppm	7	8	11.5	TRUE
Harrim 3019	Ash (NOS)	Arsenic	ppm	150.449	150.449	150.449	TRUE
Harrim 3019	Bottom ash	Arsenic	ppm	74.325	82.55	90.775	TRUE
Harrim 3019	Fly ash	Arsenic	ppm	12.075	25	43.8	TRUE
an Coal Corporatio	Ash (NOS)	Arsenic	ppm	23.3	37.9	76.15	TRUE
an Coal Corporatio	Bottom ash	Arsenic	ppm	2	4.07	10.75	TRUE
an Coal Corporatio	Fly ash	Arsenic	ppm	43.8	48.9	54	TRUE
Coal Corporation 5	Ash (NOS)	Arsenic	ppm	13	13	13	TRUE
Coal Corporation 5	Bottom ash	Arsenic	ppm	32.275	35.75	39.225	TRUE
Coal Corporation 5	Fly ash	Arsenic	ppm	18.95	20.4	21.85	TRUE
ddo Highland Coal (	Ash (NOS)	Arsenic	ppm	1.3	2.3	8.45	TRUE
ddo Highland Coal (	Bottom ash	Arsenic	ppm	35.9	35.9	35.9	TRUE
Kentucky	Bottom ash	Arsenic	ppm	17.25	25.5	33.75	TRUE
Kentucky	Fly ash	Arsenic	ppm	426.5	547.5	663.5	TRUE
Knickerbocker Pit	FBC	Arsenic	ppm	10.63	14.95	40.045	TRUE
KY	FGD waste	Arsenic	ppm	7.5	9.5	14.75	TRUE
gh Coal and Naviga	Ash (NOS)	Arsenic	ppm	16.7	18.4	22.125	TRUE
LIMB Site	Ash (NOS)	Arsenic	ppm	61.5	63	64.5	TRUE
ttle Sandy #10 Min	Bottom ash	Arsenic	ppm	14	14	14	TRUE
ttle Sandy #10 Min	Combined ash	Arsenic	ppm	7.23	11	14	TRUE
ttle Sandy #10 Min	FGD waste	Arsenic	ppm	31	33	33.35	TRUE
ttle Sandy #10 Min	Fly ash	Arsenic	ppm	220	220	220	TRUE
Lone Mtn	Fly ash	Arsenic	ppm	76	76	76	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Mandan	FBC	Arsenic	ppm	21.65	21.65	21.65	TRUE
Martins Creek	Bottom ash	Arsenic	ppm	4.285	5.25	8.196	TRUE
Martins Creek	Fly ash	Arsenic	ppm	60.36	75.71	123	TRUE
McCloskey Site	FBC	Arsenic	ppm	41.6325	45.355	49.0775	TRUE
McKay Site	FBC	Arsenic	ppm	40.25	51.5	62.75	TRUE
Miller	Fly ash	Arsenic	ppm	18	18	18	TRUE
Miller Creek Mine	Bottom ash	Arsenic	ppm	2.823	50.49	51.776	TRUE
Miller Creek Mine	Combined ash	Arsenic	ppm	6.465	19.965	45.25	TRUE
Miller Creek Mine	Fly ash	Arsenic	ppm	39.25	90.5	152.7175	TRUE
N & L Coal Co.	Ash (NOS)	Arsenic	ppm	15.7	20.95	113.0078	TRUE
N & L Coal Co.-2	Ash (NOS)	Arsenic	ppm	24.1	63.6	158	TRUE
Nepco	FBC	Arsenic	ppm	21	21	21	TRUE
NETL	Bottom ash	Arsenic	ppm	29	29	29	TRUE
NETL	FBC	Arsenic	ppm	65.5	79	92.5	TRUE
NETL	Fly ash	Arsenic	ppm	50	95.5	143.25	TRUE
NETL	Slag	Arsenic	ppm	20	20	20	TRUE
o. 1 Contracting Co	Ash (NOS)	Arsenic	ppm	18.275	18.85	19.425	TRUE
uel Supply Company	Ash (NOS)	Arsenic	ppm	11.4	26.4	40.6	TRUE
uel Supply Company	Ash (NOS)	Arsenic	ppm	15.7	24	30	TRUE
uel Supply Company	Ash (NOS)	Arsenic	ppm	19.725	25.75	31.775	TRUE
orthampton400002	Ash (NOS)	Arsenic	ppm	40.6	40.6	40.6	TRUE
heast Energy Com	Ash (NOS)	Arsenic	ppm	1.257	13.4	22.15	TRUE
heast Energy Com	Bottom ash	Arsenic	ppm	2.5	2.5	2.5	TRUE
heast Energy Com	Fly ash	Arsenic	ppm	12	12	12	TRUE
eastern Power Cor	Ash (NOS)	Arsenic	ppm	3.985	6	6.1375	TRUE
eastern Power Cor	Bottom ash	Arsenic	ppm	1.8725	2.645	3.1625	TRUE
eastern Power Cor	Fly ash	Arsenic	ppm	8.57	10	12.4	TRUE
Nucla	FBC	Arsenic	ppm	7.25	7.4	7.55	TRUE
Nucla2	FBC	Arsenic	ppm	16.9	31	40.5	TRUE
Oak Creek	Bottom ash	Arsenic	ppm	0.5	0.5	0.5	TRUE
aceAnalytical (201	Slag	Arsenic	ppm	0.245	0.245	0.245	TRUE
Pacton Corp	Ash (NOS)	Arsenic	ppm	24	24	24	TRUE
Pacton Corp	Bottom ash	Arsenic	ppm	133	133	133	TRUE
Pacton Corp	Fly ash	Arsenic	ppm	54.2	208	219	TRUE
Pagnotti Coal Co.	Ash (NOS)	Arsenic	ppm	4.158225	7.27	27.3325	TRUE
Pagnotti Coal Co.	Fly ash	Arsenic	ppm	250	250	250	TRUE
Panther Creek	FBC	Arsenic	ppm	11.25	17.85	19.15	TRUE
Paradise	Fly ash	Arsenic	ppm	75	75	75	TRUE
ett et al. (1993) Co	Fly Ash	Arsenic	ppm	30.75	52.5	76	TRUE
Plant 10	FBC	Arsenic	ppm	52.1	64.1	88.8	TRUE
Plant 12	FBC	Arsenic	ppm	84.3	112	118	TRUE
Plant 8	FBC	Arsenic	ppm	36.8	41	45.35	TRUE
Plant 9	FBC	Arsenic	ppm	1.6	2.2	3.7	TRUE
Pleasant Prairie	Bottom ash	Arsenic	ppm	0.5	0.5	0.5	TRUE
Pleasant Prairie	Fly ash	Arsenic	ppm	38	38	38	TRUE
Porter Associates	Ash (NOS)	Arsenic	ppm	13.325	20.47	47.425	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Porter Associates	Bottom ash	Arsenic	ppm	3.275	8.565	11.475	TRUE
ylkill Reclamation (	Ash (NOS)	Arsenic	ppm	2.1	2.1	2.1	TRUE
Scrubgrass	FBC	Arsenic	ppm	59	59	59	TRUE
SFA	Fly ash	Arsenic	ppm	180	180	180	TRUE
Shawnee	FBC	Arsenic	ppm	7.5	12	19	TRUE
Silverton	Ash (NOS)	Arsenic	ppm	47	48.5	50	TRUE
Sioux	Fly ash	Arsenic	ppm	79.25	84.5	89.75	TRUE
Stanton	Fly ash	Arsenic	ppm	63	63	63	TRUE
STK	Fly ash	Arsenic	ppm	115	120	125	TRUE
ehanna Coal Comp	Ash (NOS)	Arsenic	ppm	16.45	26.95	31.25	TRUE
hanna Coal Compa	Ash (NOS)	Arsenic	ppm	10.575	15.5	24.4175	TRUE
SW	Bottom ash	Arsenic	ppm	22.3	25.2	29.5	TRUE
SW	Fly ash	Arsenic	ppm	25.9	31.25	38.575	TRUE
Tracy Vein Slope	Ash (NOS)	Arsenic	ppm	60.4	75.75	98.225	TRUE
Tracy Vein Slope	Bottom ash	Arsenic	ppm	14.525	18.25	21.975	TRUE
Tracy Vein Slope	FBC	Arsenic	ppm	6.97	6.97	6.97	TRUE
Universal	Combined ash	Arsenic	ppm	35.5	48	54.5	TRUE
USGS	Fly ash	Arsenic	ppm	6.45	16.4	49.5	TRUE
wood Energy Prop	Ash (NOS)	Arsenic	ppm	8.7175	11.15	12.425	TRUE
Wheelabrator	FBC	Arsenic	ppm	10.435	13.6	15.32	TRUE
Xcel/MSI	Fly ash	Arsenic	ppm	14.675	15.45	17.1	TRUE
Yates	Fly ash	Arsenic	ppm	106	106	106	TRUE
Zhang et al. (2001)	Fly Ash	Arsenic	ppm	26	60	505	TRUE
1	FBC	Arsenic	ppm	1.1775	1.92	4.3875	TRUE
10	FBC	Arsenic	ppm	3.175	3.85	4.525	TRUE
11	FBC	Arsenic	ppm	48.5	51	53.5	TRUE
12	FBC	Arsenic	ppm	22.7025	44.73	97.2375	TRUE
14	FBC	Arsenic	ppm	26	26	26	TRUE
17	FBC	Arsenic	ppm	58.425	74.3	94.15	TRUE
18	FBC	Arsenic	ppm	40	44	62	TRUE
19	FBC	Arsenic	ppm	6.25	6.25	6.25	TRUE
2	FBC	Arsenic	ppm	9.017	9.017	9.017	TRUE
20	FBC	Arsenic	ppm	4.465	9.85	24.01	TRUE
21	FBC	Arsenic	ppm	8.75	11	11.75	TRUE
23	FBC	Arsenic	ppm	29.975	36.11	39.6375	TRUE
26	FBC	Arsenic	ppm	2.16875	2.6375	3.2	TRUE
27	FBC	Arsenic	ppm	12	12	12	TRUE
28	FBC	Arsenic	ppm	18.445	41.85	50.3	TRUE
29	FBC	Arsenic	ppm	13.25	17.4	86.05	TRUE
3	FBC	Arsenic	ppm	3.1	3.2	3.3	TRUE
30	FBC	Arsenic	ppm	25.56	36.2	63.05	TRUE
31	FBC	Arsenic	ppm	23.4125	26.825	30.2375	TRUE
37	FBC	Arsenic	ppm	3.795	5.79	7.785	TRUE
38	FBC	Arsenic	ppm	8.15875	14.3	16.375	TRUE
39	FBC	Arsenic	ppm	13.25	14.5	15.75	TRUE
4	FBC	Arsenic	ppm	8.925	12.5	27.982	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
5	FBC	Arsenic	ppm	3.125	4.25	4.4	TRUE
6	FBC	Arsenic	ppm	101.9	126.6	151.3	TRUE
7	FBC	Arsenic	ppm	81.26	81.26	81.26	TRUE
8	FBC	Arsenic	ppm	56	56	56	TRUE
A/C Fuels Company	Ash (NOS)	Arsenic	ppm	2	2	2	TRUE
Baldwin	Fly ash	Arsenic	ppm	50	50	50	TRUE
B-D Mining Co.	Ash (NOS)	Arsenic	ppm	9.23	18	22.3	TRUE
B-D Mining Co.	Bottom ash	Arsenic	ppm	3.14725	5.814	9.4625	TRUE
B-D Mining Co.	Fly ash	Arsenic	ppm	2.792	6.25	21	TRUE
CLSM	Combined ash	Arsenic	ppm	306	306	306	TRUE
CLSM	FBC	Arsenic	ppm	113.7	113.7	113.7	TRUE
Coal Creek	Bottom ash	Arsenic	ppm	0.04	0.04	0.04	TRUE
Coal Creek	Fly ash	Arsenic	ppm	0.132	0.132	0.132	TRUE
Deer Ridge Mine	Fly ash	Arsenic	ppm	9.35	22.82	27.00475	TRUE
DPC	Bottom ash	Arsenic	ppm	6.17	6.17	6.17	TRUE
DPC	Fly ash	Arsenic	ppm	104	104	104	TRUE
ern Analytical, ID: 5	Slag	Arsenic	ppm	1.1	1.1	1.1	TRUE
Edgewater	Bottom ash	Arsenic	ppm	13.95	13.95	13.95	TRUE
EERC?	Combined ash	Arsenic	ppm	16.675	18.65	20.625	TRUE
EERC?	FGD	Arsenic	ppm	0.5	21.8	53.4	TRUE
EERC?	FGD gypsum	Arsenic	ppm	0.5	0.75	1.1625	TRUE
EERC?	FGD gypsum liquids	Arsenic	mg/L	0.0828	0.0828	0.0828	TRUE
EERC?	FGD liquids	Arsenic	mg/L	0.049075	0.0842	0.11575	TRUE
EERC?	FGD liquids	Arsenic	ppm	0.5	0.5	0.5	TRUE
EERC?	Fly Ash	Arsenic	ppm	37.05	44.75	74.925	TRUE
Bowen	Fly ash	Barium	ppm	974	974	974	TRUE
CAER	Bottom ash	Barium	ppm	442.5	550	755	TRUE
CAER	FGD waste	Barium	ppm	123	123	123	TRUE
CAER	Fly ash	Barium	ppm	393	426	640	TRUE
Cardinal	Fly ash	Barium	ppm	375	375	375	TRUE
City Mine	FBC	Barium	ppm	293.5	341	342.5	TRUE
Philadelphia Girard	Ash (NOS)	Barium	ppm	172	172	172	TRUE
Emerald Anthracite	Ash (NOS)	Barium	ppm	147.65	207.5	266.125	TRUE
Fleming	FBC	Barium	ppm	150	150	150	TRUE
Freeport Mine	FGD waste	Barium	ppm	11	11	11	TRUE
Gale	Ash (NOS)	Barium	ppm	143	143	143	TRUE
Girard Estate	Ash (NOS)	Barium	ppm	100	100	100	TRUE
HA	Ash & coal waste	Barium	ppm	175	210	210	TRUE
Harrim 3019	Ash (NOS)	Barium	ppm	800	800	800	TRUE
Harrim 3019	Bottom ash	Barium	ppm	176.375	190.25	204.125	TRUE
Harrim 3019	Fly ash	Barium	ppm	251.5	298	321.2	TRUE
an Coal Corporatio	Ash (NOS)	Barium	ppm	97.45	166.5	286.25	TRUE
an Coal Corporatio	Bottom ash	Barium	ppm	19.75	33.1	65.25	TRUE
an Coal Corporatio	Fly ash	Barium	ppm	320.3	321.2	322.1	TRUE
Coal Corporation 5	Ash (NOS)	Barium	ppm	210	210	210	TRUE
Coal Corporation 5	Bottom ash	Barium	ppm	207.75	250.5	293.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Coal Corporation 5	Fly ash	Barium	ppm	414.5	453	491.5	TRUE
ddo Highland Coal (	Ash (NOS)	Barium	ppm	116	198	400	TRUE
ddo Highland Coal (	Bottom ash	Barium	ppm	144	144	144	TRUE
Knickerbocker Pit	FBC	Barium	ppm	165.025	218.4	289.25	TRUE
KY	FGD waste	Barium	ppm	95	97	103.5	TRUE
gh Coal and Naviga	Ash (NOS)	Barium	ppm	160	188	260	TRUE
LIMB Site	Ash (NOS)	Barium	ppm	252.5	255	257.5	TRUE
ttle Sandy #10 Min	Bottom ash	Barium	ppm	68	68	68	TRUE
ttle Sandy #10 Min	Combined ash	Barium	ppm	26	41	44	TRUE
ttle Sandy #10 Min	FGD waste	Barium	ppm	27.55	29	29.5	TRUE
ttle Sandy #10 Min	Fly ash	Barium	ppm	150	150	150	TRUE
Lone Mtn	Fly ash	Barium	ppm	1483.2	1483.2	1483.2	TRUE
Mandan	FBC	Barium	ppm	5100	5100	5100	TRUE
Martins Creek	Bottom ash	Barium	ppm	571	665	760	TRUE
Martins Creek	Fly ash	Barium	ppm	396	550	675	TRUE
McCloskey Site	FBC	Barium	ppm	16.325	32.55	48.775	TRUE
McKay Site	FBC	Barium	ppm	167.5	215	262.5	TRUE
Miller	Fly ash	Barium	ppm	7140	7140	7140	TRUE
Miller Creek Mine	Bottom ash	Barium	ppm	14	43.13	57	TRUE
Miller Creek Mine	Combined ash	Barium	ppm	24	36.5	82.4425	TRUE
Miller Creek Mine	Fly ash	Barium	ppm	41.75	64	108.25	TRUE
N & L Coal Co.	Ash (NOS)	Barium	ppm	155	200	446.175	TRUE
N & L Coal Co.-2	Ash (NOS)	Barium	ppm	232	786	971	TRUE
NETL	Bottom ash	Barium	ppm	1110	1110	1110	TRUE
NETL	FBC	Barium	ppm	362.75	457.5	552.25	TRUE
NETL	Fly ash	Barium	ppm	524.5	846.5	1016.75	TRUE
NETL	Slag	Barium	ppm	321	321	321	TRUE
o. 1 Contracting Co	Ash (NOS)	Barium	ppm	231.25	237.5	243.75	TRUE
el Supply Company	Ash (NOS)	Barium	ppm	170	177	242	TRUE
el Supply Company	Ash (NOS)	Barium	ppm	109.5	115.95	153.25	TRUE
el Supply Company	Ash (NOS)	Barium	ppm	142.75	161.5	180.25	TRUE
rthampton400002	Ash (NOS)	Barium	ppm	242	242	242	TRUE
heast Energy Com	Ash (NOS)	Barium	ppm	175.25	212.5	292.5	TRUE
heast Energy Com	Bottom ash	Barium	ppm	15	15	15	TRUE
heast Energy Com	Fly ash	Barium	ppm	160	160	160	TRUE
eastern Power Con	Ash (NOS)	Barium	ppm	172.5	176	199	TRUE
eastern Power Con	Bottom ash	Barium	ppm	92.125	105.5	132.75	TRUE
eastern Power Con	Fly ash	Barium	ppm	150	195	243	TRUE
Nucla	FBC	Barium	ppm	145	190	235	TRUE
Nucla2	FBC	Barium	ppm	199	330	335	TRUE
Pacton Corp	Ash (NOS)	Barium	ppm	174	174	174	TRUE
Pacton Corp	Bottom ash	Barium	ppm	75	75	75	TRUE
Pacton Corp	Fly ash	Barium	ppm	289	360	860	TRUE
Pagnotti Coal Co.	Ash (NOS)	Barium	ppm	217	226	297.4	TRUE
Pagnotti Coal Co.	Fly ash	Barium	ppm	800	800	800	TRUE
Panther Creek	FBC	Barium	ppm	182.525	227.5	277.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ett et al. (1993) Co	Fly Ash	Barium	ppm	6050	6450	8875	TRUE
Pleasant Prairie	Fly ash	Barium	ppm	6220	6220	6220	TRUE
Porter Associates	Ash (NOS)	Barium	ppm	94.45	130	209.5	TRUE
Porter Associates	Bottom ash	Barium	ppm	42	104	207	TRUE
ylkill Reclamation (	Ash (NOS)	Barium	ppm	36	36	36	TRUE
SFA	Fly ash	Barium	ppm	1370	1370	1370	TRUE
Shawnee	FBC	Barium	ppm	57	190	1200	TRUE
Silverton	Ash (NOS)	Barium	ppm	162.25	181.5	200.75	TRUE
Sioux	Fly ash	Barium	ppm	420.2	420.2	420.2	TRUE
Stanton	Fly ash	Barium	ppm	1370	1370	1370	TRUE
STK	Fly ash	Barium	ppm	1047.5	1085	1122.5	TRUE
ehanna Coal Comp	Ash (NOS)	Barium	ppm	194.75	248	282.25	TRUE
hanna Coal Compa	Ash (NOS)	Barium	ppm	204.675	249.2	259.875	TRUE
SW	Bottom ash	Barium	ppm	1950	2590	3010	TRUE
SW	Fly ash	Barium	ppm	2230	2500	3040	TRUE
Tracy Vein Slope	Ash (NOS)	Barium	ppm	95.675	118.35	143.75	TRUE
Tracy Vein Slope	Bottom ash	Barium	ppm	48.7	55.8	62.9	TRUE
Tracy Vein Slope	FBC	Barium	ppm	68.9	68.9	68.9	TRUE
Universal	Combined ash	Barium	ppm	41.5	55	83	TRUE
wood Energy Prop	Ash (NOS)	Barium	ppm	91.025	137	189.075	TRUE
Wheelabrator	FBC	Barium	ppm	136.075	150.5	199.825	TRUE
Xcel/MSI	Fly ash	Barium	ppm	385.5	5071	6593.25	TRUE
Zhang et al. (2001)	Fly Ash	Barium	ppm	830	2900	4000	TRUE
1	FBC	Barium	ppm	103.825	281.05	420.55	TRUE
10	FBC	Barium	ppm	540.75	628.5	716.25	TRUE
11	FBC	Barium	ppm	162.25	174.5	186.75	TRUE
12	FBC	Barium	ppm	215.175	235.1	246.1	TRUE
14	FBC	Barium	ppm	46.75	46.75	46.75	TRUE
17	FBC	Barium	ppm	140.35	151.5	172.25	TRUE
18	FBC	Barium	ppm	171	276	284	TRUE
19	FBC	Barium	ppm	39.2	39.2	39.2	TRUE
2	FBC	Barium	ppm	88	204.165	320.33	TRUE
20	FBC	Barium	ppm	192.8	212	269.75	TRUE
21	FBC	Barium	ppm	109.4	158.8	225	TRUE
26	FBC	Barium	ppm	457	539	592.5	TRUE
27	FBC	Barium	ppm	2689	2689	2689	TRUE
28	FBC	Barium	ppm	154.775	169	296.5	TRUE
29	FBC	Barium	ppm	0.05	26.225	250.175	TRUE
3	FBC	Barium	ppm	645.75	860.5	1075.25	TRUE
30	FBC	Barium	ppm	61.625	85.34	190.325	TRUE
31	FBC	Barium	ppm	165.125	170.25	175.375	TRUE
38	FBC	Barium	ppm	132.275	153.5	225.225	TRUE
39	FBC	Barium	ppm	415	590	765	TRUE
4	FBC	Barium	ppm	92.1	110.15	170.84	TRUE
5	FBC	Barium	ppm	274	287	463.5	TRUE
6	FBC	Barium	ppm	182.25	221.5	260.75	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
7	FBC	Barium	ppm	450.69	450.69	450.69	TRUE
8	FBC	Barium	ppm	650	650	650	TRUE
A/C Fuels Company	Ash (NOS)	Barium	ppm	160	160	160	TRUE
Baldwin	Fly ash	Barium	ppm	416	416	416	TRUE
B-D Mining Co.	Ash (NOS)	Barium	ppm	149.25	217	270.575	TRUE
B-D Mining Co.	Bottom ash	Barium	ppm	194.2	204.05	213.9	TRUE
B-D Mining Co.	Fly ash	Barium	ppm	268.8	283.5	576	TRUE
CLSM	Combined ash	Barium	ppm	187.4	187.4	187.4	TRUE
CLSM	FBC	Barium	ppm	61.7	61.7	61.7	TRUE
Coal Creek	Bottom ash	Barium	ppm	4.3	4.3	4.3	TRUE
Coal Creek	Fly ash	Barium	ppm	5.22	5.22	5.22	TRUE
Deer Ridge Mine	Fly ash	Barium	ppm	36.1675	52	562.5	TRUE
DPC	Bottom ash	Barium	ppm	24	24	24	TRUE
DPC	Fly ash	Barium	ppm	51.4	51.4	51.4	TRUE
ern Analytical, ID: 5	Slag	Barium	ppm	230	230	230	TRUE
Bowen	Fly ash	Beryllium	ppm	22.1	22.1	22.1	TRUE
Cardinal	Fly ash	Beryllium	ppm	10.775	11.45	12.125	TRUE
City Mine	FBC	Beryllium	ppm	0.25	0.25	0.25	TRUE
Freeport Mine	FGD waste	Beryllium	ppm	0.25	0.25	0.25	TRUE
Lone Mtn	Fly ash	Beryllium	ppm	24	24	24	TRUE
Martins Creek	Bottom ash	Beryllium	ppm	0.5	2.5	6.25	TRUE
Martins Creek	Fly ash	Beryllium	ppm	2.975	4	5.25	TRUE
Miller	Fly ash	Beryllium	ppm	2.2	2.2	2.2	TRUE
NETL	Bottom ash	Beryllium	ppm	9	9	9	TRUE
NETL	FBC	Beryllium	ppm	6.75	9.5	12.25	TRUE
NETL	Fly ash	Beryllium	ppm	4.75	9	12.25	TRUE
NETL	Slag	Beryllium	ppm	1	1	1	TRUE
Nucla	FBC	Beryllium	ppm	3.05	4.1	5.15	TRUE
Nucla2	FBC	Beryllium	ppm	3.4	5.5	5.5	TRUE
aceAnalytical (2010	Slag	Beryllium	ppm	3.4	3.4	3.4	TRUE
Paradise	Fly ash	Beryllium	ppm	10	10	10	TRUE
Pleasant Prairie	Fly ash	Beryllium	ppm	3.2	3.2	3.2	TRUE
Shawnee	FBC	Beryllium	ppm	0.1	0.1	0.1	TRUE
Sioux	Fly ash	Beryllium	ppm	8.725	8.85	8.975	TRUE
Stanton	Fly ash	Beryllium	ppm	28.5	28.5	28.5	TRUE
USGS	Fly ash	Beryllium	ppm	13.5	16	18.25	TRUE
Xcel/MSI	Fly ash	Beryllium	ppm	2.625	3.7	4.625	TRUE
Yates	Fly ash	Beryllium	ppm	16.6	16.6	16.6	TRUE
Zhang et al. (2001)	Fly Ash	Beryllium	ppm	10	10	10	TRUE
1	FBC	Beryllium	ppm	0.9425	1.1	1.2725	TRUE
10	FBC	Beryllium	ppm	1.5625	1.875	2.1875	TRUE
17	FBC	Beryllium	ppm	1.95	2.7	2.775	TRUE
18	FBC	Beryllium	ppm	9.5	11	11.5	TRUE
19	FBC	Beryllium	ppm	2.5	2.5	2.5	TRUE
2	FBC	Beryllium	ppm	0.5	0.7875	1.075	TRUE
26	FBC	Beryllium	ppm	1.2125	1.725	2.275	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
28	FBC	Beryllium	ppm	7	7	7	TRUE
3	FBC	Beryllium	ppm	1.25	1.25	1.25	TRUE
30	FBC	Beryllium	ppm	1.2825	2.075	2.7625	TRUE
39	FBC	Beryllium	ppm	1.875	3.25	4.625	TRUE
5	FBC	Beryllium	ppm	1.025	1.1	1.925	TRUE
8	FBC	Beryllium	ppm	9.5	9.5	9.5	TRUE
Baldwin	Fly ash	Beryllium	ppm	15.8	15.8	15.8	TRUE
CLSM	Combined ash	Beryllium	ppm	3.7	3.7	3.7	TRUE
CLSM	FBC	Beryllium	ppm	19	19	19	TRUE
Cleveland	Fly ash	Boron	ppm	0.186	0.186	0.186	TRUE
Emerald Anthracite	Ash (NOS)	Boron	ppm	26.98	28.04	29.35	TRUE
Fleming	FBC	Boron	ppm	190	190	190	TRUE
Gale	Ash (NOS)	Boron	ppm	25	25	25	TRUE
HA	Ash & coal waste	Boron	ppm	12	12	15	TRUE
Harrim 3019	Ash (NOS)	Boron	ppm	85	85	85	TRUE
Harrim 3019	Bottom ash	Boron	ppm	76	89	102	TRUE
Harrim 3019	Fly ash	Boron	ppm	83.65	94.9	130	TRUE
an Coal Corporatio	Ash (NOS)	Boron	ppm	99.1	190	243	TRUE
an Coal Corporatio	Bottom ash	Boron	ppm	18.275	30.55	87.825	TRUE
an Coal Corporatio	Fly ash	Boron	ppm	95.25	108.5	121.75	TRUE
Coal Corporation 5	Bottom ash	Boron	ppm	114.35	125.7	137.05	TRUE
Coal Corporation 5	Fly ash	Boron	ppm	150.6	153.2	155.8	TRUE
ddo Highland Coal (	Ash (NOS)	Boron	ppm	28.3	39.6	329.3	TRUE
ddo Highland Coal (	Bottom ash	Boron	ppm	83.4	83.4	83.4	TRUE
Knickerbocker Pit	FBC	Boron	ppm	13.825	19.68	28.06	TRUE
gh Coal and Naviga	Ash (NOS)	Boron	ppm	21.1	26	55	TRUE
LIMB Site	Ash (NOS)	Boron	ppm	400	400	400	TRUE
ttle Sandy #10 Min	Bottom ash	Boron	ppm	300	300	300	TRUE
ttle Sandy #10 Min	Combined ash	Boron	ppm	5.1	68	76	TRUE
ttle Sandy #10 Min	FGD waste	Boron	ppm	128	146	153	TRUE
ttle Sandy #10 Min	Fly ash	Boron	ppm	530	530	530	TRUE
Martins Creek	Bottom ash	Boron	ppm	145	162	247.2	TRUE
Martins Creek	Fly ash	Boron	ppm	345	425	520	TRUE
McCloskey Site	FBC	Boron	ppm	0.083	0.092	0.101	TRUE
McKay Site	FBC	Boron	ppm	37.75	41.5	45.25	TRUE
Miller Creek Mine	Bottom ash	Boron	ppm	13	68	266	TRUE
Miller Creek Mine	Combined ash	Boron	ppm	32.75	68.5	110	TRUE
Miller Creek Mine	Fly ash	Boron	ppm	160.25	200	290.75	TRUE
N & L Coal Co.	Ash (NOS)	Boron	ppm	10.1	60	144	TRUE
N & L Coal Co.-2	Ash (NOS)	Boron	ppm	17	133	195	TRUE
o. 1 Contracting Co	Ash (NOS)	Boron	ppm	33	33	33	TRUE
el Supply Company	Ash (NOS)	Boron	ppm	18.8	54.4	55	TRUE
el Supply Company	Ash (NOS)	Boron	ppm	25.6	30.4	33.7	TRUE
el Supply Company	Ash (NOS)	Boron	ppm	58.55	58.6	58.65	TRUE
rthampton400002	Ash (NOS)	Boron	ppm	17.3	17.3	17.3	TRUE
heast Energy Com	Ash (NOS)	Boron	ppm	48.65	112.7	190.9	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
heast Energy Com	Bottom ash	Boron	ppm	50	50	50	TRUE
heast Energy Com	Fly ash	Boron	ppm	130	130	130	TRUE
eastern Power Cor	Ash (NOS)	Boron	ppm	19	19	19	TRUE
eastern Power Cor	Bottom ash	Boron	ppm	3.3	5	16.2	TRUE
eastern Power Cor	Fly ash	Boron	ppm	6.175	22.5	34.975	TRUE
Nucla	FBC	Boron	ppm	56.25	57.5	58.75	TRUE
Nucla2	FBC	Boron	ppm	58.75	90	90	TRUE
Oak Creek	Bottom ash	Boron	ppm	100	100	100	TRUE
Pacton Corp	Bottom ash	Boron	ppm	244	244	244	TRUE
Pacton Corp	Fly ash	Boron	ppm	84	237	239.5	TRUE
Pagnotti Coal Co.	Ash (NOS)	Boron	ppm	25.01	33.34	41.67	TRUE
Pagnotti Coal Co.	Fly ash	Boron	ppm	3	3	3	TRUE
Panther Creek	FBC	Boron	ppm	17.5	21.5	27.715	TRUE
ett et al. (1993) Co	Fly Ash	Boron	ppm	730	935	1125	TRUE
Pleasant Prairie	Bottom ash	Boron	ppm	340	340	340	TRUE
Porter Associates	Ash (NOS)	Boron	ppm	7.655	84.2	155.5	TRUE
Porter Associates	Bottom ash	Boron	ppm	15.775	27.3	74.475	TRUE
Shawnee	FBC	Boron	ppm	5	131	170	TRUE
Silverton	Ash (NOS)	Boron	ppm	18.25	20.5	22.75	TRUE
ehanna Coal Comp	Ash (NOS)	Boron	ppm	17.425	20.3	24.75	TRUE
hanna Coal Compa	Ash (NOS)	Boron	ppm	12.235	20.5	27.8375	TRUE
Tracy Vein Slope	Ash (NOS)	Boron	ppm	151.575	192	198.75	TRUE
Tracy Vein Slope	Bottom ash	Boron	ppm	44.375	50.65	56.925	TRUE
Tracy Vein Slope	FBC	Boron	ppm	7.43	7.43	7.43	TRUE
Universal	Combined ash	Boron	ppm	181	193	215	TRUE
wood Energy Prop	Ash (NOS)	Boron	ppm	7.2	10.4	17.3	TRUE
Wheelabrator	FBC	Boron	ppm	6.8	14.4	32.19	TRUE
Xcel/MSI	Fly ash	Boron	ppm	589.25	737.5	1304.25	TRUE
Zhang et al. (2001)	Fly Ash	Boron	ppm	140	360	860	TRUE
12	FBC	Boron	ppm	17	19.03	19.64	TRUE
14	FBC	Boron	ppm	20.8	20.8	20.8	TRUE
17	FBC	Boron	ppm	28.25	29.65	37.575	TRUE
18	FBC	Boron	ppm	472.5	641	646.5	TRUE
2	FBC	Boron	ppm	0.056	0.38385	0.7117	TRUE
20	FBC	Boron	ppm	20.145	24	45.375	TRUE
21	FBC	Boron	ppm	5.5	15	20	TRUE
22	FBC	Boron	ppm	49	49	49	TRUE
26	FBC	Boron	ppm	1.25	1.25	1.25	TRUE
27	FBC	Boron	ppm	571	571	571	TRUE
28	FBC	Boron	ppm	91.775	105.45	117.25	TRUE
29	FBC	Boron	ppm	0.025	0.025	0.025	TRUE
30	FBC	Boron	ppm	20.4625	32.25	43.495	TRUE
31	FBC	Boron	ppm	560	930	1300	TRUE
37	FBC	Boron	ppm	10.35	15.9	21.45	TRUE
38	FBC	Boron	ppm	15.585	31.9	38.1925	TRUE
4	FBC	Boron	ppm	8.026	14.65	19.65	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
6	FBC	Boron	ppm	56.7	73.8	90.9	TRUE
7	FBC	Boron	ppm	2473	2473	2473	TRUE
A/C Fuels Company	Ash (NOS)	Boron	ppm	28	28	28	TRUE
B-D Mining Co.	Ash (NOS)	Boron	ppm	20.445	25.975	35.5	TRUE
B-D Mining Co.	Bottom ash	Boron	ppm	6	6	8	TRUE
B-D Mining Co.	Fly ash	Boron	ppm	23.5	37.5	50	TRUE
CLSM	Combined ash	Boron	ppm	79	79	79	TRUE
CLSM	FBC	Boron	ppm	78	78	78	TRUE
Coal Creek	Bottom ash	Boron	ppm	0.901	0.901	0.901	TRUE
Coal Creek	Fly ash	Boron	ppm	1.32	1.32	1.32	TRUE
Deer Ridge Mine	Fly ash	Boron	ppm	35.5	53	125.5	TRUE
DPC	Bottom ash	Boron	ppm	54.1	54.1	54.1	TRUE
DPC	Fly ash	Boron	ppm	754	754	754	TRUE
ern Analytical, ID: 5	Slag	Boron	ppm	23	23	23	TRUE
Edgewater	Bottom ash	Boron	ppm	290	290	290	TRUE
Zhang et al. (2001)	Fly Ash	Bromine	ppm	10	10	10	FALSE
ern Analytical, ID: 5	Slag	CaCO3	ppm	21000	21000	21000	FALSE
Bowen	Fly ash	Cadmium	ppm	0.7	0.7	0.7	TRUE
Cardinal	Fly ash	Cadmium	ppm	1.085	1.17	1.255	TRUE
City Mine	FBC	Cadmium	ppm	2.5	2.5	2.5	TRUE
Cleveland	Fly ash	Cadmium	ppm	0.000165	0.000165	0.000165	TRUE
Emerald Anthracite	Ash (NOS)	Cadmium	ppm	1.144	1.188	2.394	TRUE
EORDC	FGD waste	Cadmium	ppm	0.1	0.1	0.1	TRUE
Fleming	FBC	Cadmium	ppm	1	1	1	TRUE
Freeport Mine	FGD waste	Cadmium	ppm	1	1	1	TRUE
Gale	Ash (NOS)	Cadmium	ppm	1	1	1	TRUE
HA	Ash & coal waste	Cadmium	ppm	0.25	0.25	0.25	TRUE
Harrim 3019	Ash (NOS)	Cadmium	ppm	2	2	2	TRUE
Harrim 3019	Fly ash	Cadmium	ppm	0.5	0.5	0.5	TRUE
an Coal Corporatio	Ash (NOS)	Cadmium	ppm	0.5375	1.335	3.0075	TRUE
an Coal Corporatio	Bottom ash	Cadmium	ppm	1.04	2.4	3.7	TRUE
an Coal Corporatio	Fly ash	Cadmium	ppm	2.5	2.5	2.5	TRUE
Coal Corporation 5	Bottom ash	Cadmium	ppm	1.7125	3.175	4.6375	TRUE
Coal Corporation 5	Fly ash	Cadmium	ppm	1.375	2.25	3.125	TRUE
ddo Highland Coal (	Ash (NOS)	Cadmium	ppm	0.5	0.5	1.245	TRUE
ddo Highland Coal (	Bottom ash	Cadmium	ppm	0.5	0.5	0.5	TRUE
Knickerbocker Pit	FBC	Cadmium	ppm	1	1.05	1.2	TRUE
gh Coal and Naviga	Ash (NOS)	Cadmium	ppm	0.5	0.5	0.5	TRUE
LIMB Site	Ash (NOS)	Cadmium	ppm	0.305	0.31	0.315	TRUE
ttle Sandy #10 Min	Bottom ash	Cadmium	ppm	2.5	2.5	2.5	TRUE
ttle Sandy #10 Min	Combined ash	Cadmium	ppm	0.65	1.02	1.25	TRUE
ttle Sandy #10 Min	FGD waste	Cadmium	ppm	0.73	0.96	1.03	TRUE
ttle Sandy #10 Min	Fly ash	Cadmium	ppm	2.2	2.2	2.2	TRUE
Lone Mtn	Fly ash	Cadmium	ppm	11.86	11.86	11.86	TRUE
Mandan	FBC	Cadmium	ppm	0.33	0.33	0.33	TRUE
Martins Creek	Bottom ash	Cadmium	ppm	1	2	4	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Martins Creek	Fly ash	Cadmium	ppm	1	1	2	TRUE
McCloskey Site	FBC	Cadmium	ppm	0.025	0.025	0.025	TRUE
McKay Site	FBC	Cadmium	ppm	2.5	2.5	2.5	TRUE
Miller	Fly ash	Cadmium	ppm	1.6	1.6	1.6	TRUE
Miller Creek Mine	Bottom ash	Cadmium	ppm	0.7	2.19	2.7	TRUE
Miller Creek Mine	Combined ash	Cadmium	ppm	0.09575	0.4	1.725	TRUE
Miller Creek Mine	Fly ash	Cadmium	ppm	0.65	0.65	2.475	TRUE
N & L Coal Co.	Ash (NOS)	Cadmium	ppm	1.42	2.7	5	TRUE
N & L Coal Co.-2	Ash (NOS)	Cadmium	ppm	2	2	3	TRUE
Nepco	FBC	Cadmium	ppm	0.5	0.5	0.5	TRUE
NETL	Bottom ash	Cadmium	ppm	0.2	0.2	0.2	TRUE
NETL	FBC	Cadmium	ppm	0.9	1.1	1.3	TRUE
NETL	Fly ash	Cadmium	ppm	0.5	3.75	8.125	TRUE
NETL	Slag	Cadmium	ppm	5	5	5	TRUE
o. 1 Contracting Co	Ash (NOS)	Cadmium	ppm	3.6	3.6	3.6	TRUE
uel Supply Company	Ash (NOS)	Cadmium	ppm	0.5	0.5	0.5	TRUE
uel Supply Company	Ash (NOS)	Cadmium	ppm	1.025975	2.05065	3.075325	TRUE
uel Supply Company	Ash (NOS)	Cadmium	ppm	0.5	0.5	0.5	TRUE
orthampton400002	Ash (NOS)	Cadmium	ppm	0.5	0.5	0.5	TRUE
heast Energy Comp	Ash (NOS)	Cadmium	ppm	0.3375	0.75	0.975	TRUE
heast Energy Comp	Bottom ash	Cadmium	ppm	0.05	0.05	0.05	TRUE
heast Energy Comp	Fly ash	Cadmium	ppm	0.4	0.4	0.4	TRUE
eastern Power Con	Bottom ash	Cadmium	ppm	0.52125	0.7175	0.8725	TRUE
eastern Power Con	Fly ash	Cadmium	ppm	0.64075	1	1.465	TRUE
Nucla	FBC	Cadmium	ppm	1.825	1.95	2.075	TRUE
Nucla2	FBC	Cadmium	ppm	0.22	0.34	0.345	TRUE
Oak Creek	Bottom ash	Cadmium	ppm	0.8	0.8	0.8	TRUE
aceAnalytical (2010	Slag	Cadmium	ppm	0.0245	0.0245	0.0245	TRUE
Pacton Corp	Bottom ash	Cadmium	ppm	8	8	8	TRUE
Pacton Corp	Fly ash	Cadmium	ppm	8	10	20	TRUE
Pagnotti Coal Co.	Ash (NOS)	Cadmium	ppm	0.95	1.5	1.65	TRUE
Pagnotti Coal Co.	Fly ash	Cadmium	ppm	0.25	0.25	0.25	TRUE
Panther Creek	FBC	Cadmium	ppm	0.625	0.75	0.875	TRUE
Paradise	Fly ash	Cadmium	ppm	5.2	5.2	5.2	TRUE
ett et al. (1993) Co	Fly Ash	Cadmium	ppm	0.5	0.5	0.5	TRUE
Plant 10	FBC	Cadmium	ppm	1.1	1.6	2.275	TRUE
Plant 12	FBC	Cadmium	ppm	1.9	2.1	2.5	TRUE
Plant 8	FBC	Cadmium	ppm	0.75	2.49	3.5	TRUE
Plant 9	FBC	Cadmium	ppm	0.025	0.025	0.025	TRUE
Pleasant Prairie	Bottom ash	Cadmium	ppm	0.05	0.05	0.05	TRUE
Pleasant Prairie	Fly ash	Cadmium	ppm	1.8	1.8	1.8	TRUE
Porter Associates	Ash (NOS)	Cadmium	ppm	0.5	1.49	3.5075	TRUE
Porter Associates	Bottom ash	Cadmium	ppm	0.5	0.5	0.725	TRUE
Scrubgrass	FBC	Cadmium	ppm	0.7	0.7	0.7	TRUE
Shawnee	FBC	Cadmium	ppm	0.21	0.4	1.1	TRUE
Silverton	Ash (NOS)	Cadmium	ppm	2	2	2	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Sioux	Fly ash	Cadmium	ppm	2.85	3.3	3.75	TRUE
Stanton	Fly ash	Cadmium	ppm	0.9	0.9	0.9	TRUE
ehanna Coal Comp	Ash (NOS)	Cadmium	ppm	0.25	0.425	0.8	TRUE
hanna Coal Compa	Ash (NOS)	Cadmium	ppm	0.6	1.4	2.8	TRUE
SW	Bottom ash	Cadmium	ppm	0.1	0.1	0.1	TRUE
SW	Fly ash	Cadmium	ppm	1.05	1.05	1.05	TRUE
Tracy Vein Slope	Ash (NOS)	Cadmium	ppm	0.74725	0.8995	1.4475	TRUE
Tracy Vein Slope	Bottom ash	Cadmium	ppm	0.613	0.62	0.627	TRUE
Universal	Combined ash	Cadmium	ppm	0.925	1.6	2.25	TRUE
USGS	Fly ash	Cadmium	ppm	0.4	0.6	2.55	TRUE
wood Energy Prop	Ash (NOS)	Cadmium	ppm	0.632	0.7285	0.8525	TRUE
Wheelabrator	FBC	Cadmium	ppm	0.95	1.1	1.3	TRUE
Xcel/MSI	Fly ash	Cadmium	ppm	1.0725	1.22	1.735	TRUE
Yates	Fly ash	Cadmium	ppm	0.9	0.9	0.9	TRUE
Zhang et al. (2001)	Fly Ash	Cadmium	ppm	2.5	2.5	24	TRUE
1	FBC	Cadmium	ppm	1.34	1.75	2.29	TRUE
10	FBC	Cadmium	ppm	1.5625	1.875	2.1875	TRUE
11	FBC	Cadmium	ppm	0.34375	6.675	13.25	TRUE
12	FBC	Cadmium	ppm	0.125	0.125	0.40625	TRUE
14	FBC	Cadmium	ppm	0.125	0.125	0.125	TRUE
17	FBC	Cadmium	ppm	1.6	3.15	3.875	TRUE
18	FBC	Cadmium	ppm	1.75	3	3.5	TRUE
19	FBC	Cadmium	ppm	2.5	2.5	2.5	TRUE
2	FBC	Cadmium	ppm	0.458	0.458	0.458	TRUE
20	FBC	Cadmium	ppm	1.15	1.4	2.55	TRUE
21	FBC	Cadmium	ppm	0.125	0.125	0.125	TRUE
23	FBC	Cadmium	ppm	0.455	0.49	0.545	TRUE
26	FBC	Cadmium	ppm	0.25	0.75	1.5625	TRUE
27	FBC	Cadmium	ppm	1	1	1	TRUE
28	FBC	Cadmium	ppm	0.875	1.125	1.3625	TRUE
29	FBC	Cadmium	ppm	0.0125	0.0125	0.0125	TRUE
3	FBC	Cadmium	ppm	1.25	1.25	1.25	TRUE
30	FBC	Cadmium	ppm	0.625	1.35	2.275	TRUE
31	FBC	Cadmium	ppm	5.225	5.45	5.675	TRUE
37	FBC	Cadmium	ppm	2.775	4.3	5.65	TRUE
38	FBC	Cadmium	ppm	0.125	0.535	1.15	TRUE
39	FBC	Cadmium	ppm	0.5	0.5	0.5	TRUE
4	FBC	Cadmium	ppm	0.031875	0.7979	1.038	TRUE
5	FBC	Cadmium	ppm	0.25	0.25	0.25	TRUE
6	FBC	Cadmium	ppm	1.258125	1.29625	1.334375	TRUE
7	FBC	Cadmium	ppm	5.96	5.96	5.96	TRUE
8	FBC	Cadmium	ppm	0.9	0.9	0.9	TRUE
A/C Fuels Company	Ash (NOS)	Cadmium	ppm	0.5	0.5	0.5	TRUE
Baldwin	Fly ash	Cadmium	ppm	11.3	11.3	11.3	TRUE
B-D Mining Co.	Ash (NOS)	Cadmium	ppm	0.31	0.6	0.8	TRUE
B-D Mining Co.	Bottom ash	Cadmium	ppm	1.3	3	3.6	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
B-D Mining Co.	Fly ash	Cadmium	ppm	1.3	1.5	2	TRUE
CLSM	Combined ash	Cadmium	ppm	760.25	760.25	760.25	TRUE
CLSM	FBC	Cadmium	ppm	292.8	292.8	292.8	TRUE
Coal Creek	Bottom ash	Cadmium	ppm	0.0002	0.0002	0.0002	TRUE
Coal Creek	Fly ash	Cadmium	ppm	0.0007	0.0007	0.0007	TRUE
Deer Ridge Mine	Fly ash	Cadmium	ppm	0.0575	0.65	1	TRUE
DPC	Bottom ash	Cadmium	ppm	0.28	0.28	0.28	TRUE
DPC	Fly ash	Cadmium	ppm	0.84	0.84	0.84	TRUE
ern Analytical, ID: 5	Slag	Cadmium	ppm	0.25	0.25	0.25	TRUE
Edgewater	Bottom ash	Cadmium	ppm	0.5	0.5	0.5	TRUE
EERC?	Combined ash	Cadmium	ppm	0.5	0.5	0.5	TRUE
EERC?	FGD	Cadmium	ppm	0.5	0.5	1.08	TRUE
EERC?	FGD gypsum	Cadmium	ppm	0.5	0.5	0.8475	TRUE
EERC?	FGD gypsum liquids	Cadmium	mg/L	0.00479	0.00479	0.00479	TRUE
EERC?	FGD liquids	Cadmium	mg/L	0.001765	0.00249	0.003253	TRUE
EERC?	FGD liquids	Cadmium	ppm	0.5	0.5	0.5	TRUE
EERC?	Fly Ash	Cadmium	ppm	0.5	0.5	1.8625	TRUE
City Mine	FBC	Calcium	ppm	1534.5	2403	4515	TRUE
Cleveland	Fly ash	Calcium	ppm	15.4	15.4	15.4	TRUE
Freeport Mine	FGD waste	Calcium	ppm	207000	207000	207000	TRUE
HA	Ash & coal waste	Calcium	ppm	3000	3600	4550	TRUE
Martins Creek	Bottom ash	Calcium	ppm	10400	12426	21810	TRUE
Martins Creek	Fly ash	Calcium	ppm	14700	16439	19700	TRUE
McKay Site	FBC	Calcium	ppm	85250	103500	121750	TRUE
Miller Creek Mine	Bottom ash	Calcium	ppm	1385	2050	6348	TRUE
Miller Creek Mine	Combined ash	Calcium	ppm	979.75	2450	14250	TRUE
Miller Creek Mine	Fly ash	Calcium	ppm	3227	5089	6243.13	TRUE
Nucla	FBC	Calcium	ppm	87075	93050	99025	TRUE
Nucla2	FBC	Calcium	ppm	60500	64000	82000	TRUE
Oak Creek	Bottom ash	Calcium	ppm	12094	12094	12094	TRUE
Pagnotti Coal Co.	Ash (NOS)	Calcium	ppm	22280	22280	22280	TRUE
Pleasant Prairie	Bottom ash	Calcium	ppm	31360	31360	31360	TRUE
Shawnee	FBC	Calcium	ppm	260000	260000	279500	TRUE
CLSM	Combined ash	Calcium	ppm	594.6	594.6	594.6	TRUE
CLSM	FBC	Calcium	ppm	40581.5	40581.5	40581.5	TRUE
Deer Ridge Mine	Fly ash	Calcium	ppm	657.25	1210	3072.825	TRUE
DPC	Bottom ash	Calcium	ppm	5330	5330	5330	TRUE
DPC	Fly ash	Calcium	ppm	12700	12700	12700	TRUE
ern Analytical, ID: 5	Slag	Calcium	ppm	6200	6200	6200	TRUE
Edgewater	Bottom ash	Calcium	ppm	113000	113000	113000	TRUE
Bowen	Fly ash	Chloride	ppm	9	9	9	TRUE
Cardinal	Fly ash	Chloride	ppm	146.25	200.5	254.75	TRUE
ttle Sandy #10 Min	Bottom ash	Chloride	ppm	29	29	29	TRUE
ttle Sandy #10 Min	Combined ash	Chloride	ppm	10	17	63	TRUE
ttle Sandy #10 Min	FGD waste	Chloride	ppm	171.5	330	376.5	TRUE
ttle Sandy #10 Min	Fly ash	Chloride	ppm	10	10	10	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Lone Mtn	Fly ash	Chloride	ppm	333	333	333	TRUE
Miller	Fly ash	Chloride	ppm	9	9	9	TRUE
Miller Creek Mine	Bottom ash	Chloride	ppm	2.5	2.5	72	TRUE
Miller Creek Mine	Combined ash	Chloride	ppm	2.5	40	225	TRUE
Miller Creek Mine	Fly ash	Chloride	ppm	5	5	5	TRUE
Paradise	Fly ash	Chloride	ppm	94	94	94	TRUE
Pleasant Prairie	Fly ash	Chloride	ppm	18	18	18	TRUE
Sioux	Fly ash	Chloride	ppm	165	321	477	TRUE
Stanton	Fly ash	Chloride	ppm	216	216	216	TRUE
Universal	Combined ash	Chloride	ppm	10.5	14	20	TRUE
Yates	Fly ash	Chloride	ppm	108	108	108	TRUE
Baldwin	Fly ash	Chloride	ppm	415	415	415	TRUE
CLSM	Combined ash	Chloride	ppm	65.5	65.5	65.5	TRUE
CLSM	FBC	Chloride	ppm	1781	1781	1781	TRUE
Deer Ridge Mine	Fly ash	Chloride	ppm	6.9	150	180.75	TRUE
DPC	Bottom ash	Chloride	ppm	21.3	21.3	21.3	TRUE
DPC	Fly ash	Chloride	ppm	85.4	85.4	85.4	TRUE
Zhang et al. (2001)	Fly Ash	Chlorine	ppm	15	19	43	FALSE
Bowen	Fly ash	Chromium	ppm	168.1	168.1	168.1	TRUE
CAER	Bottom ash	Chromium	ppm	87.5	95	104	TRUE
CAER	Fly ash	Chromium	ppm	136	179	182	TRUE
Cardinal	Fly ash	Chromium	ppm	166.35	170.6	174.85	TRUE
City Mine	FBC	Chromium	ppm	156.5	181	181.5	TRUE
Philadelphia Girard	Ash (NOS)	Chromium	ppm	28.4	28.4	28.4	TRUE
Cleveland	Fly ash	Chromium	ppm	0.051	0.051	0.051	TRUE
Emerald Anthracite	Ash (NOS)	Chromium	ppm	31.075	40.067	50.875	TRUE
EORDC	FGD waste	Chromium	ppm	24	24	24	TRUE
Fleming	FBC	Chromium	ppm	37	37	37	TRUE
Freeport Mine	FGD waste	Chromium	ppm	2	2	2	TRUE
Gale	Ash (NOS)	Chromium	ppm	40	40	40	TRUE
Girard Estate	Ash (NOS)	Chromium	ppm	20	20	20	TRUE
HA	Ash & coal waste	Chromium	ppm	11.5	12	14	TRUE
Harrim 3019	Ash (NOS)	Chromium	ppm	294.991	294.991	294.991	TRUE
Harrim 3019	Bottom ash	Chromium	ppm	61.725	65.85	69.975	TRUE
Harrim 3019	Fly ash	Chromium	ppm	52.25	64.5	85.2	TRUE
an Coal Corporatio	Ash (NOS)	Chromium	ppm	21.325	32.55	48.175	TRUE
an Coal Corporatio	Bottom ash	Chromium	ppm	4.025	8.8	26	TRUE
an Coal Corporatio	Fly ash	Chromium	ppm	85.2	104	122.8	TRUE
Coal Corporation 5	Ash (NOS)	Chromium	ppm	26	26	26	TRUE
Coal Corporation 5	Bottom ash	Chromium	ppm	38.25	44.5	50.75	TRUE
Coal Corporation 5	Fly ash	Chromium	ppm	47.75	55.5	63.25	TRUE
ldo Highland Coal (	Ash (NOS)	Chromium	ppm	10.5	48	54.5	TRUE
ldo Highland Coal (	Bottom ash	Chromium	ppm	14.8	14.8	14.8	TRUE
Kentucky	Bottom ash	Chromium	ppm	102.5	125	142.5	TRUE
Kentucky	Fly ash	Chromium	ppm	198	216	235.75	TRUE
Knickerbocker Pit	FBC	Chromium	ppm	28.25	35.5	41.075	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
KY	FGD waste	Chromium	ppm	0.005	0.005	0.005	TRUE
gh Coal and Naviga	Ash (NOS)	Chromium	ppm	40	51	52	TRUE
LIMB Site	Ash (NOS)	Chromium	ppm	54.5	69	83.5	TRUE
ttle Sandy #10 Min	Bottom ash	Chromium	ppm	13	13	13	TRUE
ttle Sandy #10 Min	Combined ash	Chromium	ppm	5.1	5.9	7.6	TRUE
ttle Sandy #10 Min	FGD waste	Chromium	ppm	8.85	9.4	10.35	TRUE
ttle Sandy #10 Min	Fly ash	Chromium	ppm	63	63	63	TRUE
Lone Mtn	Fly ash	Chromium	ppm	148.7	148.7	148.7	TRUE
Mandan	FBC	Chromium	ppm	10.2	10.2	10.2	TRUE
Martins Creek	Bottom ash	Chromium	ppm	191	197	247	TRUE
Martins Creek	Fly ash	Chromium	ppm	173.1	196	213.52	TRUE
McCloskey Site	FBC	Chromium	ppm	33.21875	66.3125	99.40625	TRUE
McKay Site	FBC	Chromium	ppm	57.25	58.5	59.75	TRUE
Miller	Fly ash	Chromium	ppm	59.6	59.6	59.6	TRUE
Miller Creek Mine	Bottom ash	Chromium	ppm	0.38	14	20.37	TRUE
Miller Creek Mine	Combined ash	Chromium	ppm	4.925	9.9	22	TRUE
Miller Creek Mine	Fly ash	Chromium	ppm	21.25	26	34	TRUE
N & L Coal Co.	Ash (NOS)	Chromium	ppm	19.55	132.7	246.4695	TRUE
N & L Coal Co.-2	Ash (NOS)	Chromium	ppm	57	157	203	TRUE
Nepco	FBC	Chromium	ppm	1380	1380	1380	TRUE
NETL	Bottom ash	Chromium	ppm	119	119	119	TRUE
NETL	FBC	Chromium	ppm	97.5	108	118.5	TRUE
NETL	Fly ash	Chromium	ppm	95.75	167.5	176.75	TRUE
NETL	Slag	Chromium	ppm	5970	5970	5970	TRUE
o. 1 Contracting Co	Ash (NOS)	Chromium	ppm	15.15	24.3	33.45	TRUE
uel Supply Company	Ash (NOS)	Chromium	ppm	29	31	76	TRUE
uel Supply Company	Ash (NOS)	Chromium	ppm	27.5	41.5	72.875	TRUE
uel Supply Company	Ash (NOS)	Chromium	ppm	32.25	43.5	54.75	TRUE
orthampton400002	Ash (NOS)	Chromium	ppm	31	31	31	TRUE
heast Energy Com	Ash (NOS)	Chromium	ppm	29.75	36	40	TRUE
heast Energy Com	Bottom ash	Chromium	ppm	6.2	6.2	6.2	TRUE
heast Energy Com	Fly ash	Chromium	ppm	26	26	26	TRUE
eastern Power Con	Ash (NOS)	Chromium	ppm	18.35	22.5	25.5	TRUE
eastern Power Con	Bottom ash	Chromium	ppm	7.98	10.25	15.125	TRUE
eastern Power Con	Fly ash	Chromium	ppm	18.25	25.25	29.475	TRUE
Nucla	FBC	Chromium	ppm	27.5	29	30.5	TRUE
Nucla2	FBC	Chromium	ppm	9.2	13	13.5	TRUE
Oak Creek	Bottom ash	Chromium	ppm	140	140	140	TRUE
aceAnalytical (2010	Slag	Chromium	ppm	45.1	45.1	45.1	TRUE
Pacton Corp	Ash (NOS)	Chromium	ppm	49	49	49	TRUE
Pacton Corp	Bottom ash	Chromium	ppm	40	40	40	TRUE
Pacton Corp	Fly ash	Chromium	ppm	66.5	84	160	TRUE
Pagnotti Coal Co.	Ash (NOS)	Chromium	ppm	27.5	29.4	45.5	TRUE
Pagnotti Coal Co.	Fly ash	Chromium	ppm	46	46	46	TRUE
Panther Creek	FBC	Chromium	ppm	40.5	44.8	49.075	TRUE
Paradise	Fly ash	Chromium	ppm	148.5	148.5	148.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ett et al. (1993) Co	Fly Ash	Chromium	ppm	53.25	61.5	70.25	TRUE
Plant 10	FBC	Chromium	ppm	23.95	30.8	42.45	TRUE
Plant 12	FBC	Chromium	ppm	21.8	22.8	33.8	TRUE
Plant 8	FBC	Chromium	ppm	26.5	30	33.75	TRUE
Plant 9	FBC	Chromium	ppm	79.5	97.3	109.375	TRUE
Pleasant Prairie	Bottom ash	Chromium	ppm	37	37	37	TRUE
Pleasant Prairie	Fly ash	Chromium	ppm	114.3	114.3	114.3	TRUE
Porter Associates	Ash (NOS)	Chromium	ppm	18.5	27	46.7	TRUE
Porter Associates	Bottom ash	Chromium	ppm	8.975	29.5	58.25	TRUE
ylkill Reclamation (	Ash (NOS)	Chromium	ppm	23	23	23	TRUE
Scrubgrass	FBC	Chromium	ppm	95	95	95	TRUE
Shawnee	FBC	Chromium	ppm	0.9	9.7	76	TRUE
Silverton	Ash (NOS)	Chromium	ppm	46.375	52.75	59.125	TRUE
Sioux	Fly ash	Chromium	ppm	120.925	134.95	148.975	TRUE
Stanton	Fly ash	Chromium	ppm	170	170	170	TRUE
ehanna Coal Comp	Ash (NOS)	Chromium	ppm	33.9	43	48.5	TRUE
hanna Coal Compa	Ash (NOS)	Chromium	ppm	25.425	34.5	40.325	TRUE
SW	Bottom ash	Chromium	ppm	23.6	25.6	27.5	TRUE
SW	Fly ash	Chromium	ppm	15.4	18.6	28	TRUE
Tracy Vein Slope	Ash (NOS)	Chromium	ppm	30.175	41.45	52.325	TRUE
Tracy Vein Slope	Bottom ash	Chromium	ppm	15.9	21.7	27.5	TRUE
Tracy Vein Slope	FBC	Chromium	ppm	6.43	6.43	6.43	TRUE
Universal	Combined ash	Chromium	ppm	16	17	22.5	TRUE
USGS	Fly ash	Chromium	ppm	140	150	165	TRUE
wood Energy Prop	Ash (NOS)	Chromium	ppm	9.9375	15.6	19.4	TRUE
Wheelabrator	FBC	Chromium	ppm	15.175	18.15	27.3	TRUE
Xcel/MSI	Fly ash	Chromium	ppm	55.25	74.5	83	TRUE
Yates	Fly ash	Chromium	ppm	181	181	181	TRUE
Zhang et al. (2001)	Fly Ash	Chromium	ppm	31	60	81	TRUE
1	FBC	Chromium	ppm	14.96	16.39	19.6	TRUE
10	FBC	Chromium	ppm	33	37	41	TRUE
11	FBC	Chromium	ppm	59.25	63.5	67.75	TRUE
12	FBC	Chromium	ppm	38	44.05	51.3	TRUE
14	FBC	Chromium	ppm	48	48	48	TRUE
17	FBC	Chromium	ppm	27.5	37.5	50.5	TRUE
18	FBC	Chromium	ppm	25.5	30	30	TRUE
19	FBC	Chromium	ppm	12.9	12.9	12.9	TRUE
2	FBC	Chromium	ppm	4.1	12.715	21.33	TRUE
20	FBC	Chromium	ppm	36	47.3	52.19	TRUE
21	FBC	Chromium	ppm	30.5	40.5	47.575	TRUE
23	FBC	Chromium	ppm	26.9475	29.215	31.3325	TRUE
26	FBC	Chromium	ppm	18.5	21	23.5	TRUE
27	FBC	Chromium	ppm	37	37	37	TRUE
28	FBC	Chromium	ppm	56.125	72.75	99.5	TRUE
29	FBC	Chromium	ppm	45.625	52.85	72.75	TRUE
3	FBC	Chromium	ppm	28.75	29.5	30.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
30	FBC	Chromium	ppm	26.925	45.8	56.55	TRUE
31	FBC	Chromium	ppm	55.5	55.5	55.5	TRUE
37	FBC	Chromium	ppm	60	86	99.5	TRUE
38	FBC	Chromium	ppm	14.875	19.3	41.3	TRUE
39	FBC	Chromium	ppm	42.25	47.5	52.75	TRUE
4	FBC	Chromium	ppm	13.08	20.64	23.8	TRUE
5	FBC	Chromium	ppm	17.5	21	23	TRUE
6	FBC	Chromium	ppm	35.875	42.65	49.425	TRUE
7	FBC	Chromium	ppm	54.51	54.51	54.51	TRUE
8	FBC	Chromium	ppm	45	45	45	TRUE
A/C Fuels Company	Ash (NOS)	Chromium	ppm	4	4	4	TRUE
Baldwin	Fly ash	Chromium	ppm	448.8	448.8	448.8	TRUE
B-D Mining Co.	Ash (NOS)	Chromium	ppm	33.1	47.5	51.875	TRUE
B-D Mining Co.	Bottom ash	Chromium	ppm	30.5	38.5	44.775	TRUE
B-D Mining Co.	Fly ash	Chromium	ppm	61.85	73.2	86.725	TRUE
CLSM	Combined ash	Chromium	ppm	75.5	75.5	75.5	TRUE
CLSM	FBC	Chromium	ppm	26.7	26.7	26.7	TRUE
Coal Creek	Bottom ash	Chromium	ppm	0.045	0.045	0.045	TRUE
Coal Creek	Fly ash	Chromium	ppm	0.059	0.059	0.059	TRUE
Deer Ridge Mine	Fly ash	Chromium	ppm	8.575	11.12	38.6075	TRUE
DPC	Bottom ash	Chromium	ppm	9.8	9.8	9.8	TRUE
DPC	Fly ash	Chromium	ppm	50.2	50.2	50.2	TRUE
ern Analytical, ID: 5	Slag	Chromium	ppm	23	23	23	TRUE
Edgewater	Bottom ash	Chromium	ppm	54.4	54.4	54.4	TRUE
EERC?	Combined ash	Chromium	ppm	30.425	34.55	38.675	TRUE
EERC?	FGD	Chromium	ppm	10.4	37.3	51.6	TRUE
EERC?	FGD gypsum	Chromium	ppm	3.2675	3.67	3.995	TRUE
EERC?	FGD gypsum liquids	Chromium	mg/L	0.0099	0.0099	0.0099	TRUE
EERC?	FGD liquids	Chromium	mg/L	0.00395	0.005	0.0068	TRUE
EERC?	FGD liquids	Chromium	ppm	6.61	6.61	6.61	TRUE
EERC?	Fly Ash	Chromium	ppm	45.4	71.1	125	TRUE
Bowen	Fly ash	Cobalt	ppm	79.9	79.9	79.9	TRUE
CAER	Bottom ash	Cobalt	ppm	43	59	65.5	TRUE
CAER	Fly ash	Cobalt	ppm	71	72	76	TRUE
Cardinal	Fly ash	Cobalt	ppm	46.1	46.1	46.1	TRUE
Philadelphia Girard	Ash (NOS)	Cobalt	ppm	7.1	7.1	7.1	TRUE
Emerald Anthracite	Ash (NOS)	Cobalt	ppm	11.9	14.9	17.35	TRUE
Freeport Mine	FGD waste	Cobalt	ppm	2.5	2.5	2.5	TRUE
Girard Estate	Ash (NOS)	Cobalt	ppm	2	2	2	TRUE
Harrim 3019	Ash (NOS)	Cobalt	ppm	27	27	27	TRUE
Harrim 3019	Bottom ash	Cobalt	ppm	57.45	81.1	104.75	TRUE
Harrim 3019	Fly ash	Cobalt	ppm	24.5	29.7	36.5	TRUE
an Coal Corporatio	Ash (NOS)	Cobalt	ppm	4.6	8.1	10	TRUE
an Coal Corporatio	Bottom ash	Cobalt	ppm	1.37	3.37	19.06	TRUE
an Coal Corporatio	Fly ash	Cobalt	ppm	66.9	104.1	141.3	TRUE
Coal Corporation 5	Ash (NOS)	Cobalt	ppm	20	20	20	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Knickerbocker Pit	FBC	Cobalt	ppm	7.05	10	10.8	TRUE
KY	FGD waste	Cobalt	ppm	0.005	0.005	0.005	TRUE
gh Coal and Naviga	Ash (NOS)	Cobalt	ppm	9.7	12	17	TRUE
Lone Mtn	Fly ash	Cobalt	ppm	87.3	87.3	87.3	TRUE
Martins Creek	Bottom ash	Cobalt	ppm	53	55.5	64.35	TRUE
Martins Creek	Fly ash	Cobalt	ppm	24.83	27.4	35.415	TRUE
Miller	Fly ash	Cobalt	ppm	42.3	42.3	42.3	TRUE
N & L Coal Co.	Ash (NOS)	Cobalt	ppm	6.1675	27.75	47.2125	TRUE
N & L Coal Co.-2	Ash (NOS)	Cobalt	ppm	9	23.45	25.1	TRUE
NETL	Bottom ash	Cobalt	ppm	26	26	26	TRUE
NETL	FBC	Cobalt	ppm	28.75	29.5	30.25	TRUE
NETL	Fly ash	Cobalt	ppm	25	39.5	50	TRUE
NETL	Slag	Cobalt	ppm	10	10	10	TRUE
el Supply Company	Ash (NOS)	Cobalt	ppm	5.1	7	7.7	TRUE
heast Energy Com	Ash (NOS)	Cobalt	ppm	15	17	19	TRUE
eastern Power Con	Bottom ash	Cobalt	ppm	1.29	1.34	1.345	TRUE
eastern Power Con	Fly ash	Cobalt	ppm	3.15	3.22	3.41	TRUE
Nucla	FBC	Cobalt	ppm	10	10	10	TRUE
Nucla2	FBC	Cobalt	ppm	5	8.1	8.2	TRUE
aceAnalytical (2010	Slag	Cobalt	ppm	16.1	16.1	16.1	TRUE
Pacton Corp	Ash (NOS)	Cobalt	ppm	8	8	8	TRUE
Panther Creek	FBC	Cobalt	ppm	3.25	5.5	8.975	TRUE
ett et al. (1993) Cor	Fly Ash	Cobalt	ppm	28.5	34.5	42	TRUE
Pleasant Prairie	Fly ash	Cobalt	ppm	54.1	54.1	54.1	TRUE
Porter Associates	Ash (NOS)	Cobalt	ppm	5.765	8.63	28.05	TRUE
Porter Associates	Bottom ash	Cobalt	ppm	2.45	14	28	TRUE
Shawnee	FBC	Cobalt	ppm	0.95	1	5.2	TRUE
Sioux	Fly ash	Cobalt	ppm	134.7	134.7	134.7	TRUE
Stanton	Fly ash	Cobalt	ppm	86.1	86.1	86.1	TRUE
ehanna Coal Comp	Ash (NOS)	Cobalt	ppm	16.325	18.4	19.875	TRUE
hanna Coal Compa	Ash (NOS)	Cobalt	ppm	6.3	9	9.65	TRUE
USGS	Fly ash	Cobalt	ppm	40.85	48.6	56.55	TRUE
wood Energy Prop	Ash (NOS)	Cobalt	ppm	1.86	2.01	3.3	TRUE
Wheelabrator	FBC	Cobalt	ppm	3.55	3.815	4.34	TRUE
Xcel/MSI	Fly ash	Cobalt	ppm	17.95	26.15	27.825	TRUE
Zhang et al. (2001)	Fly Ash	Cobalt	ppm	44	54	120	TRUE
1	FBC	Cobalt	ppm	4.3375	5.725	7.5	TRUE
10	FBC	Cobalt	ppm	7.8125	9.375	10.9375	TRUE
12	FBC	Cobalt	ppm	1.25	4.175	7.325	TRUE
14	FBC	Cobalt	ppm	5.1	5.1	5.1	TRUE
18	FBC	Cobalt	ppm	9.5	13	13.5	TRUE
19	FBC	Cobalt	ppm	18.7	18.7	18.7	TRUE
2	FBC	Cobalt	ppm	1.4	3.4835	5.567	TRUE
20	FBC	Cobalt	ppm	9.5	9.8	9.8	TRUE
21	FBC	Cobalt	ppm	3.25	4.5	7.25	TRUE
26	FBC	Cobalt	ppm	3.7625	9.3	15.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
28	FBC	Cobalt	ppm	34.9	49.55	111.6	TRUE
29	FBC	Cobalt	ppm	10.04688	45.7	69.325	TRUE
3	FBC	Cobalt	ppm	6.25	6.25	6.25	TRUE
30	FBC	Cobalt	ppm	16.4	21.05	23.6	TRUE
31	FBC	Cobalt	ppm	4.63	6.42	8.21	TRUE
38	FBC	Cobalt	ppm	3.58	4.29	5.225	TRUE
39	FBC	Cobalt	ppm	9.5	13	16.5	TRUE
4	FBC	Cobalt	ppm	2.0575	2.105	2.1525	TRUE
5	FBC	Cobalt	ppm	14	16.5	23.5	TRUE
6	FBC	Cobalt	ppm	2.725	2.725	2.725	TRUE
7	FBC	Cobalt	ppm	35.13	35.13	35.13	TRUE
Baldwin	Fly ash	Cobalt	ppm	59.2	59.2	59.2	TRUE
B-D Mining Co.	Ash (NOS)	Cobalt	ppm	9	9.8	11	TRUE
CLSM	Combined ash	Cobalt	ppm	46.4	46.4	46.4	TRUE
CLSM	FBC	Cobalt	ppm	7	7	7	TRUE
Bowen	Fly ash	Copper	ppm	220.6	220.6	220.6	TRUE
CAER	Bottom ash	Copper	ppm	81	81	81	TRUE
CAER	Fly ash	Copper	ppm	21	42	45	TRUE
Cardinal	Fly ash	Copper	ppm	71.625	79.05	86.475	TRUE
Philadelphia Girard	Ash (NOS)	Copper	ppm	22.3	22.3	22.3	TRUE
Cleveland	Fly ash	Copper	ppm	0.058	0.058	0.058	TRUE
Emerald Anthracite	Ash (NOS)	Copper	ppm	40.025	42.8835	50.85	TRUE
EORDC	FGD waste	Copper	ppm	19	19	19	TRUE
Freeport Mine	FGD waste	Copper	ppm	2	2	2	TRUE
Gale	Ash (NOS)	Copper	ppm	33	33	33	TRUE
Girard Estate	Ash (NOS)	Copper	ppm	17	17	17	TRUE
HA	Ash & coal waste	Copper	ppm	33.5	38	39	TRUE
Harrim 3019	Ash (NOS)	Copper	ppm	98.177	98.177	98.177	TRUE
Harrim 3019	Bottom ash	Copper	ppm	32.425	35.85	39.275	TRUE
Harrim 3019	Fly ash	Copper	ppm	41.25	49	50.45	TRUE
an Coal Corporatio	Ash (NOS)	Copper	ppm	18.65	27.35	43.45	TRUE
an Coal Corporatio	Bottom ash	Copper	ppm	6.635	10.8	25.6	TRUE
an Coal Corporatio	Fly ash	Copper	ppm	60.05	70.5	80.95	TRUE
Coal Corporation 5	Ash (NOS)	Copper	ppm	49	49	49	TRUE
Coal Corporation 5	Bottom ash	Copper	ppm	24	27	30	TRUE
Coal Corporation 5	Fly ash	Copper	ppm	60	65	70	TRUE
ldo Highland Coal (	Ash (NOS)	Copper	ppm	21.4	36	43	TRUE
ldo Highland Coal (	Bottom ash	Copper	ppm	14.9	14.9	14.9	TRUE
Kentucky	Bottom ash	Copper	ppm	45.5	52	60	TRUE
Kentucky	Fly ash	Copper	ppm	214	241	263.5	TRUE
Knickerbocker Pit	FBC	Copper	ppm	20.97	23.8	26.9	TRUE
KY	FGD waste	Copper	ppm	0.005	0.005	0.005	TRUE
gh Coal and Naviga	Ash (NOS)	Copper	ppm	19	29	33	TRUE
LIMB Site	Ash (NOS)	Copper	ppm	15.25	16.5	17.75	TRUE
ttle Sandy #10 Min	Bottom ash	Copper	ppm	28	28	28	TRUE
ttle Sandy #10 Min	Combined ash	Copper	ppm	10	15	15	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ttle Sandy #10 Min	FGD waste	Copper	ppm	10	11	12.85	TRUE
ttle Sandy #10 Min	Fly ash	Copper	ppm	110	110	110	TRUE
Lone Mtn	Fly ash	Copper	ppm	220.8	220.8	220.8	TRUE
Martins Creek	Bottom ash	Copper	ppm	53.8	70.26	74.3	TRUE
Martins Creek	Fly ash	Copper	ppm	52.11	55.1	66.53	TRUE
McCloskey Site	FBC	Copper	ppm	58.75	60	61.25	TRUE
McKay Site	FBC	Copper	ppm	50.5	53	55.5	TRUE
Miller	Fly ash	Copper	ppm	348.7	348.7	348.7	TRUE
Miller Creek Mine	Bottom ash	Copper	ppm	42	54.16	84	TRUE
Miller Creek Mine	Combined ash	Copper	ppm	21	45.5	94.9675	TRUE
Miller Creek Mine	Fly ash	Copper	ppm	18	30.5	51.75	TRUE
N & L Coal Co.	Ash (NOS)	Copper	ppm	36.55	90.77	122.968	TRUE
N & L Coal Co.-2	Ash (NOS)	Copper	ppm	58.85	115.5	135.5	TRUE
NETL	Bottom ash	Copper	ppm	6130	6130	6130	TRUE
NETL	FBC	Copper	ppm	66.75	80.5	94.25	TRUE
NETL	Fly ash	Copper	ppm	71.75	99	142.25	TRUE
NETL	Slag	Copper	ppm	95	95	95	TRUE
o. 1 Contracting Co	Ash (NOS)	Copper	ppm	226	424	622	TRUE
uel Supply Company	Ash (NOS)	Copper	ppm	27	35.1	60	TRUE
uel Supply Company	Ash (NOS)	Copper	ppm	19.25	22.7	26.625	TRUE
uel Supply Company	Ash (NOS)	Copper	ppm	43.75	67.5	91.25	TRUE
orthampton400002	Ash (NOS)	Copper	ppm	35.1	35.1	35.1	TRUE
heast Energy Com	Ash (NOS)	Copper	ppm	33.675	37.9	48.75	TRUE
heast Energy Com	Bottom ash	Copper	ppm	11	11	11	TRUE
heast Energy Com	Fly ash	Copper	ppm	55	55	55	TRUE
eastern Power Cor	Ash (NOS)	Copper	ppm	12.3	12.6	12.9	TRUE
eastern Power Cor	Bottom ash	Copper	ppm	5.8925	7.16	9.405	TRUE
eastern Power Cor	Fly ash	Copper	ppm	17.9	20.35	25.8	TRUE
Nucla	FBC	Copper	ppm	26.25	29.5	32.75	TRUE
Nucla2	FBC	Copper	ppm	14.6	25	25.5	TRUE
Oak Creek	Bottom ash	Copper	ppm	84	84	84	TRUE
aceAnalytical (201	Slag	Copper	ppm	22.5	22.5	22.5	TRUE
Pacton Corp	Ash (NOS)	Copper	ppm	25	25	25	TRUE
Pacton Corp	Bottom ash	Copper	ppm	18	18	18	TRUE
Pacton Corp	Fly ash	Copper	ppm	38	120	165	TRUE
Pagnotti Coal Co.	Ash (NOS)	Copper	ppm	15.6	23.9	26.2	TRUE
Pagnotti Coal Co.	Fly ash	Copper	ppm	53.5	53.5	53.5	TRUE
Panther Creek	FBC	Copper	ppm	35.025	37	40.75	TRUE
Paradise	Fly ash	Copper	ppm	288.9	288.9	288.9	TRUE
ett et al. (1993) Co	Fly Ash	Copper	ppm	147.5	192.5	227.5	TRUE
Pleasant Prairie	Bottom ash	Copper	ppm	69	69	69	TRUE
Pleasant Prairie	Fly ash	Copper	ppm	331.1	331.1	331.1	TRUE
Porter Associates	Ash (NOS)	Copper	ppm	18.125	27.3	47	TRUE
Porter Associates	Bottom ash	Copper	ppm	18	25.9	31.5	TRUE
ylkill Reclamation C	Ash (NOS)	Copper	ppm	9	9	9	TRUE
SFA	Fly ash	Copper	ppm	890	890	890	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Shawnee	FBC	Copper	ppm	12	19	28	TRUE
Silverton	Ash (NOS)	Copper	ppm	34.25	35.5	36.75	TRUE
Sioux	Fly ash	Copper	ppm	364.65	382.2	399.75	TRUE
Stanton	Fly ash	Copper	ppm	230.4	230.4	230.4	TRUE
STK	Fly ash	Copper	ppm	25	25	25	TRUE
ehanna Coal Comp	Ash (NOS)	Copper	ppm	43.25	46.65	53	TRUE
hanna Coal Compa	Ash (NOS)	Copper	ppm	18.525	22.25	26.1	TRUE
Tracy Vein Slope	Ash (NOS)	Copper	ppm	24.775	32.95	45.65	TRUE
Tracy Vein Slope	Bottom ash	Copper	ppm	39.9	57.6	75.3	TRUE
Tracy Vein Slope	FBC	Copper	ppm	5.52	5.52	5.52	TRUE
Universal	Combined ash	Copper	ppm	18.5	24	32.25	TRUE
wood Energy Prop	Ash (NOS)	Copper	ppm	10.775	11.7	18.175	TRUE
Wheelabrator	FBC	Copper	ppm	17.475	21.1	22.05	TRUE
Yates	Fly ash	Copper	ppm	229.7	229.7	229.7	TRUE
Zhang et al. (2001)	Fly Ash	Copper	ppm	57	81	120	TRUE
1	FBC	Copper	ppm	47.325	175.8	330	TRUE
10	FBC	Copper	ppm	33.5	38	42.5	TRUE
11	FBC	Copper	ppm	12.525	15.35	18.175	TRUE
12	FBC	Copper	ppm	21.8	23.6	28.6	TRUE
14	FBC	Copper	ppm	22.4	22.4	22.4	TRUE
17	FBC	Copper	ppm	31.2	35	47	TRUE
19	FBC	Copper	ppm	37.3	37.3	37.3	TRUE
2	FBC	Copper	ppm	5.1	39.225	73.35	TRUE
20	FBC	Copper	ppm	18	30.8	40.3	TRUE
21	FBC	Copper	ppm	28.5	38	42.625	TRUE
23	FBC	Copper	ppm	26.1925	26.67	27.05	TRUE
26	FBC	Copper	ppm	9.35	13	15.75	TRUE
27	FBC	Copper	ppm	99	99	99	TRUE
28	FBC	Copper	ppm	29.1	40.85	45.175	TRUE
29	FBC	Copper	ppm	40.125	45.65	60.55	TRUE
3	FBC	Copper	ppm	15.25	18.5	21.75	TRUE
30	FBC	Copper	ppm	19.125	28.342	41.15	TRUE
31	FBC	Copper	ppm	30.125	34.25	38.375	TRUE
37	FBC	Copper	ppm	44	44	44	TRUE
38	FBC	Copper	ppm	16.425	20.5	24.925	TRUE
39	FBC	Copper	ppm	45	53	61	TRUE
4	FBC	Copper	ppm	11.4	15.1	19.2	TRUE
5	FBC	Copper	ppm	5.05	8.4	10.7	TRUE
6	FBC	Copper	ppm	21.6	22.5	23.4	TRUE
7	FBC	Copper	ppm	31.29	31.29	31.29	TRUE
8	FBC	Copper	ppm	83	83	83	TRUE
A/C Fuels Company	Ash (NOS)	Copper	ppm	19	19	19	TRUE
Baldwin	Fly ash	Copper	ppm	226.4	226.4	226.4	TRUE
B-D Mining Co.	Ash (NOS)	Copper	ppm	23	33.05	41.55	TRUE
B-D Mining Co.	Bottom ash	Copper	ppm	12.925	16.85	17.85	TRUE
B-D Mining Co.	Fly ash	Copper	ppm	32.75	45.8	62.525	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
CLSM	Combined ash	Copper	ppm	233.1	233.1	233.1	TRUE
CLSM	FBC	Copper	ppm	282.1	282.1	282.1	TRUE
Deer Ridge Mine	Fly ash	Copper	ppm	67.725	82.095	129.08	TRUE
DPC	Bottom ash	Copper	ppm	22.4	22.4	22.4	TRUE
DPC	Fly ash	Copper	ppm	39.3	39.3	39.3	TRUE
ern Analytical, ID: 5	Slag	Copper	ppm	16	16	16	TRUE
Edgewater	Bottom ash	Copper	ppm	81.8	81.8	81.8	TRUE
KY	FGD waste	Fluoride	ppm	596	816	850.25	TRUE
ttle Sandy #10 Min	Bottom ash	Fluoride	ppm	0.375	0.375	0.375	TRUE
ttle Sandy #10 Min	Combined ash	Fluoride	ppm	1.4	2.2	5	TRUE
ttle Sandy #10 Min	FGD waste	Fluoride	ppm	6.2	7.4	9.2	TRUE
ttle Sandy #10 Min	Fly ash	Fluoride	ppm	25	25	25	TRUE
Miller Creek Mine	Bottom ash	Fluoride	ppm	1	3	4.9	TRUE
Miller Creek Mine	Combined ash	Fluoride	ppm	0.2	1	5	TRUE
Miller Creek Mine	Fly ash	Fluoride	ppm	3.65	6.95	8.05	TRUE
Universal	Combined ash	Fluoride	ppm	9	15	24.5	TRUE
CLSM	Combined ash	Fluoride	ppm	2.5	2.5	2.5	TRUE
CLSM	FBC	Fluoride	ppm	13	13	13	TRUE
Deer Ridge Mine	Fly ash	Fluoride	ppm	2.175	5.4	15	TRUE
Zhang et al. (2001)	Fly Ash	Gallium	ppm	17	21	25	FALSE
Zhang et al. (2001)	Fly Ash	Germanium	ppm	9	11	21	FALSE
City Mine	FBC	Iron	ppm	134000	138000	145500	TRUE
Philadelphia Girard	Ash (NOS)	Iron	ppm	17100	17100	17100	TRUE
Cleveland	Fly ash	Iron	ppm	69.4	69.4	69.4	TRUE
Emerald Anthracite	Ash (NOS)	Iron	ppm	14832.3	15700	21806.5	TRUE
Freeport Mine	FGD waste	Iron	ppm	957	957	957	TRUE
Gale	Ash (NOS)	Iron	ppm	10675	10675	10675	TRUE
Girard Estate	Ash (NOS)	Iron	ppm	10900	10900	10900	TRUE
HA	Ash & coal waste	Iron	ppm	3450	4000	4350	TRUE
Harrim 3019	Bottom ash	Iron	ppm	14335	14770	15205	TRUE
Harrim 3019	Fly ash	Iron	ppm	16375	23650	27450	TRUE
an Coal Corporatio	Ash (NOS)	Iron	ppm	7905	16800	33750	TRUE
an Coal Corporatio	Bottom ash	Iron	ppm	4890	9590	16830	TRUE
an Coal Corporatio	Fly ash	Iron	ppm	28950	31400	33850	TRUE
Coal Corporation 5	Ash (NOS)	Iron	ppm	11800	11800	11800	TRUE
Coal Corporation 5	Bottom ash	Iron	ppm	11450	12800	14150	TRUE
Coal Corporation 5	Fly ash	Iron	ppm	15200	16800	18400	TRUE
ddo Highland Coal (	Ash (NOS)	Iron	ppm	3300	4770	7060	TRUE
ddo Highland Coal (	Bottom ash	Iron	ppm	37400	37400	37400	TRUE
Knickerbocker Pit	FBC	Iron	ppm	12352.5	16085	17845	TRUE
gh Coal and Naviga	Ash (NOS)	Iron	ppm	930	12900	15000	TRUE
LIMB Site	Ash (NOS)	Iron	ppm	27450	47300	67150	TRUE
ttle Sandy #10 Min	Bottom ash	Iron	ppm	22000	22000	22000	TRUE
ttle Sandy #10 Min	Combined ash	Iron	ppm	14200	17000	25000	TRUE
ttle Sandy #10 Min	FGD waste	Iron	ppm	3150	3300	3500	TRUE
ttle Sandy #10 Min	Fly ash	Iron	ppm	40000	40000	40000	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Martins Creek	Bottom ash	Iron	ppm	119000	120459	129051	TRUE
Martins Creek	Fly ash	Iron	ppm	59000	67880	71500	TRUE
McCloskey Site	FBC	Iron	ppm	29125	36000	42875	TRUE
McKay Site	FBC	Iron	ppm	18750	19500	20250	TRUE
Miller Creek Mine	Bottom ash	Iron	ppm	10626	35210	85470.09	TRUE
Miller Creek Mine	Combined ash	Iron	ppm	7788.5	13780.5	78500	TRUE
Miller Creek Mine	Fly ash	Iron	ppm	18000	19000	32205	TRUE
N & L Coal Co.	Ash (NOS)	Iron	ppm	8922.5	46150	67972.5	TRUE
N & L Coal Co.-2	Ash (NOS)	Iron	ppm	9410	49400	66500	TRUE
o. 1 Contracting Co	Ash (NOS)	Iron	ppm	13675	13950	14225	TRUE
uel Supply Company	Ash (NOS)	Iron	ppm	10200	13600	17900	TRUE
uel Supply Company	Ash (NOS)	Iron	ppm	8895	9590	13306.55	TRUE
uel Supply Company	Ash (NOS)	Iron	ppm	15975	16350	16725	TRUE
orthampton400002	Ash (NOS)	Iron	ppm	23100	23100	23100	TRUE
heast Energy Com	Ash (NOS)	Iron	ppm	3468.5	10187.5	22800	TRUE
heast Energy Com	Bottom ash	Iron	ppm	4200	4200	4200	TRUE
heast Energy Com	Fly ash	Iron	ppm	10000	10000	10000	TRUE
eastern Power Con	Ash (NOS)	Iron	ppm	4665	6280	8190	TRUE
eastern Power Con	Bottom ash	Iron	ppm	2015	2660	4090	TRUE
eastern Power Con	Fly ash	Iron	ppm	3860	5890	8210	TRUE
Nucla	FBC	Iron	ppm	25300	29500	33700	TRUE
Nucla2	FBC	Iron	ppm	14500	15000	16000	TRUE
Oak Creek	Bottom ash	Iron	ppm	154000	154000	154000	TRUE
Pacton Corp	Ash (NOS)	Iron	ppm	10800	10800	10800	TRUE
Pacton Corp	Bottom ash	Iron	ppm	8775	8775	8775	TRUE
Pacton Corp	Fly ash	Iron	ppm	21612.5	34200	43600	TRUE
Pagnotti Coal Co.	Ash (NOS)	Iron	ppm	10855	15325	19895	TRUE
Pagnotti Coal Co.	Bottom ash	Iron	ppm	625	625	625	TRUE
Pagnotti Coal Co.	Fly ash	Iron	ppm	6487.5	10825	15162.5	TRUE
Panther Creek	FBC	Iron	ppm	15500	16515	17530	TRUE
Pleasant Prairie	Bottom ash	Iron	ppm	28000	28000	28000	TRUE
Porter Associates	Ash (NOS)	Iron	ppm	6390	12000	16700	TRUE
Porter Associates	Bottom ash	Iron	ppm	6395	9960	25400	TRUE
ylkill Reclamation (	Ash (NOS)	Iron	ppm	1790	1790	1790	TRUE
Shawnee	FBC	Iron	ppm	16700	21000	59900	TRUE
Silverton	Ash (NOS)	Iron	ppm	11601.25	12527.5	13453.75	TRUE
ehanna Coal Comp	Ash (NOS)	Iron	ppm	14400	17250	18600	TRUE
hanna Coal Compa	Ash (NOS)	Iron	ppm	8420	11150	13195	TRUE
SW	Bottom ash	Iron	ppm	27000	29100	31500	TRUE
SW	Fly ash	Iron	ppm	23100	24200	24900	TRUE
Tracy Vein Slope	Ash (NOS)	Iron	ppm	10426.93	15100	16425	TRUE
Tracy Vein Slope	Bottom ash	Iron	ppm	32000	43600	55200	TRUE
Tracy Vein Slope	FBC	Iron	ppm	2600	2600	2600	TRUE
Universal	Combined ash	Iron	ppm	8610	13000	19350	TRUE
wood Energy Prop	Ash (NOS)	Iron	ppm	2815	4983	5625	TRUE
Wheelabrator	FBC	Iron	ppm	6177.5	10367.5	14586.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Xcel/MSI	Fly ash	Iron	ppm	30760	37008.5	41217	TRUE
Zhang et al. (2001)	Fly Ash	Iron	ppm	100	200	200	TRUE
12	FBC	Iron	ppm	8050	8680	11550	TRUE
14	FBC	Iron	ppm	9090	9090	9090	TRUE
17	FBC	Iron	ppm	14613	26741	28990	TRUE
18	FBC	Iron	ppm	40097	71721	76519.5	TRUE
19	FBC	Iron	ppm	5700	5700	5700	TRUE
2	FBC	Iron	ppm	6.2	14.185	22.17	TRUE
20	FBC	Iron	ppm	12210	17000	25740	TRUE
21	FBC	Iron	ppm	14775	18150	22575	TRUE
23	FBC	Iron	ppm	27375	28351.4	29815.92	TRUE
26	FBC	Iron	ppm	7430	7430	7430	TRUE
27	FBC	Iron	ppm	47961	47961	47961	TRUE
28	FBC	Iron	ppm	4422.5	14520	31135	TRUE
29	FBC	Iron	ppm	14348.8	17757.6	20488.33	TRUE
30	FBC	Iron	ppm	14337.49	18135	25340	TRUE
31	FBC	Iron	ppm	16775	16775	16775	TRUE
38	FBC	Iron	ppm	5775	10617.5	15512.5	TRUE
39	FBC	Iron	ppm	23025	26750	30475	TRUE
4	FBC	Iron	ppm	5011.75	8256	10110	TRUE
6	FBC	Iron	ppm	34660.5	41761	48861.5	TRUE
7	FBC	Iron	ppm	25335.62	25335.62	25335.62	TRUE
8	FBC	Iron	ppm	16000	16000	16000	TRUE
A/C Fuels Company	Ash (NOS)	Iron	ppm	8640	8640	8640	TRUE
B-D Mining Co.	Ash (NOS)	Iron	ppm	13433.75	20125	26050	TRUE
B-D Mining Co.	Bottom ash	Iron	ppm	11595	12210	12506.25	TRUE
B-D Mining Co.	Fly ash	Iron	ppm	25275	29030	32042.5	TRUE
CLSM	Combined ash	Iron	ppm	22610	22610	22610	TRUE
CLSM	FBC	Iron	ppm	13525	13525	13525	TRUE
Deer Ridge Mine	Fly ash	Iron	ppm	4645.355	6264.3	42500	TRUE
DPC	Bottom ash	Iron	ppm	4780	4780	4780	TRUE
DPC	Fly ash	Iron	ppm	10200	10200	10200	TRUE
ern Analytical, ID: 5	Slag	Iron	ppm	18000	18000	18000	TRUE
Zhang et al. (2001)	Fly Ash	Lanthanum	ppm	47	49	61	TRUE
Bowen	Fly ash	Lead	ppm	63.9	63.9	63.9	TRUE
CAER	Bottom ash	Lead	ppm	20.835	32.49	53.585	TRUE
CAER	Fly ash	Lead	ppm	76.51	88.68	109.04	TRUE
Cardinal	Fly ash	Lead	ppm	46.125	48.75	51.375	TRUE
City Mine	FBC	Lead	ppm	1335	1355	1404	TRUE
Philadelphia Girard	Ash (NOS)	Lead	ppm	21.6	21.6	21.6	TRUE
Cleveland	Fly ash	Lead	ppm	0.013	0.013	0.013	TRUE
Emerald Anthracite	Ash (NOS)	Lead	ppm	16.8	43.8	50.787	TRUE
EORDC	FGD waste	Lead	ppm	9.7	9.7	9.7	TRUE
Fleming	FBC	Lead	ppm	15	15	15	TRUE
Freeport Mine	FGD waste	Lead	ppm	0.5	0.5	0.5	TRUE
Gale	Ash (NOS)	Lead	ppm	21	21	21	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Girard Estate	Ash (NOS)	Lead	ppm	6	6	6	TRUE
HA	Ash & coal waste	Lead	ppm	8.05	9.6	9.8	TRUE
Harrim 3019	Ash (NOS)	Lead	ppm	26	26	26	TRUE
Harrim 3019	Bottom ash	Lead	ppm	18.025	25.55	33.075	TRUE
Harrim 3019	Fly ash	Lead	ppm	12.5	20.5	38.4	TRUE
an Coal Corporatio	Ash (NOS)	Lead	ppm	11	16.55	33.5	TRUE
an Coal Corporatio	Bottom ash	Lead	ppm	3.34	7.02	17.4	TRUE
an Coal Corporatio	Fly ash	Lead	ppm	44.8	45.4	46	TRUE
Coal Corporation 5	Bottom ash	Lead	ppm	6.25	7.5	8.75	TRUE
Coal Corporation 5	Fly ash	Lead	ppm	28.5	31	33.5	TRUE
ddo Highland Coal (	Ash (NOS)	Lead	ppm	7.5	18	19.5	TRUE
ddo Highland Coal (	Bottom ash	Lead	ppm	33	33	33	TRUE
Kentucky	Bottom ash	Lead	ppm	20	20	20	TRUE
Kentucky	Fly ash	Lead	ppm	330.75	334.5	338.25	TRUE
Knickerbocker Pit	FBC	Lead	ppm	14.5	22.3	32.0425	TRUE
gh Coal and Naviga	Ash (NOS)	Lead	ppm	12.5	16	20	TRUE
LIMB Site	Ash (NOS)	Lead	ppm	13.75	14.5	15.25	TRUE
ttle Sandy #10 Min	Bottom ash	Lead	ppm	120	120	120	TRUE
ttle Sandy #10 Min	Combined ash	Lead	ppm	4.7	7.2	24	TRUE
ttle Sandy #10 Min	FGD waste	Lead	ppm	12.5	13	13.5	TRUE
ttle Sandy #10 Min	Fly ash	Lead	ppm	240	240	240	TRUE
Lone Mtn	Fly ash	Lead	ppm	69.8	69.8	69.8	TRUE
Mandan	FBC	Lead	ppm	11.8	11.8	11.8	TRUE
McCloskey Site	FBC	Lead	ppm	48.75	50	51.25	TRUE
McKay Site	FBC	Lead	ppm	36	49	62	TRUE
Miller	Fly ash	Lead	ppm	38	38	38	TRUE
Miller Creek Mine	Bottom ash	Lead	ppm	5.7	15.4	63.5	TRUE
Miller Creek Mine	Combined ash	Lead	ppm	8.95	17	43.325	TRUE
Miller Creek Mine	Fly ash	Lead	ppm	35.5	48	93.625	TRUE
N & L Coal Co.	Ash (NOS)	Lead	ppm	29.475	45.75	103.75	TRUE
N & L Coal Co.-2	Ash (NOS)	Lead	ppm	20.7	22.9	41.3875	TRUE
Nepco	FBC	Lead	ppm	39	39	39	TRUE
NETL	Bottom ash	Lead	ppm	762	762	762	TRUE
NETL	FBC	Lead	ppm	46.25	52.5	58.75	TRUE
NETL	Fly ash	Lead	ppm	24.75	68	110.5	TRUE
NETL	Slag	Lead	ppm	29	29	29	TRUE
o. 1 Contracting Co	Ash (NOS)	Lead	ppm	29.125	38.75	48.375	TRUE
el Supply Company	Ash (NOS)	Lead	ppm	11	15	18	TRUE
el Supply Company	Ash (NOS)	Lead	ppm	12.025	21	26.55	TRUE
el Supply Company	Ash (NOS)	Lead	ppm	15.5	18	20.5	TRUE
rthampton400002	Ash (NOS)	Lead	ppm	18	18	18	TRUE
heast Energy Com	Ash (NOS)	Lead	ppm	21	25	33.5	TRUE
heast Energy Com	Bottom ash	Lead	ppm	2.2	2.2	2.2	TRUE
heast Energy Com	Fly ash	Lead	ppm	19	19	19	TRUE
eastern Power Cor	Ash (NOS)	Lead	ppm	11.525	14.05	16.575	TRUE
eastern Power Cor	Bottom ash	Lead	ppm	8.7	11.2	15.95	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
eastern Power Con	Fly ash	Lead	ppm	17.5	25.2	37.9	TRUE
Nucla	FBC	Lead	ppm	34.75	35.5	36.25	TRUE
Nucla2	FBC	Lead	ppm	0.945	1.8	12.4	TRUE
Oak Creek	Bottom ash	Lead	ppm	33	33	33	TRUE
aceAnalytical (2010	Slag	Lead	ppm	8.1	8.1	8.1	TRUE
Pacton Corp	Ash (NOS)	Lead	ppm	39	39	39	TRUE
Pacton Corp	Bottom ash	Lead	ppm	40	40	40	TRUE
Pacton Corp	Fly ash	Lead	ppm	56.5	63	101.5	TRUE
Pagnotti Coal Co.	Ash (NOS)	Lead	ppm	20	34	35.7	TRUE
Pagnotti Coal Co.	Fly ash	Lead	ppm	72.5	72.5	72.5	TRUE
Panther Creek	FBC	Lead	ppm	21.125	23.5	29.75	TRUE
Paradise	Fly ash	Lead	ppm	76	76	76	TRUE
ett et al. (1993) Cor	Fly Ash	Lead	ppm	16.7	19.5	20.75	TRUE
Plant 10	FBC	Lead	ppm	29.1	34.8	53.45	TRUE
Plant 12	FBC	Lead	ppm	39.2	50.5	58	TRUE
Plant 8	FBC	Lead	ppm	15.05	20	43.1	TRUE
Plant 9	FBC	Lead	ppm	46.625	52.5	66.875	TRUE
Pleasant Prairie	Bottom ash	Lead	ppm	0.5	0.5	0.5	TRUE
Pleasant Prairie	Fly ash	Lead	ppm	43.5	43.5	43.5	TRUE
Porter Associates	Ash (NOS)	Lead	ppm	12.3	19.15	27.5	TRUE
Porter Associates	Bottom ash	Lead	ppm	3.76	7.05	16	TRUE
Scrubgrass	FBC	Lead	ppm	50	50	50	TRUE
SFA	Fly ash	Lead	ppm	80	80	80	TRUE
Shawnee	FBC	Lead	ppm	4.8	6.6	7.3	TRUE
Silverton	Ash (NOS)	Lead	ppm	25.25	29.5	33.75	TRUE
Sioux	Fly ash	Lead	ppm	182.475	205.95	229.425	TRUE
Stanton	Fly ash	Lead	ppm	65.2	65.2	65.2	TRUE
STK	Fly ash	Lead	ppm	140	140	140	TRUE
ehanna Coal Comp	Ash (NOS)	Lead	ppm	28	41.5	53.925	TRUE
hanna Coal Compa	Ash (NOS)	Lead	ppm	23.15	26.5	34.9	TRUE
SW	Bottom ash	Lead	ppm	9.67	12.4	20	TRUE
SW	Fly ash	Lead	ppm	47.025	52.3	64.15	TRUE
Tracy Vein Slope	Ash (NOS)	Lead	ppm	13.5425	22.4	32.375	TRUE
Tracy Vein Slope	Bottom ash	Lead	ppm	6.435	9.69	12.945	TRUE
Tracy Vein Slope	FBC	Lead	ppm	4.23	4.23	4.23	TRUE
Universal	Combined ash	Lead	ppm	26	32	35	TRUE
USGS	Fly ash	Lead	ppm	45	75	125	TRUE
wood Energy Prop	Ash (NOS)	Lead	ppm	7.02	8.96	14.9	TRUE
Wheelabrator	FBC	Lead	ppm	13.65	20.45	21.5	TRUE
Xcel/MSI	Fly ash	Lead	ppm	41.5	49.55	50.85	TRUE
Yates	Fly ash	Lead	ppm	46	46	46	TRUE
Zhang et al. (2001)	Fly Ash	Lead	ppm	38	48	54	TRUE
1	FBC	Lead	ppm	2.975	10.835	14.0525	TRUE
10	FBC	Lead	ppm	7.8125	9.375	10.9375	TRUE
11	FBC	Lead	ppm	7.375	40.875	73	TRUE
12	FBC	Lead	ppm	39.175	46.9	54.625	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
14	FBC	Lead	ppm	31.2	31.2	31.2	TRUE
17	FBC	Lead	ppm	34.5	50.8	69.5	TRUE
18	FBC	Lead	ppm	16	30	32	TRUE
19	FBC	Lead	ppm	3.75	3.75	3.75	TRUE
2	FBC	Lead	ppm	2	3.1335	4.267	TRUE
20	FBC	Lead	ppm	25.4	28	44.35	TRUE
21	FBC	Lead	ppm	22.25	23.5	36.6	TRUE
23	FBC	Lead	ppm	13.475	14.955	16.295	TRUE
26	FBC	Lead	ppm	4.6625	6.025	7.9375	TRUE
27	FBC	Lead	ppm	16	16	16	TRUE
28	FBC	Lead	ppm	44.2	50.25	60.55	TRUE
29	FBC	Lead	ppm	23.025	35.85	39.675	TRUE
3	FBC	Lead	ppm	6.25	6.25	6.25	TRUE
30	FBC	Lead	ppm	24.7	31.945	46.825	TRUE
31	FBC	Lead	ppm	1.19	1.19	1.19	TRUE
37	FBC	Lead	ppm	44	58	67.5	TRUE
38	FBC	Lead	ppm	21.1	25.7	34.85	TRUE
39	FBC	Lead	ppm	10	15	20	TRUE
4	FBC	Lead	ppm	9.005	14.2	22.5185	TRUE
5	FBC	Lead	ppm	1.71875	4.4625	6.1375	TRUE
6	FBC	Lead	ppm	5.30625	8.1125	10.91875	TRUE
7	FBC	Lead	ppm	105.48	105.48	105.48	TRUE
8	FBC	Lead	ppm	67	67	67	TRUE
A/C Fuels Company	Ash (NOS)	Lead	ppm	13	13	13	TRUE
Baldwin	Fly ash	Lead	ppm	133.2	133.2	133.2	TRUE
B-D Mining Co.	Ash (NOS)	Lead	ppm	23	25	28	TRUE
B-D Mining Co.	Bottom ash	Lead	ppm	26	28	56	TRUE
B-D Mining Co.	Fly ash	Lead	ppm	40.8	44.35	62.375	TRUE
CLSM	Combined ash	Lead	ppm	33	33	33	TRUE
CLSM	FBC	Lead	ppm	18	18	18	TRUE
Coal Creek	Bottom ash	Lead	ppm	0.0087	0.0087	0.0087	TRUE
Coal Creek	Fly ash	Lead	ppm	0.0318	0.0318	0.0318	TRUE
Deer Ridge Mine	Fly ash	Lead	ppm	25	64.295	80.85	TRUE
DPC	Bottom ash	Lead	ppm	4.6	4.6	4.6	TRUE
DPC	Fly ash	Lead	ppm	52.8	52.8	52.8	TRUE
ern Analytical, ID: 5	Slag	Lead	ppm	6.7	6.7	6.7	TRUE
Edgewater	Bottom ash	Lead	ppm	19.9	19.9	19.9	TRUE
EERC?	Combined ash	Lead	ppm	23.2	27.8	32.4	TRUE
EERC?	FGD	Lead	ppm	4.4	20.9	80.3	TRUE
EERC?	FGD gypsum	Lead	ppm	1.5	1.5	1.5	TRUE
EERC?	FGD gypsum liquids	Lead	mg/L	0.001	0.001	0.001	TRUE
EERC?	FGD liquids	Lead	mg/L	0.001	0.001	0.001	TRUE
EERC?	FGD liquids	Lead	ppm	1.5	1.5	1.5	TRUE
EERC?	Fly Ash	Lead	ppm	38.75	63.75	82.5	TRUE
City Mine	FBC	Magnesium	ppm	1601.5	1779	1837	TRUE
Cleveland	Fly ash	Magnesium	ppm	2.26	2.26	2.26	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Freeport Mine	FGD waste	Magnesium	ppm	1470	1470	1470	TRUE
ttle Sandy #10 Mir	Combined ash	Magnesium	ppm	310.5	330	380	TRUE
ttle Sandy #10 Mir	FGD waste	Magnesium	ppm	1015	1160	1230	TRUE
Martins Creek	Bottom ash	Magnesium	ppm	2550	3513	4923	TRUE
Martins Creek	Fly ash	Magnesium	ppm	2140	3100	3166	TRUE
McKay Site	FBC	Magnesium	ppm	45750	57500	69250	TRUE
Miller Creek Mine	Bottom ash	Magnesium	ppm	199	623	1222.42	TRUE
Miller Creek Mine	Combined ash	Magnesium	ppm	171	264.35	2825	TRUE
Miller Creek Mine	Fly ash	Magnesium	ppm	842	977	992	TRUE
Nucla	FBC	Magnesium	ppm	4610	4960	5310	TRUE
Nucla2	FBC	Magnesium	ppm	3750	3900	4650	TRUE
Oak Creek	Bottom ash	Magnesium	ppm	6031	6031	6031	TRUE
Pagnotti Coal Co.	Ash (NOS)	Magnesium	ppm	2330	2330	2330	TRUE
Pleasant Prairie	Bottom ash	Magnesium	ppm	19899	19899	19899	TRUE
Shawnee	FBC	Magnesium	ppm	3240	3730	12000	TRUE
SW	Bottom ash	Magnesium	ppm	4190	4380	4690	TRUE
SW	Fly ash	Magnesium	ppm	4810	5110	5250	TRUE
Universal	Combined ash	Magnesium	ppm	530	633	730	TRUE
CLSM	Combined ash	Magnesium	ppm	6101.8	6101.8	6101.8	TRUE
CLSM	FBC	Magnesium	ppm	2098.2	2098.2	2098.2	TRUE
Deer Ridge Mine	Fly ash	Magnesium	ppm	199.1875	256.5	1963.75	TRUE
DPC	Bottom ash	Magnesium	ppm	899	899	899	TRUE
DPC	Fly ash	Magnesium	ppm	3360	3360	3360	TRUE
ern Analytical, ID: 5	Slag	Magnesium	ppm	1300	1300	1300	TRUE
Edgewater	Bottom ash	Magnesium	ppm	17550	17550	17550	TRUE
Bowen	Fly ash	Manganese	ppm	186.8	186.8	186.8	TRUE
CAER	Bottom ash	Manganese	ppm	211.5	220	254	TRUE
CAER	FGD waste	Manganese	ppm	95	95	95	TRUE
CAER	Fly ash	Manganese	ppm	75	224	242	TRUE
Cardinal	Fly ash	Manganese	ppm	271.85	303.2	334.55	TRUE
Philadelphia Girard	Ash (NOS)	Manganese	ppm	54.6	54.6	54.6	TRUE
Cleveland	Fly ash	Manganese	ppm	0.098	0.098	0.098	TRUE
Emerald Anthracite	Ash (NOS)	Manganese	ppm	74.81925	158.7	228.75	TRUE
Fleming	FBC	Manganese	ppm	50	50	50	TRUE
Freeport Mine	FGD waste	Manganese	ppm	12.3	12.3	12.3	TRUE
Gale	Ash (NOS)	Manganese	ppm	81	81	81	TRUE
Girard Estate	Ash (NOS)	Manganese	ppm	44	44	44	TRUE
HA	Ash & coal waste	Manganese	ppm	37.5	39	104.5	TRUE
Harrim 3019	Ash (NOS)	Manganese	ppm	230.427	230.427	230.427	TRUE
Harrim 3019	Bottom ash	Manganese	ppm	204.1	338.4	472.7	TRUE
Harrim 3019	Fly ash	Manganese	ppm	52.25	72.45	82.5	TRUE
an Coal Corporatio	Ash (NOS)	Manganese	ppm	51.3	85.45	135.75	TRUE
an Coal Corporatio	Bottom ash	Manganese	ppm	15.625	36	73.4	TRUE
an Coal Corporatio	Fly ash	Manganese	ppm	73.075	77.25	81.425	TRUE
Coal Corporation 5	Ash (NOS)	Manganese	ppm	7	7	7	TRUE
Coal Corporation 5	Bottom ash	Manganese	ppm	141.75	147.5	153.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Coal Corporation 5	Fly ash	Manganese	ppm	76	87	98	TRUE
ddo Highland Coal (	Ash (NOS)	Manganese	ppm	37.5	40	52	TRUE
ddo Highland Coal (	Bottom ash	Manganese	ppm	39	39	39	TRUE
Kentucky	Bottom ash	Manganese	ppm	230.5	262	291.5	TRUE
Kentucky	Fly ash	Manganese	ppm	126	150.5	169.25	TRUE
Knickerbocker Pit	FBC	Manganese	ppm	55.2	63.24	76.55	TRUE
KY	FGD waste	Manganese	ppm	64	82	96.5	TRUE
gh Coal and Naviga	Ash (NOS)	Manganese	ppm	54	85	103	TRUE
LIMB Site	Ash (NOS)	Manganese	ppm	1050	1100	1150	TRUE
ttle Sandy #10 Min	Bottom ash	Manganese	ppm	200	200	200	TRUE
ttle Sandy #10 Min	Combined ash	Manganese	ppm	36	51	76	TRUE
ttle Sandy #10 Min	FGD waste	Manganese	ppm	25.45	27.9	27.95	TRUE
ttle Sandy #10 Min	Fly ash	Manganese	ppm	86	86	86	TRUE
Lone Mtn	Fly ash	Manganese	ppm	228.4	228.4	228.4	TRUE
Martins Creek	Bottom ash	Manganese	ppm	101	108.15	147.83	TRUE
Martins Creek	Fly ash	Manganese	ppm	63.23	73.9	81.8	TRUE
McCloskey Site	FBC	Manganese	ppm	530	567.5	605	TRUE
McKay Site	FBC	Manganese	ppm	410	490	570	TRUE
Miller	Fly ash	Manganese	ppm	534.3	534.3	534.3	TRUE
Miller Creek Mine	Bottom ash	Manganese	ppm	56	61	120.25	TRUE
Miller Creek Mine	Combined ash	Manganese	ppm	13.695	26	92.5	TRUE
Miller Creek Mine	Fly ash	Manganese	ppm	57.5	72.5	95.4175	TRUE
N & L Coal Co.	Ash (NOS)	Manganese	ppm	91.48575	112.65	184.5	TRUE
N & L Coal Co.-2	Ash (NOS)	Manganese	ppm	99.2	138	200	TRUE
o. 1 Contracting Co	Ash (NOS)	Manganese	ppm	121	124	127	TRUE
uel Supply Company	Ash (NOS)	Manganese	ppm	80.5	92	108	TRUE
uel Supply Company	Ash (NOS)	Manganese	ppm	41.4	51	76.2	TRUE
uel Supply Company	Ash (NOS)	Manganese	ppm	57.85	67.7	77.55	TRUE
orthampton400002	Ash (NOS)	Manganese	ppm	108	108	108	TRUE
heast Energy Com	Ash (NOS)	Manganese	ppm	49.25	79.5	88.625	TRUE
heast Energy Com	Bottom ash	Manganese	ppm	64	64	64	TRUE
heast Energy Com	Fly ash	Manganese	ppm	120	120	120	TRUE
eastern Power Con	Ash (NOS)	Manganese	ppm	21.9	28	41.1	TRUE
eastern Power Con	Bottom ash	Manganese	ppm	22	23.5	42.8	TRUE
eastern Power Con	Fly ash	Manganese	ppm	38.2	48	52.5	TRUE
Nucla	FBC	Manganese	ppm	99	106	113	TRUE
Nucla2	FBC	Manganese	ppm	115	120	140	TRUE
aceAnalytical (2010	Slag	Manganese	ppm	288	288	288	TRUE
Pacton Corp	Ash (NOS)	Manganese	ppm	43	43	43	TRUE
Pacton Corp	Bottom ash	Manganese	ppm	208	208	208	TRUE
Pacton Corp	Fly ash	Manganese	ppm	172.5	200	310	TRUE
Pagnotti Coal Co.	Ash (NOS)	Manganese	ppm	46.4875	66.5	76.65	TRUE
Pagnotti Coal Co.	Fly ash	Manganese	ppm	115	115	115	TRUE
Panther Creek	FBC	Manganese	ppm	73.2	86	97.175	TRUE
Paradise	Fly ash	Manganese	ppm	366.7	366.7	366.7	TRUE
ett et al. (1993) Co	Fly Ash	Manganese	ppm	300	370	480	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Pleasant Prairie	Fly ash	Manganese	ppm	312.7	312.7	312.7	TRUE
Porter Associates	Ash (NOS)	Manganese	ppm	38.5	52.1	81.5	TRUE
Porter Associates	Bottom ash	Manganese	ppm	28.4	48.9	57.75	TRUE
ylkill Reclamation (	Ash (NOS)	Manganese	ppm	47	47	47	TRUE
Shawnee	FBC	Manganese	ppm	110	160	540	TRUE
Silverton	Ash (NOS)	Manganese	ppm	86.25	91.5	96.75	TRUE
Sioux	Fly ash	Manganese	ppm	179.85	189.2	198.55	TRUE
Stanton	Fly ash	Manganese	ppm	284.9	284.9	284.9	TRUE
ehanna Coal Comp	Ash (NOS)	Manganese	ppm	123	147	167	TRUE
hanna Coal Compa	Ash (NOS)	Manganese	ppm	46.95	53.05	63	TRUE
SW	Bottom ash	Manganese	ppm	165	186	203	TRUE
SW	Fly ash	Manganese	ppm	159	175	187	TRUE
Tracy Vein Slope	Ash (NOS)	Manganese	ppm	61.175	80.15	325.1	TRUE
Tracy Vein Slope	Bottom ash	Manganese	ppm	78.275	89.85	101.425	TRUE
Tracy Vein Slope	FBC	Manganese	ppm	25.6	25.6	25.6	TRUE
Universal	Combined ash	Manganese	ppm	55	77	110	TRUE
USGS	Fly ash	Manganese	ppm	270	330	360	TRUE
wood Energy Prop	Ash (NOS)	Manganese	ppm	39.875	54.25	70.1	TRUE
Wheelabrator	FBC	Manganese	ppm	42.925	55.55	76.825	TRUE
Xcel/MSI	Fly ash	Manganese	ppm	135.75	146	343.75	TRUE
Yates	Fly ash	Manganese	ppm	339.4	339.4	339.4	TRUE
Zhang et al. (2001)	Fly Ash	Manganese	ppm	140	480	700	TRUE
12	FBC	Manganese	ppm	34.35	83.75	260	TRUE
14	FBC	Manganese	ppm	41.8	41.8	41.8	TRUE
17	FBC	Manganese	ppm	59.95	63.55	128.575	TRUE
18	FBC	Manganese	ppm	87.5	101	103.5	TRUE
19	FBC	Manganese	ppm	45.8	45.8	45.8	TRUE
2	FBC	Manganese	ppm	110	118.2	126.4	TRUE
20	FBC	Manganese	ppm	53.4	63	82.2	TRUE
21	FBC	Manganese	ppm	57.25	82	91.525	TRUE
27	FBC	Manganese	ppm	409	409	409	TRUE
28	FBC	Manganese	ppm	48.8	63.3	82.9	TRUE
29	FBC	Manganese	ppm	565.975	635.8	719.425	TRUE
3	FBC	Manganese	ppm	0.05	0.05	0.05	TRUE
30	FBC	Manganese	ppm	115.65	177.65	280.075	TRUE
31	FBC	Manganese	ppm	141	141	141	TRUE
37	FBC	Manganese	ppm	672	672	672	TRUE
38	FBC	Manganese	ppm	45.4	61.1	89.775	TRUE
39	FBC	Manganese	ppm	485	500	515	TRUE
4	FBC	Manganese	ppm	56.65	80.46	90.775	TRUE
6	FBC	Manganese	ppm	81.55	91.7	101.85	TRUE
7	FBC	Manganese	ppm	524.88	524.88	524.88	TRUE
8	FBC	Manganese	ppm	89	89	89	TRUE
A/C Fuels Company	Ash (NOS)	Manganese	ppm	64	64	64	TRUE
Baldwin	Fly ash	Manganese	ppm	414.3	414.3	414.3	TRUE
B-D Mining Co.	Ash (NOS)	Manganese	ppm	54.325	65.65	79.925	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
B-D Mining Co.	Bottom ash	Manganese	ppm	49.5	51.8	52.675	TRUE
B-D Mining Co.	Fly ash	Manganese	ppm	82.775	88.7	92.3	TRUE
CLSM	Combined ash	Manganese	ppm	607.8	607.8	607.8	TRUE
CLSM	FBC	Manganese	ppm	1561.8	1561.8	1561.8	TRUE
Deer Ridge Mine	Fly ash	Manganese	ppm	11.8675	17.45	88.5	TRUE
DPC	Bottom ash	Manganese	ppm	144	144	144	TRUE
DPC	Fly ash	Manganese	ppm	209	209	209	TRUE
ern Analytical, ID: 5	Slag	Manganese	ppm	46	46	46	TRUE
City Mine	FBC	Mercury	ppm	0.25	0.25	0.25	TRUE
Philadelphia Girard	Ash (NOS)	Mercury	ppm	0.22	0.22	0.22	TRUE
Emerald Anthracite	Ash (NOS)	Mercury	ppm	0.36875	0.445	0.5925	TRUE
EORDC	FGD waste	Mercury	ppm	0.5	0.5	0.5	TRUE
Freeport Mine	FGD waste	Mercury	ppm	1.1125	1.115	1.1175	TRUE
Gale	Ash (NOS)	Mercury	ppm	2.5	2.5	2.5	TRUE
Girard Estate	Ash (NOS)	Mercury	ppm	0.25	0.25	0.25	TRUE
HA	Ash & coal waste	Mercury	ppm	0.065	0.065	0.065	TRUE
Harrim 3019	Ash (NOS)	Mercury	ppm	8.5	8.5	8.5	TRUE
Harrim 3019	Bottom ash	Mercury	ppm	0.408	0.408	0.408	TRUE
Harrim 3019	Fly ash	Mercury	ppm	0.19	0.2	0.44	TRUE
an Coal Corporatio	Ash (NOS)	Mercury	ppm	0.23875	0.449	1.36	TRUE
an Coal Corporatio	Bottom ash	Mercury	ppm	0.22	0.285	0.342	TRUE
an Coal Corporatio	Fly ash	Mercury	ppm	1.98	3.77	5.56	TRUE
Coal Corporation 5	Ash (NOS)	Mercury	ppm	0.1	0.1	0.1	TRUE
Coal Corporation 5	Bottom ash	Mercury	ppm	0.017	0.024	0.031	TRUE
Coal Corporation 5	Fly ash	Mercury	ppm	0.08	0.15	0.22	TRUE
ddo Highland Coal (	Ash (NOS)	Mercury	ppm	0.02	0.0765	23.28325	TRUE
ddo Highland Coal (	Bottom ash	Mercury	ppm	0.02	0.02	0.02	TRUE
Knickerbocker Pit	FBC	Mercury	ppm	0.33	0.42	0.61	TRUE
gh Coal and Naviga	Ash (NOS)	Mercury	ppm	0.4425	0.5	0.538	TRUE
ttle Sandy #10 Min	Bottom ash	Mercury	ppm	0.0125	0.0125	0.0125	TRUE
ttle Sandy #10 Min	Combined ash	Mercury	ppm	0.0125	0.013	0.5	TRUE
ttle Sandy #10 Min	FGD waste	Mercury	ppm	0.425	0.5	0.5	TRUE
ttle Sandy #10 Min	Fly ash	Mercury	ppm	0.043	0.043	0.043	TRUE
Mandan	FBC	Mercury	ppm	0.6058	0.6058	0.6058	TRUE
McCloskey Site	FBC	Mercury	ppm	0.34825	0.4465	0.54475	TRUE
McKay Site	FBC	Mercury	ppm	0.3225	0.345	0.3675	TRUE
Miller Creek Mine	Bottom ash	Mercury	ppm	0.00037	0.00715	0.01	TRUE
Miller Creek Mine	Combined ash	Mercury	ppm	0.00015	0.01	0.1335	TRUE
Miller Creek Mine	Fly ash	Mercury	ppm	0.0125	0.02625	0.113	TRUE
N & L Coal Co.	Ash (NOS)	Mercury	ppm	0.48425	8.5	13.8875	TRUE
N & L Coal Co.-2	Ash (NOS)	Mercury	ppm	1.6625	5.425	7.5	TRUE
Nepco	FBC	Mercury	ppm	0.01	0.01	0.01	TRUE
o. 1 Contracting Co	Ash (NOS)	Mercury	ppm	0.3	0.3	0.3	TRUE
uel Supply Company	Ash (NOS)	Mercury	ppm	0.194	0.277	0.535	TRUE
uel Supply Company	Ash (NOS)	Mercury	ppm	0.1835	0.222	0.311	TRUE
uel Supply Company	Ash (NOS)	Mercury	ppm	0.25275	0.4485	0.64425	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
rthampton400002	Ash (NOS)	Mercury	ppm	0.535	0.535	0.535	TRUE
heast Energy Com	Ash (NOS)	Mercury	ppm	0.02	0.255	1	TRUE
heast Energy Com	Bottom ash	Mercury	ppm	0.05	0.05	0.05	TRUE
heast Energy Com	Fly ash	Mercury	ppm	0.13	0.13	0.13	TRUE
eastern Power Con	Ash (NOS)	Mercury	ppm	0.44	0.61	0.645	TRUE
eastern Power Con	Bottom ash	Mercury	ppm	0.03	0.05	0.05	TRUE
eastern Power Con	Fly ash	Mercury	ppm	0.4825	0.712	1.0025	TRUE
Nucla2	FBC	Mercury	ppm	0.15625	0.29	0.31	TRUE
Oak Creek	Bottom ash	Mercury	ppm	0.05	0.05	0.05	TRUE
Pacton Corp	Fly ash	Mercury	ppm	0.2	0.4	0.4	TRUE
Pagnotti Coal Co.	Ash (NOS)	Mercury	ppm	0.23225	0.425	0.61	TRUE
Pagnotti Coal Co.	Fly ash	Mercury	ppm	0.01	0.01	0.01	TRUE
Panther Creek	FBC	Mercury	ppm	0.4	0.6	0.6	TRUE
ett et al. (1993) Co	Fly Ash	Mercury	ppm	0.1975	0.275	0.3925	TRUE
Plant 10	FBC	Mercury	ppm	0.7325	0.93	1.4125	TRUE
Plant 12	FBC	Mercury	ppm	0.05	0.69	1.94	TRUE
Plant 8	FBC	Mercury	ppm	0.01	0.01	0.015	TRUE
Plant 9	FBC	Mercury	ppm	0.3425	0.56	0.7875	TRUE
Pleasant Prairie	Bottom ash	Mercury	ppm	0.05	0.05	0.05	TRUE
Porter Associates	Ash (NOS)	Mercury	ppm	0.2625	0.377	0.9985	TRUE
Porter Associates	Bottom ash	Mercury	ppm	0.19	0.32	0.42	TRUE
Scrubgrass	FBC	Mercury	ppm	0.01	0.01	0.01	TRUE
Shawnee	FBC	Mercury	ppm	0.05	0.16	0.19	TRUE
ehanna Coal Comp	Ash (NOS)	Mercury	ppm	0.142	0.2405	0.29625	TRUE
hanna Coal Compa	Ash (NOS)	Mercury	ppm	0.19625	0.2265	0.455	TRUE
SW	Bottom ash	Mercury	ppm	0.025	0.025	0.025	TRUE
SW	Fly ash	Mercury	ppm	0.01	0.025	0.05	TRUE
Tracy Vein Slope	Ash (NOS)	Mercury	ppm	0.9245	1.38	3.36	TRUE
Tracy Vein Slope	Bottom ash	Mercury	ppm	0.24925	0.3775	0.50575	TRUE
Tracy Vein Slope	FBC	Mercury	ppm	0.288	0.288	0.288	TRUE
Universal	Combined ash	Mercury	ppm	0.0625	0.15	0.2	TRUE
wood Energy Prop	Ash (NOS)	Mercury	ppm	0.157	0.266	0.3345	TRUE
Wheelabrator	FBC	Mercury	ppm	0.26	0.29	0.32	TRUE
Xcel/MSI	Fly ash	Mercury	ppm	0.1975	0.2585	0.345	TRUE
Zhang et al. (2001)	Fly Ash	Mercury	ppm	0.15	0.15	0.15	TRUE
1	FBC	Mercury	ppm	0.03	0.03	0.057	TRUE
10	FBC	Mercury	ppm	0.05	0.05	0.05	TRUE
11	FBC	Mercury	ppm	0.06875	0.1325	0.19625	TRUE
12	FBC	Mercury	ppm	0.34875	0.655	0.7775	TRUE
14	FBC	Mercury	ppm	0.222	0.222	0.222	TRUE
17	FBC	Mercury	ppm	1.2375	1.715	2.1775	TRUE
18	FBC	Mercury	ppm	0.1525	0.3	0.4	TRUE
19	FBC	Mercury	ppm	0.125	0.125	0.125	TRUE
2	FBC	Mercury	ppm	0.161	0.161	0.161	TRUE
20	FBC	Mercury	ppm	0.305	0.41	0.61	TRUE
21	FBC	Mercury	ppm	0.2725	0.375	0.5525	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
23	FBC	Mercury	ppm	0.36	0.385	0.4425	TRUE
26	FBC	Mercury	ppm	0.05	0.05	0.125	TRUE
27	FBC	Mercury	ppm	0.47	0.47	0.47	TRUE
28	FBC	Mercury	ppm	0.03125	0.474	1.1675	TRUE
29	FBC	Mercury	ppm	0.027669	0.4232	0.897125	TRUE
3	FBC	Mercury	ppm	0.05	0.05	0.05	TRUE
30	FBC	Mercury	ppm	0.01	0.44	1.475	TRUE
31	FBC	Mercury	ppm	0.61	0.61	0.61	TRUE
37	FBC	Mercury	ppm	0.006875	0.01125	0.015625	TRUE
38	FBC	Mercury	ppm	0.0081	0.1145	0.25875	TRUE
39	FBC	Mercury	ppm	0.095	0.17	0.245	TRUE
4	FBC	Mercury	ppm	0.00005	0.0002	0.13	TRUE
5	FBC	Mercury	ppm	0.05	0.05	0.05	TRUE
6	FBC	Mercury	ppm	0.9	1.16	1.42	TRUE
7	FBC	Mercury	ppm	0.05	0.05	0.05	TRUE
8	FBC	Mercury	ppm	0.45	0.45	0.45	TRUE
A/C Fuels Company	Ash (NOS)	Mercury	ppm	0.7	0.7	0.7	TRUE
B-D Mining Co.	Ash (NOS)	Mercury	ppm	0.28025	0.452	0.64075	TRUE
B-D Mining Co.	Fly ash	Mercury	ppm	0.27	0.34	0.365	TRUE
CLSM	Combined ash	Mercury	ppm	27.3	27.3	27.3	TRUE
CLSM	FBC	Mercury	ppm	4	4	4	TRUE
Coal Creek	Bottom ash	Mercury	ppm	0.0009	0.0009	0.0009	TRUE
Coal Creek	Fly ash	Mercury	ppm	0.0003	0.0003	0.0003	TRUE
Deer Ridge Mine	Fly ash	Mercury	ppm	0.02025	0.0735	0.1625	TRUE
DPC	Bottom ash	Mercury	ppm	0.007	0.007	0.007	TRUE
DPC	Fly ash	Mercury	ppm	0.247	0.247	0.247	TRUE
ern Analytical, ID: 5	Slag	Mercury	ppm	0.05	0.05	0.05	TRUE
EERC?	Combined ash	Mercury	ppm	0.03175	0.0585	0.08525	TRUE
EERC?	FGD	Mercury	ppm	0.1755	0.233	0.263	TRUE
EERC?	FGD gypsum	Mercury	ppm	0.04475	0.05	0.0845	TRUE
EERC?	FGD gypsum liquids	Mercury	mg/L	0.000005	0.000005	0.000005	TRUE
EERC?	FGD liquids	Mercury	mg/L	0.000075	0.000075	0.000075	TRUE
EERC?	FGD liquids	Mercury	ppm	0.085	0.12	0.158	TRUE
EERC?	Fly Ash	Mercury	ppm	0.157	0.48	1.00375	TRUE
CAER	Bottom ash	Molybdenum	ppm	20.5	22	24.5	TRUE
CAER	FGD waste	Molybdenum	ppm	28	28	28	TRUE
CAER	Fly ash	Molybdenum	ppm	38	91	92	TRUE
Emerald Anthracite	Ash (NOS)	Molybdenum	ppm	25.55	28	34	TRUE
EORDC	FGD waste	Molybdenum	ppm	3.8	3.8	3.8	TRUE
Gale	Ash (NOS)	Molybdenum	ppm	5	5	5	TRUE
HA	Ash & coal waste	Molybdenum	ppm	0.5	0.5	0.5	TRUE
Harrim 3019	Ash (NOS)	Molybdenum	ppm	10.5	10.5	10.5	TRUE
Harrim 3019	Bottom ash	Molybdenum	ppm	25	25	25	TRUE
Harrim 3019	Fly ash	Molybdenum	ppm	16	17	19	TRUE
an Coal Corporatio	Ash (NOS)	Molybdenum	ppm	6.1425	9.635	25.75	TRUE
an Coal Corporatio	Bottom ash	Molybdenum	ppm	5.15	10.8	20	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
an Coal Corporatio	Fly ash	Molybdenum	ppm	10.5875	12.325	14.0625	TRUE
Coal Corporation 5	Ash (NOS)	Molybdenum	ppm	19	19	19	TRUE
Coal Corporation 5	Bottom ash	Molybdenum	ppm	17.25	17.5	17.75	TRUE
Coal Corporation 5	Fly ash	Molybdenum	ppm	14	14	14	TRUE
ddo Highland Coal (	Ash (NOS)	Molybdenum	ppm	7.5	19	136	TRUE
ddo Highland Coal (	Bottom ash	Molybdenum	ppm	5	5	5	TRUE
Knickerbocker Pit	FBC	Molybdenum	ppm	3.3	13	46.97	TRUE
KY	FGD waste	Molybdenum	ppm	24.5	26	26.5	TRUE
gh Coal and Naviga	Ash (NOS)	Molybdenum	ppm	10	12	13	TRUE
LIMB Site	Ash (NOS)	Molybdenum	ppm	2.5	2.5	2.5	TRUE
ttle Sandy #10 Min	Bottom ash	Molybdenum	ppm	2.5	2.5	2.5	TRUE
ttle Sandy #10 Min	Combined ash	Molybdenum	ppm	2.5	2.54	3.6	TRUE
ttle Sandy #10 Min	FGD waste	Molybdenum	ppm	8.05	9.8	12.55	TRUE
ttle Sandy #10 Min	Fly ash	Molybdenum	ppm	15	15	15	TRUE
McCloskey Site	FBC	Molybdenum	ppm	0.15	0.15	0.15	TRUE
McKay Site	FBC	Molybdenum	ppm	4.375	6.25	8.125	TRUE
Miller Creek Mine	Bottom ash	Molybdenum	ppm	0.316	2.7	5.66	TRUE
Miller Creek Mine	Combined ash	Molybdenum	ppm	1.7625	3.795	16	TRUE
Miller Creek Mine	Fly ash	Molybdenum	ppm	3.075	4.55	13.7725	TRUE
N & L Coal Co.	Ash (NOS)	Molybdenum	ppm	10	15.715	30	TRUE
N & L Coal Co.-2	Ash (NOS)	Molybdenum	ppm	6.0625	7	10.1125	TRUE
o. 1 Contracting Co	Ash (NOS)	Molybdenum	ppm	4.725	9.15	13.575	TRUE
el Supply Company	Ash (NOS)	Molybdenum	ppm	10	17	31	TRUE
el Supply Company	Ash (NOS)	Molybdenum	ppm	0.0443	0.0443	0.0443	TRUE
el Supply Company	Ash (NOS)	Molybdenum	ppm	36.25	52.5	68.75	TRUE
rthampton400002	Ash (NOS)	Molybdenum	ppm	10	10	10	TRUE
heast Energy Com	Ash (NOS)	Molybdenum	ppm	11	14	25	TRUE
heast Energy Com	Bottom ash	Molybdenum	ppm	0.5	0.5	0.5	TRUE
heast Energy Com	Fly ash	Molybdenum	ppm	1.2	1.2	1.2	TRUE
eastern Power Con	Ash (NOS)	Molybdenum	ppm	2.9	2.9	2.9	TRUE
eastern Power Con	Bottom ash	Molybdenum	ppm	0.4735	0.785	7.29	TRUE
eastern Power Con	Fly ash	Molybdenum	ppm	0.7625	3.135	17.525	TRUE
Nucla	FBC	Molybdenum	ppm	82	83	84	TRUE
Nucla2	FBC	Molybdenum	ppm	2.375	2.45	3.825	TRUE
aceAnalytical (201(	Slag	Molybdenum	ppm	2.3	2.3	2.3	TRUE
Pacton Corp	Ash (NOS)	Molybdenum	ppm	17	17	17	TRUE
Pacton Corp	Bottom ash	Molybdenum	ppm	15	15	15	TRUE
Pacton Corp	Fly ash	Molybdenum	ppm	9	18	20	TRUE
Pagnotti Coal Co.	Ash (NOS)	Molybdenum	ppm	12.625	13.25	13.875	TRUE
Pagnotti Coal Co.	Fly ash	Molybdenum	ppm	50	50	50	TRUE
Panther Creek	FBC	Molybdenum	ppm	1.3	3.3	16	TRUE
ett et al. (1993) Co	Fly Ash	Molybdenum	ppm	11	16	31	TRUE
Porter Associates	Ash (NOS)	Molybdenum	ppm	5	15.585	26.75	TRUE
Porter Associates	Bottom ash	Molybdenum	ppm	9	21	34	TRUE
Shawnee	FBC	Molybdenum	ppm	4.8	5	6	TRUE
Silverton	Ash (NOS)	Molybdenum	ppm	5	5	5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ehanna Coal Comp	Ash (NOS)	Molybdenum	ppm	17	31	33.25	TRUE
hanna Coal Compa	Ash (NOS)	Molybdenum	ppm	10.25	13	26.5	TRUE
Tracy Vein Slope	Ash (NOS)	Molybdenum	ppm	8.22	9.385	10.65	TRUE
Tracy Vein Slope	Bottom ash	Molybdenum	ppm	3.4025	4.195	4.9875	TRUE
Tracy Vein Slope	FBC	Molybdenum	ppm	0.84	0.84	0.84	TRUE
Universal	Combined ash	Molybdenum	ppm	2.73	3.3	3.97	TRUE
wood Energy Prop	Ash (NOS)	Molybdenum	ppm	0.83	0.92	1.37	TRUE
Wheelabrator	FBC	Molybdenum	ppm	1.5475	2.865	18.0475	TRUE
Xcel/MSI	Fly ash	Molybdenum	ppm	8.675	9.25	10.95	TRUE
Zhang et al. (2001)	Fly Ash	Molybdenum	ppm	160	170	200	TRUE
1	FBC	Molybdenum	ppm	9.48	15.1	16.14	TRUE
10	FBC	Molybdenum	ppm	15.625	18.75	21.875	TRUE
12	FBC	Molybdenum	ppm	10	13	18.5	TRUE
14	FBC	Molybdenum	ppm	2.5	2.5	2.5	TRUE
17	FBC	Molybdenum	ppm	1.25	2.3	5	TRUE
18	FBC	Molybdenum	ppm	7	8	8.5	TRUE
19	FBC	Molybdenum	ppm	24	24	24	TRUE
2	FBC	Molybdenum	ppm	3.1	3.1	3.1	TRUE
20	FBC	Molybdenum	ppm	7	12	19	TRUE
21	FBC	Molybdenum	ppm	1.25	1.25	1.25	TRUE
23	FBC	Molybdenum	ppm	2.19	2.345	2.5	TRUE
26	FBC	Molybdenum	ppm	4.9	6.025	8.6875	TRUE
27	FBC	Molybdenum	ppm	3	3	3	TRUE
28	FBC	Molybdenum	ppm	9.06875	35.5	57.75	TRUE
29	FBC	Molybdenum	ppm	0.075	0.075	107.7188	TRUE
3	FBC	Molybdenum	ppm	6.25	6.25	6.25	TRUE
30	FBC	Molybdenum	ppm	0.675	12.75	21.075	TRUE
31	FBC	Molybdenum	ppm	8	8	8	TRUE
37	FBC	Molybdenum	ppm	6.875	8.25	9.625	TRUE
38	FBC	Molybdenum	ppm	2.5	13.25	23.25	TRUE
39	FBC	Molybdenum	ppm	9.25	13.5	17.75	TRUE
4	FBC	Molybdenum	ppm	0.365	18.945	22.469	TRUE
5	FBC	Molybdenum	ppm	7.1	11.5	15	TRUE
6	FBC	Molybdenum	ppm	0.775	1.425	2.075	TRUE
7	FBC	Molybdenum	ppm	4.04	4.04	4.04	TRUE
A/C Fuels Company	Ash (NOS)	Molybdenum	ppm	5	5	5	TRUE
B-D Mining Co.	Ash (NOS)	Molybdenum	ppm	10.955	13.5	19.5	TRUE
B-D Mining Co.	Fly ash	Molybdenum	ppm	3.5	3.5	3.5	TRUE
CLSM	Combined ash	Molybdenum	ppm	33.15	33.15	33.15	TRUE
CLSM	FBC	Molybdenum	ppm	125.7	125.7	125.7	TRUE
Deer Ridge Mine	Fly ash	Molybdenum	ppm	1.825	2.55	4.02625	TRUE
DPC	Bottom ash	Molybdenum	ppm	2.38	2.38	2.38	TRUE
DPC	Fly ash	Molybdenum	ppm	14.3	14.3	14.3	TRUE
ern Analytical, ID: 5	Slag	Molybdenum	ppm	3	3	3	TRUE
Bowen	Fly ash	Nickel	ppm	130.1	130.1	130.1	TRUE
CAER	Bottom ash	Nickel	ppm	62.5	67	94	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
CAER	FGD waste	Nickel	ppm	5	5	5	TRUE
CAER	Fly ash	Nickel	ppm	127	151	156	TRUE
Cardinal	Fly ash	Nickel	ppm	138.425	140.25	142.075	TRUE
City Mine	FBC	Nickel	ppm	321.5	399	432.5	TRUE
Philadelphia Girard	Ash (NOS)	Nickel	ppm	12.2	12.2	12.2	TRUE
Cleveland	Fly ash	Nickel	ppm	0.049	0.049	0.049	TRUE
Emerald Anthracite	Ash (NOS)	Nickel	ppm	19.55	36.95	95.34225	TRUE
EORDC	FGD waste	Nickel	ppm	18	18	18	TRUE
Fleming	FBC	Nickel	ppm	23	23	23	TRUE
Freeport Mine	FGD waste	Nickel	ppm	2.5	2.5	2.5	TRUE
Gale	Ash (NOS)	Nickel	ppm	17	17	17	TRUE
HA	Ash & coal waste	Nickel	ppm	10.5	11	12.5	TRUE
Harrim 3019	Ash (NOS)	Nickel	ppm	112.5	112.5	112.5	TRUE
Harrim 3019	Bottom ash	Nickel	ppm	62.8	64.1	65.4	TRUE
Harrim 3019	Fly ash	Nickel	ppm	45.5	55.75	68.85	TRUE
an Coal Corporatio	Ash (NOS)	Nickel	ppm	15.95	26.5	42.15	TRUE
an Coal Corporatio	Bottom ash	Nickel	ppm	5.42	11.5	40.15	TRUE
an Coal Corporatio	Fly ash	Nickel	ppm	67.725	79.95	92.175	TRUE
Coal Corporation 5	Ash (NOS)	Nickel	ppm	34	34	34	TRUE
Coal Corporation 5	Bottom ash	Nickel	ppm	42.75	45.5	48.25	TRUE
Coal Corporation 5	Fly ash	Nickel	ppm	47	51	55	TRUE
ddo Highland Coal (	Ash (NOS)	Nickel	ppm	27.5	32	45	TRUE
ddo Highland Coal (	Bottom ash	Nickel	ppm	31.3	31.3	31.3	TRUE
Kentucky	Bottom ash	Nickel	ppm	64.5	67	137	TRUE
Kentucky	Fly ash	Nickel	ppm	241.25	320.5	500.25	TRUE
Knickerbocker Pit	FBC	Nickel	ppm	8.575	10.1	13.0825	TRUE
KY	FGD waste	Nickel	ppm	0.005	0.005	3.5	TRUE
gh Coal and Naviga	Ash (NOS)	Nickel	ppm	19	22	31	TRUE
LIMB Site	Ash (NOS)	Nickel	ppm	65.25	76.5	87.75	TRUE
ttle Sandy #10 Min	Bottom ash	Nickel	ppm	21	21	21	TRUE
ttle Sandy #10 Min	Combined ash	Nickel	ppm	12	13	13	TRUE
ttle Sandy #10 Min	FGD waste	Nickel	ppm	0.5	0.5	0.73	TRUE
ttle Sandy #10 Min	Fly ash	Nickel	ppm	270	270	270	TRUE
Lone Mtn	Fly ash	Nickel	ppm	195.6	195.6	195.6	TRUE
Martins Creek	Bottom ash	Nickel	ppm	65.19	77.2	127.86	TRUE
Martins Creek	Fly ash	Nickel	ppm	66.3	77.06	80.97	TRUE
McCloskey Site	FBC	Nickel	ppm	156.25	165	173.75	TRUE
McKay Site	FBC	Nickel	ppm	43.75	47.5	51.25	TRUE
Miller	Fly ash	Nickel	ppm	130.1	130.1	130.1	TRUE
Miller Creek Mine	Bottom ash	Nickel	ppm	75.6	130	145.1	TRUE
Miller Creek Mine	Combined ash	Nickel	ppm	40.5	66.46	138.5	TRUE
Miller Creek Mine	Fly ash	Nickel	ppm	19.5	34	131.25	TRUE
N & L Coal Co.	Ash (NOS)	Nickel	ppm	75.205	116	148.5	TRUE
N & L Coal Co.-2	Ash (NOS)	Nickel	ppm	61.5	92.6	132	TRUE
Nepco	FBC	Nickel	ppm	545	545	545	TRUE
NETL	Bottom ash	Nickel	ppm	199	199	199	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
NETL	FBC	Nickel	ppm	427	728	1029	TRUE
NETL	Fly ash	Nickel	ppm	50	106.5	124.25	TRUE
NETL	Slag	Nickel	ppm	710	710	710	TRUE
ɔ. 1 Contracting Co	Ash (NOS)	Nickel	ppm	356.75	694.5	1032.25	TRUE
ıel Supply Compan	Ash (NOS)	Nickel	ppm	24	27	28	TRUE
ıel Supply Compan	Ash (NOS)	Nickel	ppm	10.55	18.5	39.15	TRUE
ıel Supply Compan	Ash (NOS)	Nickel	ppm	18.75	20.5	22.25	TRUE
ɔrthampton400002	Ash (NOS)	Nickel	ppm	28	28	28	TRUE
heast Energy Com	Ash (NOS)	Nickel	ppm	16.5	29	39.5	TRUE
heast Energy Com	Bottom ash	Nickel	ppm	6.4	6.4	6.4	TRUE
heast Energy Com	Fly ash	Nickel	ppm	31	31	31	TRUE
eastern Power Cor	Ash (NOS)	Nickel	ppm	10.8	10.8	10.8	TRUE
eastern Power Cor	Bottom ash	Nickel	ppm	4.23	4.41	5.23	TRUE
eastern Power Cor	Fly ash	Nickel	ppm	7.95	10.03	10.75	TRUE
Nucla	FBC	Nickel	ppm	26.25	27.5	28.75	TRUE
Nucla2	FBC	Nickel	ppm	12.4	18	18	TRUE
Oak Creek	Bottom ash	Nickel	ppm	140	140	140	TRUE
aceAnalytical (2010	Slag	Nickel	ppm	24.8	24.8	24.8	TRUE
Pacton Corp	Ash (NOS)	Nickel	ppm	18	18	18	TRUE
Pacton Corp	Bottom ash	Nickel	ppm	23	23	23	TRUE
Pacton Corp	Fly ash	Nickel	ppm	45	58	145	TRUE
Pagnotti Coal Co.	Ash (NOS)	Nickel	ppm	10	10.5	16.4	TRUE
Pagnotti Coal Co.	Fly ash	Nickel	ppm	2	2	2	TRUE
Panther Creek	FBC	Nickel	ppm	14.5	19	23.775	TRUE
Paradise	Fly ash	Nickel	ppm	162.2	162.2	162.2	TRUE
ett et al. (1993) Cor	Fly Ash	Nickel	ppm	30.25	32.5	265.5	TRUE
Plant 10	FBC	Nickel	ppm	21.35	26.8	39.75	TRUE
Plant 12	FBC	Nickel	ppm	30	38.4	43.5	TRUE
Plant 8	FBC	Nickel	ppm	24	25	28	TRUE
Plant 9	FBC	Nickel	ppm	87.95	121.55	145	TRUE
Pleasant Prairie	Bottom ash	Nickel	ppm	48	48	48	TRUE
Pleasant Prairie	Fly ash	Nickel	ppm	93.8	93.8	93.8	TRUE
Porter Associates	Ash (NOS)	Nickel	ppm	16.7	38.25	66.85	TRUE
Porter Associates	Bottom ash	Nickel	ppm	17	31	41	TRUE
ylkill Reclamation (	Ash (NOS)	Nickel	ppm	9	9	9	TRUE
Scrubgrass	FBC	Nickel	ppm	45	45	45	TRUE
SFA	Fly ash	Nickel	ppm	130	130	130	TRUE
Shawnee	FBC	Nickel	ppm	2	33	80	TRUE
Silverton	Ash (NOS)	Nickel	ppm	17.75	18.5	19.25	TRUE
Sioux	Fly ash	Nickel	ppm	178.4	187.9	197.4	TRUE
Stanton	Fly ash	Nickel	ppm	70.2	70.2	70.2	TRUE
STK	Fly ash	Nickel	ppm	10	10	10	TRUE
ehanna Coal Comp	Ash (NOS)	Nickel	ppm	178.5	192.5	199	TRUE
hanna Coal Compa	Ash (NOS)	Nickel	ppm	11.05	14	16.85	TRUE
Tracy Vein Slope	Ash (NOS)	Nickel	ppm	28.225	36.75	48.375	TRUE
Tracy Vein Slope	Bottom ash	Nickel	ppm	43.8	59	74.2	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Tracy Vein Slope	FBC	Nickel	ppm	2.87	2.87	2.87	TRUE
Universal	Combined ash	Nickel	ppm	31	38.25	65	TRUE
USGS	Fly ash	Nickel	ppm	145.5	200	340	TRUE
wood Energy Prop	Ash (NOS)	Nickel	ppm	5.7375	7.165	8.425	TRUE
Wheelabrator	FBC	Nickel	ppm	9.5	11.2	15.4	TRUE
Xcel/MSI	Fly ash	Nickel	ppm	39	59	75.5	TRUE
Yates	Fly ash	Nickel	ppm	147.1	147.1	147.1	TRUE
Zhang et al. (2001)	Fly Ash	Nickel	ppm	33	39	100	TRUE
1	FBC	Nickel	ppm	13.85	14.56	14.955	TRUE
10	FBC	Nickel	ppm	7.8125	9.375	10.9375	TRUE
11	FBC	Nickel	ppm	28.5	31	33.5	TRUE
12	FBC	Nickel	ppm	14.2	18	19.9	TRUE
14	FBC	Nickel	ppm	23	23	23	TRUE
17	FBC	Nickel	ppm	19.925	27.75	37.075	TRUE
18	FBC	Nickel	ppm	19.5	21	31.5	TRUE
19	FBC	Nickel	ppm	593.5	724	854.5	TRUE
2	FBC	Nickel	ppm	3.1	9.6835	16.267	TRUE
20	FBC	Nickel	ppm	12	20.2	31.95	TRUE
21	FBC	Nickel	ppm	11	12.5	26.75	TRUE
23	FBC	Nickel	ppm	29.785	31.54	33.9475	TRUE
26	FBC	Nickel	ppm	525.75	761	846.5	TRUE
27	FBC	Nickel	ppm	43	43	43	TRUE
28	FBC	Nickel	ppm	51.5	58.95	66.4	TRUE
29	FBC	Nickel	ppm	54.725	57.45	65.65	TRUE
3	FBC	Nickel	ppm	6.25	6.25	6.25	TRUE
30	FBC	Nickel	ppm	30.1395	34.6	41.225	TRUE
31	FBC	Nickel	ppm	0.77	0.77	0.77	TRUE
37	FBC	Nickel	ppm	65	71	77	TRUE
38	FBC	Nickel	ppm	8.34	13.375	19.8	TRUE
39	FBC	Nickel	ppm	4.25	7.5	10.75	TRUE
4	FBC	Nickel	ppm	9.084	13.76	15.35	TRUE
5	FBC	Nickel	ppm	697	761	971.25	TRUE
6	FBC	Nickel	ppm	18.8	21.4	24	TRUE
7	FBC	Nickel	ppm	46.43	46.43	46.43	TRUE
8	FBC	Nickel	ppm	44	44	44	TRUE
A/C Fuels Company	Ash (NOS)	Nickel	ppm	7	7	7	TRUE
Baldwin	Fly ash	Nickel	ppm	275.1	275.1	275.1	TRUE
B-D Mining Co.	Ash (NOS)	Nickel	ppm	14.85	20.6	30.5	TRUE
B-D Mining Co.	Bottom ash	Nickel	ppm	10.05	10.7	12	TRUE
B-D Mining Co.	Fly ash	Nickel	ppm	23.05	25.8	45.275	TRUE
CLSM	Combined ash	Nickel	ppm	2097	2097	2097	TRUE
CLSM	FBC	Nickel	ppm	54055	54055	54055	TRUE
Deer Ridge Mine	Fly ash	Nickel	ppm	98.0575	158.115	409	TRUE
DPC	Bottom ash	Nickel	ppm	6.88	6.88	6.88	TRUE
DPC	Fly ash	Nickel	ppm	32.7	32.7	32.7	TRUE
ern Analytical, ID: 5	Slag	Nickel	ppm	23	23	23	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Edgewater	Bottom ash	Nickel	ppm	29.9	29.9	29.9	TRUE
EERC?	Combined ash	Nickel	ppm	17.1	21.3	25.5	TRUE
EERC?	FGD	Nickel	ppm	3.98	25.3	87.2	TRUE
EERC?	FGD gypsum	Nickel	ppm	0.5	3.655	6.815	TRUE
EERC?	FGD gypsum liquids	Nickel	mg/L	0.338	0.338	0.338	TRUE
EERC?	FGD liquids	Nickel	mg/L	0.11445	0.1905	0.27675	TRUE
EERC?	FGD liquids	Nickel	ppm	2.87	2.87	2.87	TRUE
EERC?	Fly Ash	Nickel	ppm	23.675	51	74.85	TRUE
DPC	Bottom ash	Nitrate Nitrogen	ppm	0.235	0.235	0.235	TRUE
DPC	Fly ash	Nitrate Nitrogen	ppm	0.25	0.25	0.25	TRUE
Cleveland	Fly ash	Nitrogen	ppm	1.9	1.9	1.9	FALSE
Philadelphia Girard	Ash (NOS)	pH	pH	10.72	10.72	10.72	FALSE
Emerald Anthracite	Ash (NOS)	pH	pH	10.6025	11.685	11.8	FALSE
Gale	Ash (NOS)	pH	pH	9.02	9.02	9.02	FALSE
Girard Estate	Ash (NOS)	pH	pH	12.51	12.51	12.51	FALSE
HA	Ash & coal waste	pH	pH	8.55	9.1	9.1	FALSE
Harrim 3019	Ash (NOS)	pH	pH	11.56	11.56	11.56	FALSE
Harrim 3019	Bottom ash	pH	pH	11.94	12.06	12.18	FALSE
Harrim 3019	Fly ash	pH	pH	11.7075	11.825	12.0525	FALSE
an Coal Corporatio	Ash (NOS)	pH	pH	9.0675	10.38	11.2225	FALSE
an Coal Corporatio	Bottom ash	pH	pH	8.3225	8.715	9.11	FALSE
an Coal Corporatio	Fly ash	pH	pH	11.9775	12.085	12.1925	FALSE
Coal Corporation 5	Ash (NOS)	pH	pH	12.05	12.05	12.05	FALSE
Coal Corporation 5	Bottom ash	pH	pH	11.1125	11.365	11.6175	FALSE
Coal Corporation 5	Fly ash	pH	pH	11.1775	11.395	11.6125	FALSE
ddo Highland Coal (	Ash (NOS)	pH	pH	7.5	7.82	9.975	FALSE
ddo Highland Coal (	Bottom ash	pH	pH	8.64	8.64	8.64	FALSE
Knickerbocker Pit	FBC	pH	pH	9.735	10.435	10.84	FALSE
gh Coal and Naviga	Ash (NOS)	pH	pH	10.44	10.45	11.06	FALSE
ttle Sandy #10 Min	Bottom ash	pH	pH	11.3	11.3	11.3	FALSE
ttle Sandy #10 Min	Combined ash	pH	pH	9.34	9.63	9.7	FALSE
ttle Sandy #10 Min	FGD waste	pH	pH	12	12.2	12.3	FALSE
ttle Sandy #10 Min	Fly ash	pH	pH	4.01	4.01	4.01	FALSE
Martins Creek	Bottom ash	pH	pH	6.82	7.4	7.99	FALSE
Martins Creek	Fly ash	pH	pH	10.1	11.6	12.1	FALSE
McCloskey Site	FBC	pH	pH	12.1	12.2	12.3	FALSE
McKay Site	FBC	pH	pH	11.7	11.8	11.9	FALSE
Miller Creek Mine	Bottom ash	pH	pH	4.475	6.9	9.55	FALSE
Miller Creek Mine	Combined ash	pH	pH	6.825	7.75	9.8	FALSE
Miller Creek Mine	Fly ash	pH	pH	7.75	9.1	9.485	FALSE
N & L Coal Co.	Ash (NOS)	pH	pH	9.355	11.1	12.285	FALSE
N & L Coal Co.-2	Ash (NOS)	pH	pH	4.54	11.75	12.3	FALSE
o. 1 Contracting Co	Ash (NOS)	pH	pH	11.1	11.4	11.7	FALSE
uel Supply Company	Ash (NOS)	pH	pH	11.41	11.65	12.27	FALSE
uel Supply Company	Ash (NOS)	pH	pH	10.68	10.86	11.735	FALSE
uel Supply Company	Ash (NOS)	pH	pH	12.005	12.13	12.255	FALSE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
rthampton400002	Ash (NOS)	pH	pH	11.41	11.41	11.41	FALSE
heast Energy Com	Ash (NOS)	pH	pH	8.3725	9.15	9.6925	FALSE
heast Energy Com	Bottom ash	pH	pH	8	8	8	FALSE
heast Energy Com	Fly ash	pH	pH	9.7	9.7	9.7	FALSE
eastern Power Con	Ash (NOS)	pH	pH	10.005	10.01	10.24	FALSE
eastern Power Con	Bottom ash	pH	pH	11	11.2	11.56	FALSE
eastern Power Con	Fly ash	pH	pH	10.6	10.6	10.8	FALSE
Pacton Corp	Ash (NOS)	pH	pH	10.46	10.54	10.62	FALSE
Pacton Corp	Bottom ash	pH	pH	11.7	11.7	11.7	FALSE
Pacton Corp	Fly ash	pH	pH	10.175	10.95	11.65	FALSE
Pagnotti Coal Co.	Ash (NOS)	pH	pH	10.1	10.45	11.1	FALSE
Pagnotti Coal Co.	Fly ash	pH	pH	11.75	11.75	11.75	FALSE
Panther Creek	FBC	pH	pH	10.45	11.17	11.5075	FALSE
nther Creek Partne	Ash (NOS)	pH	pH	10.6725	11	11.4025	FALSE
Porter Associates	Ash (NOS)	pH	pH	10.6325	11.83	12.2225	FALSE
Porter Associates	Bottom ash	pH	pH	8.28	9.21	11.465	FALSE
ading Anthracite C	Ash (NOS)	pH	pH	9.64	10.22	10.56	FALSE
ading Anthracite C	Bottom ash	pH	pH	11.31	11.31	11.31	FALSE
ading Anthracite C	Fly ash	pH	pH	10.995	11.11	11.225	FALSE
ylkill Reclamation C	Ash (NOS)	pH	pH	8.07	8.07	8.07	FALSE
Silverton	Ash (NOS)	pH	pH	8.495	8.67	8.845	FALSE
ehanna Coal Comp	Ash (NOS)	pH	pH	11.1875	11.93	12.195	FALSE
hanna Coal Compa	Ash (NOS)	pH	pH	10.5925	11.135	11.4775	FALSE
Tracy Vein Slope	Ash (NOS)	pH	pH	8.775	9.72	11.04	FALSE
Tracy Vein Slope	Bottom ash	pH	pH	7.5775	7.685	7.7925	FALSE
Tracy Vein Slope	FBC	pH	pH	10.5	10.5	10.5	FALSE
Universal	Combined ash	pH	pH	8.4	9.04	9.58	FALSE
wood Energy Prop	Ash (NOS)	pH	pH	10.75	11.685	11.7925	FALSE
Wheelabrator	FBC	pH	pH	10.9	10.995	11.2425	FALSE
brator Culm Servic	Ash (NOS)	pH	pH	10.59	10.95	11.18	FALSE
A/C Fuels Company	Ash (NOS)	pH	pH	11.85	11.85	11.85	FALSE
B-D Mining Co.	Ash (NOS)	pH	pH	10.0925	10.185	10.5325	FALSE
B-D Mining Co.	Bottom ash	pH	pH	7.545	11.045	11.53	FALSE
B-D Mining Co.	Fly ash	pH	pH	11.3475	11.815	11.9075	FALSE
Deer Ridge Mine	Fly ash	pH	pH	4.75	6.1	6.4375	FALSE
DPC	Bottom ash	pH	pH	11.78	11.78	11.78	FALSE
DPC	Fly ash	pH	pH	10.7	10.7	10.7	FALSE
EERC?	FGD gypsum liquids	pH (lab)	pH	5.3	5.4	5.42	FALSE
EERC?	FGD liquids	pH (lab)	pH	6.73	6.75	7.2	FALSE
Cleveland	Fly ash	Phosphorus	ppm	0.464	0.464	0.464	FALSE
Miller Creek Mine	Combined ash	Phosphorus	ppm	3.265	26.645	56.125	FALSE
Oak Creek	Bottom ash	Phosphorus	ppm	2640	2640	2640	FALSE
Pleasant Prairie	Bottom ash	Phosphorus	ppm	2288	2288	2288	FALSE
Deer Ridge Mine	Fly ash	Phosphorus	ppm	16.13	340	680	FALSE
DPC	Bottom ash	Phosphorus	ppm	0.05	0.05	0.05	FALSE
DPC	Fly ash	Phosphorus	ppm	0.05	0.05	0.05	FALSE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ern Analytical, ID: 5	Slag	Phosphorus	ppm	200	200	200	FALSE
Edgewater	Bottom ash	Phosphorus	ppm	1750	1750	1750	FALSE
Philadelphia Girard	Ash (NOS)	Potassium	ppm	6600	6600	6600	TRUE
Cleveland	Fly ash	Potassium	ppm	3.06	3.06	3.06	TRUE
Emerald Anthracite	Ash (NOS)	Potassium	ppm	5100	6400	7700	TRUE
Freeport Mine	FGD waste	Potassium	ppm	215	215	215	TRUE
Girard Estate	Ash (NOS)	Potassium	ppm	2800	2800	2800	TRUE
Harrim 3019	Bottom ash	Potassium	ppm	1890	2370	2850	TRUE
Harrim 3019	Fly ash	Potassium	ppm	2030	3860	6060	TRUE
an Coal Corporatio	Ash (NOS)	Potassium	ppm	726.25	1175	1792.5	TRUE
an Coal Corporatio	Bottom ash	Potassium	ppm	111	143	974.5	TRUE
an Coal Corporatio	Fly ash	Potassium	ppm	7735	10050	12365	TRUE
Coal Corporation 5	Ash (NOS)	Potassium	ppm	1510	1510	1510	TRUE
Knickerbocker Pit	FBC	Potassium	ppm	6300	7155	8312.5	TRUE
gh Coal and Naviga	Ash (NOS)	Potassium	ppm	4075	4100	4750	TRUE
ttle Sandy #10 Min	Combined ash	Potassium	ppm	608	656	748	TRUE
ttle Sandy #10 Min	FGD waste	Potassium	ppm	625	730	791	TRUE
Martins Creek	Bottom ash	Potassium	ppm	9620	10550	11500	TRUE
Martins Creek	Fly ash	Potassium	ppm	9059	10200	11544	TRUE
Miller Creek Mine	Bottom ash	Potassium	ppm	232	477	1580	TRUE
Miller Creek Mine	Combined ash	Potassium	ppm	262.5	438	978.25	TRUE
Miller Creek Mine	Fly ash	Potassium	ppm	1790	2640	3640	TRUE
N & L Coal Co.	Ash (NOS)	Potassium	ppm	4525	15771	19270	TRUE
N & L Coal Co.-2	Ash (NOS)	Potassium	ppm	15335	21500	23650	TRUE
el Supply Company	Ash (NOS)	Potassium	ppm	2895	4710	29027.9	TRUE
heast Energy Comp	Ash (NOS)	Potassium	ppm	1200	1200	2170	TRUE
eastern Power Con	Bottom ash	Potassium	ppm	4175	5390	5895	TRUE
eastern Power Con	Fly ash	Potassium	ppm	5885	7530	7575	TRUE
Nucla	FBC	Potassium	ppm	7875	8750	9625	TRUE
Nucla2	FBC	Potassium	ppm	6400	6700	7850	TRUE
Oak Creek	Bottom ash	Potassium	ppm	2075	2075	2075	TRUE
Pacton Corp	Ash (NOS)	Potassium	ppm	4900	4900	4900	TRUE
Panther Creek	FBC	Potassium	ppm	3692.5	5650	6150	TRUE
Pleasant Prairie	Bottom ash	Potassium	ppm	1660	1660	1660	TRUE
Porter Associates	Ash (NOS)	Potassium	ppm	827	1200	2220	TRUE
Porter Associates	Bottom ash	Potassium	ppm	344.5	477.5	1162.5	TRUE
ylkill Reclamation (	Ash (NOS)	Potassium	ppm	370	370	370	TRUE
Shawnee	FBC	Potassium	ppm	3010	6000	8020	TRUE
ehanna Coal Comp	Ash (NOS)	Potassium	ppm	1922.5	4035	5075	TRUE
hanna Coal Compa	Ash (NOS)	Potassium	ppm	5230	5745	7127.5	TRUE
Universal	Combined ash	Potassium	ppm	880	1200	1300	TRUE
wood Energy Prop	Ash (NOS)	Potassium	ppm	1860	2200	2560	TRUE
Wheelabrator	FBC	Potassium	ppm	3987.5	4560	5007.5	TRUE
1	FBC	Potassium	ppm	2.82	2.82	2.82	TRUE
11	FBC	Potassium	ppm	755	1270	1785	TRUE
12	FBC	Potassium	ppm	4750	5400	5881	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
14	FBC	Potassium	ppm	4710	4710	4710	TRUE
18	FBC	Potassium	ppm	1397.5	2211	2287.5	TRUE
19	FBC	Potassium	ppm	637	637	637	TRUE
2	FBC	Potassium	ppm	1.125	1.2125	1.3	TRUE
20	FBC	Potassium	ppm	3580	3845	4575	TRUE
21	FBC	Potassium	ppm	3692.5	5200	5725	TRUE
26	FBC	Potassium	ppm	1340	1340	1340	TRUE
27	FBC	Potassium	ppm	1543	1543	1543	TRUE
28	FBC	Potassium	ppm	448.5	2010	4230	TRUE
29	FBC	Potassium	ppm	6947.7	10876.9	11547.95	TRUE
30	FBC	Potassium	ppm	1182.5	2865	4697.5	TRUE
31	FBC	Potassium	ppm	9163	9163	9163	TRUE
38	FBC	Potassium	ppm	3987.5	4180	4330	TRUE
4	FBC	Potassium	ppm	2220	2580	2940	TRUE
6	FBC	Potassium	ppm	10239	10239	10239	TRUE
7	FBC	Potassium	ppm	8332.49	8332.49	8332.49	TRUE
8	FBC	Potassium	ppm	5000	5000	5000	TRUE
B-D Mining Co.	Ash (NOS)	Potassium	ppm	2775	3740	5250	TRUE
CLSM	Combined ash	Potassium	ppm	14385	14385	14385	TRUE
CLSM	FBC	Potassium	ppm	2894.5	2894.5	2894.5	TRUE
Deer Ridge Mine	Fly ash	Potassium	ppm	138.825	570	759	TRUE
DPC	Bottom ash	Potassium	ppm	374	374	374	TRUE
DPC	Fly ash	Potassium	ppm	2120	2120	2120	TRUE
ern Analytical, ID: 5	Slag	Potassium	ppm	1900	1900	1900	TRUE
Edgewater	Bottom ash	Potassium	ppm	650	650	650	TRUE
Zhang et al. (2001)	Fly Ash	Scandium	ppm	23	28	35	FALSE
City Mine	FBC	Selenium	ppm	12.5	12.5	12.5	TRUE
Cleveland	Fly ash	Selenium	ppm	0.01	0.01	0.01	TRUE
EERC?	FGD gypsum	Selenium	ppm	1	1.78	2.59	TRUE
EERC?	FGD gypsum liquids	Selenium	mg/L	0.684	0.684	0.684	TRUE
EERC?	FGD liquids	Selenium	mg/L	0.26725	0.532	0.85425	TRUE
EERC?	FGD liquids	Selenium	ppm	3.01	3.01	3.01	TRUE
EERC?	Fly Ash	Selenium	ppm	10.6	14.8	29.1	TRUE
Emerald Anthracite	Ash (NOS)	Selenium	ppm	2.0475	5.915	17.1775	TRUE
EORDC	FGD waste	Selenium	ppm	4.2	4.2	4.2	TRUE
Fleming	FBC	Selenium	ppm	1.3	1.3	1.3	TRUE
Freeport Mine	FGD waste	Selenium	ppm	10.85	11.8	12.75	TRUE
Gale	Ash (NOS)	Selenium	ppm	4.4	4.4	4.4	TRUE
Girard Estate	Ash (NOS)	Selenium	ppm	5	5	5	TRUE
HA	Ash & coal waste	Selenium	ppm	0.25125	0.5	0.8	TRUE
Harrim 3019	Ash (NOS)	Selenium	ppm	3.5	3.5	3.5	TRUE
Harrim 3019	Bottom ash	Selenium	ppm	1	1	1	TRUE
Harrim 3019	Fly ash	Selenium	ppm	0.9	1	1.1	TRUE
an Coal Corporatio	Ash (NOS)	Selenium	ppm	2.29	4.875	8.03	TRUE
an Coal Corporatio	Bottom ash	Selenium	ppm	0.5	0.907	1.2275	TRUE
an Coal Corporatio	Fly ash	Selenium	ppm	2.3425	2.845	3.3475	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Coal Corporation 5	Ash (NOS)	Selenium	ppm	0.9	0.9	0.9	TRUE
Coal Corporation 5	Bottom ash	Selenium	ppm	0.89	1.28	1.67	TRUE
Coal Corporation 5	Fly ash	Selenium	ppm	22.575	26.05	29.525	TRUE
ldo Highland Coal (	Ash (NOS)	Selenium	ppm	1.1	2.56	9.4	TRUE
ldo Highland Coal (	Bottom ash	Selenium	ppm	0.5	0.5	0.5	TRUE
Knickerbocker Pit	FBC	Selenium	ppm	1.905	2.385	4.8775	TRUE
gh Coal and Naviga	Ash (NOS)	Selenium	ppm	1.9	3.3	3.3	TRUE
LIMB Site	Ash (NOS)	Selenium	ppm	0.25	0.25	0.25	TRUE
ttle Sandy #10 Min	Bottom ash	Selenium	ppm	0.125	0.125	0.125	TRUE
ttle Sandy #10 Min	Combined ash	Selenium	ppm	0.5	1.02	1.8	TRUE
ttle Sandy #10 Min	FGD waste	Selenium	ppm	2.65	2.8	2.87	TRUE
ttle Sandy #10 Min	Fly ash	Selenium	ppm	41	41	41	TRUE
Mandan	FBC	Selenium	ppm	1.78	1.78	1.78	TRUE
Martins Creek	Bottom ash	Selenium	ppm	2.8915	3.0485	4.895	TRUE
Martins Creek	Fly ash	Selenium	ppm	2.415	3.12	3.85	TRUE
McCloskey Site	FBC	Selenium	ppm	44.6525	52.315	59.9775	TRUE
McKay Site	FBC	Selenium	ppm	1	1	1	TRUE
Miller Creek Mine	Bottom ash	Selenium	ppm	0.25	1.39	2.005	TRUE
Miller Creek Mine	Combined ash	Selenium	ppm	0.665	1.725	5.12	TRUE
Miller Creek Mine	Fly ash	Selenium	ppm	9.1725	12.5	12.5	TRUE
N & L Coal Co.	Ash (NOS)	Selenium	ppm	4.2875	6.785	12.475	TRUE
N & L Coal Co.-2	Ash (NOS)	Selenium	ppm	2.795	7.13	7.3	TRUE
Nepco	FBC	Selenium	ppm	12.6	12.6	12.6	TRUE
NETL	Bottom ash	Selenium	ppm	0.4	0.4	0.4	TRUE
NETL	FBC	Selenium	ppm	7.475	11.65	15.825	TRUE
NETL	Fly ash	Selenium	ppm	3.1	7.45	11.15	TRUE
NETL	Slag	Selenium	ppm	2.1	2.1	2.1	TRUE
o. 1 Contracting Co	Ash (NOS)	Selenium	ppm	16.6	22.4	28.2	TRUE
uel Supply Company	Ash (NOS)	Selenium	ppm	0.5	2.2	8.9	TRUE
uel Supply Company	Ash (NOS)	Selenium	ppm	1.9	2.7	5.535	TRUE
uel Supply Company	Ash (NOS)	Selenium	ppm	0.9	1.3	1.7	TRUE
rthampton400002	Ash (NOS)	Selenium	ppm	8.9	8.9	8.9	TRUE
heast Energy Com	Ash (NOS)	Selenium	ppm	4.5	7.8	8.56	TRUE
heast Energy Com	Bottom ash	Selenium	ppm	3.9	3.9	3.9	TRUE
heast Energy Com	Fly ash	Selenium	ppm	21	21	21	TRUE
eastern Power Con	Ash (NOS)	Selenium	ppm	3.8925	6.275	6.3875	TRUE
eastern Power Con	Bottom ash	Selenium	ppm	0.65875	0.965	7.2375	TRUE
eastern Power Con	Fly ash	Selenium	ppm	4.93	12.165	13.9125	TRUE
Nucla	FBC	Selenium	ppm	8.025	9.35	10.675	TRUE
Nucla2	FBC	Selenium	ppm	0.9925	1.9	2.05	TRUE
Oak Creek	Bottom ash	Selenium	ppm	0.05	0.05	0.05	TRUE
Pacton Corp	Ash (NOS)	Selenium	ppm	2.6	2.6	2.6	TRUE
Pacton Corp	Fly ash	Selenium	ppm	4	4	4	TRUE
Pagnotti Coal Co.	Ash (NOS)	Selenium	ppm	2.92554	6.0965	9.36475	TRUE
Pagnotti Coal Co.	Fly ash	Selenium	ppm	0.1	0.1	0.1	TRUE
Panther Creek	FBC	Selenium	ppm	7.1	11	16	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ett et al. (1993) Co	Fly Ash	Selenium	ppm	7.4	13.4	17.75	TRUE
Plant 10	FBC	Selenium	ppm	0.735	2	3.75	TRUE
Plant 12	FBC	Selenium	ppm	0.295	1.25	3.79	TRUE
Plant 8	FBC	Selenium	ppm	1.15	2.7	92.3	TRUE
Plant 9	FBC	Selenium	ppm	1.3475	2.485	2.8175	TRUE
Pleasant Prairie	Bottom ash	Selenium	ppm	0.05	0.05	0.05	TRUE
Porter Associates	Ash (NOS)	Selenium	ppm	1.875	4.085	6.845	TRUE
Porter Associates	Bottom ash	Selenium	ppm	1.29	1.76	5.15	TRUE
Scrubgrass	FBC	Selenium	ppm	21.7	21.7	21.7	TRUE
Shawnee	FBC	Selenium	ppm	0.2	0.35	1	TRUE
Silverton	Ash (NOS)	Selenium	ppm	5.55	6.7	7.85	TRUE
ehanna Coal Comp	Ash (NOS)	Selenium	ppm	2.1575	3.765	12.25	TRUE
hanna Coal Compa	Ash (NOS)	Selenium	ppm	1.2405	2.43	4.12	TRUE
SW	Bottom ash	Selenium	ppm	0.6	0.6	0.6	TRUE
SW	Fly ash	Selenium	ppm	0.6	0.6	0.6	TRUE
Tracy Vein Slope	Ash (NOS)	Selenium	ppm	9.14	11.3	12.25	TRUE
Tracy Vein Slope	Bottom ash	Selenium	ppm	5.255	5.78	6.305	TRUE
Tracy Vein Slope	FBC	Selenium	ppm	3.22	3.22	3.22	TRUE
Universal	Combined ash	Selenium	ppm	5.285	7.2	8.6	TRUE
USGS	Fly ash	Selenium	ppm	2	2.75	4.7	TRUE
wood Energy Prop	Ash (NOS)	Selenium	ppm	3.615	5.02	5.665	TRUE
Wheelabrator	FBC	Selenium	ppm	3.04	3.45	8.7	TRUE
Xcel/MSI	Fly ash	Selenium	ppm	19.7	20.9	22.1	TRUE
Zhang et al. (2001)	Fly Ash	Selenium	ppm	3.6	8.1	9.9	TRUE
1	FBC	Selenium	ppm	0.64	1.5	2.45	TRUE
10	FBC	Selenium	ppm	4.625	6.75	8.875	TRUE
11	FBC	Selenium	ppm	45.25	45.5	45.75	TRUE
12	FBC	Selenium	ppm	0.89	5.29	9.645	TRUE
14	FBC	Selenium	ppm	3.68	3.68	3.68	TRUE
17	FBC	Selenium	ppm	0.915	3.4	5.075	TRUE
18	FBC	Selenium	ppm	0.5	0.5	0.5	TRUE
19	FBC	Selenium	ppm	6.25	6.25	6.25	TRUE
2	FBC	Selenium	ppm	4.767	4.767	4.767	TRUE
20	FBC	Selenium	ppm	0.59	2.48	6.155	TRUE
21	FBC	Selenium	ppm	6.5	12.2	15.35	TRUE
23	FBC	Selenium	ppm	1.065	1.39	2.145	TRUE
26	FBC	Selenium	ppm	3.325	4.75	6.05	TRUE
27	FBC	Selenium	ppm	9	9	9	TRUE
28	FBC	Selenium	ppm	0.5	1.4925	2.075	TRUE
29	FBC	Selenium	ppm	3.485	10.895	17.825	TRUE
3	FBC	Selenium	ppm	2.6875	5.125	7.5625	TRUE
30	FBC	Selenium	ppm	0.044375	0.96	2.885	TRUE
31	FBC	Selenium	ppm	7.54	7.54	7.54	TRUE
37	FBC	Selenium	ppm	2.565	3.42	4.275	TRUE
38	FBC	Selenium	ppm	0.625	1.4565	13.76	TRUE
39	FBC	Selenium	ppm	12.75	21.5	30.25	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
4	FBC	Selenium	ppm	0.201	0.4117	0.6795	TRUE
5	FBC	Selenium	ppm	1	2.15	3.9	TRUE
6	FBC	Selenium	ppm	43.84375	84.5625	125.2813	TRUE
7	FBC	Selenium	ppm	32.7	32.7	32.7	TRUE
8	FBC	Selenium	ppm	18	18	18	TRUE
A/C Fuels Company	Ash (NOS)	Selenium	ppm	1	1	1	TRUE
B-D Mining Co.	Ash (NOS)	Selenium	ppm	0.742	3.11	6.995	TRUE
B-D Mining Co.	Bottom ash	Selenium	ppm	0.57225	0.5925	0.61275	TRUE
B-D Mining Co.	Fly ash	Selenium	ppm	0.457	0.472	0.487	TRUE
CLSM	Combined ash	Selenium	ppm	673	673	673	TRUE
CLSM	FBC	Selenium	ppm	223.3	223.3	223.3	TRUE
Coal Creek	Bottom ash	Selenium	ppm	0.0002	0.0002	0.0002	TRUE
Coal Creek	Fly ash	Selenium	ppm	0.0099	0.0099	0.0099	TRUE
Deer Ridge Mine	Fly ash	Selenium	ppm	6.45	13.0175	17.8345	TRUE
DPC	Bottom ash	Selenium	ppm	0.159	0.159	0.159	TRUE
DPC	Fly ash	Selenium	ppm	6.73	6.73	6.73	TRUE
ern Analytical, ID: 5	Slag	Selenium	ppm	0.25	0.25	0.25	TRUE
Edgewater	Bottom ash	Selenium	ppm	9.5	9.5	9.5	TRUE
EERC?	Combined ash	Selenium	ppm	9.3425	9.535	9.7275	TRUE
EERC?	FGD	Selenium	ppm	1.41	3.175	4.2725	TRUE
City Mine	FBC	Silicon	ppm	174500	183000	187000	TRUE
Martins Creek	Bottom ash	Silicon	ppm	190000	199000	256500	TRUE
Martins Creek	Fly ash	Silicon	ppm	167464	183000	210219	TRUE
Miller Creek Mine	Bottom ash	Silicon	ppm	266.25	332.5	372	TRUE
Miller Creek Mine	Combined ash	Silicon	ppm	201.75	297.5	587.55	TRUE
Miller Creek Mine	Fly ash	Silicon	ppm	187.195	293	1725.25	TRUE
Nucla	FBC	Silicon	ppm	206250	209500	212750	TRUE
Nucla2	FBC	Silicon	ppm	185000	200000	200000	TRUE
Oak Creek	Bottom ash	Silicon	ppm	288000	288000	288000	TRUE
Pleasant Prairie	Bottom ash	Silicon	ppm	172800	172800	172800	TRUE
Shawnee	FBC	Silicon	ppm	28200	71200	120000	TRUE
SW	Bottom ash	Silicon	ppm	256000	262000	280000	TRUE
SW	Fly ash	Silicon	ppm	253250	263000	279750	TRUE
CLSM	Combined ash	Silicon	ppm	3900	3900	3900	TRUE
CLSM	FBC	Silicon	ppm	9300	9300	9300	TRUE
Deer Ridge Mine	Fly ash	Silicon	ppm	19.75	39	216.5	TRUE
DPC	Bottom ash	Silicon	ppm	577	577	577	TRUE
DPC	Fly ash	Silicon	ppm	586	586	586	TRUE
B-D Mining Co.	Ash (NOS)	Silver	ppm	1.65	1.9	4.25	TRUE
B-D Mining Co.	Bottom ash	Silver	ppm	1	1	1	TRUE
B-D Mining Co.	Fly ash	Silver	ppm	1.25	1.5	1.75	TRUE
City Mine	FBC	Silver	ppm	12.5	12.5	12.5	TRUE
Emerald Anthracite	Ash (NOS)	Silver	ppm	2.45	2.7	2.95	TRUE
Freeport Mine	FGD waste	Silver	ppm	1	1	1	TRUE
HA	Ash & coal waste	Silver	ppm	0.5	0.5	0.5	TRUE
Harrim 3019	Ash (NOS)	Silver	ppm	6.5	6.5	6.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Harrim 3019	Bottom ash	Silver	ppm	87.575	171.05	254.525	TRUE
Harrim 3019	Fly ash	Silver	ppm	2	2	2.3	TRUE
an Coal Corporatio	Ash (NOS)	Silver	ppm	3.9	6.5	9.18	TRUE
an Coal Corporatio	Bottom ash	Silver	ppm	10.3	16.5	177.25	TRUE
an Coal Corporatio	Fly ash	Silver	ppm	6.5375	10.775	15.0125	TRUE
Coal Corporation 5	Ash (NOS)	Silver	ppm	2	2	2	TRUE
Knickerbocker Pit	FBC	Silver	ppm	0.55	1.4	1.95	TRUE
LIMB Site	Ash (NOS)	Silver	ppm	950.9375	1900.625	2850.313	TRUE
ttle Sandy #10 Min	Bottom ash	Silver	ppm	5	5	5	TRUE
ttle Sandy #10 Min	Combined ash	Silver	ppm	0.5	1.02	1.25	TRUE
ttle Sandy #10 Min	FGD waste	Silver	ppm	0.5	0.5	0.73	TRUE
ttle Sandy #10 Min	Fly ash	Silver	ppm	1.25	1.25	1.25	TRUE
Mandan	FBC	Silver	ppm	0.25	0.25	0.25	TRUE
McKay Site	FBC	Silver	ppm	2.5	2.5	2.5	TRUE
Miller Creek Mine	Bottom ash	Silver	ppm	0.06	0.1	0.3	TRUE
Miller Creek Mine	Combined ash	Silver	ppm	0.1275	0.25	1.25	TRUE
Miller Creek Mine	Fly ash	Silver	ppm	1.25	1.25	4.025	TRUE
N & L Coal Co.	Ash (NOS)	Silver	ppm	3	28.25	40.6375	TRUE
N & L Coal Co.-2	Ash (NOS)	Silver	ppm	22.225	25.7	26.15	TRUE
el Supply Company	Ash (NOS)	Silver	ppm	1.15	1.3	1.45	TRUE
heast Energy Comp	Ash (NOS)	Silver	ppm	5	5	5	TRUE
eastern Power Con	Bottom ash	Silver	ppm	3.805	6.11	16.555	TRUE
eastern Power Con	Fly ash	Silver	ppm	0.5	2.26	3.94	TRUE
Nucla	FBC	Silver	ppm	1.2	1.2	1.2	TRUE
Nucla2	FBC	Silver	ppm	0.47025	0.49	0.49	TRUE
Oak Creek	Bottom ash	Silver	ppm	2.5	2.5	2.5	TRUE
Pacton Corp	Ash (NOS)	Silver	ppm	1	1	1	TRUE
Pacton Corp	Bottom ash	Silver	ppm	5	5	5	TRUE
Pacton Corp	Fly ash	Silver	ppm	2.5	2.5	3.25	TRUE
Pagnotti Coal Co.	Ash (NOS)	Silver	ppm	1	1	1	TRUE
Pagnotti Coal Co.	Fly ash	Silver	ppm	0.5	0.5	0.5	TRUE
Panther Creek	FBC	Silver	ppm	1.6	7.6	8	TRUE
ett et al. (1993) Co	Fly Ash	Silver	ppm	0.1	0.1	0.1	TRUE
Pleasant Prairie	Bottom ash	Silver	ppm	2.5	2.5	2.5	TRUE
Porter Associates	Ash (NOS)	Silver	ppm	1.22	2	3.475	TRUE
Porter Associates	Bottom ash	Silver	ppm	2.75	3.5	4.25	TRUE
Shawnee	FBC	Silver	ppm	0.9	1.1	2	TRUE
ehanna Coal Comp	Ash (NOS)	Silver	ppm	1.75	2.15	2.65	TRUE
hanna Coal Compa	Ash (NOS)	Silver	ppm	1.1	1.8	2.575	TRUE
SW	Bottom ash	Silver	ppm	0.25	0.25	0.25	TRUE
SW	Fly ash	Silver	ppm	0.25	0.25	0.25	TRUE
Universal	Combined ash	Silver	ppm	0.25	0.33	1.2	TRUE
wood Energy Prop	Ash (NOS)	Silver	ppm	3.3	3.3	3.3	TRUE
Wheelabrator	FBC	Silver	ppm	0.58	0.58	0.58	TRUE
Xcel/MSI	Fly ash	Silver	ppm	1.42	1.585	1.78	TRUE
Zhang et al. (2001)	Fly Ash	Silver	ppm	0.25	0.25	0.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
1	FBC	Silver	ppm	0.43	0.82	2	TRUE
10	FBC	Silver	ppm	6.25	7.5	8.75	TRUE
11	FBC	Silver	ppm	1	1	1	TRUE
12	FBC	Silver	ppm	0.5	1.1	2	TRUE
14	FBC	Silver	ppm	1.6	1.6	1.6	TRUE
17	FBC	Silver	ppm	1.5	1.85	2.8	TRUE
18	FBC	Silver	ppm	1	1	1	TRUE
19	FBC	Silver	ppm	21.8	21.8	21.8	TRUE
2	FBC	Silver	ppm	0.288	0.288	0.288	TRUE
20	FBC	Silver	ppm	1	1.6	1.9	TRUE
21	FBC	Silver	ppm	0.25	0.25	0.4375	TRUE
26	FBC	Silver	ppm	1	1.725	3.0875	TRUE
27	FBC	Silver	ppm	0.5	0.5	0.5	TRUE
28	FBC	Silver	ppm	2.6	4.05	13.675	TRUE
29	FBC	Silver	ppm	0.05	0.05	0.05	TRUE
3	FBC	Silver	ppm	5	5	5	TRUE
30	FBC	Silver	ppm	0.005	0.5	2.5	TRUE
31	FBC	Silver	ppm	0.67	0.67	0.67	TRUE
38	FBC	Silver	ppm	0.25	0.5	0.685	TRUE
39	FBC	Silver	ppm	1	1	1	TRUE
4	FBC	Silver	ppm	0.065	0.693	1.88795	TRUE
5	FBC	Silver	ppm	1	1	1	TRUE
6	FBC	Silver	ppm	2.1125	3.225	4.3375	TRUE
7	FBC	Silver	ppm	0.51	0.51	0.51	TRUE
8	FBC	Silver	ppm	0.5	0.5	0.5	TRUE
CLSM	Combined ash	Silver	ppm	18.5	18.5	18.5	TRUE
CLSM	FBC	Silver	ppm	3.3	3.3	3.3	TRUE
Deer Ridge Mine	Fly ash	Silver	ppm	0.0575	0.225	1	TRUE
ern Analytical, ID: 5	Slag	Silver	ppm	0.25	0.25	0.25	TRUE
City Mine	FBC	Sodium	ppm	2465.5	3143	3793	TRUE
ttle Sandy #10 Min	Bottom ash	Sodium	ppm	970	970	970	TRUE
ttle Sandy #10 Min	Combined ash	Sodium	ppm	164	200	200	TRUE
ttle Sandy #10 Min	FGD waste	Sodium	ppm	250	250	253	TRUE
ttle Sandy #10 Min	Fly ash	Sodium	ppm	790	790	790	TRUE
Martins Creek	Bottom ash	Sodium	ppm	575	2739	4684	TRUE
Martins Creek	Fly ash	Sodium	ppm	650	3279	4250	TRUE
Miller Creek Mine	Bottom ash	Sodium	ppm	226	258	340	TRUE
Miller Creek Mine	Combined ash	Sodium	ppm	275	387	1016.075	TRUE
Miller Creek Mine	Fly ash	Sodium	ppm	465	520.5	781.5	TRUE
Nucla	FBC	Sodium	ppm	2650	2850	3050	TRUE
Nucla2	FBC	Sodium	ppm	1325	1400	1450	TRUE
Oak Creek	Bottom ash	Sodium	ppm	444	444	444	TRUE
Pleasant Prairie	Bottom ash	Sodium	ppm	518	518	518	TRUE
Shawnee	FBC	Sodium	ppm	1070	1260	15000	TRUE
Universal	Combined ash	Sodium	ppm	191.5	230	415.5	TRUE
CLSM	Combined ash	Sodium	ppm	1166.5	1166.5	1166.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
CLSM	FBC	Sodium	ppm	4552.5	4552.5	4552.5	TRUE
Deer Ridge Mine	Fly ash	Sodium	ppm	181.5	285	783.25	TRUE
DPC	Bottom ash	Sodium	ppm	262	262	262	TRUE
DPC	Fly ash	Sodium	ppm	1840	1840	1840	TRUE
ern Analytical, ID: 5	Slag	Sodium	ppm	900	900	900	TRUE
Edgewater	Bottom ash	Sodium	ppm	3498	3498	3498	TRUE
CAER	Bottom ash	Strontium	ppm	644	900	1870	TRUE
CAER	FGD waste	Strontium	ppm	680	680	680	TRUE
CAER	Fly ash	Strontium	ppm	481	540	1290	TRUE
Fleming	FBC	Strontium	ppm	160	160	160	TRUE
HA	Ash & coal waste	Strontium	ppm	91	96	158	TRUE
Kentucky	Bottom ash	Strontium	ppm	170.5	195	227	TRUE
Kentucky	Fly ash	Strontium	ppm	175.25	210.5	247.25	TRUE
KY	FGD waste	Strontium	ppm	115.5	118	374	TRUE
LIMB Site	Ash (NOS)	Strontium	ppm	57	88	119	TRUE
Martins Creek	Bottom ash	Strontium	ppm	606	631.57	765	TRUE
Martins Creek	Fly ash	Strontium	ppm	711	781	914.55	TRUE
Nucla	FBC	Strontium	ppm	210	210	210	TRUE
Nucla2	FBC	Strontium	ppm	265	270	275	TRUE
SFA	Fly ash	Strontium	ppm	810	810	810	TRUE
Shawnee	FBC	Strontium	ppm	220	250	2600	TRUE
STK	Fly ash	Strontium	ppm	815	850	885	TRUE
Zhang et al. (2001)	Fly Ash	Strontium	ppm	580	790	1400	TRUE
CLSM	Combined ash	Strontium	ppm	123.3	123.3	123.3	TRUE
CLSM	FBC	Strontium	ppm	5.6	5.6	5.6	TRUE
ttle Sandy #10 Min	Bottom ash	Sulfate	ppm	200	200	200	TRUE
ttle Sandy #10 Min	Combined ash	Sulfate	ppm	79	660	3500	TRUE
ttle Sandy #10 Min	FGD waste	Sulfate	ppm	633.5	1100	1200	TRUE
ttle Sandy #10 Min	Fly ash	Sulfate	ppm	7300	7300	7300	TRUE
Miller Creek Mine	Bottom ash	Sulfate	ppm	36.005	72	1006	TRUE
Miller Creek Mine	Combined ash	Sulfate	ppm	257.5	753	2600	TRUE
Miller Creek Mine	Fly ash	Sulfate	ppm	210	380	3680	TRUE
Pagnotti Coal Co.	Ash (NOS)	Sulfate	ppm	4150	4150	4150	TRUE
Pagnotti Coal Co.	Bottom ash	Sulfate	ppm	900	900	900	TRUE
Pagnotti Coal Co.	Fly ash	Sulfate	ppm	13500	16500	19500	TRUE
Universal	Combined ash	Sulfate	ppm	340	420	670	TRUE
Deer Ridge Mine	Fly ash	Sulfate	ppm	204.5	209	394.5	TRUE
DPC	Bottom ash	Sulfate	ppm	2750	2750	2750	TRUE
DPC	Fly ash	Sulfate	ppm	9630	9630	9630	TRUE
ttle Sandy #10 Min	Bottom ash	Sulfide	ppm	12	12	12	TRUE
ttle Sandy #10 Min	Combined ash	Sulfide	ppm	11	25	25	TRUE
ttle Sandy #10 Min	FGD waste	Sulfide	ppm	25	25	62	TRUE
ttle Sandy #10 Min	Fly ash	Sulfide	ppm	0.05	0.05	0.05	TRUE
Miller Creek Mine	Bottom ash	Sulfide	ppm	5.5	10	14.5	TRUE
Miller Creek Mine	Combined ash	Sulfide	ppm	0.1	1	32.5	TRUE
Miller Creek Mine	Fly ash	Sulfide	ppm	0.15	14	28	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Universal	Combined ash	Sulfide	ppm	0.5	2.8	5.85	TRUE
Deer Ridge Mine	Fly ash	Sulfide	ppm	0.025	0.025	0.025	TRUE
HA	Ash & coal waste	Sulfur	ppm	0.01	0.01	0.01	TRUE
Martins Creek	Bottom ash	Sulfur	ppm	851	1434	1944	TRUE
Martins Creek	Fly ash	Sulfur	ppm	6300	7089	7342	TRUE
Nucla2	FBC	Sulfur	ppm	20850	21700	35850	TRUE
Shawnee	FBC	Sulfur	ppm	36000	36000	48000	TRUE
City Mine	FBC	Thallium	ppm	0.25	0.25	0.25	TRUE
Freeport Mine	FGD waste	Thallium	ppm	1	1	1	TRUE
Nucla	FBC	Thallium	ppm	100	100	100	TRUE
Nucla2	FBC	Thallium	ppm	4.725	4.9	7.35	TRUE
Shawnee	FBC	Thallium	ppm	9	9	9	TRUE
Xcel/MSI	Fly ash	Thallium	ppm	0.4075	0.475	0.5025	TRUE
1	FBC	Thallium	ppm	8.7	9.83	10.96	TRUE
10	FBC	Thallium	ppm	15.625	18.75	21.875	TRUE
18	FBC	Thallium	ppm	0.5	0.5	1.25	TRUE
19	FBC	Thallium	ppm	12.5	12.5	12.5	TRUE
2	FBC	Thallium	ppm	2.792	2.792	2.792	TRUE
26	FBC	Thallium	ppm	2.5	2.5	5	TRUE
3	FBC	Thallium	ppm	12.5	12.5	12.5	TRUE
4	FBC	Thallium	ppm	39.011	39.011	39.011	TRUE
5	FBC	Thallium	ppm	0.34375	1.5625	2.5	TRUE
8	FBC	Thallium	ppm	2.8	2.8	2.8	TRUE
CLSM	Combined ash	Thallium	ppm	1.3	1.3	1.3	TRUE
CLSM	FBC	Thallium	ppm	0.15	0.15	0.15	TRUE
Zhang et al. (2001)	Fly Ash	Tin	ppm	10	10	10	FALSE
ern Analytical, ID: 5	Slag	Tin	ppm	1	1	1	FALSE
ern Analytical, ID: 5	Slag	Titanium	ppm	630	630	630	FALSE
ttle Sandy #10 Min	Bottom ash	TOC	ppm	6200	6200	6200	FALSE
ttle Sandy #10 Min	Combined ash	TOC	ppm	4800	12000	18000	FALSE
ttle Sandy #10 Min	FGD waste	TOC	ppm	5925	6650	6775	FALSE
ttle Sandy #10 Min	Fly ash	TOC	ppm	12000	12000	12000	FALSE
Miller Creek Mine	Bottom ash	TOC	ppm	807.5	3379.5	8540	FALSE
Miller Creek Mine	Combined ash	TOC	ppm	859.5	5600	17500	FALSE
Miller Creek Mine	Fly ash	TOC	ppm	9625	13000	26400	FALSE
Nepco	FBC	TOC	ppm	48600	48600	48600	FALSE
Scrubgrass	FBC	TOC	ppm	21200	21200	21200	FALSE
Universal	Combined ash	TOC	ppm	6340	45700	69800	FALSE
DPC	Bottom ash	TOC	ppm	41400	41400	41400	FALSE
DPC	Fly ash	TOC	ppm	92700	92700	92700	FALSE
Zhang et al. (2001)	Fly Ash	Uranium	ppm	5	5	5	TRUE
Bowen	Fly ash	Vanadium	ppm	307.4	307.4	307.4	TRUE
CAER	Bottom ash	Vanadium	ppm	194	197	211.5	TRUE
CAER	FGD waste	Vanadium	ppm	49	49	49	TRUE
CAER	Fly ash	Vanadium	ppm	241	367	429	TRUE
Cardinal	Fly ash	Vanadium	ppm	276.375	285.45	294.525	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
City Mine	FBC	Vanadium	ppm	12.5	12.5	12.5	TRUE
Freeport Mine	FGD waste	Vanadium	ppm	3.3	3.3	3.3	TRUE
Kentucky	Bottom ash	Vanadium	ppm	213	252	399.5	TRUE
Kentucky	Fly ash	Vanadium	ppm	365.75	556	876.5	TRUE
KY	FGD waste	Vanadium	ppm	20	24	28	TRUE
LIMB Site	Ash (NOS)	Vanadium	ppm	24.825	29.65	34.475	TRUE
ttle Sandy #10 Min	Combined ash	Vanadium	ppm	16.2	17	19.5	TRUE
ttle Sandy #10 Min	FGD waste	Vanadium	ppm	18	20	22.5	TRUE
Lone Mtn	Fly ash	Vanadium	ppm	561.9	561.9	561.9	TRUE
Martins Creek	Bottom ash	Vanadium	ppm	34.1	128.3	197.37	TRUE
Martins Creek	Fly ash	Vanadium	ppm	24.95	114.3	165	TRUE
Miller	Fly ash	Vanadium	ppm	308.8	308.8	308.8	TRUE
Miller Creek Mine	Bottom ash	Vanadium	ppm	29.75	42.5	55.25	TRUE
Miller Creek Mine	Combined ash	Vanadium	ppm	19	36	360	TRUE
Miller Creek Mine	Fly ash	Vanadium	ppm	61.5	70	73.5	TRUE
Nucla	FBC	Vanadium	ppm	25.325	30.65	35.975	TRUE
Nucla2	FBC	Vanadium	ppm	34.5	50	51	TRUE
aceAnalytical (2010	Slag	Vanadium	ppm	121	121	121	TRUE
Paradise	Fly ash	Vanadium	ppm	470.7	470.7	470.7	TRUE
ett et al. (1993) Co	Fly Ash	Vanadium	ppm	165	195	607.5	TRUE
Pleasant Prairie	Fly ash	Vanadium	ppm	330.8	330.8	330.8	TRUE
SFA	Fly ash	Vanadium	ppm	300	300	300	TRUE
Shawnee	FBC	Vanadium	ppm	110	120	150	TRUE
Sioux	Fly ash	Vanadium	ppm	327	344.3	361.6	TRUE
Stanton	Fly ash	Vanadium	ppm	316	316	316	TRUE
STK	Fly ash	Vanadium	ppm	325	330	335	TRUE
Universal	Combined ash	Vanadium	ppm	38	40	64	TRUE
Xcel/MSI	Fly ash	Vanadium	ppm	163.75	181.5	197.5	TRUE
Yates	Fly ash	Vanadium	ppm	351.4	351.4	351.4	TRUE
Zhang et al. (2001)	Fly Ash	Vanadium	ppm	75	150	190	TRUE
1	FBC	Vanadium	ppm	20.8025	24.2	30.1775	TRUE
10	FBC	Vanadium	ppm	43	49	55	TRUE
18	FBC	Vanadium	ppm	54	61	61.5	TRUE
19	FBC	Vanadium	ppm	2441.75	3294.5	4147.25	TRUE
2	FBC	Vanadium	ppm	12	36.333	36.333	TRUE
26	FBC	Vanadium	ppm	593.75	808	916	TRUE
3	FBC	Vanadium	ppm	38	39	40	TRUE
39	FBC	Vanadium	ppm	97.75	118.5	139.25	TRUE
4	FBC	Vanadium	ppm	36.43	36.43	36.43	TRUE
5	FBC	Vanadium	ppm	863.5	1135	1150	TRUE
Baldwin	Fly ash	Vanadium	ppm	517.4	517.4	517.4	TRUE
CLSM	Combined ash	Vanadium	ppm	200.8	200.8	200.8	TRUE
CLSM	FBC	Vanadium	ppm	3086.8	3086.8	3086.8	TRUE
Deer Ridge Mine	Fly ash	Vanadium	ppm	18.25	22.385	135.21	TRUE
ern Analytical, ID: 5	Slag	Vanadium	ppm	40	40	40	TRUE
Zhang et al. (2001)	Fly Ash	Ytterbium	ppm	2.5	2.5	2.5	FALSE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
ett et al. (1993) Co	Fly Ash	Yttrium	ppm	37.75	42	46.25	FALSE
Zhang et al. (2001)	Fly Ash	Yttrium	ppm	31	33	37	FALSE
B-D Mining Co.	Ash (NOS)	Zinc	ppm	15.05	20.7	24.725	TRUE
B-D Mining Co.	Bottom ash	Zinc	ppm	11.725	17	20.625	TRUE
B-D Mining Co.	Fly ash	Zinc	ppm	20.175	24.5	33.25	TRUE
Bowen	Fly ash	Zinc	ppm	141.4	141.4	141.4	TRUE
CAER	Bottom ash	Zinc	ppm	29.5	37	64.5	TRUE
CAER	FGD waste	Zinc	ppm	38	38	38	TRUE
CAER	Fly ash	Zinc	ppm	179	495	570	TRUE
Cardinal	Fly ash	Zinc	ppm	172.5	184.6	196.7	TRUE
City Mine	FBC	Zinc	ppm	571	669	707	TRUE
Philadelphia Girard	Ash (NOS)	Zinc	ppm	15	15	15	TRUE
Cleveland	Fly ash	Zinc	ppm	0.034	0.034	0.034	TRUE
Emerald Anthracite	Ash (NOS)	Zinc	ppm	24.275	27.7	36.875	TRUE
EORDC	FGD waste	Zinc	ppm	44	44	44	TRUE
Freeport Mine	FGD waste	Zinc	ppm	5	5	5	TRUE
Gale	Ash (NOS)	Zinc	ppm	29	29	29	TRUE
Girard Estate	Ash (NOS)	Zinc	ppm	14	14	14	TRUE
HA	Ash & coal waste	Zinc	ppm	17.5	21	21.5	TRUE
Harrim 3019	Ash (NOS)	Zinc	ppm	124.323	124.323	124.323	TRUE
Harrim 3019	Bottom ash	Zinc	ppm	53.175	59.15	65.125	TRUE
Harrim 3019	Fly ash	Zinc	ppm	39.3	45.3	54.725	TRUE
an Coal Corporatio	Ash (NOS)	Zinc	ppm	22.75	35	71	TRUE
an Coal Corporatio	Bottom ash	Zinc	ppm	5.05	11	41	TRUE
an Coal Corporatio	Fly ash	Zinc	ppm	75	79.9	84.8	TRUE
Coal Corporation 5	Ash (NOS)	Zinc	ppm	31	31	31	TRUE
Coal Corporation 5	Bottom ash	Zinc	ppm	21.05	21.7	22.35	TRUE
Coal Corporation 5	Fly ash	Zinc	ppm	34.8	36.2	37.6	TRUE
ddo Highland Coal (	Ash (NOS)	Zinc	ppm	18.15	24.9	44.2	TRUE
ddo Highland Coal (	Bottom ash	Zinc	ppm	12.8	12.8	12.8	TRUE
Kentucky	Bottom ash	Zinc	ppm	171	252	263.5	TRUE
Kentucky	Fly ash	Zinc	ppm	2275	4085	5867.5	TRUE
Knickerbocker Pit	FBC	Zinc	ppm	17.2675	19.85	23	TRUE
KY	FGD waste	Zinc	ppm	7.25	10	17	TRUE
gh Coal and Naviga	Ash (NOS)	Zinc	ppm	28.4	33	46.5	TRUE
LIMB Site	Ash (NOS)	Zinc	ppm	137.5	145	152.5	TRUE
ttle Sandy #10 Min	Bottom ash	Zinc	ppm	33	33	33	TRUE
ttle Sandy #10 Min	Combined ash	Zinc	ppm	20	22.5	48	TRUE
ttle Sandy #10 Min	FGD waste	Zinc	ppm	35	35	38.1	TRUE
ttle Sandy #10 Min	Fly ash	Zinc	ppm	600	600	600	TRUE
Lone Mtn	Fly ash	Zinc	ppm	168.5	168.5	168.5	TRUE
Martins Creek	Bottom ash	Zinc	ppm	45.76	57.5	65.3	TRUE
Martins Creek	Fly ash	Zinc	ppm	86	93.46	114.1	TRUE
McCloskey Site	FBC	Zinc	ppm	205.625	248.75	291.875	TRUE
McKay Site	FBC	Zinc	ppm	220	230	240	TRUE
Miller	Fly ash	Zinc	ppm	90.5	90.5	90.5	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Miller Creek Mine	Bottom ash	Zinc	ppm	131	248.46	319	TRUE
Miller Creek Mine	Combined ash	Zinc	ppm	40	83.75	167.75	TRUE
Miller Creek Mine	Fly ash	Zinc	ppm	63	131.5	223.2025	TRUE
N & L Coal Co.	Ash (NOS)	Zinc	ppm	23.6	37.9	185.7765	TRUE
N & L Coal Co.-2	Ash (NOS)	Zinc	ppm	47	113	142	TRUE
NETL	Bottom ash	Zinc	ppm	600	600	600	TRUE
NETL	FBC	Zinc	ppm	8499.75	16666.5	24833.25	TRUE
NETL	Fly ash	Zinc	ppm	100.25	137.5	201.25	TRUE
NETL	Slag	Zinc	ppm	75	75	75	TRUE
o. 1 Contracting Co	Ash (NOS)	Zinc	ppm	18.55	21.7	24.85	TRUE
uel Supply Company	Ash (NOS)	Zinc	ppm	17.7	19.8	23.7	TRUE
uel Supply Company	Ash (NOS)	Zinc	ppm	11.25	12.95	31.675	TRUE
uel Supply Company	Ash (NOS)	Zinc	ppm	15.1	17.9	20.7	TRUE
orthampton400002	Ash (NOS)	Zinc	ppm	23.87	23.87	23.87	TRUE
heast Energy Com	Ash (NOS)	Zinc	ppm	21.8	30.85	40.5	TRUE
heast Energy Com	Bottom ash	Zinc	ppm	24	24	24	TRUE
heast Energy Com	Fly ash	Zinc	ppm	54	54	54	TRUE
eastern Power Con	Ash (NOS)	Zinc	ppm	7.05	8	8.95	TRUE
eastern Power Con	Bottom ash	Zinc	ppm	5.1025	6.14	8.92	TRUE
eastern Power Con	Fly ash	Zinc	ppm	10.575	14.15	17.1	TRUE
Nucla	FBC	Zinc	ppm	322.5	355	387.5	TRUE
Nucla2	FBC	Zinc	ppm	25	37	38	TRUE
Oak Creek	Bottom ash	Zinc	ppm	250	250	250	TRUE
aceAnalytical (201	Slag	Zinc	ppm	10.7	10.7	10.7	TRUE
Pacton Corp	Ash (NOS)	Zinc	ppm	15	15	15	TRUE
Pacton Corp	Bottom ash	Zinc	ppm	23	23	23	TRUE
Pacton Corp	Fly ash	Zinc	ppm	73.5	120	184	TRUE
Pagnotti Coal Co.	Ash (NOS)	Zinc	ppm	17.2	19.9	29.25	TRUE
Pagnotti Coal Co.	Fly ash	Zinc	ppm	125	125	125	TRUE
Panther Creek	FBC	Zinc	ppm	16.5	21.5	23.75	TRUE
Paradise	Fly ash	Zinc	ppm	582.5	582.5	582.5	TRUE
ett et al. (1993) Co	Fly Ash	Zinc	ppm	67	87.5	147.5	TRUE
Pleasant Prairie	Bottom ash	Zinc	ppm	46	46	46	TRUE
Pleasant Prairie	Fly ash	Zinc	ppm	158.8	158.8	158.8	TRUE
Porter Associates	Ash (NOS)	Zinc	ppm	22.2	32.5	43.35	TRUE
Porter Associates	Bottom ash	Zinc	ppm	19.6	31.8	40	TRUE
ylkill Reclamation C	Ash (NOS)	Zinc	ppm	4.4	4.4	4.4	TRUE
SFA	Fly ash	Zinc	ppm	210	210	210	TRUE
Shawnee	FBC	Zinc	ppm	17	62	69	TRUE
Silverton	Ash (NOS)	Zinc	ppm	34.125	39.25	44.375	TRUE
Sioux	Fly ash	Zinc	ppm	3330.625	3999.25	4667.875	TRUE
Stanton	Fly ash	Zinc	ppm	153.2	153.2	153.2	TRUE
STK	Fly ash	Zinc	ppm	300	310	320	TRUE
ehanna Coal Comp	Ash (NOS)	Zinc	ppm	37.225	42	52.675	TRUE
hanna Coal Compa	Ash (NOS)	Zinc	ppm	13.675	15	20.225	TRUE
Tracy Vein Slope	Ash (NOS)	Zinc	ppm	28.1	38.4	68.05	TRUE

Attachment C-4. Quartile Data for CCR Whole Waste

Site	New WasteType	Analyte	Units	25th	50th	75th	Risk
Tracy Vein Slope	Bottom ash	Zinc	ppm	22.035	38.99	55.945	TRUE
Tracy Vein Slope	FBC	Zinc	ppm	2.48	2.48	2.48	TRUE
Universal	Combined ash	Zinc	ppm	69	110	133	TRUE
wood Energy Prop	Ash (NOS)	Zinc	ppm	7.92	12.2	13.975	TRUE
Wheelabrator	FBC	Zinc	ppm	12.2	14.925	18.125	TRUE
Xcel/MSI	Fly ash	Zinc	ppm	60.5	96	160	TRUE
Yates	Fly ash	Zinc	ppm	153.9	153.9	153.9	TRUE
Zhang et al. (2001)	Fly Ash	Zinc	ppm	47	57	170	TRUE
1	FBC	Zinc	ppm	19.9	20.6	20.71	TRUE
10	FBC	Zinc	ppm	32	32	32	TRUE
11	FBC	Zinc	ppm	52.5	65	77.5	TRUE
12	FBC	Zinc	ppm	12.025	13.7	14.7	TRUE
17	FBC	Zinc	ppm	27.3	50	54.5	TRUE
18	FBC	Zinc	ppm	52.5	72	74	TRUE
19	FBC	Zinc	ppm	1440	1440	1440	TRUE
2	FBC	Zinc	ppm	28	28.5	29	TRUE
20	FBC	Zinc	ppm	15.7	19.9	24.05	TRUE
21	FBC	Zinc	ppm	16.5	20	23.5	TRUE
23	FBC	Zinc	ppm	55.675	69.485	80.255	TRUE
26	FBC	Zinc	ppm	24.5	28.5	31.5	TRUE
27	FBC	Zinc	ppm	105	105	105	TRUE
28	FBC	Zinc	ppm	43.175	52.95	65.875	TRUE
29	FBC	Zinc	ppm	122.675	149.2	154.95	TRUE
3	FBC	Zinc	ppm	29.75	31.5	33.25	TRUE
30	FBC	Zinc	ppm	25.6775	45.05	55.625	TRUE
31	FBC	Zinc	ppm	48.1	48.1	48.1	TRUE
37	FBC	Zinc	ppm	192	257	328	TRUE
38	FBC	Zinc	ppm	11.27	14.925	19.225	TRUE
39	FBC	Zinc	ppm	26.75	29.5	32.25	TRUE
4	FBC	Zinc	ppm	12.225	18.65	23.824	TRUE
5	FBC	Zinc	ppm	21.5	28.5	31	TRUE
6	FBC	Zinc	ppm	36.075	39.05	42.025	TRUE
7	FBC	Zinc	ppm	51.48	51.48	51.48	TRUE
8	FBC	Zinc	ppm	56	56	56	TRUE
A/C Fuels Company	Ash (NOS)	Zinc	ppm	11	11	11	TRUE
Baldwin	Fly ash	Zinc	ppm	1432.9	1432.9	1432.9	TRUE
CLSM	Combined ash	Zinc	ppm	12.9	12.9	12.9	TRUE
CLSM	FBC	Zinc	ppm	10.1	10.1	10.1	TRUE
Deer Ridge Mine	Fly ash	Zinc	ppm	193.185	323.495	415	TRUE
DPC	Bottom ash	Zinc	ppm	66.4	66.4	66.4	TRUE
DPC	Fly ash	Zinc	ppm	102	102	102	TRUE
ern Analytical, ID: 5	Slag	Zinc	ppm	23	23	23	TRUE
Edgewater	Bottom ash	Zinc	ppm	67.7	67.7	67.7	TRUE
ett et al. (1993) Co	Fly Ash	Zirconium	ppm	187.5	210	222.5	FALSE
Zhang et al. (2001)	Fly Ash	Zirconium	ppm	157	306	349	FALSE

Attachment C-5.

LEAF Leachate Data

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	2.88E-01	S	2.73E+00	W	3.19E-02	W	2.95E-01	S
3	2.46E-01	S	2.65E+00	W	3.12E-02	W	2.66E-01	S
3.2	2.12E-01	S	2.57E+00	W	3.05E-02	W	2.42E-01	S
3.4	1.85E-01	S	2.51E+00	W	2.98E-02	W	2.22E-01	S
3.6	1.62E-01	S	2.44E+00	W	2.92E-02	W	2.04E-01	S
3.8	1.64E-01	S	2.41E+00	W	2.95E-02	W	2.00E-01	S
4	1.65E-01	S	2.38E+00	W	2.97E-02	W	1.96E-01	S
4.2	1.67E-01	S	2.36E+00	W	2.99E-02	W	1.92E-01	S
4.4	1.75E-01	S	2.31E+00	W	2.66E-02	W	1.48E-01	S
4.6	2.13E-01	S	2.21E+00	W	1.48E-02	S	4.42E-02	S
4.8	2.58E-01	S	2.12E+00	W	8.39E-03	S	1.39E-02	S
5	3.09E-01	S	2.03E+00	W	4.88E-03	S	4.60E-03	S
5.2	3.53E-01	S	1.97E+00	W	3.31E-03	S	2.06E-03	S
5.4	3.55E-01	S	1.98E+00	W	3.34E-03	S	2.06E-03	S
5.6	3.56E-01	S	1.99E+00	W	3.37E-03	S	2.06E-03	S
5.8	3.58E-01	S	2.00E+00	W	3.41E-03	S	2.06E-03	S
6	3.59E-01	S	2.01E+00	W	3.44E-03	S	2.06E-03	S
6.2	3.60E-01	S	2.02E+00	W	3.47E-03	S	2.06E-03	S
6.4	3.61E-01	S	2.03E+00	W	3.50E-03	S	2.06E-03	S
6.6	3.63E-01	S	2.04E+00	W	3.53E-03	S	2.06E-03	S
6.8	3.64E-01	S	2.05E+00	W	3.56E-03	S	2.06E-03	S
7	3.65E-01	S	2.06E+00	W	3.59E-03	S	2.06E-03	S
7.2	3.66E-01	S	2.06E+00	W	3.61E-03	S	2.06E-03	S
7.4	3.67E-01	S	2.07E+00	W	3.64E-03	S	2.06E-03	S
7.6	3.68E-01	S	2.08E+00	W	3.67E-03	S	2.06E-03	S
7.8	3.69E-01	S	2.09E+00	W	3.69E-03	S	2.06E-03	S
8	3.70E-01	S	2.09E+00	W	3.72E-03	S	2.06E-03	S
8.2	3.71E-01	S	2.10E+00	W	3.74E-03	W	2.06E-03	S
8.4	3.72E-01	S	2.11E+00	W	3.77E-03	W	2.06E-03	S
8.6	3.73E-01	S	2.11E+00	W	3.79E-03	W	2.06E-03	S

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Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.8	3.91E-01	S	2.12E+00	W	3.81E-03	W	2.06E-03	S
9	4.38E-01	S	2.12E+00	W	3.81E-03	W	2.06E-03	S
9.2	4.89E-01	S	2.11E+00	W	3.82E-03	W	2.06E-03	S
9.4	5.44E-01	S	2.11E+00	W	3.82E-03	W	2.06E-03	S
9.6	6.05E-01	S	2.11E+00	W	3.82E-03	W	2.06E-03	S
9.8	6.71E-01	S	2.11E+00	W	3.83E-03	W	2.06E-03	S
10	7.42E-01	S	2.11E+00	W	3.83E-03	W	2.06E-03	S
10.2	8.19E-01	S	2.11E+00	W	3.83E-03	W	2.06E-03	S
10.4	9.03E-01	S	2.10E+00	W	3.84E-03	W	2.06E-03	S
10.6	9.93E-01	S	2.10E+00	W	3.84E-03	W	2.06E-03	S
10.8	1.09E+00	S	2.10E+00	W	3.84E-03	W	2.06E-03	S
11	1.13E+00	S	2.10E+00	W	3.86E-03	W	2.06E-03	S
11.2	1.14E+00	S	2.11E+00	W	3.87E-03	W	2.06E-03	S
11.4	1.14E+00	S	2.11E+00	W	3.89E-03	W	2.06E-03	S
11.6	1.14E+00	S	2.12E+00	W	3.91E-03	W	2.06E-03	S
11.8	1.15E+00	S	2.13E+00	W	3.93E-03	W	2.06E-03	S
12	1.15E+00	S	2.13E+00	W	3.95E-03	W	2.06E-03	S
12.2	1.25E+00	S	2.15E+00	W	4.03E-03	W	2.06E-03	S
12.4	1.60E+00	S	2.20E+00	W	4.22E-03	W	2.06E-03	S
12.6	2.02E+00	S	2.25E+00	W	4.42E-03	W	2.06E-03	S
12.8	2.55E+00	S	2.30E+00	W	4.63E-03	W	2.06E-03	S
13	3.21E+00	S	2.35E+00	W	4.85E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	3.37E+01		3.03E+01		3.19E-01		2.95E+00	

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Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	6.73E-01	S	3.00E-06	S	3.27E-01	S	3.06E-02	S
3	4.23E-01	S	3.00E-06	S	2.73E-01	S	3.42E-02	S
3.2	2.74E-01	S	3.00E-06	S	2.31E-01	S	3.79E-02	S
3.4	1.82E-01	S	3.00E-06	S	1.97E-01	S	4.17E-02	S
3.6	1.24E-01	S	3.00E-06	S	1.70E-01	S	4.57E-02	S
3.8	8.60E-02	S	3.00E-06	S	1.59E-01	S	4.73E-02	S
4	6.08E-02	S	3.00E-06	S	1.50E-01	S	4.89E-02	S
4.2	4.37E-02	S	3.00E-06	S	1.42E-01	S	5.04E-02	S
4.4	3.41E-02	S	3.00E-06	S	1.60E-01	S	5.45E-02	S
4.6	3.50E-02	S	3.00E-06	S	3.50E-01	S	7.15E-02	S
4.8	3.59E-02	S	3.00E-06	S	7.44E-01	S	9.28E-02	S
5	3.67E-02	S	3.00E-06	S	1.53E+00	S	1.19E-01	S
5.2	3.75E-02	S	3.00E-06	S	2.59E+00	W	1.43E-01	W
5.4	3.79E-02	S	3.00E-06	S	2.60E+00	W	1.43E-01	W
5.6	3.84E-02	S	3.00E-06	S	2.61E+00	W	1.43E-01	W
5.8	3.88E-02	S	3.00E-06	S	2.62E+00	W	1.43E-01	W
6	3.92E-02	S	3.00E-06	S	2.63E+00	W	1.43E-01	W
6.2	3.96E-02	S	3.00E-06	S	2.64E+00	W	1.44E-01	W
6.4	4.00E-02	S	3.00E-06	S	2.65E+00	W	1.44E-01	W
6.6	4.04E-02	S	3.00E-06	S	2.65E+00	W	1.44E-01	W
6.8	4.08E-02	S	3.00E-06	S	2.66E+00	W	1.44E-01	W
7	4.11E-02	S	3.00E-06	S	2.67E+00	W	1.44E-01	W
7.2	4.15E-02	S	2.32E-06	S	2.68E+00	W	1.44E-01	W
7.4	4.19E-02	S	3.00E-06	S	2.69E+00	W	1.44E-01	W
7.6	4.22E-02	S	3.00E-06	S	2.69E+00	W	1.44E-01	W
7.8	4.26E-02	S	3.00E-06	S	2.70E+00	W	1.45E-01	W
8	4.29E-02	S	3.00E-06	S	2.71E+00	W	1.45E-01	W
8.2	4.32E-02	S	3.00E-06	S	2.71E+00	W	1.45E-01	W
8.4	4.36E-02	S	3.00E-06	S	2.72E+00	W	1.45E-01	W
8.6	4.39E-02	S	3.00E-06	S	2.73E+00	W	1.45E-01	W

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Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.8	4.52E-02	S	3.00E-06	S	2.73E+00	W	1.45E-01	W
9	4.82E-02	S	3.00E-06	S	2.74E+00	W	1.43E-01	W
9.2	5.12E-02	S	3.00E-06	S	2.75E+00	W	1.42E-01	W
9.4	5.44E-02	S	3.00E-06	S	2.76E+00	W	1.41E-01	W
9.6	5.77E-02	S	3.00E-06	S	2.76E+00	W	1.40E-01	W
9.8	6.12E-02	S	3.00E-06	S	2.77E+00	W	1.39E-01	W
10	6.48E-02	S	3.00E-06	S	2.78E+00	W	1.38E-01	W
10.2	6.85E-02	S	3.00E-06	S	2.79E+00	W	1.37E-01	W
10.4	7.23E-02	S	3.00E-06	S	2.79E+00	W	1.36E-01	W
10.6	7.63E-02	S	3.00E-06	S	2.80E+00	W	1.35E-01	W
10.8	8.04E-02	S	3.00E-06	S	2.81E+00	W	1.35E-01	W
11	8.45E-02	S	3.00E-06	S	2.81E+00	W	1.35E-01	W
11.2	8.85E-02	S	3.00E-06	S	2.82E+00	W	1.35E-01	W
11.4	9.26E-02	S	3.00E-06	S	2.82E+00	W	1.35E-01	W
11.6	9.69E-02	S	3.00E-06	S	2.83E+00	W	1.36E-01	W
11.8	1.01E-01	S	3.00E-06	S	2.83E+00	W	1.36E-01	W
12	1.06E-01	S	3.00E-06	S	2.84E+00	W	1.37E-01	W
12.2	1.15E-01	S	3.00E-06	S	2.83E+00	W	1.38E-01	W
12.4	1.34E-01	S	3.00E-06	S	2.79E+00	W	1.40E-01	W
12.6	1.56E-01	S	3.00E-06	S	2.76E+00	W	1.42E-01	W
12.8	1.80E-01	S	3.00E-06	S	2.73E+00	W	1.44E-01	W
13	2.09E-01	S	3.00E-06	S	2.69E+00	W	1.47E-01	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	6.73E+00		3.26E-05		3.60E+01		1.91E+00	

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Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	5.09E-01	S	6.75E-02	S	8.13E-01	S
3	4.00E-01	S	5.59E-02	S	3.67E-01	S
3.2	3.19E-01	S	4.68E-02	S	1.75E-01	S
3.4	2.58E-01	S	3.96E-02	S	8.69E-02	S
3.6	2.11E-01	S	3.39E-02	S	4.50E-02	S
3.8	2.12E-01	S	3.38E-02	S	4.40E-02	S
4	2.13E-01	S	3.38E-02	S	4.30E-02	S
4.2	2.13E-01	S	3.38E-02	S	4.22E-02	S
4.4	2.43E-01	S	3.05E-02	S	4.83E-02	S
4.6	4.55E-01	S	1.86E-02	S	1.01E-01	S
4.8	8.30E-01	S	1.16E-02	S	2.04E-01	S
5	1.48E+00	S	7.37E-03	S	4.02E-01	S
5.2	2.24E+00	W	5.24E-03	S	6.57E-01	S
5.4	2.26E+00	W	4.97E-03	S	6.63E-01	S
5.6	2.27E+00	W	4.72E-03	S	6.68E-01	S
5.8	2.28E+00	W	4.49E-03	S	6.73E-01	S
6	2.30E+00	W	4.28E-03	S	6.77E-01	S
6.2	2.31E+00	W	4.09E-03	S	6.82E-01	S
6.4	2.32E+00	W	3.91E-03	S	6.87E-01	S
6.6	2.33E+00	W	3.75E-03	S	6.91E-01	S
6.8	2.35E+00	W	3.59E-03	S	6.95E-01	S
7	2.36E+00	W	3.45E-03	S	6.99E-01	S
7.2	2.37E+00	W	3.31E-03	S	7.04E-01	S
7.4	2.38E+00	W	3.19E-03	S	7.08E-01	S
7.6	2.39E+00	W	3.07E-03	S	7.11E-01	S
7.8	2.40E+00	W	2.96E-03	S	7.15E-01	S
8	2.41E+00	W	2.86E-03	S	7.19E-01	S
8.2	2.42E+00	W	2.76E-03	S	7.23E-01	S
8.4	2.43E+00	W	2.67E-03	S	7.26E-01	S
8.6	2.44E+00	W	2.58E-03	S	7.30E-01	S

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Table C-5-1. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFA Med

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.8	2.48E+00	W	2.53E-03	S	7.78E-01	S
9	2.59E+00	W	2.53E-03	S	9.03E-01	S
9.2	2.69E+00	W	2.53E-03	S	1.04E+00	S
9.4	2.80E+00	W	2.53E-03	S	1.20E+00	S
9.6	2.91E+00	W	2.53E-03	S	1.38E+00	S
9.8	3.02E+00	W	2.53E-03	S	1.59E+00	S
10	3.13E+00	W	2.53E-03	S	1.81E+00	S
10.2	3.24E+00	W	2.53E-03	S	2.07E+00	S
10.4	3.36E+00	W	2.53E-03	S	2.35E+00	S
10.6	3.47E+00	W	2.53E-03	S	2.67E+00	S
10.8	3.59E+00	W	2.53E-03	S	3.02E+00	S
11	3.64E+00	W	2.53E-03	S	3.21E+00	S
11.2	3.63E+00	W	2.53E-03	S	3.27E+00	W
11.4	3.62E+00	W	2.53E-03	S	3.33E+00	W
11.6	3.62E+00	W	2.53E-03	S	3.40E+00	W
11.8	3.61E+00	W	2.53E-03	S	3.46E+00	W
12	3.60E+00	W	2.53E-03	S	3.52E+00	W
12.2	3.57E+00	W	2.53E-03	S	3.65E+00	W
12.4	3.50E+00	W	2.53E-03	S	3.91E+00	W
12.6	3.44E+00	W	2.53E-03	S	4.18E+00	W
12.8	3.37E+00	W	2.53E-03	S	4.47E+00	W
13	3.31E+00	W	2.53E-03	S	4.77E+00	W
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.45E+01		6.75E-01		5.90E+01	

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.27E+00	S	3.22E+00	W	5.48E-02	S	4.21E-01	S
3	1.15E+00	S	3.12E+00	W	5.36E-02	S	3.78E-01	S
3.2	1.04E+00	S	3.02E+00	W	5.25E-02	S	3.42E-01	S
3.4	9.44E-01	S	2.93E+00	W	5.15E-02	S	3.11E-01	S
3.6	8.64E-01	S	2.85E+00	W	5.05E-02	S	2.84E-01	S
3.8	7.95E-01	S	2.77E+00	W	4.96E-02	S	2.61E-01	S
4	6.79E-01	S	2.71E+00	W	4.50E-02	S	2.34E-01	S
4.2	5.22E-01	S	2.66E+00	W	3.65E-02	S	2.01E-01	S
4.4	4.06E-01	S	2.62E+00	W	2.99E-02	S	1.73E-01	S
4.6	3.19E-01	S	2.57E+00	W	2.46E-02	S	1.51E-01	S
4.8	2.53E-01	S	2.53E+00	W	2.05E-02	S	1.32E-01	S
5	2.03E-01	S	2.50E+00	W	1.72E-02	S	1.16E-01	S
5.2	1.64E-01	S	2.46E+00	W	1.45E-02	S	1.03E-01	S
5.4	1.34E-01	S	2.43E+00	W	1.23E-02	S	9.15E-02	S
5.6	1.10E-01	S	2.39E+00	W	1.06E-02	S	8.16E-02	S
5.8	9.73E-02	S	2.37E+00	W	9.42E-03	S	6.97E-02	S
6	9.74E-02	S	2.36E+00	W	9.05E-03	S	5.48E-02	S
6.2	9.75E-02	S	2.34E+00	W	8.71E-03	S	4.35E-02	S
6.4	9.76E-02	S	2.33E+00	W	8.39E-03	S	3.47E-02	S
6.6	9.77E-02	S	2.32E+00	W	8.09E-03	S	2.79E-02	S
6.8	9.78E-02	S	2.31E+00	W	7.81E-03	S	2.26E-02	S
7	9.80E-02	S	2.29E+00	W	7.54E-03	S	1.84E-02	S
7.2	9.81E-02	S	2.28E+00	W	7.30E-03	S	1.51E-02	S
7.4	1.18E-01	S	2.27E+00	W	7.19E-03	S	1.21E-02	S
7.6	1.42E-01	S	2.27E+00	W	7.09E-03	S	9.71E-03	S
7.8	1.71E-01	S	2.26E+00	W	6.99E-03	S	7.86E-03	S
8	2.05E-01	S	2.25E+00	W	6.90E-03	S	6.39E-03	S
8.2	2.44E-01	S	2.25E+00	W	6.81E-03	W	5.23E-03	S
8.4	2.89E-01	S	2.24E+00	W	6.73E-03	W	4.29E-03	S

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.6	3.41E-01	S	2.23E+00	W	6.64E-03	W	3.54E-03	S
8.8	4.02E-01	S	2.23E+00	W	6.56E-03	W	2.94E-03	S
9	4.71E-01	S	2.22E+00	W	6.49E-03	W	2.45E-03	S
9.2	5.48E-01	S	2.21E+00	W	6.41E-03	W	2.06E-03	S
9.4	5.98E-01	S	2.22E+00	W	6.32E-03	W	2.06E-03	S
9.6	6.52E-01	S	2.23E+00	W	6.24E-03	W	2.06E-03	S
9.8	7.09E-01	S	2.24E+00	W	6.16E-03	W	2.06E-03	S
10	7.70E-01	S	2.24E+00	W	6.08E-03	W	2.06E-03	S
10.2	8.34E-01	S	2.25E+00	W	6.00E-03	W	2.06E-03	S
10.4	9.03E-01	S	2.26E+00	W	5.92E-03	W	2.06E-03	S
10.6	9.35E-01	S	2.27E+00	W	5.94E-03	W	2.06E-03	S
10.8	9.65E-01	S	2.28E+00	W	5.96E-03	W	2.06E-03	S
11	9.96E-01	S	2.29E+00	W	5.98E-03	W	2.06E-03	S
11.2	1.03E+00	S	2.30E+00	W	6.00E-03	W	2.06E-03	S
11.4	1.06E+00	S	2.31E+00	W	6.02E-03	W	2.06E-03	S
11.6	1.09E+00	S	2.32E+00	W	6.04E-03	W	2.06E-03	S
11.8	1.12E+00	S	2.33E+00	W	6.06E-03	W	2.06E-03	S
12	1.16E+00	S	2.34E+00	W	6.08E-03	W	2.06E-03	S
12.2	1.20E+00	S	2.35E+00	W	6.12E-03	W	2.06E-03	S
12.4	1.57E+00	S	2.42E+00	W	6.53E-03	W	2.06E-03	S
12.6	2.04E+00	S	2.48E+00	W	6.96E-03	W	2.06E-03	S
12.8	2.63E+00	S	2.55E+00	W	7.42E-03	W	2.06E-03	S
13	3.39E+00	S	2.62E+00	W	7.89E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	3.68E+01		3.57E+01		5.48E-01		4.21E+00	

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
2.8	1.05E+00	S	3.00E-06	S	1.86E-01	S	2.91E-02	S
3	7.64E-01	S	3.00E-06	S	1.52E-01	S	3.37E-02	S
3.2	5.69E-01	S	3.00E-06	S	1.25E-01	S	3.88E-02	S
3.4	4.31E-01	S	3.00E-06	S	1.05E-01	S	4.41E-02	S
3.6	3.32E-01	S	3.00E-06	S	8.85E-02	S	4.99E-02	S
3.8	2.60E-01	S	3.00E-06	S	7.54E-02	S	5.61E-02	S
4	1.93E-01	S	3.00E-06	S	8.29E-02	S	6.31E-02	S
4.2	1.33E-01	S	3.00E-06	S	1.30E-01	S	7.16E-02	S
4.4	9.34E-02	S	3.00E-06	S	2.00E-01	S	8.08E-02	S
4.6	6.66E-02	S	3.00E-06	S	3.02E-01	S	9.06E-02	S
4.8	4.81E-02	S	3.00E-06	S	4.47E-01	S	1.01E-01	S
5	3.53E-02	S	3.00E-06	S	6.53E-01	S	1.12E-01	S
5.2	2.61E-02	S	3.00E-06	S	9.38E-01	S	1.24E-01	S
5.4	1.96E-02	S	3.00E-06	S	1.33E+00	S	1.37E-01	S
5.6	1.49E-02	S	3.00E-06	S	1.86E+00	S	1.51E-01	S
5.8	1.37E-02	S	3.00E-06	S	2.33E+00	S	1.60E-01	S
6	1.80E-02	S	3.00E-06	S	2.40E+00	S	1.62E-01	S
6.2	2.33E-02	S	3.00E-06	S	2.47E+00	S	1.63E-01	W
6.4	3.00E-02	S	3.00E-06	S	2.54E+00	S	1.64E-01	W
6.6	3.83E-02	S	3.00E-06	S	2.62E+00	S	1.65E-01	W
6.8	4.86E-02	S	3.00E-06	S	2.69E+00	S	1.66E-01	W
7	6.11E-02	S	3.00E-06	S	2.76E+00	S	1.67E-01	W
7.2	7.65E-02	S	3.00E-06	S	2.83E+00	W	1.68E-01	W
7.4	8.86E-02	S	3.00E-06	S	2.85E+00	W	1.67E-01	W
7.6	1.02E-01	S	3.00E-06	S	2.87E+00	W	1.66E-01	W
7.8	1.17E-01	S	3.00E-06	S	2.89E+00	W	1.65E-01	W
8	1.34E-01	S	3.00E-06	S	2.90E+00	W	1.64E-01	W
8.2	1.52E-01	S	3.00E-06	S	2.92E+00	W	1.63E-01	W
8.4	1.73E-01	S	3.00E-06	S	2.94E+00	W	1.62E-01	W

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.6	1.95E-01	S	3.00E-06	S	2.96E+00	W	1.61E-01	W
8.8	2.20E-01	S	3.00E-06	S	2.97E+00	W	1.60E-01	W
9	2.48E-01	S	3.00E-06	S	2.99E+00	W	1.59E-01	W
9.2	2.78E-01	S	3.00E-06	S	3.00E+00	W	1.58E-01	W
9.4	2.95E-01	S	3.00E-06	S	3.03E+00	W	1.58E-01	W
9.6	3.13E-01	S	3.00E-06	S	3.05E+00	W	1.58E-01	W
9.8	3.32E-01	S	3.00E-06	S	3.07E+00	W	1.58E-01	W
10	3.51E-01	S	3.00E-06	S	3.09E+00	W	1.58E-01	W
10.2	3.71E-01	S	3.00E-06	S	3.11E+00	W	1.59E-01	W
10.4	3.92E-01	S	3.00E-06	S	3.13E+00	W	1.59E-01	W
10.6	4.10E-01	S	3.00E-06	S	3.14E+00	W	1.60E-01	W
10.8	4.27E-01	S	3.00E-06	S	3.15E+00	W	1.61E-01	W
11	4.45E-01	S	3.00E-06	S	3.16E+00	W	1.62E-01	W
11.2	4.64E-01	S	3.00E-06	S	3.17E+00	W	1.62E-01	W
11.4	4.83E-01	S	3.00E-06	S	3.18E+00	W	1.63E-01	W
11.6	5.02E-01	S	3.00E-06	S	3.19E+00	W	1.64E-01	W
11.8	5.22E-01	S	3.00E-06	S	3.19E+00	W	1.65E-01	W
12	5.42E-01	S	3.00E-06	S	3.20E+00	W	1.66E-01	W
12.2	5.66E-01	S	3.00E-06	S	3.22E+00	W	1.67E-01	W
12.4	6.54E-01	S	3.00E-06	S	3.29E+00	W	1.70E-01	W
12.6	7.55E-01	S	3.00E-06	S	3.37E+00	W	1.72E-01	W
12.8	8.69E-01	S	3.00E-06	S	3.44E+00	W	1.75E-01	W
13	9.99E-01	S	3.00E-06	S	3.52E+00	W	1.78E-01	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.22E+01		4.20E-05		4.82E+01		2.45E+00	

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	1.48E+00	S	7.85E-02	S	8.27E-01	S
3	1.18E+00	S	6.77E-02	S	4.89E-01	S
3.2	9.58E-01	S	5.90E-02	S	2.99E-01	S
3.4	7.87E-01	S	5.19E-02	S	1.88E-01	S
3.6	6.54E-01	S	4.59E-02	S	1.22E-01	S
3.8	5.49E-01	S	4.09E-02	S	8.06E-02	S
4	5.22E-01	S	3.63E-02	S	6.71E-02	S
4.2	5.91E-01	S	3.19E-02	S	7.65E-02	S
4.4	6.65E-01	S	2.83E-02	S	8.67E-02	S
4.6	7.44E-01	S	2.52E-02	S	9.76E-02	S
4.8	8.29E-01	S	2.25E-02	S	1.09E-01	S
5	9.20E-01	S	2.02E-02	S	1.22E-01	S
5.2	1.02E+00	S	1.83E-02	S	1.36E-01	S
5.4	1.12E+00	S	1.65E-02	S	1.50E-01	S
5.6	1.23E+00	S	1.50E-02	S	1.65E-01	S
5.8	1.33E+00	S	1.38E-02	S	1.79E-01	S
6	1.42E+00	S	1.28E-02	S	1.88E-01	S
6.2	1.51E+00	S	1.20E-02	S	1.97E-01	S
6.4	1.60E+00	S	1.12E-02	S	2.07E-01	S
6.6	1.69E+00	S	1.05E-02	S	2.16E-01	S
6.8	1.79E+00	S	9.86E-03	S	2.26E-01	S
7	1.89E+00	S	9.27E-03	S	2.35E-01	S
7.2	1.99E+00	S	8.74E-03	S	2.45E-01	S
7.4	2.22E+00	S	7.63E-03	S	2.88E-01	S
7.6	2.48E+00	S	6.66E-03	S	3.39E-01	S
7.8	2.77E+00	S	5.84E-03	S	3.98E-01	S
8	3.07E+00	S	5.13E-03	S	4.65E-01	S
8.2	3.41E+00	S	4.52E-03	S	5.41E-01	S
8.4	3.77E+00	S	4.00E-03	S	6.27E-01	S

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Table C-5-2. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFB Med

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.6	4.15E+00	S	3.55E-03	S	7.25E-01	S
8.8	4.57E+00	S	3.16E-03	S	8.35E-01	S
9	5.01E+00	S	2.81E-03	S	9.58E-01	S
9.2	5.48E+00	S	2.53E-03	S	1.10E+00	S
9.4	5.78E+00	S	2.53E-03	S	1.29E+00	S
9.6	6.08E+00	S	2.53E-03	S	1.51E+00	S
9.8	6.39E+00	S	2.53E-03	S	1.75E+00	S
10	6.70E+00	S	2.53E-03	S	2.04E+00	S
10.2	7.03E+00	S	2.53E-03	S	2.36E+00	S
10.4	7.37E+00	S	2.53E-03	S	2.73E+00	S
10.6	7.38E+00	S	2.53E-03	S	2.88E+00	S
10.8	7.38E+00	S	2.53E-03	S	3.02E+00	S
11	7.37E+00	S	2.53E-03	S	3.17E+00	S
11.2	7.36E+00	S	2.53E-03	S	3.32E+00	S
11.4	7.36E+00	S	2.53E-03	S	3.48E+00	S
11.6	7.35E+00	S	2.53E-03	S	3.64E+00	S
11.8	7.35E+00	S	2.53E-03	S	3.81E+00	S
12	7.34E+00	S	2.53E-03	S	3.98E+00	S
12.2	7.33E+00	S	2.53E-03	S	4.17E+00	S
12.4	7.11E+00	S	2.53E-03	S	4.70E+00	S
12.6	6.90E+00	S	2.53E-03	S	5.29E+00	S
12.8	6.70E+00	S	2.53E-03	S	5.95E+00	S
13	6.51E+00	S	2.53E-03	S	6.67E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	9.38E+01		7.85E-01		8.32E+01	

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Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID	AaFC-[Med] (P,1,1)
Date Exported	8/27/2011, 6:47 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term moc
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	9.32E-01	S	1.18E+01	W	5.82E-02	S	4.81E-01	S
3	6.19E-01	S	1.13E+01	W	5.43E-02	S	4.12E-01	S
3.2	4.22E-01	S	1.09E+01	W	5.09E-02	S	3.57E-01	S
3.4	2.94E-01	S	1.06E+01	W	4.79E-02	S	3.12E-01	S
3.6	2.10E-01	S	1.02E+01	W	4.53E-02	S	2.75E-01	S
3.8	1.52E-01	S	9.91E+00	W	4.29E-02	S	2.43E-01	S
4	1.29E-01	S	9.89E+00	W	4.01E-02	S	2.32E-01	S
4.2	1.18E-01	S	9.98E+00	W	3.73E-02	S	2.27E-01	S
4.4	1.08E-01	S	1.01E+01	W	3.48E-02	S	2.23E-01	S
4.6	9.91E-02	S	1.01E+01	W	3.26E-02	S	2.19E-01	S
4.8	9.13E-02	S	1.02E+01	W	3.06E-02	S	2.15E-01	S
5	8.45E-02	S	1.03E+01	W	2.88E-02	S	2.11E-01	S
5.2	7.84E-02	S	1.04E+01	W	2.72E-02	S	2.08E-01	S
5.4	7.94E-02	S	1.03E+01	W	2.08E-02	S	1.69E-01	S
5.6	8.03E-02	S	1.02E+01	W	1.61E-02	S	1.38E-01	S
5.8	8.13E-02	S	1.02E+01	W	1.26E-02	S	1.14E-01	S
6	8.22E-02	S	1.01E+01	W	9.90E-03	S	9.45E-02	S
6.2	8.32E-02	S	1.01E+01	W	7.85E-03	S	7.89E-02	S
6.4	8.40E-02	S	9.99E+00	W	6.28E-03	S	6.63E-02	S
6.6	8.75E-02	S	9.92E+00	W	5.30E-03	S	5.39E-02	S
6.8	9.96E-02	S	9.80E+00	W	5.17E-03	S	3.95E-02	S
7	1.13E-01	S	9.69E+00	W	5.04E-03	S	2.93E-02	S
7.2	1.28E-01	S	9.58E+00	W	4.93E-03	S	2.19E-02	S
7.4	1.44E-01	S	9.48E+00	W	4.82E-03	S	1.64E-02	S
7.6	1.61E-01	S	9.38E+00	W	4.71E-03	S	1.25E-02	S

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Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID	AaFC-[Med] (P,1,1)
Date Exported	8/27/2011, 6:47 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term moc
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
7.8	1.80E-01	S	9.28E+00	W	4.61E-03	S	9.53E-03	S
8	2.01E-01	S	9.19E+00	W	4.51E-03	S	7.33E-03	S
8.2	2.24E-01	S	9.10E+00	W	4.42E-03	W	5.67E-03	S
8.4	2.49E-01	S	9.01E+00	W	4.34E-03	W	4.42E-03	S
8.6	2.75E-01	S	8.92E+00	W	4.25E-03	W	3.46E-03	S
8.8	3.04E-01	S	8.84E+00	W	4.17E-03	W	2.73E-03	S
9	3.35E-01	S	8.76E+00	W	4.09E-03	W	2.16E-03	S
9.2	3.34E-01	S	8.64E+00	W	4.12E-03	W	2.06E-03	S
9.4	3.26E-01	S	8.51E+00	W	4.17E-03	W	2.06E-03	S
9.6	3.18E-01	S	8.39E+00	W	4.22E-03	W	2.06E-03	S
9.8	3.10E-01	S	8.27E+00	W	4.27E-03	W	2.06E-03	S
10	3.02E-01	S	8.15E+00	W	4.32E-03	W	2.06E-03	S
10.2	2.95E-01	S	8.04E+00	W	4.37E-03	W	2.06E-03	S
10.4	2.88E-01	S	7.93E+00	W	4.42E-03	W	2.06E-03	S
10.6	2.82E-01	S	7.83E+00	W	4.47E-03	W	2.06E-03	S
10.8	2.75E-01	S	7.73E+00	W	4.52E-03	W	2.06E-03	S
11	2.69E-01	S	7.63E+00	W	4.57E-03	W	2.06E-03	S
11.2	2.63E-01	S	7.53E+00	W	4.61E-03	W	2.06E-03	S
11.4	2.58E-01	S	7.44E+00	W	4.66E-03	W	2.06E-03	S
11.6	2.68E-01	S	7.14E+00	W	4.65E-03	W	2.06E-03	S
11.8	3.06E-01	S	6.58E+00	W	4.57E-03	W	2.06E-03	S
12	3.48E-01	S	6.07E+00	W	4.49E-03	W	2.06E-03	S
12.2	3.95E-01	S	5.60E+00	W	4.42E-03	W	2.06E-03	S
12.4	5.08E-01	S	5.45E+00	W	4.54E-03	W	2.06E-03	S
12.6	7.90E-01	S	5.73E+00	W	4.98E-03	W	2.06E-03	S
12.8	1.22E+00	S	6.01E+00	W	5.46E-03	W	2.06E-03	S
13	1.87E+00	S	6.31E+00	W	5.98E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.70E+01		1.18E+02		5.82E-01		4.81E+00	

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Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID
Date Exported
Database Name deling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.35E-01	S	3.00E-06	S	1.47E+00	S	7.88E-02	S
3	6.29E-02	S	3.00E-06	S	1.37E+00	S	8.05E-02	S
3.2	3.07E-02	S	3.00E-06	S	1.29E+00	S	8.21E-02	S
3.4	1.56E-02	S	3.00E-06	S	1.22E+00	S	8.36E-02	S
3.6	8.29E-03	S	3.00E-06	S	1.15E+00	S	8.51E-02	S
3.8	4.54E-03	S	3.00E-06	S	1.09E+00	S	8.65E-02	S
4	3.51E-03	S	3.00E-06	S	1.14E+00	S	8.89E-02	S
4.2	3.13E-03	S	3.00E-06	S	1.24E+00	S	9.18E-02	S
4.4	2.81E-03	S	3.00E-06	S	1.35E+00	S	9.45E-02	S
4.6	2.53E-03	S	3.00E-06	S	1.46E+00	S	9.73E-02	S
4.8	2.29E-03	S	3.00E-06	S	1.57E+00	S	1.00E-01	S
5	2.08E-03	S	3.00E-06	S	1.68E+00	S	1.03E-01	S
5.2	1.90E-03	S	1.80E-06	S	1.80E+00	S	1.05E-01	S
5.4	2.35E-03	S	3.00E-06	S	1.95E+00	S	1.10E-01	S
5.6	2.89E-03	S	3.00E-06	S	2.11E+00	S	1.15E-01	S
5.8	3.53E-03	S	3.00E-06	S	2.27E+00	S	1.20E-01	S
6	4.28E-03	S	3.00E-06	S	2.44E+00	S	1.25E-01	S
6.2	5.16E-03	S	3.00E-06	S	2.61E+00	S	1.30E-01	S
6.4	6.18E-03	S	3.00E-06	S	2.79E+00	S	1.35E-01	S
6.6	7.34E-03	S	3.00E-06	S	2.94E+00	S	1.39E-01	S
6.8	8.59E-03	S	3.00E-06	S	2.99E+00	S	1.39E-01	S
7	1.00E-02	S	3.00E-06	S	3.03E+00	S	1.40E-01	S
7.2	1.16E-02	S	3.00E-06	S	3.07E+00	W	1.40E-01	S
7.4	1.34E-02	S	3.00E-06	S	3.11E+00	W	1.41E-01	S
7.6	1.55E-02	S	3.00E-06	S	3.15E+00	W	1.41E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID
Date Exported
Database Name deling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
7.8	1.77E-02	S	3.00E-06	S	3.19E+00	W	1.42E-01	S
8	2.03E-02	S	3.00E-06	S	3.23E+00	W	1.43E-01	S
8.2	2.31E-02	S	3.00E-06	S	3.27E+00	W	1.43E-01	S
8.4	2.62E-02	S	3.00E-06	S	3.31E+00	W	1.43E-01	S
8.6	2.97E-02	S	3.00E-06	S	3.35E+00	W	1.44E-01	S
8.8	3.36E-02	S	3.00E-06	S	3.39E+00	W	1.44E-01	S
9	3.78E-02	S	3.00E-06	S	3.42E+00	W	1.45E-01	S
9.2	4.41E-02	S	3.00E-06	S	3.46E+00	W	1.38E-01	S
9.4	5.17E-02	S	3.00E-06	S	3.49E+00	W	1.30E-01	S
9.6	6.04E-02	S	3.00E-06	S	3.53E+00	W	1.23E-01	S
9.8	7.04E-02	S	3.00E-06	S	3.57E+00	W	1.16E-01	S
10	8.17E-02	S	3.00E-06	S	3.60E+00	W	1.09E-01	S
10.2	9.46E-02	S	3.00E-06	S	3.63E+00	W	1.03E-01	S
10.4	1.09E-01	S	3.00E-06	S	3.67E+00	W	9.80E-02	S
10.6	1.26E-01	S	3.00E-06	S	3.70E+00	W	9.29E-02	S
10.8	1.45E-01	S	3.00E-06	S	3.74E+00	W	8.81E-02	S
11	1.66E-01	S	3.00E-06	S	3.77E+00	W	8.37E-02	S
11.2	1.89E-01	S	3.00E-06	S	3.80E+00	W	7.96E-02	S
11.4	2.16E-01	S	3.00E-06	S	3.83E+00	W	7.58E-02	S
11.6	2.34E-01	S	3.00E-06	S	3.84E+00	W	6.40E-02	S
11.8	2.37E-01	S	3.00E-06	S	3.81E+00	W	4.53E-02	S
12	2.39E-01	S	3.00E-06	S	3.78E+00	W	3.23E-02	S
12.2	2.41E-01	S	3.00E-06	S	3.74E+00	W	2.31E-02	S
12.4	2.52E-01	S	3.00E-06	S	3.78E+00	W	2.23E-02	S
12.6	2.77E-01	S	3.00E-06	S	3.92E+00	W	3.31E-02	S
12.8	3.05E-01	S	3.00E-06	S	4.06E+00	W	4.90E-02	S
13	3.35E-01	S	3.00E-06	S	4.20E+00	W	7.19E-02	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.24E+00		4.17E-05		5.64E+01		1.45E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	2.92E-01	S	1.38E-01	S	1.15E+00	S
3	2.19E-01	S	1.19E-01	S	6.22E-01	S
3.2	1.67E-01	S	1.03E-01	S	3.50E-01	S
3.4	1.29E-01	S	9.05E-02	S	2.04E-01	S
3.6	1.02E-01	S	8.00E-02	S	1.22E-01	S
3.8	8.10E-02	S	7.12E-02	S	7.56E-02	S
4	7.26E-02	S	6.67E-02	S	6.59E-02	S
4.2	6.84E-02	S	6.40E-02	S	6.61E-02	S
4.4	6.46E-02	S	6.15E-02	S	6.62E-02	S
4.6	6.11E-02	S	5.92E-02	S	6.64E-02	S
4.8	5.80E-02	S	5.71E-02	S	6.66E-02	S
5	5.51E-02	S	5.51E-02	S	6.67E-02	S
5.2	5.25E-02	S	5.33E-02	S	6.69E-02	S
5.4	6.07E-02	S	4.84E-02	S	7.58E-02	S
5.6	6.97E-02	S	4.41E-02	S	8.54E-02	S
5.8	7.97E-02	S	4.03E-02	S	9.59E-02	S
6	9.08E-02	S	3.70E-02	S	1.07E-01	S
6.2	1.03E-01	S	3.40E-02	S	1.19E-01	S
6.4	1.16E-01	S	3.14E-02	S	1.33E-01	S
6.6	1.24E-01	S	2.91E-02	S	1.47E-01	S
6.8	1.12E-01	S	2.72E-02	S	1.65E-01	S
7	1.01E-01	S	2.55E-02	S	1.83E-01	S
7.2	9.22E-02	S	2.40E-02	S	2.03E-01	S
7.4	8.41E-02	S	2.26E-02	S	2.25E-01	S
7.6	7.68E-02	S	2.13E-02	S	2.49E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-3. Leachate Concentrations for Bituminous Fly Ash, Waste ID AaFC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
7.8	7.04E-02	S	2.01E-02	S	2.74E-01	S
8	6.46E-02	S	1.90E-02	S	3.01E-01	S
8.2	5.94E-02	S	1.80E-02	S	3.30E-01	S
8.4	5.48E-02	S	1.70E-02	S	3.60E-01	S
8.6	5.06E-02	S	1.62E-02	S	3.93E-01	S
8.8	4.68E-02	S	1.54E-02	S	4.28E-01	S
9	4.34E-02	S	1.46E-02	S	4.66E-01	S
9.2	4.31E-02	S	1.28E-02	S	4.93E-01	S
9.4	4.35E-02	S	1.09E-02	S	5.18E-01	S
9.6	4.40E-02	S	9.39E-03	S	5.44E-01	S
9.8	4.44E-02	S	8.09E-03	S	5.71E-01	S
10	4.48E-02	S	7.00E-03	S	5.99E-01	S
10.2	4.52E-02	S	6.07E-03	S	6.27E-01	S
10.4	4.56E-02	S	5.28E-03	S	6.56E-01	S
10.6	4.60E-02	S	4.60E-03	S	6.86E-01	S
10.8	4.64E-02	S	4.02E-03	S	7.16E-01	S
11	4.68E-02	S	3.53E-03	S	7.47E-01	S
11.2	4.72E-02	S	3.10E-03	S	7.79E-01	S
11.4	4.76E-02	S	2.73E-03	S	8.12E-01	S
11.6	4.86E-02	S	2.53E-03	S	8.39E-01	S
11.8	5.07E-02	S	2.53E-03	S	8.54E-01	S
12	5.28E-02	S	2.53E-03	S	8.70E-01	S
12.2	5.49E-02	S	2.53E-03	S	8.86E-01	S
12.4	5.75E-02	S	2.53E-03	S	9.91E-01	S
12.6	6.07E-02	S	2.53E-03	S	1.28E+00	S
12.8	6.39E-02	S	2.53E-03	S	1.64E+00	S
13	6.73E-02	S	2.53E-03	S	2.09E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.92E+00		1.38E+00		2.27E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID	AFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:47 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	6.16E-01	S	1.24E+01	W	2.25E-02	S	4.84E-01	S
3	5.51E-01	S	1.23E+01	W	2.34E-02	S	4.48E-01	S
3.2	4.72E-01	S	1.22E+01	W	2.43E-02	S	3.83E-01	S
3.4	4.08E-01	S	1.21E+01	W	2.43E-02	S	3.26E-01	S
3.6	3.37E-01	S	1.20E+01	W	2.44E-02	S	2.86E-01	S
3.8	3.02E-01	S	1.20E+01	W	2.56E-02	S	2.67E-01	S
4	2.75E-01	S	1.19E+01	W	2.53E-02	S	2.49E-01	S
4.2	2.58E-01	S	1.18E+01	W	2.50E-02	S	2.34E-01	S
4.4	2.43E-01	S	1.16E+01	W	2.47E-02	S	2.20E-01	S
4.6	2.29E-01	S	1.14E+01	W	2.44E-02	S	2.07E-01	S
4.8	2.15E-01	S	1.13E+01	W	2.40E-02	S	1.96E-01	S
5	2.01E-01	S	1.11E+01	W	2.37E-02	S	1.85E-01	S
5.2	1.89E-01	S	1.11E+01	W	2.34E-02	S	1.74E-01	S
5.4	1.78E-01	S	1.10E+01	W	2.32E-02	S	1.64E-01	S
5.6	1.67E-01	S	1.10E+01	W	2.29E-02	S	1.55E-01	S
5.8	1.63E-01	S	1.09E+01	W	2.13E-02	S	1.46E-01	S
6	1.62E-01	S	1.08E+01	W	1.85E-02	S	1.36E-01	S
6.2	1.60E-01	S	1.07E+01	W	1.62E-02	S	1.29E-01	S
6.4	1.59E-01	S	1.05E+01	W	1.42E-02	S	1.22E-01	S
6.6	1.58E-01	S	1.04E+01	W	1.25E-02	S	1.15E-01	S
6.8	1.51E-01	S	1.03E+01	W	1.06E-02	S	1.09E-01	S
7	1.44E-01	S	1.03E+01	W	8.95E-03	S	9.03E-02	S
7.2	1.37E-01	S	1.03E+01	W	7.60E-03	S	6.08E-02	S
7.4	1.31E-01	S	1.02E+01	W	5.94E-03	S	4.13E-02	S
7.6	1.30E-01	S	1.02E+01	W	4.42E-03	S	3.07E-02	S
7.8	1.33E-01	S	9.48E+00	W	3.11E-03	S	2.57E-02	S
8	1.35E-01	S	8.60E+00	S	2.00E-03	S	2.14E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID	AFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:47 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	1.35E-01	S	6.90E+00	S	1.93E-03	S	1.68E-02	S
8.4	1.10E-01	S	5.56E+00	S	1.87E-03	S	1.34E-02	S
8.6	9.70E-02	S	3.78E+00	S	1.62E-03	S	1.12E-02	S
8.8	1.03E-01	S	2.79E+00	S	1.35E-03	S	1.07E-02	S
9	9.28E-02	S	2.21E+00	S	1.13E-03	S	1.03E-02	S
9.2	8.39E-02	S	1.76E+00	S	9.48E-04	S	9.97E-03	S
9.4	7.59E-02	S	1.41E+00	S	7.98E-04	S	9.65E-03	S
9.6	6.89E-02	S	1.14E+00	S	7.46E-04	S	8.96E-03	S
9.8	6.27E-02	S	9.18E-01	S	7.46E-04	S	8.69E-03	S
10	5.71E-02	S	7.45E-01	S	7.46E-04	S	8.43E-03	S
10.2	5.08E-02	S	6.07E-01	S	7.46E-04	S	8.18E-03	S
10.4	4.50E-02	S	4.97E-01	S	7.46E-04	S	7.95E-03	S
10.6	4.02E-02	S	4.08E-01	S	7.46E-04	S	7.73E-03	S
10.8	3.89E-02	S	3.36E-01	S	7.46E-04	S	7.51E-03	S
11	3.76E-02	S	3.00E-01	S	7.46E-04	S	7.57E-03	S
11.2	3.63E-02	S	2.80E-01	S	7.46E-04	S	7.76E-03	S
11.4	3.49E-02	S	2.62E-01	S	7.46E-04	S	7.76E-03	S
11.6	3.36E-02	S	2.45E-01	S	7.46E-04	S	7.61E-03	S
11.8	3.25E-02	S	2.31E-01	S	7.46E-04	S	7.25E-03	S
12	3.37E-02	S	2.23E-01	S	7.46E-04	S	4.57E-03	S
12.2	3.49E-02	S	2.16E-01	S	7.46E-04	S	2.90E-03	S
12.4	3.62E-02	S	2.09E-01	S	7.46E-04	S	1.85E-03	S
12.6	3.75E-02	S	2.02E-01	S	7.46E-04	S	1.19E-03	S
12.8	3.88E-02	S	1.95E-01	S	7.46E-04	S	8.06E-04	S
13	4.02E-02	S	1.86E-01	S	7.46E-04	S	5.81E-04	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	6.16E+00		1.24E+02		2.56E-01		4.84E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.97E+00	S	2.20E-05	S	1.48E-01	S	3.80E-01	S
3	2.65E+00	S	2.10E-05	S	1.30E-01	S	2.59E-01	S
3.2	2.16E+00	S	2.01E-05	S	1.12E-01	S	1.34E-01	S
3.4	1.68E+00	S	1.93E-05	S	9.53E-02	S	6.58E-02	S
3.6	1.32E+00	S	1.85E-05	S	8.40E-02	S	3.36E-02	S
3.8	1.22E+00	S	1.81E-05	S	9.22E-02	S	3.27E-02	S
4	1.16E+00	S	1.95E-05	S	1.05E-01	S	3.43E-02	S
4.2	1.11E+00	S	2.09E-05	S	1.18E-01	S	3.58E-02	S
4.4	1.07E+00	S	2.24E-05	S	1.31E-01	S	3.74E-02	S
4.6	1.03E+00	S	2.38E-05	S	1.44E-01	S	3.89E-02	S
4.8	1.00E+00	S	2.54E-05	S	1.58E-01	S	4.04E-02	S
5	9.70E-01	S	2.69E-05	S	1.73E-01	S	4.19E-02	S
5.2	9.41E-01	S	2.85E-05	S	1.89E-01	S	4.34E-02	S
5.4	9.14E-01	S	2.88E-05	S	2.06E-01	S	4.48E-02	S
5.6	8.89E-01	S	3.17E-05	S	2.25E-01	S	4.65E-02	S
5.8	8.83E-01	S	3.60E-05	S	2.96E-01	S	5.17E-02	S
6	9.01E-01	S	4.06E-05	S	4.54E-01	S	5.99E-02	S
6.2	9.15E-01	S	4.84E-05	S	6.07E-01	S	6.59E-02	S
6.4	9.29E-01	S	6.15E-05	S	7.66E-01	S	7.23E-02	S
6.6	9.43E-01	S	7.76E-05	S	9.94E-01	S	8.12E-02	S
6.8	9.90E-01	S	1.02E-04	S	1.32E+00	S	9.08E-02	S
7	1.04E+00	S	1.31E-04	S	1.99E+00	S	1.03E-01	S
7.2	1.07E+00	S	1.83E-04	S	3.62E+00	S	1.20E-01	S
7.4	1.15E+00	S	2.53E-04	S	6.50E+00	S	1.38E-01	S
7.6	1.20E+00	S	3.25E-04	S	7.95E+00	S	1.53E-01	S
7.8	1.25E+00	S	3.68E-04	S	6.87E+00	S	1.59E-01	S
8	1.26E+00	S	4.16E-04	S	6.58E+00	S	1.65E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.26E+00	S	4.13E-04	S	3.98E+00	S	1.41E-01	S
8.4	1.31E+00	S	3.98E-04	S	2.70E+00	S	9.81E-02	S
8.6	1.25E+00	S	3.52E-04	S	2.16E+00	S	7.64E-02	S
8.8	1.25E+00	S	3.84E-04	S	1.58E+00	S	7.64E-02	S
9	1.26E+00	S	3.54E-04	S	1.42E+00	S	6.30E-02	S
9.2	1.26E+00	S	3.25E-04	S	1.29E+00	S	5.22E-02	S
9.4	1.26E+00	S	2.89E-04	S	1.17E+00	S	4.34E-02	S
9.6	1.23E+00	S	2.57E-04	S	1.05E+00	S	3.62E-02	S
9.8	1.19E+00	S	2.29E-04	S	9.32E-01	S	3.03E-02	S
10	1.18E+00	S	1.94E-04	S	8.37E-01	S	2.55E-02	S
10.2	1.17E+00	S	1.53E-04	S	7.60E-01	S	2.15E-02	S
10.4	1.17E+00	S	1.21E-04	S	6.92E-01	S	1.82E-02	S
10.6	1.17E+00	S	9.64E-05	S	6.31E-01	S	1.55E-02	S
10.8	1.16E+00	S	7.74E-05	S	5.76E-01	S	1.32E-02	S
11	1.16E+00	S	7.39E-05	S	5.66E-01	S	9.94E-03	S
11.2	1.16E+00	S	7.06E-05	S	5.61E-01	S	7.04E-03	S
11.4	1.14E+00	S	6.75E-05	S	5.57E-01	S	6.35E-03	S
11.6	1.13E+00	S	6.45E-05	S	5.51E-01	S	5.85E-03	S
11.8	1.12E+00	S	5.68E-05	S	5.50E-01	S	5.77E-03	S
12	1.15E+00	S	5.01E-05	S	5.71E-01	S	5.69E-03	S
12.2	1.17E+00	S	4.43E-05	S	5.94E-01	S	5.62E-03	S
12.4	1.20E+00	S	3.92E-05	S	6.17E-01	S	5.54E-03	S
12.6	1.22E+00	S	3.48E-05	S	6.40E-01	S	5.47E-03	S
12.8	1.25E+00	S	3.09E-05	S	6.64E-01	S	5.40E-03	S
13	1.27E+00	S	2.76E-05	S	6.88E-01	S	5.33E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.97E+01		4.16E-03		7.95E+01		3.80E+00	

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Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.57E-01	S	1.39E-01	S	2.19E-01	S
3	1.37E-01	S	1.29E-01	S	1.55E-01	S
3.2	1.20E-01	S	1.11E-01	S	1.10E-01	S
3.4	1.01E-01	S	9.51E-02	S	7.51E-02	S
3.6	8.57E-02	S	8.54E-02	S	5.24E-02	S
3.8	8.63E-02	S	7.86E-02	S	5.06E-02	S
4	8.78E-02	S	7.27E-02	S	5.10E-02	S
4.2	8.93E-02	S	6.75E-02	S	5.14E-02	S
4.4	9.08E-02	S	6.28E-02	S	5.17E-02	S
4.6	9.29E-02	S	5.87E-02	S	5.21E-02	S
4.8	9.50E-02	S	5.50E-02	S	5.24E-02	S
5	9.71E-02	S	5.17E-02	S	5.27E-02	S
5.2	9.90E-02	S	4.86E-02	S	5.31E-02	S
5.4	1.01E-01	S	4.59E-02	S	5.34E-02	S
5.6	1.03E-01	S	4.34E-02	S	5.37E-02	S
5.8	1.07E-01	S	3.89E-02	S	5.89E-02	S
6	1.10E-01	S	3.34E-02	S	6.89E-02	S
6.2	1.14E-01	S	3.03E-02	S	8.01E-02	S
6.4	1.18E-01	S	2.79E-02	S	9.27E-02	S
6.6	1.23E-01	S	2.57E-02	S	1.07E-01	S
6.8	1.29E-01	S	2.32E-02	S	1.20E-01	S
7	1.38E-01	S	2.01E-02	S	1.35E-01	S
7.2	1.56E-01	S	1.63E-02	S	1.50E-01	S
7.4	1.75E-01	S	1.32E-02	S	1.60E-01	S
7.6	1.90E-01	S	1.10E-02	S	1.68E-01	S
7.8	2.05E-01	S	9.37E-03	S	1.88E-01	S
8	2.19E-01	S	8.01E-03	S	2.07E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-4. Leachate Concentrations for Bituminous Fly Ash, Waste ID AFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.39E-01	S	5.46E-03	S	2.04E-01	S
8.4	2.13E-01	S	3.19E-03	S	1.95E-01	S
8.6	1.93E-01	S	2.53E-03	S	1.85E-01	S
8.8	1.83E-01	S	2.53E-03	S	1.79E-01	S
9	1.49E-01	S	2.53E-03	S	1.74E-01	S
9.2	1.21E-01	S	2.53E-03	S	1.69E-01	S
9.4	9.94E-02	S	2.53E-03	S	1.64E-01	S
9.6	8.18E-02	S	2.53E-03	S	1.61E-01	S
9.8	6.76E-02	S	2.53E-03	S	1.60E-01	S
10	5.61E-02	S	2.53E-03	S	1.55E-01	S
10.2	4.67E-02	S	2.53E-03	S	1.48E-01	S
10.4	3.90E-02	S	2.53E-03	S	1.42E-01	S
10.6	3.27E-02	S	2.53E-03	S	1.36E-01	S
10.8	2.75E-02	S	2.53E-03	S	1.31E-01	S
11	2.90E-02	S	2.53E-03	S	1.26E-01	S
11.2	3.41E-02	S	2.53E-03	S	1.36E-01	S
11.4	4.00E-02	S	2.53E-03	S	1.28E-01	S
11.6	4.22E-02	S	2.53E-03	S	1.20E-01	S
11.8	4.53E-02	S	2.53E-03	S	1.25E-01	S
12	3.83E-02	S	2.53E-03	S	1.39E-01	S
12.2	3.30E-02	S	2.53E-03	S	1.54E-01	S
12.4	3.05E-02	S	2.53E-03	S	1.41E-01	S
12.6	2.66E-02	S	2.53E-03	S	1.50E-01	S
12.8	2.28E-02	S	2.53E-03	S	1.61E-01	S
13	1.95E-02	S	2.53E-03	S	1.72E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.39E+00		1.39E+00		2.19E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID	BFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	5.37E-01	S	3.46E+01	W	2.25E-02	W	1.61E-01	S
3	4.68E-01	S	3.39E+01	W	2.21E-02	W	1.43E-01	S
3.2	4.13E-01	S	3.36E+01	W	2.16E-02	W	1.27E-01	S
3.4	3.67E-01	S	3.32E+01	W	2.12E-02	W	1.13E-01	S
3.6	3.29E-01	S	3.29E+01	W	2.08E-02	W	1.02E-01	S
3.8	2.34E-01	S	3.05E+01	W	1.97E-02	W	8.87E-02	S
4	2.08E-01	S	2.97E+01	W	1.82E-02	S	8.27E-02	S
4.2	1.97E-01	S	2.95E+01	W	1.65E-02	S	7.91E-02	S
4.4	1.87E-01	S	2.93E+01	W	1.54E-02	S	7.59E-02	S
4.6	1.78E-01	S	2.91E+01	W	1.43E-02	S	7.29E-02	S
4.8	1.69E-01	S	2.90E+01	W	1.33E-02	S	7.02E-02	S
5	1.62E-01	S	2.88E+01	W	1.24E-02	S	6.77E-02	S
5.2	1.55E-01	S	2.86E+01	W	1.03E-02	S	5.89E-02	S
5.4	1.49E-01	S	2.83E+01	W	8.19E-03	S	5.09E-02	S
5.6	1.43E-01	S	2.80E+01	W	6.55E-03	S	4.42E-02	S
5.8	1.38E-01	S	2.77E+01	W	5.27E-03	S	3.86E-02	S
6	1.33E-01	S	2.74E+01	W	4.28E-03	S	3.39E-02	S
6.2	1.29E-01	S	2.72E+01	W	3.50E-03	S	2.98E-02	S
6.4	1.25E-01	S	2.69E+01	W	2.88E-03	S	2.64E-02	S
6.6	1.21E-01	S	2.67E+01	W	2.38E-03	S	2.34E-02	S
6.8	1.16E-01	S	2.65E+01	W	1.98E-03	S	2.09E-02	S
7	1.12E-01	S	2.63E+01	W	1.66E-03	S	1.87E-02	S
7.2	1.09E-01	S	2.61E+01	W	1.39E-03	S	1.67E-02	S
7.4	1.07E-01	S	2.59E+01	W	1.21E-03	S	1.50E-02	S
7.6	1.05E-01	S	2.57E+01	W	1.07E-03	S	1.36E-02	S
7.8	1.02E-01	S	2.55E+01	W	9.55E-04	S	1.23E-02	S
8	9.96E-02	S	2.53E+01	W	8.51E-04	S	1.12E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID	BFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	9.71E-02	S	2.52E+01	S	7.61E-04	W	1.08E-02	S
8.4	8.82E-02	S	2.21E+01	S	7.46E-04	W	1.04E-02	S
8.6	7.65E-02	S	1.64E+01	S	7.46E-04	W	1.01E-02	S
8.8	6.94E-02	S	1.21E+01	S	7.46E-04	W	9.59E-03	S
9	6.39E-02	S	8.98E+00	S	7.46E-04	W	9.05E-03	S
9.2	5.89E-02	S	7.26E+00	S	7.46E-04	W	8.55E-03	S
9.4	5.24E-02	S	7.29E+00	S	7.46E-04	W	8.02E-03	S
9.6	4.33E-02	S	7.32E+00	S	7.46E-04	W	7.54E-03	S
9.8	3.59E-02	S	7.35E+00	S	7.46E-04	W	7.09E-03	S
10	3.08E-02	S	7.11E+00	S	7.46E-04	W	6.67E-03	S
10.2	4.02E-02	S	6.73E+00	S	7.46E-04	W	5.84E-03	S
10.4	3.74E-02	S	6.11E+00	S	7.46E-04	W	4.79E-03	S
10.6	3.49E-02	S	5.56E+00	S	7.46E-04	W	3.94E-03	S
10.8	3.26E-02	S	5.07E+00	S	7.46E-04	W	3.26E-03	S
11	3.04E-02	S	4.65E+00	S	7.46E-04	W	2.70E-03	S
11.2	2.86E-02	S	4.31E+00	S	7.46E-04	W	2.25E-03	S
11.4	2.63E-02	S	3.83E+00	S	7.46E-04	W	2.06E-03	S
11.6	2.54E-02	S	3.31E+00	S	7.46E-04	W	2.06E-03	S
11.8	2.53E-02	S	2.89E+00	S	7.46E-04	W	2.06E-03	S
12	2.52E-02	S	2.56E+00	S	7.46E-04	W	2.06E-03	S
12.2	2.52E-02	S	2.30E+00	S	7.46E-04	W	2.06E-03	S
12.4	2.54E-02	S	2.18E+00	S	7.46E-04	W	2.06E-03	S
12.6	2.56E-02	S	2.07E+00	S	7.46E-04	W	2.06E-03	S
12.8	2.57E-02	S	1.97E+00	S	7.46E-04	W	2.06E-03	S
13	2.57E-02	S	1.88E+00	S	7.46E-04	W	2.06E-03	S
tection Limit (min, mg/	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg/	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.37E+00		3.46E+02		2.25E-01		1.61E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.62E+00	S	4.71E-05	S	8.61E-02	S	9.00E-02	S
3	3.84E+00	S	5.56E-05	S	7.03E-02	S	6.04E-02	S
3.2	3.04E+00	S	6.18E-05	S	6.26E-02	S	3.98E-02	S
3.4	2.43E+00	S	6.88E-05	S	5.61E-02	S	2.58E-02	S
3.6	1.98E+00	S	7.88E-05	S	5.15E-02	S	1.69E-02	S
3.8	1.11E+00	S	1.48E-04	S	6.01E-02	S	9.19E-03	S
4	9.43E-01	S	1.39E-04	S	6.68E-02	S	9.06E-03	S
4.2	8.77E-01	S	1.31E-04	S	7.17E-02	S	1.00E-02	S
4.4	8.12E-01	S	1.23E-04	S	7.67E-02	S	1.10E-02	S
4.6	7.54E-01	S	1.16E-04	S	8.19E-02	S	1.21E-02	S
4.8	7.03E-01	S	1.10E-04	S	8.72E-02	S	1.32E-02	S
5	6.87E-01	S	1.05E-04	S	9.25E-02	S	1.44E-02	S
5.2	6.72E-01	W	8.52E-05	S	1.18E-01	S	1.59E-02	S
5.4	6.70E-01	W	7.12E-05	S	1.53E-01	S	1.76E-02	S
5.6	6.80E-01	W	6.34E-05	S	1.97E-01	S	1.94E-02	S
5.8	6.89E-01	W	5.67E-05	S	2.51E-01	S	2.12E-02	S
6	6.98E-01	W	5.09E-05	S	3.16E-01	S	2.32E-02	S
6.2	7.07E-01	W	4.58E-05	S	3.97E-01	S	2.53E-02	S
6.4	7.16E-01	W	4.14E-05	S	4.93E-01	S	2.75E-02	S
6.6	7.24E-01	W	3.76E-05	S	6.09E-01	S	2.99E-02	S
6.8	7.29E-01	W	3.41E-05	S	7.48E-01	S	3.23E-02	S
7	7.34E-01	W	3.11E-05	S	9.13E-01	S	3.49E-02	S
7.2	7.38E-01	W	2.85E-05	S	1.11E+00	S	3.76E-02	S
7.4	7.41E-01	W	2.61E-05	S	1.34E+00	S	4.01E-02	S
7.6	7.45E-01	W	2.39E-05	S	1.58E+00	S	4.22E-02	S
7.8	7.49E-01	W	2.20E-05	S	1.79E+00	S	4.43E-02	S
8	7.53E-01	W	2.03E-05	S	2.01E+00	S	4.36E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	7.57E-01	W	1.88E-05	S	2.10E+00	W	4.69E-02	S
8.4	7.66E-01	W	1.85E-05	S	2.25E+00	W	3.95E-02	S
8.6	7.77E-01	W	2.02E-05	S	2.15E+00	W	2.42E-02	S
8.8	7.88E-01	W	2.19E-05	S	2.03E+00	W	1.48E-02	S
9	7.98E-01	W	2.37E-05	S	1.91E+00	W	9.14E-03	S
9.2	8.09E-01	W	2.39E-05	S	1.83E+00	W	6.42E-03	S
9.4	8.19E-01	W	1.99E-05	S	1.84E+00	W	6.27E-03	S
9.6	8.30E-01	W	1.66E-05	S	1.84E+00	W	6.12E-03	S
9.8	8.40E-01	W	1.39E-05	S	1.84E+00	W	5.98E-03	S
10	8.50E-01	W	1.35E-05	S	1.80E+00	W	5.74E-03	S
10.2	8.49E-01	W	1.47E-05	S	1.80E+00	W	5.40E-03	S
10.4	8.48E-01	W	1.60E-05	S	1.81E+00	W	4.76E-03	S
10.6	8.47E-01	W	1.74E-05	S	1.81E+00	W	4.21E-03	S
10.8	8.46E-01	W	1.89E-05	S	1.82E+00	W	3.73E-03	S
11	8.45E-01	W	2.04E-05	S	1.82E+00	W	3.21E-03	S
11.2	8.44E-01	W	2.11E-05	S	1.81E+00	W	2.78E-03	S
11.4	8.47E-01	W	1.97E-05	S	1.84E+00	W	2.78E-03	S
11.6	8.54E-01	W	1.84E-05	S	1.86E+00	W	2.78E-03	S
11.8	8.61E-01	W	2.03E-05	S	1.86E+00	W	2.78E-03	S
12	8.65E-01	W	5.72E-05	S	1.84E+00	W	2.78E-03	S
12.2	8.68E-01	W	6.48E-05	S	1.83E+00	W	2.78E-03	S
12.4	8.72E-01	W	7.33E-05	S	1.81E+00	W	2.78E-03	S
12.6	8.76E-01	W	8.28E-05	S	1.79E+00	W	2.78E-03	S
12.8	8.80E-01	W	9.33E-05	S	1.77E+00	W	2.78E-03	S
13	8.84E-01	W	1.05E-04	S	1.76E+00	W	2.78E-03	S
tection Limit (min, mg/	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
tection Limit (max, mg/	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.62E+01		1.48E-03		2.25E+01		9.00E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	8.41E-02	S	3.17E-01	S	2.84E-01	S
3	7.20E-02	S	2.89E-01	S	1.51E-01	S
3.2	6.24E-02	S	2.67E-01	S	8.33E-02	S
3.4	5.45E-02	S	2.47E-01	S	4.65E-02	S
3.6	4.82E-02	S	2.29E-01	S	2.69E-02	S
3.8	4.40E-02	S	2.09E-01	S	2.22E-02	S
4	4.12E-02	S	1.93E-01	S	2.20E-02	S
4.2	3.91E-02	S	1.83E-01	S	2.27E-02	S
4.4	3.71E-02	S	1.73E-01	S	2.27E-02	S
4.6	3.54E-02	S	1.64E-01	S	2.27E-02	S
4.8	3.37E-02	S	1.56E-01	S	2.27E-02	S
5	3.31E-02	S	1.48E-01	S	2.37E-02	S
5.2	3.35E-02	S	1.23E-01	S	2.60E-02	S
5.4	3.39E-02	S	1.01E-01	S	2.69E-02	S
5.6	3.37E-02	S	8.32E-02	S	2.93E-02	S
5.8	3.35E-02	S	6.92E-02	S	3.18E-02	S
6	3.34E-02	S	5.79E-02	S	3.44E-02	S
6.2	3.32E-02	S	4.87E-02	S	3.71E-02	S
6.4	3.30E-02	S	4.12E-02	S	4.00E-02	S
6.6	3.29E-02	S	3.51E-02	S	4.30E-02	S
6.8	3.27E-02	S	3.00E-02	S	4.61E-02	S
7	3.26E-02	S	2.57E-02	S	4.93E-02	S
7.2	3.24E-02	S	2.26E-02	S	5.27E-02	S
7.4	3.26E-02	S	2.06E-02	S	5.62E-02	S
7.6	3.28E-02	S	1.89E-02	S	5.98E-02	S
7.8	3.31E-02	S	1.73E-02	S	6.35E-02	S
8	3.33E-02	S	1.59E-02	S	7.04E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-5. Leachate Concentrations for Bituminous Fly Ash, Waste ID BFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	3.36E-02	S	1.46E-02	S	7.71E-02	S
8.4	3.33E-02	S	1.21E-02	S	8.13E-02	S
8.6	3.20E-02	S	7.98E-03	S	8.56E-02	S
8.8	2.94E-02	S	5.20E-03	S	8.16E-02	S
9	2.75E-02	S	3.42E-03	S	8.67E-02	S
9.2	2.58E-02	S	2.53E-03	S	9.21E-02	S
9.4	2.37E-02	S	2.53E-03	S	9.76E-02	S
9.6	2.04E-02	S	2.53E-03	S	1.03E-01	S
9.8	1.87E-02	S	2.53E-03	S	1.12E-01	S
10	1.72E-02	S	2.53E-03	S	1.19E-01	S
10.2	1.89E-02	S	2.53E-03	S	1.22E-01	S
10.4	1.79E-02	S	2.53E-03	S	1.29E-01	S
10.6	1.69E-02	S	2.53E-03	S	1.34E-01	S
10.8	1.60E-02	S	2.53E-03	S	1.41E-01	S
11	1.51E-02	S	2.53E-03	S	1.48E-01	S
11.2	1.42E-02	S	2.53E-03	S	1.52E-01	S
11.4	1.27E-02	S	2.53E-03	S	1.44E-01	S
11.6	1.22E-02	S	2.53E-03	S	1.36E-01	S
11.8	1.21E-02	S	2.53E-03	S	1.24E-01	S
12	1.25E-02	S	2.53E-03	S	1.10E-01	S
12.2	1.28E-02	S	2.53E-03	S	9.89E-02	S
12.4	1.32E-02	S	2.53E-03	S	8.87E-02	S
12.6	1.35E-02	S	2.53E-03	S	7.97E-02	S
12.8	1.39E-02	S	2.53E-03	S	7.17E-02	S
13	1.42E-02	S	2.53E-03	S	6.46E-02	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg/	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	8.41E-01		3.17E+00		2.84E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID	BPB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.09E-02	S	7.11E+01	S	2.82E-02	S	5.60E-01	S
3	4.70E-02	S	7.11E+01	S	2.66E-02	S	5.60E-01	S
3.2	6.96E-02	S	7.11E+01	S	2.52E-02	S	5.60E-01	S
3.4	1.01E-01	S	6.40E+01	S	2.39E-02	S	4.76E-01	S
3.6	1.05E-01	S	5.36E+01	S	2.41E-02	S	4.43E-01	S
3.8	8.17E-02	S	4.88E+01	S	2.48E-02	S	4.53E-01	S
4	6.76E-02	S	4.46E+01	S	2.56E-02	S	3.94E-01	S
4.2	5.65E-02	S	4.10E+01	S	2.64E-02	S	3.50E-01	S
4.4	4.83E-02	S	3.82E+01	S	2.71E-02	S	3.12E-01	S
4.6	4.43E-02	S	3.75E+01	S	2.78E-02	S	2.80E-01	S
4.8	4.09E-02	S	3.67E+01	S	2.85E-02	S	2.53E-01	S
5	3.78E-02	S	3.60E+01	S	2.92E-02	S	2.29E-01	S
5.2	3.51E-02	S	3.54E+01	S	2.99E-02	S	2.09E-01	S
5.4	3.26E-02	S	3.48E+01	S	3.11E-02	S	2.01E-01	S
5.6	3.04E-02	S	3.42E+01	S	3.24E-02	S	1.93E-01	S
5.8	2.84E-02	S	3.36E+01	S	3.37E-02	S	1.86E-01	S
6	2.67E-02	S	3.31E+01	S	3.50E-02	S	1.80E-01	S
6.2	2.50E-02	S	3.26E+01	S	3.63E-02	S	1.71E-01	S
6.4	2.36E-02	S	3.21E+01	S	3.76E-02	S	1.55E-01	S
6.6	2.22E-02	S	3.16E+01	S	3.90E-02	S	1.42E-01	S
6.8	2.10E-02	S	3.12E+01	S	4.03E-02	S	1.30E-01	S
7	1.98E-02	S	3.08E+01	S	3.99E-02	S	1.19E-01	S
7.2	1.90E-02	S	2.69E+01	S	3.88E-02	S	9.62E-02	W
7.4	1.82E-02	S	2.35E+01	S	3.77E-02	S	7.75E-02	W
7.6	1.75E-02	S	2.06E+01	S	3.75E-02	S	6.28E-02	W
7.8	1.68E-02	S	1.82E+01	S	3.72E-02	S	5.12E-02	W
8	1.61E-02	S	1.60E+01	S	3.64E-02	S	4.20E-02	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID	BPB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	1.55E-02	S	1.42E+01	S	3.55E-02	W	3.45E-02	W
8.4	1.50E-02	S	1.26E+01	S	3.47E-02	W	2.86E-02	W
8.6	1.44E-02	S	1.12E+01	S	3.40E-02	W	2.37E-02	W
8.8	1.39E-02	S	1.00E+01	S	3.33E-02	W	1.98E-02	W
9	1.35E-02	S	8.97E+00	S	3.26E-02	W	1.66E-02	W
9.2	1.30E-02	S	8.05E+00	S	3.19E-02	W	1.40E-02	W
9.4	1.26E-02	S	7.24E+00	S	3.13E-02	W	1.21E-02	W
9.6	1.22E-02	S	6.52E+00	S	3.07E-02	W	1.04E-02	W
9.8	1.18E-02	S	5.89E+00	S	3.01E-02	W	9.04E-03	W
10	1.14E-02	S	5.34E+00	S	2.96E-02	W	7.86E-03	W
10.2	1.11E-02	S	4.84E+00	S	2.90E-02	W	6.86E-03	W
10.4	1.08E-02	S	4.40E+00	S	2.85E-02	W	5.99E-03	W
10.6	1.05E-02	S	4.00E+00	S	2.80E-02	W	5.25E-03	W
10.8	1.02E-02	S	3.65E+00	S	2.75E-02	W	4.62E-03	W
11	9.88E-03	S	3.34E+00	S	2.71E-02	W	4.07E-03	W
11.2	9.61E-03	S	3.05E+00	S	2.66E-02	W	3.59E-03	W
11.4	9.35E-03	S	2.80E+00	S	2.62E-02	W	3.18E-03	W
11.6	8.51E-03	S	2.57E+00	S	2.58E-02	W	2.46E-03	W
11.8	8.17E-03	S	2.63E+00	S	2.55E-02	W	2.06E-03	W
12	8.44E-03	S	3.29E+00	S	2.54E-02	W	2.06E-03	W
12.2	8.71E-03	S	4.09E+00	S	2.53E-02	W	2.06E-03	W
12.4	8.99E-03	S	5.08E+00	S	2.51E-02	W	2.06E-03	W
12.6	9.27E-03	S	6.28E+00	S	2.66E-02	W	2.06E-03	W
12.8	9.55E-03	S	7.74E+00	S	2.84E-02	W	2.06E-03	W
13	2.00E-02	S	3.40E+00	S	2.63E-02	W	2.06E-03	W
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.05E+00		7.11E+02		4.03E-01		5.60E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.73E-01	S	2.07E-06	S	2.24E-01	S	4.01E-01	W
3	4.73E-01	S	2.07E-06	S	1.36E-01	S	5.81E-01	W
3.2	4.73E-01	S	2.07E-06	S	8.49E-02	S	8.20E-01	W
3.4	4.31E-01	S	2.07E-06	S	5.46E-02	S	1.13E+00	W
3.6	3.80E-01	S	2.07E-06	S	3.96E-02	S	1.17E+00	W
3.8	3.65E-01	S	2.07E-06	S	3.08E-02	S	1.04E+00	W
4	3.15E-01	S	2.07E-06	S	2.42E-02	S	9.34E-01	W
4.2	2.59E-01	S	2.07E-06	S	1.92E-02	S	8.41E-01	W
4.4	2.14E-01	S	2.07E-06	S	1.72E-02	S	7.93E-01	W
4.6	1.79E-01	S	2.07E-06	S	2.55E-02	S	9.09E-01	W
4.8	1.51E-01	S	2.07E-06	S	3.73E-02	S	1.04E+00	W
5	1.28E-01	S	2.07E-06	S	5.35E-02	S	1.18E+00	W
5.2	1.10E-01	S	2.07E-06	S	7.57E-02	S	1.33E+00	W
5.4	9.65E-02	S	2.07E-06	S	1.06E-01	S	1.49E+00	W
5.6	8.60E-02	S	2.07E-06	S	1.46E-01	S	1.67E+00	W
5.8	7.69E-02	S	2.07E-06	S	1.99E-01	S	1.86E+00	W
6	6.90E-02	S	2.07E-06	S	2.69E-01	S	2.06E+00	W
6.2	6.22E-02	S	2.07E-06	S	3.60E-01	S	2.28E+00	W
6.4	5.54E-02	S	2.07E-06	S	4.77E-01	S	2.52E+00	W
6.6	4.80E-02	S	2.07E-06	S	6.26E-01	S	2.77E+00	W
6.8	4.18E-02	S	2.07E-06	S	8.16E-01	S	3.03E+00	W
7	3.65E-02	S	2.07E-06	S	1.06E+00	S	3.32E+00	S
7.2	3.56E-02	W	2.07E-06	S	1.05E+00	W	2.29E+00	S
7.4	3.50E-02	W	2.07E-06	S	1.04E+00	W	1.57E+00	S
7.6	3.42E-02	W	2.07E-06	S	1.03E+00	W	1.09E+00	S
7.8	3.38E-02	W	2.07E-06	S	1.02E+00	W	7.63E-01	S
8	3.32E-02	W	2.07E-06	S	1.01E+00	W	5.39E-01	S

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Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.27E-02	W	2.07E-06	S	9.98E-01	W	3.83E-01	S
8.4	3.22E-02	W	2.07E-06	S	9.88E-01	W	2.75E-01	S
8.6	3.23E-02	W	2.07E-06	S	9.78E-01	W	1.99E-01	S
8.8	3.19E-02	W	2.07E-06	S	9.69E-01	W	1.45E-01	S
9	3.16E-02	W	2.07E-06	S	9.60E-01	W	1.07E-01	S
9.2	3.12E-02	W	2.07E-06	S	9.51E-01	W	7.87E-02	S
9.4	3.09E-02	W	2.07E-06	S	9.43E-01	W	5.86E-02	S
9.6	3.06E-02	W	2.07E-06	S	9.34E-01	W	4.38E-02	S
9.8	3.03E-02	W	2.07E-06	S	9.26E-01	W	3.30E-02	S
10	3.00E-02	W	2.07E-06	S	9.18E-01	W	2.50E-02	S
10.2	2.97E-02	W	2.07E-06	S	9.11E-01	W	1.90E-02	S
10.4	2.95E-02	W	2.07E-06	S	9.03E-01	W	1.46E-02	S
10.6	2.92E-02	W	2.07E-06	S	8.96E-01	W	1.12E-02	S
10.8	2.89E-02	W	2.07E-06	S	8.89E-01	W	8.67E-03	S
11	2.87E-02	W	2.07E-06	S	8.82E-01	W	6.74E-03	S
11.2	2.84E-02	W	2.07E-06	S	8.76E-01	W	5.26E-03	S
11.4	2.82E-02	W	2.07E-06	S	8.69E-01	W	4.12E-03	S
11.6	2.80E-02	W	2.07E-06	S	8.63E-01	W	3.24E-03	S
11.8	2.77E-02	W	2.07E-06	S	8.64E-01	W	3.91E-03	S
12	2.71E-02	W	2.07E-06	S	8.78E-01	W	1.02E-02	S
12.2	2.68E-02	W	2.07E-06	S	8.92E-01	W	2.62E-02	S
12.4	2.62E-02	W	2.07E-06	S	9.06E-01	W	6.63E-02	S
12.6	2.53E-02	W	2.07E-06	S	9.20E-01	W	1.65E-01	S
12.8	2.45E-02	W	2.07E-06	S	9.33E-01	W	4.06E-01	S
13	2.51E-02	W	2.07E-06	S	8.25E-01	W	2.46E-02	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	4.73E+00		2.18E-05		1.06E+01		3.32E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	6.28E-02	S	1.46E-02	S	2.42E-02	S
3	7.13E-02	S	1.13E-01	S	2.92E-02	S
3.2	8.04E-02	S	7.62E-01	S	3.48E-02	S
3.4	8.99E-02	S	4.59E+00	S	4.10E-02	S
3.6	1.04E-01	S	7.45E+00	S	4.36E-02	S
3.8	1.23E-01	S	6.16E+00	S	4.44E-02	S
4	1.43E-01	S	5.15E+00	S	4.51E-02	S
4.2	1.53E-01	S	4.34E+00	S	4.59E-02	S
4.4	1.51E-01	S	3.69E+00	S	4.69E-02	S
4.6	1.50E-01	S	3.19E+00	S	4.94E-02	S
4.8	1.48E-01	S	2.77E+00	S	5.19E-02	S
5	1.47E-01	S	2.42E+00	S	5.27E-02	S
5.2	1.45E-01	S	2.12E+00	S	4.93E-02	S
5.4	1.44E-01	S	1.87E+00	S	4.99E-02	S
5.6	1.43E-01	S	1.66E+00	S	5.05E-02	S
5.8	1.42E-01	S	1.48E+00	S	5.11E-02	S
6	1.40E-01	S	1.32E+00	S	5.17E-02	S
6.2	1.39E-01	S	1.18E+00	S	5.23E-02	S
6.4	1.44E-01	S	1.06E+00	S	5.28E-02	S
6.6	1.50E-01	S	9.60E-01	S	5.34E-02	S
6.8	1.50E-01	S	8.70E-01	S	5.39E-02	S
7	1.48E-01	S	7.90E-01	S	5.45E-02	S
7.2	1.42E-01	S	6.33E-01	S	5.50E-02	S
7.4	1.34E-01	S	5.08E-01	S	5.55E-02	S
7.6	1.33E-01	S	4.10E-01	S	5.60E-02	S
7.8	1.32E-01	S	3.32E-01	S	5.65E-02	S
8	1.31E-01	S	2.71E-01	S	5.49E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-6. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.38E-01	S	2.22E-01	S	5.19E-02	S
8.4	1.47E-01	S	1.83E-01	S	4.90E-02	S
8.6	1.56E-01	S	1.51E-01	S	4.64E-02	S
8.8	1.65E-01	S	1.26E-01	S	4.36E-02	S
9	1.75E-01	S	1.05E-01	S	4.09E-02	S
9.2	1.83E-01	S	8.79E-02	S	3.85E-02	S
9.4	1.69E-01	S	7.40E-02	S	3.77E-02	S
9.6	1.57E-01	S	6.24E-02	S	3.59E-02	S
9.8	1.46E-01	S	5.29E-02	S	3.42E-02	S
10	1.36E-01	S	4.49E-02	S	3.27E-02	S
10.2	1.26E-01	S	3.83E-02	S	3.12E-02	S
10.4	1.18E-01	S	3.28E-02	S	2.98E-02	S
10.6	1.10E-01	S	2.81E-02	S	2.85E-02	S
10.8	1.03E-01	S	2.42E-02	S	2.73E-02	S
11	9.62E-02	S	2.09E-02	S	2.62E-02	S
11.2	9.02E-02	S	1.80E-02	S	2.60E-02	S
11.4	8.46E-02	S	1.56E-02	S	2.62E-02	S
11.6	7.95E-02	S	1.36E-02	S	2.63E-02	S
11.8	8.98E-02	S	1.36E-02	S	2.98E-02	S
12	1.25E-01	S	1.77E-02	S	3.15E-02	S
12.2	1.73E-01	S	2.30E-02	S	3.18E-02	S
12.4	2.38E-01	S	2.96E-02	S	3.21E-02	S
12.6	3.26E-01	S	3.80E-02	S	3.24E-02	S
12.8	4.44E-01	S	4.86E-02	S	3.80E-02	S
13	7.08E-01	S	2.07E-02	S	6.03E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.68E+00		7.45E+01		5.65E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID	BPT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	1.40E-01	S	2.70E+01	W	1.08E-02	S	1.19E-01	S
3	1.17E-01	S	2.74E+01	W	1.00E-02	S	1.16E-01	S
3.2	9.97E-02	S	2.77E+01	W	9.27E-03	S	1.14E-01	S
3.4	8.46E-02	S	2.80E+01	W	8.62E-03	S	1.12E-01	S
3.6	7.07E-02	S	2.83E+01	W	8.04E-03	S	1.12E-01	S
3.8	5.96E-02	S	2.86E+01	W	7.47E-03	S	1.11E-01	S
4	4.19E-02	S	2.81E+01	W	6.25E-03	S	1.08E-01	S
4.2	2.77E-02	S	2.73E+01	W	5.27E-03	S	1.05E-01	S
4.4	1.95E-02	S	2.66E+01	W	4.61E-03	S	1.02E-01	S
4.6	1.40E-02	S	2.60E+01	W	4.40E-03	S	9.91E-02	S
4.8	1.01E-02	S	2.53E+01	W	4.20E-03	S	9.63E-02	S
5	7.46E-03	S	2.48E+01	W	3.88E-03	S	9.37E-02	S
5.2	5.29E-03	S	2.42E+01	W	3.57E-03	S	9.12E-02	S
5.4	3.77E-03	S	2.37E+01	W	3.44E-03	S	8.89E-02	S
5.6	3.20E-03	S	2.36E+01	W	3.74E-03	S	7.94E-02	S
5.8	3.20E-03	S	2.36E+01	W	4.79E-03	S	6.53E-02	S
6	3.20E-03	S	2.37E+01	W	6.09E-03	S	5.41E-02	S
6.2	3.20E-03	S	2.38E+01	W	7.68E-03	S	4.51E-02	S
6.4	3.20E-03	S	2.39E+01	W	9.60E-03	S	3.78E-02	S
6.6	3.20E-03	S	2.40E+01	W	1.19E-02	S	3.19E-02	S
6.8	3.20E-03	S	2.41E+01	W	1.47E-02	S	2.60E-02	S
7	3.20E-03	S	2.41E+01	W	1.81E-02	S	2.11E-02	S
7.2	3.20E-03	S	2.42E+01	W	2.24E-02	S	1.72E-02	S
7.4	3.20E-03	S	2.43E+01	W	2.75E-02	S	1.42E-02	S
7.6	3.20E-03	S	2.48E+01	W	3.36E-02	S	1.17E-02	S
7.8	3.20E-03	S	2.65E+01	W	3.62E-02	S	9.27E-03	S
8	3.20E-03	S	2.84E+01	W	3.70E-02	S	7.28E-03	S

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Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID	BPT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	3.03E+01	W	3.79E-02	W	5.75E-03	S
8.4	3.20E-03	S	3.23E+01	W	3.88E-02	W	4.57E-03	S
8.6	3.20E-03	S	3.43E+01	W	3.97E-02	W	3.65E-03	S
8.8	3.20E-03	S	3.65E+01	W	4.06E-02	W	2.93E-03	S
9	3.20E-03	S	3.87E+01	W	4.15E-02	W	2.37E-03	S
9.2	3.20E-03	S	3.90E+01	W	4.26E-02	W	2.06E-03	S
9.4	3.20E-03	S	3.86E+01	W	4.33E-02	W	2.06E-03	S
9.6	3.20E-03	S	3.07E+01	W	4.37E-02	W	2.06E-03	S
9.8	3.20E-03	S	2.46E+01	W	4.40E-02	W	2.06E-03	S
10	3.20E-03	S	2.32E+01	W	4.44E-02	W	2.06E-03	S
10.2	4.05E-03	S	2.28E+01	W	4.42E-02	W	2.06E-03	S
10.4	5.17E-03	S	2.25E+01	W	4.41E-02	W	2.06E-03	S
10.6	6.55E-03	S	2.21E+01	W	4.39E-02	W	2.06E-03	S
10.8	8.27E-03	S	2.18E+01	W	4.37E-02	W	2.06E-03	S
11	1.20E-02	S	2.14E+01	W	4.36E-02	W	2.06E-03	S
11.2	1.86E-02	S	2.11E+01	W	4.34E-02	W	2.06E-03	S
11.4	2.24E-02	S	2.16E+01	W	4.34E-02	W	2.06E-03	S
11.6	2.57E-02	S	2.27E+01	W	4.36E-02	W	2.06E-03	S
11.8	2.93E-02	S	2.39E+01	W	4.39E-02	W	2.06E-03	S
12	3.33E-02	S	2.51E+01	W	4.42E-02	W	2.06E-03	S
12.2	3.78E-02	S	2.64E+01	W	4.44E-02	W	2.06E-03	S
12.4	5.41E-02	S	2.71E+01	W	4.30E-02	W	2.06E-03	S
12.6	1.25E-01	S	2.62E+01	W	4.07E-02	W	2.06E-03	S
12.8	1.85E-01	S	2.53E+01	W	4.12E-02	W	2.06E-03	S
13	1.85E-01	S	2.45E+01	W	4.12E-02	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	2.37E+00		3.90E+02		5.27E-01		1.19E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	9.94E-01	S	2.07E-06	S	6.10E-02	S	7.45E-02	S
3	7.73E-01	S	2.07E-06	S	4.80E-02	S	9.75E-02	S
3.2	6.59E-01	S	2.07E-06	S	3.84E-02	S	1.26E-01	S
3.4	5.73E-01	S	2.07E-06	S	3.11E-02	S	1.59E-01	S
3.6	5.02E-01	S	2.07E-06	S	2.55E-02	S	1.99E-01	S
3.8	4.10E-01	S	2.07E-06	S	2.12E-02	S	2.46E-01	S
4	1.22E-01	S	2.07E-06	S	1.94E-02	S	2.22E-01	S
4.2	3.73E-02	S	2.07E-06	S	1.85E-02	S	1.77E-01	S
4.4	1.60E-02	S	2.07E-06	S	1.77E-02	S	1.43E-01	S
4.6	1.09E-02	S	2.07E-06	S	1.70E-02	S	1.17E-01	S
4.8	7.13E-03	S	2.07E-06	S	1.63E-02	S	9.58E-02	S
5	4.73E-03	S	2.07E-06	S	1.57E-02	S	7.94E-02	S
5.2	3.30E-03	S	2.07E-06	S	1.51E-02	S	6.63E-02	S
5.4	2.48E-03	S	2.07E-06	S	1.46E-02	S	5.57E-02	S
5.6	2.09E-03	S	2.07E-06	S	1.94E-02	S	6.40E-02	S
5.8	2.45E-03	S	2.07E-06	S	3.09E-02	S	8.84E-02	S
6	2.84E-03	S	2.07E-06	S	4.87E-02	S	1.21E-01	S
6.2	3.29E-03	S	2.07E-06	S	7.54E-02	S	1.63E-01	S
6.4	3.38E-03	S	2.07E-06	S	1.15E-01	S	2.18E-01	S
6.6	3.07E-03	S	2.07E-06	S	1.74E-01	S	2.90E-01	S
6.8	2.80E-03	S	2.07E-06	S	2.59E-01	S	3.81E-01	S
7	2.56E-03	S	2.07E-06	S	3.82E-01	S	4.98E-01	S
7.2	2.34E-03	W	2.07E-06	S	5.56E-01	W	6.45E-01	S
7.4	2.15E-03	W	2.07E-06	S	8.02E-01	W	8.29E-01	S
7.6	1.98E-03	W	2.07E-06	S	1.08E+00	W	1.05E+00	S
7.8	2.33E-03	W	2.07E-06	S	1.22E+00	W	1.30E+00	S
8	3.06E-03	W	2.07E-06	S	1.37E+00	W	1.60E+00	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.99E-03	W	2.07E-06	S	1.54E+00	W	1.95E+00	S
8.4	5.17E-03	W	2.07E-06	S	1.73E+00	W	2.38E+00	S
8.6	6.66E-03	W	2.07E-06	S	1.93E+00	W	2.88E+00	S
8.8	8.53E-03	W	2.07E-06	S	2.15E+00	W	3.47E+00	S
9	8.70E-03	W	2.07E-06	S	2.39E+00	W	4.17E+00	S
9.2	1.14E-02	W	2.07E-06	S	2.49E+00	W	1.67E+00	S
9.4	1.48E-02	W	2.07E-06	S	2.52E+00	W	5.35E-01	S
9.6	1.85E-02	W	2.07E-06	S	1.90E+00	W	2.68E-01	S
9.8	3.64E-02	W	2.07E-06	S	1.45E+00	W	1.36E-01	S
10	6.41E-02	W	2.07E-06	S	1.44E+00	W	1.38E-01	S
10.2	6.21E-02	W	2.07E-06	S	1.53E+00	W	1.66E-01	S
10.4	6.02E-02	W	2.07E-06	S	1.62E+00	W	1.98E-01	S
10.6	5.83E-02	W	2.07E-06	S	1.71E+00	W	2.36E-01	S
10.8	5.75E-02	W	2.07E-06	S	1.81E+00	W	2.80E-01	S
11	5.74E-02	W	2.07E-06	S	1.92E+00	W	3.31E-01	S
11.2	5.73E-02	W	2.07E-06	S	2.02E+00	W	3.91E-01	S
11.4	5.17E-02	W	2.07E-06	S	2.01E+00	W	3.86E-01	S
11.6	4.58E-02	W	2.07E-06	S	1.91E+00	W	3.34E-01	S
11.8	4.06E-02	W	2.07E-06	S	1.82E+00	W	2.90E-01	S
12	3.61E-02	W	2.07E-06	S	1.74E+00	W	2.52E-01	S
12.2	3.22E-02	W	2.07E-06	S	1.66E+00	W	2.19E-01	S
12.4	2.96E-02	W	2.07E-06	S	1.60E+00	W	1.95E-01	S
12.6	3.33E-02	W	2.07E-06	S	1.60E+00	W	1.83E-01	S
12.8	3.97E-02	W	2.07E-06	S	1.60E+00	W	1.72E-01	S
13	4.72E-02	W	2.07E-06	S	1.60E+00	W	1.61E-01	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	9.94E+00		2.65E-05		2.52E+01		4.17E+01	

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Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.75E-01	S	9.24E-02	S	7.72E-01	S
3	1.55E-01	S	1.01E-01	S	3.74E-01	S
3.2	1.38E-01	S	1.10E-01	S	2.35E-01	S
3.4	1.24E-01	S	1.19E-01	S	1.52E-01	S
3.6	1.13E-01	S	1.28E-01	S	9.65E-02	S
3.8	1.03E-01	S	1.38E-01	S	6.11E-02	S
4	9.56E-02	S	1.28E-01	S	2.16E-02	S
4.2	8.93E-02	S	1.12E-01	S	6.21E-03	S
4.4	8.84E-02	S	9.91E-02	S	4.45E-03	S
4.6	9.31E-02	S	8.80E-02	S	4.71E-03	S
4.8	9.97E-02	S	7.85E-02	S	4.97E-03	S
5	1.08E-01	S	7.04E-02	S	5.23E-03	S
5.2	1.16E-01	S	6.33E-02	S	5.50E-03	S
5.4	1.25E-01	S	5.72E-02	S	6.06E-03	S
5.6	1.39E-01	S	5.86E-02	S	6.80E-03	S
5.8	1.55E-01	S	6.45E-02	S	7.57E-03	S
6	1.68E-01	S	7.08E-02	S	8.41E-03	S
6.2	1.83E-01	S	7.75E-02	S	9.30E-03	S
6.4	1.99E-01	S	8.46E-02	S	1.03E-02	S
6.6	2.24E-01	S	9.21E-02	S	1.13E-02	S
6.8	2.52E-01	S	9.99E-02	S	1.24E-02	S
7	2.83E-01	S	1.08E-01	S	1.35E-02	S
7.2	3.16E-01	S	1.17E-01	S	1.47E-02	S
7.4	3.52E-01	S	1.26E-01	S	1.60E-02	S
7.6	3.91E-01	S	1.35E-01	S	1.74E-02	S
7.8	3.29E-01	S	1.41E-01	S	1.97E-02	S
8	2.69E-01	S	1.48E-01	S	2.16E-02	S

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Table C-5-7. Leachate Concentrations for Bituminous Fly Ash, Waste ID BPT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.22E-01	S	1.55E-01	S	2.35E-02	S
8.4	1.91E-01	S	1.62E-01	S	2.56E-02	S
8.6	1.66E-01	S	1.69E-01	S	2.79E-02	S
8.8	1.45E-01	S	1.76E-01	S	3.06E-02	S
9	1.26E-01	S	1.83E-01	S	3.38E-02	S
9.2	1.27E-01	S	1.05E-01	S	4.64E-02	S
9.4	1.65E-01	S	5.37E-02	S	6.58E-02	S
9.6	1.97E-01	S	3.69E-02	S	6.83E-02	S
9.8	2.19E-01	S	2.56E-02	S	7.08E-02	S
10	2.64E-01	S	2.96E-02	S	7.97E-02	S
10.2	3.19E-01	S	3.87E-02	S	9.12E-02	S
10.4	3.82E-01	S	5.02E-02	S	1.04E-01	S
10.6	4.57E-01	S	6.48E-02	S	1.19E-01	S
10.8	5.44E-01	S	8.33E-02	S	1.35E-01	S
11	7.09E-01	S	1.07E-01	S	1.53E-01	S
11.2	9.46E-01	S	1.36E-01	S	1.73E-01	S
11.4	1.15E+00	S	1.46E-01	S	1.86E-01	S
11.6	1.36E+00	S	1.40E-01	S	1.94E-01	S
11.8	1.61E+00	S	1.33E-01	S	2.01E-01	S
12	1.90E+00	S	1.27E-01	S	2.09E-01	S
12.2	2.23E+00	S	1.21E-01	S	2.17E-01	S
12.4	2.82E+00	S	9.93E-02	S	2.77E-01	S
12.6	4.18E+00	S	5.47E-02	S	5.44E-01	S
12.8	4.18E+00	S	3.04E-02	S	9.29E-01	S
13	4.18E+00	S	1.71E-02	S	1.57E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	5.35E+01		1.83E+00		1.19E+01	

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Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID	CFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	8.37E-02	S	1.22E+01	W	1.65E-02	S	1.96E-01	S
3	8.37E-02	S	1.22E+01	W	1.65E-02	S	1.96E-01	S
3.2	7.79E-02	S	1.22E+01	W	1.63E-02	S	1.94E-01	S
3.4	6.80E-02	S	1.21E+01	W	1.60E-02	S	1.88E-01	S
3.6	6.04E-02	S	1.19E+01	W	1.58E-02	S	1.83E-01	S
3.8	5.52E-02	S	1.17E+01	W	1.55E-02	S	1.78E-01	S
4	5.07E-02	S	1.15E+01	W	1.53E-02	S	1.74E-01	S
4.2	4.67E-02	S	1.13E+01	W	1.51E-02	S	1.70E-01	S
4.4	4.32E-02	S	1.13E+01	W	1.49E-02	S	1.63E-01	S
4.6	4.12E-02	S	1.13E+01	W	1.47E-02	S	1.61E-01	S
4.8	4.09E-02	S	1.13E+01	W	1.43E-02	S	1.58E-01	S
5	4.07E-02	S	1.13E+01	W	1.37E-02	S	1.55E-01	S
5.2	4.09E-02	S	1.13E+01	W	1.32E-02	S	1.53E-01	S
5.4	4.11E-02	S	1.13E+01	W	1.27E-02	S	1.50E-01	S
5.6	4.23E-02	S	1.11E+01	W	1.16E-02	S	1.48E-01	S
5.8	4.43E-02	S	1.10E+01	W	1.07E-02	S	1.46E-01	S
6	4.63E-02	S	1.10E+01	W	9.82E-03	S	1.38E-01	S
6.2	4.79E-02	S	1.10E+01	W	8.78E-03	S	1.30E-01	S
6.4	5.07E-02	S	1.10E+01	W	7.76E-03	S	1.23E-01	S
6.6	5.49E-02	S	1.12E+01	W	6.42E-03	S	1.09E-01	S
6.8	6.24E-02	S	1.15E+01	W	5.03E-03	S	9.44E-02	S
7	6.96E-02	S	1.08E+01	W	3.84E-03	S	6.97E-02	S
7.2	7.51E-02	S	8.45E+00	W	2.64E-03	S	4.05E-02	S
7.4	8.08E-02	S	5.64E+00	W	1.87E-03	S	2.39E-02	S
7.6	8.28E-02	S	6.28E+00	W	1.36E-03	S	1.25E-02	S
7.8	8.33E-02	S	7.05E+00	W	9.68E-04	S	5.81E-03	S
8	8.22E-02	S	7.89E+00	S	7.46E-04	S	2.75E-03	S

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Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID	CFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	7.73E-02	S	8.61E+00	S	7.46E-04	S	2.06E-03	S
8.4	6.97E-02	S	8.99E+00	S	7.46E-04	S	2.06E-03	S
8.6	5.94E-02	S	8.19E+00	S	7.46E-04	S	2.06E-03	S
8.8	5.01E-02	S	6.78E+00	S	7.46E-04	S	2.06E-03	S
9	4.24E-02	S	5.63E+00	S	7.46E-04	S	2.06E-03	S
9.2	3.61E-02	S	4.70E+00	S	7.46E-04	S	2.06E-03	S
9.4	3.08E-02	S	3.93E+00	S	7.46E-04	S	2.06E-03	S
9.6	2.64E-02	S	3.29E+00	S	7.46E-04	S	2.06E-03	S
9.8	2.27E-02	S	2.39E+00	S	7.46E-04	S	2.06E-03	S
10	1.87E-02	S	1.79E+00	S	7.46E-04	S	2.06E-03	S
10.2	1.43E-02	S	1.48E+00	S	7.46E-04	S	2.06E-03	S
10.4	1.32E-02	S	1.19E+00	S	7.46E-04	S	2.06E-03	S
10.6	1.26E-02	S	1.06E+00	S	7.46E-04	S	2.06E-03	S
10.8	1.22E-02	S	9.16E-01	S	7.46E-04	S	2.06E-03	S
11	1.30E-02	S	8.58E-01	S	7.46E-04	S	2.06E-03	S
11.2	1.39E-02	S	7.73E-01	S	7.46E-04	S	2.06E-03	S
11.4	1.48E-02	S	7.64E-01	S	7.46E-04	S	2.06E-03	S
11.6	1.57E-02	S	7.60E-01	S	7.46E-04	S	2.06E-03	S
11.8	1.67E-02	S	7.56E-01	S	7.46E-04	S	2.06E-03	S
12	1.77E-02	S	7.52E-01	S	7.46E-04	S	2.06E-03	S
12.2	1.82E-02	S	7.47E-01	S	7.46E-04	S	2.06E-03	S
12.4	1.84E-02	S	7.44E-01	S	7.46E-04	S	2.06E-03	S
12.6	1.87E-02	S	7.40E-01	S	7.46E-04	S	2.06E-03	S
12.8	1.89E-02	S	7.36E-01	S	7.46E-04	S	2.06E-03	S
13	1.92E-02	S	7.32E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	8.37E-01		1.22E+02		1.65E-01		1.96E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	8.31E-01	S	4.09E-05	S	3.65E-02	S	2.19E-01	S
3	8.31E-01	S	3.96E-05	S	4.62E-02	S	2.19E-01	S
3.2	6.66E-01	S	3.75E-05	S	5.77E-02	S	1.81E-01	S
3.4	3.47E-01	S	3.49E-05	S	7.11E-02	S	1.34E-01	S
3.6	2.19E-01	S	3.26E-05	S	8.42E-02	S	1.07E-01	S
3.8	1.45E-01	S	3.06E-05	S	9.60E-02	S	8.92E-02	S
4	9.83E-02	S	2.88E-05	S	1.09E-01	S	7.50E-02	S
4.2	6.79E-02	S	2.87E-05	S	1.23E-01	S	6.32E-02	S
4.4	4.76E-02	S	2.80E-05	S	1.37E-01	S	5.43E-02	S
4.6	4.65E-02	S	2.72E-05	S	1.72E-01	S	4.86E-02	S
4.8	6.27E-02	S	2.76E-05	S	2.28E-01	S	5.46E-02	S
5	8.35E-02	S	2.91E-05	S	3.30E-01	S	6.25E-02	S
5.2	1.08E-01	S	3.07E-05	S	4.69E-01	S	7.10E-02	S
5.4	1.28E-01	S	3.23E-05	S	6.59E-01	S	8.04E-02	S
5.6	1.49E-01	S	3.04E-05	S	9.14E-01	S	9.06E-02	S
5.8	1.73E-01	S	2.88E-05	S	8.23E-01	S	8.73E-02	S
6	2.08E-01	S	2.72E-05	S	9.82E-01	S	9.19E-02	S
6.2	2.49E-01	S	2.58E-05	S	7.31E-01	S	8.34E-02	S
6.4	2.96E-01	S	2.45E-05	S	5.29E-01	S	7.41E-02	S
6.6	3.12E-01	S	2.33E-05	S	8.21E-01	S	1.06E-01	S
6.8	3.71E-01	S	2.21E-05	S	1.47E+00	S	1.64E-01	S
7	3.81E-01	S	2.27E-05	S	2.02E+00	S	1.96E-01	S
7.2	3.72E-01	W	3.20E-05	S	1.75E+00	S	1.52E-01	S
7.4	4.49E-01	W	4.64E-05	S	1.46E+00	S	1.06E-01	S
7.6	4.40E-01	W	4.42E-05	S	1.54E+00	S	1.15E-01	S
7.8	4.31E-01	W	4.21E-05	S	1.69E+00	S	1.35E-01	S
8	4.22E-01	W	4.02E-05	S	1.85E+00	S	1.57E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.91E-01	W	3.95E-05	S	1.97E+00	S	1.60E-01	S
8.4	3.87E-01	W	3.95E-05	S	2.05E+00	S	1.58E-01	S
8.6	3.58E-01	W	4.13E-05	S	1.87E+00	S	1.32E-01	S
8.8	3.31E-01	W	3.96E-05	S	1.60E+00	S	1.05E-01	S
9	3.06E-01	W	3.60E-05	S	1.37E+00	S	8.38E-02	S
9.2	2.83E-01	W	3.71E-05	S	1.18E+00	S	6.73E-02	S
9.4	2.63E-01	W	3.83E-05	S	1.02E+00	S	5.43E-02	S
9.6	2.44E-01	W	3.95E-05	S	8.85E-01	S	4.40E-02	S
9.8	2.27E-01	W	4.08E-05	S	7.69E-01	S	3.58E-02	S
10	2.12E-01	W	4.20E-05	S	6.40E-01	S	2.81E-02	S
10.2	1.98E-01	W	4.27E-05	S	5.45E-01	S	2.23E-02	S
10.4	1.92E-01	W	4.03E-05	S	5.14E-01	S	1.93E-02	S
10.6	1.87E-01	W	3.81E-05	S	4.94E-01	S	1.69E-02	S
10.8	1.81E-01	W	4.26E-05	S	4.84E-01	S	1.44E-02	S
11	1.84E-01	W	3.89E-05	S	4.93E-01	S	1.25E-02	S
11.2	1.84E-01	W	3.55E-05	S	5.20E-01	S	1.08E-02	S
11.4	1.82E-01	W	3.42E-05	S	5.48E-01	S	9.44E-03	S
11.6	1.80E-01	W	3.63E-05	S	5.77E-01	S	8.23E-03	S
11.8	1.78E-01	W	3.85E-05	S	6.07E-01	S	7.19E-03	S
12	1.77E-01	W	4.08E-05	S	6.38E-01	S	6.30E-03	S
12.2	1.85E-01	W	4.32E-05	S	6.70E-01	S	5.53E-03	S
12.4	2.00E-01	W	4.56E-05	S	7.03E-01	S	4.87E-03	S
12.6	2.02E-01	W	4.82E-05	S	7.38E-01	S	4.29E-03	S
12.8	2.05E-01	W	5.03E-05	S	7.73E-01	S	3.79E-03	S
13	2.07E-01	W	5.03E-05	S	8.09E-01	S	3.36E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	8.31E+00		5.10E-04		2.05E+01		2.19E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.69E-01	S	1.43E-01	S	6.44E-02	S
3	2.42E-01	S	1.43E-01	S	6.15E-02	S
3.2	2.19E-01	S	1.37E-01	S	5.89E-02	S
3.4	1.99E-01	S	1.22E-01	S	5.66E-02	S
3.6	1.82E-01	S	1.12E-01	S	5.45E-02	S
3.8	1.67E-01	S	1.03E-01	S	5.25E-02	S
4	1.54E-01	S	9.58E-02	S	5.08E-02	S
4.2	1.43E-01	S	8.81E-02	S	4.91E-02	S
4.4	1.33E-01	S	8.04E-02	S	4.76E-02	S
4.6	1.25E-01	S	7.37E-02	S	4.83E-02	S
4.8	1.28E-01	S	6.68E-02	S	5.47E-02	S
5	1.31E-01	S	5.79E-02	S	6.17E-02	S
5.2	1.35E-01	S	5.04E-02	S	6.93E-02	S
5.4	1.38E-01	S	4.41E-02	S	7.72E-02	S
5.6	1.45E-01	S	4.12E-02	S	8.55E-02	S
5.8	1.56E-01	S	4.43E-02	S	9.43E-02	S
6	1.66E-01	S	4.03E-02	S	1.04E-01	S
6.2	1.80E-01	S	4.46E-02	S	1.17E-01	S
6.4	2.01E-01	S	5.20E-02	S	1.35E-01	S
6.6	2.13E-01	S	4.44E-02	S	1.46E-01	S
6.8	2.45E-01	S	3.46E-02	S	1.68E-01	S
7	2.72E-01	S	2.58E-02	S	1.82E-01	S
7.2	2.77E-01	S	1.52E-02	S	1.72E-01	S
7.4	2.70E-01	S	8.92E-03	S	1.63E-01	S
7.6	2.77E-01	S	8.38E-03	S	1.45E-01	S
7.8	2.83E-01	S	9.13E-03	S	1.27E-01	S
8	2.90E-01	S	9.47E-03	S	1.13E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-8. Leachate Concentrations for Bituminous Fly Ash, Waste ID CFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	2.93E-01	S	1.04E-02	S	1.06E-01	S
8.4	2.79E-01	S	1.10E-02	S	9.90E-02	S
8.6	2.24E-01	S	1.02E-02	S	9.95E-02	S
8.8	1.68E-01	S	8.68E-03	S	1.03E-01	S
9	1.30E-01	S	7.37E-03	S	1.07E-01	S
9.2	1.02E-01	S	6.28E-03	S	1.11E-01	S
9.4	8.06E-02	S	5.37E-03	S	1.15E-01	S
9.6	6.39E-02	S	4.60E-03	S	1.19E-01	S
9.8	4.44E-02	S	3.96E-03	S	1.22E-01	S
10	3.40E-02	S	3.10E-03	S	1.26E-01	S
10.2	2.65E-02	S	2.63E-03	S	1.27E-01	S
10.4	2.36E-02	S	2.53E-03	S	1.28E-01	S
10.6	2.20E-02	S	2.53E-03	S	1.44E-01	S
10.8	2.08E-02	S	2.53E-03	S	1.56E-01	S
11	2.18E-02	S	2.53E-03	S	1.63E-01	S
11.2	2.28E-02	S	2.53E-03	S	1.70E-01	S
11.4	2.38E-02	S	2.53E-03	S	1.77E-01	S
11.6	2.48E-02	S	2.53E-03	S	1.85E-01	S
11.8	2.58E-02	S	2.53E-03	S	1.85E-01	S
12	2.69E-02	S	2.53E-03	S	1.85E-01	S
12.2	2.80E-02	S	2.53E-03	S	1.85E-01	S
12.4	2.87E-02	S	2.53E-03	S	1.85E-01	S
12.6	2.96E-02	S	2.53E-03	S	1.90E-01	S
12.8	3.15E-02	S	2.53E-03	S	1.90E-01	S
13	3.27E-02	S	2.53E-03	S	1.90E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.93E+00		1.43E+00		1.93E+00	

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Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID	DaFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	1.27E+00	S	2.20E+00	W	5.20E-02	S	2.66E-01	S
3	1.02E+00	S	2.07E+00	W	4.96E-02	S	2.31E-01	S
3.2	8.38E-01	S	1.97E+00	W	4.74E-02	S	2.02E-01	S
3.4	6.95E-01	S	1.87E+00	W	4.55E-02	S	1.79E-01	S
3.6	5.82E-01	S	1.78E+00	W	4.37E-02	S	1.59E-01	S
3.8	4.92E-01	S	1.70E+00	W	4.21E-02	S	1.43E-01	S
4	4.20E-01	S	1.63E+00	W	4.07E-02	S	1.29E-01	S
4.2	3.61E-01	S	1.57E+00	W	3.93E-02	S	1.16E-01	S
4.4	3.22E-01	S	1.53E+00	W	3.76E-02	S	1.09E-01	S
4.6	3.01E-01	S	1.54E+00	W	3.55E-02	S	1.07E-01	S
4.8	2.83E-01	S	1.54E+00	W	3.35E-02	S	1.06E-01	S
5	2.66E-01	S	1.54E+00	W	3.17E-02	S	1.04E-01	S
5.2	2.50E-01	S	1.55E+00	W	3.01E-02	S	1.02E-01	S
5.4	2.37E-01	S	1.55E+00	W	2.86E-02	S	1.01E-01	S
5.6	2.34E-01	S	1.55E+00	W	2.53E-02	S	9.31E-02	S
5.8	2.46E-01	S	1.54E+00	W	2.01E-02	S	7.79E-02	S
6	2.58E-01	S	1.53E+00	W	1.61E-02	S	6.56E-02	S
6.2	2.70E-01	S	1.52E+00	W	1.30E-02	S	5.55E-02	S
6.4	2.83E-01	S	1.51E+00	W	1.06E-02	S	4.72E-02	S
6.6	2.95E-01	S	1.50E+00	W	8.67E-03	S	4.04E-02	S
6.8	3.08E-01	S	1.50E+00	W	7.14E-03	S	3.47E-02	S
7	3.21E-01	S	1.49E+00	W	5.91E-03	S	2.99E-02	S
7.2	3.48E-01	S	1.48E+00	W	5.25E-03	S	2.45E-02	S
7.4	3.95E-01	S	1.48E+00	W	5.05E-03	S	1.87E-02	S
7.6	4.47E-01	S	1.48E+00	W	4.87E-03	S	1.44E-02	S
7.8	5.04E-01	S	1.47E+00	W	4.71E-03	S	1.12E-02	S
8	5.66E-01	S	1.47E+00	W	4.55E-03	S	8.76E-03	S

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Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID	DaFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	6.35E-01	S	1.46E+00	W	4.40E-03	W	6.89E-03	S
8.4	7.09E-01	S	1.46E+00	W	4.25E-03	W	5.44E-03	S
8.6	7.91E-01	S	1.46E+00	W	4.12E-03	W	4.33E-03	S
8.8	8.79E-01	S	1.46E+00	W	3.99E-03	W	3.46E-03	S
9	9.75E-01	S	1.45E+00	W	3.87E-03	W	2.78E-03	S
9.2	1.08E+00	S	1.45E+00	W	3.76E-03	W	2.24E-03	S
9.4	1.17E+00	S	1.45E+00	W	3.74E-03	W	2.06E-03	S
9.6	1.25E+00	S	1.44E+00	W	3.78E-03	W	2.06E-03	S
9.8	1.34E+00	S	1.44E+00	W	3.83E-03	W	2.06E-03	S
10	1.43E+00	S	1.43E+00	W	3.87E-03	W	2.06E-03	S
10.2	1.52E+00	S	1.43E+00	W	3.91E-03	W	2.06E-03	S
10.4	1.62E+00	S	1.43E+00	W	3.95E-03	W	2.06E-03	S
10.6	1.72E+00	S	1.42E+00	W	3.99E-03	W	2.06E-03	S
10.8	1.82E+00	S	1.42E+00	W	4.03E-03	W	2.06E-03	S
11	1.90E+00	S	1.42E+00	W	4.06E-03	W	2.06E-03	S
11.2	1.87E+00	S	1.43E+00	W	4.04E-03	W	2.06E-03	S
11.4	1.85E+00	S	1.43E+00	W	4.03E-03	W	2.06E-03	S
11.6	1.82E+00	S	1.44E+00	W	4.01E-03	W	2.06E-03	S
11.8	1.79E+00	S	1.45E+00	W	4.00E-03	W	2.06E-03	S
12	1.98E+00	S	1.47E+00	W	4.08E-03	W	2.06E-03	S
12.2	2.51E+00	S	1.52E+00	W	4.27E-03	W	2.06E-03	S
12.4	3.16E+00	S	1.57E+00	W	4.47E-03	W	2.06E-03	S
12.6	3.97E+00	S	1.63E+00	W	4.67E-03	W	2.06E-03	S
12.8	4.97E+00	S	1.68E+00	W	4.89E-03	W	2.06E-03	S
13	6.21E+00	S	1.73E+00	W	5.10E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	6.14E+01		2.20E+01		5.20E-01		2.66E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.52E+00	S	3.00E-06	S	6.42E-01	S	4.51E-02	S
3	8.24E-01	S	3.00E-06	S	5.84E-01	S	5.34E-02	S
3.2	4.64E-01	S	3.00E-06	S	5.35E-01	S	6.25E-02	S
3.4	2.71E-01	S	3.00E-06	S	4.93E-01	S	7.25E-02	S
3.6	1.63E-01	S	3.00E-06	S	4.56E-01	S	8.34E-02	S
3.8	1.01E-01	S	3.00E-06	S	4.24E-01	S	9.51E-02	S
4	6.40E-02	S	3.00E-06	S	3.96E-01	S	1.08E-01	S
4.2	4.15E-02	S	3.00E-06	S	3.70E-01	S	1.21E-01	S
4.4	2.61E-02	S	3.00E-06	S	4.01E-01	S	1.33E-01	S
4.6	1.56E-02	S	3.00E-06	S	5.35E-01	S	1.40E-01	S
4.8	9.55E-03	S	3.00E-06	S	7.04E-01	S	1.47E-01	S
5	5.96E-03	S	3.00E-06	S	9.16E-01	S	1.54E-01	S
5.2	3.79E-03	S	3.00E-06	S	1.18E+00	S	1.61E-01	S
5.4	2.45E-03	S	3.00E-06	S	1.51E+00	S	1.69E-01	S
5.6	2.02E-03	S	3.00E-06	S	1.80E+00	S	1.76E-01	S
5.8	2.34E-03	S	3.00E-06	S	1.95E+00	S	1.85E-01	S
6	2.70E-03	S	3.00E-06	S	2.11E+00	S	1.94E-01	S
6.2	3.10E-03	S	3.00E-06	S	2.28E+00	S	2.03E-01	S
6.4	3.54E-03	S	3.00E-06	S	2.46E+00	S	2.11E-01	S
6.6	4.03E-03	S	3.00E-06	S	2.65E+00	S	2.20E-01	S
6.8	4.57E-03	S	3.00E-06	S	2.84E+00	S	2.29E-01	S
7	5.16E-03	S	3.00E-06	S	3.04E+00	S	2.39E-01	S
7.2	6.00E-03	S	3.00E-06	S	3.16E+00	W	2.42E-01	W
7.4	7.22E-03	S	3.00E-06	S	3.18E+00	W	2.39E-01	W
7.6	8.65E-03	S	3.00E-06	S	3.19E+00	W	2.35E-01	W
7.8	1.03E-02	S	3.00E-06	S	3.21E+00	W	2.32E-01	W
8	1.22E-02	S	3.00E-06	S	3.23E+00	W	2.29E-01	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.2	1.44E-02	S	3.00E-06	S	3.24E+00	W	2.26E-01	W
8.4	1.70E-02	S	3.00E-06	S	3.26E+00	W	2.23E-01	W
8.6	1.99E-02	S	3.00E-06	S	3.27E+00	W	2.20E-01	W
8.8	2.33E-02	S	3.00E-06	S	3.29E+00	W	2.18E-01	W
9	2.71E-02	S	3.00E-06	S	3.30E+00	W	2.15E-01	W
9.2	3.14E-02	S	3.00E-06	S	3.32E+00	W	2.13E-01	W
9.4	3.55E-02	S	3.00E-06	S	3.34E+00	W	2.12E-01	W
9.6	3.95E-02	S	3.00E-06	S	3.35E+00	W	2.13E-01	W
9.8	4.38E-02	S	3.00E-06	S	3.37E+00	W	2.13E-01	W
10	4.85E-02	S	3.00E-06	S	3.39E+00	W	2.14E-01	W
10.2	5.36E-02	S	3.00E-06	S	3.40E+00	W	2.15E-01	W
10.4	5.92E-02	S	3.00E-06	S	3.42E+00	W	2.15E-01	W
10.6	6.51E-02	S	3.00E-06	S	3.43E+00	W	2.16E-01	W
10.8	7.16E-02	S	3.00E-06	S	3.45E+00	W	2.17E-01	W
11	7.82E-02	S	3.00E-06	S	3.46E+00	W	2.18E-01	W
11.2	8.41E-02	S	3.00E-06	S	3.48E+00	W	2.20E-01	W
11.4	9.02E-02	S	3.00E-06	S	3.50E+00	W	2.23E-01	W
11.6	9.67E-02	S	3.00E-06	S	3.51E+00	W	2.25E-01	W
11.8	1.04E-01	S	3.00E-06	S	3.53E+00	W	2.28E-01	W
12	1.12E-01	S	3.00E-06	S	3.55E+00	W	2.30E-01	W
12.2	1.24E-01	S	3.00E-06	S	3.56E+00	W	2.33E-01	W
12.4	1.37E-01	S	3.00E-06	S	3.58E+00	W	2.36E-01	W
12.6	1.51E-01	S	3.00E-06	S	3.59E+00	W	2.39E-01	W
12.8	1.67E-01	S	3.00E-06	S	3.60E+00	W	2.41E-01	W
13	1.83E-01	S	3.00E-06	S	3.62E+00	W	2.44E-01	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.52E+01		3.70E-05		4.45E+01		2.98E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	5.61E-01	S	3.04E-01	S	3.75E+00	S
3	4.94E-01	S	2.83E-01	S	2.38E+00	S
3.2	4.38E-01	S	2.65E-01	S	1.55E+00	S
3.4	3.91E-01	S	2.48E-01	S	1.04E+00	S
3.6	3.52E-01	S	2.34E-01	S	7.14E-01	S
3.8	3.18E-01	S	2.21E-01	S	4.99E-01	S
4	2.89E-01	S	2.09E-01	S	3.56E-01	S
4.2	2.64E-01	S	1.99E-01	S	2.58E-01	S
4.4	2.58E-01	S	1.89E-01	S	2.21E-01	S
4.6	2.77E-01	S	1.79E-01	S	2.37E-01	S
4.8	2.97E-01	S	1.70E-01	S	2.54E-01	S
5	3.17E-01	S	1.62E-01	S	2.72E-01	S
5.2	3.37E-01	S	1.55E-01	S	2.89E-01	S
5.4	3.58E-01	S	1.48E-01	S	3.08E-01	S
5.6	3.90E-01	S	1.40E-01	S	3.36E-01	S
5.8	4.42E-01	S	1.31E-01	S	3.81E-01	S
6	4.98E-01	S	1.22E-01	S	4.30E-01	S
6.2	5.59E-01	S	1.14E-01	S	4.84E-01	S
6.4	6.26E-01	S	1.07E-01	S	5.42E-01	S
6.6	6.98E-01	S	1.01E-01	S	6.06E-01	S
6.8	7.75E-01	S	9.46E-02	S	6.74E-01	S
7	8.59E-01	S	8.92E-02	S	7.48E-01	S
7.2	9.34E-01	S	8.21E-02	S	8.21E-01	S
7.4	9.94E-01	S	7.34E-02	S	8.90E-01	S
7.6	1.06E+00	S	6.58E-02	S	9.63E-01	S
7.8	1.12E+00	S	5.92E-02	S	1.04E+00	S
8	1.19E+00	S	5.33E-02	S	1.12E+00	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-9. Leachate Concentrations for Bituminous Fly Ash, Waste ID DaFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.26E+00	S	4.82E-02	S	1.20E+00	S
8.4	1.33E+00	S	4.37E-02	S	1.29E+00	S
8.6	1.40E+00	S	3.97E-02	S	1.38E+00	S
8.8	1.48E+00	S	3.61E-02	S	1.48E+00	S
9	1.56E+00	S	3.29E-02	S	1.58E+00	S
9.2	1.64E+00	S	3.01E-02	S	1.69E+00	S
9.4	1.70E+00	S	2.59E-02	S	1.85E+00	S
9.6	1.76E+00	S	2.15E-02	S	2.06E+00	S
9.8	1.82E+00	S	1.79E-02	S	2.28E+00	S
10	1.87E+00	S	1.50E-02	S	2.53E+00	S
10.2	1.93E+00	S	1.26E-02	S	2.80E+00	S
10.4	1.99E+00	S	1.06E-02	S	3.09E+00	S
10.6	2.05E+00	S	8.96E-03	S	3.40E+00	S
10.8	2.11E+00	S	7.59E-03	S	3.74E+00	S
11	2.17E+00	S	6.59E-03	S	4.05E+00	S
11.2	2.22E+00	S	6.24E-03	S	4.16E+00	S
11.4	2.28E+00	S	5.91E-03	S	4.28E+00	S
11.6	2.34E+00	S	5.60E-03	S	4.40E+00	S
11.8	2.40E+00	S	5.31E-03	S	4.52E+00	S
12	2.44E+00	S	5.54E-03	S	4.69E+00	S
12.2	2.46E+00	S	6.47E-03	S	4.93E+00	S
12.4	2.48E+00	S	7.53E-03	S	5.18E+00	S
12.6	2.49E+00	S	8.75E-03	S	5.44E+00	S
12.8	2.51E+00	S	1.01E-02	S	5.70E+00	S
13	2.53E+00	S	1.17E-02	S	5.97E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.10E+01		3.04E+00		7.03E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID	DFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	5.41E-01	S	3.07E+01	W	2.46E-02	S	5.44E-02	S
3	4.17E-01	S	3.00E+01	W	2.38E-02	S	5.20E-02	S
3.2	3.56E-01	S	2.92E+01	W	2.28E-02	S	4.89E-02	S
3.4	2.95E-01	S	2.82E+01	W	2.19E-02	S	4.61E-02	S
3.6	2.46E-01	S	2.74E+01	W	2.10E-02	S	4.36E-02	S
3.8	2.07E-01	S	2.66E+01	W	2.04E-02	S	4.10E-02	S
4	1.75E-01	S	2.58E+01	W	1.97E-02	S	3.85E-02	S
4.2	1.50E-01	S	2.51E+01	W	1.90E-02	S	3.63E-02	S
4.4	1.46E-01	S	2.52E+01	W	1.82E-02	S	3.54E-02	S
4.6	1.43E-01	S	2.54E+01	W	1.75E-02	S	3.49E-02	S
4.8	1.41E-01	S	2.56E+01	W	1.68E-02	S	3.45E-02	S
5	1.38E-01	S	2.56E+01	W	1.62E-02	S	3.39E-02	S
5.2	1.36E-01	S	2.56E+01	W	1.56E-02	S	3.23E-02	S
5.4	1.41E-01	S	2.56E+01	W	1.47E-02	S	3.08E-02	S
5.6	1.47E-01	S	2.56E+01	W	1.22E-02	S	2.63E-02	S
5.8	1.55E-01	S	2.56E+01	W	1.14E-02	S	2.55E-02	S
6	1.66E-01	S	2.57E+01	W	1.07E-02	S	2.47E-02	S
6.2	1.68E-01	S	2.56E+01	W	9.97E-03	S	2.36E-02	S
6.4	1.74E-01	S	2.56E+01	W	7.15E-03	S	1.74E-02	S
6.6	1.80E-01	S	2.54E+01	W	5.18E-03	S	1.29E-02	S
6.8	1.86E-01	S	2.51E+01	W	3.79E-03	S	9.69E-03	S
7	1.92E-01	S	2.49E+01	S	2.79E-03	S	7.32E-03	S
7.2	1.99E-01	S	2.46E+01	S	2.20E-03	S	5.84E-03	S
7.4	1.95E-01	S	2.36E+01	S	1.82E-03	S	4.87E-03	S
7.6	2.17E-01	S	2.09E+01	S	1.51E-03	S	4.07E-03	S
7.8	2.25E-01	S	1.97E+01	S	1.26E-03	S	3.43E-03	S
8	2.34E-01	S	1.88E+01	S	1.06E-03	S	2.90E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID	DFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	2.28E-01	S	1.78E+01	S	8.95E-04	W	2.46E-03	S
8.4	2.27E-01	S	1.70E+01	S	7.57E-04	W	2.09E-03	S
8.6	2.27E-01	S	1.51E+01	S	7.46E-04	W	2.06E-03	S
8.8	2.01E-01	S	1.35E+01	S	7.46E-04	W	2.06E-03	S
9	1.79E-01	S	1.20E+01	S	7.46E-04	W	2.06E-03	S
9.2	1.60E-01	S	9.88E+00	S	7.46E-04	W	2.06E-03	S
9.4	1.34E-01	S	8.81E+00	S	7.46E-04	W	2.06E-03	S
9.6	1.13E-01	S	8.10E+00	S	7.46E-04	W	2.06E-03	S
9.8	8.93E-02	S	6.82E+00	S	7.46E-04	W	2.06E-03	S
10	6.57E-02	S	5.46E+00	S	7.46E-04	W	2.06E-03	S
10.2	5.83E-02	S	4.39E+00	S	7.46E-04	W	2.06E-03	S
10.4	4.91E-02	S	3.55E+00	S	7.46E-04	W	2.06E-03	S
10.6	3.90E-02	S	2.89E+00	S	7.46E-04	W	2.06E-03	S
10.8	3.86E-02	S	2.36E+00	S	7.46E-04	W	2.06E-03	S
11	3.82E-02	S	1.94E+00	S	7.46E-04	W	2.06E-03	S
11.2	3.78E-02	S	1.52E+00	S	7.46E-04	W	2.06E-03	S
11.4	3.99E-02	S	1.23E+00	S	7.46E-04	W	2.06E-03	S
11.6	4.83E-02	S	1.12E+00	S	7.46E-04	W	2.06E-03	S
11.8	5.84E-02	S	1.01E+00	S	7.46E-04	W	2.06E-03	S
12	7.03E-02	S	9.24E-01	S	7.46E-04	W	2.06E-03	S
12.2	8.44E-02	S	8.20E-01	S	7.46E-04	W	2.06E-03	S
12.4	1.01E-01	S	7.28E-01	S	7.46E-04	W	2.06E-03	S
12.6	1.21E-01	S	6.48E-01	S	7.46E-04	W	2.06E-03	S
12.8	1.43E-01	S	5.78E-01	S	7.46E-04	W	2.06E-03	S
13	1.70E-01	S	5.16E-01	S	7.46E-04	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.41E+00		3.07E+02		2.46E-01		5.44E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.34E+00	S	2.22E-05	S	7.68E-02	S	7.66E-02	S
3	1.06E+00	S	2.31E-05	S	5.95E-02	S	6.74E-02	S
3.2	6.16E-01	S	2.65E-05	S	5.95E-02	S	4.89E-02	S
3.4	3.72E-01	S	3.00E-05	S	6.16E-02	S	3.62E-02	S
3.6	2.32E-01	S	3.38E-05	S	6.42E-02	S	2.73E-02	S
3.8	1.49E-01	S	3.79E-05	S	6.69E-02	S	2.09E-02	S
4	9.77E-02	S	4.22E-05	S	6.96E-02	S	1.62E-02	S
4.2	6.55E-02	S	4.67E-05	S	7.23E-02	S	1.38E-02	S
4.4	5.44E-02	S	4.45E-05	S	8.38E-02	S	1.48E-02	S
4.6	4.15E-02	S	4.25E-05	S	1.01E-01	S	1.66E-02	S
4.8	3.08E-02	S	4.07E-05	S	1.20E-01	S	1.85E-02	S
5	2.36E-02	S	3.91E-05	S	1.44E-01	S	2.06E-02	S
5.2	2.21E-02	S	3.75E-05	S	1.91E-01	S	2.30E-02	S
5.4	2.08E-02	S	3.61E-05	S	2.50E-01	S	2.55E-02	S
5.6	1.96E-02	S	3.49E-05	S	3.24E-01	S	2.82E-02	S
5.8	1.85E-02	S	3.38E-05	S	4.17E-01	S	3.11E-02	S
6	1.75E-02	S	3.27E-05	S	5.32E-01	S	3.41E-02	S
6.2	1.66E-02	S	3.17E-05	S	6.72E-01	S	3.74E-02	S
6.4	1.57E-02	S	3.11E-05	S	8.44E-01	S	4.08E-02	S
6.6	1.60E-02	S	3.34E-05	S	9.76E-01	S	4.33E-02	S
6.8	1.50E-02	S	3.58E-05	S	1.09E+00	S	4.53E-02	S
7	1.47E-02	S	3.63E-05	S	1.21E+00	S	4.73E-02	S
7.2	1.45E-02	S	3.58E-05	S	1.45E+00	W	5.22E-02	S
7.4	1.68E-02	S	3.59E-05	S	1.78E+00	W	5.45E-02	S
7.6	2.96E-02	S	3.04E-05	S	1.77E+00	W	5.23E-02	S
7.8	3.59E-02	S	2.88E-05	S	1.78E+00	W	5.01E-02	S
8	4.33E-02	S	3.20E-05	S	1.79E+00	W	4.81E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	5.20E-02	S	3.55E-05	S	1.77E+00	W	4.62E-02	S
8.4	6.23E-02	S	3.92E-05	S	1.76E+00	W	4.45E-02	S
8.6	6.84E-02	S	4.33E-05	S	1.73E+00	W	3.85E-02	S
8.8	7.45E-02	S	4.14E-05	S	1.71E+00	W	3.31E-02	S
9	9.45E-02	S	3.36E-05	S	1.69E+00	W	2.85E-02	S
9.2	1.08E-01	W	2.74E-05	S	1.66E+00	W	2.34E-02	S
9.4	1.11E-01	W	2.24E-05	S	1.64E+00	W	1.80E-02	S
9.6	1.14E-01	W	2.26E-05	S	1.62E+00	W	1.60E-02	S
9.8	1.17E-01	W	2.73E-05	S	1.62E+00	W	1.32E-02	S
10	1.19E-01	W	2.87E-05	S	1.73E+00	W	1.05E-02	S
10.2	1.22E-01	W	2.49E-05	S	1.85E+00	W	8.31E-03	S
10.4	1.24E-01	W	2.14E-05	S	1.86E+00	W	6.66E-03	S
10.6	1.24E-01	W	2.06E-05	S	1.85E+00	W	5.50E-03	S
10.8	1.23E-01	W	1.99E-05	S	1.76E+00	W	4.56E-03	S
11	1.22E-01	W	1.91E-05	S	1.67E+00	W	3.80E-03	S
11.2	1.22E-01	W	1.84E-05	S	1.59E+00	W	3.17E-03	S
11.4	1.21E-01	W	1.88E-05	S	1.54E+00	W	2.78E-03	S
11.6	1.20E-01	W	2.21E-05	S	1.55E+00	W	2.78E-03	S
11.8	1.18E-01	W	2.60E-05	S	1.56E+00	W	2.78E-03	S
12	1.17E-01	W	2.55E-05	S	1.58E+00	W	2.78E-03	S
12.2	1.16E-01	W	2.48E-05	S	1.61E+00	W	2.78E-03	S
12.4	1.15E-01	W	2.41E-05	S	1.63E+00	W	2.78E-03	S
12.6	1.14E-01	W	2.39E-05	S	1.65E+00	W	2.78E-03	S
12.8	1.13E-01	W	2.58E-05	S	1.66E+00	W	2.78E-03	S
13	1.13E-01	W	2.77E-05	S	1.66E+00	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.34E+01		4.67E-04		1.86E+01		7.66E-01	

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Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	3.32E-02	S	3.40E-01	S	2.09E-01	S
3	2.98E-02	S	3.04E-01	S	1.03E-01	S
3.2	2.80E-02	S	2.66E-01	S	6.48E-02	S
3.4	2.65E-02	S	2.34E-01	S	4.63E-02	S
3.6	2.51E-02	S	2.07E-01	S	3.37E-02	S
3.8	2.39E-02	S	1.85E-01	S	2.50E-02	S
4	2.27E-02	S	1.66E-01	S	1.87E-02	S
4.2	2.20E-02	S	1.50E-01	S	1.44E-02	S
4.4	2.35E-02	S	1.46E-01	S	1.54E-02	S
4.6	2.53E-02	S	1.40E-01	S	1.66E-02	S
4.8	2.62E-02	S	1.34E-01	S	1.88E-02	S
5	2.67E-02	S	1.28E-01	S	2.13E-02	S
5.2	2.65E-02	S	1.15E-01	S	2.40E-02	S
5.4	2.64E-02	S	1.04E-01	S	2.69E-02	S
5.6	2.63E-02	S	9.36E-02	S	3.04E-02	S
5.8	2.62E-02	S	8.49E-02	S	3.49E-02	S
6	2.63E-02	S	7.72E-02	S	3.99E-02	S
6.2	2.70E-02	S	7.05E-02	S	4.53E-02	S
6.4	2.59E-02	S	6.45E-02	S	5.13E-02	S
6.6	2.82E-02	S	5.80E-02	S	5.65E-02	S
6.8	3.19E-02	S	5.17E-02	S	6.46E-02	S
7	3.60E-02	S	4.63E-02	S	7.45E-02	S
7.2	4.05E-02	S	3.83E-02	S	8.09E-02	S
7.4	5.19E-02	S	2.40E-02	S	8.38E-02	S
7.6	5.76E-02	S	1.13E-02	S	8.67E-02	S
7.8	6.05E-02	S	7.71E-03	S	8.97E-02	S
8	6.35E-02	S	5.33E-03	S	9.30E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-10. Leachate Concentrations for Bituminous Fly Ash, Waste ID DFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	6.27E-02	S	3.71E-03	S	9.68E-02	S
8.4	6.59E-02	S	2.61E-03	S	1.01E-01	S
8.6	6.09E-02	S	2.53E-03	S	1.04E-01	S
8.8	5.24E-02	S	2.53E-03	S	1.06E-01	S
9	4.53E-02	S	2.53E-03	S	1.10E-01	S
9.2	3.93E-02	S	2.53E-03	S	1.14E-01	S
9.4	3.16E-02	S	2.53E-03	S	1.18E-01	S
9.6	2.84E-02	S	2.53E-03	S	1.22E-01	S
9.8	2.17E-02	S	2.53E-03	S	1.26E-01	S
10	1.51E-02	S	2.53E-03	S	1.21E-01	S
10.2	1.14E-02	S	2.53E-03	S	1.15E-01	S
10.4	9.62E-03	S	2.53E-03	S	1.14E-01	S
10.6	7.59E-03	S	2.53E-03	S	1.13E-01	S
10.8	7.43E-03	S	2.53E-03	S	1.12E-01	S
11	7.48E-03	S	2.53E-03	S	1.11E-01	S
11.2	7.53E-03	S	2.53E-03	S	1.11E-01	S
11.4	7.66E-03	S	2.53E-03	S	1.13E-01	S
11.6	7.98E-03	S	2.53E-03	S	1.24E-01	S
11.8	8.31E-03	S	2.53E-03	S	1.26E-01	S
12	8.65E-03	S	2.53E-03	S	1.35E-01	S
12.2	8.99E-03	S	2.53E-03	S	1.44E-01	S
12.4	9.34E-03	S	2.53E-03	S	1.54E-01	S
12.6	9.70E-03	S	2.53E-03	S	1.63E-01	S
12.8	1.01E-02	S	2.53E-03	S	1.74E-01	S
13	1.04E-02	S	2.53E-03	S	1.85E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	6.59E-01		3.40E+00		2.09E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID	EaFA-Ref-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	3.84E-01	S	3.50E+00	W	2.81E-02	S	2.99E-01	S
3	2.86E-01	S	3.57E+00	W	2.78E-02	S	2.78E-01	S
3.2	2.15E-01	S	3.63E+00	W	2.76E-02	S	2.61E-01	S
3.4	1.66E-01	S	3.69E+00	W	2.74E-02	S	2.45E-01	S
3.6	1.30E-01	S	3.75E+00	W	2.72E-02	S	2.31E-01	S
3.8	1.03E-01	S	3.80E+00	W	2.70E-02	S	2.18E-01	S
4	8.68E-02	S	3.89E+00	W	2.71E-02	S	2.13E-01	S
4.2	7.93E-02	S	4.02E+00	W	2.71E-02	S	2.16E-01	S
4.4	7.17E-02	S	4.15E+00	W	2.75E-02	S	2.20E-01	S
4.6	6.52E-02	S	4.28E+00	W	2.79E-02	S	2.23E-01	S
4.8	5.94E-02	S	4.41E+00	W	2.82E-02	S	2.26E-01	S
5	5.44E-02	S	4.54E+00	W	2.84E-02	S	2.29E-01	S
5.2	5.01E-02	S	4.67E+00	W	2.86E-02	S	2.32E-01	S
5.4	4.64E-02	S	4.80E+00	W	2.88E-02	S	2.35E-01	S
5.6	4.68E-02	S	4.82E+00	W	2.28E-02	S	2.01E-01	S
5.8	4.94E-02	S	4.80E+00	W	1.56E-02	S	1.46E-01	S
6	5.20E-02	S	4.77E+00	W	1.05E-02	S	1.08E-01	S
6.2	5.46E-02	S	4.72E+00	W	6.87E-03	S	8.21E-02	S
6.4	5.73E-02	S	4.66E+00	W	4.33E-03	S	6.14E-02	S
6.6	6.12E-02	S	4.61E+00	W	2.77E-03	S	4.73E-02	S
6.8	6.44E-02	S	4.55E+00	W	1.80E-03	S	3.70E-02	S
7	6.85E-02	S	4.50E+00	W	1.23E-03	S	2.87E-02	S
7.2	8.05E-02	S	4.47E+00	W	1.10E-03	S	1.64E-02	S
7.4	9.24E-02	S	4.43E+00	W	1.10E-03	S	9.83E-03	S
7.6	1.12E-01	S	4.42E+00	W	1.10E-03	S	6.30E-03	S
7.8	1.38E-01	S	4.39E+00	W	1.10E-03	S	4.16E-03	S
8	1.78E-01	S	4.36E+00	W	1.10E-03	S	2.60E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID	EaFA-Ref-[Med] (P,1,1)
Date Exported	8/27/2011, 6:48 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	2.11E-01	S	4.35E+00	W	1.10E-03	W	2.17E-03	S
8.4	2.49E-01	S	4.35E+00	W	1.10E-03	W	1.82E-03	S
8.6	2.93E-01	S	4.35E+00	W	1.10E-03	W	1.52E-03	S
8.8	3.44E-01	S	4.34E+00	W	1.10E-03	W	1.25E-03	S
9	4.08E-01	S	4.33E+00	W	1.10E-03	W	1.03E-03	S
9.2	4.76E-01	S	4.31E+00	W	1.10E-03	W	9.02E-04	S
9.4	5.44E-01	S	4.32E+00	W	1.10E-03	W	9.00E-04	S
9.6	6.28E-01	S	4.33E+00	W	1.10E-03	W	9.00E-04	S
9.8	7.31E-01	S	4.32E+00	W	1.10E-03	W	9.00E-04	S
10	8.31E-01	S	4.32E+00	W	1.10E-03	W	9.00E-04	S
10.2	8.73E-01	S	4.32E+00	W	1.10E-03	W	9.00E-04	S
10.4	8.63E-01	S	4.33E+00	W	1.10E-03	W	9.00E-04	S
10.6	8.53E-01	S	4.33E+00	W	1.10E-03	W	9.00E-04	S
10.8	8.45E-01	S	4.33E+00	W	1.10E-03	W	9.00E-04	S
11	8.38E-01	S	4.34E+00	W	1.10E-03	W	9.00E-04	S
11.2	8.32E-01	S	4.34E+00	W	1.10E-03	W	9.00E-04	S
11.4	8.33E-01	S	4.34E+00	W	1.10E-03	W	9.00E-04	S
11.6	8.29E-01	S	4.35E+00	W	1.10E-03	W	9.00E-04	S
11.8	8.25E-01	S	4.36E+00	W	1.10E-03	W	9.00E-04	S
12	9.89E-01	S	4.39E+00	W	1.10E-03	W	9.00E-04	S
12.2	1.55E+00	S	4.69E+00	W	1.10E-03	W	9.00E-04	S
12.4	2.38E+00	S	5.05E+00	W	1.10E-03	W	9.00E-04	S
12.6	3.61E+00	S	5.43E+00	W	1.10E-03	W	9.00E-04	S
12.8	5.40E+00	S	5.82E+00	W	1.10E-03	W	9.00E-04	S
13	8.00E+00	S	6.24E+00	W	1.10E-03	W	9.00E-04	S
Detection Limit (min, mg/L)	1.10E-02		1.00E-03		2.20E-03		1.80E-03	
Detection Limit (max, mg/L)	1.10E-02		1.00E-03		2.20E-03		1.80E-03	
Availability (mg/kg)	5.40E+01		5.82E+01		2.88E-01		2.99E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	5.80E-01	S	NA	1.83E-01	S	8.61E-03	S
3	4.49E-01	S	NA	1.63E-01	S	1.03E-02	S
3.2	3.53E-01	S	NA	1.46E-01	S	1.21E-02	S
3.4	2.82E-01	S	NA	1.31E-01	S	1.42E-02	S
3.6	2.27E-01	S	NA	1.19E-01	S	1.64E-02	S
3.8	1.85E-01	S	NA	1.08E-01	S	1.88E-02	S
4	1.14E-01	S	NA	1.18E-01	S	2.18E-02	S
4.2	5.66E-02	S	NA	1.51E-01	S	2.55E-02	S
4.4	2.92E-02	S	NA	1.92E-01	S	2.97E-02	S
4.6	1.56E-02	S	NA	2.42E-01	S	3.43E-02	S
4.8	8.68E-03	S	NA	3.02E-01	S	3.94E-02	S
5	4.93E-03	S	NA	3.73E-01	S	4.50E-02	S
5.2	2.87E-03	S	NA	4.58E-01	S	4.99E-02	S
5.4	1.70E-03	S	NA	5.52E-01	S	5.66E-02	S
5.6	1.91E-03	S	NA	6.83E-01	S	6.36E-02	S
5.8	2.62E-03	S	NA	8.49E-01	S	6.94E-02	S
6	3.90E-03	S	NA	1.04E+00	S	7.66E-02	S
6.2	6.73E-03	S	NA	1.26E+00	S	8.46E-02	S
6.4	1.14E-02	S	NA	1.59E+00	S	9.31E-02	S
6.6	1.77E-02	S	NA	1.97E+00	S	1.02E-01	S
6.8	2.88E-02	S	NA	2.42E+00	S	1.11E-01	S
7	4.56E-02	S	NA	2.96E+00	S	1.21E-01	S
7.2	6.01E-02	S	NA	3.19E+00	W	1.25E-01	S
7.4	7.57E-02	S	NA	3.26E+00	W	1.28E-01	S
7.6	9.57E-02	S	NA	3.34E+00	W	1.30E-01	S
7.8	1.20E-01	S	NA	3.40E+00	W	1.32E-01	S
8	1.44E-01	S	NA	3.44E+00	W	1.32E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.55E-01	S	NA	3.46E+00	W	1.32E-01	S
8.4	1.65E-01	S	NA	3.48E+00	W	1.32E-01	S
8.6	1.76E-01	S	NA	3.50E+00	W	1.32E-01	S
8.8	1.88E-01	S	NA	3.51E+00	W	1.32E-01	S
9	2.02E-01	S	NA	3.52E+00	W	1.32E-01	S
9.2	2.16E-01	S	NA	3.54E+00	W	1.31E-01	S
9.4	2.26E-01	S	NA	3.57E+00	W	1.28E-01	S
9.6	2.37E-01	S	NA	3.62E+00	W	1.26E-01	S
9.8	2.47E-01	S	NA	3.65E+00	W	1.29E-01	S
10	2.57E-01	S	NA	3.68E+00	W	1.30E-01	S
10.2	2.64E-01	S	NA	3.70E+00	W	1.28E-01	S
10.4	2.71E-01	S	NA	3.70E+00	W	1.26E-01	S
10.6	2.78E-01	S	NA	3.71E+00	W	1.26E-01	S
10.8	2.84E-01	S	NA	3.71E+00	W	1.27E-01	S
11	2.88E-01	S	NA	3.72E+00	W	1.27E-01	S
11.2	2.95E-01	S	NA	3.72E+00	W	1.27E-01	S
11.4	3.01E-01	S	NA	3.72E+00	W	1.27E-01	S
11.6	3.08E-01	S	NA	3.73E+00	W	1.28E-01	S
11.8	3.15E-01	S	NA	3.73E+00	W	1.28E-01	S
12	3.25E-01	S	NA	3.74E+00	W	1.31E-01	S
12.2	3.44E-01	S	NA	3.78E+00	W	1.40E-01	S
12.4	3.65E-01	S	NA	3.82E+00	W	1.49E-01	S
12.6	3.86E-01	S	NA	3.86E+00	W	1.57E-01	S
12.8	4.08E-01	S	NA	3.91E+00	W	1.69E-01	S
13	4.31E-01	S	NA	3.94E+00	W	1.81E-01	S
Detection Limit (min, mg/L)	1.20E-03		NA	1.20E-03		7.50E-03	
Detection Limit (max, mg/L)	1.20E-03		NA	1.20E-03		7.50E-03	
Availability (mg/kg)	5.80E+00		NA	3.91E+01		1.69E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.14E-01	S	5.56E-02	S	7.69E-01	S
3	1.73E-01	S	5.26E-02	S	4.82E-01	S
3.2	1.42E-01	S	4.94E-02	S	3.09E-01	S
3.4	1.18E-01	S	4.66E-02	S	2.06E-01	S
3.6	9.95E-02	S	4.42E-02	S	1.40E-01	S
3.8	8.44E-02	S	4.23E-02	S	9.73E-02	S
4	9.01E-02	S	3.79E-02	S	8.16E-02	S
4.2	1.05E-01	S	3.08E-02	S	8.10E-02	S
4.4	1.22E-01	S	2.52E-02	S	8.04E-02	S
4.6	1.40E-01	S	2.08E-02	S	7.99E-02	S
4.8	1.61E-01	S	1.72E-02	S	7.94E-02	S
5	1.82E-01	S	1.42E-02	S	7.92E-02	S
5.2	2.02E-01	S	1.18E-02	S	7.90E-02	S
5.4	2.23E-01	S	9.90E-03	S	7.88E-02	S
5.6	2.55E-01	S	8.27E-03	S	8.14E-02	S
5.8	2.98E-01	S	6.96E-03	S	8.70E-02	S
6	3.51E-01	S	5.89E-03	S	9.45E-02	S
6.2	4.10E-01	S	5.02E-03	S	1.03E-01	S
6.4	4.90E-01	S	4.29E-03	S	1.12E-01	S
6.6	5.91E-01	S	3.64E-03	S	1.22E-01	S
6.8	6.99E-01	S	2.93E-03	S	1.32E-01	S
7	8.16E-01	S	2.37E-03	S	1.42E-01	S
7.2	9.51E-01	S	2.30E-03	S	1.55E-01	S
7.4	1.11E+00	S	2.30E-03	S	1.70E-01	S
7.6	1.28E+00	S	2.30E-03	S	1.85E-01	S
7.8	1.47E+00	S	2.30E-03	S	2.00E-01	S
8	1.68E+00	S	2.30E-03	S	2.27E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-11. Leachate Concentrations for Bituminous Fly Ash, Waste ID EaFa-Ref Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	1.93E+00	S	2.30E-03	S	2.75E-01	S
8.4	2.21E+00	S	2.30E-03	S	3.35E-01	S
8.6	2.53E+00	S	2.30E-03	S	4.02E-01	S
8.8	2.89E+00	S	2.30E-03	S	4.79E-01	S
9	3.30E+00	S	2.30E-03	S	5.74E-01	S
9.2	3.70E+00	S	2.30E-03	S	6.90E-01	S
9.4	3.93E+00	S	2.30E-03	S	8.33E-01	S
9.6	4.17E+00	S	2.30E-03	S	1.01E+00	S
9.8	4.42E+00	S	2.30E-03	S	1.22E+00	S
10	4.66E+00	S	2.30E-03	S	1.46E+00	S
10.2	4.78E+00	S	2.30E-03	S	1.59E+00	S
10.4	4.89E+00	S	2.30E-03	S	1.67E+00	S
10.6	4.98E+00	S	2.30E-03	S	1.74E+00	S
10.8	5.05E+00	S	2.30E-03	S	1.82E+00	S
11	5.12E+00	S	2.30E-03	S	1.92E+00	S
11.2	5.19E+00	S	2.30E-03	S	2.00E+00	S
11.4	5.26E+00	S	2.30E-03	S	2.09E+00	S
11.6	5.32E+00	S	2.30E-03	S	2.18E+00	S
11.8	5.39E+00	S	2.30E-03	S	2.27E+00	S
12	5.50E+00	S	2.30E-03	S	2.48E+00	S
12.2	5.78E+00	S	2.30E-03	S	2.83E+00	S
12.4	6.03E+00	S	2.30E-03	S	3.22E+00	S
12.6	6.28E+00	S	2.30E-03	S	3.65E+00	S
12.8	6.54E+00	S	2.30E-03	S	4.14E+00	S
13	6.80E+00	S	2.30E-03	S	4.68E+00	S
Detection Limit (min, mg/L)	1.50E-02		4.60E-03		1.50E-03	
Detection Limit (max, mg/L)	1.50E-02		4.60E-03		1.50E-03	
Availability (mg/kg)	6.54E+01		5.56E-01		4.14E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID	EFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.51E-01	S	3.43E+00	W	7.21E-03	S	2.59E-01	S
3	1.77E-01	S	3.41E+00	W	7.05E-03	S	2.58E-01	S
3.2	1.28E-01	S	3.40E+00	W	6.90E-03	S	2.57E-01	S
3.4	9.38E-02	S	3.39E+00	W	6.76E-03	S	2.57E-01	S
3.6	7.01E-02	S	3.38E+00	W	6.64E-03	S	2.56E-01	S
3.8	5.33E-02	S	3.37E+00	W	6.52E-03	S	2.55E-01	S
4	4.42E-02	S	3.27E+00	W	6.43E-03	S	2.67E-01	S
4.2	1.86E-02	S	2.99E+00	W	5.37E-03	S	3.02E-01	S
4.4	1.91E-02	S	2.89E+00	W	4.33E-03	S	2.78E-01	S
4.6	1.96E-02	S	2.80E+00	W	3.52E-03	S	2.58E-01	S
4.8	2.01E-02	S	2.71E+00	W	2.89E-03	S	2.39E-01	S
5	2.06E-02	S	2.63E+00	W	2.39E-03	S	2.23E-01	S
5.2	2.11E-02	S	2.56E+00	W	2.00E-03	S	2.08E-01	S
5.4	2.01E-02	S	2.49E+00	W	1.81E-03	S	1.88E-01	S
5.6	1.68E-02	S	2.47E+00	W	1.49E-03	S	1.59E-01	S
5.8	1.42E-02	S	2.45E+00	W	1.25E-03	S	1.36E-01	S
6	1.20E-02	S	2.43E+00	W	1.04E-03	S	1.16E-01	S
6.2	1.02E-02	S	2.41E+00	W	8.80E-04	S	1.00E-01	S
6.4	8.73E-03	S	2.40E+00	W	7.46E-04	S	8.69E-02	S
6.6	6.95E-03	S	2.54E+00	W	7.46E-04	S	6.17E-02	S
6.8	9.67E-03	S	2.56E+00	W	7.46E-04	S	3.32E-02	S
7	1.33E-02	S	2.53E+00	W	7.46E-04	S	1.79E-02	S
7.2	1.82E-02	S	2.50E+00	W	7.46E-04	S	9.80E-03	S
7.4	2.46E-02	S	2.47E+00	W	7.46E-04	S	5.46E-03	S
7.6	3.30E-02	S	2.44E+00	W	7.46E-04	S	3.09E-03	S
7.8	4.57E-02	S	2.41E+00	W	7.46E-04	S	2.06E-03	S
8	6.61E-02	S	2.35E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID	EFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	8.48E-02	S	2.29E+00	W	7.46E-04	S	2.06E-03	S
8.4	9.68E-02	S	2.24E+00	W	7.46E-04	S	2.06E-03	S
8.6	1.02E-01	S	2.22E+00	W	7.46E-04	S	2.06E-03	S
8.8	9.84E-02	S	2.25E+00	W	7.46E-04	S	2.06E-03	S
9	9.53E-02	S	2.27E+00	W	7.46E-04	S	2.06E-03	S
9.2	9.23E-02	S	2.29E+00	W	7.46E-04	S	2.06E-03	S
9.4	8.96E-02	S	2.31E+00	W	7.46E-04	S	2.06E-03	S
9.6	8.69E-02	S	2.33E+00	W	7.46E-04	S	2.06E-03	S
9.8	8.44E-02	S	2.36E+00	W	7.46E-04	S	2.06E-03	S
10	8.20E-02	S	2.38E+00	W	7.46E-04	S	2.06E-03	S
10.2	7.97E-02	S	2.40E+00	W	7.46E-04	S	2.06E-03	S
10.4	7.75E-02	S	2.42E+00	W	7.46E-04	S	2.06E-03	S
10.6	7.55E-02	S	2.44E+00	W	7.46E-04	S	2.06E-03	S
10.8	7.35E-02	S	2.46E+00	W	7.46E-04	S	2.06E-03	S
11	7.14E-02	S	2.46E+00	W	7.46E-04	S	2.06E-03	S
11.2	6.92E-02	S	2.47E+00	W	7.46E-04	S	2.06E-03	S
11.4	6.71E-02	S	2.49E+00	W	7.46E-04	S	2.06E-03	S
11.6	6.51E-02	S	2.50E+00	W	7.46E-04	S	2.06E-03	S
11.8	6.32E-02	S	2.51E+00	W	7.46E-04	S	2.06E-03	S
12	6.13E-02	S	2.52E+00	W	7.46E-04	S	2.06E-03	S
12.2	5.86E-02	S	2.54E+00	W	7.46E-04	S	2.06E-03	S
12.4	5.52E-02	S	2.55E+00	W	7.46E-04	S	2.06E-03	S
12.6	5.20E-02	S	2.56E+00	W	7.46E-04	S	2.06E-03	S
12.8	4.90E-02	S	2.57E+00	W	7.46E-04	S	2.06E-03	S
13	4.63E-02	S	2.58E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.51E+00		3.43E+01		7.21E-02		3.02E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.10E-01	S	1.05E-05	S	2.51E-02	S	1.59E-02	S
3	2.34E-01	S	1.06E-05	S	1.66E-02	S	1.36E-02	S
3.2	1.39E-01	S	1.07E-05	S	1.13E-02	S	1.19E-02	S
3.4	8.47E-02	S	1.07E-05	S	7.88E-03	S	1.04E-02	S
3.6	5.32E-02	S	1.08E-05	S	5.60E-03	S	9.16E-03	S
3.8	3.43E-02	S	9.02E-06	S	4.06E-03	S	8.14E-03	S
4	1.99E-02	S	1.12E-05	S	3.80E-03	S	9.62E-03	S
4.2	5.40E-03	S	9.83E-06	S	1.29E-02	S	1.31E-02	S
4.4	4.85E-03	S	1.17E-05	S	2.33E-02	S	1.63E-02	S
4.6	4.37E-03	S	1.15E-05	S	4.10E-02	S	2.00E-02	S
4.8	3.96E-03	S	1.13E-05	S	7.05E-02	S	2.43E-02	S
5	3.60E-03	S	1.12E-05	S	1.18E-01	S	2.94E-02	S
5.2	3.28E-03	S	1.10E-05	S	1.95E-01	S	3.52E-02	S
5.4	2.78E-03	S	1.09E-05	S	2.68E-01	S	3.91E-02	S
5.6	2.57E-03	S	1.09E-05	S	3.46E-01	S	4.02E-02	S
5.8	2.37E-03	S	1.09E-05	S	4.44E-01	S	4.12E-02	S
6	2.20E-03	S	1.09E-05	S	5.65E-01	S	4.22E-02	S
6.2	2.04E-03	S	1.09E-05	S	7.13E-01	S	4.31E-02	S
6.4	1.90E-03	S	9.04E-06	S	8.93E-01	S	4.41E-02	S
6.6	1.90E-03	S	1.09E-05	S	1.12E+00	S	4.85E-02	S
6.8	1.90E-03	S	1.09E-05	S	1.30E+00	S	5.41E-02	S
7	2.26E-03	S	1.09E-05	S	1.37E+00	S	5.73E-02	S
7.2	2.67E-03	S	1.09E-05	S	1.44E+00	W	6.05E-02	S
7.4	3.15E-03	S	1.09E-05	S	1.51E+00	W	6.38E-02	S
7.6	3.69E-03	S	1.09E-05	S	1.58E+00	W	6.73E-02	S
7.8	4.61E-03	S	1.09E-05	S	1.63E+00	W	6.93E-02	S
8	5.61E-03	S	1.21E-05	S	1.62E+00	W	6.90E-02	S

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Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	5.22E-03	S	1.19E-05	S	1.61E+00	W	6.72E-02	W
8.4	3.76E-03	S	1.05E-05	S	1.61E+00	W	6.41E-02	W
8.6	3.37E-03	S	9.85E-06	S	1.61E+00	W	6.31E-02	W
8.8	3.71E-03	S	9.85E-06	S	1.61E+00	W	6.38E-02	W
9	4.09E-03	S	9.85E-06	S	1.62E+00	W	6.45E-02	W
9.2	4.50E-03	S	9.85E-06	S	1.62E+00	W	6.52E-02	W
9.4	4.93E-03	S	9.85E-06	S	1.63E+00	W	6.60E-02	W
9.6	5.40E-03	S	9.85E-06	S	1.63E+00	W	6.67E-02	W
9.8	5.90E-03	S	9.85E-06	S	1.64E+00	W	6.74E-02	W
10	6.43E-03	S	9.85E-06	S	1.64E+00	W	6.81E-02	W
10.2	7.01E-03	S	9.85E-06	S	1.65E+00	W	6.87E-02	W
10.4	7.62E-03	S	9.85E-06	S	1.65E+00	W	6.94E-02	W
10.6	8.27E-03	S	9.85E-06	S	1.66E+00	W	7.01E-02	W
10.8	8.96E-03	S	9.85E-06	S	1.66E+00	W	7.08E-02	W
11	1.02E-02	S	9.85E-06	S	1.68E+00	W	7.18E-02	W
11.2	1.35E-02	S	1.05E-05	S	1.70E+00	W	7.33E-02	W
11.4	1.77E-02	S	1.11E-05	S	1.73E+00	W	7.48E-02	W
11.6	2.32E-02	S	1.18E-05	S	1.75E+00	W	7.62E-02	W
11.8	3.03E-02	S	1.24E-05	S	1.78E+00	W	7.77E-02	W
12	3.93E-02	S	1.32E-05	S	1.81E+00	W	7.92E-02	W
12.2	5.08E-02	S	1.35E-05	S	1.82E+00	W	7.99E-02	W
12.4	6.54E-02	S	1.35E-05	S	1.82E+00	W	7.99E-02	W
12.6	8.39E-02	S	1.35E-05	S	1.82E+00	W	7.99E-02	W
12.8	1.07E-01	S	1.35E-05	S	1.82E+00	W	7.99E-02	W
13	1.36E-01	S	1.35E-05	S	1.82E+00	W	7.99E-02	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.10E+00		1.42E-04		1.91E+01		8.39E-01	

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Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.64E-01	S	9.63E-02	S	2.63E-01	S
3	1.92E-01	S	8.23E-02	S	8.46E-02	S
3.2	1.42E-01	S	7.10E-02	S	2.93E-02	S
3.4	1.08E-01	S	6.19E-02	S	1.08E-02	S
3.6	8.27E-02	S	5.43E-02	S	4.23E-03	S
3.8	6.44E-02	S	4.80E-02	S	1.74E-03	S
4	5.90E-02	S	4.25E-02	S	1.43E-03	S
4.2	8.16E-02	S	2.19E-02	S	1.43E-03	S
4.4	8.91E-02	S	1.73E-02	S	1.80E-03	S
4.6	9.69E-02	S	1.38E-02	S	2.25E-03	S
4.8	1.05E-01	S	1.11E-02	S	2.79E-03	S
5	1.13E-01	S	9.02E-03	S	3.42E-03	S
5.2	1.22E-01	S	7.38E-03	S	4.16E-03	S
5.4	1.16E-01	S	6.79E-03	S	4.37E-03	S
5.6	1.08E-01	S	6.75E-03	S	4.61E-03	S
5.8	1.01E-01	S	6.72E-03	S	4.85E-03	S
6	9.51E-02	S	6.69E-03	S	5.10E-03	S
6.2	8.94E-02	S	6.66E-03	S	5.35E-03	S
6.4	8.42E-02	S	6.63E-03	S	5.61E-03	S
6.6	1.03E-01	S	4.73E-03	S	7.82E-03	S
6.8	1.39E-01	S	3.40E-03	S	1.14E-02	S
7	1.73E-01	S	3.17E-03	S	1.35E-02	S
7.2	2.13E-01	S	2.97E-03	S	1.58E-02	S
7.4	2.62E-01	S	2.78E-03	S	1.85E-02	S
7.6	3.20E-01	S	2.61E-03	S	2.15E-02	S
7.8	4.00E-01	S	2.53E-03	S	2.70E-02	S
8	5.03E-01	S	2.53E-03	S	3.92E-02	S

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Table C-5-12. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	6.07E-01	S	2.53E-03	S	5.03E-02	S
8.4	7.04E-01	S	2.53E-03	S	5.70E-02	S
8.6	7.72E-01	S	2.53E-03	S	6.67E-02	S
8.8	8.03E-01	S	2.53E-03	S	8.05E-02	S
9	8.34E-01	S	2.53E-03	S	9.67E-02	S
9.2	8.67E-01	S	2.53E-03	S	1.16E-01	S
9.4	8.99E-01	S	2.53E-03	S	1.38E-01	S
9.6	9.32E-01	S	2.53E-03	S	1.64E-01	S
9.8	9.66E-01	S	2.53E-03	S	1.94E-01	S
10	1.00E+00	S	2.53E-03	S	2.28E-01	S
10.2	1.03E+00	S	2.53E-03	S	2.68E-01	S
10.4	1.07E+00	S	2.53E-03	S	3.14E-01	S
10.6	1.11E+00	S	2.53E-03	S	3.67E-01	S
10.8	1.14E+00	S	2.53E-03	S	4.28E-01	S
11	1.18E+00	S	2.53E-03	S	4.90E-01	S
11.2	1.23E+00	S	2.53E-03	S	5.19E-01	S
11.4	1.27E+00	S	2.53E-03	S	5.49E-01	S
11.6	1.31E+00	S	2.53E-03	S	5.81E-01	S
11.8	1.35E+00	S	2.53E-03	S	6.13E-01	S
12	1.39E+00	S	2.53E-03	S	6.47E-01	S
12.2	1.42E+00	S	2.53E-03	S	6.82E-01	S
12.4	1.42E+00	S	2.53E-03	S	7.19E-01	S
12.6	1.42E+00	S	2.53E-03	S	7.56E-01	S
12.8	1.42E+00	S	2.53E-03	S	7.95E-01	S
13	1.42E+00	S	2.53E-03	S	8.36E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.49E+01		9.63E-01		8.35E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID	EFB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.34E-01	S	3.19E+00	W	1.22E-02	S	1.25E-01	S
3	1.82E-01	S	3.20E+00	W	1.20E-02	S	1.25E-01	S
3.2	1.53E-01	S	3.16E+00	W	1.16E-02	S	1.25E-01	S
3.4	1.30E-01	S	3.12E+00	W	1.12E-02	S	1.24E-01	S
3.6	1.12E-01	S	3.08E+00	W	1.10E-02	S	1.23E-01	S
3.8	9.02E-02	S	2.91E+00	W	1.08E-02	S	1.18E-01	S
4	7.32E-02	S	2.76E+00	W	1.06E-02	S	1.14E-01	S
4.2	6.00E-02	S	2.62E+00	W	1.05E-02	S	1.10E-01	S
4.4	5.30E-02	S	2.53E+00	W	1.03E-02	S	1.07E-01	S
4.6	4.18E-02	S	2.44E+00	W	7.40E-03	S	6.59E-02	S
4.8	3.32E-02	S	2.35E+00	W	5.40E-03	S	4.15E-02	S
5	2.67E-02	S	2.28E+00	W	4.00E-03	S	2.66E-02	S
5.2	2.11E-02	S	2.21E+00	W	2.68E-03	S	1.46E-02	S
5.4	1.83E-02	S	2.21E+00	W	2.17E-03	S	1.23E-02	S
5.6	1.76E-02	S	2.27E+00	W	2.34E-03	S	1.81E-02	S
5.8	1.70E-02	S	2.29E+00	W	2.13E-03	S	1.75E-02	S
6	1.65E-02	S	2.25E+00	W	1.66E-03	S	1.14E-02	S
6.2	1.59E-02	S	2.22E+00	W	1.30E-03	S	7.48E-03	S
6.4	1.66E-02	S	2.21E+00	W	1.13E-03	S	5.76E-03	S
6.6	1.86E-02	S	2.21E+00	W	1.08E-03	S	5.15E-03	S
6.8	2.08E-02	S	2.22E+00	W	1.03E-03	S	4.63E-03	S
7	2.32E-02	S	2.23E+00	W	9.91E-04	S	4.16E-03	S
7.2	2.57E-02	S	2.24E+00	W	9.51E-04	S	3.76E-03	S
7.4	2.85E-02	S	2.24E+00	W	9.13E-04	S	3.41E-03	S
7.6	3.14E-02	S	2.25E+00	W	8.79E-04	S	3.09E-03	S
7.8	3.46E-02	S	2.26E+00	W	8.46E-04	S	2.81E-03	S
8	3.80E-02	S	2.26E+00	W	8.15E-04	S	2.57E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID	EFB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	4.17E-02	S	2.27E+00	W	7.86E-04	S	2.35E-03	S
8.4	4.85E-02	S	2.26E+00	W	7.59E-04	S	2.15E-03	S
8.6	5.87E-02	S	2.25E+00	W	7.46E-04	S	2.06E-03	S
8.8	7.40E-02	S	2.24E+00	W	7.46E-04	S	2.06E-03	S
9	9.29E-02	S	2.23E+00	W	7.46E-04	S	2.06E-03	S
9.2	1.16E-01	S	2.22E+00	W	7.46E-04	S	2.06E-03	S
9.4	1.39E-01	S	2.31E+00	W	7.46E-04	S	2.06E-03	S
9.6	1.66E-01	S	2.44E+00	W	7.46E-04	S	2.06E-03	S
9.8	1.98E-01	S	2.58E+00	W	7.46E-04	S	2.06E-03	S
10	2.56E-01	S	2.57E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.27E-01	S	2.51E+00	W	7.46E-04	S	2.06E-03	S
10.4	4.16E-01	S	2.44E+00	W	7.46E-04	S	2.06E-03	S
10.6	5.02E-01	S	2.46E+00	W	7.46E-04	S	2.06E-03	S
10.8	5.73E-01	S	2.56E+00	W	7.46E-04	S	2.06E-03	S
11	6.53E-01	S	2.66E+00	W	7.46E-04	S	2.06E-03	S
11.2	7.43E-01	S	2.76E+00	W	7.46E-04	S	2.06E-03	S
11.4	8.42E-01	S	2.86E+00	W	7.46E-04	S	2.06E-03	S
11.6	9.53E-01	S	2.97E+00	W	7.46E-04	S	2.06E-03	S
11.8	1.08E+00	S	3.08E+00	W	7.46E-04	S	2.06E-03	S
12	1.21E+00	S	3.19E+00	W	7.46E-04	S	2.06E-03	S
12.2	1.24E+00	S	3.23E+00	W	7.46E-04	S	2.06E-03	S
12.4	1.24E+00	S	3.27E+00	W	7.46E-04	S	2.06E-03	S
12.6	1.24E+00	S	3.31E+00	W	7.46E-04	S	2.06E-03	S
12.8	1.24E+00	S	3.35E+00	W	7.46E-04	S	2.06E-03	S
13	1.24E+00	S	3.40E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.32E+01		3.57E+01		1.22E-01		1.25E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.38E-01	S	1.99E-05	S	3.85E-02	S	3.11E-02	S
3	3.16E-01	S	2.18E-05	S	2.89E-02	S	3.27E-02	S
3.2	2.90E-01	S	2.57E-05	S	2.25E-02	S	3.41E-02	S
3.4	2.68E-01	S	3.00E-05	S	1.77E-02	S	3.54E-02	S
3.6	2.15E-01	S	3.12E-05	S	1.45E-02	S	3.60E-02	S
3.8	1.01E-01	S	2.06E-05	S	1.27E-02	S	3.37E-02	S
4	4.89E-02	S	1.39E-05	S	1.12E-02	S	3.17E-02	S
4.2	2.46E-02	S	9.59E-06	S	9.87E-03	S	2.99E-02	S
4.4	1.43E-02	S	1.13E-05	S	1.10E-02	S	2.96E-02	S
4.6	1.10E-02	S	1.46E-05	S	2.38E-02	S	3.32E-02	S
4.8	8.48E-03	S	1.86E-05	S	4.99E-02	S	3.71E-02	S
5	6.63E-03	S	2.36E-05	S	1.01E-01	S	4.14E-02	S
5.2	6.39E-03	S	2.67E-05	S	2.20E-01	S	4.73E-02	S
5.4	6.59E-03	S	2.57E-05	S	3.32E-01	S	5.04E-02	S
5.6	6.00E-03	S	2.37E-05	S	3.19E-01	S	4.90E-02	S
5.8	6.40E-03	S	2.30E-05	S	3.78E-01	S	5.04E-02	S
6	7.94E-03	S	2.34E-05	S	5.46E-01	S	5.48E-02	S
6.2	9.78E-03	S	2.39E-05	S	7.77E-01	S	5.94E-02	S
6.4	1.15E-02	S	2.43E-05	S	9.62E-01	S	6.26E-02	S
6.6	1.30E-02	S	2.48E-05	S	1.04E+00	S	6.41E-02	S
6.8	1.46E-02	S	2.52E-05	S	1.12E+00	S	6.57E-02	S
7	1.64E-02	S	2.56E-05	S	1.21E+00	S	6.72E-02	S
7.2	1.83E-02	S	2.61E-05	S	1.30E+00	W	6.88E-02	S
7.4	2.04E-02	S	2.65E-05	S	1.40E+00	W	7.03E-02	S
7.6	2.26E-02	S	2.69E-05	S	1.50E+00	W	7.19E-02	S
7.8	2.50E-02	S	2.73E-05	S	1.60E+00	W	7.34E-02	S
8	2.77E-02	S	2.77E-05	S	1.71E+00	W	7.49E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.05E-02	S	2.81E-05	S	1.82E+00	W	7.64E-02	W
8.4	3.12E-02	S	2.95E-05	S	1.95E+00	W	7.93E-02	W
8.6	3.13E-02	S	3.04E-05	S	2.03E+00	W	8.18E-02	W
8.8	3.08E-02	S	3.09E-05	S	2.06E+00	W	8.39E-02	W
9	3.02E-02	S	3.13E-05	S	2.10E+00	W	8.60E-02	W
9.2	2.97E-02	S	3.18E-05	S	2.14E+00	W	8.80E-02	W
9.4	3.04E-02	S	2.89E-05	S	2.15E+00	W	8.80E-02	W
9.6	3.13E-02	S	2.77E-05	S	2.16E+00	W	8.78E-02	W
9.8	3.22E-02	S	2.66E-05	S	2.17E+00	W	8.77E-02	W
10	3.41E-02	S	2.36E-05	S	2.24E+00	W	9.00E-02	W
10.2	3.60E-02	S	1.63E-05	S	2.33E+00	W	9.32E-02	W
10.4	3.78E-02	S	1.14E-05	S	2.42E+00	W	9.64E-02	W
10.6	3.93E-02	S	1.03E-05	S	2.48E+00	W	9.86E-02	W
10.8	4.04E-02	S	1.21E-05	S	2.49E+00	W	9.99E-02	W
11	4.15E-02	S	1.42E-05	S	2.51E+00	W	1.01E-01	W
11.2	4.26E-02	S	1.66E-05	S	2.52E+00	W	1.03E-01	W
11.4	4.37E-02	S	1.93E-05	S	2.54E+00	W	1.04E-01	W
11.6	4.48E-02	S	2.24E-05	S	2.55E+00	W	1.05E-01	W
11.8	4.59E-02	S	2.60E-05	S	2.57E+00	W	1.06E-01	W
12	4.71E-02	S	3.01E-05	S	2.58E+00	W	1.08E-01	W
12.2	4.82E-02	S	3.47E-05	S	2.58E+00	W	1.08E-01	W
12.4	4.93E-02	S	3.99E-05	S	2.58E+00	W	1.08E-01	W
12.6	5.05E-02	S	4.46E-05	S	2.58E+00	W	1.08E-01	W
12.8	5.17E-02	S	4.46E-05	S	2.58E+00	W	1.08E-01	W
13	5.28E-02	S	4.46E-05	S	2.58E+00	W	1.08E-01	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.38E+00		4.75E-04		2.75E+01		1.15E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.07E-01	S	2.43E-01	S	7.82E-01	S
3	9.44E-02	S	2.11E-01	S	3.63E-01	S
3.2	8.36E-02	S	1.74E-01	S	1.68E-01	S
3.4	7.46E-02	S	1.45E-01	S	8.18E-02	S
3.6	6.70E-02	S	1.27E-01	S	4.40E-02	S
3.8	5.54E-02	S	1.15E-01	S	2.57E-02	S
4	4.62E-02	S	1.04E-01	S	1.54E-02	S
4.2	3.89E-02	S	9.53E-02	S	9.44E-03	S
4.4	3.66E-02	S	9.57E-02	S	7.35E-03	S
4.6	3.72E-02	S	8.57E-02	S	7.07E-03	S
4.8	3.77E-02	S	7.72E-02	S	6.82E-03	S
5	3.83E-02	S	6.98E-02	S	6.58E-03	S
5.2	3.85E-02	S	5.83E-02	S	6.54E-03	S
5.4	3.60E-02	S	5.43E-02	S	6.26E-03	S
5.6	3.16E-02	S	6.07E-02	S	5.63E-03	S
5.8	3.05E-02	S	5.85E-02	S	5.57E-03	S
6	3.21E-02	S	4.91E-02	S	6.02E-03	S
6.2	3.37E-02	S	4.14E-02	S	6.50E-03	S
6.4	3.65E-02	S	3.65E-02	S	7.16E-03	S
6.6	4.06E-02	S	3.35E-02	S	8.04E-03	S
6.8	4.50E-02	S	3.09E-02	S	8.99E-03	S
7	4.98E-02	S	2.85E-02	S	1.00E-02	S
7.2	5.49E-02	S	2.64E-02	S	1.12E-02	S
7.4	6.03E-02	S	2.45E-02	S	1.24E-02	S
7.6	6.61E-02	S	2.27E-02	S	1.37E-02	S
7.8	7.23E-02	S	2.12E-02	S	1.51E-02	S
8	7.89E-02	S	1.98E-02	S	1.66E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-13. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	8.60E-02	S	1.85E-02	S	1.82E-02	S
8.4	1.00E-01	S	1.69E-02	S	2.15E-02	S
8.6	1.23E-01	S	1.52E-02	S	2.66E-02	S
8.8	1.57E-01	S	1.35E-02	S	3.43E-02	S
9	1.99E-01	S	1.20E-02	S	4.40E-02	S
9.2	2.52E-01	S	1.06E-02	S	5.61E-02	S
9.4	3.04E-01	S	9.45E-03	S	7.65E-02	S
9.6	3.60E-01	S	8.43E-03	S	1.08E-01	S
9.8	4.25E-01	S	7.54E-03	S	1.50E-01	S
10	4.91E-01	S	6.31E-03	S	2.09E-01	S
10.2	5.53E-01	S	5.07E-03	S	2.82E-01	S
10.4	6.21E-01	S	4.09E-03	S	3.77E-01	S
10.6	6.69E-01	S	3.58E-03	S	4.61E-01	S
10.8	6.91E-01	S	3.40E-03	S	5.15E-01	S
11	7.14E-01	S	3.23E-03	S	5.73E-01	S
11.2	7.37E-01	S	3.07E-03	S	6.37E-01	S
11.4	7.61E-01	S	2.92E-03	S	7.07E-01	S
11.6	7.85E-01	S	2.78E-03	S	7.83E-01	S
11.8	8.09E-01	S	2.65E-03	S	8.66E-01	S
12	8.34E-01	S	2.53E-03	S	9.56E-01	S
12.2	8.34E-01	S	2.42E-03	S	1.00E+00	S
12.4	8.34E-01	S	2.31E-03	S	1.05E+00	S
12.6	8.34E-01	S	2.21E-03	S	1.10E+00	S
12.8	8.34E-01	S	2.11E-03	S	1.15E+00	S
13	8.34E-01	S	2.02E-03	S	1.20E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	8.88E+00		2.43E+00		1.22E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID	EFC-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.11E-01	S	5.40E+00	W	1.71E-02	S	1.49E-01	S
3	1.50E-01	S	5.27E+00	W	1.67E-02	S	1.43E-01	S
3.2	1.09E-01	S	5.16E+00	W	1.64E-02	S	1.39E-01	S
3.4	8.12E-02	S	5.05E+00	W	1.61E-02	S	1.36E-01	S
3.6	6.14E-02	S	4.95E+00	W	1.59E-02	S	1.33E-01	S
3.8	4.71E-02	S	4.86E+00	W	1.55E-02	S	1.30E-01	S
4	3.66E-02	S	4.75E+00	W	1.48E-02	S	1.27E-01	S
4.2	2.77E-02	S	4.46E+00	W	1.33E-02	S	1.20E-01	S
4.4	1.52E-02	S	4.18E+00	W	1.12E-02	S	9.85E-02	S
4.6	1.30E-02	S	3.93E+00	W	9.58E-03	S	8.17E-02	S
4.8	9.84E-03	S	3.70E+00	W	8.21E-03	S	6.84E-02	S
5	8.43E-03	S	3.60E+00	W	7.09E-03	S	5.91E-02	S
5.2	4.68E-03	S	3.58E+00	W	6.15E-03	S	5.08E-02	S
5.4	3.79E-03	S	3.56E+00	W	5.15E-03	S	3.43E-02	S
5.6	3.31E-03	S	3.55E+00	W	3.97E-03	S	2.35E-02	S
5.8	4.11E-03	S	3.53E+00	W	3.09E-03	S	1.23E-02	S
6	5.06E-03	S	3.51E+00	W	2.42E-03	S	6.14E-03	S
6.2	6.19E-03	S	3.50E+00	W	1.91E-03	S	3.13E-03	S
6.4	7.36E-03	S	3.48E+00	W	1.52E-03	S	2.06E-03	S
6.6	7.24E-03	S	3.47E+00	W	1.22E-03	S	2.06E-03	S
6.8	7.12E-03	S	3.45E+00	W	9.86E-04	S	2.06E-03	S
7	8.97E-03	S	3.44E+00	W	8.01E-04	S	2.06E-03	S
7.2	1.20E-02	S	3.44E+00	W	7.46E-04	S	2.06E-03	S
7.4	1.58E-02	S	3.45E+00	W	7.46E-04	S	2.06E-03	S
7.6	2.08E-02	S	3.45E+00	W	7.46E-04	S	2.06E-03	S
7.8	2.54E-02	S	3.46E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID	EFC-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8	2.96E-02	S	3.47E+00	W	7.46E-04	S	2.06E-03	S
8.2	3.45E-02	S	3.48E+00	W	7.46E-04	S	2.06E-03	S
8.4	4.14E-02	S	3.55E+00	W	7.46E-04	S	2.06E-03	S
8.6	5.11E-02	S	3.70E+00	W	7.46E-04	S	2.06E-03	S
8.8	6.73E-02	S	3.69E+00	W	7.46E-04	S	2.06E-03	S
9	8.81E-02	S	3.54E+00	W	7.46E-04	S	2.06E-03	S
9.2	1.15E-01	S	3.45E+00	W	7.46E-04	S	2.06E-03	S
9.4	1.48E-01	S	3.62E+00	W	7.46E-04	S	2.06E-03	S
9.6	1.81E-01	S	3.66E+00	W	7.46E-04	S	2.06E-03	S
9.8	2.13E-01	S	3.73E+00	W	7.46E-04	S	2.06E-03	S
10	2.50E-01	S	3.81E+00	W	7.46E-04	S	2.06E-03	S
10.2	2.92E-01	S	3.88E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.12E-01	S	3.90E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.34E-01	S	3.86E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.56E-01	S	3.84E+00	W	7.46E-04	S	2.06E-03	S
11	3.79E-01	S	3.86E+00	W	7.46E-04	S	2.06E-03	S
11.2	4.04E-01	S	3.88E+00	W	7.46E-04	S	2.06E-03	S
11.4	4.30E-01	S	3.90E+00	W	7.46E-04	S	2.06E-03	S
11.6	4.52E-01	S	4.02E+00	W	7.46E-04	S	2.06E-03	S
11.8	5.01E-01	S	4.34E+00	W	7.46E-04	S	2.06E-03	S
12	5.50E-01	S	4.49E+00	W	7.46E-04	S	2.06E-03	S
12.2	6.03E-01	S	4.65E+00	W	7.46E-04	S	2.06E-03	S
12.4	6.60E-01	S	4.81E+00	W	7.46E-04	S	2.06E-03	S
12.6	7.22E-01	S	4.97E+00	W	7.46E-04	S	2.06E-03	S
12.8	7.88E-01	S	5.21E+00	W	7.46E-04	S	2.06E-03	S
13	8.60E-01	S	5.38E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	8.44E+00		5.58E+01		1.71E-01		1.49E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.71E-01	S	1.49E-05	S	3.80E-01	S	2.96E-02	S
3	3.38E-01	S	1.44E-05	S	3.80E-01	S	2.96E-02	S
3.2	2.48E-01	S	1.40E-05	S	3.80E-01	S	2.90E-02	S
3.4	1.85E-01	S	1.43E-05	S	3.80E-01	S	2.98E-02	S
3.6	1.30E-01	S	1.44E-05	S	3.80E-01	S	3.06E-02	S
3.8	9.45E-02	S	1.36E-05	S	3.80E-01	S	3.14E-02	S
4	7.24E-02	S	1.28E-05	S	3.80E-01	S	3.22E-02	S
4.2	4.26E-02	S	1.25E-05	S	3.80E-01	S	3.23E-02	S
4.4	3.29E-02	S	1.25E-05	S	3.80E-01	S	3.16E-02	S
4.6	1.82E-02	S	1.25E-05	S	3.80E-01	S	3.57E-02	S
4.8	1.04E-02	S	1.25E-05	S	3.80E-01	S	4.13E-02	S
5	8.79E-03	S	1.25E-05	S	4.05E-01	S	4.75E-02	S
5.2	9.24E-03	S	1.25E-05	S	4.54E-01	S	4.97E-02	S
5.4	9.69E-03	S	1.32E-05	S	5.07E-01	S	3.99E-02	S
5.6	1.02E-02	S	1.57E-05	S	5.63E-01	S	4.05E-02	S
5.8	1.11E-02	S	1.66E-05	S	6.24E-01	S	4.39E-02	S
6	1.20E-02	S	1.85E-05	S	6.96E-01	S	4.82E-02	S
6.2	1.30E-02	S	1.73E-05	S	8.18E-01	S	5.28E-02	S
6.4	1.40E-02	S	1.67E-05	S	9.17E-01	S	5.77E-02	S
6.6	1.51E-02	S	1.69E-05	S	9.53E-01	S	6.28E-02	S
6.8	1.62E-02	S	1.70E-05	S	9.90E-01	S	6.82E-02	S
7	1.74E-02	S	1.53E-05	S	1.04E+00	S	7.39E-02	S
7.2	1.86E-02	S	1.39E-05	S	1.06E+00	W	7.63E-02	S
7.4	1.98E-02	S	1.56E-05	S	1.10E+00	W	7.69E-02	S
7.6	2.11E-02	S	1.78E-05	S	1.14E+00	W	7.84E-02	S
7.8	2.24E-02	S	1.82E-05	S	1.15E+00	W	7.93E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8	2.38E-02	S	1.84E-05	S	1.16E+00	W	8.01E-02	S
8.2	2.53E-02	S	1.87E-05	S	1.18E+00	W	8.09E-02	W
8.4	2.62E-02	S	1.59E-05	S	1.26E+00	W	8.89E-02	W
8.6	3.02E-02	S	1.10E-05	S	1.32E+00	W	9.72E-02	W
8.8	3.45E-02	S	9.38E-06	S	1.36E+00	W	9.61E-02	W
9	3.47E-02	S	9.38E-06	S	1.39E+00	W	9.51E-02	W
9.2	3.49E-02	S	9.38E-06	S	1.43E+00	W	9.41E-02	W
9.4	4.45E-02	S	9.38E-06	S	1.46E+00	W	9.31E-02	W
9.6	5.85E-02	S	9.93E-06	S	1.50E+00	W	9.48E-02	W
9.8	5.97E-02	S	1.08E-05	S	1.53E+00	W	9.64E-02	W
10	6.08E-02	S	1.16E-05	S	1.56E+00	W	9.71E-02	W
10.2	6.19E-02	S	1.39E-05	S	1.59E+00	W	9.92E-02	W
10.4	6.31E-02	S	1.78E-05	S	1.59E+00	W	1.01E-01	W
10.6	6.55E-02	S	1.83E-05	S	1.60E+00	W	1.03E-01	W
10.8	7.25E-02	S	1.83E-05	S	1.62E+00	W	1.04E-01	W
11	7.82E-02	S	1.65E-05	S	1.64E+00	W	1.04E-01	W
11.2	8.42E-02	S	1.50E-05	S	1.67E+00	W	1.04E-01	W
11.4	9.05E-02	S	1.36E-05	S	1.70E+00	W	1.04E-01	W
11.6	9.72E-02	S	1.25E-05	S	1.73E+00	W	1.03E-01	W
11.8	1.10E-01	S	1.25E-05	S	1.79E+00	W	1.03E-01	W
12	1.27E-01	S	1.25E-05	S	1.77E+00	W	1.02E-01	W
12.2	1.28E-01	S	1.25E-05	S	1.78E+00	W	9.67E-02	W
12.4	1.29E-01	S	1.25E-05	S	1.78E+00	W	9.15E-02	W
12.6	1.31E-01	S	1.25E-05	S	1.78E+00	W	8.66E-02	W
12.8	1.32E-01	S	1.25E-05	S	1.78E+00	W	8.21E-02	W
13	1.37E-01	S	1.25E-05	S	1.78E+00	W	7.79E-02	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.71E+00		1.88E-04		1.90E+01		1.10E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.91E-01	S	1.36E-01	S	8.59E-01	S
3	1.58E-01	S	1.16E-01	S	4.52E-01	S
3.2	1.33E-01	S	1.00E-01	S	2.48E-01	S
3.4	1.12E-01	S	8.72E-02	S	9.67E-02	S
3.6	9.60E-02	S	7.66E-02	S	4.92E-02	S
3.8	8.28E-02	S	6.77E-02	S	2.83E-02	S
4	7.07E-02	S	6.03E-02	S	1.67E-02	S
4.2	6.20E-02	S	5.32E-02	S	1.11E-02	S
4.4	5.83E-02	S	4.00E-02	S	9.35E-03	S
4.6	6.01E-02	S	3.05E-02	S	8.54E-03	S
4.8	6.08E-02	S	2.35E-02	S	8.10E-03	S
5	6.49E-02	S	1.93E-02	S	9.35E-03	S
5.2	7.32E-02	S	2.69E-02	S	1.03E-02	S
5.4	8.21E-02	S	2.40E-02	S	9.02E-03	S
5.6	9.18E-02	S	2.15E-02	S	9.81E-03	S
5.8	1.02E-01	S	1.94E-02	S	1.06E-02	S
6	1.13E-01	S	1.75E-02	S	1.15E-02	S
6.2	1.25E-01	S	1.59E-02	S	1.24E-02	S
6.4	1.38E-01	S	1.44E-02	S	1.33E-02	S
6.6	1.52E-01	S	1.31E-02	S	1.43E-02	S
6.8	1.66E-01	S	1.20E-02	S	1.53E-02	S
7	1.81E-01	S	1.10E-02	S	1.64E-02	S
7.2	2.01E-01	S	1.03E-02	S	2.09E-02	S
7.4	2.24E-01	S	9.80E-03	S	2.71E-02	S
7.6	2.49E-01	S	9.32E-03	S	3.47E-02	S
7.8	2.76E-01	S	8.87E-03	S	3.88E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-14. Leachate Concentrations for Bituminous Fly Ash, Waste ID EFC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8	3.05E-01	S	8.45E-03	S	4.19E-02	S
8.2	3.56E-01	S	8.06E-03	S	4.53E-02	S
8.4	4.23E-01	S	6.86E-03	S	5.34E-02	S
8.6	5.59E-01	S	5.63E-03	S	6.81E-02	S
8.8	7.35E-01	S	4.64E-03	S	8.65E-02	S
9	9.60E-01	S	3.84E-03	S	1.09E-01	S
9.2	1.16E+00	S	3.19E-03	S	1.45E-01	S
9.4	1.34E+00	S	2.66E-03	S	1.98E-01	S
9.6	1.55E+00	S	2.53E-03	S	2.67E-01	S
9.8	1.87E+00	S	2.53E-03	S	3.24E-01	S
10	2.04E+00	S	2.53E-03	S	3.91E-01	S
10.2	2.22E+00	S	2.53E-03	S	4.70E-01	S
10.4	2.30E+00	S	2.53E-03	S	5.63E-01	S
10.6	2.38E+00	S	2.53E-03	S	6.72E-01	S
10.8	2.47E+00	S	2.53E-03	S	7.73E-01	S
11	2.55E+00	S	2.53E-03	S	8.06E-01	S
11.2	2.64E+00	S	2.53E-03	S	8.66E-01	S
11.4	2.72E+00	S	2.53E-03	S	9.39E-01	S
11.6	2.81E+00	S	2.53E-03	S	1.02E+00	S
11.8	2.74E+00	S	2.53E-03	S	1.08E+00	S
12	2.67E+00	S	2.53E-03	S	1.15E+00	S
12.2	2.59E+00	S	2.53E-03	S	1.22E+00	S
12.4	2.52E+00	S	2.53E-03	S	1.30E+00	S
12.6	2.45E+00	S	2.53E-03	S	1.36E+00	S
12.8	2.39E+00	S	2.53E-03	S	1.43E+00	S
13	2.32E+00	S	2.53E-03	S	1.51E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.92E+01		1.36E+00		1.53E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID	FFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	2.94E-01	S	3.53E+00	W	1.23E-02	W	1.31E-01	W
3	2.04E-01	S	3.45E+00	W	1.19E-02	W	1.26E-01	W
3.2	1.58E-01	S	3.34E+00	W	1.16E-02	W	1.20E-01	W
3.4	1.25E-01	S	3.24E+00	W	1.13E-02	W	1.14E-01	W
3.6	1.00E-01	S	3.15E+00	W	1.10E-02	W	1.10E-01	W
3.8	8.10E-02	S	3.07E+00	W	1.07E-02	W	1.05E-01	W
4	6.63E-02	S	3.00E+00	W	1.05E-02	S	1.01E-01	S
4.2	5.48E-02	S	2.93E+00	W	1.02E-02	S	9.76E-02	S
4.4	4.92E-02	S	2.84E+00	W	9.29E-03	S	8.97E-02	S
4.6	4.42E-02	S	2.77E+00	W	8.28E-03	S	8.22E-02	S
4.8	4.01E-02	S	2.71E+00	W	7.06E-03	S	7.45E-02	S
5	3.67E-02	S	2.66E+00	W	5.77E-03	S	6.69E-02	S
5.2	3.37E-02	S	2.62E+00	W	4.75E-03	S	6.03E-02	S
5.4	3.11E-02	S	2.57E+00	W	3.94E-03	S	5.46E-02	S
5.6	3.00E-02	S	2.54E+00	W	3.31E-03	S	4.65E-02	S
5.8	3.03E-02	S	2.51E+00	W	2.82E-03	S	3.74E-02	S
6	3.09E-02	S	2.48E+00	W	2.31E-03	S	2.91E-02	S
6.2	3.19E-02	S	2.44E+00	W	1.82E-03	S	2.20E-02	S
6.4	3.29E-02	S	2.40E+00	W	1.44E-03	S	1.68E-02	S
6.6	3.53E-02	S	2.39E+00	W	1.22E-03	S	1.28E-02	S
6.8	4.77E-02	S	2.39E+00	W	9.94E-04	S	6.48E-03	S
7	7.74E-02	S	2.38E+00	W	7.46E-04	S	2.25E-03	S
7.2	9.91E-02	S	2.42E+00	W	7.46E-04	S	2.06E-03	S
7.4	1.25E-01	S	2.43E+00	W	7.46E-04	S	2.06E-03	S
7.6	1.40E-01	S	2.37E+00	W	7.46E-04	S	2.06E-03	S
7.8	1.57E-01	S	2.32E+00	W	7.46E-04	S	2.06E-03	S
8	1.84E-01	S	2.29E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID	FFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	2.15E-01	S	2.26E+00	W	7.46E-04	W	2.06E-03	S
8.4	2.69E-01	S	2.22E+00	W	7.46E-04	W	2.06E-03	S
8.6	3.73E-01	S	2.29E+00	W	7.46E-04	W	2.06E-03	S
8.8	5.14E-01	S	2.35E+00	W	7.46E-04	W	2.06E-03	S
9	7.03E-01	S	2.42E+00	W	7.46E-04	W	2.06E-03	S
9.2	9.55E-01	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
9.4	1.09E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
9.6	1.19E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
9.8	1.26E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
10	1.33E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
10.2	1.40E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
10.4	1.48E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
10.6	1.56E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
10.8	1.64E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
11	1.72E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
11.2	1.80E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
11.4	1.89E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
11.6	1.98E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
11.8	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
12	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
12.2	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
12.4	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
12.6	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
12.8	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
13	2.00E+00	S	2.49E+00	W	7.46E-04	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.08E+01		3.53E+01		1.23E-01		1.31E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.68E-01	S	3.56E-05	S	3.80E-01	S	2.34E-02	S
3	2.64E-01	S	3.84E-05	S	3.80E-01	S	2.64E-02	S
3.2	1.74E-01	S	4.15E-05	S	3.80E-01	S	2.98E-02	S
3.4	1.17E-01	S	4.46E-05	S	3.80E-01	S	3.33E-02	S
3.6	8.09E-02	S	4.77E-05	S	3.80E-01	S	3.70E-02	S
3.8	5.70E-02	S	5.08E-05	S	3.80E-01	S	4.09E-02	S
4	4.08E-02	S	5.40E-05	S	3.80E-01	S	4.50E-02	S
4.2	2.98E-02	S	5.72E-05	S	3.80E-01	S	4.92E-02	S
4.4	1.49E-02	S	5.99E-05	S	3.80E-01	S	5.44E-02	S
4.6	7.72E-03	S	6.45E-05	S	3.80E-01	S	6.03E-02	S
4.8	5.58E-03	S	6.73E-05	S	4.08E-01	S	6.80E-02	S
5	5.50E-03	S	6.81E-05	S	4.69E-01	S	7.78E-02	S
5.2	5.43E-03	S	6.89E-05	S	5.36E-01	S	8.86E-02	S
5.4	5.36E-03	S	6.96E-05	S	6.09E-01	S	1.00E-01	S
5.6	5.37E-03	S	7.24E-05	S	6.65E-01	S	1.10E-01	S
5.8	5.47E-03	S	7.72E-05	S	6.98E-01	S	1.17E-01	S
6	6.19E-03	S	7.65E-05	S	7.87E-01	S	1.23E-01	S
6.2	7.75E-03	S	7.08E-05	S	9.51E-01	S	1.29E-01	S
6.4	9.62E-03	S	6.57E-05	S	1.14E+00	S	1.36E-01	S
6.6	1.20E-02	S	5.62E-05	S	1.34E+00	S	1.40E-01	S
6.8	1.66E-02	S	4.96E-05	S	1.56E+00	S	1.44E-01	S
7	2.49E-02	S	4.86E-05	S	1.82E+00	S	1.49E-01	S
7.2	2.97E-02	S	4.15E-05	S	1.81E+00	W	1.49E-01	S
7.4	3.39E-02	S	3.80E-05	S	1.79E+00	W	1.49E-01	S
7.6	3.71E-02	S	3.80E-05	S	1.81E+00	W	1.50E-01	S
7.8	4.04E-02	S	3.80E-05	S	1.82E+00	W	1.51E-01	S
8	4.37E-02	S	4.71E-05	S	1.80E+00	W	1.55E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.2	4.72E-02	S	5.81E-05	S	1.78E+00	W	1.59E-01	W
8.4	5.23E-02	S	6.00E-05	S	1.74E+00	W	1.61E-01	W
8.6	5.58E-02	S	6.31E-05	S	1.77E+00	W	1.61E-01	W
8.8	5.95E-02	S	6.62E-05	S	1.80E+00	W	1.61E-01	W
9	6.32E-02	S	6.94E-05	S	1.83E+00	W	1.61E-01	W
9.2	6.72E-02	S	7.26E-05	S	1.86E+00	W	1.61E-01	W
9.4	6.96E-02	S	7.30E-05	S	1.87E+00	W	1.61E-01	W
9.6	7.18E-02	S	7.24E-05	S	1.88E+00	W	1.62E-01	W
9.8	7.39E-02	S	7.10E-05	S	1.87E+00	W	1.65E-01	W
10	7.59E-02	S	6.96E-05	S	1.87E+00	W	1.68E-01	W
10.2	7.80E-02	S	6.83E-05	S	1.87E+00	W	1.71E-01	W
10.4	8.01E-02	S	6.71E-05	S	1.87E+00	W	1.74E-01	W
10.6	8.21E-02	S	6.59E-05	S	1.86E+00	W	1.76E-01	W
10.8	8.43E-02	S	6.47E-05	S	1.86E+00	W	1.79E-01	W
11	8.64E-02	S	6.36E-05	S	1.86E+00	W	1.82E-01	W
11.2	8.85E-02	S	6.25E-05	S	1.86E+00	W	1.85E-01	W
11.4	9.07E-02	S	6.15E-05	S	1.85E+00	W	1.88E-01	W
11.6	9.28E-02	S	6.04E-05	S	1.85E+00	W	1.91E-01	W
11.8	9.50E-02	S	5.95E-05	S	1.85E+00	W	1.92E-01	W
12	9.72E-02	S	5.85E-05	S	1.85E+00	W	1.92E-01	W
12.2	9.94E-02	S	5.76E-05	S	1.84E+00	W	1.92E-01	W
12.4	1.02E-01	S	5.67E-05	S	1.84E+00	W	1.92E-01	W
12.6	1.04E-01	S	5.59E-05	S	1.84E+00	W	1.92E-01	W
12.8	1.06E-01	S	5.50E-05	S	1.84E+00	W	1.92E-01	W
13	1.08E-01	S	5.42E-05	S	1.83E+00	W	1.92E-01	W
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.68E+00		7.79E-04		1.94E+01		1.99E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.71E-01	S	5.39E-02	S	2.35E+00	S
3	1.97E-01	S	4.02E-02	S	1.06E+00	S
3.2	1.53E-01	S	3.03E-02	S	4.73E-01	S
3.4	1.20E-01	S	2.32E-02	S	2.22E-01	S
3.6	9.58E-02	S	1.81E-02	S	1.09E-01	S
3.8	7.73E-02	S	1.43E-02	S	5.53E-02	S
4	6.31E-02	S	1.14E-02	S	2.91E-02	S
4.2	5.20E-02	S	9.19E-03	S	1.58E-02	S
4.4	5.55E-02	S	8.48E-03	S	1.48E-02	S
4.6	6.27E-02	S	8.03E-03	S	1.58E-02	S
4.8	7.43E-02	S	7.15E-03	S	1.79E-02	S
5	9.22E-02	S	6.01E-03	S	2.13E-02	S
5.2	1.13E-01	S	5.08E-03	S	2.53E-02	S
5.4	1.38E-01	S	4.33E-03	S	2.97E-02	S
5.6	1.61E-01	S	3.95E-03	S	3.35E-02	S
5.8	1.79E-01	S	3.85E-03	S	3.63E-02	S
6	2.02E-01	S	3.60E-03	S	4.01E-02	S
6.2	2.29E-01	S	3.24E-03	S	4.50E-02	S
6.4	2.60E-01	S	2.93E-03	S	5.04E-02	S
6.6	2.97E-01	S	2.65E-03	S	5.57E-02	S
6.8	3.79E-01	S	2.53E-03	S	6.64E-02	S
7	5.32E-01	S	2.53E-03	S	8.58E-02	S
7.2	6.16E-01	S	2.53E-03	S	9.73E-02	S
7.4	7.00E-01	S	2.53E-03	S	1.12E-01	S
7.6	7.43E-01	S	2.53E-03	S	1.18E-01	S
7.8	7.88E-01	S	2.53E-03	S	1.24E-01	S
8	8.45E-01	S	2.53E-03	S	1.41E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-15. Leachate Concentrations for Bituminous Fly Ash, Waste ID FFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	9.04E-01	S	2.53E-03	S	1.59E-01	S
8.4	1.03E+00	S	2.53E-03	S	1.97E-01	S
8.6	1.12E+00	S	2.53E-03	S	2.72E-01	S
8.8	1.23E+00	S	2.53E-03	S	3.74E-01	S
9	1.34E+00	S	2.53E-03	S	5.09E-01	S
9.2	1.46E+00	W	2.53E-03	S	6.89E-01	S
9.4	1.51E+00	W	2.53E-03	S	7.81E-01	S
9.6	1.54E+00	W	2.53E-03	S	8.49E-01	S
9.8	1.55E+00	W	2.53E-03	S	8.88E-01	S
10	1.56E+00	W	2.53E-03	S	9.27E-01	S
10.2	1.57E+00	W	2.53E-03	S	9.67E-01	S
10.4	1.58E+00	W	2.53E-03	S	1.01E+00	S
10.6	1.59E+00	W	2.53E-03	S	1.05E+00	S
10.8	1.60E+00	W	2.53E-03	S	1.09E+00	S
11	1.61E+00	W	2.53E-03	S	1.14E+00	S
11.2	1.62E+00	W	2.53E-03	S	1.18E+00	S
11.4	1.63E+00	W	2.53E-03	S	1.23E+00	S
11.6	1.64E+00	W	2.53E-03	S	1.27E+00	S
11.8	1.64E+00	W	2.53E-03	S	1.32E+00	S
12	1.64E+00	W	2.53E-03	S	1.37E+00	S
12.2	1.64E+00	W	2.53E-03	S	1.42E+00	S
12.4	1.64E+00	W	2.53E-03	S	1.47E+00	S
12.6	1.64E+00	W	2.53E-03	S	1.52E+00	S
12.8	1.64E+00	W	2.53E-03	S	1.57E+00	S
13	1.64E+00	W	2.53E-03	S	1.62E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.71E+01		5.39E-01		2.35E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID	GAB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.58E-01	S	5.06E+00	S	4.53E-02	S	1.97E-01	S
3	3.73E-01	S	5.43E+00	S	4.43E-02	S	1.80E-01	S
3.2	3.87E-01	S	5.80E+00	S	4.34E-02	S	1.66E-01	S
3.4	4.01E-01	S	6.17E+00	S	4.25E-02	S	1.54E-01	S
3.6	4.14E-01	S	6.54E+00	S	4.17E-02	W	1.43E-01	S
3.8	4.28E-01	S	6.91E+00	S	4.10E-02	W	1.34E-01	S
4	3.16E-01	S	7.73E+00	S	3.95E-02	W	1.25E-01	S
4.2	2.35E-01	S	8.61E+00	S	3.75E-02	W	1.17E-01	S
4.4	1.80E-01	S	9.54E+00	S	3.56E-02	W	1.12E-01	S
4.6	1.94E-01	S	9.66E+00	W	2.21E-02	S	1.05E-01	S
4.8	2.08E-01	S	9.78E+00	W	1.41E-02	S	9.82E-02	S
5	2.22E-01	S	9.89E+00	W	9.98E-03	S	9.24E-02	S
5.2	2.51E-01	S	1.00E+01	W	7.17E-03	S	8.72E-02	S
5.4	2.82E-01	S	1.01E+01	W	5.21E-03	S	8.25E-02	S
5.6	3.16E-01	S	1.02E+01	W	3.84E-03	S	7.82E-02	S
5.8	3.38E-01	S	1.03E+01	W	2.85E-03	S	6.95E-02	S
6	3.59E-01	S	1.04E+01	W	2.14E-03	S	6.21E-02	S
6.2	3.81E-01	S	1.05E+01	W	1.63E-03	S	5.56E-02	S
6.4	4.04E-01	S	1.06E+01	W	1.24E-03	S	5.00E-02	S
6.6	4.48E-01	S	1.05E+01	W	9.60E-04	S	4.51E-02	S
6.8	5.57E-01	S	1.06E+01	W	7.46E-04	S	4.07E-02	S
7	5.82E-01	S	1.08E+01	W	7.46E-04	S	2.95E-02	S
7.2	6.06E-01	S	1.09E+01	W	7.46E-04	S	2.15E-02	S
7.4	6.56E-01	S	1.11E+01	W	7.46E-04	S	1.58E-02	S
7.6	7.37E-01	S	1.07E+01	W	7.46E-04	S	1.03E-02	S
7.8	9.84E-01	S	9.96E+00	W	7.46E-04	S	6.54E-03	S
8	8.47E-01	S	9.59E+00	W	7.46E-04	S	5.47E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID	GAB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	8.01E-01	S	9.54E+00	W	7.46E-04	W	4.66E-03	S
8.4	7.57E-01	S	9.51E+00	W	7.46E-04	W	3.76E-03	S
8.6	7.17E-01	S	9.48E+00	W	7.46E-04	W	3.15E-03	S
8.8	5.97E-01	S	9.45E+00	W	7.46E-04	W	2.65E-03	S
9	5.12E-01	S	9.24E+00	S	7.46E-04	W	2.24E-03	S
9.2	4.40E-01	S	8.91E+00	S	7.46E-04	W	2.06E-03	S
9.4	3.80E-01	S	8.59E+00	S	7.46E-04	W	2.06E-03	S
9.6	3.36E-01	S	8.30E+00	S	7.46E-04	W	2.06E-03	S
9.8	3.17E-01	S	7.86E+00	S	7.46E-04	W	2.06E-03	S
10	3.02E-01	S	7.82E+00	S	7.46E-04	W	2.06E-03	S
10.2	2.91E-01	S	7.63E+00	S	7.46E-04	W	2.06E-03	S
10.4	2.80E-01	S	7.19E+00	S	7.46E-04	W	2.06E-03	S
10.6	2.70E-01	S	6.79E+00	S	7.46E-04	W	2.06E-03	S
10.8	2.60E-01	S	6.41E+00	S	7.46E-04	W	2.06E-03	S
11	2.49E-01	S	6.07E+00	S	7.46E-04	W	2.06E-03	S
11.2	2.43E-01	S	5.74E+00	S	7.46E-04	W	2.06E-03	S
11.4	2.47E-01	S	4.77E+00	S	7.46E-04	W	2.06E-03	S
11.6	2.52E-01	S	3.97E+00	S	7.46E-04	W	2.06E-03	S
11.8	2.56E-01	S	3.32E+00	S	7.46E-04	W	2.06E-03	S
12	2.61E-01	S	2.79E+00	S	7.46E-04	W	2.06E-03	S
12.2	2.65E-01	S	2.34E+00	S	7.46E-04	W	2.06E-03	S
12.4	2.70E-01	S	1.97E+00	S	7.46E-04	W	2.06E-03	S
12.6	2.74E-01	S	1.67E+00	S	7.46E-04	W	2.06E-03	S
12.8	2.79E-01	S	1.42E+00	S	7.46E-04	W	2.06E-03	S
13	2.83E-01	S	1.20E+00	S	7.46E-04	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	9.85E+00		1.11E+02		4.53E-01		1.97E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	9.63E-01	S	4.81E-05	S	1.79E-02	S	1.84E-02	S
3	6.24E-01	S	7.24E-05	S	2.05E-02	S	2.00E-02	S
3.2	4.15E-01	S	1.11E-04	S	2.32E-02	S	2.17E-02	S
3.4	2.83E-01	S	1.66E-04	S	2.62E-02	S	2.33E-02	S
3.6	1.97E-01	S	2.06E-04	S	2.93E-02	S	2.50E-02	S
3.8	1.40E-01	S	2.51E-04	S	3.28E-02	S	2.68E-02	S
4	3.11E-02	S	2.32E-04	S	3.85E-02	S	3.14E-02	S
4.2	7.43E-03	S	1.70E-04	S	4.51E-02	S	3.86E-02	S
4.4	1.90E-03	S	1.26E-04	S	5.71E-02	S	4.37E-02	S
4.6	1.90E-03	S	1.03E-04	S	8.28E-02	S	4.80E-02	S
4.8	1.90E-03	S	8.54E-05	S	1.16E-01	S	5.31E-02	S
5	1.90E-03	S	7.13E-05	S	1.59E-01	S	5.86E-02	S
5.2	1.90E-03	S	5.99E-05	S	2.17E-01	S	6.45E-02	S
5.4	1.90E-03	S	5.07E-05	S	2.92E-01	S	7.08E-02	S
5.6	1.90E-03	S	4.31E-05	S	3.99E-01	S	7.73E-02	S
5.8	1.90E-03	S	4.12E-05	S	5.46E-01	S	8.43E-02	S
6	1.90E-03	S	3.71E-05	S	7.40E-01	S	9.15E-02	S
6.2	1.90E-03	S	3.35E-05	S	9.92E-01	S	9.92E-02	S
6.4	1.90E-03	S	3.03E-05	S	1.32E+00	S	1.07E-01	S
6.6	1.90E-03	S	2.76E-05	S	1.47E+00	S	1.11E-01	S
6.8	1.90E-03	S	2.51E-05	S	1.78E+00	S	1.12E-01	S
7	1.90E-03	S	2.28E-05	S	1.87E+00	S	1.12E-01	S
7.2	1.90E-03	S	2.07E-05	S	1.96E+00	W	1.12E-01	S
7.4	1.90E-03	S	1.88E-05	S	2.05E+00	W	1.14E-01	S
7.6	1.90E-03	S	1.80E-05	S	2.11E+00	W	1.17E-01	S
7.8	1.90E-03	S	1.80E-05	S	2.12E+00	W	1.21E-01	S
8	1.90E-03	S	2.51E-05	S	2.06E+00	W	1.21E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.90E-03	S	2.64E-05	S	2.09E+00	W	1.19E-01	S
8.4	1.90E-03	S	2.77E-05	S	2.15E+00	W	1.16E-01	S
8.6	1.90E-03	S	2.90E-05	S	2.22E+00	W	1.14E-01	S
8.8	1.90E-03	S	3.03E-05	S	2.29E+00	W	1.12E-01	S
9	1.90E-03	S	3.16E-05	S	2.32E+00	W	1.07E-01	S
9.2	1.90E-03	S	3.13E-05	S	2.31E+00	W	9.64E-02	S
9.4	1.90E-03	S	2.93E-05	S	2.30E+00	W	8.72E-02	S
9.6	1.90E-03	S	2.76E-05	S	2.29E+00	W	8.43E-02	S
9.8	1.90E-03	S	2.59E-05	S	2.28E+00	W	8.55E-02	S
10	1.90E-03	S	2.51E-05	S	2.34E+00	W	7.94E-02	S
10.2	1.90E-03	S	2.51E-05	S	2.48E+00	W	6.94E-02	S
10.4	1.90E-03	S	2.51E-05	S	2.56E+00	W	6.03E-02	S
10.6	1.90E-03	S	2.51E-05	S	2.64E+00	W	5.25E-02	S
10.8	1.90E-03	S	2.51E-05	S	2.72E+00	W	4.59E-02	S
11	1.90E-03	S	2.32E-05	S	2.80E+00	W	4.01E-02	S
11.2	1.90E-03	S	2.32E-05	S	2.88E+00	W	3.44E-02	S
11.4	1.90E-03	S	1.64E-05	S	2.57E+00	W	1.82E-02	S
11.6	1.90E-03	S	1.08E-05	S	2.10E+00	W	1.06E-02	S
11.8	1.90E-03	S	7.13E-06	S	1.72E+00	W	5.90E-03	S
12	1.90E-03	S	4.75E-06	S	1.42E+00	W	4.00E-03	S
12.2	1.90E-03	S	3.19E-06	S	1.17E+00	W	4.00E-03	S
12.4	1.90E-03	S	2.15E-06	S	9.68E-01	W	4.00E-03	S
12.6	1.90E-03	S	2.07E-06	S	8.04E-01	W	4.00E-03	S
12.8	1.90E-03	S	2.07E-06	S	6.70E-01	W	4.00E-03	S
13	1.90E-03	S	2.07E-06	S	5.60E-01	W	4.00E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-03	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-03	
Availability (mg/kg)	9.63E+00		2.52E-03		2.88E+01		1.21E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	6.84E-01	S	2.68E-02	S	3.14E+00	S
3	6.39E-01	S	3.22E-02	S	1.60E+00	S
3.2	5.99E-01	S	3.80E-02	S	8.48E-01	S
3.4	5.64E-01	S	4.45E-02	S	4.68E-01	S
3.6	5.32E-01	S	5.16E-02	S	2.67E-01	S
3.8	5.04E-01	S	6.05E-02	S	1.67E-01	S
4	5.09E-01	S	6.84E-02	S	1.19E-01	S
4.2	5.50E-01	S	7.68E-02	S	9.13E-02	S
4.4	5.50E-01	S	8.58E-02	S	7.13E-02	S
4.6	6.20E-01	S	9.44E-02	S	8.60E-02	S
4.8	6.94E-01	S	1.02E-01	S	1.01E-01	S
5	7.43E-01	S	1.10E-01	S	1.10E-01	S
5.2	7.91E-01	S	1.19E-01	S	1.19E-01	S
5.4	8.40E-01	S	1.28E-01	S	1.28E-01	S
5.6	8.91E-01	S	1.37E-01	S	1.38E-01	S
5.8	9.43E-01	S	1.46E-01	S	1.51E-01	S
6	9.95E-01	S	1.57E-01	S	1.66E-01	S
6.2	1.07E+00	S	1.72E-01	S	1.81E-01	S
6.4	1.14E+00	S	1.89E-01	S	1.98E-01	S
6.6	1.22E+00	S	2.06E-01	S	2.19E-01	S
6.8	1.27E+00	S	1.97E-01	S	2.20E-01	S
7	1.27E+00	S	1.95E-01	S	2.07E-01	S
7.2	1.27E+00	S	1.94E-01	S	1.95E-01	S
7.4	1.33E+00	S	1.93E-01	S	1.98E-01	S
7.6	1.46E+00	S	1.71E-01	S	2.16E-01	S
7.8	1.64E+00	S	1.53E-01	S	2.86E-01	S
8	1.70E+00	S	1.54E-01	S	2.50E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-16. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.76E+00	S	1.64E-01	S	2.61E-01	S
8.4	1.86E+00	S	1.75E-01	S	2.71E-01	S
8.6	2.01E+00	S	1.86E-01	S	2.81E-01	S
8.8	2.12E+00	S	1.98E-01	S	2.38E-01	S
9	2.24E+00	S	1.80E-01	S	2.29E-01	S
9.2	2.35E+00	S	1.47E-01	S	2.20E-01	S
9.4	2.45E+00	S	1.21E-01	S	2.15E-01	S
9.6	2.55E+00	S	9.94E-02	S	2.30E-01	S
9.8	2.66E+00	S	6.69E-02	S	2.46E-01	S
10	2.68E+00	S	5.39E-02	S	2.36E-01	S
10.2	2.77E+00	S	5.39E-02	S	2.05E-01	S
10.4	2.87E+00	S	5.47E-02	S	1.78E-01	S
10.6	2.96E+00	S	5.55E-02	S	1.55E-01	S
10.8	3.06E+00	S	5.63E-02	S	1.35E-01	S
11	3.15E+00	S	5.70E-02	S	1.18E-01	S
11.2	3.32E+00	S	5.07E-02	S	1.09E-01	S
11.4	3.33E+00	S	4.44E-02	S	1.15E-01	S
11.6	3.40E+00	S	3.88E-02	S	1.27E-01	S
11.8	3.40E+00	S	2.46E-02	S	1.41E-01	S
12	3.40E+00	S	1.95E-02	S	1.55E-01	S
12.2	3.40E+00	S	1.55E-02	S	1.71E-01	S
12.4	3.40E+00	S	1.24E-02	S	1.88E-01	S
12.6	3.40E+00	S	9.89E-03	S	2.07E-01	S
12.8	3.40E+00	S	7.95E-03	S	2.27E-01	S
13	3.40E+00	S	6.41E-03	S	2.48E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.00E-03		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.00E-03		3.10E-04	
Availability (mg/kg)	3.49E+01		2.06E+00		3.14E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID	GAT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	1.67E-01	S	5.54E+00	S	3.23E-02	S	1.86E-01	S
3	1.15E-01	S	5.66E+00	S	3.26E-02	S	1.88E-01	S
3.2	1.00E-01	S	6.15E+00	S	2.81E-02	S	1.78E-01	S
3.4	8.69E-02	S	6.85E+00	S	2.19E-02	S	1.63E-01	S
3.6	7.62E-02	S	7.60E+00	S	1.73E-02	S	1.50E-01	S
3.8	6.72E-02	S	8.37E+00	S	1.39E-02	S	1.38E-01	S
4	6.81E-02	S	8.94E+00	S	1.24E-02	S	1.33E-01	S
4.2	7.84E-02	S	9.29E+00	S	1.24E-02	S	1.32E-01	S
4.4	8.96E-02	S	9.63E+00	S	1.24E-02	S	1.32E-01	S
4.6	1.02E-01	S	9.96E+00	W	1.24E-02	S	1.31E-01	S
4.8	1.15E-01	S	1.03E+01	W	1.24E-02	S	1.31E-01	S
5	1.29E-01	S	1.06E+01	W	1.24E-02	S	1.30E-01	S
5.2	1.44E-01	S	1.09E+01	W	1.26E-02	S	1.30E-01	S
5.4	1.59E-01	S	1.10E+01	W	1.30E-02	S	1.29E-01	S
5.6	1.65E-01	S	1.11E+01	W	1.29E-02	S	1.26E-01	S
5.8	1.62E-01	S	1.12E+01	W	1.26E-02	S	1.21E-01	S
6	1.72E-01	S	1.10E+01	W	9.55E-03	S	1.17E-01	S
6.2	1.67E-01	S	1.07E+01	W	7.66E-03	S	8.34E-02	S
6.4	1.58E-01	S	1.02E+01	W	5.77E-03	S	5.31E-02	S
6.6	1.51E-01	S	9.75E+00	W	4.39E-03	S	3.43E-02	S
6.8	1.44E-01	S	9.33E+00	W	3.36E-03	S	2.25E-02	S
7	1.37E-01	S	8.95E+00	W	2.59E-03	S	1.49E-02	S
7.2	1.31E-01	S	8.59E+00	W	2.02E-03	S	9.98E-03	S
7.4	1.26E-01	S	8.26E+00	W	1.58E-03	S	6.77E-03	S
7.6	1.20E-01	S	7.95E+00	W	1.25E-03	S	4.63E-03	S
7.8	1.15E-01	S	7.65E+00	W	9.88E-04	S	3.21E-03	S
8	1.18E-01	S	7.45E+00	W	8.98E-04	S	2.76E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID	GAT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:49 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	1.21E-01	S	7.25E+00	W	8.18E-04	W	2.38E-03	S
8.4	1.24E-01	S	7.14E+00	W	7.46E-04	W	2.06E-03	S
8.6	1.29E-01	S	7.27E+00	W	7.46E-04	W	2.06E-03	S
8.8	1.31E-01	S	7.29E+00	W	7.46E-04	W	2.06E-03	S
9	1.36E-01	S	7.49E+00	S	7.46E-04	W	2.06E-03	S
9.2	1.41E-01	S	7.74E+00	S	7.46E-04	W	2.06E-03	S
9.4	1.46E-01	S	8.00E+00	S	7.46E-04	W	2.06E-03	S
9.6	1.51E-01	S	8.26E+00	S	7.46E-04	W	2.06E-03	S
9.8	1.33E-01	S	6.74E+00	S	7.46E-04	W	2.06E-03	S
10	1.38E-01	S	6.52E+00	S	7.46E-04	W	2.06E-03	S
10.2	1.42E-01	S	6.31E+00	S	7.46E-04	W	2.06E-03	S
10.4	1.60E-01	S	6.34E+00	S	7.46E-04	W	2.06E-03	S
10.6	1.77E-01	S	5.99E+00	S	7.46E-04	W	2.06E-03	S
10.8	1.93E-01	S	5.34E+00	S	7.46E-04	W	2.06E-03	S
11	2.11E-01	S	4.77E+00	S	7.46E-04	W	2.06E-03	S
11.2	2.30E-01	S	4.27E+00	S	7.46E-04	W	2.06E-03	S
11.4	2.50E-01	S	3.83E+00	S	7.46E-04	W	2.06E-03	S
11.6	2.72E-01	S	3.44E+00	S	7.46E-04	W	2.06E-03	S
11.8	2.95E-01	S	3.10E+00	S	7.46E-04	W	2.06E-03	S
12	3.20E-01	S	2.80E+00	S	7.46E-04	W	2.06E-03	S
12.2	3.46E-01	S	2.53E+00	S	7.46E-04	W	2.06E-03	S
12.4	3.75E-01	S	2.29E+00	S	7.46E-04	W	2.06E-03	S
12.6	4.04E-01	S	2.07E+00	S	7.46E-04	W	2.06E-03	S
12.8	4.36E-01	S	1.88E+00	S	7.46E-04	W	2.06E-03	S
13	4.62E-01	S	1.71E+00	S	7.46E-04	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	4.80E+00		1.12E+02		3.26E-01		1.88E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.01E-01	S	1.33E-05	S	1.11E-02	S	1.20E-02	S
3	4.13E-01	S	6.78E-06	S	9.35E-03	S	1.41E-02	S
3.2	2.07E-01	S	6.30E-06	S	1.31E-02	S	1.73E-02	S
3.4	7.49E-02	S	8.44E-06	S	2.26E-02	S	2.07E-02	S
3.6	2.87E-02	S	1.11E-05	S	3.77E-02	S	2.45E-02	S
3.8	1.16E-02	S	1.45E-05	S	6.11E-02	S	2.87E-02	S
4	6.58E-03	S	1.52E-05	S	8.39E-02	S	3.33E-02	S
4.2	5.12E-03	S	1.32E-05	S	9.86E-02	S	3.84E-02	S
4.4	4.04E-03	S	1.16E-05	S	1.15E-01	S	4.40E-02	S
4.6	3.22E-03	S	1.02E-05	S	1.33E-01	S	5.01E-02	S
4.8	2.59E-03	S	9.02E-06	S	1.53E-01	S	5.68E-02	S
5	2.10E-03	S	8.02E-06	S	1.76E-01	S	6.39E-02	S
5.2	1.90E-03	S	7.36E-06	S	2.11E-01	S	7.14E-02	S
5.4	1.90E-03	S	6.96E-06	S	2.66E-01	S	7.90E-02	S
5.6	1.90E-03	S	6.58E-06	S	3.39E-01	S	8.52E-02	S
5.8	1.90E-03	S	6.24E-06	S	4.37E-01	S	8.96E-02	S
6	1.90E-03	S	5.70E-06	S	5.04E-01	S	9.27E-02	S
6.2	2.30E-03	S	5.89E-06	S	5.65E-01	S	8.88E-02	S
6.4	3.07E-03	S	6.85E-06	S	6.30E-01	S	8.16E-02	S
6.6	4.07E-03	S	7.94E-06	S	7.00E-01	S	7.51E-02	S
6.8	5.34E-03	S	9.15E-06	S	7.75E-01	S	6.94E-02	S
7	6.96E-03	S	1.05E-05	S	8.55E-01	S	6.42E-02	S
7.2	9.01E-03	S	1.20E-05	S	9.41E-01	W	5.96E-02	S
7.4	1.16E-02	S	1.37E-05	S	1.03E+00	W	5.54E-02	S
7.6	1.48E-02	S	1.55E-05	S	1.13E+00	W	5.15E-02	S
7.8	1.87E-02	S	1.76E-05	S	1.24E+00	W	4.81E-02	S
8	2.04E-02	S	1.82E-05	S	1.26E+00	W	4.70E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.21E-02	W	1.87E-05	S	1.29E+00	W	4.60E-02	S
8.4	2.40E-02	W	2.03E-05	S	1.35E+00	W	4.56E-02	S
8.6	2.66E-02	W	2.29E-05	S	1.43E+00	W	4.59E-02	S
8.8	3.08E-02	W	2.59E-05	S	1.55E+00	W	4.46E-02	S
9	3.20E-02	W	1.68E-05	S	1.67E+00	W	4.54E-02	S
9.2	3.09E-02	W	1.07E-05	S	1.74E+00	W	4.69E-02	S
9.4	2.99E-02	W	6.92E-06	S	1.81E+00	W	4.84E-02	S
9.6	2.89E-02	W	4.50E-06	S	1.88E+00	W	4.99E-02	S
9.8	3.90E-02	W	1.38E-05	S	1.55E+00	W	3.27E-02	S
10	3.94E-02	W	1.13E-05	S	1.58E+00	W	3.03E-02	S
10.2	3.97E-02	W	9.28E-06	S	1.61E+00	W	2.81E-02	S
10.4	4.26E-02	W	1.80E-05	S	1.75E+00	W	2.75E-02	S
10.6	4.43E-02	W	2.03E-05	S	1.82E+00	W	2.50E-02	S
10.8	4.48E-02	W	1.35E-05	S	1.85E+00	W	2.11E-02	S
11	4.52E-02	W	9.11E-06	S	1.87E+00	W	1.78E-02	S
11.2	4.57E-02	W	6.17E-06	S	1.89E+00	W	1.51E-02	S
11.4	4.62E-02	W	4.21E-06	S	1.91E+00	W	1.29E-02	S
11.6	4.66E-02	W	2.89E-06	S	1.91E+00	W	1.10E-02	S
11.8	4.71E-02	W	2.25E-06	S	1.89E+00	W	9.41E-03	S
12	4.75E-02	W	1.80E-06	S	1.87E+00	W	8.07E-03	S
12.2	4.80E-02	W	1.80E-06	S	1.86E+00	W	6.95E-03	S
12.4	4.84E-02	W	1.80E-06	S	1.84E+00	W	6.36E-03	S
12.6	4.88E-02	W	1.80E-06	S	1.82E+00	W	6.18E-03	S
12.8	4.93E-02	W	1.80E-06	S	1.81E+00	W	6.01E-03	S
13	4.97E-02	W	1.80E-06	S	1.79E+00	W	5.85E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-03	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-03	
Availability (mg/kg)	4.13E+00		2.63E-04		2.10E+01		9.27E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.81E-01	S	2.49E-02	S	6.81E-01	S
3	3.98E-01	S	2.42E-02	S	3.76E-01	S
3.2	4.16E-01	S	2.88E-02	S	2.49E-01	S
3.4	4.80E-01	S	3.71E-02	S	1.67E-01	S
3.6	5.49E-01	S	4.70E-02	S	1.15E-01	S
3.8	6.23E-01	S	5.90E-02	S	8.04E-02	S
4	6.74E-01	S	6.75E-02	S	6.60E-02	S
4.2	6.99E-01	S	7.09E-02	S	6.27E-02	S
4.4	7.23E-01	S	7.44E-02	S	5.98E-02	S
4.6	7.46E-01	S	7.79E-02	S	5.71E-02	S
4.8	7.69E-01	S	8.13E-02	S	5.46E-02	S
5	7.93E-01	S	8.48E-02	S	5.23E-02	S
5.2	8.40E-01	S	8.96E-02	S	4.92E-02	S
5.4	9.15E-01	S	9.59E-02	S	4.55E-02	S
5.6	9.90E-01	S	1.00E-01	S	4.13E-02	S
5.8	1.06E+00	S	1.03E-01	S	3.68E-02	S
6	1.21E+00	S	8.52E-02	S	6.51E-02	S
6.2	1.32E+00	S	8.43E-02	S	6.38E-02	S
6.4	1.47E+00	S	8.61E-02	S	6.07E-02	S
6.6	1.64E+00	S	8.79E-02	S	5.79E-02	S
6.8	1.82E+00	S	8.96E-02	S	5.53E-02	S
7	2.01E+00	S	9.13E-02	S	5.29E-02	S
7.2	2.21E+00	S	9.31E-02	S	5.06E-02	S
7.4	2.43E+00	S	9.48E-02	S	4.85E-02	S
7.6	2.67E+00	S	9.65E-02	S	4.66E-02	S
7.8	2.92E+00	S	9.81E-02	S	4.47E-02	S
8	3.23E+00	S	1.01E-01	S	4.82E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-17. Leachate Concentrations for Bituminous Fly Ash, Waste ID GAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	3.56E+00	S	1.04E-01	S	5.19E-02	S
8.4	3.81E+00	S	1.12E-01	S	5.50E-02	S
8.6	4.09E+00	S	1.14E-01	S	5.90E-02	S
8.8	4.35E+00	S	1.85E-01	S	6.17E-02	S
9	4.75E+00	S	2.15E-01	S	7.69E-02	S
9.2	5.04E+00	S	1.55E-01	S	9.82E-02	S
9.4	5.35E+00	S	1.13E-01	S	1.25E-01	S
9.6	5.67E+00	S	8.26E-02	S	1.58E-01	S
9.8	5.02E+00	S	8.73E-02	S	1.12E-01	S
10	5.31E+00	S	7.42E-02	S	1.27E-01	S
10.2	5.60E+00	S	6.34E-02	S	1.44E-01	S
10.4	6.57E+00	S	5.66E-02	S	1.65E-01	S
10.6	7.44E+00	S	5.25E-02	S	1.87E-01	S
10.8	8.15E+00	S	5.06E-02	S	2.06E-01	S
11	8.92E+00	S	4.87E-02	S	2.27E-01	S
11.2	9.74E+00	S	4.70E-02	S	2.50E-01	S
11.4	1.06E+01	S	4.53E-02	S	2.75E-01	S
11.6	1.13E+01	S	4.38E-02	S	3.02E-01	S
11.8	1.15E+01	S	4.23E-02	S	3.30E-01	S
12	1.15E+01	S	4.09E-02	S	3.61E-01	S
12.2	1.15E+01	S	3.95E-02	S	3.95E-01	S
12.4	1.15E+01	S	3.83E-02	S	4.30E-01	S
12.6	1.15E+01	S	3.70E-02	S	4.69E-01	S
12.8	1.15E+01	S	3.59E-02	S	5.10E-01	S
13	1.15E+01	S	3.48E-02	S	5.53E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.00E-03		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.00E-03		3.10E-04	
Availability (mg/kg)	1.27E+02		2.18E+00		6.81E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID	GFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.08E-01	S	3.03E+00	W	7.30E-03	S	1.11E-01	S
3	1.33E-01	S	2.97E+00	W	7.20E-03	S	1.09E-01	S
3.2	8.76E-02	S	2.85E+00	W	6.95E-03	S	1.05E-01	S
3.4	5.92E-02	S	2.68E+00	W	6.57E-03	S	9.86E-02	S
3.6	4.55E-02	S	2.54E+00	W	6.29E-03	S	9.29E-02	S
3.8	4.21E-02	S	2.37E+00	W	6.00E-03	S	8.41E-02	S
4	3.90E-02	S	2.22E+00	W	5.74E-03	S	7.65E-02	S
4.2	3.63E-02	S	2.08E+00	W	5.51E-03	S	7.00E-02	S
4.4	3.42E-02	S	1.98E+00	W	5.25E-03	S	6.48E-02	S
4.6	3.28E-02	S	1.94E+00	W	4.83E-03	S	6.19E-02	S
4.8	3.15E-02	S	1.91E+00	W	4.45E-03	S	5.91E-02	S
5	3.04E-02	S	1.87E+00	W	4.12E-03	S	5.66E-02	S
5.2	2.93E-02	S	1.84E+00	W	3.82E-03	S	5.43E-02	S
5.4	2.83E-02	S	1.82E+00	W	3.48E-03	S	5.02E-02	S
5.6	2.74E-02	S	1.81E+00	W	3.12E-03	S	4.48E-02	S
5.8	2.72E-02	S	1.80E+00	W	2.61E-03	S	3.59E-02	S
6	2.78E-02	S	1.77E+00	W	2.05E-03	S	2.60E-02	S
6.2	2.83E-02	S	1.75E+00	W	1.63E-03	S	1.90E-02	S
6.4	3.25E-02	S	1.70E+00	W	1.14E-03	S	1.01E-02	S
6.6	3.71E-02	S	1.65E+00	W	8.02E-04	S	5.48E-03	S
6.8	3.46E-02	S	1.67E+00	W	9.00E-04	S	6.40E-03	S
7	4.60E-02	S	1.67E+00	W	8.98E-04	S	4.58E-03	S
7.2	7.54E-02	S	1.64E+00	W	7.46E-04	S	2.38E-03	S
7.4	8.89E-02	S	1.64E+00	W	7.46E-04	S	2.21E-03	S
7.6	1.04E-01	S	1.64E+00	W	7.46E-04	S	2.06E-03	S
7.8	1.29E-01	S	1.64E+00	W	7.46E-04	S	2.06E-03	S
8	1.58E-01	S	1.64E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID	GFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	1.92E-01	S	1.65E+00	W	7.46E-04	W	2.06E-03	S
8.4	2.34E-01	S	1.65E+00	W	7.46E-04	W	2.06E-03	S
8.6	2.96E-01	S	1.65E+00	W	7.46E-04	W	2.06E-03	S
8.8	4.07E-01	S	1.66E+00	W	7.46E-04	W	2.06E-03	S
9	5.54E-01	S	1.68E+00	W	7.46E-04	W	2.06E-03	S
9.2	7.49E-01	S	1.69E+00	W	7.46E-04	W	2.06E-03	S
9.4	8.50E-01	S	1.73E+00	W	7.87E-04	W	2.06E-03	S
9.6	9.62E-01	S	1.76E+00	W	8.28E-04	W	2.06E-03	S
9.8	1.09E+00	S	1.79E+00	W	8.71E-04	W	2.06E-03	S
10	1.14E+00	S	1.83E+00	W	9.60E-04	W	2.06E-03	S
10.2	1.21E+00	S	1.86E+00	W	1.06E-03	W	2.06E-03	S
10.4	1.27E+00	S	1.90E+00	W	1.16E-03	W	2.06E-03	S
10.6	1.33E+00	S	1.94E+00	W	1.27E-03	W	2.06E-03	S
10.8	1.40E+00	S	1.97E+00	W	1.39E-03	W	2.06E-03	S
11	1.47E+00	S	2.01E+00	W	1.52E-03	W	2.06E-03	S
11.2	1.54E+00	S	2.01E+00	W	1.59E-03	W	2.06E-03	S
11.4	1.62E+00	S	2.02E+00	W	1.66E-03	W	2.06E-03	S
11.6	1.70E+00	S	2.02E+00	W	1.69E-03	W	2.06E-03	S
11.8	1.77E+00	S	2.04E+00	W	1.67E-03	W	2.06E-03	S
12	1.77E+00	S	2.05E+00	W	1.66E-03	W	2.06E-03	S
12.2	1.77E+00	S	2.06E+00	W	1.64E-03	W	2.06E-03	S
12.4	1.77E+00	S	2.07E+00	W	1.62E-03	W	2.06E-03	S
12.6	1.77E+00	S	2.08E+00	W	1.61E-03	W	2.06E-03	S
12.8	1.77E+00	S	2.09E+00	W	1.59E-03	W	2.06E-03	S
13	1.77E+00	S	2.10E+00	W	1.58E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.81E+01		3.03E+01		7.30E-02		1.11E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.17E-01	S	1.76E-05	S	3.80E-01	S	2.74E-02	S
3	3.06E-01	S	1.36E-05	S	3.80E-01	S	1.54E-02	S
3.2	2.83E-01	S	1.07E-05	S	3.80E-01	S	8.97E-03	S
3.4	2.53E-01	S	9.41E-06	S	3.80E-01	S	5.40E-03	S
3.6	1.88E-01	S	7.06E-06	S	3.80E-01	S	4.73E-03	S
3.8	7.83E-02	S	8.97E-06	S	3.80E-01	S	7.99E-03	S
4	3.41E-02	S	1.06E-05	S	3.80E-01	S	1.32E-02	S
4.2	1.55E-02	S	1.27E-05	S	3.80E-01	S	2.11E-02	S
4.4	8.62E-03	S	1.56E-05	S	3.80E-01	S	3.03E-02	S
4.6	6.90E-03	S	2.13E-05	S	3.80E-01	S	3.32E-02	S
4.8	5.59E-03	S	2.88E-05	S	3.80E-01	S	3.62E-02	S
5	4.56E-03	S	3.85E-05	S	3.80E-01	S	3.94E-02	S
5.2	3.75E-03	S	5.08E-05	S	3.80E-01	S	4.28E-02	S
5.4	3.36E-03	S	5.20E-05	S	4.01E-01	S	4.37E-02	S
5.6	3.27E-03	S	4.20E-05	S	4.47E-01	S	4.21E-02	S
5.8	3.37E-03	S	3.32E-05	S	5.25E-01	S	3.82E-02	S
6	3.65E-03	S	2.57E-05	S	6.48E-01	S	3.26E-02	S
6.2	3.95E-03	S	2.01E-05	S	7.95E-01	S	2.80E-02	S
6.4	7.18E-03	S	2.25E-05	S	8.95E-01	S	2.52E-02	S
6.6	1.28E-02	S	2.51E-05	S	1.00E+00	S	2.27E-02	S
6.8	1.25E-02	S	2.99E-05	S	1.02E+00	S	2.17E-02	S
7	1.65E-02	S	3.06E-05	S	1.03E+00	S	2.07E-02	S
7.2	2.54E-02	S	2.71E-05	S	1.09E+00	W	2.10E-02	S
7.4	2.84E-02	S	2.83E-05	S	1.10E+00	W	2.27E-02	S
7.6	3.16E-02	S	2.96E-05	S	1.11E+00	W	2.44E-02	S
7.8	3.29E-02	S	2.53E-05	S	1.12E+00	W	2.91E-02	S
8	3.43E-02	S	2.18E-05	S	1.13E+00	W	3.47E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.56E-02	S	1.88E-05	S	1.15E+00	W	4.11E-02	S
8.4	3.70E-02	S	1.63E-05	S	1.16E+00	W	4.85E-02	S
8.6	3.96E-02	S	1.61E-05	S	1.17E+00	W	5.45E-02	S
8.8	4.34E-02	S	1.72E-05	S	1.16E+00	W	5.82E-02	S
9	4.75E-02	S	1.83E-05	S	1.16E+00	W	6.21E-02	S
9.2	5.19E-02	S	1.95E-05	S	1.16E+00	W	6.61E-02	S
9.4	5.37E-02	S	2.07E-05	S	1.17E+00	W	7.03E-02	S
9.6	5.56E-02	S	2.20E-05	S	1.17E+00	W	7.47E-02	S
9.8	5.75E-02	S	2.33E-05	S	1.17E+00	W	7.93E-02	S
10	5.92E-02	S	2.50E-05	S	1.17E+00	W	8.14E-02	S
10.2	6.09E-02	S	2.67E-05	S	1.18E+00	W	8.36E-02	S
10.4	6.26E-02	S	2.86E-05	S	1.18E+00	W	8.58E-02	S
10.6	6.44E-02	S	3.05E-05	S	1.18E+00	W	8.80E-02	S
10.8	6.61E-02	S	3.26E-05	S	1.19E+00	W	9.03E-02	S
11	6.79E-02	S	3.47E-05	S	1.19E+00	W	9.25E-02	S
11.2	7.09E-02	S	2.87E-05	S	1.19E+00	W	9.41E-02	S
11.4	7.40E-02	S	2.38E-05	S	1.19E+00	W	9.58E-02	S
11.6	8.07E-02	S	2.27E-05	S	1.20E+00	W	9.71E-02	S
11.8	9.20E-02	S	2.48E-05	S	1.23E+00	W	9.81E-02	S
12	1.05E-01	S	2.41E-05	S	1.22E+00	W	9.81E-02	S
12.2	1.19E-01	S	2.05E-05	S	1.22E+00	W	9.81E-02	S
12.4	1.34E-01	S	1.75E-05	S	1.22E+00	W	9.81E-02	S
12.6	1.52E-01	S	1.50E-05	S	1.22E+00	W	9.81E-02	S
12.8	1.71E-01	S	1.29E-05	S	1.22E+00	W	9.81E-02	S
13	1.93E-01	S	1.26E-05	S	1.21E+00	W	9.81E-02	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.17E+00		5.22E-04		1.26E+01		1.01E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.50E-01	S	5.92E-02	S	9.73E-01	S
3	1.54E-01	S	4.85E-02	S	6.90E-01	S
3.2	9.81E-02	S	3.20E-02	S	3.14E-01	S
3.4	6.41E-02	S	1.73E-02	S	1.10E-01	S
3.6	5.02E-02	S	1.27E-02	S	5.34E-02	S
3.8	5.32E-02	S	1.66E-02	S	3.77E-02	S
4	5.61E-02	S	2.15E-02	S	2.70E-02	S
4.2	5.90E-02	S	2.75E-02	S	1.97E-02	S
4.4	6.28E-02	S	3.24E-02	S	1.61E-02	S
4.6	7.11E-02	S	2.84E-02	S	1.83E-02	S
4.8	8.02E-02	S	2.50E-02	S	2.07E-02	S
5	8.99E-02	S	2.22E-02	S	2.32E-02	S
5.2	1.00E-01	S	1.97E-02	S	2.60E-02	S
5.4	1.13E-01	S	1.66E-02	S	2.92E-02	S
5.6	1.28E-01	S	1.32E-02	S	3.29E-02	S
5.8	1.50E-01	S	9.52E-03	S	3.84E-02	S
6	1.81E-01	S	6.27E-03	S	4.65E-02	S
6.2	2.18E-01	S	4.19E-03	S	5.59E-02	S
6.4	2.72E-01	S	3.41E-03	S	6.44E-02	S
6.6	3.36E-01	S	2.79E-03	S	7.39E-02	S
6.8	3.31E-01	S	2.53E-03	S	7.21E-02	S
7	3.77E-01	S	2.53E-03	S	7.91E-02	S
7.2	4.82E-01	S	2.53E-03	S	9.96E-02	S
7.4	5.15E-01	S	2.53E-03	S	1.09E-01	S
7.6	5.51E-01	S	2.53E-03	S	1.19E-01	S
7.8	5.90E-01	S	2.53E-03	S	1.39E-01	S
8	6.32E-01	S	2.53E-03	S	1.62E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-18. Leachate Concentrations for Bituminous Fly Ash, Waste ID GFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	6.75E-01	S	2.53E-03	S	1.88E-01	S
8.4	7.20E-01	S	2.53E-03	S	2.17E-01	S
8.6	7.73E-01	S	2.53E-03	S	2.62E-01	S
8.8	8.32E-01	S	2.53E-03	S	3.45E-01	S
9	8.94E-01	S	2.53E-03	S	4.51E-01	S
9.2	9.59E-01	W	2.53E-03	S	5.86E-01	S
9.4	9.85E-01	W	2.53E-03	S	6.56E-01	S
9.6	1.01E+00	W	2.53E-03	S	7.32E-01	S
9.8	1.04E+00	W	2.53E-03	S	8.16E-01	S
10	1.05E+00	W	2.53E-03	S	8.60E-01	S
10.2	1.06E+00	W	2.53E-03	S	9.05E-01	S
10.4	1.07E+00	W	2.53E-03	S	9.52E-01	S
10.6	1.08E+00	W	2.53E-03	S	1.00E+00	S
10.8	1.09E+00	W	2.53E-03	S	1.05E+00	S
11	1.10E+00	W	2.53E-03	S	1.10E+00	S
11.2	1.11E+00	W	2.53E-03	S	1.14E+00	S
11.4	1.13E+00	W	2.53E-03	S	1.17E+00	S
11.6	1.17E+00	W	2.53E-03	S	1.20E+00	S
11.8	1.24E+00	W	2.53E-03	S	1.22E+00	S
12	1.24E+00	W	2.53E-03	S	1.22E+00	S
12.2	1.24E+00	W	2.53E-03	S	1.22E+00	S
12.4	1.24E+00	W	2.53E-03	S	1.22E+00	S
12.6	1.24E+00	W	2.53E-03	S	1.22E+00	S
12.8	1.24E+00	W	2.53E-03	S	1.22E+00	S
13	1.24E+00	W	2.53E-03	S	1.22E+00	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.27E+01		5.92E-01		1.25E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID	HFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.10E+00	S	3.22E+01	W	2.53E-01	W	8.37E-02	W
3	1.04E+00	S	3.15E+01	W	2.51E-01	W	8.24E-02	W
3.2	9.77E-01	S	3.08E+01	W	2.49E-01	W	8.11E-02	W
3.4	9.24E-01	S	3.02E+01	W	2.47E-01	W	8.00E-02	W
3.6	8.78E-01	S	2.97E+01	W	2.45E-01	W	7.90E-02	W
3.8	8.36E-01	S	2.91E+01	W	2.44E-01	W	7.80E-02	W
4	7.98E-01	S	2.87E+01	W	2.42E-01	S	7.71E-02	W
4.2	4.90E-01	S	2.71E+01	W	2.33E-01	S	7.20E-02	W
4.4	3.65E-01	S	2.60E+01	W	2.28E-01	S	6.85E-02	W
4.6	3.33E-01	S	2.57E+01	W	2.26E-01	S	6.68E-02	W
4.8	3.02E-01	S	2.60E+01	W	2.06E-01	S	6.08E-02	W
5	2.61E-01	S	2.61E+01	W	1.60E-01	S	4.72E-02	S
5.2	2.23E-01	S	2.59E+01	W	1.16E-01	S	3.41E-02	S
5.4	1.91E-01	S	2.57E+01	W	8.52E-02	S	2.50E-02	S
5.6	1.65E-01	S	2.55E+01	W	6.32E-02	S	1.85E-02	S
5.8	1.43E-01	S	2.53E+01	W	4.74E-02	S	1.38E-02	S
6	1.25E-01	S	2.52E+01	W	3.59E-02	S	1.04E-02	S
6.2	1.09E-01	S	2.50E+01	W	2.74E-02	S	7.97E-03	S
6.4	9.60E-02	S	2.48E+01	W	2.11E-02	S	6.12E-03	S
6.6	8.48E-02	S	2.47E+01	W	1.64E-02	S	4.75E-03	S
6.8	7.51E-02	S	2.45E+01	W	1.28E-02	S	3.71E-03	S
7	6.68E-02	S	2.44E+01	W	1.01E-02	S	2.92E-03	S
7.2	5.96E-02	S	2.43E+01	W	8.03E-03	S	2.31E-03	S
7.4	5.43E-02	S	2.39E+01	W	7.10E-03	S	2.06E-03	S
7.6	5.04E-02	S	2.32E+01	W	6.96E-03	S	2.06E-03	S
7.8	4.69E-02	S	2.27E+01	W	6.82E-03	S	2.06E-03	S
8	4.38E-02	S	2.21E+01	W	6.69E-03	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID	HFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

8.2	4.09E-02	S	2.16E+01	W	6.57E-03	W	2.06E-03	S
8.4	3.83E-02	S	2.11E+01	W	6.45E-03	W	2.06E-03	S
8.6	3.62E-02	S	2.05E+01	W	6.37E-03	W	2.06E-03	S
8.8	3.55E-02	S	1.99E+01	W	6.55E-03	W	2.06E-03	S
9	3.48E-02	S	1.92E+01	W	6.73E-03	W	2.06E-03	S
9.2	3.41E-02	S	1.85E+01	W	6.84E-03	W	2.06E-03	S
9.4	3.42E-02	S	1.80E+01	W	6.87E-03	W	2.06E-03	S
9.6	3.49E-02	S	1.77E+01	W	6.91E-03	W	2.06E-03	S
9.8	3.79E-02	S	1.80E+01	W	6.96E-03	W	2.06E-03	S
10	4.21E-02	S	1.81E+01	W	7.09E-03	W	2.06E-03	S
10.2	4.66E-02	S	1.83E+01	W	7.22E-03	W	2.06E-03	S
10.4	4.97E-02	S	1.80E+01	W	7.24E-03	W	2.06E-03	S
10.6	5.30E-02	S	1.75E+01	W	7.31E-03	W	2.06E-03	S
10.8	5.63E-02	S	1.71E+01	W	7.38E-03	W	2.06E-03	S
11	5.98E-02	S	1.66E+01	W	7.45E-03	W	2.06E-03	S
11.2	6.35E-02	S	1.62E+01	W	7.52E-03	W	2.06E-03	S
11.4	6.73E-02	S	1.58E+01	W	7.58E-03	W	2.06E-03	S
11.6	7.13E-02	S	1.55E+01	W	7.65E-03	W	2.06E-03	S
11.8	7.54E-02	S	1.51E+01	W	7.71E-03	W	2.06E-03	S
12	7.97E-02	S	1.48E+01	W	7.78E-03	W	2.06E-03	S
12.2	8.42E-02	S	1.44E+01	W	7.84E-03	W	2.06E-03	S
12.4	8.89E-02	S	1.41E+01	W	7.91E-03	W	2.06E-03	S
12.6	9.37E-02	S	1.38E+01	W	7.97E-03	W	2.06E-03	S
12.8	9.87E-02	S	1.35E+01	W	8.03E-03	W	2.06E-03	S
13	1.04E-01	S	1.32E+01	W	8.10E-03	W	2.06E-03	S
tection Limit (min, mg/	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
tection Limit (max, mg/	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.10E+01		3.22E+02		2.53E+00		8.37E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	9.47E-01	S	9.85E-06	S	3.57E-01	S	1.69E-02	S
3	7.23E-01	S	9.74E-06	S	2.82E-01	S	1.81E-02	S
3.2	5.61E-01	S	9.63E-06	S	2.26E-01	S	1.93E-02	S
3.4	4.43E-01	S	9.54E-06	S	1.83E-01	S	2.06E-02	S
3.6	3.54E-01	S	9.45E-06	S	1.50E-01	S	2.18E-02	S
3.8	2.87E-01	S	9.36E-06	S	1.25E-01	S	2.30E-02	S
4	2.34E-01	S	7.71E-06	S	1.05E-01	S	2.43E-02	S
4.2	3.40E-02	S	8.88E-06	S	7.86E-02	S	2.33E-02	S
4.4	9.11E-03	S	8.84E-06	S	7.01E-02	S	2.32E-02	S
4.6	5.74E-03	S	9.14E-06	S	8.26E-02	S	2.32E-02	S
4.8	5.07E-03	S	9.31E-06	S	1.05E-01	S	2.22E-02	S
5	4.98E-03	S	9.36E-06	S	1.22E-01	S	2.19E-02	S
5.2	5.24E-03	S	9.41E-06	S	1.37E-01	S	2.23E-02	S
5.4	5.50E-03	S	9.46E-06	S	1.54E-01	S	2.26E-02	S
5.6	5.77E-03	S	9.50E-06	S	1.72E-01	S	2.30E-02	S
5.8	6.03E-03	S	9.55E-06	S	1.91E-01	S	2.33E-02	S
6	6.30E-03	S	9.59E-06	S	2.11E-01	S	2.36E-02	S
6.2	6.58E-03	S	9.64E-06	S	2.33E-01	S	2.39E-02	S
6.4	6.85E-03	S	9.68E-06	S	2.56E-01	S	2.42E-02	S
6.6	7.13E-03	S	9.72E-06	S	2.81E-01	S	2.45E-02	S
6.8	7.41E-03	S	9.75E-06	S	3.07E-01	S	2.48E-02	S
7	7.69E-03	S	9.79E-06	S	3.35E-01	S	2.51E-02	S
7.2	7.97E-03	S	9.83E-06	S	3.64E-01	W	2.54E-02	S
7.4	8.79E-03	S	9.89E-06	S	3.80E-01	W	2.63E-02	S
7.6	1.03E-02	S	9.98E-06	S	3.80E-01	W	2.79E-02	S
7.8	1.19E-02	S	1.01E-05	S	3.80E-01	W	2.95E-02	S
8	1.38E-02	S	1.01E-05	S	3.80E-01	W	3.12E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

8.2	1.60E-02	S	1.02E-05	S	3.80E-01	W	3.29E-02	S
8.4	1.84E-02	S	1.03E-05	S	3.80E-01	W	3.47E-02	S
8.6	2.14E-02	S	1.04E-05	S	3.80E-01	W	3.45E-02	S
8.8	2.67E-02	S	9.65E-06	S	3.80E-01	W	3.40E-02	S
9	3.31E-02	S	8.99E-06	S	3.80E-01	W	3.36E-02	S
9.2	3.91E-02	S	8.80E-06	S	3.80E-01	W	3.74E-02	S
9.4	4.31E-02	S	9.04E-06	S	3.80E-01	W	3.94E-02	S
9.6	4.67E-02	S	9.28E-06	S	3.80E-01	W	3.51E-02	S
9.8	5.21E-02	S	9.28E-06	S	3.80E-01	W	3.33E-02	S
10	5.84E-02	S	9.28E-06	S	3.80E-01	W	4.22E-02	S
10.2	6.54E-02	S	7.71E-06	S	3.80E-01	W	5.33E-02	S
10.4	6.97E-02	S	9.41E-06	S	3.80E-01	W	4.88E-02	S
10.6	7.33E-02	S	9.65E-06	S	3.80E-01	W	4.35E-02	S
10.8	7.70E-02	S	9.89E-06	S	3.80E-01	W	3.89E-02	S
11	8.08E-02	S	1.01E-05	S	3.80E-01	W	3.49E-02	S
11.2	8.48E-02	S	1.04E-05	S	3.80E-01	W	3.13E-02	S
11.4	8.88E-02	S	1.06E-05	S	3.80E-01	W	2.82E-02	S
11.6	9.30E-02	S	9.04E-06	S	3.80E-01	W	2.54E-02	S
11.8	9.72E-02	S	1.11E-05	S	3.80E-01	W	2.29E-02	S
12	1.02E-01	S	1.14E-05	S	3.80E-01	W	2.07E-02	S
12.2	1.06E-01	S	1.14E-05	S	3.80E-01	W	1.88E-02	S
12.4	1.11E-01	S	1.14E-05	S	3.80E-01	W	1.71E-02	S
12.6	1.16E-01	S	1.14E-05	S	3.80E-01	W	1.55E-02	S
12.8	1.20E-01	S	1.14E-05	S	3.80E-01	W	1.41E-02	S
13	1.25E-01	S	1.14E-05	S	3.80E-01	W	1.29E-02	S
tection Limit (min, mg/	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
tection Limit (max, mg/	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	9.47E+00		1.19E-04		3.98E+00		5.47E-01	

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Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.01E-02	S	3.89E-02	S	1.12E+00	S
3	2.08E-02	S	6.07E-02	S	5.91E-01	S
3.2	2.14E-02	S	9.20E-02	S	3.26E-01	S
3.4	2.20E-02	S	1.36E-01	S	1.87E-01	S
3.6	2.25E-02	S	1.97E-01	S	1.10E-01	S
3.8	2.31E-02	S	2.79E-01	S	6.70E-02	S
4	2.36E-02	S	3.88E-01	S	4.18E-02	S
4.2	1.69E-02	S	3.31E-01	S	9.80E-03	S
4.4	1.39E-02	S	2.91E-01	S	4.84E-03	S
4.6	1.33E-02	S	2.52E-01	S	4.92E-03	S
4.8	1.31E-02	S	2.12E-01	S	4.60E-03	S
5	1.29E-02	S	1.77E-01	S	4.61E-03	S
5.2	1.24E-02	S	1.47E-01	S	5.50E-03	S
5.4	1.20E-02	S	1.23E-01	S	6.50E-03	S
5.6	1.16E-02	S	1.03E-01	S	7.65E-03	S
5.8	1.13E-02	S	8.76E-02	S	8.94E-03	S
6	1.09E-02	S	7.46E-02	S	1.04E-02	S
6.2	1.06E-02	S	6.38E-02	S	1.20E-02	S
6.4	1.03E-02	S	5.49E-02	S	1.39E-02	S
6.6	1.00E-02	S	4.75E-02	S	1.59E-02	S
6.8	9.74E-03	S	4.12E-02	S	1.82E-02	S
7	9.49E-03	S	3.59E-02	S	2.07E-02	S
7.2	9.25E-03	S	3.14E-02	S	2.35E-02	S
7.4	9.67E-03	S	2.94E-02	S	2.57E-02	S
7.6	1.08E-02	S	2.92E-02	S	2.71E-02	S
7.8	1.21E-02	S	2.91E-02	S	2.87E-02	S
8	1.34E-02	S	2.90E-02	S	3.02E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-19. Leachate Concentrations for Bituminous Fly Ash, Waste ID HFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

8.2	1.49E-02	S	2.88E-02	S	3.18E-02	S
8.4	1.65E-02	S	2.87E-02	S	3.35E-02	S
8.6	1.88E-02	S	2.69E-02	S	3.55E-02	S
8.8	2.40E-02	S	2.61E-02	S	3.88E-02	S
9	3.06E-02	S	2.53E-02	S	4.23E-02	S
9.2	3.75E-02	S	2.78E-02	S	4.56E-02	S
9.4	4.38E-02	S	2.96E-02	S	5.01E-02	S
9.6	5.06E-02	S	2.72E-02	S	5.65E-02	S
9.8	5.79E-02	S	2.52E-02	S	6.68E-02	S
10	6.61E-02	S	3.08E-02	S	7.93E-02	S
10.2	7.52E-02	S	3.75E-02	S	9.37E-02	S
10.4	8.11E-02	S	3.61E-02	S	1.06E-01	S
10.6	8.65E-02	S	3.52E-02	S	1.19E-01	S
10.8	9.22E-02	S	3.43E-02	S	1.33E-01	S
11	9.82E-02	S	3.35E-02	S	1.48E-01	S
11.2	1.04E-01	S	3.27E-02	S	1.65E-01	S
11.4	1.11E-01	S	3.19E-02	S	1.84E-01	S
11.6	1.18E-01	S	3.12E-02	S	2.04E-01	S
11.8	1.18E-01	S	3.05E-02	S	2.26E-01	S
12	1.18E-01	S	2.98E-02	S	2.51E-01	S
12.2	1.18E-01	S	2.91E-02	S	2.77E-01	S
12.4	1.18E-01	S	2.85E-02	S	3.05E-01	S
12.6	1.18E-01	S	2.79E-02	S	3.36E-01	S
12.8	1.18E-01	S	2.73E-02	S	3.70E-01	S
13	1.18E-01	S	2.67E-02	S	4.06E-01	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg/	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.24E+00		3.88E+00		1.12E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID	KFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.34E+00	S	5.62E+01	W	2.65E-02	W	7.84E-02	S
3	1.19E+00	S	5.45E+01	W	2.58E-02	W	7.25E-02	S
3.2	1.06E+00	S	5.29E+01	W	2.52E-02	W	6.74E-02	S
3.4	9.53E-01	S	5.15E+01	W	2.46E-02	W	6.29E-02	S
3.6	8.61E-01	S	5.02E+01	W	2.41E-02	W	5.89E-02	S
3.8	7.82E-01	S	4.90E+01	W	2.36E-02	W	5.54E-02	S
4	6.16E-01	S	4.71E+01	W	2.33E-02	S	5.23E-02	S
4.2	4.31E-01	S	4.47E+01	W	2.25E-02	S	4.91E-02	S
4.4	3.06E-01	S	4.27E+01	W	2.12E-02	S	4.62E-02	S
4.6	2.32E-01	S	4.16E+01	W	1.76E-02	S	4.20E-02	S
4.8	1.89E-01	S	4.12E+01	W	1.44E-02	S	3.49E-02	S
5	1.64E-01	S	4.10E+01	W	1.22E-02	S	1.07E-02	S
5.2	1.52E-01	S	4.08E+01	W	1.05E-02	S	5.88E-03	S
5.4	1.41E-01	S	4.07E+01	W	9.10E-03	S	5.13E-03	S
5.6	1.32E-01	S	4.05E+01	W	7.93E-03	S	4.50E-03	S
5.8	1.24E-01	S	4.04E+01	W	6.94E-03	S	3.96E-03	S
6	1.17E-01	S	4.03E+01	W	6.10E-03	S	3.51E-03	S
6.2	1.13E-01	W	3.99E+01	W	4.65E-03	S	3.11E-03	S
6.4	1.14E-01	W	3.93E+01	W	3.10E-03	S	2.78E-03	S
6.6	1.14E-01	W	3.87E+01	W	2.09E-03	S	2.49E-03	S
6.8	1.14E-01	W	3.81E+01	W	1.43E-03	S	2.23E-03	S
7	1.13E-01	W	3.76E+01	W	1.06E-03	S	2.06E-03	S
7.2	1.11E-01	W	3.73E+01	W	9.86E-04	S	2.06E-03	S
7.4	1.09E-01	W	3.70E+01	W	9.18E-04	S	2.06E-03	S
7.6	1.07E-01	W	3.67E+01	W	8.56E-04	S	2.06E-03	S
7.8	1.05E-01	W	3.64E+01	W	8.00E-04	S	2.06E-03	S
8	1.03E-01	W	3.62E+01	W	7.49E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID	KFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	9.83E-02	W	3.57E+01	W	7.46E-04	W	2.06E-03	S
8.4	9.08E-02	W	3.49E+01	W	7.46E-04	W	2.06E-03	S
8.6	8.40E-02	W	3.42E+01	W	7.46E-04	W	2.06E-03	S
8.8	7.79E-02	W	3.36E+01	W	7.46E-04	W	2.06E-03	S
9	7.24E-02	W	3.29E+01	W	7.46E-04	W	2.06E-03	S
9.2	6.83E-02	W	3.25E+01	W	7.46E-04	W	2.06E-03	S
9.4	6.80E-02	W	3.28E+01	W	7.46E-04	W	2.06E-03	S
9.6	6.91E-02	W	3.32E+01	W	7.46E-04	W	2.06E-03	S
9.8	7.27E-02	W	3.31E+01	W	7.46E-04	W	2.06E-03	S
10	7.76E-02	W	3.28E+01	W	7.46E-04	W	2.06E-03	S
10.2	8.09E-02	W	3.28E+01	W	7.46E-04	W	2.06E-03	S
10.4	8.16E-02	W	3.30E+01	W	7.46E-04	W	2.06E-03	S
10.6	8.09E-02	W	3.27E+01	W	7.46E-04	W	2.06E-03	S
10.8	8.06E-02	W	3.20E+01	W	7.46E-04	W	2.06E-03	S
11	8.03E-02	W	3.14E+01	W	7.46E-04	W	2.06E-03	S
11.2	8.00E-02	W	3.09E+01	W	7.46E-04	W	2.06E-03	S
11.4	7.97E-02	W	3.03E+01	W	7.46E-04	W	2.06E-03	S
11.6	7.94E-02	W	2.97E+01	W	7.46E-04	W	2.06E-03	S
11.8	7.91E-02	W	2.92E+01	W	7.46E-04	W	2.06E-03	S
12	7.89E-02	W	2.87E+01	W	7.46E-04	W	2.06E-03	S
12.2	7.86E-02	W	2.82E+01	W	7.46E-04	W	2.06E-03	S
12.4	7.84E-02	W	2.77E+01	W	7.46E-04	W	2.06E-03	S
12.6	7.81E-02	W	2.73E+01	W	7.46E-04	W	2.06E-03	S
12.8	7.79E-02	W	2.68E+01	W	7.46E-04	W	2.06E-03	S
13	7.76E-02	W	2.64E+01	W	7.46E-04	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.34E+01		5.62E+02		2.65E-01		7.84E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.14E+00	S	9.11E-05	S	9.45E-02	S	1.81E-02	S
3	6.93E-01	S	6.74E-05	S	8.78E-02	S	1.59E-02	S
3.2	4.36E-01	S	5.08E-05	S	8.20E-02	S	1.40E-02	S
3.4	2.82E-01	S	3.90E-05	S	7.68E-02	S	1.25E-02	S
3.6	1.87E-01	S	3.04E-05	S	7.23E-02	S	1.12E-02	S
3.8	1.27E-01	S	2.40E-05	S	6.83E-02	S	1.01E-02	S
4	5.09E-02	S	2.33E-05	S	6.46E-02	S	1.02E-02	S
4.2	1.17E-02	S	2.60E-05	S	6.08E-02	S	1.13E-02	S
4.4	3.22E-03	S	2.87E-05	S	6.52E-02	S	1.27E-02	S
4.6	1.90E-03	S	2.89E-05	S	1.23E-01	S	1.52E-02	S
4.8	1.90E-03	S	2.63E-05	S	2.75E-01	S	1.82E-02	S
5	2.86E-03	S	2.48E-05	S	4.45E-01	S	2.25E-02	S
5.2	3.51E-03	S	2.43E-05	S	5.62E-01	S	2.47E-02	S
5.4	3.61E-03	S	2.39E-05	S	7.03E-01	S	2.59E-02	S
5.6	3.72E-03	S	2.36E-05	S	8.72E-01	S	2.70E-02	S
5.8	3.82E-03	S	2.32E-05	S	1.07E+00	S	2.81E-02	S
6	3.92E-03	S	2.29E-05	S	1.31E+00	S	2.92E-02	S
6.2	4.28E-03	S	2.31E-05	S	1.51E+00	S	3.04E-02	S
6.4	4.97E-03	S	2.37E-05	S	1.65E+00	S	3.17E-02	S
6.6	5.73E-03	S	2.44E-05	S	1.80E+00	S	3.30E-02	S
6.8	6.59E-03	S	2.50E-05	S	1.96E+00	S	3.43E-02	S
7	7.47E-03	S	2.54E-05	S	2.09E+00	S	3.53E-02	S
7.2	8.20E-03	S	2.51E-05	S	2.14E+00	W	3.53E-02	S
7.4	8.98E-03	S	2.47E-05	S	2.18E+00	W	3.52E-02	S
7.6	9.81E-03	S	2.44E-05	S	2.23E+00	W	3.52E-02	S
7.8	1.07E-02	S	2.40E-05	S	2.28E+00	W	3.52E-02	S
8	1.16E-02	S	2.37E-05	S	2.32E+00	W	3.52E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.30E-02	S	2.33E-05	S	2.34E+00	W	3.47E-02	S
8.4	1.46E-02	S	2.33E-05	S	2.33E+00	W	3.37E-02	S
8.6	1.62E-02	S	2.33E-05	S	2.32E+00	W	3.26E-02	S
8.8	1.80E-02	S	2.33E-05	S	2.31E+00	W	3.17E-02	S
9	1.99E-02	S	2.33E-05	S	2.30E+00	W	3.08E-02	S
9.2	2.19E-02	W	2.62E-05	S	2.30E+00	W	3.01E-02	S
9.4	2.39E-02	W	3.63E-05	S	2.33E+00	W	3.00E-02	S
9.6	2.30E-02	W	3.03E-05	S	2.40E+00	W	2.98E-02	S
9.8	2.00E-02	W	2.30E-05	S	2.45E+00	W	2.90E-02	S
10	2.08E-02	W	2.51E-05	S	2.47E+00	W	2.79E-02	S
10.2	2.30E-02	W	2.85E-05	S	2.51E+00	W	2.68E-02	S
10.4	2.67E-02	W	3.36E-05	S	2.56E+00	W	2.55E-02	S
10.6	2.82E-02	W	3.80E-05	S	2.58E+00	W	2.37E-02	S
10.8	2.80E-02	W	3.61E-05	S	2.58E+00	W	2.17E-02	S
11	2.78E-02	W	3.43E-05	S	2.57E+00	W	1.99E-02	S
11.2	2.76E-02	W	3.26E-05	S	2.56E+00	W	1.83E-02	S
11.4	2.74E-02	W	3.11E-05	S	2.56E+00	W	1.68E-02	S
11.6	2.72E-02	W	2.96E-05	S	2.55E+00	W	1.55E-02	S
11.8	2.70E-02	W	2.83E-05	S	2.54E+00	W	1.43E-02	S
12	2.69E-02	W	2.70E-05	S	2.54E+00	W	1.32E-02	S
12.2	2.67E-02	W	2.58E-05	S	2.53E+00	W	1.22E-02	S
12.4	2.65E-02	W	2.47E-05	S	2.52E+00	W	1.13E-02	S
12.6	2.64E-02	W	2.36E-05	S	2.52E+00	W	1.05E-02	S
12.8	2.62E-02	W	2.26E-05	S	2.51E+00	W	9.78E-03	S
13	2.60E-02	W	2.17E-05	S	2.51E+00	W	9.09E-03	S
tection Limit (min, mg	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
tection Limit (max, mg	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.14E+01		9.11E-04		2.68E+01		3.53E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.22E-02	S	1.03E+00	S	1.27E-01	S
3	2.00E-02	S	9.51E-01	S	8.96E-02	S
3.2	1.82E-02	S	8.85E-01	S	6.46E-02	S
3.4	1.67E-02	S	8.27E-01	S	4.75E-02	S
3.6	1.53E-02	S	7.76E-01	S	3.56E-02	S
3.8	1.41E-02	S	7.31E-01	S	2.71E-02	S
4	1.32E-02	S	6.83E-01	S	1.70E-02	S
4.2	1.23E-02	S	6.25E-01	S	9.79E-03	S
4.4	1.18E-02	S	5.59E-01	S	6.32E-03	S
4.6	1.27E-02	S	4.52E-01	S	6.37E-03	S
4.8	1.42E-02	S	3.65E-01	S	7.83E-03	S
5	2.03E-02	S	2.27E-01	S	1.34E-02	S
5.2	2.43E-02	S	1.81E-01	S	1.72E-02	S
5.4	2.56E-02	S	1.69E-01	S	1.84E-02	S
5.6	2.69E-02	S	1.58E-01	S	1.96E-02	S
5.8	2.82E-02	S	1.48E-01	S	2.08E-02	S
6	2.95E-02	S	1.39E-01	S	2.21E-02	S
6.2	3.22E-02	S	1.24E-01	S	2.44E-02	S
6.4	3.66E-02	S	1.07E-01	S	2.81E-02	S
6.6	4.14E-02	S	9.20E-02	S	3.22E-02	S
6.8	4.67E-02	S	7.97E-02	S	3.67E-02	S
7	5.20E-02	S	7.08E-02	S	4.08E-02	S
7.2	5.61E-02	S	6.73E-02	S	4.22E-02	S
7.4	6.05E-02	S	6.41E-02	S	4.36E-02	S
7.6	6.51E-02	S	6.12E-02	S	4.50E-02	S
7.8	6.99E-02	S	5.84E-02	S	4.64E-02	S
8	7.49E-02	S	5.58E-02	S	4.78E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-20. Leachate Concentrations for Bituminous Fly Ash, Waste ID KFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	8.28E-02	S	5.27E-02	S	5.03E-02	S
8.4	9.02E-02	S	4.90E-02	S	5.28E-02	S
8.6	9.82E-02	S	4.57E-02	S	5.54E-02	S
8.8	1.07E-01	S	4.26E-02	S	5.81E-02	S
9	1.16E-01	S	3.99E-02	S	6.08E-02	S
9.2	1.25E-01	S	3.96E-02	S	6.35E-02	S
9.4	1.34E-01	S	4.65E-02	S	6.75E-02	S
9.6	1.42E-01	S	5.21E-02	S	7.23E-02	S
9.8	1.51E-01	S	5.68E-02	S	7.68E-02	S
10	1.57E-01	S	6.07E-02	S	9.18E-02	S
10.2	1.64E-01	W	6.37E-02	S	1.14E-01	S
10.4	1.71E-01	W	6.57E-02	S	1.43E-01	S
10.6	1.76E-01	W	6.87E-02	S	1.56E-01	S
10.8	1.82E-01	W	7.38E-02	S	1.55E-01	S
11	1.87E-01	W	7.92E-02	S	1.54E-01	S
11.2	1.93E-01	W	8.48E-02	S	1.53E-01	S
11.4	1.99E-01	W	9.07E-02	S	1.51E-01	S
11.6	2.05E-01	W	9.70E-02	S	1.50E-01	S
11.8	2.11E-01	W	1.04E-01	S	1.49E-01	S
12	2.13E-01	W	1.10E-01	S	1.48E-01	S
12.2	2.13E-01	W	1.18E-01	S	1.47E-01	S
12.4	2.13E-01	W	1.25E-01	S	1.46E-01	S
12.6	2.13E-01	W	1.33E-01	S	1.45E-01	S
12.8	2.13E-01	W	1.41E-01	S	1.44E-01	S
13	2.13E-01	W	1.50E-01	S	1.43E-01	S
tection Limit (min, mg	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.24E+00		1.03E+01		1.59E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID	LAB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	1.03E-01	S	1.27E+00	S	3.88E-03	S	2.31E-02	W
3	7.13E-02	S	1.22E+00	S	3.72E-03	S	2.21E-02	W
3.2	5.07E-02	S	1.17E+00	S	3.58E-03	S	2.13E-02	W
3.4	3.67E-02	S	1.12E+00	S	3.45E-03	S	2.05E-02	W
3.6	2.71E-02	S	1.08E+00	S	3.33E-03	S	1.99E-02	W
3.8	2.04E-02	S	1.05E+00	S	3.22E-03	S	1.92E-02	W
4	1.76E-02	S	9.65E-01	S	2.79E-03	S	1.90E-02	W
4.2	1.60E-02	S	8.79E-01	S	2.30E-03	S	1.87E-02	W
4.4	1.45E-02	S	8.05E-01	S	1.91E-03	S	1.85E-02	W
4.6	1.33E-02	S	7.40E-01	S	1.60E-03	S	1.82E-02	W
4.8	1.21E-02	S	6.82E-01	S	1.36E-03	S	1.80E-02	W
5	1.43E-02	S	6.24E-01	S	1.00E-03	S	1.35E-02	S
5.2	1.67E-02	S	5.74E-01	S	7.46E-04	S	1.03E-02	S
5.4	2.27E-02	S	5.68E-01	S	7.46E-04	S	7.33E-03	S
5.6	3.07E-02	S	5.63E-01	S	7.46E-04	S	5.28E-03	S
5.8	4.03E-02	S	5.59E-01	S	7.46E-04	S	4.30E-03	S
6	5.16E-02	S	5.57E-01	S	7.46E-04	S	3.94E-03	S
6.2	6.56E-02	S	5.55E-01	S	7.46E-04	S	3.62E-03	S
6.4	9.06E-02	S	5.44E-01	S	7.46E-04	S	3.12E-03	S
6.6	1.36E-01	S	5.24E-01	S	7.46E-04	S	2.53E-03	S
6.8	1.81E-01	S	5.18E-01	S	7.46E-04	S	2.06E-03	S
7	2.29E-01	S	5.20E-01	S	7.46E-04	S	2.06E-03	S
7.2	2.88E-01	S	5.22E-01	S	7.46E-04	S	2.06E-03	S
7.4	3.59E-01	S	5.24E-01	S	7.46E-04	S	2.06E-03	S
7.6	4.46E-01	S	5.26E-01	S	7.46E-04	S	2.06E-03	S
7.8	4.97E-01	S	5.36E-01	S	7.46E-04	S	2.06E-03	S
8	5.54E-01	S	5.46E-01	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID	LAB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	6.15E-01	S	5.57E-01	S	7.46E-04	W	2.06E-03	S
8.4	6.65E-01	S	5.58E-01	S	7.46E-04	W	2.06E-03	S
8.6	7.17E-01	S	5.59E-01	S	7.46E-04	W	2.06E-03	S
8.8	7.73E-01	S	5.60E-01	S	7.46E-04	W	2.06E-03	S
9	8.02E-01	S	5.68E-01	S	7.46E-04	W	2.06E-03	S
9.2	8.33E-01	S	5.75E-01	S	7.46E-04	W	2.06E-03	S
9.4	8.63E-01	S	5.83E-01	S	7.46E-04	W	2.06E-03	S
9.6	8.98E-01	S	5.95E-01	S	7.46E-04	W	2.06E-03	S
9.8	9.38E-01	S	6.10E-01	S	7.46E-04	W	2.06E-03	S
10	9.79E-01	S	6.26E-01	S	7.46E-04	W	2.06E-03	S
10.2	1.02E+00	S	6.41E-01	S	7.46E-04	W	2.06E-03	S
10.4	1.06E+00	S	6.72E-01	S	7.46E-04	W	2.06E-03	S
10.6	1.12E+00	S	7.59E-01	S	7.46E-04	W	2.06E-03	S
10.8	1.17E+00	S	8.55E-01	S	7.46E-04	W	2.06E-03	S
11	1.23E+00	S	9.62E-01	S	7.46E-04	W	2.06E-03	S
11.2	1.28E+00	S	1.08E+00	S	7.46E-04	W	2.06E-03	S
11.4	1.34E+00	S	1.21E+00	S	7.46E-04	W	2.06E-03	S
11.6	1.40E+00	S	1.35E+00	S	7.46E-04	W	2.06E-03	S
11.8	1.46E+00	S	1.51E+00	S	7.46E-04	W	2.06E-03	S
12	1.53E+00	S	1.68E+00	S	7.46E-04	W	2.06E-03	S
12.2	1.57E+00	S	1.82E+00	S	7.46E-04	W	2.06E-03	S
12.4	1.57E+00	S	1.82E+00	S	7.46E-04	W	2.06E-03	S
12.6	1.57E+00	S	1.82E+00	S	7.46E-04	W	2.06E-03	S
12.8	1.57E+00	S	1.82E+00	S	7.46E-04	W	2.06E-03	S
13	1.57E+00	S	1.82E+00	S	7.46E-04	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.67E+01		1.92E+01		3.88E-02		2.31E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.04E-02	S	9.68E-06	S	1.80E-02	S	1.46E-02	S
3	2.92E-02	S	7.90E-06	S	1.60E-02	S	1.63E-02	S
3.2	2.15E-02	S	6.53E-06	S	1.44E-02	S	1.81E-02	S
3.4	1.61E-02	S	5.46E-06	S	1.30E-02	S	2.00E-02	S
3.6	1.23E-02	S	4.61E-06	S	1.18E-02	S	2.20E-02	S
3.8	9.54E-03	S	3.93E-06	S	1.07E-02	S	2.40E-02	S
4	7.05E-03	S	4.73E-06	S	1.33E-02	S	2.66E-02	S
4.2	5.25E-03	S	5.76E-06	S	1.80E-02	S	2.87E-02	S
4.4	3.96E-03	S	6.94E-06	S	2.39E-02	S	3.09E-02	S
4.6	3.02E-03	S	8.29E-06	S	3.15E-02	S	3.31E-02	S
4.8	2.34E-03	S	9.83E-06	S	4.09E-02	S	3.53E-02	S
5	2.10E-03	S	8.07E-06	S	6.52E-02	S	3.74E-02	S
5.2	1.90E-03	S	6.68E-06	S	1.02E-01	S	3.95E-02	S
5.4	1.90E-03	S	7.66E-06	S	1.28E-01	S	4.24E-02	S
5.6	1.90E-03	S	8.75E-06	S	1.59E-01	S	4.55E-02	S
5.8	1.90E-03	S	8.13E-06	S	1.93E-01	S	4.89E-02	S
6	1.90E-03	S	6.21E-06	S	2.29E-01	S	5.28E-02	S
6.2	1.90E-03	S	4.79E-06	S	2.70E-01	W	5.69E-02	S
6.4	1.90E-03	S	3.64E-06	S	3.01E-01	W	5.83E-02	S
6.6	1.90E-03	S	2.73E-06	S	3.20E-01	W	5.68E-02	S
6.8	2.08E-03	S	3.24E-06	S	3.39E-01	W	5.53E-02	S
7	2.27E-03	S	5.29E-06	S	3.49E-01	W	5.92E-02	S
7.2	2.48E-03	S	8.52E-06	S	3.60E-01	W	6.31E-02	S
7.4	2.69E-03	S	1.35E-05	S	3.70E-01	W	6.72E-02	S
7.6	2.92E-03	S	2.13E-05	S	3.80E-01	W	7.15E-02	S
7.8	3.60E-03	S	1.98E-05	S	3.88E-01	W	7.07E-02	S
8	4.41E-03	S	1.85E-05	S	3.95E-01	W	6.99E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	5.37E-03	S	1.73E-05	S	4.02E-01	W	6.91E-02	S
8.4	6.09E-03	S	1.35E-05	S	3.97E-01	W	6.77E-02	S
8.6	6.89E-03	S	1.05E-05	S	3.92E-01	W	6.64E-02	S
8.8	7.77E-03	S	8.31E-06	S	3.88E-01	W	6.52E-02	S
9	7.93E-03	S	7.47E-06	S	3.82E-01	W	7.06E-02	S
9.2	8.09E-03	S	6.73E-06	S	3.77E-01	W	7.63E-02	S
9.4	8.25E-03	S	6.08E-06	S	3.71E-01	W	8.23E-02	S
9.6	8.48E-03	S	6.32E-06	S	3.70E-01	W	8.86E-02	S
9.8	8.82E-03	S	7.75E-06	S	3.72E-01	W	8.90E-02	S
10	9.22E-03	S	9.74E-06	S	3.72E-01	W	8.35E-02	S
10.2	9.62E-03	S	1.22E-05	S	3.73E-01	W	7.84E-02	S
10.4	1.01E-02	S	1.57E-05	S	3.74E-01	W	7.64E-02	S
10.6	1.09E-02	S	1.51E-05	S	3.76E-01	W	7.97E-02	S
10.8	1.17E-02	S	1.45E-05	S	3.78E-01	W	8.31E-02	S
11	1.26E-02	S	1.39E-05	S	3.80E-01	W	8.66E-02	S
11.2	1.35E-02	S	1.33E-05	S	3.82E-01	W	9.01E-02	S
11.4	1.45E-02	S	1.28E-05	S	3.83E-01	W	9.37E-02	S
11.6	1.55E-02	S	1.23E-05	S	3.85E-01	W	9.74E-02	S
11.8	1.66E-02	S	1.19E-05	S	3.87E-01	W	1.01E-01	S
12	1.77E-02	S	1.14E-05	S	3.89E-01	W	1.05E-01	S
12.2	1.89E-02	S	1.10E-05	S	3.91E-01	W	1.07E-01	S
12.4	2.02E-02	S	1.06E-05	S	3.92E-01	W	1.08E-01	S
12.6	2.15E-02	S	1.03E-05	S	3.94E-01	W	1.09E-01	S
12.8	2.29E-02	S	9.90E-06	S	3.96E-01	W	1.10E-01	S
13	2.43E-02	S	9.57E-06	S	3.97E-01	W	1.11E-01	S
tection Limit (min, mg/	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
tection Limit (max, mg	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	4.04E-01		2.13E-04		4.19E+00		1.17E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.93E-02	S	5.48E-02	S	1.87E-01	S
3	4.34E-02	S	4.87E-02	S	9.62E-02	S
3.2	3.86E-02	S	4.37E-02	S	5.17E-02	S
3.4	3.45E-02	S	3.95E-02	S	2.89E-02	S
3.6	3.10E-02	S	3.58E-02	S	1.67E-02	S
3.8	2.81E-02	S	3.27E-02	S	9.90E-03	S
4	2.30E-02	S	2.78E-02	S	9.81E-03	S
4.2	1.85E-02	S	2.30E-02	S	1.12E-02	S
4.4	1.50E-02	S	1.92E-02	S	1.28E-02	S
4.6	1.23E-02	S	1.62E-02	S	1.45E-02	S
4.8	1.02E-02	S	1.37E-02	S	1.63E-02	S
5	8.99E-03	S	1.11E-02	S	2.25E-02	S
5.2	7.97E-03	S	9.10E-03	S	3.06E-02	S
5.4	8.42E-03	S	8.30E-03	S	3.68E-02	S
5.6	8.87E-03	S	7.59E-03	S	4.39E-02	S
5.8	9.50E-03	S	6.88E-03	S	5.18E-02	S
6	1.03E-02	S	6.18E-03	S	6.02E-02	S
6.2	1.12E-02	S	5.57E-03	S	6.97E-02	S
6.4	1.25E-02	S	4.77E-03	S	8.30E-02	S
6.6	1.41E-02	S	3.89E-03	S	1.02E-01	S
6.8	1.53E-02	S	3.18E-03	S	1.20E-01	S
7	1.69E-02	S	3.07E-03	S	1.38E-01	S
7.2	1.86E-02	S	2.97E-03	S	1.58E-01	S
7.4	2.04E-02	S	2.87E-03	S	1.80E-01	S
7.6	2.24E-02	S	2.78E-03	S	2.04E-01	S
7.8	2.36E-02	S	2.69E-03	S	2.27E-01	S
8	2.49E-02	S	2.61E-03	S	2.52E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-21. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	2.62E-02	S	2.53E-03	S	2.80E-01	S
8.4	2.72E-02	S	2.53E-03	S	3.03E-01	S
8.6	2.83E-02	S	2.53E-03	S	3.28E-01	S
8.8	2.93E-02	S	2.53E-03	S	3.54E-01	S
9	3.00E-02	S	2.53E-03	S	3.74E-01	S
9.2	3.06E-02	S	2.53E-03	S	3.95E-01	S
9.4	3.13E-02	S	2.53E-03	S	4.17E-01	S
9.6	3.19E-02	S	2.53E-03	S	4.41E-01	S
9.8	3.25E-02	S	2.53E-03	S	4.65E-01	S
10	3.32E-02	S	2.53E-03	S	4.86E-01	S
10.2	3.39E-02	S	2.53E-03	S	5.08E-01	S
10.4	3.45E-02	S	2.62E-03	S	5.29E-01	S
10.6	3.55E-02	S	3.13E-03	S	5.51E-01	S
10.8	3.66E-02	S	3.74E-03	S	5.72E-01	S
11	3.77E-02	S	4.44E-03	S	5.94E-01	S
11.2	3.88E-02	S	5.26E-03	S	6.16E-01	S
11.4	3.99E-02	S	6.22E-03	S	6.39E-01	S
11.6	4.10E-02	S	7.33E-03	S	6.62E-01	S
11.8	4.22E-02	S	8.61E-03	S	6.86E-01	S
12	4.33E-02	S	1.01E-02	S	7.10E-01	S
12.2	4.45E-02	S	1.18E-02	S	7.27E-01	S
12.4	4.56E-02	S	1.37E-02	S	7.27E-01	S
12.6	4.68E-02	S	1.60E-02	S	7.27E-01	S
12.8	4.80E-02	S	1.85E-02	S	7.27E-01	S
13	4.92E-02	S	2.15E-02	S	7.27E-01	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	5.09E-01		5.48E-01		7.71E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID	LAT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	6.29E-02	S	1.18E+00	S	3.64E-03	S	2.33E-02	S
3	4.47E-02	S	1.14E+00	S	3.49E-03	S	2.24E-02	S
3.2	3.25E-02	S	1.10E+00	S	3.35E-03	S	2.16E-02	S
3.4	2.41E-02	S	1.06E+00	S	3.23E-03	S	2.08E-02	S
3.6	1.82E-02	S	1.02E+00	S	3.11E-03	S	2.02E-02	S
3.8	1.44E-02	S	9.42E-01	S	2.87E-03	S	1.92E-02	S
4	1.80E-02	S	7.50E-01	S	1.82E-03	S	1.18E-02	S
4.2	2.32E-02	S	6.44E-01	S	1.44E-03	S	8.41E-03	S
4.4	3.27E-02	S	5.90E-01	S	1.31E-03	S	6.30E-03	S
4.6	3.98E-02	S	5.58E-01	S	1.21E-03	S	5.27E-03	S
4.8	4.21E-02	S	5.44E-01	S	1.11E-03	S	4.88E-03	S
5	4.45E-02	S	5.31E-01	S	1.03E-03	S	4.53E-03	S
5.2	4.70E-02	S	5.19E-01	S	9.52E-04	S	4.22E-03	S
5.4	4.95E-02	S	5.07E-01	S	8.85E-04	S	3.95E-03	S
5.6	5.20E-02	S	4.96E-01	S	8.25E-04	S	3.70E-03	S
5.8	5.45E-02	S	4.86E-01	S	7.71E-04	S	3.47E-03	S
6	6.42E-02	S	4.76E-01	S	7.46E-04	S	3.15E-03	S
6.2	8.80E-02	S	4.64E-01	S	7.46E-04	S	2.78E-03	S
6.4	1.24E-01	S	4.51E-01	S	7.46E-04	S	2.46E-03	S
6.6	1.74E-01	S	4.39E-01	S	7.46E-04	S	2.18E-03	S
6.8	2.27E-01	S	4.30E-01	S	7.46E-04	S	2.06E-03	S
7	2.76E-01	S	4.24E-01	S	7.46E-04	S	2.06E-03	S
7.2	3.35E-01	S	4.18E-01	S	7.46E-04	S	2.06E-03	S
7.4	3.94E-01	S	4.15E-01	S	7.46E-04	S	2.06E-03	S
7.6	4.41E-01	S	4.20E-01	S	7.46E-04	S	2.06E-03	S
7.8	4.81E-01	S	4.28E-01	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID	LAT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8	5.23E-01	S	4.37E-01	S	7.46E-04	S	2.06E-03	S
8.2	5.69E-01	S	4.45E-01	S	7.46E-04	W	2.06E-03	S
8.4	6.17E-01	S	4.53E-01	S	7.46E-04	W	2.06E-03	S
8.6	6.58E-01	S	4.62E-01	S	7.46E-04	W	2.06E-03	S
8.8	6.84E-01	S	4.71E-01	S	7.46E-04	W	2.06E-03	S
9	7.10E-01	S	4.79E-01	S	7.46E-04	W	2.06E-03	S
9.2	7.36E-01	S	4.88E-01	S	7.46E-04	W	2.06E-03	S
9.4	7.63E-01	S	4.96E-01	S	7.46E-04	W	2.06E-03	S
9.6	7.84E-01	S	5.09E-01	S	7.46E-04	W	2.06E-03	S
9.8	8.06E-01	S	5.39E-01	S	7.46E-04	W	2.06E-03	S
10	8.34E-01	S	5.84E-01	S	7.46E-04	W	2.06E-03	S
10.2	8.62E-01	S	6.31E-01	S	7.46E-04	W	2.06E-03	S
10.4	8.91E-01	S	6.81E-01	S	7.46E-04	W	2.06E-03	S
10.6	9.33E-01	S	7.67E-01	S	7.46E-04	W	2.06E-03	S
10.8	9.77E-01	S	8.62E-01	S	7.46E-04	W	2.06E-03	S
11	1.02E+00	S	9.66E-01	S	7.46E-04	W	2.06E-03	S
11.2	1.07E+00	S	1.08E+00	S	7.46E-04	W	2.06E-03	S
11.4	1.11E+00	S	1.21E+00	S	7.46E-04	W	2.06E-03	S
11.6	1.16E+00	S	1.35E+00	S	7.46E-04	W	2.06E-03	S
11.8	1.21E+00	S	1.50E+00	S	7.46E-04	W	2.06E-03	S
12	1.26E+00	S	1.66E+00	S	7.46E-04	W	2.06E-03	S
12.2	1.30E+00	S	1.80E+00	S	7.46E-04	W	2.06E-03	S
12.4	1.30E+00	S	1.80E+00	S	7.46E-04	W	2.06E-03	S
12.6	1.30E+00	S	1.80E+00	S	7.46E-04	W	2.06E-03	S
12.8	1.30E+00	S	1.80E+00	S	7.46E-04	W	2.06E-03	S
13	1.30E+00	S	1.80E+00	S	7.46E-04	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.38E+01		1.91E+01		3.64E-02		2.33E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.21E-02	S	5.45E-06	S	8.74E-03	S	9.05E-03	S
3	2.89E-02	S	5.45E-06	S	8.18E-03	S	1.05E-02	S
3.2	2.03E-02	S	5.45E-06	S	7.69E-03	S	1.21E-02	S
3.4	1.46E-02	S	5.45E-06	S	7.26E-03	S	1.39E-02	S
3.6	1.07E-02	S	5.45E-06	S	6.87E-03	S	1.57E-02	S
3.8	4.27E-03	S	5.45E-06	S	6.21E-03	S	1.75E-02	S
4	2.82E-03	S	7.22E-06	S	2.10E-02	S	2.71E-02	S
4.2	1.90E-03	S	9.44E-06	S	3.92E-02	S	3.55E-02	S
4.4	1.90E-03	S	8.89E-06	S	5.57E-02	S	3.93E-02	S
4.6	1.90E-03	S	8.40E-06	S	7.36E-02	S	4.24E-02	S
4.8	1.90E-03	S	7.95E-06	S	9.07E-02	S	4.46E-02	S
5	1.90E-03	S	7.54E-06	S	1.11E-01	S	4.67E-02	S
5.2	1.90E-03	S	7.17E-06	S	1.34E-01	S	4.89E-02	S
5.4	1.90E-03	S	6.83E-06	S	1.62E-01	S	5.11E-02	S
5.6	1.90E-03	S	6.52E-06	S	1.93E-01	S	5.33E-02	S
5.8	1.90E-03	S	6.23E-06	S	2.30E-01	S	5.55E-02	S
6	1.90E-03	S	6.01E-06	S	2.56E-01	S	5.63E-02	S
6.2	2.02E-03	S	5.84E-06	S	2.71E-01	W	5.60E-02	S
6.4	2.29E-03	S	5.68E-06	S	2.87E-01	W	5.61E-02	S
6.6	2.59E-03	S	5.52E-06	S	3.05E-01	W	5.61E-02	S
6.8	2.92E-03	S	5.45E-06	S	3.17E-01	W	5.67E-02	S
7	3.27E-03	S	5.45E-06	S	3.24E-01	W	5.79E-02	S
7.2	3.65E-03	S	5.45E-06	S	3.31E-01	W	5.90E-02	S
7.4	4.34E-03	S	5.71E-06	S	3.38E-01	W	6.01E-02	S
7.6	5.25E-03	S	6.24E-06	S	3.44E-01	W	6.08E-02	S
7.8	6.08E-03	S	6.81E-06	S	3.50E-01	W	6.14E-02	S

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Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8	7.01E-03	S	7.41E-06	S	3.55E-01	W	6.20E-02	S
8.2	8.07E-03	S	8.05E-06	S	3.60E-01	W	6.26E-02	S
8.4	9.25E-03	S	8.73E-06	S	3.66E-01	W	6.31E-02	S
8.6	1.04E-02	S	9.44E-06	S	3.71E-01	W	6.42E-02	S
8.8	1.06E-02	S	6.65E-06	S	3.67E-01	W	6.30E-02	S
9	1.08E-02	S	4.72E-06	S	3.64E-01	W	6.19E-02	S
9.2	1.10E-02	S	3.38E-06	S	3.60E-01	W	6.09E-02	S
9.4	1.13E-02	S	2.43E-06	S	3.57E-01	W	5.98E-02	S
9.6	1.13E-02	S	2.66E-06	S	3.56E-01	W	6.12E-02	S
9.8	1.16E-02	S	4.37E-06	S	3.59E-01	W	6.57E-02	S
10	1.20E-02	S	7.11E-06	S	3.62E-01	W	7.12E-02	S
10.2	1.25E-02	S	1.15E-05	S	3.64E-01	W	7.70E-02	S
10.4	1.30E-02	S	1.83E-05	S	3.67E-01	W	8.32E-02	S
10.6	1.40E-02	S	1.60E-05	S	3.68E-01	W	8.82E-02	S
10.8	1.51E-02	S	1.41E-05	S	3.69E-01	W	9.33E-02	S
11	1.63E-02	S	1.24E-05	S	3.70E-01	W	9.86E-02	S
11.2	1.75E-02	S	1.10E-05	S	3.71E-01	W	1.04E-01	S
11.4	1.87E-02	S	9.72E-06	S	3.72E-01	W	1.10E-01	S
11.6	2.01E-02	S	8.63E-06	S	3.73E-01	W	1.16E-01	S
11.8	2.15E-02	S	7.67E-06	S	3.73E-01	W	1.22E-01	S
12	2.30E-02	S	6.83E-06	S	3.74E-01	W	1.28E-01	S
12.2	2.45E-02	S	6.10E-06	S	3.75E-01	W	1.33E-01	S
12.4	2.61E-02	S	5.45E-06	S	3.76E-01	W	1.33E-01	S
12.6	2.78E-02	S	4.88E-06	S	3.76E-01	W	1.33E-01	S
12.8	2.96E-02	S	4.38E-06	S	3.77E-01	W	1.33E-01	S
13	3.15E-02	S	3.94E-06	S	3.77E-01	W	1.33E-01	S
:tection Limit (min, mg/	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
tection Limit (max, mg/	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	4.21E-01		1.84E-04		3.99E+00		1.41E+00	

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Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	4.93E-02	S	3.86E-02	S	1.10E-01	S
3	4.33E-02	S	3.54E-02	S	5.55E-02	S
3.2	3.84E-02	S	3.27E-02	S	2.92E-02	S
3.4	3.43E-02	S	3.03E-02	S	1.60E-02	S
3.6	3.08E-02	S	2.82E-02	S	9.06E-03	S
3.8	2.56E-02	S	2.17E-02	S	6.18E-03	S
4	1.47E-02	S	1.45E-02	S	1.13E-02	S
4.2	1.25E-02	S	1.03E-02	S	1.72E-02	S
4.4	1.53E-02	S	7.69E-03	S	2.63E-02	S
4.6	1.60E-02	S	6.45E-03	S	3.40E-02	S
4.8	1.44E-02	S	6.04E-03	S	3.75E-02	S
5	1.30E-02	S	5.66E-03	S	4.11E-02	S
5.2	1.18E-02	S	5.33E-03	S	4.49E-02	S
5.4	1.08E-02	S	5.03E-03	S	4.89E-02	S
5.6	9.87E-03	S	4.75E-03	S	5.32E-02	S
5.8	9.05E-03	S	4.50E-03	S	5.76E-02	S
6	9.02E-03	S	4.30E-03	S	6.30E-02	S
6.2	1.01E-02	S	4.16E-03	S	7.34E-02	S
6.4	1.16E-02	S	4.02E-03	S	8.98E-02	S
6.6	1.33E-02	S	3.90E-03	S	1.09E-01	S
6.8	1.50E-02	S	3.82E-03	S	1.30E-01	S
7	1.68E-02	S	3.77E-03	S	1.51E-01	S
7.2	1.87E-02	S	3.73E-03	S	1.74E-01	S
7.4	2.04E-02	S	3.60E-03	S	2.00E-01	S
7.6	2.17E-02	S	3.38E-03	S	2.25E-01	S
7.8	2.28E-02	S	3.18E-03	S	2.47E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-22. Leachate Concentrations for Bituminous Fly Ash, Waste ID LAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8	2.39E-02	S	3.00E-03	S	2.72E-01	S
8.2	2.51E-02	S	2.83E-03	S	2.98E-01	S
8.4	2.62E-02	S	2.67E-03	S	3.26E-01	S
8.6	2.72E-02	S	2.53E-03	S	3.51E-01	S
8.8	2.80E-02	S	2.76E-03	S	3.68E-01	S
9	2.87E-02	S	3.00E-03	S	3.84E-01	S
9.2	2.95E-02	S	3.26E-03	S	4.02E-01	S
9.4	3.02E-02	S	3.54E-03	S	4.19E-01	S
9.6	3.06E-02	S	3.79E-03	S	4.35E-01	S
9.8	3.08E-02	S	4.17E-03	S	4.50E-01	S
10	3.12E-02	S	4.75E-03	S	4.68E-01	S
10.2	3.15E-02	S	5.40E-03	S	4.87E-01	S
10.4	3.18E-02	S	6.12E-03	S	5.05E-01	S
10.6	3.28E-02	S	6.87E-03	S	5.24E-01	S
10.8	3.37E-02	S	7.71E-03	S	5.44E-01	S
11	3.47E-02	S	8.62E-03	S	5.64E-01	S
11.2	3.57E-02	S	9.62E-03	S	5.84E-01	S
11.4	3.67E-02	S	1.07E-02	S	6.04E-01	S
11.6	3.78E-02	S	1.19E-02	S	6.25E-01	S
11.8	3.88E-02	S	1.32E-02	S	6.46E-01	S
12	3.98E-02	S	1.47E-02	S	6.67E-01	S
12.2	4.09E-02	S	1.62E-02	S	6.84E-01	S
12.4	4.19E-02	S	1.79E-02	S	6.84E-01	S
12.6	4.30E-02	S	1.97E-02	S	6.84E-01	S
12.8	4.41E-02	S	2.17E-02	S	6.84E-01	S
13	4.52E-02	S	2.39E-02	S	6.84E-01	S
tection Limit (min, mg	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.93E-01		3.86E-01		7.25E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID	SHB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term modeling\EPA Rpt 4 (5
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	0.209397476	S	15.91046042	S	0.0815702	W	0.078701556	W
3	1.88E-01	S	1.53E+01	S	8.07E-02	W	7.91E-02	W
3.2	1.70E-01	S	1.47E+01	S	8.00E-02	W	7.80E-02	W
3.4	1.54E-01	S	1.44E+01	S	7.82E-02	W	7.69E-02	W
3.6	1.47E-01	S	1.44E+01	S	7.58E-02	W	7.26E-02	W
3.8	1.41E-01	S	1.43E+01	S	7.36E-02	W	6.87E-02	W
4	1.36E-01	S	1.61E+01	S	6.64E-02	S	6.42E-02	S
4.2	1.20E-01	S	1.58E+01	S	6.02E-02	S	6.02E-02	S
4.4	1.07E-01	S	1.55E+01	S	5.48E-02	S	5.66E-02	S
4.6	9.64E-02	S	1.52E+01	S	5.02E-02	S	5.34E-02	S
4.8	9.03E-02	S	1.49E+01	S	4.62E-02	S	5.09E-02	S
5	9.06E-02	S	1.47E+01	S	4.31E-02	S	4.95E-02	S
5.2	9.08E-02	S	1.44E+01	S	4.03E-02	S	4.82E-02	S
5.4	9.10E-02	S	1.42E+01	S	3.77E-02	S	4.69E-02	S
5.6	9.13E-02	S	1.39E+01	S	3.54E-02	S	4.57E-02	S
5.8	9.15E-02	S	1.37E+01	S	3.33E-02	S	4.46E-02	S
6	9.08E-02	S	1.35E+01	S	3.14E-02	S	4.35E-02	S
6.2	8.78E-02	S	1.33E+01	S	2.97E-02	S	4.25E-02	S
6.4	8.51E-02	S	1.31E+01	S	2.81E-02	S	4.16E-02	S
6.6	8.25E-02	S	1.29E+01	S	2.66E-02	S	4.07E-02	S
6.8	8.00E-02	S	1.28E+01	S	2.53E-02	S	3.99E-02	S
7	7.77E-02	S	1.26E+01	S	2.41E-02	S	3.91E-02	S
7.2	7.90E-02	S	1.25E+01	S	1.85E-02	S	2.50E-02	S
7.4	8.04E-02	S	1.24E+01	S	1.18E-02	S	1.50E-02	S
7.6	8.18E-02	S	1.24E+01	S	7.59E-03	S	8.68E-03	S
7.8	8.37E-02	S	1.24E+01	S	5.64E-03	S	5.36E-03	S
8	8.80E-02	S	1.24E+01	S	5.72E-03	S	3.55E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID	SHB-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term modeling\EPA Rpt 4 (5
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	8.99E-02	S	1.09E+01	S	5.61E-03	W	2.37E-03	S
8.4	8.46E-02	S	1.07E+01	S	5.51E-03	W	2.06E-03	S
8.6	7.57E-02	S	1.05E+01	S	5.42E-03	W	2.06E-03	S
8.8	6.80E-02	S	1.09E+01	S	5.34E-03	W	2.06E-03	S
9	6.11E-02	S	1.13E+01	S	5.25E-03	W	2.06E-03	S
9.2	5.51E-02	S	1.16E+01	S	5.17E-03	W	2.06E-03	S
9.4	4.98E-02	S	1.20E+01	S	5.09E-03	W	2.06E-03	S
9.6	4.52E-02	S	1.13E+01	S	5.02E-03	W	2.06E-03	S
9.8	4.12E-02	S	1.03E+01	S	4.95E-03	W	2.06E-03	S
10	3.76E-02	S	9.38E+00	S	4.88E-03	W	2.06E-03	S
10.2	3.43E-02	S	8.59E+00	S	4.81E-03	W	2.06E-03	S
10.4	3.14E-02	S	7.87E+00	S	4.75E-03	W	2.06E-03	S
10.6	2.88E-02	S	7.23E+00	S	4.68E-03	W	2.06E-03	S
10.8	2.65E-02	S	6.65E+00	S	4.62E-03	W	2.06E-03	S
11	2.44E-02	S	6.13E+00	S	4.56E-03	W	2.06E-03	S
11.2	2.26E-02	S	5.65E+00	S	4.51E-03	W	2.06E-03	S
11.4	2.08E-02	S	5.22E+00	S	4.45E-03	W	2.06E-03	S
11.6	2.08E-02	S	5.15E+00	S	4.40E-03	W	2.06E-03	S
11.8	2.09E-02	S	5.58E+00	S	4.39E-03	W	2.06E-03	S
12	2.33E-02	S	5.05E+00	S	4.48E-03	W	2.06E-03	S
12.2	2.64E-02	S	4.68E+00	S	4.60E-03	W	2.06E-03	S
12.4	2.96E-02	S	4.35E+00	S	4.72E-03	W	2.06E-03	S
12.6	3.02E-02	S	4.05E+00	S	4.84E-03	W	2.06E-03	S
12.8	3.21E-02	S	3.77E+00	S	4.97E-03	W	2.06E-03	S
13	3.47E-02	S	3.51E+00	S	5.09E-03	W	2.06E-03	S
tection Limit (min, mg/	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	2.09E+00		1.61E+02		8.16E-01		7.91E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID
Date Exported
Database Name -25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.7169583	S	4.50116E-05	S	0.040655719	S	0.032823	S
3	1.68E+00	S	4.43E-05	S	2.96E-02	S	3.51E-02	S
3.2	1.47E+00	S	4.37E-05	S	2.50E-02	S	3.72E-02	S
3.4	1.07E+00	S	4.32E-05	S	2.75E-02	S	4.05E-02	S
3.6	5.04E-01	S	4.51E-05	S	3.44E-02	S	4.51E-02	S
3.8	2.45E-01	S	4.73E-05	S	4.26E-02	S	5.00E-02	S
4	7.81E-02	S	4.94E-05	S	3.07E-01	S	7.74E-02	S
4.2	2.63E-02	S	4.95E-05	S	4.16E-01	S	8.11E-02	S
4.4	9.34E-03	S	4.81E-05	S	5.57E-01	S	8.49E-02	S
4.6	3.47E-03	S	4.68E-05	S	7.35E-01	S	8.87E-02	S
4.8	3.08E-03	S	4.55E-05	S	8.83E-01	S	9.17E-02	S
5	3.39E-03	S	4.44E-05	S	9.20E-01	S	9.34E-02	S
5.2	3.72E-03	S	4.33E-05	S	9.57E-01	S	9.51E-02	S
5.4	4.06E-03	S	4.23E-05	S	9.94E-01	S	9.68E-02	S
5.6	4.42E-03	S	4.14E-05	S	1.03E+00	S	9.84E-02	S
5.8	4.79E-03	S	4.05E-05	S	1.07E+00	S	1.00E-01	S
6	5.19E-03	S	3.96E-05	S	1.11E+00	S	1.02E-01	S
6.2	5.24E-03	S	3.88E-05	S	1.14E+00	S	1.03E-01	S
6.4	4.03E-03	S	3.81E-05	S	1.18E+00	S	1.05E-01	S
6.6	3.79E-03	S	3.73E-05	S	1.22E+00	S	1.06E-01	S
6.8	4.03E-03	S	3.67E-05	S	1.25E+00	S	1.08E-01	S
7	4.28E-03	S	3.60E-05	S	1.29E+00	S	1.09E-01	S
7.2	5.54E-03	S	3.86E-05	S	1.35E+00	S	1.12E-01	S
7.4	8.53E-03	S	4.15E-05	S	1.45E+00	S	1.17E-01	S
7.6	1.18E-02	S	4.45E-05	S	1.57E+00	S	1.22E-01	S
7.8	1.81E-02	S	4.77E-05	S	1.69E+00	S	1.26E-01	S
8	2.91E-02	S	5.09E-05	S	1.81E+00	S	1.31E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID
Date Exported
Database Name -25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	6.29E-02	S	5.42E-05	S	1.83E+00	W	1.01E-01	S
8.4	8.82E-02	S	5.76E-05	S	1.87E+00	W	9.40E-02	S
8.6	1.07E-01	S	6.10E-05	S	1.92E+00	W	8.76E-02	S
8.8	1.28E-01	S	5.82E-05	S	2.09E+00	W	8.47E-02	S
9	1.54E-01	S	5.21E-05	S	2.28E+00	W	8.20E-02	S
9.2	1.83E-01	S	4.68E-05	S	2.47E+00	W	7.94E-02	S
9.4	2.18E-01	S	4.20E-05	S	2.68E+00	W	7.70E-02	S
9.6	2.47E-01	S	3.97E-05	S	2.64E+00	W	6.65E-02	S
9.8	2.63E-01	S	4.00E-05	S	2.53E+00	W	5.55E-02	S
10	2.81E-01	S	4.03E-05	S	2.43E+00	W	4.65E-02	S
10.2	3.01E-01	W	4.07E-05	S	2.33E+00	W	3.91E-02	S
10.4	3.22E-01	W	4.10E-05	S	2.24E+00	W	3.29E-02	S
10.6	3.44E-01	W	4.13E-05	S	2.16E+00	W	2.79E-02	S
10.8	3.66E-01	W	4.16E-05	S	2.08E+00	W	2.37E-02	S
11	3.90E-01	W	4.19E-05	S	2.00E+00	W	2.01E-02	S
11.2	4.12E-01	W	4.23E-05	S	1.93E+00	W	1.72E-02	S
11.4	4.25E-01	W	4.26E-05	S	1.86E+00	W	1.47E-02	S
11.6	4.32E-01	W	4.29E-05	S	1.90E+00	W	1.73E-02	S
11.8	4.48E-01	W	4.19E-05	S	2.16E+00	W	3.48E-02	S
12	4.42E-01	W	3.65E-05	S	2.12E+00	W	2.87E-02	S
12.2	4.23E-01	W	3.72E-05	S	1.96E+00	W	1.85E-02	S
12.4	4.03E-01	W	3.86E-05	S	1.81E+00	W	1.20E-02	S
12.6	3.85E-01	W	3.83E-05	S	1.68E+00	W	7.88E-03	S
12.8	3.68E-01	W	3.58E-05	S	1.56E+00	W	5.19E-03	S
13	3.52E-01	W	3.36E-05	S	1.45E+00	W	3.44E-03	S
tection Limit (min, mg/	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
tection Limit (max, mg	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	1.72E+01		6.10E-04		2.68E+01		1.31E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.10652918	S	0.07857581	S	0.20440248	S
3	9.76E-02	S	7.06E-02	S	1.29E-01	S
3.2	9.13E-02	S	6.36E-02	S	8.42E-02	S
3.4	9.17E-02	S	5.65E-02	S	5.63E-02	S
3.6	9.21E-02	S	4.99E-02	S	3.38E-02	S
3.8	9.25E-02	S	4.44E-02	S	1.72E-02	S
4	1.14E-01	S	2.30E-02	S	1.95E-02	S
4.2	1.34E-01	S	1.96E-02	S	2.03E-02	S
4.4	1.55E-01	S	1.69E-02	S	2.10E-02	S
4.6	1.78E-01	S	1.47E-02	S	2.27E-02	S
4.8	2.02E-01	S	1.32E-02	S	2.46E-02	S
5	2.26E-01	S	1.24E-02	S	2.66E-02	S
5.2	2.51E-01	S	1.18E-02	S	2.87E-02	S
5.4	2.78E-01	S	1.12E-02	S	3.09E-02	S
5.6	3.07E-01	S	1.06E-02	S	3.31E-02	S
5.8	3.37E-01	S	1.01E-02	S	3.54E-02	S
6	3.63E-01	S	9.68E-03	S	3.78E-02	S
6.2	3.88E-01	S	9.25E-03	S	4.03E-02	S
6.4	4.13E-01	S	8.85E-03	S	4.29E-02	S
6.6	4.40E-01	S	8.49E-03	S	4.55E-02	S
6.8	4.67E-01	S	8.14E-03	S	4.82E-02	S
7	4.94E-01	S	7.83E-03	S	5.10E-02	S
7.2	5.23E-01	S	7.07E-03	S	5.84E-02	S
7.4	5.77E-01	S	5.81E-03	S	6.68E-02	S
7.6	6.42E-01	S	4.74E-03	S	7.62E-02	S
7.8	7.13E-01	S	3.89E-03	S	8.86E-02	S
8	7.89E-01	S	3.21E-03	S	1.08E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-23. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	9.30E-01	S	2.86E-03	S	1.31E-01	S
8.4	1.07E+00	S	2.68E-03	S	1.27E-01	S
8.6	1.16E+00	S	2.53E-03	S	1.20E-01	S
8.8	1.25E+00	S	2.53E-03	S	1.14E-01	S
9	1.35E+00	S	2.53E-03	S	1.08E-01	S
9.2	1.45E+00	S	2.53E-03	S	1.02E-01	S
9.4	1.50E+00	S	2.53E-03	S	9.73E-02	S
9.6	1.52E+00	S	2.53E-03	S	9.26E-02	S
9.8	1.54E+00	S	2.53E-03	S	8.82E-02	S
10	1.57E+00	S	2.53E-03	S	8.41E-02	S
10.2	1.60E+00	S	2.53E-03	S	8.03E-02	S
10.4	1.62E+00	S	2.53E-03	S	7.67E-02	S
10.6	1.65E+00	S	2.53E-03	S	7.34E-02	S
10.8	1.65E+00	S	2.53E-03	S	7.02E-02	S
11	1.65E+00	S	2.53E-03	S	6.73E-02	S
11.2	1.67E+00	S	2.53E-03	S	6.45E-02	S
11.4	1.69E+00	S	2.53E-03	S	6.19E-02	S
11.6	1.71E+00	S	2.53E-03	S	5.94E-02	S
11.8	1.79E+00	S	2.53E-03	S	6.79E-02	S
12	2.05E+00	S	2.53E-03	S	5.80E-02	S
12.2	2.09E+00	S	2.53E-03	S	4.79E-02	S
12.4	2.17E+00	S	2.53E-03	S	3.90E-02	S
12.6	2.21E+00	S	2.53E-03	S	3.32E-02	S
12.8	2.21E+00	S	2.53E-03	S	2.84E-02	S
13	2.21E+00	S	2.53E-03	S	2.44E-02	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.45E+01		7.86E-01		2.04E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID	SHT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.85E-01	S	1.29E+01	W	6.83E-02	S	8.20E-02	S
3	2.58E-01	S	1.29E+01	W	6.60E-02	S	7.82E-02	S
3.2	2.34E-01	S	1.29E+01	W	6.39E-02	S	7.58E-02	S
3.4	2.14E-01	S	1.29E+01	W	6.21E-02	S	7.11E-02	S
3.6	1.81E-01	S	1.28E+01	W	5.75E-02	S	6.65E-02	S
3.8	1.44E-01	S	1.24E+01	W	5.30E-02	S	5.96E-02	S
4	1.34E-01	S	1.24E+01	W	5.19E-02	S	5.48E-02	S
4.2	1.26E-01	S	1.28E+01	W	5.24E-02	S	5.16E-02	S
4.4	1.18E-01	S	1.31E+01	W	5.27E-02	S	4.88E-02	S
4.6	1.12E-01	S	1.35E+01	W	5.35E-02	S	4.62E-02	S
4.8	1.05E-01	S	1.38E+01	W	5.47E-02	S	4.38E-02	S
5	9.98E-02	S	1.41E+01	W	5.53E-02	S	4.09E-02	S
5.2	9.47E-02	S	1.45E+01	W	5.59E-02	S	3.83E-02	S
5.4	9.00E-02	S	1.48E+01	W	5.65E-02	S	3.55E-02	S
5.6	8.58E-02	S	1.51E+01	W	5.71E-02	S	3.21E-02	S
5.8	8.58E-02	S	1.51E+01	W	5.80E-02	S	2.74E-02	S
6	8.91E-02	S	1.47E+01	W	5.96E-02	S	1.99E-02	S
6.2	9.25E-02	S	1.43E+01	W	6.12E-02	S	1.46E-02	S
6.4	9.58E-02	S	1.39E+01	W	6.27E-02	S	1.08E-02	S
6.6	9.92E-02	S	1.34E+01	W	6.43E-02	S	8.07E-03	S
6.8	1.03E-01	S	1.30E+01	W	6.58E-02	S	6.08E-03	S
7	1.06E-01	S	1.27E+01	W	6.74E-02	S	4.62E-03	S
7.2	1.09E-01	S	1.23E+01	W	6.89E-02	S	3.54E-03	S
7.4	1.13E-01	S	1.20E+01	W	7.04E-02	S	2.73E-03	S
7.6	1.18E-01	S	1.17E+01	W	7.19E-02	S	2.12E-03	S
7.8	1.27E-01	S	1.14E+01	W	7.34E-02	S	2.06E-03	S
8	1.39E-01	S	1.11E+01	W	7.48E-02	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID	SHT-[Med] (P,1,1)
Date Exported	8/27/2011, 6:50 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	1.45E-01	S	1.08E+01	W	7.62E-02	W	2.06E-03	S
8.4	1.51E-01	S	1.06E+01	W	7.75E-02	W	2.06E-03	S
8.6	1.59E-01	S	1.07E+01	W	7.73E-02	W	2.06E-03	S
8.8	1.63E-01	S	1.07E+01	W	7.72E-02	W	2.06E-03	S
9	1.62E-01	S	1.07E+01	W	7.71E-02	W	2.06E-03	S
9.2	1.65E-01	S	1.07E+01	W	7.69E-02	W	2.06E-03	S
9.4	1.72E-01	S	1.06E+01	W	7.68E-02	W	2.06E-03	S
9.6	1.72E-01	S	1.03E+01	W	7.67E-02	W	2.06E-03	S
9.8	1.67E-01	S	9.96E+00	W	7.65E-02	W	2.06E-03	S
10	1.63E-01	S	9.64E+00	S	7.62E-02	W	2.06E-03	S
10.2	1.58E-01	S	9.33E+00	S	7.55E-02	W	2.06E-03	S
10.4	1.54E-01	S	9.03E+00	S	7.56E-02	W	2.06E-03	S
10.6	1.44E-01	S	8.75E+00	S	7.58E-02	W	2.06E-03	S
10.8	1.34E-01	S	8.48E+00	S	7.61E-02	W	2.06E-03	S
11	1.26E-01	S	8.23E+00	S	7.64E-02	W	2.06E-03	S
11.2	1.18E-01	S	7.99E+00	S	7.67E-02	W	2.06E-03	S
11.4	1.11E-01	S	7.76E+00	S	7.70E-02	W	2.06E-03	S
11.6	1.06E-01	S	7.54E+00	S	7.73E-02	W	2.06E-03	S
11.8	1.02E-01	S	7.32E+00	S	7.77E-02	W	2.06E-03	S
12	1.12E-01	S	7.15E+00	S	7.79E-02	W	2.06E-03	S
12.2	1.32E-01	S	7.01E+00	S	7.84E-02	W	2.06E-03	S
12.4	1.55E-01	S	6.87E+00	S	7.89E-02	W	2.06E-03	S
12.6	2.64E-01	S	7.04E+00	S	7.87E-02	W	2.06E-03	S
12.8	4.37E-01	S	7.40E+00	S	7.81E-02	W	2.06E-03	S
13	7.17E-01	S	7.77E+00	S	7.77E-02	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.81E+00		1.51E+02		1.04E+00		8.20E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID
Date Exported
Database Name leling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.28E-01	S	3.49E-06	S	1.62E-01	S	1.23E-01	S
3	2.39E-01	S	2.98E-06	S	1.10E-01	S	1.26E-01	S
3.2	1.78E-01	S	2.57E-06	S	7.71E-02	S	1.28E-01	S
3.4	1.35E-01	S	2.24E-06	S	5.51E-02	S	1.31E-01	S
3.6	3.86E-02	S	2.07E-06	S	4.74E-02	S	1.42E-01	S
3.8	1.22E-02	S	2.07E-06	S	5.05E-02	S	1.64E-01	S
4	5.01E-03	S	2.25E-06	S	7.23E-02	S	1.71E-01	S
4.2	4.92E-03	S	2.68E-06	S	1.10E-01	S	1.78E-01	S
4.4	4.39E-03	S	3.17E-06	S	1.64E-01	S	1.84E-01	S
4.6	3.65E-03	S	3.73E-06	S	2.41E-01	S	1.91E-01	S
4.8	3.06E-03	S	4.36E-06	S	3.48E-01	S	1.97E-01	S
5	2.59E-03	S	5.05E-06	S	4.94E-01	S	2.04E-01	S
5.2	2.36E-03	S	5.83E-06	S	6.92E-01	S	2.10E-01	S
5.4	2.17E-03	S	6.68E-06	S	9.58E-01	S	2.17E-01	S
5.6	2.14E-03	S	7.63E-06	S	1.31E+00	S	2.23E-01	S
5.8	2.39E-03	S	8.67E-06	S	1.65E+00	S	2.30E-01	S
6	2.66E-03	S	9.80E-06	S	1.86E+00	S	2.37E-01	S
6.2	2.95E-03	S	1.10E-05	S	2.08E+00	W	2.44E-01	S
6.4	3.25E-03	S	1.24E-05	S	2.32E+00	W	2.50E-01	S
6.6	3.59E-03	S	1.05E-05	S	2.43E+00	W	2.61E-01	S
6.8	3.94E-03	S	8.51E-06	S	2.50E+00	W	2.71E-01	S
7	4.31E-03	S	6.91E-06	S	2.57E+00	W	2.82E-01	S
7.2	4.71E-03	S	5.65E-06	S	2.65E+00	W	2.93E-01	S
7.4	4.85E-03	S	4.64E-06	S	2.72E+00	W	3.05E-01	S
7.6	4.98E-03	S	3.83E-06	S	2.80E+00	W	3.16E-01	S
7.8	5.12E-03	S	3.18E-06	S	2.87E+00	W	3.27E-01	S
8	5.26E-03	S	2.65E-06	S	2.95E+00	W	3.39E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID
Date Exported
Database Name leling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	6.33E-03	S	2.22E-06	S	3.02E+00	W	3.50E-01	S
8.4	9.34E-03	S	2.07E-06	S	3.10E+00	W	3.54E-01	S
8.6	1.28E-02	S	2.07E-06	S	3.18E+00	W	3.61E-01	S
8.8	1.73E-02	S	2.07E-06	S	3.27E+00	W	3.68E-01	S
9	2.33E-02	S	2.07E-06	S	3.35E+00	W	3.75E-01	S
9.2	2.92E-02	S	2.07E-06	S	3.44E+00	W	3.82E-01	S
9.4	3.83E-02	S	2.07E-06	S	3.47E+00	W	3.88E-01	S
9.6	4.32E-02	S	2.07E-06	S	3.41E+00	W	3.89E-01	S
9.8	4.87E-02	S	2.07E-06	S	3.34E+00	W	3.91E-01	S
10	5.48E-02	S	2.07E-06	S	3.27E+00	W	3.75E-01	S
10.2	6.23E-02	W	2.07E-06	S	3.20E+00	W	3.52E-01	S
10.4	7.13E-02	W	2.07E-06	S	3.12E+00	W	3.31E-01	S
10.6	7.68E-02	W	2.07E-06	S	3.06E+00	W	3.11E-01	S
10.8	8.05E-02	W	2.57E-06	S	3.01E+00	W	2.89E-01	S
11	8.19E-02	W	3.49E-06	S	2.97E+00	W	2.66E-01	S
11.2	8.33E-02	W	4.73E-06	S	2.93E+00	W	2.46E-01	S
11.4	8.47E-02	W	6.38E-06	S	2.89E+00	W	2.27E-01	S
11.6	8.68E-02	W	8.55E-06	S	2.85E+00	W	2.11E-01	S
11.8	8.95E-02	W	1.14E-05	S	2.82E+00	W	1.95E-01	S
12	9.20E-02	W	1.33E-05	S	2.79E+00	W	1.82E-01	S
12.2	9.45E-02	W	1.44E-05	S	2.76E+00	W	1.78E-01	S
12.4	9.68E-02	W	1.56E-05	S	2.72E+00	W	1.74E-01	S
12.6	9.28E-02	W	1.61E-05	S	2.75E+00	W	1.92E-01	S
12.8	8.35E-02	W	1.61E-05	S	2.81E+00	W	2.28E-01	S
13	7.52E-02	W	1.61E-05	S	2.87E+00	W	2.69E-01	S
tection Limit (min, mg/	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
tection Limit (max, mg	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	3.28E+00		2.14E-04		3.74E+01		3.91E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.28E-01	S	1.83E-01	S	1.38E+00	S
3	1.15E-01	S	1.51E-01	S	5.01E-01	S
3.2	1.04E-01	S	1.26E-01	S	1.94E-01	S
3.4	9.49E-02	S	1.06E-01	S	7.93E-02	S
3.6	9.13E-02	S	8.45E-02	S	4.30E-02	S
3.8	9.21E-02	S	6.37E-02	S	2.72E-02	S
4	9.46E-02	S	5.12E-02	S	3.06E-02	S
4.2	9.94E-02	S	4.36E-02	S	3.51E-02	S
4.4	1.10E-01	S	3.74E-02	S	3.99E-02	S
4.6	1.23E-01	S	3.24E-02	S	4.52E-02	S
4.8	1.38E-01	S	2.82E-02	S	5.14E-02	S
5	1.53E-01	S	2.46E-02	S	6.56E-02	S
5.2	1.65E-01	S	2.17E-02	S	8.20E-02	S
5.4	1.76E-01	S	1.92E-02	S	9.37E-02	S
5.6	1.87E-01	S	1.70E-02	S	1.07E-01	S
5.8	2.04E-01	S	1.50E-02	S	1.20E-01	S
6	2.32E-01	S	1.30E-02	S	1.35E-01	S
6.2	2.64E-01	S	1.13E-02	S	1.51E-01	S
6.4	2.98E-01	S	9.90E-03	S	1.69E-01	S
6.6	3.35E-01	S	8.48E-03	S	1.87E-01	S
6.8	3.75E-01	S	7.27E-03	S	2.08E-01	S
7	4.09E-01	S	6.25E-03	S	2.29E-01	S
7.2	4.46E-01	S	5.40E-03	S	2.52E-01	S
7.4	4.84E-01	S	4.69E-03	S	2.77E-01	S
7.6	5.24E-01	S	4.08E-03	S	3.04E-01	S
7.8	5.67E-01	S	3.57E-03	S	3.42E-01	S
8	6.11E-01	S	3.13E-03	S	3.84E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-24. Leachate Concentrations for Bituminous Fly Ash, Waste ID SHT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	6.58E-01	S	2.75E-03	S	4.31E-01	S
8.4	7.07E-01	S	2.53E-03	S	4.83E-01	S
8.6	7.58E-01	S	2.53E-03	S	5.43E-01	S
8.8	8.12E-01	S	2.53E-03	S	5.88E-01	S
9	8.68E-01	S	2.53E-03	S	6.36E-01	S
9.2	9.68E-01	S	2.53E-03	S	7.24E-01	S
9.4	1.07E+00	S	2.53E-03	S	8.08E-01	S
9.6	1.13E+00	S	2.53E-03	S	8.61E-01	S
9.8	1.20E+00	S	2.53E-03	S	9.16E-01	S
10	1.33E+00	S	2.53E-03	S	9.73E-01	S
10.2	1.43E+00	S	2.53E-03	S	1.03E+00	S
10.4	1.46E+00	S	2.53E-03	S	1.09E+00	S
10.6	1.49E+00	S	2.53E-03	S	1.06E+00	S
10.8	1.53E+00	S	2.53E-03	S	1.03E+00	S
11	1.57E+00	S	2.53E-03	S	1.00E+00	S
11.2	1.61E+00	S	2.53E-03	S	9.73E-01	S
11.4	1.66E+00	S	2.53E-03	S	9.47E-01	S
11.6	1.66E+00	S	2.53E-03	S	9.21E-01	S
11.8	1.70E+00	S	2.53E-03	S	8.98E-01	S
12	1.77E+00	S	2.53E-03	S	8.89E-01	S
12.2	1.89E+00	S	2.53E-03	S	8.95E-01	S
12.4	2.01E+00	S	2.53E-03	S	9.06E-01	S
12.6	2.12E+00	S	2.53E-03	S	1.08E+00	S
12.8	2.21E+00	S	2.53E-03	S	1.30E+00	S
13	2.21E+00	S	2.53E-03	S	1.55E+00	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.94E+01		1.83E+00		1.72E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID	TFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:51 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.23E+00	S	1.25E+01	W	8.07E-02	W	2.47E-01	S
3	1.57E+00	S	1.22E+01	W	7.86E-02	W	2.24E-01	S
3.2	9.19E-01	S	1.18E+01	W	7.62E-02	W	1.99E-01	S
3.4	5.54E-01	S	1.14E+01	W	7.39E-02	W	1.79E-01	S
3.6	3.43E-01	S	1.10E+01	W	7.19E-02	W	1.61E-01	S
3.8	2.19E-01	S	1.07E+01	W	7.00E-02	W	1.47E-01	S
4	2.14E-01	S	1.04E+01	W	3.43E-02	S	9.25E-02	S
4.2	2.41E-01	S	1.01E+01	W	1.54E-02	S	5.57E-02	S
4.4	2.59E-01	S	1.00E+01	W	1.11E-02	S	3.96E-02	S
4.6	2.75E-01	S	9.91E+00	W	8.65E-03	S	2.94E-02	S
4.8	2.91E-01	S	9.81E+00	W	6.83E-03	S	2.20E-02	S
5	3.07E-01	S	9.72E+00	W	5.51E-03	S	1.67E-02	S
5.2	3.21E-01	S	9.65E+00	W	5.37E-03	S	1.28E-02	S
5.4	3.34E-01	S	9.58E+00	W	5.24E-03	S	9.90E-03	S
5.6	3.47E-01	S	9.51E+00	W	5.12E-03	S	7.73E-03	S
5.8	3.40E-01	S	8.91E+00	W	5.21E-03	S	8.33E-03	S
6	3.59E-01	S	8.87E+00	W	5.16E-03	S	6.41E-03	S
6.2	3.72E-01	S	8.87E+00	W	5.10E-03	S	5.06E-03	S
6.4	3.85E-01	S	8.87E+00	W	5.03E-03	S	4.03E-03	S
6.6	3.98E-01	S	8.88E+00	W	4.98E-03	S	3.23E-03	S
6.8	4.11E-01	S	8.88E+00	W	4.92E-03	S	2.60E-03	S
7	4.24E-01	S	8.87E+00	W	4.87E-03	S	2.14E-03	S
7.2	4.39E-01	S	8.77E+00	W	4.90E-03	S	2.06E-03	S
7.4	4.52E-01	S	8.67E+00	W	4.95E-03	S	2.06E-03	S
7.6	4.65E-01	S	8.57E+00	W	4.99E-03	S	2.06E-03	S
7.8	4.77E-01	S	8.47E+00	W	5.03E-03	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID	TFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:51 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8	4.90E-01	S	8.38E+00	W	5.07E-03	S	2.06E-03	S
8.2	4.95E-01	S	8.34E+00	W	5.07E-03	W	2.06E-03	S
8.4	4.98E-01	S	8.31E+00	W	5.05E-03	W	2.06E-03	S
8.6	5.01E-01	S	8.28E+00	W	5.03E-03	W	2.06E-03	S
8.8	5.06E-01	S	8.23E+00	W	4.99E-03	W	2.06E-03	S
9	5.15E-01	S	8.13E+00	W	4.90E-03	W	2.06E-03	S
9.2	5.43E-01	S	8.00E+00	W	4.84E-03	W	2.06E-03	S
9.4	5.76E-01	S	7.88E+00	W	4.79E-03	W	2.06E-03	S
9.6	6.11E-01	S	7.76E+00	W	4.74E-03	W	2.06E-03	S
9.8	6.45E-01	S	7.70E+00	W	4.75E-03	W	2.06E-03	S
10	6.78E-01	S	7.71E+00	W	4.80E-03	W	2.06E-03	S
10.2	6.88E-01	S	7.76E+00	W	4.87E-03	W	2.06E-03	S
10.4	6.91E-01	S	7.82E+00	W	4.95E-03	W	2.06E-03	S
10.6	7.16E-01	S	7.85E+00	W	4.99E-03	W	2.06E-03	S
10.8	7.79E-01	S	7.86E+00	W	5.02E-03	W	2.06E-03	S
11	8.78E-01	S	7.86E+00	W	5.07E-03	W	2.06E-03	S
11.2	9.88E-01	S	7.86E+00	W	5.11E-03	W	2.06E-03	S
11.4	1.11E+00	S	7.86E+00	W	5.16E-03	W	2.06E-03	S
11.6	1.24E+00	S	7.86E+00	W	5.20E-03	W	2.06E-03	S
11.8	1.39E+00	S	7.86E+00	W	5.25E-03	W	2.06E-03	S
12	1.55E+00	S	7.86E+00	W	5.29E-03	W	2.06E-03	S
12.2	1.73E+00	S	7.86E+00	W	5.33E-03	W	2.06E-03	S
12.4	1.92E+00	S	7.86E+00	W	5.37E-03	W	2.06E-03	S
12.6	2.13E+00	S	7.86E+00	W	5.42E-03	W	2.06E-03	S
12.8	2.36E+00	S	7.86E+00	W	5.46E-03	W	2.06E-03	S
13	2.61E+00	S	7.86E+00	W	5.50E-03	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.67E+01		1.25E+02		8.07E-01		2.47E+00	

Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.53E+00	S	3.00E-06	S	1.17E-01	S	3.07E-02	S
3	1.59E+00	S	3.00E-06	S	1.00E-01	S	3.11E-02	S
3.2	6.48E-01	S	3.00E-06	S	9.72E-02	S	2.98E-02	S
3.4	2.78E-01	S	3.00E-06	S	9.45E-02	S	2.87E-02	S
3.6	1.25E-01	S	3.00E-06	S	9.20E-02	S	2.76E-02	S
3.8	5.90E-02	S	2.32E-06	S	8.97E-02	S	2.67E-02	S
4	3.11E-02	S	3.00E-06	S	1.43E-01	S	3.50E-02	S
4.2	2.01E-02	S	3.00E-06	S	2.51E-01	S	4.82E-02	S
4.4	1.87E-02	S	3.00E-06	S	3.48E-01	S	5.53E-02	S
4.6	1.86E-02	S	3.00E-06	S	4.59E-01	S	6.12E-02	S
4.8	1.85E-02	S	3.00E-06	S	5.99E-01	S	6.75E-02	S
5	1.85E-02	S	3.00E-06	S	7.65E-01	S	7.38E-02	S
5.2	1.99E-02	S	3.00E-06	S	8.26E-01	W	7.49E-02	S
5.4	2.14E-02	S	3.00E-06	S	8.89E-01	W	7.59E-02	S
5.6	2.30E-02	S	3.00E-06	S	9.55E-01	W	7.69E-02	S
5.8	2.40E-02	S	3.00E-06	S	9.87E-01	W	7.92E-02	S
6	2.55E-02	S	3.00E-06	S	1.01E+00	W	7.98E-02	S
6.2	2.60E-02	S	3.00E-06	S	9.91E-01	W	8.01E-02	S
6.4	2.65E-02	S	3.00E-06	S	9.73E-01	W	8.04E-02	S
6.6	2.69E-02	S	3.00E-06	S	9.55E-01	W	8.07E-02	S
6.8	2.74E-02	S	3.00E-06	S	9.39E-01	W	8.10E-02	S
7	2.80E-02	S	3.00E-06	S	9.26E-01	W	8.13E-02	S
7.2	3.02E-02	S	3.00E-06	S	9.39E-01	W	8.11E-02	S
7.4	3.27E-02	S	3.00E-06	S	9.52E-01	W	8.07E-02	S
7.6	3.53E-02	S	3.00E-06	S	9.65E-01	W	8.02E-02	S
7.8	3.80E-02	S	3.00E-06	S	9.78E-01	W	7.98E-02	S

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Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8	4.09E-02	S	3.00E-06	S	9.91E-01	W	7.94E-02	S
8.2	4.48E-02	S	3.00E-06	S	1.00E+00	W	7.77E-02	S
8.4	4.92E-02	S	3.00E-06	S	1.01E+00	W	7.57E-02	S
8.6	5.40E-02	S	3.00E-06	S	1.02E+00	W	7.39E-02	S
8.8	5.93E-02	S	3.00E-06	S	1.02E+00	W	7.19E-02	S
9	6.55E-02	S	3.00E-06	S	1.03E+00	W	6.96E-02	S
9.2	7.16E-02	S	3.00E-06	S	1.04E+00	W	6.71E-02	S
9.4	7.79E-02	S	3.00E-06	S	1.05E+00	W	6.48E-02	S
9.6	8.47E-02	S	3.00E-06	S	1.06E+00	W	6.26E-02	S
9.8	9.09E-02	S	3.00E-06	S	1.07E+00	W	5.99E-02	S
10	9.64E-02	S	3.00E-06	S	1.07E+00	W	5.68E-02	S
10.2	1.01E-01	S	3.00E-06	S	1.08E+00	W	5.34E-02	S
10.4	1.04E-01	S	3.00E-06	S	1.09E+00	W	5.01E-02	S
10.6	1.08E-01	S	3.00E-06	S	1.11E+00	W	4.79E-02	S
10.8	1.13E-01	S	3.00E-06	S	1.12E+00	W	4.66E-02	S
11	1.18E-01	S	3.00E-06	S	1.14E+00	W	4.60E-02	S
11.2	1.23E-01	S	3.00E-06	S	1.15E+00	W	4.54E-02	S
11.4	1.28E-01	S	3.00E-06	S	1.16E+00	W	4.48E-02	S
11.6	1.33E-01	S	3.00E-06	S	1.18E+00	W	4.42E-02	S
11.8	1.38E-01	S	3.00E-06	S	1.19E+00	W	4.36E-02	S
12	1.44E-01	S	3.00E-06	S	1.20E+00	W	4.31E-02	S
12.2	1.49E-01	S	3.00E-06	S	1.22E+00	W	4.25E-02	S
12.4	1.55E-01	S	3.00E-06	S	1.22E+00	W	4.20E-02	S
12.6	1.61E-01	S	3.00E-06	S	1.22E+00	W	4.15E-02	S
12.8	1.66E-01	S	3.00E-06	S	1.22E+00	W	4.10E-02	S
13	1.72E-01	S	3.00E-06	S	1.22E+00	W	4.05E-02	S
tection Limit (min, mg	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
tection Limit (max, mg	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.53E+01		3.40E-05		1.38E+01		8.13E-01	

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Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	3.69E-01	S	2.57E-01	S	1.64E+00	S
3	3.22E-01	S	2.23E-01	S	7.94E-01	S
3.2	2.68E-01	S	1.89E-01	S	3.05E-01	S
3.4	2.26E-01	S	1.62E-01	S	1.24E-01	S
3.6	1.92E-01	S	1.40E-01	S	5.31E-02	S
3.8	1.65E-01	S	1.21E-01	S	2.38E-02	S
4	1.38E-01	S	6.79E-02	S	2.59E-02	S
4.2	1.19E-01	S	3.67E-02	S	3.62E-02	S
4.4	1.18E-01	S	2.73E-02	S	4.34E-02	S
4.6	1.20E-01	S	2.17E-02	S	5.04E-02	S
4.8	1.22E-01	S	1.73E-02	S	5.82E-02	S
5	1.24E-01	S	1.41E-02	S	6.66E-02	S
5.2	1.38E-01	S	1.29E-02	S	7.11E-02	S
5.4	1.52E-01	S	1.18E-02	S	7.57E-02	S
5.6	1.67E-01	S	1.09E-02	S	8.05E-02	S
5.8	1.72E-01	S	1.07E-02	S	7.57E-02	S
6	1.91E-01	S	1.00E-02	S	8.10E-02	S
6.2	2.02E-01	S	9.57E-03	S	8.46E-02	S
6.4	2.14E-01	S	9.16E-03	S	8.82E-02	S
6.6	2.25E-01	S	8.79E-03	S	9.18E-02	S
6.8	2.37E-01	S	8.44E-03	S	9.55E-02	S
7	2.50E-01	S	8.10E-03	S	9.94E-02	S
7.2	2.70E-01	S	7.42E-03	S	1.05E-01	S
7.4	2.91E-01	S	6.70E-03	S	1.11E-01	S
7.6	3.13E-01	S	6.07E-03	S	1.17E-01	S
7.8	3.35E-01	S	5.51E-03	S	1.24E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-25. Leachate Concentrations for Bituminous Fly Ash, Waste ID TFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8	3.59E-01	S	5.01E-03	S	1.31E-01	S
8.2	3.93E-01	S	4.64E-03	S	1.42E-01	S
8.4	4.30E-01	S	4.32E-03	S	1.55E-01	S
8.6	4.71E-01	S	4.03E-03	S	1.69E-01	S
8.8	5.20E-01	S	3.84E-03	S	1.89E-01	S
9	5.85E-01	S	3.82E-03	S	2.18E-01	S
9.2	6.59E-01	S	3.55E-03	S	2.60E-01	S
9.4	7.42E-01	S	3.27E-03	S	3.11E-01	S
9.6	8.32E-01	S	3.01E-03	S	3.71E-01	S
9.8	9.11E-01	S	2.78E-03	S	4.31E-01	S
10	9.74E-01	S	2.57E-03	S	4.89E-01	S
10.2	1.01E+00	S	2.53E-03	S	5.34E-01	S
10.4	1.04E+00	S	2.53E-03	S	5.76E-01	S
10.6	1.08E+00	S	2.53E-03	S	6.19E-01	S
10.8	1.13E+00	S	2.53E-03	S	6.60E-01	S
11	1.18E+00	S	2.53E-03	S	7.00E-01	S
11.2	1.23E+00	S	2.53E-03	S	7.42E-01	S
11.4	1.29E+00	S	2.53E-03	S	7.85E-01	S
11.6	1.34E+00	S	2.53E-03	S	8.30E-01	S
11.8	1.40E+00	S	2.53E-03	S	8.77E-01	S
12	1.46E+00	S	2.53E-03	S	9.26E-01	S
12.2	1.51E+00	S	2.53E-03	S	9.76E-01	S
12.4	1.51E+00	S	2.53E-03	S	1.03E+00	S
12.6	1.51E+00	S	2.53E-03	S	1.08E+00	S
12.8	1.51E+00	S	2.53E-03	S	1.14E+00	S
13	1.51E+00	S	2.53E-03	S	1.20E+00	S
tection Limit (min, mg	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.71E+01		2.57E+00		1.64E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID UFA-[Med] (P,1,1)
Date Exported 8/27/2011, 6:51 PM
Database Name C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version 1.2.12.11227

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.57E+00	S	4.69E+01	W	1.52E+00	S	3.32E-01	S
3	1.46E+00	S	4.66E+01	W	1.49E+00	S	3.20E-01	S
3.2	1.30E+00	S	4.54E+01	W	1.16E+00	S	2.85E-01	S
3.4	1.16E+00	S	4.43E+01	W	9.13E-01	S	2.56E-01	S
3.6	1.05E+00	S	4.32E+01	W	7.29E-01	S	2.30E-01	S
3.8	9.54E-01	S	4.23E+01	W	5.90E-01	S	2.09E-01	S
4	8.74E-01	S	4.14E+01	W	4.74E-01	S	1.89E-01	S
4.2	8.75E-01	S	4.14E+01	W	2.80E-01	S	1.45E-01	S
4.4	8.75E-01	S	4.14E+01	W	1.69E-01	S	1.13E-01	S
4.6	8.75E-01	S	4.13E+01	W	1.05E-01	S	8.88E-02	S
4.8	8.75E-01	S	4.13E+01	W	6.63E-02	S	7.05E-02	S
5	8.73E-01	S	4.12E+01	W	4.47E-02	S	5.69E-02	S
5.2	8.56E-01	S	4.09E+01	W	3.98E-02	S	4.80E-02	S
5.4	8.40E-01	S	4.06E+01	W	3.57E-02	S	4.07E-02	S
5.6	8.25E-01	S	4.04E+01	W	3.20E-02	S	3.47E-02	S
5.8	8.10E-01	S	4.01E+01	W	2.89E-02	S	2.98E-02	S
6	7.97E-01	S	3.99E+01	W	2.61E-02	S	2.57E-02	S
6.2	7.84E-01	S	3.96E+01	W	2.37E-02	S	2.23E-02	S
6.4	7.71E-01	S	3.94E+01	W	2.20E-02	S	1.97E-02	S
6.6	7.60E-01	S	3.91E+01	W	2.19E-02	S	1.89E-02	S
6.8	7.49E-01	S	3.88E+01	W	2.18E-02	S	1.81E-02	S
7	7.39E-01	S	3.85E+01	W	2.18E-02	S	1.73E-02	S
7.2	7.29E-01	S	3.83E+01	W	2.17E-02	S	1.66E-02	S
7.4	7.19E-01	S	3.80E+01	W	2.16E-02	S	1.60E-02	S
7.6	7.10E-01	S	3.78E+01	W	2.15E-02	S	1.54E-02	S
7.8	7.02E-01	S	3.75E+01	W	2.15E-02	S	1.48E-02	S
8	6.16E-01	S	3.69E+01	W	2.09E-02	S	1.31E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID UFA-[Med] (P,1,1)
Date Exported 8/27/2011, 6:51 PM
Database Name C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version 1.2.12.11227

	Concentration (mg/L)							
pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	5.32E-01	S	3.62E+01	W	2.03E-02	W	1.14E-02	S
8.4	4.61E-01	S	3.55E+01	W	1.97E-02	W	1.00E-02	S
8.6	4.01E-01	S	3.48E+01	W	1.91E-02	W	8.82E-03	S
8.8	3.23E-01	S	3.42E+01	W	1.88E-02	W	8.03E-03	S
9	2.53E-01	S	3.36E+01	S	1.87E-02	W	7.42E-03	S
9.2	1.99E-01	S	3.30E+01	S	1.85E-02	W	6.87E-03	S
9.4	1.57E-01	S	3.24E+01	S	1.83E-02	W	6.37E-03	S
9.6	1.22E-01	S	3.20E+01	S	1.89E-02	W	6.17E-03	S
9.8	9.42E-02	S	3.16E+01	S	1.96E-02	W	6.05E-03	S
10	7.33E-02	S	3.12E+01	S	2.04E-02	W	5.93E-03	S
10.2	5.73E-02	S	3.08E+01	S	2.12E-02	W	5.83E-03	S
10.4	4.50E-02	S	3.05E+01	S	2.20E-02	W	5.72E-03	S
10.6	3.83E-02	S	2.87E+01	S	2.26E-02	W	5.37E-03	S
10.8	3.87E-02	S	2.43E+01	S	2.28E-02	W	4.55E-03	S
11	3.92E-02	S	2.06E+01	S	2.29E-02	W	3.87E-03	S
11.2	3.96E-02	S	1.75E+01	S	2.31E-02	W	3.30E-03	S
11.4	4.01E-02	S	1.49E+01	S	2.32E-02	W	2.82E-03	S
11.6	4.05E-02	S	1.27E+01	S	2.33E-02	W	2.42E-03	S
11.8	4.09E-02	S	1.09E+01	S	2.35E-02	W	2.08E-03	S
12	4.26E-02	S	1.01E+01	S	2.39E-02	W	2.06E-03	S
12.2	4.43E-02	S	9.48E+00	S	2.43E-02	W	2.06E-03	S
12.4	4.61E-02	S	8.86E+00	S	2.47E-02	W	2.06E-03	S
12.6	4.80E-02	S	8.30E+00	S	2.51E-02	W	2.06E-03	S
12.8	4.99E-02	S	7.77E+00	S	2.55E-02	W	2.06E-03	S
13	5.18E-02	S	7.29E+00	S	2.59E-02	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.57E+01		4.69E+02		1.52E+01		3.32E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.43E+01	S	3.00E-06	S	6.06E-01	S	7.19E-02	W
3	1.43E+01	S	1.80E-06	S	4.70E-01	S	7.31E-02	W
3.2	6.50E+00	S	3.00E-06	S	8.59E-01	S	6.90E-02	W
3.4	3.11E+00	S	3.00E-06	S	1.51E+00	S	6.53E-02	W
3.6	1.55E+00	S	3.00E-06	S	2.58E+00	S	6.20E-02	W
3.8	8.02E-01	S	3.00E-06	S	4.28E+00	S	5.91E-02	W
4	4.34E-01	S	3.00E-06	S	6.78E+00	S	5.66E-02	W
4.2	2.98E-01	S	3.00E-06	S	7.32E+00	S	5.74E-02	W
4.4	2.08E-01	S	3.00E-06	S	7.88E+00	S	5.81E-02	W
4.6	1.47E-01	S	3.00E-06	S	8.45E+00	S	5.89E-02	W
4.8	1.06E-01	S	3.00E-06	S	9.04E+00	S	5.96E-02	W
5	8.18E-02	S	3.00E-06	S	9.56E+00	S	6.01E-02	W
5.2	8.68E-02	S	3.00E-06	S	9.65E+00	W	5.98E-02	W
5.4	9.18E-02	S	3.00E-06	S	9.73E+00	W	5.95E-02	W
5.6	9.70E-02	S	3.00E-06	S	9.81E+00	W	5.92E-02	W
5.8	1.02E-01	S	3.00E-06	S	9.89E+00	W	5.90E-02	W
6	1.08E-01	S	3.00E-06	S	9.96E+00	W	5.87E-02	W
6.2	1.13E-01	S	3.00E-06	S	1.00E+01	W	5.85E-02	W
6.4	1.26E-01	S	3.00E-06	S	1.01E+01	W	5.83E-02	W
6.6	1.80E-01	S	3.00E-06	S	1.02E+01	W	5.84E-02	W
6.8	2.54E-01	S	3.00E-06	S	1.03E+01	W	5.85E-02	W
7	3.54E-01	S	3.00E-06	S	1.03E+01	W	5.87E-02	W
7.2	4.90E-01	S	3.00E-06	S	1.04E+01	W	5.88E-02	W
7.4	6.71E-01	S	3.00E-06	S	1.05E+01	W	5.89E-02	W
7.6	9.13E-01	S	3.00E-06	S	1.05E+01	W	5.90E-02	W
7.8	1.23E+00	S	3.00E-06	S	1.06E+01	W	5.91E-02	W
8	1.23E+00	S	3.00E-06	S	1.07E+01	W	5.85E-02	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.16E+00	W	3.00E-06	S	1.09E+01	W	5.77E-02	S
8.4	1.10E+00	W	3.00E-06	S	1.10E+01	W	5.70E-02	S
8.6	1.04E+00	W	3.00E-06	S	1.11E+01	W	5.64E-02	S
8.8	1.15E+00	W	3.00E-06	S	1.12E+01	W	5.34E-02	S
9	1.34E+00	W	6.05E-06	S	1.13E+01	W	4.97E-02	S
9.2	1.56E+00	W	1.21E-05	S	1.13E+01	W	4.64E-02	S
9.4	1.81E+00	W	2.38E-05	S	1.14E+01	W	4.34E-02	S
9.6	1.95E+00	W	1.89E-05	S	1.17E+01	W	3.71E-02	S
9.8	2.06E+00	W	1.13E-05	S	1.22E+01	W	3.09E-02	S
10	2.16E+00	W	6.77E-06	S	1.27E+01	W	2.58E-02	S
10.2	2.27E+00	W	4.11E-06	S	1.32E+01	W	2.16E-02	S
10.4	2.39E+00	W	3.00E-06	S	1.37E+01	W	1.82E-02	S
10.6	2.44E+00	W	3.00E-06	S	1.41E+01	W	1.48E-02	S
10.8	2.33E+00	W	3.00E-06	S	1.41E+01	W	1.11E-02	S
11	2.23E+00	W	3.00E-06	S	1.42E+01	W	8.35E-03	S
11.2	2.14E+00	W	3.00E-06	S	1.42E+01	W	6.32E-03	S
11.4	2.05E+00	W	3.00E-06	S	1.43E+01	W	4.80E-03	S
11.6	1.97E+00	W	3.00E-06	S	1.43E+01	W	3.67E-03	S
11.8	1.89E+00	W	3.00E-06	S	1.44E+01	W	2.82E-03	S
12	1.77E+00	W	5.88E-06	S	1.45E+01	W	2.78E-03	S
12.2	1.67E+00	W	2.00E-05	S	1.45E+01	W	2.78E-03	S
12.4	1.57E+00	W	3.75E-05	S	1.45E+01	W	2.78E-03	S
12.6	1.48E+00	W	3.75E-05	S	1.45E+01	W	2.78E-03	S
12.8	1.40E+00	W	3.75E-05	S	1.45E+01	W	2.78E-03	S
13	1.32E+00	W	3.75E-05	S	1.45E+01	W	2.78E-03	S
tection Limit (min, mg/	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
tection Limit (max, mg	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.43E+02		3.79E-04		1.47E+02		7.31E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	4.39E-01	S	9.37E-01	S	1.21E+01	S
3	4.19E-01	S	8.96E-01	S	1.07E+01	S
3.2	3.23E-01	S	7.26E-01	S	8.20E+00	S
3.4	2.53E-01	S	5.96E-01	S	6.39E+00	S
3.6	2.02E-01	S	4.95E-01	S	5.05E+00	S
3.8	1.62E-01	S	4.15E-01	S	4.04E+00	S
4	1.33E-01	S	3.52E-01	S	3.31E+00	S
4.2	1.26E-01	S	3.22E-01	S	3.39E+00	W
4.4	1.20E-01	S	2.95E-01	S	3.46E+00	W
4.6	1.15E-01	S	2.72E-01	S	3.54E+00	W
4.8	1.10E-01	S	2.51E-01	S	3.61E+00	W
5	1.06E-01	S	2.35E-01	S	3.67E+00	W
5.2	1.07E-01	S	2.29E-01	S	3.63E+00	W
5.4	1.09E-01	S	2.23E-01	S	3.59E+00	W
5.6	1.10E-01	S	2.18E-01	S	3.55E+00	W
5.8	1.12E-01	S	2.13E-01	S	3.52E+00	W
6	1.13E-01	S	2.08E-01	S	3.48E+00	W
6.2	1.14E-01	S	2.03E-01	S	3.45E+00	W
6.4	1.15E-01	S	2.00E-01	S	3.42E+00	W
6.6	1.15E-01	S	2.01E-01	S	3.41E+00	W
6.8	1.15E-01	S	2.02E-01	S	3.40E+00	W
7	1.14E-01	S	2.04E-01	S	3.39E+00	W
7.2	1.14E-01	S	2.05E-01	S	3.38E+00	W
7.4	1.14E-01	S	2.06E-01	S	3.37E+00	W
7.6	1.13E-01	S	2.07E-01	S	3.36E+00	W
7.8	1.13E-01	S	2.08E-01	S	3.35E+00	W
8	1.15E-01	S	2.01E-01	S	3.30E+00	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-26. Leachate Concentrations for Bituminous Fly Ash, Waste ID UFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.18E-01	S	1.94E-01	S	3.24E+00	W
8.4	1.20E-01	S	1.87E-01	S	3.18E+00	W
8.6	1.23E-01	S	1.80E-01	S	3.13E+00	W
8.8	1.28E-01	S	1.72E-01	S	3.11E+00	W
9	1.34E-01	S	1.63E-01	S	3.12E+00	S
9.2	1.39E-01	S	1.56E-01	S	3.12E+00	S
9.4	1.46E-01	S	1.48E-01	S	3.12E+00	S
9.6	1.51E-01	S	1.46E-01	S	2.70E+00	S
9.8	1.56E-01	S	1.45E-01	S	2.23E+00	S
10	1.62E-01	S	1.43E-01	S	1.85E+00	S
10.2	1.67E-01	S	1.42E-01	S	1.54E+00	S
10.4	1.73E-01	S	1.42E-01	S	1.29E+00	S
10.6	1.66E-01	S	1.40E-01	S	1.09E+00	S
10.8	1.36E-01	S	1.36E-01	S	9.43E-01	S
11	1.12E-01	S	1.32E-01	S	8.18E-01	S
11.2	9.20E-02	S	1.29E-01	S	7.11E-01	S
11.4	7.60E-02	S	1.25E-01	S	6.19E-01	S
11.6	6.30E-02	S	1.22E-01	S	5.41E-01	S
11.8	5.24E-02	S	1.19E-01	S	4.74E-01	S
12	5.08E-02	S	1.82E-01	S	4.61E-01	S
12.2	4.96E-02	S	2.83E-01	S	4.51E-01	S
12.4	4.85E-02	S	4.38E-01	S	4.42E-01	S
12.6	4.74E-02	S	6.71E-01	S	4.33E-01	S
12.8	4.64E-02	S	1.02E+00	S	4.24E-01	S
13	4.54E-02	S	1.31E+00	S	4.16E-01	S
tection Limit (min, mg/	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.39E+00		1.03E+01		1.21E+02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID	WFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:51 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	6.82E-01	S	5.00E+00	W	4.02E-02	S	2.43E-01	S
3	4.77E-01	S	4.97E+00	W	3.96E-02	S	2.30E-01	S
3.2	3.41E-01	S	4.94E+00	W	3.91E-02	S	2.18E-01	S
3.4	3.18E-01	S	4.81E+00	W	3.76E-02	S	1.92E-01	S
3.6	3.01E-01	S	4.69E+00	W	3.63E-02	S	1.70E-01	S
3.8	2.85E-01	S	4.57E+00	W	3.51E-02	S	1.51E-01	S
4	2.58E-01	S	4.48E+00	W	3.38E-02	S	1.39E-01	S
4.2	2.20E-01	S	4.38E+00	W	3.29E-02	S	1.29E-01	S
4.4	1.87E-01	S	4.29E+00	W	3.21E-02	S	1.21E-01	S
4.6	1.60E-01	S	4.21E+00	W	3.13E-02	S	1.13E-01	S
4.8	1.38E-01	S	4.13E+00	W	3.06E-02	S	1.07E-01	S
5	1.19E-01	S	4.06E+00	W	2.99E-02	S	1.01E-01	S
5.2	1.12E-01	S	4.00E+00	W	2.87E-02	S	9.53E-02	S
5.4	1.19E-01	S	3.96E+00	W	2.68E-02	S	9.18E-02	S
5.6	1.27E-01	S	3.93E+00	W	2.51E-02	S	8.86E-02	S
5.8	1.34E-01	S	3.90E+00	W	2.36E-02	S	8.56E-02	S
6	1.41E-01	S	3.87E+00	W	2.21E-02	S	8.28E-02	S
6.2	1.48E-01	S	3.84E+00	W	2.07E-02	S	8.01E-02	S
6.4	1.68E-01	S	3.79E+00	W	1.76E-02	S	7.38E-02	S
6.6	1.91E-01	S	3.74E+00	W	1.49E-02	S	6.80E-02	S
6.8	2.20E-01	S	3.69E+00	W	1.25E-02	S	6.05E-02	S
7	2.65E-01	S	3.64E+00	W	1.00E-02	S	4.85E-02	S
7.2	3.18E-01	S	3.59E+00	W	8.04E-03	S	3.91E-02	S
7.4	4.19E-01	S	3.53E+00	W	5.54E-03	S	2.54E-02	S
7.6	5.48E-01	S	3.46E+00	W	3.86E-03	S	1.67E-02	S
7.8	6.87E-01	S	3.41E+00	W	3.00E-03	S	1.13E-02	S
8	8.39E-01	S	3.38E+00	W	2.51E-03	S	7.89E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID	WFA-[Med] (P,1,1)
Date Exported	8/27/2011, 6:51 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	1.01E+00	S	3.34E+00	W	2.37E-03	W	5.87E-03	S
8.4	1.20E+00	S	3.30E+00	W	2.25E-03	W	4.39E-03	S
8.6	1.43E+00	S	3.26E+00	W	2.14E-03	W	3.31E-03	S
8.8	1.70E+00	S	3.23E+00	W	2.03E-03	W	2.51E-03	S
9	1.98E+00	S	3.20E+00	W	1.94E-03	W	2.15E-03	S
9.2	2.19E+00	S	3.18E+00	W	1.95E-03	W	2.06E-03	S
9.4	2.37E+00	S	3.17E+00	W	2.00E-03	W	2.06E-03	S
9.6	2.56E+00	S	3.16E+00	W	2.04E-03	W	2.06E-03	S
9.8	2.77E+00	S	3.16E+00	W	2.09E-03	W	2.06E-03	S
10	2.98E+00	S	3.15E+00	W	2.13E-03	W	2.06E-03	S
10.2	3.20E+00	S	3.14E+00	W	2.19E-03	W	2.06E-03	S
10.4	3.30E+00	S	3.13E+00	W	2.26E-03	W	2.06E-03	S
10.6	3.41E+00	S	3.14E+00	W	2.30E-03	W	2.06E-03	S
10.8	3.52E+00	S	3.15E+00	W	2.33E-03	W	2.06E-03	S
11	3.63E+00	S	3.15E+00	W	2.36E-03	W	2.06E-03	S
11.2	3.73E+00	W	3.16E+00	W	2.36E-03	W	2.06E-03	S
11.4	3.89E+00	W	3.21E+00	W	2.34E-03	W	2.06E-03	S
11.6	4.07E+00	W	3.27E+00	W	2.33E-03	W	2.06E-03	S
11.8	4.24E+00	W	3.34E+00	W	2.32E-03	W	2.06E-03	S
12	4.42E+00	W	3.40E+00	W	2.32E-03	W	2.06E-03	S
12.2	4.47E+00	W	3.46E+00	W	2.31E-03	W	2.06E-03	S
12.4	4.48E+00	W	3.53E+00	W	2.30E-03	W	2.06E-03	S
12.6	4.49E+00	W	3.59E+00	W	2.30E-03	W	2.06E-03	S
12.8	4.49E+00	W	3.65E+00	W	2.29E-03	W	2.06E-03	S
13	4.50E+00	W	3.66E+00	W	2.28E-03	W	2.06E-03	S
tection Limit (min, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
tection Limit (max, mg	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	4.87E+01		4.98E+01		4.01E-01		2.43E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.81E+00	S	3.00E-06	S	2.84E-01	S	3.68E-02	S
3	2.72E+00	S	3.00E-06	S	2.19E-01	S	4.37E-02	S
3.2	2.65E+00	S	3.00E-06	S	1.72E-01	S	5.12E-02	S
3.4	2.14E+00	S	3.00E-06	S	1.82E-01	S	5.68E-02	S
3.6	1.74E+00	S	3.00E-06	S	1.95E-01	S	6.25E-02	S
3.8	1.41E+00	S	3.00E-06	S	2.09E-01	S	6.84E-02	S
4	9.32E-01	S	3.00E-06	S	2.37E-01	S	7.35E-02	S
4.2	5.24E-01	S	3.00E-06	S	2.82E-01	S	7.79E-02	S
4.4	2.89E-01	S	3.00E-06	S	3.37E-01	S	8.20E-02	S
4.6	1.64E-01	S	3.00E-06	S	4.00E-01	S	8.63E-02	S
4.8	9.50E-02	S	3.00E-06	S	4.72E-01	S	9.05E-02	S
5	5.64E-02	S	3.00E-06	S	5.53E-01	S	9.47E-02	S
5.2	3.45E-02	S	3.00E-06	S	6.56E-01	S	9.99E-02	S
5.4	2.44E-02	S	3.00E-06	S	7.75E-01	S	1.06E-01	S
5.6	1.77E-02	S	3.00E-06	S	9.10E-01	S	1.12E-01	S
5.8	1.29E-02	S	3.00E-06	S	1.06E+00	S	1.19E-01	S
6	9.96E-03	S	3.00E-06	S	1.21E+00	S	1.25E-01	S
6.2	9.23E-03	S	3.00E-06	S	1.30E+00	S	1.28E-01	W
6.4	1.00E-02	S	3.00E-06	S	1.38E+00	S	1.31E-01	W
6.6	1.10E-02	S	3.00E-06	S	1.46E+00	S	1.34E-01	W
6.8	1.26E-02	S	3.00E-06	S	1.53E+00	S	1.36E-01	W
7	1.65E-02	S	3.00E-06	S	1.59E+00	S	1.37E-01	W
7.2	2.15E-02	S	2.32E-06	S	1.65E+00	W	1.38E-01	W
7.4	3.83E-02	S	3.00E-06	S	1.72E+00	W	1.36E-01	W
7.6	6.73E-02	S	3.00E-06	S	1.80E+00	W	1.35E-01	W
7.8	1.04E-01	S	3.00E-06	S	1.86E+00	W	1.34E-01	W
8	1.48E-01	S	3.00E-06	S	1.91E+00	W	1.32E-01	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.67E-01	S	3.00E-06	S	1.91E+00	W	1.31E-01	W
8.4	1.88E-01	S	3.00E-06	S	1.92E+00	W	1.30E-01	W
8.6	2.11E-01	S	3.00E-06	S	1.92E+00	W	1.28E-01	W
8.8	2.36E-01	S	3.00E-06	S	1.93E+00	W	1.27E-01	W
9	2.55E-01	S	3.00E-06	S	1.93E+00	W	1.27E-01	W
9.2	2.64E-01	W	3.00E-06	S	1.93E+00	W	1.27E-01	W
9.4	2.69E-01	W	3.00E-06	S	1.94E+00	W	1.28E-01	W
9.6	2.74E-01	W	3.00E-06	S	1.95E+00	W	1.29E-01	W
9.8	2.79E-01	W	3.00E-06	S	1.95E+00	W	1.30E-01	W
10	2.84E-01	W	3.00E-06	S	1.96E+00	W	1.31E-01	W
10.2	2.89E-01	W	3.00E-06	S	1.97E+00	W	1.32E-01	W
10.4	2.91E-01	W	3.00E-06	S	1.97E+00	W	1.34E-01	W
10.6	2.92E-01	W	3.00E-06	S	1.97E+00	W	1.37E-01	W
10.8	2.94E-01	W	3.00E-06	S	1.97E+00	W	1.40E-01	W
11	2.96E-01	W	3.00E-06	S	1.97E+00	W	1.42E-01	W
11.2	2.97E-01	W	3.00E-06	S	1.97E+00	W	1.45E-01	W
11.4	3.01E-01	W	3.00E-06	S	1.97E+00	W	1.49E-01	W
11.6	3.05E-01	W	3.00E-06	S	1.97E+00	W	1.53E-01	W
11.8	3.10E-01	W	3.00E-06	S	1.97E+00	W	1.58E-01	W
12	3.15E-01	W	3.00E-06	S	1.98E+00	W	1.62E-01	W
12.2	3.19E-01	W	3.00E-06	S	1.97E+00	W	1.63E-01	W
12.4	3.24E-01	W	3.00E-06	S	1.97E+00	W	1.62E-01	W
12.6	3.28E-01	W	3.00E-06	S	1.97E+00	W	1.62E-01	W
12.8	3.33E-01	W	3.00E-06	S	1.96E+00	W	1.61E-01	W
13	3.38E-01	W	3.00E-06	S	1.96E+00	W	1.60E-01	W
tection Limit (min, mg	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
tection Limit (max, mg	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.80E+01		3.26E-05		2.14E+01		1.77E+00	

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Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	1.24E+00	S	1.32E-01	S	3.59E+00	S
3	1.10E+00	S	1.25E-01	S	3.11E+00	S
3.2	9.85E-01	S	1.19E-01	S	2.71E+00	S
3.4	9.65E-01	S	1.09E-01	S	1.91E+00	S
3.6	9.52E-01	S	9.95E-02	S	1.36E+00	S
3.8	9.40E-01	S	9.15E-02	S	9.86E-01	S
4	9.40E-01	S	8.35E-02	S	7.97E-01	S
4.2	9.49E-01	S	7.62E-02	S	7.03E-01	S
4.4	9.59E-01	S	6.97E-02	S	6.35E-01	S
4.6	9.68E-01	S	6.41E-02	S	5.77E-01	S
4.8	9.78E-01	S	5.91E-02	S	5.26E-01	S
5	9.87E-01	S	5.47E-02	S	4.81E-01	S
5.2	1.02E+00	S	5.05E-02	S	4.70E-01	S
5.4	1.09E+00	S	4.56E-02	S	5.13E-01	S
5.6	1.16E+00	S	4.12E-02	S	5.60E-01	S
5.8	1.23E+00	S	3.75E-02	S	6.10E-01	S
6	1.31E+00	S	3.44E-02	S	6.56E-01	S
6.2	1.36E+00	S	3.23E-02	S	6.76E-01	S
6.4	1.44E+00	S	3.11E-02	S	6.83E-01	S
6.6	1.53E+00	S	2.99E-02	S	6.89E-01	S
6.8	1.62E+00	S	2.83E-02	S	7.01E-01	S
7	1.70E+00	S	2.54E-02	S	7.36E-01	S
7.2	1.79E+00	S	2.28E-02	S	7.70E-01	S
7.4	1.90E+00	S	1.84E-02	S	8.23E-01	S
7.6	2.02E+00	S	1.50E-02	S	8.78E-01	S
7.8	2.13E+00	S	1.27E-02	S	9.34E-01	S
8	2.24E+00	S	1.10E-02	S	9.96E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-27. Leachate Concentrations for Bituminous Fly Ash, Waste ID WFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.33E+00	S	9.99E-03	S	1.10E+00	S
8.4	2.41E+00	S	9.07E-03	S	1.20E+00	S
8.6	2.50E+00	S	8.25E-03	S	1.32E+00	S
8.8	2.60E+00	S	7.52E-03	S	1.44E+00	S
9	2.66E+00	S	6.68E-03	S	1.61E+00	S
9.2	2.70E+00	W	5.74E-03	S	1.78E+00	S
9.4	2.73E+00	W	4.88E-03	S	1.96E+00	S
9.6	2.76E+00	W	4.16E-03	S	2.16E+00	S
9.8	2.79E+00	W	3.57E-03	S	2.37E+00	S
10	2.82E+00	W	3.06E-03	S	2.60E+00	S
10.2	2.85E+00	W	2.65E-03	S	2.83E+00	S
10.4	2.88E+00	W	2.53E-03	S	2.97E+00	S
10.6	2.90E+00	W	2.53E-03	S	3.09E+00	S
10.8	2.92E+00	W	2.53E-03	S	3.20E+00	S
11	2.94E+00	W	2.53E-03	S	3.33E+00	S
11.2	2.96E+00	W	2.58E-03	S	3.43E+00	S
11.4	2.97E+00	W	3.04E-03	S	3.56E+00	S
11.6	2.98E+00	W	3.60E-03	S	3.69E+00	S
11.8	2.99E+00	W	4.26E-03	S	3.83E+00	S
12	3.00E+00	W	5.02E-03	S	3.97E+00	S
12.2	3.00E+00	W	5.90E-03	S	4.11E+00	S
12.4	3.00E+00	W	6.92E-03	S	4.26E+00	S
12.6	3.00E+00	W	8.09E-03	S	4.40E+00	S
12.8	3.00E+00	W	9.44E-03	S	4.55E+00	S
13	3.00E+00	W	1.10E-02	S	4.70E+00	S
tection Limit (min, mg	5.20E-04		5.10E-04		3.10E-04	
tection Limit (max, mg	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.26E+01		1.32E+00		4.94E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID	CaFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	2.11E+00	S	5.64E+01	W	1.85E-01	W	8.92E-01	S
3	1.77E+00	S	5.51E+01	W	1.80E-01	W	7.61E-01	S
3.2	1.50E+00	S	5.40E+01	W	1.76E-01	W	6.56E-01	S
3.4	1.29E+00	S	5.29E+01	W	1.72E-01	W	5.71E-01	S
3.6	1.12E+00	S	5.19E+01	W	1.68E-01	W	5.00E-01	S
3.8	9.72E-01	S	5.10E+01	W	1.65E-01	W	4.42E-01	S
4	8.08E-01	S	5.01E+01	W	1.60E-01	W	3.95E-01	S
4.2	5.48E-01	S	4.91E+01	W	1.51E-01	W	3.62E-01	S
4.4	3.78E-01	S	4.81E+01	W	1.42E-01	W	3.33E-01	S
4.6	2.65E-01	S	4.72E+01	W	1.34E-01	W	3.08E-01	S
4.8	1.89E-01	S	4.64E+01	W	1.27E-01	W	2.86E-01	S
5	1.36E-01	S	4.56E+01	W	1.21E-01	S	2.66E-01	S
5.2	9.99E-02	S	4.49E+01	W	1.15E-01	S	2.48E-01	S
5.4	7.39E-02	S	4.42E+01	W	1.09E-01	S	2.32E-01	S
5.6	5.93E-02	S	4.36E+01	W	1.05E-01	S	2.21E-01	S
5.8	5.62E-02	S	4.32E+01	W	1.03E-01	S	2.17E-01	S
6	5.33E-02	S	4.28E+01	W	1.01E-01	S	2.14E-01	S
6.2	5.07E-02	S	4.25E+01	W	9.84E-02	S	2.11E-01	S
6.4	4.83E-02	S	4.21E+01	W	9.64E-02	S	2.08E-01	S
6.6	4.60E-02	S	4.18E+01	W	9.44E-02	S	2.05E-01	S
6.8	4.84E-02	S	4.11E+01	W	7.35E-02	S	1.57E-01	S
7	5.20E-02	S	4.03E+01	W	5.44E-02	S	1.13E-01	S
7.2	5.58E-02	S	3.96E+01	W	4.06E-02	S	8.28E-02	S
7.4	5.98E-02	S	3.89E+01	W	3.06E-02	S	6.10E-02	S
7.6	6.39E-02	S	3.82E+01	W	2.32E-02	S	4.54E-02	S
7.8	6.81E-02	S	3.75E+01	W	1.77E-02	S	3.40E-02	S
8	7.26E-02	S	3.69E+01	W	1.36E-02	S	2.56E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID	CaFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	7.72E-02	S	3.63E+01	W	1.06E-02	S	1.95E-02	S
8.4	8.20E-02	S	3.57E+01	W	8.23E-03	S	1.49E-02	S
8.6	8.69E-02	S	3.52E+01	W	6.45E-03	S	1.14E-02	S
8.8	9.21E-02	S	3.46E+01	W	5.08E-03	S	8.86E-03	S
9	9.74E-02	S	3.41E+01	W	4.03E-03	S	6.90E-03	S
9.2	1.00E-01	S	3.35E+01	W	3.40E-03	W	5.56E-03	S
9.4	9.43E-02	S	3.28E+01	W	3.40E-03	W	4.90E-03	S
9.6	8.90E-02	S	3.20E+01	W	3.40E-03	W	4.33E-03	S
9.8	8.42E-02	S	3.13E+01	W	3.40E-03	W	3.84E-03	S
10	7.97E-02	S	3.06E+01	W	3.40E-03	W	3.41E-03	S
10.2	7.55E-02	S	2.99E+01	W	3.40E-03	W	3.04E-03	S
10.4	7.16E-02	S	2.93E+01	W	3.40E-03	W	2.71E-03	S
10.6	6.80E-02	S	2.87E+01	W	3.40E-03	W	2.43E-03	S
10.8	6.46E-02	S	2.81E+01	W	3.41E-03	W	2.18E-03	S
11	5.94E-02	S	2.66E+01	S	3.41E-03	W	2.06E-03	S
11.2	5.28E-02	S	2.44E+01	S	3.41E-03	W	2.06E-03	S
11.4	4.70E-02	S	2.25E+01	S	3.42E-03	W	2.06E-03	S
11.6	4.20E-02	S	2.07E+01	S	3.42E-03	W	2.06E-03	S
11.8	3.76E-02	S	1.91E+01	S	3.43E-03	W	2.06E-03	S
12	3.37E-02	S	1.76E+01	S	3.43E-03	W	2.06E-03	S
12.2	4.37E-02	S	1.63E+01	S	3.54E-03	W	2.06E-03	S
12.4	5.64E-02	S	1.50E+01	S	3.65E-03	W	2.06E-03	S
12.6	7.25E-02	S	1.39E+01	S	3.77E-03	W	2.06E-03	S
12.8	9.29E-02	S	1.29E+01	S	3.88E-03	W	2.06E-03	S
13	1.19E-01	S	1.19E+01	S	4.00E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.11E+01		5.64E+02		1.85E+00		8.92E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.75E+00	S	2.53E-05	S	1.58E+00	S	2.58E-01	S
3	2.13E+00	S	2.68E-05	S	1.32E+00	S	2.11E-01	S
3.2	1.68E+00	S	2.83E-05	S	1.12E+00	S	1.75E-01	S
3.4	1.34E+00	S	2.98E-05	S	9.57E-01	S	1.47E-01	S
3.6	1.08E+00	S	3.13E-05	S	8.25E-01	S	1.24E-01	S
3.8	8.87E-01	S	3.28E-05	S	7.17E-01	S	1.06E-01	S
4	6.57E-01	S	3.11E-05	S	6.55E-01	S	9.06E-02	S
4.2	3.22E-01	S	2.03E-05	S	7.08E-01	S	7.54E-02	S
4.4	1.63E-01	S	1.35E-05	S	7.62E-01	S	6.33E-02	S
4.6	8.52E-02	S	9.16E-06	S	8.18E-01	S	5.36E-02	S
4.8	4.57E-02	S	6.31E-06	S	8.75E-01	S	4.57E-02	S
5	2.52E-02	S	4.42E-06	S	9.33E-01	S	3.92E-02	S
5.2	1.42E-02	S	3.13E-06	S	9.93E-01	S	3.38E-02	S
5.4	8.18E-03	S	3.00E-06	S	1.05E+00	S	2.93E-02	S
5.6	6.27E-03	S	3.00E-06	S	1.11E+00	S	2.68E-02	S
5.8	8.92E-03	S	3.00E-06	S	1.14E+00	S	2.73E-02	S
6	1.26E-02	S	3.66E-06	S	1.17E+00	S	2.78E-02	S
6.2	1.75E-02	S	4.89E-06	S	1.21E+00	S	2.83E-02	S
6.4	2.40E-02	S	6.49E-06	S	1.24E+00	S	2.88E-02	S
6.6	3.27E-02	S	8.53E-06	S	1.27E+00	S	2.93E-02	S
6.8	3.52E-02	S	7.99E-06	S	1.32E+00	S	3.07E-02	S
7	3.57E-02	S	6.90E-06	S	1.37E+00	S	3.24E-02	S
7.2	3.62E-02	S	5.99E-06	S	1.42E+00	S	3.41E-02	S
7.4	3.67E-02	S	5.22E-06	S	1.47E+00	S	3.59E-02	S
7.6	3.71E-02	S	4.57E-06	S	1.52E+00	S	3.77E-02	S
7.8	3.76E-02	S	4.01E-06	S	1.58E+00	S	3.96E-02	S
8	3.80E-02	S	3.53E-06	S	1.63E+00	S	4.15E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.2	3.85E-02	S	3.12E-06	S	1.68E+00	W	4.34E-02	S
8.4	3.89E-02	S	3.00E-06	S	1.73E+00	W	4.54E-02	S
8.6	3.94E-02	S	3.00E-06	S	1.79E+00	W	4.74E-02	S
8.8	3.98E-02	S	3.00E-06	S	1.84E+00	W	4.94E-02	S
9	4.03E-02	S	3.00E-06	S	1.89E+00	W	5.15E-02	S
9.2	4.09E-02	S	3.00E-06	S	1.93E+00	W	5.37E-02	S
9.4	4.21E-02	S	3.00E-06	S	1.93E+00	W	5.61E-02	S
9.6	4.32E-02	S	3.00E-06	S	1.92E+00	W	5.85E-02	S
9.8	4.44E-02	S	3.00E-06	S	1.91E+00	W	6.09E-02	S
10	4.56E-02	S	3.00E-06	S	1.90E+00	W	6.34E-02	S
10.2	4.69E-02	S	3.00E-06	S	1.89E+00	W	6.60E-02	S
10.4	4.81E-02	S	3.00E-06	S	1.89E+00	W	6.86E-02	S
10.6	4.93E-02	S	3.00E-06	S	1.88E+00	W	7.12E-02	S
10.8	5.05E-02	S	3.00E-06	S	1.87E+00	W	7.39E-02	S
11	6.49E-02	S	3.00E-06	S	1.88E+00	W	5.50E-02	S
11.2	1.04E-01	S	3.00E-06	S	1.90E+00	W	2.97E-02	S
11.4	1.64E-01	S	3.00E-06	S	1.92E+00	W	1.62E-02	S
11.6	2.59E-01	S	3.00E-06	S	1.94E+00	W	8.90E-03	S
11.8	4.04E-01	S	3.00E-06	S	1.96E+00	W	4.95E-03	S
12	6.26E-01	S	1.80E-06	S	1.99E+00	W	2.78E-03	S
12.2	6.63E-01	S	3.00E-06	S	2.03E+00	W	3.29E-03	S
12.4	7.02E-01	S	3.00E-06	S	2.07E+00	W	3.88E-03	S
12.6	7.42E-01	S	3.00E-06	S	2.11E+00	W	4.57E-03	S
12.8	7.84E-01	S	3.00E-06	S	2.15E+00	W	5.36E-03	S
13	8.28E-01	S	3.00E-06	S	2.19E+00	W	6.28E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.75E+01		3.28E-04		3.06E+01		2.58E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.07E+00	S	6.87E-02	S	1.14E+01	S
3	1.75E+00	S	6.34E-02	S	8.96E+00	S
3.2	1.50E+00	S	5.88E-02	S	7.14E+00	S
3.4	1.30E+00	S	5.48E-02	S	5.77E+00	S
3.6	1.13E+00	S	5.13E-02	S	4.72E+00	S
3.8	9.95E-01	S	4.82E-02	S	3.91E+00	S
4	8.53E-01	S	4.46E-02	S	3.10E+00	S
4.2	6.52E-01	S	3.83E-02	S	2.03E+00	S
4.4	5.04E-01	S	3.31E-02	S	1.36E+00	S
4.6	3.95E-01	S	2.88E-02	S	9.23E-01	S
4.8	3.12E-01	S	2.52E-02	S	6.38E-01	S
5	2.50E-01	S	2.22E-02	S	4.48E-01	S
5.2	2.01E-01	S	1.96E-02	S	3.19E-01	S
5.4	1.63E-01	S	1.74E-02	S	2.30E-01	S
5.6	1.42E-01	S	1.60E-02	S	1.85E-01	S
5.8	1.42E-01	S	1.58E-02	S	1.87E-01	S
6	1.42E-01	S	1.55E-02	S	1.89E-01	S
6.2	1.41E-01	S	1.53E-02	S	1.91E-01	S
6.4	1.41E-01	S	1.50E-02	S	1.93E-01	S
6.6	1.41E-01	S	1.48E-02	S	1.95E-01	S
6.8	1.51E-01	S	1.30E-02	S	2.16E-01	S
7	1.63E-01	S	1.10E-02	S	2.44E-01	S
7.2	1.76E-01	S	9.46E-03	S	2.75E-01	S
7.4	1.89E-01	S	8.14E-03	S	3.08E-01	S
7.6	2.03E-01	S	7.03E-03	S	3.44E-01	S
7.8	2.18E-01	S	6.09E-03	S	3.84E-01	S
8	2.34E-01	S	5.30E-03	S	4.27E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-28. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID CaFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	2.50E-01	S	4.62E-03	S	4.73E-01	S
8.4	2.67E-01	S	4.05E-03	S	5.23E-01	S
8.6	2.84E-01	S	3.56E-03	S	5.77E-01	S
8.8	3.02E-01	S	3.14E-03	S	6.36E-01	S
9	3.21E-01	S	2.77E-03	S	6.98E-01	S
9.2	3.41E-01	S	2.53E-03	S	7.58E-01	S
9.4	3.62E-01	S	2.53E-03	S	7.96E-01	S
9.6	3.84E-01	S	2.53E-03	S	8.35E-01	S
9.8	4.07E-01	S	2.53E-03	S	8.76E-01	S
10	4.31E-01	S	2.53E-03	S	9.17E-01	S
10.2	4.55E-01	S	2.53E-03	S	9.60E-01	S
10.4	4.81E-01	S	2.53E-03	S	1.00E+00	S
10.6	5.07E-01	S	2.53E-03	S	1.05E+00	S
10.8	5.34E-01	S	2.53E-03	S	1.09E+00	S
11	5.24E-01	S	2.53E-03	S	1.00E+00	S
11.2	4.78E-01	S	2.53E-03	S	8.13E-01	S
11.4	4.38E-01	S	2.53E-03	S	6.61E-01	S
11.6	4.01E-01	S	2.53E-03	S	5.39E-01	S
11.8	3.68E-01	S	2.53E-03	S	4.42E-01	S
12	3.39E-01	S	2.53E-03	S	3.63E-01	S
12.2	3.94E-01	S	2.53E-03	S	3.82E-01	S
12.4	4.56E-01	S	2.53E-03	S	4.02E-01	S
12.6	5.28E-01	S	2.53E-03	S	4.22E-01	S
12.8	6.09E-01	S	2.53E-03	S	4.44E-01	S
13	7.01E-01	S	2.53E-03	S	4.66E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.07E+01		6.87E-01		1.14E+02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID	JAB-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	1.70E+01	W	3.46E-02	S	9.28E-01	S
3	3.20E-03	S	1.70E+01	W	3.46E-02	S	9.28E-01	S
3.2	3.20E-03	S	1.65E+01	W	3.46E-02	S	9.28E-01	S
3.4	3.20E-03	S	1.51E+01	W	3.46E-02	S	9.28E-01	S
3.6	3.20E-03	S	1.39E+01	W	3.46E-02	S	9.28E-01	S
3.8	3.20E-03	S	1.11E+01	W	2.69E-02	S	7.59E-01	S
4	3.20E-03	S	7.72E+00	W	4.16E-03	S	1.74E-01	S
4.2	3.20E-03	S	7.13E+00	W	2.64E-03	S	1.17E-01	S
4.4	3.20E-03	S	6.77E+00	W	2.11E-03	S	9.40E-02	S
4.6	3.20E-03	S	6.60E+00	W	2.11E-03	S	8.95E-02	S
4.8	3.20E-03	S	6.44E+00	W	2.10E-03	S	8.55E-02	S
5	3.20E-03	S	6.73E+00	W	1.51E-03	S	7.12E-02	S
5.2	3.20E-03	S	6.69E+00	W	1.47E-03	S	6.30E-02	S
5.4	3.20E-03	S	6.65E+00	W	1.43E-03	S	5.61E-02	S
5.6	3.20E-03	S	6.61E+00	W	1.34E-03	S	4.81E-02	S
5.8	3.20E-03	S	6.57E+00	W	1.19E-03	S	4.00E-02	S
6	3.20E-03	S	6.53E+00	W	1.07E-03	S	3.34E-02	S
6.2	3.20E-03	S	6.48E+00	W	9.60E-04	S	2.81E-02	S
6.4	3.20E-03	S	6.44E+00	W	8.66E-04	S	2.37E-02	S
6.6	3.20E-03	S	6.74E+00	W	7.94E-04	S	1.89E-02	S
6.8	3.20E-03	S	7.05E+00	W	7.29E-04	S	1.51E-02	S
7	3.20E-03	S	7.60E+00	W	6.78E-04	S	1.16E-02	S
7.2	3.20E-03	S	8.44E+00	W	6.39E-04	S	8.48E-03	S
7.4	3.20E-03	S	9.35E+00	W	6.02E-04	S	6.27E-03	S
7.6	3.20E-03	S	1.05E+01	W	6.35E-04	S	4.52E-03	S
7.8	3.20E-03	S	1.18E+01	W	6.69E-04	S	3.29E-03	S
8	3.20E-03	S	1.32E+01	W	7.04E-04	S	2.41E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID	JAB-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	1.43E+01	W	7.44E-04	S	2.06E-03	S
8.4	3.20E-03	S	1.49E+01	W	7.07E-04	S	2.06E-03	S
8.6	3.20E-03	S	1.55E+01	W	6.73E-04	S	2.06E-03	S
8.8	3.20E-03	S	1.62E+01	W	6.41E-04	S	2.06E-03	S
9	3.20E-03	S	1.60E+01	W	6.11E-04	S	2.06E-03	S
9.2	3.20E-03	S	1.51E+01	W	5.84E-04	W	2.06E-03	S
9.4	3.20E-03	S	1.31E+01	W	2.82E-04	W	2.06E-03	S
9.6	3.20E-03	S	1.14E+01	W	1.84E-04	W	2.06E-03	S
9.8	3.20E-03	S	8.59E+00	W	1.73E-04	W	2.06E-03	S
10	3.20E-03	S	6.16E+00	S	1.62E-04	W	2.06E-03	S
10.2	3.20E-03	S	4.45E+00	S	1.52E-04	W	2.06E-03	S
10.4	3.20E-03	S	3.23E+00	S	1.43E-04	W	2.06E-03	S
10.6	3.20E-03	S	2.36E+00	S	1.35E-04	W	2.06E-03	S
10.8	3.20E-03	S	1.74E+00	S	1.27E-04	W	2.06E-03	S
11	3.20E-03	S	1.29E+00	S	1.20E-04	W	2.06E-03	S
11.2	3.20E-03	S	9.56E-01	S	1.13E-04	W	2.06E-03	S
11.4	3.20E-03	S	7.15E-01	S	1.07E-04	W	2.06E-03	S
11.6	3.20E-03	S	5.37E-01	S	1.01E-04	W	2.06E-03	S
11.8	3.20E-03	S	4.17E-01	S	9.52E-05	W	2.06E-03	S
12	3.20E-03	S	3.27E-01	S	1.22E-04	W	2.06E-03	S
12.2	3.80E-03	S	3.44E-01	S	1.39E-04	W	2.06E-03	S
12.4	5.35E-03	S	4.83E-01	S	2.17E-04	W	2.06E-03	S
12.6	5.35E-03	S	6.73E-01	S	4.34E-04	W	2.06E-03	S
12.8	5.35E-03	S	9.35E-01	S	8.58E-04	W	2.06E-03	S
13	5.35E-03	S	1.29E+00	S	1.68E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.75E-02		1.70E+02		3.46E-01		9.28E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.49E-03	S	5.70E-05	S	5.00E-04	S	4.09E-04	S
3	3.21E-03	S	5.70E-05	S	5.00E-04	S	6.86E-04	S
3.2	4.08E-03	S	5.70E-05	S	7.97E-04	S	1.11E-03	S
3.4	5.10E-03	S	5.70E-05	S	1.29E-03	S	1.75E-03	S
3.6	1.73E-02	S	5.70E-05	S	2.03E-03	S	2.69E-03	S
3.8	8.95E-02	S	5.36E-05	S	3.13E-03	S	4.03E-03	S
4	4.27E-01	S	2.21E-05	S	7.74E-02	S	5.92E-03	S
4.2	5.14E-01	S	2.20E-05	S	1.16E-01	S	7.02E-03	S
4.4	5.69E-01	S	2.14E-05	S	1.44E-01	S	7.56E-03	S
4.6	5.84E-01	S	2.01E-05	S	1.49E-01	S	7.44E-03	S
4.8	5.98E-01	S	1.89E-05	S	1.54E-01	S	7.33E-03	S
5	6.19E-01	S	2.34E-05	S	1.83E-01	S	7.61E-03	S
5.2	6.29E-01	W	2.59E-05	S	1.95E-01	S	7.82E-03	S
5.4	6.39E-01	W	2.85E-05	S	2.07E-01	S	8.03E-03	S
5.6	6.55E-01	W	2.87E-05	S	2.25E-01	S	8.13E-03	S
5.8	6.79E-01	W	2.65E-05	S	2.49E-01	S	8.13E-03	S
6	7.03E-01	W	2.45E-05	S	2.76E-01	S	8.13E-03	S
6.2	7.26E-01	W	2.27E-05	S	3.03E-01	S	8.14E-03	S
6.4	7.50E-01	W	2.11E-05	S	3.33E-01	S	8.14E-03	S
6.6	7.72E-01	W	1.98E-05	S	3.72E-01	S	8.34E-03	S
6.8	7.94E-01	W	1.86E-05	S	4.14E-01	S	8.54E-03	S
7	8.12E-01	W	1.74E-05	S	4.61E-01	S	8.91E-03	S
7.2	8.25E-01	W	1.63E-05	S	5.14E-01	S	9.48E-03	S
7.4	8.39E-01	W	1.52E-05	S	5.71E-01	S	1.01E-02	S
7.6	8.31E-01	W	1.52E-05	S	6.06E-01	S	1.07E-02	S
7.8	8.23E-01	W	1.52E-05	S	6.44E-01	S	1.13E-02	S
8	8.16E-01	W	1.52E-05	S	6.82E-01	S	1.19E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.2	8.17E-01	W	1.50E-05	S	7.03E-01	W	1.15E-02	S
8.4	8.37E-01	W	1.74E-05	S	7.07E-01	W	1.05E-02	S
8.6	8.57E-01	W	2.00E-05	S	7.11E-01	W	9.68E-03	S
8.8	8.77E-01	W	2.30E-05	S	7.14E-01	W	8.91E-03	S
9	8.90E-01	S	2.30E-05	S	7.19E-01	W	7.59E-03	S
9.2	8.97E-01	S	2.02E-05	S	7.23E-01	W	6.00E-03	S
9.4	5.03E-01	S	1.80E-05	S	7.25E-01	W	4.81E-03	S
9.6	2.86E-01	S	1.61E-05	S	7.26E-01	W	3.88E-03	S
9.8	2.12E-01	S	1.63E-05	S	7.11E-01	W	3.74E-03	S
10	2.18E-01	S	1.67E-05	S	6.88E-01	W	3.62E-03	S
10.2	2.24E-01	S	1.71E-05	S	6.66E-01	W	3.50E-03	S
10.4	2.29E-01	S	1.74E-05	S	6.44E-01	W	3.39E-03	S
10.6	2.35E-01	S	1.78E-05	S	6.24E-01	W	3.28E-03	S
10.8	2.41E-01	S	1.81E-05	S	6.05E-01	W	3.18E-03	S
11	2.47E-01	S	1.85E-05	S	5.87E-01	W	3.09E-03	S
11.2	2.53E-01	S	1.89E-05	S	5.70E-01	W	2.99E-03	S
11.4	2.59E-01	S	1.92E-05	S	5.53E-01	W	2.91E-03	S
11.6	2.65E-01	S	1.96E-05	S	5.37E-01	W	2.82E-03	S
11.8	3.58E-01	S	2.19E-05	S	5.77E-01	W	3.86E-03	S
12	5.13E-01	S	2.71E-05	S	6.35E-01	W	5.99E-03	S
12.2	6.49E-01	S	2.54E-05	S	6.88E-01	W	9.03E-03	S
12.4	7.27E-01	S	1.83E-05	S	7.33E-01	W	1.32E-02	S
12.6	8.13E-01	S	1.33E-05	S	7.69E-01	W	1.32E-02	S
12.8	8.98E-01	S	9.64E-06	S	7.71E-01	W	1.32E-02	S
13	8.98E-01	S	8.54E-06	S	7.71E-01	W	1.32E-02	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	9.65E+00		5.70E-04		8.29E+00		1.42E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.38E-01	S	5.02E-02	S	1.43E-03	S
3	2.38E-01	S	5.02E-02	S	1.43E-03	S
3.2	2.38E-01	S	5.02E-02	S	1.43E-03	S
3.4	2.38E-01	S	5.02E-02	S	1.43E-03	S
3.6	2.38E-01	S	5.02E-02	S	1.43E-03	S
3.8	2.32E-01	S	4.64E-02	S	1.43E-03	S
4	1.41E-01	S	2.41E-02	S	1.43E-03	S
4.2	1.35E-01	S	2.06E-02	S	1.54E-03	S
4.4	1.25E-01	S	1.90E-02	S	1.65E-03	S
4.6	1.11E-01	S	1.87E-02	S	1.76E-03	S
4.8	9.97E-02	S	1.85E-02	S	1.87E-03	S
5	9.27E-02	S	1.80E-02	S	2.06E-03	S
5.2	9.33E-02	W	1.76E-02	S	2.34E-03	S
5.4	9.38E-02	W	1.72E-02	S	2.63E-03	S
5.6	9.40E-02	W	1.68E-02	S	2.85E-03	S
5.8	9.39E-02	W	1.62E-02	S	2.96E-03	S
6	9.37E-02	W	1.56E-02	S	3.06E-03	S
6.2	9.36E-02	W	1.51E-02	S	3.17E-03	S
6.4	9.35E-02	W	1.47E-02	S	3.28E-03	S
6.6	9.42E-02	W	1.44E-02	S	4.02E-03	S
6.8	9.49E-02	W	1.42E-02	S	4.90E-03	S
7	9.56E-02	W	1.42E-02	S	6.10E-03	S
7.2	9.63E-02	W	1.42E-02	S	7.74E-03	S
7.4	9.70E-02	W	1.43E-02	S	9.77E-03	S
7.6	9.73E-02	W	1.43E-02	S	1.08E-02	S
7.8	9.76E-02	W	1.43E-02	S	1.19E-02	S
8	9.79E-02	W	1.44E-02	S	1.31E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-29. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	9.95E-02	W	1.37E-02	S	1.37E-02	S
8.4	1.02E-01	W	1.26E-02	S	1.45E-02	S
8.6	1.05E-01	W	1.17E-02	S	1.52E-02	S
8.8	1.09E-01	W	1.08E-02	S	1.60E-02	S
9	1.11E-01	W	1.01E-02	S	1.71E-02	S
9.2	1.14E-01	W	9.47E-03	S	1.88E-02	S
9.4	1.21E-01	W	9.29E-03	S	2.07E-02	S
9.6	1.28E-01	W	9.12E-03	S	2.28E-02	S
9.8	1.22E-01	W	8.98E-03	S	2.24E-02	S
10	1.12E-01	S	8.84E-03	S	2.16E-02	S
10.2	1.02E-01	S	8.70E-03	S	2.08E-02	S
10.4	9.41E-02	S	8.57E-03	S	2.00E-02	S
10.6	8.66E-02	S	8.45E-03	S	1.93E-02	S
10.8	7.97E-02	S	8.33E-03	S	1.86E-02	S
11	7.36E-02	S	8.21E-03	S	1.80E-02	S
11.2	6.80E-02	S	8.10E-03	S	1.74E-02	S
11.4	6.29E-02	S	7.99E-03	S	1.68E-02	S
11.6	5.82E-02	S	7.88E-03	S	1.63E-02	S
11.8	5.68E-02	S	7.12E-03	S	3.31E-02	S
12	5.25E-02	S	6.22E-03	S	8.17E-02	S
12.2	5.37E-02	S	7.27E-03	S	1.79E-01	S
12.4	6.05E-02	S	1.13E-02	S	3.52E-01	S
12.6	6.80E-02	S	1.75E-02	S	3.52E-01	S
12.8	7.62E-02	S	2.68E-02	S	3.52E-01	S
13	8.53E-02	S	4.08E-02	S	3.52E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.38E+00		5.02E-01		3.78E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID	JAT-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	1.61E+01	W	2.12E-02	S	5.53E-01	S
3	3.20E-03	S	1.54E+01	W	2.12E-02	S	5.53E-01	S
3.2	3.20E-03	S	1.48E+01	W	2.12E-02	S	5.53E-01	S
3.4	3.20E-03	S	1.42E+01	W	2.12E-02	S	5.53E-01	S
3.6	3.20E-03	S	1.37E+01	W	2.12E-02	S	5.53E-01	S
3.8	3.20E-03	S	1.32E+01	W	2.12E-02	S	5.53E-01	S
4	3.20E-03	S	1.20E+01	W	1.95E-02	S	5.29E-01	S
4.2	3.20E-03	S	1.05E+01	W	1.67E-02	S	4.85E-01	S
4.4	3.20E-03	S	9.28E+00	W	1.09E-02	S	4.02E-01	S
4.6	3.20E-03	S	8.52E+00	W	6.73E-03	S	3.11E-01	S
4.8	3.20E-03	S	8.21E+00	W	5.19E-03	S	2.34E-01	S
5	3.20E-03	S	7.91E+00	W	4.04E-03	S	1.78E-01	S
5.2	3.20E-03	S	7.64E+00	W	3.17E-03	S	1.37E-01	S
5.4	3.20E-03	S	7.45E+00	W	2.59E-03	S	1.05E-01	S
5.6	3.20E-03	S	7.33E+00	W	2.20E-03	S	8.01E-02	S
5.8	3.20E-03	S	7.21E+00	W	1.87E-03	S	6.16E-02	S
6	3.20E-03	S	7.29E+00	W	1.66E-03	S	4.76E-02	S
6.2	3.20E-03	S	7.36E+00	W	1.48E-03	S	3.71E-02	S
6.4	3.20E-03	S	7.43E+00	W	1.32E-03	S	2.91E-02	S
6.6	3.20E-03	S	7.51E+00	W	1.18E-03	S	2.31E-02	S
6.8	3.20E-03	S	7.58E+00	W	1.06E-03	S	1.84E-02	S
7	3.20E-03	S	7.64E+00	W	9.58E-04	S	1.47E-02	S
7.2	3.20E-03	S	7.93E+00	W	8.62E-04	S	1.20E-02	S
7.4	3.20E-03	S	8.44E+00	W	7.72E-04	S	1.00E-02	S
7.6	3.20E-03	S	8.98E+00	W	6.94E-04	S	8.36E-03	S
7.8	3.20E-03	S	9.61E+00	W	6.52E-04	S	6.55E-03	S
8	3.20E-03	S	1.03E+01	W	5.18E-04	S	4.68E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID	JAT-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	1.12E+01	W	1.65E-04	S	3.44E-03	S
8.4	3.20E-03	S	1.23E+01	W	8.50E-05	S	2.55E-03	S
8.6	3.20E-03	S	1.31E+01	W	4.61E-05	S	2.06E-03	S
8.8	3.20E-03	S	1.37E+01	W	8.50E-05	S	2.06E-03	S
9	3.20E-03	S	1.44E+01	W	8.50E-05	S	2.06E-03	S
9.2	3.20E-03	S	1.50E+01	W	8.50E-05	W	2.06E-03	S
9.4	3.20E-03	S	1.56E+01	W	8.50E-05	W	2.06E-03	S
9.6	3.20E-03	S	1.60E+01	W	8.50E-05	W	2.06E-03	S
9.8	3.20E-03	S	1.41E+01	W	8.50E-05	W	2.06E-03	S
10	3.20E-03	S	9.31E+00	S	8.50E-05	W	2.06E-03	S
10.2	3.20E-03	S	5.35E+00	S	8.50E-05	W	2.06E-03	S
10.4	3.20E-03	S	3.11E+00	S	2.50E-05	W	2.06E-03	S
10.6	3.20E-03	S	2.31E+00	S	8.50E-05	W	2.06E-03	S
10.8	3.20E-03	S	1.72E+00	S	8.50E-05	W	2.06E-03	S
11	3.20E-03	S	1.29E+00	S	8.50E-05	W	2.06E-03	S
11.2	3.20E-03	S	9.75E-01	S	8.50E-05	W	2.06E-03	S
11.4	3.20E-03	S	7.39E-01	S	8.50E-05	W	2.06E-03	S
11.6	3.20E-03	S	5.63E-01	S	8.50E-05	W	2.06E-03	S
11.8	3.20E-03	S	4.31E-01	S	8.50E-05	W	2.06E-03	S
12	3.20E-03	S	3.31E-01	S	8.50E-05	W	2.06E-03	S
12.2	3.20E-03	S	2.56E-01	S	2.50E-05	W	2.06E-03	S
12.4	4.38E-03	S	3.05E-01	S	1.06E-04	W	2.06E-03	S
12.6	5.11E-03	S	3.63E-01	S	4.37E-04	W	2.06E-03	S
12.8	5.11E-03	S	4.31E-01	S	1.77E-03	W	2.06E-03	S
13	5.11E-03	S	5.10E-01	S	7.00E-03	W	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.37E-02		1.61E+02		2.12E-01		5.53E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.12E-04	S	3.30E-06	S	1.50E-03	S	1.16E-03	S
3	4.11E-04	S	3.50E-06	S	1.79E-03	S	1.39E-03	S
3.2	5.31E-04	S	3.71E-06	S	2.11E-03	S	1.65E-03	S
3.4	6.76E-04	S	3.91E-06	S	2.46E-03	S	1.94E-03	S
3.6	8.50E-04	S	4.11E-06	S	3.71E-03	S	2.25E-03	S
3.8	1.05E-03	S	4.31E-06	S	6.95E-03	S	2.60E-03	S
4	1.29E-03	S	4.50E-06	S	1.26E-02	S	2.98E-03	S
4.2	2.59E-03	S	4.70E-06	S	2.23E-02	S	3.39E-03	S
4.4	8.62E-03	S	6.03E-06	S	3.83E-02	S	3.83E-03	S
4.6	1.81E-02	S	7.53E-06	S	5.64E-02	S	4.58E-03	S
4.8	2.33E-02	S	8.24E-06	S	7.37E-02	S	5.13E-03	S
5	2.96E-02	S	8.98E-06	S	9.53E-02	S	5.72E-03	S
5.2	3.73E-02	S	9.76E-06	S	1.22E-01	S	6.35E-03	S
5.4	4.56E-02	S	9.76E-06	S	1.52E-01	S	6.66E-03	S
5.6	5.43E-02	S	9.04E-06	S	1.84E-01	S	6.61E-03	S
5.8	6.42E-02	S	8.39E-06	S	2.22E-01	S	6.57E-03	S
6	7.33E-02	S	7.67E-06	S	2.52E-01	S	6.61E-03	S
6.2	8.35E-02	S	7.03E-06	S	2.86E-01	S	6.64E-03	S
6.4	9.46E-02	S	6.47E-06	S	3.23E-01	S	6.68E-03	S
6.6	1.07E-01	S	5.96E-06	S	3.63E-01	S	6.71E-03	S
6.8	1.20E-01	S	5.51E-06	S	4.08E-01	S	6.74E-03	S
7	1.35E-01	S	5.11E-06	S	4.55E-01	S	6.77E-03	S
7.2	1.48E-01	S	5.30E-06	S	5.02E-01	S	6.91E-03	S
7.4	1.59E-01	S	6.13E-06	S	5.47E-01	S	7.15E-03	S
7.6	1.71E-01	S	7.07E-06	S	5.94E-01	S	7.40E-03	S
7.8	1.84E-01	S	9.42E-06	S	6.34E-01	S	7.63E-03	S
8	2.00E-01	S	1.28E-05	S	6.54E-01	S	7.75E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.24E-01	S	1.24E-05	S	6.71E-01	W	7.87E-03	S
8.4	2.50E-01	S	1.21E-05	S	6.88E-01	W	7.99E-03	S
8.6	2.74E-01	S	1.15E-05	S	7.01E-01	W	8.09E-03	S
8.8	2.81E-01	S	1.61E-05	S	7.15E-01	W	8.29E-03	S
9	2.87E-01	S	2.17E-05	S	7.25E-01	W	8.36E-03	S
9.2	2.91E-01	S	2.84E-05	S	7.30E-01	W	8.32E-03	S
9.4	2.95E-01	S	3.68E-05	S	7.35E-01	W	8.28E-03	S
9.6	3.11E-01	S	1.82E-05	S	7.17E-01	W	6.03E-03	S
9.8	3.32E-01	S	8.58E-06	S	6.88E-01	W	4.38E-03	S
10	3.57E-01	S	1.01E-05	S	6.75E-01	W	3.97E-03	S
10.2	3.94E-01	S	1.21E-05	S	6.65E-01	W	3.32E-03	S
10.4	4.35E-01	S	1.44E-05	S	6.56E-01	W	2.78E-03	S
10.6	4.55E-01	S	1.46E-05	S	6.60E-01	W	2.95E-03	S
10.8	4.75E-01	S	1.49E-05	S	6.63E-01	W	3.13E-03	S
11	4.96E-01	S	1.52E-05	S	6.67E-01	W	3.32E-03	S
11.2	5.17E-01	S	1.55E-05	S	6.70E-01	W	3.51E-03	S
11.4	5.39E-01	S	1.57E-05	S	6.74E-01	W	3.71E-03	S
11.6	5.61E-01	S	1.60E-05	S	6.77E-01	W	3.92E-03	S
11.8	5.84E-01	S	1.63E-05	S	6.80E-01	W	4.14E-03	S
12	6.08E-01	S	1.66E-05	S	6.84E-01	W	4.36E-03	S
12.2	6.32E-01	W	1.68E-05	S	6.87E-01	W	4.59E-03	S
12.4	7.00E-01	W	2.89E-05	S	7.38E-01	W	7.25E-03	S
12.6	7.37E-01	W	4.33E-05	S	7.72E-01	W	1.01E-02	S
12.8	7.37E-01	W	4.20E-05	S	7.72E-01	W	1.01E-02	S
13	7.37E-01	W	4.07E-05	S	7.72E-01	W	1.01E-02	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	7.74E+00		4.55E-04		8.10E+00		1.06E-01	

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Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.32E-01	S	1.04E-02	S	1.43E-03	S
3	2.32E-01	S	1.04E-02	S	1.43E-03	S
3.2	2.32E-01	S	1.04E-02	S	1.43E-03	S
3.4	2.32E-01	S	1.04E-02	S	1.43E-03	S
3.6	2.32E-01	S	1.04E-02	S	1.43E-03	S
3.8	2.28E-01	S	1.04E-02	S	1.43E-03	S
4	2.19E-01	S	1.00E-02	S	1.43E-03	S
4.2	2.11E-01	S	9.27E-03	S	1.43E-03	S
4.4	1.58E-01	S	6.98E-03	S	1.43E-03	S
4.6	1.19E-01	S	5.29E-03	S	1.43E-03	S
4.8	1.15E-01	S	5.03E-03	S	1.43E-03	S
5	1.11E-01	S	4.79E-03	S	1.43E-03	S
5.2	1.07E-01	W	4.57E-03	S	1.43E-03	S
5.4	1.04E-01	W	4.37E-03	S	1.49E-03	S
5.6	1.00E-01	W	4.19E-03	S	1.63E-03	S
5.8	9.74E-02	W	4.02E-03	S	1.77E-03	S
6	9.79E-02	W	3.80E-03	S	2.13E-03	S
6.2	9.85E-02	W	3.60E-03	S	2.55E-03	S
6.4	9.90E-02	W	3.42E-03	S	3.03E-03	S
6.6	9.95E-02	W	3.25E-03	S	3.59E-03	S
6.8	1.00E-01	W	3.10E-03	S	4.23E-03	S
7	1.01E-01	W	2.96E-03	S	4.96E-03	S
7.2	1.00E-01	W	2.82E-03	S	5.78E-03	S
7.4	9.96E-02	W	2.70E-03	S	6.70E-03	S
7.6	9.88E-02	W	2.58E-03	S	7.73E-03	S
7.8	9.82E-02	W	2.53E-03	S	8.56E-03	S
8	9.86E-02	W	2.53E-03	S	9.18E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-30. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID JAT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.01E-01	W	2.53E-03	S	1.06E-02	S
8.4	1.02E-01	W	2.53E-03	S	1.23E-02	S
8.6	1.06E-01	W	2.53E-03	S	1.39E-02	S
8.8	1.11E-01	W	2.53E-03	S	1.49E-02	S
9	1.17E-01	W	2.53E-03	S	1.62E-02	S
9.2	1.26E-01	W	2.53E-03	S	1.80E-02	S
9.4	1.34E-01	W	2.53E-03	S	2.00E-02	S
9.6	1.45E-01	W	2.53E-03	S	2.46E-02	S
9.8	1.45E-01	W	2.53E-03	S	3.03E-02	S
10	1.25E-01	S	2.53E-03	S	3.30E-02	S
10.2	1.00E-01	S	2.53E-03	S	3.53E-02	S
10.4	8.10E-02	S	2.53E-03	S	3.78E-02	S
10.6	7.78E-02	S	2.53E-03	S	4.36E-02	S
10.8	7.48E-02	S	2.53E-03	S	5.03E-02	S
11	7.20E-02	S	2.53E-03	S	5.78E-02	S
11.2	6.93E-02	S	2.53E-03	S	6.63E-02	S
11.4	6.68E-02	S	2.53E-03	S	7.59E-02	S
11.6	6.44E-02	S	2.53E-03	S	8.66E-02	S
11.8	6.21E-02	S	2.53E-03	S	9.86E-02	S
12	6.00E-02	S	2.53E-03	S	1.12E-01	S
12.2	5.79E-02	S	2.53E-03	S	1.27E-01	S
12.4	6.04E-02	S	2.53E-03	S	2.32E-01	S
12.6	6.30E-02	S	2.53E-03	S	3.11E-01	S
12.8	6.56E-02	S	2.53E-03	S	3.11E-01	S
13	6.83E-02	S	2.53E-03	S	3.11E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.32E+00		1.04E-01		3.27E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID	PPB-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	6.75E+00	W	4.83E-02	S	8.55E-01	S
3	3.20E-03	S	6.84E+00	W	4.83E-02	S	8.55E-01	S
3.2	3.20E-03	S	6.92E+00	W	4.83E-02	S	8.55E-01	S
3.4	3.20E-03	S	7.00E+00	W	4.83E-02	S	8.55E-01	S
3.6	3.20E-03	S	7.08E+00	W	1.05E-02	S	3.56E-01	S
3.8	3.20E-03	S	7.16E+00	W	1.19E-02	S	2.81E-01	S
4	3.20E-03	S	7.23E+00	W	1.81E-02	S	5.16E-01	S
4.2	3.20E-03	S	7.30E+00	W	2.70E-02	S	6.13E-01	S
4.4	3.20E-03	S	7.36E+00	W	3.54E-02	S	5.75E-01	S
4.6	3.20E-03	S	7.42E+00	W	3.34E-02	S	4.27E-01	S
4.8	3.20E-03	S	7.49E+00	W	4.08E-02	S	6.51E-01	S
5	3.20E-03	S	7.54E+00	W	3.65E-02	S	7.11E-01	S
5.2	3.20E-03	S	7.39E+00	W	2.13E-02	S	2.86E-01	S
5.4	3.20E-03	S	7.09E+00	W	1.39E-02	S	1.46E-01	S
5.6	3.20E-03	S	6.81E+00	W	1.69E-02	S	1.37E-01	S
5.8	3.20E-03	S	7.60E+00	W	1.67E-02	S	3.42E-01	S
6	3.20E-03	S	8.61E+00	W	1.65E-02	S	2.53E-01	S
6.2	3.20E-03	S	9.72E+00	W	1.62E-02	S	1.78E-01	S
6.4	3.20E-03	S	1.09E+01	W	1.60E-02	S	1.25E-01	S
6.6	3.20E-03	S	1.22E+01	W	1.58E-02	S	8.80E-02	S
6.8	3.20E-03	S	1.37E+01	W	1.56E-02	S	6.28E-02	S
7	3.20E-03	S	1.52E+01	W	1.54E-02	S	4.52E-02	S
7.2	3.20E-03	S	1.68E+01	W	1.52E-02	S	3.29E-02	S
7.4	3.20E-03	S	1.86E+01	W	1.51E-02	S	2.41E-02	S
7.6	3.20E-03	S	2.06E+01	W	1.49E-02	S	1.79E-02	S
7.8	3.20E-03	S	2.26E+01	W	1.47E-02	S	1.33E-02	S
8	3.20E-03	S	2.48E+01	W	1.46E-02	S	1.04E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID	PPB-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	2.72E+01	W	1.44E-02	S	8.84E-03	S
8.4	3.20E-03	S	2.72E+01	W	1.43E-02	S	7.52E-03	S
8.6	3.20E-03	S	1.85E+01	W	1.41E-02	S	6.43E-03	S
8.8	3.20E-03	S	1.27E+01	W	1.40E-02	S	5.90E-03	S
9	3.20E-03	S	9.54E+00	W	1.16E-02	S	5.33E-03	S
9.2	3.20E-03	S	9.26E+00	W	1.03E-02	S	4.07E-03	S
9.4	3.20E-03	S	8.99E+00	W	9.80E-03	S	3.51E-03	S
9.6	3.20E-03	S	8.87E+00	W	8.41E-03	S	3.04E-03	S
9.8	3.20E-03	S	8.94E+00	W	6.21E-03	S	2.63E-03	S
10	3.20E-03	S	9.02E+00	S	4.61E-03	S	2.29E-03	S
10.2	3.20E-03	S	9.09E+00	S	3.44E-03	S	2.06E-03	S
10.4	3.20E-03	S	9.17E+00	S	3.31E-03	S	2.06E-03	S
10.6	3.20E-03	S	9.24E+00	S	6.66E-03	S	4.03E-03	S
10.8	3.20E-03	S	9.31E+00	S	6.58E-03	S	3.66E-03	S
11	3.20E-03	S	9.38E+00	S	4.98E-03	S	3.33E-03	S
11.2	3.20E-03	S	9.46E+00	S	3.58E-03	S	3.04E-03	S
11.4	3.20E-03	S	8.60E+00	S	2.58E-03	S	2.78E-03	S
11.6	3.20E-03	S	6.80E+00	S	1.88E-03	S	2.54E-03	S
11.8	3.20E-03	S	5.40E+00	S	2.77E-03	S	2.33E-03	S
12	3.20E-03	S	4.31E+00	S	4.69E-03	S	2.14E-03	S
12.2	3.22E-03	S	3.45E+00	S	6.13E-03	S	2.06E-03	S
12.4	6.26E-03	S	2.77E+00	S	6.07E-03	S	2.06E-03	S
12.6	7.10E-03	S	2.24E+00	S	1.30E-02	S	2.06E-03	S
12.8	7.10E-03	S	1.81E+00	S	3.54E-02	S	2.06E-03	S
13	7.10E-03	S	1.47E+00	S	4.83E-02	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	8.09E-02		2.72E+02		4.83E-01		8.55E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.50E-04	S	6.21E-05	S	8.33E-02	S	4.42E-01	W
3	2.50E-04	S	6.21E-05	S	7.16E-02	S	4.42E-01	W
3.2	1.91E-03	S	6.21E-05	S	6.21E-02	S	4.42E-01	W
3.4	1.56E-02	S	6.21E-05	S	5.43E-02	S	4.42E-01	W
3.6	8.29E-01	S	3.48E-05	S	4.79E-02	S	4.08E-01	W
3.8	7.38E-01	S	2.88E-05	S	4.25E-02	S	3.24E-01	W
4	5.74E-01	S	4.42E-05	S	3.80E-02	S	2.61E-01	W
4.2	4.64E-01	S	4.93E-05	S	3.41E-02	S	2.12E-01	W
4.4	4.88E-01	S	5.48E-05	S	3.08E-02	S	1.74E-01	W
4.6	4.54E-01	S	6.07E-05	S	2.79E-02	S	1.44E-01	W
4.8	3.46E-01	S	5.91E-05	S	2.54E-02	S	1.20E-01	W
5	3.76E-01	S	5.55E-05	S	2.32E-02	S	1.01E-01	W
5.2	5.85E-01	S	3.49E-05	S	2.85E-02	S	1.09E-01	W
5.4	7.11E-01	S	1.62E-05	S	4.41E-02	S	1.44E-01	W
5.6	7.13E-01	S	5.29E-05	S	6.70E-02	S	1.88E-01	W
5.8	7.38E-01	S	4.84E-05	S	5.20E-02	S	2.22E-01	W
6	7.64E-01	S	4.44E-05	S	6.68E-02	S	2.34E-01	W
6.2	7.89E-01	W	4.08E-05	S	8.51E-02	S	2.47E-01	W
6.4	8.15E-01	W	3.77E-05	S	1.08E-01	S	2.60E-01	W
6.6	8.41E-01	W	3.48E-05	S	1.35E-01	S	2.73E-01	W
6.8	8.66E-01	W	3.23E-05	S	1.68E-01	S	2.87E-01	W
7	8.92E-01	W	3.00E-05	S	2.08E-01	S	3.00E-01	W
7.2	9.17E-01	W	2.79E-05	S	2.57E-01	W	3.14E-01	W
7.4	9.39E-01	W	2.60E-05	S	3.14E-01	W	3.28E-01	W
7.6	9.41E-01	W	2.43E-05	S	3.82E-01	W	3.43E-01	W
7.8	9.43E-01	W	2.28E-05	S	4.63E-01	W	3.57E-01	W
8	9.45E-01	W	2.14E-05	S	5.58E-01	W	3.72E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	**Chromium**	**Solubility/ Washout**	**Mercury**	**Solubility/ Washout**	**Molybdenum**	**Solubility/ Washout**	**Antimony**	**Solubility/ Washout**
8.2	9.59E-01	W	2.01E-05	S	6.70E-01	W	3.87E-01	S
8.4	9.84E-01	W	1.89E-05	S	7.16E-01	W	2.90E-01	S
8.6	1.01E+00	W	1.77E-05	S	4.72E-01	W	5.18E-02	S
8.8	1.03E+00	W	1.67E-05	S	3.14E-01	W	9.65E-03	S
9	6.80E-01	S	1.47E-05	S	2.33E-01	S	3.65E-03	S
9.2	5.02E-01	S	1.41E-05	S	2.37E-01	S	1.09E-02	S
9.4	4.71E-01	S	1.53E-05	S	2.40E-01	S	3.19E-02	S
9.6	3.46E-01	S	1.59E-05	S	2.40E-01	S	5.77E-02	S
9.8	1.80E-01	S	1.55E-05	S	2.34E-01	S	5.39E-02	S
10	9.50E-02	S	1.50E-05	S	2.28E-01	S	5.05E-02	S
10.2	5.08E-02	S	1.46E-05	S	2.23E-01	S	4.74E-02	S
10.4	5.32E-02	S	1.42E-05	S	2.18E-01	S	4.45E-02	S
10.6	1.76E-01	S	1.38E-05	S	2.13E-01	S	4.18E-02	S
10.8	1.14E-01	S	1.35E-05	S	2.09E-01	S	3.93E-02	S
11	6.84E-02	S	1.32E-05	S	2.04E-01	S	3.70E-02	S
11.2	4.15E-02	S	1.28E-05	S	2.00E-01	S	3.49E-02	S
11.4	2.54E-02	S	1.33E-05	S	1.96E-01	S	3.30E-02	S
11.6	1.56E-02	S	1.52E-05	S	1.92E-01	S	3.12E-02	S
11.8	2.66E-02	S	1.72E-05	S	1.88E-01	S	2.95E-02	S
12	7.68E-02	S	1.94E-05	S	1.84E-01	S	2.79E-02	S
12.2	1.29E-01	S	2.08E-05	S	1.81E-01	S	2.65E-02	S
12.4	1.21E-01	S	2.47E-05	S	1.77E-01	S	2.51E-02	S
12.6	4.88E-01	S	2.78E-05	S	1.74E-01	S	2.38E-02	S
12.8	1.40E+00	S	3.12E-05	S	1.71E-01	S	2.26E-02	S
13	1.40E+00	S	3.50E-05	S	1.68E-01	S	2.15E-02	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	1.60E+01		6.21E-04		7.16E+00		4.42E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.27E-02	S	1.82E-01	S	2.73E-04	S
3	5.35E-02	S	1.82E-01	S	4.85E-04	S
3.2	6.61E-02	S	1.82E-01	S	8.29E-04	S
3.4	8.07E-02	S	1.82E-01	S	1.37E-03	S
3.6	9.73E-02	S	1.75E-01	S	2.66E-03	S
3.8	1.16E-01	S	1.56E-01	S	3.45E-03	S
4	1.08E-01	S	1.39E-01	S	2.81E-03	S
4.2	1.27E-01	S	1.25E-01	S	2.82E-03	S
4.4	1.49E-01	S	1.13E-01	S	3.10E-03	S
4.6	1.74E-01	S	1.03E-01	S	3.11E-03	S
4.8	1.83E-01	S	9.40E-02	S	3.22E-03	S
5	1.40E-01	S	8.61E-02	S	4.02E-03	S
5.2	1.23E-01	S	9.59E-02	S	4.35E-03	S
5.4	9.82E-02	S	1.24E-01	S	3.37E-03	S
5.6	9.77E-02	S	1.59E-01	S	3.09E-03	S
5.8	9.83E-02	S	1.02E-01	S	2.80E-03	S
6	9.90E-02	S	9.89E-02	S	3.23E-03	S
6.2	9.96E-02	S	9.61E-02	S	3.72E-03	S
6.4	1.00E-01	S	9.35E-02	S	4.25E-03	S
6.6	1.01E-01	S	9.10E-02	S	4.85E-03	S
6.8	1.01E-01	S	8.86E-02	S	5.51E-03	S
7	1.02E-01	S	8.64E-02	S	6.23E-03	S
7.2	1.03E-01	S	8.43E-02	S	7.03E-03	S
7.4	1.03E-01	S	8.23E-02	S	7.90E-03	S
7.6	1.04E-01	S	8.04E-02	S	8.85E-03	S
7.8	1.04E-01	S	7.86E-02	S	9.88E-03	S
8	1.05E-01	S	7.69E-02	S	1.04E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-31. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPB Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	1.05E-01	S	7.52E-02	S	1.10E-02	S
8.4	1.06E-01	S	5.94E-02	S	1.15E-02	S
8.6	1.06E-01	S	1.84E-02	S	1.24E-02	S
8.8	1.07E-01	S	5.89E-03	S	1.36E-02	S
9	1.07E-01	S	2.96E-03	S	1.38E-02	S
9.2	1.05E-01	S	5.53E-03	S	1.33E-02	S
9.4	1.04E-01	S	1.02E-02	S	1.29E-02	S
9.6	1.03E-01	S	1.39E-02	S	1.15E-02	S
9.8	1.02E-01	S	1.24E-02	S	9.12E-03	S
10	1.01E-01	S	1.11E-02	S	7.30E-03	S
10.2	1.01E-01	S	9.92E-03	S	5.86E-03	S
10.4	9.98E-02	S	8.91E-03	S	6.09E-03	S
10.6	9.90E-02	S	8.01E-03	S	1.01E-02	S
10.8	1.00E-01	S	7.22E-03	S	8.47E-03	S
11	1.03E-01	S	6.53E-03	S	6.80E-03	S
11.2	1.06E-01	S	5.91E-03	S	5.47E-03	S
11.4	1.08E-01	S	5.66E-03	S	4.42E-03	S
11.6	1.52E-01	S	5.87E-03	S	7.34E-03	S
11.8	2.14E-01	S	6.08E-03	S	1.89E-02	S
12	2.99E-01	S	6.29E-03	S	4.81E-02	S
12.2	3.54E-01	S	6.50E-03	S	7.68E-02	S
12.4	3.54E-01	S	6.72E-03	S	7.68E-02	S
12.6	3.54E-01	S	6.95E-03	S	8.04E-02	S
12.8	3.54E-01	S	7.17E-03	S	8.04E-02	S
13	3.54E-01	S	7.40E-03	S	8.04E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.04E+00		1.82E+00		9.17E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID	PPT-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	7.37E+00	W	5.86E-02	S	2.05E-04	S
3	3.20E-03	S	7.96E+00	W	5.86E-02	S	2.05E-04	S
3.2	3.20E-03	S	8.55E+00	W	3.80E-02	S	2.05E-04	S
3.4	3.20E-03	S	9.14E+00	W	2.06E-02	S	1.71E-02	S
3.6	3.20E-03	S	9.73E+00	W	5.04E-02	S	8.88E-01	S
3.8	3.20E-03	S	1.03E+01	W	2.89E-02	S	3.94E-01	S
4	3.20E-03	S	1.09E+01	W	1.71E-02	S	2.59E-01	S
4.2	3.20E-03	S	1.15E+01	W	4.18E-02	S	9.19E-01	S
4.4	3.20E-03	S	8.15E+00	W	2.54E-02	S	6.71E-01	S
4.6	3.20E-03	S	8.10E+00	W	1.78E-02	S	4.36E-01	S
4.8	3.20E-03	S	8.06E+00	W	1.62E-02	S	2.88E-01	S
5	3.20E-03	S	8.02E+00	W	1.95E-02	S	2.90E-01	S
5.2	3.20E-03	S	7.53E+00	W	2.33E-02	S	2.16E-01	S
5.4	3.20E-03	S	6.47E+00	W	2.62E-02	S	1.62E-01	S
5.6	3.20E-03	S	5.81E+00	W	2.28E-02	S	1.47E-01	S
5.8	3.20E-03	S	6.24E+00	W	1.99E-02	S	1.18E-01	S
6	3.20E-03	S	6.69E+00	W	1.74E-02	S	9.49E-02	S
6.2	3.20E-03	S	7.16E+00	W	1.54E-02	S	7.71E-02	S
6.4	3.20E-03	S	7.70E+00	W	1.36E-02	S	6.07E-02	S
6.6	3.20E-03	S	8.34E+00	W	1.21E-02	S	4.56E-02	S
6.8	3.20E-03	S	9.01E+00	W	1.11E-02	S	3.45E-02	S
7	3.20E-03	S	9.72E+00	W	1.18E-02	S	2.63E-02	S
7.2	3.20E-03	S	1.05E+01	W	1.25E-02	S	2.02E-02	S
7.4	3.20E-03	S	1.12E+01	W	1.33E-02	S	1.57E-02	S
7.6	3.20E-03	S	1.20E+01	W	1.41E-02	S	1.22E-02	S
7.8	3.20E-03	S	1.29E+01	W	1.49E-02	S	1.00E-02	S
8	3.20E-03	S	1.30E+01	W	1.53E-02	S	8.29E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID	PPT-[Med] (P,1,1)
Date Exported	8/27/2011, 2:09 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	1.23E+01	W	1.46E-02	S	6.98E-03	S
8.4	3.20E-03	S	1.17E+01	W	1.43E-02	S	6.17E-03	S
8.6	3.20E-03	S	1.11E+01	W	1.39E-02	S	5.48E-03	S
8.8	3.20E-03	S	1.05E+01	W	1.35E-02	S	4.86E-03	S
9	3.20E-03	S	9.99E+00	W	1.32E-02	S	3.84E-03	S
9.2	3.20E-03	S	9.51E+00	W	1.29E-02	S	3.14E-03	S
9.4	3.20E-03	S	9.05E+00	W	1.26E-02	S	2.71E-03	S
9.6	3.20E-03	S	8.63E+00	W	1.23E-02	S	2.34E-03	S
9.8	3.20E-03	S	8.24E+00	W	1.19E-02	S	2.06E-03	S
10	3.20E-03	S	7.87E+00	S	1.08E-02	S	2.06E-03	S
10.2	3.20E-03	S	7.53E+00	S	9.89E-03	S	2.06E-03	S
10.4	3.20E-03	S	7.20E+00	S	9.05E-03	S	2.06E-03	S
10.6	3.20E-03	S	5.20E+00	S	8.29E-03	S	2.06E-03	S
10.8	3.20E-03	S	3.69E+00	S	7.60E-03	S	2.06E-03	S
11	3.20E-03	S	2.63E+00	S	6.99E-03	S	2.06E-03	S
11.2	3.20E-03	S	1.89E+00	S	6.43E-03	S	2.06E-03	S
11.4	3.20E-03	S	1.37E+00	S	5.93E-03	S	2.06E-03	S
11.6	3.20E-03	S	9.93E-01	S	5.33E-03	S	2.06E-03	S
11.8	3.20E-03	S	7.25E-01	S	4.89E-03	S	2.06E-03	S
12	3.20E-03	S	5.38E-01	S	5.00E-03	S	2.06E-03	S
12.2	3.20E-03	S	4.18E-01	S	7.18E-03	S	2.06E-03	S
12.4	3.88E-03	S	4.11E-01	S	1.00E-02	S	2.06E-03	S
12.6	7.88E-03	S	7.56E-01	S	1.02E-02	S	2.06E-03	S
12.8	1.58E-02	S	1.38E+00	S	1.05E-02	S	2.06E-03	S
13	3.14E-02	S	2.48E+00	S	1.06E-02	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	2.50E-01		1.30E+02		5.86E-01		9.19E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	8.97E-02	S	2.07E-06	S	5.00E-04	S	6.53E-02	W
3	8.29E-02	S	2.07E-06	S	5.00E-04	S	8.80E-02	W
3.2	7.70E-02	S	2.07E-06	S	5.00E-04	S	1.16E-01	W
3.4	7.18E-02	S	2.07E-06	S	5.00E-04	S	1.51E-01	W
3.6	6.76E-03	S	2.07E-06	S	5.00E-04	S	1.94E-01	W
3.8	8.86E-03	S	2.07E-06	S	5.00E-04	S	2.45E-01	W
4	1.14E-02	S	3.23E-06	S	1.98E-03	S	3.06E-01	W
4.2	1.21E-02	S	2.18E-06	S	9.12E-03	S	3.78E-01	W
4.4	1.34E-02	S	3.35E-06	S	2.28E-03	S	2.46E-01	W
4.6	1.57E-02	S	6.13E-06	S	8.10E-03	S	2.97E-01	W
4.8	1.84E-02	S	7.02E-06	S	2.72E-02	S	3.56E-01	W
5	2.13E-02	S	1.18E-05	S	8.71E-02	S	4.22E-01	W
5.2	2.46E-02	S	1.11E-05	S	1.61E-01	S	4.47E-01	W
5.4	2.83E-02	S	4.92E-06	S	1.31E-01	S	3.97E-01	W
5.6	3.23E-02	S	4.55E-06	S	1.15E-01	S	3.59E-01	W
5.8	3.67E-02	S	4.23E-06	S	1.37E-01	S	3.46E-01	W
6	4.16E-02	S	4.69E-06	S	1.62E-01	S	3.33E-01	W
6.2	4.68E-02	W	6.70E-06	S	1.91E-01	S	3.21E-01	W
6.4	5.26E-02	W	5.04E-06	S	2.17E-01	S	3.13E-01	W
6.6	5.89E-02	W	3.39E-06	S	2.36E-01	S	3.09E-01	W
6.8	7.70E-02	W	3.02E-06	S	2.55E-01	S	3.05E-01	W
7	8.80E-02	W	2.84E-06	S	2.76E-01	S	3.01E-01	W
7.2	9.52E-02	W	2.67E-06	S	2.97E-01	W	2.97E-01	W
7.4	1.03E-01	W	2.52E-06	S	3.20E-01	W	2.94E-01	W
7.6	1.09E-01	W	2.44E-06	S	3.43E-01	W	2.91E-01	W
7.8	1.08E-01	W	5.15E-06	S	3.68E-01	W	2.87E-01	W
8	1.13E-01	W	1.06E-05	S	3.80E-01	W	2.59E-01	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.20E-01	W	2.16E-05	S	3.74E-01	W	2.07E-01	S
8.4	1.28E-01	W	2.39E-05	S	3.68E-01	W	1.66E-01	S
8.6	1.36E-01	W	2.22E-05	S	3.63E-01	W	1.34E-01	S
8.8	1.46E-01	W	2.07E-05	S	3.57E-01	W	1.09E-01	S
9	1.64E-01	S	1.93E-05	S	3.52E-01	W	8.87E-02	S
9.2	1.84E-01	S	1.80E-05	S	3.47E-01	W	7.26E-02	S
9.4	2.06E-01	S	1.69E-05	S	3.43E-01	W	5.97E-02	S
9.6	2.17E-01	S	1.61E-05	S	3.38E-01	W	4.93E-02	S
9.8	1.95E-01	S	1.61E-05	S	3.34E-01	W	4.09E-02	S
10	1.98E-01	S	1.61E-05	S	3.29E-01	S	3.40E-02	S
10.2	2.07E-01	S	1.61E-05	S	3.25E-01	S	2.84E-02	S
10.4	1.87E-01	S	1.61E-05	S	3.21E-01	S	2.38E-02	S
10.6	1.69E-01	S	1.61E-05	S	2.75E-01	S	1.96E-02	S
10.8	1.53E-01	S	1.61E-05	S	2.33E-01	S	1.62E-02	S
11	1.39E-01	S	1.61E-05	S	1.98E-01	S	1.34E-02	S
11.2	1.22E-01	S	1.61E-05	S	1.69E-01	S	1.12E-02	S
11.4	1.06E-01	S	1.61E-05	S	1.45E-01	S	9.33E-03	S
11.6	9.21E-02	S	1.61E-05	S	1.24E-01	S	7.81E-03	S
11.8	9.59E-02	S	1.72E-05	S	1.07E-01	S	6.55E-03	S
12	9.72E-02	S	1.63E-05	S	1.05E-01	S	5.79E-03	S
12.2	1.91E-01	S	4.91E-06	S	1.83E-01	S	6.25E-03	S
12.4	3.47E-01	S	2.49E-06	S	2.70E-01	S	8.43E-03	S
12.6	3.68E-01	S	4.92E-06	S	2.64E-01	S	2.06E-02	S
12.8	3.89E-01	S	9.60E-06	S	2.59E-01	S	4.97E-02	S
13	4.13E-01	S	1.86E-05	S	2.53E-01	S	1.18E-01	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		1.00E-03		8.00E-05	
Availability (mg/kg)	6.15E+00		2.39E-04		4.09E+00		4.47E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	7.70E-03	S	1.95E-01	S	2.59E-02	S
3	1.28E-02	S	2.37E-01	S	1.69E-02	S
3.2	2.06E-02	S	2.83E-01	S	1.14E-02	S
3.4	3.22E-02	S	3.35E-01	S	7.83E-03	S
3.6	8.88E-02	S	3.93E-01	S	3.46E-03	S
3.8	8.34E-02	S	4.57E-01	S	3.75E-03	S
4	7.64E-02	S	5.27E-01	S	3.36E-03	S
4.2	7.69E-02	S	6.04E-01	S	2.55E-03	S
4.4	6.87E-02	S	5.46E-01	S	3.59E-03	S
4.6	6.83E-02	S	4.78E-01	S	3.33E-03	S
4.8	6.80E-02	S	4.21E-01	S	3.33E-03	S
5	6.77E-02	S	3.73E-01	S	3.69E-03	S
5.2	6.74E-02	S	3.57E-01	S	4.08E-03	S
5.4	6.74E-02	S	3.84E-01	S	4.32E-03	S
5.6	6.80E-02	S	3.92E-01	S	4.36E-03	S
5.8	6.88E-02	S	3.21E-01	S	4.54E-03	S
6	6.97E-02	S	2.65E-01	S	4.72E-03	S
6.2	7.05E-02	S	2.20E-01	S	4.90E-03	S
6.4	7.09E-02	S	1.92E-01	S	5.28E-03	S
6.6	7.06E-02	S	1.82E-01	S	6.01E-03	S
6.8	7.03E-02	S	1.73E-01	S	6.83E-03	S
7	7.00E-02	S	1.65E-01	S	7.72E-03	S
7.2	6.97E-02	S	1.57E-01	S	8.70E-03	S
7.4	6.94E-02	S	1.50E-01	S	9.78E-03	S
7.6	6.96E-02	S	1.43E-01	S	1.07E-02	S
7.8	6.89E-02	S	1.37E-01	S	1.14E-02	S
8	6.91E-02	S	1.27E-01	S	1.22E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-32. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID PPT Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	6.97E-02	S	1.13E-01	S	1.30E-02	S
8.4	7.04E-02	S	1.01E-01	S	1.39E-02	S
8.6	7.25E-02	S	9.05E-02	S	1.54E-02	S
8.8	7.47E-02	S	8.13E-02	S	1.63E-02	S
9	7.69E-02	S	7.32E-02	S	1.71E-02	S
9.2	7.92E-02	S	6.61E-02	S	1.79E-02	S
9.4	8.14E-02	S	5.98E-02	S	1.88E-02	S
9.6	8.29E-02	S	5.42E-02	S	1.97E-02	S
9.8	7.44E-02	S	4.92E-02	S	2.05E-02	S
10	7.50E-02	S	4.48E-02	S	1.86E-02	S
10.2	6.76E-02	S	4.09E-02	S	1.66E-02	S
10.4	6.06E-02	S	3.73E-02	S	1.48E-02	S
10.6	5.44E-02	S	2.64E-02	S	1.33E-02	S
10.8	4.89E-02	S	1.84E-02	S	1.19E-02	S
11	4.41E-02	S	1.29E-02	S	1.08E-02	S
11.2	3.81E-02	S	9.06E-03	S	9.94E-03	S
11.4	3.22E-02	S	6.43E-03	S	9.13E-03	S
11.6	2.87E-02	S	4.59E-03	S	8.39E-03	S
11.8	2.97E-02	S	3.29E-03	S	8.32E-03	S
12	2.81E-02	S	2.53E-03	S	1.02E-02	S
12.2	3.45E-02	S	2.53E-03	S	5.00E-02	S
12.4	5.77E-02	S	2.95E-03	S	1.69E-01	S
12.6	1.20E-01	S	5.17E-03	S	2.21E-01	S
12.8	2.46E-01	S	8.98E-03	S	2.88E-01	S
13	4.98E-01	S	1.55E-02	S	3.73E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.88E+00		6.04E+00		4.55E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID	XFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:10 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	8.64E+00	W	7.68E-02	S	1.76E+00	S
3	3.20E-03	S	7.47E+00	W	7.68E-02	S	1.76E+00	S
3.2	3.20E-03	S	6.52E+00	W	3.51E-02	S	9.64E-01	S
3.4	3.20E-03	S	5.73E+00	W	7.85E-03	S	3.05E-01	S
3.6	3.20E-03	S	5.08E+00	W	1.91E-03	S	1.03E-01	S
3.8	3.20E-03	S	4.74E+00	W	7.46E-04	S	5.12E-02	S
4	3.20E-03	S	4.91E+00	W	7.46E-04	S	5.60E-02	S
4.2	3.20E-03	S	5.07E+00	W	7.46E-04	S	6.08E-02	S
4.4	3.20E-03	S	5.17E+00	W	8.13E-04	S	6.29E-02	S
4.6	3.20E-03	S	5.14E+00	W	1.07E-03	S	5.85E-02	S
4.8	3.20E-03	S	5.11E+00	W	1.40E-03	S	5.45E-02	S
5	3.20E-03	S	5.07E+00	W	1.79E-03	S	4.61E-02	S
5.2	3.20E-03	S	5.10E+00	W	2.06E-03	W	3.97E-02	S
5.4	3.20E-03	S	5.23E+00	W	2.06E-03	W	3.69E-02	S
5.6	3.20E-03	S	5.36E+00	W	2.06E-03	W	3.44E-02	S
5.8	3.20E-03	S	5.49E+00	W	2.06E-03	W	3.21E-02	S
6	3.20E-03	S	5.62E+00	W	2.06E-03	W	3.01E-02	S
6.2	3.20E-03	S	5.74E+00	W	2.06E-03	W	2.82E-02	S
6.4	3.20E-03	S	5.86E+00	W	2.06E-03	W	2.65E-02	S
6.6	3.20E-03	S	5.99E+00	W	2.06E-03	W	2.50E-02	S
6.8	3.20E-03	S	6.11E+00	W	2.06E-03	W	2.36E-02	S
7	3.20E-03	S	6.96E+00	W	2.11E-03	W	2.10E-02	S
7.2	3.20E-03	S	7.90E+00	W	2.16E-03	W	1.88E-02	S
7.4	3.20E-03	S	8.94E+00	W	2.20E-03	W	1.69E-02	S
7.6	3.20E-03	S	1.01E+01	W	2.25E-03	W	1.52E-02	S
7.8	3.20E-03	S	1.02E+01	W	2.24E-03	W	1.41E-02	S
8	3.20E-03	S	1.04E+01	W	2.24E-03	W	1.32E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID	XFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:10 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	1.05E+01	W	2.23E-03	W	1.23E-02	S
8.4	3.20E-03	S	1.07E+01	W	2.23E-03	W	1.15E-02	S
8.6	3.20E-03	S	1.08E+01	W	2.22E-03	W	1.07E-02	S
8.8	3.20E-03	S	1.10E+01	W	2.22E-03	W	1.00E-02	S
9	3.20E-03	S	1.11E+01	W	2.21E-03	W	9.42E-03	S
9.2	3.20E-03	S	1.07E+01	W	2.28E-03	W	8.43E-03	S
9.4	3.20E-03	S	1.00E+01	W	2.39E-03	W	7.40E-03	S
9.6	3.20E-03	S	9.46E+00	W	2.50E-03	W	6.51E-03	S
9.8	3.20E-03	S	8.92E+00	W	2.61E-03	W	5.75E-03	S
10	3.20E-03	S	7.36E+00	S	2.45E-03	S	5.07E-03	S
10.2	3.20E-03	S	5.34E+00	S	2.07E-03	S	4.46E-03	S
10.4	3.20E-03	S	3.90E+00	S	1.75E-03	S	3.94E-03	S
10.6	3.20E-03	S	2.86E+00	S	1.49E-03	S	3.48E-03	S
10.8	3.20E-03	S	2.11E+00	S	1.27E-03	S	3.09E-03	S
11	3.20E-03	S	1.57E+00	S	1.09E-03	S	2.74E-03	S
11.2	3.20E-03	S	1.17E+00	S	9.34E-04	S	2.44E-03	S
11.4	3.20E-03	S	8.78E-01	S	8.04E-04	S	2.18E-03	S
11.6	3.20E-03	S	1.03E+00	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.89E+00	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	3.43E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	6.16E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.10E+01	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.11E+01	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.11E+01	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.11E+01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	3.26E-02		1.14E+02		7.68E-01		1.76E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.13E-02	S	1.00E-04	S	1.07E-02	S	2.78E-03	S
3	1.00E-01	S	1.00E-04	S	3.45E-02	S	2.78E-03	S
3.2	2.30E-01	S	8.21E-05	S	1.03E-01	S	2.78E-03	S
3.4	5.01E-01	S	5.64E-05	S	2.89E-01	S	2.78E-03	S
3.6	1.04E+00	S	3.96E-05	S	7.62E-01	S	2.78E-03	S
3.8	1.67E+00	S	3.13E-05	S	1.44E+00	S	2.78E-03	S
4	1.57E+00	S	3.13E-05	S	1.40E+00	S	2.78E-03	S
4.2	1.48E+00	S	3.13E-05	S	1.36E+00	S	2.78E-03	S
4.4	1.48E+00	S	3.08E-05	S	1.36E+00	S	2.78E-03	S
4.6	1.67E+00	S	2.96E-05	S	1.47E+00	S	2.78E-03	S
4.8	1.87E+00	S	2.84E-05	S	1.58E+00	S	2.78E-03	S
5	2.03E+00	S	2.24E-05	S	1.75E+00	S	2.78E-03	S
5.2	2.12E+00	W	1.93E-05	S	1.88E+00	W	2.78E-03	S
5.4	2.16E+00	W	2.06E-05	S	1.92E+00	W	2.78E-03	S
5.6	2.19E+00	W	2.20E-05	S	1.96E+00	W	2.78E-03	S
5.8	2.23E+00	W	2.35E-05	S	1.99E+00	W	2.78E-03	S
6	2.26E+00	W	2.49E-05	S	2.03E+00	W	2.78E-03	S
6.2	2.29E+00	W	2.65E-05	S	2.06E+00	W	2.78E-03	S
6.4	2.32E+00	W	2.80E-05	S	2.10E+00	W	2.78E-03	S
6.6	2.35E+00	W	2.96E-05	S	2.13E+00	W	2.78E-03	S
6.8	2.38E+00	W	3.13E-05	S	2.16E+00	W	2.78E-03	S
7	2.54E+00	W	2.95E-05	S	2.20E+00	W	2.78E-03	S
7.2	2.69E+00	W	2.79E-05	S	2.23E+00	W	2.78E-03	S
7.4	2.86E+00	W	2.64E-05	S	2.26E+00	W	2.78E-03	S
7.6	3.03E+00	W	2.50E-05	S	2.29E+00	W	2.78E-03	S
7.8	3.08E+00	W	2.65E-05	S	2.28E+00	W	2.78E-03	S
8	3.14E+00	W	2.81E-05	S	2.28E+00	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.20E+00	W	2.98E-05	S	2.27E+00	W	2.78E-03	S
8.4	3.26E+00	W	3.15E-05	S	2.27E+00	W	2.78E-03	S
8.6	3.31E+00	W	3.33E-05	S	2.26E+00	W	2.78E-03	S
8.8	3.37E+00	W	3.51E-05	S	2.26E+00	W	2.78E-03	S
9	3.43E+00	W	3.69E-05	S	2.25E+00	W	2.78E-03	S
9.2	3.40E+00	W	3.69E-05	S	2.28E+00	W	2.78E-03	S
9.4	3.35E+00	W	3.62E-05	S	2.31E+00	W	2.78E-03	S
9.6	3.29E+00	W	3.54E-05	S	2.35E+00	W	2.78E-03	S
9.8	3.24E+00	W	3.47E-05	S	2.39E+00	W	2.78E-03	S
10	2.66E+00	S	3.46E-05	S	2.18E+00	S	2.78E-03	S
10.2	1.83E+00	S	3.50E-05	S	1.79E+00	S	2.78E-03	S
10.4	1.26E+00	S	3.54E-05	S	1.48E+00	S	2.78E-03	S
10.6	8.80E-01	S	3.58E-05	S	1.22E+00	S	2.78E-03	S
10.8	6.17E-01	S	3.62E-05	S	1.02E+00	S	2.78E-03	S
11	4.35E-01	S	3.65E-05	S	8.48E-01	S	2.78E-03	S
11.2	3.09E-01	S	3.69E-05	S	7.09E-01	S	2.78E-03	S
11.4	2.21E-01	S	3.73E-05	S	5.95E-01	S	2.78E-03	S
11.6	1.10E-01	S	3.37E-05	S	3.15E-01	S	2.78E-03	S
11.8	3.85E-02	S	2.74E-05	S	1.06E-01	S	2.78E-03	S
12	1.37E-02	S	2.23E-05	S	3.64E-02	S	2.78E-03	S
12.2	4.98E-03	S	1.83E-05	S	1.27E-02	S	2.78E-03	S
12.4	1.84E-03	S	1.50E-05	S	4.52E-03	S	2.78E-03	S
12.6	6.89E-04	S	1.23E-05	S	1.63E-03	S	2.78E-03	S
12.8	2.62E-04	S	1.02E-05	S	6.00E-04	S	2.78E-03	S
13	2.50E-04	S	8.42E-06	S	3.80E-04	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.43E+01		1.00E-03		2.39E+01		2.84E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
2.8	5.04E-01	S	8.63E-03	S	1.73E-03	S
3	5.04E-01	S	8.63E-03	S	2.49E-03	S
3.2	4.11E-01	S	7.01E-03	S	3.51E-03	S
3.4	2.78E-01	S	4.72E-03	S	4.84E-03	S
3.6	1.93E-01	S	3.25E-03	S	6.55E-03	S
3.8	1.51E-01	S	2.53E-03	S	8.23E-03	S
4	1.52E-01	S	2.53E-03	S	8.98E-03	S
4.2	1.53E-01	S	2.53E-03	S	9.76E-03	S
4.4	1.54E-01	S	2.53E-03	S	1.07E-02	S
4.6	1.57E-01	S	2.53E-03	S	1.21E-02	S
4.8	1.59E-01	S	2.53E-03	S	1.36E-02	S
5	1.65E-01	S	2.53E-03	S	1.61E-02	S
5.2	1.70E-01	S	2.53E-03	S	1.83E-02	S
5.4	1.72E-01	S	2.53E-03	S	1.95E-02	S
5.6	1.74E-01	S	2.53E-03	S	2.07E-02	S
5.8	1.77E-01	S	2.53E-03	S	2.19E-02	S
6	1.79E-01	S	2.53E-03	S	2.32E-02	S
6.2	1.81E-01	S	2.53E-03	S	2.45E-02	S
6.4	1.84E-01	S	2.53E-03	S	2.58E-02	S
6.6	1.86E-01	S	2.53E-03	S	2.71E-02	S
6.8	1.88E-01	S	2.53E-03	S	2.85E-02	S
7	1.90E-01	S	2.53E-03	S	3.14E-02	S
7.2	1.93E-01	S	2.53E-03	S	3.45E-02	S
7.4	1.95E-01	S	2.53E-03	S	3.78E-02	S
7.6	1.97E-01	S	2.53E-03	S	4.13E-02	S
7.8	1.93E-01	S	2.53E-03	S	4.42E-02	S
8	1.90E-01	S	2.53E-03	S	4.72E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-33. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID XFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	1.86E-01	S	2.53E-03	S	5.03E-02	S
8.4	1.83E-01	S	2.53E-03	S	5.36E-02	S
8.6	1.80E-01	S	2.53E-03	S	5.70E-02	S
8.8	1.77E-01	S	2.53E-03	S	6.05E-02	S
9	1.74E-01	S	2.53E-03	S	6.41E-02	S
9.2	1.73E-01	S	2.53E-03	S	6.49E-02	S
9.4	1.71E-01	S	2.53E-03	S	6.44E-02	S
9.6	1.70E-01	S	2.53E-03	S	6.40E-02	S
9.8	1.69E-01	S	2.53E-03	S	6.36E-02	S
10	1.47E-01	S	2.53E-03	S	6.22E-02	S
10.2	1.13E-01	S	2.53E-03	S	5.99E-02	S
10.4	8.68E-02	S	2.53E-03	S	5.77E-02	S
10.6	6.72E-02	S	2.53E-03	S	5.56E-02	S
10.8	5.22E-02	S	2.53E-03	S	5.37E-02	S
11	4.08E-02	S	2.53E-03	S	5.18E-02	S
11.2	3.20E-02	S	2.53E-03	S	5.01E-02	S
11.4	2.52E-02	S	2.53E-03	S	4.84E-02	S
11.6	2.12E-02	S	2.53E-03	S	3.33E-02	S
11.8	1.89E-02	S	2.53E-03	S	1.64E-02	S
12	1.69E-02	S	2.53E-03	S	8.15E-03	S
12.2	1.52E-02	S	2.53E-03	S	4.11E-03	S
12.4	1.36E-02	S	2.53E-03	S	2.09E-03	S
12.6	1.22E-02	S	2.53E-03	S	1.08E-03	S
12.8	1.10E-02	S	2.53E-03	S	5.61E-04	S
13	9.94E-03	S	2.53E-03	S	2.95E-04	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	5.04E+00		8.63E-02		6.49E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID	ZFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:10 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
2.8	3.20E-03	S	7.19E+00	S	1.83E-01	S	2.83E+00	S
3	3.20E-03	S	6.32E+00	S	1.83E-01	S	3.06E+00	S
3.2	3.20E-03	S	5.60E+00	S	1.83E-01	S	3.28E+00	S
3.4	3.20E-03	S	5.00E+00	S	1.83E-01	S	3.50E+00	S
3.6	3.20E-03	S	4.50E+00	S	1.80E-01	S	3.73E+00	S
3.8	3.20E-03	S	4.06E+00	S	1.29E-01	S	3.96E+00	S
4	3.20E-03	S	3.69E+00	S	9.36E-02	S	4.19E+00	S
4.2	3.20E-03	S	3.37E+00	S	6.92E-02	S	4.42E+00	S
4.4	3.20E-03	S	3.27E+00	S	5.63E-02	S	4.15E+00	S
4.6	3.20E-03	S	3.19E+00	S	4.66E-02	S	3.86E+00	S
4.8	3.20E-03	S	3.12E+00	S	3.89E-02	S	3.60E+00	S
5	3.20E-03	S	3.05E+00	S	3.27E-02	S	3.37E+00	S
5.2	3.20E-03	S	3.00E+00	S	2.26E-02	S	2.77E+00	S
5.4	3.20E-03	S	2.96E+00	S	1.18E-02	S	1.89E+00	S
5.6	3.20E-03	S	2.93E+00	S	6.32E-03	S	1.31E+00	S
5.8	3.20E-03	S	2.89E+00	S	3.46E-03	S	9.21E-01	S
6	3.20E-03	S	2.86E+00	S	1.93E-03	S	6.54E-01	S
6.2	3.20E-03	S	2.83E+00	S	1.10E-03	S	4.70E-01	S
6.4	3.20E-03	S	2.86E+00	S	7.46E-04	S	3.18E-01	S
6.6	3.20E-03	S	3.00E+00	S	7.46E-04	S	1.86E-01	S
6.8	3.20E-03	S	3.15E+00	S	7.46E-04	S	1.11E-01	S
7	3.20E-03	S	3.30E+00	S	7.46E-04	S	6.67E-02	S
7.2	3.20E-03	S	3.45E+00	S	7.46E-04	S	4.08E-02	S
7.4	3.20E-03	S	3.71E+00	S	7.46E-04	S	2.86E-02	S
7.6	3.20E-03	S	4.26E+00	S	7.46E-04	S	2.68E-02	S
7.8	3.20E-03	S	4.87E+00	S	7.46E-04	S	2.52E-02	S
8	3.20E-03	S	5.54E+00	S	7.46E-04	S	2.36E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID	ZFA-[Med] (P,1,1)
Date Exported	8/27/2011, 2:10 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

	Concentration (mg/L)							
pH	**Arsenic**	**Solubility/ Washout**	**Boron**	**Solubility/ Washout**	**Cadmium**	**Solubility/ Washout**	**Cobalt**	**Solubility/ Washout**
8.2	3.20E-03	S	6.22E+00	W	7.46E-04	S	2.01E-02	S
8.4	3.20E-03	S	6.96E+00	W	7.46E-04	S	1.73E-02	S
8.6	3.20E-03	S	7.76E+00	W	7.46E-04	S	1.49E-02	S
8.8	3.20E-03	S	8.04E+00	W	7.46E-04	S	1.38E-02	S
9	3.20E-03	S	8.21E+00	W	7.46E-04	S	1.29E-02	S
9.2	3.20E-03	S	8.37E+00	W	7.46E-04	S	1.22E-02	S
9.4	3.20E-03	S	8.54E+00	W	7.46E-04	S	1.15E-02	S
9.6	3.20E-03	S	6.65E+00	W	7.46E-04	S	1.07E-02	S
9.8	3.20E-03	S	4.50E+00	W	7.46E-04	S	9.94E-03	S
10	3.20E-03	S	3.07E+00	S	7.46E-04	S	9.25E-03	S
10.2	3.20E-03	S	2.11E+00	S	7.46E-04	S	8.61E-03	S
10.4	3.20E-03	S	1.46E+00	S	7.46E-04	S	8.03E-03	S
10.6	3.20E-03	S	1.02E+00	S	7.46E-04	S	7.50E-03	S
10.8	3.20E-03	S	7.17E-01	S	7.46E-04	S	7.01E-03	S
11	3.20E-03	S	5.45E-01	S	7.46E-04	S	6.45E-03	S
11.2	3.20E-03	S	8.01E-01	S	7.46E-04	S	5.07E-03	S
11.4	3.20E-03	S	1.17E+00	S	7.46E-04	S	4.00E-03	S
11.6	3.20E-03	S	1.69E+00	S	7.46E-04	S	3.17E-03	S
11.8	3.20E-03	S	2.43E+00	S	7.46E-04	S	2.52E-03	S
12	3.20E-03	S	3.42E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	4.12E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	4.94E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	5.91E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	7.05E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	8.38E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	3.37E-02		8.54E+01		1.83E+00		4.42E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.50E-04	S	3.00E-06	S	3.80E-04	S	2.78E-03	S
3	2.50E-04	S	3.00E-06	S	3.80E-04	S	2.78E-03	S
3.2	2.58E-04	S	3.00E-06	S	7.10E-04	S	2.78E-03	S
3.4	7.39E-04	S	3.00E-06	S	1.72E-03	S	2.78E-03	S
3.6	1.99E-03	S	3.00E-06	S	3.95E-03	S	2.78E-03	S
3.8	5.08E-03	S	3.00E-06	S	8.69E-03	S	2.78E-03	S
4	1.24E-02	S	3.00E-06	S	1.84E-02	S	2.78E-03	S
4.2	2.88E-02	S	3.00E-06	S	3.74E-02	S	2.78E-03	S
4.4	3.57E-02	S	3.00E-06	S	4.66E-02	S	2.78E-03	S
4.6	4.12E-02	S	3.00E-06	S	5.46E-02	S	2.78E-03	S
4.8	4.71E-02	S	3.00E-06	S	6.37E-02	S	2.78E-03	S
5	5.36E-02	S	3.00E-06	S	7.37E-02	S	2.78E-03	S
5.2	6.43E-02	S	3.00E-06	S	9.18E-02	S	2.78E-03	S
5.4	8.32E-02	S	3.00E-06	S	1.27E-01	S	2.78E-03	S
5.6	1.07E-01	S	3.00E-06	S	1.75E-01	S	2.78E-03	S
5.8	1.36E-01	S	3.00E-06	S	2.37E-01	S	2.78E-03	S
6	1.71E-01	S	3.00E-06	S	3.19E-01	S	2.78E-03	S
6.2	2.14E-01	S	3.00E-06	S	4.24E-01	S	2.78E-03	S
6.4	2.66E-01	S	3.00E-06	S	5.22E-01	S	2.78E-03	S
6.6	3.29E-01	S	3.00E-06	S	5.50E-01	S	2.78E-03	S
6.8	4.03E-01	S	3.00E-06	S	5.78E-01	S	2.78E-03	S
7	4.91E-01	S	3.00E-06	S	6.06E-01	S	2.78E-03	S
7.2	5.95E-01	S	3.00E-06	S	6.35E-01	W	2.78E-03	S
7.4	7.01E-01	S	3.00E-06	S	6.61E-01	W	2.78E-03	S
7.6	7.80E-01	S	3.00E-06	S	6.76E-01	W	2.78E-03	S
7.8	8.65E-01	S	3.00E-06	S	6.91E-01	W	2.78E-03	S
8	9.61E-01	S	3.00E-06	S	7.04E-01	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.14E+00	S	3.00E-06	S	6.78E-01	W	2.78E-03	S
8.4	1.36E+00	S	3.00E-06	S	6.53E-01	W	2.78E-03	S
8.6	1.60E+00	S	3.00E-06	S	6.29E-01	W	2.78E-03	S
8.8	1.70E+00	S	3.00E-06	S	6.19E-01	W	2.78E-03	S
9	1.76E+00	S	3.00E-06	S	6.12E-01	W	2.78E-03	S
9.2	1.83E+00	S	3.00E-06	S	6.05E-01	W	2.78E-03	S
9.4	1.90E+00	S	3.00E-06	S	5.98E-01	W	2.78E-03	S
9.6	1.53E+00	S	3.00E-06	S	5.31E-01	W	2.78E-03	S
9.8	1.08E+00	S	3.00E-06	S	4.46E-01	W	2.78E-03	S
10	7.72E-01	S	3.00E-06	S	3.76E-01	S	2.78E-03	S
10.2	5.55E-01	S	3.00E-06	S	3.18E-01	S	2.78E-03	S
10.4	4.01E-01	S	3.00E-06	S	2.70E-01	S	2.78E-03	S
10.6	2.91E-01	S	3.00E-06	S	2.30E-01	S	2.78E-03	S
10.8	2.13E-01	S	3.00E-06	S	1.96E-01	S	2.78E-03	S
11	1.51E-01	S	3.00E-06	S	1.61E-01	S	2.78E-03	S
11.2	7.73E-02	S	3.00E-06	S	8.66E-02	S	2.78E-03	S
11.4	4.00E-02	S	3.00E-06	S	4.72E-02	S	2.78E-03	S
11.6	2.09E-02	S	3.00E-06	S	2.60E-02	S	2.78E-03	S
11.8	1.11E-02	S	3.00E-06	S	1.45E-02	S	2.78E-03	S
12	6.37E-03	S	3.00E-06	S	8.59E-03	S	2.78E-03	S
12.2	7.08E-03	S	3.00E-06	S	8.28E-03	S	2.78E-03	S
12.4	7.85E-03	S	3.00E-06	S	7.98E-03	S	2.78E-03	S
12.6	8.68E-03	S	3.00E-06	S	7.70E-03	S	2.78E-03	S
12.8	9.60E-03	S	3.00E-06	S	7.44E-03	S	2.78E-03	S
13	1.06E-02	S	3.00E-06	S	7.18E-03	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.90E+01		3.16E-05		7.04E+00		2.93E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.58E+00	S	2.49E-02	S	2.67E-03	S
3	1.58E+00	S	2.49E-02	S	3.78E-03	S
3.2	1.58E+00	S	2.49E-02	S	5.23E-03	S
3.4	1.58E+00	S	2.49E-02	S	7.10E-03	S
3.6	1.57E+00	S	2.47E-02	S	9.47E-03	S
3.8	1.35E+00	S	2.10E-02	S	1.24E-02	S
4	1.17E+00	S	1.80E-02	S	1.61E-02	S
4.2	1.02E+00	S	1.56E-02	S	2.06E-02	S
4.4	9.82E-01	S	1.46E-02	S	2.15E-02	S
4.6	9.57E-01	S	1.38E-02	S	2.20E-02	S
4.8	9.33E-01	S	1.31E-02	S	2.24E-02	S
5	9.12E-01	S	1.24E-02	S	2.28E-02	S
5.2	8.53E-01	S	1.16E-02	S	2.29E-02	S
5.4	7.50E-01	S	1.06E-02	S	2.25E-02	S
5.6	6.63E-01	S	9.77E-03	S	2.21E-02	S
5.8	5.88E-01	S	9.00E-03	S	2.17E-02	S
6	5.24E-01	S	8.31E-03	S	2.14E-02	S
6.2	4.69E-01	S	7.70E-03	S	2.10E-02	S
6.4	4.24E-01	S	6.82E-03	S	2.14E-02	S
6.6	3.92E-01	S	5.46E-03	S	2.36E-02	S
6.8	3.64E-01	S	4.40E-03	S	2.59E-02	S
7	3.38E-01	S	3.57E-03	S	2.83E-02	S
7.2	3.14E-01	S	2.91E-03	S	3.09E-02	S
7.4	2.99E-01	S	2.53E-03	S	3.31E-02	S
7.6	2.98E-01	S	2.53E-03	S	3.43E-02	S
7.8	2.97E-01	S	2.53E-03	S	3.56E-02	S
8	2.97E-01	S	2.53E-03	S	3.70E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-34. Leachate Concentrations for Sub bituminous lignite fly ash, Waste ID ZFA Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	**Selenium**	**Solubility/ Washout**	**Thallium**	**Solubility/ Washout**	**Vanadium**	**Solubility/ Washout**
8.2	3.04E-01	S	2.53E-03	S	4.32E-02	S
8.4	3.12E-01	S	2.53E-03	S	5.02E-02	S
8.6	3.19E-01	S	2.53E-03	S	5.82E-02	S
8.8	3.23E-01	S	2.53E-03	S	5.82E-02	S
9	3.25E-01	S	2.53E-03	S	5.67E-02	S
9.2	3.28E-01	S	2.53E-03	S	5.54E-02	S
9.4	3.31E-01	S	2.53E-03	S	5.40E-02	S
9.6	2.91E-01	S	2.53E-03	S	4.96E-02	S
9.8	2.39E-01	S	2.53E-03	S	4.42E-02	S
10	1.98E-01	S	2.53E-03	S	3.94E-02	S
10.2	1.64E-01	S	2.53E-03	S	3.53E-02	S
10.4	1.36E-01	S	2.53E-03	S	3.16E-02	S
10.6	1.13E-01	S	2.53E-03	S	2.84E-02	S
10.8	9.50E-02	S	2.53E-03	S	2.56E-02	S
11	7.85E-02	S	2.53E-03	S	2.25E-02	S
11.2	5.65E-02	S	2.53E-03	S	1.62E-02	S
11.4	4.09E-02	S	2.53E-03	S	1.17E-02	S
11.6	2.98E-02	S	2.53E-03	S	8.46E-03	S
11.8	2.18E-02	S	2.53E-03	S	6.18E-03	S
12	1.73E-02	S	2.53E-03	S	4.73E-03	S
12.2	2.70E-02	S	2.53E-03	S	5.27E-03	S
12.4	4.18E-02	S	2.53E-03	S	5.87E-03	S
12.6	6.44E-02	S	2.53E-03	S	6.52E-03	S
12.8	9.84E-02	S	2.53E-03	S	7.24E-03	S
13	1.49E-01	S	2.53E-03	S	8.02E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.58E+01		2.49E-01		5.82E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID	AaAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	4.45E-02	S	8.43E-01	W	7.46E-04	S	8.97E-03	S
3	3.14E-02	S	8.42E-01	W	7.46E-04	S	7.79E-03	S
3.2	2.27E-02	S	8.41E-01	W	7.46E-04	S	6.83E-03	S
3.4	1.67E-02	S	8.40E-01	W	7.46E-04	S	6.03E-03	S
3.6	1.25E-02	S	8.39E-01	W	7.46E-04	S	5.36E-03	S
3.8	9.54E-03	S	8.38E-01	W	7.46E-04	S	4.80E-03	S
4	7.91E-03	S	8.36E-01	W	7.46E-04	S	4.17E-03	S
4.2	6.64E-03	S	8.34E-01	W	7.46E-04	S	3.64E-03	S
4.4	5.62E-03	S	8.32E-01	W	7.46E-04	S	3.20E-03	S
4.6	4.80E-03	S	8.30E-01	W	7.46E-04	S	2.82E-03	S
4.8	4.12E-03	S	8.28E-01	W	7.46E-04	S	2.51E-03	S
5	3.56E-03	S	8.26E-01	W	7.46E-04	S	2.24E-03	S
5.2	3.20E-03	S	8.21E-01	W	7.46E-04	S	2.06E-03	S
5.4	3.20E-03	S	8.08E-01	W	7.46E-04	S	2.06E-03	S
5.6	3.20E-03	S	7.95E-01	W	7.46E-04	S	2.06E-03	S
5.8	3.20E-03	S	7.83E-01	W	7.46E-04	S	2.06E-03	S
6	3.20E-03	S	7.72E-01	W	7.46E-04	S	2.06E-03	S
6.2	3.20E-03	S	7.61E-01	W	7.46E-04	S	2.06E-03	S
6.4	3.20E-03	S	7.51E-01	W	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	7.41E-01	W	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	7.31E-01	W	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	7.22E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	7.17E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	7.20E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	7.23E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	7.26E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	7.28E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID	AaAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	7.31E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	7.34E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	7.36E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	7.39E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	7.41E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	7.45E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	7.51E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	7.57E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	7.63E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	7.68E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	7.74E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	7.66E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	7.56E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	7.46E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	7.37E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	7.27E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	7.19E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	7.10E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	7.01E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	7.32E-01	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	8.99E-01	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.10E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.34E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.63E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.98E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.32E-01		1.90E+01		8.70E-03		5.76E-02	

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Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID
Date Exported
Database Name leling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.74E-02	S	7.34E-05	S	1.13E-02	S	4.23E-03	S
3	3.07E-02	S	5.92E-05	S	8.84E-03	S	3.85E-03	S
3.2	2.55E-02	S	4.83E-05	S	7.04E-03	S	3.53E-03	S
3.4	2.15E-02	S	4.00E-05	S	5.68E-03	S	3.25E-03	S
3.6	1.82E-02	S	3.34E-05	S	4.64E-03	S	3.01E-03	S
3.8	1.56E-02	S	2.82E-05	S	3.83E-03	S	2.79E-03	S
4	1.10E-02	S	3.78E-05	S	3.80E-03	S	2.78E-03	S
4.2	7.86E-03	S	5.11E-05	S	3.80E-03	S	2.78E-03	S
4.4	5.69E-03	S	6.81E-05	S	3.80E-03	S	2.78E-03	S
4.6	4.17E-03	S	8.96E-05	S	3.80E-03	S	2.78E-03	S
4.8	3.10E-03	S	1.17E-04	S	3.80E-03	S	2.78E-03	S
5	2.33E-03	S	1.50E-04	S	3.80E-03	S	2.78E-03	S
5.2	1.96E-03	S	1.57E-04	S	3.80E-03	S	2.78E-03	S
5.4	2.23E-03	S	9.23E-05	S	3.80E-03	S	2.78E-03	S
5.6	2.51E-03	S	5.53E-05	S	3.80E-03	S	2.78E-03	S
5.8	2.83E-03	S	3.37E-05	S	3.80E-03	S	2.78E-03	S
6	3.17E-03	S	2.09E-05	S	3.80E-03	S	2.78E-03	S
6.2	3.54E-03	S	1.32E-05	S	3.80E-03	S	2.78E-03	S
6.4	3.94E-03	S	8.42E-06	S	3.80E-03	S	2.78E-03	S
6.6	4.37E-03	S	5.45E-06	S	3.80E-03	S	2.78E-03	S
6.8	4.83E-03	S	3.58E-06	S	3.80E-03	S	2.78E-03	S
7	5.32E-03	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
7.2	5.70E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
7.4	5.74E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
7.6	5.78E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
7.8	5.82E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
8	5.86E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID
Date Exported
Database Name leling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	5.89E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
8.4	5.93E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
8.6	5.97E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
8.8	6.00E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
9	6.04E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
9.2	6.16E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
9.4	6.52E-03	S	3.00E-06	S	3.80E-03	W	2.78E-03	S
9.6	6.88E-03	S	3.04E-06	S	3.80E-03	W	2.78E-03	S
9.8	7.25E-03	S	3.79E-06	S	3.80E-03	W	2.78E-03	S
10	7.64E-03	S	4.71E-06	S	3.80E-03	S	2.78E-03	S
10.2	8.04E-03	S	5.81E-06	S	3.80E-03	S	2.78E-03	S
10.4	8.23E-03	S	5.28E-06	S	4.18E-03	S	2.78E-03	S
10.6	8.38E-03	S	4.56E-06	S	4.67E-03	S	2.78E-03	S
10.8	8.54E-03	S	3.94E-06	S	5.20E-03	S	2.78E-03	S
11	8.69E-03	S	3.42E-06	S	5.79E-03	S	2.78E-03	S
11.2	8.84E-03	S	3.00E-06	S	6.43E-03	S	2.78E-03	S
11.4	8.99E-03	S	3.00E-06	S	7.12E-03	S	2.78E-03	S
11.6	9.14E-03	S	3.00E-06	S	7.88E-03	S	2.78E-03	S
11.8	9.29E-03	S	3.00E-06	S	8.70E-03	S	2.78E-03	S
12	9.54E-03	S	3.00E-06	S	9.33E-03	S	2.78E-03	S
12.2	1.01E-02	S	3.00E-06	S	9.21E-03	S	2.78E-03	S
12.4	1.06E-02	S	4.39E-06	S	9.09E-03	S	2.78E-03	S
12.6	1.12E-02	S	6.47E-06	S	8.98E-03	S	2.78E-03	S
12.8	1.18E-02	S	9.46E-06	S	8.86E-03	S	2.78E-03	S
13	1.24E-02	S	1.38E-05	S	8.75E-03	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.27E-01		1.16E-03		1.05E-01		3.24E-02	

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Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	6.71E-01	S	7.65E-03	S	2.47E-02	S
3	5.80E-01	S	7.37E-03	S	1.90E-02	S
3.2	5.06E-01	S	7.11E-03	S	1.48E-02	S
3.4	4.45E-01	S	6.87E-03	S	1.18E-02	S
3.6	3.94E-01	S	6.66E-03	S	9.45E-03	S
3.8	3.51E-01	S	6.46E-03	S	7.69E-03	S
4	3.44E-01	S	6.41E-03	S	7.30E-03	S
4.2	3.39E-01	W	6.36E-03	S	7.00E-03	S
4.4	3.35E-01	W	6.32E-03	S	6.73E-03	S
4.6	3.30E-01	W	6.28E-03	S	6.47E-03	S
4.8	3.26E-01	W	6.24E-03	S	6.24E-03	S
5	3.22E-01	W	6.20E-03	S	6.03E-03	S
5.2	3.17E-01	W	6.15E-03	S	5.86E-03	S
5.4	3.09E-01	W	6.04E-03	S	5.81E-03	S
5.6	3.00E-01	W	5.95E-03	S	5.76E-03	S
5.8	2.93E-01	W	5.85E-03	S	5.71E-03	S
6	2.86E-01	W	5.76E-03	S	5.67E-03	S
6.2	2.79E-01	W	5.68E-03	S	5.62E-03	S
6.4	2.72E-01	W	5.60E-03	S	5.58E-03	S
6.6	2.66E-01	W	5.52E-03	S	5.54E-03	S
6.8	2.61E-01	W	5.45E-03	S	5.50E-03	S
7	2.55E-01	W	5.38E-03	S	5.47E-03	S
7.2	2.51E-01	W	5.36E-03	S	5.46E-03	S
7.4	2.51E-01	W	5.46E-03	S	5.52E-03	S
7.6	2.51E-01	W	5.57E-03	S	5.58E-03	S
7.8	2.50E-01	W	5.67E-03	S	5.64E-03	S
8	2.50E-01	W	5.77E-03	S	5.69E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-35. Leachate Concentrations for Gypsum Export, Waste ID AaAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.50E-01	W	5.87E-03	S	5.75E-03	S
8.4	2.49E-01	W	5.97E-03	S	5.81E-03	S
8.6	2.49E-01	W	6.07E-03	S	5.86E-03	S
8.8	2.49E-01	W	6.17E-03	S	5.92E-03	S
9	2.49E-01	W	6.27E-03	S	5.97E-03	S
9.2	2.49E-01	W	6.34E-03	S	5.96E-03	S
9.4	2.53E-01	W	6.35E-03	S	5.81E-03	S
9.6	2.56E-01	W	6.36E-03	S	5.67E-03	S
9.8	2.60E-01	W	6.37E-03	S	5.54E-03	S
10	2.63E-01	W	6.37E-03	S	5.41E-03	S
10.2	2.67E-01	W	6.38E-03	S	5.29E-03	S
10.4	2.71E-01	W	6.28E-03	S	5.25E-03	S
10.6	2.75E-01	W	6.16E-03	S	5.23E-03	S
10.8	2.79E-01	W	6.05E-03	S	5.20E-03	S
11	2.83E-01	W	5.94E-03	S	5.18E-03	S
11.2	2.88E-01	W	5.84E-03	S	5.16E-03	S
11.4	2.92E-01	W	5.74E-03	S	5.14E-03	S
11.6	2.96E-01	W	5.64E-03	S	5.11E-03	S
11.8	3.00E-01	W	5.54E-03	S	5.09E-03	S
12	3.19E-01	S	5.31E-03	S	4.96E-03	S
12.2	3.87E-01	S	4.68E-03	S	4.53E-03	S
12.4	4.69E-01	S	4.14E-03	S	4.14E-03	S
12.6	5.66E-01	S	3.66E-03	S	3.79E-03	S
12.8	6.81E-01	S	3.25E-03	S	3.47E-03	S
13	8.17E-01	S	2.89E-03	S	3.19E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	7.93E+00		5.45E-02		1.40E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID	AaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	4.49E-02	S	1.70E-01	S	7.46E-04	S	1.55E-02	S
3	3.12E-02	S	1.65E-01	S	7.46E-04	S	1.40E-02	S
3.2	2.22E-02	S	1.61E-01	S	7.46E-04	S	1.27E-02	S
3.4	1.61E-02	S	1.56E-01	S	7.46E-04	S	1.16E-02	S
3.6	1.19E-02	S	1.52E-01	S	7.46E-04	S	1.06E-02	S
3.8	8.96E-03	S	1.49E-01	S	7.46E-04	S	9.82E-03	S
4	7.63E-03	S	1.46E-01	S	7.46E-04	S	9.29E-03	S
4.2	6.68E-03	S	1.44E-01	S	7.46E-04	S	8.86E-03	S
4.4	5.88E-03	S	1.43E-01	S	7.46E-04	S	8.46E-03	S
4.6	5.21E-03	S	1.41E-01	S	7.46E-04	S	8.10E-03	S
4.8	4.64E-03	S	1.39E-01	S	7.46E-04	S	7.76E-03	S
5	4.15E-03	S	1.38E-01	S	7.46E-04	S	7.46E-03	S
5.2	3.73E-03	S	1.36E-01	S	7.46E-04	S	7.17E-03	S
5.4	3.36E-03	S	1.35E-01	S	7.46E-04	S	6.91E-03	S
5.6	3.20E-03	S	1.31E-01	S	7.46E-04	S	6.16E-03	S
5.8	3.20E-03	S	1.25E-01	S	7.46E-04	S	5.10E-03	S
6	3.20E-03	S	1.20E-01	S	7.46E-04	S	4.25E-03	S
6.2	3.20E-03	S	1.15E-01	S	7.46E-04	S	3.56E-03	S
6.4	3.20E-03	S	1.10E-01	S	7.46E-04	S	3.00E-03	S
6.6	3.20E-03	S	1.06E-01	S	7.46E-04	S	2.54E-03	S
6.8	3.20E-03	S	1.02E-01	S	7.46E-04	S	2.16E-03	S
7	3.20E-03	S	1.02E-01	S	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	1.02E-01	S	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	1.03E-01	S	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	1.04E-01	S	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	1.05E-01	S	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	1.05E-01	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID	AaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	1.06E-01	S	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	1.07E-01	S	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	1.08E-01	S	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	1.08E-01	S	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	1.09E-01	S	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	1.10E-01	S	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	1.11E-01	S	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	1.13E-01	S	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	1.14E-01	S	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	1.15E-01	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	1.16E-01	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	1.18E-01	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	1.19E-01	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	1.20E-01	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	1.20E-01	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	1.20E-01	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.19E-01	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.18E-01	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.18E-01	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.17E-01	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.75E-01	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	2.60E-01	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	3.83E-01	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	5.62E-01	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	8.20E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID	AaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
Availability (mg/kg)	2.31E-01		7.72E+00		1.02E-02		1.03E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	3.93E-02	S	4.54E-05	S	1.15E-02	S	4.30E-03	S
3	3.19E-02	S	3.45E-05	S	9.03E-03	S	3.91E-03	S
3.2	2.63E-02	S	2.67E-05	S	7.18E-03	S	3.57E-03	S
3.4	2.19E-02	S	2.09E-05	S	5.79E-03	S	3.28E-03	S
3.6	1.85E-02	S	1.66E-05	S	4.73E-03	S	3.03E-03	S
3.8	1.57E-02	S	1.34E-05	S	3.90E-03	S	2.81E-03	S
4	1.49E-02	S	1.33E-05	S	3.80E-03	S	2.78E-03	S
4.2	1.45E-02	S	1.37E-05	S	3.80E-03	S	2.78E-03	S
4.4	1.40E-02	S	1.41E-05	S	3.80E-03	S	2.78E-03	S
4.6	1.36E-02	S	1.44E-05	S	3.80E-03	S	2.78E-03	S
4.8	1.33E-02	S	1.48E-05	S	3.80E-03	S	2.78E-03	S
5	1.29E-02	S	1.51E-05	S	3.80E-03	S	2.78E-03	S
5.2	1.26E-02	S	1.55E-05	S	3.80E-03	S	2.78E-03	S
5.4	1.23E-02	S	1.58E-05	S	3.80E-03	S	2.78E-03	S
5.6	1.20E-02	S	1.57E-05	S	3.80E-03	S	2.78E-03	S
5.8	1.16E-02	S	1.52E-05	S	3.80E-03	S	2.78E-03	S
6	1.13E-02	S	1.47E-05	S	3.80E-03	S	2.78E-03	S
6.2	1.10E-02	S	1.43E-05	S	3.80E-03	S	2.78E-03	S
6.4	1.07E-02	S	1.39E-05	S	3.80E-03	S	2.78E-03	S
6.6	1.04E-02	S	1.35E-05	S	3.80E-03	S	2.78E-03	S
6.8	1.01E-02	S	1.31E-05	S	3.80E-03	S	2.78E-03	S
7	1.02E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
7.2	1.03E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
7.4	1.05E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
7.6	1.06E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
7.8	1.08E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
8	1.09E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.11E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
8.4	1.12E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
8.6	1.14E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
8.8	1.15E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
9	1.16E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
9.2	1.16E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
9.4	1.17E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
9.6	1.17E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
9.8	1.17E-02	S	1.30E-05	S	3.80E-03	W	2.78E-03	S
10	1.17E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
10.2	1.17E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
10.4	1.17E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
10.6	1.17E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
10.8	1.17E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
11	1.21E-02	S	1.26E-05	S	4.23E-03	S	2.78E-03	S
11.2	1.31E-02	S	1.17E-05	S	5.37E-03	S	2.78E-03	S
11.4	1.41E-02	S	1.10E-05	S	6.79E-03	S	2.78E-03	S
11.6	1.52E-02	S	1.03E-05	S	8.55E-03	S	2.78E-03	S
11.8	1.63E-02	S	9.60E-06	S	1.07E-02	S	2.78E-03	S
12	1.76E-02	S	9.00E-06	S	1.34E-02	S	2.78E-03	S
12.2	1.79E-02	S	1.07E-05	S	1.34E-02	S	2.78E-03	S
12.4	1.81E-02	S	1.27E-05	S	1.33E-02	S	2.78E-03	S
12.6	1.84E-02	S	1.50E-05	S	1.33E-02	S	2.78E-03	S
12.8	1.87E-02	S	1.77E-05	S	1.32E-02	S	2.78E-03	S
13	1.90E-02	S	2.09E-05	S	1.32E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
Availability (mg/kg)	2.56E-01		2.55E-04		1.81E-01		3.82E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	5.68E-01	S	2.53E-03	S	2.57E-02	S
3	4.83E-01	S	2.53E-03	S	1.95E-02	S
3.2	4.15E-01	S	2.53E-03	S	1.51E-02	S
3.4	3.60E-01	S	2.53E-03	S	1.18E-02	S
3.6	3.15E-01	S	2.53E-03	S	9.43E-03	S
3.8	2.77E-01	S	2.53E-03	S	7.61E-03	S
4	2.71E-01	S	2.53E-03	S	7.31E-03	S
4.2	2.69E-01	W	2.53E-03	S	7.24E-03	S
4.4	2.67E-01	W	2.53E-03	S	7.18E-03	S
4.6	2.66E-01	W	2.53E-03	S	7.12E-03	S
4.8	2.64E-01	W	2.53E-03	S	7.06E-03	S
5	2.63E-01	W	2.53E-03	S	7.00E-03	S
5.2	2.61E-01	W	2.53E-03	S	6.95E-03	S
5.4	2.60E-01	W	2.53E-03	S	6.90E-03	S
5.6	2.52E-01	W	2.53E-03	S	6.85E-03	S
5.8	2.39E-01	W	2.53E-03	S	6.81E-03	S
6	2.26E-01	W	2.53E-03	S	6.77E-03	S
6.2	2.15E-01	W	2.53E-03	S	6.73E-03	S
6.4	2.05E-01	W	2.53E-03	S	6.69E-03	S
6.6	1.95E-01	W	2.53E-03	S	6.66E-03	S
6.8	1.86E-01	W	2.53E-03	S	6.62E-03	S
7	1.84E-01	W	2.53E-03	S	6.60E-03	S
7.2	1.85E-01	W	2.53E-03	S	6.59E-03	S
7.4	1.85E-01	W	2.53E-03	S	6.58E-03	S
7.6	1.86E-01	W	2.53E-03	S	6.57E-03	S
7.8	1.87E-01	W	2.53E-03	S	6.55E-03	S
8	1.87E-01	W	2.53E-03	S	6.54E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.88E-01	W	2.53E-03	S	6.53E-03	S
8.4	1.88E-01	W	2.53E-03	S	6.52E-03	S
8.6	1.89E-01	W	2.53E-03	S	6.51E-03	S
8.8	1.89E-01	W	2.53E-03	S	6.50E-03	S
9	1.90E-01	W	2.53E-03	S	6.49E-03	S
9.2	1.92E-01	W	2.53E-03	S	6.41E-03	S
9.4	1.94E-01	W	2.53E-03	S	6.33E-03	S
9.6	1.96E-01	W	2.53E-03	S	6.25E-03	S
9.8	1.98E-01	W	2.53E-03	S	6.17E-03	S
10	2.00E-01	W	2.53E-03	S	6.10E-03	S
10.2	2.02E-01	W	2.53E-03	S	6.03E-03	S
10.4	2.05E-01	W	2.53E-03	S	5.96E-03	S
10.6	2.07E-01	W	2.53E-03	S	5.89E-03	S
10.8	2.09E-01	W	2.53E-03	S	5.82E-03	S
11	2.49E-01	W	2.53E-03	S	5.73E-03	S
11.2	3.62E-01	W	2.53E-03	S	5.61E-03	S
11.4	5.22E-01	W	2.53E-03	S	5.49E-03	S
11.6	7.49E-01	W	2.53E-03	S	5.38E-03	S
11.8	1.07E+00	W	2.53E-03	S	5.27E-03	S
12	1.51E+00	S	2.53E-03	S	5.17E-03	S
12.2	1.52E+00	S	2.53E-03	S	5.09E-03	S
12.4	1.52E+00	S	2.53E-03	S	5.02E-03	S
12.6	1.52E+00	S	2.53E-03	S	4.94E-03	S
12.8	1.52E+00	S	2.53E-03	S	4.87E-03	S
13	1.52E+00	S	2.53E-03	S	4.80E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-36. Leachate Concentrations for Gypsum Export, Waste ID AaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
Availability (mg/kg)	2.09E+01		3.47E-02		1.44E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID	CaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	3.14E-02	S	7.23E+00	W	6.28E-03	S	5.89E-02	S
3	2.74E-02	S	7.21E+00	W	6.25E-03	S	5.96E-02	S
3.2	2.42E-02	S	7.20E+00	W	6.22E-03	S	6.03E-02	S
3.4	2.15E-02	S	7.19E+00	W	6.19E-03	S	6.09E-02	S
3.6	1.92E-02	S	7.17E+00	W	6.16E-03	S	6.15E-02	S
3.8	1.73E-02	S	7.16E+00	W	6.13E-03	S	6.20E-02	S
4	1.56E-02	S	7.15E+00	W	6.11E-03	S	6.26E-02	S
4.2	1.42E-02	S	7.14E+00	W	6.09E-03	S	6.31E-02	S
4.4	1.31E-02	S	7.24E+00	W	6.04E-03	S	6.39E-02	S
4.6	1.21E-02	S	7.34E+00	W	5.99E-03	S	6.47E-02	S
4.8	1.12E-02	S	7.44E+00	W	5.95E-03	S	6.55E-02	S
5	1.04E-02	S	7.54E+00	W	5.91E-03	S	6.63E-02	S
5.2	9.67E-03	S	7.63E+00	W	5.87E-03	S	6.70E-02	S
5.4	9.04E-03	S	7.72E+00	W	5.84E-03	S	6.78E-02	S
5.6	8.47E-03	S	7.81E+00	W	5.80E-03	S	6.85E-02	S
5.8	7.95E-03	S	7.90E+00	W	5.77E-03	S	6.92E-02	S
6	6.98E-03	S	7.82E+00	W	4.34E-03	S	4.24E-02	S
6.2	6.14E-03	S	7.74E+00	W	3.25E-03	S	2.58E-02	S
6.4	5.42E-03	S	7.67E+00	W	2.45E-03	S	1.59E-02	S
6.6	4.80E-03	S	7.60E+00	W	1.87E-03	S	9.96E-03	S
6.8	4.27E-03	S	7.53E+00	W	1.43E-03	S	6.32E-03	S
7	3.81E-03	S	7.46E+00	W	1.11E-03	S	4.07E-03	S
7.2	3.41E-03	S	7.40E+00	W	8.64E-04	S	2.65E-03	S
7.4	3.20E-03	S	7.39E+00	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	7.47E+00	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	7.50E+00	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	7.42E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID	CaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	7.34E+00	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	7.26E+00	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	7.19E+00	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	7.12E+00	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	7.05E+00	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	7.04E+00	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	7.06E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	7.07E+00	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	7.08E+00	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	7.10E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	7.11E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	7.12E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	7.13E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	7.14E+00	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	7.16E+00	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	7.17E+00	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	7.18E+00	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	7.19E+00	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	7.20E+00	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	7.21E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	7.38E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	7.87E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	8.38E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	8.91E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	9.47E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.70E-01		1.00E+02		3.86E-02		4.28E-01	

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Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.27E-01	S	1.38E-04	S	3.41E-02	S	1.27E-02	S
3	1.15E-01	S	1.05E-04	S	3.12E-02	S	1.21E-02	S
3.2	1.04E-01	S	8.15E-05	S	2.88E-02	S	1.16E-02	S
3.4	9.50E-02	S	6.43E-05	S	2.66E-02	S	1.12E-02	S
3.6	8.71E-02	S	5.13E-05	S	2.47E-02	S	1.08E-02	S
3.8	8.03E-02	S	4.15E-05	S	2.31E-02	S	1.04E-02	S
4	7.43E-02	S	3.39E-05	S	2.16E-02	S	1.01E-02	S
4.2	6.90E-02	S	2.80E-05	S	2.03E-02	S	9.79E-03	S
4.4	5.34E-02	S	2.25E-05	S	2.36E-02	S	9.28E-03	S
4.6	4.18E-02	S	1.82E-05	S	2.73E-02	S	8.83E-03	S
4.8	3.31E-02	S	1.49E-05	S	3.14E-02	S	8.41E-03	S
5	2.64E-02	S	1.22E-05	S	3.59E-02	S	8.04E-03	S
5.2	2.13E-02	S	1.02E-05	S	4.08E-02	S	7.69E-03	S
5.4	1.73E-02	S	8.49E-06	S	4.62E-02	S	7.37E-03	S
5.6	1.42E-02	S	7.15E-06	S	5.21E-02	S	7.07E-03	S
5.8	1.17E-02	S	6.05E-06	S	5.84E-02	S	6.79E-03	S
6	1.17E-02	S	6.35E-06	S	6.18E-02	S	5.99E-03	S
6.2	1.18E-02	S	6.72E-06	S	6.51E-02	S	5.28E-03	S
6.4	1.19E-02	S	7.11E-06	S	6.84E-02	S	4.67E-03	S
6.6	1.20E-02	S	7.50E-06	S	7.18E-02	S	4.15E-03	S
6.8	1.21E-02	S	7.91E-06	S	7.53E-02	S	3.70E-03	S
7	1.22E-02	S	8.32E-06	S	7.88E-02	S	3.31E-03	S
7.2	1.24E-02	S	8.74E-06	S	8.24E-02	W	2.97E-03	S
7.4	1.26E-02	S	1.09E-05	S	8.59E-02	W	2.78E-03	S
7.6	1.31E-02	S	1.76E-05	S	8.91E-02	W	2.78E-03	S
7.8	1.36E-02	S	2.47E-05	S	9.21E-02	W	2.78E-03	S
8	1.39E-02	S	2.34E-05	S	9.43E-02	W	2.78E-03	S

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Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.43E-02	S	2.22E-05	S	9.64E-02	W	2.78E-03	S
8.4	1.46E-02	S	2.11E-05	S	9.86E-02	W	2.78E-03	S
8.6	1.50E-02	S	2.01E-05	S	1.01E-01	W	2.78E-03	S
8.8	1.53E-02	S	1.91E-05	S	1.03E-01	W	2.78E-03	S
9	1.57E-02	S	1.82E-05	S	1.05E-01	W	2.78E-03	S
9.2	1.59E-02	S	1.69E-05	S	1.07E-01	W	2.92E-03	S
9.4	1.62E-02	S	1.56E-05	S	1.09E-01	W	3.11E-03	S
9.6	1.64E-02	S	1.44E-05	S	1.10E-01	W	3.30E-03	S
9.8	1.66E-02	S	1.34E-05	S	1.12E-01	W	3.51E-03	S
10	1.69E-02	S	1.24E-05	S	1.14E-01	W	3.72E-03	S
10.2	1.71E-02	S	1.15E-05	S	1.15E-01	W	3.94E-03	S
10.4	1.73E-02	S	1.07E-05	S	1.17E-01	W	4.17E-03	S
10.6	1.75E-02	S	9.95E-06	S	1.19E-01	W	4.41E-03	S
10.8	1.78E-02	S	9.28E-06	S	1.20E-01	W	4.65E-03	S
11	1.80E-02	S	8.66E-06	S	1.22E-01	W	4.91E-03	S
11.2	1.82E-02	S	8.09E-06	S	1.24E-01	W	5.17E-03	S
11.4	1.84E-02	S	7.57E-06	S	1.25E-01	W	5.45E-03	S
11.6	1.86E-02	S	7.09E-06	S	1.27E-01	W	5.73E-03	S
11.8	1.89E-02	S	6.65E-06	S	1.29E-01	W	6.02E-03	S
12	1.91E-02	S	6.25E-06	S	1.30E-01	W	6.32E-03	S
12.2	1.97E-02	S	6.85E-06	S	1.32E-01	W	6.16E-03	S
12.4	2.10E-02	S	9.98E-06	S	1.35E-01	W	5.24E-03	S
12.6	2.24E-02	S	1.44E-05	S	1.38E-01	W	4.46E-03	S
12.8	2.39E-02	S	2.08E-05	S	1.40E-01	W	3.81E-03	S
13	2.54E-02	S	2.97E-05	S	1.43E-01	W	3.27E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	7.09E-01		6.50E-04		1.58E+00		7.51E-02	

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Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.06E+00	S	1.59E-02	S	2.71E-01	S
3	1.97E+00	S	1.58E-02	S	2.24E-01	S
3.2	1.90E+00	S	1.57E-02	S	1.88E-01	S
3.4	1.83E+00	S	1.56E-02	S	1.60E-01	S
3.6	1.77E+00	S	1.55E-02	S	1.37E-01	S
3.8	1.71E+00	S	1.54E-02	S	1.18E-01	S
4	1.66E+00	S	1.53E-02	S	1.03E-01	S
4.2	1.61E+00	W	1.52E-02	S	8.99E-02	S
4.4	1.65E+00	W	1.48E-02	S	8.65E-02	S
4.6	1.69E+00	W	1.45E-02	S	8.33E-02	S
4.8	1.73E+00	W	1.42E-02	S	8.04E-02	S
5	1.77E+00	W	1.39E-02	S	7.77E-02	S
5.2	1.80E+00	W	1.36E-02	S	7.52E-02	S
5.4	1.84E+00	W	1.33E-02	S	7.29E-02	S
5.6	1.88E+00	W	1.31E-02	S	7.07E-02	S
5.8	1.91E+00	W	1.28E-02	S	6.86E-02	S
6	1.88E+00	W	1.26E-02	S	6.59E-02	S
6.2	1.84E+00	W	1.24E-02	S	6.33E-02	S
6.4	1.81E+00	W	1.23E-02	S	6.09E-02	S
6.6	1.77E+00	W	1.21E-02	S	5.86E-02	S
6.8	1.74E+00	W	1.19E-02	S	5.65E-02	S
7	1.71E+00	W	1.17E-02	S	5.45E-02	S
7.2	1.69E+00	W	1.16E-02	S	5.27E-02	S
7.4	1.74E+00	W	1.12E-02	S	5.21E-02	S
7.6	1.92E+00	W	1.07E-02	S	5.33E-02	S
7.8	2.09E+00	W	1.03E-02	S	5.55E-02	S
8	2.18E+00	W	1.06E-02	S	6.08E-02	S

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Table C-5-37. Leachate Concentrations for Gypsum Export, Waste ID CaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.27E+00	W	1.08E-02	S	6.64E-02	S
8.4	2.36E+00	W	1.11E-02	S	7.25E-02	S
8.6	2.45E+00	W	1.13E-02	S	7.89E-02	S
8.8	2.55E+00	W	1.16E-02	S	8.58E-02	S
9	2.65E+00	W	1.18E-02	S	9.30E-02	S
9.2	2.68E+00	W	1.19E-02	S	9.51E-02	S
9.4	2.70E+00	W	1.19E-02	S	9.53E-02	S
9.6	2.72E+00	W	1.20E-02	S	9.55E-02	S
9.8	2.74E+00	W	1.20E-02	S	9.58E-02	S
10	2.75E+00	W	1.20E-02	S	9.60E-02	S
10.2	2.77E+00	W	1.21E-02	S	9.62E-02	S
10.4	2.79E+00	W	1.21E-02	S	9.64E-02	S
10.6	2.80E+00	W	1.21E-02	S	9.66E-02	S
10.8	2.82E+00	W	1.21E-02	S	9.68E-02	S
11	2.83E+00	W	1.22E-02	S	9.70E-02	S
11.2	2.85E+00	W	1.22E-02	S	9.72E-02	S
11.4	2.86E+00	W	1.22E-02	S	9.74E-02	S
11.6	2.88E+00	W	1.22E-02	S	9.76E-02	S
11.8	2.89E+00	W	1.23E-02	S	9.78E-02	S
12	2.91E+00	S	1.23E-02	S	9.80E-02	S
12.2	2.95E+00	S	1.21E-02	S	8.60E-02	S
12.4	3.04E+00	S	1.17E-02	S	5.92E-02	S
12.6	3.13E+00	S	1.12E-02	S	4.10E-02	S
12.8	3.22E+00	S	1.08E-02	S	2.86E-02	S
13	3.32E+00	S	1.05E-02	S	2.00E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.63E+01		1.22E-01		1.39E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID	DaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	9.58E-02	S	2.23E-01	W	7.46E-04	S	1.19E-02	S
3	7.55E-02	S	2.19E-01	W	7.46E-04	S	1.03E-02	S
3.2	6.04E-02	S	2.15E-01	W	7.46E-04	S	8.97E-03	S
3.4	4.90E-02	S	2.12E-01	W	7.46E-04	S	7.90E-03	S
3.6	4.02E-02	S	2.09E-01	W	7.46E-04	S	7.01E-03	S
3.8	3.19E-02	S	2.05E-01	W	7.46E-04	S	6.19E-03	S
4	2.37E-02	S	2.02E-01	W	7.46E-04	S	5.37E-03	S
4.2	1.79E-02	S	1.98E-01	W	7.46E-04	S	4.69E-03	S
4.4	1.36E-02	S	1.95E-01	W	7.46E-04	S	4.12E-03	S
4.6	1.05E-02	S	1.92E-01	W	7.46E-04	S	3.64E-03	S
4.8	8.24E-03	S	1.90E-01	W	7.46E-04	S	3.24E-03	S
5	6.50E-03	S	1.87E-01	W	7.46E-04	S	2.89E-03	S
5.2	5.18E-03	S	1.84E-01	W	7.46E-04	S	2.59E-03	S
5.4	4.16E-03	S	1.82E-01	W	7.46E-04	S	2.34E-03	S
5.6	3.37E-03	S	1.80E-01	W	7.46E-04	S	2.11E-03	S
5.8	3.20E-03	S	1.78E-01	W	7.46E-04	S	2.06E-03	S
6	3.20E-03	S	1.76E-01	W	7.46E-04	S	2.06E-03	S
6.2	3.20E-03	S	1.75E-01	W	7.46E-04	S	2.06E-03	S
6.4	3.20E-03	S	1.73E-01	W	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	1.72E-01	W	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	1.69E-01	W	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	1.67E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	1.64E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	1.62E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	1.60E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	1.58E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	1.59E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID	DaAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	1.60E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	1.61E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	1.62E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	1.63E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	1.64E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	1.66E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	1.69E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	1.71E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	1.73E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	1.75E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	1.77E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	1.79E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	1.81E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	1.83E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	1.85E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	1.87E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.89E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.91E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.93E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.95E-01	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	2.52E-01	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	3.40E-01	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	4.55E-01	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	6.06E-01	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	8.05E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	5.76E-01		7.36E+00		9.06E-03		7.83E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	9.59E-02	S	1.24E-05	S	9.57E-03	S	8.27E-03	S
3	8.81E-02	S	7.80E-06	S	7.66E-03	S	7.66E-03	S
3.2	8.15E-02	S	5.05E-06	S	6.22E-03	S	7.14E-03	S
3.4	7.56E-02	S	3.36E-06	S	5.12E-03	S	6.67E-03	S
3.6	7.06E-02	S	3.00E-06	S	4.25E-03	S	6.27E-03	S
3.8	6.38E-02	S	3.00E-06	S	3.80E-03	S	5.82E-03	S
4	5.44E-02	S	3.00E-06	S	3.80E-03	S	5.29E-03	S
4.2	4.68E-02	S	3.00E-06	S	3.80E-03	S	4.83E-03	S
4.4	4.05E-02	S	3.00E-06	S	3.80E-03	S	4.43E-03	S
4.6	3.53E-02	S	3.00E-06	S	3.80E-03	S	4.08E-03	S
4.8	3.09E-02	S	3.00E-06	S	3.80E-03	S	3.77E-03	S
5	2.72E-02	S	3.00E-06	S	3.80E-03	S	3.49E-03	S
5.2	2.41E-02	S	3.00E-06	S	3.80E-03	S	3.25E-03	S
5.4	2.14E-02	S	3.00E-06	S	3.80E-03	S	3.03E-03	S
5.6	1.92E-02	S	3.00E-06	S	3.80E-03	S	2.83E-03	S
5.8	1.93E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6	2.02E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.2	2.11E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.4	2.21E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.6	2.29E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.8	2.32E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
7	2.34E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
7.2	2.36E-02	S	3.51E-06	S	3.80E-03	S	2.78E-03	S
7.4	2.38E-02	S	4.30E-06	S	3.80E-03	S	2.78E-03	S
7.6	2.41E-02	S	5.24E-06	S	3.80E-03	S	2.78E-03	S
7.8	2.47E-02	S	5.65E-06	S	4.03E-03	S	2.78E-03	S
8	2.63E-02	S	4.64E-06	S	4.92E-03	S	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.79E-02	S	3.82E-06	S	5.98E-03	S	2.78E-03	S
8.4	2.96E-02	S	3.17E-06	S	7.24E-03	S	2.78E-03	S
8.6	3.13E-02	S	3.00E-06	S	8.71E-03	S	2.78E-03	S
8.8	3.31E-02	S	3.00E-06	S	1.04E-02	S	2.78E-03	S
9	3.50E-02	S	3.00E-06	S	1.25E-02	S	2.78E-03	S
9.2	3.50E-02	S	3.00E-06	S	1.28E-02	S	2.78E-03	S
9.4	3.46E-02	S	3.00E-06	S	1.28E-02	S	2.78E-03	S
9.6	3.42E-02	S	3.00E-06	S	1.28E-02	S	2.78E-03	S
9.8	3.38E-02	S	3.00E-06	S	1.27E-02	S	2.78E-03	S
10	3.35E-02	S	3.00E-06	S	1.27E-02	S	2.78E-03	S
10.2	3.31E-02	S	3.00E-06	S	1.27E-02	S	2.78E-03	S
10.4	3.28E-02	S	3.26E-06	S	1.27E-02	S	2.78E-03	S
10.6	3.24E-02	S	3.53E-06	S	1.27E-02	S	2.78E-03	S
10.8	3.21E-02	S	3.82E-06	S	1.27E-02	S	2.78E-03	S
11	3.18E-02	S	4.12E-06	S	1.27E-02	S	2.78E-03	S
11.2	3.15E-02	S	4.44E-06	S	1.27E-02	S	2.78E-03	S
11.4	3.12E-02	S	4.79E-06	S	1.27E-02	S	2.78E-03	S
11.6	3.09E-02	S	5.15E-06	S	1.26E-02	S	2.78E-03	S
11.8	3.07E-02	S	5.53E-06	S	1.26E-02	S	2.78E-03	S
12	3.04E-02	S	5.94E-06	S	1.26E-02	S	2.78E-03	S
12.2	3.03E-02	S	6.31E-06	S	1.45E-02	S	2.78E-03	S
12.4	3.02E-02	S	6.68E-06	S	1.70E-02	S	2.78E-03	S
12.6	3.01E-02	S	7.08E-06	S	1.98E-02	S	2.78E-03	S
12.8	3.00E-02	S	7.48E-06	S	2.31E-02	S	2.78E-03	S
13	2.99E-02	S	7.91E-06	S	2.69E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	6.73E-01		9.08E-05		2.80E-01		5.85E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.69E+00	S	2.53E-03	S	3.21E-02	S
3	2.41E+00	S	2.53E-03	S	2.35E-02	S
3.2	2.18E+00	S	2.53E-03	S	1.76E-02	S
3.4	1.98E+00	S	2.53E-03	S	1.34E-02	S
3.6	1.81E+00	S	2.53E-03	S	1.03E-02	S
3.8	1.64E+00	S	2.53E-03	S	8.12E-03	S
4	1.46E+00	S	2.53E-03	S	6.48E-03	S
4.2	1.30E+00	S	2.53E-03	S	5.24E-03	S
4.4	1.17E+00	S	2.53E-03	S	4.27E-03	S
4.6	1.05E+00	S	2.53E-03	S	3.52E-03	S
4.8	9.51E-01	S	2.53E-03	S	2.92E-03	S
5	8.64E-01	S	2.53E-03	S	2.44E-03	S
5.2	7.89E-01	S	2.53E-03	S	2.06E-03	S
5.4	7.22E-01	S	2.53E-03	S	1.74E-03	S
5.6	6.63E-01	S	2.53E-03	S	1.49E-03	S
5.8	5.49E-01	S	2.53E-03	S	1.43E-03	S
6	4.41E-01	S	2.53E-03	S	1.43E-03	S
6.2	3.57E-01	S	2.53E-03	S	1.43E-03	S
6.4	2.91E-01	S	2.53E-03	S	1.43E-03	S
6.6	2.35E-01	S	2.53E-03	S	1.43E-03	S
6.8	1.68E-01	S	2.53E-03	S	1.43E-03	S
7	1.20E-01	S	2.53E-03	S	1.43E-03	S
7.2	8.75E-02	S	2.53E-03	S	1.43E-03	S
7.4	6.41E-02	S	2.53E-03	S	1.43E-03	S
7.6	4.73E-02	S	2.53E-03	S	1.43E-03	S
7.8	3.84E-02	S	2.53E-03	S	1.43E-03	S
8	3.83E-02	S	2.53E-03	S	1.43E-03	S

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Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	3.83E-02	S	2.53E-03	S	1.43E-03	S
8.4	3.82E-02	S	2.53E-03	S	1.43E-03	S
8.6	3.81E-02	S	2.53E-03	S	1.43E-03	S
8.8	3.81E-02	S	2.53E-03	S	1.43E-03	S
9	3.80E-02	S	2.53E-03	S	1.43E-03	S
9.2	4.35E-02	S	2.53E-03	S	1.43E-03	S
9.4	5.09E-02	S	2.53E-03	S	1.43E-03	S
9.6	5.94E-02	S	2.53E-03	S	1.43E-03	S
9.8	6.91E-02	S	2.53E-03	S	1.43E-03	S
10	8.01E-02	S	2.53E-03	S	1.43E-03	S
10.2	9.26E-02	S	2.53E-03	S	1.43E-03	S
10.4	1.07E-01	S	2.53E-03	S	1.43E-03	S
10.6	1.23E-01	S	2.53E-03	S	1.43E-03	S
10.8	1.41E-01	S	2.53E-03	S	1.43E-03	S
11	1.61E-01	S	2.53E-03	S	1.43E-03	S
11.2	1.84E-01	S	2.53E-03	S	1.43E-03	S
11.4	2.09E-01	S	2.53E-03	S	1.43E-03	S
11.6	2.37E-01	S	2.53E-03	S	1.43E-03	S
11.8	2.69E-01	S	2.53E-03	S	1.43E-03	S
12	3.04E-01	S	2.53E-03	S	1.43E-03	S
12.2	3.78E-01	S	2.53E-03	S	1.43E-03	S
12.4	4.75E-01	S	2.53E-03	S	1.43E-03	S
12.6	5.95E-01	S	2.53E-03	S	1.43E-03	S
12.8	7.43E-01	S	2.53E-03	S	1.43E-03	S
13	9.25E-01	S	2.53E-03	S	1.43E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.84E+01		3.07E-02		1.80E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID	NAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	2.17E-02	S	2.03E+00	W	1.22E-02	S	4.14E-03	S
3	2.01E-02	S	2.00E+00	W	1.19E-02	S	4.58E-03	S
3.2	1.89E-02	S	1.98E+00	W	1.16E-02	S	4.82E-03	S
3.4	1.80E-02	S	1.97E+00	W	1.13E-02	S	4.84E-03	S
3.6	1.72E-02	S	1.95E+00	W	1.11E-02	S	4.87E-03	S
3.8	1.65E-02	S	1.94E+00	W	1.08E-02	S	4.89E-03	S
4	1.59E-02	S	1.93E+00	W	1.06E-02	S	4.91E-03	S
4.2	1.55E-02	S	1.92E+00	W	1.04E-02	S	4.95E-03	S
4.4	1.54E-02	S	1.91E+00	W	1.04E-02	S	4.99E-03	S
4.6	1.53E-02	S	1.90E+00	W	1.03E-02	S	5.03E-03	S
4.8	1.35E-02	S	1.87E+00	W	9.96E-03	S	4.74E-03	S
5	1.19E-02	S	1.84E+00	W	9.62E-03	S	4.44E-03	S
5.2	9.34E-03	S	1.78E+00	W	9.02E-03	S	4.09E-03	S
5.4	7.37E-03	S	1.73E+00	W	8.47E-03	S	3.78E-03	S
5.6	5.86E-03	S	1.68E+00	W	7.97E-03	S	3.50E-03	S
5.8	4.70E-03	S	1.63E+00	W	7.52E-03	S	3.25E-03	S
6	3.80E-03	S	1.58E+00	W	7.10E-03	S	3.03E-03	S
6.2	3.31E-03	S	1.56E+00	W	6.72E-03	S	2.94E-03	S
6.4	3.20E-03	S	1.56E+00	W	6.32E-03	S	2.70E-03	S
6.6	3.20E-03	S	1.58E+00	W	5.95E-03	S	2.43E-03	S
6.8	3.20E-03	S	1.60E+00	W	5.61E-03	S	2.18E-03	S
7	3.20E-03	S	1.70E+00	W	3.64E-03	S	2.06E-03	S
7.2	3.20E-03	S	1.85E+00	W	1.61E-03	S	2.06E-03	S
7.4	3.20E-03	S	1.69E+00	W	1.36E-03	S	2.06E-03	S
7.6	3.20E-03	S	1.55E+00	W	1.16E-03	S	2.06E-03	S
7.8	3.20E-03	S	1.52E+00	W	9.98E-04	S	2.06E-03	S
8	3.20E-03	S	1.52E+00	W	8.58E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID	NAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:36 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	1.52E+00	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	1.52E+00	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	1.54E+00	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	1.55E+00	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	1.56E+00	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	1.58E+00	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	1.59E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	1.60E+00	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	1.62E+00	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	1.63E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	1.64E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	1.63E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	1.60E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	1.57E+00	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	1.58E+00	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	1.65E+00	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.72E+00	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.79E+00	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.87E+00	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.94E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	2.02E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	2.09E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	2.15E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	2.18E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	2.21E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	2.01E-01		2.29E+01		1.19E-01		5.03E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	5.51E-01	S	3.09E-05	S	9.26E-03	S	3.52E-03	S
3	4.77E-01	S	2.12E-05	S	8.67E-03	S	3.01E-03	S
3.2	4.02E-01	S	1.50E-05	S	8.55E-03	S	2.78E-03	S
3.4	3.29E-01	S	1.36E-05	S	8.90E-03	S	2.78E-03	S
3.6	2.73E-01	S	1.24E-05	S	9.24E-03	S	2.78E-03	S
3.8	2.29E-01	S	1.14E-05	S	9.58E-03	S	2.78E-03	S
4	1.93E-01	S	1.05E-05	S	9.91E-03	S	2.78E-03	S
4.2	1.68E-01	S	1.13E-05	S	1.02E-02	S	2.78E-03	S
4.4	1.52E-01	S	1.50E-05	S	1.06E-02	S	2.78E-03	S
4.6	1.38E-01	S	1.97E-05	S	1.09E-02	S	2.78E-03	S
4.8	1.11E-01	S	2.57E-05	S	1.13E-02	S	2.78E-03	S
5	8.99E-02	S	3.30E-05	S	1.16E-02	S	2.78E-03	S
5.2	6.02E-02	S	2.05E-05	S	1.20E-02	S	2.78E-03	S
5.4	4.06E-02	S	1.25E-05	S	1.25E-02	S	2.78E-03	S
5.6	2.77E-02	S	7.76E-06	S	1.29E-02	S	2.78E-03	S
5.8	1.92E-02	S	4.90E-06	S	1.33E-02	S	2.78E-03	S
6	1.35E-02	S	3.14E-06	S	1.36E-02	S	2.78E-03	S
6.2	1.10E-02	S	2.32E-06	S	1.40E-02	S	2.78E-03	S
6.4	1.04E-02	S	2.40E-06	S	1.42E-02	S	2.78E-03	S
6.6	1.02E-02	S	2.82E-06	S	1.44E-02	S	2.78E-03	S
6.8	1.00E-02	S	3.29E-06	S	1.45E-02	S	2.78E-03	S
7	8.12E-03	S	3.43E-06	S	1.48E-02	S	2.78E-03	S
7.2	5.51E-03	S	3.06E-06	S	1.55E-02	W	2.78E-03	S
7.4	6.48E-03	S	2.73E-06	S	1.64E-02	W	2.78E-03	S
7.6	7.60E-03	S	2.45E-06	S	1.73E-02	W	2.78E-03	S
7.8	8.00E-03	S	2.20E-06	S	1.79E-02	W	2.78E-03	S
8	8.13E-03	S	1.98E-06	S	1.84E-02	W	2.78E-03	S

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Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	9.21E-03	S	1.80E-06	S	1.95E-02	W	2.78E-03	S
8.4	1.11E-02	S	1.80E-06	S	2.05E-02	W	2.78E-03	S
8.6	1.21E-02	S	1.80E-06	S	2.09E-02	W	2.78E-03	S
8.8	1.30E-02	S	1.80E-06	S	2.12E-02	W	2.78E-03	S
9	1.38E-02	S	1.80E-06	S	2.15E-02	W	2.78E-03	S
9.2	1.46E-02	S	1.80E-06	S	2.17E-02	W	2.78E-03	S
9.4	1.55E-02	S	1.80E-06	S	2.20E-02	W	2.78E-03	S
9.6	1.63E-02	S	1.80E-06	S	2.23E-02	W	2.78E-03	S
9.8	1.72E-02	S	1.80E-06	S	2.25E-02	W	2.78E-03	S
10	1.82E-02	S	1.80E-06	S	2.28E-02	W	2.78E-03	S
10.2	1.91E-02	S	1.80E-06	S	2.31E-02	W	2.78E-03	S
10.4	2.24E-02	S	1.80E-06	S	2.32E-02	W	2.78E-03	S
10.6	2.78E-02	S	1.80E-06	S	2.33E-02	W	2.78E-03	S
10.8	3.42E-02	S	1.80E-06	S	2.34E-02	W	2.78E-03	S
11	3.37E-02	S	1.86E-06	S	2.38E-02	W	2.78E-03	S
11.2	3.01E-02	S	2.52E-06	S	2.45E-02	W	2.78E-03	S
11.4	2.70E-02	S	3.39E-06	S	2.51E-02	W	2.78E-03	S
11.6	2.42E-02	S	4.55E-06	S	2.57E-02	W	2.78E-03	S
11.8	2.18E-02	S	6.08E-06	S	2.63E-02	W	2.78E-03	S
12	1.96E-02	S	8.07E-06	S	2.67E-02	W	2.78E-03	S
12.2	1.77E-02	S	1.07E-05	S	2.67E-02	W	2.78E-03	S
12.4	1.60E-02	S	1.40E-05	S	2.67E-02	W	2.78E-03	S
12.6	1.45E-02	S	1.84E-05	S	2.67E-02	W	2.78E-03	S
12.8	1.31E-02	S	2.40E-05	S	2.67E-02	W	2.78E-03	S
13	1.19E-02	S	3.12E-05	S	2.67E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.77E+00		3.30E-04		2.81E-01		3.01E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.68E-01	S	2.53E-03	S	3.02E-01	S
3	1.64E-01	S	2.53E-03	S	2.70E-01	S
3.2	1.63E-01	S	2.53E-03	S	2.38E-01	S
3.4	1.65E-01	S	2.53E-03	S	2.07E-01	S
3.6	1.67E-01	S	2.53E-03	S	1.82E-01	S
3.8	1.69E-01	S	2.53E-03	S	1.60E-01	S
4	1.71E-01	S	2.53E-03	S	1.42E-01	S
4.2	1.73E-01	S	2.53E-03	S	1.27E-01	S
4.4	1.75E-01	S	2.53E-03	S	1.14E-01	S
4.6	1.76E-01	S	2.53E-03	S	1.03E-01	S
4.8	1.75E-01	S	2.53E-03	S	9.50E-02	S
5	1.73E-01	S	2.53E-03	S	8.81E-02	S
5.2	1.67E-01	S	2.53E-03	S	8.06E-02	S
5.4	1.62E-01	S	2.53E-03	S	7.39E-02	S
5.6	1.56E-01	S	2.53E-03	S	6.80E-02	S
5.8	1.52E-01	S	2.53E-03	S	6.28E-02	S
6	1.47E-01	S	2.53E-03	S	5.81E-02	S
6.2	1.41E-01	S	2.53E-03	S	5.35E-02	S
6.4	1.33E-01	S	2.53E-03	S	4.94E-02	S
6.6	1.25E-01	S	2.53E-03	S	4.57E-02	S
6.8	1.18E-01	S	2.53E-03	S	4.23E-02	S
7	7.75E-02	S	2.53E-03	S	3.06E-02	S
7.2	3.51E-02	S	2.53E-03	S	1.75E-02	S
7.4	2.78E-02	S	2.53E-03	S	1.72E-02	S
7.6	2.23E-02	S	2.53E-03	S	1.69E-02	S
7.8	1.89E-02	S	2.53E-03	S	1.68E-02	S
8	1.63E-02	S	2.53E-03	S	1.67E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-38. Leachate Concentrations for Gypsum Export, Waste ID DaAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.42E-02	S	2.53E-03	S	1.99E-02	S
8.4	1.35E-02	S	2.53E-03	S	2.60E-02	S
8.6	1.30E-02	S	2.53E-03	S	2.86E-02	S
8.8	1.25E-02	S	2.53E-03	S	3.13E-02	S
9	1.24E-02	S	2.53E-03	S	3.34E-02	S
9.2	1.24E-02	S	2.53E-03	S	3.56E-02	S
9.4	1.23E-02	S	2.53E-03	S	3.79E-02	S
9.6	1.22E-02	S	2.53E-03	S	4.03E-02	S
9.8	1.22E-02	S	2.53E-03	S	4.28E-02	S
10	1.21E-02	S	2.53E-03	S	4.54E-02	S
10.2	1.21E-02	S	2.53E-03	S	4.81E-02	S
10.4	1.57E-02	S	2.53E-03	S	4.87E-02	S
10.6	2.32E-02	S	2.53E-03	S	4.86E-02	S
10.8	3.39E-02	S	2.53E-03	S	4.86E-02	S
11	4.27E-02	S	2.53E-03	S	4.89E-02	S
11.2	5.27E-02	S	2.53E-03	S	4.95E-02	S
11.4	6.47E-02	S	2.53E-03	S	5.01E-02	S
11.6	7.92E-02	S	2.53E-03	S	5.07E-02	S
11.8	9.66E-02	S	2.53E-03	S	5.13E-02	S
12	1.17E-01	S	2.53E-03	S	5.19E-02	S
12.2	1.42E-01	S	2.53E-03	S	5.24E-02	S
12.4	1.72E-01	S	2.53E-03	S	5.30E-02	S
12.6	1.95E-01	S	2.53E-03	S	5.36E-02	S
12.8	2.03E-01	S	2.53E-03	S	5.42E-02	S
13	2.03E-01	S	2.53E-03	S	5.47E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.13E+00		2.66E-02		2.70E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID	NAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.81E-02	S	8.14E-02	W	1.05E-02	S	4.42E-03	S
3	1.71E-02	S	7.89E-02	W	1.03E-02	S	4.51E-03	S
3.2	1.63E-02	S	7.68E-02	W	1.00E-02	S	4.49E-03	S
3.4	1.56E-02	S	7.48E-02	W	9.81E-03	S	4.48E-03	S
3.6	1.49E-02	S	7.34E-02	W	9.61E-03	S	4.38E-03	S
3.8	1.41E-02	S	7.24E-02	W	9.42E-03	S	4.21E-03	S
4	1.34E-02	S	7.14E-02	W	9.24E-03	S	4.05E-03	S
4.2	1.28E-02	S	7.05E-02	W	9.08E-03	S	3.90E-03	S
4.4	1.22E-02	S	6.97E-02	W	8.92E-03	S	3.77E-03	S
4.6	1.17E-02	S	6.89E-02	W	8.78E-03	S	3.64E-03	S
4.8	1.12E-02	S	6.82E-02	W	8.64E-03	S	3.52E-03	S
5	1.08E-02	S	6.75E-02	W	8.51E-03	S	3.42E-03	S
5.2	1.04E-02	S	6.68E-02	W	8.39E-03	S	3.32E-03	S
5.4	9.95E-03	S	6.61E-02	W	8.26E-03	S	3.18E-03	S
5.6	8.70E-03	S	6.40E-02	W	7.80E-03	S	2.37E-03	S
5.8	7.37E-03	S	6.17E-02	W	7.37E-03	S	2.06E-03	S
6	6.46E-03	S	5.96E-02	W	7.07E-03	S	2.06E-03	S
6.2	5.69E-03	S	5.77E-02	W	6.78E-03	S	2.06E-03	S
6.4	5.54E-03	S	5.57E-02	W	6.03E-03	S	2.06E-03	S
6.6	4.78E-03	S	5.31E-02	W	3.76E-03	S	2.06E-03	S
6.8	3.92E-03	S	5.05E-02	W	2.14E-03	S	2.06E-03	S
7	3.95E-03	S	4.87E-02	W	1.11E-03	S	2.06E-03	S
7.2	5.29E-03	S	4.79E-02	W	1.18E-03	S	2.06E-03	S
7.4	5.15E-03	S	4.89E-02	W	1.30E-03	S	2.06E-03	S
7.6	4.52E-03	S	5.13E-02	W	1.18E-03	S	2.06E-03	S
7.8	3.97E-03	S	5.37E-02	W	1.07E-03	S	2.06E-03	S
8	3.51E-03	S	5.62E-02	W	9.77E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID	NAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	5.90E-02	W	8.92E-04	S	2.06E-03	S
8.4	3.20E-03	S	6.27E-02	W	8.17E-04	S	2.06E-03	S
8.6	3.20E-03	S	6.66E-02	W	7.50E-04	S	2.06E-03	S
8.8	3.20E-03	S	6.97E-02	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	7.29E-02	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	7.58E-02	W	7.57E-04	S	2.06E-03	S
9.4	3.20E-03	S	7.82E-02	W	7.92E-04	S	2.06E-03	S
9.6	3.20E-03	S	8.06E-02	W	8.29E-04	S	2.06E-03	S
9.8	3.20E-03	S	8.30E-02	W	8.66E-04	S	2.06E-03	S
10	3.20E-03	S	8.54E-02	W	9.04E-04	S	2.06E-03	S
10.2	3.20E-03	S	9.05E-02	W	9.43E-04	S	2.06E-03	S
10.4	3.20E-03	S	9.76E-02	W	9.83E-04	S	2.06E-03	S
10.6	3.20E-03	S	1.05E-01	W	1.02E-03	S	2.06E-03	S
10.8	3.20E-03	S	1.14E-01	W	1.07E-03	S	2.06E-03	S
11	3.20E-03	S	1.26E-01	W	1.05E-03	S	2.06E-03	S
11.2	3.20E-03	S	1.38E-01	W	8.99E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.46E-01	W	7.74E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.47E-01	W	6.69E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.47E-01	W	5.79E-04	S	2.06E-03	S
12	3.20E-03	S	1.47E-01	S	5.03E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.47E-01	S	4.38E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.47E-01	S	3.82E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.47E-01	S	3.33E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.47E-01	S	2.92E-04	S	2.06E-03	S
13	3.20E-03	S	1.47E-01	S	2.56E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.71E-01		1.49E+00		1.03E-01		4.51E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.88E-01	S	1.80E-06	S	3.92E-03	S	2.78E-03	S
3	2.11E-01	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.2	1.57E-01	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.4	1.19E-01	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.6	9.65E-02	S	1.80E-06	S	3.87E-03	S	2.78E-03	S
3.8	8.36E-02	S	1.80E-06	S	4.02E-03	S	2.78E-03	S
4	7.30E-02	S	1.80E-06	S	4.18E-03	S	2.78E-03	S
4.2	6.41E-02	S	1.80E-06	S	4.33E-03	S	2.78E-03	S
4.4	5.67E-02	S	1.80E-06	S	4.49E-03	S	2.78E-03	S
4.6	5.04E-02	S	1.80E-06	S	4.64E-03	S	2.78E-03	S
4.8	4.50E-02	S	1.80E-06	S	4.78E-03	S	2.78E-03	S
5	4.04E-02	S	1.80E-06	S	4.93E-03	S	2.78E-03	S
5.2	3.64E-02	S	1.80E-06	S	5.08E-03	S	2.78E-03	S
5.4	3.23E-02	S	1.80E-06	S	5.29E-03	S	2.78E-03	S
5.6	1.99E-02	S	1.80E-06	S	7.02E-03	S	2.78E-03	S
5.8	1.20E-02	S	1.80E-06	S	8.14E-03	S	2.78E-03	S
6	7.58E-03	S	1.80E-06	S	8.38E-03	S	2.78E-03	S
6.2	4.85E-03	S	1.80E-06	S	8.61E-03	S	2.78E-03	S
6.4	3.09E-03	S	1.80E-06	S	8.75E-03	S	2.78E-03	S
6.6	2.41E-03	S	1.80E-06	S	8.74E-03	S	2.78E-03	S
6.8	2.02E-03	S	1.80E-06	S	8.69E-03	S	2.78E-03	S
7	1.90E-03	S	1.80E-06	S	8.98E-03	S	2.78E-03	S
7.2	1.90E-03	S	1.80E-06	S	9.32E-03	W	2.78E-03	S
7.4	2.04E-03	S	1.80E-06	S	9.81E-03	W	2.78E-03	S
7.6	2.23E-03	S	1.80E-06	S	1.06E-02	W	2.78E-03	S
7.8	2.44E-03	S	1.80E-06	S	1.14E-02	W	2.78E-03	S
8	2.67E-03	S	1.80E-06	S	1.22E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.93E-03	S	1.80E-06	S	1.30E-02	W	2.78E-03	S
8.4	3.31E-03	S	1.80E-06	S	1.36E-02	W	2.78E-03	S
8.6	3.73E-03	S	1.80E-06	S	1.41E-02	W	2.78E-03	S
8.8	4.70E-03	S	1.80E-06	S	1.42E-02	W	2.78E-03	S
9	5.93E-03	S	1.80E-06	S	1.43E-02	W	2.78E-03	S
9.2	7.22E-03	S	1.80E-06	S	1.44E-02	W	2.78E-03	S
9.4	8.16E-03	S	1.80E-06	S	1.44E-02	W	2.78E-03	S
9.6	9.19E-03	S	1.80E-06	S	1.44E-02	W	2.78E-03	S
9.8	1.03E-02	S	1.80E-06	S	1.44E-02	W	2.78E-03	S
10	1.16E-02	S	1.80E-06	S	1.44E-02	W	2.78E-03	S
10.2	1.23E-02	S	1.80E-06	S	1.46E-02	W	2.78E-03	S
10.4	1.25E-02	S	1.80E-06	S	1.48E-02	W	2.78E-03	S
10.6	1.27E-02	S	1.80E-06	S	1.51E-02	W	2.78E-03	S
10.8	1.29E-02	S	1.80E-06	S	1.53E-02	W	2.78E-03	S
11	1.33E-02	S	1.80E-06	S	1.55E-02	W	2.78E-03	S
11.2	1.40E-02	S	1.80E-06	S	1.56E-02	W	2.78E-03	S
11.4	1.48E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
11.6	1.56E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
11.8	1.64E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
12	1.73E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
12.2	1.81E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
12.4	1.90E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
12.6	2.00E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
12.8	2.09E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
13	2.19E-02	S	1.80E-06	S	1.57E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.11E+00		1.83E-05		1.60E-01		2.82E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.47E-01	W	2.53E-03	S	2.61E-01	S
3	1.46E-01	W	2.53E-03	S	2.27E-01	S
3.2	1.45E-01	W	2.53E-03	S	1.98E-01	S
3.4	1.45E-01	W	2.53E-03	S	1.74E-01	S
3.6	1.46E-01	W	2.53E-03	S	1.56E-01	S
3.8	1.47E-01	W	2.53E-03	S	1.41E-01	S
4	1.49E-01	W	2.53E-03	S	1.28E-01	S
4.2	1.51E-01	W	2.53E-03	S	1.17E-01	S
4.4	1.52E-01	W	2.53E-03	S	1.07E-01	S
4.6	1.54E-01	W	2.53E-03	S	9.90E-02	S
4.8	1.55E-01	W	2.53E-03	S	9.15E-02	S
5	1.56E-01	W	2.53E-03	S	8.49E-02	S
5.2	1.58E-01	W	2.53E-03	S	7.90E-02	S
5.4	1.59E-01	W	2.53E-03	S	7.37E-02	S
5.6	1.60E-01	W	2.53E-03	S	6.92E-02	S
5.8	1.56E-01	W	2.53E-03	S	6.49E-02	S
6	1.51E-01	S	2.53E-03	S	6.12E-02	S
6.2	1.45E-01	S	2.53E-03	S	5.77E-02	S
6.4	1.31E-01	S	2.53E-03	S	5.02E-02	S
6.6	8.42E-02	S	2.53E-03	S	3.30E-02	S
6.8	4.94E-02	S	2.53E-03	S	2.03E-02	S
7	2.37E-02	S	2.53E-03	S	1.18E-02	S
7.2	2.54E-02	S	2.53E-03	S	1.29E-02	S
7.4	2.87E-02	S	2.53E-03	S	1.64E-02	S
7.6	2.49E-02	S	2.53E-03	S	1.86E-02	S
7.8	2.17E-02	S	2.53E-03	S	2.11E-02	S
8	1.90E-02	S	2.53E-03	S	2.39E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-40. Leachate Concentrations for Gypsum Export, Waste ID NAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.70E-02	S	2.53E-03	S	2.65E-02	S
8.4	1.61E-02	S	2.53E-03	S	2.82E-02	S
8.6	1.52E-02	S	2.53E-03	S	2.99E-02	S
8.8	1.65E-02	S	2.53E-03	S	3.21E-02	S
9	1.79E-02	S	2.53E-03	S	3.45E-02	S
9.2	1.90E-02	S	2.53E-03	S	3.65E-02	S
9.4	1.91E-02	S	2.53E-03	S	3.74E-02	S
9.6	1.93E-02	S	2.53E-03	S	3.83E-02	S
9.8	1.95E-02	S	2.53E-03	S	3.92E-02	S
10	1.96E-02	S	2.53E-03	S	4.01E-02	S
10.2	2.02E-02	S	2.53E-03	S	4.10E-02	S
10.4	2.10E-02	S	2.53E-03	S	4.19E-02	S
10.6	2.19E-02	S	2.53E-03	S	4.27E-02	S
10.8	2.40E-02	S	2.53E-03	S	4.43E-02	S
11	2.98E-02	S	2.53E-03	S	4.76E-02	S
11.2	4.12E-02	S	2.53E-03	S	5.29E-02	S
11.4	5.67E-02	S	2.53E-03	S	5.87E-02	S
11.6	7.76E-02	S	2.53E-03	S	6.49E-02	S
11.8	1.06E-01	S	2.53E-03	S	7.18E-02	S
12	1.43E-01	S	2.53E-03	S	7.92E-02	S
12.2	1.67E-01	S	2.53E-03	S	8.72E-02	S
12.4	1.78E-01	S	2.53E-03	S	9.59E-02	S
12.6	1.78E-01	S	2.53E-03	S	1.05E-01	S
12.8	1.78E-01	S	2.53E-03	S	1.15E-01	S
13	1.78E-01	S	2.53E-03	S	1.26E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.80E+00		2.57E-02		2.27E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID	OAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	7.96E-03	S	5.94E+00	W	1.33E-02	W	1.83E-02	W
3	5.50E-03	S	5.89E+00	W	1.31E-02	W	1.80E-02	W
3.2	4.58E-03	S	5.85E+00	W	1.30E-02	W	1.78E-02	W
3.4	4.34E-03	S	5.83E+00	W	1.30E-02	W	1.78E-02	W
3.6	4.13E-03	S	5.81E+00	W	1.30E-02	W	1.78E-02	W
3.8	3.94E-03	S	5.79E+00	W	1.30E-02	W	1.78E-02	W
4	3.76E-03	S	5.77E+00	W	1.29E-02	W	1.78E-02	W
4.2	3.60E-03	S	5.75E+00	W	1.29E-02	W	1.78E-02	W
4.4	3.46E-03	S	5.73E+00	W	1.29E-02	W	1.78E-02	W
4.6	3.32E-03	S	5.69E+00	W	1.28E-02	W	1.77E-02	W
4.8	3.20E-03	S	5.65E+00	W	1.27E-02	W	1.76E-02	W
5	3.20E-03	S	5.64E+00	W	1.26E-02	S	1.75E-02	S
5.2	3.20E-03	S	5.63E+00	W	1.24E-02	S	1.74E-02	S
5.4	3.20E-03	S	5.65E+00	W	1.23E-02	S	1.69E-02	S
5.6	3.20E-03	S	5.70E+00	W	1.14E-02	S	1.45E-02	S
5.8	3.20E-03	S	5.69E+00	W	1.09E-02	S	1.27E-02	S
6	3.20E-03	S	5.65E+00	W	1.00E-02	S	1.03E-02	S
6.2	3.20E-03	S	5.62E+00	W	9.17E-03	S	8.32E-03	S
6.4	3.20E-03	S	5.58E+00	W	8.43E-03	S	6.75E-03	S
6.6	3.20E-03	S	5.54E+00	W	7.77E-03	S	5.51E-03	S
6.8	3.20E-03	S	5.50E+00	W	6.78E-03	S	4.52E-03	S
7	3.20E-03	S	5.42E+00	W	3.69E-03	S	3.62E-03	S
7.2	3.20E-03	S	5.35E+00	W	1.99E-03	S	2.91E-03	S
7.4	3.20E-03	S	5.27E+00	W	1.09E-03	S	2.35E-03	S
7.6	3.20E-03	S	5.24E+00	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	5.28E+00	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	5.31E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID	OAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	5.34E+00	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	5.38E+00	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	5.41E+00	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	5.45E+00	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	5.45E+00	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	5.43E+00	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	5.40E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	5.40E+00	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	5.44E+00	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	5.48E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	5.52E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	5.61E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	5.70E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	5.79E+00	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	5.87E+00	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	5.96E+00	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	6.05E+00	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	6.14E+00	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	6.23E+00	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	6.30E+00	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	6.33E+00	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	6.33E+00	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	6.33E+00	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	6.33E+00	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	6.33E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	5.50E-02		6.65E+01		1.31E-01		1.80E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.01E-01	S	1.80E-06	S	6.32E-03	S	3.06E-03	S
3	8.96E-02	S	1.80E-06	S	4.42E-03	S	2.87E-03	S
3.2	6.93E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.4	4.76E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.6	3.34E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.8	2.39E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
4	1.74E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
4.2	1.29E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
4.4	9.42E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
4.6	5.70E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
4.8	3.53E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
5	2.66E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
5.2	2.03E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
5.4	1.90E-03	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
5.6	1.90E-03	S	1.80E-06	S	3.90E-03	S	2.78E-03	S
5.8	1.90E-03	S	1.80E-06	S	4.48E-03	S	2.78E-03	S
6	1.90E-03	S	1.80E-06	S	5.93E-03	S	2.78E-03	S
6.2	1.90E-03	S	1.80E-06	S	8.08E-03	S	2.78E-03	S
6.4	1.90E-03	S	1.80E-06	S	1.09E-02	S	2.78E-03	S
6.6	1.90E-03	S	1.80E-06	S	1.45E-02	S	2.78E-03	S
6.8	1.90E-03	S	1.80E-06	S	1.86E-02	S	2.78E-03	S
7	1.90E-03	S	2.14E-06	S	1.88E-02	S	2.78E-03	S
7.2	1.90E-03	S	2.59E-06	S	1.88E-02	W	2.78E-03	S
7.4	1.90E-03	S	3.11E-06	S	1.87E-02	W	2.78E-03	S
7.6	1.90E-03	S	3.51E-06	S	1.88E-02	W	2.78E-03	S
7.8	1.90E-03	S	3.14E-06	S	1.90E-02	W	2.78E-03	S
8	1.90E-03	S	2.81E-06	S	1.92E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.90E-03	S	2.53E-06	S	1.94E-02	W	2.78E-03	S
8.4	1.90E-03	S	2.28E-06	S	1.95E-02	W	2.78E-03	S
8.6	1.90E-03	S	2.06E-06	S	1.99E-02	W	2.78E-03	S
8.8	1.90E-03	S	1.86E-06	S	2.04E-02	W	2.78E-03	S
9	2.06E-03	S	1.80E-06	S	2.14E-02	W	2.78E-03	S
9.2	2.33E-03	S	1.80E-06	S	2.25E-02	W	2.78E-03	S
9.4	2.63E-03	S	1.80E-06	S	2.37E-02	W	2.78E-03	S
9.6	3.06E-03	S	1.94E-06	S	2.45E-02	W	2.78E-03	S
9.8	3.61E-03	S	2.37E-06	S	2.46E-02	W	2.78E-03	S
10	4.25E-03	S	2.90E-06	S	2.48E-02	W	2.78E-03	S
10.2	4.78E-03	S	3.53E-06	S	2.50E-02	W	2.78E-03	S
10.4	4.92E-03	S	3.34E-06	S	2.57E-02	W	2.78E-03	S
10.6	5.06E-03	S	3.07E-06	S	2.65E-02	W	2.78E-03	S
10.8	5.20E-03	S	2.84E-06	S	2.72E-02	W	2.78E-03	S
11	5.35E-03	S	2.62E-06	S	2.80E-02	W	2.78E-03	S
11.2	5.49E-03	S	2.43E-06	S	2.88E-02	W	2.78E-03	S
11.4	5.64E-03	S	2.25E-06	S	2.96E-02	W	2.78E-03	S
11.6	5.79E-03	S	2.09E-06	S	3.04E-02	W	2.78E-03	S
11.8	5.94E-03	S	1.94E-06	S	3.12E-02	W	2.78E-03	S
12	6.09E-03	S	1.81E-06	S	3.17E-02	W	2.78E-03	S
12.2	6.24E-03	S	1.80E-06	S	3.17E-02	W	2.78E-03	S
12.4	6.39E-03	S	1.80E-06	S	3.17E-02	W	2.78E-03	S
12.6	6.55E-03	S	1.80E-06	S	3.17E-02	W	2.78E-03	S
12.8	6.70E-03	S	1.80E-06	S	3.17E-02	W	2.78E-03	S
13	6.86E-03	S	1.80E-06	S	3.17E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	8.96E-01		3.56E-05		3.33E-01		2.92E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.05E-01	W	2.53E-03	S	7.19E-02	S
3	1.02E-01	W	2.53E-03	S	5.80E-02	S
3.2	1.01E-01	W	2.53E-03	S	3.81E-02	S
3.4	1.01E-01	W	2.53E-03	S	2.17E-02	S
3.6	1.01E-01	W	2.53E-03	S	1.28E-02	S
3.8	1.01E-01	W	2.53E-03	S	7.72E-03	S
4	1.01E-01	W	2.53E-03	S	4.80E-03	S
4.2	1.01E-01	W	2.53E-03	S	3.05E-03	S
4.4	1.01E-01	W	2.53E-03	S	2.03E-03	S
4.6	1.01E-01	W	2.53E-03	S	1.70E-03	S
4.8	1.01E-01	W	2.53E-03	S	1.43E-03	S
5	1.01E-01	W	2.53E-03	S	1.43E-03	S
5.2	1.02E-01	W	2.53E-03	S	1.43E-03	S
5.4	1.02E-01	W	2.53E-03	S	1.43E-03	S
5.6	1.05E-01	W	2.53E-03	S	1.45E-03	S
5.8	1.03E-01	W	2.53E-03	S	1.55E-03	S
6	1.01E-01	W	2.53E-03	S	1.66E-03	S
6.2	9.92E-02	W	2.53E-03	S	1.76E-03	S
6.4	9.75E-02	W	2.53E-03	S	1.87E-03	S
6.6	9.59E-02	W	2.53E-03	S	1.99E-03	S
6.8	9.43E-02	W	2.53E-03	S	2.11E-03	S
7	9.27E-02	W	2.53E-03	S	1.92E-03	S
7.2	9.11E-02	W	2.53E-03	S	1.72E-03	S
7.4	8.97E-02	W	2.53E-03	S	1.55E-03	S
7.6	8.86E-02	W	2.53E-03	S	1.43E-03	S
7.8	8.83E-02	W	2.53E-03	S	1.43E-03	S
8	8.80E-02	W	2.53E-03	S	1.43E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-41. Leachate Concentrations for Gypsum Export, Waste ID OAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	8.77E-02	W	2.53E-03	S	1.43E-03	S
8.4	8.75E-02	W	2.53E-03	S	1.43E-03	S
8.6	8.78E-02	W	2.53E-03	S	1.58E-03	S
8.8	8.86E-02	W	2.53E-03	S	1.90E-03	S
9	9.03E-02	W	2.53E-03	S	2.76E-03	S
9.2	9.25E-02	W	2.53E-03	S	4.40E-03	S
9.4	9.47E-02	W	2.53E-03	S	6.94E-03	S
9.6	9.53E-02	W	2.53E-03	S	9.16E-03	S
9.8	9.34E-02	W	2.53E-03	S	9.18E-03	S
10	9.15E-02	W	2.53E-03	S	9.19E-03	S
10.2	8.98E-02	W	2.53E-03	S	9.20E-03	S
10.4	9.02E-02	W	2.53E-03	S	9.19E-03	S
10.6	9.08E-02	W	2.53E-03	S	9.20E-03	S
10.8	9.13E-02	W	2.53E-03	S	9.20E-03	S
11	9.19E-02	W	2.53E-03	S	9.21E-03	S
11.2	9.25E-02	W	2.53E-03	S	9.21E-03	S
11.4	9.30E-02	W	2.53E-03	S	9.21E-03	S
11.6	9.36E-02	W	2.53E-03	S	9.22E-03	S
11.8	9.41E-02	W	2.53E-03	S	9.22E-03	S
12	9.46E-02	W	2.53E-03	S	9.22E-03	S
12.2	9.52E-02	W	2.53E-03	S	9.22E-03	S
12.4	9.57E-02	W	2.53E-03	S	9.23E-03	S
12.6	9.62E-02	W	2.53E-03	S	9.23E-03	S
12.8	9.67E-02	W	2.53E-03	S	9.23E-03	S
13	9.72E-02	W	2.53E-03	S	9.24E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.05E+00		2.66E-02		5.80E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID	OAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.10E-02	S	7.88E-01	S	8.81E-03	W	1.82E-02	W
3	8.69E-03	S	7.54E-01	S	8.61E-03	W	1.78E-02	W
3.2	6.90E-03	S	7.12E-01	S	8.47E-03	W	1.76E-02	W
3.4	5.54E-03	S	6.73E-01	S	8.36E-03	W	1.75E-02	W
3.6	4.51E-03	S	6.38E-01	S	8.25E-03	W	1.73E-02	W
3.8	4.06E-03	S	6.03E-01	S	8.13E-03	W	1.71E-02	W
4	3.83E-03	S	5.70E-01	S	8.01E-03	W	1.69E-02	W
4.2	3.62E-03	S	5.41E-01	S	7.90E-03	W	1.67E-02	W
4.4	3.43E-03	S	5.14E-01	S	7.79E-03	W	1.65E-02	W
4.6	3.26E-03	S	4.90E-01	S	7.70E-03	W	1.63E-02	W
4.8	3.20E-03	S	4.67E-01	S	7.46E-03	W	1.54E-02	W
5	3.20E-03	S	4.47E-01	S	7.16E-03	S	1.43E-02	S
5.2	3.20E-03	S	4.28E-01	S	6.89E-03	S	1.34E-02	S
5.4	3.20E-03	S	4.10E-01	S	6.64E-03	S	1.25E-02	S
5.6	3.20E-03	S	3.94E-01	S	6.41E-03	S	1.17E-02	S
5.8	3.20E-03	S	3.79E-01	S	6.19E-03	S	1.10E-02	S
6	3.20E-03	S	3.74E-01	S	5.67E-03	S	8.96E-03	S
6.2	3.20E-03	S	3.71E-01	W	5.16E-03	S	7.16E-03	S
6.4	3.54E-03	S	3.66E-01	W	3.46E-03	S	5.26E-03	S
6.6	4.04E-03	S	3.60E-01	W	1.99E-03	S	3.75E-03	S
6.8	4.60E-03	S	3.54E-01	W	1.17E-03	S	2.71E-03	S
7	5.21E-03	S	3.49E-01	W	7.90E-04	S	2.13E-03	S
7.2	4.78E-03	S	3.20E-01	W	7.46E-04	S	2.06E-03	S
7.4	4.10E-03	S	2.88E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.54E-03	S	2.59E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	2.42E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	2.42E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID	OAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	2.42E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	2.42E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	2.61E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	2.90E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	3.22E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	3.52E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	3.53E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	3.54E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	3.54E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	3.55E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	3.56E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	3.57E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	3.58E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	3.71E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	3.91E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	4.11E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	4.32E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	4.54E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	4.76E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	4.99E-01	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	5.23E-01	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	5.47E-01	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	5.73E-01	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	5.98E-01	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	6.25E-01	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	8.69E-02		7.54E+00		8.61E-02		1.78E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.01E-01	S	1.80E-06	S	4.80E-03	S	3.04E-03	S
3	7.27E-02	S	1.80E-06	S	3.91E-03	S	2.81E-03	S
3.2	5.49E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.4	4.23E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.6	3.31E-02	S	1.80E-06	S	3.80E-03	S	2.78E-03	S
3.8	2.30E-02	S	1.93E-06	S	3.80E-03	S	2.78E-03	S
4	1.54E-02	S	2.14E-06	S	3.80E-03	S	2.78E-03	S
4.2	1.05E-02	S	2.34E-06	S	3.80E-03	S	2.78E-03	S
4.4	7.32E-03	S	2.56E-06	S	3.80E-03	S	2.78E-03	S
4.6	5.17E-03	S	2.79E-06	S	3.80E-03	S	2.78E-03	S
4.8	4.12E-03	S	3.03E-06	S	3.97E-03	S	2.78E-03	S
5	3.50E-03	S	3.28E-06	S	4.24E-03	S	2.78E-03	S
5.2	2.99E-03	S	3.54E-06	S	4.52E-03	S	2.78E-03	S
5.4	2.58E-03	S	3.80E-06	S	4.80E-03	S	2.78E-03	S
5.6	2.23E-03	S	4.08E-06	S	5.09E-03	S	2.78E-03	S
5.8	1.94E-03	S	4.36E-06	S	5.39E-03	S	2.78E-03	S
6	1.90E-03	S	3.14E-06	S	6.85E-03	S	2.78E-03	S
6.2	1.90E-03	S	2.13E-06	S	8.92E-03	S	2.78E-03	S
6.4	1.90E-03	S	1.80E-06	S	1.02E-02	S	2.78E-03	S
6.6	1.90E-03	S	1.80E-06	S	1.07E-02	S	2.78E-03	S
6.8	1.90E-03	S	1.80E-06	S	1.13E-02	S	2.78E-03	S
7	1.90E-03	S	1.80E-06	S	1.15E-02	S	2.78E-03	S
7.2	1.90E-03	S	1.84E-06	S	1.16E-02	W	2.78E-03	S
7.4	1.90E-03	S	2.07E-06	S	1.20E-02	W	2.78E-03	S
7.6	1.90E-03	S	2.32E-06	S	1.24E-02	W	2.78E-03	S
7.8	1.90E-03	S	2.59E-06	S	1.28E-02	W	2.78E-03	S
8	1.90E-03	S	2.89E-06	S	1.33E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.90E-03	S	3.21E-06	S	1.38E-02	W	2.78E-03	S
8.4	1.90E-03	S	3.56E-06	S	1.44E-02	W	2.78E-03	S
8.6	2.16E-03	S	2.80E-06	S	1.48E-02	W	2.78E-03	S
8.8	2.58E-03	S	2.14E-06	S	1.51E-02	W	2.78E-03	S
9	3.22E-03	S	1.80E-06	S	1.54E-02	W	2.78E-03	S
9.2	4.26E-03	S	1.80E-06	S	1.56E-02	W	2.78E-03	S
9.4	5.04E-03	S	1.80E-06	S	1.58E-02	W	2.78E-03	S
9.6	5.95E-03	S	1.80E-06	S	1.61E-02	W	2.78E-03	S
9.8	6.99E-03	S	1.80E-06	S	1.64E-02	W	2.78E-03	S
10	8.20E-03	S	1.80E-06	S	1.66E-02	W	2.78E-03	S
10.2	9.58E-03	S	1.80E-06	S	1.69E-02	W	2.78E-03	S
10.4	1.12E-02	S	1.80E-06	S	1.71E-02	W	2.78E-03	S
10.6	1.15E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
10.8	1.15E-02	S	1.80E-06	S	1.74E-02	W	2.78E-03	S
11	1.13E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
11.2	1.11E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
11.4	1.09E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
11.6	1.08E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
11.8	1.06E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
12	1.04E-02	S	1.80E-06	S	1.73E-02	W	2.78E-03	S
12.2	1.03E-02	S	1.80E-06	S	1.72E-02	W	2.78E-03	S
12.4	1.01E-02	S	1.80E-06	S	1.72E-02	W	2.78E-03	S
12.6	9.99E-03	S	1.80E-06	S	1.72E-02	W	2.78E-03	S
12.8	9.85E-03	S	1.80E-06	S	1.72E-02	W	2.78E-03	S
13	9.71E-03	S	1.80E-06	S	1.72E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	7.27E-01		4.36E-05		1.80E-01		2.88E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.97E-02	W	2.53E-03	S	9.19E-02	S
3	4.84E-02	W	2.53E-03	S	6.61E-02	S
3.2	4.81E-02	W	2.53E-03	S	3.70E-02	S
3.4	4.81E-02	W	2.53E-03	S	2.05E-02	S
3.6	4.80E-02	W	2.53E-03	S	1.17E-02	S
3.8	4.75E-02	W	2.53E-03	S	8.31E-03	S
4	4.69E-02	W	2.53E-03	S	6.49E-03	S
4.2	4.63E-02	W	2.53E-03	S	5.13E-03	S
4.4	4.57E-02	W	2.53E-03	S	4.10E-03	S
4.6	4.52E-02	W	2.53E-03	S	3.30E-03	S
4.8	4.42E-02	W	2.53E-03	S	2.97E-03	S
5	4.31E-02	W	2.53E-03	S	2.82E-03	S
5.2	4.21E-02	W	2.53E-03	S	2.68E-03	S
5.4	4.11E-02	W	2.53E-03	S	2.56E-03	S
5.6	4.02E-02	W	2.53E-03	S	2.44E-03	S
5.8	3.93E-02	W	2.53E-03	S	2.34E-03	S
6	3.75E-02	W	2.53E-03	S	2.33E-03	S
6.2	3.57E-02	W	2.53E-03	S	2.35E-03	S
6.4	3.42E-02	W	2.53E-03	S	2.41E-03	S
6.6	3.26E-02	W	2.53E-03	S	2.50E-03	S
6.8	3.11E-02	W	2.53E-03	S	2.58E-03	S
7	3.14E-02	W	2.53E-03	S	2.66E-03	S
7.2	3.21E-02	W	2.53E-03	S	2.58E-03	S
7.4	3.06E-02	W	2.53E-03	S	2.57E-03	S
7.6	2.93E-02	W	2.53E-03	S	2.56E-03	S
7.8	2.85E-02	W	2.53E-03	S	2.62E-03	S
8	2.88E-02	W	2.53E-03	S	2.88E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-42. Leachate Concentrations for Gypsum Export, Waste ID OAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.91E-02	W	2.53E-03	S	3.15E-03	S
8.4	2.94E-02	W	2.53E-03	S	3.44E-03	S
8.6	2.85E-02	W	2.53E-03	S	3.70E-03	S
8.8	2.75E-02	W	2.53E-03	S	3.99E-03	S
9	2.70E-02	W	2.53E-03	S	4.37E-03	S
9.2	2.75E-02	W	2.53E-03	S	4.94E-03	S
9.4	2.76E-02	W	2.53E-03	S	5.50E-03	S
9.6	2.77E-02	W	2.53E-03	S	6.12E-03	S
9.8	2.78E-02	W	2.53E-03	S	6.79E-03	S
10	2.79E-02	W	2.53E-03	S	7.52E-03	S
10.2	2.80E-02	W	2.53E-03	S	8.31E-03	S
10.4	2.81E-02	W	2.53E-03	S	9.17E-03	S
10.6	2.78E-02	W	2.53E-03	S	9.56E-03	S
10.8	2.79E-02	W	2.53E-03	S	9.71E-03	S
11	2.80E-02	W	2.53E-03	S	9.74E-03	S
11.2	2.81E-02	W	2.53E-03	S	9.77E-03	S
11.4	2.83E-02	W	2.53E-03	S	9.81E-03	S
11.6	2.84E-02	W	2.53E-03	S	9.84E-03	S
11.8	2.85E-02	W	2.53E-03	S	9.87E-03	S
12	2.87E-02	W	2.53E-03	S	9.90E-03	S
12.2	2.88E-02	W	2.53E-03	S	9.93E-03	S
12.4	2.89E-02	W	2.53E-03	S	9.96E-03	S
12.6	2.90E-02	W	2.53E-03	S	9.99E-03	S
12.8	2.92E-02	W	2.53E-03	S	1.00E-02	S
13	2.93E-02	W	2.53E-03	S	1.00E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.84E-01		2.62E-02		6.61E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID	PAD-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	2.01E-02	S	3.14E-01	W	7.46E-04	W	2.13E-02	S
3	1.35E-02	S	3.14E-01	W	7.46E-04	W	1.66E-02	S
3.2	9.36E-03	S	3.15E-01	W	7.46E-04	W	1.31E-02	S
3.4	7.48E-03	S	3.19E-01	W	7.46E-04	W	1.13E-02	S
3.6	6.06E-03	S	3.24E-01	W	7.46E-04	W	9.86E-03	S
3.8	4.96E-03	S	3.28E-01	W	7.46E-04	W	8.64E-03	S
4	4.10E-03	S	3.32E-01	W	7.46E-04	W	7.63E-03	S
4.2	3.61E-03	S	3.33E-01	W	7.46E-04	W	6.77E-03	S
4.4	3.45E-03	S	3.31E-01	W	7.46E-04	W	6.04E-03	S
4.6	3.30E-03	S	3.29E-01	W	7.46E-04	W	5.41E-03	S
4.8	3.20E-03	S	3.26E-01	W	7.46E-04	W	4.75E-03	S
5	3.20E-03	S	3.20E-01	W	7.46E-04	S	3.92E-03	S
5.2	3.20E-03	S	3.14E-01	W	7.46E-04	S	3.26E-03	S
5.4	3.20E-03	S	3.09E-01	W	7.46E-04	S	2.73E-03	S
5.6	3.20E-03	S	3.04E-01	W	7.46E-04	S	2.30E-03	S
5.8	3.20E-03	S	3.01E-01	W	7.46E-04	S	2.07E-03	S
6	3.20E-03	S	3.06E-01	W	7.46E-04	S	2.06E-03	S
6.2	3.20E-03	S	3.14E-01	W	7.46E-04	S	2.06E-03	S
6.4	3.20E-03	S	3.20E-01	W	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	3.16E-01	W	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	2.97E-01	W	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	3.01E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	3.05E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	3.09E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	3.17E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	3.25E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	3.33E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID	PAD-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	3.38E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	3.41E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	3.44E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	3.47E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	3.50E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	3.53E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	3.55E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	3.58E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	3.63E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	3.81E-01	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	4.02E-01	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	4.28E-01	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	4.80E-01	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	5.85E-01	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	7.15E-01	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	8.69E-01	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.05E+00	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.27E+00	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.46E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.35E-01		1.54E+01		7.84E-03		1.66E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.19E-02	S	6.92E-06	S	3.80E-03	W	4.08E-03	S
3	3.13E-02	S	8.18E-06	S	3.80E-03	W	3.65E-03	S
3.2	2.39E-02	S	9.57E-06	S	3.80E-03	W	3.28E-03	S
3.4	2.01E-02	S	1.03E-05	S	3.80E-03	W	3.15E-03	S
3.6	1.71E-02	S	1.10E-05	S	3.80E-03	W	3.04E-03	S
3.8	1.46E-02	S	1.17E-05	S	3.80E-03	W	2.93E-03	S
4	1.26E-02	S	1.24E-05	S	3.80E-03	W	2.84E-03	S
4.2	1.09E-02	S	1.25E-05	S	3.80E-03	W	2.78E-03	S
4.4	9.24E-03	S	1.16E-05	S	3.80E-03	W	2.78E-03	S
4.6	7.93E-03	S	1.08E-05	S	3.80E-03	W	2.78E-03	S
4.8	6.78E-03	S	1.04E-05	S	3.80E-03	W	2.78E-03	S
5	5.67E-03	S	1.12E-05	S	3.80E-03	W	2.78E-03	S
5.2	4.77E-03	S	1.21E-05	S	3.80E-03	W	2.78E-03	S
5.4	4.05E-03	S	1.29E-05	S	3.80E-03	W	2.78E-03	S
5.6	3.45E-03	S	1.38E-05	S	3.80E-03	W	2.78E-03	S
5.8	2.63E-03	S	1.28E-05	S	3.80E-03	W	2.78E-03	S
6	2.02E-03	S	1.11E-05	S	3.80E-03	W	2.78E-03	S
6.2	2.24E-03	S	8.38E-06	S	3.80E-03	W	2.78E-03	S
6.4	2.97E-03	S	6.62E-06	S	3.80E-03	W	2.78E-03	S
6.6	5.69E-03	S	8.81E-06	S	3.80E-03	W	2.78E-03	S
6.8	3.55E-03	S	1.68E-05	S	3.80E-03	W	2.78E-03	S
7	3.14E-03	S	2.31E-05	S	3.80E-03	W	2.78E-03	S
7.2	2.79E-03	S	3.15E-05	S	3.80E-03	W	2.78E-03	S
7.4	2.62E-03	S	3.98E-05	S	3.80E-03	W	2.78E-03	S
7.6	2.86E-03	S	4.12E-05	S	3.80E-03	W	2.78E-03	S
7.8	3.12E-03	S	4.27E-05	S	3.80E-03	W	2.78E-03	S
8	3.39E-03	S	4.41E-05	S	3.80E-03	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.39E-03	S	4.35E-05	S	3.80E-03	W	2.78E-03	S
8.4	3.13E-03	S	4.10E-05	S	3.80E-03	W	2.78E-03	S
8.6	2.89E-03	S	3.87E-05	S	3.80E-03	W	2.78E-03	S
8.8	2.68E-03	S	3.66E-05	S	3.80E-03	W	2.78E-03	S
9	2.48E-03	S	3.46E-05	S	3.80E-03	W	2.78E-03	S
9.2	2.31E-03	S	3.28E-05	S	3.80E-03	W	2.78E-03	S
9.4	2.14E-03	S	3.11E-05	S	3.80E-03	W	2.78E-03	S
9.6	2.00E-03	S	2.96E-05	S	3.80E-03	W	2.78E-03	S
9.8	1.97E-03	S	2.89E-05	S	3.80E-03	W	2.78E-03	S
10	2.27E-03	S	2.94E-05	S	3.80E-03	W	2.78E-03	S
10.2	2.61E-03	S	2.97E-05	S	3.80E-03	W	2.78E-03	S
10.4	3.00E-03	S	3.02E-05	S	3.85E-03	W	2.78E-03	S
10.6	3.43E-03	S	3.19E-05	S	4.22E-03	W	2.78E-03	S
10.8	3.11E-03	S	3.27E-05	S	4.98E-03	W	2.78E-03	S
11	2.79E-03	S	3.36E-05	S	5.89E-03	S	2.78E-03	S
11.2	2.51E-03	S	3.45E-05	S	6.94E-03	S	2.78E-03	S
11.4	2.26E-03	S	3.53E-05	S	8.16E-03	S	2.78E-03	S
11.6	2.04E-03	S	3.62E-05	S	9.57E-03	S	2.78E-03	S
11.8	1.84E-03	S	3.68E-05	S	1.08E-02	S	2.78E-03	S
12	1.67E-03	S	3.66E-05	S	1.08E-02	S	2.78E-03	S
12.2	1.51E-03	S	3.65E-05	S	1.08E-02	S	2.78E-03	S
12.4	1.37E-03	S	3.63E-05	S	1.08E-02	S	2.78E-03	S
12.6	1.25E-03	S	3.62E-05	S	1.08E-02	S	2.78E-03	S
12.8	1.14E-03	S	3.60E-05	S	1.08E-02	S	2.78E-03	S
13	1.04E-03	S	3.59E-05	S	1.08E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.13E-01		4.42E-04		1.13E-01		3.65E-02	

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Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.43E-01	W	2.53E-03	S	8.97E-03	S
3	2.35E-01	W	2.53E-03	S	5.24E-03	S
3.2	2.28E-01	W	2.53E-03	S	3.16E-03	S
3.4	2.25E-01	W	2.53E-03	S	2.61E-03	S
3.6	2.22E-01	W	2.53E-03	S	2.18E-03	S
3.8	2.19E-01	W	2.53E-03	S	1.84E-03	S
4	2.17E-01	W	2.53E-03	S	1.57E-03	S
4.2	2.16E-01	W	2.53E-03	S	1.43E-03	S
4.4	2.16E-01	W	2.53E-03	S	1.43E-03	S
4.6	2.17E-01	W	2.53E-03	S	1.43E-03	S
4.8	2.18E-01	W	2.53E-03	S	1.43E-03	S
5	2.20E-01	W	2.53E-03	S	1.43E-03	S
5.2	2.22E-01	W	2.53E-03	S	1.43E-03	S
5.4	2.24E-01	W	2.53E-03	S	1.43E-03	S
5.6	2.26E-01	W	2.53E-03	S	1.43E-03	S
5.8	2.23E-01	W	2.53E-03	S	1.43E-03	S
6	2.13E-01	W	2.53E-03	S	1.43E-03	S
6.2	2.08E-01	W	2.53E-03	S	1.43E-03	S
6.4	2.05E-01	W	2.53E-03	S	1.43E-03	S
6.6	1.99E-01	W	2.53E-03	S	1.43E-03	S
6.8	1.95E-01	W	2.53E-03	S	1.53E-03	S
7	1.95E-01	W	2.53E-03	S	2.13E-03	S
7.2	1.95E-01	W	2.53E-03	S	2.94E-03	S
7.4	1.95E-01	W	2.53E-03	S	3.78E-03	S
7.6	1.94E-01	W	2.53E-03	S	3.99E-03	S
7.8	1.94E-01	W	2.53E-03	S	4.21E-03	S
8	1.94E-01	W	2.53E-03	S	4.43E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-43. Leachate Concentrations for Gypsum Export, Waste ID PAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.94E-01	W	2.53E-03	S	4.43E-03	S
8.4	1.94E-01	W	2.53E-03	S	4.19E-03	S
8.6	1.95E-01	W	2.53E-03	S	3.98E-03	S
8.8	1.96E-01	W	2.53E-03	S	3.78E-03	S
9	1.96E-01	W	2.53E-03	S	3.59E-03	S
9.2	1.97E-01	W	2.53E-03	S	3.42E-03	S
9.4	1.97E-01	W	2.53E-03	S	3.26E-03	S
9.6	1.98E-01	W	2.53E-03	S	3.11E-03	S
9.8	1.98E-01	W	2.53E-03	S	3.01E-03	S
10	1.99E-01	W	2.53E-03	S	3.21E-03	S
10.2	2.00E-01	W	2.53E-03	S	3.46E-03	S
10.4	2.01E-01	W	2.53E-03	S	3.71E-03	S
10.6	2.03E-01	W	2.53E-03	S	3.86E-03	S
10.8	2.07E-01	W	2.53E-03	S	3.98E-03	S
11	2.11E-01	W	2.53E-03	S	4.10E-03	S
11.2	2.15E-01	W	2.53E-03	S	4.23E-03	S
11.4	2.18E-01	W	2.53E-03	S	4.35E-03	S
11.6	2.22E-01	W	2.53E-03	S	4.48E-03	S
11.8	2.26E-01	W	2.53E-03	S	4.61E-03	S
12	2.30E-01	W	2.53E-03	S	4.73E-03	S
12.2	2.34E-01	W	2.53E-03	S	4.87E-03	S
12.4	2.37E-01	W	2.53E-03	S	5.00E-03	S
12.6	2.41E-01	W	2.53E-03	S	5.13E-03	S
12.8	2.45E-01	W	2.53E-03	S	5.26E-03	S
13	2.49E-01	W	2.53E-03	S	5.40E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.57E+00		2.66E-02		5.53E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID	QAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.02E-01	S	4.10E+00	W	5.69E-02	W	5.92E-02	S
3	9.62E-02	S	4.02E+00	W	5.71E-02	W	5.70E-02	S
3.2	8.86E-02	S	4.04E+00	W	5.66E-02	W	5.49E-02	S
3.4	8.21E-02	S	3.94E+00	W	5.63E-02	W	5.33E-02	S
3.6	7.65E-02	S	3.96E+00	W	5.62E-02	W	5.24E-02	S
3.8	7.15E-02	S	3.97E+00	W	5.61E-02	W	5.16E-02	S
4	6.76E-02	S	3.94E+00	W	5.60E-02	W	5.09E-02	S
4.2	6.45E-02	S	3.89E+00	W	5.59E-02	W	5.01E-02	S
4.4	6.16E-02	S	3.84E+00	W	5.57E-02	W	4.94E-02	S
4.6	5.72E-02	S	3.80E+00	W	5.55E-02	W	4.86E-02	S
4.8	5.06E-02	S	3.79E+00	W	5.52E-02	W	4.75E-02	S
5	4.49E-02	S	3.78E+00	W	5.49E-02	S	4.65E-02	S
5.2	4.01E-02	S	3.77E+00	W	5.47E-02	S	4.56E-02	S
5.4	2.94E-02	S	3.77E+00	W	5.39E-02	S	4.47E-02	S
5.6	1.69E-02	S	3.78E+00	W	5.25E-02	S	4.39E-02	S
5.8	9.94E-03	S	3.79E+00	W	5.12E-02	S	4.31E-02	S
6	7.76E-03	S	3.75E+00	W	3.51E-02	S	3.24E-02	S
6.2	6.29E-03	S	3.71E+00	W	2.30E-02	S	2.36E-02	S
6.4	5.13E-03	S	3.67E+00	W	1.53E-02	S	1.74E-02	S
6.6	4.22E-03	S	3.63E+00	W	1.03E-02	S	1.29E-02	S
6.8	3.48E-03	S	3.60E+00	W	6.99E-03	S	9.69E-03	S
7	3.20E-03	S	3.58E+00	W	5.21E-03	S	7.59E-03	S
7.2	3.20E-03	S	3.56E+00	W	3.87E-03	S	5.96E-03	S
7.4	3.20E-03	S	3.54E+00	W	2.90E-03	S	4.71E-03	S
7.6	3.20E-03	S	3.53E+00	W	2.19E-03	S	3.74E-03	S
7.8	3.20E-03	S	3.51E+00	W	1.66E-03	S	2.99E-03	S
8	3.20E-03	S	3.49E+00	W	1.27E-03	S	2.41E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID	QAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	3.44E+00	W	1.05E-03	S	2.06E-03	S
8.4	3.20E-03	S	3.33E+00	W	9.89E-04	S	2.06E-03	S
8.6	3.20E-03	S	3.22E+00	W	9.29E-04	S	2.06E-03	S
8.8	3.20E-03	S	3.11E+00	W	8.75E-04	S	2.06E-03	S
9	3.20E-03	S	3.02E+00	W	8.25E-04	S	2.06E-03	S
9.2	3.20E-03	S	2.92E+00	W	7.79E-04	S	2.06E-03	S
9.4	3.20E-03	S	2.88E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	2.92E+00	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	2.96E+00	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	3.00E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	3.04E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	3.07E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.30E-03	S	3.16E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.72E-03	S	3.32E+00	W	7.46E-04	S	2.06E-03	S
11	4.22E-03	S	3.50E+00	W	7.46E-04	S	2.06E-03	S
11.2	4.78E-03	S	3.68E+00	W	7.46E-04	S	2.06E-03	S
11.4	5.39E-03	S	3.86E+00	W	7.46E-04	S	2.06E-03	S
11.6	6.07E-03	S	4.06E+00	W	7.46E-04	S	2.06E-03	S
11.8	6.83E-03	S	4.25E+00	W	7.46E-04	S	2.06E-03	S
12	7.66E-03	S	4.42E+00	W	7.46E-04	S	2.06E-03	S
12.2	8.58E-03	S	4.53E+00	W	7.46E-04	S	2.06E-03	S
12.4	9.59E-03	S	4.63E+00	W	7.46E-04	S	2.06E-03	S
12.6	1.07E-02	S	4.74E+00	W	7.46E-04	S	2.06E-03	S
12.8	1.19E-02	S	4.77E+00	W	7.46E-04	S	2.06E-03	S
13	1.33E-02	S	4.77E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	9.62E-01		5.13E+01		5.71E-01		5.70E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	6.47E-01	S	6.99E-05	S	1.95E-02	W	1.17E-02	S
3	6.14E-01	S	6.66E-05	S	1.79E-02	W	1.13E-02	S
3.2	5.70E-01	S	4.69E-05	S	1.62E-02	W	1.11E-02	S
3.4	5.10E-01	S	3.66E-05	S	1.57E-02	W	1.12E-02	S
3.6	4.61E-01	S	2.81E-05	S	1.49E-02	W	1.09E-02	S
3.8	4.18E-01	S	2.19E-05	S	1.43E-02	W	1.07E-02	S
4	3.70E-01	S	3.36E-05	S	1.42E-02	W	1.05E-02	S
4.2	3.25E-01	S	6.66E-05	S	1.43E-02	W	1.03E-02	S
4.4	2.87E-01	S	1.28E-04	S	1.43E-02	W	1.02E-02	S
4.6	2.26E-01	S	2.26E-04	S	1.45E-02	W	9.78E-03	S
4.8	1.45E-01	S	3.55E-04	S	1.47E-02	W	8.97E-03	S
5	9.51E-02	S	5.47E-04	S	1.49E-02	W	8.26E-03	S
5.2	6.33E-02	S	8.27E-04	S	1.51E-02	W	7.62E-03	S
5.4	3.77E-02	S	9.23E-04	S	1.53E-02	W	7.07E-03	S
5.6	2.01E-02	S	6.88E-04	S	1.55E-02	W	6.62E-03	S
5.8	1.10E-02	S	5.18E-04	S	1.58E-02	W	6.20E-03	S
6	8.90E-03	S	2.04E-04	S	1.55E-02	W	5.35E-03	S
6.2	7.44E-03	S	7.67E-05	S	1.52E-02	W	4.58E-03	S
6.4	6.25E-03	S	2.97E-05	S	1.49E-02	W	3.93E-03	S
6.6	5.28E-03	S	1.19E-05	S	1.47E-02	W	3.40E-03	S
6.8	4.48E-03	S	4.87E-06	S	1.44E-02	W	2.94E-03	S
7	4.24E-03	S	3.65E-06	S	1.41E-02	W	2.78E-03	S
7.2	4.28E-03	S	3.89E-06	S	1.39E-02	W	2.78E-03	S
7.4	4.31E-03	S	4.14E-06	S	1.37E-02	W	2.78E-03	S
7.6	4.34E-03	S	4.39E-06	S	1.35E-02	W	2.78E-03	S
7.8	4.37E-03	S	4.65E-06	S	1.34E-02	W	2.78E-03	S
8	4.40E-03	S	4.92E-06	S	1.32E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	4.69E-03	S	4.72E-06	S	1.32E-02	W	2.83E-03	S
8.4	5.65E-03	S	3.93E-06	S	1.39E-02	W	2.95E-03	S
8.6	6.78E-03	S	3.29E-06	S	1.46E-02	W	3.07E-03	S
8.8	8.09E-03	S	2.76E-06	S	1.53E-02	W	3.20E-03	S
9	9.62E-03	S	2.33E-06	S	1.60E-02	W	3.32E-03	S
9.2	1.14E-02	S	1.97E-06	S	1.67E-02	W	3.45E-03	S
9.4	1.27E-02	S	1.94E-06	S	1.73E-02	W	3.66E-03	S
9.6	1.27E-02	S	2.29E-06	S	1.77E-02	W	4.12E-03	S
9.8	1.27E-02	S	2.70E-06	S	1.80E-02	W	4.63E-03	S
10	1.26E-02	S	3.16E-06	S	1.84E-02	W	5.18E-03	S
10.2	1.26E-02	S	3.70E-06	S	1.87E-02	W	5.80E-03	S
10.4	1.26E-02	S	4.31E-06	S	1.91E-02	W	6.47E-03	S
10.6	1.27E-02	S	5.01E-06	S	1.96E-02	W	6.65E-03	S
10.8	1.20E-02	S	5.24E-06	S	2.02E-02	W	5.82E-03	S
11	1.13E-02	S	5.41E-06	S	2.08E-02	W	5.06E-03	S
11.2	1.06E-02	S	5.58E-06	S	2.14E-02	W	4.40E-03	S
11.4	9.97E-03	S	5.76E-06	S	2.21E-02	W	3.84E-03	S
11.6	9.39E-03	S	5.94E-06	S	2.27E-02	W	3.36E-03	S
11.8	8.85E-03	S	6.12E-06	S	2.33E-02	W	2.94E-03	S
12	8.36E-03	S	6.30E-06	S	2.40E-02	W	2.59E-03	S
12.2	7.90E-03	S	6.49E-06	S	2.47E-02	W	2.28E-03	S
12.4	7.47E-03	S	6.68E-06	S	2.53E-02	W	2.01E-03	S
12.6	7.07E-03	S	6.87E-06	S	2.60E-02	W	1.78E-03	S
12.8	6.70E-03	S	7.06E-06	S	2.67E-02	W	1.57E-03	S
13	6.35E-03	S	7.25E-06	S	2.74E-02	W	1.40E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	6.14E+00		9.23E-03		2.87E-01		1.13E-01	

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Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.06E+00	S	2.53E-03	S	2.10E+00	S
3	3.99E+00	S	2.53E-03	S	2.06E+00	S
3.2	3.85E+00	S	2.53E-03	S	1.98E+00	S
3.4	3.71E+00	S	2.53E-03	S	1.81E+00	S
3.6	3.59E+00	S	2.53E-03	S	1.66E+00	S
3.8	3.49E+00	S	2.53E-03	S	1.53E+00	S
4	3.38E+00	S	2.53E-03	S	1.39E+00	S
4.2	3.26E+00	S	2.53E-03	S	1.25E+00	S
4.4	3.16E+00	S	2.53E-03	S	1.13E+00	S
4.6	3.04E+00	S	2.53E-03	S	1.02E+00	S
4.8	2.89E+00	S	2.53E-03	S	9.11E-01	S
5	2.75E+00	S	2.53E-03	S	8.19E-01	S
5.2	2.62E+00	S	2.53E-03	S	7.40E-01	S
5.4	2.35E+00	S	2.53E-03	S	6.76E-01	S
5.6	1.96E+00	S	2.53E-03	S	6.26E-01	S
5.8	1.64E+00	S	2.53E-03	S	5.82E-01	S
6	1.21E+00	S	2.53E-03	S	4.13E-01	S
6.2	8.83E-01	S	2.53E-03	S	2.83E-01	S
6.4	6.50E-01	S	2.53E-03	S	1.96E-01	S
6.6	4.84E-01	S	2.53E-03	S	1.37E-01	S
6.8	3.63E-01	S	2.53E-03	S	9.71E-02	S
7	3.23E-01	S	2.53E-03	S	8.45E-02	S
7.2	3.18E-01	S	2.53E-03	S	8.43E-02	S
7.4	3.13E-01	S	2.53E-03	S	8.41E-02	S
7.6	3.08E-01	S	2.53E-03	S	8.39E-02	S
7.8	3.04E-01	S	2.53E-03	S	8.37E-02	S
8	3.00E-01	S	2.53E-03	S	8.35E-02	S

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Table C-5-44. Leachate Concentrations for Gypsum Export, Waste ID QAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	3.00E-01	S	2.53E-03	S	8.54E-02	S
8.4	3.14E-01	S	2.53E-03	S	9.28E-02	S
8.6	3.28E-01	S	2.53E-03	S	1.01E-01	S
8.8	3.42E-01	S	2.53E-03	S	1.09E-01	S
9	3.56E-01	S	2.53E-03	S	1.18E-01	S
9.2	3.70E-01	S	2.53E-03	S	1.27E-01	S
9.4	3.98E-01	S	2.53E-03	S	1.38E-01	S
9.6	4.52E-01	S	2.53E-03	S	1.54E-01	S
9.8	5.12E-01	S	2.53E-03	S	1.72E-01	S
10	5.79E-01	S	2.53E-03	S	1.91E-01	S
10.2	6.53E-01	S	2.53E-03	S	2.12E-01	S
10.4	7.34E-01	S	2.53E-03	S	2.35E-01	S
10.6	8.08E-01	S	2.53E-03	S	2.37E-01	S
10.8	8.59E-01	S	2.53E-03	S	1.98E-01	S
11	9.12E-01	S	2.53E-03	S	1.64E-01	S
11.2	9.67E-01	S	2.53E-03	S	1.36E-01	S
11.4	1.02E+00	S	2.53E-03	S	1.13E-01	S
11.6	1.08E+00	S	2.53E-03	S	9.48E-02	S
11.8	1.14E+00	S	2.53E-03	S	7.95E-02	S
12	1.21E+00	S	2.53E-03	S	6.69E-02	S
12.2	1.27E+00	S	2.53E-03	S	5.64E-02	S
12.4	1.34E+00	S	2.53E-03	S	4.77E-02	S
12.6	1.41E+00	S	2.53E-03	S	4.05E-02	S
12.8	1.49E+00	S	2.53E-03	S	3.44E-02	S
13	1.56E+00	S	2.53E-03	S	2.94E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.99E+01		2.72E-02		2.06E+01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID	RAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	3.20E-03	S	9.03E-02	S	2.73E-03	W	6.18E-02	S
3	3.20E-03	S	8.84E-02	S	2.70E-03	W	6.02E-02	S
3.2	3.20E-03	S	8.67E-02	S	2.68E-03	W	5.87E-02	S
3.4	3.20E-03	S	8.51E-02	S	2.66E-03	W	5.74E-02	S
3.6	3.20E-03	S	8.36E-02	S	2.64E-03	W	5.61E-02	S
3.8	3.20E-03	S	8.22E-02	S	2.62E-03	W	5.50E-02	S
4	3.20E-03	S	8.11E-02	S	2.60E-03	W	5.04E-02	S
4.2	3.20E-03	S	8.00E-02	S	2.57E-03	W	4.54E-02	S
4.4	3.20E-03	S	7.91E-02	S	2.54E-03	W	4.10E-02	S
4.6	3.20E-03	S	7.81E-02	S	2.52E-03	W	3.73E-02	S
4.8	3.20E-03	S	7.73E-02	S	2.50E-03	W	3.40E-02	S
5	3.20E-03	S	7.65E-02	S	2.48E-03	S	3.11E-02	S
5.2	3.20E-03	S	7.57E-02	S	2.45E-03	S	2.86E-02	S
5.4	3.20E-03	S	7.49E-02	S	2.43E-03	S	2.63E-02	S
5.6	3.20E-03	S	7.37E-02	S	2.34E-03	S	2.22E-02	S
5.8	3.20E-03	S	7.22E-02	S	2.22E-03	S	1.74E-02	S
6	3.20E-03	S	7.07E-02	S	2.11E-03	S	1.38E-02	S
6.2	3.20E-03	S	6.92E-02	S	1.94E-03	S	1.07E-02	S
6.4	3.20E-03	S	6.75E-02	S	1.68E-03	S	8.08E-03	S
6.6	3.20E-03	S	6.57E-02	S	1.42E-03	S	5.84E-03	S
6.8	3.20E-03	S	6.14E-02	S	9.09E-04	S	2.82E-03	S
7	3.20E-03	S	7.00E-02	S	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	9.68E-02	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	1.33E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	1.80E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	2.03E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	2.28E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID	RAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	2.56E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	2.75E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	2.79E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	2.84E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	2.88E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	2.92E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	2.97E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	3.11E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	3.26E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	3.42E-01	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	3.59E-01	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	3.81E-01	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	4.27E-01	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	4.80E-01	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	5.73E-01	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	7.38E-01	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	9.52E-01	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.22E+00	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.56E+00	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.92E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.96E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.96E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.96E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.96E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.96E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.50E-02		1.53E+01		1.94E-02		4.32E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.33E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3	3.83E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.2	3.41E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.4	3.06E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.6	2.76E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.8	2.51E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4	2.34E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.2	2.20E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.4	2.07E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.6	1.96E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.8	1.85E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5	1.76E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.2	1.67E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.4	1.59E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.6	1.46E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.8	1.36E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6	1.26E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.2	1.21E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.4	1.21E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.6	1.23E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6.8	1.32E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
7	1.44E-02	S	3.00E-06	S	4.10E-03	S	2.78E-03	S
7.2	1.51E-02	S	3.00E-06	S	4.82E-03	W	2.78E-03	S
7.4	1.59E-02	S	3.00E-06	S	5.65E-03	W	2.78E-03	S
7.6	1.66E-02	S	2.32E-06	S	6.59E-03	W	2.78E-03	S
7.8	1.60E-02	S	3.00E-06	S	7.03E-03	W	2.78E-03	S
8	1.55E-02	S	3.00E-06	S	7.49E-03	W	2.78E-03	S

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Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.50E-02	S	3.00E-06	S	7.96E-03	W	2.78E-03	S
8.4	1.45E-02	S	3.00E-06	S	8.32E-03	W	2.78E-03	S
8.6	1.41E-02	S	3.00E-06	S	8.48E-03	W	2.78E-03	S
8.8	1.37E-02	S	3.00E-06	S	8.64E-03	W	2.78E-03	S
9	1.33E-02	S	3.00E-06	S	8.79E-03	W	2.78E-03	S
9.2	1.30E-02	S	3.00E-06	S	8.95E-03	W	2.78E-03	S
9.4	1.26E-02	S	3.00E-06	S	9.12E-03	W	2.78E-03	S
9.6	1.18E-02	S	3.00E-06	S	9.05E-03	W	2.78E-03	S
9.8	1.10E-02	S	3.00E-06	S	8.91E-03	W	2.78E-03	S
10	1.02E-02	S	3.00E-06	S	8.77E-03	W	2.78E-03	S
10.2	9.55E-03	S	3.00E-06	S	8.63E-03	W	2.78E-03	S
10.4	9.25E-03	S	3.00E-06	S	8.77E-03	W	2.78E-03	S
10.6	9.44E-03	S	3.00E-06	S	9.36E-03	W	2.78E-03	S
10.8	9.68E-03	S	3.00E-06	S	1.00E-02	W	2.78E-03	S
11	1.01E-02	S	3.00E-06	S	1.12E-02	S	2.78E-03	S
11.2	1.07E-02	S	3.00E-06	S	1.30E-02	S	2.78E-03	S
11.4	1.14E-02	S	3.00E-06	S	1.52E-02	S	2.78E-03	S
11.6	1.20E-02	S	3.00E-06	S	1.77E-02	S	2.78E-03	S
11.8	1.27E-02	S	3.00E-06	S	2.06E-02	S	2.78E-03	S
12	1.34E-02	S	3.00E-06	S	2.33E-02	S	2.78E-03	S
12.2	1.42E-02	S	3.00E-06	S	2.37E-02	S	2.78E-03	S
12.4	1.49E-02	S	3.00E-06	S	2.37E-02	S	2.78E-03	S
12.6	1.58E-02	S	3.00E-06	S	2.37E-02	S	2.78E-03	S
12.8	1.66E-02	S	3.00E-06	S	2.37E-02	S	2.78E-03	S
13	1.74E-02	S	3.00E-06	S	2.37E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.75E-01		2.35E-05		1.85E-01		2.18E-02	

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Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	9.69E-02	W	2.53E-03	S	1.80E-02	S
3	9.55E-02	W	2.53E-03	S	1.36E-02	S
3.2	9.42E-02	W	2.53E-03	S	1.04E-02	S
3.4	9.30E-02	W	2.53E-03	S	8.11E-03	S
3.6	9.19E-02	W	2.53E-03	S	6.41E-03	S
3.8	9.09E-02	W	2.53E-03	S	5.13E-03	S
4	8.99E-02	W	2.53E-03	S	4.93E-03	S
4.2	8.90E-02	W	2.53E-03	S	5.07E-03	S
4.4	8.80E-02	W	2.53E-03	S	5.21E-03	S
4.6	8.72E-02	W	2.53E-03	S	5.35E-03	S
4.8	8.64E-02	W	2.53E-03	S	5.48E-03	S
5	8.56E-02	W	2.53E-03	S	5.61E-03	S
5.2	8.48E-02	W	2.53E-03	S	5.74E-03	S
5.4	8.41E-02	W	2.53E-03	S	5.84E-03	S
5.6	8.29E-02	W	2.53E-03	S	5.54E-03	S
5.8	8.21E-02	W	2.53E-03	S	5.22E-03	S
6	8.13E-02	W	2.53E-03	S	4.93E-03	S
6.2	8.03E-02	W	2.53E-03	S	4.78E-03	S
6.4	7.90E-02	W	2.53E-03	S	4.80E-03	S
6.6	7.75E-02	W	2.53E-03	S	4.81E-03	S
6.8	7.35E-02	W	2.53E-03	S	4.74E-03	S
7	7.53E-02	W	2.53E-03	S	5.16E-03	S
7.2	8.33E-02	W	2.53E-03	S	6.06E-03	S
7.4	9.19E-02	W	2.53E-03	S	7.08E-03	S
7.6	1.01E-01	W	2.53E-03	S	8.24E-03	S
7.8	1.05E-01	W	2.53E-03	S	8.70E-03	S
8	1.08E-01	W	2.53E-03	S	9.17E-03	S

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Table C-5-45. Leachate Concentrations for Gypsum Export, Waste ID RAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.12E-01	W	2.53E-03	S	9.65E-03	S
8.4	1.14E-01	W	2.53E-03	S	1.01E-02	S
8.6	1.14E-01	W	2.53E-03	S	1.04E-02	S
8.8	1.15E-01	W	2.53E-03	S	1.07E-02	S
9	1.15E-01	W	2.53E-03	S	1.11E-02	S
9.2	1.16E-01	W	2.53E-03	S	1.14E-02	S
9.4	1.17E-01	W	2.53E-03	S	1.18E-02	S
9.6	1.17E-01	W	2.53E-03	S	1.18E-02	S
9.8	1.18E-01	W	2.53E-03	S	1.17E-02	S
10	1.18E-01	W	2.53E-03	S	1.16E-02	S
10.2	1.19E-01	W	2.53E-03	S	1.15E-02	S
10.4	1.21E-01	W	2.53E-03	S	1.16E-02	S
10.6	1.25E-01	W	2.53E-03	S	1.21E-02	S
10.8	1.29E-01	W	2.53E-03	S	1.26E-02	S
11	1.32E-01	W	2.53E-03	S	1.27E-02	S
11.2	1.27E-01	W	2.53E-03	S	1.15E-02	S
11.4	1.20E-01	W	2.53E-03	S	1.02E-02	S
11.6	1.15E-01	W	2.53E-03	S	9.12E-03	S
11.8	1.09E-01	W	2.53E-03	S	8.15E-03	S
12	1.04E-01	W	2.53E-03	S	7.30E-03	S
12.2	9.91E-02	W	2.53E-03	S	6.55E-03	S
12.4	9.46E-02	W	2.53E-03	S	5.89E-03	S
12.6	9.03E-02	W	2.53E-03	S	5.30E-03	S
12.8	8.63E-02	W	2.53E-03	S	4.78E-03	S
13	8.26E-02	W	2.53E-03	S	4.32E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	9.62E-01		1.98E-02		9.74E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID	SAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.85E-01	S	2.12E+01	W	2.52E-02	S	4.82E-02	S
3	1.50E-01	S	2.12E+01	W	2.48E-02	S	4.61E-02	S
3.2	1.23E-01	S	2.12E+01	W	2.46E-02	S	4.44E-02	S
3.4	1.02E-01	S	2.11E+01	W	2.44E-02	S	4.29E-02	S
3.6	8.57E-02	S	2.10E+01	W	2.42E-02	S	4.16E-02	S
3.8	7.26E-02	S	2.10E+01	W	2.40E-02	S	4.03E-02	S
4	6.21E-02	S	2.09E+01	W	2.39E-02	S	3.92E-02	S
4.2	5.57E-02	S	2.09E+01	W	2.37E-02	S	3.83E-02	S
4.4	5.08E-02	S	2.10E+01	W	2.35E-02	S	3.77E-02	S
4.6	4.67E-02	S	2.10E+01	W	2.32E-02	S	3.71E-02	S
4.8	4.31E-02	S	2.11E+01	W	2.29E-02	S	3.66E-02	S
5	3.99E-02	S	2.12E+01	W	2.26E-02	S	3.61E-02	S
5.2	3.71E-02	S	2.13E+01	W	2.23E-02	S	3.56E-02	S
5.4	3.45E-02	S	2.13E+01	W	2.21E-02	S	3.51E-02	S
5.6	2.74E-02	S	2.15E+01	W	2.13E-02	S	3.41E-02	S
5.8	2.16E-02	S	2.16E+01	W	2.04E-02	S	3.30E-02	S
6	1.84E-02	S	2.17E+01	W	1.87E-02	S	3.11E-02	S
6.2	1.67E-02	S	2.17E+01	W	1.64E-02	S	2.68E-02	S
6.4	1.53E-02	S	2.17E+01	W	1.29E-02	S	2.22E-02	S
6.6	1.43E-02	S	2.17E+01	W	9.85E-03	S	1.86E-02	S
6.8	1.34E-02	S	2.18E+01	W	7.56E-03	S	1.56E-02	S
7	1.25E-02	S	2.18E+01	W	5.84E-03	S	1.32E-02	S
7.2	1.24E-02	S	2.17E+01	W	4.83E-03	S	1.14E-02	S
7.4	1.31E-02	S	2.16E+01	W	4.20E-03	S	1.02E-02	S
7.6	1.40E-02	S	2.15E+01	W	3.70E-03	S	9.16E-03	S
7.8	1.49E-02	S	2.14E+01	W	3.27E-03	S	8.25E-03	S
8	1.57E-02	S	2.13E+01	W	2.85E-03	S	7.30E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID	SAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	1.56E-02	S	2.10E+01	W	2.15E-03	S	5.59E-03	S
8.4	1.54E-02	S	2.08E+01	W	1.63E-03	S	4.30E-03	S
8.6	1.53E-02	S	2.06E+01	W	1.24E-03	S	3.33E-03	S
8.8	1.51E-02	S	2.05E+01	W	9.54E-04	S	2.60E-03	S
9	1.46E-02	S	2.02E+01	W	7.56E-04	S	2.09E-03	S
9.2	1.20E-02	S	1.99E+01	W	7.46E-04	S	2.06E-03	S
9.4	9.72E-03	S	1.96E+01	W	7.46E-04	S	2.06E-03	S
9.6	9.29E-03	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
9.8	8.88E-03	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
10	8.50E-03	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
10.2	8.67E-03	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
10.4	9.57E-03	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
10.6	1.00E-02	S	1.97E+01	W	7.46E-04	S	2.06E-03	S
10.8	9.66E-03	S	1.99E+01	W	7.46E-04	S	2.06E-03	S
11	9.31E-03	S	2.01E+01	W	7.46E-04	S	2.06E-03	S
11.2	8.99E-03	S	2.03E+01	W	7.46E-04	S	2.06E-03	S
11.4	8.68E-03	S	2.05E+01	W	7.46E-04	S	2.06E-03	S
11.6	8.39E-03	S	2.06E+01	W	7.46E-04	S	2.06E-03	S
11.8	8.11E-03	S	2.08E+01	W	7.46E-04	S	2.06E-03	S
12	7.85E-03	S	2.10E+01	W	7.46E-04	S	2.06E-03	S
12.2	7.59E-03	S	2.12E+01	W	7.46E-04	S	2.06E-03	S
12.4	7.35E-03	S	2.13E+01	W	7.46E-04	S	2.06E-03	S
12.6	7.13E-03	S	2.15E+01	W	7.46E-04	S	2.06E-03	S
12.8	6.91E-03	S	2.17E+01	W	7.46E-04	S	2.06E-03	S
13	6.70E-03	S	2.18E+01	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.50E+00		2.44E+02		2.48E-01		4.61E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.42E-01	S	3.52E-06	S	8.75E-02	S	3.04E-02	S
3	2.11E-01	S	3.00E-06	S	7.25E-02	S	2.71E-02	S
3.2	1.86E-01	S	3.00E-06	S	6.64E-02	S	2.52E-02	S
3.4	1.65E-01	S	3.49E-06	S	6.44E-02	S	2.40E-02	S
3.6	1.47E-01	S	5.10E-06	S	6.27E-02	S	2.29E-02	S
3.8	1.32E-01	S	7.32E-06	S	6.10E-02	S	2.19E-02	S
4	1.19E-01	S	1.02E-05	S	5.98E-02	S	2.11E-02	S
4.2	9.89E-02	S	1.15E-05	S	6.27E-02	S	2.04E-02	S
4.4	7.74E-02	S	1.25E-05	S	6.84E-02	S	1.99E-02	S
4.6	5.93E-02	S	1.34E-05	S	7.54E-02	S	1.95E-02	S
4.8	4.60E-02	S	1.43E-05	S	8.28E-02	S	1.91E-02	S
5	3.61E-02	S	1.52E-05	S	9.06E-02	S	1.87E-02	S
5.2	2.85E-02	S	1.61E-05	S	9.88E-02	S	1.83E-02	S
5.4	2.28E-02	S	1.70E-05	S	1.07E-01	S	1.80E-02	S
5.6	1.75E-02	S	2.23E-05	S	1.17E-01	S	1.63E-02	S
5.8	1.36E-02	S	2.96E-05	S	1.26E-01	S	1.46E-02	S
6	1.15E-02	S	3.22E-05	S	1.34E-01	S	1.34E-02	S
6.2	1.09E-02	S	1.35E-05	S	1.46E-01	S	1.10E-02	S
6.4	1.10E-02	S	6.75E-06	S	1.56E-01	S	8.66E-03	S
6.6	1.12E-02	S	4.64E-06	S	1.64E-01	S	7.03E-03	S
6.8	1.15E-02	S	3.48E-06	S	1.72E-01	S	5.75E-03	S
7	1.17E-02	S	3.00E-06	S	1.79E-01	S	4.73E-03	S
7.2	1.11E-02	S	3.00E-06	S	1.85E-01	W	3.82E-03	S
7.4	1.04E-02	S	3.00E-06	S	1.83E-01	W	3.45E-03	S
7.6	9.74E-03	S	3.00E-06	S	1.78E-01	W	3.20E-03	S
7.8	9.16E-03	S	3.00E-06	S	1.74E-01	W	2.98E-03	S
8	8.72E-03	S	2.32E-06	S	1.71E-01	W	2.85E-03	S

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Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	9.21E-03	S	3.00E-06	S	1.71E-01	W	3.50E-03	S
8.4	9.72E-03	S	3.00E-06	S	1.70E-01	W	4.27E-03	S
8.6	1.02E-02	S	3.00E-06	S	1.70E-01	W	5.18E-03	S
8.8	1.08E-02	S	3.00E-06	S	1.70E-01	W	6.27E-03	S
9	1.14E-02	S	3.00E-06	S	1.70E-01	W	7.62E-03	S
9.2	1.25E-02	S	3.00E-06	S	1.73E-01	W	9.08E-03	S
9.4	1.38E-02	S	2.32E-06	S	1.76E-01	W	1.07E-02	S
9.6	1.47E-02	S	3.00E-06	S	1.78E-01	W	1.12E-02	S
9.8	1.57E-02	S	3.00E-06	S	1.80E-01	W	1.17E-02	S
10	1.67E-02	S	3.00E-06	S	1.81E-01	W	1.22E-02	S
10.2	1.75E-02	S	3.00E-06	S	1.83E-01	W	1.28E-02	S
10.4	1.68E-02	S	3.00E-06	S	1.86E-01	W	1.32E-02	S
10.6	1.42E-02	S	3.00E-06	S	1.90E-01	W	1.29E-02	S
10.8	1.08E-02	S	3.00E-06	S	1.93E-01	W	1.17E-02	S
11	8.19E-03	S	3.00E-06	S	1.97E-01	W	1.07E-02	S
11.2	6.26E-03	S	3.00E-06	S	2.01E-01	W	9.75E-03	S
11.4	4.81E-03	S	3.00E-06	S	2.05E-01	W	8.91E-03	S
11.6	3.71E-03	S	3.00E-06	S	2.09E-01	W	8.16E-03	S
11.8	2.88E-03	S	3.00E-06	S	2.13E-01	W	7.48E-03	S
12	2.24E-03	S	3.00E-06	S	2.17E-01	W	6.86E-03	S
12.2	1.75E-03	S	3.00E-06	S	2.21E-01	W	6.31E-03	S
12.4	1.37E-03	S	3.00E-06	S	2.22E-01	W	5.81E-03	S
12.6	1.08E-03	S	3.00E-06	S	2.23E-01	W	5.36E-03	S
12.8	8.55E-04	S	3.00E-06	S	2.24E-01	W	4.94E-03	S
13	6.78E-04	S	3.00E-06	S	2.25E-01	W	4.57E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.11E+00		3.22E-04		2.52E+00		2.71E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.58E-01	S	1.88E-02	S	2.85E-01	S
3	2.28E-01	S	1.85E-02	S	2.53E-01	S
3.2	2.13E-01	S	1.82E-02	S	1.99E-01	S
3.4	2.07E-01	S	1.78E-02	S	1.44E-01	S
3.6	2.00E-01	S	1.75E-02	S	1.07E-01	S
3.8	1.95E-01	S	1.73E-02	S	8.02E-02	S
4	1.90E-01	S	1.70E-02	S	6.16E-02	S
4.2	1.87E-01	S	1.68E-02	S	5.38E-02	S
4.4	1.85E-01	S	1.66E-02	S	4.97E-02	S
4.6	1.83E-01	S	1.65E-02	S	4.70E-02	S
4.8	1.81E-01	S	1.64E-02	S	4.46E-02	S
5	1.78E-01	S	1.63E-02	S	4.25E-02	S
5.2	1.77E-01	S	1.62E-02	S	4.05E-02	S
5.4	1.75E-01	S	1.61E-02	S	3.86E-02	S
5.6	1.71E-01	S	1.52E-02	S	3.53E-02	S
5.8	1.68E-01	S	1.43E-02	S	3.22E-02	S
6	1.68E-01	S	1.38E-02	S	3.00E-02	S
6.2	1.89E-01	S	1.27E-02	S	3.11E-02	S
6.4	2.09E-01	S	1.20E-02	S	3.10E-02	S
6.6	2.21E-01	S	1.16E-02	S	2.97E-02	S
6.8	2.33E-01	S	1.13E-02	S	2.84E-02	S
7	2.45E-01	S	1.10E-02	S	2.73E-02	S
7.2	2.54E-01	S	1.10E-02	S	2.69E-02	S
7.4	2.58E-01	S	1.12E-02	S	2.72E-02	S
7.6	2.60E-01	S	1.14E-02	S	2.77E-02	S
7.8	2.63E-01	S	1.16E-02	S	2.81E-02	S
8	2.64E-01	S	1.18E-02	S	2.89E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-46. Leachate Concentrations for Gypsum Export, Waste ID SAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.60E-01	S	1.22E-02	S	3.19E-02	S
8.4	2.55E-01	S	1.26E-02	S	3.51E-02	S
8.6	2.51E-01	S	1.30E-02	S	3.86E-02	S
8.8	2.47E-01	S	1.34E-02	S	4.23E-02	S
9	2.46E-01	S	1.36E-02	S	4.64E-02	S
9.2	2.62E-01	S	1.24E-02	S	4.94E-02	S
9.4	2.78E-01	S	1.13E-02	S	5.24E-02	S
9.6	2.82E-01	S	1.08E-02	S	5.34E-02	S
9.8	2.87E-01	S	1.04E-02	S	5.43E-02	S
10	2.91E-01	S	9.97E-03	S	5.53E-02	S
10.2	2.96E-01	S	9.76E-03	S	5.67E-02	S
10.4	3.00E-01	S	9.58E-03	S	5.69E-02	S
10.6	3.03E-01	S	8.74E-03	S	5.27E-02	S
10.8	3.03E-01	S	7.36E-03	S	4.52E-02	S
11	3.03E-01	S	6.22E-03	S	3.88E-02	S
11.2	3.03E-01	S	5.27E-03	S	3.34E-02	S
11.4	3.03E-01	S	4.48E-03	S	2.88E-02	S
11.6	3.02E-01	S	3.82E-03	S	2.50E-02	S
11.8	3.02E-01	S	3.26E-03	S	2.17E-02	S
12	3.02E-01	S	2.80E-03	S	1.88E-02	S
12.2	3.02E-01	S	2.40E-03	S	1.64E-02	S
12.4	3.02E-01	S	2.07E-03	S	1.44E-02	S
12.6	3.01E-01	S	1.79E-03	S	1.26E-02	S
12.8	3.01E-01	S	1.55E-03	S	1.10E-02	S
13	3.01E-01	S	1.34E-03	S	9.70E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.40E+00		1.85E-01		2.53E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID	SAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.13E-01	S	5.19E-01	W	5.88E-03	S	2.05E-02	S
3	8.75E-02	S	5.06E-01	W	5.63E-03	S	1.89E-02	S
3.2	7.40E-02	S	4.96E-01	W	5.61E-03	S	1.79E-02	S
3.4	6.33E-02	S	4.88E-01	W	5.59E-03	S	1.71E-02	S
3.6	5.48E-02	S	4.81E-01	W	5.57E-03	S	1.64E-02	S
3.8	4.96E-02	S	4.77E-01	W	5.58E-03	S	1.59E-02	S
4	4.48E-02	S	4.76E-01	W	5.52E-03	S	1.55E-02	S
4.2	4.05E-02	S	4.75E-01	W	5.46E-03	S	1.52E-02	S
4.4	3.69E-02	S	4.74E-01	W	5.40E-03	S	1.48E-02	S
4.6	3.37E-02	S	4.73E-01	W	5.35E-03	S	1.46E-02	S
4.8	3.09E-02	S	4.72E-01	W	5.30E-03	S	1.43E-02	S
5	2.68E-02	S	4.62E-01	W	4.59E-03	S	1.23E-02	S
5.2	2.14E-02	S	4.41E-01	W	3.31E-03	S	8.94E-03	S
5.4	1.73E-02	S	4.23E-01	W	2.42E-03	S	6.55E-03	S
5.6	1.41E-02	S	4.05E-01	W	1.79E-03	S	4.86E-03	S
5.8	1.15E-02	S	3.89E-01	W	1.33E-03	S	3.64E-03	S
6	9.49E-03	S	3.74E-01	W	1.00E-03	S	2.75E-03	S
6.2	9.89E-03	S	3.70E-01	W	8.79E-04	S	2.42E-03	S
6.4	1.06E-02	S	3.68E-01	W	7.85E-04	S	2.16E-03	S
6.6	1.26E-02	S	3.69E-01	W	7.46E-04	S	2.06E-03	S
6.8	1.63E-02	S	3.73E-01	W	7.46E-04	S	2.06E-03	S
7	2.10E-02	S	3.77E-01	W	7.46E-04	S	2.06E-03	S
7.2	2.68E-02	S	3.82E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.13E-02	S	3.84E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.48E-02	S	3.85E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.87E-02	S	3.87E-01	W	7.46E-04	S	2.06E-03	S
8	4.17E-02	S	3.88E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID	SAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:37 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	4.14E-02	S	3.89E-01	W	7.46E-04	S	2.06E-03	S
8.4	4.11E-02	S	3.90E-01	W	7.46E-04	S	2.06E-03	S
8.6	4.08E-02	S	3.91E-01	W	7.46E-04	S	2.06E-03	S
8.8	4.06E-02	S	3.92E-01	W	7.46E-04	S	2.06E-03	S
9	4.03E-02	S	3.93E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.97E-02	S	3.93E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.92E-02	S	3.92E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.92E-02	S	3.93E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.94E-02	S	3.94E-01	W	7.46E-04	S	2.06E-03	S
10	3.96E-02	S	3.97E-01	S	7.46E-04	S	2.06E-03	S
10.2	3.97E-02	S	4.01E-01	S	7.46E-04	S	2.06E-03	S
10.4	3.97E-02	S	4.06E-01	S	7.46E-04	S	2.06E-03	S
10.6	3.99E-02	S	4.10E-01	S	7.46E-04	S	2.06E-03	S
10.8	4.01E-02	S	4.14E-01	S	7.46E-04	S	2.06E-03	S
11	3.62E-02	S	4.38E-01	S	7.46E-04	S	2.06E-03	S
11.2	2.93E-02	S	4.87E-01	S	7.46E-04	S	2.06E-03	S
11.4	2.38E-02	S	5.40E-01	S	7.46E-04	S	2.06E-03	S
11.6	1.94E-02	S	5.99E-01	S	7.46E-04	S	2.06E-03	S
11.8	1.58E-02	S	6.62E-01	S	7.46E-04	S	2.06E-03	S
12	1.30E-02	S	7.32E-01	S	7.46E-04	S	2.06E-03	S
12.2	1.07E-02	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
12.4	8.84E-03	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
12.6	7.32E-03	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
12.8	6.08E-03	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
13	5.06E-03	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	6.70E-01		6.50E+00		4.30E-02		1.44E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.06E-01	S	5.30E-06	S	3.10E-02	S	2.39E-02	S
3	1.75E-01	S	5.35E-06	S	2.39E-02	S	2.10E-02	S
3.2	1.64E-01	S	5.86E-06	S	2.21E-02	S	2.02E-02	S
3.4	1.54E-01	S	6.84E-06	S	2.05E-02	S	1.95E-02	S
3.6	1.44E-01	S	8.34E-06	S	1.93E-02	S	1.88E-02	S
3.8	1.21E-01	S	7.97E-06	S	2.02E-02	S	1.84E-02	S
4	8.90E-02	S	6.06E-06	S	2.27E-02	S	1.81E-02	S
4.2	6.52E-02	S	4.55E-06	S	2.56E-02	S	1.77E-02	S
4.4	4.84E-02	S	3.47E-06	S	2.87E-02	S	1.75E-02	S
4.6	3.65E-02	S	3.00E-06	S	3.20E-02	S	1.72E-02	S
4.8	2.78E-02	S	3.00E-06	S	3.56E-02	S	1.69E-02	S
5	2.27E-02	S	3.00E-06	S	3.92E-02	S	1.48E-02	S
5.2	2.02E-02	S	3.00E-06	S	4.30E-02	S	1.09E-02	S
5.4	1.81E-02	S	3.00E-06	S	4.70E-02	S	8.19E-03	S
5.6	1.63E-02	S	3.00E-06	S	5.11E-02	S	6.19E-03	S
5.8	1.47E-02	S	3.00E-06	S	5.55E-02	S	4.73E-03	S
6	1.33E-02	S	3.00E-06	S	6.01E-02	S	3.65E-03	S
6.2	1.25E-02	S	3.00E-06	S	6.37E-02	S	3.23E-03	S
6.4	1.18E-02	S	3.00E-06	S	6.72E-02	S	2.91E-03	S
6.6	1.15E-02	S	3.00E-06	S	6.99E-02	S	2.78E-03	S
6.8	1.16E-02	S	3.00E-06	S	7.19E-02	S	2.78E-03	S
7	1.16E-02	S	3.00E-06	S	7.39E-02	S	2.78E-03	S
7.2	1.17E-02	S	3.00E-06	S	7.59E-02	W	2.78E-03	S
7.4	1.18E-02	S	3.00E-06	S	7.72E-02	W	2.78E-03	S
7.6	1.19E-02	S	3.00E-06	S	7.80E-02	W	2.78E-03	S
7.8	1.21E-02	S	3.00E-06	S	7.89E-02	W	2.78E-03	S
8	1.22E-02	S	3.00E-06	S	7.96E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.21E-02	S	3.00E-06	S	7.98E-02	W	2.78E-03	S
8.4	1.20E-02	S	3.00E-06	S	8.00E-02	W	2.78E-03	S
8.6	1.20E-02	S	3.00E-06	S	8.02E-02	W	2.78E-03	S
8.8	1.19E-02	S	3.00E-06	S	8.04E-02	W	2.78E-03	S
9	1.18E-02	S	3.00E-06	S	8.06E-02	W	2.78E-03	S
9.2	1.18E-02	S	3.00E-06	S	8.13E-02	W	2.78E-03	S
9.4	1.18E-02	S	3.00E-06	S	8.21E-02	W	2.78E-03	S
9.6	1.18E-02	S	3.00E-06	S	8.20E-02	W	2.78E-03	S
9.8	1.19E-02	S	3.22E-06	S	8.17E-02	W	2.78E-03	S
10	1.10E-02	S	3.88E-06	S	8.15E-02	W	2.78E-03	S
10.2	9.95E-03	S	4.33E-06	S	8.18E-02	W	2.78E-03	S
10.4	9.28E-03	S	4.33E-06	S	8.26E-02	W	2.78E-03	S
10.6	9.09E-03	S	4.33E-06	S	8.35E-02	W	2.78E-03	S
10.8	8.90E-03	S	4.33E-06	S	8.44E-02	W	2.78E-03	S
11	8.91E-03	S	4.44E-06	S	8.54E-02	W	2.78E-03	S
11.2	9.12E-03	S	4.72E-06	S	8.62E-02	W	2.78E-03	S
11.4	9.33E-03	S	5.02E-06	S	8.70E-02	W	2.78E-03	S
11.6	9.55E-03	S	5.33E-06	S	8.79E-02	W	2.78E-03	S
11.8	9.76E-03	S	5.65E-06	S	8.87E-02	W	2.78E-03	S
12	9.98E-03	S	5.99E-06	S	8.95E-02	W	2.78E-03	S
12.2	1.02E-02	S	6.12E-06	S	9.03E-02	W	2.78E-03	S
12.4	1.04E-02	S	6.12E-06	S	9.11E-02	W	2.78E-03	S
12.6	1.06E-02	S	6.12E-06	S	9.19E-02	W	2.78E-03	S
12.8	1.09E-02	S	6.12E-06	S	9.27E-02	W	2.78E-03	S
13	1.11E-02	S	6.12E-06	S	9.35E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.34E+00		6.38E-05		7.90E-01		1.61E-01	

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Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.28E-01	S	2.53E-03	S	1.72E-01	S
3	1.13E-01	S	2.53E-03	S	1.40E-01	S
3.2	1.10E-01	S	2.53E-03	S	9.66E-02	S
3.4	1.08E-01	S	2.53E-03	S	6.81E-02	S
3.6	1.06E-01	S	2.53E-03	S	4.95E-02	S
3.8	1.03E-01	S	2.53E-03	S	3.99E-02	S
4	1.02E-01	S	2.53E-03	S	3.52E-02	S
4.2	1.01E-01	S	2.53E-03	S	3.15E-02	S
4.4	1.00E-01	S	2.53E-03	S	2.83E-02	S
4.6	9.91E-02	S	2.53E-03	S	2.56E-02	S
4.8	9.82E-02	S	2.53E-03	S	2.32E-02	S
5	9.18E-02	S	2.53E-03	S	2.07E-02	S
5.2	7.94E-02	S	2.53E-03	S	1.80E-02	S
5.4	6.91E-02	S	2.53E-03	S	1.58E-02	S
5.6	6.05E-02	S	2.53E-03	S	1.39E-02	S
5.8	5.31E-02	S	2.53E-03	S	1.23E-02	S
6	4.69E-02	S	2.53E-03	S	1.09E-02	S
6.2	4.20E-02	S	2.53E-03	S	1.20E-02	S
6.4	3.79E-02	S	2.53E-03	S	1.34E-02	S
6.6	3.40E-02	S	2.53E-03	S	1.64E-02	S
6.8	3.03E-02	S	2.53E-03	S	2.15E-02	S
7	2.72E-02	S	2.53E-03	S	2.81E-02	S
7.2	2.44E-02	S	2.53E-03	S	3.64E-02	S
7.4	2.26E-02	S	2.53E-03	S	4.32E-02	S
7.6	2.13E-02	S	2.53E-03	S	4.90E-02	S
7.8	2.01E-02	S	2.53E-03	S	5.52E-02	S
8	1.92E-02	S	2.53E-03	S	6.06E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-47. Leachate Concentrations for Gypsum Export, Waste ID SAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.92E-02	S	2.53E-03	S	6.15E-02	S
8.4	1.92E-02	S	2.53E-03	S	6.24E-02	S
8.6	1.92E-02	S	2.53E-03	S	6.32E-02	S
8.8	1.92E-02	S	2.53E-03	S	6.41E-02	S
9	1.92E-02	S	2.53E-03	S	6.50E-02	S
9.2	2.10E-02	S	2.53E-03	S	6.73E-02	S
9.4	2.32E-02	S	2.53E-03	S	6.99E-02	S
9.6	2.56E-02	S	2.53E-03	S	7.15E-02	S
9.8	2.81E-02	S	2.53E-03	S	7.26E-02	S
10	3.31E-02	S	2.53E-03	S	7.37E-02	S
10.2	3.99E-02	S	2.53E-03	S	7.48E-02	S
10.4	5.03E-02	S	2.53E-03	S	7.52E-02	S
10.6	6.49E-02	S	2.53E-03	S	7.54E-02	S
10.8	8.34E-02	S	2.53E-03	S	7.56E-02	S
11	9.29E-02	S	2.53E-03	S	6.63E-02	S
11.2	8.98E-02	S	2.53E-03	S	5.04E-02	S
11.4	8.68E-02	S	2.53E-03	S	3.85E-02	S
11.6	8.40E-02	S	2.53E-03	S	2.95E-02	S
11.8	8.14E-02	S	2.53E-03	S	2.28E-02	S
12	7.88E-02	S	2.53E-03	S	1.76E-02	S
12.2	7.64E-02	S	2.53E-03	S	1.37E-02	S
12.4	7.41E-02	S	2.53E-03	S	1.07E-02	S
12.6	7.19E-02	S	2.53E-03	S	8.38E-03	S
12.8	6.98E-02	S	2.53E-03	S	6.59E-03	S
13	6.78E-02	S	2.53E-03	S	5.20E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	8.63E-01		2.16E-02		1.07E+00	

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Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID	TAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.77E-02	S	1.20E+01	W	1.09E-02	S	5.61E-02	S
3	1.25E-02	S	1.19E+01	W	9.53E-03	S	5.22E-02	S
3.2	9.02E-03	S	1.19E+01	W	8.38E-03	S	4.87E-02	S
3.4	6.92E-03	S	1.19E+01	W	8.07E-03	S	4.73E-02	S
3.6	5.58E-03	S	1.19E+01	W	8.31E-03	S	4.72E-02	S
3.8	4.55E-03	S	1.20E+01	W	8.55E-03	S	4.71E-02	S
4	3.75E-03	S	1.20E+01	W	8.78E-03	S	4.71E-02	S
4.2	3.46E-03	S	1.21E+01	W	8.55E-03	S	4.89E-02	S
4.4	3.26E-03	S	1.21E+01	W	8.90E-03	S	4.99E-02	S
4.6	3.20E-03	S	1.19E+01	W	9.31E-03	S	4.98E-02	S
4.8	3.20E-03	S	1.17E+01	W	9.59E-03	S	4.94E-02	S
5	3.20E-03	S	1.15E+01	W	9.87E-03	S	4.90E-02	S
5.2	3.20E-03	S	1.13E+01	W	1.01E-02	S	4.86E-02	S
5.4	3.20E-03	S	1.11E+01	W	1.04E-02	S	4.83E-02	S
5.6	3.20E-03	S	1.11E+01	W	1.08E-02	S	4.84E-02	S
5.8	3.20E-03	S	1.12E+01	W	1.17E-02	S	4.98E-02	S
6	3.20E-03	S	1.16E+01	W	1.33E-02	S	5.30E-02	S
6.2	3.20E-03	S	1.15E+01	W	1.02E-02	S	4.77E-02	S
6.4	3.20E-03	S	1.14E+01	W	5.90E-03	S	3.85E-02	S
6.6	3.20E-03	S	1.12E+01	W	3.21E-03	S	3.03E-02	S
6.8	3.20E-03	S	1.11E+01	W	1.78E-03	S	2.41E-02	S
7	3.20E-03	S	1.09E+01	W	1.03E-03	S	1.90E-02	S
7.2	3.20E-03	S	1.09E+01	W	7.87E-04	S	1.37E-02	S
7.4	3.20E-03	S	1.09E+01	W	7.46E-04	S	8.55E-03	S
7.6	3.20E-03	S	1.08E+01	W	7.46E-04	S	5.20E-03	S
7.8	3.20E-03	S	1.07E+01	W	7.46E-04	S	3.21E-03	S
8	3.20E-03	S	1.07E+01	W	7.46E-04	S	2.14E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID	TAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	1.07E+01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	1.06E+01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	1.06E+01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	1.06E+01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	1.05E+01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	1.03E+01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	1.00E+01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	9.97E+00	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	9.99E+00	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	1.04E+01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.07E+01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.08E+01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.09E+01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.10E+01	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.11E+01	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.12E+01	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.13E+01	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.14E+01	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.15E+01	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	7.66E-02		8.03E+01		8.14E-02		3.25E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	6.89E-02	S	1.44E-04	S	7.45E-03	S	2.78E-03	S
3	5.34E-02	S	9.77E-05	S	6.17E-03	S	2.78E-03	S
3.2	4.21E-02	S	6.80E-05	S	5.18E-03	S	2.78E-03	S
3.4	3.50E-02	S	5.51E-05	S	4.62E-03	S	2.78E-03	S
3.6	3.05E-02	S	5.02E-05	S	4.32E-03	S	2.78E-03	S
3.8	2.67E-02	S	4.59E-05	S	4.06E-03	S	2.78E-03	S
4	2.36E-02	S	4.21E-05	S	3.83E-03	S	2.78E-03	S
4.2	2.49E-02	S	4.26E-05	S	3.80E-03	S	2.78E-03	S
4.4	2.46E-02	S	3.62E-05	S	3.80E-03	S	2.78E-03	S
4.6	2.37E-02	S	2.28E-05	S	3.80E-03	S	2.78E-03	S
4.8	2.29E-02	S	1.30E-05	S	3.80E-03	S	2.78E-03	S
5	2.23E-02	S	7.60E-06	S	3.80E-03	S	2.78E-03	S
5.2	2.16E-02	S	4.58E-06	S	3.80E-03	S	2.78E-03	S
5.4	2.10E-02	S	3.48E-06	S	3.80E-03	S	2.78E-03	S
5.6	2.03E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.8	1.90E-02	S	3.88E-06	S	3.80E-03	S	2.78E-03	S
6	1.70E-02	S	5.02E-06	S	3.80E-03	S	2.78E-03	S
6.2	1.55E-02	S	6.44E-06	S	4.24E-03	S	2.78E-03	S
6.4	1.36E-02	S	5.75E-06	S	5.20E-03	S	2.78E-03	S
6.6	1.18E-02	S	4.59E-06	S	6.53E-03	S	2.78E-03	S
6.8	1.03E-02	S	3.68E-06	S	8.15E-03	S	2.78E-03	S
7	9.12E-03	S	3.00E-06	S	9.96E-03	S	2.78E-03	S
7.2	8.98E-03	S	3.00E-06	S	1.07E-02	W	2.78E-03	S
7.4	1.02E-02	S	3.00E-06	S	1.05E-02	W	2.78E-03	S
7.6	1.19E-02	S	3.00E-06	S	9.93E-03	W	2.78E-03	S
7.8	1.39E-02	S	3.00E-06	S	9.44E-03	W	2.78E-03	S
8	1.55E-02	S	3.00E-06	S	9.08E-03	W	2.78E-03	S

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Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.52E-02	S	3.00E-06	S	9.35E-03	W	2.78E-03	S
8.4	1.48E-02	S	3.00E-06	S	9.71E-03	W	2.78E-03	S
8.6	1.44E-02	S	3.00E-06	S	1.01E-02	W	2.78E-03	S
8.8	1.40E-02	S	3.00E-06	S	1.04E-02	W	2.78E-03	S
9	1.46E-02	S	3.00E-06	S	1.09E-02	W	2.78E-03	S
9.2	1.92E-02	S	3.00E-06	S	1.16E-02	W	2.78E-03	S
9.4	2.51E-02	S	2.32E-06	S	1.23E-02	W	2.78E-03	S
9.6	2.36E-02	S	3.45E-06	S	1.31E-02	W	2.78E-03	S
9.8	2.23E-02	S	4.04E-06	S	1.39E-02	W	2.78E-03	S
10	2.10E-02	S	4.72E-06	S	1.47E-02	W	2.78E-03	S
10.2	1.98E-02	S	5.49E-06	S	1.56E-02	W	2.78E-03	S
10.4	1.90E-02	S	6.38E-06	S	1.63E-02	W	2.78E-03	S
10.6	1.87E-02	S	7.39E-06	S	1.66E-02	W	2.78E-03	S
10.8	1.84E-02	S	8.53E-06	S	1.69E-02	W	2.78E-03	S
11	1.81E-02	S	8.91E-06	S	1.73E-02	W	2.78E-03	S
11.2	1.83E-02	S	3.93E-06	S	1.76E-02	W	2.78E-03	S
11.4	1.82E-02	S	3.00E-06	S	1.82E-02	W	2.78E-03	S
11.6	1.74E-02	S	3.00E-06	S	1.95E-02	W	2.78E-03	S
11.8	1.67E-02	S	3.00E-06	S	2.09E-02	W	2.78E-03	S
12	1.61E-02	S	3.00E-06	S	2.23E-02	W	2.78E-03	S
12.2	1.54E-02	S	3.00E-06	S	2.38E-02	W	2.78E-03	S
12.4	1.49E-02	S	3.00E-06	S	2.42E-02	W	2.78E-03	S
12.6	1.43E-02	S	3.00E-06	S	2.42E-02	W	2.78E-03	S
12.8	1.38E-02	S	3.00E-06	S	2.42E-02	W	2.78E-03	S
13	1.33E-02	S	3.00E-06	S	2.42E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.28E-01		6.00E-04		1.70E-01		1.96E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.42E-01	S	1.05E-02	S	4.28E-02	S
3	1.17E-01	S	1.04E-02	S	3.48E-02	S
3.2	9.83E-02	S	1.03E-02	S	2.87E-02	S
3.4	8.72E-02	S	1.02E-02	S	2.52E-02	S
3.6	8.09E-02	S	1.02E-02	S	2.33E-02	S
3.8	7.53E-02	S	1.02E-02	S	2.16E-02	S
4	7.04E-02	S	1.01E-02	S	2.01E-02	S
4.2	7.08E-02	S	1.03E-02	S	1.98E-02	S
4.4	7.00E-02	S	1.03E-02	S	1.97E-02	S
4.6	6.87E-02	S	1.03E-02	S	1.99E-02	S
4.8	6.76E-02	S	1.04E-02	S	2.02E-02	S
5	6.66E-02	S	1.05E-02	S	2.04E-02	S
5.2	6.56E-02	S	1.05E-02	S	2.07E-02	S
5.4	6.47E-02	S	1.06E-02	S	2.10E-02	S
5.6	6.51E-02	S	1.06E-02	S	2.22E-02	S
5.8	6.60E-02	S	1.01E-02	S	2.37E-02	S
6	6.76E-02	S	9.18E-03	S	2.53E-02	S
6.2	6.60E-02	S	8.54E-03	S	2.67E-02	S
6.4	6.19E-02	S	7.25E-03	S	2.71E-02	S
6.6	5.76E-02	S	6.01E-03	S	2.72E-02	S
6.8	5.36E-02	S	5.00E-03	S	2.73E-02	S
7	5.01E-02	S	4.23E-03	S	2.73E-02	S
7.2	4.73E-02	S	3.96E-03	S	2.69E-02	S
7.4	4.43E-02	S	4.67E-03	S	2.66E-02	S
7.6	4.16E-02	S	5.82E-03	S	2.64E-02	S
7.8	3.90E-02	S	7.20E-03	S	2.62E-02	S
8	3.72E-02	S	8.52E-03	S	2.59E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-48. Leachate Concentrations for Gypsum Export, Waste ID TAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	3.79E-02	S	8.69E-03	S	2.56E-02	S
8.4	3.89E-02	S	8.81E-03	S	2.53E-02	S
8.6	3.98E-02	S	8.93E-03	S	2.50E-02	S
8.8	4.07E-02	S	9.04E-03	S	2.47E-02	S
9	4.20E-02	S	9.10E-03	S	2.42E-02	S
9.2	4.59E-02	S	8.87E-03	S	2.31E-02	S
9.4	5.13E-02	S	8.49E-03	S	2.21E-02	S
9.6	5.96E-02	S	8.31E-03	S	2.20E-02	S
9.8	6.90E-02	S	8.13E-03	S	2.19E-02	S
10	7.96E-02	S	7.96E-03	S	2.19E-02	S
10.2	9.17E-02	S	7.80E-03	S	2.18E-02	S
10.4	1.03E-01	S	7.65E-03	S	2.16E-02	S
10.6	1.11E-01	S	7.51E-03	S	2.14E-02	S
10.8	1.20E-01	S	7.37E-03	S	2.12E-02	S
11	1.30E-01	S	7.25E-03	S	2.11E-02	S
11.2	1.48E-01	S	7.26E-03	S	2.18E-02	S
11.4	1.65E-01	S	7.28E-03	S	2.19E-02	S
11.6	1.74E-01	S	7.32E-03	S	2.12E-02	S
11.8	1.83E-01	S	7.36E-03	S	2.04E-02	S
12	1.93E-01	S	7.39E-03	S	1.97E-02	S
12.2	2.03E-01	S	7.43E-03	S	1.90E-02	S
12.4	2.14E-01	S	7.47E-03	S	1.84E-02	S
12.6	2.25E-01	S	7.50E-03	S	1.78E-02	S
12.8	2.36E-01	S	7.54E-03	S	1.72E-02	S
13	2.48E-01	S	7.57E-03	S	1.67E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.67E+00		6.50E-02		2.14E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID	TAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.24E-02	S	7.92E-01	W	1.56E-03	S	2.19E-02	S
3	8.31E-03	S	7.82E-01	W	1.40E-03	S	2.13E-02	S
3.2	5.71E-03	S	7.73E-01	W	1.27E-03	S	2.08E-02	S
3.4	4.08E-03	S	7.72E-01	W	1.02E-03	S	1.76E-02	S
3.6	3.42E-03	S	7.73E-01	W	8.14E-04	S	1.38E-02	S
3.8	3.20E-03	S	7.68E-01	W	7.46E-04	S	1.23E-02	S
4	3.20E-03	S	7.62E-01	W	7.46E-04	S	1.21E-02	S
4.2	3.20E-03	S	7.56E-01	W	7.46E-04	S	1.19E-02	S
4.4	3.20E-03	S	7.51E-01	W	7.46E-04	S	1.17E-02	S
4.6	3.20E-03	S	7.46E-01	W	7.46E-04	S	1.15E-02	S
4.8	3.20E-03	S	7.41E-01	W	7.46E-04	S	1.13E-02	S
5	3.20E-03	S	7.36E-01	W	7.46E-04	S	1.12E-02	S
5.2	3.20E-03	S	7.26E-01	W	7.46E-04	S	8.00E-03	S
5.4	3.20E-03	S	7.14E-01	W	7.46E-04	S	5.23E-03	S
5.6	3.20E-03	S	7.03E-01	W	7.46E-04	S	3.47E-03	S
5.8	3.20E-03	S	7.07E-01	W	7.46E-04	S	2.90E-03	S
6	3.20E-03	S	7.14E-01	W	7.46E-04	S	2.58E-03	S
6.2	3.20E-03	S	7.21E-01	W	7.46E-04	S	2.29E-03	S
6.4	3.20E-03	S	7.18E-01	W	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	7.12E-01	W	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	7.06E-01	W	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	7.00E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	6.97E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	7.24E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	7.40E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	7.38E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	7.36E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID	TAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	7.34E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	7.32E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	7.30E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	7.28E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	7.22E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	7.13E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	7.04E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	6.96E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	6.87E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	6.86E-01	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	7.03E-01	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	7.26E-01	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	7.50E-01	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	7.74E-01	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	8.02E-01	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	8.89E-01	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	1.00E+00	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.12E+00	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.26E+00	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	1.41E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	1.54E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	1.54E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	1.54E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	1.54E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	1.54E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	6.16E-02		1.28E+01		1.04E-02		1.58E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	5.82E-02	S	8.29E-06	S	6.77E-03	S	2.78E-03	S
3	4.51E-02	S	7.99E-06	S	5.35E-03	S	2.78E-03	S
3.2	3.55E-02	S	7.71E-06	S	4.28E-03	S	2.78E-03	S
3.4	2.86E-02	S	7.58E-06	S	3.80E-03	S	2.78E-03	S
3.6	2.41E-02	S	8.13E-06	S	3.80E-03	S	2.78E-03	S
3.8	2.15E-02	S	8.71E-06	S	3.80E-03	S	2.78E-03	S
4	2.04E-02	S	1.27E-05	S	3.80E-03	S	2.78E-03	S
4.2	1.93E-02	S	1.93E-05	S	3.80E-03	S	2.78E-03	S
4.4	1.83E-02	S	2.86E-05	S	3.80E-03	S	2.78E-03	S
4.6	1.74E-02	S	4.17E-05	S	3.80E-03	S	2.78E-03	S
4.8	1.66E-02	S	5.99E-05	S	3.80E-03	S	2.78E-03	S
5	1.59E-02	S	8.47E-05	S	3.80E-03	S	2.78E-03	S
5.2	1.57E-02	S	4.91E-05	S	4.50E-03	S	2.78E-03	S
5.4	1.56E-02	S	2.18E-05	S	5.62E-03	S	2.78E-03	S
5.6	1.55E-02	S	1.13E-05	S	6.95E-03	S	2.78E-03	S
5.8	1.56E-02	S	9.90E-06	S	6.68E-03	S	2.78E-03	S
6	1.56E-02	S	8.70E-06	S	6.06E-03	S	2.78E-03	S
6.2	1.57E-02	S	5.95E-06	S	5.52E-03	S	2.78E-03	S
6.4	1.59E-02	S	6.75E-06	S	6.60E-03	S	2.78E-03	S
6.6	1.64E-02	S	5.09E-06	S	6.69E-03	S	2.78E-03	S
6.8	1.69E-02	S	3.87E-06	S	6.78E-03	S	2.78E-03	S
7	1.74E-02	S	3.00E-06	S	6.87E-03	S	2.78E-03	S
7.2	1.78E-02	S	2.32E-06	S	7.14E-03	W	2.78E-03	S
7.4	1.78E-02	S	4.93E-06	S	1.08E-02	W	2.78E-03	S
7.6	1.79E-02	S	7.50E-06	S	1.39E-02	W	2.78E-03	S
7.8	1.83E-02	S	7.50E-06	S	1.41E-02	W	2.78E-03	S
8	1.87E-02	S	7.50E-06	S	1.43E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.91E-02	S	7.50E-06	S	1.45E-02	W	2.78E-03	S
8.4	1.95E-02	S	7.50E-06	S	1.46E-02	W	2.78E-03	S
8.6	1.99E-02	S	7.50E-06	S	1.48E-02	W	2.78E-03	S
8.8	2.01E-02	S	7.31E-06	S	1.48E-02	W	2.78E-03	S
9	2.00E-02	S	7.10E-06	S	1.48E-02	W	2.78E-03	S
9.2	1.99E-02	S	6.90E-06	S	1.47E-02	W	2.78E-03	S
9.4	1.98E-02	S	6.71E-06	S	1.46E-02	W	2.78E-03	S
9.6	1.96E-02	S	6.53E-06	S	1.45E-02	W	2.78E-03	S
9.8	1.95E-02	S	6.36E-06	S	1.44E-02	W	2.78E-03	S
10	1.96E-02	S	6.20E-06	S	1.44E-02	W	2.78E-03	S
10.2	1.95E-02	S	6.12E-06	S	1.45E-02	W	2.78E-03	S
10.4	1.89E-02	S	6.12E-06	S	1.47E-02	W	2.78E-03	S
10.6	1.85E-02	S	6.12E-06	S	1.49E-02	W	2.78E-03	S
10.8	1.80E-02	S	6.12E-06	S	1.51E-02	W	2.78E-03	S
11	1.75E-02	S	6.10E-06	S	1.54E-02	W	2.78E-03	S
11.2	1.55E-02	S	5.95E-06	S	1.67E-02	W	2.78E-03	S
11.4	1.34E-02	S	5.80E-06	S	1.82E-02	W	2.78E-03	S
11.6	1.16E-02	S	5.66E-06	S	1.99E-02	W	2.78E-03	S
11.8	1.01E-02	S	5.53E-06	S	2.17E-02	W	2.78E-03	S
12	8.76E-03	S	5.40E-06	S	2.37E-02	W	2.78E-03	S
12.2	7.64E-03	S	5.28E-06	S	2.58E-02	W	2.78E-03	S
12.4	6.68E-03	S	5.16E-06	S	2.76E-02	W	2.78E-03	S
12.6	5.85E-03	S	5.05E-06	S	2.83E-02	W	2.78E-03	S
12.8	5.13E-03	S	4.94E-06	S	2.83E-02	W	2.78E-03	S
13	4.51E-03	S	4.83E-06	S	2.83E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.35E-01		6.29E-04		2.35E-01		2.31E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	6.21E-02	S	2.53E-03	S	2.09E-02	S
3	4.70E-02	S	2.53E-03	S	1.55E-02	S
3.2	3.63E-02	S	2.53E-03	S	1.17E-02	S
3.4	3.14E-02	S	2.53E-03	S	9.43E-03	S
3.6	3.04E-02	S	2.53E-03	S	8.84E-03	S
3.8	2.93E-02	S	2.53E-03	S	8.80E-03	S
4	2.96E-02	S	2.53E-03	S	8.98E-03	S
4.2	2.99E-02	S	2.53E-03	S	9.15E-03	S
4.4	3.02E-02	S	2.53E-03	S	9.31E-03	S
4.6	3.04E-02	S	2.53E-03	S	9.47E-03	S
4.8	3.07E-02	S	2.53E-03	S	9.63E-03	S
5	3.09E-02	S	2.53E-03	S	9.79E-03	S
5.2	2.81E-02	S	2.53E-03	S	9.31E-03	S
5.4	2.48E-02	S	2.53E-03	S	8.69E-03	S
5.6	2.19E-02	S	2.53E-03	S	8.13E-03	S
5.8	2.20E-02	S	2.53E-03	S	7.81E-03	S
6	2.28E-02	S	2.53E-03	S	7.55E-03	S
6.2	2.35E-02	S	2.53E-03	S	7.31E-03	S
6.4	2.21E-02	S	2.53E-03	S	7.13E-03	S
6.6	2.18E-02	S	2.53E-03	S	7.25E-03	S
6.8	2.15E-02	S	2.53E-03	S	7.37E-03	S
7	2.12E-02	S	2.53E-03	S	7.49E-03	S
7.2	2.11E-02	S	2.53E-03	S	7.63E-03	S
7.4	2.39E-02	S	2.53E-03	S	8.25E-03	S
7.6	2.60E-02	S	2.53E-03	S	8.76E-03	S
7.8	2.67E-02	S	2.53E-03	S	9.06E-03	S
8	2.75E-02	S	2.53E-03	S	9.35E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-49. Leachate Concentrations for Gypsum Export, Waste ID TAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.82E-02	S	2.53E-03	S	9.65E-03	S
8.4	2.90E-02	S	2.53E-03	S	9.95E-03	S
8.6	2.97E-02	S	2.53E-03	S	1.03E-02	S
8.8	3.03E-02	S	2.53E-03	S	1.01E-02	S
9	3.19E-02	S	2.53E-03	S	9.70E-03	S
9.2	3.42E-02	S	2.53E-03	S	9.32E-03	S
9.4	3.67E-02	S	2.53E-03	S	8.96E-03	S
9.6	3.92E-02	S	2.53E-03	S	8.62E-03	S
9.8	4.19E-02	S	2.53E-03	S	8.31E-03	S
10	4.50E-02	S	2.53E-03	S	8.05E-03	S
10.2	5.11E-02	S	2.53E-03	S	8.14E-03	S
10.4	6.01E-02	S	2.53E-03	S	8.42E-03	S
10.6	7.05E-02	S	2.53E-03	S	8.71E-03	S
10.8	8.24E-02	S	2.53E-03	S	9.01E-03	S
11	9.55E-02	S	2.53E-03	S	9.32E-03	S
11.2	1.06E-01	S	2.53E-03	S	9.99E-03	S
11.4	1.18E-01	S	2.53E-03	S	1.09E-02	S
11.6	1.30E-01	S	2.53E-03	S	1.18E-02	S
11.8	1.44E-01	S	2.53E-03	S	1.28E-02	S
12	1.59E-01	S	2.53E-03	S	1.38E-02	S
12.2	1.75E-01	S	2.53E-03	S	1.50E-02	S
12.4	1.93E-01	S	2.53E-03	S	1.61E-02	S
12.6	2.12E-01	S	2.53E-03	S	1.74E-02	S
12.8	2.32E-01	S	2.53E-03	S	1.87E-02	S
13	2.55E-01	S	2.53E-03	S	2.02E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.93E+00		2.10E-02		1.56E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID	UAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	6.67E-02	S	6.56E-01	W	5.30E-02	S	4.08E-02	S
3	6.86E-02	S	6.59E-01	W	5.26E-02	S	4.05E-02	S
3.2	7.04E-02	S	6.62E-01	W	5.23E-02	S	4.03E-02	S
3.4	7.22E-02	S	6.65E-01	W	5.19E-02	S	4.00E-02	S
3.6	7.39E-02	S	6.67E-01	W	5.16E-02	S	3.98E-02	S
3.8	7.56E-02	S	6.70E-01	W	5.13E-02	S	3.96E-02	S
4	7.72E-02	S	6.72E-01	W	5.11E-02	S	3.94E-02	S
4.2	7.87E-02	S	6.75E-01	W	5.08E-02	S	3.92E-02	S
4.4	8.03E-02	S	6.77E-01	W	5.05E-02	S	3.90E-02	S
4.6	5.51E-02	S	6.89E-01	W	4.28E-02	S	3.32E-02	S
4.8	3.49E-02	S	7.03E-01	W	3.50E-02	S	2.75E-02	S
5	2.25E-02	S	7.17E-01	W	2.89E-02	S	2.29E-02	S
5.2	1.39E-02	S	6.82E-01	W	1.23E-02	S	1.30E-02	S
5.4	8.69E-03	S	6.45E-01	W	5.01E-03	S	7.20E-03	S
5.6	5.52E-03	S	6.12E-01	W	2.11E-03	S	4.08E-03	S
5.8	3.56E-03	S	5.81E-01	W	9.15E-04	S	2.36E-03	S
6	3.20E-03	S	5.70E-01	W	7.46E-04	S	2.06E-03	S
6.2	3.20E-03	S	5.65E-01	W	7.46E-04	S	2.06E-03	S
6.4	3.20E-03	S	5.60E-01	W	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	5.56E-01	W	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	5.51E-01	W	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	5.47E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	5.46E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	5.45E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	5.44E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	5.43E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	5.43E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID	UAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	5.42E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	5.57E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	5.74E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	5.90E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	6.07E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	6.23E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	6.19E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	6.16E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	6.12E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	6.09E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	5.97E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	5.75E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	5.54E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	5.53E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	5.59E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	5.64E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	5.70E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	5.76E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	5.81E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	5.87E-01	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	5.92E-01	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	5.98E-01	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	6.03E-01	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	6.09E-01	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	6.14E-01	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	5.90E-01		5.27E+00		3.87E-01		2.98E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	5.18E-02	S	3.23E-04	S	6.72E-02	W	1.26E-02	S
3	5.33E-02	S	3.22E-04	S	6.77E-02	W	1.26E-02	S
3.2	5.48E-02	S	3.20E-04	S	6.81E-02	W	1.25E-02	S
3.4	5.62E-02	S	3.19E-04	S	6.85E-02	W	1.24E-02	S
3.6	5.75E-02	S	3.17E-04	S	6.89E-02	W	1.23E-02	S
3.8	5.88E-02	S	3.16E-04	S	6.92E-02	W	1.23E-02	S
4	6.01E-02	S	3.15E-04	S	6.96E-02	W	1.22E-02	S
4.2	6.13E-02	S	3.14E-04	S	6.99E-02	W	1.22E-02	S
4.4	6.25E-02	S	3.13E-04	S	7.02E-02	W	1.21E-02	S
4.6	4.05E-02	S	2.36E-04	S	6.78E-02	W	9.84E-03	S
4.8	2.40E-02	S	1.69E-04	S	6.49E-02	W	7.68E-03	S
5	1.45E-02	S	1.23E-04	S	6.22E-02	W	6.06E-03	S
5.2	1.33E-02	S	4.53E-05	S	6.18E-02	W	4.97E-03	S
5.4	1.28E-02	S	1.61E-05	S	6.17E-02	W	4.13E-03	S
5.6	1.24E-02	S	5.95E-06	S	6.16E-02	W	3.45E-03	S
5.8	1.20E-02	S	3.00E-06	S	6.15E-02	W	2.90E-03	S
6	1.22E-02	S	3.00E-06	S	6.06E-02	W	2.78E-03	S
6.2	1.26E-02	S	3.05E-06	S	5.96E-02	W	2.78E-03	S
6.4	1.30E-02	S	4.06E-06	S	5.86E-02	W	2.78E-03	S
6.6	1.34E-02	S	5.36E-06	S	5.76E-02	W	2.78E-03	S
6.8	1.38E-02	S	7.03E-06	S	5.67E-02	W	2.78E-03	S
7	1.42E-02	S	9.14E-06	S	5.59E-02	W	2.78E-03	S
7.2	1.45E-02	S	7.18E-06	S	5.58E-02	W	2.78E-03	S
7.4	1.48E-02	S	5.38E-06	S	5.57E-02	W	2.78E-03	S
7.6	1.51E-02	S	4.06E-06	S	5.57E-02	W	2.78E-03	S
7.8	1.54E-02	S	3.09E-06	S	5.57E-02	W	2.78E-03	S
8	1.57E-02	S	3.00E-06	S	5.56E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.60E-02	S	3.00E-06	S	5.56E-02	W	2.78E-03	S
8.4	1.65E-02	S	3.00E-06	S	5.73E-02	W	2.78E-03	S
8.6	1.70E-02	S	3.00E-06	S	5.91E-02	W	2.78E-03	S
8.8	1.74E-02	S	3.00E-06	S	6.09E-02	W	2.78E-03	S
9	1.79E-02	S	3.00E-06	S	6.27E-02	W	2.78E-03	S
9.2	1.83E-02	S	3.00E-06	S	6.44E-02	W	2.78E-03	S
9.4	1.73E-02	S	3.00E-06	S	6.44E-02	W	2.78E-03	S
9.6	1.64E-02	S	4.37E-06	S	6.43E-02	W	2.78E-03	S
9.8	1.56E-02	S	6.64E-06	S	6.43E-02	W	2.78E-03	S
10	1.48E-02	S	1.00E-05	S	6.42E-02	W	2.78E-03	S
10.2	1.46E-02	S	8.99E-06	S	6.21E-02	W	2.78E-03	S
10.4	1.50E-02	S	4.36E-06	S	5.77E-02	W	2.78E-03	S
10.6	1.55E-02	S	3.00E-06	S	5.37E-02	W	2.78E-03	S
10.8	1.58E-02	S	3.00E-06	S	5.36E-02	W	2.78E-03	S
11	1.61E-02	S	3.00E-06	S	5.46E-02	W	2.78E-03	S
11.2	1.65E-02	S	3.81E-06	S	5.57E-02	W	2.78E-03	S
11.4	1.68E-02	S	4.96E-06	S	5.67E-02	W	2.78E-03	S
11.6	1.71E-02	S	6.43E-06	S	5.78E-02	W	2.78E-03	S
11.8	1.74E-02	S	8.29E-06	S	5.88E-02	W	2.78E-03	S
12	1.77E-02	S	1.06E-05	S	5.99E-02	W	2.78E-03	S
12.2	1.80E-02	S	1.36E-05	S	6.10E-02	W	2.78E-03	S
12.4	1.84E-02	S	1.74E-05	S	6.20E-02	W	2.78E-03	S
12.6	1.87E-02	S	2.20E-05	S	6.31E-02	W	2.78E-03	S
12.8	1.90E-02	S	2.78E-05	S	6.41E-02	W	2.78E-03	S
13	1.93E-02	S	3.51E-05	S	6.52E-02	W	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.60E-01		2.37E-03		5.16E-01		9.23E-02	

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Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.04E-01	S	1.34E-02	S	1.90E-01	S
3	4.00E-01	S	1.33E-02	S	1.88E-01	S
3.2	3.97E-01	S	1.32E-02	S	1.86E-01	S
3.4	3.94E-01	S	1.31E-02	S	1.85E-01	S
3.6	3.91E-01	S	1.31E-02	S	1.83E-01	S
3.8	3.88E-01	S	1.30E-02	S	1.82E-01	S
4	3.85E-01	S	1.29E-02	S	1.81E-01	S
4.2	3.83E-01	S	1.28E-02	S	1.79E-01	S
4.4	3.80E-01	S	1.28E-02	S	1.78E-01	S
4.6	3.21E-01	S	1.07E-02	S	1.27E-01	S
4.8	2.62E-01	S	8.74E-03	S	8.46E-02	S
5	2.16E-01	S	7.17E-03	S	5.73E-02	S
5.2	1.57E-01	S	5.56E-03	S	4.49E-02	S
5.4	1.13E-01	S	4.32E-03	S	3.60E-02	S
5.6	8.31E-02	S	3.39E-03	S	2.91E-02	S
5.8	6.15E-02	S	2.68E-03	S	2.37E-02	S
6	5.81E-02	S	3.03E-03	S	2.71E-02	S
6.2	5.93E-02	S	3.83E-03	S	3.46E-02	S
6.4	6.04E-02	S	4.80E-03	S	4.37E-02	S
6.6	6.16E-02	S	5.98E-03	S	5.48E-02	S
6.8	6.28E-02	S	7.40E-03	S	6.83E-02	S
7	6.39E-02	S	9.10E-03	S	8.46E-02	S
7.2	6.30E-02	S	9.19E-03	S	8.47E-02	S
7.4	6.18E-02	S	9.10E-03	S	8.28E-02	S
7.6	6.08E-02	S	9.01E-03	S	8.11E-02	S
7.8	5.97E-02	S	8.92E-03	S	7.94E-02	S
8	5.88E-02	S	8.83E-03	S	7.78E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-50. Leachate Concentrations for Gypsum Export, Waste ID UAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	5.78E-02	S	8.75E-03	S	7.63E-02	S
8.4	5.68E-02	S	8.90E-03	S	7.95E-02	S
8.6	5.57E-02	S	9.06E-03	S	8.30E-02	S
8.8	5.47E-02	S	9.22E-03	S	8.65E-02	S
9	5.38E-02	S	9.39E-03	S	9.02E-02	S
9.2	5.30E-02	S	9.55E-03	S	9.37E-02	S
9.4	5.41E-02	S	9.74E-03	S	9.44E-02	S
9.6	5.53E-02	S	9.92E-03	S	9.50E-02	S
9.8	5.65E-02	S	1.01E-02	S	9.57E-02	S
10	5.77E-02	S	1.03E-02	S	9.63E-02	S
10.2	5.91E-02	S	1.05E-02	S	9.52E-02	S
10.4	6.08E-02	S	1.06E-02	S	9.23E-02	S
10.6	6.25E-02	S	1.07E-02	S	8.94E-02	S
10.8	6.56E-02	S	1.08E-02	S	8.40E-02	S
11	6.93E-02	S	1.09E-02	S	7.82E-02	S
11.2	7.30E-02	S	1.09E-02	S	7.29E-02	S
11.4	7.70E-02	S	1.10E-02	S	6.81E-02	S
11.6	8.10E-02	S	1.10E-02	S	6.36E-02	S
11.8	8.52E-02	S	1.11E-02	S	5.95E-02	S
12	8.96E-02	S	1.11E-02	S	5.58E-02	S
12.2	9.41E-02	S	1.11E-02	S	5.23E-02	S
12.4	9.87E-02	S	1.12E-02	S	4.91E-02	S
12.6	1.04E-01	S	1.12E-02	S	4.61E-02	S
12.8	1.08E-01	S	1.13E-02	S	4.34E-02	S
13	1.14E-01	S	1.13E-02	S	4.08E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.94E+00		9.81E-02		1.38E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID	WAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.43E-01	S	8.39E+00	W	1.20E-03	S	1.48E-02	S
3	1.44E-01	S	8.38E+00	W	8.16E-04	S	1.47E-02	S
3.2	1.51E-01	S	8.33E+00	W	7.46E-04	S	1.42E-02	S
3.4	1.57E-01	S	8.27E+00	W	7.46E-04	S	1.37E-02	S
3.6	1.63E-01	S	8.23E+00	W	7.46E-04	S	1.31E-02	S
3.8	1.70E-01	S	8.18E+00	W	7.46E-04	S	1.27E-02	S
4	1.76E-01	S	8.14E+00	W	7.46E-04	S	1.22E-02	S
4.2	1.82E-01	S	8.10E+00	W	7.46E-04	S	1.18E-02	S
4.4	1.86E-01	S	8.06E+00	W	7.46E-04	S	1.15E-02	S
4.6	1.65E-01	S	8.07E+00	W	7.46E-04	S	1.15E-02	S
4.8	1.45E-01	S	8.08E+00	W	7.46E-04	S	1.15E-02	S
5	1.18E-01	S	8.10E+00	W	7.46E-04	S	1.13E-02	S
5.2	1.13E-01	S	8.21E+00	W	7.46E-04	S	1.09E-02	S
5.4	1.08E-01	S	8.32E+00	W	7.46E-04	S	1.04E-02	S
5.6	9.56E-02	S	8.43E+00	W	7.46E-04	S	9.59E-03	S
5.8	7.29E-02	S	8.55E+00	W	7.46E-04	S	8.19E-03	S
6	5.05E-02	S	8.66E+00	W	7.46E-04	S	6.78E-03	S
6.2	2.59E-02	S	8.75E+00	W	7.46E-04	S	5.06E-03	S
6.4	1.36E-02	S	8.84E+00	W	7.46E-04	S	3.81E-03	S
6.6	7.66E-03	S	8.92E+00	W	7.46E-04	S	2.95E-03	S
6.8	5.85E-03	S	8.94E+00	W	7.46E-04	S	2.55E-03	S
7	4.50E-03	S	8.97E+00	W	7.46E-04	S	2.22E-03	S
7.2	4.51E-03	S	8.95E+00	W	7.46E-04	S	2.06E-03	S
7.4	6.16E-03	S	8.86E+00	W	7.46E-04	S	2.06E-03	S
7.6	8.33E-03	S	8.78E+00	W	7.46E-04	S	2.06E-03	S
7.8	1.12E-02	S	8.70E+00	W	7.46E-04	S	2.06E-03	S
8	1.49E-02	S	8.62E+00	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID	WAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	2.18E-02	S	8.54E+00	W	7.46E-04	S	2.06E-03	S
8.4	3.52E-02	S	8.46E+00	W	7.46E-04	S	2.06E-03	S
8.6	4.37E-02	S	8.39E+00	W	7.46E-04	S	2.06E-03	S
8.8	5.41E-02	S	8.33E+00	W	7.46E-04	S	2.06E-03	S
9	5.60E-02	S	8.27E+00	W	7.46E-04	S	2.06E-03	S
9.2	4.54E-02	S	8.19E+00	W	7.46E-04	S	2.06E-03	S
9.4	3.86E-02	S	8.02E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.29E-02	S	7.87E+00	W	7.46E-04	S	2.06E-03	S
9.8	2.81E-02	S	7.72E+00	W	7.46E-04	S	2.06E-03	S
10	2.45E-02	S	7.68E+00	W	7.46E-04	S	2.06E-03	S
10.2	2.06E-02	S	7.75E+00	W	7.46E-04	S	2.06E-03	S
10.4	1.73E-02	S	7.82E+00	W	7.46E-04	S	2.06E-03	S
10.6	1.46E-02	S	7.89E+00	W	7.46E-04	S	2.06E-03	S
10.8	1.24E-02	S	7.96E+00	W	7.46E-04	S	2.06E-03	S
11	1.22E-02	S	8.02E+00	W	7.46E-04	S	2.06E-03	S
11.2	1.62E-02	S	8.03E+00	W	7.46E-04	S	2.06E-03	S
11.4	2.14E-02	S	8.03E+00	W	7.46E-04	S	2.06E-03	S
11.6	2.82E-02	S	8.04E+00	W	7.46E-04	S	2.06E-03	S
11.8	3.69E-02	S	8.04E+00	W	7.46E-04	S	2.06E-03	S
12	4.81E-02	S	8.05E+00	W	7.46E-04	S	2.06E-03	S
12.2	6.25E-02	S	8.05E+00	W	7.46E-04	S	2.06E-03	S
12.4	8.07E-02	S	8.06E+00	W	7.46E-04	S	2.06E-03	S
12.6	1.04E-01	S	8.07E+00	W	7.46E-04	S	2.06E-03	S
12.8	1.26E-01	S	8.07E+00	W	7.46E-04	S	2.06E-03	S
13	1.37E-01	S	8.08E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	1.20E+00		5.77E+01		5.34E-03		9.42E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	4.84E-02	S	8.35E-06	S	4.24E-03	S	4.53E-03	S
3	4.67E-02	S	7.28E-06	S	3.80E-03	S	4.50E-03	S
3.2	4.30E-02	S	6.00E-06	S	3.80E-03	S	4.15E-03	S
3.4	3.87E-02	S	5.00E-06	S	3.80E-03	S	3.84E-03	S
3.6	3.51E-02	S	4.21E-06	S	3.80E-03	S	3.57E-03	S
3.8	3.20E-02	S	3.58E-06	S	3.80E-03	S	3.34E-03	S
4	2.92E-02	S	3.07E-06	S	3.80E-03	S	3.13E-03	S
4.2	2.69E-02	S	3.00E-06	S	3.80E-03	S	2.94E-03	S
4.4	2.47E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.6	2.10E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.8	1.79E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5	1.40E-02	S	2.32E-06	S	3.80E-03	S	2.78E-03	S
5.2	1.18E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.4	9.92E-03	S	3.71E-06	S	3.80E-03	S	2.78E-03	S
5.6	8.90E-03	S	4.64E-06	S	3.90E-03	S	2.78E-03	S
5.8	8.82E-03	S	5.74E-06	S	4.19E-03	S	2.78E-03	S
6	8.82E-03	S	6.38E-06	S	4.58E-03	S	2.78E-03	S
6.2	9.03E-03	S	5.25E-06	S	5.23E-03	W	2.78E-03	S
6.4	9.23E-03	S	4.35E-06	S	5.96E-03	W	2.78E-03	S
6.6	9.40E-03	S	3.62E-06	S	6.71E-03	W	2.78E-03	S
6.8	9.35E-03	S	3.03E-06	S	7.24E-03	W	2.78E-03	S
7	9.30E-03	S	3.00E-06	S	7.80E-03	W	2.78E-03	S
7.2	9.21E-03	S	3.00E-06	S	8.35E-03	W	2.78E-03	S
7.4	9.06E-03	S	3.00E-06	S	8.87E-03	W	2.78E-03	S
7.6	8.92E-03	S	3.00E-06	S	9.40E-03	W	2.78E-03	S
7.8	8.79E-03	S	3.00E-06	S	9.96E-03	W	2.78E-03	S
8	8.66E-03	S	3.00E-06	S	1.05E-02	W	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	8.40E-03	S	3.00E-06	S	1.11E-02	W	2.78E-03	S
8.4	7.99E-03	S	3.00E-06	S	1.15E-02	W	2.78E-03	S
8.6	7.52E-03	S	3.00E-06	S	1.13E-02	W	2.78E-03	S
8.8	7.10E-03	S	3.00E-06	S	1.11E-02	W	2.78E-03	S
9	6.67E-03	S	3.00E-06	S	1.11E-02	W	2.78E-03	S
9.2	6.27E-03	S	3.00E-06	S	1.14E-02	W	2.78E-03	S
9.4	6.08E-03	S	3.00E-06	S	1.18E-02	W	2.78E-03	S
9.6	5.90E-03	S	3.00E-06	S	1.22E-02	W	2.78E-03	S
9.8	5.73E-03	S	3.00E-06	S	1.27E-02	W	2.78E-03	S
10	5.81E-03	S	3.00E-06	S	1.28E-02	W	2.78E-03	S
10.2	5.90E-03	S	3.00E-06	S	1.28E-02	W	2.78E-03	S
10.4	6.00E-03	S	3.00E-06	S	1.28E-02	W	2.78E-03	S
10.6	6.09E-03	S	3.00E-06	S	1.28E-02	W	2.78E-03	S
10.8	6.19E-03	S	3.00E-06	S	1.28E-02	W	2.78E-03	S
11	6.33E-03	S	3.00E-06	S	1.35E-02	S	2.78E-03	S
11.2	6.68E-03	S	3.05E-06	S	1.56E-02	S	2.78E-03	S
11.4	7.05E-03	S	3.80E-06	S	1.80E-02	S	2.78E-03	S
11.6	7.43E-03	S	4.73E-06	S	2.07E-02	S	2.78E-03	S
11.8	7.83E-03	S	5.86E-06	S	2.37E-02	S	2.78E-03	S
12	8.24E-03	S	7.23E-06	S	2.71E-02	S	2.78E-03	S
12.2	8.66E-03	S	8.89E-06	S	2.86E-02	S	2.78E-03	S
12.4	9.10E-03	S	1.09E-05	S	2.86E-02	S	2.78E-03	S
12.6	9.55E-03	S	1.33E-05	S	2.86E-02	S	2.78E-03	S
12.8	1.00E-02	S	1.62E-05	S	2.86E-02	S	2.78E-03	S
13	1.05E-02	S	1.83E-05	S	2.86E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	3.00E-01		1.16E-04		2.05E-01		2.89E-02	

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Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	7.40E-01	S	3.23E-02	S	1.78E-01	S
3	7.05E-01	S	3.26E-02	S	1.61E-01	S
3.2	7.02E-01	S	3.28E-02	S	1.33E-01	S
3.4	7.15E-01	S	3.29E-02	S	1.07E-01	S
3.6	7.28E-01	S	3.30E-02	S	8.78E-02	S
3.8	7.40E-01	S	3.31E-02	S	7.26E-02	S
4	7.52E-01	S	3.32E-02	S	6.07E-02	S
4.2	7.63E-01	S	3.32E-02	S	5.11E-02	S
4.4	7.67E-01	S	3.33E-02	S	4.36E-02	S
4.6	6.54E-01	S	3.35E-02	S	3.98E-02	S
4.8	5.53E-01	S	3.36E-02	S	3.64E-02	S
5	4.09E-01	S	3.30E-02	S	3.36E-02	S
5.2	4.05E-01	S	3.19E-02	S	2.98E-02	S
5.4	4.00E-01	S	3.09E-02	S	2.66E-02	S
5.6	3.81E-01	S	2.95E-02	S	2.44E-02	S
5.8	3.38E-01	S	2.73E-02	S	2.37E-02	S
6	2.70E-01	S	2.50E-02	S	2.34E-02	S
6.2	1.58E-01	S	2.19E-02	S	2.38E-02	W
6.4	9.36E-02	S	1.93E-02	S	2.43E-02	W
6.6	5.84E-02	S	1.74E-02	S	2.46E-02	W
6.8	4.44E-02	S	1.70E-02	S	2.43E-02	W
7	3.41E-02	S	1.67E-02	S	2.40E-02	W
7.2	3.22E-02	S	1.71E-02	S	2.32E-02	W
7.4	3.87E-02	S	1.85E-02	S	2.20E-02	W
7.6	4.63E-02	S	1.99E-02	S	2.09E-02	W
7.8	5.52E-02	S	2.14E-02	S	1.98E-02	W
8	6.55E-02	S	2.29E-02	S	1.89E-02	W

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-51. Leachate Concentrations for Gypsum Export, Waste ID WAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	8.49E-02	S	2.42E-02	S	1.84E-02	W
8.4	1.21E-01	S	2.51E-02	S	1.85E-02	W
8.6	1.39E-01	S	2.58E-02	S	2.09E-02	W
8.8	1.60E-01	S	2.64E-02	S	2.36E-02	W
9	1.58E-01	S	2.68E-02	S	2.59E-02	W
9.2	1.28E-01	S	2.69E-02	S	2.68E-02	W
9.4	1.18E-01	S	2.62E-02	S	2.55E-02	W
9.6	1.09E-01	S	2.55E-02	S	2.44E-02	W
9.8	1.01E-01	S	2.49E-02	S	2.33E-02	W
10	1.07E-01	S	2.46E-02	S	2.27E-02	W
10.2	1.17E-01	S	2.47E-02	S	2.26E-02	W
10.4	1.28E-01	S	2.48E-02	S	2.25E-02	W
10.6	1.40E-01	S	2.49E-02	S	2.25E-02	W
10.8	1.52E-01	S	2.50E-02	S	2.24E-02	W
11	1.61E-01	S	2.50E-02	S	2.24E-02	W
11.2	1.74E-01	S	2.48E-02	S	2.22E-02	W
11.4	1.89E-01	S	2.45E-02	S	2.21E-02	W
11.6	2.05E-01	S	2.43E-02	S	2.19E-02	W
11.8	2.21E-01	S	2.40E-02	S	2.18E-02	W
12	2.39E-01	S	2.38E-02	S	2.16E-02	W
12.2	2.58E-01	S	2.36E-02	S	2.15E-02	W
12.4	2.78E-01	S	2.33E-02	S	2.14E-02	W
12.6	2.99E-01	S	2.31E-02	S	2.12E-02	W
12.8	3.21E-01	S	2.29E-02	S	2.11E-02	W
13	3.44E-01	S	2.27E-02	S	2.10E-02	W
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	4.93E+00		2.16E-01		1.03E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID	WAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	8.63E-03	S	2.88E-01	W	2.66E-03	S	1.80E-02	S
3	7.43E-03	S	2.82E-01	W	2.57E-03	S	1.75E-02	S
3.2	6.47E-03	S	2.76E-01	W	2.49E-03	S	1.70E-02	S
3.4	5.67E-03	S	2.71E-01	W	2.42E-03	S	1.66E-02	S
3.6	5.01E-03	S	2.66E-01	W	2.35E-03	S	1.63E-02	S
3.8	4.46E-03	S	2.61E-01	W	2.29E-03	S	1.59E-02	S
4	3.99E-03	S	2.57E-01	W	2.23E-03	S	1.56E-02	S
4.2	3.60E-03	S	2.53E-01	W	2.18E-03	S	1.53E-02	S
4.4	3.38E-03	S	2.54E-01	W	2.17E-03	S	1.46E-02	S
4.6	3.20E-03	S	2.53E-01	W	2.16E-03	S	1.41E-02	S
4.8	3.20E-03	S	2.42E-01	W	2.13E-03	S	1.34E-02	S
5	3.20E-03	S	2.32E-01	W	2.10E-03	S	1.29E-02	S
5.2	3.20E-03	S	2.23E-01	W	2.07E-03	S	1.23E-02	S
5.4	3.20E-03	S	2.28E-01	W	2.09E-03	S	1.15E-02	S
5.6	3.20E-03	S	2.41E-01	W	2.09E-03	S	1.03E-02	S
5.8	3.20E-03	S	2.40E-01	W	1.24E-03	S	4.22E-03	S
6	3.20E-03	S	2.43E-01	W	1.22E-03	S	3.96E-03	S
6.2	3.20E-03	S	2.44E-01	W	1.19E-03	S	3.67E-03	S
6.4	3.20E-03	S	2.33E-01	W	1.03E-03	S	3.07E-03	S
6.6	3.20E-03	S	2.24E-01	W	8.95E-04	S	2.58E-03	S
6.8	3.20E-03	S	2.15E-01	W	7.82E-04	S	2.18E-03	S
7	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID	WAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	2.12E-01	W	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	2.13E-01	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	2.14E-01	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	2.15E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	2.15E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	2.16E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	2.17E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	2.18E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	2.19E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	2.21E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	2.25E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	2.27E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	2.28E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	2.29E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	2.32E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	2.44E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	2.58E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	2.71E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	2.85E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	3.00E-01	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	3.01E-01	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	3.02E-01	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	3.04E-01	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	3.05E-01	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	3.06E-01	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	5.63E-02		2.47E+00		1.95E-02		1.32E-01	

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Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	7.67E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3	6.97E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.2	6.38E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.4	5.87E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.6	5.42E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
3.8	5.03E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4	4.69E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.2	4.38E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.4	4.12E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.6	3.88E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
4.8	3.64E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5	3.42E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.2	3.22E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.4	3.02E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.6	2.75E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
5.8	1.97E-02	S	3.00E-06	S	3.80E-03	S	2.78E-03	S
6	1.88E-02	S	3.00E-06	S	3.89E-03	S	2.78E-03	S
6.2	1.81E-02	S	3.00E-06	S	3.98E-03	S	2.78E-03	S
6.4	1.78E-02	S	3.00E-06	S	4.06E-03	S	2.78E-03	S
6.6	1.75E-02	S	3.00E-06	S	4.15E-03	S	2.78E-03	S
6.8	1.73E-02	S	3.00E-06	S	4.23E-03	S	2.78E-03	S
7	1.75E-02	S	3.00E-06	S	4.49E-03	S	2.78E-03	S
7.2	1.80E-02	S	3.00E-06	S	4.85E-03	S	2.78E-03	S
7.4	1.84E-02	S	3.00E-06	S	5.24E-03	S	2.78E-03	S
7.6	1.89E-02	S	3.00E-06	S	5.64E-03	S	2.78E-03	S
7.8	1.93E-02	S	3.00E-06	S	6.06E-03	S	2.78E-03	S
8	1.98E-02	S	3.00E-06	S	6.51E-03	S	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.03E-02	S	3.00E-06	S	6.97E-03	S	2.78E-03	S
8.4	2.02E-02	S	3.00E-06	S	7.17E-03	S	2.78E-03	S
8.6	2.00E-02	S	3.00E-06	S	7.35E-03	S	2.78E-03	S
8.8	1.99E-02	S	3.00E-06	S	7.52E-03	S	2.78E-03	S
9	1.97E-02	S	3.00E-06	S	7.70E-03	S	2.78E-03	S
9.2	1.96E-02	S	3.00E-06	S	7.87E-03	S	2.78E-03	S
9.4	1.94E-02	S	3.00E-06	S	8.05E-03	S	2.78E-03	S
9.6	1.93E-02	S	3.00E-06	S	8.22E-03	S	2.78E-03	S
9.8	1.78E-02	S	3.00E-06	S	7.42E-03	S	2.78E-03	S
10	1.52E-02	S	3.00E-06	S	5.94E-03	S	2.78E-03	S
10.2	1.34E-02	S	3.00E-06	S	5.81E-03	S	2.78E-03	S
10.4	1.22E-02	S	3.00E-06	S	5.69E-03	S	2.78E-03	S
10.6	1.25E-02	S	3.00E-06	S	6.94E-03	S	2.78E-03	S
10.8	1.29E-02	S	3.00E-06	S	8.51E-03	S	2.78E-03	S
11	1.32E-02	S	2.32E-06	S	9.92E-03	S	2.78E-03	S
11.2	1.27E-02	S	3.00E-06	S	1.14E-02	S	2.78E-03	S
11.4	1.23E-02	S	3.00E-06	S	1.32E-02	S	2.78E-03	S
11.6	1.18E-02	S	3.00E-06	S	1.51E-02	S	2.78E-03	S
11.8	1.14E-02	S	3.00E-06	S	1.73E-02	S	2.78E-03	S
12	1.11E-02	S	1.80E-06	S	1.98E-02	S	2.78E-03	S
12.2	1.07E-02	S	3.00E-06	S	1.98E-02	S	2.78E-03	S
12.4	1.04E-02	S	3.00E-06	S	1.98E-02	S	2.78E-03	S
12.6	1.00E-02	S	3.00E-06	S	1.98E-02	S	2.78E-03	S
12.8	9.73E-03	S	3.00E-06	S	1.98E-02	S	2.78E-03	S
13	9.43E-03	S	3.00E-06	S	1.98E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	5.28E-01		2.43E-05		1.60E-01		2.26E-02	

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Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	4.30E-01	S	2.53E-03	S	1.59E-01	S
3	3.76E-01	S	2.53E-03	S	1.16E-01	S
3.2	3.32E-01	S	2.53E-03	S	8.68E-02	S
3.4	2.96E-01	S	2.53E-03	S	6.61E-02	S
3.6	2.65E-01	S	2.53E-03	S	5.11E-02	S
3.8	2.38E-01	S	2.53E-03	S	4.00E-02	S
4	2.16E-01	S	2.53E-03	S	3.17E-02	S
4.2	1.98E-01	S	2.53E-03	S	2.56E-02	S
4.4	1.97E-01	S	2.53E-03	S	2.37E-02	S
4.6	1.98E-01	S	2.53E-03	S	2.21E-02	S
4.8	2.04E-01	S	2.53E-03	S	2.23E-02	S
5	2.10E-01	S	2.53E-03	S	2.25E-02	S
5.2	2.16E-01	S	2.53E-03	S	2.27E-02	S
5.4	2.13E-01	S	2.53E-03	S	2.12E-02	S
5.6	1.95E-01	S	2.53E-03	S	1.76E-02	S
5.8	5.77E-02	S	2.53E-03	S	1.03E-02	S
6	5.51E-02	S	2.53E-03	S	9.23E-03	S
6.2	5.16E-02	S	2.53E-03	S	8.36E-03	S
6.4	4.09E-02	S	2.53E-03	S	8.31E-03	S
6.6	3.26E-02	S	2.53E-03	S	8.26E-03	S
6.8	2.61E-02	S	2.53E-03	S	8.21E-03	S
7	2.52E-02	S	2.53E-03	S	8.45E-03	S
7.2	2.66E-02	S	2.53E-03	S	8.84E-03	S
7.4	2.80E-02	S	2.53E-03	S	9.25E-03	S
7.6	2.95E-02	S	2.53E-03	S	9.66E-03	S
7.8	3.11E-02	S	2.53E-03	S	1.01E-02	S
8	3.26E-02	S	2.53E-03	S	1.05E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-52. Leachate Concentrations for Gypsum Export, Waste ID WAW Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	3.43E-02	S	2.53E-03	S	1.09E-02	S
8.4	3.47E-02	S	2.53E-03	S	1.11E-02	S
8.6	3.50E-02	S	2.53E-03	S	1.12E-02	S
8.8	3.52E-02	S	2.53E-03	S	1.14E-02	S
9	3.55E-02	S	2.53E-03	S	1.15E-02	S
9.2	3.58E-02	S	2.53E-03	S	1.17E-02	S
9.4	3.60E-02	S	2.53E-03	S	1.18E-02	S
9.6	3.63E-02	S	2.53E-03	S	1.19E-02	S
9.8	3.63E-02	S	2.53E-03	S	1.21E-02	S
10	3.62E-02	S	2.53E-03	S	1.22E-02	S
10.2	3.64E-02	S	2.53E-03	S	1.03E-02	S
10.4	3.95E-02	S	2.53E-03	S	8.32E-03	S
10.6	4.94E-02	S	2.53E-03	S	8.41E-03	S
10.8	6.17E-02	S	2.53E-03	S	8.54E-03	S
11	7.68E-02	S	2.53E-03	S	8.72E-03	S
11.2	9.47E-02	S	2.53E-03	S	9.16E-03	S
11.4	1.16E-01	S	2.53E-03	S	9.61E-03	S
11.6	1.42E-01	S	2.53E-03	S	1.01E-02	S
11.8	1.74E-01	S	2.53E-03	S	1.05E-02	S
12	2.11E-01	S	2.53E-03	S	1.10E-02	S
12.2	2.55E-01	S	2.53E-03	S	1.15E-02	S
12.4	3.09E-01	S	2.53E-03	S	1.20E-02	S
12.6	3.71E-01	S	2.53E-03	S	1.26E-02	S
12.8	4.46E-01	S	2.53E-03	S	1.31E-02	S
13	5.34E-01	S	2.53E-03	S	1.37E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	3.62E+00		2.05E-02		8.80E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID	XAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	8.22E-03	S	5.63E-01	W	3.38E-03	S	2.37E-02	S
3	6.71E-03	S	5.64E-01	W	3.32E-03	S	2.28E-02	S
3.2	5.55E-03	S	5.65E-01	W	3.26E-03	S	2.19E-02	S
3.4	4.65E-03	S	5.66E-01	W	3.21E-03	S	2.11E-02	S
3.6	3.93E-03	S	5.67E-01	W	3.16E-03	S	2.04E-02	S
3.8	3.35E-03	S	5.68E-01	W	3.11E-03	S	1.97E-02	S
4	3.20E-03	S	5.66E-01	W	2.98E-03	S	1.92E-02	S
4.2	3.20E-03	S	5.63E-01	W	2.83E-03	S	1.88E-02	S
4.4	3.20E-03	S	5.60E-01	W	2.69E-03	S	1.84E-02	S
4.6	3.20E-03	S	5.57E-01	W	2.56E-03	S	1.80E-02	S
4.8	3.20E-03	S	5.55E-01	W	2.44E-03	S	1.77E-02	S
5	3.20E-03	S	5.52E-01	W	2.34E-03	S	1.73E-02	S
5.2	3.20E-03	S	5.50E-01	W	2.24E-03	S	1.70E-02	S
5.4	3.20E-03	S	5.48E-01	W	2.15E-03	S	1.67E-02	S
5.6	3.20E-03	S	5.46E-01	W	2.07E-03	S	1.65E-02	S
5.8	3.20E-03	S	5.44E-01	W	1.83E-03	S	1.58E-02	S
6	3.20E-03	S	5.42E-01	W	1.56E-03	S	1.50E-02	S
6.2	3.20E-03	S	5.39E-01	W	1.33E-03	S	1.43E-02	S
6.4	3.20E-03	S	5.37E-01	W	1.15E-03	S	1.36E-02	S
6.6	3.20E-03	S	5.35E-01	W	9.93E-04	S	1.30E-02	S
6.8	3.20E-03	S	5.34E-01	W	8.62E-04	S	1.24E-02	S
7	3.20E-03	S	5.32E-01	W	7.51E-04	S	1.19E-02	S
7.2	3.20E-03	S	5.42E-01	W	7.46E-04	S	1.11E-02	S
7.4	3.20E-03	S	5.52E-01	W	7.46E-04	S	1.03E-02	S
7.6	3.20E-03	S	5.63E-01	W	7.46E-04	S	9.65E-03	S
7.8	3.20E-03	S	5.70E-01	W	7.46E-04	S	8.25E-03	S
8	3.20E-03	S	5.70E-01	W	7.46E-04	S	5.98E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID	XAU-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mod
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	5.71E-01	W	7.46E-04	S	4.37E-03	S
8.4	3.20E-03	S	5.72E-01	W	7.46E-04	S	3.22E-03	S
8.6	3.20E-03	S	5.72E-01	W	7.46E-04	S	2.39E-03	S
8.8	3.20E-03	S	5.72E-01	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	5.71E-01	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	5.71E-01	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	5.70E-01	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	5.69E-01	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	5.68E-01	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	5.67E-01	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	5.67E-01	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	5.66E-01	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	5.65E-01	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	5.64E-01	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	5.64E-01	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	5.63E-01	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	5.62E-01	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	5.62E-01	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	5.61E-01	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	5.61E-01	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	5.60E-01	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	6.10E-01	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	6.83E-01	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	7.63E-01	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	8.51E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	4.39E-02		5.38E+00		2.17E-02		1.49E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	7.53E-02	S	4.21E-04	S	1.19E-02	S	7.55E-03	S
3	6.20E-02	S	3.36E-04	S	9.33E-03	S	6.09E-03	S
3.2	5.16E-02	S	2.72E-04	S	7.41E-03	S	4.98E-03	S
3.4	4.35E-02	S	2.23E-04	S	5.97E-03	S	4.13E-03	S
3.6	3.70E-02	S	1.85E-04	S	4.87E-03	S	3.46E-03	S
3.8	3.17E-02	S	1.55E-04	S	4.01E-03	S	2.92E-03	S
4	2.77E-02	S	1.36E-04	S	4.16E-03	S	2.78E-03	S
4.2	2.44E-02	S	1.22E-04	S	4.71E-03	S	2.78E-03	S
4.4	2.16E-02	S	1.10E-04	S	5.30E-03	S	2.78E-03	S
4.6	1.92E-02	S	9.99E-05	S	5.94E-03	S	2.78E-03	S
4.8	1.72E-02	S	9.09E-05	S	6.62E-03	S	2.78E-03	S
5	1.55E-02	S	8.31E-05	S	7.35E-03	S	2.78E-03	S
5.2	1.40E-02	S	7.62E-05	S	8.12E-03	S	2.78E-03	S
5.4	1.27E-02	S	7.02E-05	S	8.94E-03	S	2.78E-03	S
5.6	1.15E-02	S	6.47E-05	S	9.81E-03	S	2.78E-03	S
5.8	1.18E-02	S	4.90E-05	S	1.04E-02	S	2.78E-03	S
6	1.28E-02	S	3.37E-05	S	1.09E-02	S	2.78E-03	S
6.2	1.38E-02	S	2.34E-05	S	1.14E-02	W	2.78E-03	S
6.4	1.49E-02	S	1.65E-05	S	1.18E-02	W	2.78E-03	S
6.6	1.60E-02	S	1.17E-05	S	1.23E-02	W	2.78E-03	S
6.8	1.71E-02	S	8.41E-06	S	1.28E-02	W	2.78E-03	S
7	1.83E-02	S	6.10E-06	S	1.33E-02	W	2.78E-03	S
7.2	1.81E-02	S	4.32E-06	S	1.38E-02	W	2.78E-03	S
7.4	1.77E-02	S	3.08E-06	S	1.43E-02	W	2.78E-03	S
7.6	1.74E-02	S	3.00E-06	S	1.47E-02	W	2.78E-03	S
7.8	1.72E-02	S	3.00E-06	S	1.50E-02	W	2.78E-03	S
8	1.73E-02	S	3.00E-06	S	1.49E-02	W	2.78E-03	S

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Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.73E-02	S	3.00E-06	S	1.49E-02	W	2.78E-03	S
8.4	1.74E-02	S	3.00E-06	S	1.48E-02	W	2.78E-03	S
8.6	1.74E-02	S	3.00E-06	S	1.47E-02	W	2.78E-03	S
8.8	1.78E-02	S	3.00E-06	S	1.49E-02	W	2.78E-03	S
9	1.84E-02	S	3.00E-06	S	1.55E-02	W	2.78E-03	S
9.2	1.91E-02	S	3.00E-06	S	1.61E-02	W	2.78E-03	S
9.4	1.98E-02	S	3.00E-06	S	1.67E-02	W	2.78E-03	S
9.6	2.05E-02	S	3.18E-06	S	1.73E-02	W	2.78E-03	S
9.8	2.11E-02	S	3.58E-06	S	1.79E-02	W	2.78E-03	S
10	2.18E-02	S	4.02E-06	S	1.85E-02	W	2.78E-03	S
10.2	2.26E-02	S	4.51E-06	S	1.91E-02	W	2.78E-03	S
10.4	2.33E-02	S	5.05E-06	S	1.97E-02	W	2.78E-03	S
10.6	2.40E-02	S	5.64E-06	S	2.03E-02	W	2.78E-03	S
10.8	2.47E-02	S	6.28E-06	S	2.10E-02	W	2.78E-03	S
11	2.55E-02	S	6.98E-06	S	2.16E-02	S	2.78E-03	S
11.2	2.62E-02	S	7.75E-06	S	2.23E-02	S	2.78E-03	S
11.4	2.70E-02	S	8.58E-06	S	2.29E-02	S	2.78E-03	S
11.6	2.78E-02	S	9.49E-06	S	2.36E-02	S	2.78E-03	S
11.8	2.85E-02	S	1.05E-05	S	2.43E-02	S	2.78E-03	S
12	2.93E-02	S	1.15E-05	S	2.50E-02	S	2.78E-03	S
12.2	3.01E-02	S	1.27E-05	S	2.57E-02	S	2.78E-03	S
12.4	3.08E-02	S	1.65E-05	S	2.65E-02	S	2.78E-03	S
12.6	3.15E-02	S	2.24E-05	S	2.74E-02	S	2.78E-03	S
12.8	3.21E-02	S	3.04E-05	S	2.83E-02	S	2.78E-03	S
13	3.28E-02	S	4.11E-05	S	2.93E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	4.06E-01		2.20E-03		2.00E-01		3.99E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	8.56E-01	S	1.38E-02	S	4.39E-02	S
3	7.29E-01	S	1.38E-02	S	3.27E-02	S
3.2	6.27E-01	S	1.38E-02	S	2.49E-02	S
3.4	5.44E-01	S	1.38E-02	S	1.92E-02	S
3.6	4.76E-01	S	1.37E-02	S	1.51E-02	S
3.8	4.19E-01	S	1.37E-02	S	1.20E-02	S
4	4.18E-01	S	1.36E-02	S	1.11E-02	S
4.2	4.37E-01	S	1.33E-02	S	1.09E-02	S
4.4	4.56E-01	S	1.31E-02	S	1.07E-02	S
4.6	4.76E-01	S	1.29E-02	S	1.06E-02	S
4.8	4.95E-01	S	1.28E-02	S	1.04E-02	S
5	5.14E-01	S	1.26E-02	S	1.03E-02	S
5.2	5.33E-01	S	1.24E-02	S	1.01E-02	S
5.4	5.52E-01	S	1.23E-02	S	1.00E-02	S
5.6	5.70E-01	S	1.21E-02	S	9.87E-03	S
5.8	5.81E-01	S	1.20E-02	S	9.87E-03	S
6	5.86E-01	S	1.19E-02	S	9.92E-03	S
6.2	5.92E-01	S	1.17E-02	S	9.96E-03	S
6.4	5.97E-01	S	1.16E-02	S	1.00E-02	S
6.6	6.03E-01	S	1.15E-02	S	1.01E-02	S
6.8	6.08E-01	S	1.14E-02	S	1.01E-02	S
7	6.13E-01	S	1.13E-02	S	1.01E-02	S
7.2	6.39E-01	S	1.12E-02	S	1.04E-02	S
7.4	6.66E-01	S	1.12E-02	S	1.07E-02	S
7.6	6.94E-01	S	1.11E-02	S	1.10E-02	S
7.8	7.25E-01	S	1.10E-02	S	1.12E-02	S
8	7.61E-01	S	1.09E-02	S	1.13E-02	S

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Table C-5-53. Leachate Concentrations for Gypsum Export, Waste ID XAU Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	7.97E-01	S	1.09E-02	S	1.14E-02	S
8.4	8.35E-01	S	1.09E-02	S	1.15E-02	S
8.6	8.74E-01	S	1.08E-02	S	1.16E-02	S
8.8	8.69E-01	S	1.07E-02	S	1.17E-02	S
9	8.24E-01	S	1.06E-02	S	1.18E-02	S
9.2	7.83E-01	S	1.05E-02	S	1.20E-02	S
9.4	7.44E-01	S	1.04E-02	S	1.21E-02	S
9.6	7.08E-01	S	1.03E-02	S	1.22E-02	S
9.8	6.74E-01	S	1.02E-02	S	1.24E-02	S
10	6.42E-01	S	1.01E-02	S	1.25E-02	S
10.2	6.13E-01	S	1.00E-02	S	1.26E-02	S
10.4	5.85E-01	S	9.91E-03	S	1.28E-02	S
10.6	5.60E-01	S	9.82E-03	S	1.29E-02	S
10.8	5.35E-01	S	9.73E-03	S	1.30E-02	S
11	5.13E-01	S	9.65E-03	S	1.32E-02	S
11.2	4.91E-01	S	9.57E-03	S	1.33E-02	S
11.4	4.71E-01	S	9.49E-03	S	1.34E-02	S
11.6	4.52E-01	S	9.41E-03	S	1.35E-02	S
11.8	4.34E-01	S	9.33E-03	S	1.37E-02	S
12	4.17E-01	S	9.26E-03	S	1.38E-02	S
12.2	4.01E-01	S	9.18E-03	S	1.39E-02	S
12.4	4.78E-01	S	9.11E-03	S	1.46E-02	S
12.6	6.08E-01	S	9.03E-03	S	1.54E-02	S
12.8	7.71E-01	S	8.95E-03	S	1.63E-02	S
13	9.74E-01	S	8.88E-03	S	1.73E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	5.75E+00		9.03E-02		2.14E-01	

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Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID XAW-[Med] (P,1,1)
Date Exported 9/20/2011, 7:38 PM
Database Name C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term modeling\EPA Rpt 4 (5

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.003608426	S	0.024720832	S	0.002836	S	0.010197185	S
3	3.20E-03	S	2.35E-02	S	2.81E-03	S	9.86E-03	S
3.2	3.20E-03	S	2.34E-02	S	2.80E-03	S	9.72E-03	S
3.4	3.20E-03	S	2.33E-02	S	2.78E-03	S	9.59E-03	S
3.6	3.20E-03	S	2.32E-02	S	2.77E-03	S	9.47E-03	S
3.8	3.20E-03	S	2.32E-02	S	2.76E-03	S	9.35E-03	S
4	3.20E-03	S	2.31E-02	S	2.74E-03	S	9.25E-03	S
4.2	3.20E-03	S	2.30E-02	S	2.73E-03	S	9.14E-03	S
4.4	3.20E-03	S	2.24E-02	S	2.62E-03	S	8.88E-03	S
4.6	3.20E-03	S	2.18E-02	S	2.52E-03	S	8.63E-03	S
4.8	3.20E-03	S	2.13E-02	S	2.42E-03	S	8.40E-03	S
5	3.20E-03	S	2.08E-02	S	2.33E-03	S	8.18E-03	S
5.2	3.20E-03	S	1.85E-02	S	1.85E-03	S	6.20E-03	S
5.4	3.20E-03	S	1.65E-02	S	1.47E-03	S	4.68E-03	S
5.6	3.20E-03	S	1.48E-02	S	1.17E-03	S	3.57E-03	S
5.8	3.20E-03	S	1.33E-02	S	9.47E-04	S	2.75E-03	S
6	3.20E-03	S	1.20E-02	S	7.70E-04	S	2.14E-03	S
6.2	3.20E-03	S	1.34E-02	S	7.46E-04	S	2.06E-03	S
6.4	3.20E-03	S	1.55E-02	S	7.46E-04	S	2.06E-03	S
6.6	3.20E-03	S	1.79E-02	S	7.46E-04	S	2.06E-03	S
6.8	3.20E-03	S	2.05E-02	S	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	2.35E-02	S	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	2.70E-02	S	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	3.08E-02	S	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	3.50E-02	S	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	3.97E-02	S	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	4.43E-02	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID	XAW-[Med] (P,1,1)
Date Exported	9/20/2011, 7:38 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term modeling\EPA Rpt 4 (5

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	4.41E-02	S	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	4.39E-02	S	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	4.38E-02	S	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	4.36E-02	S	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	4.35E-02	S	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	4.33E-02	S	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	4.46E-02	S	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	4.68E-02	S	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	4.90E-02	S	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	5.12E-02	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	5.39E-02	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	5.77E-02	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	6.17E-02	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	6.59E-02	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	7.04E-02	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	7.50E-02	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	9.37E-02	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	1.33E-01	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	1.87E-01	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	2.62E-01	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	3.65E-01	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	3.96E-01	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	3.96E-01	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	3.96E-01	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	3.96E-01	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		1.00E-03		1.70E-04		4.10E-04	
Availability (mg/kg)	2.56E-02		3.17E+00		2.13E-02		7.47E-02	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID
Date Exported
Database Name 5-25-11 working db 3 reference-source term rev2).mdb

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.07718966	S	1.64626E-05	S	0.004344573	S	0.007361	S
3	6.91E-02	S	1.56E-05	S	3.80E-03	S	6.27E-03	S
3.2	6.44E-02	S	1.56E-05	S	3.80E-03	S	5.37E-03	S
3.4	6.04E-02	S	1.56E-05	S	3.80E-03	S	4.64E-03	S
3.6	5.68E-02	S	1.56E-05	S	3.80E-03	S	4.05E-03	S
3.8	5.36E-02	S	1.56E-05	S	3.80E-03	S	3.56E-03	S
4	5.07E-02	S	1.56E-05	S	3.80E-03	S	3.15E-03	S
4.2	4.81E-02	S	1.56E-05	S	3.80E-03	S	2.80E-03	S
4.4	4.19E-02	S	3.45E-05	S	3.80E-03	S	2.78E-03	S
4.6	3.65E-02	S	7.65E-05	S	3.80E-03	S	2.78E-03	S
4.8	3.21E-02	S	1.64E-04	S	3.80E-03	S	2.78E-03	S
5	2.83E-02	S	3.41E-04	S	3.80E-03	S	2.78E-03	S
5.2	2.93E-02	S	1.96E-04	S	3.80E-03	S	2.78E-03	S
5.4	3.05E-02	S	1.08E-04	S	3.80E-03	S	2.78E-03	S
5.6	3.17E-02	S	6.05E-05	S	3.80E-03	S	2.78E-03	S
5.8	3.30E-02	S	3.47E-05	S	3.80E-03	S	2.78E-03	S
6	3.42E-02	S	2.03E-05	S	3.80E-03	S	2.78E-03	S
6.2	3.43E-02	S	1.80E-05	S	4.50E-03	W	2.78E-03	S
6.4	3.43E-02	S	1.72E-05	S	5.48E-03	W	2.78E-03	S
6.6	3.42E-02	S	1.65E-05	S	6.62E-03	W	2.78E-03	S
6.8	3.41E-02	S	1.58E-05	S	7.95E-03	W	2.78E-03	S
7	3.32E-02	S	1.79E-05	S	8.65E-03	W	2.78E-03	S
7.2	3.21E-02	S	2.13E-05	S	9.10E-03	W	2.78E-03	S
7.4	3.11E-02	S	2.53E-05	S	9.57E-03	W	2.78E-03	S
7.6	3.01E-02	S	2.99E-05	S	1.00E-02	W	2.78E-03	S
7.8	2.91E-02	S	3.52E-05	S	1.05E-02	W	2.78E-03	S
8	2.84E-02	S	4.01E-05	S	1.10E-02	W	2.78E-03	S

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Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID
Date Exported
Database Name 5-25-11 working db 3 reference-source term rev2).mdb

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	2.86E-02	S	3.53E-05	S	1.09E-02	W	2.78E-03	S
8.4	2.88E-02	S	3.12E-05	S	1.09E-02	W	2.78E-03	S
8.6	2.90E-02	S	2.76E-05	S	1.08E-02	W	2.78E-03	S
8.8	2.92E-02	S	2.45E-05	S	1.08E-02	W	2.78E-03	S
9	2.94E-02	S	2.18E-05	S	1.07E-02	W	2.78E-03	S
9.2	2.96E-02	S	1.95E-05	S	1.07E-02	W	2.78E-03	S
9.4	2.97E-02	S	1.82E-05	S	1.09E-02	W	2.78E-03	S
9.6	2.98E-02	S	1.75E-05	S	1.13E-02	W	2.78E-03	S
9.8	2.98E-02	S	1.67E-05	S	1.17E-02	W	2.78E-03	S
10	2.98E-02	S	1.61E-05	S	1.21E-02	W	2.78E-03	S
10.2	3.01E-02	S	1.52E-05	S	1.23E-02	W	2.78E-03	S
10.4	3.10E-02	S	1.39E-05	S	1.22E-02	W	2.78E-03	S
10.6	3.18E-02	S	1.27E-05	S	1.21E-02	W	2.78E-03	S
10.8	3.27E-02	S	1.16E-05	S	1.19E-02	W	2.78E-03	S
11	3.36E-02	S	1.06E-05	S	1.18E-02	S	2.78E-03	S
11.2	3.45E-02	S	9.74E-06	S	1.17E-02	S	2.78E-03	S
11.4	3.43E-02	S	9.96E-06	S	1.16E-02	S	2.78E-03	S
11.6	3.32E-02	S	1.11E-05	S	1.14E-02	S	2.78E-03	S
11.8	3.22E-02	S	1.24E-05	S	1.13E-02	S	2.78E-03	S
12	3.12E-02	S	1.37E-05	S	1.12E-02	S	2.78E-03	S
12.2	3.03E-02	S	1.52E-05	S	1.10E-02	S	2.78E-03	S
12.4	2.94E-02	S	1.69E-05	S	1.09E-02	S	2.78E-03	S
12.6	2.86E-02	S	1.86E-05	S	1.08E-02	S	2.78E-03	S
12.8	2.78E-02	S	2.06E-05	S	1.07E-02	S	2.78E-03	S
13	2.70E-02	S	2.27E-05	S	1.05E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		6.00E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	5.23E-01		2.58E-03		9.38E-02		4.75E-02	

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Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID
Date Exported
Database Name

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.3427866	S	0.00253	S	0.0547779	S
3	2.72E-01	S	2.53E-03	S	3.97E-02	S
3.2	2.22E-01	S	2.53E-03	S	2.79E-02	S
3.4	1.83E-01	S	2.53E-03	S	2.01E-02	S
3.6	1.52E-01	S	2.53E-03	S	1.47E-02	S
3.8	1.28E-01	S	2.53E-03	S	1.09E-02	S
4	1.09E-01	S	2.53E-03	S	8.27E-03	S
4.2	9.29E-02	S	2.53E-03	S	6.34E-03	S
4.4	8.86E-02	S	2.53E-03	S	6.13E-03	S
4.6	8.52E-02	S	2.53E-03	S	6.00E-03	S
4.8	8.20E-02	S	2.53E-03	S	5.88E-03	S
5	7.91E-02	S	2.53E-03	S	5.76E-03	S
5.2	7.74E-02	S	2.53E-03	S	5.86E-03	S
5.4	7.59E-02	S	2.53E-03	S	5.97E-03	S
5.6	7.45E-02	S	2.53E-03	S	6.07E-03	S
5.8	7.31E-02	S	2.53E-03	S	6.18E-03	S
6	7.18E-02	S	2.53E-03	S	6.28E-03	S
6.2	6.78E-02	W	2.53E-03	S	6.63E-03	S
6.4	6.36E-02	W	2.53E-03	S	7.04E-03	S
6.6	5.98E-02	W	2.53E-03	S	7.46E-03	S
6.8	5.63E-02	W	2.53E-03	S	7.90E-03	S
7	6.83E-02	W	2.53E-03	S	9.21E-03	S
7.2	8.97E-02	W	2.53E-03	S	1.10E-02	S
7.4	1.17E-01	W	2.53E-03	S	1.32E-02	S
7.6	1.51E-01	W	2.53E-03	S	1.56E-02	S
7.8	1.94E-01	W	2.53E-03	S	1.85E-02	S
8	2.42E-01	W	2.53E-03	S	2.14E-02	S

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Table C-5-54. Leachate Concentrations for Gypsum Export, Waste ID XAW Med

Sample ID
Date Exported
Database Name

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.42E-01	W	2.53E-03	S	2.09E-02	S
8.4	2.42E-01	W	2.53E-03	S	2.05E-02	S
8.6	2.42E-01	W	2.53E-03	S	2.01E-02	S
8.8	2.41E-01	W	2.53E-03	S	1.97E-02	S
9	2.41E-01	W	2.53E-03	S	1.94E-02	S
9.2	2.41E-01	W	2.53E-03	S	1.90E-02	S
9.4	2.45E-01	W	2.53E-03	S	1.95E-02	S
9.6	2.51E-01	W	2.53E-03	S	2.06E-02	S
9.8	2.57E-01	W	2.53E-03	S	2.16E-02	S
10	2.63E-01	W	2.53E-03	S	2.27E-02	S
10.2	2.68E-01	W	2.53E-03	S	2.36E-02	S
10.4	2.73E-01	W	2.53E-03	S	2.41E-02	S
10.6	2.77E-01	W	2.53E-03	S	2.45E-02	S
10.8	2.82E-01	W	2.53E-03	S	2.50E-02	S
11	2.87E-01	S	2.53E-03	S	2.54E-02	S
11.2	2.91E-01	S	2.53E-03	S	2.58E-02	S
11.4	2.90E-01	S	2.53E-03	S	2.43E-02	S
11.6	2.84E-01	S	2.53E-03	S	2.16E-02	S
11.8	2.78E-01	S	2.53E-03	S	1.92E-02	S
12	2.73E-01	S	2.53E-03	S	1.70E-02	S
12.2	2.68E-01	S	2.53E-03	S	1.52E-02	S
12.4	2.63E-01	S	2.53E-03	S	1.36E-02	S
12.6	2.58E-01	S	2.53E-03	S	1.21E-02	S
12.8	2.53E-01	S	2.53E-03	S	1.09E-02	S
13	2.49E-01	S	2.53E-03	S	9.76E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	2.23E+00		2.02E-02		3.00E-01	

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.066084	S	7.307756	W	0.001781	S	0.0887829	W
3	0.045071	S	7.196089	W	0.001769	S	0.0883382	W
3.2	0.031509	S	7.093176	W	0.001757	S	0.0879243	W
3.4	0.022026	S	6.997846	W	0.001742	S	0.0875372	W
3.6	0.015458	S	6.90914	W	0.001712	S	0.0871738	W
3.8	0.010582	S	6.837153	W	0.001719	S	0.0868501	W
4	0.009131	S	6.810452	W	0.001716	S	0.0866143	W
4.2	0.008896	S	6.78515	W	0.001696	S	0.0863906	W
4.4	0.008678	S	6.772903	W	0.001677	S	0.0856465	W
4.6	0.008475	S	6.769568	W	0.001659	S	0.0845701	W
4.8	0.008284	S	6.766377	W	0.001642	S	0.0835523	W
5	0.008106	S	6.763318	W	0.001626	S	0.0825875	W
5.2	0.007869	S	6.76038	W	0.00161	S	0.081671	W
5.4	0.006988	S	6.751062	W	0.001528	S	0.0808791	W
5.6	0.004691	S	6.721415	W	0.001519	S	0.0803781	W
5.8	0.0032	S	6.692595	W	0.001508	S	0.0798667	W
6	0.0032	S	6.599711	W	0.001219	S	0.0735792	S
6.2	0.0032	S	6.511099	W	0.000992	S	0.0679691	S
6.4	0.0032	S	6.426435	W	0.000813	S	0.0629451	S
6.6	0.00352	S	6.328562	W	0.000746	S	0.0508885	S
6.8	0.004156	S	6.376549	W	0.000746	S	0.0555803	S
7	0.004884	S	6.423493	W	0.000746	S	0.0585954	S
7.2	0.005705	S	6.397274	W	0.000746	W	0.0090067	S
7.4	0.006599	S	6.395388	W	0.000746	W	0.002062	S
7.6	0.00661	S	6.247808	W	0.000746	W	0.002062	S
7.8	0.00661	S	6.037282	W	0.000746	W	0.002062	S
8	0.006631	S	5.838914	W	0.000746	W	0.002062	S

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.006687	S	5.651726	W	0.000746	W	0.002062	S
8.4	0.006741	S	5.474835	W	0.000746	W	0.002062	S
8.6	0.006795	S	5.307451	W	0.000746	W	0.002062	S
8.8	0.006848	S	5.148859	W	0.000746	W	0.002062	S
9	0.00689	S	5.017067	W	0.000746	W	0.002062	S
9.2	0.006888	S	5.027445	W	0.000746	W	0.002062	S
9.4	0.006885	S	5.096129	W	0.000746	W	0.002062	S
9.6	0.006598	S	5.164276	W	0.000746	W	0.002062	S
9.8	0.006602	S	5.231901	W	0.000746	W	0.002062	S
10	0.006605	S	5.299019	W	0.000746	W	0.002062	S
10.2	0.006608	S	5.365643	W	0.000746	W	0.002062	S
10.4	0.006611	S	5.427014	W	0.000746	W	0.002062	S
10.6	0.006614	S	5.483464	W	0.000746	W	0.002062	S
10.8	0.006617	S	5.539429	W	0.000746	W	0.002062	S
11	0.00662	S	5.598123	W	0.000746	W	0.002062	S
11.2	0.006623	S	5.691801	W	0.000746	W	0.002062	S
11.4	0.006626	S	5.755721	W	0.000746	W	0.002062	S
11.6	0.006629	S	5.819228	W	0.000746	W	0.002062	S
11.8	0.006631	S	5.882333	W	0.000746	W	0.002062	S
12	0.006634	S	5.945044	W	0.000746	W	0.002062	S
12.2	0.006637	S	6.00737	W	0.000746	W	0.002062	S
12.4	0.006639	S	6.069321	W	0.000746	W	0.002062	S
12.6	0.006642	S	6.130904	W	0.000746	W	0.002062	S
12.8	0.006645	S	6.192127	W	0.000746	W	0.002062	S
13	0.006647	S	6.252998	W	0.000746	W	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	0.450711		71.96089		0.017686		0.8833822	

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.7568581	S	1.28437E-05	S	0.02815497	S	0.018813	S
3	0.750013	S	1.46388E-05	S	0.01760686	S	0.017904	S
3.2	0.7436659	S	1.65444E-05	S	0.01101181	S	0.017093	S
3.4	0.7365715	S	1.85599E-05	S	0.00751322	S	0.016365	S
3.6	0.7265664	S	2.06113E-05	S	0.00509241	S	0.015707	S
3.8	0.6892985	S	1.9154E-05	S	0.003795	S	0.011293	S
4	0.6692473	S	1.63999E-05	S	0.003795	S	0.008317	S
4.2	0.6519085	S	1.563E-05	S	0.003795	S	0.007018	S
4.4	0.6376217	S	1.76681E-05	S	0.003795	S	0.005968	S
4.6	0.6267923	S	1.66885E-05	S	0.003795	S	0.005113	S
4.8	0.6171115	S	1.58015E-05	S	0.003795	S	0.004409	S
5	0.6079664	S	1.49951E-05	S	0.003795	S	0.003824	S
5.2	0.5993076	S	1.42591E-05	S	0.003795	S	0.003262	S
5.4	0.5910922	S	1.3585E-05	S	0.003795	S	0.002783	S
5.6	0.590496	S	1.29656E-05	S	0.003795	S	0.002783	S
5.8	0.5940076	S	1.23947E-05	S	0.00380491	S	0.002783	S
6	0.5970769	S	1.30672E-05	S	0.00635446	S	0.002783	S
6.2	0.600381	S	1.61636E-05	S	0.0104354	S	0.002783	S
6.4	0.6014909	S	1.79486E-05	S	0.01686937	S	0.002783	S
6.6	0.601169	S	1.50877E-05	S	0.03253571	S	0.002783	S
6.8	0.601493	S	2.36318E-05	S	0.02695917	S	0.002783	S
7	0.6018077	S	2.30296E-05	S	0.02877251	S	0.002783	S
7.2	0.6008583	S	2.22821E-05	S	0.03248639	W	0.002783	S
7.4	0.6007295	S	2.11775E-05	S	0.0384734	W	0.002783	S
7.6	0.601728	S	1.7043E-05	S	0.03933924	W	0.002783	S
7.8	0.6027021	S	1.49128E-05	S	0.04020132	W	0.002783	S
8	0.6036531	S	1.30931E-05	S	0.04105974	W	0.002783	S

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.604582	S	1.15324E-05	S	0.04191462	W	0.002783	S
8.4	0.6054899	S	1.01888E-05	S	0.04276606	W	0.002783	S
8.6	0.6063778	S	9.02811E-06	S	0.04361415	W	0.002783	S
8.8	0.6072465	S	8.02188E-06	S	0.04445898	W	0.002783	S
9	0.607882	S	7.31891E-06	S	0.04525756	W	0.002783	S
9.2	0.606869	S	8.01996E-06	S	0.04626985	W	0.002783	S
9.4	0.6058794	S	8.7709E-06	S	0.04758863	W	0.002783	S
9.6	0.6049122	S	9.57408E-06	S	0.04891605	W	0.002783	S
9.8	0.6039665	S	1.0432E-05	S	0.05025198	W	0.002783	S
10	0.6030413	S	1.1347E-05	S	0.0515963	W	0.002783	S
10.2	0.6021358	S	1.23218E-05	S	0.0529489	W	0.002783	S
10.4	0.6012492	S	1.33589E-05	S	0.05430965	W	0.002783	S
10.6	0.6003808	S	1.44611E-05	S	0.05567846	W	0.002783	S
10.8	0.5995298	S	1.5631E-05	S	0.05705521	W	0.002783	S
11	0.5986956	S	1.68714E-05	S	0.05843981	W	0.002783	S
11.2	0.5978776	S	1.81852E-05	S	0.05983215	W	0.002783	S
11.4	0.5970751	S	1.95754E-05	S	0.06123213	W	0.002783	S
11.6	0.5962877	S	2.10448E-05	S	0.06268585	W	0.002783	S
11.8	0.5955147	S	2.16092E-05	S	0.06420281	W	0.002783	S
12	0.5947557	S	2.16092E-05	S	0.06573006	W	0.002783	S
12.2	0.5940101	S	2.16092E-05	S	0.06726749	W	0.002783	S
12.4	0.5932776	S	2.16092E-05	S	0.068815	W	0.002783	S
12.6	0.5925578	S	2.16092E-05	S	0.0703725	W	0.002783	S
12.8	0.5918501	S	2.16092E-05	S	0.07193989	W	0.002783	S
13	0.5911542	S	2.16092E-05	S	0.07351708	W	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	7.5001304		0.000236318		0.75536885		0.179039	

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.050728	S	0.007681	S	0.038851	S
3	0.045029	S	0.007598	S	0.026784	S
3.2	0.040279	S	0.00752	S	0.018913	S
3.4	0.036274	S	0.007449	S	0.013641	S
3.6	0.032864	S	0.007381	S	0.010023	S
3.8	0.027792	S	0.007399	S	0.006509	S
4	0.025527	S	0.007277	S	0.003515	S
4.2	0.024711	S	0.007162	S	0.003272	S
4.4	0.023859	S	0.007163	S	0.003354	S
4.6	0.023959	S	0.007242	S	0.003435	S
4.8	0.024054	S	0.007318	S	0.003513	S
5	0.024146	S	0.007392	S	0.003591	S
5.2	0.024234	S	0.007464	S	0.004137	S
5.4	0.023801	S	0.007507	S	0.004244	S
5.6	0.021835	S	0.007463	S	0.003857	S
5.8	0.020098	S	0.007421	S	0.004001	S
6	0.019728	S	0.007422	S	0.004144	S
6.2	0.019376	S	0.007415	S	0.004288	W
6.4	0.018832	S	0.007099	S	0.004788	W
6.6	0.017749	S	0.006887	S	0.00512	W
6.8	0.018038	S	0.006989	S	0.004898	W
7	0.018324	S	0.00709	S	0.004692	W
7.2	0.014994	S	0.007039	S	0.005194	W
7.4	0.013708	S	0.006805	S	0.005754	W
7.6	0.01314	S	0.006606	S	0.0058	W
7.8	0.012609	S	0.006418	S	0.005846	W
8	0.012113	S	0.006239	S	0.005891	W

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Table C-5-55. Leachate Concentrations for Sludge Scrubber, Waste ID AGD Med

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.011647	S	0.00607	S	0.005935	W
8.4	0.01121	S	0.00591	S	0.005979	W
8.6	0.010799	S	0.005757	S	0.006021	W
8.8	0.010419	S	0.005611	S	0.006063	W
9	0.010188	S	0.005547	S	0.006111	W
9.2	0.009702	S	0.005487	S	0.00621	W
9.4	0.009691	S	0.005362	S	0.006307	W
9.6	0.009685	S	0.005021	S	0.006404	W
9.8	0.009679	S	0.004674	S	0.006501	W
10	0.009674	S	0.004357	S	0.006597	W
10.2	0.009613	S	0.004067	S	0.006692	W
10.4	0.009527	S	0.003801	S	0.006787	W
10.6	0.009494	S	0.003558	S	0.006881	W
10.8	0.009501	S	0.003334	S	0.006975	W
11	0.009508	S	0.003128	S	0.007069	W
11.2	0.009514	S	0.002938	S	0.007161	W
11.4	0.00952	S	0.002763	S	0.007254	W
11.6	0.009527	S	0.0026	S	0.007346	W
11.8	0.009533	S	0.002451	S	0.007438	W
12	0.009539	S	0.002333	S	0.007529	W
12.2	0.009545	S	0.002222	S	0.00762	W
12.4	0.009551	S	0.002118	S	0.00771	W
12.6	0.009556	S	0.00202	S	0.0078	W
12.8	0.009562	S	0.001929	S	0.00789	W
13	0.009568	S	0.001842	S	0.007979	W
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	0.450291		0.075977		0.267838	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Sample ID	BGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:44 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

2.8	1.03E-01	S	1.54E+01	W	7.46E-04	S	6.06E-02	S
3	9.73E-02	S	1.53E+01	W	7.46E-04	S	5.59E-02	S
3.2	9.28E-02	S	1.51E+01	W	7.46E-04	S	5.18E-02	S
3.4	8.88E-02	S	1.50E+01	W	7.46E-04	S	4.82E-02	S
3.6	8.51E-02	S	1.48E+01	W	7.46E-04	S	4.51E-02	S
3.8	8.18E-02	S	1.47E+01	W	7.46E-04	S	4.37E-02	S
4	7.88E-02	S	1.46E+01	W	7.46E-04	S	4.25E-02	S
4.2	7.60E-02	S	1.45E+01	W	7.46E-04	S	4.13E-02	S
4.4	7.35E-02	S	1.44E+01	W	7.46E-04	S	4.02E-02	S
4.6	7.11E-02	S	1.43E+01	W	7.46E-04	S	3.92E-02	S
4.8	6.89E-02	S	1.42E+01	W	7.46E-04	S	3.83E-02	S
5	6.69E-02	S	1.41E+01	W	7.46E-04	S	3.74E-02	S
5.2	6.50E-02	S	1.40E+01	W	7.46E-04	S	3.66E-02	S
5.4	6.32E-02	S	1.39E+01	W	7.46E-04	S	3.58E-02	S
5.6	6.16E-02	S	1.38E+01	W	7.46E-04	S	3.51E-02	S
5.8	6.00E-02	S	1.37E+01	W	7.46E-04	S	3.44E-02	S
6	5.85E-02	S	1.36E+01	W	7.46E-04	S	3.37E-02	S
6.2	5.71E-02	S	1.36E+01	W	7.46E-04	S	3.31E-02	S
6.4	5.56E-02	S	1.35E+01	W	7.46E-04	S	3.25E-02	S
6.6	5.05E-02	S	1.34E+01	W	7.46E-04	S	2.37E-02	S
6.8	4.60E-02	S	1.33E+01	W	7.46E-04	S	2.12E-02	S
7	4.39E-02	S	1.32E+01	S	7.46E-04	S	1.18E-02	S
7.2	2.54E-02	S	1.10E+01	S	7.46E-04	S	2.43E-03	S
7.4	1.97E-02	S	1.05E+01	S	7.46E-04	S	2.06E-03	S
7.6	1.96E-02	S	7.22E+00	S	7.46E-04	S	2.06E-03	S
7.8	1.95E-02	S	5.00E+00	S	7.46E-04	S	2.06E-03	S
8	1.94E-02	S	3.49E+00	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Sample ID	BGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:44 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

8.2	1.93E-02	S	2.79E+00	S	7.46E-04	S	2.06E-03	S
8.4	1.61E-02	S	2.40E+00	S	7.46E-04	S	2.06E-03	S
8.6	1.30E-02	S	2.06E+00	S	7.46E-04	S	2.06E-03	S
8.8	1.70E-02	S	2.03E+00	S	7.46E-04	S	2.06E-03	S
9	2.11E-02	S	2.41E+00	S	7.46E-04	S	2.06E-03	S
9.2	1.91E-02	S	2.38E+00	S	7.46E-04	S	2.06E-03	S
9.4	1.72E-02	S	2.35E+00	S	7.46E-04	S	2.06E-03	S
9.6	1.56E-02	S	2.02E+00	S	7.46E-04	S	2.06E-03	S
9.8	1.42E-02	S	1.35E+00	S	7.46E-04	S	2.06E-03	S
10	1.06E-02	S	1.48E+00	S	7.46E-04	S	2.06E-03	S
10.2	7.46E-03	S	1.67E+00	S	7.46E-04	S	2.06E-03	S
10.4	5.29E-03	S	1.88E+00	S	7.46E-04	S	2.06E-03	S
10.6	3.77E-03	S	2.11E+00	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	2.19E+00	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	2.16E+00	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	2.14E+00	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	2.12E+00	S	7.46E-04	S	2.06E-03	S
11.6	3.73E-03	S	2.15E+00	S	7.46E-04	S	2.06E-03	S
11.8	5.66E-03	S	2.28E+00	S	7.46E-04	S	2.06E-03	S
12	8.53E-03	S	2.42E+00	S	7.46E-04	S	2.06E-03	S
12.2	1.28E-02	S	2.57E+00	S	7.46E-04	S	2.06E-03	S
12.4	1.84E-02	S	2.72E+00	S	7.46E-04	S	2.06E-03	S
12.6	2.81E-02	S	2.87E+00	S	7.46E-04	S	2.06E-03	S
12.8	4.13E-02	S	3.04E+00	S	7.46E-04	S	2.06E-03	S
13	6.03E-02	S	3.21E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	9.73E-01		1.53E+02		8.21E-03		5.59E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Table C-5-56. Leachate Concer
Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

2.8	1.90E-01	S	2.14E-03	S	2.11E-01	S	9.13E-03	S
3	1.90E-01	S	2.18E-03	S	2.12E-01	S	9.20E-03	S
3.2	1.90E-01	S	2.21E-03	S	2.16E-01	S	9.22E-03	S
3.4	1.90E-01	S	2.25E-03	S	2.21E-01	S	9.25E-03	S
3.6	1.90E-01	S	2.28E-03	S	2.25E-01	S	9.27E-03	S
3.8	1.90E-01	S	2.31E-03	S	2.28E-01	S	9.29E-03	S
4	1.90E-01	S	2.34E-03	S	2.32E-01	S	9.31E-03	S
4.2	1.90E-01	S	2.36E-03	S	2.36E-01	S	9.33E-03	S
4.4	1.90E-01	S	2.39E-03	S	2.39E-01	S	9.35E-03	S
4.6	1.90E-01	S	2.42E-03	S	2.43E-01	S	9.37E-03	S
4.8	1.90E-01	S	2.44E-03	S	2.46E-01	S	9.38E-03	S
5	1.90E-01	S	2.46E-03	S	2.49E-01	S	9.40E-03	S
5.2	1.90E-01	S	2.49E-03	S	2.52E-01	S	9.42E-03	S
5.4	1.90E-01	S	2.51E-03	S	2.55E-01	S	9.43E-03	S
5.6	1.90E-01	S	2.53E-03	S	2.58E-01	S	9.45E-03	S
5.8	1.90E-01	S	2.55E-03	S	2.61E-01	S	9.46E-03	S
6	1.90E-01	S	2.57E-03	S	2.64E-01	S	9.47E-03	S
6.2	1.90E-01	S	2.60E-03	S	2.67E-01	S	9.49E-03	S
6.4	1.90E-01	S	2.62E-03	S	2.71E-01	S	9.52E-03	S
6.6	1.90E-01	S	2.63E-03	S	2.94E-01	S	9.79E-03	S
6.8	1.90E-01	S	3.16E-03	S	3.19E-01	S	1.01E-02	S
7	1.90E-01	S	2.76E-03	S	3.30E-01	S	9.73E-03	S
7.2	1.90E-01	S	1.94E-03	S	3.58E-01	S	1.15E-02	S
7.4	1.90E-01	S	1.34E-03	S	3.32E-01	S	1.06E-02	S
7.6	1.90E-01	S	3.57E-04	S	2.51E-01	S	7.05E-03	S
7.8	1.90E-01	S	9.82E-05	S	1.91E-01	S	4.72E-03	S
8	1.90E-01	S	2.80E-05	S	1.46E-01	S	3.20E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Table C-5-56. Leachate Concer
Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

8.2	1.90E-01	S	2.81E-05	S	1.24E-01	S	2.78E-03	S
8.4	1.90E-01	S	2.92E-05	S	1.10E-01	S	2.78E-03	S
8.6	1.90E-01	S	3.03E-05	S	1.09E-01	S	2.78E-03	S
8.8	1.90E-01	S	3.13E-05	S	1.21E-01	S	2.78E-03	S
9	1.90E-01	S	3.25E-05	S	1.32E-01	S	2.78E-03	S
9.2	1.90E-01	S	3.44E-05	S	1.23E-01	S	2.78E-03	S
9.4	1.90E-01	S	3.63E-05	S	1.14E-01	S	2.78E-03	S
9.6	1.90E-01	S	3.83E-05	S	1.07E-01	S	2.78E-03	S
9.8	1.90E-01	S	3.69E-05	S	9.94E-02	S	2.78E-03	S
10	1.90E-01	S	3.51E-05	S	9.29E-02	S	2.78E-03	S
10.2	1.90E-01	S	3.35E-05	S	8.69E-02	S	2.78E-03	S
10.4	1.90E-01	S	3.20E-05	S	7.63E-02	S	2.78E-03	S
10.6	1.90E-01	S	3.06E-05	S	6.67E-02	S	2.78E-03	S
10.8	1.90E-01	S	2.93E-05	S	6.21E-02	S	2.78E-03	S
11	1.90E-01	S	2.81E-05	S	6.15E-02	S	2.78E-03	S
11.2	1.90E-01	S	2.69E-05	S	6.11E-02	S	2.78E-03	S
11.4	1.90E-01	S	2.58E-05	S	6.04E-02	S	2.78E-03	S
11.6	1.90E-01	S	2.80E-05	S	5.98E-02	S	2.78E-03	S
11.8	1.90E-01	S	3.78E-05	S	6.19E-02	S	2.78E-03	S
12	1.90E-01	S	3.05E-05	S	6.53E-02	S	2.78E-03	S
12.2	1.90E-01	S	2.28E-05	S	6.90E-02	S	2.78E-03	S
12.4	1.90E-01	S	1.71E-05	S	7.27E-02	S	2.78E-03	S
12.6	1.90E-01	S	1.29E-05	S	7.59E-02	S	2.78E-03	S
12.8	1.90E-01	S	9.79E-06	S	7.89E-02	S	2.78E-03	S
13	1.90E-01	S	7.68E-06	S	8.20E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	2.09E+00		3.16E-02		3.58E+00		1.15E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Table C-5-56. Leachate Concer
Sample ID
Date Exported
Database Name
LeachXS Version

2.8	9.29E-02	S	2.66E-02	S	1.86E-02	S
3	8.87E-02	S	2.60E-02	S	1.72E-02	S
3.2	8.50E-02	S	2.55E-02	S	1.53E-02	S
3.4	8.17E-02	S	2.50E-02	S	1.40E-02	S
3.6	7.86E-02	S	2.45E-02	S	1.28E-02	S
3.8	7.59E-02	S	2.41E-02	S	1.19E-02	S
4	7.33E-02	S	2.37E-02	S	1.10E-02	S
4.2	7.10E-02	S	2.33E-02	S	1.03E-02	S
4.4	6.89E-02	S	2.29E-02	S	9.73E-03	S
4.6	6.69E-02	S	2.26E-02	S	9.23E-03	S
4.8	6.50E-02	S	2.23E-02	S	8.78E-03	S
5	6.33E-02	S	2.20E-02	S	8.36E-03	S
5.2	6.17E-02	S	2.17E-02	S	7.98E-03	S
5.4	6.01E-02	S	2.14E-02	S	7.64E-03	S
5.6	5.85E-02	S	2.11E-02	S	7.31E-03	S
5.8	5.67E-02	S	2.09E-02	S	7.02E-03	S
6	5.50E-02	S	2.06E-02	S	6.74E-03	S
6.2	5.34E-02	S	2.04E-02	S	6.48E-03	S
6.4	5.20E-02	S	2.02E-02	S	6.24E-03	S
6.6	5.11E-02	S	1.91E-02	S	8.11E-03	S
6.8	5.01E-02	S	1.80E-02	S	1.15E-02	S
7	4.97E-02	S	1.70E-02	S	1.21E-02	S
7.2	4.06E-02	S	1.11E-02	S	1.45E-02	S
7.4	3.47E-02	S	1.10E-02	S	1.99E-02	S
7.6	2.56E-02	S	8.70E-03	S	2.99E-02	S
7.8	1.90E-02	S	6.94E-03	S	4.45E-02	S
8	1.42E-02	S	5.57E-03	S	5.38E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-56. Leachate Concentrations for Sludge Scrubber, Waste ID BGD Med

Table C-5-56. Leachate Concer
Sample ID
Date Exported
Database Name
LeachXS Version

8.2	1.10E-02	S	4.81E-03	S	5.74E-02	S
8.4	8.70E-03	S	4.34E-03	S	6.12E-02	S
8.6	8.45E-03	S	4.24E-03	S	6.21E-02	S
8.8	1.06E-02	S	4.68E-03	S	5.79E-02	S
9	1.26E-02	S	5.06E-03	S	5.40E-02	S
9.2	1.10E-02	S	4.76E-03	S	5.14E-02	S
9.4	9.55E-03	S	4.48E-03	S	5.91E-02	S
9.6	8.36E-03	S	4.22E-03	S	6.58E-02	S
9.8	7.33E-03	S	3.99E-03	S	6.06E-02	S
10	6.45E-03	S	3.77E-03	S	5.60E-02	S
10.2	5.17E-03	S	3.43E-03	S	5.18E-02	S
10.4	3.91E-03	S	3.03E-03	S	5.18E-02	S
10.6	2.97E-03	S	2.68E-03	S	5.32E-02	S
10.8	2.60E-03	S	2.53E-03	S	5.47E-02	S
11	2.60E-03	S	2.53E-03	S	5.61E-02	S
11.2	2.60E-03	S	2.53E-03	S	5.76E-02	S
11.4	2.60E-03	S	2.53E-03	S	5.91E-02	S
11.6	2.60E-03	S	2.72E-03	S	6.15E-02	S
11.8	2.60E-03	S	3.42E-03	S	6.58E-02	S
12	2.60E-03	S	4.27E-03	S	7.04E-02	S
12.2	2.60E-03	S	5.32E-03	S	7.52E-02	S
12.4	2.60E-03	S	6.77E-03	S	8.02E-02	S
12.6	2.60E-03	S	8.62E-03	S	8.74E-02	S
12.8	2.60E-03	S	1.09E-02	S	9.38E-02	S
13	2.60E-03	S	1.38E-02	S	9.94E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	8.87E-01		2.60E-01		1.03E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID	CGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	2.17E-02	S	6.74E+00	S	7.46E-04	S	3.02E-02	S
3	1.57E-02	S	6.76E+00	S	7.46E-04	S	2.83E-02	S
3.2	1.27E-02	S	6.77E+00	S	7.46E-04	S	2.66E-02	S
3.4	1.05E-02	S	6.78E+00	S	7.46E-04	S	2.52E-02	S
3.6	8.67E-03	S	6.79E+00	S	7.46E-04	S	2.39E-02	S
3.8	7.26E-03	S	6.80E+00	S	7.46E-04	S	2.27E-02	S
4	6.14E-03	S	6.81E+00	S	7.46E-04	S	2.17E-02	S
4.2	5.23E-03	S	6.82E+00	S	7.46E-04	S	2.08E-02	S
4.4	4.49E-03	S	6.83E+00	S	7.46E-04	S	2.00E-02	S
4.6	3.72E-03	S	6.84E+00	S	7.46E-04	S	1.92E-02	S
4.8	3.20E-03	S	6.82E+00	S	7.46E-04	S	1.80E-02	S
5	3.20E-03	S	6.71E+00	S	7.46E-04	S	1.57E-02	S
5.2	3.20E-03	S	6.63E+00	S	7.46E-04	S	1.22E-02	S
5.4	3.20E-03	S	6.54E+00	S	7.46E-04	S	9.57E-03	S
5.6	3.20E-03	S	6.46E+00	S	7.46E-04	S	7.58E-03	S
5.8	3.20E-03	S	6.38E+00	S	7.46E-04	S	6.55E-03	S
6	3.20E-03	S	6.33E+00	S	7.46E-04	S	5.75E-03	S
6.2	3.20E-03	S	6.28E+00	S	7.46E-04	S	4.89E-03	S
6.4	3.20E-03	S	6.27E+00	S	7.46E-04	S	3.62E-03	S
6.6	3.20E-03	S	6.29E+00	S	7.46E-04	S	2.48E-03	S
6.8	3.20E-03	S	5.93E+00	S	7.46E-04	S	2.06E-03	S
7	3.20E-03	S	5.66E+00	S	7.46E-04	S	2.06E-03	S
7.2	3.20E-03	S	5.52E+00	S	7.46E-04	S	2.06E-03	S
7.4	3.20E-03	S	5.38E+00	S	7.46E-04	S	2.06E-03	S
7.6	3.20E-03	S	5.38E+00	S	7.46E-04	S	2.06E-03	S
7.8	3.20E-03	S	5.45E+00	S	7.46E-04	S	2.06E-03	S
8	3.20E-03	S	5.51E+00	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID	CGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	3.20E-03	S	5.57E+00	S	7.46E-04	S	2.06E-03	S
8.4	3.20E-03	S	5.63E+00	S	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	5.69E+00	S	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	5.67E+00	S	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	5.47E+00	S	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	5.52E+00	S	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	5.46E+00	S	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	5.37E+00	S	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	5.31E+00	S	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	5.32E+00	S	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	5.33E+00	S	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	5.35E+00	S	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	5.28E+00	S	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	5.18E+00	S	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	5.08E+00	S	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	4.91E+00	S	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	4.71E+00	S	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	4.52E+00	S	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	4.34E+00	S	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	4.19E+00	S	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	4.09E+00	S	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	4.00E+00	S	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	3.91E+00	S	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	3.82E+00	S	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	3.74E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	1.57E-01		6.84E+01		8.02E-03		2.83E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.03E-01	S	4.09E-05	S	1.97E-02	S	1.18E-02	S
3	7.64E-02	S	3.98E-05	S	1.22E-02	S	9.86E-03	S
3.2	5.63E-02	S	3.98E-05	S	9.47E-03	S	8.33E-03	S
3.4	4.23E-02	S	3.98E-05	S	8.20E-03	S	7.12E-03	S
3.6	3.27E-02	S	3.97E-05	S	7.16E-03	S	6.14E-03	S
3.8	2.62E-02	S	3.97E-05	S	6.30E-03	S	5.33E-03	S
4	2.06E-02	S	3.96E-05	S	5.58E-03	S	4.67E-03	S
4.2	1.60E-02	S	3.96E-05	S	4.99E-03	S	4.09E-03	S
4.4	1.26E-02	S	3.96E-05	S	4.58E-03	S	3.50E-03	S
4.6	1.01E-02	S	3.96E-05	S	4.23E-03	S	3.04E-03	S
4.8	8.40E-03	S	3.95E-05	S	3.80E-03	S	2.78E-03	S
5	7.55E-03	S	3.84E-05	S	3.80E-03	S	2.78E-03	S
5.2	6.40E-03	S	3.65E-05	S	3.80E-03	S	2.78E-03	S
5.4	5.59E-03	S	3.49E-05	S	3.80E-03	S	2.78E-03	S
5.6	4.99E-03	S	3.33E-05	S	3.80E-03	S	2.78E-03	S
5.8	4.61E-03	S	3.18E-05	S	3.80E-03	S	2.78E-03	S
6	3.81E-03	S	3.03E-05	S	3.80E-03	S	2.78E-03	S
6.2	4.08E-03	S	2.88E-05	S	3.80E-03	S	2.78E-03	S
6.4	4.66E-03	S	2.99E-05	S	4.70E-03	S	2.78E-03	S
6.6	5.09E-03	S	3.12E-05	S	6.55E-03	S	2.78E-03	S
6.8	4.78E-03	S	3.25E-05	S	8.41E-03	S	2.78E-03	S
7	4.85E-03	S	3.35E-05	S	9.96E-03	S	2.78E-03	S
7.2	3.16E-03	S	3.46E-05	S	1.07E-02	S	2.78E-03	S
7.4	2.08E-03	S	3.57E-05	S	1.07E-02	S	2.78E-03	S
7.6	2.18E-03	S	3.40E-05	S	1.15E-02	S	2.78E-03	S
7.8	2.59E-03	S	3.17E-05	S	1.24E-02	S	2.78E-03	S
8	2.94E-03	S	2.96E-05	S	1.33E-02	S	2.78E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	3.10E-03	S	2.76E-05	S	1.42E-02	S	2.78E-03	S
8.4	3.49E-03	S	2.59E-05	S	1.52E-02	S	2.78E-03	S
8.6	3.92E-03	S	2.43E-05	S	1.62E-02	S	2.78E-03	S
8.8	4.38E-03	S	2.28E-05	S	1.73E-02	S	2.78E-03	S
9	4.82E-03	S	2.19E-05	S	1.85E-02	S	2.78E-03	S
9.2	4.43E-03	S	2.72E-05	S	1.95E-02	S	2.78E-03	S
9.4	4.09E-03	S	3.04E-05	S	2.01E-02	S	3.40E-03	S
9.6	3.66E-03	S	3.27E-05	S	2.08E-02	S	4.40E-03	S
9.8	3.28E-03	S	3.52E-05	S	2.14E-02	S	5.67E-03	S
10	2.95E-03	S	3.77E-05	S	2.20E-02	S	7.27E-03	S
10.2	2.66E-03	S	4.04E-05	S	2.26E-02	S	9.27E-03	S
10.4	2.40E-03	S	4.32E-05	S	2.33E-02	S	1.18E-02	S
10.6	2.17E-03	S	4.62E-05	S	2.39E-02	S	1.49E-02	S
10.8	1.96E-03	S	4.93E-05	S	2.46E-02	S	1.87E-02	S
11	2.14E-03	S	5.19E-05	S	2.71E-02	S	1.55E-02	S
11.2	2.40E-03	S	5.44E-05	S	2.98E-02	S	1.09E-02	S
11.4	2.69E-03	S	5.69E-05	S	3.30E-02	S	7.87E-03	S
11.6	3.01E-03	S	6.44E-05	S	3.67E-02	S	5.88E-03	S
11.8	3.36E-03	S	7.51E-05	S	4.06E-02	S	4.41E-03	S
12	3.74E-03	S	8.74E-05	S	4.49E-02	S	3.33E-03	S
12.2	4.16E-03	S	9.70E-05	S	4.92E-02	S	2.52E-03	S
12.4	4.61E-03	S	9.70E-05	S	5.39E-02	S	1.91E-03	S
12.6	5.11E-03	S	9.70E-05	S	5.89E-02	S	1.44E-03	S
12.8	5.65E-03	S	9.70E-05	S	6.43E-02	S	1.09E-03	S
13	6.24E-03	S	9.70E-05	S	7.02E-02	S	8.25E-04	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	7.64E-01		1.04E-03		6.92E-01		1.91E-01	

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Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	2.36E-01	S	2.53E-03	S	3.28E-02	S
3	1.88E-01	S	2.53E-03	S	2.47E-02	S
3.2	1.65E-01	S	2.53E-03	S	1.89E-02	S
3.4	1.46E-01	S	2.53E-03	S	1.47E-02	S
3.6	1.31E-01	S	2.53E-03	S	1.16E-02	S
3.8	1.17E-01	S	2.53E-03	S	9.28E-03	S
4	1.06E-01	S	2.53E-03	S	7.51E-03	S
4.2	9.51E-02	S	2.53E-03	S	6.14E-03	S
4.4	8.08E-02	S	2.53E-03	S	5.06E-03	S
4.6	6.92E-02	S	2.53E-03	S	4.21E-03	S
4.8	6.92E-02	S	2.53E-03	S	3.78E-03	S
5	7.97E-02	S	2.53E-03	S	3.99E-03	S
5.2	9.53E-02	S	2.53E-03	S	4.22E-03	S
5.4	1.10E-01	S	2.53E-03	S	4.44E-03	S
5.6	1.25E-01	S	2.53E-03	S	4.67E-03	S
5.8	1.42E-01	S	2.53E-03	S	4.90E-03	S
6	1.45E-01	S	2.53E-03	S	5.05E-03	S
6.2	1.45E-01	S	2.53E-03	S	5.06E-03	S
6.4	1.17E-01	S	2.53E-03	S	5.02E-03	S
6.6	9.40E-02	S	2.53E-03	S	5.01E-03	S
6.8	5.10E-02	S	2.53E-03	S	4.87E-03	S
7	2.73E-02	S	2.53E-03	S	4.72E-03	S
7.2	1.49E-02	S	2.53E-03	S	4.58E-03	S
7.4	8.30E-03	S	2.53E-03	S	4.45E-03	S
7.6	7.74E-03	S	2.53E-03	S	4.75E-03	S
7.8	7.80E-03	S	2.53E-03	S	5.09E-03	S
8	7.85E-03	S	2.53E-03	S	5.45E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-57. Leachate Concentrations for Sludge Scrubber, Waste ID CGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	7.91E-03	S	2.53E-03	S	5.67E-03	S
8.4	7.96E-03	S	2.53E-03	S	5.82E-03	S
8.6	8.01E-03	S	2.53E-03	S	5.98E-03	S
8.8	8.32E-03	S	2.53E-03	S	6.13E-03	S
9	9.13E-03	S	2.53E-03	S	6.27E-03	S
9.2	1.00E-02	S	2.53E-03	S	5.76E-03	S
9.4	1.24E-02	S	2.53E-03	S	5.48E-03	S
9.6	1.54E-02	S	2.53E-03	S	5.71E-03	S
9.8	1.90E-02	S	2.53E-03	S	5.94E-03	S
10	2.34E-02	S	2.53E-03	S	6.17E-03	S
10.2	2.90E-02	S	2.53E-03	S	6.41E-03	S
10.4	3.61E-02	S	2.53E-03	S	6.65E-03	S
10.6	4.47E-02	S	2.53E-03	S	6.90E-03	S
10.8	5.51E-02	S	2.53E-03	S	7.15E-03	S
11	5.96E-02	S	2.53E-03	S	6.88E-03	S
11.2	5.83E-02	S	2.53E-03	S	6.37E-03	S
11.4	5.43E-02	S	2.53E-03	S	5.90E-03	S
11.6	5.06E-02	S	2.53E-03	S	5.47E-03	S
11.8	4.94E-02	S	2.53E-03	S	5.08E-03	S
12	4.91E-02	S	2.53E-03	S	4.73E-03	S
12.2	4.88E-02	S	2.53E-03	S	4.40E-03	S
12.4	4.85E-02	S	2.53E-03	S	4.10E-03	S
12.6	4.82E-02	S	2.53E-03	S	3.83E-03	S
12.8	4.79E-02	S	2.53E-03	S	3.58E-03	S
13	4.76E-02	S	2.53E-03	S	3.35E-03	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.88E+00		2.72E-02		2.47E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID	DGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	3.27E-01	S	1.38E+01	S	4.18E-03	S	5.99E-02	S
3	2.44E-01	S	1.20E+01	S	1.73E-03	S	2.69E-02	S
3.2	1.31E-01	S	1.05E+01	S	7.46E-04	S	1.18E-02	S
3.4	9.28E-02	S	1.04E+01	S	7.46E-04	S	1.07E-02	S
3.6	6.72E-02	S	1.03E+01	S	7.46E-04	S	9.77E-03	S
3.8	5.00E-02	S	1.03E+01	S	7.46E-04	S	9.00E-03	S
4	4.38E-02	S	1.02E+01	S	7.46E-04	S	8.32E-03	S
4.2	3.87E-02	S	1.01E+01	S	7.46E-04	S	7.73E-03	S
4.4	3.43E-02	S	1.01E+01	S	7.46E-04	S	7.20E-03	S
4.6	3.06E-02	S	1.00E+01	S	7.46E-04	S	6.73E-03	S
4.8	2.75E-02	S	9.98E+00	S	7.46E-04	S	6.31E-03	S
5	2.67E-02	S	9.98E+00	S	7.46E-04	S	5.93E-03	S
5.2	2.60E-02	S	1.00E+01	S	7.46E-04	S	5.30E-03	S
5.4	2.54E-02	S	1.00E+01	S	7.46E-04	S	4.41E-03	S
5.6	2.48E-02	S	1.01E+01	S	7.46E-04	S	3.69E-03	S
5.8	2.34E-02	S	1.02E+01	S	7.46E-04	S	3.11E-03	S
6	2.12E-02	S	1.03E+01	S	7.46E-04	S	2.63E-03	S
6.2	1.92E-02	S	1.03E+01	S	7.46E-04	S	2.32E-03	S
6.4	1.75E-02	S	1.02E+01	S	7.46E-04	S	2.15E-03	S
6.6	1.60E-02	S	1.00E+01	S	7.46E-04	S	2.06E-03	S
6.8	1.45E-02	S	9.76E+00	S	7.46E-04	S	2.06E-03	S
7	1.32E-02	S	9.51E+00	S	7.46E-04	S	2.06E-03	S
7.2	1.19E-02	S	9.22E+00	S	7.46E-04	S	2.06E-03	S
7.4	1.09E-02	S	8.56E+00	S	7.46E-04	S	2.06E-03	S
7.6	9.93E-03	S	7.97E+00	S	7.46E-04	S	2.06E-03	S
7.8	9.04E-03	S	7.28E+00	S	7.46E-04	S	2.06E-03	S
8	8.25E-03	S	6.26E+00	S	7.46E-04	S	2.06E-03	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID	DGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	5.91E-03	S	5.41E+00	W	7.46E-04	S	2.06E-03	S
8.4	3.94E-03	S	4.79E+00	W	7.46E-04	S	2.06E-03	S
8.6	3.20E-03	S	4.34E+00	W	7.46E-04	S	2.06E-03	S
8.8	3.20E-03	S	3.92E+00	W	7.46E-04	S	2.06E-03	S
9	3.20E-03	S	3.55E+00	W	7.46E-04	S	2.06E-03	S
9.2	3.20E-03	S	3.53E+00	W	7.46E-04	S	2.06E-03	S
9.4	3.20E-03	S	3.42E+00	W	7.46E-04	S	2.06E-03	S
9.6	3.20E-03	S	3.51E+00	W	7.46E-04	S	2.06E-03	S
9.8	3.20E-03	S	3.62E+00	W	7.46E-04	S	2.06E-03	S
10	3.20E-03	S	3.76E+00	W	7.46E-04	S	2.06E-03	S
10.2	3.20E-03	S	3.90E+00	W	7.46E-04	S	2.06E-03	S
10.4	3.20E-03	S	4.06E+00	W	7.46E-04	S	2.06E-03	S
10.6	3.20E-03	S	4.20E+00	W	7.46E-04	S	2.06E-03	S
10.8	3.20E-03	S	4.30E+00	W	7.46E-04	S	2.06E-03	S
11	3.20E-03	S	4.39E+00	W	7.46E-04	S	2.06E-03	S
11.2	3.20E-03	S	4.49E+00	W	7.46E-04	S	2.06E-03	S
11.4	3.20E-03	S	4.62E+00	W	7.46E-04	S	2.06E-03	S
11.6	3.20E-03	S	5.00E+00	W	7.46E-04	S	2.06E-03	S
11.8	3.20E-03	S	5.48E+00	W	7.46E-04	S	2.06E-03	S
12	3.20E-03	S	6.00E+00	W	7.46E-04	S	2.06E-03	S
12.2	3.20E-03	S	6.47E+00	W	7.46E-04	S	2.06E-03	S
12.4	3.20E-03	S	7.15E+00	W	7.46E-04	S	2.06E-03	S
12.6	3.20E-03	S	7.82E+00	W	7.46E-04	S	2.06E-03	S
12.8	3.20E-03	S	8.52E+00	W	7.46E-04	S	2.06E-03	S
13	3.20E-03	S	9.26E+00	W	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Availability (mg/kg)	2.44E+00		1.20E+02		1.73E-02		2.69E-01	

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Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	1.85E-02	S	1.14E-02	S	2.27E-01	S	6.32E-03	S
3	1.63E-02	S	1.10E-02	S	2.12E-01	S	7.69E-03	S
3.2	1.26E-02	S	1.02E-02	S	2.11E-01	S	8.57E-03	S
3.4	9.85E-03	S	9.31E-03	S	2.21E-01	S	8.62E-03	S
3.6	7.82E-03	S	8.54E-03	S	2.23E-01	S	8.66E-03	S
3.8	6.29E-03	S	7.86E-03	S	2.28E-01	S	8.72E-03	S
4	5.12E-03	S	7.27E-03	S	2.33E-01	S	8.77E-03	S
4.2	4.21E-03	S	6.70E-03	S	2.39E-01	S	8.82E-03	S
4.4	3.49E-03	S	6.06E-03	S	2.44E-01	S	8.91E-03	S
4.6	2.92E-03	S	5.51E-03	S	2.49E-01	S	8.98E-03	S
4.8	2.46E-03	S	5.03E-03	S	2.54E-01	S	9.06E-03	S
5	2.09E-03	S	4.60E-03	S	2.58E-01	S	9.13E-03	S
5.2	1.90E-03	S	4.23E-03	S	2.66E-01	S	9.20E-03	S
5.4	1.90E-03	S	3.90E-03	S	2.78E-01	S	9.27E-03	S
5.6	1.90E-03	S	3.61E-03	S	2.90E-01	S	9.34E-03	S
5.8	1.90E-03	S	3.35E-03	S	3.01E-01	S	9.41E-03	S
6	1.90E-03	S	3.11E-03	S	3.05E-01	S	9.58E-03	S
6.2	1.90E-03	S	2.90E-03	S	3.09E-01	S	9.78E-03	S
6.4	1.90E-03	S	2.71E-03	S	3.13E-01	S	9.85E-03	S
6.6	1.90E-03	S	2.28E-03	S	3.29E-01	S	1.03E-02	S
6.8	1.90E-03	S	1.67E-03	S	3.45E-01	S	1.07E-02	S
7	1.90E-03	S	7.67E-04	S	3.60E-01	S	1.15E-02	S
7.2	1.90E-03	S	3.60E-04	S	3.65E-01	S	1.22E-02	S
7.4	1.90E-03	S	1.73E-04	S	3.58E-01	S	1.24E-02	S
7.6	1.90E-03	S	1.25E-04	S	3.64E-01	S	1.23E-02	S
7.8	1.90E-03	S	9.44E-05	S	3.57E-01	S	1.24E-02	S
8	1.90E-03	S	7.14E-05	S	3.46E-01	S	1.18E-02	S

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Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	1.90E-03	S	5.79E-05	S	3.36E-01	S	1.14E-02	S
8.4	1.90E-03	S	4.47E-05	S	3.32E-01	S	1.11E-02	S
8.6	2.15E-03	S	3.75E-05	S	2.84E-01	S	9.83E-03	S
8.8	2.78E-03	S	4.16E-05	S	2.00E-01	S	7.57E-03	S
9	3.57E-03	S	4.49E-05	S	1.46E-01	S	5.60E-03	S
9.2	3.99E-03	S	4.12E-05	S	1.24E-01	S	3.47E-03	S
9.4	4.25E-03	S	3.93E-05	S	1.14E-01	S	2.78E-03	S
9.6	4.51E-03	S	3.88E-05	S	1.06E-01	S	2.78E-03	S
9.8	4.78E-03	S	3.84E-05	S	9.76E-02	S	2.78E-03	S
10	5.07E-03	S	3.79E-05	S	9.04E-02	S	2.78E-03	S
10.2	5.34E-03	S	3.75E-05	S	8.38E-02	S	2.78E-03	S
10.4	4.20E-03	S	3.71E-05	S	7.78E-02	S	2.78E-03	S
10.6	3.31E-03	S	3.89E-05	S	7.24E-02	S	2.78E-03	S
10.8	2.62E-03	S	4.04E-05	S	6.74E-02	S	2.78E-03	S
11	2.09E-03	S	3.98E-05	S	6.25E-02	S	2.78E-03	S
11.2	1.90E-03	S	3.84E-05	S	6.05E-02	S	2.78E-03	S
11.4	1.90E-03	S	4.16E-05	S	6.01E-02	S	2.78E-03	S
11.6	1.90E-03	S	4.24E-05	S	6.09E-02	S	2.78E-03	S
11.8	1.90E-03	S	4.12E-05	S	6.30E-02	S	2.78E-03	S
12	1.90E-03	S	4.77E-05	S	6.49E-02	S	2.78E-03	S
12.2	1.90E-03	S	4.55E-05	S	6.63E-02	S	2.78E-03	S
12.4	1.90E-03	S	4.35E-05	S	6.86E-02	S	2.78E-03	S
12.6	1.90E-03	S	4.16E-05	S	7.12E-02	S	2.78E-03	S
12.8	1.90E-03	S	3.99E-05	S	7.38E-02	S	2.78E-03	S
13	1.90E-03	S	3.82E-05	S	7.64E-02	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Availability (mg/kg)	1.63E-01		1.10E-01		3.65E+00		1.24E-01	

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Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.62E-01	S	5.06E-02	S	2.32E-01	S
3	1.58E-01	S	3.52E-02	S	1.42E-01	S
3.2	1.45E-01	S	2.45E-02	S	7.87E-02	S
3.4	1.35E-01	S	2.36E-02	S	5.98E-02	S
3.6	1.27E-01	S	2.30E-02	S	5.08E-02	S
3.8	1.19E-01	S	2.24E-02	S	4.56E-02	S
4	1.13E-01	S	2.19E-02	S	4.11E-02	S
4.2	1.06E-01	S	2.15E-02	S	3.72E-02	S
4.4	9.63E-02	S	2.10E-02	S	3.39E-02	S
4.6	8.81E-02	S	2.06E-02	S	3.10E-02	S
4.8	8.29E-02	S	2.02E-02	S	2.84E-02	S
5	8.03E-02	S	1.99E-02	S	2.62E-02	S
5.2	7.54E-02	S	1.93E-02	S	2.58E-02	S
5.4	6.77E-02	S	1.85E-02	S	2.61E-02	S
5.6	6.11E-02	S	1.78E-02	S	2.63E-02	S
5.8	5.53E-02	S	1.71E-02	S	2.63E-02	S
6	5.17E-02	S	1.65E-02	S	2.43E-02	S
6.2	4.84E-02	S	1.60E-02	S	2.31E-02	S
6.4	4.54E-02	S	1.57E-02	S	2.21E-02	S
6.6	4.05E-02	S	1.50E-02	S	2.05E-02	S
6.8	3.37E-02	S	1.38E-02	S	2.08E-02	S
7	2.81E-02	S	1.26E-02	S	2.05E-02	S
7.2	2.54E-02	S	1.17E-02	S	1.79E-02	S
7.4	2.31E-02	S	1.12E-02	S	1.58E-02	S
7.6	2.23E-02	S	1.08E-02	S	1.40E-02	S
7.8	2.17E-02	S	1.02E-02	S	1.25E-02	S
8	2.18E-02	S	9.45E-03	S	1.12E-02	S

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Table C-5-58. Leachate Concentrations for Sludge Scrubber, Waste ID DGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	2.19E-02	S	8.91E-03	S	1.00E-02	S
8.4	2.20E-02	S	8.43E-03	S	8.99E-03	S
8.6	2.24E-02	S	6.72E-03	S	8.54E-03	S
8.8	2.28E-02	S	4.25E-03	S	8.77E-03	S
9	2.24E-02	S	2.81E-03	S	8.62E-03	S
9.2	2.23E-02	S	2.53E-03	S	8.84E-03	S
9.4	2.24E-02	S	2.53E-03	S	9.31E-03	S
9.6	2.24E-02	S	2.53E-03	S	9.78E-03	S
9.8	2.24E-02	S	2.53E-03	S	1.02E-02	S
10	2.24E-02	S	2.53E-03	S	1.05E-02	S
10.2	2.24E-02	S	2.53E-03	S	1.08E-02	S
10.4	2.24E-02	S	2.53E-03	S	1.12E-02	S
10.6	2.24E-02	S	2.53E-03	S	1.15E-02	S
10.8	2.24E-02	S	2.53E-03	S	1.18E-02	S
11	2.24E-02	S	2.53E-03	S	1.22E-02	S
11.2	2.23E-02	S	2.53E-03	S	1.26E-02	S
11.4	2.21E-02	S	2.53E-03	S	1.32E-02	S
11.6	2.20E-02	S	2.90E-03	S	1.37E-02	S
11.8	2.39E-02	S	3.70E-03	S	1.34E-02	S
12	2.38E-02	S	4.81E-03	S	1.30E-02	S
12.2	2.38E-02	S	5.94E-03	S	1.27E-02	S
12.4	2.50E-02	S	7.45E-03	S	1.24E-02	S
12.6	2.61E-02	S	9.34E-03	S	1.21E-02	S
12.8	2.73E-02	S	1.17E-02	S	1.18E-02	S
13	2.86E-02	S	1.45E-02	S	1.16E-02	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Availability (mg/kg)	1.58E+00		3.52E-01		1.42E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID	KGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	9.12E-03	S	1.19E+01	W	4.42E-03	S	2.11E-01	S
3	3.19E-02	S	1.59E+01	W	4.68E-03	S	2.95E-01	S
3.2	1.21E-01	S	2.08E+01	W	4.93E-03	S	4.03E-01	S
3.4	1.86E-01	S	2.31E+01	W	4.93E-03	S	4.42E-01	S
3.6	1.46E-01	S	2.26E+01	W	4.75E-03	S	4.10E-01	S
3.8	1.16E-01	S	2.21E+01	W	4.58E-03	S	3.83E-01	S
4	9.52E-02	S	2.18E+01	W	4.43E-03	S	3.62E-01	S
4.2	7.92E-02	S	2.15E+01	W	4.30E-03	S	3.44E-01	S
4.4	7.28E-02	S	2.13E+01	W	4.23E-03	S	3.32E-01	S
4.6	6.82E-02	S	2.11E+01	W	4.16E-03	S	3.22E-01	S
4.8	6.40E-02	S	2.10E+01	W	4.10E-03	S	3.13E-01	S
5	6.03E-02	S	2.09E+01	W	4.05E-03	S	3.04E-01	S
5.2	5.69E-02	S	2.07E+01	W	4.00E-03	S	2.96E-01	S
5.4	5.31E-02	S	2.05E+01	W	3.87E-03	S	2.78E-01	S
5.6	4.95E-02	S	2.02E+01	W	3.74E-03	S	2.60E-01	S
5.8	4.39E-02	S	1.99E+01	W	3.58E-03	S	2.34E-01	S
6	3.76E-02	S	1.95E+01	S	3.40E-03	S	2.05E-01	S
6.2	2.99E-02	S	1.88E+01	S	3.24E-03	S	1.61E-01	S
6.4	2.37E-02	S	1.80E+01	S	3.09E-03	S	1.26E-01	S
6.6	1.89E-02	S	1.73E+01	S	2.95E-03	S	9.86E-02	S
6.8	1.66E-02	S	1.67E+01	S	2.80E-03	S	7.72E-02	S
7	1.51E-02	S	1.60E+01	S	2.66E-03	S	6.07E-02	S
7.2	1.54E-02	S	1.53E+01	S	2.57E-03	S	4.44E-02	S
7.4	1.66E-02	S	1.45E+01	S	2.50E-03	S	3.14E-02	S
7.6	1.84E-02	S	1.36E+01	S	2.45E-03	S	2.22E-02	S
7.8	2.08E-02	S	1.27E+01	S	2.41E-03	S	1.59E-02	S
8	2.28E-02	S	1.12E+01	S	2.25E-03	S	1.10E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID	KGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	2.51E-02	S	9.53E+00	S	1.89E-03	S	7.60E-03	S
8.4	2.90E-02	S	7.85E+00	S	1.45E-03	S	5.26E-03	S
8.6	3.35E-02	S	6.49E+00	S	1.13E-03	S	3.67E-03	S
8.8	3.86E-02	S	5.40E+00	S	8.78E-04	S	2.59E-03	S
9	4.01E-02	S	4.61E+00	S	7.57E-04	S	2.10E-03	S
9.2	3.61E-02	S	4.02E+00	S	7.46E-04	S	2.06E-03	S
9.4	3.20E-02	S	3.52E+00	S	7.46E-04	S	2.06E-03	S
9.6	2.85E-02	S	3.09E+00	S	7.46E-04	S	2.06E-03	S
9.8	2.59E-02	S	2.76E+00	S	7.46E-04	S	2.06E-03	S
10	2.42E-02	S	2.54E+00	S	7.46E-04	S	2.06E-03	S
10.2	2.29E-02	S	2.37E+00	S	7.46E-04	S	2.06E-03	S
10.4	2.17E-02	S	2.21E+00	S	7.46E-04	S	2.06E-03	S
10.6	2.06E-02	S	2.07E+00	S	7.46E-04	S	2.06E-03	S
10.8	1.95E-02	S	1.94E+00	S	7.46E-04	S	2.06E-03	S
11	1.91E-02	S	1.83E+00	S	7.46E-04	S	2.06E-03	S
11.2	2.71E-02	S	1.87E+00	S	7.46E-04	S	2.06E-03	S
11.4	3.82E-02	S	1.91E+00	S	7.46E-04	S	2.06E-03	S
11.6	5.35E-02	S	1.95E+00	S	7.46E-04	S	2.06E-03	S
11.8	7.45E-02	S	1.99E+00	S	7.46E-04	S	2.06E-03	S
12	1.03E-01	S	2.03E+00	S	7.46E-04	S	2.06E-03	S
12.2	1.42E-01	S	2.08E+00	S	7.46E-04	S	2.06E-03	S
12.4	1.95E-01	S	2.12E+00	S	7.46E-04	S	2.06E-03	S
12.6	2.66E-01	S	2.16E+00	S	7.46E-04	S	2.06E-03	S
12.8	2.81E-01	S	2.20E+00	S	7.46E-04	S	2.06E-03	S
13	2.81E-01	S	2.24E+00	S	7.46E-04	S	2.06E-03	S
Detection Limit (min, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	
Detection Limit (max, mg/L)	6.40E-04		6.50E-04		1.70E-04		4.10E-04	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID	KGD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:45 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
Availability (mg/kg)	3.09E+00		2.31E+02		4.93E-02		4.42E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.56E-03	S	1.08E-04	S	6.15E-01	S	9.70E-03	W
3	2.42E-03	S	4.54E-04	S	6.44E-01	S	9.73E-03	W
3.2	1.04E-02	S	2.44E-03	S	5.03E-01	S	9.51E-03	W
3.4	2.02E-02	S	4.04E-03	S	4.00E-01	S	9.08E-03	W
3.6	1.77E-02	S	2.78E-03	S	4.46E-01	S	9.12E-03	W
3.8	1.56E-02	S	1.95E-03	S	4.95E-01	S	9.15E-03	W
4	1.44E-02	S	1.44E-03	S	5.34E-01	S	9.12E-03	W
4.2	1.34E-02	S	1.08E-03	S	5.73E-01	S	9.08E-03	W
4.4	1.36E-02	S	9.44E-04	S	5.91E-01	S	9.05E-03	W
4.6	1.41E-02	S	8.54E-04	S	6.06E-01	S	9.02E-03	W
4.8	1.46E-02	S	7.77E-04	S	6.20E-01	S	9.00E-03	W
5	1.51E-02	S	7.09E-04	S	6.34E-01	S	8.98E-03	W
5.2	1.55E-02	S	6.50E-04	S	6.48E-01	S	8.96E-03	W
5.4	1.53E-02	S	5.73E-04	S	6.72E-01	S	9.05E-03	W
5.6	1.50E-02	S	5.02E-04	S	6.99E-01	S	9.17E-03	W
5.8	1.42E-02	S	4.29E-04	S	7.32E-01	S	9.26E-03	W
6	1.31E-02	S	3.62E-04	S	7.69E-01	S	9.33E-03	W
6.2	1.34E-02	S	2.85E-04	S	8.25E-01	S	9.32E-03	W
6.4	1.38E-02	S	2.24E-04	S	8.87E-01	S	9.30E-03	W
6.6	1.43E-02	S	1.77E-04	S	9.51E-01	S	9.28E-03	W
6.8	1.32E-02	S	1.75E-04	S	9.89E-01	S	9.35E-03	W
7	1.19E-02	S	1.86E-04	S	1.02E+00	S	9.43E-03	W
7.2	1.06E-02	S	2.23E-04	S	1.03E+00	S	9.65E-03	W
7.4	9.52E-03	S	2.82E-04	S	1.05E+00	S	9.95E-03	W
7.6	8.45E-03	S	3.92E-04	S	1.05E+00	S	1.02E-02	W
7.8	7.46E-03	S	5.77E-04	S	1.04E+00	S	1.04E-02	W
8	6.68E-03	S	1.00E-03	S	1.01E+00	S	1.04E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	6.62E-03	S	9.80E-04	S	9.26E-01	S	9.57E-03	S
8.4	6.52E-03	S	4.75E-04	S	8.09E-01	S	7.46E-03	S
8.6	6.42E-03	S	2.34E-04	S	7.08E-01	S	5.86E-03	S
8.8	6.32E-03	S	1.17E-04	S	6.22E-01	S	4.62E-03	S
9	5.68E-03	S	7.55E-05	S	5.40E-01	S	4.11E-03	S
9.2	4.68E-03	S	6.94E-05	S	4.52E-01	S	3.78E-03	S
9.4	3.85E-03	S	6.64E-05	S	3.78E-01	S	3.46E-03	S
9.6	3.18E-03	S	6.36E-05	S	3.17E-01	S	3.18E-03	S
9.8	3.04E-03	S	6.17E-05	S	2.73E-01	S	2.92E-03	S
10	3.55E-03	S	6.11E-05	S	2.44E-01	S	2.78E-03	S
10.2	4.46E-03	S	6.11E-05	S	2.23E-01	S	2.78E-03	S
10.4	5.58E-03	S	6.11E-05	S	2.04E-01	S	2.78E-03	S
10.6	6.96E-03	S	6.11E-05	S	1.87E-01	S	2.78E-03	S
10.8	8.64E-03	S	6.11E-05	S	1.72E-01	S	2.78E-03	S
11	1.06E-02	S	6.05E-05	S	1.60E-01	S	2.78E-03	S
11.2	1.09E-02	S	5.69E-05	S	1.67E-01	S	2.78E-03	S
11.4	1.12E-02	S	5.37E-05	S	1.75E-01	S	2.78E-03	S
11.6	1.16E-02	S	5.07E-05	S	1.82E-01	S	2.78E-03	S
11.8	1.19E-02	S	4.79E-05	S	1.90E-01	S	2.78E-03	S
12	1.22E-02	S	4.53E-05	S	1.98E-01	S	2.78E-03	S
12.2	1.26E-02	S	4.29E-05	S	2.06E-01	S	2.78E-03	S
12.4	1.29E-02	S	4.06E-05	S	2.15E-01	S	2.78E-03	S
12.6	1.32E-02	S	3.85E-05	S	2.24E-01	S	2.78E-03	S
12.8	1.36E-02	S	3.65E-05	S	2.32E-01	S	2.78E-03	S
13	1.39E-02	S	3.47E-05	S	2.42E-01	S	2.78E-03	S
Detection Limit (min, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	
Detection Limit (max, mg/L)	5.00E-04		3.60E-06		7.60E-04		8.00E-05	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
Availability (mg/kg)	2.02E-01		4.04E-02		1.05E+01		1.04E-01	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.86E-01	S	5.13E-02	S	3.15E-03	S
3	2.64E-01	S	8.90E-02	S	2.74E-03	S
3.2	3.66E-01	S	1.49E-01	S	1.52E-02	S
3.4	4.05E-01	S	1.76E-01	S	4.08E-02	S
3.6	3.80E-01	S	1.60E-01	S	2.90E-02	S
3.8	3.57E-01	S	1.47E-01	S	2.10E-02	S
4	3.42E-01	S	1.37E-01	S	1.65E-02	S
4.2	3.29E-01	S	1.29E-01	S	1.31E-02	S
4.4	3.23E-01	S	1.25E-01	S	1.23E-02	S
4.6	3.18E-01	S	1.22E-01	S	1.20E-02	S
4.8	3.14E-01	S	1.20E-01	S	1.16E-02	S
5	3.10E-01	S	1.17E-01	S	1.13E-02	S
5.2	3.06E-01	S	1.15E-01	S	1.09E-02	S
5.4	2.95E-01	S	1.13E-01	S	1.10E-02	S
5.6	2.83E-01	S	1.10E-01	S	1.11E-02	S
5.8	2.67E-01	S	1.07E-01	S	1.11E-02	S
6	2.49E-01	S	1.03E-01	S	1.10E-02	S
6.2	2.26E-01	S	9.55E-02	S	9.98E-03	S
6.4	2.04E-01	S	8.82E-02	S	8.91E-03	S
6.6	1.85E-01	S	8.17E-02	S	7.99E-03	S
6.8	1.74E-01	S	7.69E-02	S	8.27E-03	S
7	1.66E-01	S	7.29E-02	S	8.94E-03	S
7.2	1.63E-01	S	6.91E-02	S	1.05E-02	S
7.4	1.62E-01	S	6.57E-02	S	1.28E-02	S
7.6	1.67E-01	S	6.29E-02	S	1.59E-02	S
7.8	1.78E-01	S	6.06E-02	S	2.01E-02	S
8	1.93E-01	S	5.71E-02	S	2.55E-02	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	1.82E-01	S	5.26E-02	S	3.31E-02	S
8.4	1.47E-01	S	4.88E-02	S	4.67E-02	S
8.6	1.20E-01	S	4.53E-02	S	6.55E-02	S
8.8	9.85E-02	S	4.22E-02	S	9.12E-02	S
9	7.89E-02	S	3.92E-02	S	1.10E-01	S
9.2	5.92E-02	S	3.58E-02	S	1.11E-01	S
9.4	4.44E-02	S	3.27E-02	S	1.09E-01	S
9.6	3.34E-02	S	2.99E-02	S	1.07E-01	S
9.8	2.61E-02	S	2.73E-02	S	1.06E-01	S
10	2.09E-02	S	2.46E-02	S	1.06E-01	S
10.2	1.66E-02	S	2.20E-02	S	1.07E-01	S
10.4	1.32E-02	S	1.97E-02	S	1.08E-01	S
10.6	1.06E-02	S	1.77E-02	S	1.09E-01	S
10.8	8.51E-03	S	1.59E-02	S	1.10E-01	S
11	7.19E-03	S	1.46E-02	S	1.13E-01	S
11.2	9.15E-03	S	1.66E-02	S	1.39E-01	S
11.4	1.16E-02	S	1.88E-02	S	1.71E-01	S
11.6	1.46E-02	S	2.13E-02	S	2.09E-01	S
11.8	1.84E-02	S	2.40E-02	S	2.55E-01	S
12	2.30E-02	S	2.70E-02	S	3.06E-01	S
12.2	2.87E-02	S	3.04E-02	S	3.09E-01	S
12.4	3.56E-02	S	3.41E-02	S	3.09E-01	S
12.6	4.41E-02	S	3.81E-02	S	3.09E-01	S
12.8	5.44E-02	S	4.26E-02	S	3.09E-01	S
13	6.69E-02	S	4.76E-02	S	3.09E-01	S
Detection Limit (min, mg/L)	5.20E-04		5.10E-04		3.10E-04	
Detection Limit (max, mg/L)	5.20E-04		5.10E-04		3.10E-04	

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Table C-5-59. Leachate Concentrations for Sludge Scrubber, Waste ID KGD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
Availability (mg/kg)	4.05E+00		1.76E+00		3.39E+00	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID	ACC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.236743	S	11.02168	W	0.0206406	S	0.154882	S
3	0.175572	S	10.86108	W	0.0194627	S	0.150439	S
3.2	0.13906	S	11.05345	W	0.0188857	S	0.147964	S
3.4	0.133345	S	11.80503	W	0.0186784	S	0.154114	S
3.6	0.1254	S	12.64599	W	0.0188261	S	0.160145	S
3.8	0.119509	S	13.08998	W	0.0187179	S	0.166068	S
4	0.105265	S	12.66932	W	0.0170272	S	0.15849	S
4.2	0.093295	S	12.28284	W	0.0155609	S	0.150311	S
4.4	0.083151	S	11.92532	W	0.0146307	S	0.142906	S
4.6	0.074491	S	11.59343	W	0.0138604	S	0.136172	S
4.8	0.066587	S	11.28433	W	0.0127975	S	0.12988	S
5	0.061732	S	10.95828	W	0.0117489	S	0.123276	S
5.2	0.061144	S	10.55365	W	0.0106683	S	0.116565	S
5.4	0.060483	S	10.17839	W	0.0098592	S	0.110453	S
5.6	0.059818	S	9.841586	W	0.0092419	S	0.104642	S
5.8	0.059183	S	9.989616	W	0.0082156	S	0.09583	S
6	0.058883	S	10.02367	W	0.0069289	S	0.084809	S
6.2	0.058464	S	10.04047	W	0.0058764	S	0.074506	S
6.4	0.057819	S	10.05677	W	0.0050099	S	0.065724	S
6.6	0.057201	S	10.0726	W	0.0042922	S	0.058201	S
6.8	0.056607	S	10.00001	W	0.0036944	S	0.049927	S
7	0.057121	S	9.490108	S	0.0030085	S	0.04454	S
7.2	0.060352	S	9.019494	S	0.0021755	S	0.030743	S
7.4	0.063671	S	8.584173	S	0.0015943	S	0.020168	S
7.6	0.067475	S	8.180647	S	0.0011781	S	0.01338	S
7.8	0.070567	S	7.805848	S	0.0008774	S	0.008972	S
8	0.071574	S	6.974352	S	0.0007464	S	0.006962	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID	ACC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.050594	S	4.245174	S	0.0007464	S	0.004284	S
8.4	0.041896	S	3.126153	S	0.0007464	S	0.004413	S
8.6	0.038118	S	3.035993	S	0.0007464	S	0.002828	S
8.8	0.035765	S	2.970285	S	0.0007464	S	0.002062	S
9	0.034568	S	2.907428	S	0.0007464	S	0.002062	S
9.2	0.033464	S	2.847239	S	0.0007464	S	0.002062	S
9.4	0.032419	S	2.745238	S	0.0007464	S	0.002062	S
9.6	0.031427	S	2.296872	S	0.0007464	S	0.002062	S
9.8	0.030485	S	1.928814	S	0.0007464	S	0.002062	S
10	0.02959	S	1.625461	S	0.0007464	S	0.002062	S
10.2	0.028567	S	1.374467	S	0.0007464	S	0.002062	S
10.4	0.027242	S	1.166021	S	0.0007464	S	0.002062	S
10.6	0.026384	S	0.992291	S	0.0007464	S	0.002062	S
10.8	0.025568	S	0.846997	S	0.0007464	S	0.002062	S
11	0.024792	S	0.72508	S	0.0007464	S	0.002062	S
11.2	0.024053	S	0.622453	S	0.0007464	S	0.002062	S
11.4	0.022805	S	0.521667	S	0.0007464	S	0.002062	S
11.6	0.020061	S	0.407918	S	0.0007464	S	0.002062	S
11.8	0.017686	S	0.320316	S	0.0007464	S	0.002062	S
12	0.015626	S	0.252551	S	0.0007464	S	0.002062	S
12.2	0.013891	S	0.199906	S	0.0007464	S	0.002062	S
12.4	0.012381	S	0.158838	S	0.0007464	S	0.002062	S
12.6	0.010989	S	0.126672	S	0.0007464	S	0.002062	S
12.8	0.009772	S	0.10138	S	0.0007464	S	0.002062	S
13	0.008706	S	0.081419	S	0.0007464	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	1.755723		130.8998		0.1946267		1.660681	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	2.06570089	S	2.47582E-05	S	0.027406405	S	0.17092095	S
3	1.9420914	S	2.29505E-05	S	0.015714832	S	0.1657731	S
3.2	1.74978844	S	2.20387E-05	S	0.012543319	S	0.12607312	S
3.4	1.37479786	S	2.49123E-05	S	0.014500633	S	0.0703833	S
3.6	1.09516874	S	2.79639E-05	S	0.016624972	S	0.04062476	S
3.8	0.89644455	S	3.11938E-05	S	0.018907075	S	0.02477752	S
4	0.85113208	S	3.17714E-05	S	0.021015396	S	0.02622007	S
4.2	0.81015812	S	2.66474E-05	S	0.022920126	S	0.02767009	S
4.4	0.77292899	S	2.23766E-05	S	0.024896783	S	0.02904708	S
4.6	0.73895453	S	1.89367E-05	S	0.026944629	S	0.03035326	S
4.8	0.7078265	S	1.61399E-05	S	0.029572548	S	0.03165886	S
5	0.68545255	S	1.51861E-05	S	0.037550723	S	0.0356094	S
5.2	0.69165489	S	1.89343E-05	S	0.059125928	S	0.04255597	S
5.4	0.69991529	S	2.34119E-05	S	0.085214571	S	0.04908228	S
5.6	0.70796857	S	2.87257E-05	S	0.118402391	S	0.05631645	S
5.8	0.7221928	S	2.87356E-05	S	0.153869277	S	0.06365289	S
6	0.7429065	S	2.87356E-05	S	0.187276178	S	0.07090263	S
6.2	0.76350597	S	2.87356E-05	S	0.225923973	S	0.07869921	S
6.4	0.78706195	S	2.87356E-05	S	0.272224238	S	0.08706425	S
6.6	0.82693508	S	2.87356E-05	S	0.325371444	S	0.09601946	S
6.8	0.86437692	S	2.87356E-05	S	0.386829611	S	0.10558671	S
7	0.88542201	S	2.87356E-05	S	0.439772674	S	0.11469807	S
7.2	0.90636502	S	4.16704E-05	S	0.452603004	S	0.12149973	S
7.4	0.93369198	S	6.084E-05	S	0.463052311	S	0.1283234	S
7.6	0.94813811	S	8.00805E-05	S	0.472515211	S	0.13319258	S
7.8	0.96861379	S	9.81463E-05	S	0.48367802	S	0.13908059	S
8	0.98917976	S	0.000111345	S	0.45318012	S	0.12887793	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID
Date Exported
Database Name ing\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.96941568	W	8.55865E-05	S	0.31573509	W	0.08046617	S
8.4	0.96312136	W	7.72899E-05	S	0.247049302	W	0.05831164	S
8.6	0.96238377	W	6.56608E-05	S	0.2530681	W	0.03466073	S
8.8	0.96175457	W	5.75158E-05	S	0.251715172	W	0.02802244	S
9	0.9612412	W	4.94135E-05	S	0.25519357	W	0.02276403	S
9.2	0.96073937	W	4.25945E-05	S	0.258642003	W	0.01857703	S
9.4	0.9602486	W	3.6834E-05	S	0.261756276	W	0.01523866	S
9.6	0.95943599	W	3.7761E-05	S	0.262108014	W	0.01264156	S
9.8	0.95829189	W	3.74511E-05	S	0.262452957	W	0.01052756	S
10	0.95717222	W	3.614E-05	S	0.262791372	W	0.00879955	S
10.2	0.956076	W	3.48994E-05	S	0.263123508	W	0.00738134	S
10.4	0.95500228	W	3.37243E-05	S	0.263449602	W	0.00621287	S
10.6	0.95395018	W	3.261E-05	S	0.263769877	W	0.00524656	S
10.8	0.95291888	W	3.15524E-05	S	0.265176174	W	0.00444457	S
11	0.95190759	W	3.05475E-05	S	0.266057404	W	0.00377665	S
11.2	0.95091556	W	2.95919E-05	S	0.266462947	W	0.00321853	S
11.4	0.95045844	W	2.87692E-05	S	0.264781079	W	0.002783	S
11.6	0.95806098	W	2.93294E-05	S	0.262238295	W	0.002783	S
11.8	0.96559281	W	2.98907E-05	S	0.259762778	W	0.002783	S
12	0.97305578	W	3.0453E-05	S	0.257351653	W	0.002783	S
12.2	0.98045164	W	3.10164E-05	S	0.255002211	W	0.002783	S
12.4	0.98678761	W	3.15807E-05	S	0.252711904	W	0.002783	S
12.6	0.98433165	W	3.01991E-05	S	0.250478323	W	0.002783	S
12.8	0.98192034	W	2.76E-05	S	0.248256521	W	0.002783	S
13	0.97955218	W	2.52598E-05	S	0.245405281	W	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	19.4209139		0.001113448		4.836780171		1.65773096	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.1755029	S	0.106778	S	0.1899509	S
3	0.1492192	S	0.100546	S	0.0817083	S
3.2	0.1315965	S	0.097681	S	0.04772	S
3.4	0.1276216	S	0.097985	S	0.0390276	S
3.6	0.1243241	S	0.098274	S	0.0322876	S
3.8	0.1241419	S	0.098547	S	0.0272242	S
4	0.1156928	S	0.086197	S	0.0277534	S
4.2	0.1081903	S	0.075501	S	0.0282662	S
4.4	0.1014904	S	0.067067	S	0.0287641	S
4.6	0.0951675	S	0.059889	S	0.0292479	S
4.8	0.089197	S	0.053738	S	0.0297189	S
5	0.0879027	S	0.048626	S	0.0350973	S
5.2	0.0935249	S	0.043736	S	0.0424938	S
5.4	0.0992741	S	0.039639	S	0.051079	S
5.6	0.1052196	S	0.03654	S	0.060989	S
5.8	0.1142198	S	0.033825	S	0.0697202	S
6	0.1236452	S	0.031436	S	0.0763689	S
6.2	0.1335009	S	0.029287	S	0.0834021	S
6.4	0.1449391	S	0.02697	S	0.0940797	S
6.6	0.1559934	S	0.024751	S	0.1011677	S
6.8	0.1675227	S	0.022931	S	0.1085539	S
7	0.1817246	S	0.02151	S	0.1162417	S
7.2	0.2025258	S	0.017582	S	0.1186189	S
7.4	0.2250387	S	0.014996	S	0.116845	S
7.6	0.2437273	S	0.01259	S	0.114889	S
7.8	0.2697741	S	0.0104	S	0.1130154	S
8	0.2490561	S	0.009027	S	0.1027868	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-60. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID ACC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.1280791	S	0.007799	S	0.0718773	S
8.4	0.0831313	S	0.007459	S	0.0575941	S
8.6	0.0689597	S	0.007098	S	0.065595	S
8.8	0.0635986	S	0.006665	S	0.0708521	S
9	0.0587611	S	0.006361	S	0.0824518	S
9.2	0.054386	S	0.006077	S	0.0952328	S
9.4	0.0502051	S	0.005812	S	0.1064286	S
9.6	0.0442727	S	0.005429	S	0.1107594	S
9.8	0.0392126	S	0.004951	S	0.1151717	S
10	0.0348161	S	0.004524	S	0.1196652	S
10.2	0.0309854	S	0.00414	S	0.1242399	S
10.4	0.0276387	S	0.003796	S	0.1288955	S
10.6	0.0247072	S	0.003486	S	0.1336319	S
10.8	0.0221329	S	0.003207	S	0.1384489	S
11	0.020293	S	0.002954	S	0.1488826	S
11.2	0.0189497	S	0.002725	S	0.1530481	S
11.4	0.0174161	S	0.00253	S	0.1495243	S
11.6	0.0176303	S	0.00253	S	0.1103803	S
11.8	0.0178435	S	0.00253	S	0.0819076	S
12	0.0180555	S	0.00253	S	0.0610851	S
12.2	0.0182665	S	0.00253	S	0.0457775	S
12.4	0.0184765	S	0.00253	S	0.0350846	S
12.6	0.0186855	S	0.00253	S	0.0270659	S
12.8	0.0188709	S	0.00253	S	0.0209654	S
13	0.0189166	S	0.00253	S	0.0163044	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	2.6977413		1.005461		1.5917006	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID	BCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.199934	S	8.542333	W	0.0042447	S	0.203831	S
3	0.125674	S	8.30627	W	0.0051298	S	0.189868	S
3.2	0.0814	S	8.009297	W	0.0054867	S	0.173704	S
3.4	0.068816	S	7.952334	W	0.0034694	S	0.166934	S
3.6	0.064519	S	7.843859	W	0.0034296	S	0.157403	S
3.8	0.0607	S	7.593205	W	0.0033924	S	0.148889	S
4	0.057287	S	7.469571	W	0.0033575	S	0.141237	S
4.2	0.054219	S	7.353838	W	0.0033879	S	0.133014	S
4.4	0.048171	S	7.245161	W	0.0034629	S	0.127734	S
4.6	0.042571	S	7.142816	W	0.003536	S	0.122326	S
4.8	0.037821	S	7.084383	W	0.0036075	S	0.117087	S
5	0.033764	S	7.078404	W	0.0036775	S	0.112273	S
5.2	0.032752	S	7.072663	W	0.0037459	S	0.107834	S
5.4	0.033292	S	7.067144	W	0.0039037	S	0.103728	S
5.6	0.033821	S	7.053773	W	0.0041586	S	0.09992	S
5.8	0.03434	S	6.994545	W	0.0044204	S	0.096378	S
6	0.034848	S	6.937798	W	0.004689	S	0.093075	S
6.2	0.034939	S	6.883349	W	0.0049642	S	0.089989	S
6.4	0.034686	S	6.854603	W	0.0052461	S	0.087097	S
6.6	0.036317	S	6.87511	W	0.0055346	S	0.084384	S
6.8	0.03679	S	6.895064	W	0.0058297	S	0.081832	S
7	0.037255	S	6.914496	W	0.0048916	S	0.079429	S
7.2	0.035032	S	6.779724	W	0.0039838	S	0.077513	S
7.4	0.031608	S	6.614025	W	0.0032628	S	0.072568	S
7.6	0.021083	S	6.547541	W	0.0026866	S	0.016587	S
7.8	0.017265	S	6.576364	W	0.0019579	S	0.006156	S
8	0.016822	S	6.184895	W	0.002025	S	0.005621	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID	BCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.01729	S	5.470447	W	0.0020046	S	0.005144	S
8.4	0.018248	S	5.151538	W	0.0018822	S	0.004925	S
8.6	0.019395	S	5.022557	W	0.0018169	S	0.004721	S
8.8	0.017737	S	4.899659	W	0.0017554	S	0.004349	S
9	0.016019	S	4.596382	S	0.0017564	S	0.004015	S
9.2	0.0145	S	4.191971	S	0.001803	S	0.003701	S
9.4	0.013153	S	3.830722	S	0.0018497	S	0.003405	S
9.6	0.011955	S	3.507253	S	0.0018966	S	0.003138	S
9.8	0.010888	S	3.216944	S	0.0019437	S	0.002897	S
10	0.009935	S	2.955821	S	0.001991	S	0.002678	S
10.2	0.009163	S	2.72045	S	0.0020384	S	0.00248	S
10.4	0.008553	S	2.507859	S	0.002086	S	0.0023	S
10.6	0.007994	S	2.315467	S	0.0021338	S	0.002136	S
10.8	0.007482	S	2.141027	S	0.0021818	S	0.002062	S
11	0.007359	S	2.383962	S	0.002374	S	0.002062	S
11.2	0.007357	S	2.750351	S	0.0026015	S	0.002062	S
11.4	0.007356	S	3.165031	S	0.0028463	S	0.002062	S
11.6	0.007354	S	3.633349	S	0.0031091	S	0.002062	S
11.8	0.007353	S	4.161135	S	0.0033912	S	0.002062	S
12	0.007351	S	4.754736	S	0.0036934	S	0.002062	S
12.2	0.00735	S	5.421053	S	0.0040169	S	0.002062	S
12.4	0.007348	S	6.16758	S	0.0043217	S	0.002062	S
12.6	0.007276	S	7.00244	S	0.0045025	S	0.002062	S
12.8	0.007229	S	7.855425	S	0.0046878	S	0.002062	S
13	0.007221	S	8.542333	S	0.0048777	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	1.256738		96.95547		0.0582967		1.898685	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID
Date Exported
Database Name ·ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.712	W	0.002626778	S	0.089725733	S	0.00593048	S
3	0.712	W	0.002382419	S	0.092768083	S	0.00495359	S
3.2	0.71983225	W	0.002174457	S	0.073556432	S	0.002783	S
3.4	0.712	W	0.008468502	S	0.084042383	S	0.00357361	S
3.6	0.71019022	W	0.004838015	S	0.078922408	S	0.00307855	S
3.8	0.70866417	W	0.00315747	S	0.080384084	S	0.002783	S
4	0.71100581	W	0.002743335	S	0.08272901	S	0.002783	S
4.2	0.71254435	W	0.002399928	S	0.085022953	S	0.002783	S
4.4	0.71276378	W	0.002335476	S	0.088722419	S	0.002783	S
4.6	0.71297352	W	0.002530932	S	0.092737056	S	0.002783	S
4.8	0.71317439	W	0.002733378	S	0.096750923	S	0.002783	S
5	0.71336711	W	0.002942758	S	0.100764051	S	0.002783	S
5.2	0.71355233	W	0.003159017	S	0.10477647	S	0.002783	S
5.4	0.71373059	W	0.003061236	S	0.107157865	S	0.002783	S
5.6	0.71390242	W	0.002794252	S	0.107859803	S	0.002783	S
5.8	0.71406825	W	0.002558734	S	0.108541466	S	0.002783	S
6	0.7142285	W	0.002448601	S	0.109204108	S	0.002783	S
6.2	0.71438353	W	0.002914692	S	0.109848868	W	0.002783	S
6.4	0.71453366	W	0.003450361	S	0.110476784	W	0.002783	S
6.6	0.71467921	W	0.004063324	S	0.111088801	W	0.002783	S
6.8	0.71482044	W	0.004761877	S	0.111685786	W	0.002783	S
7	0.7149576	W	0.001810003	S	0.113262292	W	0.002783	S
7.2	0.72170592	W	0.000594937	S	0.114616094	W	0.002783	S
7.4	0.72310361	W	0.000315726	S	0.116112695	W	0.002783	S
7.6	0.72446661	W	0.000147546	S	0.118355196	W	0.002783	S
7.8	0.70083886	W	3.56275E-05	S	0.126013062	W	0.002783	S
8	0.73354618	W	4.23017E-05	S	0.11990532	W	0.002783	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID
Date Exported
Database Name ·ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.73148956	W	2.39815E-05	S	0.115377678	W	0.002783	S
8.4	0.72752245	W	2.05615E-05	S	0.114344788	W	0.002783	S
8.6	0.72551659	W	2.15517E-05	S	0.114072533	W	0.002783	S
8.8	0.72356218	W	2.0723E-05	S	0.111147234	W	0.00303892	S
9	0.72165679	W	1.98674E-05	S	0.106769333	S	0.00334044	S
9.2	0.71979813	W	1.90648E-05	S	0.102654499	S	0.00366424	S
9.4	0.71798408	W	1.83109E-05	S	0.098781711	S	0.00401144	S
9.6	0.71621265	W	1.67366E-05	S	0.095132024	S	0.00437158	S
9.8	0.71448198	W	1.4489E-05	S	0.09168833	S	0.00464998	S
10	0.71279034	W	1.25798E-05	S	0.088299052	S	0.00493995	S
10.2	0.71113608	W	1.21011E-05	S	0.084634765	S	0.00524171	S
10.4	0.70951768	W	1.16698E-05	S	0.081189337	S	0.00555551	S
10.6	0.70793368	W	1.12617E-05	S	0.077945854	S	0.00588157	S
10.8	0.6975808	W	1.08751E-05	S	0.075606815	S	0.00623977	S
11	0.7026498	W	1.1478E-05	S	0.077205616	S	0.00561832	S
11.2	0.69853116	W	1.24606E-05	S	0.080088698	S	0.00488564	S
11.4	0.69440172	W	1.35076E-05	S	0.083025548	S	0.00425903	S
11.6	0.69106005	W	1.46222E-05	S	0.086016199	S	0.00372167	S
11.8	0.69149537	W	1.73039E-05	S	0.089060683	S	0.0032596	S
12	0.69192364	W	1.78638E-05	S	0.092159031	S	0.00286128	S
12.2	0.69234509	W	1.84322E-05	S	0.095311276	S	0.00251704	S
12.4	0.69275994	W	1.98173E-05	S	0.098517449	S	0.00221884	S
12.6	0.69316839	W	2.13168E-05	S	0.101044349	S	0.00195992	S
12.8	0.69357065	W	2.29034E-05	S	0.103541049	S	0.0017346	S
13	0.69396689	W	2.45807E-05	S	0.106059294	S	0.0015381	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	7.8765242		0.084685021		1.260130609		0.06582954	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.1018986	S	0.012693	S	0.121773	S
3	0.0849358	S	0.011046	S	0.106159	S
3.2	0.0716339	S	0.009697	S	0.0770586	S
3.4	0.0644091	S	0.009553	S	0.0827645	S
3.6	0.0633205	S	0.009295	S	0.0738707	S
3.8	0.0623078	S	0.009058	S	0.0684827	S
4	0.0613621	S	0.008838	S	0.0687592	S
4.2	0.0604758	S	0.008446	S	0.0676754	S
4.4	0.0596426	S	0.008083	S	0.0662203	S
4.6	0.0588572	S	0.007751	S	0.0648591	S
4.8	0.056716	S	0.007446	S	0.0635821	S
5	0.0537186	S	0.007165	S	0.0623808	S
5.2	0.0509881	S	0.006904	S	0.061248	S
5.4	0.0482442	S	0.006712	S	0.0612456	S
5.6	0.045506	S	0.00658	S	0.0623323	S
5.8	0.0430114	S	0.006455	S	0.0633992	S
6	0.0407313	S	0.006337	S	0.0644472	S
6.2	0.038641	S	0.006224	S	0.0654773	S
6.4	0.0367194	S	0.006117	S	0.0664904	S
6.6	0.0354124	S	0.006015	S	0.0674873	S
6.8	0.0348734	S	0.005918	S	0.0684687	S
7	0.032934	S	0.005603	S	0.0648724	S
7.2	0.0328193	S	0.004251	S	0.0609181	S
7.4	0.0325683	S	0.003589	S	0.0573034	S
7.6	0.0323943	S	0.003044	S	0.0537255	S
7.8	0.0322257	S	0.002593	S	0.0509492	S
8	0.0345078	S	0.00253	S	0.0482061	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-61. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID BCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.0284635	S	0.00253	S	0.0497661	S
8.4	0.0255823	S	0.00253	S	0.0513372	S
8.6	0.0222813	S	0.00253	S	0.0529192	S
8.8	0.0226155	S	0.00253	S	0.0545119	S
9	0.0232334	S	0.00253	S	0.0553451	S
9.2	0.0239398	S	0.00253	S	0.0555962	S
9.4	0.0246519	S	0.00253	S	0.055843	S
9.6	0.0252187	S	0.00253	S	0.0560857	S
9.8	0.0248625	S	0.00253	S	0.0563243	S
10	0.0245673	S	0.00253	S	0.0565592	S
10.2	0.0248843	S	0.00253	S	0.0567903	S
10.4	0.0251992	S	0.00253	S	0.0570179	S
10.6	0.025512	S	0.00253	S	0.057242	S
10.8	0.0258226	S	0.00253	S	0.0574628	S
11	0.0263923	S	0.00253	S	0.05822	S
11.2	0.0270525	S	0.00253	S	0.0590848	S
11.4	0.0277171	S	0.00253	S	0.0601884	S
11.6	0.0283861	S	0.00253	S	0.0615067	S
11.8	0.0290594	S	0.00253	S	0.0628307	S
12	0.0297369	S	0.00253	S	0.0641601	S
12.2	0.0304186	S	0.00253	S	0.065495	S
12.4	0.0309789	S	0.00253	S	0.0668353	S
12.6	0.0317945	S	0.00253	S	0.068181	S
12.8	0.0324886	S	0.00253	S	0.0695319	S
13	0.0331867	S	0.00253	S	0.070888	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	0.8493577		0.110462		1.0615901	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID	CCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.205935	S	8.72552	W	0.0155481	S	0.149959	W
3	0.151408	S	8.835719	W	0.0149606	S	0.153841	W
3.2	0.113551	S	8.684359	W	0.0144312	S	0.157237	W
3.4	0.087457	S	8.571123	W	0.014158	S	0.159286	W
3.6	0.069798	S	8.247022	W	0.0139155	S	0.161242	W
3.8	0.057054	S	8.467667	W	0.0134947	S	0.15544	W
4	0.048037	S	8.40002	W	0.0131452	S	0.149639	W
4.2	0.044498	S	8.296738	W	0.0127248	S	0.144323	W
4.4	0.041831	S	8.20085	W	0.0123394	S	0.139962	W
4.6	0.041038	S	8.12835	W	0.0118596	S	0.13778	W
4.8	0.040292	S	8.059537	W	0.0113726	S	0.135723	W
5	0.03959	S	7.994081	W	0.0109455	S	0.133778	W
5.2	0.038927	S	7.931693	W	0.0105503	S	0.131936	W
5.4	0.0383	S	7.8869	W	0.0101835	S	0.130188	W
5.6	0.037704	S	7.871295	W	0.009842	S	0.128525	W
5.8	0.037139	S	7.856267	W	0.0095235	S	0.12694	W
6	0.036601	S	7.718203	S	0.0092255	S	0.125006	S
6.2	0.039238	S	7.65784	S	0.007542	S	0.097722	S
6.4	0.042879	S	7.568779	S	0.0055979	S	0.066477	S
6.6	0.04673	S	7.351488	S	0.0041933	S	0.045761	S
6.8	0.050797	S	7.146648	S	0.0031683	S	0.031854	S
7	0.053449	S	6.953209	S	0.0024134	S	0.022408	S
7.2	0.056359	S	6.770238	S	0.0018525	S	0.01592	S
7.4	0.060479	S	6.5969	S	0.0014323	S	0.011417	S
7.6	0.064778	S	6.444356	S	0.001115	S	0.00826	S
7.8	0.06926	S	6.317882	S	0.0008737	S	0.006027	S
8	0.072352	S	5.638437	S	0.0007464	S	0.004665	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID	CCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.072448	S	4.33007	S	0.0007464	S	0.004008	S
8.4	0.071061	S	3.346527	S	0.0007464	S	0.003297	S
8.6	0.072636	S	2.602118	S	0.0007464	S	0.002647	S
8.8	0.072726	S	2.035035	S	0.0007464	S	0.002135	S
9	0.072814	S	1.600353	S	0.0007464	S	0.002062	S
9.2	0.066076	S	1.133544	S	0.0007464	S	0.002062	S
9.4	0.048868	S	0.642057	S	0.0007464	S	0.002062	S
9.6	0.036372	S	0.368049	S	0.0007464	S	0.002062	S
9.8	0.026386	S	0.213413	S	0.0007464	S	0.002062	S
10	0.019003	S	0.125118	S	0.0007464	S	0.002062	S
10.2	0.017109	S	0.081878	S	0.0007464	S	0.002062	S
10.4	0.01458	S	0.055064	S	0.0007464	S	0.002062	S
10.6	0.012463	S	0.037312	S	0.0007464	S	0.002062	S
10.8	0.010685	S	0.027404	S	0.0007464	S	0.002062	S
11	0.007647	S	0.019525	S	0.0007464	S	0.002062	S
11.2	0.005437	S	0.013504	S	0.0007464	S	0.002062	S
11.4	0.003889	S	0.009674	S	0.0007464	S	0.002062	S
11.6	0.00272	S	0.007062	S	0.0007464	S	0.002062	S
11.8	0.001822	S	0.005182	S	0.0007464	S	0.002062	S
12	0.001291	S	0.003823	S	0.0007464	S	0.002062	S
12.2	0.000946	S	0.002834	S	0.0007464	S	0.002062	S
12.4	0.000697	S	0.002112	S	0.0007464	S	0.002062	S
12.6	0.000516	S	0.001574	S	0.0007464	S	0.002062	S
12.8	0.000384	S	0.001175	S	0.0007464	S	0.002062	S
13	0.00032	S	0.000882	S	0.0007464	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	1.514078		88.35719		0.1496063		1.612415	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.71002193	S	2.87356E-05	S	0.151692518	S	0.3147164	S
3	0.69878631	S	2.87356E-05	S	0.099935515	S	0.28435651	S
3.2	0.68491351	S	2.87356E-05	S	0.067635878	S	0.25861359	S
3.4	0.55024877	S	2.87356E-05	S	0.061622082	S	0.17598522	S
3.6	0.34831533	S	2.87356E-05	S	0.08029248	S	0.08363163	S
3.8	0.21046067	S	2.87356E-05	S	0.096311463	S	0.0487192	S
4	0.10708468	S	2.81874E-05	S	0.095764382	S	0.0459106	S
4.2	0.05631238	S	2.76971E-05	S	0.093796844	S	0.04338945	S
4.4	0.03347102	S	2.86311E-05	S	0.093327919	S	0.04156904	S
4.6	0.03651076	S	2.72124E-05	S	0.117899722	S	0.04602586	S
4.8	0.04261747	S	2.59226E-05	S	0.148711086	S	0.05130698	S
5	0.04943246	S	2.64714E-05	S	0.208548376	S	0.05948979	S
5.2	0.05700457	S	2.70097E-05	S	0.2886087	S	0.06857842	S
5.4	0.06538389	S	2.7538E-05	S	0.377923094	S	0.07712667	S
5.6	0.07462177	S	2.80568E-05	S	0.478732448	S	0.08618479	S
5.8	0.08477075	S	2.85667E-05	S	0.60142075	S	0.09593215	S
6	0.09655141	S	2.72955E-05	S	0.749729266	S	0.10639471	S
6.2	0.10987771	S	2.53179E-05	S	0.86503023	S	0.11525466	S
6.4	0.12453106	S	2.35397E-05	S	0.952379788	S	0.12303242	S
6.6	0.1405959	S	2.19355E-05	S	1.045450188	S	0.13107138	S
6.8	0.15815918	S	2.04837E-05	S	1.144425658	S	0.13937199	S
7	0.17731038	S	1.91661E-05	S	1.249490596	S	0.14793469	S
7.2	0.19814148	S	1.79668E-05	S	1.360829561	S	0.15675993	S
7.4	0.22074701	S	1.79598E-05	S	1.478627272	S	0.16584811	S
7.6	0.24522396	S	1.79598E-05	S	1.603068601	S	0.17519966	S
7.8	0.27167186	S	1.79598E-05	S	1.734338571	S	0.18481497	S
8	0.30780473	S	1.79598E-05	S	1.79583582	S	0.18757983	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.29085901	W	1.90644E-05	S	1.580563263	W	0.16009956	S
8.4	0.27297018	W	2.20838E-05	S	1.424150259	W	0.1407035	S
8.6	0.25656451	W	2.63968E-05	S	1.286366409	W	0.12403362	S
8.8	0.24148871	W	3.14231E-05	S	1.164634221	W	0.10965616	S
9	0.22729191	W	3.4732E-05	S	1.056780313	W	0.09721407	S
9.2	0.21794049	W	3.33975E-05	S	0.95782662	W	0.07576129	S
9.4	0.2153394	W	4.10267E-05	S	0.864014159	W	0.04501917	S
9.6	0.21282314	W	4.44721E-05	S	0.781083259	W	0.02704624	S
9.8	0.21038727	W	4.81269E-05	S	0.707583086	W	0.01642024	S
10	0.20802765	W	4.80861E-05	S	0.642280421	W	0.01007002	S
10.2	0.19755669	W	4.34476E-05	S	0.610163108	W	0.00713118	S
10.4	0.18636857	W	3.93339E-05	S	0.583239349	W	0.00521429	S
10.6	0.17640834	W	3.56773E-05	S	0.548100328	W	0.00373156	S
10.8	0.17330597	W	3.24197E-05	S	0.52951876	W	0.00280665	S
11	0.18217124	W	3.12858E-05	S	0.559252764	W	0.002783	S
11.2	0.18984874	W	3.02651E-05	S	0.584450389	W	0.002783	S
11.4	0.1952531	W	2.92949E-05	S	0.6137081	W	0.002783	S
11.6	0.20071331	W	2.83719E-05	S	0.647467558	W	0.002783	S
11.8	0.20622895	W	2.7493E-05	S	0.682459069	W	0.002783	S
12	0.21179963	W	2.66554E-05	S	0.718705568	W	0.002783	S
12.2	0.21742497	W	2.58565E-05	S	0.756230022	W	0.002783	S
12.4	0.22310461	W	2.5094E-05	S	0.795055429	W	0.002783	S
12.6	0.22883817	W	2.43657E-05	S	0.835204815	W	0.002783	S
12.8	0.23462529	W	2.36695E-05	S	0.876701236	W	0.002783	S
13	0.24046564	W	2.30035E-05	S	0.919567777	W	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	6.98786308		0.000481269		17.95835818		2.84356508	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.1777939	S	0.108389	S	0.43297	S
3	0.1281955	S	0.104238	S	0.1973116	S
3.2	0.0987352	S	0.1005	S	0.0945982	S
3.4	0.0909932	S	0.09627	S	0.0536283	S
3.6	0.0842508	S	0.092422	S	0.0367971	S
3.8	0.0874722	S	0.085899	S	0.0295074	S
4	0.0913224	S	0.078458	S	0.0299833	S
4.2	0.0951419	S	0.072571	S	0.0313798	S
4.4	0.1003116	S	0.067075	S	0.0330425	S
4.6	0.1108609	S	0.061433	S	0.0371544	S
4.8	0.1219992	S	0.056134	S	0.0449408	S
5	0.1337328	S	0.051635	S	0.0524692	S
5.2	0.1460679	S	0.047653	S	0.0593857	S
5.4	0.1590103	S	0.044111	S	0.0669005	S
5.6	0.1725657	S	0.040947	S	0.0750404	S
5.8	0.1867398	S	0.03811	S	0.0838321	S
6	0.2015381	S	0.035556	S	0.0933027	S
6.2	0.217722	S	0.031438	S	0.097656	S
6.4	0.2351224	S	0.026979	S	0.0985599	S
6.6	0.2533134	S	0.023262	S	0.099444	S
6.8	0.2723053	S	0.020146	S	0.1003092	S
7	0.2921082	S	0.01752	S	0.1011566	S
7.2	0.3127321	S	0.015297	S	0.1019869	S
7.4	0.3341869	S	0.013405	S	0.1028011	S
7.6	0.3564821	S	0.011938	S	0.1035997	S
7.8	0.3796274	S	0.010698	S	0.1043836	S
8	0.3697696	S	0.009606	S	0.1055212	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-62. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID CCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.314441	S	0.008634	S	0.1139144	S
8.4	0.2663207	S	0.007886	S	0.1243307	S
8.6	0.2264479	S	0.007276	S	0.1333163	S
8.8	0.193264	S	0.006726	S	0.1427222	S
9	0.1655313	S	0.006228	S	0.1525578	S
9.2	0.1254723	S	0.005934	S	0.1595619	S
9.4	0.0734761	S	0.005768	S	0.1597644	S
9.6	0.0435149	S	0.005611	S	0.1599628	S
9.8	0.0261742	S	0.005461	S	0.1601574	S
10	0.0157581	S	0.004983	S	0.1614812	S
10.2	0.0136643	S	0.004191	S	0.1617901	S
10.4	0.0126928	S	0.003536	S	0.1634563	S
10.6	0.011807	S	0.002975	S	0.1651074	S
10.8	0.0105291	S	0.00253	S	0.1667439	S
11	0.0108182	S	0.00253	S	0.1420802	S
11.2	0.0113302	S	0.00253	S	0.1234525	S
11.4	0.0119468	S	0.00253	S	0.1060501	S
11.6	0.0125854	S	0.00253	S	0.0904853	S
11.8	0.0132464	S	0.00253	S	0.0774148	S
12	0.01393	S	0.00253	S	0.0664062	S
12.2	0.0146368	S	0.00253	S	0.0571076	S
12.4	0.015367	S	0.00253	S	0.0492317	S
12.6	0.0161211	S	0.00253	S	0.0425429	S
12.8	0.0168995	S	0.00253	S	0.0368475	S
13	0.0177024	S	0.00253	S	0.0319858	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	3.7962739		1.042385		1.9731164	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID	DCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.312848	S	13.87143	W	0.0007464	S	0.048173	W
3	0.299716	S	13.92666	W	0.0007464	S	0.047046	W
3.2	0.287931	S	13.91004	W	0.0007464	S	0.04895	W
3.4	0.279222	S	13.83793	W	0.0007464	S	0.046714	W
3.6	0.273802	S	13.84397	W	0.0007464	S	0.04604	W
3.8	0.268771	S	13.8497	W	0.0007464	S	0.045412	W
4	0.264084	S	13.85274	W	0.0007464	S	0.044823	W
4.2	0.258111	S	13.84284	W	0.0007464	S	0.044271	W
4.4	0.248389	S	13.86522	W	0.0007464	S	0.04375	W
4.6	0.239441	S	13.86993	W	0.0007464	S	0.043259	W
4.8	0.231177	S	13.87444	W	0.0007464	S	0.042793	W
5	0.223518	S	13.87877	W	0.0007464	S	0.042351	W
5.2	0.215873	S	13.88293	W	0.0007464	S	0.041931	W
5.4	0.199272	S	13.88693	W	0.0007464	S	0.041531	W
5.6	0.186341	S	13.89079	W	0.0007464	S	0.041148	W
5.8	0.174659	S	13.89452	W	0.0007464	S	0.040783	W
6	0.16407	S	13.89812	W	0.0007464	S	0.040433	S
6.2	0.154439	S	13.75752	W	0.0007464	S	0.040097	S
6.4	0.139519	S	13.6932	W	0.0007464	S	0.03933	S
6.6	0.124615	S	13.52253	W	0.0007464	S	0.038754	S
6.8	0.11168	S	12.9735	W	0.0007464	S	0.029999	S
7	0.100405	S	12.50582	W	0.0007464	S	0.023047	S
7.2	0.09054	S	12.06748	W	0.0007464	S	0.017839	S
7.4	0.085576	S	11.65589	W	0.0007464	S	0.013904	S
7.6	0.082846	S	11.26877	W	0.0007464	S	0.01091	S
7.8	0.08027	S	10.90406	W	0.0007464	S	0.008615	S
8	0.074931	S	10.55996	W	0.0007464	S	0.006843	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID	DCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.068236	S	10.23481	W	0.0007464	S	0.005467	S
8.4	0.06228	S	9.92715	W	0.0007464	S	0.004391	S
8.6	0.056223	S	9.635659	W	0.0007464	S	0.003545	S
8.8	0.048049	S	9.789927	W	0.0007464	S	0.002876	S
9	0.041208	S	9.438718	S	0.0007464	S	0.002345	S
9.2	0.035461	S	9.509843	S	0.0007464	S	0.002062	S
9.4	0.030614	S	11.27878	S	0.0007464	S	0.002062	S
9.6	0.026204	S	7.680139	S	0.0007464	S	0.002062	S
9.8	0.02236	S	3.521824	S	0.0007464	S	0.002062	S
10	0.01914	S	1.640617	S	0.0007464	S	0.002062	S
10.2	0.016435	S	0.77592	S	0.0007464	S	0.002062	S
10.4	0.014154	S	0.372341	S	0.0007464	S	0.002062	S
10.6	0.012224	S	0.181192	S	0.0007464	S	0.002062	S
10.8	0.010586	S	0.089369	S	0.0007464	S	0.002062	S
11	0.008773	S	0.044654	S	0.0007464	S	0.002062	S
11.2	0.006942	S	0.025315	S	0.0007464	S	0.002062	S
11.4	0.005476	S	0.017493	S	0.0007464	S	0.002062	S
11.6	0.004469	S	0.012166	S	0.0007464	S	0.002062	S
11.8	0.003731	S	0.008514	S	0.0007464	S	0.002062	S
12	0.0032	S	0.015918	S	0.0007464	S	0.002062	S
12.2	0.0032	S	0.838595	S	0.0007464	S	0.002062	S
12.4	0.0032	S	7.22491	S	0.0007464	S	0.002062	S
12.6	0.0032	S	14.42702	S	0.0007464	S	0.002062	S
12.8	0.0032	S	14.42702	S	0.0007464	S	0.002062	S
13	0.0032	S	14.42702	S	0.0007464	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	2.997157		144.2702		0.0074635		0.489504	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.01851753	S	0.002095386	S	0.350155376	S	0.01829238	S
3	0.02710016	S	0.002133795	S	0.268551421	S	0.0140037	S
3.2	0.01686711	S	0.002170361	S	0.272549856	S	0.01374165	S
3.4	0.00797204	S	0.001798469	S	0.322469032	S	0.01546756	S
3.6	0.00794736	S	0.001512458	S	0.327071236	S	0.01535029	S
3.8	0.00792409	S	0.001283902	S	0.331484981	S	0.01524018	S
4	0.00790208	S	0.001099083	S	0.335727323	S	0.01513645	S
4.2	0.0078812	S	0.000948033	S	0.33981301	S	0.01503843	S
4.4	0.00786134	S	0.000823387	S	0.343754892	S	0.01494557	S
4.6	0.00784241	S	0.000719625	S	0.326751062	S	0.01485738	S
4.8	0.00782433	S	0.000632555	S	0.299068296	S	0.01460815	S
5	0.00780702	S	0.000558955	S	0.301877132	S	0.01425159	S
5.2	0.00779043	S	0.000496322	S	0.304600635	S	0.01437463	S
5.4	0.00777451	S	0.000442688	S	0.307244533	S	0.01449403	S
5.6	0.00775919	S	0.000396496	S	0.309813978	S	0.01447329	S
5.8	0.00774443	S	0.000356499	S	0.312313617	S	0.01440582	S
6	0.00691829	S	0.000321695	S	0.314747657	S	0.01434094	S
6.2	0.00617998	S	0.000291269	S	0.317119923	S	0.01485513	S
6.4	0.00501786	S	0.000262578	S	0.320414304	S	0.0146343	S
6.6	0.00287608	S	0.000340102	S	0.350495673	S	0.01412093	S
6.8	0.00278165	S	0.000389643	S	0.364311614	S	0.0136401	S
7	0.00252897	S	0.000444643	S	0.36504576	S	0.01354171	S
7.2	0.0026561	S	0.000505524	S	0.36576064	S	0.01346085	S
7.4	0.00296064	S	0.00037281	S	0.366457275	S	0.01338266	S
7.6	0.00329056	S	0.000269183	S	0.367136606	S	0.013307	S
7.8	0.00364723	S	0.000196011	S	0.3677995	S	0.01323372	S
8	0.00403203	S	0.000143881	S	0.368446762	S	0.01316268	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.0044464	S	0.000106425	S	0.369079137	S	0.01309376	S
8.4	0.00489181	S	7.92932E-05	S	0.36969732	S	0.01302685	S
8.6	0.00536977	S	8.46647E-05	S	0.370301955	S	0.01270115	S
8.8	0.0058818	S	0.000112163	S	0.363205366	S	0.01190897	S
9	0.00642948	S	0.000147655	S	0.348195653	S	0.01182742	S
9.2	0.00828741	S	0.000103424	S	0.348175691	S	0.00936395	S
9.4	0.01424529	S	5.07313E-05	S	0.346300677	S	0.00398105	S
9.6	0.01710306	S	3.98738E-05	S	0.335299532	S	0.002783	S
9.8	0.01708549	S	4.03875E-05	S	0.329346245	S	0.002783	S
10	0.01706829	S	4.08973E-05	S	0.323615766	S	0.002783	S
10.2	0.01705145	S	2.71565E-05	S	0.318095546	S	0.002783	S
10.4	0.01718399	S	2.02412E-05	S	0.317591394	S	0.002783	S
10.6	0.01769595	S	1.83723E-05	S	0.317836997	S	0.002783	S
10.8	0.01766673	S	1.67062E-05	S	0.318078193	S	0.002783	S
11	0.01763809	S	1.52177E-05	S	0.307301314	S	0.002783	S
11.2	0.01760632	S	1.53082E-05	S	0.289809855	S	0.002783	S
11.4	0.0175691	S	1.80907E-05	S	0.273597655	S	0.002783	S
11.6	0.0175326	S	2.1317E-05	S	0.258551113	S	0.002783	S
11.8	0.01749679	S	2.50482E-05	S	0.244568434	S	0.002783	S
12	0.01646755	S	2.62858E-05	S	0.21718265	S	0.002783	S
12.2	0.01318099	S	1.3669E-05	S	0.138445453	S	0.002783	S
12.4	0.01332255	S	4.66502E-05	S	0.105640837	S	0.002783	S
12.6	0.01201362	S	4.66278E-05	S	0.074319287	S	0.002783	S
12.8	0.01085096	S	4.66057E-05	S	0.052574667	S	0.002783	S
13	0.00981629	S	4.65839E-05	S	0.037392306	S	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	0.27100163		0.021703613		3.703019558		0.15467556	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.1886928	S	0.041709	S	0.0565085	S
3	0.1827534	S	0.042222	S	0.049907	S
3.2	0.178042	S	0.03112	S	0.0444317	S
3.4	0.1716967	S	0.021918	S	0.0222266	S
3.6	0.1675786	S	0.021666	S	0.0209475	S
3.8	0.1653317	S	0.02143	S	0.0198053	S
4	0.1632281	S	0.021208	S	0.0187794	S
4.2	0.1612519	S	0.020999	S	0.0178528	S
4.4	0.1593899	S	0.020802	S	0.017012	S
4.6	0.1576309	S	0.020616	S	0.0162456	S
4.8	0.1559648	S	0.020439	S	0.0155442	S
5	0.1543834	S	0.02027	S	0.0148999	S
5.2	0.1528791	S	0.02011	S	0.0143061	S
5.4	0.15028	S	0.019957	S	0.013757	S
5.6	0.1492386	S	0.01981	S	0.0132478	S
5.8	0.1482405	S	0.01967	S	0.0127744	S
6	0.1472826	S	0.019535	S	0.0125557	S
6.2	0.1463111	S	0.019406	S	0.0123595	S
6.4	0.1353486	S	0.017659	S	0.0128033	S
6.6	0.1279588	S	0.011419	S	0.0140289	S
6.8	0.1267694	S	0.008208	S	0.01533	S
7	0.1201568	S	0.007704	S	0.0163166	S
7.2	0.1140612	S	0.007293	S	0.0154262	S
7.4	0.1084293	S	0.006914	S	0.0179591	S
7.6	0.1032148	S	0.006564	S	0.0208234	S
7.8	0.1000855	S	0.00624	S	0.0232391	S
8	0.1041874	S	0.005598	S	0.0274713	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-63. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID DCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.10835	S	0.004948	S	0.031744	S
8.4	0.1125726	S	0.004387	S	0.0362854	S
8.6	0.1135814	S	0.0039	S	0.0413463	S
8.8	0.1119869	S	0.003477	S	0.0469717	S
9	0.1104499	S	0.003107	S	0.0532098	S
9.2	0.1028605	S	0.002784	S	0.0556206	S
9.4	0.0866855	S	0.00253	S	0.0553532	S
9.6	0.0758863	S	0.00253	S	0.0547927	S
9.8	0.0683144	S	0.00253	S	0.0501178	S
10	0.0616288	S	0.00253	S	0.0459244	S
10.2	0.055711	S	0.00253	S	0.0421547	S
10.4	0.0504602	S	0.00253	S	0.0387589	S
10.6	0.0457906	S	0.00253	S	0.0356937	S
10.8	0.0416286	S	0.00253	S	0.0329216	S
11	0.0379112	S	0.00253	S	0.0253827	S
11.2	0.0333731	S	0.00253	S	0.0173164	S
11.4	0.03086	S	0.00253	S	0.0118937	S
11.6	0.0286934	S	0.00253	S	0.0082227	S
11.8	0.0267122	S	0.00253	S	0.0057208	S
12	0.0213503	S	0.002816	S	0.0043148	S
12.2	0.0163424	S	0.004727	S	0.0052392	S
12.4	0.0160652	S	0.00253	S	0.0050858	S
12.6	0.015797	S	0.00253	S	0.004441	S
12.8	0.0155374	S	0.00253	S	0.0044825	S
13	0.015286	S	0.00253	S	0.0045238	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	1.8275344		0.422215		0.5562061	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID	KCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.041684	S	33.12917	W	0.0007464	S	0.018493	S
3	0.023245	S	30.46188	W	0.0007464	S	0.013877	S
3.2	0.012599	S	27.53974	W	0.0007464	S	0.010557	S
3.4	0.011188	S	27.81901	W	0.0007464	S	0.009667	S
3.6	0.010355	S	27.72851	W	0.0007464	S	0.008866	S
3.8	0.009805	S	27.64547	W	0.0007464	S	0.008373	S
4	0.009311	S	27.56693	W	0.0007464	S	0.00793	S
4.2	0.008685	S	27.39934	W	0.0007464	S	0.007547	S
4.4	0.008086	S	27.21795	W	0.0007464	S	0.007204	S
4.6	0.007553	S	27.04574	W	0.0007464	S	0.00689	S
4.8	0.007076	S	26.88188	W	0.0007464	S	0.006603	S
5	0.006646	S	26.72565	W	0.0007464	S	0.006339	S
5.2	0.006343	S	26.70675	W	0.0007464	S	0.00599	S
5.4	0.00608	S	26.7112	W	0.0007464	S	0.005654	S
5.6	0.005836	S	26.71548	W	0.0007464	S	0.005349	S
5.8	0.00561	S	26.71962	W	0.0007464	S	0.005071	S
6	0.0054	S	26.72362	W	0.0007464	S	0.004815	S
6.2	0.005204	S	26.72749	W	0.0007464	S	0.00458	S
6.4	0.004848	S	26.4361	W	0.0007464	S	0.004097	S
6.6	0.004442	S	26.00318	W	0.0007464	S	0.003556	S
6.8	0.004081	S	25.58996	W	0.0007464	S	0.003099	S
7	0.003758	S	25.19501	S	0.0007464	S	0.002712	S
7.2	0.003535	S	22.38716	S	0.0007464	S	0.002445	S
7.4	0.003338	S	19.73261	S	0.0007464	S	0.002216	S
7.6	0.0032	S	17.14999	S	0.0007464	S	0.002062	S
7.8	0.0032	S	14.92008	S	0.0007464	S	0.002062	S
8	0.0032	S	13.50637	S	0.0007464	S	0.002062	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID	KCC-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.0032	S	11.89956	S	0.0007464	S	0.002062	S
8.4	0.0032	S	10.6694	S	0.0007464	S	0.002062	S
8.6	0.0032	S	9.729319	S	0.0007464	S	0.002062	S
8.8	0.0032	S	9.760976	S	0.0007464	S	0.002062	S
9	0.0032	S	9.176669	S	0.0007464	S	0.002062	S
9.2	0.0032	S	8.651123	S	0.0007464	S	0.002062	S
9.4	0.0032	S	8.66565	S	0.0007464	S	0.002062	S
9.6	0.0032	S	8.751344	S	0.0007464	S	0.002062	S
9.8	0.0032	S	8.836091	S	0.0007464	S	0.002062	S
10	0.0032	S	8.919923	S	0.0007464	S	0.002062	S
10.2	0.0032	S	9.002866	S	0.0007464	S	0.002062	S
10.4	0.0032	S	9.36261	S	0.0007464	S	0.002062	S
10.6	0.0032	S	9.780801	S	0.0007464	S	0.002062	S
10.8	0.0032	S	10.20933	S	0.0007464	S	0.002062	S
11	0.0032	S	10.64825	S	0.0007464	S	0.002062	S
11.2	0.0032	S	11.09762	S	0.0007464	S	0.002062	S
11.4	0.0032	S	11.55749	S	0.0007464	S	0.002062	S
11.6	0.0032	S	12.02793	S	0.0007464	S	0.002062	S
11.8	0.0032	S	12.50898	S	0.0007464	S	0.002062	S
12	0.0032	S	13.00069	S	0.0007464	S	0.002062	S
12.2	0.0032	S	13.50313	S	0.0007464	S	0.002062	S
12.4	0.0032	S	14.01634	S	0.0007464	S	0.002062	S
12.6	0.0032	S	14.54037	S	0.0007464	S	0.002062	S
12.8	0.0032	S	15.07528	S	0.0007464	S	0.002062	S
13	0.0032	S	15.62112	S	0.0007464	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	0.23245		304.6188		0.0079486		0.138774	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.00403346	S	0.046083498	S	0.03795	S	0.002783	S
3	0.00328107	S	0.037427564	S	0.03795	S	0.002783	S
3.2	0.00362233	S	0.030859778	S	0.03795	S	0.002783	S
3.4	0.00365407	S	0.025636631	S	0.03795	S	0.002783	S
3.6	0.00278571	S	0.021118003	S	0.037396064	S	0.002783	S
3.8	0.00322931	S	0.017180369	S	0.035912239	S	0.002783	S
4	0.00371528	S	0.014125704	S	0.034559002	S	0.002783	S
4.2	0.00388636	S	0.012874068	S	0.033319154	S	0.002783	S
4.4	0.00397021	S	0.012056146	S	0.032178442	S	0.002783	S
4.6	0.00405202	S	0.011323185	S	0.031124951	S	0.002783	S
4.8	0.00413193	S	0.010663216	S	0.030148639	S	0.002783	S
5	0.00421006	S	0.010066364	S	0.029240974	S	0.002783	S
5.2	0.00432942	S	0.009595235	S	0.028394663	S	0.002783	S
5.4	0.00445514	S	0.00917448	S	0.027603429	S	0.002783	S
5.6	0.00457975	S	0.008786494	S	0.026861841	S	0.002783	S
5.8	0.00470328	S	0.008427687	S	0.026165172	S	0.002783	S
6	0.00482579	S	0.008094967	S	0.025509288	S	0.002783	S
6.2	0.00494732	S	0.007785659	S	0.024890558	S	0.002783	S
6.4	0.00480423	S	0.005796946	S	0.023317965	S	0.002783	S
6.6	0.00453905	S	0.003800223	S	0.021412355	S	0.002783	S
6.8	0.00429579	S	0.002522866	S	0.019712588	S	0.002783	S
7	0.00407206	S	0.001694872	S	0.018191319	S	0.002783	S
7.2	0.00392698	S	0.001125876	S	0.016975996	S	0.002783	S
7.4	0.00379736	S	0.000754471	S	0.01588741	S	0.002783	S
7.6	0.00381591	S	0.000484153	S	0.014936734	S	0.002783	S
7.8	0.00423175	S	0.000183162	S	0.014445221	S	0.002783	S
8	0.00464044	S	5.54584E-05	S	0.014135867	S	0.002783	S

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Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.0051432	S	2.94108E-05	S	0.013374431	S	0.002783	S
8.4	0.00558026	S	1.97653E-05	S	0.012705734	S	0.002783	S
8.6	0.00593146	S	1.66899E-05	S	0.012117876	S	0.002783	S
8.8	0.00609547	S	5.98157E-05	S	0.012536637	S	0.002783	S
9	0.00633114	S	0.000101244	S	0.012316732	S	0.002783	S
9.2	0.00655901	S	0.000164635	S	0.012107627	S	0.002783	S
9.4	0.00656732	S	0.000108996	S	0.012138128	S	0.002783	S
9.6	0.00657453	S	6.67102E-05	S	0.012215721	S	0.002783	S
9.8	0.00658161	S	4.1245E-05	S	0.012292196	S	0.002783	S
10	0.00658855	S	2.57495E-05	S	0.012367589	S	0.002783	S
10.2	0.00659537	S	1.62263E-05	S	0.012441938	S	0.002783	S
10.4	0.00650405	S	1.40335E-05	S	0.01268857	S	0.002783	S
10.6	0.00639895	S	1.2843E-05	S	0.012966384	S	0.002783	S
10.8	0.00629746	S	1.17731E-05	S	0.013244918	S	0.002783	S
11	0.0061994	S	1.08095E-05	S	0.013524159	S	0.002783	S
11.2	0.0061046	S	9.94004E-06	S	0.013804098	S	0.002783	S
11.4	0.00601288	S	9.15411E-06	S	0.014084722	S	0.002783	S
11.6	0.0059241	S	8.4424E-06	S	0.014366021	S	0.002783	S
11.8	0.00583812	S	7.79681E-06	S	0.014647986	S	0.002783	S
12	0.0057548	S	7.21022E-06	S	0.014930607	S	0.002783	S
12.2	0.00567401	S	6.67639E-06	S	0.015213874	S	0.002783	S
12.4	0.00559565	S	6.18982E-06	S	0.015497778	S	0.002783	S
12.6	0.0055196	S	5.74566E-06	S	0.015782311	S	0.002783	S
12.8	0.00544575	S	5.33963E-06	S	0.016067463	S	0.002783	S
13	0.00537402	S	4.96794E-06	S	0.016353226	S	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	0.06859181		0.37427564		0.379500001		0.02963895	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.1786144	S	0.005065	S	0.0362558	S
3	0.1531948	S	0.003624	S	0.0160094	S
3.2	0.1335871	S	0.002572	S	0.0071239	S
3.4	0.1275204	S	0.00253	S	0.0065055	S
3.6	0.1173723	S	0.00253	S	0.0063966	S
3.8	0.1108855	S	0.00253	S	0.0063741	S
4	0.1050632	S	0.00253	S	0.0063528	S
4.2	0.1015488	S	0.00253	S	0.0063312	S
4.4	0.0987234	S	0.00253	S	0.0063103	S
4.6	0.0960971	S	0.00253	S	0.0062905	S
4.8	0.0936481	S	0.00253	S	0.0062715	S
5	0.0913577	S	0.00253	S	0.0062533	S
5.2	0.0859693	S	0.00253	S	0.0061688	S
5.4	0.0805667	S	0.00253	S	0.0060772	S
5.6	0.075682	S	0.00253	S	0.0059902	S
5.8	0.0712497	S	0.00253	S	0.0059074	S
6	0.0672144	S	0.00253	S	0.0058286	S
6.2	0.063529	S	0.00253	S	0.0057533	S
6.4	0.0597725	S	0.00253	S	0.0057195	S
6.6	0.0561544	S	0.00253	S	0.0057072	S
6.8	0.0528537	S	0.00253	S	0.0056953	S
7	0.0498344	S	0.00253	S	0.0056837	S
7.2	0.0445312	S	0.00253	S	0.0051901	S
7.4	0.0396738	S	0.00253	S	0.0047052	S
7.6	0.0348582	S	0.00253	S	0.0041348	S
7.8	0.0310541	S	0.00253	S	0.0035984	S
8	0.0284622	S	0.00253	S	0.0032569	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-64. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID KCC Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.0211926	S	0.00253	S	0.002176	S
8.4	0.0176403	S	0.00253	S	0.0017855	S
8.6	0.0163492	S	0.00253	S	0.0017862	S
8.8	0.0211346	S	0.00253	S	0.0028434	S
9	0.0153555	S	0.00253	S	0.0031886	S
9.2	0.0114384	S	0.00253	S	0.0035741	S
9.4	0.0117858	S	0.00253	S	0.0040126	S
9.6	0.0120802	S	0.00253	S	0.0044551	S
9.8	0.0123756	S	0.00253	S	0.0049358	S
10	0.0126721	S	0.00253	S	0.0054569	S
10.2	0.0129695	S	0.00253	S	0.0060212	S
10.4	0.0130462	S	0.00253	S	0.0068062	S
10.6	0.0130832	S	0.00253	S	0.0077106	S
10.8	0.0131196	S	0.00253	S	0.0087148	S
11	0.0131555	S	0.00253	S	0.0098278	S
11.2	0.0131908	S	0.00253	S	0.0110589	S
11.4	0.0132256	S	0.00253	S	0.0124183	S
11.6	0.0132599	S	0.00253	S	0.0139167	S
11.8	0.0132937	S	0.00253	S	0.0155655	S
12	0.0133269	S	0.00253	S	0.0173769	S
12.2	0.0133598	S	0.00253	S	0.0193639	S
12.4	0.0133921	S	0.00253	S	0.0215401	S
12.6	0.013424	S	0.00253	S	0.0239201	S
12.8	0.0134555	S	0.00253	S	0.0265193	S
13	0.0134866	S	0.00253	S	0.0293539	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	1.5319476		0.036243		0.3126189	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID	MAD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	1.91406	S	28.39436	W	0.0023115	S	0.055746	S
3	1.388512	S	28.61074	W	0.0023805	S	0.053435	S
3.2	1.29089	S	28.38692	W	0.0024469	S	0.053768	S
3.4	1.265567	S	27.9448	W	0.0027359	S	0.057435	S
3.6	1.313541	S	27.53427	W	0.0031168	S	0.062684	S
3.8	1.360592	S	27.15149	W	0.0035257	S	0.06809	S
4	1.406786	S	27.26573	W	0.0039631	S	0.07365	S
4.2	1.452181	S	27.76486	W	0.0044295	S	0.079358	S
4.4	1.496827	S	27.85418	W	0.0049251	S	0.085213	S
4.6	1.594153	S	27.30305	W	0.0054505	S	0.09121	S
4.8	1.716078	S	26.78561	W	0.0060059	S	0.097347	S
5	1.626706	S	26.2985	W	0.0065918	S	0.103621	S
5.2	1.66877	S	25.83885	W	0.0072084	S	0.11003	S
5.4	1.710272	S	25.40414	W	0.0076188	S	0.11657	S
5.6	1.499162	S	25.39124	W	0.0079241	S	0.113226	S
5.8	1.297987	S	26.07993	W	0.0082769	S	0.118548	S
6	1.129311	S	26.763	W	0.0086086	S	0.121538	S
6.2	0.987051	S	28.21581	W	0.0088802	S	0.124502	S
6.4	0.866407	S	28.4274	W	0.0089039	S	0.122955	S
6.6	0.710066	S	28.55158	W	0.0089271	S	0.113768	S
6.8	0.726675	S	28.12914	W	0.0091866	S	0.111224	S
7	1.012026	S	26.26874	S	0.0097268	S	0.103334	S
7.2	0.934538	S	25.62783	S	0.0088799	S	0.100556	S
7.4	0.864868	S	30.30964	S	0.0081269	S	0.097925	S
7.6	0.738541	S	28.24611	S	0.0072923	S	0.060064	S
7.8	0.496012	S	25.72867	S	0.0061457	S	0.031765	S
8	0.336502	S	21.464	S	0.0052019	S	0.020382	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID	MAD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.230485	S	21.04512	S	0.0044212	S	0.013222	S
8.4	0.167992	S	20.64423	S	0.0037724	S	0.008226	S
8.6	0.157415	S	20.26013	S	0.0032309	S	0.005584	S
8.8	0.135968	S	17.45974	S	0.0028641	S	0.004297	S
9	0.11376	S	14.51837	S	0.0028966	S	0.003493	S
9.2	0.095553	S	12.33208	S	0.0029287	S	0.002853	S
9.4	0.080562	S	10.35706	S	0.0026859	S	0.00234	S
9.6	0.076044	S	8.730364	S	0.0024406	S	0.002062	S
9.8	0.064787	S	7.385135	S	0.0023601	S	0.002062	S
10	0.05355	S	6.572996	S	0.0022837	S	0.002062	S
10.2	0.04443	S	5.253345	S	0.002175	S	0.002062	S
10.4	0.033448	S	4.431795	S	0.0020674	S	0.002062	S
10.6	0.024389	S	3.750855	S	0.0019671	S	0.002062	S
10.8	0.017889	S	3.184456	S	0.0018733	S	0.002062	S
11	0.013196	S	2.711719	S	0.0017974	S	0.002062	S
11.2	0.010375	S	2.022688	S	0.0017036	S	0.002062	S
11.4	0.008275	S	0.999802	S	0.0016266	S	0.002062	S
11.6	0.006637	S	0.471967	S	0.0015543	S	0.002062	S
11.8	0.005584	S	0.261975	S	0.0014865	S	0.002062	S
12	0.004712	S	0.187464	S	0.0014226	S	0.002062	S
12.2	0.003987	S	0.134889	S	0.0013625	S	0.002062	S
12.4	0.003383	S	0.09758	S	0.0013058	S	0.002062	S
12.6	0.002878	S	0.070957	S	0.0012524	S	0.002062	S
12.8	0.002454	S	0.051857	S	0.0012019	S	0.002062	S
13	0.002098	S	0.038083	S	0.0011542	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	17.16078		303.0964		0.0972683		1.245023	

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Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
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LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.00298296	S	0.008229165	S	0.568054593	S	0.04363135	S
3	0.00154628	S	0.008229165	S	0.553270615	S	0.04122161	S
3.2	0.00106593	S	0.008229165	S	0.556884691	S	0.04114483	S
3.4	0.0009112	S	0.008229165	S	0.574341046	S	0.04514608	S
3.6	0.00078594	S	0.008229165	S	0.591300197	S	0.04927429	S
3.8	0.00068335	S	0.007956873	S	0.607802814	S	0.0535261	S
4	0.00059843	S	0.007662405	S	0.623884294	S	0.05789842	S
4.2	0.00052746	S	0.007392426	S	0.639575674	S	0.06238836	S
4.4	0.00046765	S	0.007143872	S	0.654904349	S	0.06699328	S
4.6	0.00041685	S	0.006914182	S	0.669894642	S	0.07171069	S
4.8	0.00037339	S	0.006701191	S	0.678457653	S	0.07214974	S
5	0.00033597	S	0.006503064	S	0.679241627	S	0.07166413	S
5.2	0.00030355	S	0.006534311	S	0.679995703	S	0.07505117	S
5.4	0.00027531	S	0.006779088	S	0.681810282	S	0.08205055	S
5.6	0.00029588	S	0.007023634	S	0.693848594	S	0.08941225	S
5.8	0.00032299	S	0.006800015	S	0.705665874	S	0.09032922	S
6	0.00042363	S	0.005687284	S	0.717273599	S	0.08922841	S
6.2	0.00066041	S	0.005682453	S	0.728682291	S	0.08532738	S
6.4	0.00041303	S	0.006222183	S	0.741474356	S	0.08412491	S
6.6	0.00026213	S	0.006794179	S	0.775060732	S	0.08217196	S
6.8	0.00025	S	0.004873063	S	0.809097631	S	0.07025278	S
7	0.00025	S	0.006085987	S	0.853842309	S	0.07564665	S
7.2	0.00061101	S	0.006417922	S	0.884585932	S	0.08094904	S
7.4	0.00067676	S	0.006758121	S	0.878566169	S	0.08646245	S
7.6	0.00073793	S	0.006075776	S	0.912088317	S	0.08142676	S
7.8	0.00077268	S	0.004902027	S	0.926501966	S	0.06776978	S
8	0.00080811	S	0.003976583	S	0.940769844	S	0.05854378	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.00090965	S	0.003242562	S	0.954897016	S	0.04499244	S
8.4	0.001223	S	0.002657064	S	0.968888251	S	0.03479795	S
8.6	0.00163288	S	0.002187515	S	0.982748049	S	0.02707658	S
8.8	0.00196729	S	0.000639078	S	0.987136677	S	0.02004006	S
9	0.0022661	S	0.000122009	S	0.987495072	S	0.01458374	S
9.2	0.00318064	S	9.59691E-05	S	1.001884044	S	0.0190165	S
9.4	0.00297927	S	3.22287E-05	S	0.988188938	S	0.01178494	S
9.6	0.00340127	S	1.10747E-05	S	0.98852505	S	0.00706933	S
9.8	0.00387246	S	3.89034E-06	S	0.964371145	S	0.004663	S
10	0.00427396	S	0.0000018	S	0.935886438	S	0.0029748	S
10.2	0.00432612	S	0.0000018	S	0.908782511	S	0.002783	S
10.4	0.00437788	S	0.0000018	S	0.882967283	S	0.002783	S
10.6	0.00442926	S	0.0000018	S	0.858356431	S	0.002783	S
10.8	0.00448026	S	0.0000018	S	0.834872599	S	0.002783	S
11	0.00449758	S	0.0000018	S	0.812444713	S	0.002783	S
11.2	0.00391144	S	0.0000018	S	0.746642264	S	0.002783	S
11.4	0.00361218	S	0.0000018	S	0.677436756	S	0.002783	S
11.6	0.00406486	S	0.0000018	S	0.615686536	S	0.002783	S
11.8	0.00391568	S	0.0000018	S	0.584034513	S	0.002783	S
12	0.00377434	S	0.0000018	S	0.561838194	S	0.002783	S
12.2	0.00364032	S	0.0000018	S	0.54083172	S	0.002783	S
12.4	0.00351312	S	0.0000018	S	0.520933342	S	0.002783	S
12.6	0.0033923	S	0.0000018	S	0.50206812	S	0.002783	S
12.8	0.00327744	S	0.0000018	S	0.484167264	S	0.002783	S
13	0.00316816	S	0.0000018	S	0.467167543	S	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	0.0449758		0.082291646		10.01884039		0.90329221	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.3971332	S	0.053155	S	0.0298035	S
3	0.3706197	S	0.045422	S	0.0205709	S
3.2	0.3593231	S	0.04458	S	0.0163936	S
3.4	0.3793715	S	0.048501	S	0.0155638	S
3.6	0.4007104	S	0.052513	S	0.0166702	S
3.8	0.4219988	S	0.056613	S	0.017789	S
4	0.4432395	S	0.060798	S	0.0189197	S
4.2	0.4644349	S	0.065066	S	0.0200619	S
4.4	0.4855874	S	0.069414	S	0.021215	S
4.6	0.5219694	S	0.07384	S	0.0223788	S
4.8	0.5277715	S	0.078342	S	0.0235529	S
5	0.5488065	S	0.082917	S	0.0247368	S
5.2	0.5698058	S	0.087565	S	0.0259303	S
5.4	0.5907706	S	0.092283	S	0.023131	S
5.6	0.4885374	S	0.096635	S	0.0247533	S
5.8	0.3968366	S	0.098435	S	0.0256808	S
6	0.3246287	S	0.094173	S	0.022712	S
6.2	0.2921577	S	0.089982	S	0.0201674	S
6.4	0.2750503	S	0.085187	S	0.0198161	S
6.6	0.259426	S	0.080783	S	0.0224988	S
6.8	0.258985	S	0.076865	S	0.0152879	S
7	0.3144151	S	0.073399	S	0.0251514	S
7.2	0.2630267	S	0.068846	S	0.034302	S
7.4	0.2359023	S	0.069523	S	0.0292119	S
7.6	0.1817955	S	0.05789	S	0.0375282	S
7.8	0.1387417	S	0.046166	S	0.052072	S
8	0.102757	S	0.0388	S	0.0716555	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.0753816	S	0.034298	S	0.0978298	S
8.4	0.0641702	S	0.030409	S	0.132069	S
8.6	0.0502349	S	0.027037	S	0.1438477	S
8.8	0.0395478	S	0.024044	S	0.1600152	S
9	0.0383201	S	0.020995	S	0.1827922	S
9.2	0.0414587	S	0.019333	S	0.2207143	S
9.4	0.0315514	S	0.017373	S	0.2608776	S
9.6	0.0243615	S	0.017697	S	0.2486941	S
9.8	0.0222872	S	0.016951	S	0.2707381	S
10	0.0202104	S	0.016092	S	0.2393998	S
10.2	0.0177928	S	0.015891	S	0.1919029	S
10.4	0.0157031	S	0.015697	S	0.1359288	S
10.6	0.0138919	S	0.015508	S	0.0969157	S
10.8	0.0123178	S	0.015163	S	0.0695382	S
11	0.011184	S	0.013279	S	0.0501993	S
11.2	0.0107277	S	0.011657	S	0.039563	S
11.4	0.0102976	S	0.010257	S	0.0317637	S
11.6	0.0098917	S	0.009134	S	0.0255995	S
11.8	0.0095084	S	0.008814	S	0.0207078	S
12	0.0092088	S	0.008511	S	0.0150085	S
12.2	0.0089325	S	0.008222	S	0.0097672	S
12.4	0.0086689	S	0.007948	S	0.0064008	S
12.6	0.008417	S	0.007688	S	0.0042231	S
12.8	0.0081763	S	0.007439	S	0.0028047	S
13	0.007946	S	0.007203	S	0.0018745	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	5.9077064		0.984352		2.7073805	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID	MAS-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.651717	S	28.29772	W	0.0103772	S	0.189133	S
3	0.628388	S	27.92793	W	0.0104137	S	0.177573	S
3.2	0.593591	S	27.76181	W	0.0103258	S	0.168925	S
3.4	0.558516	S	27.66331	W	0.010205	S	0.161657	S
3.6	0.527347	S	27.57077	W	0.0100924	S	0.155092	S
3.8	0.499467	S	27.48351	W	0.009987	S	0.149128	S
4	0.47438	S	27.40099	W	0.009888	S	0.143682	S
4.2	0.451688	S	27.32273	W	0.0097948	S	0.138686	S
4.4	0.431063	S	27.24831	W	0.0097067	S	0.134085	S
4.6	0.412236	S	27.1774	W	0.0096233	S	0.12983	S
4.8	0.394981	S	27.10967	W	0.0095441	S	0.125884	S
5	0.38158	S	27.07321	W	0.009459	S	0.122658	S
5.2	0.371491	S	27.06602	W	0.0093684	S	0.120066	S
5.4	0.362035	S	27.0591	W	0.0092821	S	0.117624	S
5.6	0.35315	S	27.05243	W	0.0091996	S	0.115317	S
5.8	0.344784	S	27.046	W	0.0091208	S	0.113134	S
6	0.33689	S	27.03979	W	0.0090452	S	0.111065	S
6.2	0.329426	S	27.03378	W	0.0089728	S	0.109099	S
6.4	0.322358	S	27.02797	W	0.0089031	S	0.107229	S
6.6	0.315651	S	27.02234	W	0.0088362	S	0.105447	S
6.8	0.298456	S	26.94733	W	0.0084452	S	0.097359	S
7	0.264814	S	26.74821	S	0.00754	S	0.080205	S
7.2	0.219682	S	26.3556	S	0.006456	S	0.055421	S
7.4	0.162898	S	25.34095	S	0.0053631	S	0.02451	S
7.6	0.127124	S	24.12308	S	0.0047314	S	0.010971	S
7.8	0.108985	S	22.65715	S	0.0045387	S	0.005535	S
8	0.093799	S	21.31411	S	0.0043584	S	0.002841	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID	MAS-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.088573	S	20.49924	S	0.0042315	W	0.002062	S
8.4	0.099777	S	18.77486	S	0.0043164	W	0.002062	S
8.6	0.105459	S	17.89222	S	0.0043524	W	0.002062	S
8.8	0.09292	S	19.08632	S	0.0042458	W	0.002062	S
9	0.082105	S	20.33057	S	0.0041442	W	0.002062	S
9.2	0.087249	S	17.70487	S	0.0041357	W	0.002062	S
9.4	0.093475	S	15.30395	S	0.004132	W	0.002062	S
9.6	0.099999	S	13.26926	S	0.0041284	W	0.002062	S
9.8	0.106831	S	11.53898	S	0.0041249	W	0.002062	S
10	0.113976	S	10.06269	S	0.0041215	W	0.002062	S
10.2	0.121444	S	8.799103	S	0.0041181	W	0.002062	S
10.4	0.127463	S	6.666161	S	0.0041209	W	0.002062	S
10.6	0.132872	S	4.771862	S	0.0041263	W	0.002062	S
10.8	0.138403	S	3.437272	S	0.0041316	W	0.002062	S
11	0.144057	S	2.490888	S	0.0041368	W	0.002062	S
11.2	0.150819	S	1.647357	S	0.0039872	W	0.002062	S
11.4	0.159644	S	0.953913	S	0.0035516	W	0.002062	S
11.6	0.1734	S	0.543603	S	0.0034845	W	0.002062	S
11.8	0.27502	S	0.42246	S	0.0037769	W	0.002062	S
12	0.486465	S	0.36721	S	0.0040957	W	0.002062	S
12.2	0.852401	S	0.319926	S	0.0044355	W	0.002062	S
12.4	0.955732	S	0.279356	S	0.0047972	W	0.002062	S
12.6	1.058103	S	0.244461	S	0.0051819	W	0.002062	S
12.8	1.058103	S	0.214374	S	0.0055778	W	0.002062	S
13	1.058103	S	0.188374	S	0.0054845	W	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.00065		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.00065		0.00017		0.00041	
Availability (mg/kg)	11.11008		279.2793		0.1041374		1.775733	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.00501971	S	0.002968096	S	0.575310267	S	0.07267789	S
3	0.00445237	S	0.004121037	S	0.573777622	S	0.07635295	S
3.2	0.00397984	S	0.004262	S	0.585583871	S	0.07646238	S
3.4	0.00358175	S	0.004026604	S	0.601325241	S	0.0754661	S
3.6	0.00324296	S	0.003816587	S	0.616553955	S	0.07453867	S
3.8	0.00295204	S	0.003628019	S	0.63131387	S	0.07367189	S
4	0.00270021	S	0.003457745	S	0.645643009	S	0.0728589	S
4.2	0.00248063	S	0.003303202	S	0.659574583	S	0.07209391	S
4.4	0.00228792	S	0.003162287	S	0.673137801	S	0.07137199	S
4.6	0.00211778	S	0.003033257	S	0.686358512	S	0.07068893	S
4.8	0.00196675	S	0.002914656	S	0.699259715	S	0.07004107	S
5	0.0018975	S	0.002933962	S	0.717571493	S	0.07008738	S
5.2	0.0018975	S	0.003085411	S	0.741401551	S	0.07078776	S
5.4	0.0018975	S	0.003238519	S	0.765078972	S	0.0714683	S
5.6	0.0018975	S	0.003393242	S	0.788610336	S	0.07213028	S
5.8	0.0018975	S	0.003549539	S	0.812001716	S	0.07277483	S
6	0.0018975	S	0.00370737	S	0.83525873	S	0.07340301	S
6.2	0.0018975	S	0.003866699	S	0.858386593	S	0.07401574	S
6.4	0.0018975	S	0.00402749	S	0.881390156	S	0.07461389	S
6.6	0.0018975	S	0.004189712	S	0.904273941	S	0.07519825	S
6.8	0.0018975	S	0.00412917	S	0.92395426	S	0.07598802	S
7	0.0018975	S	0.00369573	S	0.937729482	S	0.07716849	S
7.2	0.0018975	S	0.00332014	S	0.957496721	W	0.07997228	S
7.4	0.0018975	S	0.003072436	S	0.996420153	W	0.08457755	S
7.6	0.0018975	S	0.002363883	S	1.031442722	W	0.08528562	S
7.8	0.0018975	S	0.001161859	S	1.048491647	W	0.0785737	S
8	0.0018975	S	0.000581422	S	1.065380061	W	0.0725404	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.00202841	S	0.000487447	S	1.083876407	W	0.0653608	S
8.4	0.00271683	S	0.000442568	S	1.106700383	W	0.05082645	S
8.6	0.0034959	S	0.00033709	S	1.123272236	W	0.03843427	S
8.8	0.00405285	S	0.000152427	S	1.121311431	W	0.02645462	S
9	0.00468295	S	7.01653E-05	S	1.119398001	W	0.01836242	S
9.2	0.00458238	S	5.30146E-05	S	1.130459367	W	0.01659988	S
9.4	0.00444815	S	4.13149E-05	S	1.1420725	W	0.01524108	S
9.6	0.00432055	S	3.23666E-05	S	1.153556679	W	0.01401869	S
9.8	0.00419913	S	2.54844E-05	S	1.164915978	W	0.01291659	S
10	0.00408347	S	2.01627E-05	S	1.176154264	W	0.01192084	S
10.2	0.00397319	S	1.60265E-05	S	1.187275208	W	0.01101934	S
10.4	0.00378353	S	1.31212E-05	S	1.196085049	W	0.00939966	S
10.6	0.00357266	S	1.08992E-05	S	1.203852265	W	0.00776767	S
10.8	0.00337716	S	9.08498E-06	S	1.211523322	W	0.00644195	S
11	0.00319566	S	7.59806E-06	S	1.21910116	W	0.00536087	S
11.2	0.00285464	S	6.85887E-06	S	1.2135952	W	0.00482936	S
11.4	0.00237606	S	7.19445E-06	S	1.18621477	W	0.00491853	S
11.6	0.00198403	S	1.06627E-05	S	1.144530319	W	0.00530963	S
11.8	0.0018975	S	2.34537E-05	S	1.103445373	W	0.00749782	S
12	0.0018975	S	5.18947E-05	S	1.068663684	W	0.01129014	S
12.2	0.0018975	S	0.000113327	S	1.035526432	W	0.01688593	S
12.4	0.0018975	S	0.00024436	S	1.003930788	W	0.02509041	S
12.6	0.0018975	S	0.000520458	S	0.973781872	W	0.03704578	S
12.8	0.0018975	S	0.001095394	S	0.944992024	W	0.05436314	S
13	0.0018975	S	0.001423162	S	0.917480155	W	0.07930268	S
Detection Limit (min, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.0000036		0.00076		0.00008	
Availability (mg/kg)	0.0468295		0.042620001		12.19101165		0.85285619	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.4248412	S	0.066133	S	0.0755979	S
3	0.4358752	S	0.060304	S	0.0737456	S
3.2	0.4243739	S	0.057141	S	0.0657652	S
3.4	0.4071126	S	0.054895	S	0.0573384	S
3.6	0.3914818	S	0.052857	S	0.0503849	S
3.8	0.3772491	S	0.051	S	0.0445852	S
4	0.3642251	S	0.049298	S	0.0397014	S
4.2	0.3522543	S	0.047732	S	0.0355534	S
4.4	0.341207	S	0.046286	S	0.0320026	S
4.6	0.3309747	S	0.044944	S	0.0289415	S
4.8	0.3214656	S	0.043696	S	0.0262854	S
5	0.3120439	S	0.042667	S	0.0248689	S
5.2	0.3027215	S	0.041831	S	0.0244495	S
5.4	0.2940139	S	0.041042	S	0.0240527	S
5.6	0.2858602	S	0.040296	S	0.0236764	S
5.8	0.278207	S	0.039589	S	0.0233189	S
6	0.2710079	S	0.038918	S	0.0229786	S
6.2	0.2642222	S	0.03828	S	0.0226542	S
6.4	0.2578139	S	0.037671	S	0.0223445	S
6.6	0.2517512	S	0.037091	S	0.0220483	S
6.8	0.2428704	S	0.035898	S	0.0227551	S
7	0.2291045	S	0.033672	S	0.0254542	S
7.2	0.2127745	S	0.030462	S	0.0299363	S
7.4	0.1954612	S	0.02579	S	0.0381287	S
7.6	0.1835515	S	0.022352	S	0.0484813	S
7.8	0.1774314	S	0.020301	S	0.0627524	S
8	0.1716626	S	0.018483	S	0.0806954	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-65. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID MAD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.1653415	S	0.017106	S	0.098127	S
8.4	0.1583139	S	0.015433	S	0.1483761	S
8.6	0.1441137	S	0.014012	S	0.2115185	S
8.8	0.1128275	S	0.012902	S	0.258482	S
9	0.0888206	S	0.011902	S	0.3144526	S
9.2	0.0836645	S	0.01141	S	0.3514403	W
9.4	0.079628	S	0.010969	S	0.3902015	W
9.6	0.0758653	S	0.010554	S	0.4322845	W
9.8	0.0723525	S	0.010162	S	0.4778958	W
10	0.0690685	S	0.009793	S	0.52725	W
10.2	0.0659942	S	0.009444	S	0.5805702	W
10.4	0.0616786	S	0.009136	S	0.6106144	W
10.6	0.0571591	S	0.008853	S	0.6297209	W
10.8	0.0530462	S	0.008584	S	0.6490514	W
11	0.0492967	S	0.008328	S	0.6686042	W
11.2	0.046187	S	0.007986	S	0.5949069	W
11.4	0.0458791	S	0.00748	S	0.3712251	W
11.6	0.0404773	S	0.007809	S	0.4852507	W
11.8	0.0413217	S	0.009843	S	1.1373979	W
12	0.0459755	S	0.012702	S	1.2449889	W
12.2	0.0510634	S	0.016321	S	1.2449889	W
12.4	0.0566175	S	0.020887	S	1.2449889	W
12.6	0.0626722	S	0.026625	S	1.2449889	W
12.8	0.0692634	S	0.033809	S	1.2449889	W
13	0.0764292	S	0.042773	S	1.2449889	W
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	4.3587517		0.603037		13.072383	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID	UGF-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.170429	S	3.33414	W	0.0519957	S	0.064309	S
3	0.14451	S	3.332239	W	0.0499608	S	0.061509	S
3.2	0.117952	S	3.323924	W	0.0473012	S	0.05875	S
3.4	0.097468	S	3.316132	W	0.0449319	S	0.056271	S
3.6	0.081425	S	3.308803	W	0.0428069	S	0.054029	S
3.8	0.068687	S	3.301885	W	0.0408894	S	0.051991	S
4	0.058449	S	3.295335	W	0.0391497	S	0.050129	S
4.2	0.053248	S	3.324343	W	0.0375171	S	0.048872	S
4.4	0.050673	S	3.37558	W	0.0359949	S	0.047995	S
4.6	0.048328	S	3.425277	W	0.034598	S	0.047171	S
4.8	0.046185	S	3.473544	W	0.0333114	S	0.046395	S
5	0.044219	S	3.52048	S	0.0321224	S	0.045663	S
5.2	0.043574	S	3.505845	S	0.031697	S	0.046014	S
5.4	0.043908	S	3.444314	S	0.0318403	S	0.047216	S
5.6	0.044232	S	3.386043	S	0.0319789	S	0.048405	S
5.8	0.037278	S	2.393761	S	0.0189193	S	0.031176	S
6	0.03131	S	1.683262	S	0.0110862	S	0.019898	S
6.2	0.026448	S	1.197395	S	0.0066111	S	0.012888	S
6.4	0.022461	S	0.861033	S	0.0040077	S	0.008463	S
6.6	0.019171	S	0.625474	S	0.0024672	S	0.00563	S
6.8	0.016441	S	0.458715	S	0.001541	S	0.003791	S
7	0.014162	S	0.339454	S	0.0009757	S	0.002583	S
7.2	0.012563	S	0.275716	S	0.0007464	S	0.002062	S
7.4	0.011606	S	0.255272	S	0.0007464	S	0.002062	S
7.6	0.010744	S	0.236831	S	0.0007464	S	0.002062	S
7.8	0.009967	S	0.22015	S	0.0007464	S	0.002062	S
8	0.009263	S	0.205023	S	0.0007464	S	0.002062	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID	UGF-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.008624	S	0.191272	S	0.0007464	S	0.002062	S
8.4	0.008003	S	0.193375	S	0.0007464	S	0.002062	S
8.6	0.007415	S	0.205852	S	0.0007464	S	0.002062	S
8.8	0.007236	S	0.206066	S	0.0007464	S	0.002062	S
9	0.007256	S	0.199782	S	0.0007464	S	0.002062	S
9.2	0.007275	S	0.193823	S	0.0007464	S	0.002062	S
9.4	0.007294	S	0.188163	S	0.0007464	S	0.002062	S
9.6	0.007313	S	0.182783	S	0.0007464	S	0.002062	S
9.8	0.007331	S	0.177663	S	0.0007464	S	0.002062	S
10	0.007349	S	0.172786	S	0.0007464	S	0.002062	S
10.2	0.007367	S	0.168135	S	0.0007464	S	0.002062	S
10.4	0.006933	S	0.140755	S	0.0007464	S	0.002062	S
10.6	0.006447	S	0.124089	S	0.0007464	S	0.002062	S
10.8	0.005828	S	0.129592	S	0.0007464	S	0.002062	S
11	0.005279	S	0.13523	S	0.0007464	S	0.002062	S
11.2	0.00479	S	0.141006	S	0.0007464	S	0.002062	S
11.4	0.004354	S	0.146919	S	0.0007464	S	0.002062	S
11.6	0.003964	S	0.152971	S	0.0007464	S	0.002062	S
11.8	0.003615	S	0.159163	S	0.0007464	S	0.002062	S
12	0.003302	S	0.165495	S	0.0007464	S	0.002062	S
12.2	0.00302	S	0.171967	S	0.0007464	S	0.002062	S
12.4	0.002767	S	0.178582	S	0.0007464	S	0.002062	S
12.6	0.002538	S	0.185339	S	0.0007464	S	0.002062	S
12.8	0.002331	S	0.192239	S	0.0007464	S	0.002062	S
13	0.002144	S	0.199283	S	0.0007464	S	0.002062	S
Detection Limit (min, mg/L)	0.00064		0.001		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.001		0.00017		0.00041	
Availability (mg/kg)	1.222073		29.7715		0.4225018		0.520161	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.33609738	S	0.000365435	S	0.299761642	S	0.01749736	S
3	0.29168755	S	0.000368326	S	0.288405559	S	0.01648806	S
3.2	0.24974311	S	0.000418263	S	0.288229902	S	0.0152672	S
3.4	0.21585299	S	0.000471321	S	0.288064995	S	0.01420284	S
3.6	0.18812383	S	0.000527496	S	0.287909603	S	0.01326739	S
3.8	0.16518057	S	0.000586782	S	0.287762691	S	0.0124393	S
4	0.14600646	S	0.000649175	S	0.287623387	S	0.01170153	S
4.2	0.11591717	S	0.000702204	S	0.296014277	S	0.01154855	S
4.4	0.08639843	S	0.000748171	S	0.310087874	S	0.01174376	S
4.6	0.06524373	S	0.000794903	S	0.324160481	S	0.01193337	S
4.8	0.04986128	S	0.000842379	S	0.338232141	S	0.01211778	S
5	0.03852617	S	0.000890579	S	0.352302894	S	0.01229734	S
5.2	0.0308847	S	0.000843331	S	0.350952214	S	0.01201672	S
5.4	0.02550761	S	0.000733785	S	0.337791319	S	0.01140675	S
5.6	0.02121376	S	0.000641707	S	0.325576264	S	0.01084828	S
5.8	0.02246646	S	0.000280713	S	0.281630261	S	0.00895113	S
6	0.02403774	S	0.000121812	S	0.243433803	S	0.00737893	S
6.2	0.02566197	S	5.43255E-05	S	0.2114259	S	0.00612153	S
6.4	0.02733912	S	2.48573E-05	S	0.184450315	S	0.00510861	S
6.6	0.02906919	S	1.16508E-05	S	0.161593866	S	0.00428709	S
6.8	0.03085218	S	5.58572E-06	S	0.142129968	S	0.00361657	S
7	0.03268807	S	0.000003	S	0.125476474	S	0.00306599	S
7.2	0.03217423	S	0.000003	S	0.116568592	W	0.002783	S
7.4	0.02847989	S	0.000003	S	0.116408003	W	0.002783	S
7.6	0.02529188	S	0.000003	S	0.116251909	W	0.002783	S
7.8	0.02253011	S	0.000003	S	0.116100072	W	0.002783	S
8	0.02012876	S	0.000003	S	0.115952269	W	0.002783	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.01803347	S	0.000003	S	0.115808298	W	0.002783	S
8.4	0.0193626	S	0.000003	S	0.118231796	W	0.002783	S
8.6	0.02334347	S	0.000003	S	0.122402557	W	0.002783	S
8.8	0.02549786	S	0.000003	S	0.122776468	W	0.002783	S
9	0.02643334	S	0.000003	S	0.121138715	W	0.002783	S
9.2	0.02738144	S	0.000003	S	0.119558093	W	0.002783	S
9.4	0.02834206	S	0.000003	S	0.118031431	W	0.002783	S
9.6	0.02931509	S	0.000003	S	0.116555796	W	0.002783	S
9.8	0.03030044	S	0.000003	S	0.115128472	W	0.002783	S
10	0.03129799	S	0.000003	S	0.113746939	W	0.002783	S
10.2	0.03230765	S	0.000003	S	0.112408855	W	0.002783	S
10.4	0.02259128	S	0.000003	S	0.116508921	W	0.002783	S
10.6	0.01726121	S	0.000003	S	0.120095338	W	0.002783	S
10.8	0.01795424	S	0.000003	S	0.121067625	W	0.002783	S
11	0.01866162	S	0.000003	S	0.122029728	W	0.002783	S
11.2	0.01938336	S	0.000003	S	0.122981934	W	0.002783	S
11.4	0.0201195	S	0.000003	S	0.123924519	W	0.002783	S
11.6	0.02087006	S	0.000003	S	0.124857748	W	0.002783	S
11.8	0.02163507	S	0.000003	S	0.125781872	W	0.002783	S
12	0.02241456	S	0.000003	S	0.126697131	W	0.002783	S
12.2	0.02320855	S	0.000003	S	0.127603757	W	0.002783	S
12.4	0.02401706	S	0.000003	S	0.128501971	W	0.002783	S
12.6	0.02484013	S	0.000003	S	0.129391984	W	0.002783	S
12.8	0.02567777	S	0.000003	S	0.130273999	W	0.002783	S
13	0.02653002	S	0.000003	S	0.131148213	W	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.000006		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.000006		0.00076		0.00008	
Availability (mg/kg)	2.4667023		0.007531323		2.979305654		0.13943391	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	0.384471	S	0.042387	S	0.7175652	S
3	0.3563424	S	0.040229	S	0.593018	S
3.2	0.3161224	S	0.037533	S	0.4609003	S
3.4	0.2824862	S	0.035164	S	0.3637343	S
3.6	0.2540579	S	0.033068	S	0.2909648	S
3.8	0.229805	S	0.031201	S	0.2355805	S
4	0.20894	S	0.029527	S	0.192816	S
4.2	0.1904101	S	0.028267	S	0.1588509	S
4.4	0.1740108	S	0.027271	S	0.1317767	S
4.6	0.1596619	S	0.026353	S	0.1102288	S
4.8	0.1470339	S	0.025503	S	0.0929079	S
5	0.135861	S	0.024714	S	0.0788571	S
5.2	0.1271408	S	0.024253	S	0.0654164	S
5.4	0.120201	S	0.024036	S	0.0533789	S
5.6	0.1138723	S	0.023828	S	0.0438799	S
5.8	0.0875445	S	0.017411	S	0.0493057	S
6	0.06717	S	0.012657	S	0.0560637	S
6.2	0.051987	S	0.009298	S	0.0634801	S
6.4	0.0405646	S	0.006897	S	0.0715945	S
6.6	0.0318944	S	0.005164	S	0.0804478	S
6.8	0.0252581	S	0.003899	S	0.0900818	S
7	0.0201384	S	0.002969	S	0.1005394	S
7.2	0.0172086	S	0.00253	S	0.1095691	S
7.4	0.0162095	S	0.00253	S	0.1155303	S
7.6	0.0152927	S	0.00253	S	0.1216438	S
7.8	0.0144497	S	0.00253	S	0.1279094	S
8	0.0136727	S	0.00253	S	0.1343268	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-67. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID UGF Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.0129552	S	0.00253	S	0.1408957	S
8.4	0.0132229	S	0.00253	S	0.1462939	S
8.6	0.014155	S	0.00253	S	0.1508676	S
8.8	0.0146814	S	0.002744	S	0.1521562	S
9	0.0149734	S	0.003102	S	0.1516743	S
9.2	0.0152647	S	0.003498	S	0.1512044	S
9.4	0.0155552	S	0.003934	S	0.1507461	S
9.6	0.015845	S	0.004413	S	0.1502987	S
9.8	0.016134	S	0.004939	S	0.1498619	S
10	0.0164222	S	0.005515	S	0.1494351	S
10.2	0.0167098	S	0.006145	S	0.149018	S
10.4	0.0124952	S	0.006647	S	0.1308095	S
10.6	0.0099833	S	0.007055	S	0.1154959	S
10.8	0.0100613	S	0.007129	S	0.1052915	S
11	0.0101384	S	0.007202	S	0.0961518	S
11.2	0.0102147	S	0.007275	S	0.0879492	S
11.4	0.0102902	S	0.007348	S	0.0805735	S
11.6	0.010365	S	0.00742	S	0.0739288	S
11.8	0.010439	S	0.007491	S	0.067932	S
12	0.0105123	S	0.007562	S	0.0625104	S
12.2	0.0105848	S	0.007632	S	0.0576007	S
12.4	0.0106567	S	0.007702	S	0.0531472	S
12.6	0.0107279	S	0.007771	S	0.0491013	S
12.8	0.0107984	S	0.00784	S	0.0454199	S
13	0.0108683	S	0.007908	S	0.0420654	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	3.0134665		0.340207		5.0149516	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID	VSD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.021922	S	25.82672	S	0.0455954	S	2.107023	S
3	0.851966	S	36.65751	S	0.1573169	S	3.112229	S
3.2	0.239429	S	33.50198	S	0.1387351	S	3.162106	S
3.4	0.096927	S	31.78382	S	0.1035519	S	3.093469	S
3.6	0.05201	S	30.45572	S	0.078247	S	2.960458	S
3.8	0.03795	S	29.49354	S	0.0597129	S	2.762408	S
4	0.028143	S	28.60883	S	0.0462054	S	2.586779	S
4.2	0.021177	S	27.79194	S	0.0362036	S	2.430095	S
4.4	0.016147	S	27.03479	S	0.0286906	S	2.289548	S
4.6	0.012461	S	26.33058	S	0.0229731	S	2.16285	S
4.8	0.009723	S	25.67354	S	0.0185698	S	2.048121	S
5	0.007977	S	25.1077	S	0.0151063	S	1.94767	S
5.2	0.008232	S	24.84377	S	0.0122298	S	1.876438	S
5.4	0.008486	S	24.59243	S	0.0099802	S	1.810355	S
5.6	0.009438	S	24.1536	S	0.008415	S	1.649638	S
5.8	0.009427	S	23.47815	S	0.0067511	S	1.430101	S
6	0.007422	S	22.27484	S	0.004802	S	1.102904	S
6.2	0.005889	S	20.89532	S	0.0030924	S	0.803378	S
6.4	0.004708	S	19.64107	S	0.0020195	S	0.591114	S
6.6	0.003789	S	18.49731	S	0.0013362	S	0.43906	S
6.8	0.0032	S	17.43887	S	0.000938	S	0.326384	S
7	0.0032	S	16.42258	S	0.0008004	S	0.237061	S
7.2	0.0032	S	15.36151	S	0.0007464	W	0.162146	S
7.4	0.0032	S	14.29759	S	0.0007464	W	0.105989	S
7.6	0.0032	S	13.33286	S	0.0007464	W	0.070071	S
7.8	0.0032	S	12.4558	S	0.0007464	W	0.046826	S
8	0.0032	S	11.65651	S	0.0007464	W	0.031613	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID	VSD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:58 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term model
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.0032	S	10.98276	S	0.0007464	W	0.022736	S
8.4	0.0032	S	10.30835	S	0.0007464	W	0.020073	S
8.6	0.0032	S	8.876371	S	0.0007464	W	0.017683	S
8.8	0.0032	S	5.422514	S	0.0007464	W	0.01531	S
9	0.0032	S	3.349469	S	0.0007464	W	0.013299	S
9.2	0.0032	S	2.0413	S	0.0007464	W	0.011921	S
9.4	0.0032	S	1.470385	S	0.0007464	W	0.011205	S
9.6	0.0032	S	1.066485	S	0.0007464	W	0.010546	S
9.8	0.0032	S	0.778672	S	0.0007464	W	0.009938	S
10	0.0032	S	0.572156	S	0.0007464	W	0.009377	S
10.2	0.0032	S	0.422985	S	0.0007464	W	0.008857	S
10.4	0.0032	S	0.314545	S	0.0007464	W	0.008375	S
10.6	0.0032	S	0.264926	S	0.0007464	W	0.008019	S
10.8	0.0032	S	0.223851	S	0.0007464	W	0.007685	S
11	0.0032	S	0.189731	S	0.0007464	W	0.00737	S
11.2	0.0032	S	0.161291	S	0.0007464	W	0.007073	S
11.4	0.0032	S	0.138952	S	0.0007464	W	0.006517	S
11.6	0.0032	S	0.12002	S	0.0007464	W	0.005765	S
11.8	0.0032	S	0.103927	S	0.0007464	W	0.005111	S
12	0.0032	S	0.090209	S	0.0007464	W	0.00454	S
12.2	0.0032	S	0.078486	S	0.0007464	W	0.004041	S
12.4	0.0032	S	0.068441	S	0.0007464	W	0.003604	S
12.6	0.0032	S	0.059813	S	0.0007464	W	0.003219	S
12.8	0.0032	S	0.052383	S	0.0007464	W	0.002881	S
13	0.0032	S	0.045971	S	0.0007464	W	0.002583	S
Detection Limit (min, mg/L)	0.00064		0.001		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.001		0.00017		0.00041	
Availability (mg/kg)	8.39375		361.1577		1.5499198		31.15375	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.04250708	S	0.009098806	S	0.068849437	S	0.00493199	S
3	6.06254728	S	0.013395627	S	0.551618162	S	0.00986152	S
3.2	2.51320264	S	0.012060639	S	0.275456235	S	0.0115007	S
3.4	1.12051008	S	0.00669879	S	0.233095889	S	0.01121921	S
3.6	0.6381568	S	0.004121433	S	0.219903653	S	0.01142478	S
3.8	0.47455319	S	0.002824807	S	0.234172134	S	0.01221124	S
4	0.35829638	S	0.001973996	S	0.248563416	S	0.01300733	S
4.2	0.2742557	S	0.001403781	S	0.263072335	S	0.01381268	S
4.4	0.21255448	S	0.00101424	S	0.277694178	S	0.01462695	S
4.6	0.16661185	S	0.00074346	S	0.292424629	S	0.01544983	S
4.8	0.13196037	S	0.000552226	S	0.307259717	S	0.01628103	S
5	0.10568938	S	0.000429166	S	0.322741181	S	0.0169329	S
5.2	0.08617447	S	0.000404867	S	0.34154435	S	0.01654077	S
5.4	0.07080633	S	0.000382785	S	0.360671291	S	0.01617201	S
5.6	0.05331939	S	0.000265673	S	0.387334633	S	0.01534605	S
5.8	0.04011867	S	0.000197625	S	0.418557868	S	0.01452174	S
6	0.02973525	S	0.000169034	S	0.460212221	S	0.0136221	S
6.2	0.02778184	S	0.000252316	S	0.503496899	S	0.01281731	S
6.4	0.02601282	S	0.000371871	S	0.549282697	S	0.0120834	S
6.6	0.02440581	S	0.000541572	S	0.597629189	S	0.01141221	S
6.8	0.02368432	S	0.000719995	S	0.643822729	S	0.01084194	S
7	0.02608248	S	0.000692722	S	0.672230016	S	0.01048689	S
7.2	0.02737354	S	0.000469278	S	0.688183475	S	0.01018451	S
7.4	0.02765787	S	0.000241877	S	0.693625741	S	0.00992357	S
7.6	0.02793744	S	0.000126892	S	0.698964191	S	0.00967601	S
7.8	0.02821247	S	6.76942E-05	S	0.704203462	S	0.00944082	S
8	0.02848314	S	3.66926E-05	S	0.709347869	S	0.00921709	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID
Date Exported
Database Name ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.03154131	S	2.27226E-05	S	0.716376565	S	0.00843234	S
8.4	0.04085896	S	2.02165E-05	S	0.714776369	S	0.00562268	S
8.6	0.05771947	S	1.80662E-05	S	0.706714258	S	0.00397304	S
8.8	0.11672267	S	1.62923E-05	S	0.674063531	S	0.00342751	S
9	0.23233513	S	1.47267E-05	S	0.643605118	S	0.00296672	S
9.2	0.35694789	S	1.40481E-05	S	0.60790774	S	0.002783	S
9.4	0.36245562	S	1.42898E-05	S	0.58009603	S	0.002783	S
9.6	0.3679297	S	1.45304E-05	S	0.554102755	S	0.002783	S
9.8	0.37337103	S	1.47699E-05	S	0.529774759	S	0.002783	S
10	0.37878047	S	1.50085E-05	S	0.506974554	S	0.002783	S
10.2	0.38415883	S	1.5246E-05	S	0.485578451	S	0.002783	S
10.4	0.38950691	S	1.54826E-05	S	0.465474934	S	0.002783	S
10.6	0.37698017	S	1.51912E-05	S	0.44190069	S	0.002783	S
10.8	0.36507932	S	1.49106E-05	S	0.419928146	S	0.002783	S
11	0.35376233	S	1.46402E-05	S	0.399421768	S	0.002783	S
11.2	0.34299071	S	1.43795E-05	S	0.380259669	S	0.002783	S
11.4	0.32226617	S	1.50321E-05	S	0.33116712	S	0.002783	S
11.6	0.29555977	S	1.62952E-05	S	0.270782496	S	0.002783	S
11.8	0.2714677	S	1.76401E-05	S	0.222171583	S	0.002783	S
12	0.24969604	S	1.90706E-05	S	0.182894539	S	0.002783	S
12.2	0.22998806	S	2.05905E-05	S	0.151046102	S	0.002783	S
12.4	0.21211899	S	2.22038E-05	S	0.125132304	S	0.002783	S
12.6	0.19589161	S	2.39146E-05	S	0.103976994	S	0.002783	S
12.8	0.18113253	S	2.57272E-05	S	0.086650641	S	0.002783	S
13	0.16768898	S	2.76458E-05	S	0.072415864	S	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.000006		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.000006		0.00076		0.00008	
Availability (mg/kg)	59.7295299		0.131976623		7.057897191		0.16682661	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.1576225	S	0.004852	S	0.0605665	S
3	5.1057843	S	0.029302	S	23.638584	S
3.2	4.1720416	S	0.021619	S	9.5885098	S
3.4	3.381112	S	0.017995	S	2.9879587	S
3.6	2.8526916	S	0.016249	S	1.4251639	S
3.8	2.5120723	S	0.016053	S	1.0844818	S
4	2.2266023	S	0.015869	S	0.8368868	S
4.2	1.9852253	S	0.015696	S	0.6540394	S
4.4	1.7794902	S	0.015532	S	0.5170381	S
4.6	1.6028536	S	0.015378	S	0.4130282	S
4.8	1.4501894	S	0.015232	S	0.333111	S
5	1.3290773	S	0.014947	S	0.2712573	S
5.2	1.2834718	S	0.01391	S	0.2237333	S
5.4	1.2410657	S	0.012979	S	0.185882	S
5.6	1.1979054	S	0.011838	S	0.1464559	S
5.8	1.1536757	S	0.01049	S	0.1136495	S
6	1.1036825	S	0.008672	S	0.0842686	S
6.2	1.039981	S	0.006511	S	0.0702142	S
6.4	0.9818077	S	0.004933	S	0.0588437	S
6.6	0.9285318	S	0.00377	S	0.0495834	S
6.8	0.8684001	S	0.002987	S	0.0438246	S
7	0.7736142	S	0.002662	S	0.0459925	S
7.2	0.6876528	S	0.00253	S	0.048754	S
7.4	0.6105198	S	0.00253	S	0.0520753	S
7.6	0.5437614	S	0.00253	S	0.0555252	S
7.8	0.4857619	S	0.00253	S	0.0591051	S
8	0.4351898	S	0.00253	S	0.0628163	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-68. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID VSD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.3941387	S	0.00253	S	0.067339	S
8.4	0.3484185	S	0.00253	S	0.0764078	S
8.6	0.3132505	S	0.00253	S	0.0871577	S
8.8	0.2983866	S	0.00253	S	0.1024114	S
9	0.2845388	S	0.00253	S	0.1198994	S
9.2	0.2612165	S	0.00253	S	0.1304109	S
9.4	0.2340072	S	0.00253	S	0.1258714	S
9.6	0.2101182	S	0.00253	S	0.1215806	S
9.8	0.1890873	S	0.00253	S	0.1175201	S
10	0.1705244	S	0.00253	S	0.1136732	S
10.2	0.1540988	S	0.00253	S	0.1100247	S
10.4	0.1395295	S	0.00253	S	0.1065607	S
10.6	0.1330512	S	0.00253	S	0.1029373	S
10.8	0.1269864	S	0.00253	S	0.0995013	S
11	0.1213018	S	0.00253	S	0.09624	S
11.2	0.1159674	S	0.00253	S	0.0931415	S
11.4	0.1077267	S	0.00253	S	0.0795324	S
11.6	0.0981852	S	0.00253	S	0.0616008	S
11.8	0.0896308	S	0.00253	S	0.047921	S
12	0.0819472	S	0.00253	S	0.0374367	S
12.2	0.0750333	S	0.00253	S	0.0293658	S
12.4	0.0688012	S	0.00253	S	0.0231261	S
12.6	0.0631744	S	0.00253	S	0.0182819	S
12.8	0.0580858	S	0.00253	S	0.014506	S
13	0.0534766	S	0.00253	S	0.0115513	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	50.303294		0.288691		232.89245	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID	YSD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:59 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
2.8	0.036033	S	13.63553	S	0.0877817	S	4.269105	S
3	0.036033	S	13.63553	S	0.0877817	S	4.269105	S
3.2	0.036033	S	13.63553	S	0.0877817	S	4.269105	S
3.4	0.036033	S	13.52439	S	0.0877817	S	4.269105	S
3.6	0.035758	S	13.40264	S	0.0869955	S	4.238166	S
3.8	0.030812	S	13.28849	S	0.0730375	S	3.679403	S
4	0.028135	S	13.24082	S	0.0656282	S	3.339878	S
4.2	0.028272	S	13.3042	S	0.0659622	S	3.259137	S
4.4	0.027683	S	13.27542	S	0.0635075	S	3.150721	S
4.6	0.027095	S	13.2434	S	0.0611126	S	3.048848	S
4.8	0.026544	S	13.21282	S	0.0589044	S	2.954399	S
5	0.026026	S	13.18355	S	0.0568614	S	2.866557	S
5.2	0.025538	S	13.15549	S	0.0549652	S	2.784622	S
5.4	0.025077	S	13.12854	S	0.0532004	S	2.707991	S
5.6	0.016965	S	12.65716	S	0.0399736	S	2.388483	S
5.8	0.011549	S	12.23764	S	0.0303797	S	2.112437	S
6	0.007123	S	12.16975	S	0.0221827	S	1.729012	S
6.2	0.0032	S	11.47057	S	0.0103728	S	1.103218	S
6.4	0.0032	S	10.98014	S	0.0054029	S	0.77459	S
6.6	0.0032	S	10.35436	S	0.0032449	S	0.53159	S
6.8	0.0032	S	9.64889	S	0.0030658	S	0.373823	S
7	0.0032	S	9.009895	S	0.0029014	S	0.265575	S
7.2	0.0032	S	8.429474	S	0.0027501	S	0.190499	S
7.4	0.0032	S	7.900847	S	0.0026105	S	0.137896	S
7.6	0.0032	S	7.418173	S	0.0024814	S	0.100682	S
7.8	0.0032	S	6.943882	S	0.0023675	S	0.076732	S
8	0.0032	S	6.391754	S	0.0022834	S	0.067535	S

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID	YSD-[Med] (P,1,1)
Date Exported	9/20/2011, 8:59 PM
Database Name	C:\Users\kossonds\Documents\LeachXS Databases\EPA Report 4 Database\Source term mode
LeachXS Version	1.2.12.11227

pH	Arsenic	Solubility/ Washout	Boron	Solubility/ Washout	Cadmium	Solubility/ Washout	Cobalt	Solubility/ Washout
8.2	0.0032	S	5.895578	S	0.0022042	W	0.059628	S
8.4	0.0032	S	5.448518	S	0.0021296	W	0.052805	S
8.6	0.0032	S	4.649074	S	0.0021454	W	0.050071	S
8.8	0.0032	S	3.867746	S	0.0021914	W	0.048374	S
9	0.0032	S	3.218893	S	0.0022392	W	0.046416	S
9.2	0.0032	S	2.803114	S	0.0022356	W	0.044437	S
9.4	0.0032	S	2.041365	S	0.0022009	W	0.043543	S
9.6	0.0032	S	1.469018	S	0.0021665	W	0.042783	S
9.8	0.0032	S	1.13143	S	0.0021338	W	0.041712	S
10	0.0032	S	0.905732	S	0.0021032	W	0.040517	S
10.2	0.0032	S	0.728258	S	0.0020737	W	0.039379	S
10.4	0.0032	S	0.520211	S	0.0021015	W	0.036291	S
10.6	0.0032	S	0.373121	S	0.00216	W	0.030166	S
10.8	0.0032	S	0.289772	S	0.002176	W	0.023902	S
11	0.0032	S	0.25874	S	0.0021146	W	0.017305	S
11.2	0.0032	S	0.231503	S	0.0020559	W	0.012602	S
11.4	0.0032	S	0.207542	S	0.0019999	W	0.009229	S
11.6	0.0032	S	0.186414	S	0.0019463	W	0.006796	S
11.8	0.0032	S	0.167745	S	0.001895	W	0.00503	S
12	0.0032	S	0.151214	S	0.0018459	W	0.003742	S
12.2	0.0032	S	0.136545	S	0.0017989	W	0.002797	S
12.4	0.0032	S	0.123505	S	0.0017538	W	0.002101	S
12.6	0.0032	S	0.111889	S	0.0017105	W	0.001586	S
12.8	0.0032	S	0.101524	S	0.001669	W	0.001202	S
13	0.0032	S	0.092257	S	0.001629	W	0.000915	S
Detection Limit (min, mg/L)	0.00064		0.001		0.00017		0.00041	
Detection Limit (max, mg/L)	0.00064		0.001		0.00017		0.00041	
Availability (mg/kg)	0.355883		134.6719		0.86698		42.164	

Electronic Filing: Received, Clerk's Office 07/01/2024

Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID
Date Exported
Database Name :ling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
2.8	0.38983051	S	0.000766976	S	0.225364982	S	0.01416645	S
3	0.24814397	S	0.000766976	S	0.220323107	S	0.01421202	S
3.2	0.16262863	S	0.000766976	S	0.215708907	S	0.01425478	S
3.4	0.10935003	S	0.000766976	S	0.211462591	S	0.01429507	S
3.6	0.07521363	S	0.000750638	S	0.207535644	S	0.0142382	S
3.8	0.05279144	S	0.000493932	S	0.20388821	S	0.0125442	S
4	0.04106211	S	0.000383435	S	0.206537868	S	0.0116513	S
4.2	0.03768771	S	0.000391101	S	0.22066657	S	0.0118124	S
4.4	0.0347289	S	0.000345502	S	0.235037039	S	0.01196808	S
4.6	0.03211892	S	0.000304657	S	0.249642138	S	0.01211876	S
4.8	0.02980404	S	0.000270084	S	0.264475243	S	0.0122648	S
5	0.02774059	S	0.000240614	S	0.279530189	S	0.01240653	S
5.2	0.02589277	S	0.000215334	S	0.294801219	S	0.01254424	S
5.4	0.024231	S	0.000193519	S	0.310282943	S	0.0126782	S
5.6	0.02560142	S	0.000180861	S	0.3670906	S	0.01228779	S
5.8	0.02705581	S	0.000172279	S	0.435190341	S	0.01188926	S
6	0.02975938	S	0.00022836	S	0.594027106	S	0.01126777	S
6.2	0.0350396	S	0.000379866	S	0.81509121	S	0.01101169	S
6.4	0.03820385	S	0.00035165	S	0.925461708	S	0.01018735	S
6.6	0.04049972	S	0.000311981	S	1.023771732	S	0.00911138	S
6.8	0.04120462	S	0.000213862	S	1.068140965	S	0.00875569	S
7	0.04190082	S	0.000148216	S	1.113063296	S	0.0084236	S
7.2	0.04258867	S	0.000103787	S	1.158529522	S	0.00811294	S
7.4	0.04326851	S	7.33888E-05	S	1.204530843	S	0.00782179	S
7.6	0.04394064	S	5.23759E-05	S	1.251058838	S	0.00754843	S
7.8	0.04438244	S	4.08286E-05	S	1.292834064	S	0.00722812	S
8	0.04393926	S	4.3843E-05	S	1.313611531	S	0.0066946	S

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Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID
Date Exported
Database Name eling\EPA Rpt 4 (5-25-11 working db 3 reference-source term rev2).mdb
LeachXS Version

pH	Chromium	Solubility/ Washout	Mercury	Solubility/ Washout	Molybdenum	Solubility/ Washout	Antimony	Solubility/ Washout
8.2	0.04351128	S	4.69972E-05	S	1.334197532	W	0.00621222	S
8.4	0.04309764	S	5.02941E-05	S	1.354598439	W	0.00577499	S
8.6	0.04228543	S	6.5437E-05	S	1.36504665	W	0.00454777	S
8.8	0.04994915	S	5.48837E-05	S	1.369060515	W	0.0035068	S
9	0.08307162	S	1.85208E-05	S	1.367410169	W	0.00286723	S
9.2	0.13724358	S	8.01966E-06	S	1.362205933	W	0.002783	S
9.4	0.099277	S	9.59506E-06	S	1.329145472	W	0.002783	S
9.6	0.06962589	S	1.41555E-05	S	1.294103151	W	0.002783	S
9.8	0.07594641	S	1.53243E-05	S	1.275161665	W	0.002783	S
10	0.0955502	S	1.52173E-05	S	1.263727195	W	0.002783	S
10.2	0.11966883	S	1.51132E-05	S	1.252618679	W	0.002783	S
10.4	0.18628329	S	1.63641E-05	S	1.224011808	W	0.002783	S
10.6	0.26566066	S	1.75464E-05	S	1.195868504	W	0.002783	S
10.8	0.36464963	S	1.83536E-05	S	1.180969879	W	0.002783	S
11	0.46951245	S	1.83707E-05	S	1.188823488	W	0.002783	S
11.2	0.60178377	S	1.83876E-05	S	1.196586405	W	0.002783	S
11.4	0.76793751	S	1.84042E-05	S	1.20426127	W	0.002783	S
11.6	0.97582	S	1.84205E-05	S	1.2118506	W	0.002783	S
11.8	1.23490894	S	1.84365E-05	S	1.219356798	W	0.002783	S
12	1.55661543	S	1.84523E-05	S	1.226782162	W	0.002783	S
12.2	1.74153615	S	1.84679E-05	S	1.234128888	W	0.002783	S
12.4	1.74153615	S	1.84832E-05	S	1.241399078	W	0.002783	S
12.6	1.74153615	S	1.84982E-05	S	1.248594745	W	0.002783	S
12.8	1.74153615	S	1.85131E-05	S	1.255717816	W	0.002783	S
13	1.74153615	S	1.85277E-05	S	1.262770143	W	0.002783	S
Detection Limit (min, mg/L)	0.0005		0.000006		0.00076		0.00008	
Detection Limit (max, mg/L)	0.0005		0.000006		0.00076		0.00008	
Availability (mg/kg)	17.200357		0.00757507		13.52158534		0.14118584	

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Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
2.8	1.2374912	S	0.011501	S	0.304672	S
3	1.2374912	S	0.011501	S	0.3009614	S
3.2	1.2374912	S	0.011501	S	0.2975313	S
3.4	1.2374912	S	0.011501	S	0.2575821	S
3.6	1.232045	S	0.011456	S	0.1991502	S
3.8	1.1308197	S	0.010606	S	0.1561307	S
4	1.0713262	S	0.010096	S	0.1343484	S
4.2	1.0692375	S	0.010056	S	0.1347777	S
4.4	1.0525282	S	0.009912	S	0.1351883	S
4.6	1.0360648	S	0.00977	S	0.1355819	S
4.8	1.0205435	S	0.009636	S	0.1359597	S
5	1.0058744	S	0.00951	S	0.1363231	S
5.2	0.9919794	S	0.00939	S	0.1366732	S
5.4	0.9787901	S	0.009276	S	0.1370109	S
5.6	0.8711547	S	0.008808	S	0.1403208	S
5.8	0.7780516	S	0.008371	S	0.1435163	S
6	0.7012639	S	0.007717	S	0.145705	S
6.2	0.5719786	S	0.006532	S	0.1510276	S
6.4	0.547017	S	0.006008	S	0.1582867	S
6.6	0.5024441	S	0.00545	S	0.1642999	S
6.8	0.4612671	S	0.004846	S	0.1680471	S
7	0.4245156	S	0.004324	S	0.1717675	S
7.2	0.3916073	S	0.00387	S	0.175462	S
7.4	0.3620496	S	0.003474	S	0.1791314	S
7.6	0.3354242	S	0.003128	S	0.1827767	S
7.8	0.3139835	S	0.00286	S	0.1880764	S
8	0.3042713	S	0.002751	S	0.2003568	S

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Table C-5-69. Leachate Concentrations for Mixed CCR's (gypsum, fly ash, sludge scrubber), Waste ID YSD Med

Sample ID
Date Exported
Database Name
LeachXS Version

pH	Selenium	Solubility/ Washout	Thallium	Solubility/ Washout	Vanadium	Solubility/ Washout
8.2	0.2950885	S	0.002649	S	0.2131059	S
8.4	0.2863941	S	0.002553	S	0.2263296	S
8.6	0.2550443	S	0.00253	S	0.2469418	S
8.8	0.2305839	S	0.00253	S	0.2754853	S
9	0.2252909	S	0.00253	S	0.3150631	S
9.2	0.2549067	S	0.00253	S	0.3654792	S
9.4	0.2440135	S	0.00253	S	0.3780552	S
9.6	0.2275782	S	0.00253	S	0.3839065	S
9.8	0.2114307	S	0.00253	S	0.3673189	S
10	0.2017247	S	0.00253	S	0.3527294	S
10.2	0.1926435	S	0.00253	S	0.3389913	S
10.4	0.179057	S	0.00253	S	0.3091858	S
10.6	0.163868	S	0.00253	S	0.2806543	S
10.8	0.1524182	S	0.00253	S	0.2592038	S
11	0.1458099	S	0.00253	S	0.2466787	S
11.2	0.1395995	S	0.00253	S	0.2349684	S
11.4	0.1337566	S	0.00253	S	0.2240068	S
11.6	0.1282537	S	0.00253	S	0.213734	S
11.8	0.1230655	S	0.00253	S	0.2040961	S
12	0.1181691	S	0.00253	S	0.195044	S
12.2	0.1135438	S	0.00253	S	0.1865332	S
12.4	0.1091703	S	0.00253	S	0.1785232	S
12.6	0.1050313	S	0.00253	S	0.1709772	S
12.8	0.1011107	S	0.00253	S	0.1638616	S
13	0.0973939	S	0.00253	S	0.1571457	S
Detection Limit (min, mg/L)	0.00052		0.00051		0.00031	
Detection Limit (max, mg/L)	0.00052		0.00051		0.00031	
Availability (mg/kg)	12.222136		0.113593		3.7916691	

Appendix D.

Human Exposure Factors

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D.1 Introduction

Exposure factors are data that quantify human behavior patterns (e.g., ingestion rates of drinking water and fish) and physiological characteristics (e.g., body weight) that affect an individual's exposure to environmental contaminants. These data can be used to construct realistic assumptions concerning the magnitude of exposure to and subsequent intake of a contaminant in the environment. The exposure factors data also enable the U.S. Environmental Protection Agency (EPA or the Agency) to differentiate the exposures of individuals of different ages. The derivation of human exposure factors used in both the screening and probabilistic analyses are described below.

D.1.1 Data Sources

The Agency relied primarily on the *Exposure Factors Handbook* (*EFH*) (U.S. EPA, 1997a,b,c) for data on adult receptors and the *Child-Specific Exposure Factors Handbook* (*CSEFH*) (U.S. EPA, 2008) for data on child receptors. Where sufficient data were available, the percentiles and corresponding data points obtained from these two sources were used to develop a cumulative distribution in order to capture variability within the U.S. population. Otherwise, EPA relied on point values selected based on the recommendations of the EFH, CSEFH or established Agency guidance (U.S. EPA, 1991).

EPA acknowledges that the 2011 *Exposure Factors Handbook* (U.S. EPA, 2011) has been completed and updates some of the data from the 1997 EFH and 2008 CSEFH. During the finalization of this risk assessment, EPA released *Office of Solid Waste and Emergency Response Directive 9200.1-120* (U.S. EPA, 2014). Although this document provides protective, default exposure factors to use as point estimates, EPA is still in the process of updating the full distributions necessary for a probabilistic analysis. Therefore, this risk assessment does not incorporate the data from the 2011 EFH and instead relies on the 1997 EFH and 2008 CSEFH, referred to simply as the "EPA exposure factor data" throughout the remainder of this appendix.

D.1.2 Age Cohorts

There has been considerable effort across the Agency to improve the accuracy and consistency of childhood exposure assessments. In the *Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants* (U.S. EPA, 2005), EPA recommended specific age cohorts (i.e., groups) intended to better capture the large variability in physiological and behavioral characteristics of child receptors during different stages of development. Narrower age cohorts were identified where rapid developmental changes occur, while broader age groups were identified where the rate of development decreases. These age groupings and the supporting rationale for their selection have been subjected to internal and external scientific peer review. In total, receptors were divided into the eight distinct age cohort groupings recommended by U.S. EPA (2005). **Table D-1** below presents a comparison between the age groups used in the 2010 Risk Assessment and those used in the revised risk assessment. As seen in this table, this risk assessment adopts the notation proposed in U.S. EPA (2005), where

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age groupings are described in terms of "X to < Y." For example, the age cohort of "3 to < 6 years" represents a 3-yr time interval from a child's third birthday up until the day before the child's sixth birthday.

Table D-1. Age Cohorts Used in the 2010 and Revised Risk Assessments

2010 Age Cohorts	Revised Age Cohorts
Not Evaluated	Infant (< 1 year)
1 to 5 years	1 to < 2 years
	2 to < 3 years
	3 to < 6 years
6 to 11 years	6 to < 11 years
11 to 20 years	11 to < 16 years
	16 to < 21 years
Adult (> 20 years)	Adult (> 21 years)

D.2 Exposure Factors for Screening Analysis

EPA conducted a deterministic screening analysis by using point estimates for all exposure factors. The majority of the exposure factors were set to median values in this analysis because the purpose was to streamline the evaluation and identify the constituents of potential concern most likely to pose risk to receptors. Where available distributions were not comprehensive enough to allow identification of a median value, high-end values were used instead. In addition, averaging time (i.e., anticipated lifetime over which cancer may occur) was set to a high-end because of the dependency between this exposure factor and many toxicity values used to calculate cancer risks. In instances where data were not available for a specific age cohort, the data fit to the closest age cohort available was used instead. Consistent with the regional screening tables used in the Superfund program, EPA screened risks using children and adult age cohorts, but not infants. The specific values used in the screening analysis are presented in **Table D-2**. These values are point estimates selected from the distributions developed for the probabilistic analysis, as described in **Section D.3**.

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Table D-2. Exposure Data Used in the Screening Analysis

Parameter		Age Cohort	Value	Units	Basis
Averaging Time		All Cohorts	70	yr	Agency Policy U.S. EPA, 1989
Body Weight		1 to < 2 yrs	11.3	kg	50th Percentile from CSEFH, Table 8-3
		2 to < 3 yrs	13.6		
		3 to < 6 yrs	17.8		
		6 to < 11 yrs	29.3		
		11 to < 16 yrs	54.2		
		16 to < 21 yrs	67.6		
		Adult	69.3		50th Percentile from EFH, Table 7-4 & 7-5
Total Exposure Duration **Note:** Total exposure durations longer than the duration of the cohort indicate that the cohort will age into each subsequent cohort until the specified total duration has elapsed.		1 to < 2 yrs	5	yr	50th Percentile from EFH, Table 15-168
		2 to < 3 yrs	5		
		3 to < 6 yrs	5		
		6 to < 11 yrs	7.7		
		11 to < 16 yrs	8.5		
		16 to < 21 yrs	7		
		Adult	10*		50th Percentile from EFH, Table 15-164
Exposure Frequency		All Cohorts	350	days/yr	Agency Policy U.S. EPA (1991)
Fraction Contaminated	All media and foods	All Cohorts	1	fraction	Agency Policy U.S. EPA (1991)
Fraction Of Fish Consumed	Trophic Level 3 (TL3)	All cohorts	0.36	fraction	Calculated from EFH Table 10-66
	Trophic Level 4 (TL4)	All cohorts	0.64	fraction	

(continued)

Table D-2. Exposure Data Used in the Screening Analysis

Parameter		Age Cohort	Value	Units	Basis
Ingestion Rate	Beef	1 to < 2 yrs	2.11	g WW/kg/day	50th Percentile from EFH, Table 13-36
		2 to < 3 yrs	2.11		
		3 to < 6 yrs	2.11		
		6 to < 11 yrs	2.11		
		11 to < 16 yrs	1.51		
		16 to < 21 yrs	1.51		
		Adult	1.64*		
	Fish	All Cohorts	2.0	g/day	50th Percentile from EFH, Table 10-64
	Drinking Water	1 to < 2 yrs	20	mL/kg-day	50th Percentile from CSEFH, Table 3-19
		2 to < 3 yrs	21		
		3 to < 6 yrs	19		
		6 to < 11 yrs	13		
		11 to < 16 yrs	10		
		16 to < 21 yrs	10		
		Adult	1,275	mL/day	50th Percentile from EFH, Table 3-6
	Exposed Fruit	1 to < 2 yrs	1.82	g WW/kg/day	50th Percentile from EFH, Table 13-61
		2 to < 3 yrs	1.82		
		3 to < 6 yrs	1.82		
		6 to < 11 yrs	1.11		
		11 to < 16 yrs	0.609		
		16 to < 21 yrs	0.609		
		Adult	1.30*		
	Exposed Vegetables	1 to < 2 yrs	1.89	g WW/kg/day	50th Percentile from EFH, Table 13-63
		2 to < 3 yrs	1.89		
		3 to < 6 yrs	1.16		
		6 to < 11 yrs	0.643		
		11 to < 16 yrs	0.656		
		16 to < 21 yrs	0.656		
		Adult	1.38*		

(continued)

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Table D-2. Exposure Data Used in the Screening Analysis

Parameter		Age Cohort	Value	Units	Basis
Ingestion Rate	Milk	1 to < 2 yrs	31.3	g/kg-day (as consumed)	50th Percentile of total dairy from CSEFH Table 11-4
		2 to < 3 yrs	31.3		
		3 to < 6 yrs	20.8		
		6 to < 11 yrs	11.7		
		11 to < 16 yrs	4.2		
		16 to < 21 yrs	4.2		
		Adult	12.1*	g WW/kg/day	50th Percentile from households that farm EFH, Table 13-28
	Protected Fruit	1 to < 2 yrs	2.34	g WW/kg/day	50th Percentile from EFH, Table 13-62
		2 to < 3 yrs	2.34		
		3 to < 6 yrs	2.34		
		6 to < 11 yrs	2.34		
		11 to < 16 yrs	1.23		
		16 to < 21 yrs	1.23		
		Adult	2.13*+		
	Protected Vegetables	1 to < 2 yrs	1.94	g WW/kg/day	50th Percentile from EFH, Table 13-64
		2 to < 3 yrs	1.94		
		3 to < 6 yrs	1.04		
		6 to < 11 yrs	0.791		
		11 to < 16 yrs	0.583		
		16 to < 21 yrs	0.583		
		Adult	0.599*		
	Root Vegetables	1 to < 2 yrs	0.920	g WW/kg/day	50th Percentile from EFH, Table 13-65
		2 to < 3 yrs	0.920		
		3 to < 6 yrs	0.462		
		6 to < 11 yrs	0.523		
		11 to < 16 yrs	0.565		
		16 to < 21 yrs	0.565		
		Adult	0.883*		
	Soil + Dust	All Child Cohorts	100	mg/day	Central tendency (no percentiles) from CSEFH Table 5-1
		Adult	50		Mean from EFH Table 4-23

(continued)

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Table D-2. Exposure Data Used in the Screening Analysis

Parameter		Age Cohort	Value	Units	Basis
Skin Surface Area		Adult	18,000	cm^2/kg	RAGS, Part E (U.S. EPA, 2004), Exhibit 3-2.
Event Frequency	Bath/ Shower	All Cohorts	1	event/day	
Event Duration		Adult	0.58	hr	

* Used data for households that farm (not broken out by age) to capture highly exposed individuals.
\+ Weighted (by number of observations) average of 20-39 and 40-69.

D.3 Exposure Factors for Probabilistic Analysis

The general methodology for collecting human exposure data for the probabilistic analysis relied on the EPA data from the 1997 EFH or 2008 CSEFH in one of three ways:

1. When the available data were adequate (as for most input variables), nonparametric approaches were used to fit distributions to the cumulative distribution (percentiles) of the data using @Risk software (available at www.palisade.com/risk/). Fitting nonparametric distributions removed parameter uncertainty associated with the fitting of specific parametric distributions (U.S. EPA, 2000).
2. When the available data were not adequate to support the statistical fitting for a specific age cohort, the data fit to the closest age cohort available was used instead.
3. When available data were not adequate for either of the above methods, variables were fixed at values recommended in the EFH or CSEFH or according to established EPA policy.

D.3.1 Variable Parameters

This section describes how the various distributions of exposure factor data were collected and processed for use in the probabilistic analysis. Probabilistic exposure analyses involve sampling values from a distribution with the same characteristics as the data using the values to estimate risk. For most variables for which distributions were developed, EPA exposure factor data were analyzed to fit nonparametric models. Steps in the development of distributions included preparing data, fitting models, assessing fit, and preparing parameters to characterize distributional uncertainty in the model inputs.

For many exposure factors, the data from the EFH and CSEFH include sample sizes and estimates of the following parameters for specific receptor types and age groups: mean, standard deviation, standard error, and percentiles corresponding to some subset of the following probabilities: 0.01, 0.02, 0.05, 0.10, 0.15, 0.25, 0.50, 0.75, 0.85, 0.90, 0.95, 0.98, and 0.99. These percentile data, where available, were used as a basis for fitting distributions. Although in no case are all of these

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percentiles provided for a single factor, seven or more are typically available. Therefore, using the percentiles provided a better representation of the available information than fitting distributions simply based on the method of moments (i.e., selecting models that agree with the data mean and standard deviation).

Neither the EFH nor the CSEFH makes use of the standardized age cohorts recommended in U.S. EPA (2005). Different exposure factors are reported for different age categories based on the information available in the scientific literature. Therefore, to obtain the percentiles for fitting the eight standardized age cohorts used for the revised risk assessment, each cohort-specific value for a given exposure factor was assigned to one of the cohorts. When multiple cohorts fitted into a single CCR cohort, the percentiles from the EFH or CSEFH were averaged within each CCR cohort (e.g., data on 6 year olds and 9 year olds were averaged for the 6 to <11 age cohort). If sample sizes were available, weighted averages were used, with weights proportional to sample sizes. If sample sizes were not available, equal weights were assumed (i.e., the percentiles were simply averaged).

Nonparametric distributions were used to characterize the data. The nonparametric approach fits an optimal smooth curve to the cumulative distribution (percentiles) of the data. The best nonparametric fit is selected as the one that minimized the distance between the smooth curve and the empirical curve generated by the percentiles of the data. The maximum, minimum are used to specify the range of the simulated values. Depending on the data set, there could be more than one distribution (parametric or nonparametric) that could be considered a good fit for the data. Selecting an incorrect exposure distribution model may bias the risk assessment results, producing incorrect conclusions. Therefore, the application of goodness-of-fit statistics was required to select between competing distributions and to reduce model uncertainty. One goodness-of-fit statistic available was the root mean squared error, defined as the root of the average of the squared differences between the predicted percentile and the observed percentile. The other goodness-of-fit statistic available was the Chi-square based comparison of the empirical cumulative distribution (derived from the cumulative data) or the nonparametric cumulative distribution. Graphical displays were also used to evaluate the appropriateness of the selected distribution. A plot of the observed percentiles (from the cumulative data) vs. the nonparametric cumulative distribution was created. In some cases, exposure distributions are highly skewed, and there is a probability, although small, that a combination of extreme values might be selected from the tails of the distributions.

Drinking Water Intake

Drinking water intake data were obtained from Table 3-19 of the *CSEFH* and Table 3-6 of the *EFH* (U.S. EPA, 1997a), for children and adults, respectively. Weighted averages of percentiles and means were calculated for the 0 to < 1 yr infant (based on birth to < 1 month, 1 to < 3 months, 3 to < 6 months and 6 to < 12 months), the 16 to < 21 years age group (based on 16 to < 18 years and 18 to < 21 years) and adults (based on 20 to 44, 45 to 64, and 64 to 74 years), using the number of observations in each subcohort as weights. **Table D-3** presents drinking water intake data used

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to prepare Monte Carlo simulations (note that the infant and child values are normalized by body weight and reported in mL/kg-day, while the adult ones are not and are reported in mL/day).

Table D-3. Drinking Water Consumption Rate Data (mL/kg-day)[1]

Age Group (Years)	N	Mean	Percentile						
			P10	P25	P50	P75	P90	P95	P99
Infant[2]	948	71	7	25	66	104	140	164	217
1 to < 2	880	27	4	9	20	36	56	75	109
2 to < 3	879	26	4	9	21	36	52	62	121
3 to < 6	3,703	24	3	8	19	33	49	65	97
6 to < 11	1,439	17	3	6	13	23	35	45	72
11 to < 16	911	13	2	5	10	17	26	34	54
16 to < 21	700	13	2	5	10	17	27	34	61
Adult	13,394	1,384	607	900	1,275	1,741	2,260	2,682	3,737

Source: Table 3-19, CSEFH for child cohorts and Table 3-6, EFH (U.S. EPA, 1997b) for adults.
1) Adult values are mL/day.
2) Weighted average based on subcohorts presented in the CSEFH or EFH.

Drinking water consumption rate data for infants (birth to < 1 month, 1 to < 3 months, 3 to < 6 months and 6 to < 12 months) are available from the CSEFH (U.S. EPA, 2008). **Table D-4** presents the water ingestion data used for infants. As drinking water concentrations are provided by the model as annual averages, the infant consumption rates were averaged to estimate a 0 to < 1 year infant. The data were weighted by sample size because the small sample sizes did not meet minimum requirements as described in the *Third Report on Nutrition Monitoring in the United States* (FASEB, 1995) for numerous percentiles in numerous subcohorts.

Table D-4. Drinking Water Consumption Rates for Infant Subcohorts (mL/kg-day)

Age Group (Months)	N	Mean	Percentile						
			P10	P25	P50	P75	P90	P95	P99
Birth to < 1	37	137	11	65	138	197	235	238	263
1 to < 3	108	119	12	71	107	151	228	285	345
3 to < 6	269	80	7	27	77	118	148	173	222
6 to < 12	534	53	5	12	47	81	112	129	186
Infant	948	71	7	25	66	104	140	164	217

Source: Table 3-19, *CSEFH*.

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Body Weight

Weighted averages of percentiles and means were calculated for the infant age group (based on birth to < 1 month, 1 to < 3 months, 3 to < 6 months and 6 to < 12 months) and adults (based on male and female data). **Table D-5** presents body weight data. Body weight data were obtained from Table 8-8 of the CSEFH and Tables 7-4 and 7-5 of the EFH (U.S. EPA, 1997a). Data in the EFH tables were presented by race, age, gender. The female and male distributions for "all races" were weighted based on sample size to develop the percentile data presented in Table D-5 for all adults.

Table D-5. Body Weight Data (kg)

Age Group (Years)	N	Mean	Percentile								
			P05	P10	P15	P25	P50	P75	P85	P90	P95
Infant	1,858	7.8	6	6.4	6.7	7.1	7.8	8.6	9.0	9.3	9.7
1 to < 2	1,176	11.4	8.9	9.3	9.7	10.3	11.3	12.4	13	13.4	14
2 to < 3	1,144	13.8	10.9	11.5	11.9	12.4	13.6	14.9	15.8	16.3	17.1
3 to < 6	2,318	18.6	13.5	14.4	14.9	15.8	17.8	20.3	22	23.6	26.2
6 to < 11	3,593	31.8	19.7	21.3	22.3	24.4	29.3	36.8	42.1	45.6	52.5
11 to < 16	5,297	56.8	34	37.2	40.6	45	54.2	65	73	79.3	88.8
16 to < 21	4,851	71.6	48.2	52	54.5	58.4	67.6	80.6	90.8	97.7	108
Adult	12,504	71.4	52.9	56.0	58.2	61.7	69.3	78.5	84.9	89.8	97.6

Sources: Table 8-3 *CSEFH* (U.S. EPA, 2008) for children and Table 7-4 and 7-5 *EFH* (U.S. EPA, 1997a) for adults.

Fish Consumption

Fish consumption data were obtained from Table 10-64 of the EFH (U.S. EPA, 1997b). These data originate from a fish consumption study of recreational anglers conducted in Maine, one of four freshwater angler studies recommended in the 1997 EFH. Fish consumption rates for subsistence anglers were not considered, in part because fish ingestion rates for Native American subsistence anglers are currently limited and can vary widely among individual tribes. EPA selected the Maine data because it was the most complete of the data sets available and because it agrees most closely with the mean intake rates reported in a separate U.S. Department of Agriculture study of national fish consumption (USDA, 1992). The Maine study provides percentile data necessary to develop a distribution that were not available in the USDA study. **Table D-6** presents fish consumption rate data used to prepare Monte Carlo simulations. Age-specific data for children were not available; children were assumed to consume the same amount of fish as adults.

Table D-6. Fish Consumption Rates for All Ages (g/day)

Age Group	N	Mean	Percentile				
			P50	P66	P75	P90	P95
All	1,053	6.4	2	4	5.8	13	26

Source: Table 10-64, *EFH* (U.S. EPA, 1997b)

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Exposure Duration

Exposure durations for adult and child residents were determined using data on residential occupancy from Tables 15-164 and 15-168 of the EFH (U.S. EPA, 1997c). The data represent the total time a person (both male and female) is expected to live at a single location, based on age. For adult residents, data reported for farm residents were used to capture highly exposed receptors within the population. For child residents, data reported for the 3-yr age group were used to represent infants to < 6 yrs. Data reported for ages 6 and 9 were averaged to represent 6 to < 11 yrs. Data on ages 12 and 15 were averaged to represent 11 to < 16 yrs. Data reported for age 18 were used to represent 16 to < 21 yrs. **Table D-7** presents exposure duration data. The underlying source for the recommended EFH distribution was a Monte Carlo simulation that estimated a probability distribution function for residential occupancy period based on the probability of moving and dying. There are no sample sizes, as these data do not derive from a survey.

Table D-7. Human Exposure Durations for All Ages (yr)

Age Group (Years)	Mean	Percentile					
		P25	P50	P75	P90	P95	P99
Infant	6.5	3	5	8	13	17	22
1 to < 2	6.5	3	5	8	13	17	22
2 to < 3	6.5	3	5	8	13	17	22
3 to < 6	6.5	3	5	8	13	17	22
6 to < 11	8.45	4.5	7.7	11	15.5	18	22
11 to < 16	9.2	5	8.5	12.5	16	18	23
16 to < 21	8.2	4	7	11	16	19	23
Adult	N/A	2.4	10.0	26.7	48.3	58.4	N/A

Sources: Children: Table 15-168, EFH (U.S. EPA, 1997c)
Adult farmer: Table 15-164, EFH (U.S. EPA, 1997c)
N/A – Not Available

D.3.2 Fixed Parameters

Certain parameters were fixed because the available data were not adequate to generate distributions. These parameters are shown in **Table D-8** along with the value selected for the risk analysis and the data source. For fraction of fish consumed that is trophic level 3 (TL 3) vs. trophic level 4 (TL 4), EFH Table 10-66 presents grams of fish consumed per year by species and type of fishing (ice fishing, lakes and ponds, and rivers and streams). The fraction of TL3 and TL4 fish consumed were calculated from these data using all fishing types and categorizing the fish species as either TL3 (i.e., carp, smelt, perch, catfish, sucker, bullhead, perch, and white fish) or TL4 (i.e., salmon, trout, bass, chub, and other).

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Table D-8. Summary of Human Exposure Factor Data Used in Modeling: Constants

Description		Value	Units	Source
Averaging Time for Carcinogens		70	yr	EPA Policy (U.S. EPA, 1989)
Exposure Frequency		350	d/yr	EPA Policy (U.S. EPA, 1991)
Fraction Contaminated: All media and food items		1	Fraction	EPA Policy (U.S. EPA, 1991)
Fraction of Fish Consumed that is:	Trophic Level 3	0.36	Fraction	Calculated from EFH, Table 10-66
	Trophic Level 4	0.64		

D.4 References

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Appendix E.

Human Health and Ecological Benchmarks

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E.1 Introduction

This appendix provides the benchmarks for human and ecological receptors used in the coal combustion residuals (CCR) risk assessment, and describes the data sources.

E.2 Human Health Benchmarks

Human health benchmarks are based on the specific adverse effects that may occur. Adverse effect is a broad term for any abnormal, harmful, or undesirable change that results from exposure to a stressor. Adverse health effects are divided into two main categories: carcinogenic and noncarcinogenic. Carcinogenic effects are those that result in the development of cancer somewhere in the organism. Noncarcinogenic effects are those that result in any adverse health effect other than cancer. Some stressors may result in both carcinogenic and noncarcinogenic effects, depending on the route through which the receptor is exposed and the magnitude of the exposure. Benchmarks were collected for ingestion and inhalation because these are the primary routes through which residential receptors who live close to CCR surface impoundments and landfills may be exposed.

E.2.1 Chronic Human Health Benchmarks

Reference doses (RfDs) and reference concentrations (RfCs) are used to evaluate noncancer effects from oral and inhalation exposures, respectively. RfDs and RfCs are estimates of a daily exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects. However, an average lifetime exposure above the RfD (or RfC) does not imply that an adverse health effect will necessarily occur.

Oral cancer slope factors (CSFo's) and inhalation unit risk factors (URFs) are used to evaluate carcinogenic effects. The CSFo is an upperbound estimate (approximating a 95% confidence limit) of the increased human cancer risk from a lifetime of exposure. The URF is a cancer benchmark for inhalation exposures, where the air concentrations are used as a threshold.

The Office of Solid Waste and Emergency Response 2003 Directive 9285.7-53 encourages prioritization of sources that are most current, those for which the basis is transparent and publicly available and those that have been peer reviewed (U.S. EPA, 2003). Accordingly, a three-tiered approach was followed to use higher priority data sources based on availability.

Tier I

Integrated Risk Information System (IRIS): IRIS (U.S. EPA, 2012a) provides the highest quality science-based chronic human health assessments to support EPA regulatory activities. IRIS assessments have been peer-reviewed and represent Agency-wide consensus. Thus, EPA used values from IRIS whenever available. IRIS contains RfDs and RfCs for chronic noncarcinogenic health effects, and oral CSFs and inhalation URFs for carcinogenic effects.

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Tier II

Provisional Peer-Reviewed Toxicity Values (PPRTVs): When a value is not available in IRIS, the Superfund Program may derive a PPRTV after a review of the relevant scientific literature using the methods, sources of data and guidance for value derivation used by the EPA IRIS Program. All provisional peer-reviewed toxicity values receive internal review by EPA scientists and external peer review by independent scientific experts. However, PPRTVs do not reflect Agency-wide consensus, because PPRTVs are developed specifically for the Superfund Program. PPTRVs included cancer and noncancer benchmarks for both oral and inhalation exposure.

Tier III

Agency for Toxic Substances and Disease Registry (ATSDR) Chronic Minimal Risk Levels (MRLs): The ATSDR MRLs (ATSDR, 2013) are substance-specific health guidance levels for noncarcinogenic effects. An MRL is intended to be an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are derived for oral and inhalation routes of exposure in a manner similar to RfDs and RfCs, respectively. MRLs have undergone both internal and external peer review.

California EPA (CalEPA) Cancer Potency Factors and Reference Exposure Levels: CalEPA has developed cancer potency factors (CalEPA, 2011) for chemicals regulated under California's Hot Spots Air Toxics Program. The cancer potency factors are analogous to the EPA's oral and inhalation CSFs. CalEPA has also developed chronic inhalation RELs, analogous to the EPA's RfC (CalEPA, 2014). The cancer potency factors and inhalation RELs have undergone peer review by various California agencies and have been made available for public comment.

Other Health Benchmarks: Some other organizations have also developed human health benchmarks. In limited cases where no other benchmarks from the above sources were available, such benchmarks were used:

- An oral cancer benchmark for chromium (VI), developed by the New Jersey Department of Environmental Protection for their soil cleanup program (NJDEP, 2009) based on information from a study by the National Toxicity Program (NTP, 2008).
- An RfD for lanthanum carbonate, compiled for the International Toxicity Estimates for Risk database, that was developed by National Sanitation Foundation (NSF) International (NSF, 2010).
- For lead, EPA currently has no consensus on the development of an RfD or CSFo because of the difficulty associated with identifying an effect threshold needed to develop these benchmarks. Therefore, the maximum contaminant level (MCL) for drinking water was used as an alternative method of approximating human health risk.

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Health Effects Assessment Summary Tables: HEAST (U.S. EPA, 1997a) is a listing of provisional noncarcinogenic and carcinogenic health toxicity values (RfDs, RfCs, URFs and CSFos) derived by the EPA. Although the health toxicity values in HEAST have undergone review and have the concurrence of individual EPA program offices, the values have not been externally reviewed as extensively as those in IRIS. Values for chemical exposures are not updated at this time.

The chronic human health benchmarks used in the CCR risk assessment are summarized in **Table E-1** (cancer benchmarks) and **Table E-2** (noncancer benchmarks). These tables provide the constituent name, Chemical Abstract Service Registry Number (CASRN), CSFo and inhalation URF (**Table E-1**) or RfD and RfC (**Table E-2**), and the reference for each benchmark. A key to the references cited is provided at the end of the tables. All values are current as of May 2014.

Table E-1. Chronic Human Health Benchmarks: Cancer

Constituent	CASRN	CSFo $(mg/kg\text{-}d)^{-1}$	Ref	Last Updated	URF $(\mu g/m^3)^{-1}$	Ref	Last Updated
Arsenic	7440-38-2	1.50E+00	IRIS	04/1998	4.30E-03	IRIS	04/1998
Beryllium	7440-41-7	—	—	—	2.40E-03	IRIS	04/1998
Cadmium	7440-43-9	—	—	—	1.80E-03	IRIS	06/1992
Chromium (VI)	18540-29-9	5.00E-01	NJDEP	06/2009	1.20E-02	IRIS	09/1998
Cobalt	7440-48-4	—	—	—	9.00E-03	PPRTV	08/2008

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Table E-2. Chronic Human Health Benchmarks: Noncancer

Constituent	CASRN	RfD (mg/kg-d)	Target Organ	Ref	Last Updated	RfC (mg/m^3)	Target Organ	Ref	Last Updated	Additional Notes
Aluminum	7429-90-5	1E+00	Neurological	PPRTV	10/2006	5E-03	Neurological	PPRTV	10/2006	—
Ammonia	7664-41-7	9.7E-01*	Sensory	HEAST	07/1997	1E-01	Respiratory	IRIS	05/1991	—
Antimony	7440-36-0	4E-04	Hematological	IRIS	02/1991	2E-04	Respiratory	IRIS	09/1995	RfC for Antimony Trioxide
Arsenic	7440-38-2	3E-04	Dermal	IRIS	02/1993	1.5E-05	Neurological	CalEPA	10/2013	—
Barium	7440-39-3	2E-01	Kidney	IRIS	07/2005	—	—	—	—	—
Beryllium	7440-41-7	2E-03	Gastrointestinal	IRIS	04/1998	2E-05	Respiratory	IRIS	04/1998	—
Boron	7440-42-8	2E-01	Developmental	IRIS	08/2004	—	—	—	—	—
Cadmium	7440-43-9	5E-04 (Water) 1E-03 (Food)	Kidney	IRIS	02/1994	1E-05	Kidney	ATSDR	09/2012	
Calcium	7440-70-2	No Benchmarks								
Chloride	16887-00-6	No Benchmarks								
Chromium III	16065-83-1	1.5E+00	NOAEL	IRIS	09/1998	—	—	—	—	—
Chromium VI	18540-29-9	3E-03	NOAEL	IRIS	09/1998	1E-04	Respiratory	IRIS	09/1998	—
Cobalt	7440-48-4	3E-04	Thyroid	PPRTV	08/2008	6E-06	Respiratory	PPRTV	08/2008	—
Copper	7440-50-8	1E-02	Gastrointestinal	ATSDR	09/2004	—	—	—	—	Intermediate Oral MRL

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Table E-2. Chronic Human Health Benchmarks: Noncancer

Constituent	CASRN	RfD (mg/kg-d)	Target Organ	Ref	Last Updated	RfC (mg/m^3)	Target Organ	Ref	Last Updated	Additional Notes
Fluoride	16984-48-8	6E-02	Bone/Teeth	IRIS	06/1989	—	—	—	—	RfD for Fluorine
Iron	7439-89-6	7E-01	Gastrointestinal	PPRTV	09/2006	—	—	—	—	—
Lanthanum	7439-91-0	5E-01	Hematological	ITER	11/2010	—	—	—	—	RfD for Lanthanum Carbonate
Lead	7439-92-1	MCL of 0.015 mg/L used for water								
Lithium	7439-93-2	2E-03	Several Organs and Systems	PPRTV	06/2008	—	—	—	—	—
Magnesium	7439-95-4	No Benchmarks								
Manganese	7439-96-5	1.4E-01 (Food/Soil) 4.7E-02 (Water)	Neurological	IRIS	05/1996	5E-05	Neurological	IRIS	12/1993	—
Mercury (Chloride)	7487-94-7	3E-04	Immunological	IRIS	05/1995	—	—	—	—	RfD used for produce, livestock, water, soil
Mercury (Elemental)	7439-97-6	—	—	—	—	3E-04	Neurological	IRIS	06/1995	RfC used for ambient air
Mercury (Methyl)	22967-92-6	1E-04	Developmental	IRIS	07/2001	—	—	—	—	RfD used for fish
Molybdenum	7439-98-7	5E-03	Metabolic	IRIS	08/1993	—	—	—	—	—
Nickel	7440-02-0	2E-02	Body Weight, Cardiovascular, Liver	IRIS	12/1996	9E-05	Respiratory	ATSDR	08/2005	—
Nitrate/ Nitrite	14797-55-8	1.6E+00	Hematological	IRIS	10/1991	—	—	—	—	—

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Table E-2. Chronic Human Health Benchmarks: Noncancer

Constituent	CASRN	RfD (mg/kg-d)	Target Organ	Ref	Last Updated	RfC (mg/m^3)	Target Organ	Ref	Last Updated	Additional Notes
Potassium	7440-09-7	No Benchmarks								
Selenium	7782-49-2	5E-03	Dermal, Hematological, Neurological	IRIS	09/1991	2E-02	Cardiovascular, Hematological, Liver, Neurological	CalEPA	10/2013	—
Silicon	7631-86-9	No Benchmarks								
Silver	7440-22-4	5E-03	Dermal	IRIS	12/1996	—	—	—	—	—
Sodium	7440-23-5	No Benchmarks								
Strontium	7440-24-6	6E-01	Bone/Teeth	IRIS	12/1996	—	—	—	—	—
Sulfate	14808-79-8	No Benchmarks								
Sulfide	18496-25-8	No Benchmarks								
Sulfur	7704-34-9	No Benchmarks								
Thallium	7440-28-0	1E-05	Hair Loss	PPRTV	10/2012	—	—	—	—	RfD for soluble thallium
Uranium	7440-61-1	3E-03	Body Weight, Kidney	IRIS	10/1989	3E-04	Kidney	ATSDR	02/2013	—
Vanadium	7440-62-2	9E-03	Hair	IRIS	12/1996	1E-04	Respiratory	ATSDR	09/2012	—
Zinc	7440-66-6	3E-01	Hematological	IRIS	08/2005	—	—	—	—	—

* RfD for ammonia was provided as a concentration in drinking water of 34 mg/L, which was converted to mg/kg-day assuming a drinking water consumption rate of 2 L/day (approximately 90th percentile for adults) and a body weight of 70 kg (approximately 50th percentile for adults). Thus, 34 mg/L × 2 L/day ÷ 70 kg = 9.7E-1 mg/kg-day.

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E.2.2 Acute Inhalation Human Health Benchmarks

In addition to chronic exposures, another exposure scenario of potential concern for the screening analysis is acute inhalation. The *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (HHRAP, U.S. EPA, 2005i) recommends evaluating an acute exposure scenario to ensure that an assessment evaluates all receptors that may be significantly exposed to emissions from facility sources. However, short-term emissions are unlikely to cause an adverse impact through the indirect exposure pathways (as compared to impacts from long-term emissions through those pathways). Therefore, HHRAP recommends evaluating acute effects only through the short-term (maximum 1-hour) inhalation of vapors and particulates.

Acute inhalation exposure guidelines and criteria are designed to protect a variety of exposure groups, including occupational workers, military personnel, and the general public. Acute guidelines are based on varying exposure durations up to 24 hours (e.g., 10, 30 and 60 minutes; 4 and 8 hours; and 1 day). Acute exposure guidelines are based on adverse health effects reflecting a wide range of severity, from mild, transient effects (e.g., respiratory irritation) to irreversible or serious effects, to potentially life threatening effects. Reflecting the conservative nature of a screening assessment, EPA used guidelines based on the mild, transient effects, as those would also be protective of more severe effects.

To identify acute inhalation guidelines, EPA used the hierarchy established by HHRAP (U.S. EPA, 2005i). Preference is given to sources and values that 1) have undergone rigorous scientific review, 2) address intermittent exposures (as opposed to one-time exposures), 3) are based on one-hour exposures, and 4) apply to the general population, including susceptible individuals. The hierarchy is as follows:

1. **CalEPA Acute Reference Exposure Levels (RELs):** concentration in air at or below which no adverse health effects are anticipated in the general population, including sensitive individuals, for a specified exposure period (1 and 8 hours). CalEPA Acute RELs are meant to address routine short-term emissions rather than industrial accidents, another reason they are the most preferred source. They are peer-reviewed by the State's Scientific Review Panel on Toxic Air Contaminants and have been made available for public comment.
2. **U.S. EPA Acute Exposure Guideline Levels (AEGL-1):** the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible upon cessation of exposure (10 and 30 minutes and 1, 4 and 8 hours). AEGLs are intended to protect against rare, typically accidental or once-in-a-lifetime exposures. AEGL values and methods undergo peer review by the National Advisory Committee for AEGLs and the National Research Council of the National Academy of Sciences, and also receive public comment.

3. **American Industrial Hygiene Association Level 1 Emergency Response Planning Guidelines (ERPG-1):** the maximum concentration in air below which it is believed nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined objectionable odor (1 hour). ERPGs are meant to anticipate adverse health effects from chemical release emergencies. ERPG-1 values are peer reviewed.
4. **U.S. Department of Energy Temporary Emergency Exposure Limits (TEEL-1):** the maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined odor. TEELs are meant to fill in where ERPGs are not available, until ERPGs are developed. The TEEL-1s are based on 15 minute exposures. Although individual TEELs are not peer reviewed, they are developed based on a peer-reviewed process.

Two constituents, chromium III and chromium VI, did not have values in any of the above sources on HHRAP's hierarchy. For these, EPA used the National Institute for Occupational Safety and Health Immediately Dangerous to Life or Health Values (IDLH) and, following the same process as EPA's Air Toxics Program, divided by 10 to more closely match the milder effect levels developed by the other sources; this approach is consistent with the methodology used to develop levels of concern under Title III of the Superfund Amendments and Reauthorization Act, and their use in the accidental release prevention requirements under section 112(r) of the Clean Air Act (see www.epa.gov/ttn/atw/toxsource/acutesources.html).

The acute inhalation health benchmarks used in the CCR risk assessment are summarized in Table E-3. All values were current as of May 2014, except the TEELs, which were current as of January 2012, when the acute benchmark data were collected. The TEELs were updated in February 2012, but those have not been incorporated here, as they occurred after the CCR modeling was completed.

Table E-3. Acute Inhalation Benchmarks

Constituent	CASRN	1-Hour Value (mg/m^3)	Source	Last Updated
Aluminum	7429-90-5	3	TEEL-1	02/2012
Ammonia	7664-41-7	3.2	CalEPA REL	01/2014
Antimony	7440-36-0	1.5	TEEL-1	02/2012
Arsenic	7440-38-2	0.0002	CalEPA REL	01/2014
Barium	7440-39-3	1.5	TEEL-1	02/2012
Beryllium	7440-41-7	0.0035	TEEL-1	02/2012
Boron	7440-42-8	4	TEEL-1	02/2012
Cadmium	7440-43-9	0.1	AEGL1	01/2012
Calcium	7440-70-2	30	TEEL-1	02/2012

(continued)

Table E-3. Acute Inhalation Benchmarks

Constituent	CASRN	1-Hour Value (mg/m^3)	Source	Last Updated
Chloride	16887-00-6	1.45	TEEL-1	02/2012
Chromium (III)	16065-83-1	2.5	IDLH/10	03/1995
Chromium (VI)	18540-29-9	1.5	IDLH/10	03/1995
Chromium (total)	7440-47-3	1	TEEL-1	02/2012
Cobalt	7440-48-4	0.3	TEEL-1	02/2012
Copper	7440-50-8	0.1	CalEPA REL	01/2014
Fluoride	16984-48-8	7.5	TEEL-1	02/2012
Iron	7439-89-6	6	TEEL-1	02/2012
Lanthanum	7439-91-0	30	TEEL-1	02/2012
Lead	7439-92-1	0.15	TEEL-1	02/2012
Magnesium	7439-95-4	4	TEEL-1	02/2012
Manganese	7439-96-5	3	TEEL-1	02/2012
Mercury (divalent)	7439-97-6	0.0006	CalEPA REL	01/2014
Molybdenum	7439-98-7	15	TEEL-1	02/2012
Nickel	7440-02-0	0.006	CalEPA REL	01/2014
Nitrate/Nitrite	14797-55-8	30	TEEL-1	02/2012
Potassium	7440-09-7	No Benchmarks		
Selenium	7782-49-2	0.6	TEEL-1	02/2012
Silicon	7631-86-9	45	TEEL-1	02/2012
Silver	7440-22-4	0.3	TEEL-1	02/2012
Sodium	7440-23-5	2	TEEL-1	02/2012
Strontium	7440-24-6	125	TEEL-1	02/2012
Sulfate	14808-79-8	0.12	CalEPA REL	01/2014
Sulfide	18496-25-8	No Benchmarks		
Sulfur	7704-34-9	No Benchmarks		
Thallium	7440-28-0	0.06	TEEL-1	02/2012
Uranium	7440-61-1	0.6	TEEL-1	02/2012
Vanadium	7440-62-2	1.5	TEEL-1	02/2012
Zinc	7440-66-6	3	TEEL-1	02/2012

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E.3 Ecological Benchmarks

Ecological benchmarks used in this assessment are medium-specific constituent concentrations that are intended to protect ecological receptors from adverse effects. Depending on the medium (surface water, sediment, or soil), the benchmarks may represent a class-specific value (e.g., an EPA Ecological Soil Screening Level for mammals) or it may represent a higher level of biological organization (e.g., National Water Quality Criteria are developed to protect a generalized aquatic community). In either case, the ecological benchmarks are considered to be environmental quality criteria and do not provide information on the likelihood or severity of the effects on the ecosystem. Ecological receptors may be exposed through the ingestion and/or direct contact with a contaminated medium, or they may be exposed through the food chain (i.e., consuming plants and prey that have, themselves, become contaminated). The ecological benchmarks presented in this section assume that the receptors are exposed to the constituent concentration over a significant portion of their life cycle (i.e., the exposure is assumed to be chronic in nature) or, for aquatic receptors, the exposure can be assumed to be indefinite. This appendix describes the ecological benchmarks used in the revised risk assessment.

E.3.1 Data Sources and Methodology

For this assessment, concentration-based ecological benchmarks for surface water, sediment and soil receptors were used to characterize the potential for adverse ecological effects. For each medium, EPA established a hierarchy for the selection of ecological benchmarks. In instances where multiple benchmarks were available at the same level of the hierarchy, EPA selected the lowest benchmark to ensure that the most sensitive ecological receptors were protected. The following sections summarize the benchmark derivation methods for each medium included in the modeling scenarios.

E.3.2 Surface Water Benchmarks

Surface water benchmarks were selected to protect animals in water bodies that may be exposed through direct contact with surface water or through ingestion of other biota that live in the water body. EPA chose aquatic criteria appropriate for species living in the freshwater bodies because brackish and coastal waters were not modeled in this risk assessment. The hierarchy for these benchmarks was originally defined during the development of the Multimedia, Multipathway, and Multireceptor Risk Assessment Modeling System (3MRA; U.S. EPA, 2003c). The hierarchy is as follows, with the selected values presented in **Table E-4**:

- Criterion Continuous Concentration (CCC) developed by the EPA Office of Water as part of the National Ambient Water Quality Program.
- Final Chronic Value (FCV) developed using the methods Stephan et al. (1985), and implemented under the Great Lakes Water Quality Initiative (U.S. EPA, 1993; 1995a,b),
- Secondary Chronic Value (SCV) as presented in Suter and Tsao (1996).

Table E-4. Ecological Benchmarks for Surface Water (Freshwater Community)

Constituent	CASRN	Aquatic Criterion (mg/L)	Type	Sources[+]
Aluminum	7429-90-5	0.087	CCC	U.S. EPA (1988)
Ammonia	7664-41-7	—	—	—
Antimony	7440-36-0	0.03	FCV	U.S. EPA (1988)
Arsenic (total)	7440-38-2	0.15	CCC	U.S. EPA (1995)
Arsenic III	22569-72-8	0.15	FCV	U.S. EPA (1995)
Arsenic V	15584-04-0	0.0081	SCV	Suter and Tsao (1996)
Barium	7440-39-3	0.004	SCV	Suter and Tsao (1996)
Beryllium	7440-41-7	0.00066	SCV	Suter and Tsao (1996)
Boron	7440-42-8	1.1	SCV	Suter and Tsao (1996)*
Cadmium	7440-43-9	0.00025	CCC	U.S. EPA (2001)
Calcium	7440-70-2	—	—	—
Carbon	7440-44-0	—	—	—
Chloride	16887-00-6	230	CCC	U.S. EPA (1986)
Chromium III	16065-83-1	0.074	CCC	U.S. EPA (1995)
Chromium VI	18540-29-9	0.011	CCC	U.S. EPA (1995)
Cobalt	7440-48-4	0.02	SCV	Suter and Tsao (1996)
Copper	7440-50-8	0.0093	FCV	U.S. EPA (1995)
Fluoride	16984-48-8	—	—	—
Iron	7439-89-6	1	CCC	U.S. EPA (1986)
Lanthanum	7439-91-0	—		
Lead	7439-92-1	0.0025	CCC	U.S. EPA (1980)
Magnesium	7439-95-4	—	—	—
Manganese	7439-96-5	—	—	—
Mercury	7487-94-7	0.00077	CCC	U.S. EPA (1995)
Molybdenum	7439-98-7	0.37	SCV	Suter and Tsao (1996)
Nickel	7440-02-0	0.052	CCC	U.S. EPA (1995)
Nitrate/Nitrite	14797-55-8	—	—	—
Phosphate	98059-61-1	—	—	—
Potassium	7440-09-7	—	—	—

(continued)

Table E-4. Ecological Benchmarks for Surface Water (Freshwater Community)

Constituent	CASRN	Aquatic Criterion (mg/L)	Type	Sources+
Selenium (total)	7782-49-2	0.005	CCC	U.S. EPA (1999)
Selenium IV	7446-08-4	0.03	FCV	U.S. EPA (1995)
Selenium VI	7782-49-2	0.0095	FCV	U.S. EPA (1995)
Silicon	7631-86-9	—	—	—
Silver	7440-22-4	0.00036	SCV	Suter and Tsao (1996)
Sodium	7440-23-5	—	—	—
Strontium	7440-24-6	—	—	—
Sulfate	14808-79-8	—	—	—
Sulfide	18496-25-8	0.002	CCC	U.S. EPA (1986)
Sulfur	7704-34-9	—	—	—
Thallium	7440-28-0	0.01	SCV	Suter and Tsao (1996)
Uranium	7440-61-1	—	—	—
Vanadium	7440-62-2	0.02	SCV	Suter and Tsao (1996)
Zinc	7440-66-6	0.12	CCC	U.S. EPA (1995)

+ Data sources for CCC are discussed online at: water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#A.

* Public commenters (EPA-HQ-RCRA-2009-0640-06526) noted that the units in the fish study from which the SCV was derived (Hamilton, 1995) had been erroneously transcribed in Suter and Tsao as µg/L instead of mg/L. The SCV was recalculated using the corrected units, resulting in a boron SCV of 1.1 mg/L. The revised value has been corroborated by EPA.

E.3.3 Sediment Benchmarks

Sediment benchmarks were selected to protect animals in sediment that may be exposed through direct contact with sediment or through ingestion of other biota that live in the sediment. The hierarchy for these benchmarks was originally defined during the development of 3MRA (U.S. EPA, 2003c). Since the completion of the 3MRA database, NOAA has updated their methodology, making this information available for national analyses. The hierarchy is as follows, with the selected values presented in **Table E-5**:

- Threshold Effect Level (TEL) from Buchman (2008), geometric mean of the 15th percentile in the effects data set and the 50th percentile in the no effects data set.
- Effects Range Low (ERL), the lower 10th percentile concentration estimated to correspond with adverse effects as identified in alternate literature sources including, for example, Long et al. (1995); Long and Morgan (1991); Jones, Suter and Hull (1997); MacDonald (1994); and U.S. EPA (1995c, 1997b).

Table E-5. Ecological Benchmarks for Sediment (Sediment Community)

Constituent	CASRN	Sediment Criterion (mg/kg DWsed)	Sediment Receptor	Type	Sources
Aluminum	7429-90-5	—	—	—	—
Ammonia	7664-41-7	—	—	—	—
Antimony	7440-36-0	2	Sediment Biota	ERL	Long et al. (1991)
Arsenic (total)	7440-38-2	5.9	Sediment Biota	TEL	Buchman (2008)
Barium	7440-39-3	190	Spotted Sandpiper	ERL	Long et al. (1995)
Beryllium	7440-41-7	—	—	—	—
Boron	7440-42-8	—	—	—	—
Cadmium	7440-43-9	0.596	Sediment Biota	TEL	Buchman (2008)
Calcium	7440-70-2	—	—	—	—
Carbon	7440-44-0	—	—	—	—
Chloride	16887-00-6	—	—	—	—
Chromium (total)	7440-47-3	37.3	Sediment Biota	TEL	Buchman (2008)
Cobalt	7440-48-4	—	—	—	—
Copper	7440-50-8	35.7	Sediment Biota	TEL	Buchman (2008)
Fluoride	16984-48-8	—	—	—	—
Iron	7439-89-6	—	—	—	—
Lanthanum	7439-91-0	—	—	—	—
Lead	7439-92-1	35	Sediment Biota	TEL	Buchman (2008)
Magnesium	7439-95-4	—	—	—	—
Manganese	7439-96-5	—	—	—	—
Mercury	7487-94-7	0.174	Sediment Biota	TEL	Buchman (2008)
Molybdenum	7439-98-7	34	Spotted Sandpiper	ERL	Long et al. (1995)
Nickel	7440-02-0	18	Sediment Biota	TEL	Buchman (2008)
Nitrate/Nitrite	14797-55-8	—	—	—	—
Phosphate	98059-61-1	—	—	—	—
Potassium	7440-09-7	—	—	—	—
Selenium	7782-49-2	—	—	—	—
Silicon	7631-86-9	—	—	—	—

(continued)

Table E-5. Ecological Benchmarks for Sediment (Sediment Community)

Constituent	CASRN	Sediment Criterion (mg/kg DWsed)	Sediment Receptor	Type	Sources
Silver	7440-22-4	0.73	Sediment Biota	TEL	MacDonald et al. (1994)
Sodium	7440-23-5	—	—	—	—
Strontium	7440-24-6	—	—	—	—
Sulfate	14808-79-8	—	—	—	—
Sulfide	18496-25-8	—	—	—	—
Sulfur	7704-34-9	—	—	—	—
Thallium	7440-28-0	—	—	—	—
Vanadium	7440-62-2	18	Spotted Sandpiper	ERL	Long et al. (1995)
Zinc	7440-66-6	123	Sediment Biota	TEL	Buchman (2008)

E.3.4 Soil Benchmarks

The soil benchmarks are developed to be protective of plants, animals and soil invertebrates that may be chronically exposed to constituents in soil through direct contact, as well as the ingestion of biota that live in or on the soil. The hierarchy is as follows, with the selected values presented in **Table E-6**:

- Ecological Soil Screening Levels (Eco-SSLs) (U.S. EPA, 2005a–h; 2006c; 2007a–e; 2008b) derived through a collaborative effort of a multi-stakeholder workgroup consisting of federal, state, consulting, industry and academic participants led by the EPA Office of Emergency and Remedial Response, as documented in *Guidance for Developing Soil Screening Levels* (U.S. EPA, 2005).
- Oak Ridge National Lab (ORNL) screening benchmarks developed for the U.S. Department of energy (Efroymson et al., 1997; Efroymson, Will, and Suter, 1997; Sample, Opresko, and Suter 1996),

Table E-6. Ecological Benchmarks for Soil (Terrestrial Receptors)

Constituent	CASRN	Soil Criterion (mg/kg DW soil)	Terrestrial Receptor	Sources
Aluminum	7429-90-5	—	—	—
Ammonia	7664-41-7	—	—	—
Antimony	7440-36-0	0.27	Mammals	U.S. EPA (2005a)
Arsenic (total)	7440-38-2	18	Plants	U.S. EPA (2005b)

(continued)

Table E-6. Ecological Benchmarks for Soil (Terrestrial Receptors)

Constituent	CASRN	Soil Criterion (mg/kg DW soil)	Terrestrial Receptor	Sources
Barium	7440-39-3	330	Soil Invertebrates	U.S. EPA (2005c)
Beryllium	7440-41-7	21	Mammalian	U.S. EPA (2005d)
Boron	7440-42-8	0.5	Plants	Efroymson et al. (1997)
Cadmium	7440-43-9	0.36	Mammalian	U.S. EPA (2005e)
Calcium	7440-70-2	—	—	—
Carbon	7440-44-0	—	—	—
Chloride	16887-00-6	—	—	—
Chromium III	16065-83-1	26	Avian	U.S. EPA (revised 2008b)
Cobalt	7440-48-4	13	Plants	U.S. EPA (2005f)
Copper	7440-50-8	28	Avian	U.S. EPA (revised 2007a)
Fluoride	16984-48-8	—	—	—
Iron	7439-89-6	—	—	—
Lanthanum	7439-91-0	—	—	—
Lead	7439-92-1	11	Avian	U.S. EPA (2005g)
Magnesium	7439-95-4	—	—	—
Manganese	7439-96-5	220	Plants	U.S. EPA (2007b)
Mercury	7487-94-7	0.1	Soil Invertebrates	Efroymson, Will, and Suter (1997)
Molybdenum	7439-98-7	42.08	American Woodcock	Sample, Opresko, and Suter (1996)
Nickel	7440-02-0	38	Plants	U.S. EPA (2007c)
Nitrate	14797-55-8	—	—	—
Nitrite	98059-61-1	—	—	—
Phosphate	7440-09-7	—	—	—
Potassium	7782-49-2	—	—	—
Selenium (total)	7446-08-4	0.52	Plants	U.S. EPA (2007d)
Silicon	7440-22-4	—	—	—
Silver	7440-23-5	4.2	Avian	U.S. EPA (2006c)
Sodium	7440-24-6	—	—	—

(continued)

Table E-6. Ecological Benchmarks for Soil (Terrestrial Receptors)

Constituent	CASRN	Soil Criterion (mg/kg DW soil)	Terrestrial Receptor	Sources
Strontium	14808-79-8	—	—	—
Sulfate	18496-25-8	—	—	—
Sulfide	7704-34-9	—	—	—
Sulfur	7440-28-0	—	—	—
Thallium	7440-61-1	—	—	—
Vanadium	7440-62-2	7.8	Avian	U.S. EPA (2005h)
Zinc	7440-66-6	46	Avian	U.S. EPA (2007e)

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Appendix F.

Air Modeling for Screening Analysis

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F.1 Introduction

Modeling was performed to estimate ambient air concentrations (for inhalation pathways) and deposition rates (for food chain pathways) for particulates released from landfills and landfill operations. Particulate emissions were estimated, and then air dispersion modeling was used to estimate air concentrations and deposition rates at off-site receptor locations.

F.2 Particulate Emissions

Particulate emission estimates were developed and evaluated for windblown emissions, as well as for vehicular activity, unloading operations and compacting operations, using established methods published by the U.S. Environmental Protection Agency (EPA or the Agency), specifically *AP-42: Compilation of Air Pollutant Emission Factors* and windblown emission equations (U.S. EPA, 1985a). The applied approach is consistent with the landfill model methodology reviewed by EPA's Science Advisory Board in 2003 (U.S. EPA, 2003). Modifications to this methodology were made to reflect coal combustion residual (CCR)–specific releases focusing on particulate matter (PM) 10 micrometers or less in diameter or smaller (PM_{10}) and fine particles or particles 2.5 micrometers or less in diameter or smaller ($PM_{2.5}$). The emissions modeling approach is described in more detail in **Attachment F-1**. The following inputs were used for the emissions modeling:

- **Meteorological Parameters:** Meteorological parameters associated with each of the 57 meteorological stations in the EPA's Industrial Waste AIR model (IWAIR; U.S EPA, 2002) were used. The IWAIR meteorological stations are described in **Section F.3**. Particulate emissions were calculated for each station to capture national variability in meteorological conditions.
- **Landfill Operations:** CCR-specific data were used to characterize landfill dimensions. **Table F-1** shows five landfill surface areas ranging from 35 to 126 acres that were modeled. These represent the 50th to the 90th percentile of the distribution of landfill areas. For other data elements, default parameter values were applied as shown in **Attachment F-1**.

Table F-1. Distribution of Landfill Sizes (acres)

Percentile	50th	60th	70th	80th	90th
Surface Area	35.3	48.3	59	85	126

- **Particle Size Distribution:** Data on particle size range mass fractions for coal ash are limited for different CCR types. EPA made the assumption that all particulate releases would have the characteristics of fly ash. Based on a literature review and data presented in Moreno et al. (2005), a profile consisting of 15 percent fine particles or $PM_{2.5}$ (< 2.5 microns) was applied.

- **Dust Controls:** EPA considered various control options such as covering or otherwise managing CCR waste to control wind dispersal of dust. Control efficiencies applied under the "controlled scenario" were based on the above particle size profile and the collection efficiencies from AP-42 (Appendix B.2; U.S. EPA, 2006) for dust suppression by wet spray or by chemical stabilization or wetting agents and are shown in **Table F-2**. Based on these data, a uniform control efficiency of 40 percent was assumed for the $PM_{2.5}$ releases. In the absence of an overall reported control efficiency for $PM_{10,}$ a CCR-specific value was calculated. The $PM_{2.5}$ control efficiency shown in the table was weighted as 15% and the efficiencies for the two size bins greater than 2.5 were averaged and weighted as 85%, reflecting the percentage of coarse particles. This results in in a control efficiency of approximately 70 percent for particulates less than 10 micrometers in diameter.

Table F-2. EPA's AP-42 Collection Efficiencies*

Type of Control	Particle Size		
	0–2.5 µm	2.5–6 µm	6–10 µm
Dust suppression by wet spray	40%	65%	90%
Dust suppression by chemical stabilizer or wetting agents	40%	65%	90%

* These efficiencies reflect ideal operating conditions with appropriate application rates and frequencies.

- **Percent Silt:** EPA assumed that fugitive dust emissions were 80 percent silt, consistent with the previous fugitive dust CCR analysis and based on the value for fly ash presented in AP-42 Chapter 13, Table 13.24-1. Although this value is potentially conservative, EPA deemed it appropriate for screening purposes in the absence of sufficient data to support a lower percent silt value.
- Other source parameters were characterized as shown in **Attachment F-1**, **Table F-1-2**.

F.3 Air Dispersion Modeling

EPA conducted dispersion modeling to estimate ambient air concentrations. Modeling was performed with the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) and its screening model AERSCREEN (U.S. EPA, 2011). Modeling was performed using a phased approach starting with AERSCREEN to estimate conservative maximum air concentrations for each landfill size/location combination discussed above. AERSCREEN also calculates maximum air concentrations for other averaging times (e.g., 3-hour, annual) by scaling the estimated 1-hour maximum air concentrations. In the case of an area source, such as a landfill, a scaling factor of 1 is applied producing very conservative short-term and long-term concentrations that are identical to the 1-hour maximum values. Thus, the 1-hour AERSCREEN results were used as an initial screen of the inhalation pathway.

Subsequent modelling was performed with AERMOD to produce results for the refined inhalation screen and to develop deposition rates to evaluate ingestion exposures (AERSCREEN does not

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produce deposition estimates). Modeling was performed using 5 years of meteorological from the weather station associated with the 90th percentile landfill PM_{10} emissions. Weather stations whose natural characteristics lead to high fugitive dust concentrations in AERSCREEN (e.g., dry, high wind speeds) are likely to also lead to high short term and long term concentrations in AERMOD especially in close proximity to the area source as was considered in this analysis. These more refined air modeling results were considered if an AERSCREEN modeled COPC concentration was above the inhalation health benchmark.

Both AERSCREEN and AERMOD modeling was conducting based on a unitized emission rate (e.g., 1 g/m^2-s). The resulting air concentrations and deposition rates are called unitized air concentrations (e.g., $\mu g\ m^{-3}$ per unit emission rate of 1 g/m^2-s) and unitized deposition rates (e.g., g/m^2-yr per unitized emission rate of 1 g/m^2-s), and these are multiplied by the constituent-specific emission rates and appropriate conversion factors to calculate chemical-specific particle-phase air concentrations and deposition rates.

Chronic exposures to specific constituents were evaluated using outputs averaged over 1 year. Acute exposures to specific constituents were evaluated using outputs averaged over 1 hour. Exposures to $PM_{2.5}$ and PM_{10} were evaluated by comparing EPA's National Ambient Air Quality Standards (NAAQS) to ambient air concentration estimates reflecting appropriate averaging times (i.e., 24-hour and annual for $PM_{2.5}$ and 24-hour for PM_{10}). Because the NAAQS for lead reflects a rolling 3-month average, which is not an available output from AERSCREEN or AERMOD, EPA evaluated those exposures using monthly concentrations.

For this screening, total particulate concentrations output by the model were adjusted with constituent-specific 90th percentile whole waste concentrations to predict corresponding constituent-specific ambient air concentrations. The total particulate concentrations were also apportioned to $PM_{2.5}$ using the particle size distribution discussed in **Section F.1**. **Attachment F-2** summarizes the inputs needed for AERSCREEN; two critical inputs are receptor distance and meteorological data. These are discussed below:

- **Receptor Distances:** Air concentrations were evaluated at a range of distances included in previous EPA analyses and models, such as the Multimedia, Multiple Exposure Pathway, Multiple Receptor Risk Assessment (3MRA) modeling system (U.S. EPA, 2003) and the solvent wipes risk assessment (U.S. EPA, 2009). The specific distances (25 m, 50 m, 75 m, 150 m, 300 m, 500 m, 1,000 m, and 2,000 m) were selected to ensure complete coverage in the air estimates, particularly near the source of the emissions.
- **Meteorological Data:** To capture national variability in the estimates, the air dispersion modeling used representative meteorological and land use data associated with the 57 IWAIR meteorological regions where coal combustion facilities are located. The IWAIR model and meteorological regions have been subjected to extensive peer review. **Figure F-1** shows the coal combustion facilities cross-referenced to the IWAIR meteorological regions (U.S. EPA, 2002). As part of the initial screening, EPA performed AERSCREEN modeling using meteorological and land use data for all of the IWAIR meteorological regions where coal

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combustion facilities are located. Because it was not feasible to run AERMOD (to obtain results for longer averaging times) for all of the 57 meteorological stations, EPA selected the location with the 90th percentile particulate air concentration (which accounts for meteorological and land use effects on both emissions and dispersion) and performed AERMOD modeling for that location. AERMOD outputs were generated for the range of receptor distances (i.e., 25 m, 50 m, 75 m, 150 m, 300 m, 500 m, 1,000 m, and 2,000 m) and included unitized 1-, 3-, 8, and 24-hour, monthly, and annual average air concentrations for $PM_{2.5}$ and PM_{10} and yearly average wet and dry deposition rates from particle phase. EPA then used those meteorological conditions to calculate emissions and used the associated dispersion factors and deposition rates as representative of the 90th percentile meteorological conditions for the chronic screening.

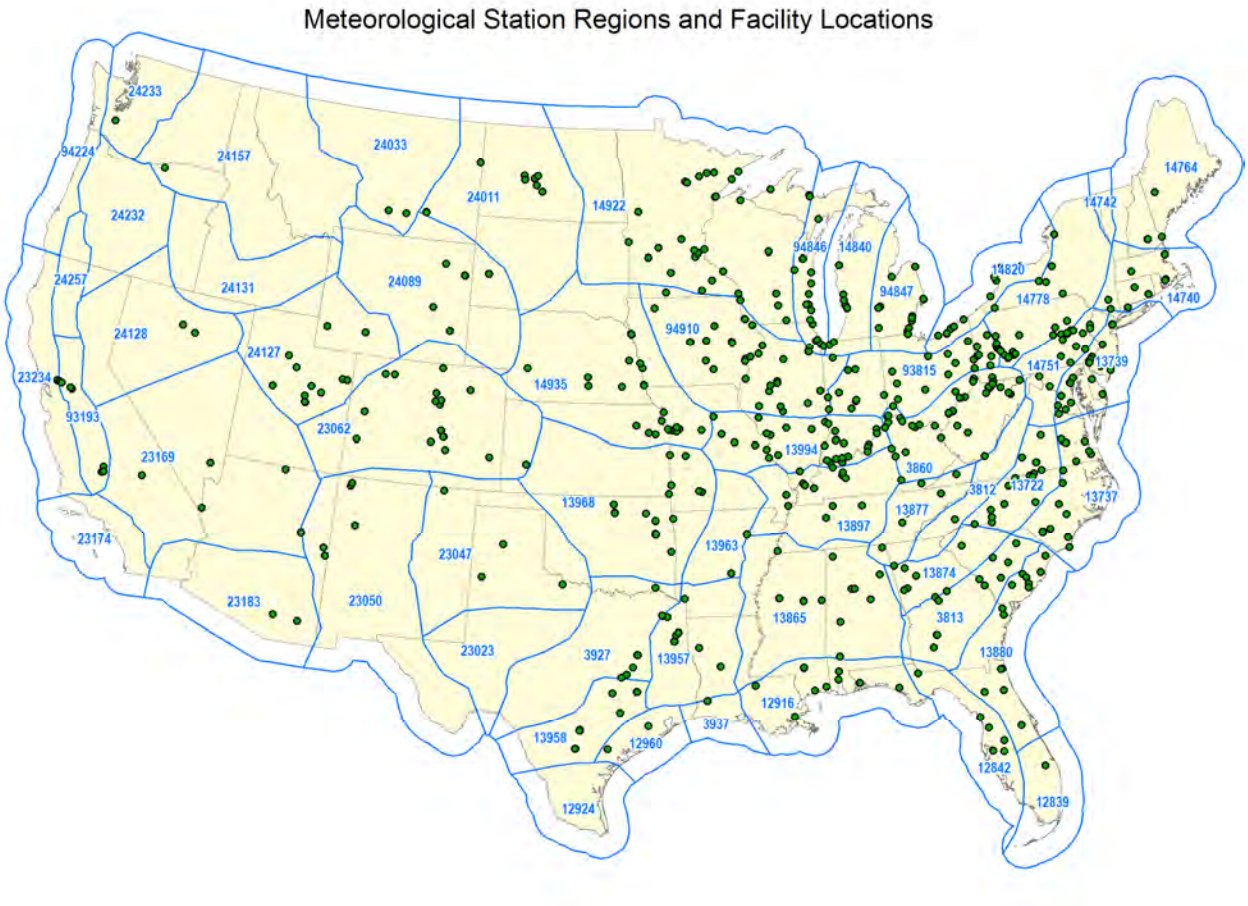

Figure F-1. IWAIR meteorological regions and coal combustion sites.

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Attachment F-1. Particulate Emissions Equations

F-1.1 Introduction

The following release mechanisms are considered: wind erosion, vehicular activity, unloading operations and spreading/ compacting operations. The sources for each of these mechanisms are summarized in **Table F-1-1**.

Table F-1-1. Mechanisms of Release of Particulate Emissions for Active Landfills

Mechanism of Release	Ei Subscript	Algorithm Reference
Wind Erosion from Open Area	wd	U.S. EPA, 1985a
Vehicular Activity	ve	AP-42 (U.S. EPA, 2006, Chapter 13.2.2: Unpaved Roads)
Unloading	un	AP-42 (U.S. EPA, 2006, Chapter 13.2.4: Aggregate Handling and Storage Piles)
Spreading/Compacting	sc	AP-42 (U.S. EPA, 1985b)*

* This equation was removed from the most recent (5th) edition of AP-42 but is still widely used, including, for example, in the 3MRA landfill model (U.S. EPA, 1999) and in Western Regional Air Partnership (see MRI, 2006). It can be found in the cited 4th edition.

This attachment describes the algorithms and assumptions used to estimate emissions for each landfill:

- Ei (g of PM/m^2-d), the annual average PM emission rate due to each release mechanism i (wind erosion, vehicular activity, unloading, and spreading and compacting)
- ∑Ei (g/m^2-d), the total annual average PM emission rate due to all release mechanisms, and
- CE (g/m^2-d), the annual average emission rate of contaminant as PM.

The equations all estimate emissions of PM_{10}, which are adjusted to $PM_{2.5}$ using the particle size distribution described in **Section F-1.3**. **Table F-1-2** presents the landfill-specific values used as inputs to these algorithms.

Table F-1-2. Emissions Equation Inputs

Variable	Units	Variable Name	Value	Comments
Waste-Specific Parameters				
Fly ash bulk density	g/cm^3	BD	1.19	U.S. EPA (1998)
Fraction $PM_{2.5}$	unitless	$PM_{2.5}$frac	0.15	See Section F-1.3
Fraction PM_{10}	unitless	PM_{10}frac	1	Reflects respirable releases*
Wind Erosion				
Mode of aggregate size distribution	mm	asdm	0.5	Based on the Soil Screening Guidance (U.S. EPA, 1996)
Silhouette area ratio	unitless	Lc	0.0003	Mean value (U.S. EPA, 1999b)
Fraction vegetative cover	frac	Veg	0	Assumed worst case
Surface roughness height	cm	z_0	1	Value of zruf for active landfill (U.S. EPA, 1999b)
Silt content (wind erosion)	%	S	80	AP-42, Chap. 13, Table 13.2.4-1 (fly ash) (U.S.EPA, 2006)
Frequency of disturbances (active)	1/mo	fd'	30	Consistent with worst case U.S. EPA, 1985a
Surface area	m^2	A	510,000	126 acres based on 90th percentile size; see Table F-2
Vehicular Emissions				
Silt content of roads	%	S_{roads}	24	Based on value from AP-42 for western surface coal mining–haul road (freshly graded) (U.S. EPA, 2006, Table 13.2.2-1). Maximum value in range of source conditions tested to develop Eqn 1a (U.S. EPA, 2006, p. 13.2.2.2-1) was 25.2%.
Mean vehicle weight	Short tons	V_w	40	Assumes trucks weigh 30 tons empty. Mean weight during travel equals half payload (i.e., approximately 10 tonsbased on truck volume and waste bulk density). Applied value is a combined weight of 40 tons.
Mean no. vehicles per day	1/day	N_v	88	Estimated based on 90th percentile loading rate, truck volume of 21 cubic yards, and waste bulk density
Meters traveled per vehicle	m	M_t	714	Length of landfill (truck travels to center of unit and back)
Dust suppression control efficiency (roads)	unitless	$EFF_{DustRoads}$	0	Assumed worst case of no controls

(continued)

Table F-1-2. Emissions Equation Inputs

Variable	Units	Variable Name	Value	Comments
Unloading Operations				
Waste moisture content	%	mcW	27	AP-42, Chap. 13, Table 13.2.4-1 (fly ash) (U.S. EPA, 2006)
Annual average waste loading rate	Mg/y	L	612,000	90th percentile value from DOE EIA-923 form data on landfill disposal in 2009 (161 plants; 675,000 sh. ton/yr; converted to Mg/yr using 0.907 Mg/sh. ton)
Surface area	m^2	A	510,000	90th percentile unit size (126 acres)
Spreading/Compacting/Tilling				
Silt content (spreading)	%	$S_{spreading}$	80	AP-42, Chap. 13, Table 13.2.4-1 (fly ash) (U.S. EPA, 2006)
No. of tilling/ spreading operations/day	1/day	NopC	3	Assumes spreading occurs once per 8-hour shift
Surface area/day	m^2	A	1,400	Estimated from daily loading rate & waste bulk density.

* EPA's Office of Air and Radiation considers PM_{10} and smaller to be respirable; available online at: www.epa.gov/airquality/particulatematter

F-1.2 Particulate Emission Rate (E_i) Algorithms

F-1.2.1 Wind Erosion from Open Fields (E10wd)

The algorithm for the estimation of PM_{10} emissions due to wind erosion from an open field is based on the procedure developed by U.S. EPA. (1985a). The input parameters are summarized in **Table F-1-3**.

Table F-1-3. Input Parameter Units and Definitions for $E10_{wd}$

Symbol	Units	Definition
asdm	mm	Mode of the aggregate particle size distribution
Lc	—	Ratio of the silhouette area of roughness elements too large to be included in sieving to total base area
veg´	—	Fraction of surface covered with vegetation (see Table F-2-2)
z´0	cm	Surface roughness height (see Table F-2-2)
S	w/w, %	Silt content of surface material
U+	m/s	Observed or probable fastest mile of wind between disturbances
PE	—	Thornthwaite Precipitation Evaporation Index
u	m/s	Mean annual wind speed
p	d/yr	Mean number of days per year with ≥0.01 in precipitation
fd´	1/mo	Frequency of disturbance per month where a disturbance is defined as an action that exposes fresh surface material

*Step 1: Calculate U*t*

Calculate the threshold friction velocity, U_{*t} (m/s), the threshold wind speed for the onset of wind erosion:

(F-2-1a) $$U_{*t} = 0.65(cf)(asdm)^{0.425}$$

Where:

(F-2-1b) $$cf = \begin{cases} 1.0 & \textbf{for } Lc < 2 \times 10^{-4} \\ 1.05 + 50.18(Lc) - 647.89(Lc)^2 + 6{,}863.5(Lc)^3 & \textbf{for } 2 \times 10^{-4} \le Lc \le 1 \times 10^{-1} \end{cases}$$

Table F-1-2 provides definitions of asdm and Lc. Lc is measured by inspection of a representative 1-m^2 transect of the site surface. Lc can range from zero to 0.1. High Lc ($\geq 2 \times 10^{-4}$) increases the threshold friction velocity, which results in a relatively low or zero particulate emission rate due to wind erosion. Low Lc ($<2 \times 10^{-4}$) is indicative of a bare surface with homogeneous finely divided material (e.g., an agricultural field). Such surfaces have a relatively low threshold friction velocity and increased particulate emissions. Equations (F-2-1a) and (F-2-1b) were derived from U.S. EPA. (1985a, Figures 3-4 and 3-5).

Step 2: Calculate U_t

U_t (m/s) is the threshold wind velocity at a height of 7.0 m (7.0 m is the typical weather station anemometer height). It is calculated using U.S. EPA. (1985a; Equation, 4-3, with z = 700 cm):

(F-2-2) $$U_t = \frac{U_{*t}}{0.4} \ln\left(\frac{700}{z'_0}\right) \qquad \textbf{for } z'_0 < 700$$

Where z'_0 is the roughness height in cm. Values for z'_0 for various surface conditions are provided in U.S. EPA. (1985a, Figure 3-6).

Step 3: Calculate $E10_{wd}$

$E10_{wd}$ is the annual average emission rate of particulate matter less than 10 μm in diameter per unit area of the contaminated surface.

For Sites with Limited Erosion Potential ($U_{*t} > 0.75$ m/s), the following equation was derived by using U.S. EPA. (1985a, Equations 4-1 to 4-3), converting units to g/m^2-d:

(F-2-3) $$E10_{wd} = \begin{cases} \dfrac{5.56(U^+ - U_t)(1 - veg')(24 \cdot fd')}{10^3 \cdot \left(\frac{PE}{50}\right)^2} & \textbf{for } U^+ \ge U_t \\ 0 & \textbf{for } U^+ < U_t \end{cases}$$

Data for peak gust wind velocities, which can be converted to U^+, and PE for locations throughout the United States can be found in the *Climatic Wind Data for the United States* (U.S. Department

of Commerce, 1998) and U.S. EPA (1985a, Figure 4-2), respectively. U.S. EPA (1985a) advises that, in the worst case, f_d should be assumed to be 30 per month. When $U_{*t} \leq 0.75$ m/s, the site is considered to have unlimited erosion potential and $E10_{wd}$ is calculated using U.S. EPA (1985a, Equation 4-4):

(F-2-4a) $$E10_{wd} = 0.036(1 - veg')\left(\frac{u}{U_t}\right)^3 g(x) \cdot 24\frac{h}{d}$$

Where:

(F-2-4b) $$x = 0.886\left(\frac{U_t}{u}\right)$$

(F-2-4c) $$g(x) = \begin{cases} 1.91 & \textbf{for } 0 \leq x < 0.5 \\ 2.2 - 0.6x & \textbf{for } 0.5 \leq x \leq 1.0 \\ 2.9 - 1.3x & \textbf{for } 1.0 < x \leq 2.0 \\ 0.18(8x^3 + 12x)e^{(-x^2)} & \textbf{for } x > 2.0 \end{cases}$$

Where g(x) was derived from U.S. EPA (1985a, Figure 4-3). Data for u for locations throughout the United States can be found in the *Climatic Wind Data for the United States* (U.S. Department of Commerce, 1998).

F-1.2.2 Vehicular Activity (E_{ve})

To estimate E_{ve} (g/m^2/d), the quantity of particulate emissions from vehicular travel on the surface of the landfill, the following equation for vehicles traveling on unpaved surfaces at industrial sites from AP-42 (updated November 2006) was used, adapted to convert from lb/VMT (vehicle mile traveled) to g/m^2/d:

(F-2-5) $$E_{ve} = 281.9k\left(\frac{S}{12}\right)^a \left(\frac{W}{3}\right)^b nv \left(\frac{mt}{A}\right)\left(\frac{km}{10^3 m}\right)$$

Where k, a and b are empirical constants that depend on particle size desired (see **Table F-1-4**) and the other parameter definitions are provided in **Table F-1-5**.

Table F-1-4. Coefficient Values for E_{ve} Equation

Symbol	Units	PM_{10}
k	lb/VMT	1.5
a	unitless	0.9
b	unitless	0.45

Table F-1-5. Parameter Units and Definitions for E_{ve}

Symbol	Units	Definition
S	w/w, %	Surface silt material content
W	tons	Mean vehicle weight
nv	1/d	Mean annual number of vehicles per day
A	m^2	Contaminated surface area
mt	m	Meters traveled per vehicle (nv) on contaminated surface

F-1.2.3 Unloading Operations (E_{un})

The equation for estimating E_{un} ($g/m^2/d$), the PM emission rate due to unloading operations at landfills, was adapted from U.S. EPA. (2006, Equation 1, p. 13.2.4-4). The EPA equation was adapted by multiplying it by the average annual loading rate (L, Mg/yr) and normalizing the emissions for the contaminated surface area:

(F-2-6) $$E_{un} = 0.0016k\frac{\left(\frac{u}{2.2}\right)^{1.3}}{\left(\frac{mcW}{2}\right)^{1.4}}\left(\frac{L}{A}\right)\left(\frac{10^3 g}{kg}\right)\left(\frac{yr}{365d}\right)$$

Where k is an empirical constant that depends on particle size desired (see **Table F-1-6**), and the other parameter definitions are provided in **Table F-1-7**.

Table F-1-6. Coefficient Values for E_{un} Equation

Symbol	Units	PM_{10}
k	Unitless	0.35

Table F-1-7. Parameter Units and Definitions for $E10_{un}$

Symbol	Units	Definition
U	m/s	Mean annual wind speed
mcW	Volume %	Waste moisture content
L	Mg/yr	Annual average waste loading rate
A	m2	Contaminated surface area

F-1.2.4 Spreading/Compacting or Tilling Operations (E_{sc})

As in the 3MRA landfill model (U.S. EPA, 1999), the equation for estimating E_{sc} ($g/m^2/d$), the rate of PM emissions due to spreading and compacting or tilling operations, was adapted from an equation in U.S. EPA (1985b, Equation 1, p. 11.2.2-1) that was developed for estimating emissions due to agricultural tilling in units of kilogram of particulate emissions per hectare per tilling (or spreading/compacting) event.

(F-2-7) $$E_{sc} = 5.38k(S^{0.6})(N_{op})\left(\frac{ha}{10^4 m^2}\right)$$

Where k is an empirical constant that depends on particle size desired (see **Table F-1-8**), and the other parameter definitions are provided in **Table F-1-9**.

Table F-1-8. Coefficient Values for E_{sc} Equation

Symbol	Units	PM_{10}
k	Unitless	0.21

Table F-1-9. Parameter Units and Definitions for E_{sc}

Symbol	Units	Definition
S	w/w, %	Silt content of surface material
Nop	1/d	Number of spreading and compacting operations per day

F-1.3 Particle Size Distribution for $PM_{2.5}$

To calculate $PM_{2.5}$ emissions of fly ash for the $PM_{2.5}$ NAAQS, EPA conducted a literature search for particle size distributions for fly ash. EPA did not find any data for U.S. coal-fired power plant sites. However, Moreno et al. (2005) provide distributions for 23 pulverized coal-fired power plant sites in Europe. These sites were selected to cover most of the fly ash types produced in the European Union. The range of coal types in this study is similar to the range used in the United States, and electrostatic precipitators are used in over 90 percent of facilities in the United States (Bein et al., 2007). Therefore, EPA used these data to estimate a particle size distribution.

Moreno et al. (2005) list the particle sizes for the 10th, 50th and 90th percentiles for selected fly ash samples from each of the listed power plants (see **Table F-1-10**. EPA omitted one plant (the power station As Pontes) because its sample was a mixture of fly ash and molten slag. All other samples were collected at the ESP. EPA plotted the 10th and 50th percentiles on log-probability paper and determined the probabilities for particle sizes 2.5 and 10 µm, and then calculated the ratio of the PM_{10} to $PM_{2.5}$ percentiles for each power plant. The overall mass ratio of PM_{10} to $PM_{2.5}$

has a mean of 6.8 and a median of 6.2. Using the mean, this suggests a particle size distribution in which $PM_{2.5}$ account for about 15 percent of the total PM_{10}.

Table F-1-10. Particle Size Distributions for Selected Power Stations in the European Union

Power Station	Location	Size Percentile			Percentile		Ratio
		10th	50th	90th	PM_{10}	$PM_{2.5}$	$PM_{10}/PM_{2.5}$
Narcea	N Spain	3.0	11.8	50.3	44	7.3	6.0
Barrios	S Spain	4.6	24.6	84.6	24	3.9	6.2
Escucha	EN Spain	8.3	53.4	183.8	13	1.8	6.9
Meirama	N Spain	8.9	40.5	248.0	12	1.0	12.6
Teruel	EN Spain	4.6	21.8	75.7	26	3.8	6.8
Espiel	S Spain	3.8	21.0	99.5	29	5.7	5.1
Compostilla	N Spain	4.2	17.3	77.4	31	4.0	7.8
La Robla	N Spain	2.3	12.3	76.2	43	11	3.9
Soto Ribera	N Spain	7.5	43.8	221.0	14	1.8	7.8
Puertollano	Central Spain	4.7	26.2	123.8	23	3.8	6.1
Alkaline	Netherlands	4.5	26.1	114.1	24	4.2	5.7
Nijmegen	Netherlands	4.7	21.4	74.2	26	3.5	7.4
Neutral	Netherlands	3.9	18.8	85.8	30	5.0	6.0
CCB	Netherlands	7.6	53.2	173.5	14	2.2	6.1
Acid	Netherlands	2.6	13.7	43.8	40	9.5	4.2
Amer-8	Netherlands	4.6	25.9	151.8	24	4.2	5.7
Amer-9	Netherlands	3.1	18.6	63.9	32	7.5	4.3
Hemweg-8	Netherlands	4.7	21.9	69.9	26	3.8	6.8
Lignite	N Greece	7.3	32.8	156.8	15	1.4	10.7
Fusina	Italy	6.5	29.3	171.2	18	1.8	10.0
Monfalcone	Italy	7.9	42.2	295.3	14	1.6	8.4
Sardegna	Italy	4.5	28.6	114.0	24	4.5	5.2
Minimum							3.9
Mean							6.8
Median							6.2
Maximum							12.6

F-1.4 References

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Attachment F-2.
AERSCREEN Inputs

In general, AERSCREEN provides added capabilities that allow refinement of the screen estimates based on environmental setting and location. **Table F-2-1** shows the inputs needed. Not all input options presented in this table apply to this assessment, given that the sources that were modeled are ground-level area sources (so inputs specific to elevated point sources, such as building parameters and terrain, will not apply). However, these inputs were included in the table to allow for a comprehensive listing of the parameters. The following key components of the AERSCREEN model allow for the refinement of the CCR high-end dispersion estimates, as follows:

- AERSCREEN executes MAKEMET to generate a site-specific matrix of meteorological conditions, interfaces with AERMAP to process terrain, interfaces with BPIPPRM (Building Profile Input Program for PRIME) to process building information and executes AERMOD with special screening options. One of its postprocessing functions is to search for and isolate the receptor distance with the highest impact.
- MAKEMET takes into account many factors when creating the matrix of meteorological conditions. These include wind speeds, cloud covers, ambient temperatures, solar elevation angles and convective velocity scales for user-specific surface characteristics (albedo, Bowen ratio and surface roughness length). MAKEMET calculates mechanical mixing height and convective mixing height for convective conditions and includes AERMET subroutines for boundary layer calculations.
- As part of its screening function, MAKEMET eliminates sets of conditions that are not necessary for identifying worst-case impacts.
- The surface characteristics can be specified using three methods: constants input by the user (i.e., no spatial or temporal variation), seasonally varying for generic land use classifications or output from AERSURFACE.

Table F-2-1. Inputs Needed for AERSCREEN

Parameter	Units*	Values or Options Available
Model basis	—	AERMOD
Averaging time options	—	1-hour, 3-hour, 8-hour, 24-hour, annual
Emission rate	Model specific	g/s
Emission type	—	Vapor and particles
Source types	—	Point, flare, capped stack, horizontal stack, volume, rectangular area, circular area
Source release height above ground	m	Set to zero
Length of larger side of the rectangular area	m	Based on modeled unit size
Length of smaller side of the rectangular area	m	Based on modeled unit size
Radius of circular source	m	Based on modeled unit size
Receptor height above ground (flagpole receptor)	m	Set to zero
Initial vertical dimension of plume	m	Not applicable
Urban/rural option	U or R	Location specific
Urban population (if urban)	Count	Location specific
Wind direction search option (yes/no)	—	Set to yes
Wind direction angle (if wind direction search option set to no)	Degrees	(0° from N; long side is x-axis)
Meteorology option	—	Site-specific matrix of screening meteorological conditions (MAKEMET)
Minimum ambient air temperature	°K	Default available
Maximum ambient air temperature	°K	Default available
Minimum wind speed	m/s	Default available

(continued)

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Table F-2-1. Inputs Needed for AERSCREEN

Parameter	Units*	Values or Options Available
Anemometer height	m	Default available
Land use type for surface characteristics	—	0=user-entered, 1=water, 2=deciduous forest, 3=coniferous forest, 4=swamp, 5=cultivated land, 6=grassland, 7=urban, 8=desert shrub land, 9=external file
Seasonally varying surface characteristics (option)	—	Not applied
Detailed temporally and spatially explicit surface characteristics (option)	—	AERSURFACE results
Climatology type	—	1=average, 2=wet, 3=dry
Albedo	—	Location-specific
Bowen ratio	—	Location-specific
Surface roughness	—	Location-specific
Distance to receptor	m	Minimum
Building parameters for wake effects	—	Executes BPIPPRM; not for area or volume sources
Terrain impacts	—	Automates AERMAP; not for rectangular area source
Geographic coordinates	—	Latitude/longitude, or UTM (UTM required for automated mode), NAD 1927 or NAD 1983

* AERSCREEN can accommodate either metric or English units; metric are shown here.

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Appendix G.

Food Chain Equations and Data

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G.1 Introduction

The equations used to calculate concentrations in food chain items and total intake for human receptors are shown in this section.

- **Attachment G-1** provides each of the chemical-specific bioconcentration and biotransfer factors needed.

G.2 Food Chain Equations

G.2.1 Concentrations in Fish

This section contains the equations for contaminant concentrations in fish:

- **Table G-1.** Concentration in Fish at Different Trophic Levels
- **Table G-2.** Average Fish Fillet Concentration Ingested by Humans.

Table G-1. Concentration in Fish at Different Trophic Levels (mg/kg)

C_{fish}	
For Nonvolatile Metals:	**For Mercury:**
$C_{fish} = C_{wTot} \times BCF_i$	$C_{fish} = 0.15 \times C_{dw} \times BCF_i$

Name	Description	Value
BCF_i	Bioconcentration factor for specified trophic level (L/kg)	See **Table G-1-1**
C_{dw}	Dissolved waterbody concentration (mg/L)	Calculated
C_{wTot}	Total waterbody concentration from loading (g/m^3 or mg/L)	Calculated
0.15	Fraction of dissolved mercury assumed to be methyl mercury (unitless)	Source: HHRAP (U.S. EPA, 2005)

Table G-2. Average Fish Fillet Concentration Ingested by Humans (mg/kg)

C_{fish_fillet}

$$C_{fish\_fillet} = F_{T3} \times C_{fishT3F} + F_{T4} \times C_{fishT4F}$$

Name	Description	Value
$C_{fishT3F}$	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated
$C_{fishT4F}$	Concentration of contaminant in fish at different trophic levels (mg/kg)	Calculated
F_{T3}	Fraction of trophic level 3 intake (unitless)	See **Appendix D**
F_{T4}	Fraction of trophic level 4 intake (unitless)	See **Appendix D**

G.2.2. Concentrations in Produce

This section contains the equations for contaminant concentration in produce, forage, silage, grain, and animal products:

- **Table G-3.** Concentration in Aboveground Produce Due to Soil Uptake
- **Table G-4.** Concentration in Root Vegetables Due to Soil Uptake
- **Table G-5.** Concentration in Aboveground Produce due to Deposition
- **Table G-6.** Concentration in Exposed Fruits and Vegetables Due to Deposition
- **Table G-7.** Concentration in Protected Fruits and Vegetables Due to Deposition
- **Table G-8.** Concentration in Forage and Silage
- **Table G-9.** Concentration in Grain.

Table G-3. Concentration in Aboveground Produce Due to Soil Uptake (mg/kg DW)

Pr_i

$$Pr_i = C_{soil} \times Br_i$$

Name	Description	Value
C_{soil}	Soil concentration (mg/kg)	Calculated
Br_i	Plant-soil bioconcentration factor for aboveground produce type i ([mg/kg DW plant]/[mg/kg soil]) (chemical specific)	See **Table G-1-1**

Table G-4. Concentration in Root Vegetables Due to Soil Uptake (mg/kg WW)

Pr_{bg}

$$Pr_{bg} = C_{soil} \times Br_{root} \times \frac{(100 - MAF_{root})}{100}$$

Name	Description	Value
C_{soil}	Soil concentration (mg/kg)	Calculated
Br_{root}	Plant-soil bioconcentration factor for root vegetables ([mg/kg DW plant]/[mg/kg soil]) = RCF (root concentration factor) divided by K_d of soil (chemical specific)	See **Table G-1-1**
MAF_{root}	Moisture adjustment factor for root vegetables (% water)	See Table G-15

Table G-5. Concentration in Aboveground Produce due to Deposition (mg/kg DW)

Pd_i

$$Pd_i = \frac{Dp \times Rp_i \times (1 - e^{-KpPart \times Tp_i})}{Yp_i \times KpPar}$$

Name	Description	Value
Dp	Deposition term for plants (mg/m^2-yr)	Calculated
Rp_i	Interception fraction for aboveground produce type i (unitless)	See **Table G-15**
KpPar	Plant surface loss coefficient for particulates (1/yr)	Mercury: 40.41* Other constituents: 18.07*
Tp_i	Length of plant exposure to deposition per harvest of edible portion of plant for aboveground produce type i (yr)	See **Table G-15**
Yp_i	Yield or standing crop biomass of the edible portion of the plant (productivity) for aboveground produce type i (kg DW/m^2)	See **Table G-15**

* Source: U.S. EPA (1997b)

Table G-6. Concentration in Exposed Produce Due to Deposition (mg/kg DW)

P_{exp}

$$P_{exp} = (Pd_i + Pr_i) \times \frac{(100 - MAF_i)}{100}$$

Name	Description	Value
Pdi	Concentration in aboveground produce type i due to deposition (mg/kg DW)	Calculated
Pri	Concentration in aboveground produce type i due to soil uptake (mg/kg DW)	Calculated
MAFi	Moisture adjustment factor for aboveground produce type i (unitless)	See **Table G-15**

Table G-7. Concentration in Protected Produce Due to Deposition (mg/kg DW)

P_{pro}

$$P_{pro} = Pr_i \times \frac{(100 - MAF_i)}{100}$$

Name	Description	Value
Pr_i	Concentration in aboveground produce type i due to soil uptake (mg/kg DW)	Calculated
MAF_i	Moisture adjustment factor for aboveground produce type i (unitless)	See **Table G-15**

Table G-8. Concentration in Forage and Silage (mg/kg DW)

P_{forage}, P_{silage}

$$P_{forage} = (Pd_{forage} + Pr_{forage})$$

$$P_{silage} = (Pd_{silage} + Pr_{silage})$$

Name	Description	Value
Pd_i	Concentration in aboveground produce type i due to deposition (mg/kg DW)	Calculated
Pr_i	Concentration in aboveground produce type i due to soil uptake (mg/kg DW)	Calculated

Table G-9. Concentration in Grain (mg/kg DW)

P_{grain}

$$P_{grain} = Pr_i$$

Name	Description	Value
Pr_i	Concentration in aboveground produce type i due to soil uptake (mg/kg DW)	Calculated

G.2.3. Concentrations in Animal Products

This section contains the equations for contaminant concentration animal products:

- **Table G-10.** Concentration in Beef
- **Table G-11.** Concentration in Dairy.

Table G-10. Concentration in Beef (mg/kg)

A_{beef}

$$A_{beef} = Ba_{beef} \times [(F_{grain} \times Q_{gbs} \times P_{grain}) + (F_{forage} \times Q_{fbs} \times P_{forage}) + (F_{silage} \times Q_{sbs} \times P_{silage}) + (Q_{soilbs} \times C_{soil})]$$

Name	Description	Value
Ba_{beef}	Biotransfer factor from soil or feed to beef ([mg/kg-WW]/[mg/day])	See **Table G-1-1**
P_{forage}	Concentration in forage (mg/kg DW)	Calculated
P_{silage}	Concentration in silage (mg/kg DW)	Calculated
P_{grain}	Concentration in grain (mg/kg DW)	Calculated
F_{forage}	Fraction of forage that is contaminated (unitless)	See **Table G-15**
F_{silage}	Fraction of silage that is contaminated (unitless)	See **Table G-15**
F_{grain}	Fraction of grain that is contaminated (unitless)	See **Table G-15**
Q_{fbs}	Quantity of forage consumed by beef cattle (kg-DW/day)	See **Table G-15**
Q_{gbs}	Quantity of grain consumed by beef cattle (kg-DW/day)	See **Table G-15**
Q_{sbs}	Quantity of silage consumed by beef cattle (kg-DW/day)	See **Table G-15**
Q_{soilbs}	Quantity of soil consumed by beef cattle (kg/day)	See **Table G-15**
C_{soil}	Concentration in soil (mg/kg)	Calculated

Table G-11. Concentration in Dairy (mg/kg)

Amilk

$$A_{milk} = Ba_{milk} \times [(F_{grain} \times Q_{gds} \times P_{grain}) + (F_{forage} \times Q_{fds} \times P_{forage}) + (F_{silage} \times Q_{sds} \times P_{silage}) + (Q_{soilds} \times C_{soil})]$$

Name	Description	Value
Ba_{milk}	Biotransfer factor from soil or feed to dairy ([mg/kg-WW]/[mg/day])	See **Table G-1-1**
P_{forage}	Concentration in forage (mg/kg DW)	Calculated
P_{silage}	Concentration in silage (mg/kg DW)	Calculated
P_{grain}	Concentration in grain (mg/kg DW)	Calculated
F_{forage}	Fraction of forage that is contaminated (unitless)	See **Table G-15**
F_{grain}	Fraction of grain that is contaminated (unitless)	See **Table G-15**
F_{silage}	Fraction of silage that is contaminated (unitless)	See **Table G-15**
Q_{fds}	Quantity of forage consumed by dairy cattle (kg-DW/day)	See **Table G-15**
Q_{gds}	Quantity of grain consumed by dairy cattle (kg-DW/day)	See **Table G-15**
Q_{sds}	Quantity of silage consumed by dairy cattle (kg-DW/day)	See **Table G-15**
Q_{soilds}	Quantity of soil consumed by dairy cattle (kg/day)	See **Table G-15**
C_{soil}	Concentration in soil (mg/kg).	Calculated

G.2.4. Intake Rates

This section contains the equations for intake of drinking water, soil, produce, animal products, and fish:

- **Table G-12.** Contaminant Intake from Drinking Water
- **Table G-13.** Daily Intake of Contaminant from Fish Ingestion
- **Table G-14.** Daily Intake of Contaminant from Produce or Animal Product Ingestion.

Table G-12. Daily Intake from Drinking Water (mg/kg-day)

I_{dw}

$$I_{dw} = \frac{C_{dw} \times CR_{dw} \times F_{dw}}{1{,}000}$$

Name	Description	Value
C_{dw}	Dissolved waterbody concentration (mg/L)	Calculated
CR_{dw}	Consumption rate of water (mL/kg-day)	See **Appendix D**
F_{dw}	Fraction of drinking water ingested that is contaminated (unitless)	See **Appendix D**

Table G-13. Daily Intake from Fish Ingestion (mg/kg-day)

I_{fish}

$$I_{fish} = \frac{C_{fish\_fillet} \times CR_{fish} \times F_{fish}}{1000 \times BW}$$

Name	Description	Value
BW	Body weight (kg)	See **Appendix D**
C_{fish_fillet}	Average fish fillet concentration ingested by humans (mg/kg)	Calculated
CR_{fish}	Consumption rate of fish (g WW/day)	See **Appendix D**
F_{fish}	Fraction of fish intake from contaminated source (unitless)	See **Appendix D**

Table G-14. Daily Intake from Produce or Animal Product Ingestion (mg/kg-day)

$I_{produce}$, I_{beef}, I_{milk}

$$I_i = \frac{C_i \times CR_i \times F_i}{1{,}000}$$

Name	Description	Value
C_i	Average concentration in plant or animal product *i* ingested by humans (mg/kg)*	Calculated
CR_i	Consumption rate of plant or animal product *i* (g/day) [a]	See **Appendix D**
F_i	Fraction of plant or animal product *i* intake from contaminated source (unitless)	See **Appendix D**

* Concentrations and consumption rates must be in dry weight for aboveground plants (so mg/kg DW or g DW/day) and whole weight for root vegetables and animal products (so mg/kg WW or g WW/day).

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G.3 Biota Data

The biota data needed for the above equations are presented in **Table G-15**. These values are all constants and were all drawn from the U.S. Environmental Protection Agency's (EPA's or the Agency's) *Parameter Guidance Document* (U.S. EPA, 1997b).

Table G-15. Biota Data

Model Code	Description	Value
F_forage	Fraction of pasture grasses grown on contaminated soil and eaten. (unitless)	1
F_grain	Fraction of grain grown on contaminated soil and eaten (unitless)	1
F_silage	Fraction of silage grown on contaminated soil and eaten (unitless)	1
MAF_exfruit	Moisture adjustment factor for exposed fruits (% water)	85
MAF_exveg	Moisture adjustment factor for exposed vegetables (% water)	92
MAF_profruit	Moisture adjustment factor for protected fruits (% water)	90
MAF_proveg	Moisture adjustment factor for protected vegetables (% water)	80
MAF_root	Moisture adjustment factor for root vegetables (% water)	87
Rp_exfruit	Interception fraction for exposed fruit (unitless)	0.052
Rp_exveg	Interception fraction for exposed vegetation (unitless)	0.052
Rp_forage	Interception fraction for forage (unitless)	0.47
Rp_silage	Interception fraction for silage (unitless)	0.44
Tp_exfruit	Length of plant exposure to deposition for exposed fruit (yr)	0.123
Tp_exveg	Length of plant exposure to deposition for exposed vegetables (yr)	0.123
Tp_forage	Length of plant exposure to deposition for forage (yr)	0.123
Tp_silage	Length of plant exposure to deposition for silage (yr)	0.164
Yp_exfruit	Crop yield for exposed fruit (kg DW/m^2)	0.09
Yp_exveg	Crop yield for exposed veg (kg DW/m^2)	0.18
Yp_forage	Crop yield for forage (kg DW/m^2)	0.31
Yp_silage	Crop yield for silage (kg DW/m^2)	0.31
Q_{fbs}	Quantity of forage consumed by beef cattle (kg-DW/day)	8.8
Q_{gbs}	Quantity of grain consumed by beef cattle (kg-DW/day)	0.47
Q_{sbs}	Quantity of silage consumed by beef cattle (kg-DW/day)	2.5
Q_{soilbs}	Quantity of soil consumed by beef cattle (kg/day)	0.39
Q_{fds}	Quantity of forage consumed by dairy cattle (kg-DW/day)	11
Q_{gds}	Quantity of grain consumed by dairy cattle (kg-DW/day)	2.6
Q_{sds}	Quantity of silage consumed by dairy cattle (kg-DW/day)	3.3
Q_{soilds}	Quantity of soil consumed by dairy cattle (kg/day)	0.41

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G.4 Bioconcentration and Biotransfer Data

Data on certain chemical-specific factors were used to estimate the degree to which constituents of potential concern (COPCs) may accumulate in exposed plants and animals. In turn, this information is used to calculate residential exposures from consumption of produce, livestock, and fish. Available data was gathered for each of the following 25 COPCs identified during hazard identification (**Section 2**):

- Aluminum
- Antimony
- Arsenic
- Barium
- Beryllium
- Boron
- Cadmium
- Chromium
- Cobalt
- Copper
- Fluoride
- Iron
- Lanthanum
- Lead
- Lithium
- Manganese
- Mercury
- Molybdenum
- Nickel
- Nitrate
- Selenium
- Silver
- Strontium
- Thallium
- Uranium
- Vanadium
- Zinc

Bioconcentration factors (BCFs) and biotransfer factors (BTFs) are based on the compilation of field and laboratory study results to develop a single factor or ratio for estimating the amount of constituent transferred into specific plant or animal tissue. EPA estimated fish tissue concentrations for trophic level 3 (TL3) and trophic level 4 (TL4) fish filets to account for the variability in fish likely consumed by human receptors. The following source hierarchy was used for fish BCFs:

- **Primary literature:** These are generally papers that may focus on a single chemical (Eisler, 1989; Kumada et al., 1973; Lemly, 1985; Murphy et al., 1978) or may contain data on multiple chemicals (Barrows et al., 1980; Stephan, 1993).
- **U.S. EPA databases/publications:** These included ECOTOX (U.S. EPA, 2009) and the Mercury Report to Congress (U.S. EPA, 1997a).
- **Other government agency resources:** These included Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles (ATSDR, 2008) and the Hazardous Substances Data Bank (HSDB; U.S. NLM, 2011).

Where data for only one trophic level of fish were available, those data were used as a surrogate for the other trophic level. Where data were only available for whole fish, those were used as a surrogate for filet. Whole fish values from the correct trophic level were preferred as surrogates to filet values from the other trophic level. So, given a TL3 whole fish value and a TL4 filet value, the TL3 whole value would be preferred to the TL4 filet as a surrogate for TL3 filet. Similarly, EPA evaluated different categories of produce and animal products to capture the variability in farm-raised foods consumed by human receptors. The key source for biotransfer factors for animal products and plants was Baes et al. (1984).

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Attachment G-1. Bioconcentration and Biotransfer Factors

Table B-1-1 lists all of the chemical-specific parameters collected for this analysis, presented in alphabetical order based on the name of the constituent. In some instances, adequate data was not available on one or more of the parameters for a given constituent. In these cases, the analysis could not quantitatively consider exposures through the associated pathway. The factor abbreviations are defined below as follows:

- **Ba_{Beef} & Ba_{Milk}:** Biotransfer factor for beef or milk (day/kg-wet weight); primary data source is Baes et al. (1984).
- **BCF_{T3F} & BCF_{T4F}:** Bioconcentration factor for trophic level 3 (TL3) and trophic level 4 (TL4) fish filet (L/kg); data mostly drawn from primary literature or ECOTOX (U.S. EPA, 2009)
- **Br_i:** Soil-to-plant bioconcentration factor for plant type *i* (µg/g-plant dry weight)/(µg/g soil); primary data source is Baes et al. (1984), but some factors are calculated based on U.S. EPA (2009) if not available in Baes et al. Plant types are:
  - **ExFruit:** Exposed fruits eaten by human receptors;
  - **ExVeg:** Exposed vegetables eaten by human receptors;
  - **Forage:** Forage eaten by cattle;
  - **Grain:** Grains eaten by cattle;
  - **ProFruit:** Protected fruits eaten by human receptors;
  - **ProVeg:** Protected vegetables eaten by human receptors;
  - **Root:** Root vegetables eaten by human receptors; and
  - **Silage:** Silage eaten by cattle.

When the reference is a compilation, the original paper from which the value was drawn is also shown, if available. For example, "ECOTOX Wright, 1977" means the value was obtained from ECOTOX, which cites Wright (1977). Similarly, "ATSDR Hope 1996" means we obtained it from the ATSDR toxicological profile, which cites Hope (1996).

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Aluminum (7429-90-5)			
Ba_{beef}	1.5E-03	Baes et al., 1984	—
Ba_{milk}	2.0E-04	Baes et al., 1984	—
BCF_{T3F}	3.6E+01	ECOTOX Cleveland, 1991	BCFfor TL4 whole fish was used as a surrogate for TL3 filet
BCF_{T4F}	3.6E+01	ECOTOX Cleveland, 1991	BCF for TL4 whole fish was used as a surrogate for TL4 filet
$Br_{Exfruit}$	6.5E-04	Baes et al., 1984	—
Br_{Exveg}	4.0E-03	Baes et al., 1984	—
Br_{Forage}	4.0E-03	Baes et al., 1984	—
Br_{Grain}	6.5E-04	Baes et al., 1984	—
$Br_{Profruit}$	6.5E-04	Baes et al., 1984	—
Br_{Proveg}	6.5E-04	Baes et al., 1984	—
Br_{Root}	4.0E-03	Baes et al., 1984	—
Br_{Silage}	4.0E-03	Baes et al., 1984	—
Antimony (7440-36-0)			
Ba_{beef}	1.0E-03	Baes et al., 1984	—
Ba_{milk}	1.0E-04	Baes et al., 1984	—
BCF_{T3F}	0	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL3 filet.
BCF_{T4F}	0	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL4 filet.
$Br_{Exfruit}$	3.0E-02	Baes et al., 1984	—
Br_{Exveg}	2.0E-01	Baes et al., 1984	—
Br_{Forage}	2.0E-01	Baes et al., 1984	—
Br_{Grain}	3.0E-02	Baes et al., 1984	—
$Br_{Profruit}$	3.0E-02	Baes et al., 1984	—
Br_{Proveg}	3.0E-02	Baes et al., 1984	—
Br_{Root}	2.0E-01	Baes et al., 1984	—
Br_{Silage}	2.0E-01	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Arsenic (7440-38-2)			
Ba_{beef}	2.0E-03	Baes et al., 1984	—
Ba_{milk}	6.0E-05	Baes et al., 1984	—
BCF_{T3F}	4.0E+00	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL3 filet.
BCF_{T4F}	4.0E+00	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL4 filet.
$Br_{Exfruit}$	2.0E-03	Calculated based on U.S. EPA, 1999	—
Br_{Exveg}	1.0E-02	Calculated based on U.S. EPA, 1999	—
Br_{Forage}	5.3E-02	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	4.3E-03	Calculated based on U.S. EPA, 1999	—
$Br_{Profruit}$	2.0E-03	Calculated based on U.S. EPA, 1999	—
Br_{Proveg}	2.0E-03	Calculated based on U.S. EPA, 1999	—
Br_{Root}	4.6E-03	Calculated based on U.S. EPA, 1999	—
Br_{Silage}	5.3E-02	Calculated based on U.S. EPA, 1999	—
Barium (7440-39-3)			
Ba_{beef}	1.5E-04	Baes et al., 1984	—
Ba_{milk}	3.5E-04	Baes et al., 1984	—
BCF_{T3F}	1.3E+02	ATSDR Hope, 1996	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL3 filet.
BCF_{T4F}	1.3E+02	ATSDR Hope, 1996	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL4 filet.
$Br_{Exfruit}$	1.5E-02	Baes et al., 1984	—
Br_{Exveg}	1.5E-01	Baes et al., 1984	—
Br_{Forage}	1.5E-01	Baes et al., 1984	—
Br_{Grain}	1.5E-02	Baes et al., 1984	—
$Br_{Profruit}$	1.5E-02	Baes et al., 1984	—
Br_{Proveg}	1.5E-02	Baes et al., 1984	—
Br_{Root}	1.5E-01	Baes et al., 1984	—
Br_{Silage}	1.5E-01	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Beryllium (7440-41-7)			
Ba_{beef}	1.0E-03	Baes et al., 1984	—
Ba_{milk}	9.0E-07	Baes et al., 1984	—
BCF_{T3F}	1.9E+01	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL3 filet.
BCF_{T4F}	1.9E+01	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL4 filet.
$Br_{Exfruit}$	1.5E-03	Baes et al., 1984	—
Br_{Exveg}	1.0E-02	Baes et al., 1984	—
Br_{Forage}	1.0E-02	Baes et al., 1984	—
Br_{Grain}	1.5E-03	Baes et al., 1984	—
$Br_{Profruit}$	1.5E-03	Baes et al., 1984	—
Br_{Proveg}	1.5E-03	Baes et al., 1984	—
Br_{Root}	1.0E-02	Baes et al., 1984	—
Br_{Silage}	1.0E-02	Baes et al., 1984	—
Boron (7440-42-8)			
Ba_{beef}	8.0E-04	Baes et al., 1984	—
Ba_{milk}	1.5E-03	Baes et al., 1984	—
BCF_{T3F}	—	—	—
BCF_{T4F}	—	—	—
$Br_{Exfruit}$	2.0E+00	Baes et al., 1984	—
Br_{Exveg}	4.0E+00	Baes et al., 1984	—
Br_{Forage}	4.0E+00	Baes et al., 1984	—
Br_{Grain}	2.0E+00	Baes et al., 1984	—
$Br_{Profruit}$	2.0E+00	Baes et al., 1984	—
Br_{Proveg}	2.0E+00	Baes et al., 1984	—
Br_{Root}	4.0E+00	Baes et al., 1984	—
Br_{Silage}	4.0E+00	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Cadmium (7440-43-9)			
Ba_{beef}	5.5E-04	Baes et al., 1984	—
Ba_{milk}	1.0E-03	Baes et al., 1984	—
BCF_{T3F}	2.7E+02	Kumada et al., 1972	BCF for TL3 whole fish (rainbow trout) was used as a surrogate for TL3 filet. Geomean of mulitple values.
BCF_{T4F}	2.7E+02	Kumada et al., 1972	BCF for TL3 whole fish (rainbow trout) was used as a surrogate for TL4 filet. Geomean of mulitple values.
$Br_{Exfruit}$	2.5E-03	Calculated based on U.S. EPA, 1999	—
Br_{Exveg}	6.7E-01	Calculated based on U.S. EPA, 1999	—
Br_{Forage}	4.0E-01	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	1.1E-01	Calculated based on U.S. EPA, 1999	—
$Br_{Profruit}$	2.5E-03	Calculated based on U.S. EPA, 1999	—
Br_{Proveg}	2.5E-03	Calculated based on U.S. EPA, 1999	—
Br_{Root}	2.5E-01	Calculated based on U.S. EPA, 1999	—
Br_{Silage}	4.0E-01	Calculated based on U.S. EPA, 1999	—
Chromium (7440-47-3)			
Ba_{beef}	5.5E-03	Baes et al., 1984	—
Ba_{milk}	1.5E-03	Baes et al., 1984	—
BCF_{T3F}	6.0E-01	Stephan, 1993	BCF for TL4 filet was used as a surrogate for TL3 filet.
BCF_{T4F}	6.0E-01	Stephan, 1993 derived from Buhler et al., 1977 and Calamari et al., 1982	—
$Br_{Exfruit}$	1.4E-04	Calculated based on U.S. EPA, 1999	—
Br_{Exveg}	5.8E-04	Calculated based on U.S. EPA, 1999	—
Br_{Forage}	1.9E-03	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	9.0E-05	Calculated based on U.S. EPA, 1999	—
$Br_{Profruit}$	1.4E-04	Calculated based on U.S. EPA, 1999	—
Br_{Proveg}	1.4E-04	Calculated based on U.S. EPA, 1999	—
Br_{Root}	9.5E-04	Calculated based on U.S. EPA, 1999	—
Br_{Silage}	1.9E-03	Calculated based on U.S. EPA, 1999	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Cobalt (7440-48-4)			
Ba_{beef}	2.0E-02	Baes et al., 1984	—
Ba_{milk}	2.0E-03	Baes et al., 1984	—
BCF_{T3F}	—	—	—
BCF_{T4F}	—	—	—
$Br_{Exfruit}$	7.0E-03	Baes et al., 1984	—
Br_{Exveg}	2.0E-02	Baes et al., 1984	—
Br_{Forage}	2.0E-02	Baes et al., 1984	—
Br_{Grain}	7.0E-03	Baes et al., 1984	—
$Br_{Profruit}$	7.0E-03	Baes et al., 1984	—
Br_{Proveg}	7.0E-03	Baes et al., 1984	—
Br_{Root}	2.0E-02	Baes et al., 1984	—
Br_{Silage}	2.0E-02	Baes et al., 1984	—
Copper (7440-50-8)			
Ba_{beef}	1.0E-02	Baes et al., 1984	—
Ba_{milk}	1.5E-03	Baes et al., 1984	—
BCF_{T3F}	0	Stephan (1993)	—
BCF_{T4F}	0	Stephan (1993)	—
$Br_{Exfruit}$	2.5E-01	Baes et al., 1984	—
Br_{Exveg}	4.0E-01	Baes et al., 1984	—
Br_{Forage}	4.0E-01	Baes et al., 1984	—
Br_{Grain}	2.5E-01	Baes et al., 1984	—
$Br_{Profruit}$	2.5E-01	Baes et al., 1984	—
Br_{Proveg}	2.5E-01	Baes et al., 1984	—
Br_{Root}	4.0E-01	Baes et al., 1984	—
Br_{Silage}	4.0E-01	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Fluoride (16984-48-8)			
BCF_{T3F}	2.3E+00	ECOTOX Wright, 1977	BCF for TL4 whole fish was used as a surrogate for TL3 filet
BCF_{T4F}	2.3E+00	ECOTOX Wright, 1977	BCF for TL4 whole fish (brown trout) was used as a surrogate for TL4 filet
Iron (7439-89-6)			
Ba_{beef}	2.0E-02	Baes et al., 1984	—
Ba_{milk}	2.5E-04	Baes et al., 1984	—
BCF_{T3F}	1.9E+01	ECOTOX Preez et al., 1993	Species is banded bream
BCF_{T4F}	1.9E+01	HSDB Nakamoto and Hassler, 1992	BCF for TL3 filet (banded bream) was used as a surrogate for TL4 filet
$Br_{Exfruit}$	1.0E-03	Baes et al., 1984	—
Br_{Exveg}	4.0E-03	Baes et al., 1984	—
Br_{Forage}	4.0E-03	Baes et al., 1984	—
Br_{Grain}	1.0E-03	Baes et al., 1984	—
$Br_{Profruit}$	1.0E-03	Baes et al., 1984	—
Br_{Proveg}	1.0E-03	Baes et al., 1984	—
Br_{Root}	4.0E-03	Baes et al., 1984	—
Br_{Silage}	4.0E-03	Baes et al., 1984	—
Lanthanum (7439-91-0)			
Ba_{beef}	3.0E-04	Baes et al., 1984	—
Ba_{milk}	2.0E-05	Baes et al., 1984	—
BCF_{T3F}	1.2E+00	ECOTOX Hao, et. al., 1996	Species was common carp
BCF_{T4F}	1.2E+00	ECOTOX Hao, et. al., 1996	BCF for TL3 filet (common carp) was used as a surrogate for TL4 filet
$Br_{Exfruit}$	4.0E-03	Baes et al., 1984	—
Br_{Exveg}	1.0E-02	Baes et al., 1984	—
Br_{Forage}	1.0E-02	Baes et al., 1984	—
Br_{Grain}	4.0E-03	Baes et al., 1984	—
$Br_{Profruit}$	4.0E-03	Baes et al., 1984	—
Br_{Proveg}	4.0E-03	Baes et al., 1984	—
Br_{Root}	1.0E-02	Baes et al., 1984	—
Br_{Silage}	1.0E-02	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Lead (7439-92-1)			
BCF_{T3F}	4.6E+01	Stephan (1993)	BCF for TL3 whole fish (bluegill) was used as a surrogate for TL3 filet
BCF_{T4F}	4.6E+01	Stephan (1993)	BCF for TL3 whole fish (bluegill) was used as a surrogate for TL4 filet
Lithium (7439-93-2)			
BCF_{T3F}	—	—	—
BCF_{T4F}	—	—	—
Manganese (7439-96-5)			
Ba_{beef}	4.0E-04	Baes et al., 1984	—
Ba_{milk}	3.5E-04	Baes et al., 1984	—
BCF_{T3F}	4.0E-01	ECOTOX Litzke and Hubel, 1993	Species was common carp
BCF_{T4F}	2.0E-01	ECOTOX Litzke and Hubel, 1993	Species was rainbow trout
$Br_{Exfruit}$	5.0E-02	Baes et al., 1984	—
Br_{Exveg}	2.5E-01	Baes et al., 1984	—
Br_{Forage}	2.5E-01	Baes et al., 1984	—
Br_{Grain}	5.0E-02	Baes et al., 1984	—
$Br_{Profruit}$	5.0E-02	Baes et al., 1984	—
Br_{Proveg}	5.0E-02	Baes et al., 1984	—
Br_{Root}	2.5E-01	Baes et al., 1984	—
Br_{Silage}	2.5E-01	Baes et al., 1984	—
Mercury (99-99-1)			
Ba_{beef}	7.7E-03	U.S. EPA, 1997a	For divalent mercury
Ba_{milk}	2.6E-03	U.S. EPA, 1997a	For divalent mercury
BCF_{T3F}	1.6E+06	U.S. EPA, 1997a	For methyl mercury
BCF_{T4F}	6.8E+06	U.S. EPA, 1997a	For methyl mercury
$Br_{Exfruit}$	1.4E-02	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Exveg}	1.7E-01	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Forage}	6.7E-01	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Grain}	8.6E-02	Calculated based on U.S. EPA, 1999	For divalent mercury
$Br_{Profruit}$	1.4E-02	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Proveg}	1.4E-02	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Root}	3.6E-02	Calculated based on U.S. EPA, 1999	For divalent mercury
Br_{Silage}	6.7E-01	Calculated based on U.S. EPA, 1999	For divalent mercury

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Molybdenum (7439-98-7)			
Ba_{beef}	6.0E-03	Baes et al., 1984	—
Ba_{milk}	1.53E-03	Baes et al., 1984	—
BCF_{T3F}	4.0E+00	Eisler, 1989	BCF for TL4 filet (rainbow trout and steelhead trout) was used as a surrogate for TL3 filet
BCF_{T4F}	4.0E+00	Eisler, 1989	Geomean of multiple values. Species were rainbow trout and steelhead trout.
$Br_{Exfruit}$	6.0E-02	Baes et al., 1984	—
Br_{Exveg}	2.5E-01	Baes et al., 1984	—
Br_{Forage}	2.5E-01	Baes et al., 1984	—
Br_{Grain}	6.0E-02	Baes et al., 1984	—
$Br_{Profruit}$	6.0E-02	Baes et al., 1984	—
Br_{Proveg}	6.0E-02	Baes et al., 1984	—
Br_{Root}	2.5E-01	Baes et al., 1984	—
Br_{Silage}	2.5E-01	Baes et al., 1984	—
Nickel (7440-02-0)			
Ba_{beef}	6.0E-03	Baes et al., 1984	—
Ba_{milk}	1.0E-03	Baes et al., 1984	—
BCF_{T3F}	8.0E-01	Stephan, 1993 dervied from Calamari et al., 1982	BCF for TL4 filet was used as a surrogate for TL3 filet
BCF_{T4F}	8.0E-01	Stephan, 1993 dervied from Calamari et al., 1982	—
$Br_{Exfruit}$	6.0E-02	Baes et al., 1984	—
Br_{Exveg}	1.0E-02	Calculated based on U.S. EPA, 1999	—
Br_{Forage}	2.0E-02	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	6.0E-02	Baes et al., 1984	—
$Br_{Profruit}$	6.0E-02	Baes et al., 1984	—
Br_{Proveg}	6.0E-02	Baes et al., 1984	—
Br_{Root}	6.0E-02	Baes et al., 1984	—
Br_{Silage}	2.0E-02	Calculated based on U.S. EPA, 1999	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Nitrate (14797-55-8)			
No Data		—	—
Selenium (7782-49-2)			
Ba_{beef}	1.5E-02	Baes et al., 1984	—
Ba_{milk}	4.0E-03	Baes et al., 1984	—
BCF_{T3F}	4.9E+02	Lemly, 1985	Species were threadfin shad and blueback herring.*
BCF_{T4F}	1.7E+03	Lemly, 1985	Species were threadfin shad and blueback herring.*
$Br_{Exfruit}$	2.5E-02	Baes et al., 1984	—
Br_{Exveg}	2.5E-02	Baes et al., 1984	—
Br_{Forage}	2.5E-02	Baes et al., 1984	—
Br_{Grain}	2.5E-02	Baes et al., 1984	—
$Br_{Profruit}$	2.5E-02	Baes et al., 1984	—
Br_{Proveg}	2.5E-02	Baes et al., 1984	—
Br_{Root}	2.5E-02	Baes et al., 1984	—
Br_{Silage}	2.5E-02	Baes et al., 1984	—
Silver (7440-22-4)			
Ba_{beef}	3.0E-03	Baes et al., 1984	—
Ba_{milk}	2.0E-02	Baes et al., 1984	—
BCF_{T3F}	—	—	—
BCF_{T4F}	—	—	—
$Br_{Exfruit}$	1.0E-01	Baes et al., 1984	—
Br_{Exveg}	4.0E-01	Baes et al., 1984	—
Br_{Forage}	4.0E-01	Baes et al., 1984	—
Br_{Grain}	1.0E-01	Baes et al., 1984	—
$Br_{Profruit}$	1.0E-01	Baes et al., 1984	—
Br_{Proveg}	1.0E-01	Baes et al., 1984	—
Br_{Root}	4.0E-01	Baes et al., 1984	—
Br_{Silage}	4.0E-01	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Strontium (7440-24-6)			
Ba_{beef}	3.0E-04	Baes et al., 1984	—
Ba_{milk}	1.5E-03	Baes et al., 1984	—
BCF_{T3F}	9.5E+00	ECOTOX Aleksanyan et al., 1978	Species was common carp
BCF_{T4F}	9.5E+00	ECOTOX Aleksanyan et al., 1978	BCF for TL3 filet (common carp) was used as a surrogate for TL4 filet
$Br_{Exfruit}$	2.5E-01	Baes et al., 1984	—
Br_{Exveg}	2.5E+00	Baes et al., 1984	—
Br_{Forage}	2.5E+00	Baes et al., 1984	—
Br_{Grain}	2.5E-01	Baes et al., 1984	—
$Br_{Profruit}$	2.5E-01	Baes et al., 1984	—
Br_{Proveg}	2.5E-01	Baes et al., 1984	—
Br_{Root}	2.5E+00	Baes et al., 1984	—
Br_{Silage}	2.5E+00	Baes et al., 1984	—
Thallium (7440-28-0)			
Ba_{beef}	4.0E-02	Baes et al., 1984	—
Ba_{milk}	2.0E-03	Baes et al., 1984	—
BCF_{T3F}	3.4E+01	Barrows et al., 1980	BCF for TL3 whole fish (sunfish) was used as a surrogate for TL3 filet
BCF_{T4F}	1.3E+02	Stephan, 1993 derived from Zitko et al., 1975	—
$Br_{Exfruit}$	4.0E-04	Baes et al., 1984	—
Br_{Exveg}	4.0E-03	Baes et al., 1984	—
Br_{Forage}	4.0E-03	Baes et al., 1984	—
Br_{Grain}	4.0E-04	Baes et al., 1984	—
$Br_{Profruit}$	4.0E-04	Baes et al., 1984	—
Br_{Proveg}	4.0E-04	Baes et al., 1984	—
Br_{Root}	4.0E-03	Baes et al., 1984	—
Br_{Silage}	4.0E-03	Baes et al., 1984	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Uranium (7440-61-1)			
Ba_{beef}	2.0E-04	Baes et al., 1984	—
Ba_{milk}	6.0E-04	Baes et al., 1984	—
BCF_{T3F}	3.7E+01	Poston, 1982	BCF for TL4 whole fish was used as a surrogate for TL3 filet
BCF_{T4F}	3.7E+01	Poston, 1982	BCF for TL4 whole fish was used as a surrogate for TL4 filet
$Br_{Exfruit}$	4.0E-03	Baes et al., 1984	—
Br_{Exveg}	8.5E-03	Baes et al., 1984	—
Br_{Forage}	8.5E-03	Baes et al., 1984	—
Br_{Grain}	4.0E-03	Baes et al., 1984	—
$Br_{Profruit}$	4.0E-03	Baes et al., 1984	—
Br_{Proveg}	4.0E-03	Baes et al., 1984	—
Br_{Root}	8.5E-03	Baes et al., 1984	—
Br_{Silage}	8.5E-03	Baes et al., 1984	—
Vanadium (7440-62-2)			
Ba_{beef}	2.5E-03	Baes et al., 1984	—
Ba_{milk}	2.0E-05	Baes et al., 1984	—
BCF_{T3F}	3.2E+01	ECOTOX Bell et al., 1980	BCF for TL4 whole fish was used as a surrogate for TL3 filet
BCF_{T4F}	3.2E+01	ECOTOX Bell et al., 1980	BCF for TL4 whole fish was used as a surrogate for TL4 filet
$Br_{Exfruit}$	3.0E-03	Baes et al., 1984	—
Br_{Exveg}	5.5E-03	Baes et al., 1984	—
Br_{Forage}	4.9E-03	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	3.0E-03	Baes et al., 1984	—
$Br_{Profruit}$	3.0E-03	Baes et al., 1984	—
Br_{Proveg}	3.0E-03	Baes et al., 1984	—
Br_{Root}	5.5E-03	Baes et al., 1984	—
Br_{Silage}	4.9E-03	Calculated based on U.S. EPA, 1999	—

Table G-1-1. Bioconcentration and Biotransfer Factors for CCR Constituents Evaluate

Parameter	Value	Reference	Comment
Zinc (7440-66-6)			
Ba_{beef}	1.0E-01	Baes et al., 1984	—
Ba_{milk}	1.0E-02	Baes et al., 1984	—
BCF_{T3F}	3.5E+02	Murphy et al., 1978	BCF for TL3 whole fish (bluegill) was used as a surrogate for TL34 filet. Geomean of multiple values.
BCF_{T4F}	3.5E+02	Murphy et al., 1978	BCF for TL3 whole fish (bluegill) was used as a surrogate for TL4 filetGeomean of multiple values
$Br_{Exfruit}$	9.0E-01	Baes et al., 1984	—
Br_{Exveg}	3.3E-01	Calculated based on U.S. EPA, 1999	—
Br_{Forage}	3.2E-01	Calculated based on U.S. EPA, 1999	—
Br_{Grain}	3.3E-01	Calculated based on U.S. EPA, 1999	—
$Br_{Profruit}$	9.0E-01	Baes et al., 1984	—
Br_{Proveg}	9.0E-01	Baes et al., 1984	—
Br_{Root}	1.3E-01	Calculated based on U.S. EPA, 1999	—
Br_{Silage}	3.2E-01	Calculated based on U.S. EPA, 1999	—

* In Lemly's paper on selenium, the BCFs are reported in L/g, but based on other data in the paper, the units are clearly actually L/kg. Used the values as L/kg.

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Appendix H.

Estimation of Contaminant Partition Coefficients for the CCR Risk Assessment

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H.1 Introduction

The following appendix details the development of soil-water partitioning coefficients used to model COPC concentrations in ground water.

- **Attachment H-1** provides a report developed for EPA by Allison Geoscience Consultants. This report summarized the statistical analysis of the concentrations of major ions in the pore water that was conducted to identify distinct waste types. This report has been reformatted by EPA for consistency; however, no substantive changes have been made to the content.
- **Attachment H-2** provides plots of the nonlinear sorption isotherms used in the CCR risk assessment, organized by waste management unit type (landfill or surface impoundment), constituent, soil/aquifer environment (carbonate or noncarbonate), and saturated (aquifer) or unsaturated (soil) zone.
- **Attachment H-3** tabulates, by constituent, K_d percentiles for the saturated and unsaturated zones from the inputs of the probabilistic modeling described in **Section 4** of this document.

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Attachment H-1. Estimation of Contaminant Partition Coefficients for the Coal Combustion Residues Risk Assessment

Prepared for:

U.S. Environmental Protection Agency
Office of Resource Conservation and Recovery
Washington, DC

Prepared by:

Allison Geoscience Consultants, Inc.
3926 Perry Lane
Flowery Branch, GA 30542

Under Subcontract to:

RTI International
P.O. Box 12194
Research Triangle Park, NC 27709

December 2011

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Executive Summary

This report describes the development of concentration-dependent partition coefficients for use in modeling subsurface leaching of Coal Combustion Residues (CCR) using the fate and transport model EPACMTP (EPA Composite Model with Transformation Products). EPACMTP incorporates the option of using nonlinear contaminant-specific tables of partitioning values in which the contaminant partitioning is presented over a range of contaminant concentration levels (isotherms) for particular settings of environmental variables that control partitioning. These tables of sorption isotherms reflect the tendency of Kd to decrease as the total contaminant concentration in the system increases. The isotherms were estimated using the geochemical speciation model MINTEQA2. For a particular contaminant, Kd values in a soil or aquifer are dependent upon the contaminant concentration and various geochemical characteristics of the soil or aquifer and the associated porewater.

Geochemical parameters that have the greatest influence on the magnitude of Kd include the pH of the system and the nature and concentration of sorbents associated with the soil or aquifer matrix. In the subsurface beneath a disposal facility, the concentration of leachate constituents may also influence Kd. This is especially true of some CCR leachates that may have high concentrations of calcium, sulfate, and other inorganic constituents. The use of a speciation model allows Kd values to be estimated for a range of total contaminant concentrations in various model systems designed to depict natural variability in those geochemical characteristics that most influence contaminant partitioning.

The CCR constituents whose partition coefficients have been estimated using MINTEQA2 correspond to those that failed the screen of CCR wastes (discussed in Appendix K of the risk assessment document) through the groundwater exposure pathways: aluminum, antimony (V), arsenic (III and V), barium, beryllium, boron, cadmium (II), chromium (III and VI), cobalt (II), copper (II), fluoride ion, iron (II), lead (II), manganese (II), mercury (II), molybdenum (VI), nickel (II), selenium (IV and VI), silver (I), thallium(I), vanadium (V), and zinc (II). Expected natural variability in Kd for a particular contaminant was included in the MINTEQA2 modeling by including variability in important input parameters upon which Kd depends.

The input parameters for which variability was incorporated include groundwater chemical composition, pH, concentration of aquifer sorbents, composition and concentration level of CCR leachate, and concentration of the contaminant. Two groundwater compositions were used: carbonate and noncarbonate. The natural pH range for each of these groundwater types is restricted (about 7 to 9 for carbonate terrain waters and 4 to 10 for noncarbonate. However, CCR leachate ranges from very acidic (pH < 2) to highly alkaline (pH > 12) and intrusion of leachate into the soil/aquifer system can impact the groundwater pH. For many contaminants modeled here, the magnitude of the partition coefficient is very much dependent on pH. This dependence was

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included in the estimated partition coefficients by equilibrating the leachate/groundwater system at a series of pH values that span the range of expected variability in mixed leachate-groundwater systems. The influence of variability in the sorption capacity of soil and aquifer materials on Kd estimates was included by equilibrating the groundwater systems with various concentrations of two commonly occurring natural sorbents: ferric oxyhydroxide and particulate organic matter (POM). CCR leachate can include elevated concentrations of inorganic constituents such as calcium, sulfate, sodium, potassium, and chloride. Elevated concentrations of leachate constituents may reduce sorption of metals due to competition for sorption sites or complexation with metals in solution. The influence of elevated concentrations of leachate constituents on Kd estimates was included in the modeling by adding leachate components at concentrations representative of CCR leachate. Examination of the major ion concentrations in a database of CCR porewater and leachate samples led to the choice of four representative leachate chemistries: ash codisposed with coal refuse, fluidized bed combustion (FBC) waste leachate, flue gas desulfurization (FGD) waste leachate, and combined ash (primarily non-FBC fly ash) leachate.

Each MINTEQA2 model execution produced an isotherm for a particular contaminant and was defined by the following selections of system variables:

- groundwater type (carbonate or noncarbonate)
- hydrologic zone (unsaturated or saturated)
- ferric oxide (FeOx) sorbent concentration level (low, medium, high)
- POM/dissolved organic matter (DOM) concentration level (low, medium, high)
- equilibrium pH (range depends on groundwater type and leachate type)
- leachate type (ash and coal refuse, FBC waste, FGD waste, or combined ash)
- leachate “richness” or ionic strength

For each constituent modeled, the results of each MINTEQA2 model run were compiled as the equilibrium distribution of the contaminant among dissolved, sorbed, and precipitated fractions. These results were saved in a separate file indexed with the settings of all variables defining the system. Such files were produced for all possible values for the variables defining the system and were compiled into a database of indexed K_d values for use in the EPACMTP fate and transport model. A typical plot of K_d versus total contaminant concentration from a MINTEQA2 output file for arsenic is shown in **Figure 1**.

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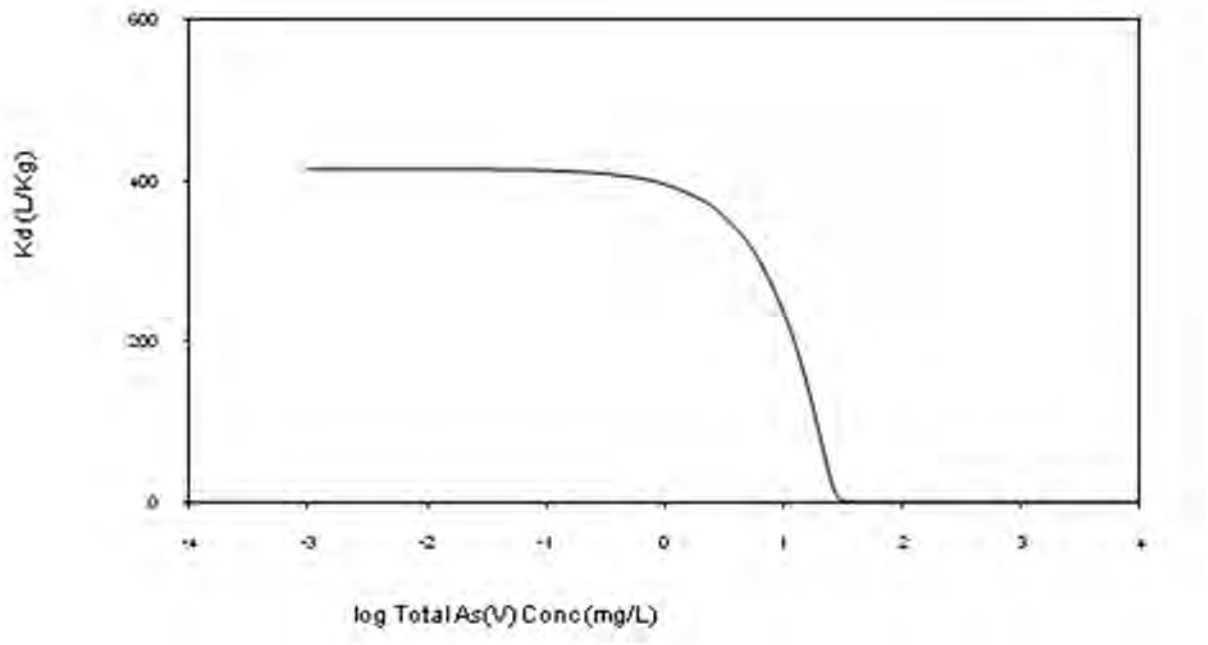

Figure 1. Typical K_d versus total contaminant concentration response curve from MINTEQA2.

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1 Introduction

This report describes the development of concentration-dependent partition coefficients for use in modeling subsurface leaching of coal combustion residues (CCR) using the groundwater fate and transport model EPACMTP. In the subsurface, metal and nonmetal contaminants undergo reactions with ligands in the porewater and with surface sites on the solid aquifer or soil matrix material. Reactions in which the contaminant is bound to the solid matrix are referred to as sorption reactions, and a contaminant that is bound to the solid is said to be sorbed. The ratio of the concentration of contaminant sorbed to the concentration in the mobile aqueous phase at equilibrium is referred to as the partition coefficient (K_d). During contaminant transport, sorption to the solid matrix results in retardation of the contaminant front. Transport models such as EPACMTP incorporate the contaminant partition coefficient into the overall retardation factor (the ratio of the average linear particle velocity to the velocity of that portion of the plume where the contaminant is at 50 percent dilution. The use of K_d in EPACMTP transport modeling implies the assumption that local equilibrium between the solutes and the sorbents is attained. This implies that the rate of sorption reactions is fast relative to advective-dispersive transport of the contaminant.

EPACMTP incorporates the option of using contaminant-specific tables of partitioning values in which the contaminant partitioning is presented over a range of contaminant concentration levels for particular settings of environmental variables that control partitioning. These tables of sorption isotherms reflect the tendency of K_d to decrease as the total contaminant concentration in the system increases. Isotherms for use in EPACMTP are specified in terms of the dissolved contaminant concentration and the corresponding sorbed concentration at a series of total contaminant concentrations. The isotherms were estimated using the geochemical speciation model MINTEQA2.

For a particular contaminant, K_d values in a soil or aquifer are dependent upon the contaminant concentration and various geochemical characteristics of the soil or aquifer and the associated porewater. Geochemical parameters that have the greatest influence on the magnitude of K_d include the pH of the system and the nature and concentration of sorbents associated with the soil or aquifer matrix. In the subsurface beneath a disposal facility, the concentration of leachate constituents may also influence K_d. This is especially true of some CCR leachates that may have high concentrations of calcium, sulfate, and other inorganic constituents. Although the dependence of partitioning on the total contaminant concentration and on pH and other geochemical characteristics is apparent from partitioning studies reported in the scientific literature, K_d values for individual contaminants are not available for the range of concentrations or geochemical conditions relevant in the CCR land disposal scenarios. It is for this reason that the U.S. Environmental Protection Agency (EPA) has chosen to use an equilibrium speciation model to estimate partition coefficients for the CCR study. The use of a speciation model allows K_d values

to be estimated for a range of total contaminant concentrations in various model systems designed to depict natural variability in those geochemical characteristics that most influence partitioning.

1.1 Description of MINTEQA2

The nonlinear sorption isotherms for contaminants were produced by using MINTEQA2,[1] a geochemical speciation model maintained and distributed by the U.S. EPA. From input data consisting of total concentrations of chemical constituents, MINTEQA2 calculates the fraction of a contaminant that is dissolved, adsorbed, and precipitated at equilibrium (see **Figure 2**). The total concentrations of major and minor ions, trace metals, and other chemicals are specified in terms of key species known as components. MINTEQA2 automatically includes an extensive database of solution species and solid phase species representing reaction products of two or more of the components. The model does not automatically include sorption reactions, but these can be included in the calculations if supplied by the user. When sorption reactions are included, the dimensionless partition coefficient can be calculated from the ratio of the sorbed contaminant concentration to the dissolved concentration at equilibrium. The dimensionless partition coefficient is converted to K_d with units of liters per kilogram (L/kg) by normalizing by the mass of soil (in kilograms) with which 1 liter of porewater is equilibrated (the phase ratio). An isotherm is generated when the equilibrium distribution between sorbed and dissolved fractions is estimated for a series of total contaminant concentrations.

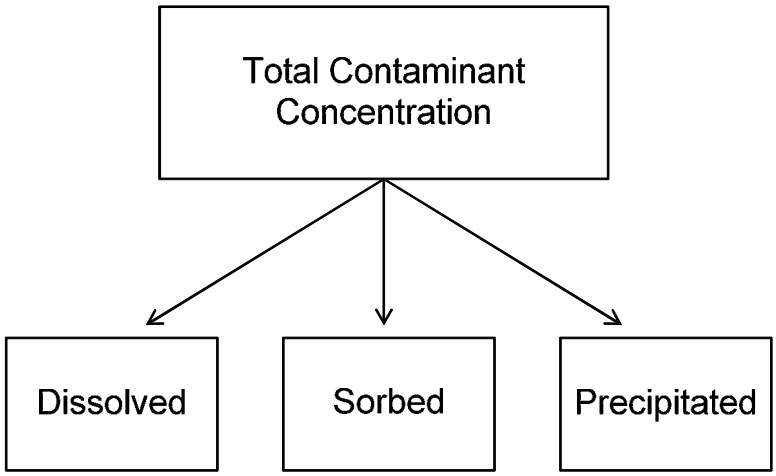

Figure 2. MINTEQA2 computes the equilibrium distribution of contaminant.

Progress in accounting for sorption in equilibrium calculations over the past decade has resulted in the development of coherent databases of sorption reactions for particular sorbents. These databases include acid-base sorption reactions and reactions for major ions in aquatic systems (calcium, magnesium, sulfate [SO_4], etc. Including such reactions along with those representing sorption of the contaminant makes it possible to estimate sorption in systems of varying pH and

[1] The version of MINTEQA2 used in this modeling was modified from version 4.02.

composition. Examples of coherent databases of sorption reactions include that for the hydrous ferric oxide (HFO) surface presented by Dzombak and Morel (1990) and a similar database for goethite presented by Mathur (1995).

1.2 Contaminants of Interest

The contaminants whose partition coefficients have been estimated using MINTEQA2 correspond to those that failed the groundwater pathway screening described in **Section 3**. These contaminants are listed in **Table 1**.

Table 1. Contaminants for which Partition Coefficients Were Computed

Contaminant	Oxidation State(s) Modeled	MINTEQA2 Component
Aluminum (Al)	+3	Al^{3+}
Antimony (Sb)	+5	$Sb(OH)_6^-$
Arsenic (As)	+3, +5	H_3AsO_3, H_3AsO_4
Barium (Ba)	+2	Ba^{2+}
Beryllium	+2	Be+2
Boron (B)	+3	H_3BO_3
Cadmium (Cd)	+2	Cd^{2+}
Chromium (Cr)	+3, +6	$Cr(OH)_2^+$, CrO_4^{2-}
Cobalt (Co)	+2	Co^{2+}
Copper (Cu)	+2	Cu^{2+}
Fluoride (F)	-1	F^-
Iron (Fe)	+2	Fe^{2+}
Lead (Pb)	+2	Pb^{2+}
Manganese	+2	Mn^{2+}
Mercury (Hg)	+2	$Hg(OH)_2$
Molybdenum (Mo)	+6	MoO_4^{2-}
Nickel (Ni)	+2	Ni^{2+}
Selenium (Se)	+4, +6	$HSeO3^-$, SeO_4^{2-}
Silver (Ag)	+1	Ag^+
Thallium (Tl)	+1	Tl^+
Vanadium (V)	+5	VO_2^+
Zinc (Zn)	+2	Zn^{2+}

Several of these contaminants occur naturally in more than one oxidation state. The modeling described here is restricted to the oxidation states that are most likely to occur in waste systems or

most likely to be mobile in groundwater-waste systems. Partition coefficients were modeled for two oxidation states each for arsenic, selenium, and chromium. These were arsenic (III) and (V), selenium (IV) and (VI), and chromium (III) and (VI). For antimony, molybdenum, thallium, copper, iron, and vanadium only one oxidation state was modeled although multiple oxidation states occur. For these metals, the choice of which state to model was dictated by practical aspects such as availability of sorption reactions and by subjective assessment of the appropriate (or predominant) oxidation state. The oxidation states modeled were antimony (V) (there were no sorption reactions available for antimony [III]), molybdenum (VI) (molybdate seems the most relevant form from literature reports), thallium (I) (this form is more frequently cited in the literature as having environmental implications), copper (II) (this oxidation state seemed to be more likely in coal ash leachate), iron (II) (ferric iron is more likely to be precipitated), and vanadium (V) (this seems the most relevant form, and sorption reactions were available for this form only. Table 1 lists the oxidation states modeled for all contaminants.

2 Modeling Approach

Expected natural variability in K_d for a particular contaminant was included in the MINTEQA2 modeling by including variability in important input parameters upon which K_d depends. The input parameters for which variability was incorporated include groundwater composition, pH, concentration of aquifer sorbents, composition and concentration level of CCR leachate, and concentration of the contaminant.

The groundwater chemistry exerts an important influence on partition coefficients. The major ions present in groundwater may compete with trace metals for sorption sites. Also, inorganic ligands may complex with some metals, reducing their tendency to sorb. For the purposes of this modeling, it is assumed that the influence of groundwater composition on sorption of the contaminant can be adequately represented by dividing the universe of groundwater compositional types into two categories: carbonate and noncarbonate. The natural pH range for each of these groundwater types is restricted (about 7 to 9 for carbonate terrain waters and 4 to 10 for noncarbonate. However, CCR leachate ranges from acidic ($pH < 2$) to highly alkaline ($pH > 12$) and intrusion of leachate into the soil/aquifer system can impact the groundwater pH. For many metals, the magnitude of the partition coefficient is very much dependent on pH. This dependence was included in the estimated partition coefficients by equilibrating the leachate/groundwater system at a series of pH values that span the range of expected variability.

The influence of variability in sorption capacity of soil and aquifer materials on K_d estimates was included by equilibrating the groundwater systems with various concentrations of two commonly occurring natural sorbents: ferric oxyhydroxide and particulate organic matter (POM). Although other sorbents such as clay minerals, carbonate minerals, hydrous aluminum and manganese oxides, and silica may sorb metals in the subsurface, representation of ferric oxyhydroxide and

particulate organic matter in the model is sufficient to provide a conservative assessment of the sorption capacity of most natural groundwater systems.

CCR leachate can include elevated concentrations of inorganic constituents such as calcium, sulfate, sodium, potassium, and chloride. Elevated concentrations of iron and manganese also occur in certain types of leachate. Upon mixing with groundwater, elevated concentrations of leachate constituents may reduce sorption of metals due to competition for sorption sites or complexation with metals in solution. The influence of elevated concentrations of leachate constituents on K_d estimates was included in the modeling by adding leachate components at concentrations representative of CCR leachate. In this way, the MINTEQA2 model systems included competitive sorption reactions, metal complexation, and elevated ionic strength effects from CCR leachate in computing the K_d values.

2.1 Characterization of Model Groundwater Systems

The extent of contaminant sorption in a groundwater system is dependent upon the chemical characteristics of the porewater solution and the interactions between all solutes and the sorbing sites present on the exposed surfaces of the soil and aquifer matrix material. Here, partition coefficients were estimated separately for two groundwater compositional types, one with composition representative of a carbonate-terrain system and one representative of a noncarbonate system. The two groundwater compositional types are correlated with the hydrogeologic environment parameter in EPACMTP. In EPACMTP, this parameter may take on 1 of 13 values, each indicative of a particular groundwater type (see **Table 2**). Issues of practicality limit the number of groundwater types for which separate partition coefficients can be estimated to just two. The broadest division that may be made of the 13 groundwater types in EPACMTP is carbonate and noncarbonate. Thus, coefficients were estimated for these two broad types. The carbonate type corresponds to the "solution limestone" hydrogeologic environment setting in EPACMTP (hydrogeologic environment parameter = 12). The other 12 possible hydrogeologic settings in EPACMTP are represented by the noncarbonate groundwater type.

Table 2. Settings for the Hydrogeologic Environment Parameter in EPACMTP

Hydrogeologic Environment Parameter	Environment (Groundwater Type) Represented
1	Metamorphic and Igneous (noncarbonate)
2	Bedded Sedimentary Rock (noncarbonate)
3	Till Over Sedimentary Rock (noncarbonate)
4	Sand and Gravel (noncarbonate)
5	Alluvial Basins Valleys and Fans (noncarbonate)
6	River Valleys and Floodplains with Overbank Deposits (noncarbonate)

(continued)

Table 2. Settings for the Hydrogeologic Environment Parameter in EPACMTP

Hydrogeologic Environment Parameter	Environment (Groundwater Type) Represented
7	River Valleys and Floodplains without Overbank Deposits (noncarbonate)
8	Outwash (noncarbonate)
9	Till and Till Over Outwash (noncarbonate)
10	Unconsolidated and Semi-consolidated Shallow Aquifers (noncarbonate)
11	Coastal Beaches (noncarbonate)
12	Solution Limestone (carbonate)
13	Others (unclassified hydrogeologic environments) (noncarbonate)

2.1.1 Model Groundwater Composition

For both groundwater types, representative charge-balanced groundwater chemistry specified in terms of major ion concentrations and natural pH was selected from the literature. The carbonate system was represented by a well sample reported for a limestone aquifer (Freeze and Cherry, 1979). This groundwater had a natural pH of 7.5 and was saturated with respect to calcite. The noncarbonate system was represented by a sample reported from an unconsolidated sand and gravel aquifer with a natural pH of 7.4 (White et al., 1963). An unconsolidated sand and gravel aquifer was selected to represent the noncarbonate compositional type because it is the most frequently occurring of the 12 (noncarbonate) hydrogeologic environments in EPACMTP. The compositions of both the carbonate and noncarbonate representative groundwater samples are shown in **Table 3**. These compositions were used in MINTEQA2 to estimate partition coefficients for carbonate and noncarbonate groundwater types. When EPACMTP is used in site-specific or Monte Carlo mode, the choice of the hydrogeologic environment by the user (or the Monte Carlo routine) dictates the set of partition coefficients (carbonate or noncarbonate) that should be accessed.

Table 3. Composition of Representative Ground Waters

Constituent Chemical	Concentrations (mg/L)	
	Carbonate Groundwater	Noncarbonate Groundwater
Ca	55	49
Mg	28	13
SO_4	20	27
HCO_3	265	384
Na	3.1	105
Cl	10	34

(continued)

Table 3. Composition of Representative Ground Waters

Constituent Chemical	Concentrations (mg/L)	
	Carbonate Groundwater	Noncarbonate Groundwater
K	1.5	3.0
NO_3	---	7.8
F	---	0.3
SiO_2	---	21
pH	7.5	7.4
Temp	18 C	14 C
Other	Equilibrium with calcite	Equilibrium with quartz

2.1.2 Model Adsorbents

Two types of adsorbents were represented in the MINTEQA2 equilibrium modeling: ferric oxide and POM. FeOx (and hydroxides) and POM are among the most important sorbents in natural systems. The former may be present as amorphous substances or crystalline minerals such as hematite, goethite, or ferrihydrite dispersed in soil as discrete particles or as coatings on particles of other materials. In recent years, databases of equilibrium sorption reactions for HFO and goethite have been compiled from studies described in the literature (Dzombak and Morel, 1990; Mathur, 1995). Both of the databases cited were designed for use with the MIT Two-Layer sorption model, also called the diffuse-layer model (DLM; Dzombak and Morel, 1990).

Owing to the complexity and variability of natural organic substances, the science of modeling surface reactions on POM is less advanced than for sorption onto hydrous metal oxides. The modeling described here assumes that reactions on POM are analogous to those on dissolved organic matter (DOM); a DOM model was adapted for the POM calculation. This model, the Gaussian distribution model (Dobbs et al., 1989), assumes that organic matter is a complex mixture of substances exhibiting highly variable binding affinities for metals. Reactions are represented like conventional pure substance reactions except that the usual single equilibrium constant is replaced by a distribution of constants (log K values). The distribution of log K is assumed to be Gaussian in shape. This model is also supplied with a database of reactions, including acid-base and major ion reactions, each with its mean log K for depicting the Gaussian distribution.

When included in equilibrium models, these databases of sorption reactions provide a means of including competition for sorption sites among major groundwater ions such as calcium, magnesium, and SO_4 and contaminants. More importantly, by including in equilibrium calculations the acid-base reactions for these surfaces, the dependence of trace metal sorption on pH can be reflected in the model.

Goethite Sorbent

Mineralogically, the FeOx sorbent was assumed to be goethite (α-FeOOH). Goethite is a common form of FeOx in soils. The database of sorption reactions for goethite reported by Mathur (1995) was used with the diffuse-layer sorption model in MINTEQA2 to represent the interactions of protons, major ions, and contaminant with the FeOx surface.

The concentration of sorption sites used in the MINTEQA2 model runs was based on a measurement of ferric iron extractable from soil samples using hydroxylamine hydrochloride as reported in EPRI (1986). This method of iron extraction is intended to provide a measure of the exposed FeOx present as mineral coatings and discrete particles and available for surface reactions with solutes in the associated pore water. The variability in FeOx sorbent concentration represented by the variability in extractable iron from these samples was included in the modeling by selecting low, medium, and high extractable iron concentrations corresponding to the 17th, 50th, and 83rd percentiles of the sample measurements. The extractable iron weight percentages used in the modeling are shown in **Table 4**.

Table 4. Concentration Levels for Goethite Sorbent

Concentration Level	Weight Percent Iron (extractable)	Geothite Sorbent Concentration (g/L)
Unsaturated zone		
Low	0.0182	1.325
Medium	0.0729	5.309
High	0.1190	8.667
Saturated zone		
Low	0.0182	1.032
Medium	0.0729	4.136
High	0.1190	6.751

Although the same distribution of extractable iron sorbent was used in modeling the saturated and unsaturated zones, the actual concentration of sorbing sites corresponding to the low, medium, and high FeOx settings in MINTEQA2 was different in the two zones because the assumed ratio of soil mass to solution volume (the phase ratio) was different. For both zones, the phase ratio was calculated as the mean soil bulk density divided by the mean water content (product of mean porosity and mean water saturation). In EPACMTP, the mean soil bulk density and mean porosity are 1.6 kg/L and 45 percent, respectively. The mean water saturation in the unsaturated zone is 77.7 percent. The water saturation in the saturated zone is, of course, 100 percent. Thus, the phase ratio for the unsaturated zone is 4.57 kg/L and that for the saturated zone is 3.56 kg/L. These values and the molar mass ratio of goethite to Fe were used to convert the weight percent extractable iron to the mass of goethite appropriate for 1 liter of porewater solution (see Table 4).

The specific surface area and site density used in the diffuse-layer adsorption model were as prescribed by Mathur (1995) for goethite. These values along with the molar concentration of FeOx sorbing sites are shown in **Table 5**. The complete database of goethite sorption reactions used in MINTEQA2, including acid-base surface reactions and reactions for major ions, is shown in **Table 6**. The reactions shown in Table 6 have been reformulated for use in MINTEQA2. The

reformulation step is necessary in order to present the reaction to MINTEQA2 in a manner consistent with its database conventions and its predetermined set of reactants (components. The MINTEQA2 conventions include the requirement that all reactions be written as formation reactions. In some cases, the reformulation may have involved adding ancillary reactions to those presented by Mathur (1995). The addition of ancillary reactions is necessary if the original reaction is not written in terms of MINTEQA2 components. All ancillary reactions used to reformulate the Mathur (1995) goethite reactions were obtained directly from the MINTEQA2 (v4.02) thermodynamic database.

Table 5. Model Parameters for the Goethite Sorbent

Parameter	Model Value
Specific surface area (m^2/g)	60
Site density (moles of sites per mole Fe)	0.018
Unsaturated zone: Site concentration (mol/L)	
Low	2.680×10^{-4}
Medium	1.074×10^{-3}
High	1.753×10^{-3}
Saturated zone: Site concentration (mol/L)	
Low	2.087×10^{-4}
Medium	8.365×10^{-4}
High	1.365×10^{-3}

Table 6. Goethite Sorption Reactions Used in MINTEQA2

Goethite Sorption Reaction	Intrinsic Equilibrium Constant
$\equiv FeOH_2^+ = \equiv FeOH^o + H^+$	$\log K_{a1} = 6.93$
$\equiv FeOH^o = \equiv FeO^- + H^+$	$\log K_{a2} = -9.65$
$\equiv FeOH^o + Ca^{2+} = \equiv FeOCa^+ + H^+$	$\log K_1 = -6.48$
$\equiv FeOH^o + Ca^{2+} = \equiv FeOHCa^{2+}$	$\log K_2 = 3.98$
$\equiv FeOH^o + Ca^{2+} + H^+ = \equiv FeOCa^+ + H_2O$	$\log K_3 = 12.26$
$\equiv FeOH^o + Mg^{2+} = \equiv FeOMg^+ + H^+$	$\log K_1 = -3.02$
$\equiv FeOH^o + Mg^{2+} = \equiv FeOHMg^{2+}$	$\log K_2 = 5.24$
$\equiv FeOH^o + Ba^{2+} = \equiv FeOBa^+ + H^+$	$\log K_1 = -5.62$
$\equiv FeOH^o + Ba^{2+} = \equiv FeOHBa^{2+}$	$\log K_2 = 3.43$
$\equiv FeOH^o + Cd^{2+} = \equiv FeOCd^+ + H^+$	$\log K_1 = -1.96$
$\equiv FeOH^o + Cd^{2+} = \equiv FeOHCd^{2+}$	$\log K_2 = 6.28$

(continued)

Table 6. Goethite Sorption Reactions Used in MINTEQA2

Goethite Sorption Reaction	Intrinsic Equilibrium Constant
$\equiv FeOH^o + Pb^{2+} = \equiv FeOPb^+ + H^+$	$\log K_1 = 0.44$
$\equiv FeOH^o + Pb^{2+} = \equiv FeOHPb^{2+}$	$\log K_2 = 8.25$
$\equiv FeOH^o + Co^{2+} = \equiv FeOCo^+ + H^+$	$\log K_1 = -0.79$
$\equiv FeOH^o + Co^{2+} = \equiv FeOHCo^{2+}$	$\log K_2 = 7.28$
$\equiv FeOH^o + Hg(OH)_2^o = \equiv FeOHgOH^o + H_2O$	$\log K_0 = 2.86$
$\equiv FeOH^o + Hg(OH)_2^o + H^+ = \equiv FeOHg^+ + 2\ H_2O$	$\log K_1 = 10.03$
$\equiv FeOH^o + Hg(OH)_2^o + 2H^+ = \equiv FeOHHg^{2+} + 2\ H_2O$	$\log K_2 = 18.58$
$\equiv FeOH^o + Hg(OH)_2^o + H^+ + Cl^- = \equiv FeOHgCl^o + 2\ H_2O$	$\log K_4 = 13.51$
$\equiv FeOH^o + Tl^+ = \equiv FeOTl^o + H^+$	$\log K_1 = -5.37$
$\equiv FeOH^o + Tl^+ = \equiv FeOHTl^+$	$\log K_2 = 3.66$
$\equiv FeOH^o + Cu^{2+} = \equiv FeOCu^+ + H^+$	$\log K_1 = 1.39$
$\equiv FeOH^o + Cu^{2+} = \equiv FeOHCu^{2+}$	$\log K_2 = 8.92$
$\equiv FeOH^o + Mn^{2+} = \equiv FeOMn^+ + H^+$	$\log K_1 = -2.66$
$\equiv FeOH^o + Mn^{2+} = \equiv FeOHMn^{2+}$	$\log K_2 = 5.99$
$\equiv FeOH^o + Fe^{2+} = \equiv FeOFe^+ + H^+$	$\log K_1 = -1.43$
$\equiv FeOH^o + Fe^{2+} = \equiv FeOHFe^{2+}$	$\log K_2 = 7.05$
$\equiv FeOH^o + Zn^{2+} = \equiv FeOZn^+ + H^+$	$\log K_1 = -0.96$
$\equiv FeOH^o + Zn^{2+} = \equiv FeOHZn^{2+}$	$\log K_2 = 7.50$
$\equiv FeOH^o + Ni^{2+} = \equiv FeONi^+ + H^+$	$\log K_1 = -1.96$
$\equiv FeOH^o + Ni^{2+} = \equiv FeOHNi^{2+}$	$\log K_2 = 6.38$
$\equiv FeOH^o + Be^{2+} = \equiv FeOBe^+ + H^+$	$\log K_1 = 2.69$
$\equiv FeOH^o + Be^{2+} = \equiv FeOHBe^{2+}$	$\log K_2 = 10.61$
$\equiv FeOH^o + Ag^+ = \equiv FeOAg + H^+$	$\log K_1 = -4.11$
$\equiv FeOH^o + Ag^+ = \equiv FeOHAg^+$	$\log K_2 = 4.74$
$\equiv FeOH^o + VO_2^+ + H_2O = \equiv FeH_2VO_4^o + H^+$	$\log K_1 = 2.35$
$\equiv FeOH^o + VO_2^+ + H_2O = \equiv FeHVO_4^- + 2H^+$	$\log K_2 = -5.91$
$\equiv FeOH^o + VO_2^+ + 2H_2O = \equiv FeOHVO_4^{3-} + 4H^+$	$\log K_3 = -17.53$
$\equiv FeOH^o + H_3AsO_3^o = \equiv FeH_2AsO_3^o + H_2O$	$\log K_1 = 4.33$
$\equiv FeOH^o + H_3AsO_4^o = \equiv FeH_2AsO_4^o + H_2O$	$\log K_1 = 6.87$
$\equiv FeOH^o + H_3AsO_4^o = \equiv FeHAsO_4^- + H^+ + H_2O$	$\log K_2 = -0.89$
$\equiv FeOH^o + H_3AsO_4^o = \equiv FeOHAsO_4^{3-} + 3H^+$	$\log K_4 = -11.09$
$\equiv FeOH^o + Sb(OH)_6^- + H^+ = \equiv FeOH_2Sb(OH)_6^o$	$\log K_1 = 11.94$
$\equiv FeOH^o + Sb(OH)_6^- = \equiv FeOHSb(OH)_6^-$	$\log K_2 = 5.76$
$\equiv FeOH^o + SO_4^{2-} + 2H^+ = \equiv FeHSO_4^o + H_2O$	$\log K_1 = 12.89$
$\equiv FeOH^o + SO_4^{2-} + H^+ = \equiv FeSO_4^- + H_2O$	$\log K_2 = 6.74$

(continued)

Table 6. Goethite Sorption Reactions Used in MINTEQA2

Goethite Sorption Reaction	Intrinsic Equilibrium Constant
$\equiv FeOH^o + SO_4^{2-} = \equiv FeOSO_4^{3-} + H^+$	$\log K_4 = -6.26$
$\equiv FeOH^o + HSeO_3^- + H^+ = \equiv FeHSeO_3^o + H_2O$	$\log K_1 = 3.25$
$\equiv FeOH^o + HSeO_3^- = \equiv FeSeO_3^- + H_2O$	$\log K_2 = 2.09$
$\equiv FeOH^o + HSeO_3^- = \equiv FeOSeO_3^{3-} + 2H^+$	$\log K_4 = -14.25$
$\equiv FeOH^o + SeO_4^{2-} + 2H^+ = \equiv FeHSeO_4^o + H_2O$	$\log K_1 = 11.65$
$\equiv FeOH^o + SeO_4^{2-} + H^+ = \equiv FeSeO_4^- + H_2O$	$\log K_2 = 6.54$
$\equiv FeOH^o + MoO_4^{2-} + 2H^+ = \equiv FeHMoO_4^o + H_2O$	$\log K_1 = 14.65$
$\equiv FeOH^o + MoO_4^{2-} + H^+ = \equiv FeMoO_4^- + H_2O$	$\log K_2 = 8.18$
$\equiv FeOH^o + CrO_4^{2-} + 2H^+ = \equiv FeHCrO_4^o + H_2O$	$\log K_1 = 17.11$
$\equiv FeOH^o + CrO_4^{2-} + H^+ = \equiv FeCrO_4^- + H_2O$	$\log K_2 = 11.17$
$\equiv FeOH^o + CrO_4^{2-} = \equiv FeOHCrO_4^{2-}$	$\log K_3 = 4.05$
$\equiv FeOH^o + Cr(OH)_2^+ = \equiv FeOCrOH^+ + H_2O$	$\log K_1 = 8.072$
$\equiv FeOH^o + Cr(OH)_2^+ + H^+ = \equiv FeOHCrOH^{2+} + H_2O$	$\log K_2 = 16.07$
$\equiv FeOH^o + F^- + H^+ = \equiv FeOH_2F$	$\log K_1 = 9.20$
$\equiv FeOH^o + F^- = \equiv FeOHF^-$	$\log K_2 = 1.59$

Particulate Organic Matter Sorbent

The concentration of the second adsorbent, POM, was obtained from organic matter distributions already present in EPACMTP. EPACMTP includes frequency distributions for organic matter for three soil types in the unsaturated zone: silty clay loam, sandy loam, and silty loam. The silty loam soil type is intermediate in weight percent organic matter in comparison with the other two and is the most frequently occurring soil type. Therefore, low, medium, and high POM content levels for the MINTEQA2 modeling in the unsaturated zone were established as the 7.5th, 50th, and 92.5th percentiles of the silty loam organic matter distribution. In the saturated zone, the EPACMTP distribution of organic matter is identical to that for the sandy loam soil type of the unsaturated zone. Low, medium, and high POM content levels in MINTEQA2 modeling of the saturated zone were established as the 7.5th, 50th, and 92.5th percentile levels, respectively, of this distribution.

As was the case for the goethite sorbent, the concentration of POM included in the MINTEQA2 modeling was determined from the low, medium, and high content levels (expressed in weight percent POM) and the mass of soil appropriate for 1 liter of porewater solution (see **Section 2.1.2**). Thus, phase ratios of 4.57 kg/L in the unsaturated zone and 3.56 kg/L in the saturated zone were used to compute the POM concentration for MINTEQA2 model runs.

A dissolved organic carbon (DOC) distribution for the saturated zone was obtained from the U.S. EPA STORET database. This distribution is based on 1,343 groundwater samples and is approximated by a log normal distribution with a median $\log_e$ DOC of 1.974 (corresponding to 7.2 mg C per liter) and $\log_e$ standard deviation of 1.092. Assuming DOM is approximately 50 percent

organic carbon, the DOC values are multiplied by two to approximate DOM concentrations. The MINTEQA2 modeling employed low, medium, and high concentrations for DOM corresponding to the 7.5th, 50th, and 92.5th percentiles, respectively, of this approximated DOM distribution. An important point to note is that POM and DOM were not treated as independent variables in the MINTEQA2 modeling: the high DOM value was associated with the high POM value, the medium DOM with the medium POM, etc.

Because no directly measured data were available for describing the variation in DOM concentration in the unsaturated zone, high, medium, and low DOM concentrations were assumed to reflect a constant ratio of POM content (in weight percent) to DOM concentration. The constant ratio was arbitrarily chosen as the ratio of the median DOM (mg/L) from the saturated zone distribution to the median value of POM (weight percent) from the saturated zone distribution. This ratio, 194.6, was applied to the low, medium, and high weight percent POM values of the unsaturated zone to obtain DOM concentrations at the low, medium, and high levels. The weight percent POM and concentration (mg/L) of both POM and DOM are shown in **Table 7** for all three concentration levels in both zones.

Table 7. POM and DOM Concentration Levels

POM Category	POM wt%	POM Concentration (mg/L)	DOM Concentration (mg/L)
Unsaturated zone			
Low	0.034	1,553.8	6.6
Medium	0.105	4,798.5	20.4
High	0.325	14,852.5	63.2
Saturated zone			
Low	0.02	712	3
Medium	0.074	2,634.4	14.4
High	0.275	9,790	69.38

For both POM and DOM, a site density of 1.2 x 10^{-6} moles of sites per mg organic matter was assumed. The site concentrations for organic matter in both zones are listed in **Table 8**.

Table 8. Site Concentrations for POM and DOM Components in MINTEQA2

POM Category	POM Site Concentration (mol/L)	DOM Site Concentration (mol/L)
Unsaturated zone		
Low	1.865 x10-3	7.896 x10-6
Medium	5.758 x10-3	2.439 x10-5
High	1.782 x10-2	7.548 x10-5
Saturated zone		
Low	8.544×10^{-4}	3.600×10^{-6}
Medium	3.161×10^{-3}	1.728×10^{-5}
High	1.175×10^{-2}	8.326×10^{-5}

A specialized submodel within MINTEQA2 was used for calculations involving the POM and DOM. This submodel, called the Gaussian distribution model, assumes that natural organic matter is a mixture of various functional groups having a mean log K for binding protons and metals and a standard deviation in log K (Dobbs et al., 1989). This is in contrast to all other reactants in MINTEQA2, which are implicitly treated as pure substances with a single equilibrium constant for a particular metal. A database of DOM reactions proposed by Susetyo et al. (1991) for the metals barium, cadmium, chromium (III), copper, lead, nickel, and zinc and for protons and various other MINTEQA2 components is included with v4.02 of the model. Adsorption of metals onto POM was included in the model calculations by assuming that the reactions were identical to those for metal complexation with DOM. **Table 9** shows Gaussian organic matter reactions used in MINTEQA2 for this work. Although the Gaussian model was proposed for metal–DOM reactions, it has been used here to account for metal–POM reactions as well. The only difference between the method of calculation for metal–DOM and metal–POM species in MINTEQA2 was that POM species were excluded from contributing to the ionic strength.

For the metals cobalt, mercury, and thallium, it was necessary to estimate the mean log K for DOM and POM binding for use in MINTEQA2. The mean log K values for cobalt and thallium were derived from a linear free-energy relationship based upon the known mean log K values for several metals, their first hydrolysis constants, and their log K values for complexation with acetate. For mercury, the mean log K was estimated from a linear regression based on binding constants for humic and fulvic acid as given by Tipping (1994).

Table 9. POM and DOM Reactions Included in MINTEQA2 Modeling

Organic Matter (OM) Reaction	Mean log K	Standard Deviation	Species Charge
OM+ H^+ = OM-H	3.87	1.7	-1.8
OM+ Ca^{2+} = OM-Ca	2.9	1.7	-0.8
OM+ Mg^{2+} = OM-Mg	1.9	1.7	-0.8
OM+ Ba^{2+} = OM-Ba	3.1	1.7	-0.8
OM+ Be^{2+} = OM-Be	3.5	1.7	-0.8
OM+ Cd^{2+} = OM-Cd	3.3	1.7	-0.8
OM+ Al^{3+} = OM-Al	5.2	1.7	0.2
OM+ $Cr(OH)2^+ + 2H^+$ = OM-Cr + $2H_2O$	15.22	1.7	0.2
OM+ Cu^{2+} = OM-Cr	4.9	1.7	-0.8
OM+ Pb^{2+} = OM-Pb	5.2	1.7	-0.8
OM+ Ni^{2+} = OM-Ni	3.3	1.7	-0.8
OM+ $Hg(OH)_2^o$ + $2H^+$ = OM-Hg+$2H_2O$	15.2	1.7	-0.8
OM+ Zn^{2+} = OM-Zn	3.5	1.7	-0.8
OM+ Co^{2+} = OM-Co	3.3	1.7	-0.8
OM+ Fe^{2+} = OM-Fe	3.4	1.7	-0.8
OM+ Mn^{2+} = OM-Mn	3.0	1.7	-0.8
OM+ Ag^+ = OM-Ag	2.0	1.7	-1.8
OM+ Tl^+ = OM-Tl	1.0	1.7	-1.8

2.2 Characterization of Model CCR Leachate

Leachate from CCR landfills and impoundments is known to span a broad pH range and to exhibit highly variable concentrations of inorganic ions. Preliminary to the CCR risk assessment modeling, EPA assembled a constituent database with CCR leachate characteristics encompassing many types of CCR wastes. The database includes analyte concentration data for three types of analyses: (1) analysis of landfill leachate from toxicity characteristic leaching procedure (TCLP), synthetic precipitation leaching procedure (SPLP), or other leaching/extraction methods; (2) analysis of surface impoundment and landfill porewater; and (3) analysis of whole waste samples from landfills and other sources. Each of these three analysis types includes waste samples from various locations representing different coal source types (bituminous, subbituminous, lignite, anthracite), different combustion processes (fluidized bed combustion [FBC], flue gas desulfurization [FGD], Na FGD, non-FBC) or combustion product types (fly ash, bottom ash, combined fly ash and bottom ash, slag, mixed ash and coal waste, and ash not otherwise specified). (Please refer to **Appendix C** for a more detailed discussion of the CCR database.)

The analysis type assumed to best represent long-term waste monofill porewater composition is the landfill and surface impoundment porewater data. Accordingly, the porewater analyte concentration data were examined to identify which constituents exhibit significantly elevated concentrations and to identify trends in concentration levels among samples from different coal source types, combustion process types, and combustion product types. MINTEQA2 sensitivity runs using extremes of analyte concentrations from the porewater data were used to determine which analytes were most likely to influence estimated K_d values. Results indicated that calcium, SO_4, sodium, and chlorine were the analytes most likely to affect partitioning. Consequently, multivariate statistical analyses were performed to identify trends in concentrations of these analytes and pH across all coal source types (bituminous, subbituminous, etc.), combustion process types (FBC, non-FBC, FGD, etc.), and combustion product types (fly ash, bottom ash, etc.). Single-variable analyses for each of the dependent variables (pH, calcium, SO_4, sodium, chlorine concentrations) were also performed because few samples presented measurements for all five dependent variables. The goal of these analyses was to evaluate similarities among these diverse samples with regard to the dependent variables for the purpose of choosing leachate chemistries for use in MINTEQA2 modeling.

Results of the statistical analyses and geochemical judgment were used to select four representative leachate chemistries. The most statistically significant differences in the porewater data for the five dependent variables occurred across combustion process type, especially FBC versus non-FBC. Statistically significant differences across coal source type occurred, but these were not consistent across combustion process or product types. Examination of the five dependent variables and the concentrations of other analytes in the porewater data and consideration of the result from the statistical analysis led to the following four choices to represent leachate chemistries:

- Leachate 1 (L1): Ash and Coal Refuse
  Characterized by low to mid pH (1.7–8.2), high SO4, elevated iron and manganese.
- Leachate 2 (L2): FBC Waste
  Characterized by very high pH (12–13), high calcium, high SO4, some CO3, may have high sodium, potassium, and chlorine
- Leachate 3 (L3): FGD Waste
  Characterized by mid to high pH (8.7–11.3), high calcium, high SO_4, high sodium, high chlorine
- Leachate 4 (L4): Combined Ash
  As a reflection of various CCR codisposal practices, this group has more variability in pH (3.9–12.3), calcium, and SO_4

The landfill and surface impoundment porewater data were grouped according to these categories. Within each category, plots of sum of anions versus sum of cations (in equivalents per liter) were prepared to assess the degree of charge balance (see example in **Figure 3**).

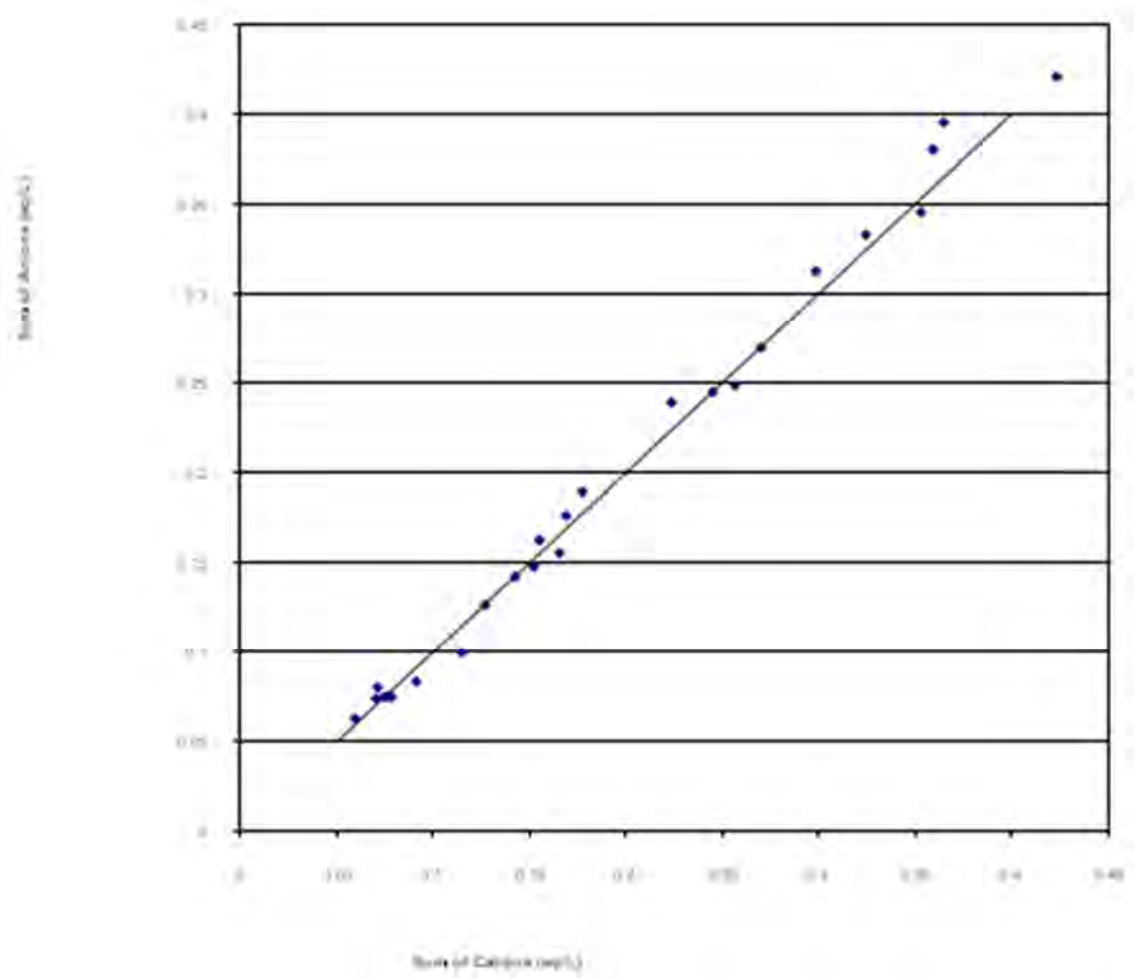

Figure 3. Sum of anions versus sum of cations plotted to assess charge balance of sample.

Although these four leachate categories served to segregate the data in accord with measurements likely to impact K_d values, considerable variability in important analyte concentrations occurred within each leachate type. Therefore, within each of the leachate categories, three representative samples were selected based on sum of anions. (Because the samples were reasonably well charge balanced, selection based on sum of cations would have resulted in the same selected samples.) Selection based on sum of anions (or cations) is analogous to selection based on ionic strength or overall leachate "richness." The samples within each of the four leachate categories were ranked according to sum of anions and the sample closest to the 17th, 50th, and 83rd percentiles were selected and labeled low, medium, and high. The composition (all major ions) of each of the low, medium, and high samples was made available to the MINTEQA2 model in the runs used to estimate K_d (see modeling procedure section below). **Table 10** gives the composition of each of the low, medium, and high porewater samples for each of the four leachate types.

Table 10. Composition of Four Leachates at Three Concentrations Levels

Analyte	Low (mg/L)	Medium (mg/L)	High (mg/L)
L1: Codisposed Ash and Coal Refuse Leachate			
Ca	12.3	572.1	602.9
Mg	7.0	179.4	333.1
Na	3.1	12.4	71.7
K	4.2	41.8	447.7
SO4	387.0	6,231.7	53,918.0
Cl	1.7	19.4	11.1
Al	53.7	58.0	58.0
Fe (II)	0.2	2,050.0	22,394.0
Mn	0.9	52.7	30.4
L2: FBC Waste Leachate			
Ca	1,346.6	809.6	697.4
Mg	0.2	0.0	0.2
Na	87.8	1,425.4	4,023.2
K	208.4	2,040.9	4,457.2
SO4	1,498.6	3,640.8	9,606.4
Cl	52.1	535.3	1,138.0
CO3	678.1	960.1	1,524.2
Al	2.2	2.2	1.1
L3: FGD Waste Leachate			
Ca	952.0	93.7	604.5
Mg	161.0	0.6	812.5
Na	913.0	2,087.0	6,115.0
K	57.0	52.8	240.0
SO4	2,040.0	4,611.0	9,630.0
Cl	898.0	29.9	4,880.0
Al	0.3	3.1	0.1
L4: Combined Ash Leachate			
Ca	159.9	250.0	500.0
Mg	21.7	0.5	0.5
Na	48.0	200.0	840.0
K	60.9	1,200.0	3,000.0
SO4	223.5	1,800.0	4,100.0
Cl	109.0	610.0	2,000.0
Al	0.3	0.1	0.1

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3 MINTEQA2 Modeling Procedure

The MINTEQA2 modeling was conducted separately for each of the 22 contaminants selected for the full-scale groundwater risk assessment (see Table 1 in **Section 1.2**). For each contaminant, the modeling was performed separately for the unsaturated and saturated zones for each of the two groundwater chemistries (carbonate and noncarbonate). Thus, results were produced in four main categories: the carbonate unsaturated zone, the carbonate saturated zone, the noncarbonate unsaturated zone, and the noncarbonate saturated zone. Within each of these four categories, separate results were produced for each of the four leachate types discussed in **Section 2.2**. A similar modeling procedure was followed for all contaminants, groundwater chemistries, hydrologic zones, and leachate types. The modeling procedure consisted of two steps, each involving execution of the MINTEQA2 model. First, the sorbents were pre-equilibrated with the groundwater at the natural groundwater pH. This step was performed with original "pristine" groundwater at the ambient pH of the original groundwater for both carbonate and noncarbonate systems and before introduction of the contaminant and leachate. In the second step, leachate and the contaminant were added to the pre-equilibrated systems and the new equilibrium distribution of contaminant among dissolved, sorbed, and precipitated phases was computed.

3.1 Pre-equilibration with Sorbents

The goethite and POM sorbents were pre-equilibrated with the groundwater at all nine combinations of their concentration levels. Because the sorbents adsorb some of the noncontaminant ions present as groundwater constituents (calcium, magnesium, sulfate), it is to be supposed that the representative compositions used for both the carbonate and noncarbonate groundwaters reflect dissolved concentrations at equilibrium with an unknown sorbed concentration. The purpose of the pre-equilibration step is to estimate this unknown sorbed concentration so that it may be included with the total concentrations for these constituents in subsequent model runs. The method of discovering the sorbed concentrations for each of the groundwater constituents that undergoes sorption was trial and error. Specifically, MINTEQA2 was executed repeatedly with adjusted total concentrations of these sorbing constituents until the equilibrium dissolved concentration for each was equal to the measured dissolved concentrations reported for the groundwater. This trial and error pre-equilibration method was performed separately for each of nine possible combinations of the FeOx and POM sorbent concentrations (low FeOx, low POM; low FeOx, medium POM; etc.).

The pre-equilibration step was conducted at the natural pH of each groundwater with calcite imposed as an equilibrium mineral for the carbonate groundwater type and quartz imposed as an equilibrium mineral for the noncarbonate groundwater type. Small additions of inert ions (Na^+, K^+, NO_3^-, etc.) were added to maintain charge balance.

3.2 Equilibration with Leachate and Contaminants

The model representations of leachate and the contaminant were introduced to the pre-equilibrated groundwater model systems. In this step, the equilibrium pH was specified at a series of discrete values selected to span the range of expected pH values given the groundwater type and leachate type modeled. For each selected pH, a preliminary run was performed to estimate the ionic strength of the system being modeled, and subsequent model runs at ever increasing contaminant concentrations were constrained to this same ionic strength. Thus, each MINTEQA2 model execution to produce an isotherm for a particular contaminant was defined by the following selections of system variables:

- groundwater type (carbonate or noncarbonate)
- hydrologic zone (unsaturated or saturated)
- FeOx sorbent concentration level (low, medium, high)
- POM/DOM concentration level (low, medium, high)
- equilibrium pH (range depends on groundwater type and leachate type; see **Table 11**)
- leachate type (ash and coal refuse, FBC waste, FGD waste, or combined ash)
- leachate "richness" or ionic strength (low, medium, or high).

Table 11. Range of Equilibrium pH Values Used in Modeling

Waste Leachate Type	pH Range	
	Carbonate GW	Non-Carbonate GW
Ash and Coal Refuse	5.1–8.2	1.8–8.2
FBC Waste	5.1–12.6	4.5–12.6
FGD Waste	5.1–12.6	4.5–12.6
Combined Ash	5.1–12.6	4.5–12.6

For the purpose of establishing the concentration of calcium, magnesium, SO_4, sodium, and other leachate ions in the saturated zone, a constant dilution ratio of one part leachate to six parts groundwater was used for all modeling. For each system modeled (defined by the selections of system variables), the system was equilibrated at a series of 44 total concentrations of the contaminant spanning the range from 0.001 to 10,000 mg/L. The results were compiled as the equilibrium distribution of the contaminant among dissolved, sorbed, and precipitated fractions for each contaminant concentration. The compilation of the equilibrium contaminant distribution at a series of total contaminant concentrations was saved in a separate file indexed with the settings of all variables defining the system.

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4 Results

The files containing the equilibrium dissolved, sorbed, and precipitated fractions, each indexed with the settings of all system variables, were compiled into a database for use in transport modeling using EPACMTP. The contaminant concentration in the dissolved and sorbed fractions, along with the corresponding total contaminant concentration, defines each nonlinear isotherm. All three concentrations (dissolved, sorbed, and precipitated) are made available for use in EPACMTP. The ratio of the equilibrium sorbed and dissolved concentrations recorded in the isotherm is the dimensionless K_d. For the sorbed fraction, the concentration recorded in the isotherm is the amount of contaminant sorbed *from* 1 liter of solution. Of course, this amount is also sorbed *onto* the mass of soil with which 1 liter was equilibrated. This mass is the phase ratio: 4.57 kg/L for the unsaturated zone and 3.56 kg/L for the saturated zone. The K_d in units of L/kg is thus computed by normalizing the dimensionless K_d by the appropriate phase ratio.

For each contaminant, the modeling resulted in 432 isotherms for the carbonate groundwater for the ash and coal refuse leachate type and 702 isotherms for all other leachate types. For the noncarbonate groundwater, 702 isotherms were produced for the ash and coal refuse leachate type and 756 for each of the other leachate types. Given the groundwater and leachate types, each isotherm corresponds to particular concentration levels of FeOx and POM sorbents, pH, and leachate richness. In Monte Carlo or site-specific mode, EPACMTP selects the appropriate isotherm based on the conditions being modeled. Isotherms were produced for all 22 contaminants listed in **Section 1.2**, Table 1.

Isotherms were computed for two environmentally relevant oxidation states of arsenic, selenium, and chromium. The different oxidation states of these contaminants exhibit differences in sorption behavior, but both arsenic and selenium tend always to behave as anions in groundwater. Separate human toxicity values have not been established for the two forms of these metals, and most of the available leachate data are based on total metal concentrations rather than concentrations of the individual species. Isotherms were generated for each to be used for separate model runs in EPACMTP to reflect the differences in fate and transport that could result depending on which form is predominant in a particular subsurface environment.

4.1 Example Isotherms

Example isotherms illustrating the influence of key variables on the estimated K_d values are shown in **Figures 4** through **8**. **Figure 4** shows K_d versus total As (V) concentration for the carbonate groundwater saturated zone for the combined ash leachate type at three levels of FeOx sorbent concentration. The isotherms plotted are for the medium level for leachate richness and the medium POM concentration level for pH 6.6. As expected, sorption is enhanced at the higher FeOx concentrations resulting in larger K_d values.

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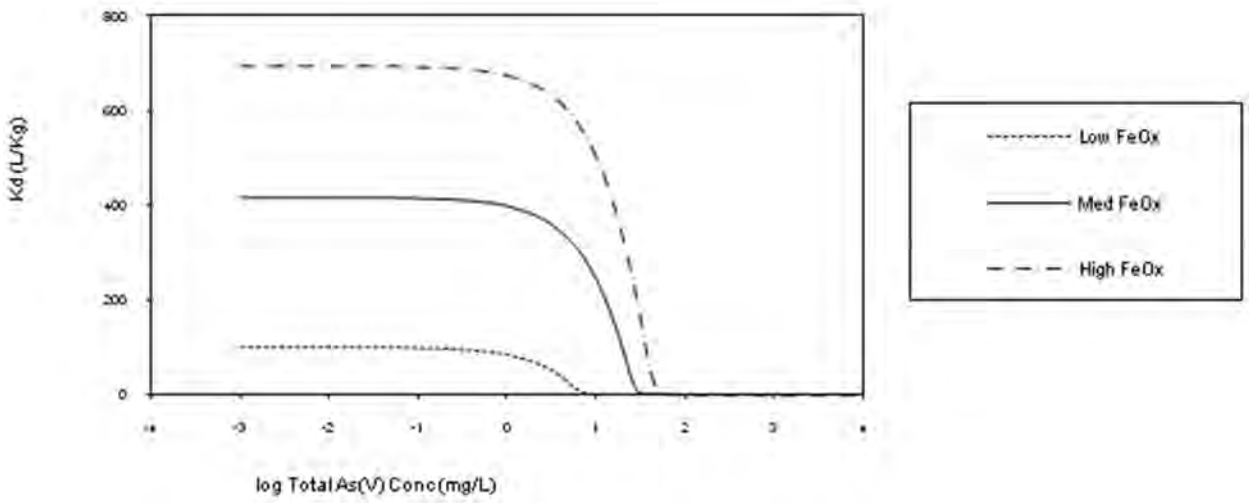

Figure 4. Estimated K_d versus total arsenic concentration for three FeOx sorbent concentration levels (combined ash).

The impact of varying the POM concentration level differs among the various metals. The effect of POM concentration level also depends on the pH. The variable impact of POM is due to two factors: the absence of organic matter reactions for anionic metals and the concurrent influence of DOM for those metals for which organic matter reactions are included. In the MINTEQA2 modeling procedure used here, increasing the POM sorbent concentration is always accompanied by a proportional increase in the DOM concentration. The overall impact on the amount of metal sorbed depends on the relative competition among all constituents in the systems for these two substances. The "winner" of this relative competition (POM or DOM) shifts with pH because both substances undergo acid-base reactions.

Figure 5 shows the impact of varying the POM/DOM concentration level on lead sorption for the noncarbonate groundwater unsaturated zone with medium FeOx concentration level and leachate richness level at pH 8.2. In this example, the highest POM level results in the highest K_d values. However, this is not true for all cases; the outcome due to increasing the POM is dependent on the aforementioned competition between the trace metal and major ions on all three sorbing surfaces (FeOx, POM, and DOM).

The influence of the leachate "richness" level is illustrated in **Figure 6** for cobalt sorption. Leachate richness refers to a general concentration level analogous to ionic strength. The low, medium, and high settings represent concentration levels for sum of anions. Figure 6 shows the K_d response for each of the three levels for the noncarbonate groundwater, unsaturated zone with ash and coal refuse leachate, and medium concentration levels of FeOx and POM sorbents. The pH for this example was 9.8.

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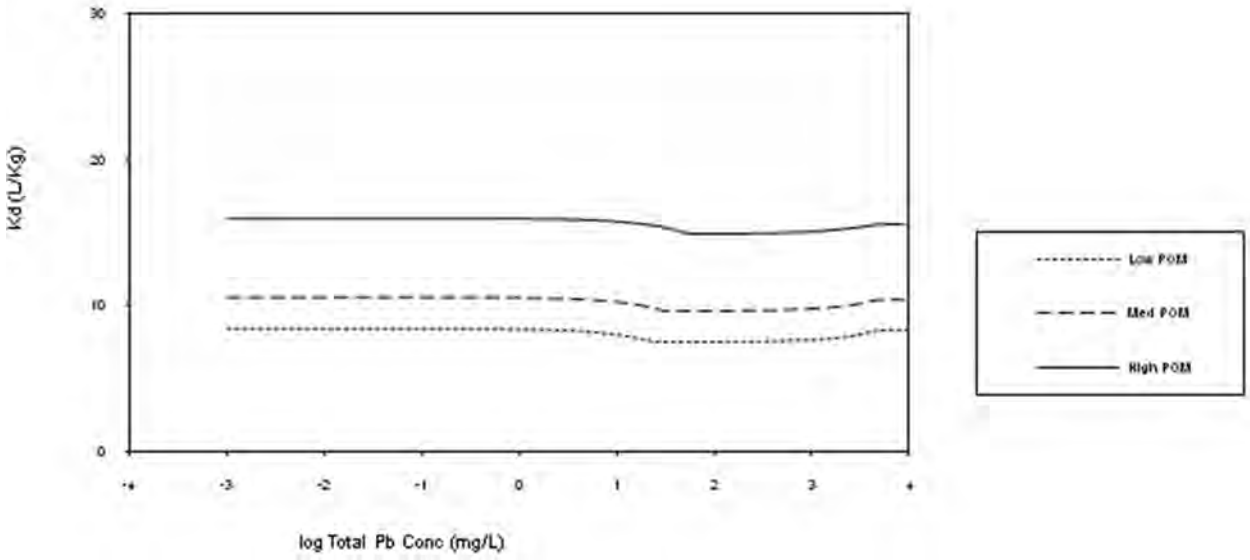

Figure 5. Estimated K_d versus total lead concentration for three POM/DOM concentration levels.

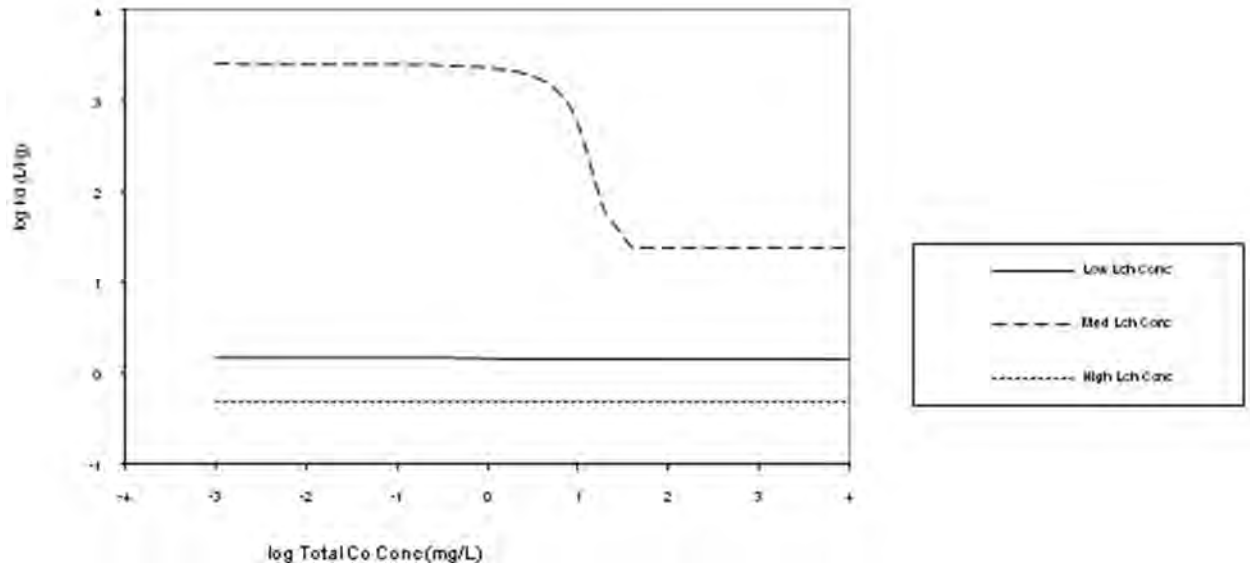

Figure 6. Estimated K_d versus total cobalt concentration for three different leachate richness levels (ash and coal refuse).

Figure 7 depicts the K_d versus pH for lead in a single system (noncarbonate groundwater, unsaturated zone, high FeOx and POM sorbent levels, medium leachate richness level for combined ash leachate type) at a single total lead concentration (0.001 mg). K_d values in this system increase steadily from pH 4 to 7, then increase more rapidly up to pH 9.8. After pH 9.8, K_d begins to decrease abruptly due to formation of lead-hydroxy solution species.

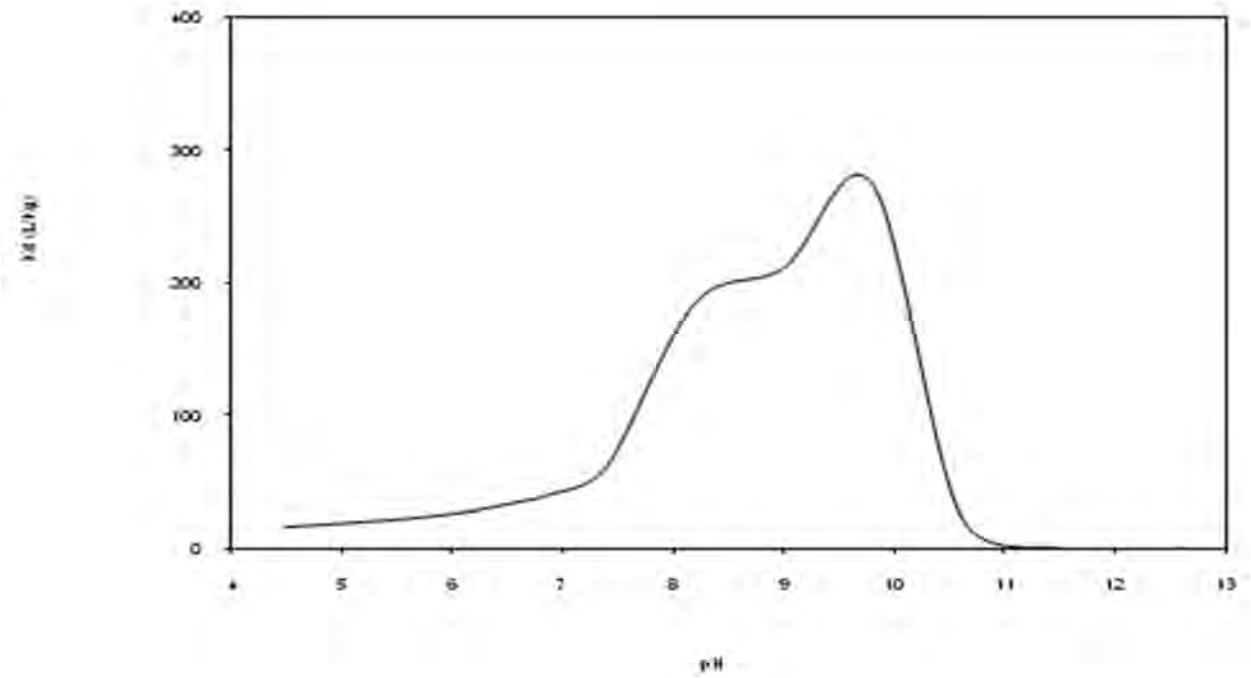

Figure 7. Estimated K_d versus pH for lead in a single system at a single total lead concentration (0.001 mg/L) (combined ash).

Figure 8 shows the K_d response for lead in a single system (noncarbonate groundwater, unsaturated zone, high FeOx and POM sorbent levels, and pH 8.2) for each of the four different waste leachate types at the high leachate richness level.

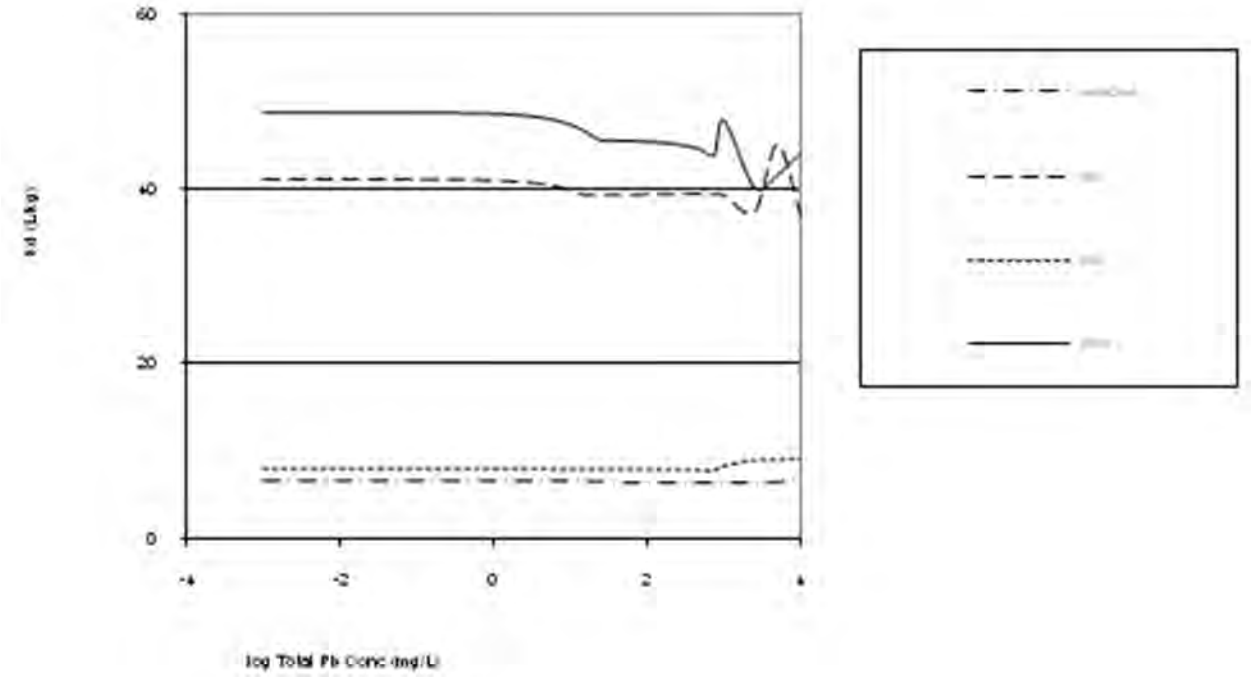

Figure 8. Estimated K_d versus pH for a single setting of system variables shown for each of four waste leachate types.

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5 Assumptions and Limitations

Many assumptions are inherent in using a speciation model to estimate partition coefficients. Some of these must be acknowledged to result in limitations on the utility of the model results. Undoubtedly, the results are better for some contaminants than for others. Various modeling assumptions and limitations are presented below. These are organized as those resulting from the manner in which the groundwater composition, the sorbents, and the leachate were characterized and certain broader, more general issues. The discussion is limited to pointing out each assumption or limitation. Although the direction of possible error in the estimated K_d values is apparent from some of these limitations, it would be difficult to quantify the uncertainty in the estimated K_d values.

5.1 Groundwater Characterization Issues

- The categorization of all groundwater chemistries into two types, carbonate and noncarbonate, is quite broad. The noncarbonate category is especially broad, and sorption behavior among different groundwater compositions that might fall into this category could be quite variable. This variability is not accounted for in the current approach.
- Although the pre-equilibration step is helpful in more realistically establishing appropriate major ion concentrations, it is somewhat artificial in the sense that the concentrations of the sorbents are not correlated with groundwater major ion concentrations. Both the FeOx and POM sorbents were represented as general concentration distributions obtained from sources separate from the groundwater data. Therefore, the sorbent concentration levels used do not correlate specifically to the groundwater compositions used.
- Both groundwater chemistries were artificially adjusted to different pHs by simply specifying a desired equilibrium pH. Potassium, sodium, and nitrate were used to balance charge in this procedure, so the result should be analogous to titrating with strong acid or base. The degree to which this procedure can result in model groundwater chemistries that adequately represent true variability in factors that impact Kd is unknown.

5.2 Sorbent Characterization Issues

- Only two sorbents are represented in the model systems. Other sorbents are important in some circumstances, including clays, hydrous aluminum and manganese oxides, calcite, and silica. Failure to include all potential sorbents could result in underestimation of sorption.
- The FeOx was accounted in the modeling as goethite. Other FeOx may be important in groundwater, including HFO. HFO has a higher specific surface area and greater reactivity for some metals than does goethite. The degree of sorption may be underestimated for some contaminants in systems where HFO is the dominant form of FeOx. Also, equilibrium constants for adsorption onto goethite were unavailable for some contaminants; estimates were used.

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- The data used to quantify the FeOx and POM sorbents (and the DOM) are sparse. The degree to which the true variability in concentration levels of these sorbents has been captured in the modeling is unknown.
- There is no provision in the modeling to account for occlusion of sorbents. Both FeOx and organic matter may form coatings over other surfaces. Failure to account for occlusion could result in overestimating the available sorption sites.
- The FeOx (goethite) sorbent is included in all model runs. This implies that it is ubiquitous. However, there are natural groundwater conditions that preclude the formation of FeOx precipitates. As illustrated in **Figure 9**, FeOx is not the stable iron solid phase at conditions of low pH and low Eh (oxidation/reduction potential), so these conditions are inconsistent with the use of FeOx as a sorbing phase. Including the goethite sorbent where it cannot exist could obviously lead to overestimating sorption, unless other sorbents that are not modeled (e.g., clays) are important. The omission of the stable iron phases siderite and pyrite as model sorbents serves to compensate for this flaw, although the extent of this compensation is unknown.

- The Gaussian model for estimating metal interactions with organic matter was developed for DOM. It has not been tested for estimating the degree of metal sorption onto POM. Also, mean log K values for some metals have not been measured, so estimates were used.

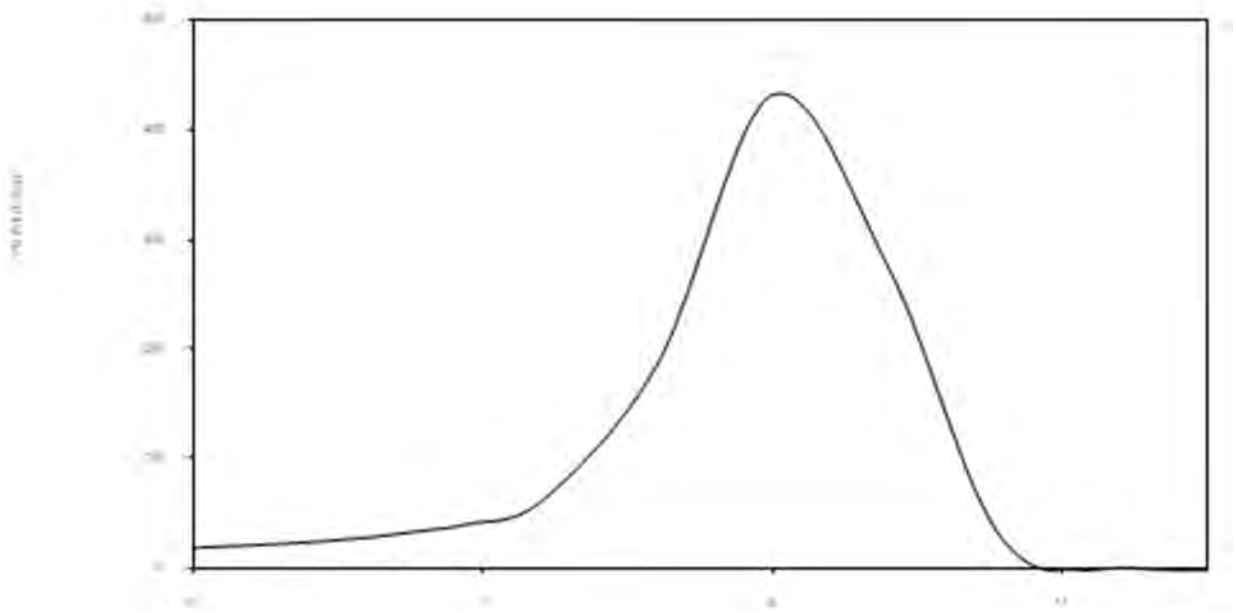

Figure 9. Stability fields for iron minerals (after Hem, 1977).

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5.3 Leachate Characterization Issues

The concentration levels for important leachate constituents (e.g., calcium, magnesium, SO_4, chlorine) is based on a limited CCR constituent data set. This is especially true for the FBC wastes; leachate and porewater data were available for only one site. (Note: Other FBC waste characterization data are available but were measured on extraction procedures such as TCLP or SPLP.)

- The presence of CCR leachate constituents at elevated concentrations is accounted for in the MINTEQA2 modeling, but the dilution of the leachate in the mixing zone is oversimplified. A single dilution ratio of one part leachate to six parts groundwater was assumed for all saturated zone modeling. Some of these constituents are themselves adsorbed onto aquifer and soil matrix materials; it is their propensity to sorb that requires they be included in the modeling. Sorbing constituents (including H^+) will be transported away from the facility at different rates in accordance with their implied retardation factors. Use of a single recipe for leachate composition for all points in the unsaturated or saturated zones cannot represent this effect. The degree to which this oversimplification will result in errors in K_d estimates of contaminants is unknown.
- Methylated forms were not accounted for in this modeling. Mercury and arsenic are known to undergo methylation in the environment.

5.4 Other Issues

- The system redox potential was not explicitly defined in the modeling. All species that might undergo oxidation–reduction reactions were constrained to remain in the form in which they were entered in the model. This restriction applied to major ions such as sulfate and to all trace metals. The impact on K_d is unknown but is expected to be contaminant specific.
- All contaminants were introduced separately and individually in the modeling. The possible simultaneous presence of multiple contaminants is unaccounted for. The impact on K_d is not expected to be great except at high contaminant concentrations where competition for sorption sites may result in less sorption for some contaminants than suggested by this modeling.

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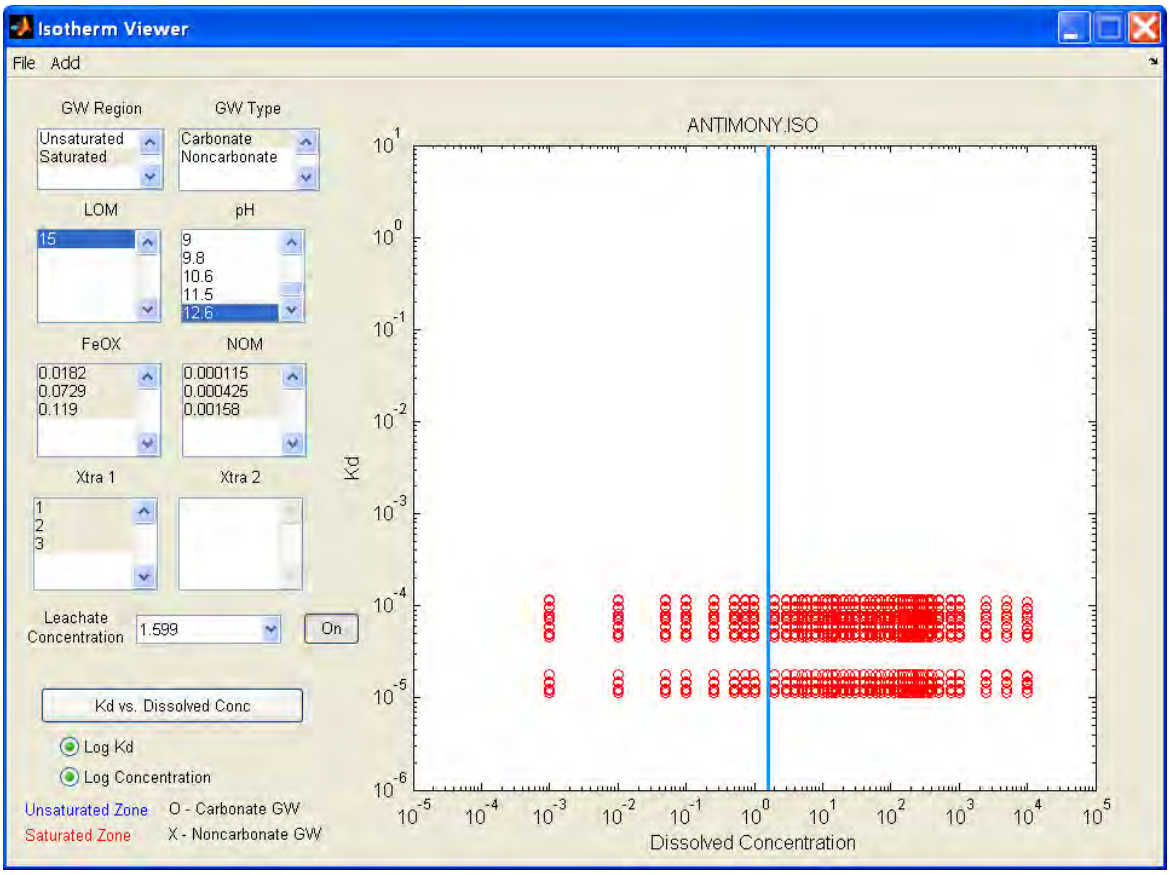
Attachment H-2.
Nonlinear Sorption Isotherm Plots

This attachment presents graphs plotting the nonlinear sorption isotherms discussed in **Appendix H**. For each model iteration of the probabilistic analysis presented in **Section 4**, EPACMTP selected values from these isotherms based on constituent concentration (x-axis), whether the groundwater composition type is carbonate or noncarbonate, the groundwater or soil pH, the natural organic matter level (NOM), the iron oxide content (FeOx), and the leachate ionic strength (Xtra 1). Each constituent's isotherms are presented separately for carbonate and noncarbonate environments as the upper and lower panels within each figure. Furthermore, separate figures are presented for the saturated zone (red plots) and the unsaturated zone (blue plots). The groundwater or soil pH, NOM, FeOx, and Xtra 1 (ionic strength) levels used to select the isotherms presented in each plot are listed in the boxes to the left in each panel; the values in these boxes are explained in **Section 2** of **Attachment H-1**. Sorption isotherms for landfills (LFs) with combined ash are presented in **Figures H-2-1** through **H-2-20**. Sorption isotherms for surface impoundments (SIs) with combined ash, ash and coal refuse, and FGD wastes are presented in **Figures H-2-21** through **H-2-50**. **Table H-2-1** summarizes which isotherms are in which figures. Isotherms are shown only for contaminant-WMU combinations that were modeled in the probabilistic analysis.

Table H-2-1. Guide to Figures Showing Isotherms

Contaminant	Landfills		Surface Impoundments	
	Saturated Zone	Unsaturated Zone	Saturated Zone	Unsaturated Zone
Antimony	Figure H-2-1	Figure H-2-2	Figure H-2-21	Figure H-2-22
Arsenic III	Figure H-2-3	Figure H-2-4	Figure H-2-23	Figure H-2-24
Arsenic V	Figure H-2-5	Figure H-2-6	Figure H-2-25	Figure H-2-26
Boron	Figure H-2-7	Figure H-2-8	Figure H-2-27	Figure H-2-28
Cadmium	Figure H-2-9	Figure H-2-10	Figure H-2-29	Figure H-2-30
Chromium III	–	–	Figure H-2-31	Figure H-2-32
Chromium VI	Figure H-2-11	Figure H-2-12	Figure H-2-33	Figure H-2-34
Cobalt	Figure H-2-13	Figure H-2-14	Figure H-2-35	Figure H-2-36
Fluoride	–	–	Figure H-2-37	Figure H-2-38
Lead	–	–	Figure H-2-39	Figure H-2-40
Mercury	Figure H-2-15	Figure H-2-16	Figure H-2-41	Figure H-2-42
Molybdenum	Figure H-2-17	Figure H-2-18	Figure H-2-43	Figure H-2-44
Selenium	–	–	Figure H-2-45	Figure H-2-46
Thallium	Figure H-2-19	Figure H-2-20	Figure H-2-47	Figure H-2-48
Vanadium	–	–	Figure H-2-49	Figure H-2-50



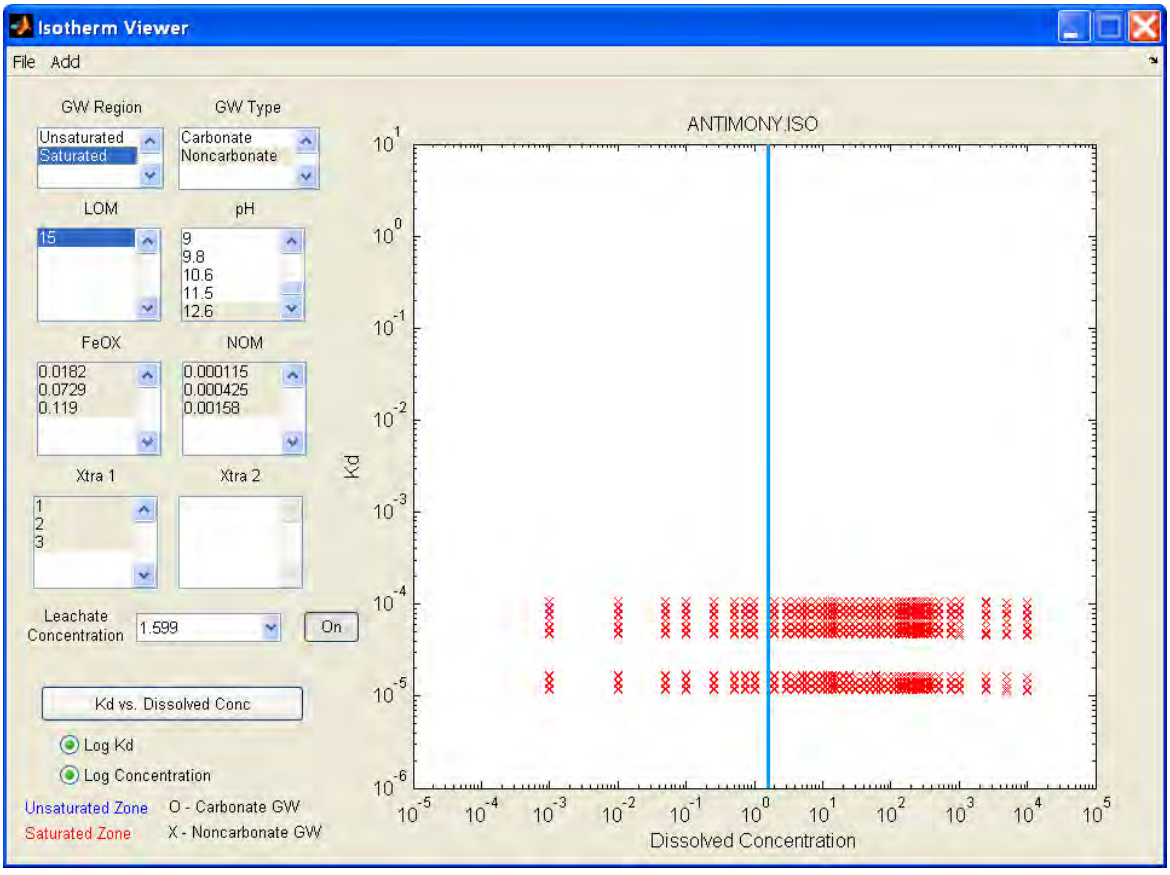


Figure H-2-1. Antimony saturated zone nonlinear sorption isotherms for LFs.

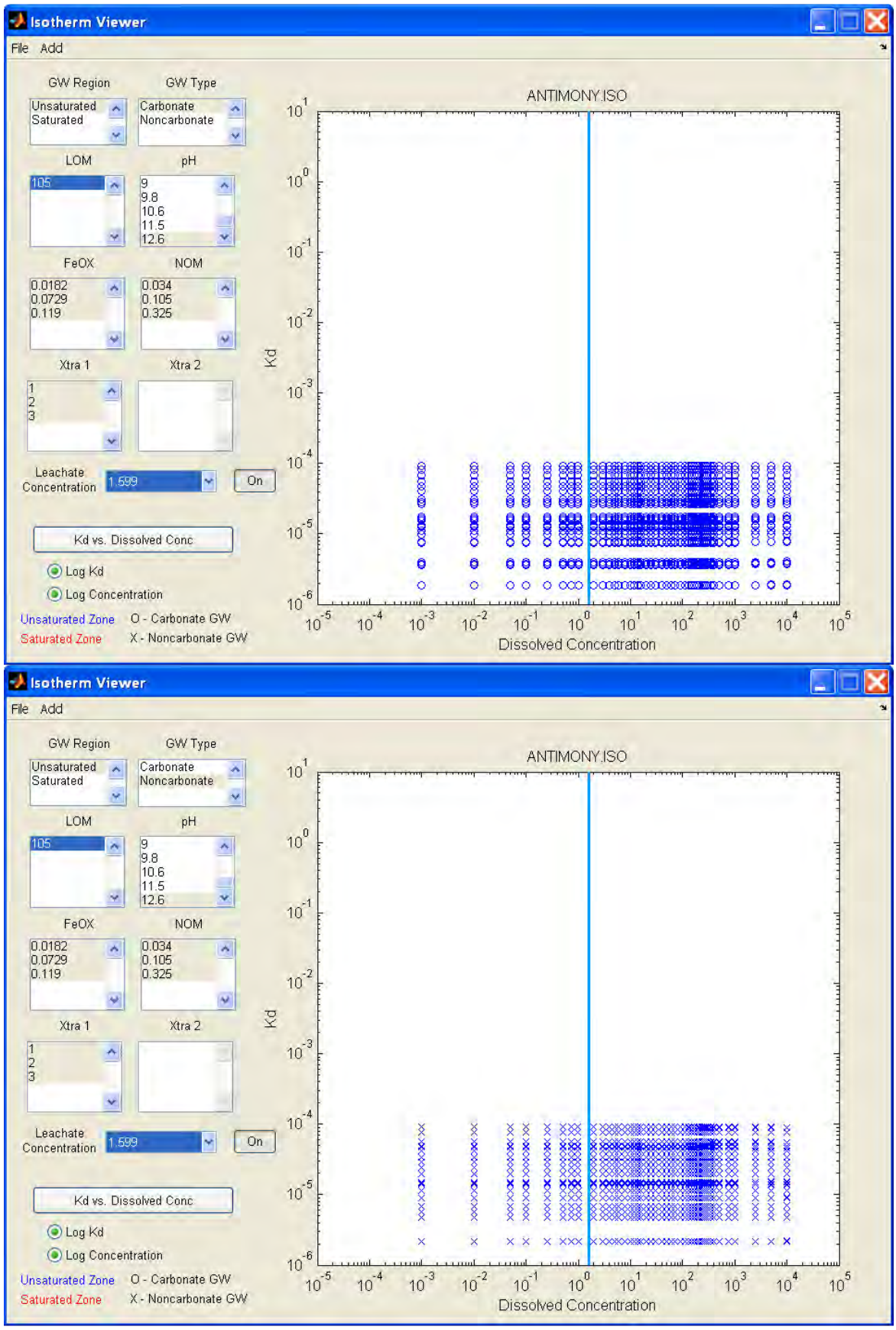


Figure H-2-2. Antimony unsaturated zone nonlinear sorption isotherms for LFs.

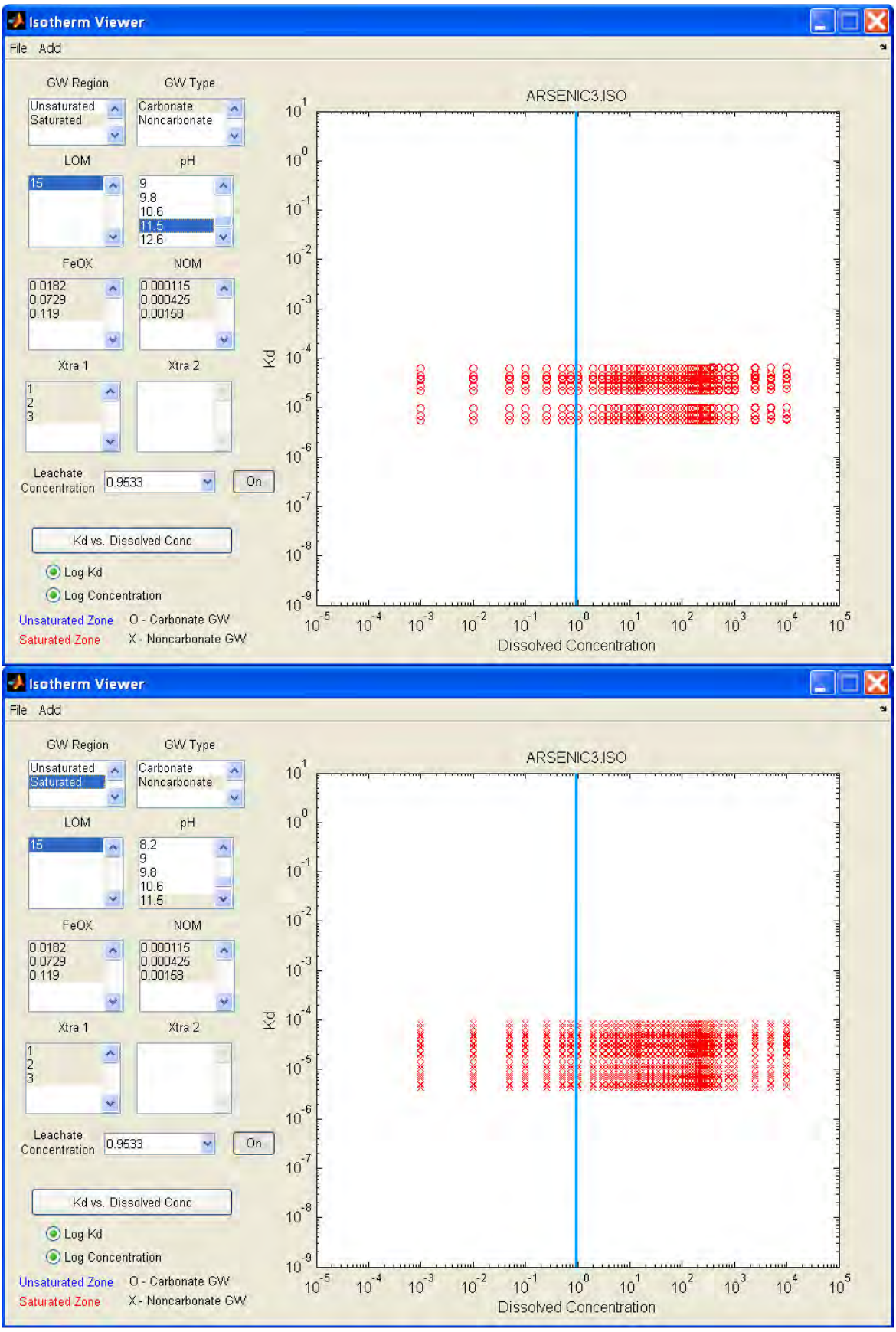


Figure H-2-3. Arsenic III saturated zone nonlinear sorption isotherms for LFs.

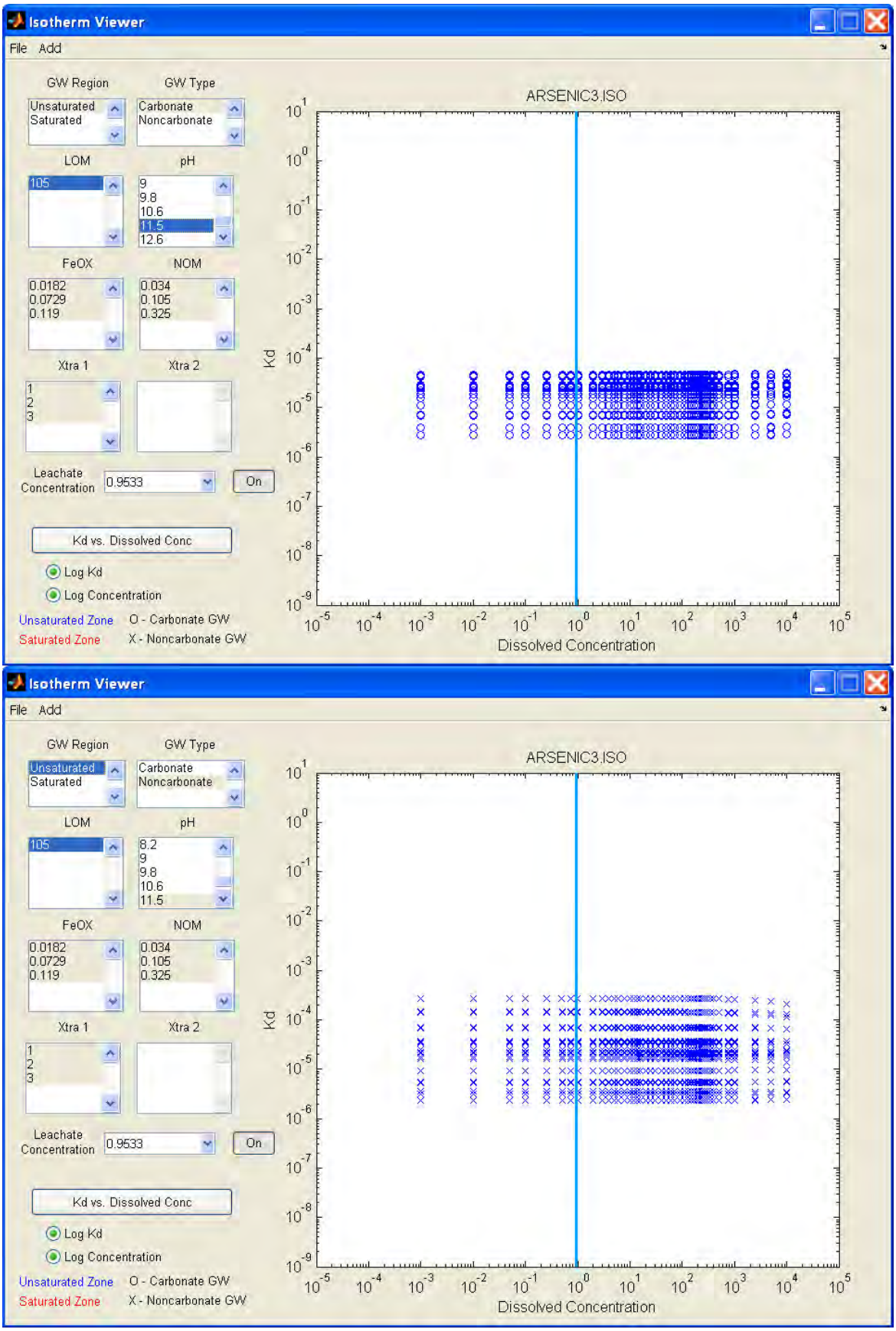


Figure H-2-4. Arsenic III unsaturated zone nonlinear sorption isotherms for LFs.

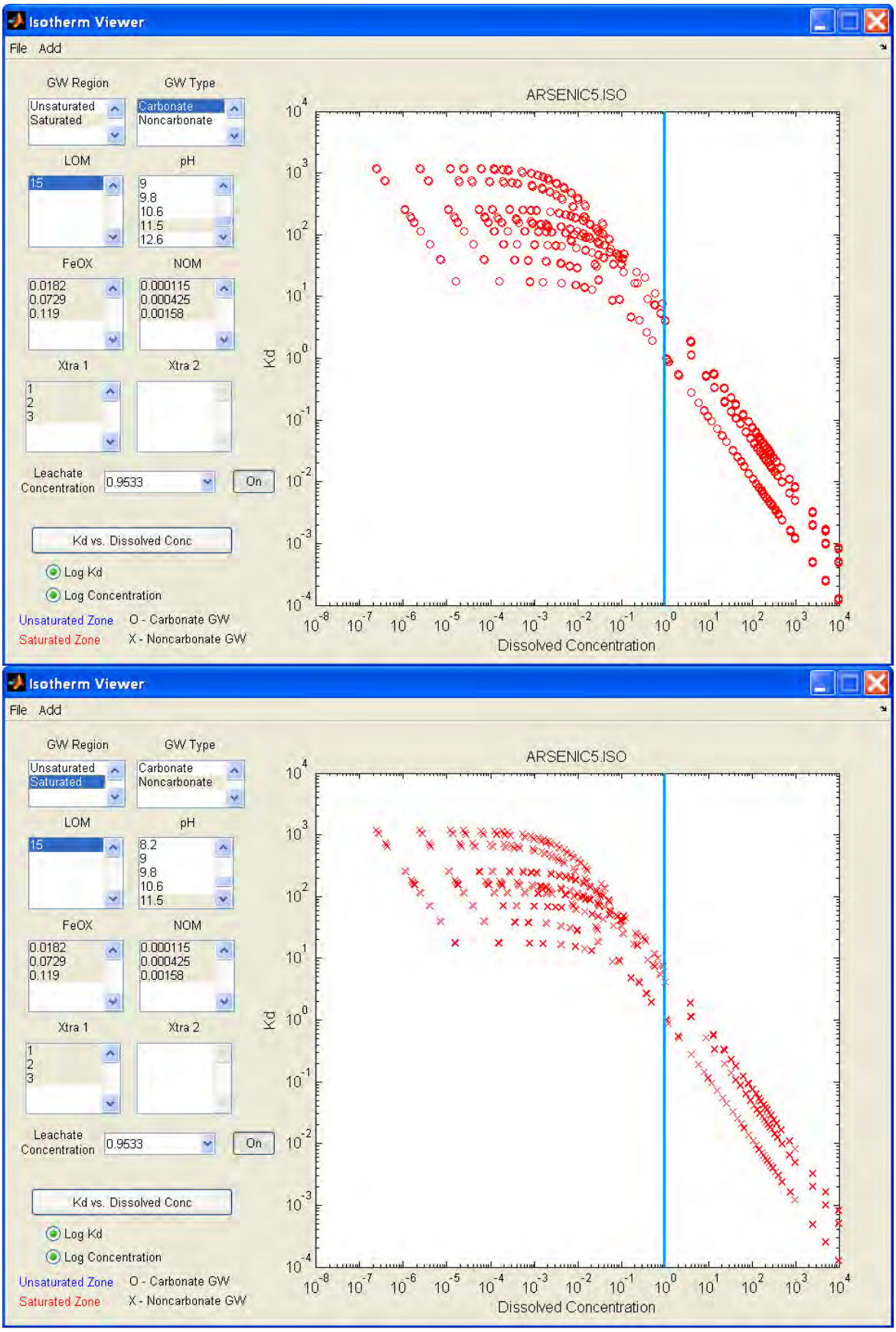


Figure H-2-5. Arsenic V saturated zone nonlinear sorption isotherms for LFs.

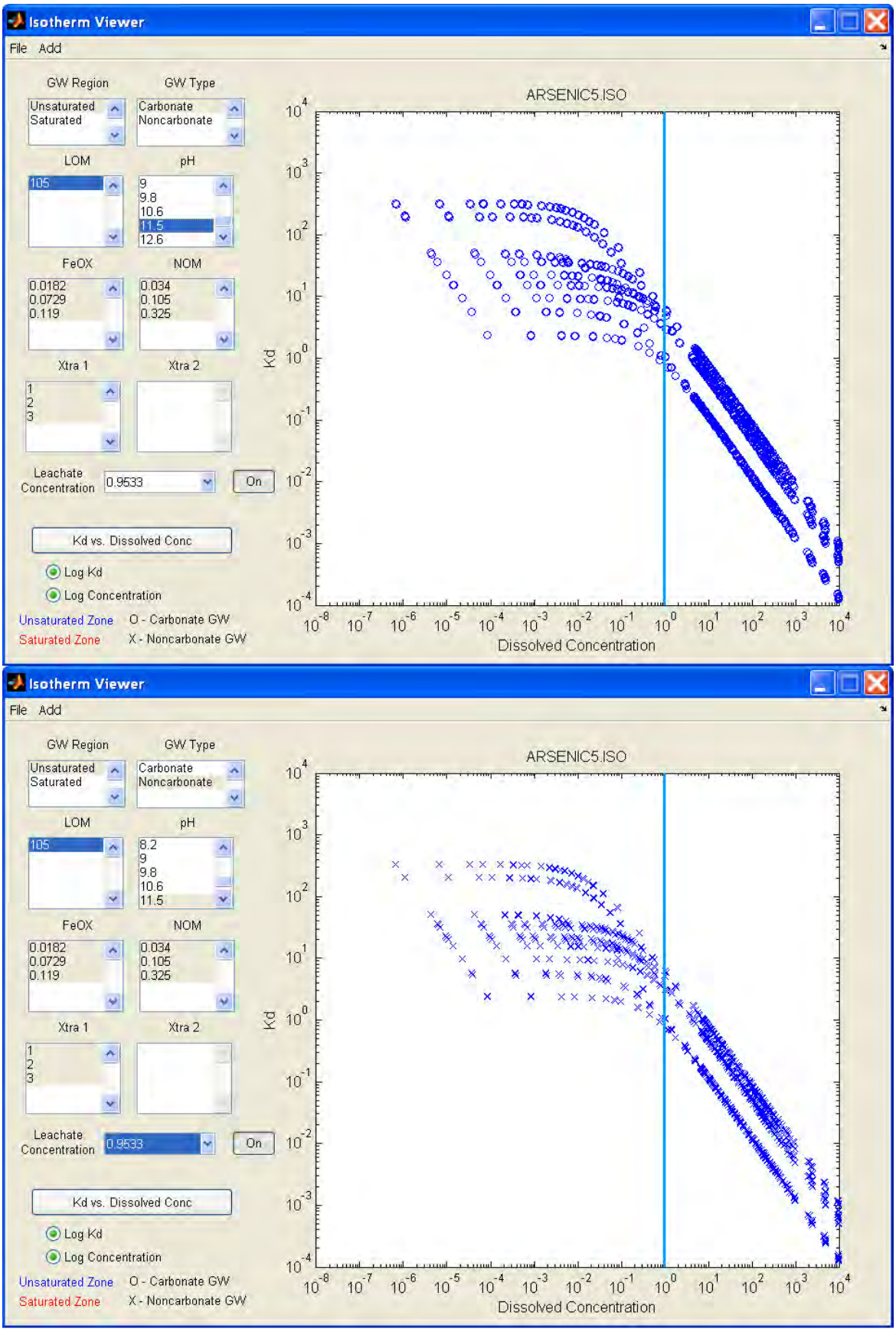


Figure H-2-6. Arsenic V unsaturated zone nonlinear sorption isotherms for LFs.

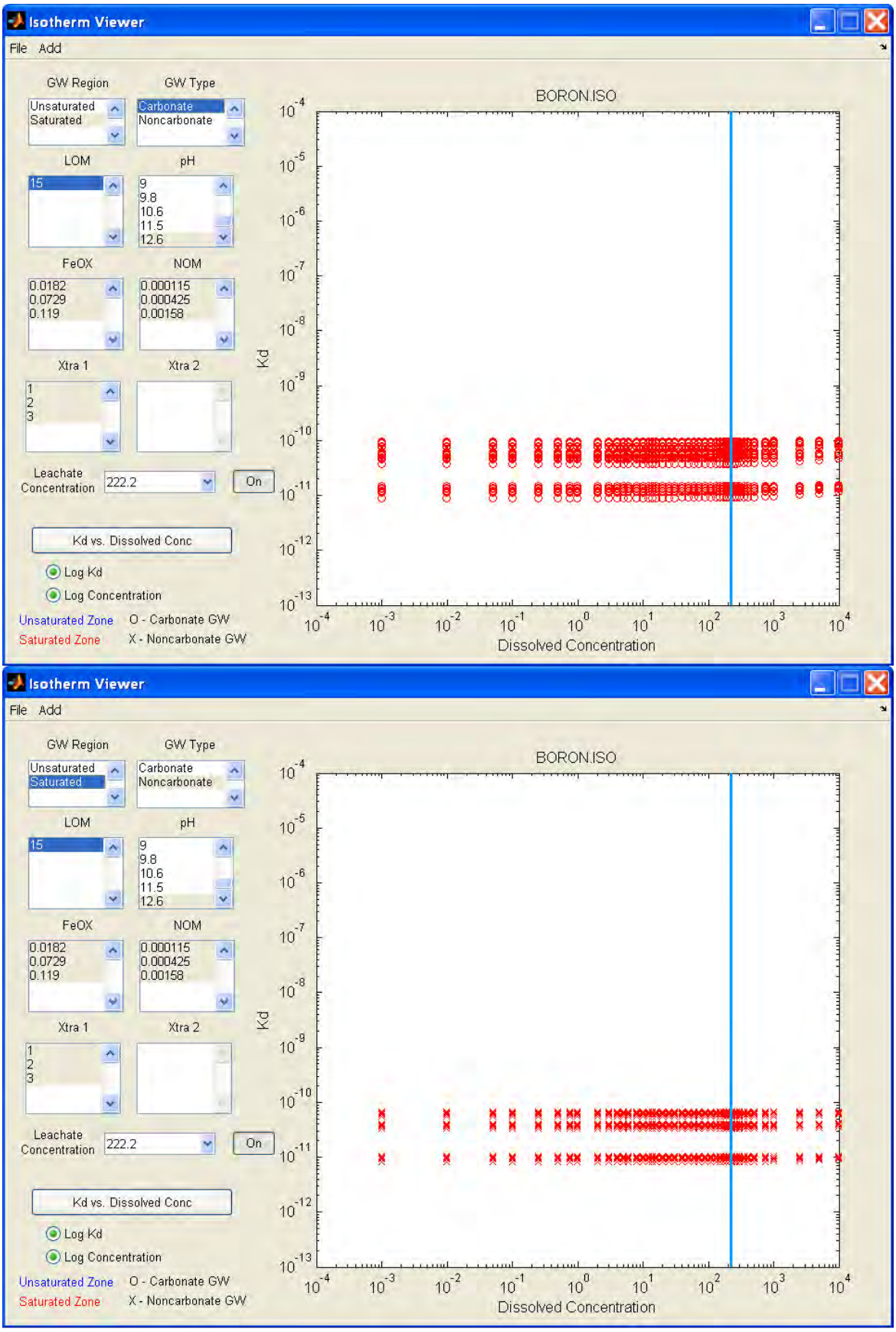


Figure H-2-7. Boron saturated zone nonlinear sorption isotherms for LFs.

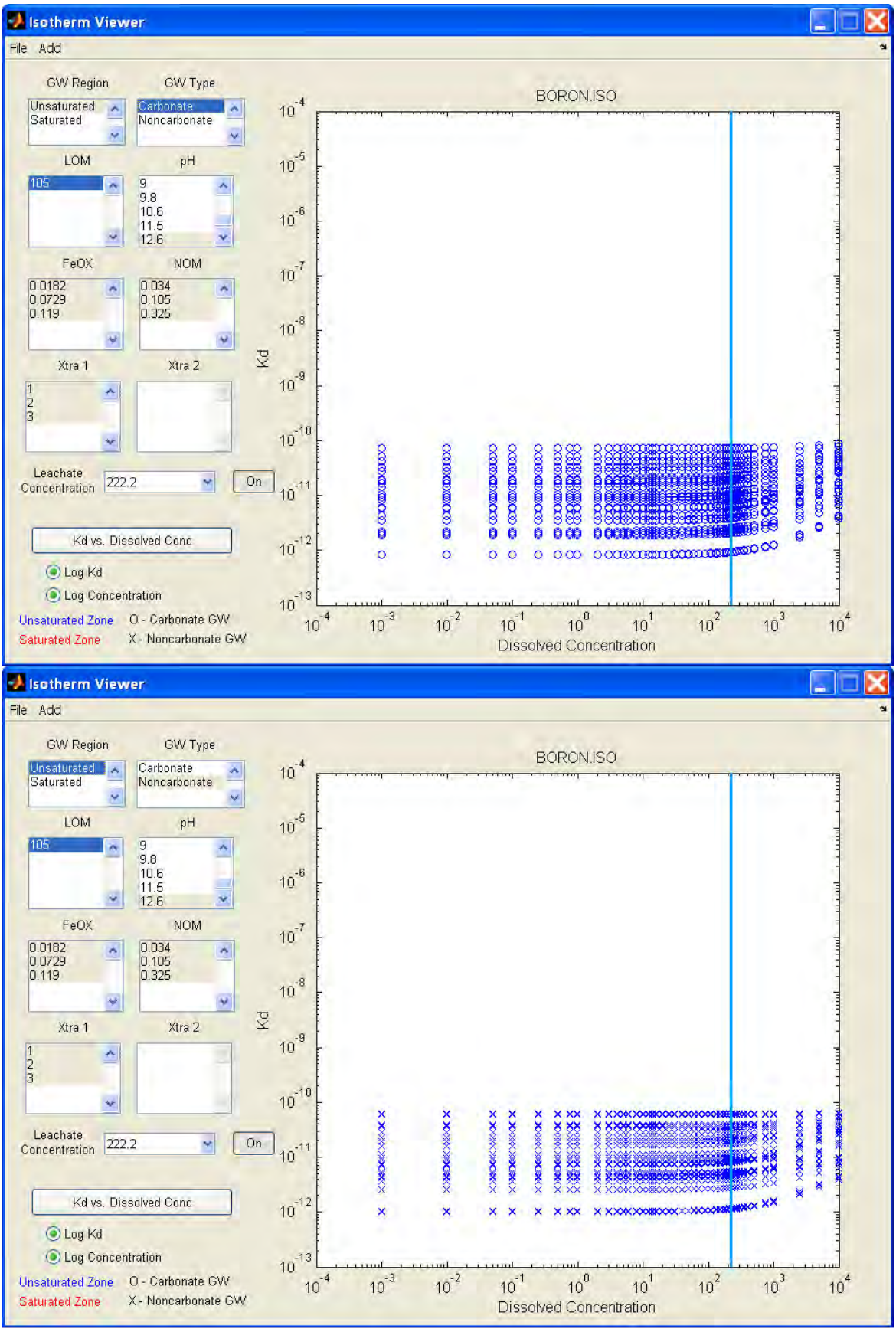


Figure H-2-8. Boron unsaturated zone nonlinear sorption isotherms for LFs.

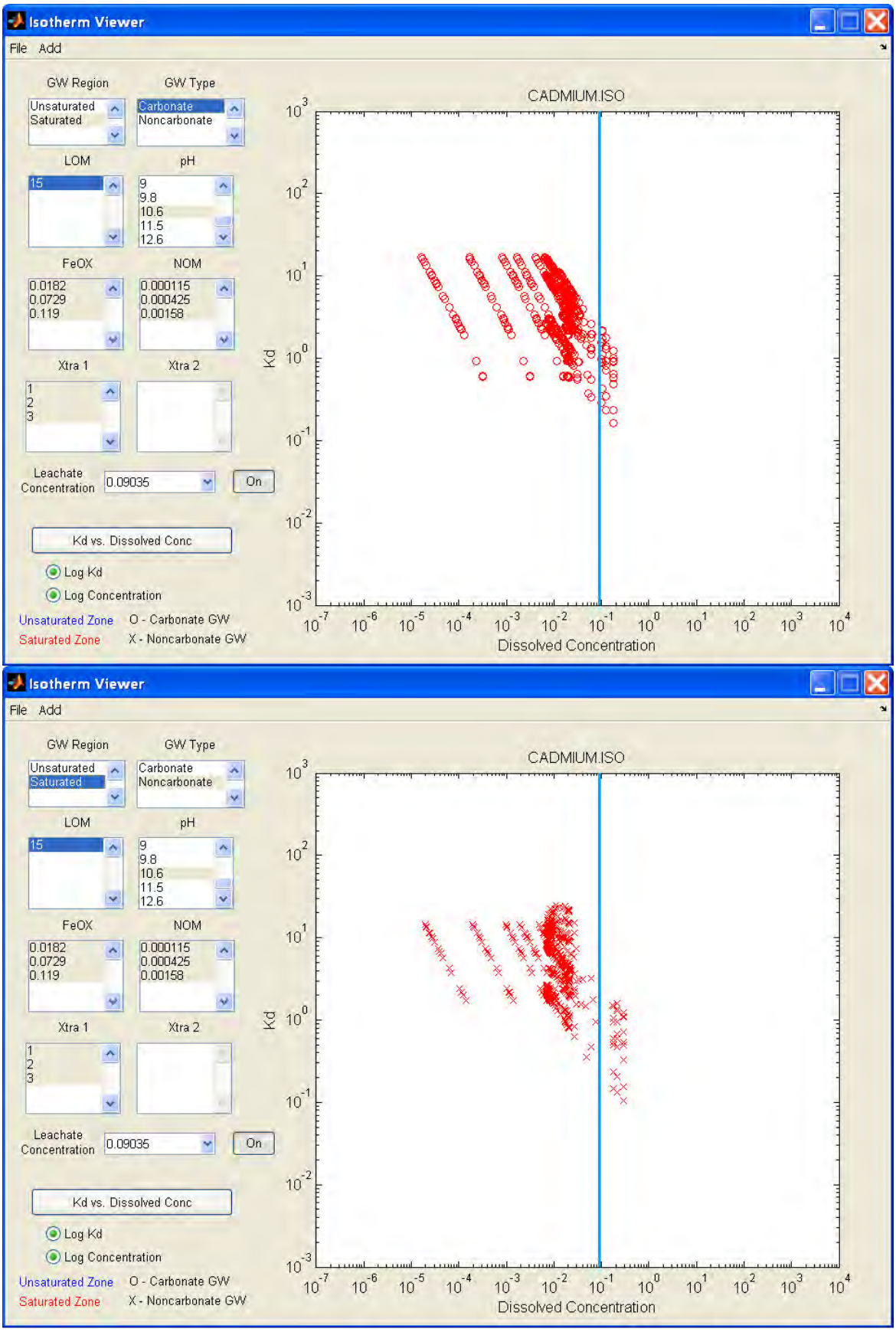


Figure H-2-9. Cadmium saturated zone nonlinear sorption isotherms for LFs.

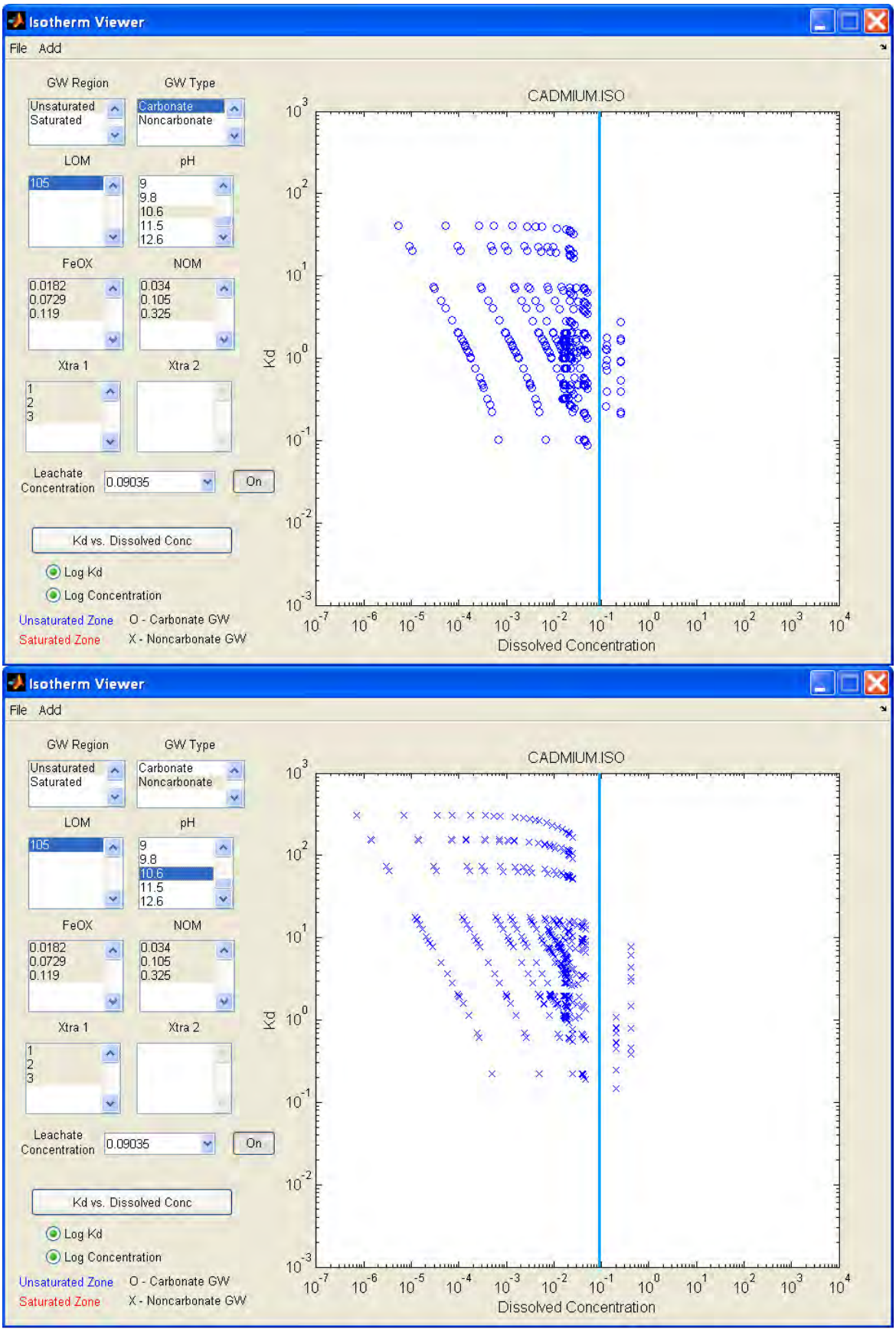


Figure H-2-10. Cadmium unsaturated zone nonlinear sorption isotherms for LFs.

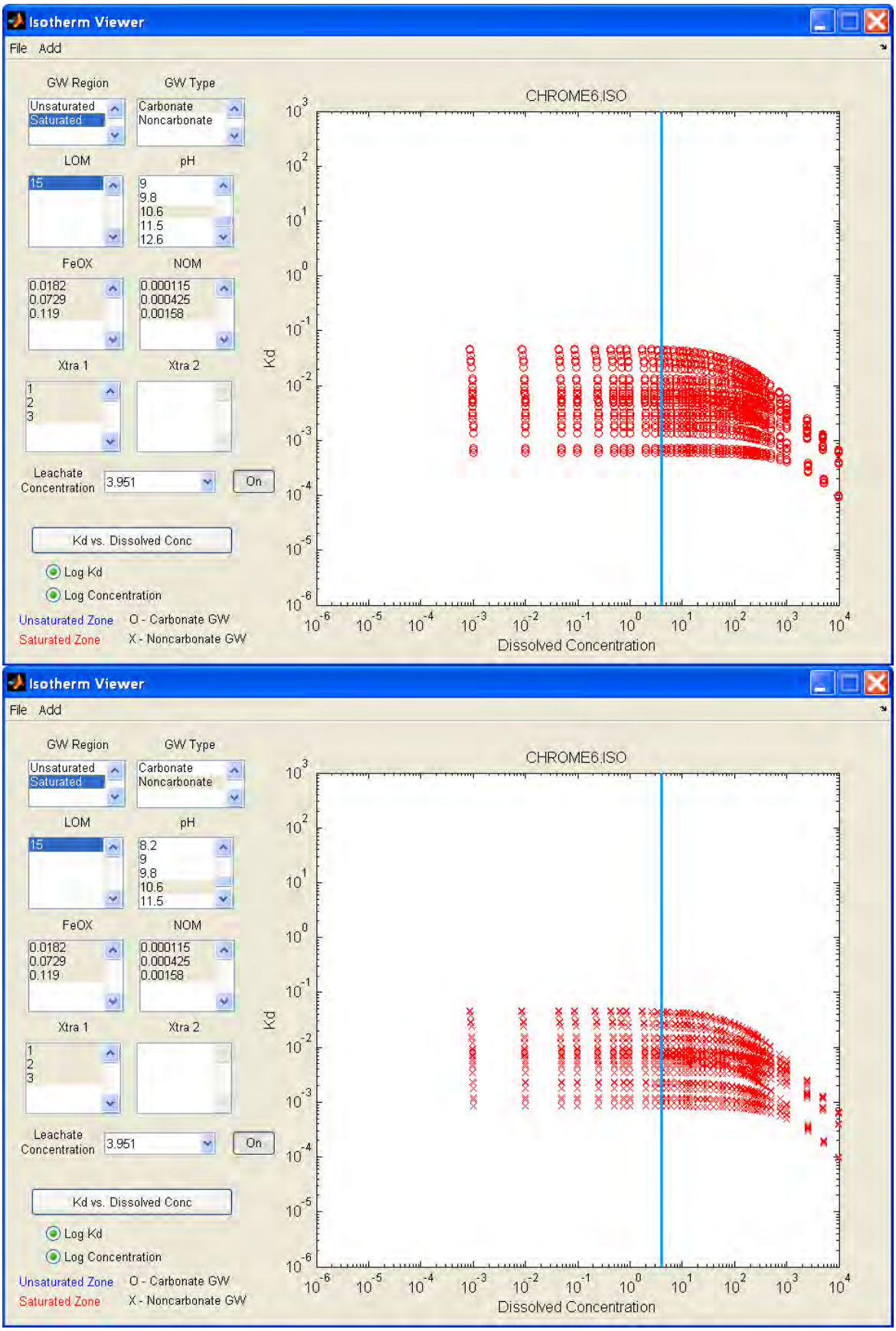
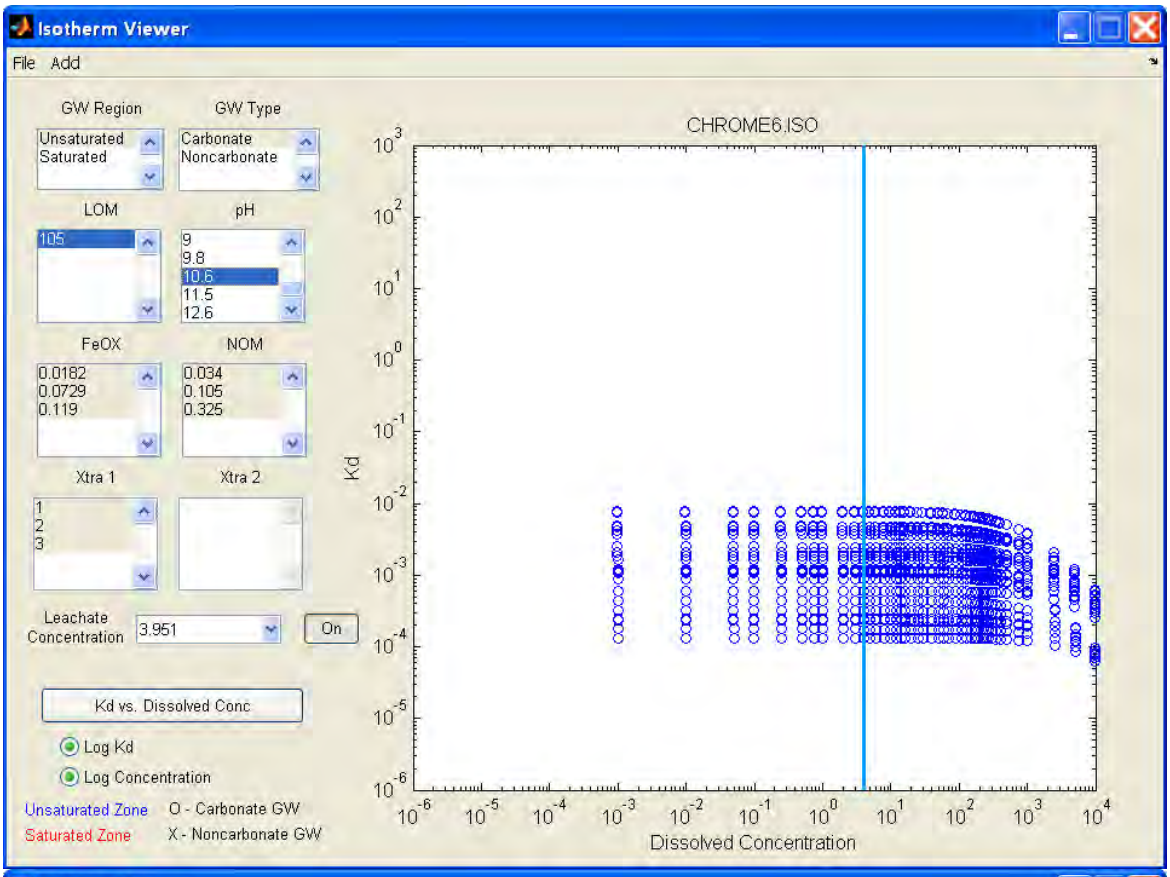


Figure H-2-11. Chromium VI saturated zone nonlinear sorption isotherms for LFs.



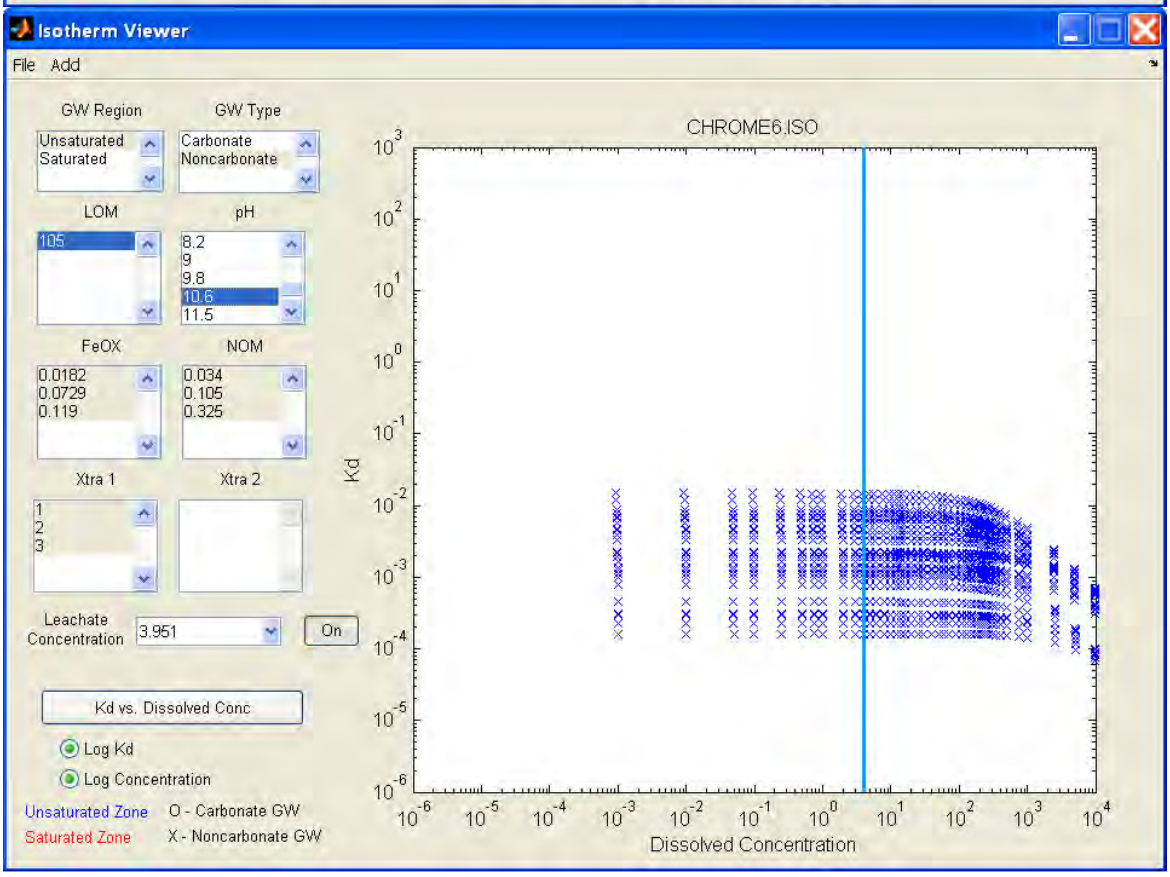


Figure H-2-12. Chromium VI unsaturated zone nonlinear sorption isotherms for LFs.

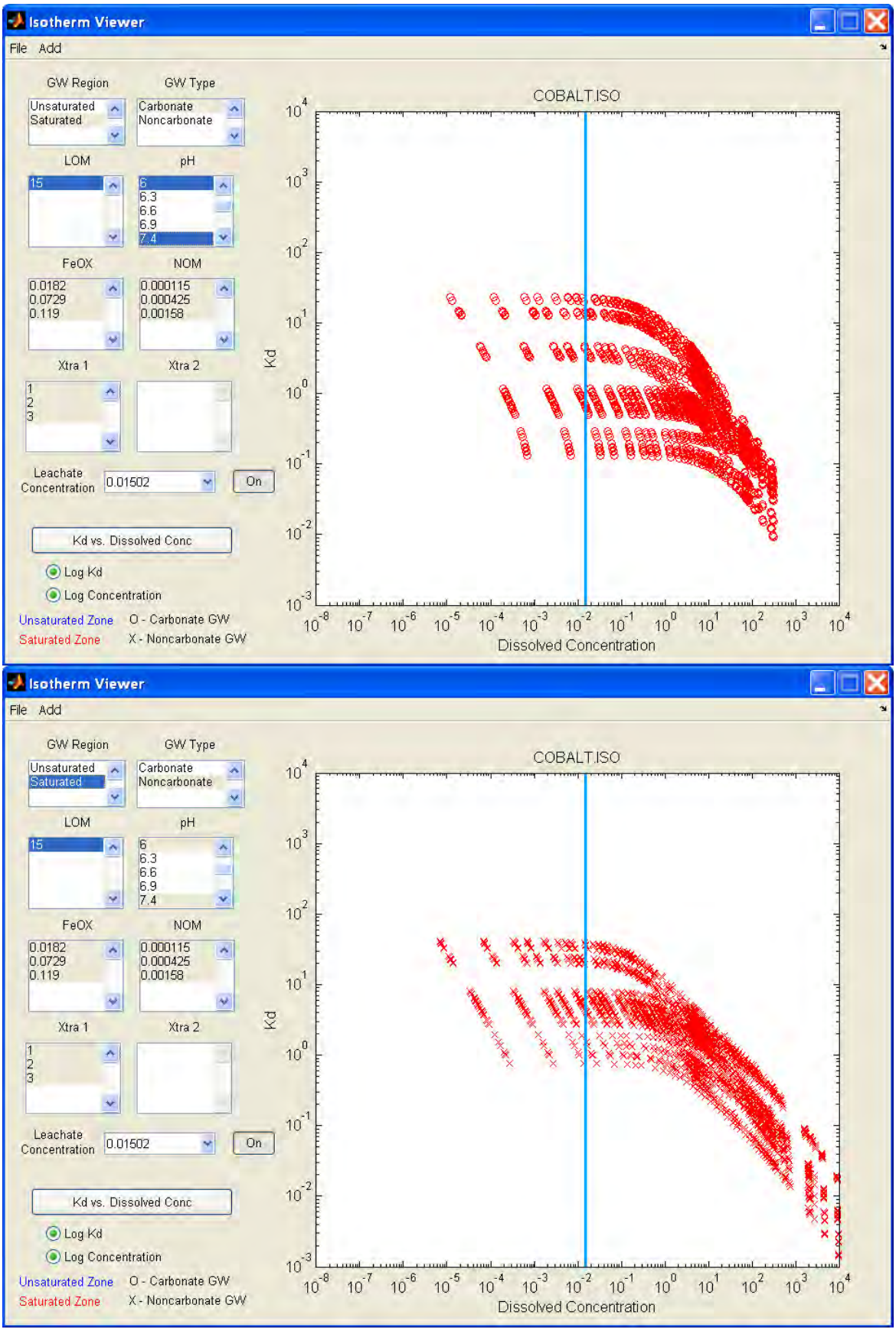


Figure H-2-13. Cobalt saturated zone nonlinear sorption isotherms for LFs.

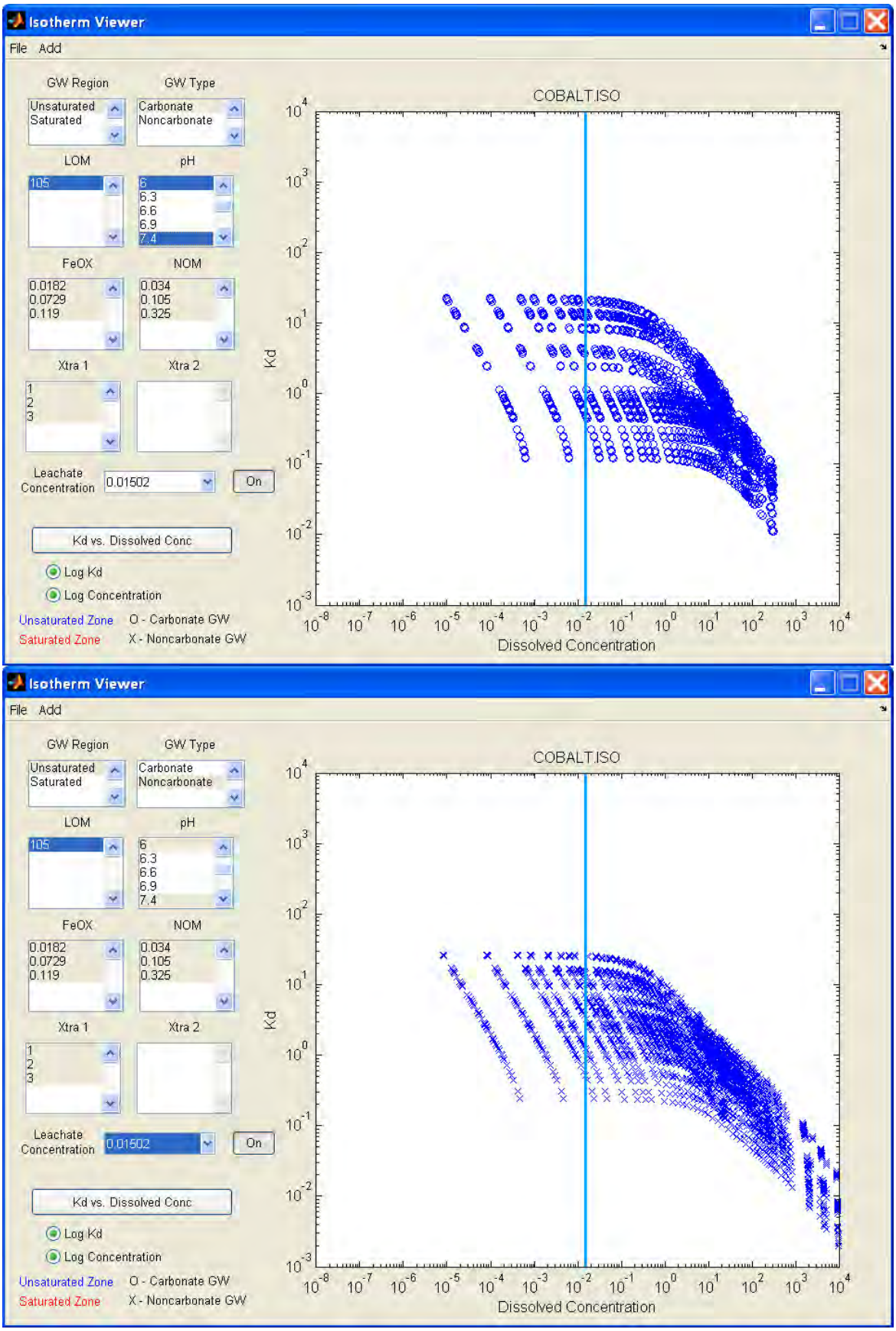


Figure H-2-14. Cobalt unsaturated zone nonlinear sorption isotherms for LFs.

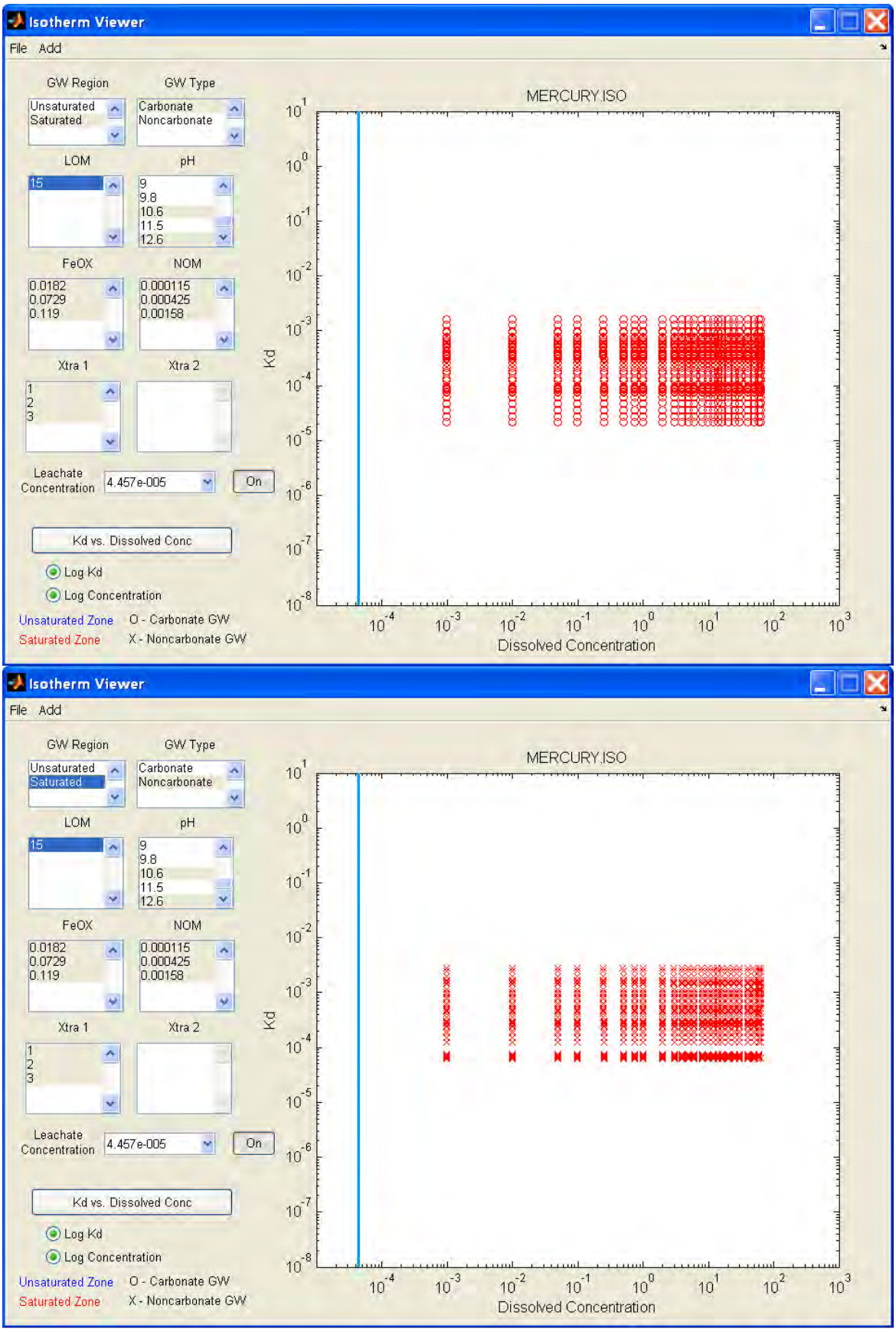


Figure H-2-15. Mercury saturated zone nonlinear sorption isotherms for LFs.

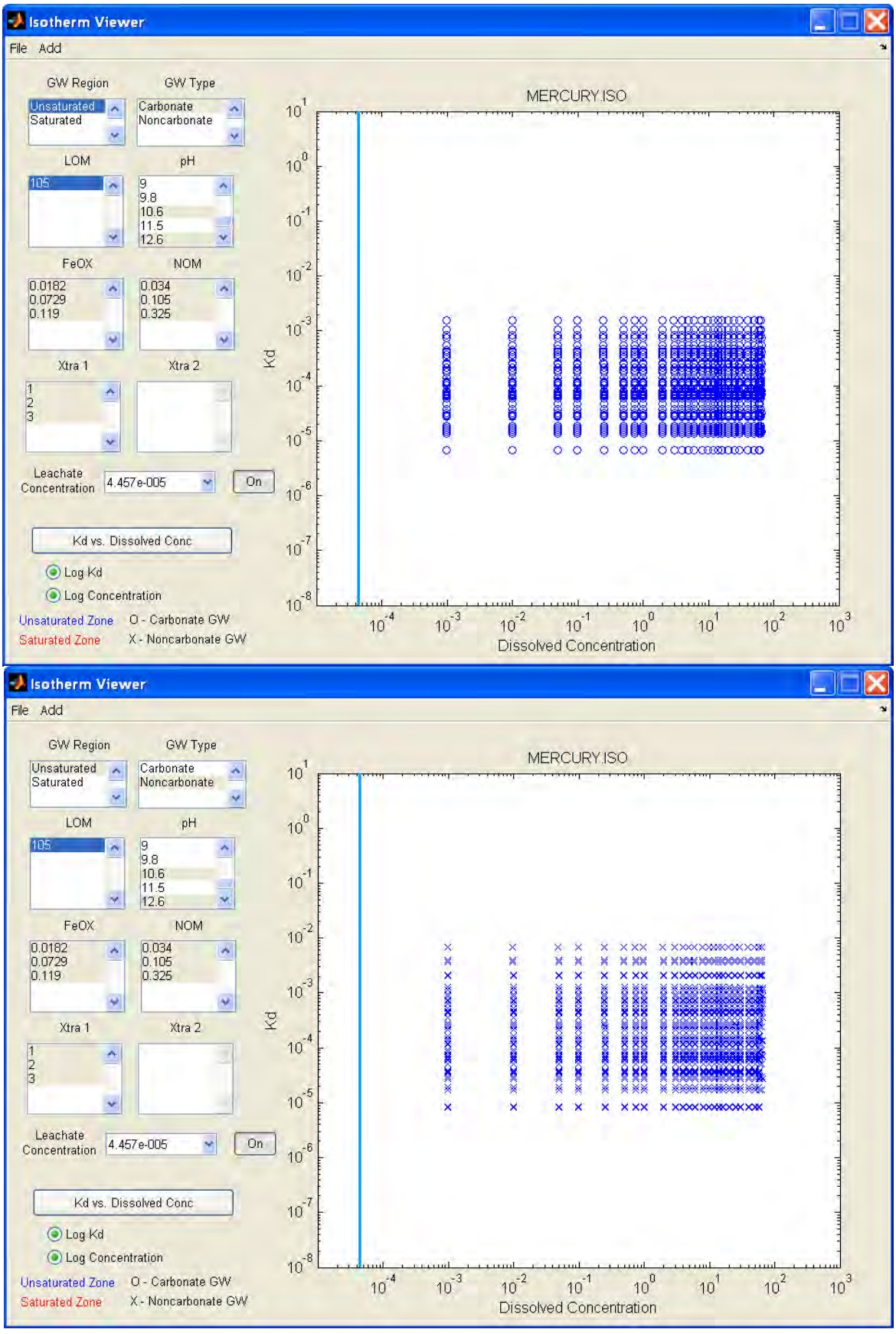


Figure H-2-16. Mercury unsaturated zone nonlinear sorption isotherms for LFs.

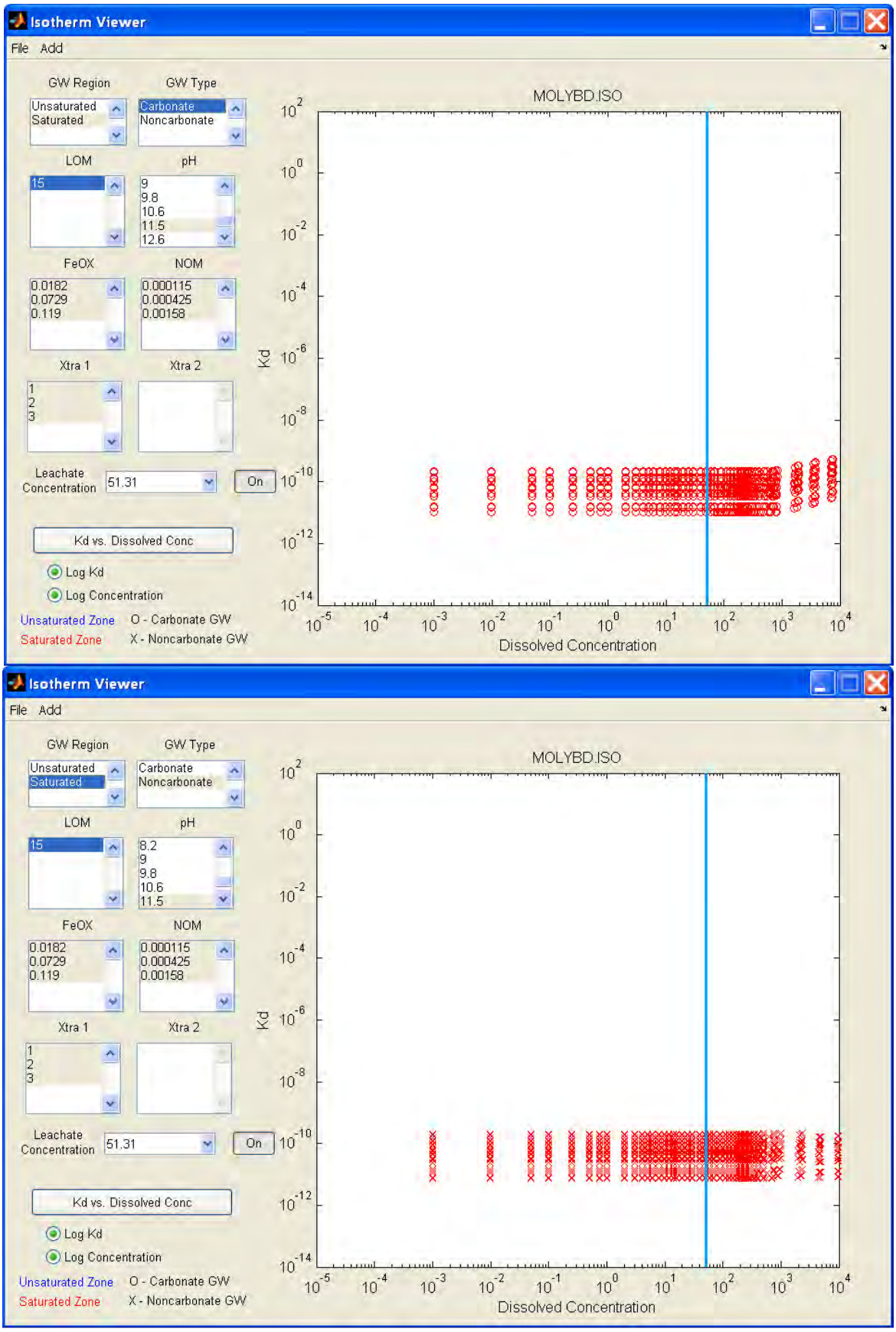


Figure H-2-17. Molybdenum saturated zone nonlinear sorption isotherms for LFs.

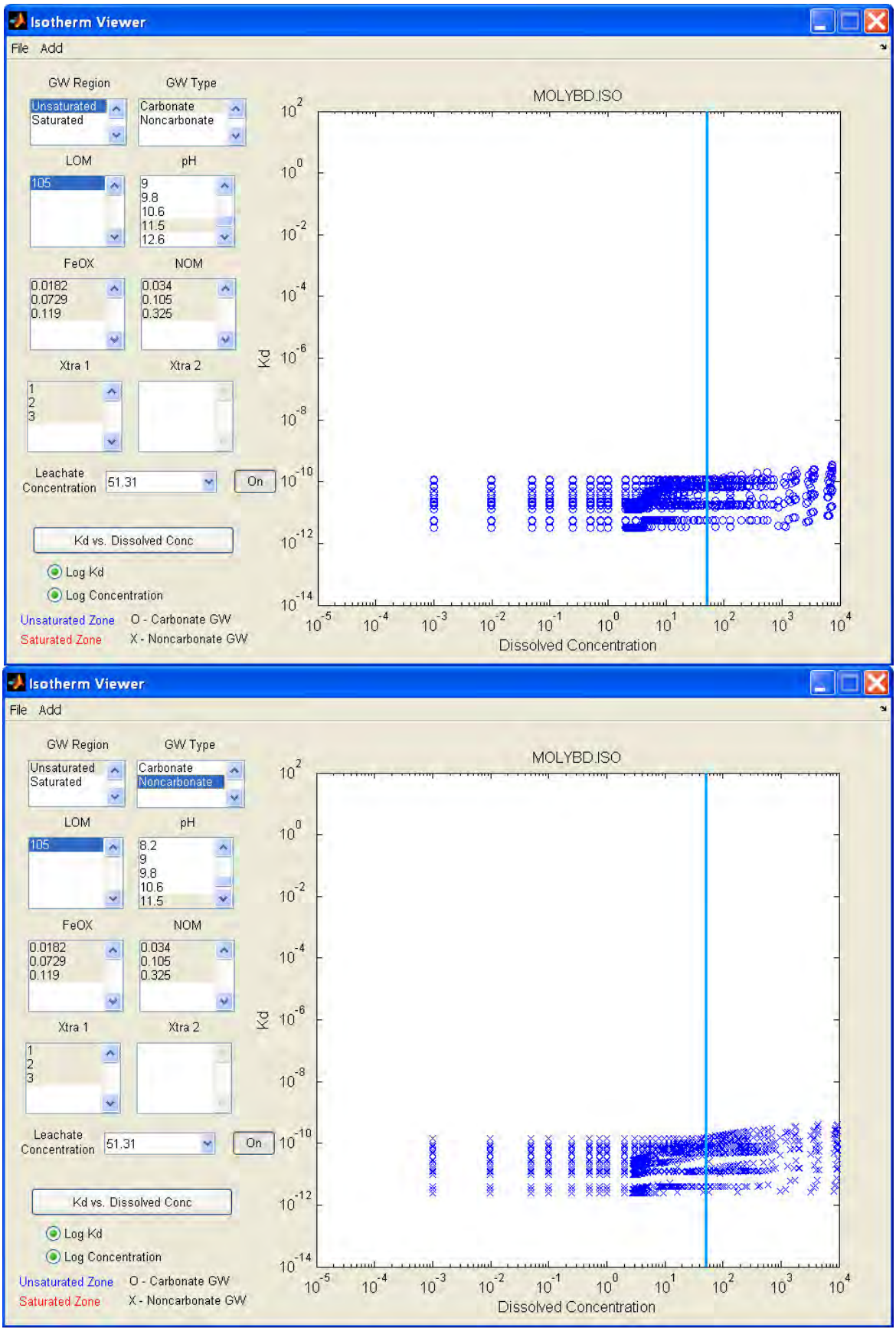


Figure H-2-18. Molybdenum unsaturated zone nonlinear sorption isotherms for LFs.

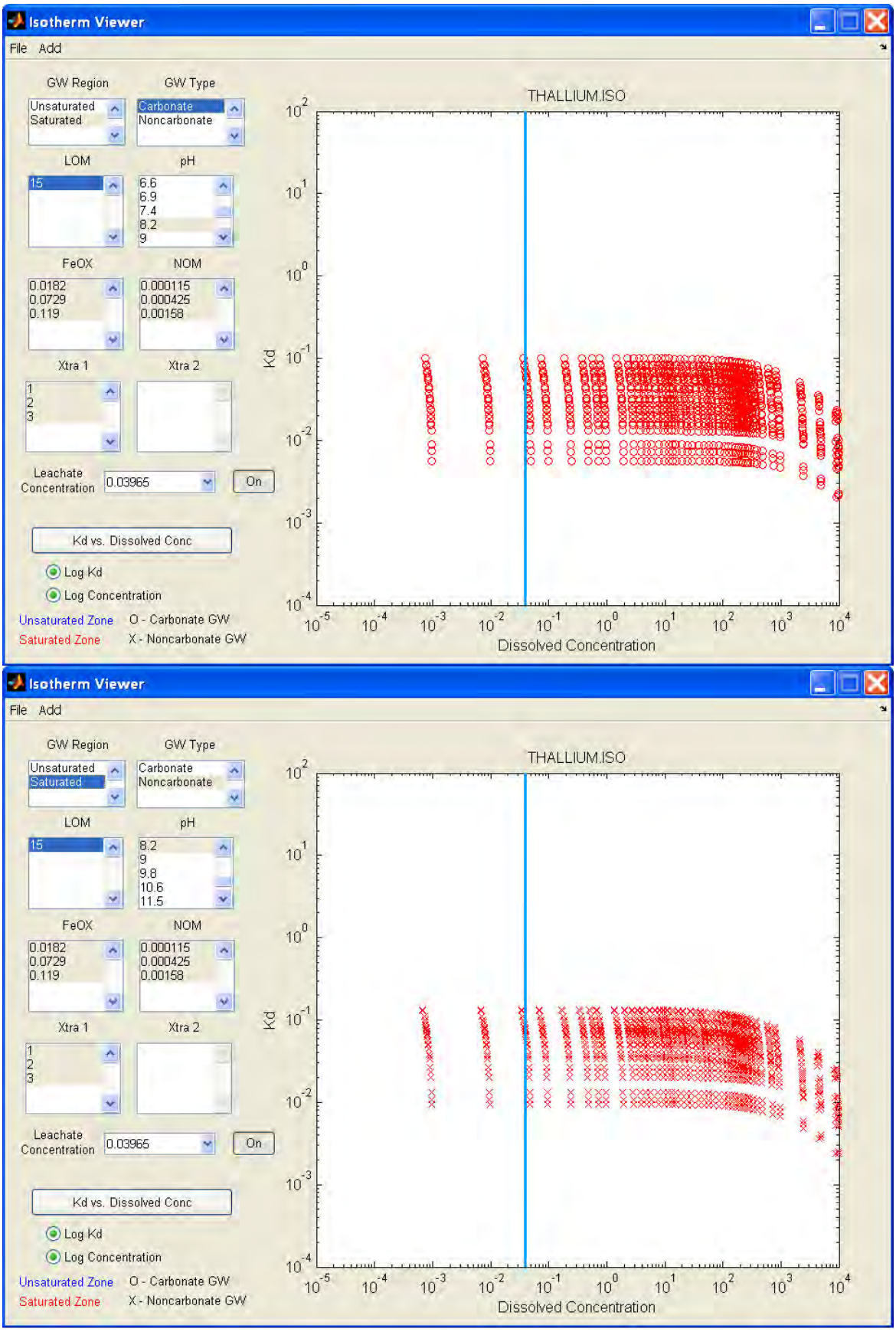
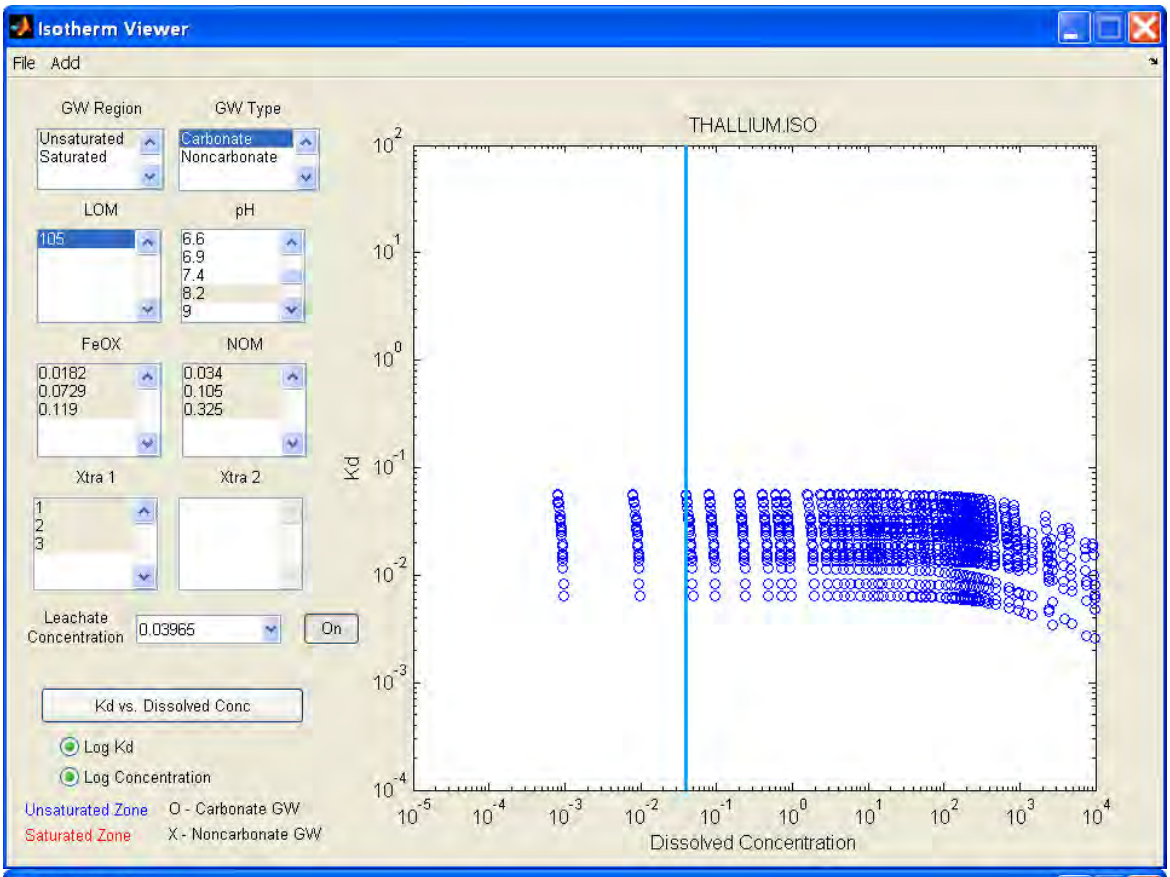


Figure H-2-19. Thallium saturated zone nonlinear sorption isotherms for LFs.



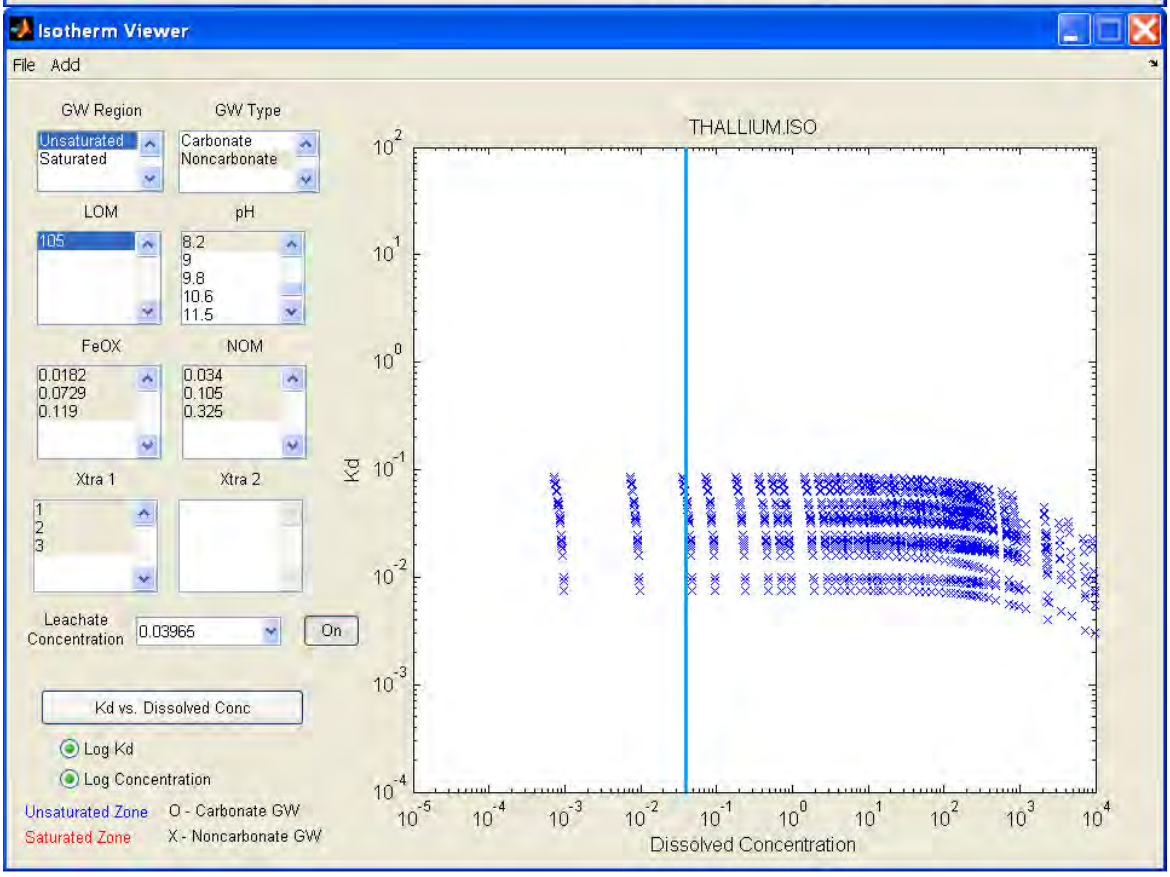


Figure H-2-20. Thallium unsaturated zone nonlinear sorption isotherms for LFs.

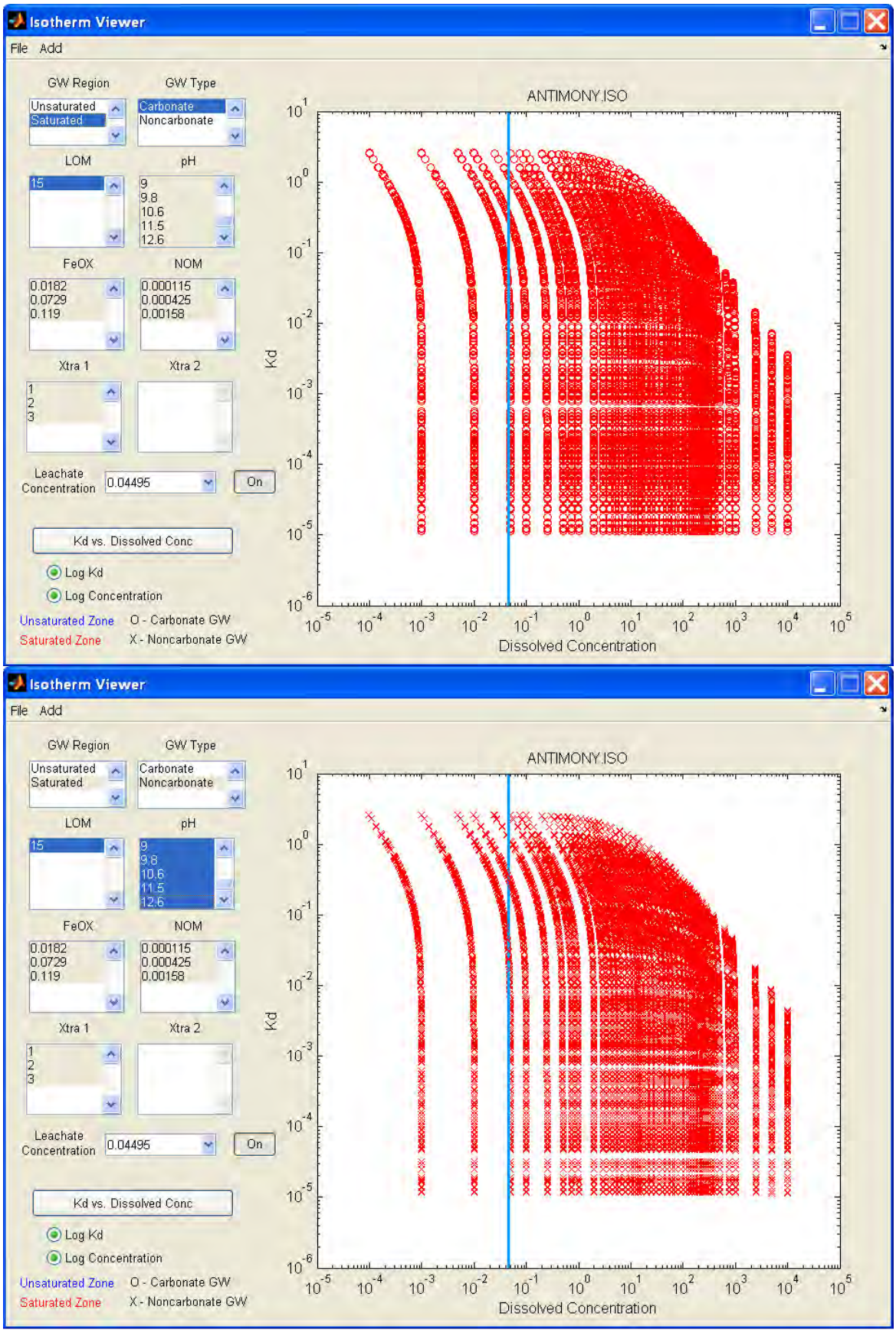


Figure H-2-21. Antimony saturated zone nonlinear sorption isotherms for SIs.

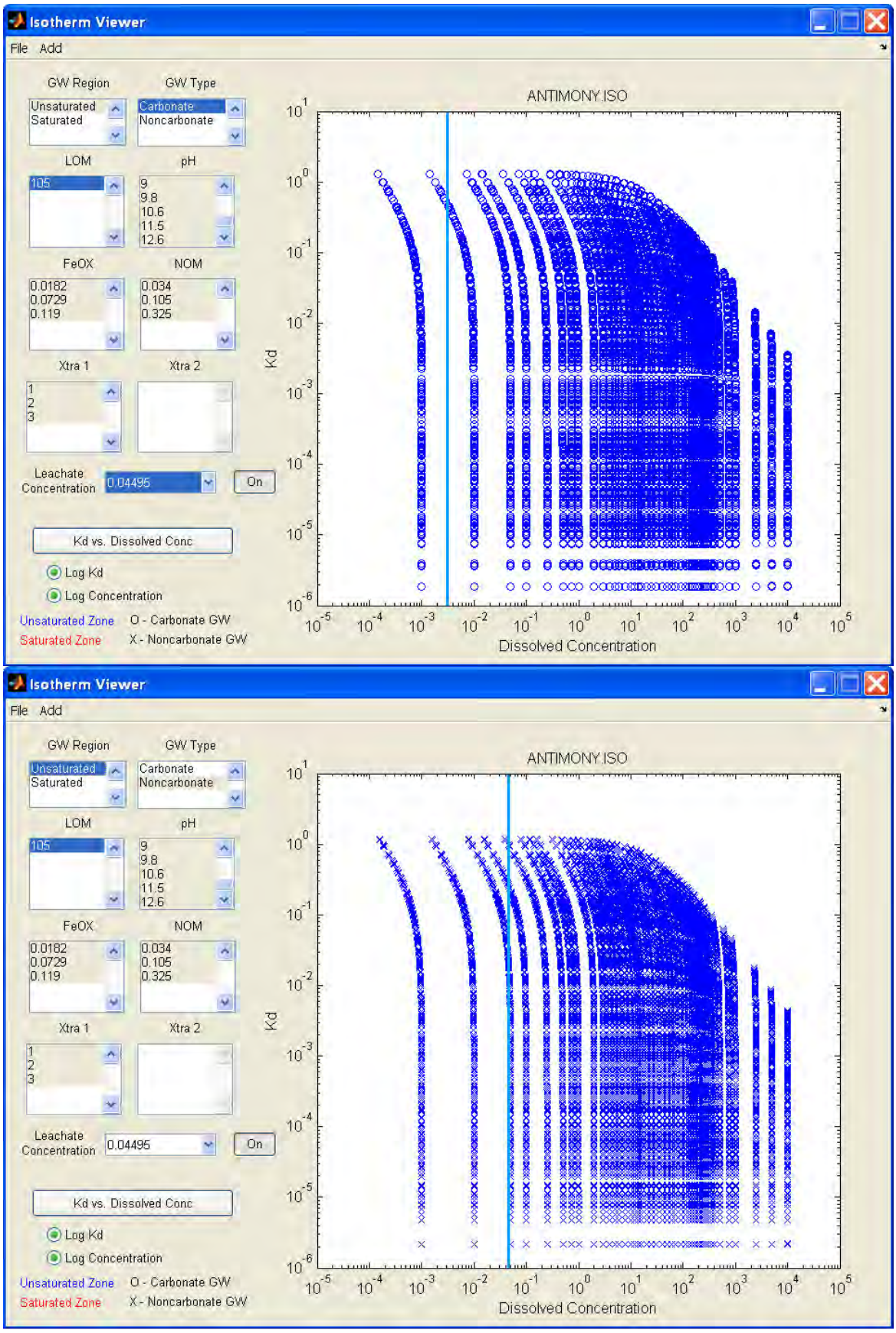
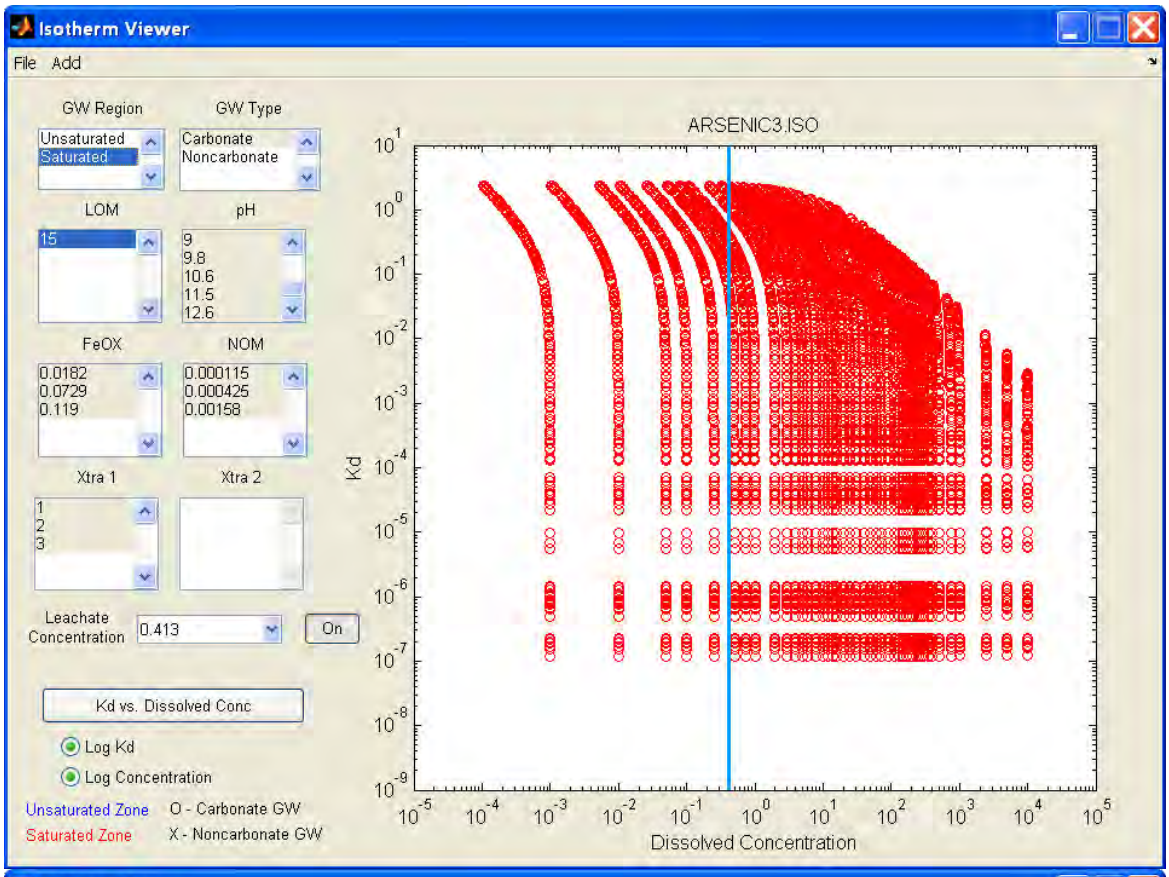


Figure H-2-22. Antimony unsaturated zone nonlinear sorption isotherms for SIs.



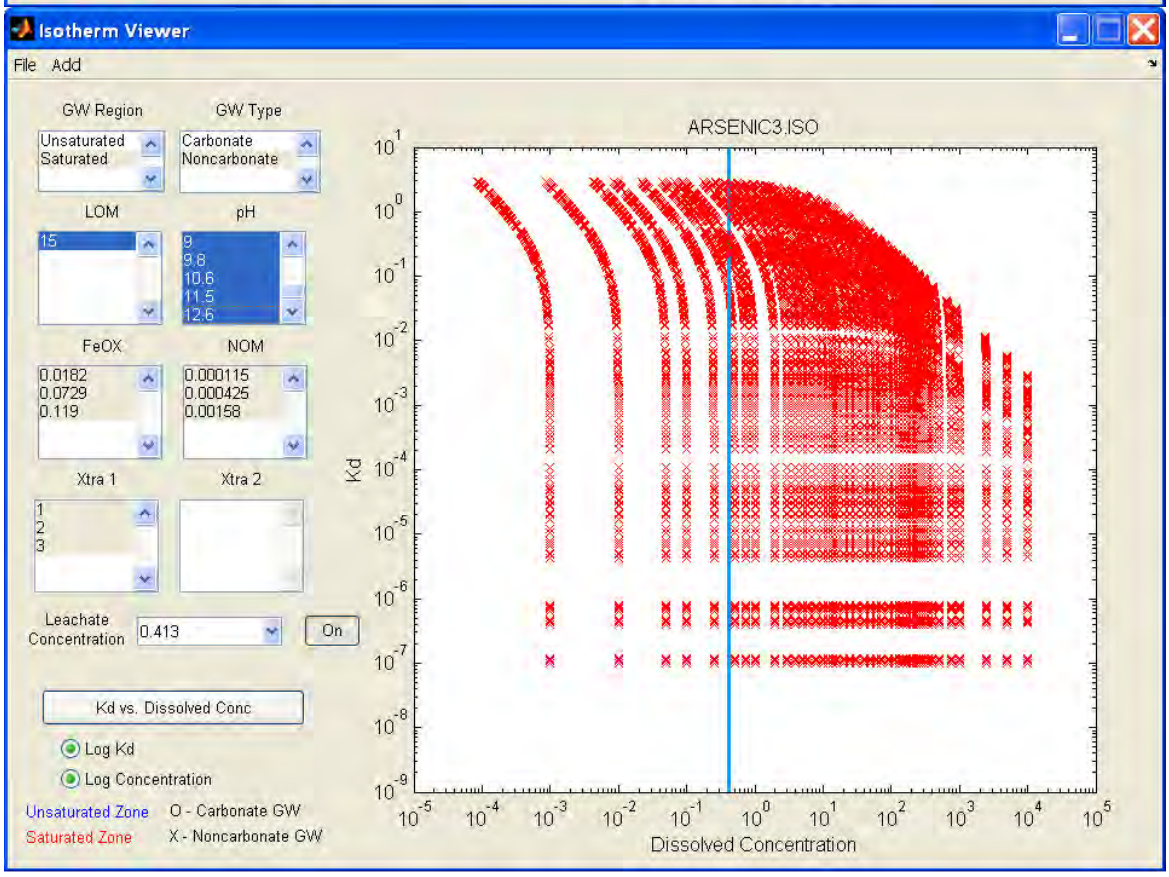


Figure H-2-23. Arsenic III saturated zone nonlinear sorption isotherms for SIs.

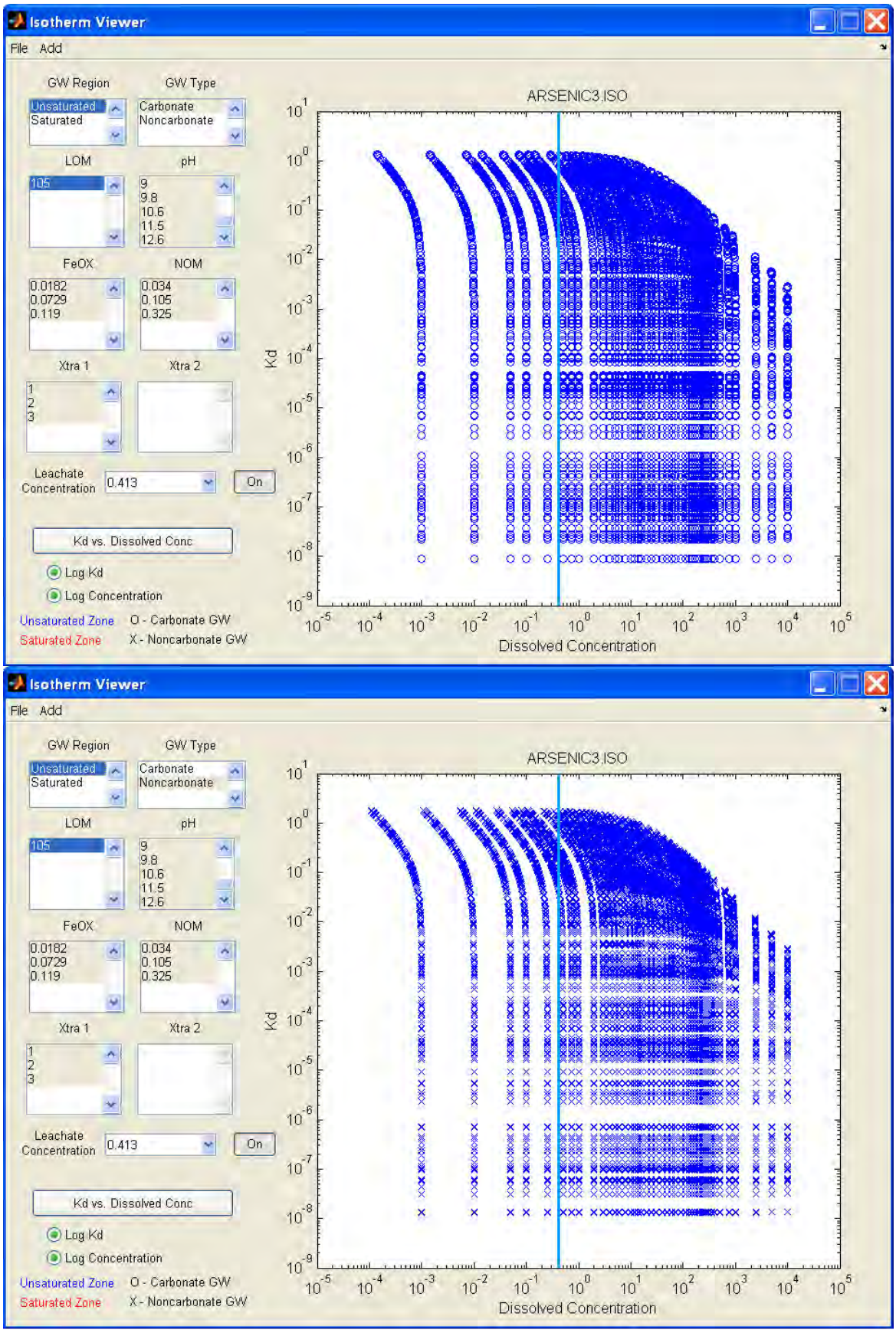


Figure H-2-24. Arsenic unsaturated zone nonlinear sorption isotherms for SIs.

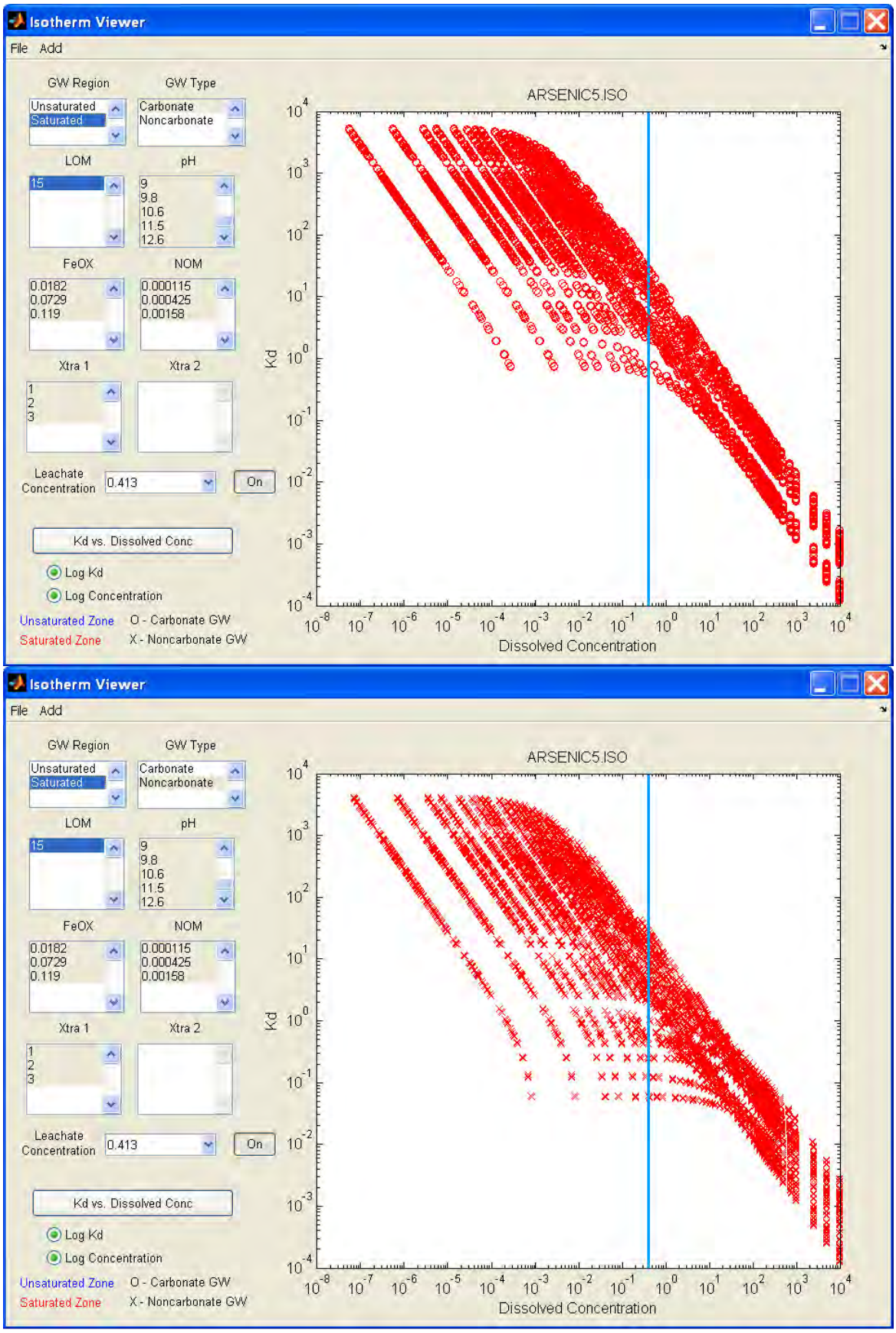


Figure H-2-25. Arsenic V saturated zone nonlinear sorption isotherms for SIs.

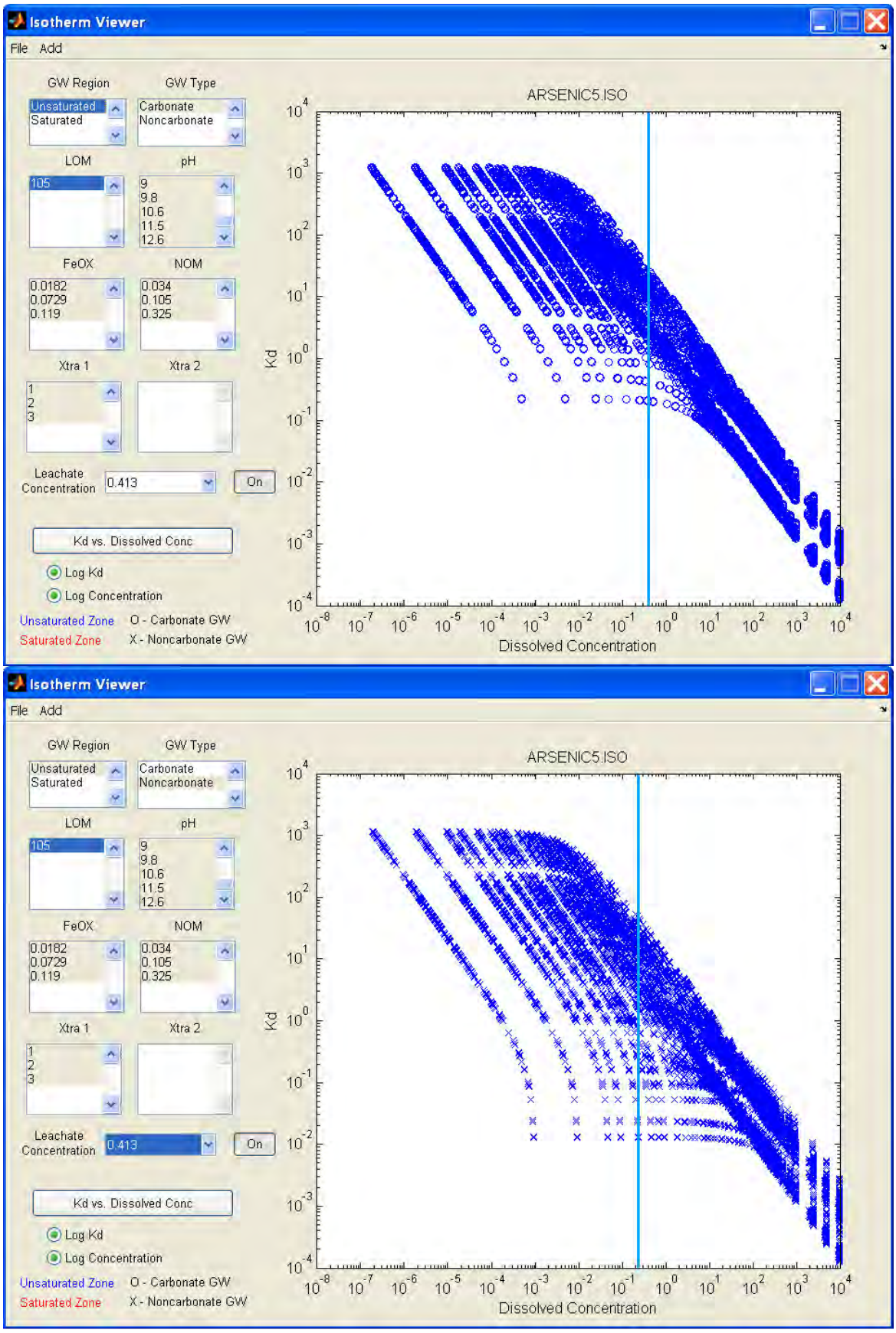


Figure H-2-26 Arsenic V unsaturated zone nonlinear sorption isotherms for SIs.

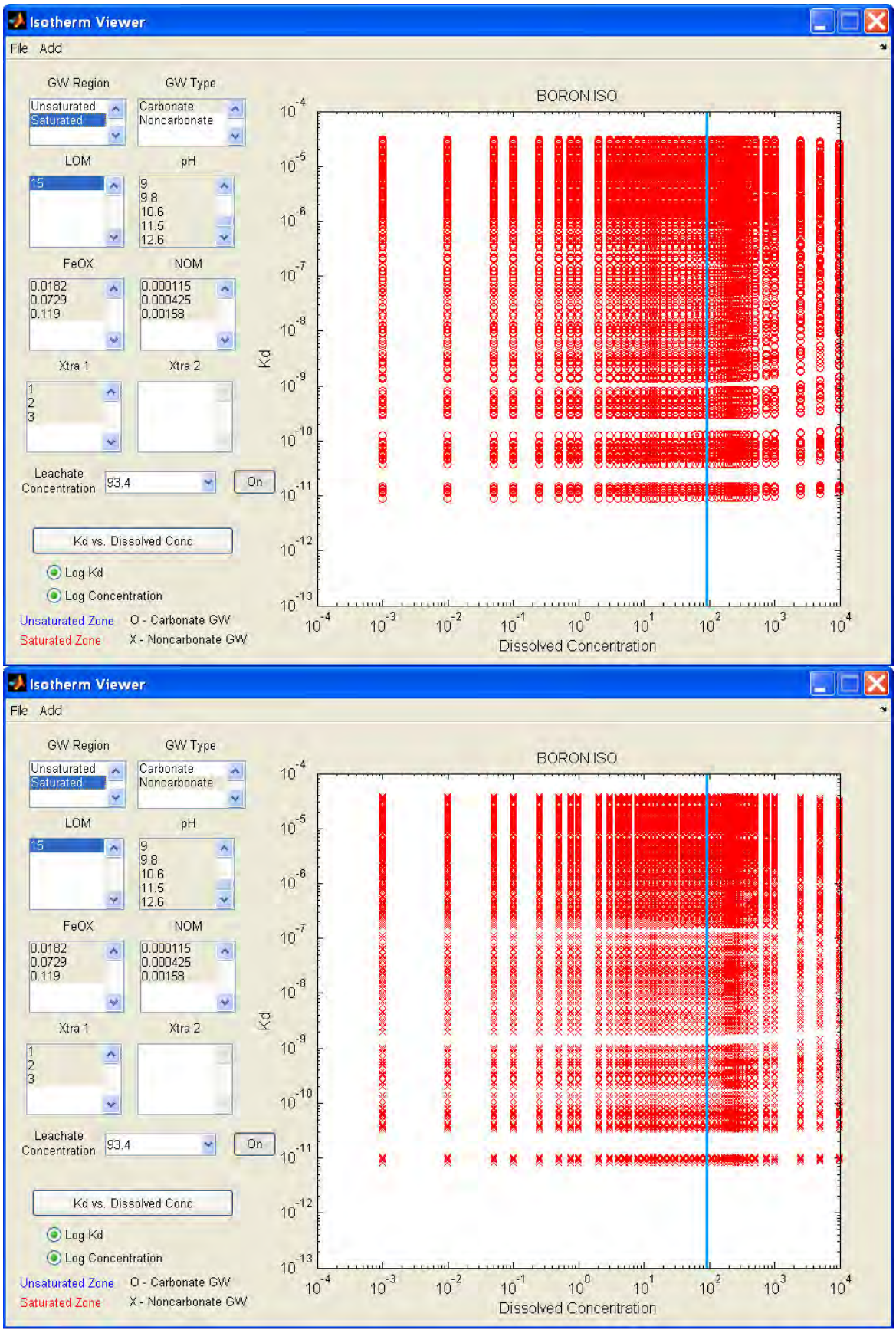


Figure H-2-27. Boron saturated zone nonlinear sorption isotherms for SIs.

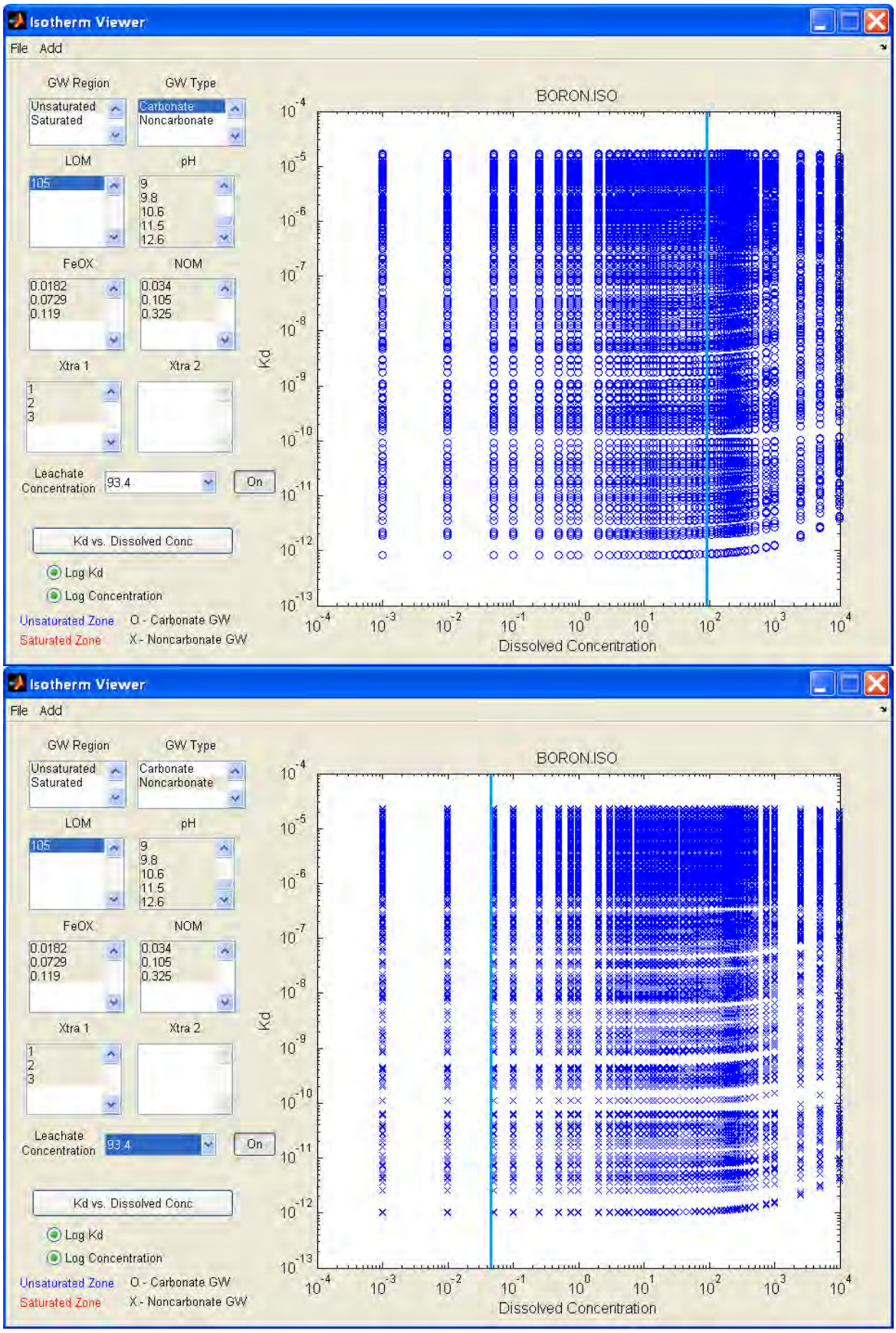


Figure H-2-28. Boron unsaturated zone nonlinear sorption isotherms for SIs.

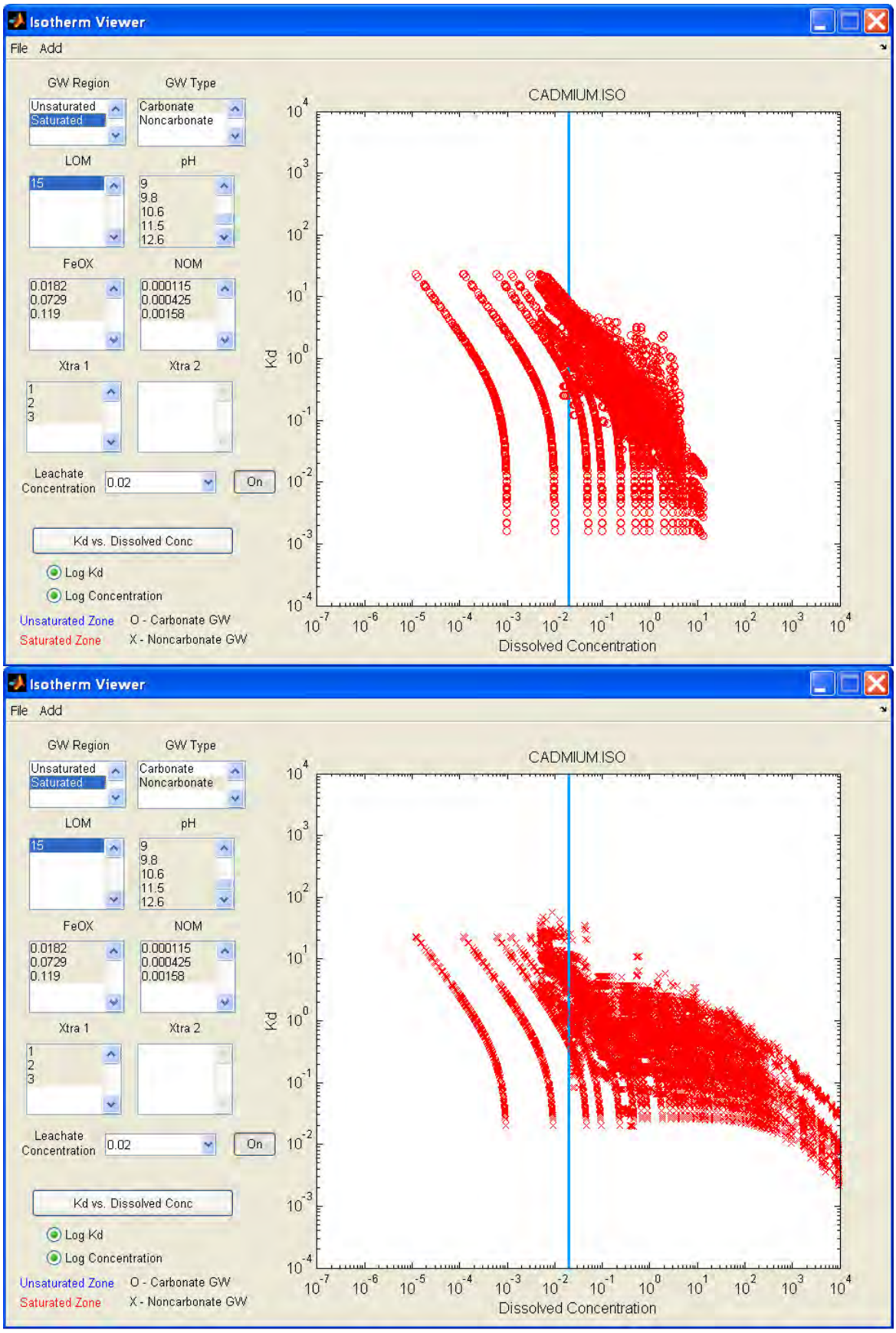


Figure H-2-29. Cadmium saturated zone nonlinear sorption isotherms for SIs.

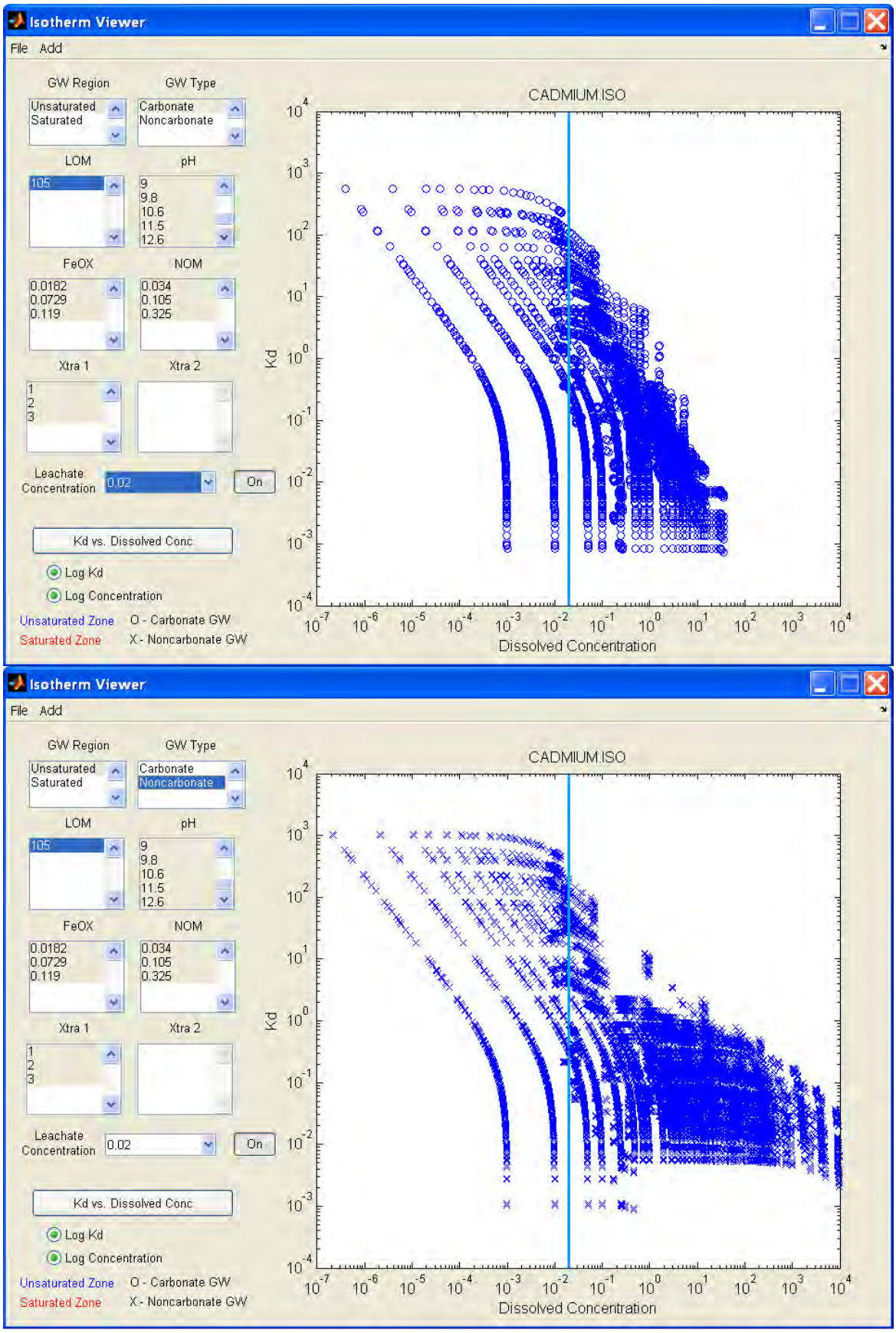
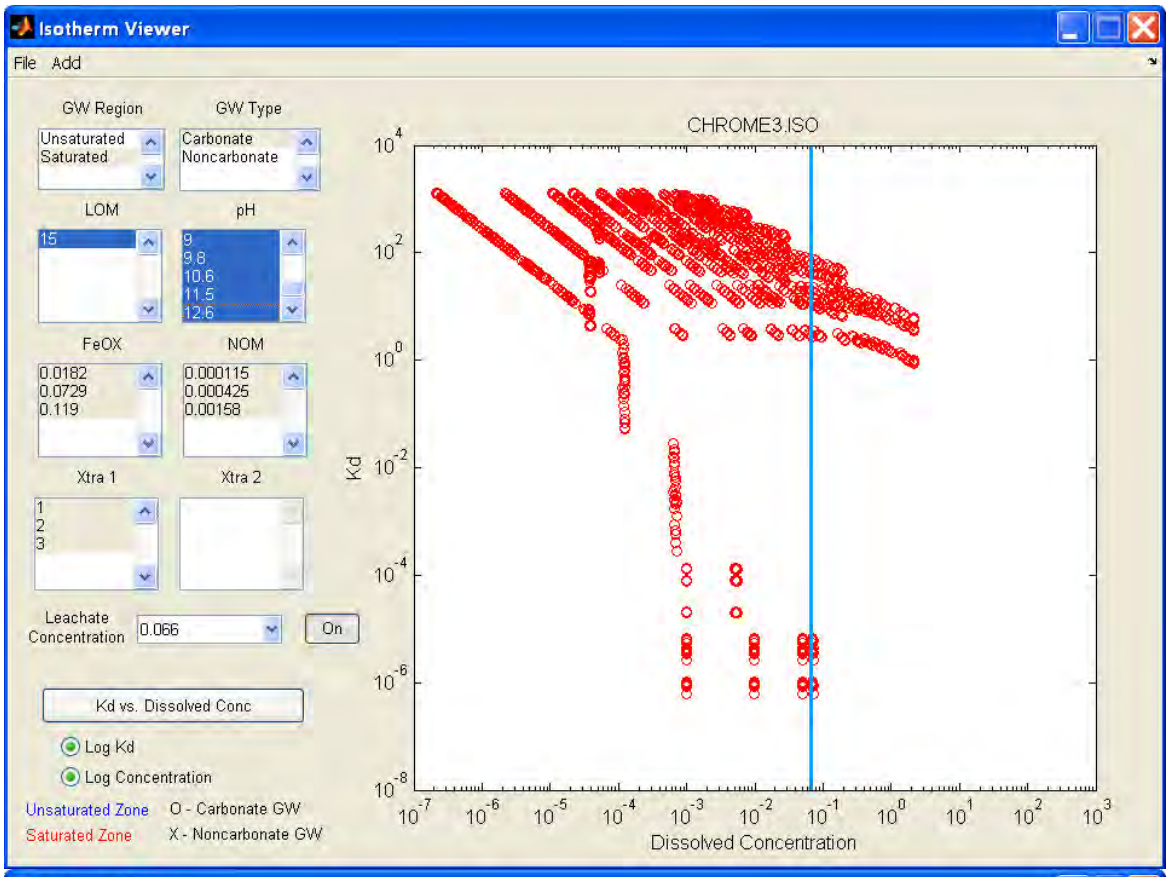


Figure H-2-30. Cadmium unsaturated zone nonlinear sorption isotherms for SIs.



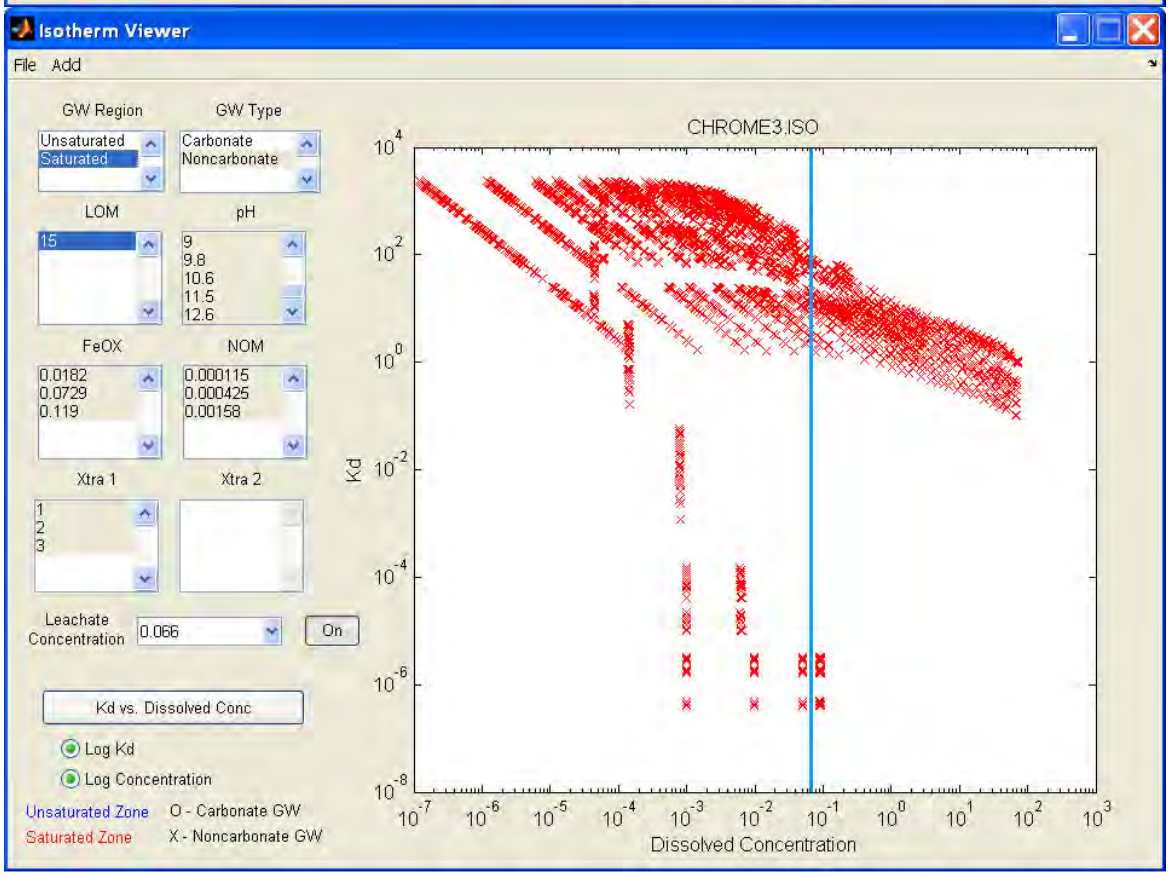


Figure H-2-31. Chromium III saturated zone nonlinear sorption isotherms for SIs.

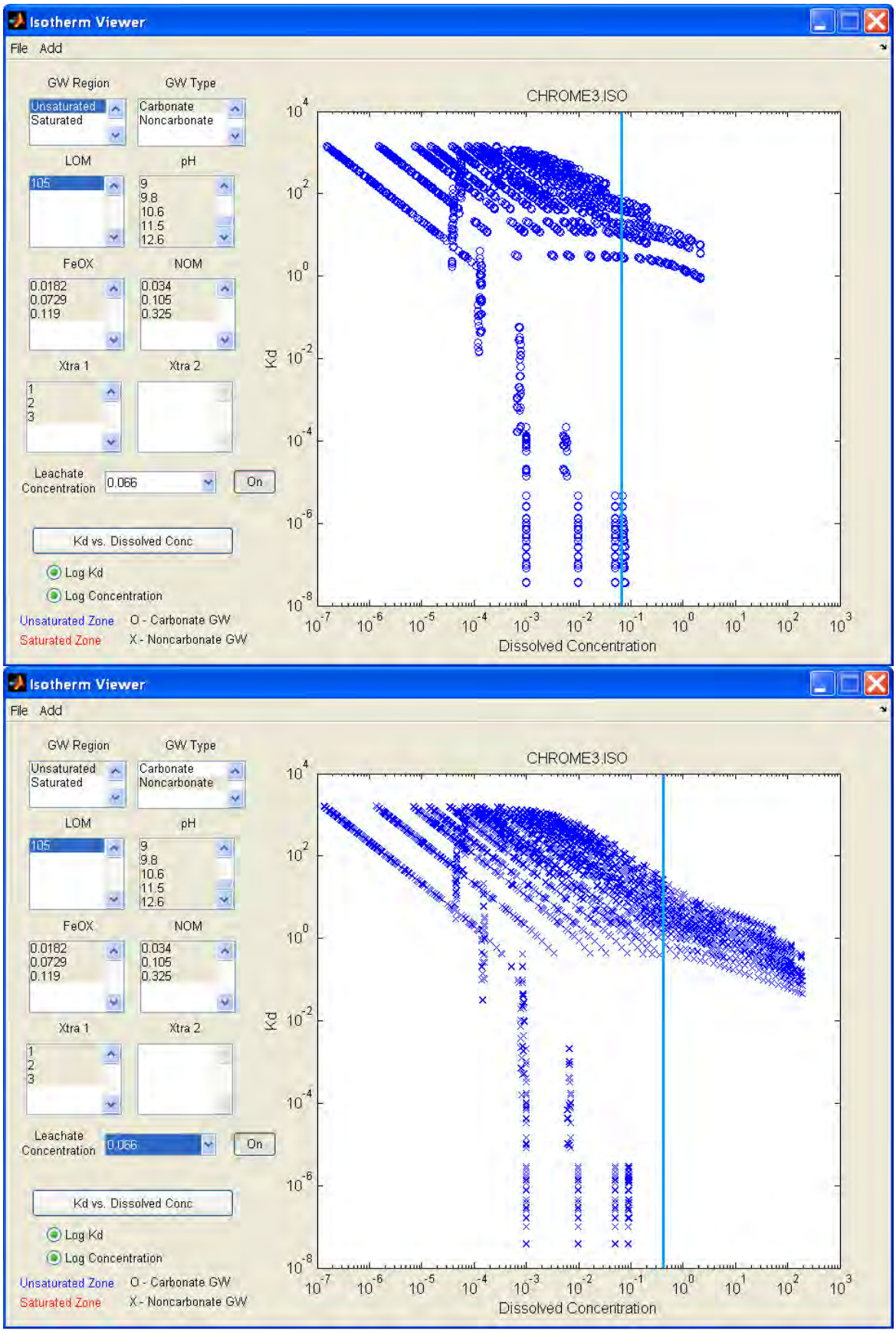
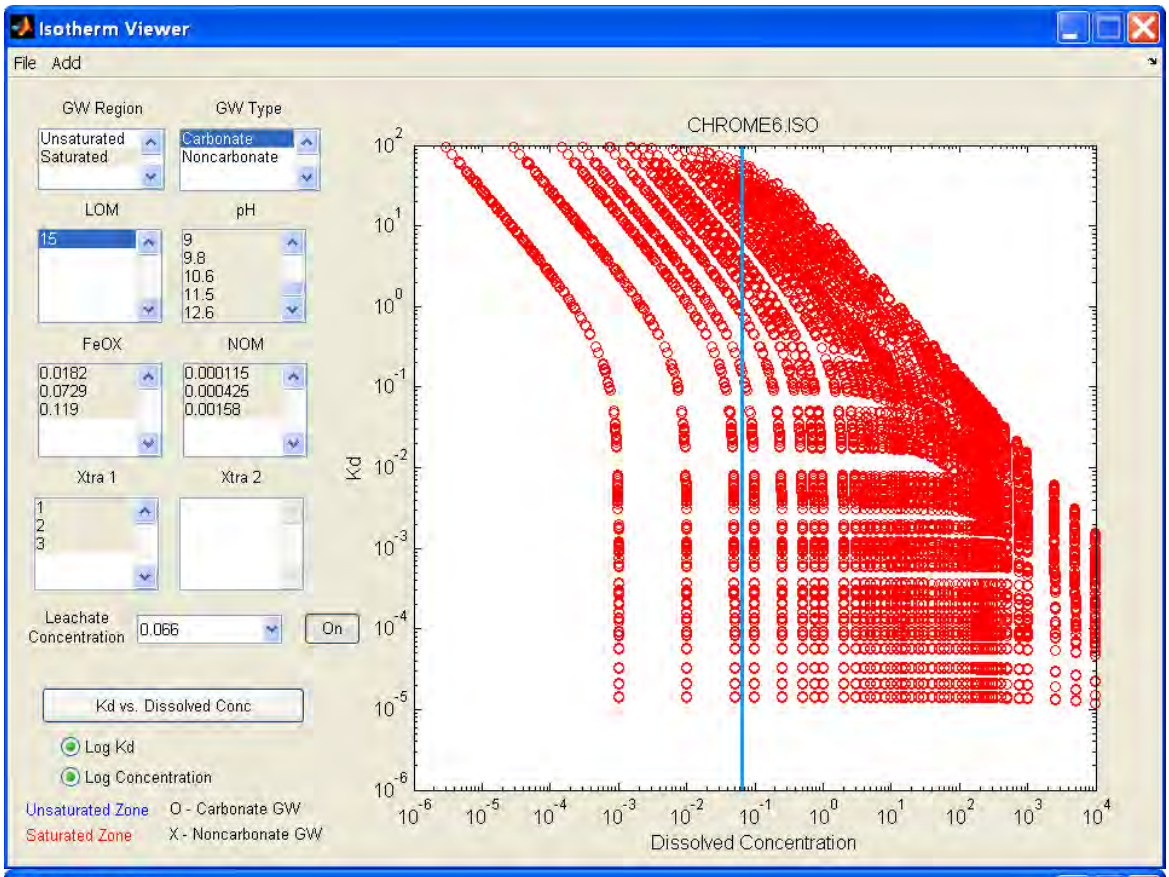


Figure H-2-32. Chromium III unsaturated zone nonlinear sorption isotherms for SIs.



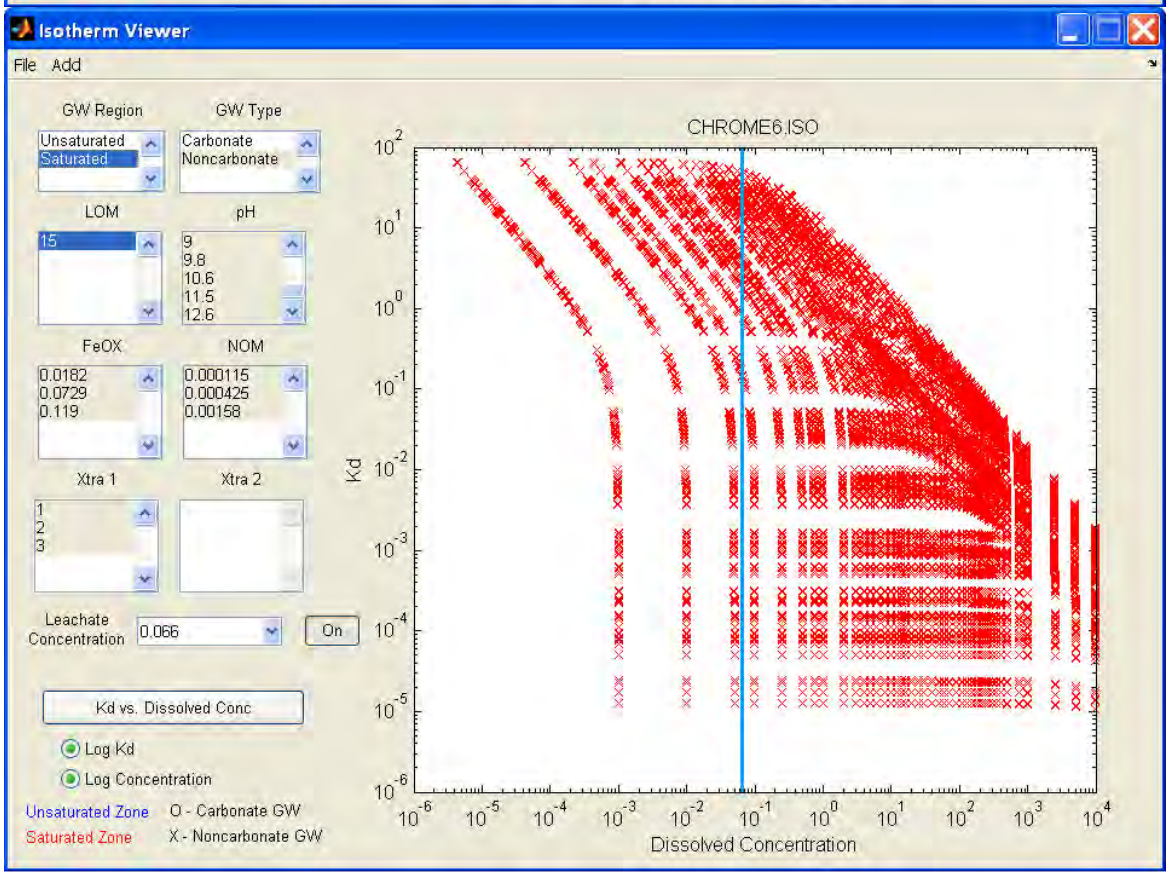


Figure H-2-33. Chromium VI saturated zone nonlinear sorption isotherms for SIs.

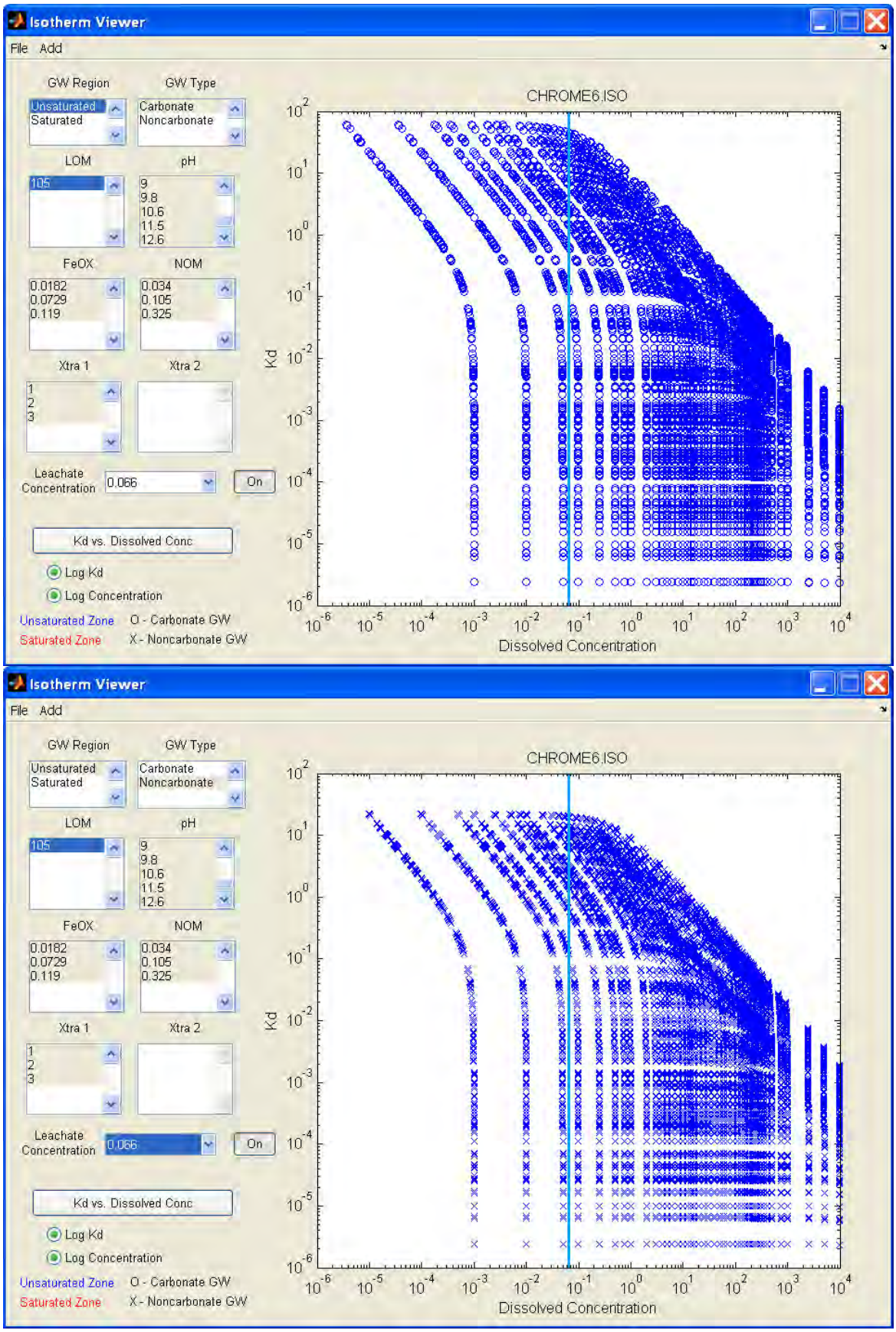


Figure H-2-34. Chromium VI unsaturated zone nonlinear sorption isotherms for SIs.

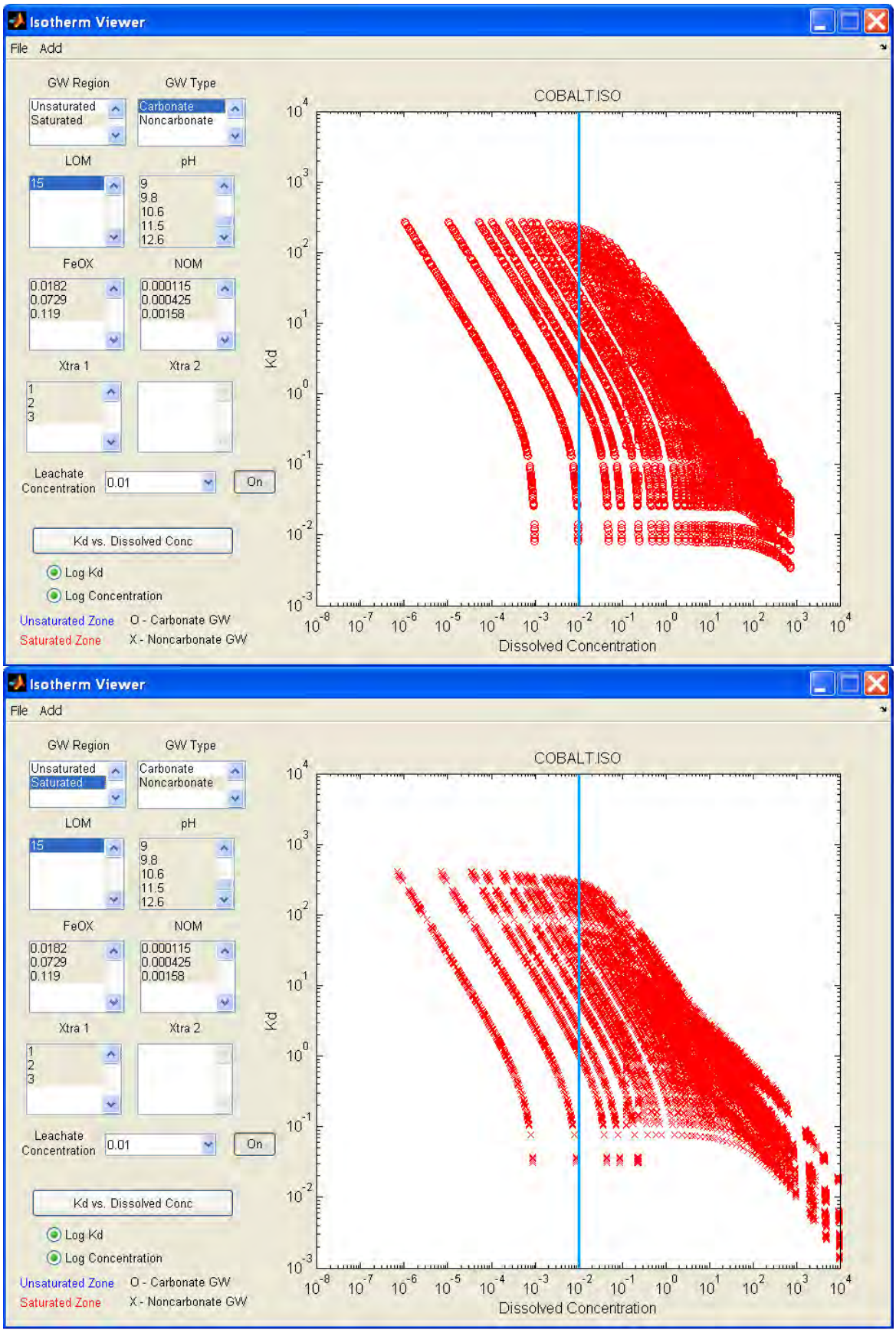


Figure H-2-35. Cobalt saturated zone nonlinear sorption isotherms for SIs.

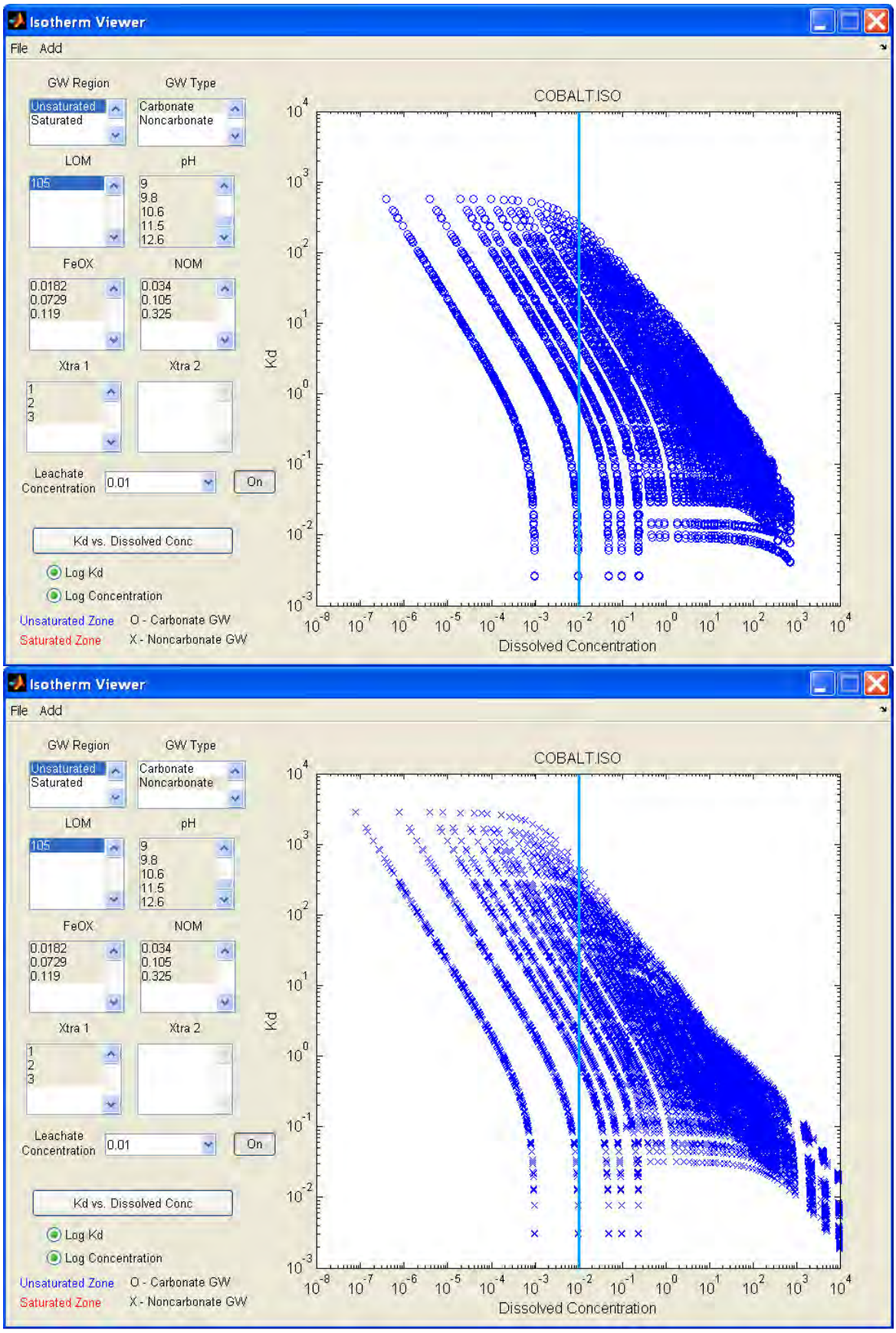


Figure H-2-36. Cobalt unsaturated zone nonlinear sorption isotherms for SIs.

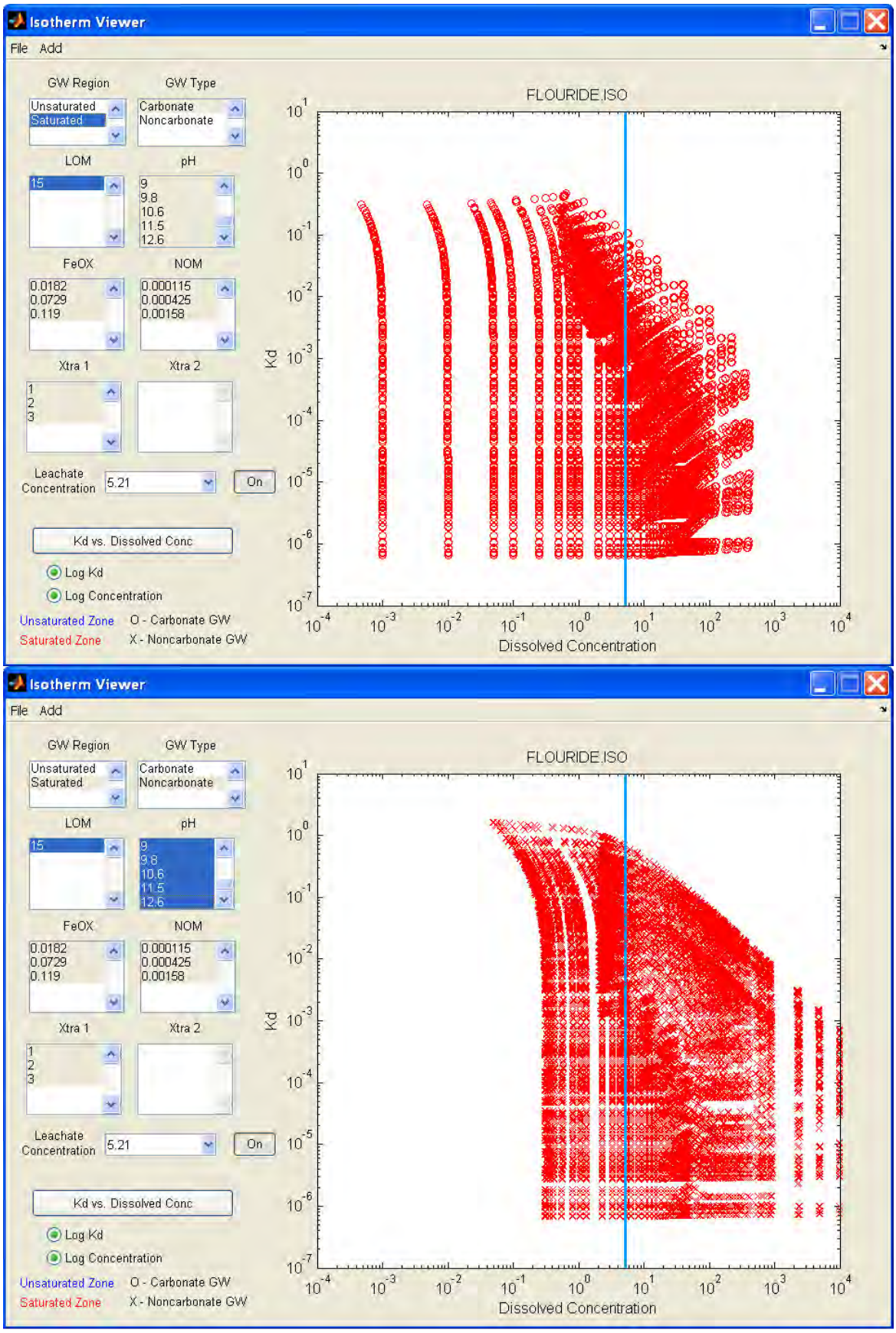


Figure H-2-37. Fluoride saturated zone nonlinear sorption isotherms for SIs.

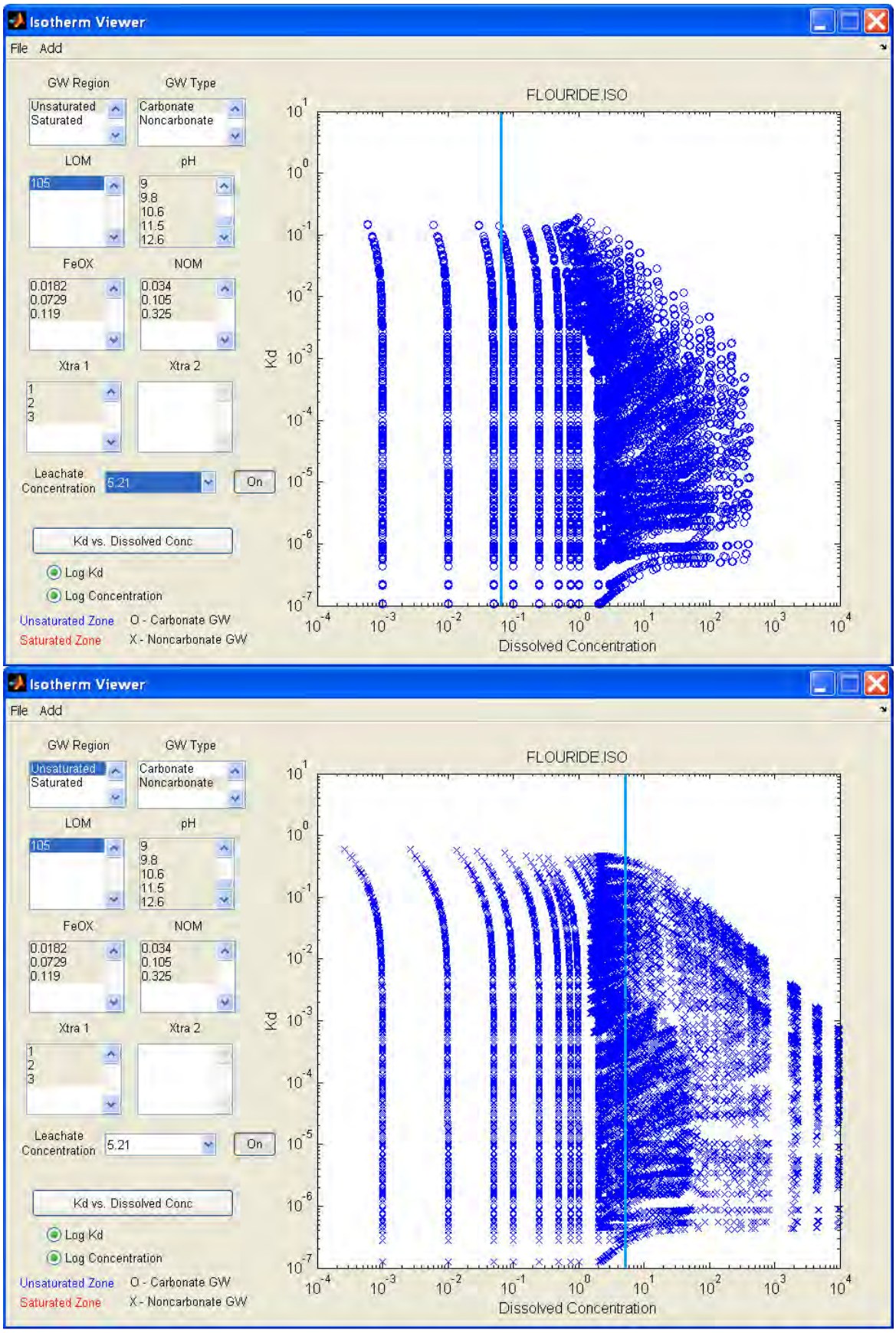


Figure H-2-38. Fluoride unsaturated zone nonlinear sorption isotherms for SIs.

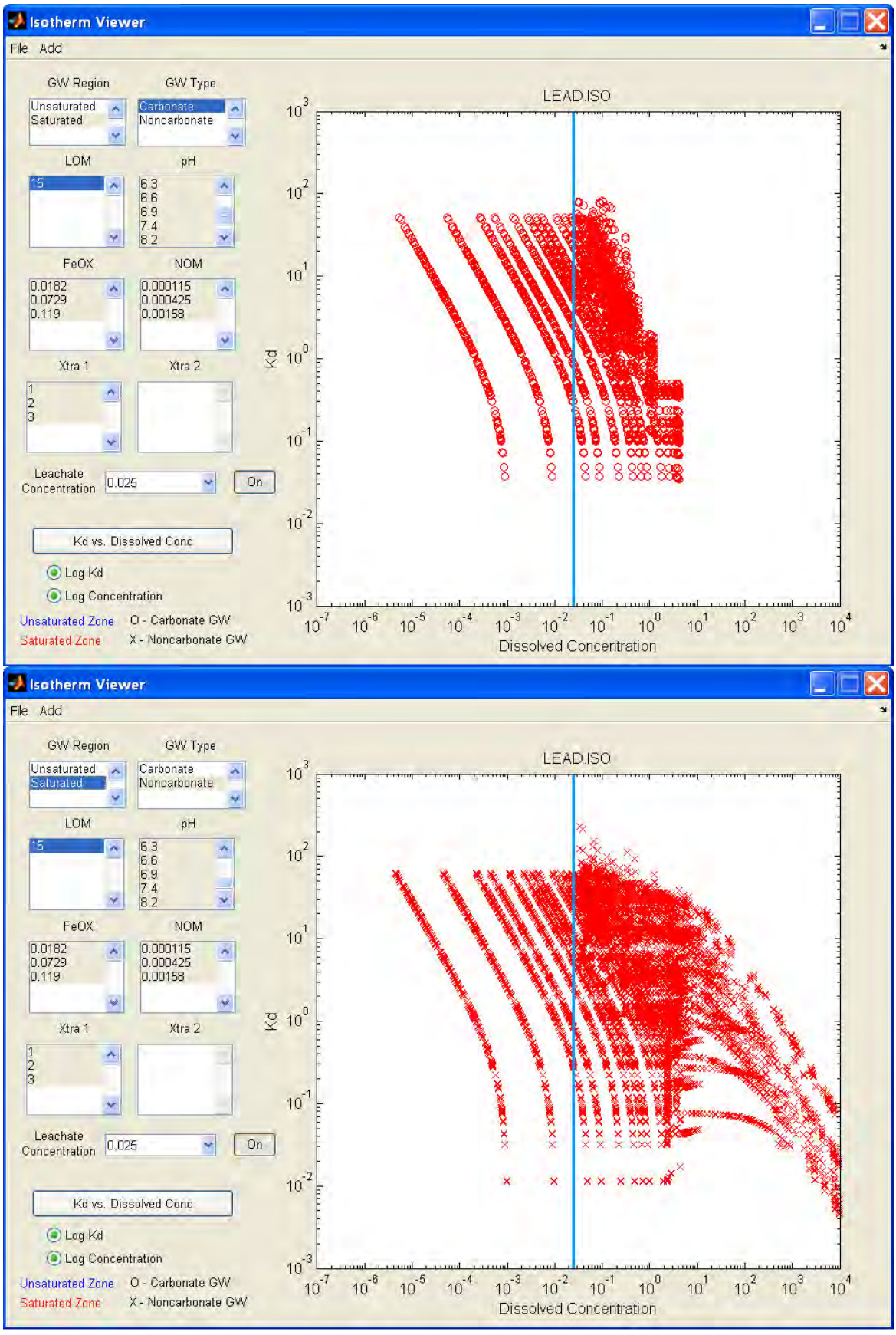
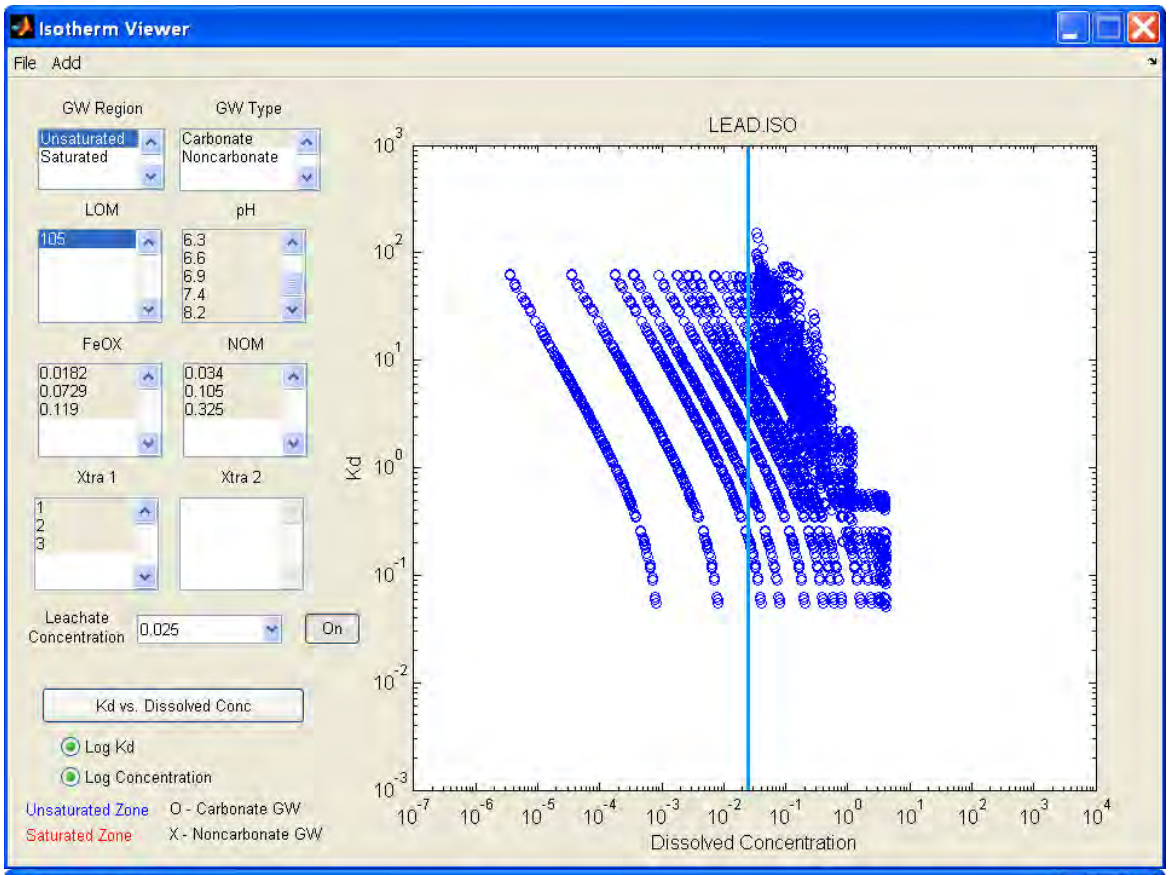


Figure H-2-39. Lead saturated zone nonlinear sorption isotherms for SIs.



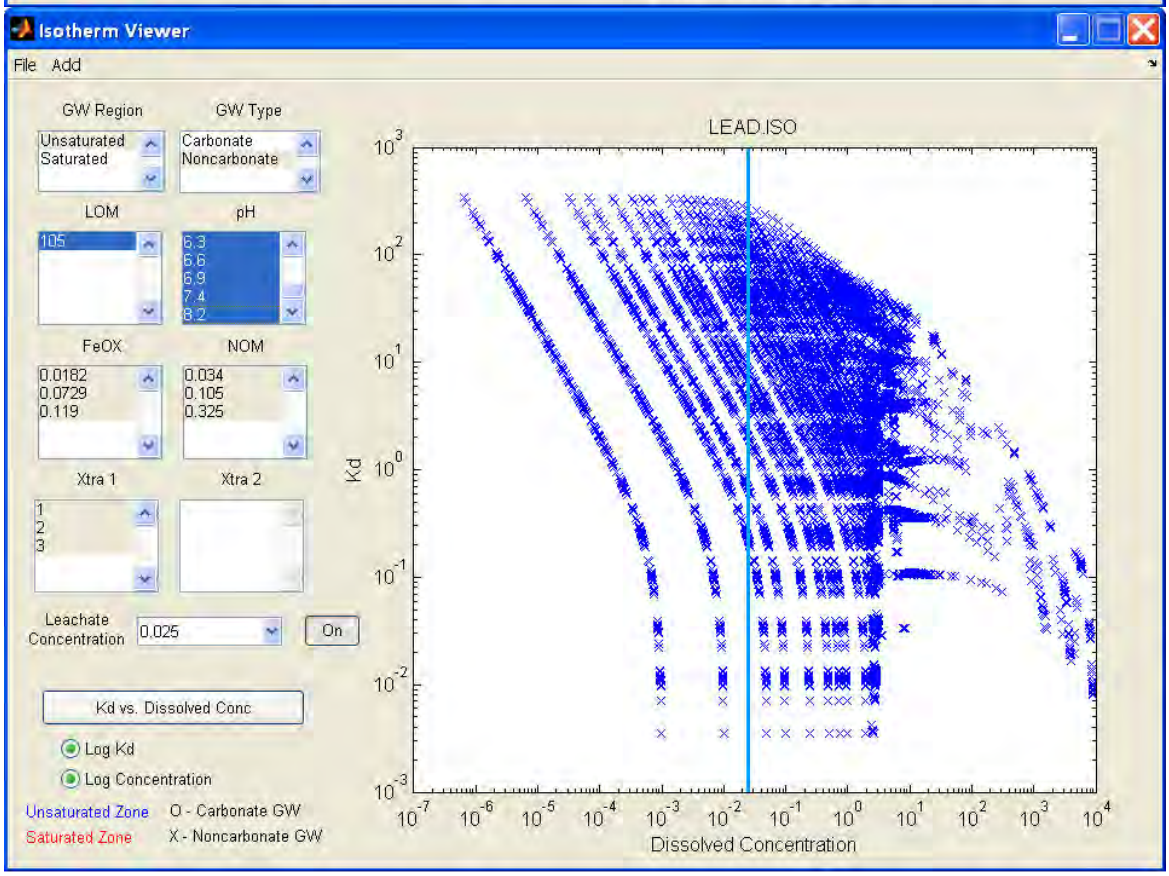
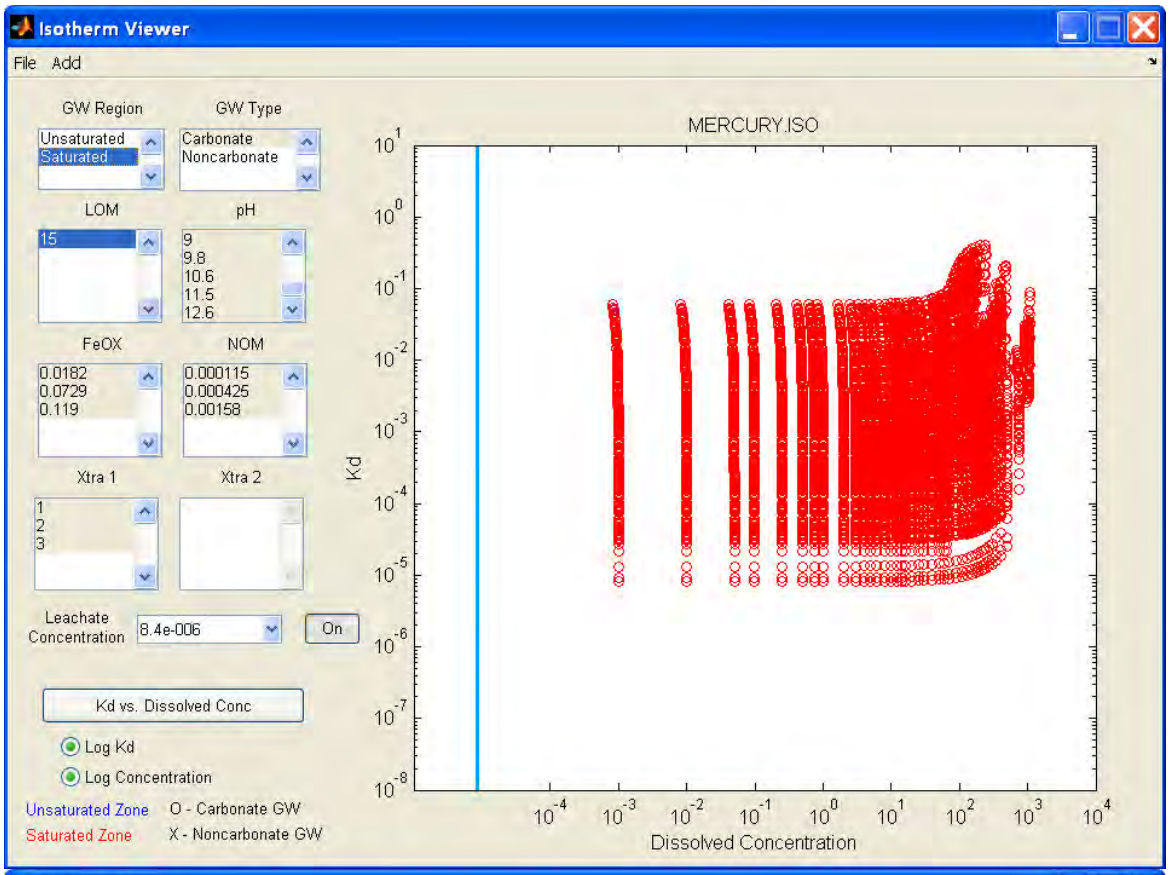


Figure H-2-40. Lead unsaturated zone nonlinear sorption isotherms for SIs.



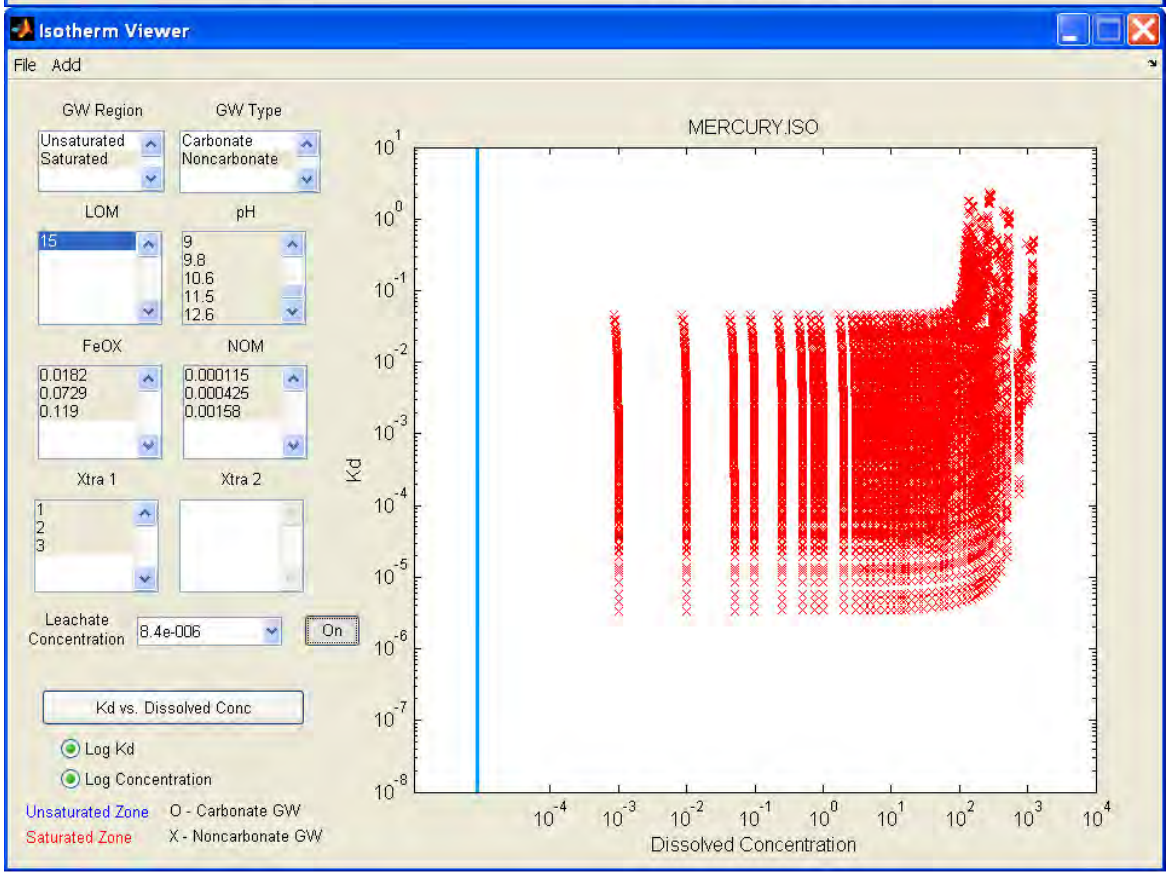


Figure H-2-40. Mercury saturated zone nonlinear sorption isotherms for SIs.

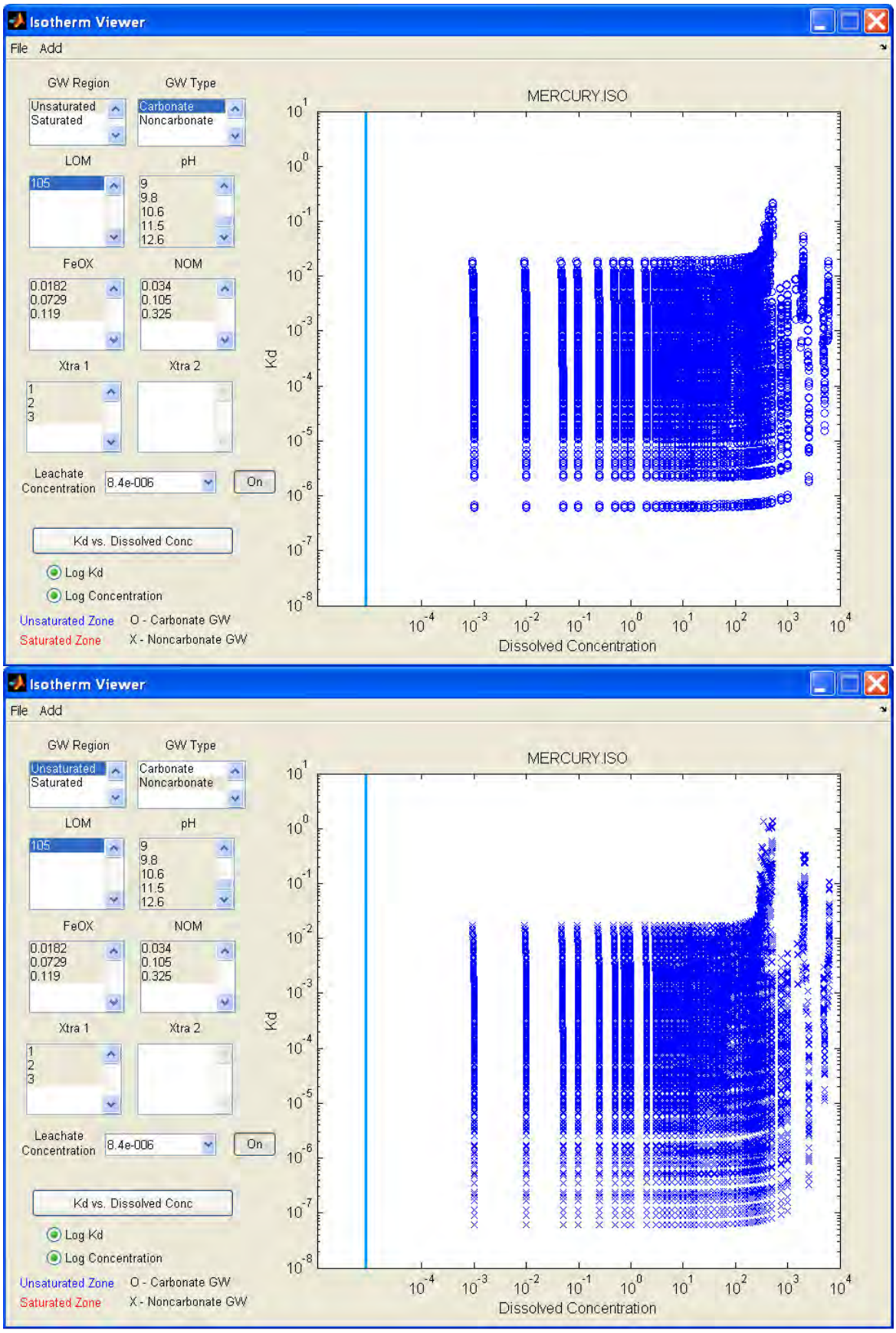


Figure H-2-40. Mercury unsaturated zone nonlinear sorption isotherms for SIs.

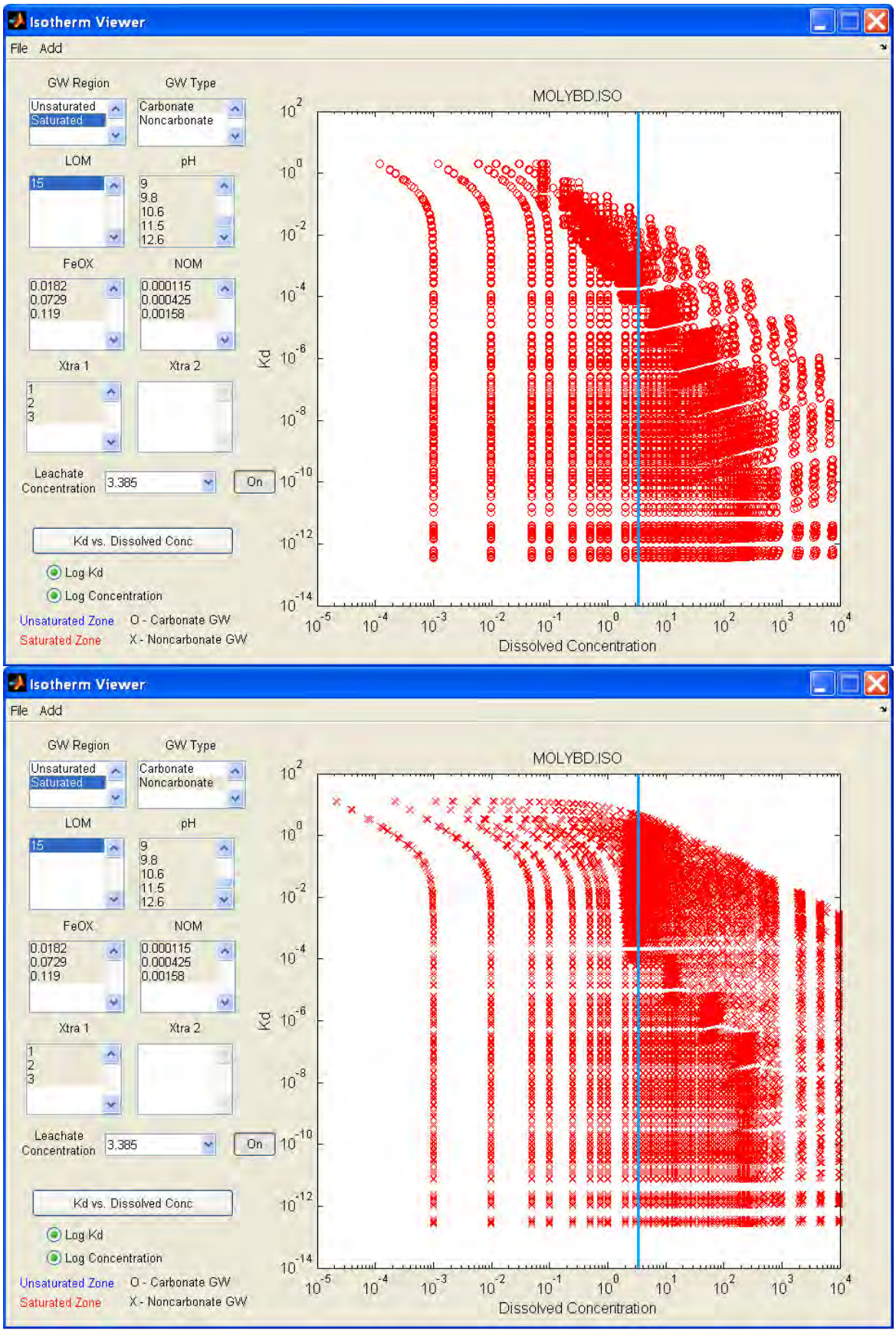


Figure H-2-41. Molybdenum saturated zone nonlinear sorption isotherms for SIs.

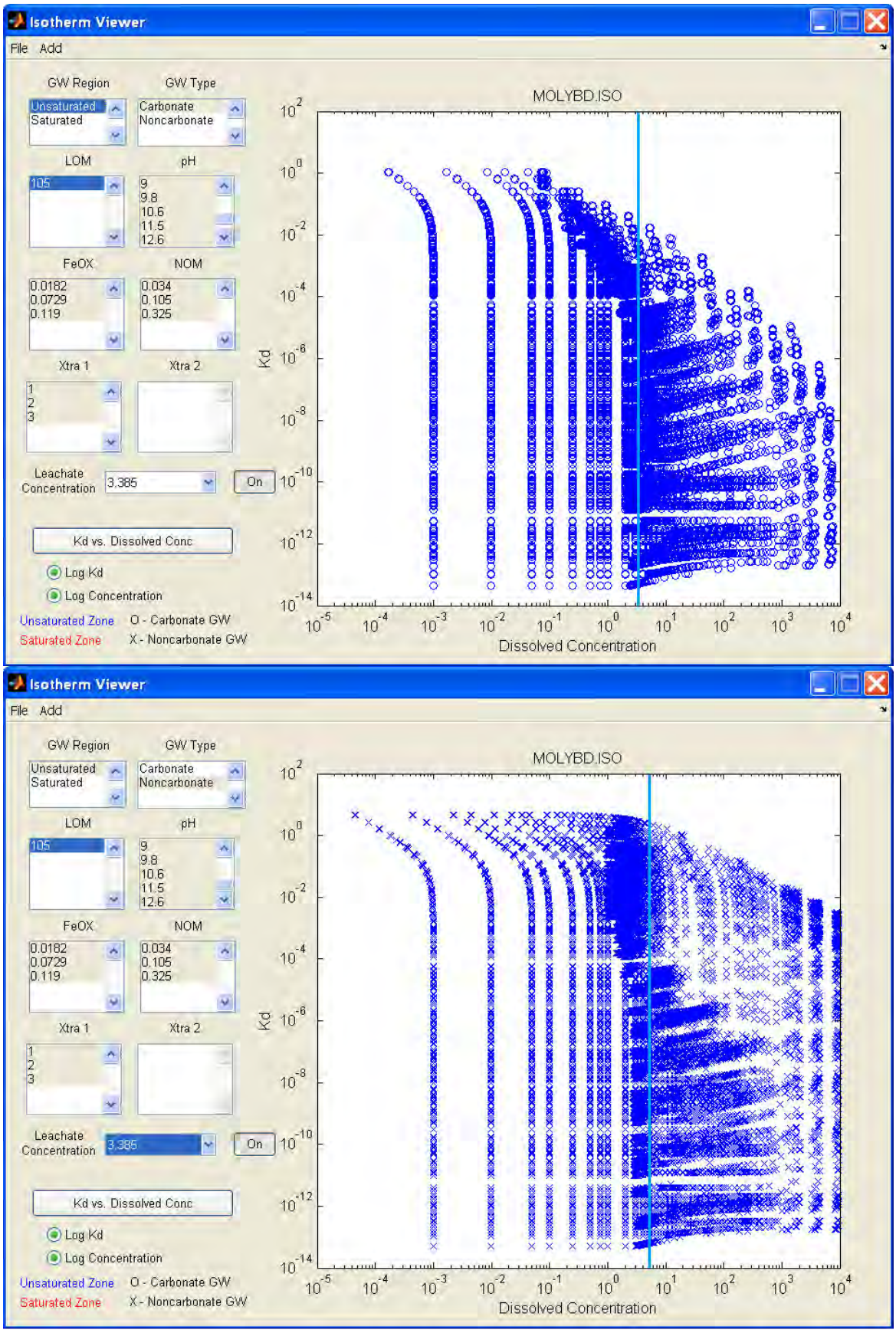
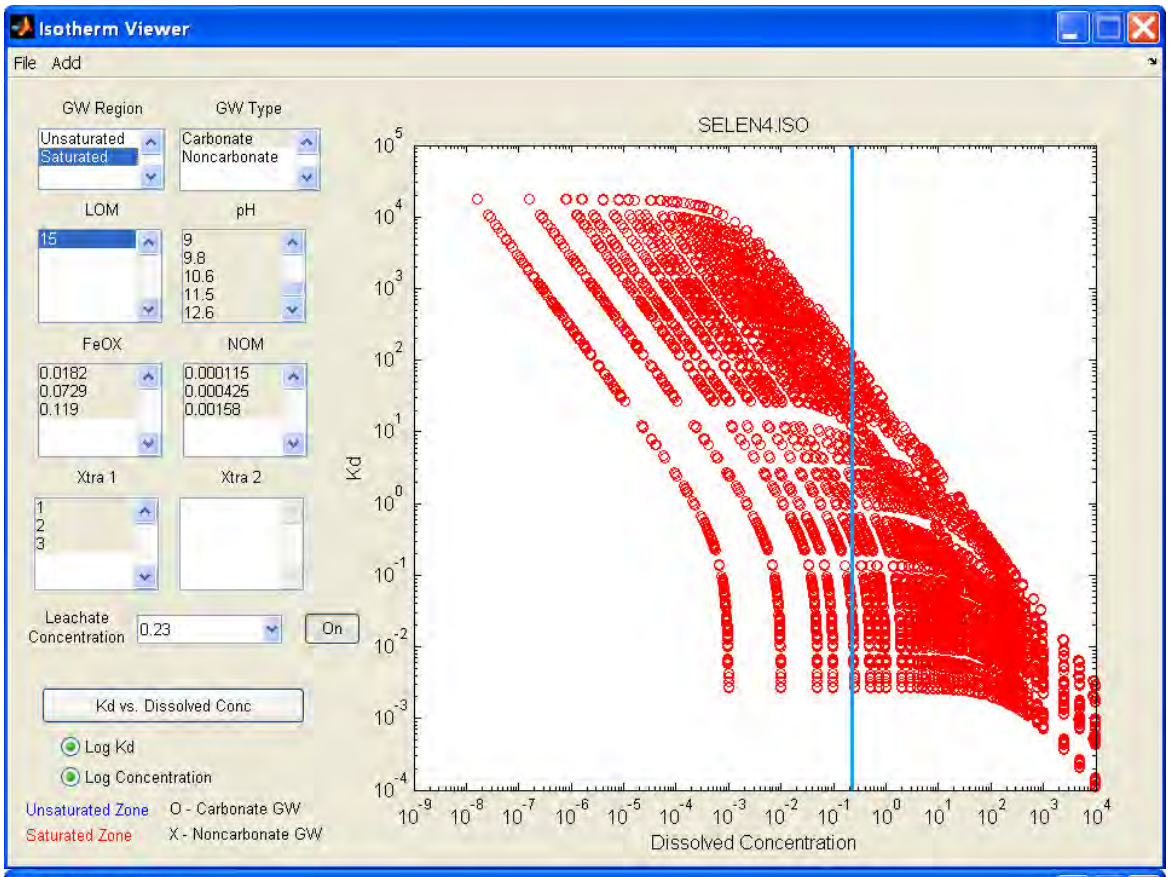


Figure H-2-42. Molybdenum unsaturated zone nonlinear sorption isotherms for SIs.



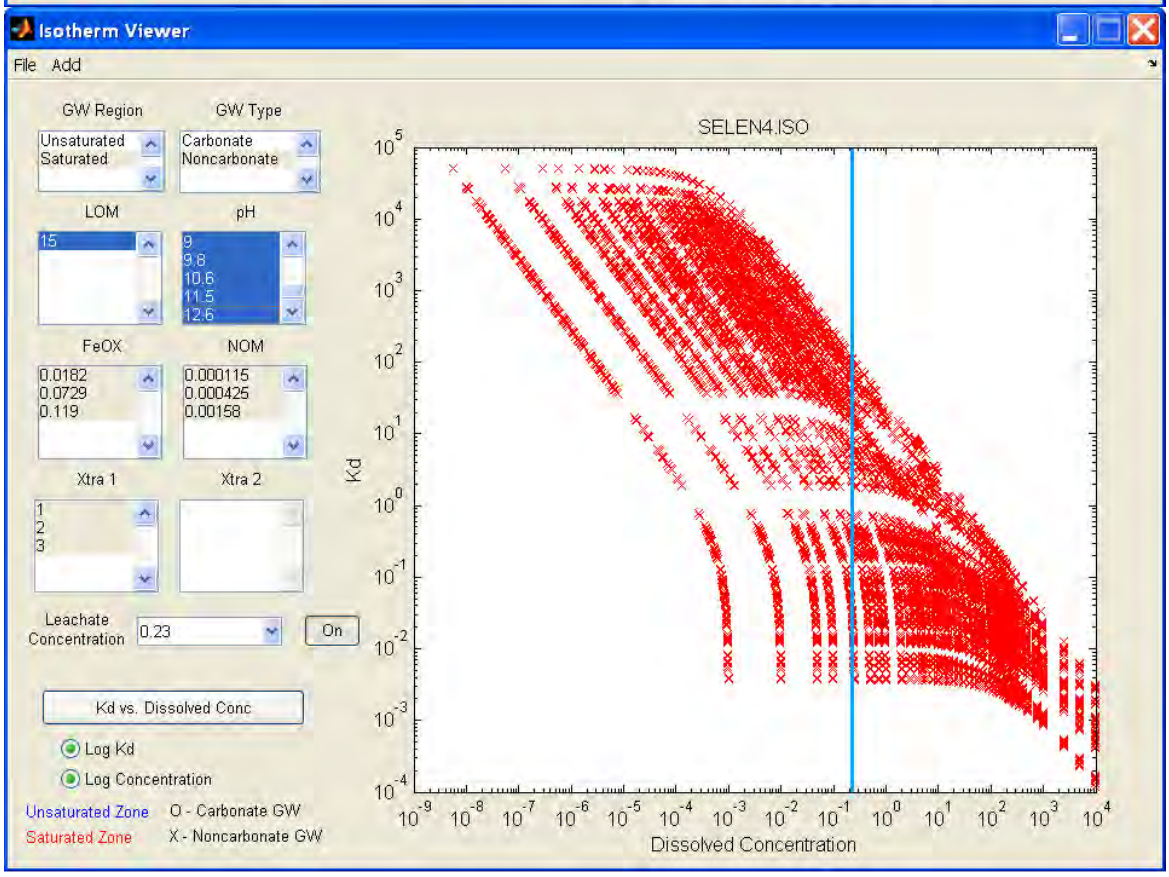


Figure H-2-43. Selenium IV saturated zone nonlinear sorption isotherms for SIs.

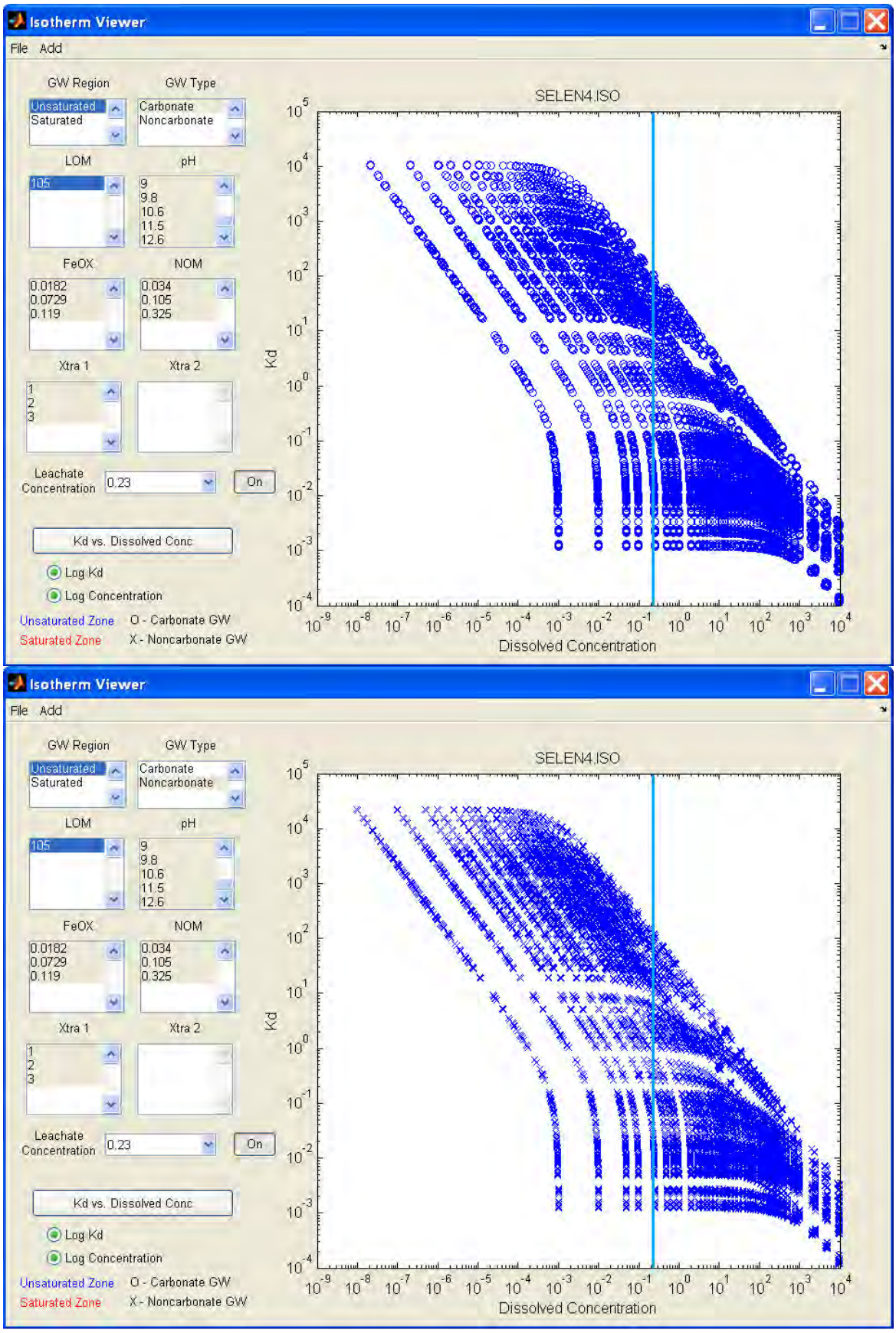


Figure H-2-44. Selenium IV saturated zone nonlinear sorption isotherms for SIs.

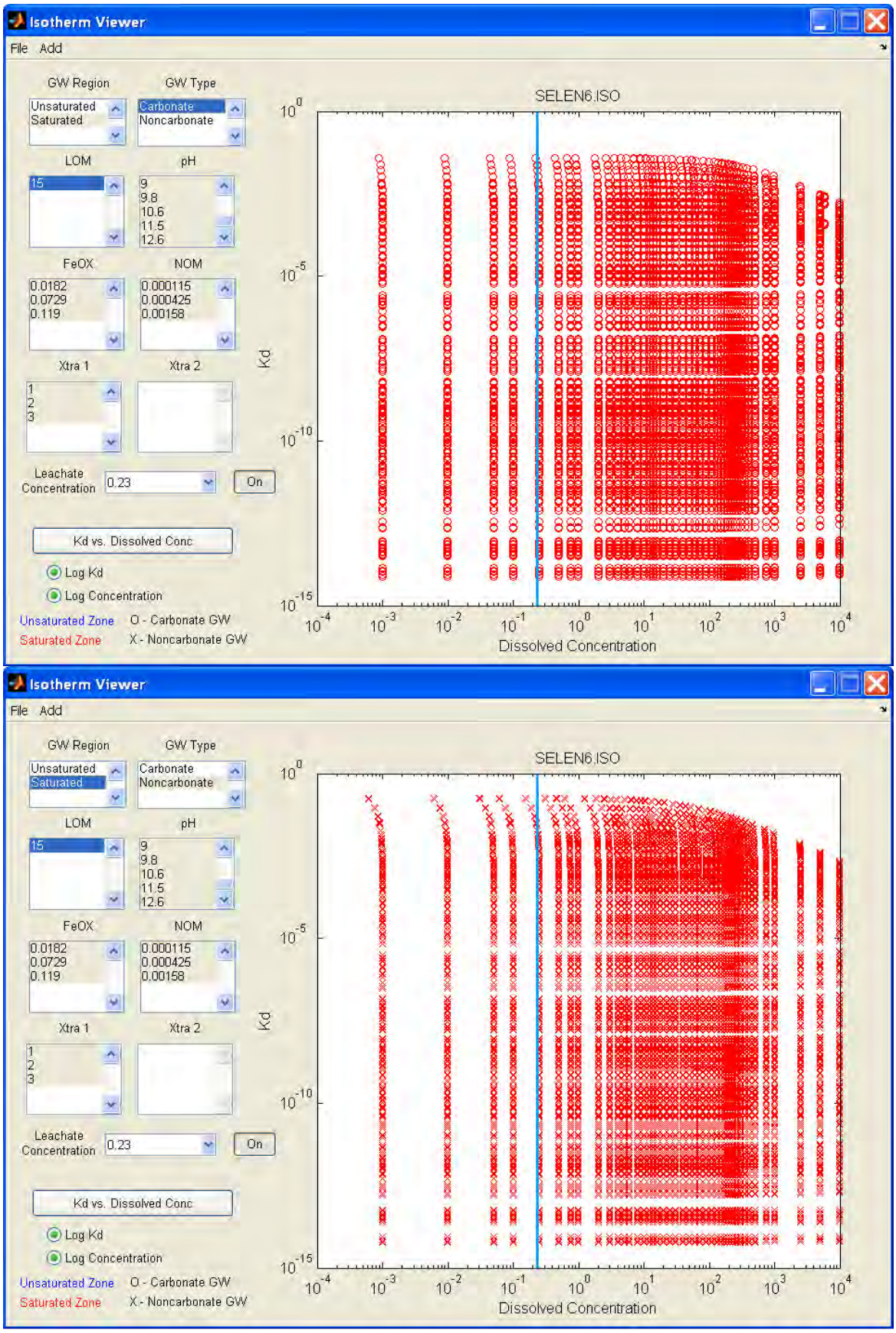


Figure H-2-45. Selenium VI saturated zone nonlinear sorption isotherms for SIs.

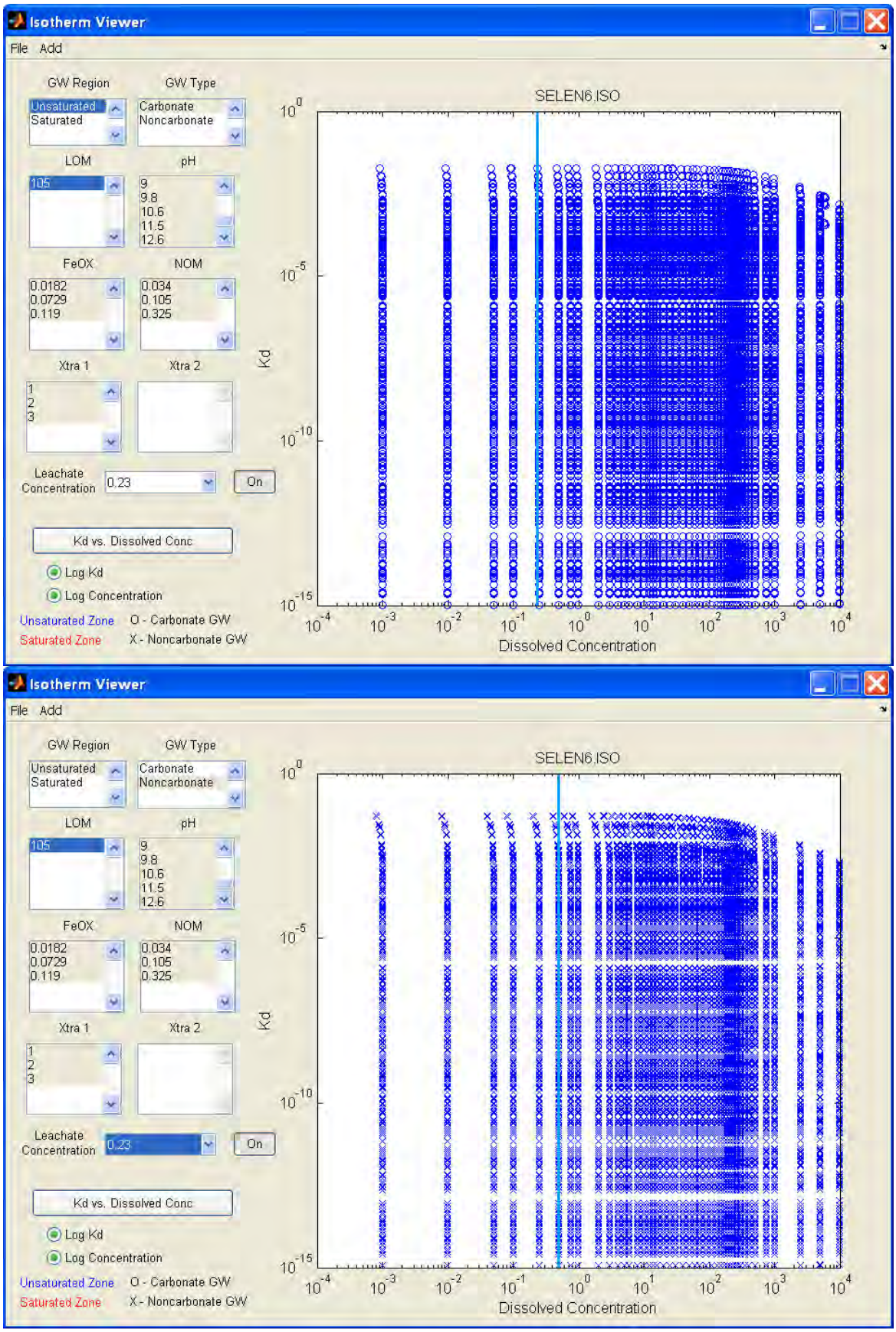
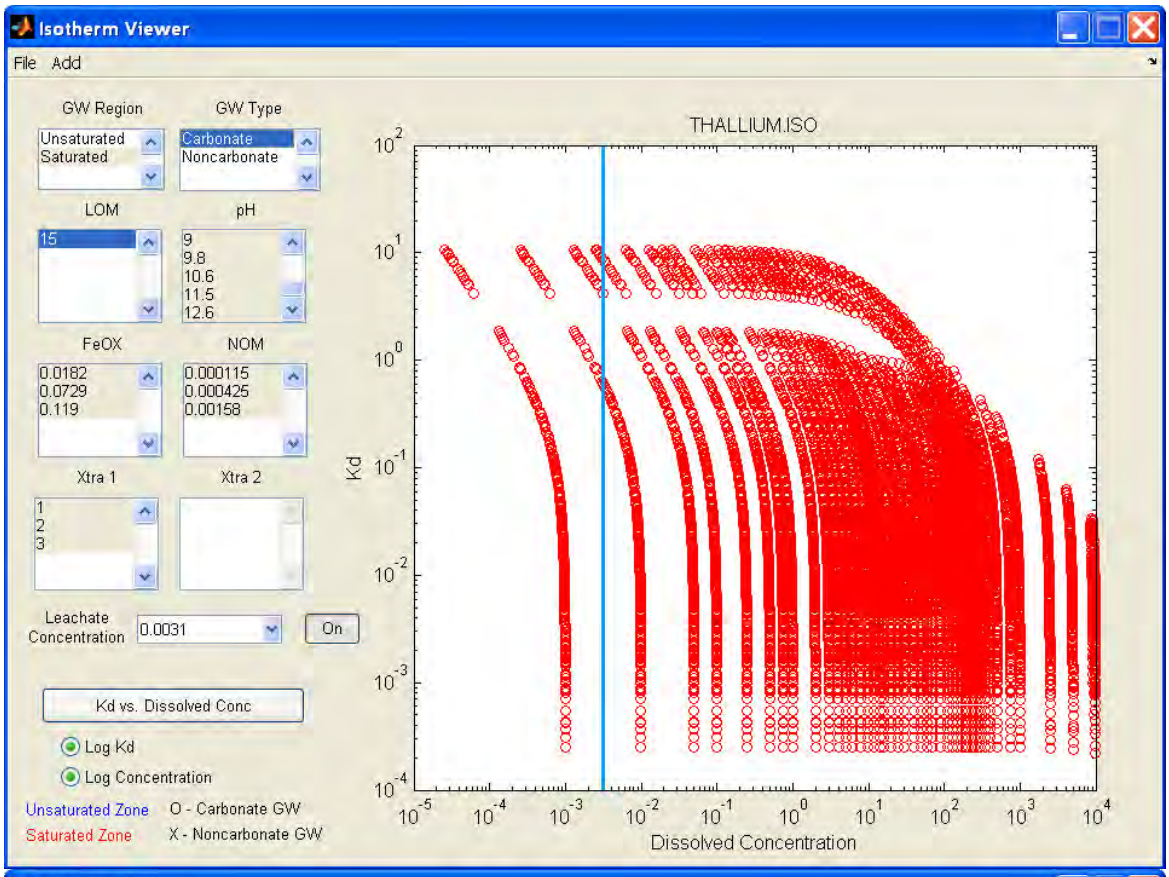


Figure H-2-46. Selenium VI unsaturated zone nonlinear sorption isotherms for SIs.



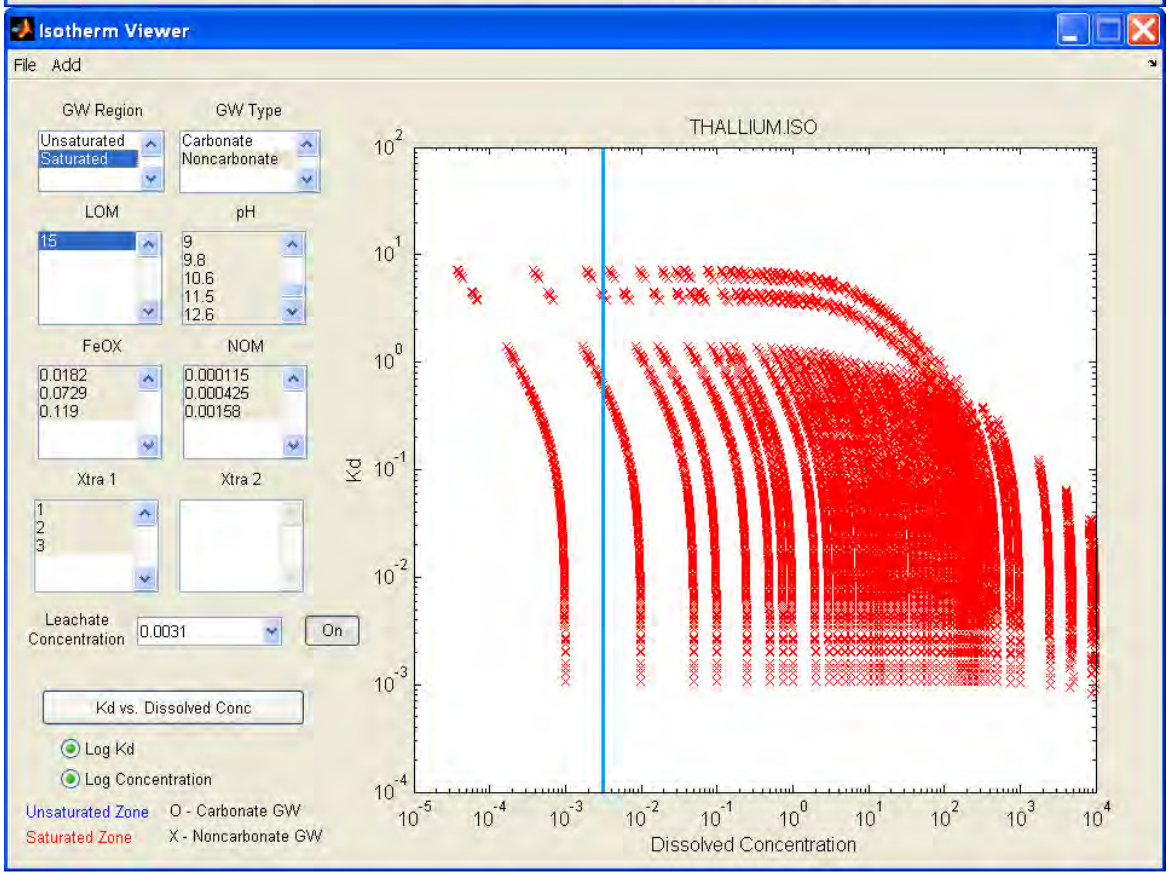


Figure H-2-47. Thallium saturated zone nonlinear sorption isotherms for SIs.

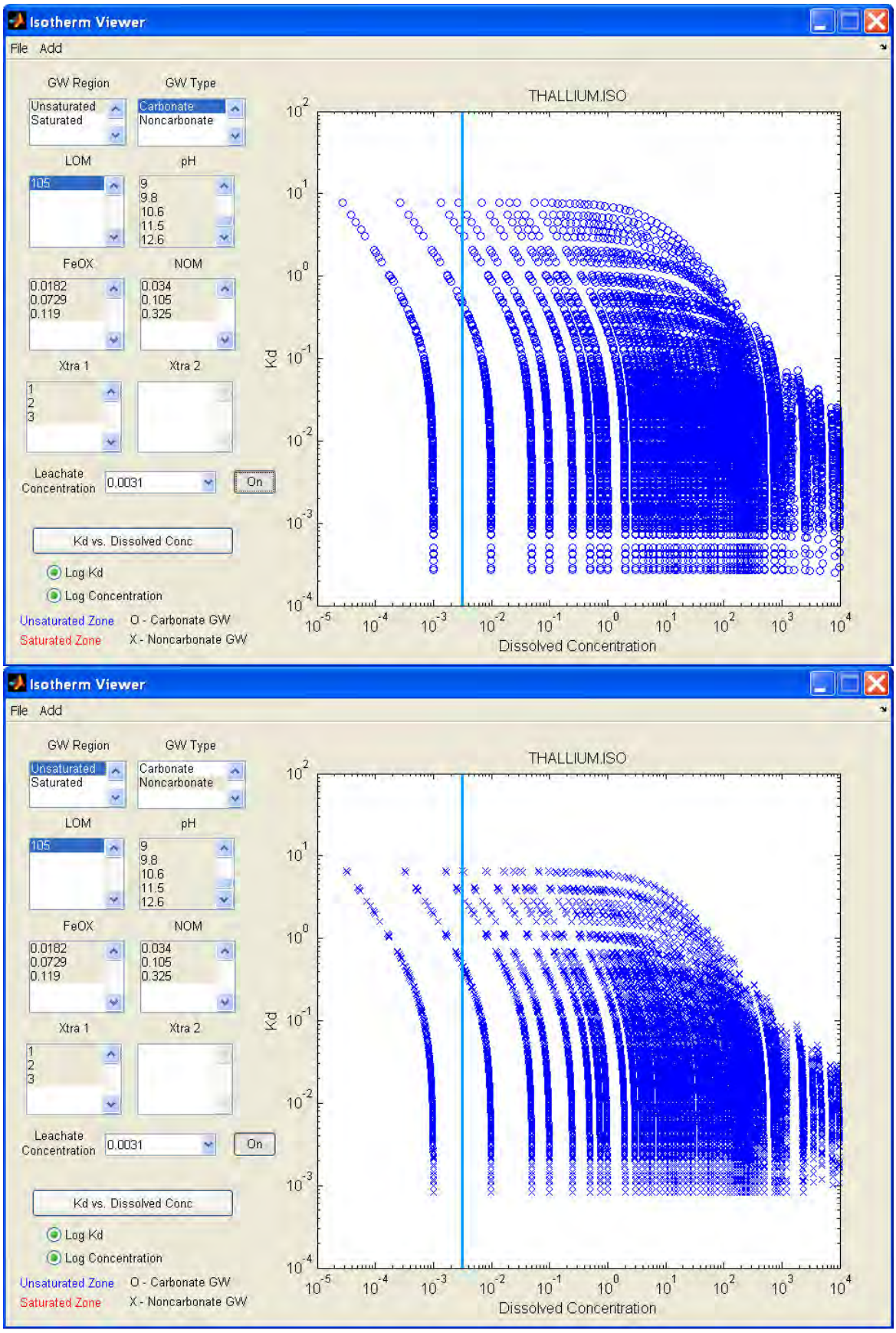


Figure H-2-48. Thallium unsaturated zone nonlinear sorption isotherms for SIs.

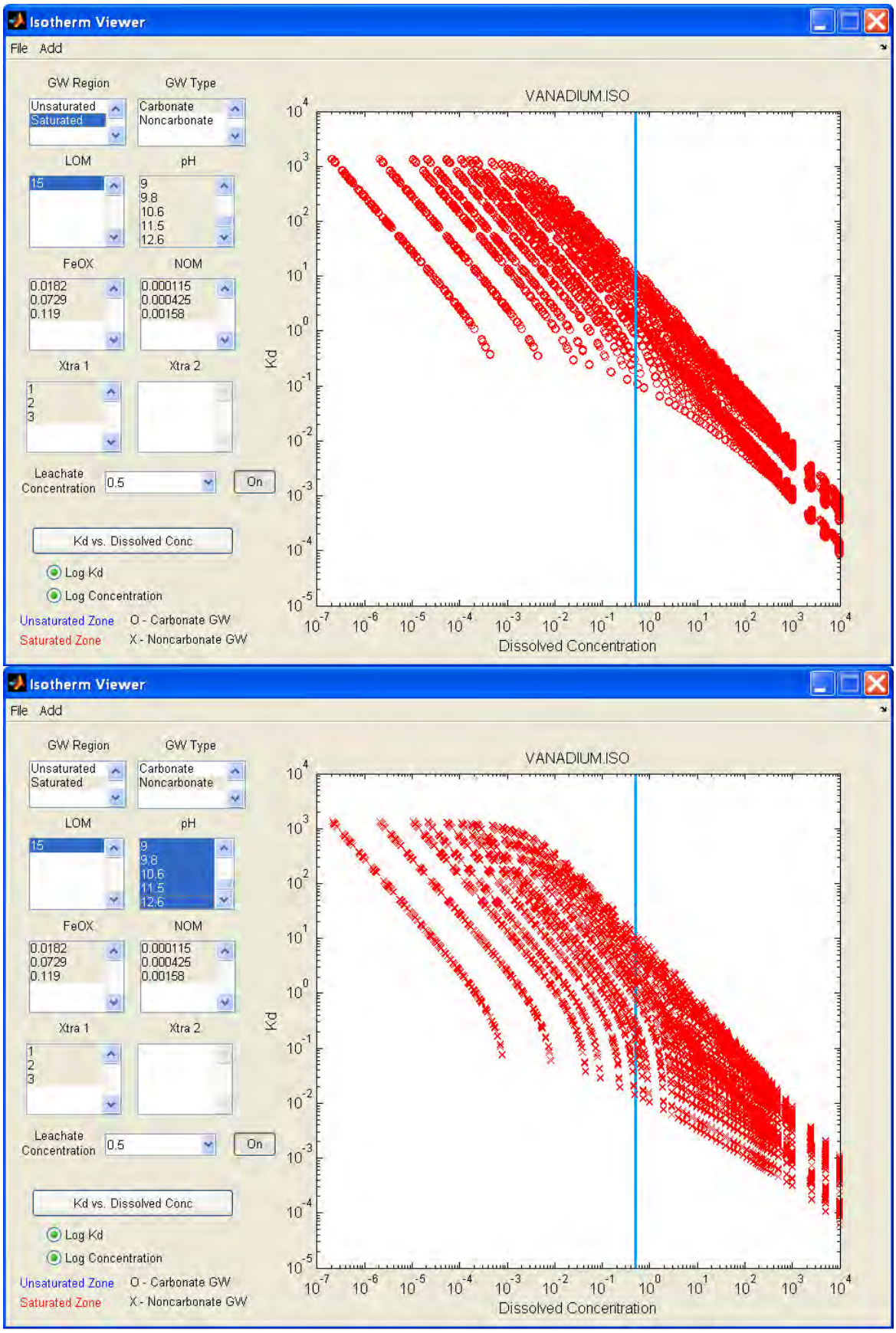


Figure H-2-49. Vanadium saturated zone nonlinear sorption isotherms for SIs.

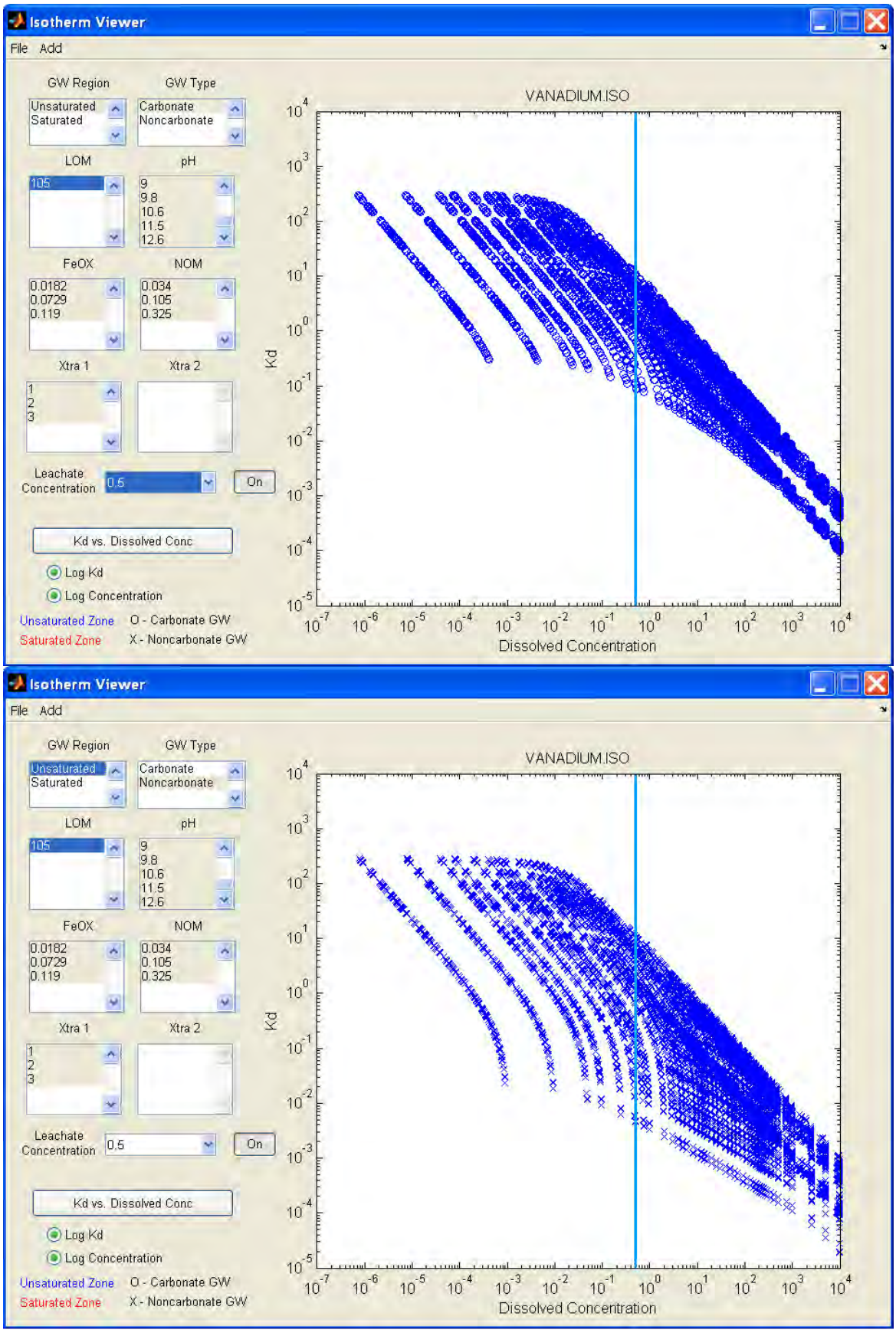


Figure H-2-50. Vanadium unsaturated zone nonlinear sorption isotherms for SIs.

Attachment H-3. Percentiles of K_d as Modeled

This attachment presents K_d percentiles selected from the inputs of the probabilistic modeling conducted in **Section 4**. For each constituent that was modeled, K_d values are presented for both the saturated and unsaturated zones[2] in the following tables:

- **Table H-3-1.** Select Percentiles of K_d (cm^3/g) for Landfills Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain
- **Table H-3-2.** Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain
- **Table H-3-3.** Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Ash and Coal Refuse Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain
- **Table H-3-4.** Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing FGD Wastes Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain.

[2] As discussed in **Section 4**, chloride and iron are ions for which EPACMTP assigns concentrations. Thus, these ions were not modeled using isotherms. Instead, the chloride and lithium K_d values were fixed at 0 and the iron K_d value was fixed at 25.

Table H-3-1. Select Percentiles of K_d (cm^3/g) for Landfills Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Arsenic III	22569728	Saturated	4.5E-07	7.4E-07	2.9E-05	2.9E-03	1.4E-01	7.2E-01	1.1E+00
		Unsaturated	9.4E-08	2.3E-07	2.1E-05	1.3E-03	9.0E-02	4.4E-01	6.4E-01
Arsenic V	15584040	Saturated	1.8E+00	4.1E+00	3.5E+01	1.3E+02	3.2E+02	6.3E+02	1.1E+03
		Unsaturated	1.0E+00	1.9E+00	9.4E+00	3.5E+01	8.8E+01	2.2E+02	4.5E+02
Boron	7440428	Saturated	1.4E-06	2.2E-06	3.9E-06	1.1E-05	1.7E-05	2.3E-05	2.9E-05
		Unsaturated	0.0E+00	0.0E+00	0.0E+00	1.2E-01	2.0E-01	3.2E-01	8.0E-01
Cadmium	7440439	Saturated	1.7E-01	2.7E-01	5.5E-01	1.2E+00	2.3E+00	4.0E+00	7.3E+00
		Unsaturated	0.0E+00	0.0E+00	0.0E+00	9.1E-01	3.4E+00	1.4E+01	2.3E+01
Cobalt	7440484	Saturated	4.5E-01	9.2E-01	2.9E+00	8.8E+00	2.1E+01	4.1E+01	1.1E+02
		Unsaturated	0.0E+00	0.0E+00	0.0E+00	4.5E+00	3.1E+01	9.0E+01	2.1E+02
Mercury	7439976	Saturated	9.6E-05	2.1E-04	9.7E-04	3.8E-03	1.1E-02	2.2E-02	2.6E-02
		Unsaturated	0.0E+00	0.0E+00	0.0E+00	1.8E-01	3.8E-01	3.5E+00	1.5E+01
Molybdenum	7439987	Saturated	2.9E-05	9.1E-05	8.5E-04	9.5E-03	1.1E-01	8.1E-01	1.8E+00
		Unsaturated	0.0E+00	0.0E+00	0.0E+00	1.4E-01	2.2E-01	4.4E-01	8.3E-01

Table H-3-2. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Aluminum	7429905	Saturated	1.6E-07	7.4E-07	7.6E-05	1.4E-02	8.1E-02	2.4E-01	4.5E-01
		Unsaturated	0.0E+00	1.3E-07	4.8E-02	1.5E-01	4.3E-01	2.8E+00	4.4E+00
Antimony	7440360	Saturated	1.9E-02	3.1E-02	8.0E-02	2.0E-01	4.1E-01	8.3E-01	1.1E+00
		Unsaturated	0.0E+00	2.9E-02	9.9E-02	2.0E-01	3.5E-01	5.0E-01	7.7E-01
Arsenic III	22569728	Saturated	1.1E-01	1.8E-01	3.1E-01	8.7E-01	1.4E+00	1.8E+00	2.2E+00
		Unsaturated	0.0E+00	4.0E-02	1.7E-01	4.2E-01	1.0E+00	1.5E+00	1.9E+00
Arsenic V	15584040	Saturated	1.1E+00	5.4E+00	2.7E+01	1.1E+02	3.4E+02	8.2E+02	1.6E+03
		Unsaturated	0.0E+00	7.2E-01	6.9E+00	3.3E+01	8.8E+01	2.0E+02	5.1E+02
Barium	7440393	Saturated	6.5E-02	8.0E-02	1.0E-01	3.2E-01	4.0E-01	1.3E+00	1.5E+00
		Unsaturated	0.0E+00	4.2E-01	1.0E+00	2.8E+00	1.0E+01	3.5E+01	5.4E+01
Beryllium	7440417	Saturated	1.0E+02	1.8E+02	4.2E+02	1.1E+03	1.9E+03	2.7E+03	2.9E+03
		Unsaturated	0.0E+00	4.2E-01	1.7E+02	5.7E+02	1.3E+03	1.8E+03	2.4E+03
Boron	7440428	Saturated	1.4E-06	2.3E-06	3.9E-06	1.1E-05	1.7E-05	2.2E-05	2.6E-05
		Unsaturated	0.0E+00	1.0E-05	3.6E-02	1.1E-01	1.9E-01	3.4E-01	4.2E-01
Cadmium	7440439	Saturated	1.6E-01	2.5E-01	5.4E-01	1.1E+00	2.2E+00	3.6E+00	5.1E+00
		Unsaturated	0.0E+00	2.3E-01	5.0E-01	1.2E+00	3.2E+00	8.5E+00	1.4E+01
Chromium III	16065831	Saturated	1.6E+01	7.1E+01	2.1E+02	5.9E+02	1.2E+03	1.7E+03	1.9E+03
		Unsaturated	0.0E+00	4.0E-01	3.9E+01	2.1E+02	7.2E+02	1.1E+03	1.4E+03

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Table H-3-2. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Chromium VI	18540299	Saturated	9.9E-01	1.8E+00	5.5E+00	1.9E+01	4.0E+01	7.0E+01	1.1E+02
		Unsaturated	0.0E+00	9.4E-02	3.9E-01	3.0E+00	1.3E+01	3.1E+01	5.3E+01
Cobalt	7440484	Saturated	4.5E-01	8.1E-01	2.2E+00	5.9E+00	1.5E+01	3.3E+01	4.2E+01
		Unsaturated	0.0E+00	4.0E-01	1.0E+00	3.7E+00	1.6E+01	6.1E+01	1.1E+02
Copper	7440508	Saturated	1.5E+01	2.3E+01	4.2E+01	1.1E+02	2.2E+02	3.1E+02	3.4E+02
		Unsaturated	0.0E+00	4.1E-01	2.3E+01	6.3E+01	1.6E+02	3.3E+02	7.9E+02
Fluoride	16984488	Saturated	1.3E-03	1.9E-03	7.1E-03	2.2E-02	8.3E-02	2.7E-01	4.0E-01
		Unsaturated	0.0E+00	5.4E-04	4.4E-02	1.2E-01	2.0E-01	3.3E-01	4.2E-01
Lead	7439921	Saturated	7.6E+00	1.0E+01	1.7E+01	2.9E+01	3.9E+01	5.4E+01	5.9E+01
		Unsaturated	0.0E+00	4.1E-01	1.3E+01	2.4E+01	4.0E+01	7.2E+01	1.6E+02
Mercury	7439976	Saturated	9.6E-05	2.1E-04	9.7E-04	3.8E-03	1.0E-02	2.2E-02	2.7E-02
		Unsaturated	0.0E+00	1.1E-02	5.4E-02	1.4E-01	2.3E-01	4.1E-01	4.4E-01
Molybdenum	7439987	Saturated	2.2E-05	6.1E-05	5.8E-04	5.6E-03	6.8E-02	8.0E-01	1.8E+00
		Unsaturated	0.0E+00	3.0E-04	4.9E-02	1.3E-01	2.3E-01	4.2E-01	6.4E-01
Nickel	7440020	Saturated	2.0E-01	3.3E-01	5.8E-01	1.3E+00	2.2E+00	3.6E+00	4.9E+00
		Unsaturated	0.0E+00	1.2E-01	4.8E-01	1.4E+00	3.6E+00	9.1E+00	1.5E+01
Selenium IV	10026036	Saturated	5.6E+00	3.2E+01	1.1E+02	6.5E+02	3.1E+03	7.5E+03	1.1E+04
		Unsaturated	0.0E+00	1.2E-01	4.1E+00	1.7E+02	1.3E+03	3.6E+03	5.8E+03

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Table H-3-2. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Combined Ash Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Selenium VI	7782492	Saturated	5.1E-07	1.4E-06	1.3E-05	1.2E-04	1.2E-03	8.6E-03	1.9E-02
		Unsaturated	0.0E+00	2.9E-05	3.8E-02	1.1E-01	1.9E-01	3.7E-01	4.2E-01
Silver	7440224	Saturated	3.6E-03	6.5E-03	1.4E-02	3.7E-02	7.9E-02	1.5E-01	2.0E-01
		Unsaturated	0.0E+00	2.1E-02	7.8E-02	1.7E-01	3.0E-01	4.3E-01	6.4E-01
Thallium	7440280	Saturated	4.8E-03	7.8E-03	1.3E-02	3.1E-02	4.7E-02	6.1E-02	8.0E-02
		Unsaturated	0.0E+00	3.9E-02	9.9E-02	2.0E-01	3.5E-01	4.8E-01	6.9E-01
Vanadium	7440622	Saturated	4.4E-01	7.9E-01	2.1E+00	9.9E+00	4.6E+01	1.6E+02	3.2E+02
		Unsaturated	0.0E+00	3.0E-01	1.2E+00	6.2E+00	3.3E+01	1.2E+02	2.1E+02
Zinc	7440666	Saturated	7.1E-01	1.4E+00	3.4E+00	8.9E+00	2.1E+01	3.5E+01	4.4E+01
		Unsaturated	0.0E+00	1.2E-01	1.2E+00	5.2E+00	1.6E+01	3.7E+01	6.0E+01

Table H-3-3. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Ash & Coal Refuse Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Aluminum	7429905	Saturated	9.1E-08	2.9E-06	6.4E-05	1.2E-02	1.1E-01	4.9E-01	1.4E+00
		Unsaturated	0.0E+00	4.0E-07	8.6E-02	2.6E-01	4.9E-01	2.3E+00	1.0E+01
Antimony	7440360	Saturated	–	–	–	–	–	–	–
		Unsaturated	–	–	–	–	–	–	–
Arsenic III	22569728	Saturated	8.4E-04	3.4E-03	2.3E-02	1.1E-01	2.5E-01	9.9E-01	1.6E+00
		Unsaturated	0.0E+00	1.3E-03	8.4E-02	2.1E-01	4.2E-01	8.2E-01	1.3E+00
Arsenic V	15584040	Saturated	1.3E-02	2.2E-02	8.6E-01	1.6E+01	9.5E+01	3.3E+02	1.0E+03
		Unsaturated	0.0E+00	2.0E-03	2.9E-01	4.0E+00	2.2E+01	5.7E+01	1.6E+02
Barium	7440393	Saturated	4.3E-03	6.5E-03	2.3E-02	7.9E-02	2.5E-01	5.4E-01	9.1E-01
		Unsaturated	0.0E+00	1.2E-02	1.3E-01	1.4E+00	9.8E+00	5.2E+01	5.5E+01
Beryllium	7440417	Saturated	–	–	–	–	–	–	–
		Unsaturated	–	–	–	–	–	–	–
Boron	7440428	Saturated	1.1E-08	4.4E-08	2.9E-07	1.5E-06	3.2E-06	1.2E-05	2.1E-05
		Unsaturated	0.0E+00	7.0E-10	1.1E-02	1.0E-01	2.0E-01	3.7E-01	4.5E-01
Cadmium	7440439	Saturated	5.2E-03	7.7E-03	4.4E-02	1.8E-01	7.0E-01	2.0E+00	3.2E+00
		Unsaturated	0.0E+00	2.6E-02	1.3E-01	3.6E-01	9.6E-01	3.9E+00	8.4E+00
Chromium III	16065831	Saturated	6.7E-02	3.0E-01	2.9E+00	3.3E+01	2.1E+02	5.9E+02	1.2E+03
		Unsaturated	0.0E+00	7.6E-02	4.8E-01	9.4E+00	9.0E+01	3.2E+02	8.7E+02

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Table H-3-3. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Ash & Coal Refuse Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Chromium VI	18540299	Saturated	1.0E-01	2.9E-01	6.9E-01	2.6E+00	1.3E+01	5.3E+01	8.1E+01
		Unsaturated	0.0E+00	2.9E-02	2.4E-01	8.0E-01	6.7E+00	3.1E+01	4.6E+01
Cobalt	7440484	Saturated	8.7E-03	1.4E-02	6.2E-02	4.1E-01	2.9E+00	1.0E+01	1.9E+01
		Unsaturated	0.0E+00	4.3E-02	2.7E-01	1.4E+00	5.9E+00	2.2E+01	4.2E+01
Copper	7440508	Saturated	3.3E-01	5.9E-01	3.0E+00	1.3E+01	5.1E+01	1.2E+02	1.9E+02
		Unsaturated	0.0E+00	2.7E-01	1.5E+00	4.5E+00	4.8E+01	1.4E+02	3.4E+02
Fluoride	16984488	Saturated	1.3E-04	2.5E-04	7.4E-04	2.4E-03	1.0E-02	3.2E-02	7.9E-02
		Unsaturated	0.0E+00	6.5E-06	1.6E-02	9.6E-02	2.1E-01	3.9E-01	4.8E-01
Lead	7439921	Saturated	2.8E-01	3.5E-01	1.6E+00	5.6E+00	1.6E+01	3.6E+01	4.2E+01
		Unsaturated	0.0E+00	1.4E-01	6.1E-01	4.8E+00	2.2E+01	4.7E+01	7.6E+01
Mercury	7439976	Saturated	1.6E-04	3.2E-04	9.6E-04	5.7E-03	1.6E-02	3.5E-02	4.6E-02
		Unsaturated	0.0E+00	1.5E-02	1.3E-01	2.9E-01	5.7E-01	2.6E+00	4.3E+00
Molybdenum	7439987	Saturated	1.1E-05	3.0E-05	2.1E-04	8.2E-03	1.1E-01	7.5E-01	2.9E+00
		Unsaturated	0.0E+00	1.8E-06	3.8E-02	1.5E-01	3.8E-01	1.5E+00	2.6E+00
Nickel	7440020	Saturated	7.6E-03	9.1E-03	4.7E-02	2.0E-01	7.3E-01	1.9E+00	2.9E+00
		Unsaturated	0.0E+00	2.4E-02	1.2E-01	4.2E-01	1.3E+00	4.2E+00	7.1E+00
Selenium IV	10026036	Saturated	1.5E+00	5.5E+00	2.4E+01	1.5E+02	8.1E+02	3.6E+03	8.1E+03
		Unsaturated	0.0E+00	1.3E-01	4.7E+00	1.1E+02	8.0E+02	4.0E+03	7.0E+03

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Table H-3-3. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing Ash & Coal Refuse Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Selenium VI	7782492	Saturated	2.4E-07	6.8E-07	4.5E-06	1.4E-04	1.9E-03	1.1E-02	7.3E-02
		Unsaturated	0.0E+00	6.4E-08	2.9E-02	1.2E-01	2.2E-01	4.1E-01	5.6E-01
Silver	7440224	Saturated	1.3E-03	2.1E-03	5.0E-03	2.7E-02	8.3E-02	1.9E-01	2.8E-01
		Unsaturated	0.0E+00	2.1E-02	1.3E-01	3.0E-01	4.8E-01	1.2E+00	1.5E+00
Thallium	7440280	Saturated	–	–	–	–	–	–	–
		Unsaturated	–	–	–	–	–	–	–
Vanadium	7440622	Saturated	5.2E-03	2.2E-02	1.8E-01	2.0E+00	1.5E+01	7.0E+01	1.7E+02
		Unsaturated	0.0E+00	4.8E-05	1.8E-01	1.7E+00	1.1E+01	4.2E+01	6.5E+01
Zinc	7440666	Saturated	1.1E-02	2.1E-02	9.5E-02	6.1E-01	3.6E+00	1.2E+01	2.5E+01
		Unsaturated	0.0E+00	1.7E-02	1.7E-01	4.9E-01	3.0E+00	1.0E+01	2.5E+01

Table H-3-4. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing FGD Wastes Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Aluminum	7429905	Saturated	8.5E-08	2.8E-07	1.0E-04	9.4E-03	6.7E-02	2.3E-01	4.0E-01
		Unsaturated	0.0E+00	0.0E+00	1.8E-02	1.5E-01	4.0E-01	1.2E+00	1.9E+00
Antimony	7440360	Saturated	6.6E-03	1.6E-02	4.2E-02	1.2E-01	2.7E-01	4.0E-01	5.7E-01
		Unsaturated	0.0E+00	0.0E+00	5.8E-02	1.6E-01	2.5E-01	4.0E-01	4.2E-01
Arsenic III	22569728	Saturated	6.0E-02	1.0E-01	1.9E-01	5.4E-01	9.2E-01	1.3E+00	1.5E+00
		Unsaturated	0.0E+00	0.0E+00	7.9E-02	2.4E-01	5.7E-01	9.7E-01	1.3E+00
Arsenic V	15584040	Saturated	3.3E-01	1.6E+00	1.2E+01	5.4E+01	1.6E+02	3.0E+02	4.3E+02
		Unsaturated	0.0E+00	0.0E+00	8.7E-01	9.7E+00	3.2E+01	6.0E+01	8.7E+01
Barium	7440393	Saturated	4.4E-02	4.9E-02	1.2E-01	2.0E-01	4.5E-01	1.0E+00	1.5E+00
		Unsaturated	0.0E+00	0.0E+00	2.4E-01	8.8E-01	5.2E+00	2.0E+01	5.1E+01
Beryllium	7440417	Saturated	7.3E+01	1.2E+02	3.2E+02	8.3E+02	1.7E+03	2.7E+03	3.7E+03
		Unsaturated	0.0E+00	0.0E+00	1.7E+01	3.0E+02	7.0E+02	2.1E+03	3.1E+03
Boron	7440428	Saturated	7.4E-07	1.3E-06	2.4E-06	7.0E-06	1.2E-05	1.7E-05	1.9E-05
		Unsaturated	0.0E+00	0.0E+00	1.6E-02	1.0E-01	1.8E-01	2.5E-01	4.0E-01
Cadmium	7440439	Saturated	9.1E-02	1.4E-01	2.9E-01	6.6E-01	1.6E+00	3.0E+00	4.0E+00
		Unsaturated	0.0E+00	0.0E+00	1.8E-01	4.3E-01	1.1E+00	6.9E+00	1.3E+01
Chromium III	16065831	Saturated	9.8E+00	2.7E+01	1.2E+02	3.7E+02	9.0E+02	1.6E+03	2.1E+03
		Unsaturated	0.0E+00	0.0E+00	6.1E+00	5.5E+01	2.8E+02	1.1E+03	1.5E+03

(continued)

Table H-3-4. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing FGD Wastes Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Chromium VI	18540299	Saturated	2.5E-01	6.5E-01	2.6E+00	7.8E+00	1.9E+01	3.2E+01	3.9E+01
		Unsaturated	0.0E+00	0.0E+00	1.2E-01	4.2E-01	5.7E+00	1.1E+01	1.7E+01
Cobalt	7440484	Saturated	2.9E-01	5.4E-01	1.5E+00	3.9E+00	1.1E+01	2.4E+01	4.1E+01
		Unsaturated	0.0E+00	0.0E+00	4.6E-01	1.9E+00	7.1E+00	5.3E+01	1.2E+02
Copper	7440508	Saturated	1.0E+01	1.6E+01	3.1E+01	7.7E+01	1.7E+02	2.6E+02	3.5E+02
		Unsaturated	0.0E+00	0.0E+00	1.0E+01	2.9E+01	9.4E+01	3.0E+02	5.8E+02
Fluoride	16984488	Saturated	3.9E-04	1.2E-03	4.3E-03	1.3E-02	4.2E-02	1.1E-01	1.7E-01
		Unsaturated	0.0E+00	0.0E+00	3.5E-02	1.2E-01	2.0E-01	3.1E-01	4.1E-01
Lead	7439921	Saturated	3.8E+00	6.4E+00	1.2E+01	1.9E+01	3.5E+01	4.7E+01	6.5E+01
		Unsaturated	0.0E+00	0.0E+00	3.8E+00	1.1E+01	2.6E+01	7.0E+01	1.4E+02
Mercury	7439976	Saturated	2.7E-05	7.1E-05	4.8E-04	3.4E-03	1.3E-02	2.5E-02	3.3E-02
		Unsaturated	0.0E+00	0.0E+00	3.9E-02	1.3E-01	2.1E-01	3.7E-01	4.1E-01
Molybdenum	7439987	Saturated	8.2E-06	2.8E-05	3.8E-04	3.6E-03	4.4E-02	3.2E-01	9.2E-01
		Unsaturated	0.0E+00	0.0E+00	1.8E-02	1.1E-01	1.9E-01	3.0E-01	4.1E-01
Nickel	7440020	Saturated	1.2E-01	2.0E-01	3.9E-01	8.1E-01	1.7E+00	3.0E+00	4.1E+00
		Unsaturated	0.0E+00	0.0E+00	2.6E-01	6.4E-01	1.5E+00	6.7E+00	1.1E+01
Selenium IV	10026036	Saturated	1.8E+00	9.6E+00	6.2E+01	3.6E+02	1.5E+03	4.3E+03	6.0E+03
		Unsaturated	0.0E+00	0.0E+00	1.8E-01	3.6E+01	6.0E+02	1.8E+03	2.4E+03

(continued)

Table H-3-4. Select Percentiles of K_d (cm^3/g) for Surface Impoundments Containing FGD Wastes Sampled from MINTEQA2 Isotherms by Updated EPACMTP via Constituent Species and Subsurface Domain

Constituent	CASID	Zone	Percentiles of K_d (cm^3/g)						
			5%	10%	25%	50%	75%	90%	95%
Selenium VI	7782492	Saturated	1.9E-07	6.4E-07	8.4E-06	7.7E-05	7.9E-04	4.4E-03	9.5E-03
		Unsaturated	0.0E+00	0.0E+00	1.6E-02	1.0E-01	1.8E-01	2.5E-01	3.9E-01
Silver	7440224	Saturated	8.0E-04	1.5E-03	3.3E-03	3.0E-02	1.5E-01	2.4E-01	2.7E-01
		Unsaturated	0.0E+00	0.0E+00	6.9E-02	2.0E-01	4.2E-01	8.9E-01	1.4E+00
Thallium	7440280	Saturated	3.5E-03	5.5E-03	1.0E-02	1.8E-02	3.5E-02	5.5E-02	6.3E-02
		Unsaturated	0.0E+00	0.0E+00	6.3E-02	1.6E-01	2.6E-01	4.1E-01	4.8E-01
Vanadium	7440622	Saturated	2.6E-01	5.0E-01	1.3E+00	5.8E+00	2.7E+01	7.9E+01	1.7E+02
		Unsaturated	0.0E+00	0.0E+00	3.7E-01	2.2E+00	2.0E+01	5.9E+01	8.5E+01
Zinc	7440666	Saturated	4.6E-01	8.6E-01	2.2E+00	5.6E+00	1.4E+01	2.9E+01	4.4E+01
		Unsaturated	0.0E+00	0.0E+00	4.6E-01	1.5E+00	5.3E+00	3.1E+01	7.9E+01

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Appendix I.

Landfill Source Term Development

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I.1 Introduction

The U.S. Environmental Protection Agency (EPA or the Agency) used SW-846 Leaching Evaluation Assessment Framework (LEAF) Methods 1313, 1314 and 1316 to characterize the leaching behavior of coal combustion residual (CCR) waste over a range of environmental conditions. These methods were developed through a collaborative research effort between EPA, Vanderbilt University, ARCADIS, Inc., the Energy Centre of the Netherlands, and Dutch and Danish partners (Kosson et al, 2002; Sanchez et al, 2002; Thorneloe et al, 2010; U.S. EPA, 2010b). EPA originally proposed the use of LEAF data in a 2011 Notice of Data Availability (NODA)[1] and further described how it might use the data in the subsequent 2013 NODA.[2] Further discussion of these LEAF methods is provided in **Appendix C**. The remainder of this appendix summarizes how data from these methods were used in the revised risk assessment to model leaching from landfills.

I.2 Source Term Development

The information provided by the three LEAF methods were used together to identify trends in leaching behavior and to characterize both the total mass available to be leached (i.e., leachable mass) and the leachate concentrations of individual COPCs in each sample. Method 1313 provided data on the equilibrium leachate concentration as a function of waste pH. Method 1314 provided data on the leachate concentration as a function of cumulative liquid to solid (L/S) ratio. Method 1316 provided data on the equilibrium leachate concentration as a function of L/S ratio.

Leachable mass was characterized using Method 1313 data. For all samples, the leachable mass was taken as the maximum concentration measured over the pH range of 2.8 to 12.8 multiplied by the L/S ratio used in Method 1313 (10 L/kg), as described in U.S. EPA (2009a). The calculated value was used by EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) to determine the duration of leaching. Once all leachable mass was depleted, leaching of that particular constituent ceased.

Leachate concentrations were characterized using Method 1313 data. The representativeness of these equilibrium concentrations was confirmed with data obtained from Methods 1314 and 1316. The application of Method 1313 data depended on the leaching behavior exhibited by a constituent at a given pH. Leaching behavior fell into one of two categories: washout-controlled and solubility-controlled. A single constituent may alternate between these two behaviors over the relevant pH range (e.g. washout-controlled at a low pH and solubility-controlled at a high pH). In addition, this behavior profile as a function of pH is not constant across all wastes. Ashes generated by different coal and pollution controls may exhibit a completely different leaching profile for the same constituent. These handling of data for these two leaching behaviors is discussed in greater detail in the following subsections.

[1] Available online at: www.regulations.gov/#!documentDetail;D=EPA-HQ-RCRA-2011-0392

[2] Available online at: www.regulations.gov/#!documentDetail;D=EPA-HQ-RCRA-2012-0028

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I.2.1 Solubility-Controlled Leaching Behavior

Solubility-controlled leaching is characterized by the releases where the leachate concentration is limited by solubility of the species. This behavior occurs when the total constituent mass available to be released from the waste is greater than the maximum amount that can be dissolved in the mass of water present. In Method 1313 data, this is characterized by highly variable leachate concentrations over the pH range because the maximum amount that can be dissolved varies with pH (U.S. EPA, 2014). **Figure I-1** shows an example of an ash (Sample ID: AaFA) for which chromium falls within the solubility-controlled zone over the entire pH range.

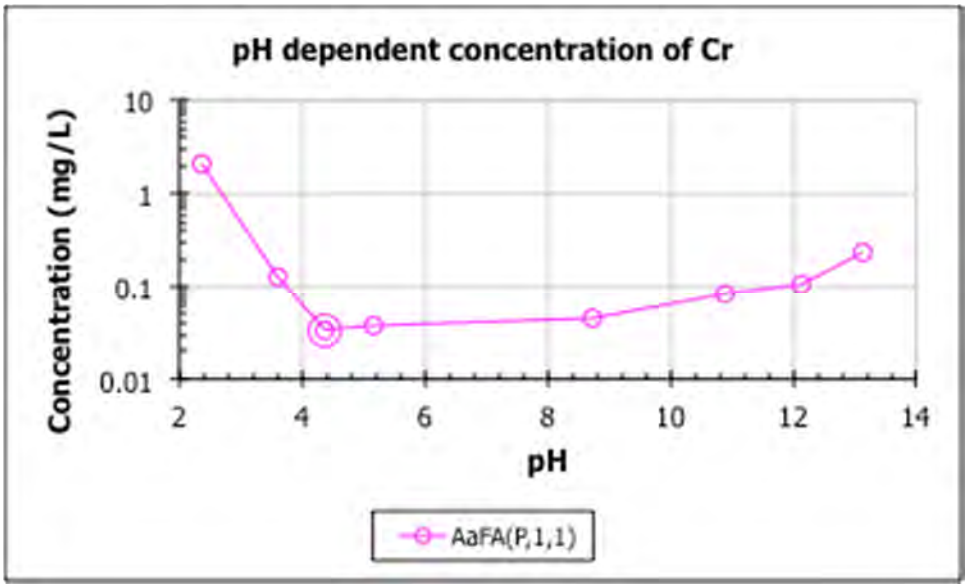

Figure I-1. Example of a solubility-controlled species over the full experimental pH domain (Adapted from data in U.S. EPA, 2009a).

If a constituent was determined to fall within the solubility-controlled zone at a particular pH, then the initial leachate concentration for that sample, C_0 (mg/L), was modeled as the concentration obtained from Method 1313. This leachate concentration was held constant over time until the leachable mass, M_0 (mg/kg), was depleted. This occurs when the cumulative L/S ratio is equal to M_0/C_0, also referred to as LS_{max}. The empirical relationship identified with Methods 1314 and 1316 agree well with this approach. **Figure I-2** illustrates this empirical relationship for solubility-controlled leaching as a function of cumulative L/S ratio.

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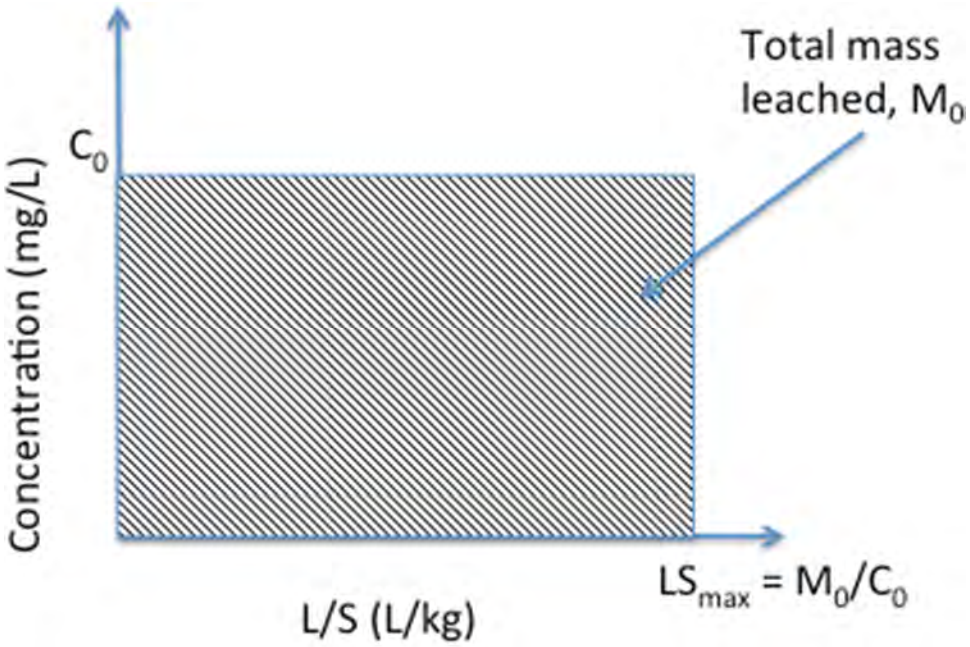

Figure I-2. L/S partitioning curve for solubility-controlled constituents at simulation pH.

I.2.2 Washout-Controlled Leaching Behavior

Washout-controlled leaching is characterized by the quick dissolution and release of the more soluble species from the CCR waste into the pore water. In Method 1313 data, this behavior is characterized by a generally constant leachate concentration over a pH range (U.S. EPA, 2014). **Figure I-3** shows an example of an ash (Sample ID: AaFA) for which boron falls in the washout-controlled zone over the entire pH range evaluated and leachate concentrations are almost constant.

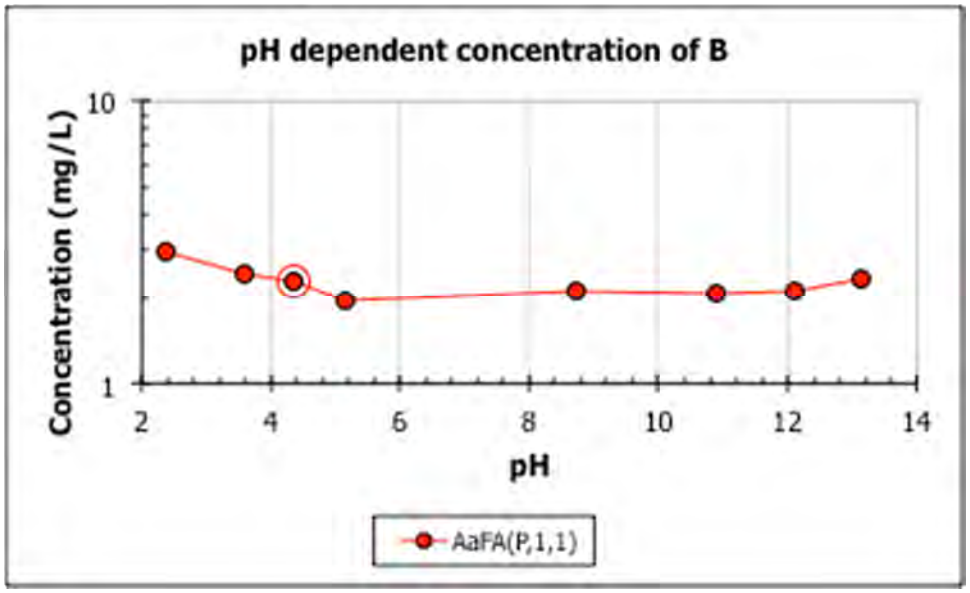

Figure I-3. Example of a washout-controlled constituent over the full experimental pH domain (Adapted from data in U.S. EPA, 2009a).

Method 1313 is carried out at a single L/S ratio of 10 mL/g (U.S. EPA, 2012). However, the L/S ratio present in the field is closer to 0.5 mL/g, based on a typical porosity of around 0.2 to 0.5 (unitless). Thus, if a constituent was determined to fall within the washout-controlled zone at a particular pH value, then C_0 was modeled as the concentration obtained from Method 1313 at that pH multiplied by a factor of 20. This factor adjusts for the difference between the L/S ratio specified in the Method 1313 test and those that occur in the field (U.S. EPA, 2014). The results of Methods 1314 and 1316 agree well with an initial leachate concentration defined by 20 times the Method 1313 leachate concentration, but show a variable leaching profile as the cumulative L/S ratio increases. The following empirical relationship was developed based on the observed changes in leachate concentration:

(I-1) $$M_0 = C_0 \cdot LS_{0.2} + \int_{0.2}^{1} 1.78C_0\left(e^{-2.9LS}\right)dLS + 0.1C_0\left(LS_{max} - LS_1\right)$$

Where:

M_0 = Total available mass (mg/kg);
C_0 = Initial leaching concentration (mg/L);
LS_X = Liquid-to-solid ratio of X (L/kg); and
LS_{max} = Liquid-to-solid ratio at which total available mass is depleted (L/kg).

At a cumulative L/S ratio of 0.2, the measured leachate concentration began to decrease exponentially until a cumulative L/S ratio of 1. At this point, the concentration stabilized at a tenth of the original value and remained at this concentration until all of the remaining leachable mass was depleted. **Figure I-4** illustrates this empirical relationship for washout-controlled leaching as a function of cumulative L/S ratio.

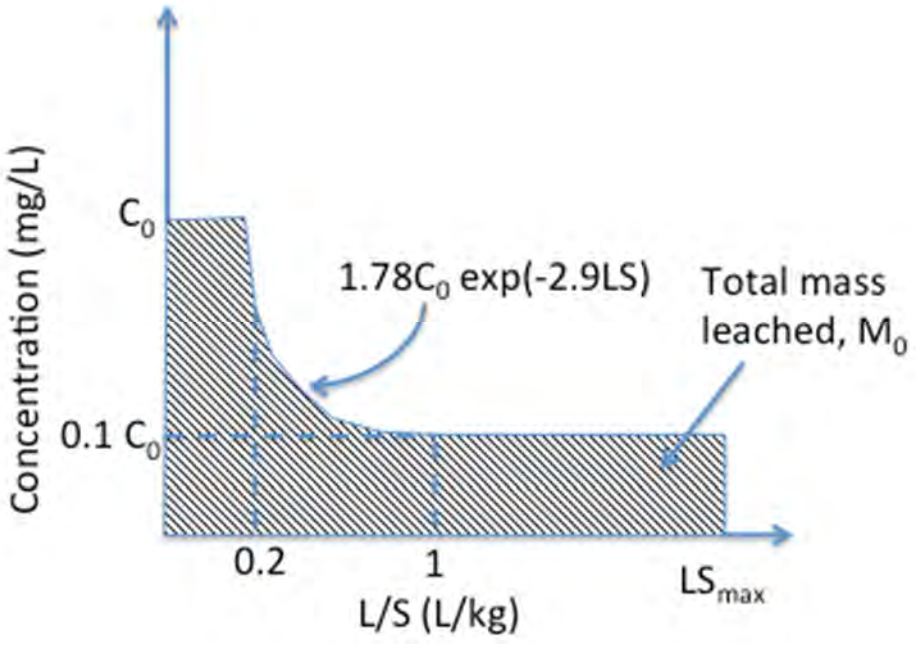

Figure I-4. L/S partitioning curve for washout-controlled species at simulated pH.

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As seen in the figure above, leaching is not constant for constituents in the washout-controlled zone. As shown in the 2009 Sensitivity Analysis, higher leachate concentrations consistently led to higher well concentrations in the 2010 Risk Assessment (U.S. EPA, 2009b). Thus, the initial pulses of higher concentration in the washout-controlled releases are anticipated to capture peak ground water concentrations in down-gradient wells. Furthermore, the use of the EPACMTP non-linear sorption isotherms requires the use of a square pulse source as described in U.S. EPA (2003a,b). As a result, EPA chose not to represent the entire washout leaching profile laid forth in the figure above. Instead, all washout-controlled releases were modeled as square pulses selected to represent leachate concentrations that would not underestimate risks. These pulses are similar to the solubility-controlled pulse portrayed in **Figure I-2**, except that C_0 was set to 20 times the Method 1313 leachate concentration.

I.3 Arsenic Source Term Development

Arsenic exhibits washout- and solubility-controlled leaching behaviors like other constituents. However, the data collected with LEAF methods have demonstrated that the leaching behavior of arsenic is also strongly influenced by the presence of calcium, which inhibits arsenic release through oxidation and complexation (Wang et al, 2007). To more accurately characterize the leaching behavior of arsenic, EPA used Method 1314 data to link arsenic leachate concentrations with the mass of calcium present as a function of the cumulative L/S ratios. **Sections I.3.1** and **I.3.2** discuss the leaching behaviors of calcium and arsenic, respectively. **Section I.3.3** discusses the integration of these data to calculate arsenic-specific leachate profiles for EPACMTP.

I.3.1 Summary of Calcium Leaching Behavior

Through a comparison of Method 1313 and 1314 data, EPA observed that the initial calcium leachate concentration is strongly dependent on the mass available to be leached. If the availability of calcium is high (> 5,000 mg/kg), then the initial leachate concentration is around 1,000 mg/L. If the calcium availability is low (≤ 5,000 mg/kg) then the initial leachate concentration of calcium is around 700 mg/L. Regardless of the initial amount of calcium available, once 90 percent of leachable mass has been depleted, the leachate concentration decreased to approximately 10 mg/L.

I.3.2 Summary of Arsenic Leaching Behavior

Arsenic leaching from landfills was modeled as having one of two relationships with dissolved calcium concentrations based on empirical data. This behavior as a function of the cumulative L/S ratio is described, as well as illustrated in **Figure I-5**, below:

- **Case (a) High Calcium Arsenic Leaching:** In high-calcium waste, arsenic complexation with the calcium restricts the amount of arsenic initially available for leaching. Empirical data shows that little to no arsenic will leach from the material after an L/S ratio of 1 is reached, as long as significant levels of calcium remain. Initially, arsenic leaches at C_0 calculated from Method 1313 data from a cumulative L/S ratio of 0 to 1. After this point, arsenic concentrations become non-detect and are assumed to be negligible. Once 90 percent of the calcium has been depleted ($LS_{90,Ca}$), the complexation that had bound the

arsenic originally can no longer be sustained at levels high enough to keep the arsenic in the material. A second pulse of arsenic leaching begins at $LS_{90,Ca}$ at the same concentration and continues until the leachable mass of arsenic has been depleted ($LS_{max,As}$).

- **Case (b) Low-Calcium Arsenic Leaching:** In low-calcium waste, little complexation occurs between arsenic and calcium. Empirical data shows that, in these cases, arsenic leaching is not inhibited. Arsenic leaching begins at C_0 calculated from Method 1313 data and is held constant until the leachable mass is depleted.

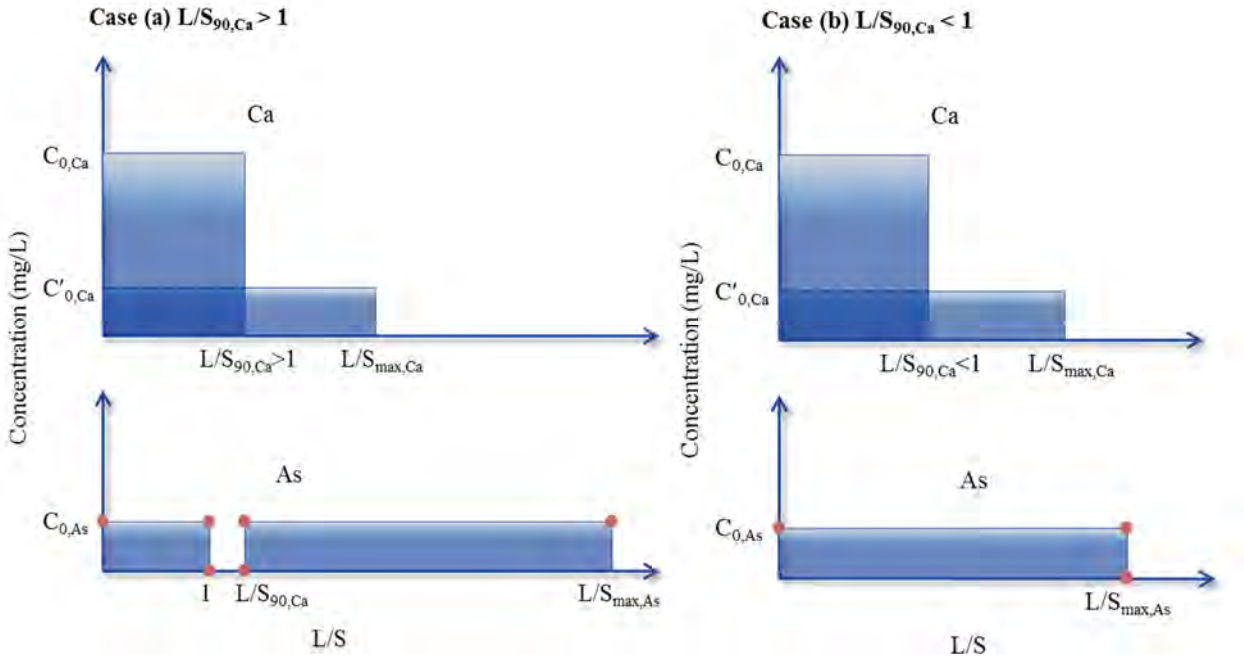
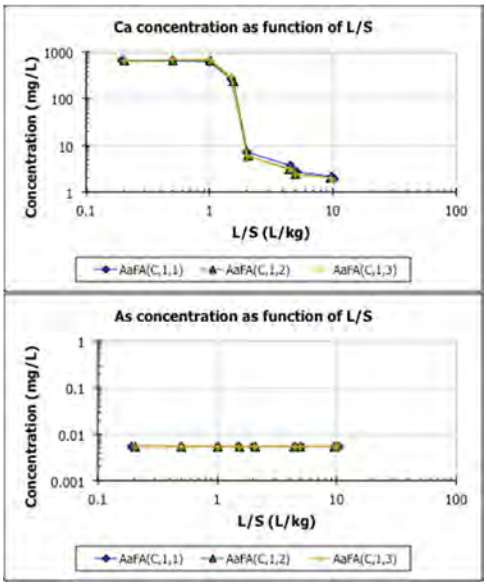


Figure I-5. Generic high- and low calcium leaching and generic calcium-dependent arsenic leaching as a function of cumulative L/S ratio.

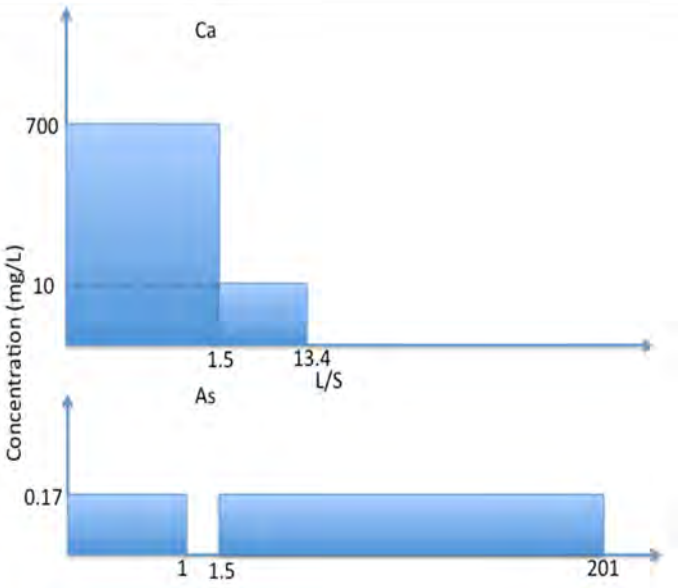
I.3.3 Calculation of Specific High-Calcium Arsenic Leachate Curves

A total of five samples analyzed with the LEAF methods contained high-calcium levels (Sample ID: AaFA, CaFA, DaFA, EaFA, and UFA). For each of these samples, EPA evaluated $LS_{90,Ca}$ and $LS_{max,As}$ to determine the duration of the first and second leachate pulses for purposes of modeling in EPACMTP. **Figures I-6** through **I-10** show the interaction between arsenic and calcium leachate over the range of cumulative L/S ratios for these five samples. These idealizations mirror the empirical Method 1314 test results.

Fly Ash Sample	Own pH	Calcium		Arsenic		
		$M_{0,Ca}$ (mg/kg)	$LS_{90,Ca}$ (L/kg)	$M_{0,As}$ (mg/kg)	$C_{0,As}$ (mg/L)	$LS_{Max,As}$ (L/kg)
AaFA	4.4	1,189	2	34	0.17	201



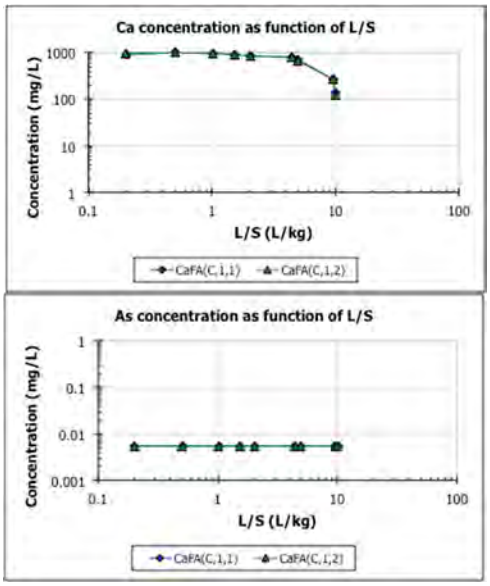
AaFA Method 1314 Results



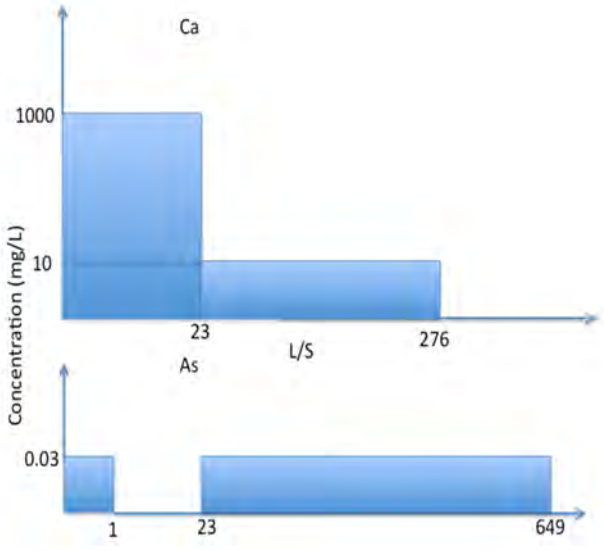
AaFA Idealized Curves

Figure I-6. Method 1314 results and idealized leaching curves for sample AaFA.

Fly Ash Sample	Own pH	Calcium		Arsenic		
		$M_{0,Ca}$ (mg/kg)	$LS_{90,Ca}$ (L/kg)	$M_{0,As}$ (mg/kg)	$C_{0,As}$ (mg/L)	$LS_{Max,As}$ (L/kg)
CaFA	12.0	25,311	23	21	0.03	649



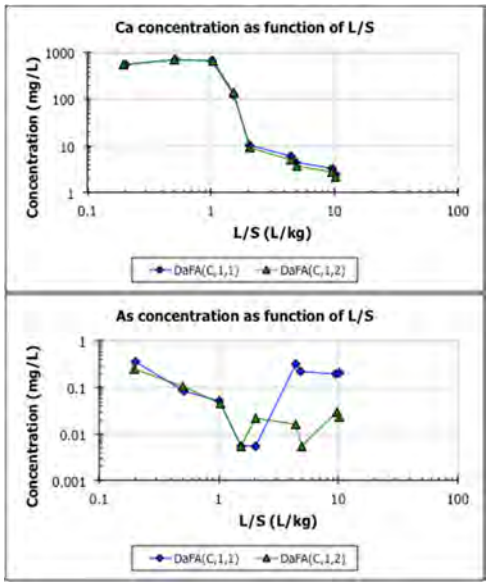
CaFA Method 1314 Results



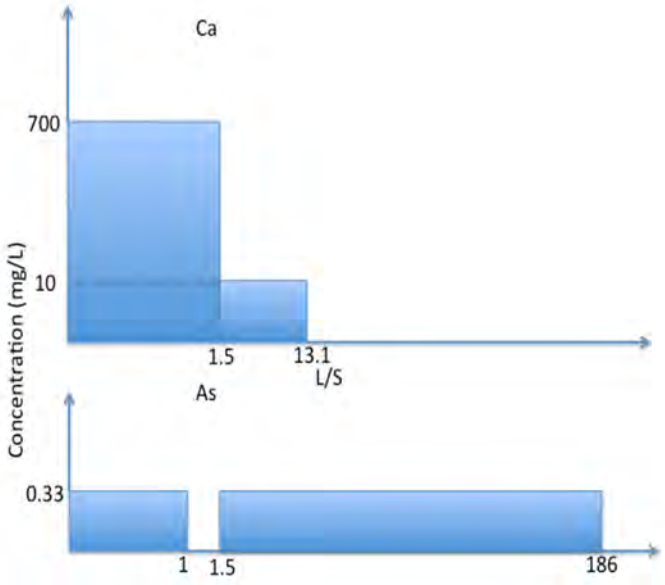
CaFA Idealized Curves

Figure I-7. Method 1314 results and idealized leaching curves for sample CaFA.

Fly Ash Sample	Own pH	Calcium		Arsenic		
		$M_{0,Ca}$ (mg/kg)	$LS_{90,Ca}$ (L/kg)	$M_{0,As}$ (mg/kg)	$C_{0,As}$ (mg/L)	$LS_{Max,As}$ (L/kg)
DaFA	4.3	1,160	1	61	0.33	186



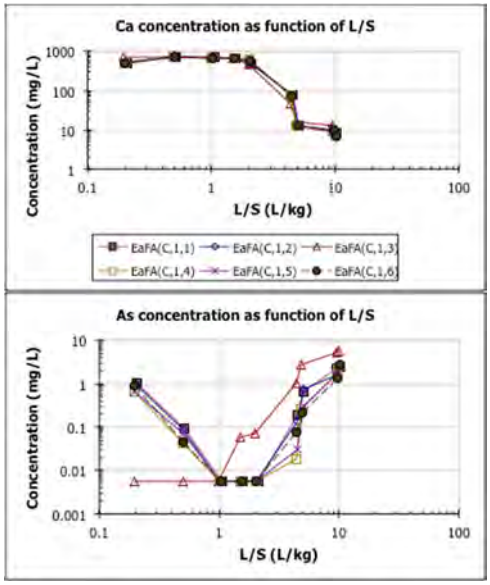
DaFA Method 1314 Results



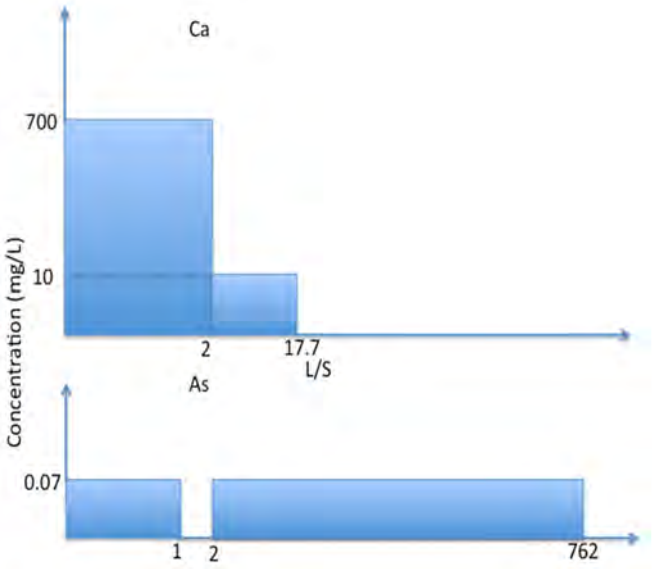
DaFA Idealized Curves

Figure I-8. Method 1314 results and idealized leaching curves for sample DaFA.

Fly Ash Sample	Own pH	Calcium		Arsenic		
		$M_{0,Ca}$ (mg/kg)	$LS_{90,Ca}$ (L/kg)	$M_{0,As}$ (mg/kg)	$C_{0,As}$ (mg/L)	$LS_{Max,As}$ (L/kg)
EaFA	7.2	1,572	2	54	0.07	762



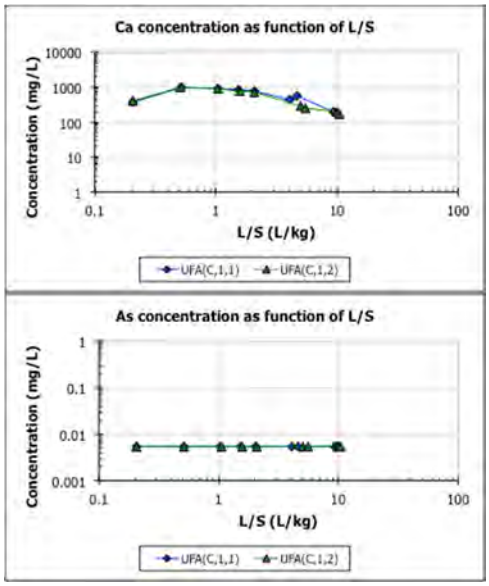
EaFA Method 1314 Results



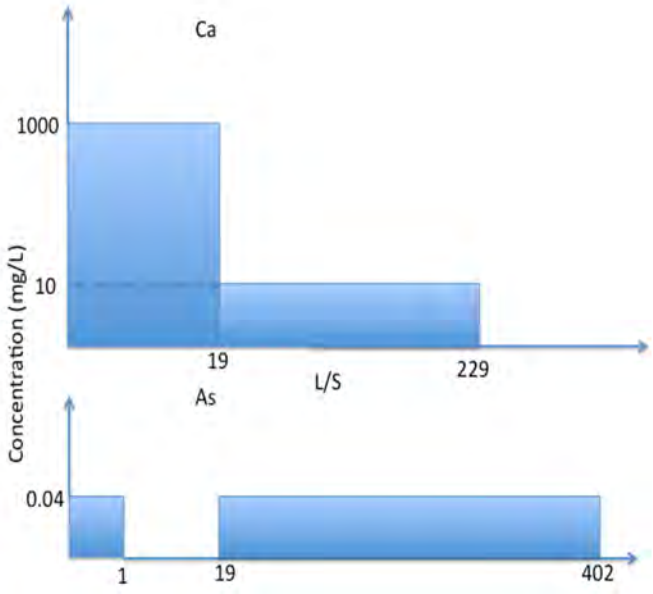
EaFA Idealized Curves

Figure I-9. Method 1314 results and idealized leaching curves for sample EaFA.

Fly Ash Sample	Own pH	Calcium		Arsenic		
		$M_{0,Ca}$ (mg/kg)	$LS_{90,Ca}$ (L/kg)	$M_{0,As}$ (mg/kg)	$C_{0,As}$ (mg/L)	$LS_{Max,As}$ (L/kg)
UFA	11.8	20,990	19	15	0.04	402



UFA Method 1314 Results



UFA Idealized Curves

Figure I-10. Method 1314 results and idealized leaching curves for sample UFA.

I.4 Estimating Flux and Leaching Duration

The leaching profiles discussed above are presented in terms of C_0 and cumulative L/S ratio. Additional steps are required to translate these data into inputs for EPACMTP. While C_0 represents a concentration released into infiltrating water (mg/L), EPACMTP requires leachate to be expressed as a mass flux per unit area of the WMU (g/m^2-yr). Similarly, while the cumulative L/S ratio is measured in units of L/kg, EPACMTP requires that leaching duration be expressed as time (yr). This subsection presents a general description of the methods used to convert C_0 into mass flux and the cumulative L/S ratio into time.

I.4.1 Converting Concentration into Flux

Mass flux, the total amount of constituent mass that is released from a landfill over specific period of time, was calculated with **Equation I-2**. EPA used C_0 calculated from Method 1313 data, together with infiltration rates calculated with precipitation data from the most representative climate center, to calculate site-based values for each landfill:

(I-2) $$\dot{m} = C_0 \cdot I \left(\frac{g}{1{,}000\ mg}\right)\left(\frac{1{,}000\ L}{m^3}\right)$$

Where:

$\dot{m}$ = Annual constituent mass flux (g/m2-yr);
C_0 = Initial Leachate Concentration (mg/L);
I = Infiltration rate (m/yr).

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I.4.2 Converting Cumulative Liquid-to-Solid Ratio into Time

The amount of time required to reach a specific cumulative L/S ratio was calculated with **Equation I-3**, adapted from U.S. EPA (2006). EPA used landfill depths drawn from survey data and infiltration rates calculated with precipitation data from the most representative climate center, together with a fixed landfill density, to calculate site-based values for each landfill.

(I-3) $$t = LS_{cum}\left(\frac{\rho_{LF} \cdot d_{LF}}{I}\right)\left(\frac{m^3}{1{,}000\ L}\right)$$

Where:

t = Time (yr);
LS = Liquid-to-solid ratio (L/kg);
ρ_{LF} = Landfill density of 1,600 kg/m3 based on Kosson et al (2006);
d_{LF} = Landfill depth (m);
I = Infiltration rate (m/yr).

Using this equation, the times to reach different cumulative L/S ratios were calculated for landfills using the regional recharge rates assigned based on the most representative climate station. For reference, percentiles of the calculated times necessary to reach cumulative L/S ratios of 1 and 10 are presented in **Table I-1**.

Table I-1. Time to Reach Cumulative L/S Ratio of 1 and 10

Percentiles	L/S Ratio of 1 (years)	L/S Ratio of 10 (years)
5th	24.4	244
10th	41.6	416
25th	85.4	854
50th	143	1,425
75th	291	2,910
90th	1,171	11,710
95th	5,087	50,870

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Appendix J.

Surface Water Modeling

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J.1 Introduction

The probabilistic analysis considered risks resulting from Constituents of Potential Concern (COPCs) in surface water that result from ground water discharges. Modeling this pathway required estimating the mass flux of ground water (and COPC mass in that ground water) into surface water, as well as modeling the fate of COPCs once in the surface water. EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP), which was used to model ground water transport, does not include transfer from ground water to surface water bodies. This appendix presents the equations used to model surface water concentrations due to ground water intercepting surface water. It also describes the surface water models used to determine constituent partitioning between water and sediments.

- **Attachment J-1** provides the equations comprising the surface water equilibrium partitioning model, including equations that estimate steady-state concentrations in the water column (dissolved and total) and sediments.

J.2 Ground Water to Surface Water Modeling

At some sites, waste management units (WMUs) are located upgradient from one or more surface water bodies (e.g., stream, lake). At these sites, it is possible that the water body intercepts the flow of ground water before it reaches a receptor well. To determine the mass flux of constituents into these surface water bodies, as well as the effect of surface water interception on receptor well concentrations further downgradient, two separate procedures were developed. These two procedures were developed only for the case of gaining streams, which are streams that receive baseflow from ground water. Losing streams, which discharge to ground water, receive no water or constituent loading from ground water. Instead, the stream may discharge to the surficial aquifer, potentially diluting the constituent concentrations that are present.

Although it is known that some water bodies alternate between gaining and losing on a seasonal basis, this analysis assumed that each modeled water body was gaining year-round. While this approach may underestimate some fraction of potential exposures from ingestion of ground water by always intercepting and capturing some ground water flow, it does not include the dilution effect from losing streams that could balance this effect. Also, this assumption will not significantly affect the high-end ground water receptor risks that are dominated by sites where no intercepting water bodies are present.

The mathematical descriptions of ground water flow into a gaining stream and chemical transport downgradient from the stream must be modified to account for the mass of both water and constituents lost to the stream. To handle these special cases, two independent procedures were developed. The first procedure was developed to estimate the mass flux of constituents into the intercepting stream. The second procedure was developed to estimate the constituent concentrations at a receptor well located downgradient from an intercepting stream.

J.2.1 Mass Flux from Aquifer into a Stream

To predict the mass flux of a constituent from an aquifer into a stream, the distribution of constituent concentrations and volumetric ground water fluxes along the upgradient edge of the stream must be known. The volumetric ground water flux depends on the difference between the stream stage and the hydraulic head in the aquifer. If the hydraulic head in the aquifer is higher than the stream stage, the ground water from the aquifer will enter the stream as baseflow. When this occurs, the stream is said to be a gaining stream. The procedure below was developed for gaining streams only. **Figure J-1** provides a graphical conceptualization of the modeled scenario.

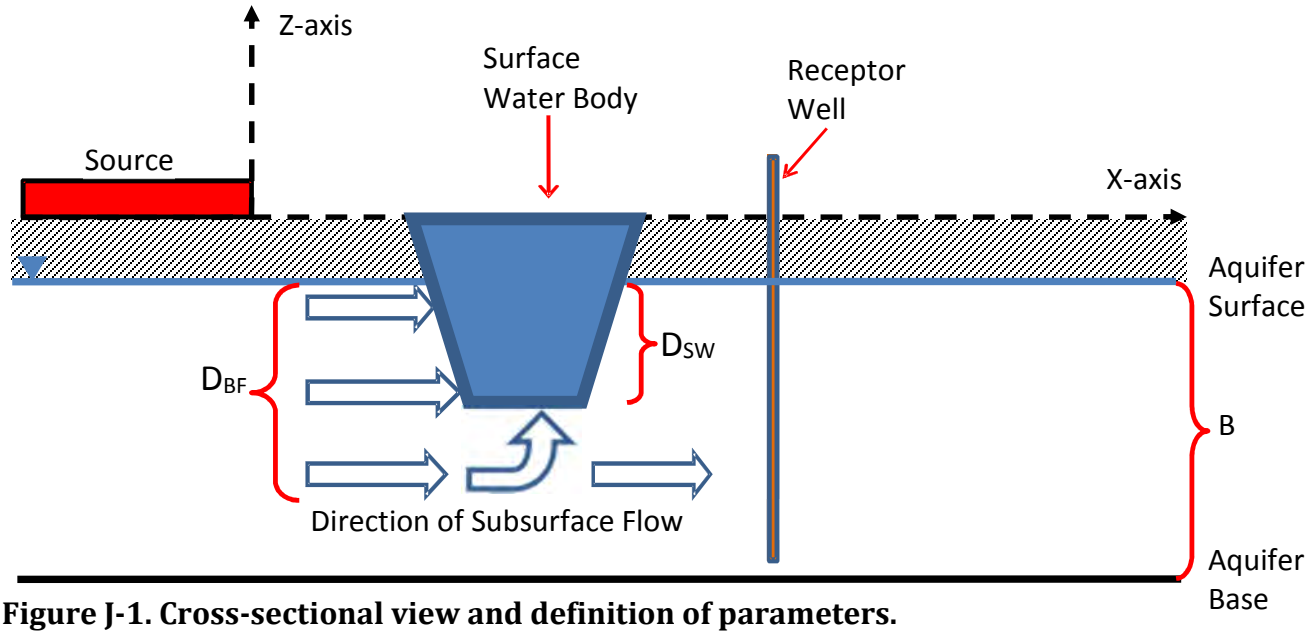

Figure J-1. Cross-sectional view and definition of parameters.

The ground water volumetric flux per unit area of stream bed is governed by the difference in ground water hydraulic head, hydraulic conductivity of streambed, and streambed thickness. In many watersheds, baseflow in terms of volumetric inflow rate per unit length of stream is available. Assuming that the base flow information is available, mass flux may be estimated by integrating the product of baseflow flux per unit area and constituent concentration over the total baseflow area. The total baseflow area is determined by the baseflow depth, D_{BF}, and the domain half width, Y_B. The total mass flux is determined using the baseflow rate and the output constituent concentration from EPACMTP according to the equation below.

(J-1)
$$M = 2\,\frac{q_{Baseflow}}{D_{BF}} \int_{y=0}^{y=Y_B} \int_{z=0}^{z=D_{BF}} C(X = X_{SW}, y, z, t)\,dy\,dz$$

Where:

D_{BF} = Baseflow depth (L);
C = Chemical concentration at $X = X_{SW}$ (M/L^3);
x = Horizontal distance of stream from the downgradient edge of the WMU (L);
X_{SW} = Distance of stream from the downgradient edge of the WMU (L);

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y = Horizontal distance (L) from the plume center line along a vertical plane at the upgradient side of the surface water body; and

z = Vertical distance (L) from the top of a vertical plane at the upgradient side of the surface water body, positive downward.

The concentration term, C, is obtained from Equation (4.92) in the EPACMTP Technical Background Document (U.S. EPA, 2003a) and baseflow depth which is defined by:

(J-2) $$D_{BF} = \left(\frac{q_{Baseflow}}{q_{Aquifer}}\right) B$$

Where:

B = saturated thickness of the aquifer.

The baseflow depth, D_{BF}, which is based on the Dupuit approximation (Bear, 1972), is considered more accurate than the surface water depth, D_{SW} for the following reasons: 1) baseflow is a measured quantity in gauged streams; 2) reference elevations for stream depth are not always known; 3) a reported stream depth for a given stream may not reflect its average depth; and 4) stream depth may not account for the contraction of ground water flow tube due to localized steepening of hydraulic gradient before entering the stream. **Figure J-2** provides a graphical conceptualization of the modeled scenario.

J.2.2 Concentration at Wells Located Downgradient from a Stream

In this scenario, a stream flows perpendicular to the direction of regional ground water flow. The distance between the downgradient edge of the WMU and the upgradient edge of the surface water body is X_{SW}. A receptor well is located at a distance of X_{RW} from the downgradient edge of the WMU. If $X_{RW} > X_{SW}$, the well is located downgradient from the surface water body, a situation the original EPACMTP transport module does not allow. This procedure was developed to overcome the deficiency.

The procedure described here estimates the surface water baseflow (the water transferred from the aquifer to the surface water body) and the ground water flow rate between the surface water body and the receptor well location. It corrects the EPACMTP transport module to reflect the presence of the surface water body, by relocating the well to a distance X'_{RW} from the downgradient edge of the WMU where the concentration is equivalent to the concentration from the actual receptor well. **Figure J-2** provides a graphical conceptualization of the modeled scenario. By relocating the receptor well location to X'_{RW} from the downgradient edge of the WMU, the concentration equivalent to the concentration from the actual receptor well (located at the distance of X_{RW}) is calculated using the solution of the ground water flow and constituent transport equations at the new well location, X'_{RW}.

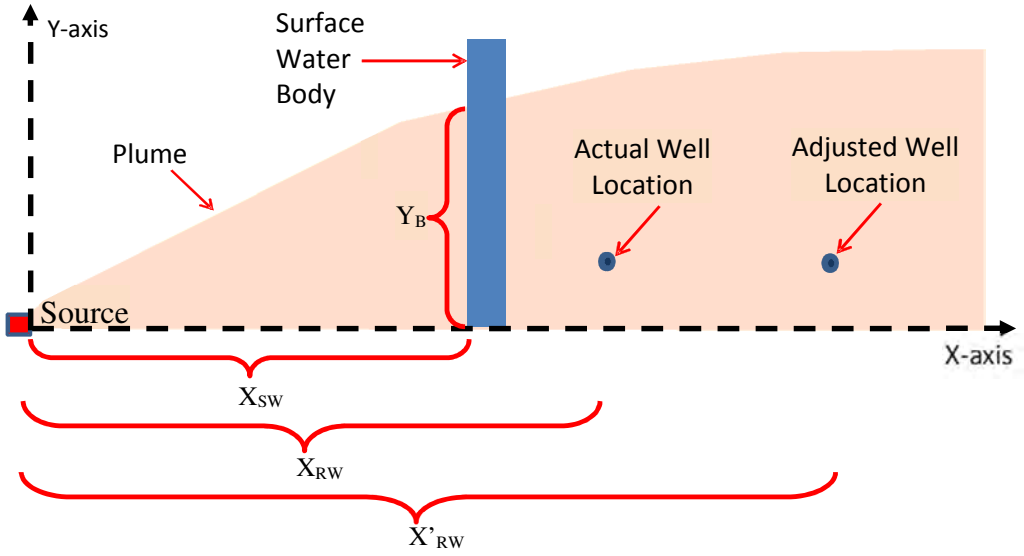

Figure J-2. Aerial view and definition of parameters.

The aquifer modeled by EPACMTP is assumed to receive clean and uniform recharge from the infiltration of precipitation across the entire area around the WMU, which includes the entire footprint of the constituent plume (U.S. EPA, 2003a). As a result, the aquifer flow rate per unit width, $q_{Aquifer}$, along the x-axis may gradually increase due to the cumulative effects of recharge along the flow direction. In the EPACMTP transport module, the aquifer flow rate is assumed to be uniform. To account for variations in the flow rate, spatial averaging of $q_{Aquifer}$ between two points of interest is performed. Between the surface water body and the receptor well, spatially averaged flow rate per unit width is given by:

(J-3) $$q_{Averageflow} = \frac{1}{X_{RW} - X_{SW}} \int_{x=X_{SW}}^{x=X_{RW}} q_{Aquifer}\, dx$$

Where:

$q_{Averageflow}$ = Averaged aquifer flow rate per unit width of the flow domain with baseflow included (L2/T);
$q_{Aquifer}$ = Aquifer flow rate per unit width of the flow domain with baseflow included (L2/T);
X_{SW} = Distance to the stream from the downgradient edge of the WMU (L); and
X_{RW} = Distance to the receptor well from the downgradient edge of the WMU (L).

However, EPACMTP is not designed to account for loss to water bodies. Therefore, $q_{Averageflow}$ is calculated as though the water body does not exist and includes the baseflow that would be intercepted. Baseflow, or the total volumetric flux of water intercepted by a gaining stream, is:

(J-4) $$Q_{Baseflow} = 2\, Y_B\, q_{Baseflow}$$

Where:

$Q_{Baseflow}$ = Total baseflow water flux intercepted by the stream (L3/T);
$q_{Baseflow}$ = Baseflow water flux intercepted per unit length of the stream (L2/T); and
Y_B = Half-width of the intercepted constituent plume (L).

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Note that because of the assumed symmetry of the plume, only half the plume is explicitly modeled; the other half is assumed to be a mirror image of that modeled. After excluding baseflow to the stream, the resulting net aquifer flow rate per unit width between the stream and the well is given by:

(J-5) $$q_{Netflow} = q_{Averageflow} - q_{Baseflow}$$

Where:

$q_{Netflow}$ = Net aquifer flow rate per unit width of with the constituent plume with baseflow removed (L^2/T).

As shown above, the interception of baseflow changes the ground water flow rate per unit width downgradient from the surface water body from $q_{Averageflow}$ to $q_{Netflow}$. Knowing $q_{Netflow}$, it is possible to use the original solution to the ground water fate and transport equations by relocating the receptor well from X_{RW} to X_{RW}', where X_{RW}' represents a new distance that will result in the same concentration based on $q_{Netflow}$ as a receptor well at X_{RW} based on $q_{Averageflow}$. This relocation procedure is based on an assumption that the dispersion is much smaller than the advection. This assumption is valid when the Peclet number is greater than 10 (Garges and Baehr, 1998).[1] An estimate of the Peclet numbers for the sites modeled in this analysis was conducted based on the dispersivity of the aquifers and the receptor well distribution data in the EPACMTP Background document (US EPA, 2003b) as the characteristic length. This estimate showed that the majority of sites modeled have Peclet numbers varying from 10 to 5,000. Therefore, a transformation procedure was developed to modify the receptor well locations using the equations below:

(J-6) $$(X'_{RW} - X_{SW}) = \frac{q_{Averageflow}}{q_{Netflow}}(X_{RW} - X_{SW})$$

Since $q_{Netflow}$ is not known *a priori*, it is necessary to locate X'_{RW} iteratively, as follows:

Step 1: As an initial estimate, assume that the new location of the receptor well is at the original position, so that the current approximate receptor well location $\bar{X}_{RW}$ is equal to X_{RW}.

Step 2: Estimate $q_{Netflow}$ using the current value of $\bar{X}_{RW}$, as follows:

(J-7) $$q_{Netflow} = \left(\frac{1}{\bar{X}_{RW} - X_{SW}} \int_{X=X_{SW}}^{X=\bar{X}_{RW}} q_{Aquifer}\, dx\right) - q_{Baseflow}$$

Step 3: Use $q_{Netflow}$ obtained in Step 2 to estimate a new value of X'_{RW}:

[1] The Peclet number (Pe) is a dimensionless number used to describe the flow of fluids. It is defined as the ratio of the rate of advection and the rate of diffusion of a fluid through a given medium. In general, where Pe >> 1, advection dominates transport and, where Pe << 1, diffusion dominates transport.

(J-8) $$X'^{i}_{RW} = \frac{q_{Averageflow}}{q_{Netflow}}(X^{o}_{RW} - X_{SW}) + X_{SW}$$

Where:

X'^{i}_{RW} = ith iteratation of X'RW.

Step 4: Update the approximate location of the receptor well (Note that $X'^{0}_{RW} = X_{RW}$).

(J-9) $$\overline{X}_{RW} = \frac{1}{2}\left(X'^{i}_{RW} + X'^{i-1}_{RW}\right)$$

Step 5: Check convergence until the difference between the most current X'_{RW} is sufficiently close to the value calculated in the previous iteration. In other words,

(J-10) $$\left|X'^{i}_{RW} - X'^{i-1}_{RW}\right| < \epsilon$$

Where:

ϵ = acceptable tolerance (a typical value is 0.1 m or 0.3 ft).

J.2.3 Post-Processor Verification

The stream interception routine was verified by comparing results obtained from a number of scenarios using EPACMTP (U.S. EPA, 2003a) and MODFLOW-based Hydrologic Modeling System (MODHMS) (HydroGeoLogic, 2011). MODHMS is an enhanced version of the U.S. Geological Survey MODFLOW modular three-dimensional ground water flow code (McDonald and Harbaugh, 1988). The MODHMS code has been selected for this verification because it can handle variable saturation, has been extensively verified and documented, and has been implemented by a number of government agencies in different settings. MODHMS can solve the equations without any approximate transformation for the case of baseflow intercepted by a surface water body. The transport equation solutions provided by the MODHMS code were considered accurate and treated as a standard against which the EPACMTP solutions were compared. The mass flux into the intercepting water body (**Section J.2.1**) and the concentration in a receptor well downgradient from an intercepting water body (**Section J.2.2**) were verified separately.

Verification Scenario Description

The verification scenario is shown in **Figure J-3**. The size of the model domain is (1,000 ft × 1,000 ft). The regional ground water gradient in the MODHMS-based model was imposed by constant heads along the upgradient (western) and downgradient (eastern) boundaries. Regional gradient across the flow domain from is 0.005 ft/ft. The model domain is homogeneous with an effective porosity of 0.3 and a hydraulic conductivity of 10 ft/day. A 60 ft × 60 ft square source is located 40 ft from the upstream boundary and 470 ft from the lateral boundary. An infiltration rate of 4.49 × 10^{-4} ft/day is imposed at the source only. A 10-ft wide stream, perpendicular to the regional flow direction, traverses the x-axis 400 ft downgradient from the source. The longitudinal, transverse and vertical dispersivities are 100 ft, 10 ft and 1 ft, respectively. The saturated thickness is 100 ft and uniform. The domain is mainly discretized into horizontally uniform grid cells with the 10 ft × 10 ft dimensions with a 1 ft thickness for the top 10 layers, a 5-ft thickness for the bottom 16 layers and increasing thickness for the middle 4 layers from 1 ft to 4 ft. To allow comparison of

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receptor well concentrations at various locations downgradient from the water body, two discrete receptor well locations were chosen. Both wells are located at 250 ft from the water body. One well is located 0 ft from the centerline of the plume and the other is offset by 30 ft. Each well is screened at depths of 0.5 ft, 1.5 ft, and 2.5 ft below the ground water table. Leachate concentration from the surface impoundment is 1 mg/L.

Constituent transport was simulated using the EPACMTP postprocessing module and MODHMS under a baseflow flux of approximately 10% and 1% of the regional aquifer flux. This range was chosen to test the accuracy of the procedures when the baseflow depth is relatively small (thus making the mass flux estimation relatively difficult) and when a large fraction of mass is allowed to travel to the receptor well (thus making the constituent concentration relatively significant). In both cases, it was assumed that the vadose zone did not exist so that the infiltration with constituent entered the water table immediately after leaving the bottom of the WMU. This configuration makes the leachate influx at the top of the water table (a model input) the same for both models, thereby allowing the mass fluxes and concentrations at the receptor well location predicted by the MODHMS and the EPACMTP models to be compared directly. It was assumed that neither adsorption nor degradation occurred in the ground water.

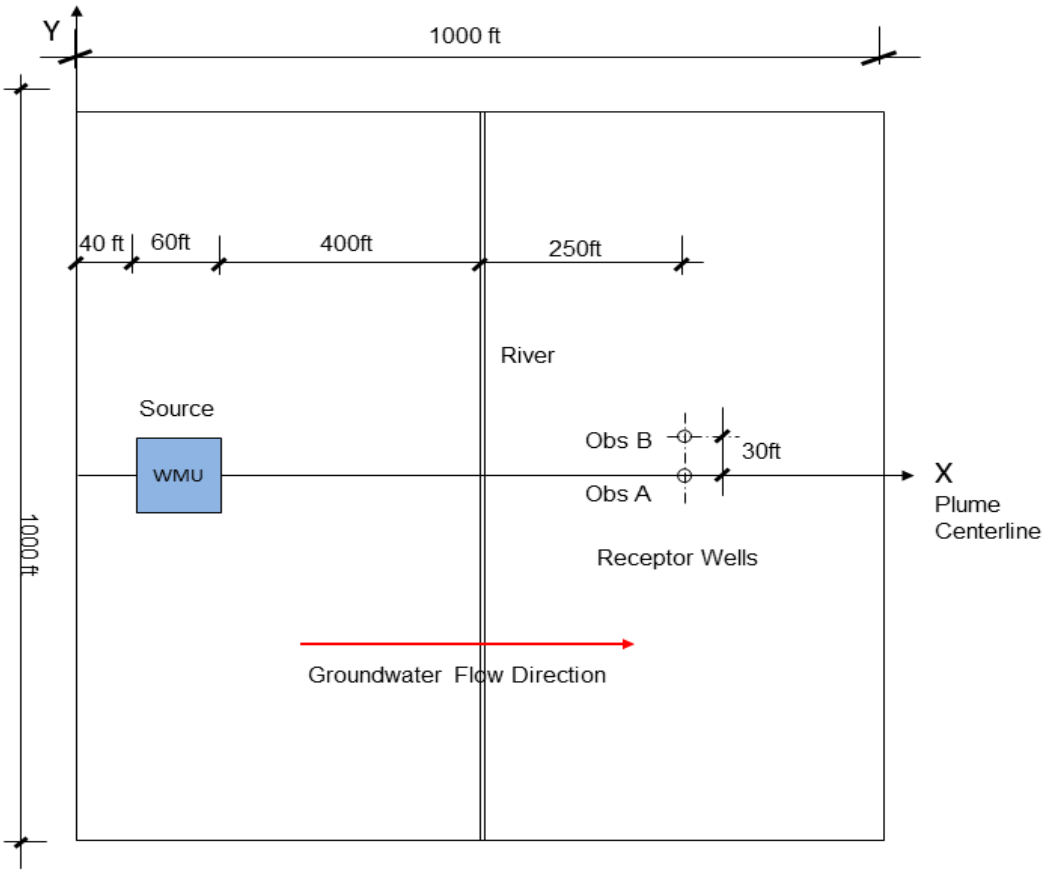
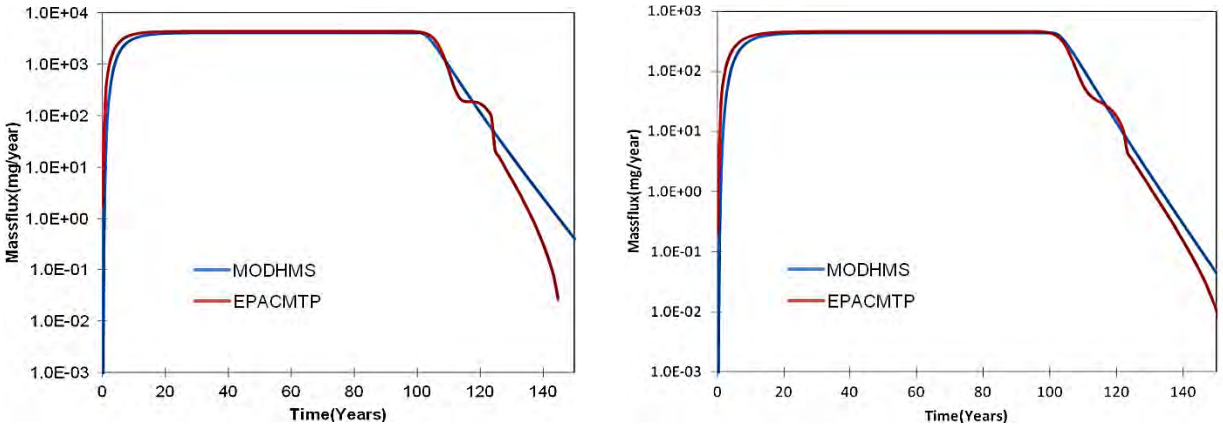


Figure J-3. Simulation domain for verifying surface water interception routine.

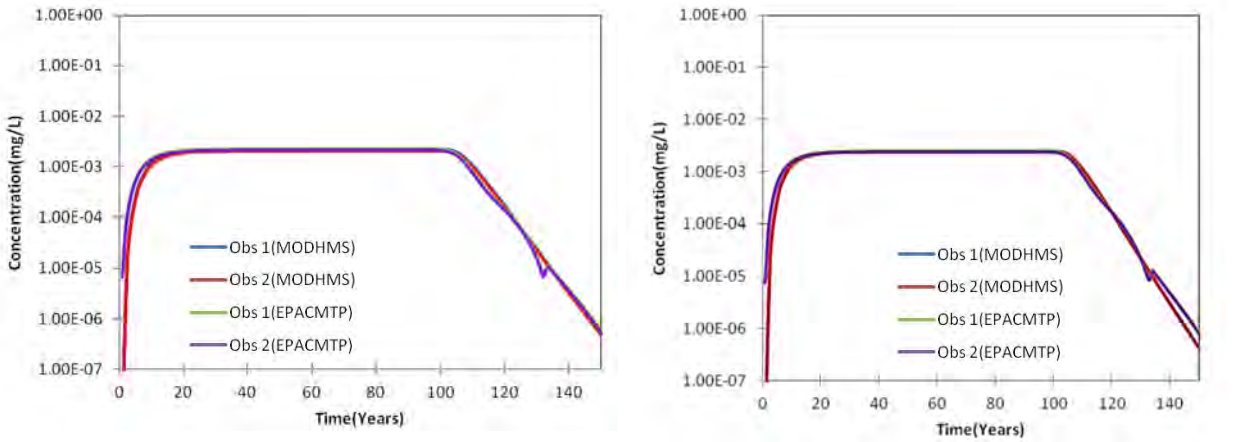
Verification Results

Figure J-4 compares the EPACMTP-generated and MODHMS-generated mass fluxes to the stream from Scenarios 1 and 2. As shown in these figures, the EPACMTP-based mass fluxes agree reasonably well with those based on the more accurate numerical MODHMS-based model. However, the EPACMTP model tends to be more conservative than the MODHMS-based model. **Figure J-5** compares the EPACMTP-generated breakthrough curves at adjusted well locations and the corresponding MODHMS-generated breakthrough curves at actual observation locations from Scenario 1, Layers 1, 2 and 3. In all of these figures, breakthrough curves are almost identical. EPACMTP tends to return slightly more conservative results than MODHMS. Minor oscillations in the EPACMTP curve as it decreases are artifacts of the limitation of computer precision in the numerical computations and should be ignored.



Scenario 1: 10% baseflow Scenario 2: 1% baseflow

Figure J-4. Mass flux entering the stream downgradient from the WMU.



Scenario 1: Obs. Locations 1 and 2 in Layer 1 Scenario 2: Obs. Locations 1 and 2 in Layer 1

Figure J-5. Breakthrough curves at various observation locations for two scenarios.

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J.3 Surface Water Model Overview

The surface water model used in this analysis is a simple steady-state model used previously in the EPA *Methodology for Assessing Health Risks Associated with Multiple Pathways of Exposure to Combustor Emissions* (U.S. EPA, 1998). The specific equations used are presented in **Attachment J-1**. The following are the key assumptions of this model and the specifics on how it was applied for the revised risk assessment:

- The model assumes steady-state flow and transport conditions. Long-term average annual stream flow and climatic data and assumptions were used.
- The model is able to account for constituent loadings into the water body through ground water discharge, waste outfalls, and direct air deposition. The only source relevant to the revised risk assessment is discharges from ground water.
- The model estimates the rate of incorporation, or burial, of constituents into bed sediments as a function of the rate at which sediments deposit from the water column onto the surficial sediment layer. For the coal combustion residual (CCR) risk assessment, the burial rate was set to zero (a protective assumption) because of the lack of national data available to estimate this process.
- The model can incorporate separate decay rate constants for the water column and the benthic sediments to allow for consideration of decay mechanisms that remove constituents from the water body. However, because all of the inorganics considered are persistent in the environment, degradation was not relevant to this risk assessment.

The model describes the partitioning of constituents between aquatic sediments, suspended solids, and surface water using linear equilibrium partition coefficients (i.e., equilibrium is maintained between dissolved constituents within the water column and constituents in suspended solids and bed sediments). **Table J-1** provides distributions for the partitioning coefficients used by the surface water model. These distributions were derived primarily from published empirical data presented in U.S. EPA (2005) and were sampled during the preparation of the input files in the Monte Carlo process.

Table J-1. Sediment/Water and Suspended Solids/Water Partition Coefficients: Empirical Distributions*

Constituent	Sediment/Water				Suspended Solids/Water			
	Min	Mean	Max	SD	Min	Mean	Max	SD
Aluminum	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Antimony	0.6	3.6	4.8	1.8	3.9	4.8	4.9	0.5
Arsenic	1.6	2.4	4.3	0.7	2	3.9	6	0.5
Barium	0.9	2.5	3.2	0.8	2.9	4	4.5	0.4

(continued)

Table J-1. Sediment/Water and Suspended Solids/Water Partition Coefficients: Empirical Distributions*

Constituent	Sediment/Water				Suspended Solids/Water			
	Min	Mean	Max	SD	Min	Mean	Max	SD
Beryllium	0.8	2.8	6.5	1.9	2.8	4.2	6.8	0.7
Boron	-0.5	0.8	1.4	0.5	3.4	3.9	4.1	0.2
Cadmium	0.5	3.3	7.3	1.8	2.8	4.9	6.3	0.6
Chloride	0	0	0	0	0	0	0	0
Chromium III	1.9	4.9	5.9	1.5	3.9	5.1	6	0.4
Chromium VI	0	1.7	4.4	1.4	3.6	4.2	5.1	0.5
Cobalt	2.9	3.1	3.6	1	3.2	4.8	6.3	0.8
Copper	0.7	3.5	6.2	1.7	3.1	4.7	6.1	0.4
Fluoride	N/A	2.2	N/A	N/A	N/A	2.2	N/A	N/A
Iron	N/A	1.4	N/A	N/A	N/A	1.4	N/A	N/A
Lead	2	4.6	7	1.9	3.4	5.7	6.5	0.4
Mercury	3.8	4.9	6	0.6	4.2	5.3	6.9	0.4
Methyl mercury	2.8	3.9	5	0.5	4.2	4.9	6.2	0.7
Molybdenum	0.4	2.5	3.7	0.8	3.5	4.4	5.7	0.4
Nickel	0.3	3.9	4	1.8	3.7	4.4	4.9	1
Selenium IV	1	3.6	4	1.2	3.8	4.4	4.8	0.4
Selenium VI	-1.4	0.6	3	1.2	3.1	3.8	4.6	1
Silver	2.1	3.6	5.8	1.1	4.4	5.2	6.3	0.6
Thallium	-0.5	1.3	3.5	1.1	3	4.1	4.5	1
Vanadium	0.4	2.1	3.2	0.9	2.5	3.7	4.5	0.6
Zinc	1.5	4.1	6.2	1.6	3.5	5	6.9	0.5

Source: U.S. EPA (2005) except for boron, iron, chloride and fluoride. The K_d distribution for boron was created by Dr. Jerry Allison for the previous CCR risk assessment in the same manner as described for the other metals in U.S. EPA (2005). The K_d values for fluoride and iron are from Baes (1984), which does not provide a full distribution. A protective K_d of 0 was assumed for chloride in the absence of other data.

*All values are log values and distribution type is log-normal.

SD = standard deviation.

N/A = data not available.

J.4 Aluminum Surface Water Precipitation

This section describes solubility-based surface water algorithms used to model aluminum in the CCR risk assessment. Because the fate and transport of aluminum is controlled more by solubility than by sorption in surface water, the surface water model includes algorithms to estimate aluminum concentrations in the water column and sediments by accounting for precipitation and fallout of aluminum in the water column. Gibbsite, a simple mineral form of aluminum hydroxide, was used as the basis for these calculations based on the prevalence of this mineral in the environment. The calculations proceed in a stepwise fashion, as follows:

Step 1: Initially, all aluminum entering the water body is assumed to be dissolved.

$$f_{water} = f_d = 1$$
$$f_{benth} = 0$$
$$C_{wctot} = C_{wd}$$

Where:

f_{water} = Fraction in water column (unitless)
f_d = Fraction dissolved (unitless)
f_{benth} = Fraction in sediment layer (unitless)
C_{wctot} = Total water column concentration (mg/L)
C_{wd} = Dissolved water column concentration (mg/L)

Step 2: Compare the dissolved water column concentration (C_{wd}) with the maximum soluble concentration (C_{sol}) calculated in Metal Speciation Equilibrium Model for Surface and Ground Water (MINTEQA2) for the water body pH, presented in **Table J-2**.

Table J-2. Aluminum Solubility Calculated by MINTEQA2 as a Function of Water Body pH

Minimum pH	Maximum pH	Solubility (mg/L)
3.5	4.5	26.2
4.5	5	1.84
5	5.5	0.196
5.5	6	0.0112
6	6.5	0.00143
6.5	7	0.000662
7	7.5	0.000915
7.5	8	0.00229
8	8.5	0.00682
8.5	9	0.0212
9	9.5	0.0666
9.5	10	0.211
10	10.5	0.668

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Step 3: If the dissolved water concentration (C_{wd}) is greater than the solubility limit (C_{sol}), reset the dissolved water concentration to the solubility limit, and precipitate and settle out the excess aluminum to the benthic sediment layer:

$$f_{water} = \frac{C_{sol}}{C_{wctot}}$$

$$f_{benth} = \frac{(C_{wctot} - C_{sol})}{C_{wctot}}$$

$$C_{wbs} = (C_{wctot} - C_{sol})\frac{d_{wc}}{d_b}$$

$$C_{wtot} = C_{wctot}\frac{d_{wc}}{d_z}$$

$$C_{wd} = C_{sol}$$

$$C_{wctot} = C_{sol}$$

Where (in addition to the variables previously defined):

C_{sol} = Solubility limit (mg/L)
C_{wbs} = Total concentration in bed sediment
C_{wtot} = Total water body concentration from loading
d_b = Depth of the upper benthic layer (m)
d_{wc} = Depth of the water column (m)
d_z = Depth of the water body (m)

Otherwise, set the dissolved concentration to the total water column concentration, and do not precipitate and settle out any aluminum to the sediment:

$$C_{dw} = C_{wctot}$$

$$C_{wbs} = 0$$

$$C_{wtot} = C_{wctot}\frac{d_{wc}}{d_z}$$

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J.5 References

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Attachment J-1.
Surface Water Concentrations

This attachment contains the equations for surface water concentrations.

- **Table J-1-1.** Fraction of Contaminant in Water Column
- **Table J-1-2.** Fraction of Contaminant in Benthic Sediments
- **Table J-1-3.** Dissolved Fraction
- **Table J-1-4.** Liquid-Phase Transfer Coefficient – Lakes (Mercury Only)
- **Table J-1-5.** Liquid-Phase Transfer Coefficient – Streams (Mercury Only)
- **Table J-1-6.** Gas-Phase Transfer Coefficient – Lakes (Mercury Only)
- **Table J-1-7.** Diffusion Transfer Rate (Mercury Only)
- **Table J-1-8.** Water Concentration Dissipation Rate Constant
- **Table J-1-9.** Total Water Body Concentration from Loading
- **Table J-1-10.** Total Water Column Concentration
- **Table J-1-11.** Dissolved Water Body Concentration
- **Table J-1-12.** Total Concentration in Bed Sediment.

Table J-1-1. Fraction of Contaminant in Water Column (Unitless)

f_{Water}

$$d_w = d_z - d_b$$

$$f_{Water} = \frac{\left[1+\left(K_{dsw}\times TSS\times 0.000001\right)\right]\times\frac{d_w}{d_z}}{\left[\left[1+\left(K_{dsw}\times TSS\times 0.000001\right)\right]\times\frac{d_w}{d_z}\right]+\left[\left(bsp+K_{dbs}\times bsc\right)\times\frac{d_b}{d_z}\right]}$$

Name	Description	Value
bsc	Bed sediment particle concentration (g/cm^3) or (kg/L)	1
bsp	Bed sediment porosity (cm^3/cm^3)	0.6
db	Depth of upper benthic layer (m)	0.03
dw	Depth of water column (m)	Calculated
dz	Depth of the water body (m)	See **Appendix B**
K_{dbs}	Sediment-water partition coefficient (mL/g)	See Table J-1
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	See **Table J-1**
TSS	Total suspended solids (mg/L)	See **Appendix B**
--	Conversion factor (L/mL)(g/mg)	0.000001

Table J-1-2. Fraction of Contaminant in Benthic Sediments (Unitless)

f_{Benth}

$$f_{Benth} = \frac{(bsp + K_{dbs} \times bsc) \times \frac{d_b}{d_z}}{\left[(1 + K_{dsw} \times TSS \times 0.000001) \times \frac{d_w}{d_z}\right] + \left[(bsp + K_{dbs} \times bsc) \times \frac{d_b}{d_z}\right]}$$

Name	Description	Value
bsc	Bed sediment particle concentration (g/cm^3) or (kg/L)	1
bsp	Bed sediment porosity (cm^3/cm^3)	0.6
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Calculated (**Table J-1-1**)
d_z	Depth of the water body (m)	See **Appendix B**
K_{dbs}	Sediment-water partition coefficient (mL/g)	See **Table J-1**
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	See **Table J-1**
TSS	Total suspended solids (mg/L)	See **Appendix B**
--	Conversion factor (L/mL)(g/mg)	0.000001

Table J-1-3. Dissolved Fraction (Unitless)

f_d

$$f_d = \frac{1}{1 + K_{dsw} \times TSS \times 0.000001}$$

Name	Description	Value
K_{dsw}	Suspended sediment-water partition coefficient (mL/g)	See **Table J-1**
TSS	Total suspended solids (mg/L)	See **Appendix B**
--	Conversion factor (L/mL)(g/mg)	0.000001

Table J-1-4. Liquid-Phase Transfer Coefficient – Lakes (m/day) (Mercury Only)

KL_{lakes}

$$KL_{Lakes} = \sqrt{C_d} \times u_w \times \sqrt{\frac{R_a}{R_w}} \times \frac{k^{0.33}}{L_2} \times \left(\frac{\mu_w}{R_w \times D_w} \right)^{-0.67} \times 86400$$

Name	Description	Value
C_d	Drag coefficient (unitless)	0.0011
D_w	Diffusivity in water (cm^2/s)	1.8×10^{-5}
k	von Karman's constant (unitless)	0.4
L_2	Viscous sublayer thickness (unitless)	4
μ_w	Viscosity of water (g/cm-s)	0.0169
R_a	Density of air (g/cm^3)	0.0012
R_w	Density of water (g/cm^3)	1
u_w	Mean annual wind speed (m/sec)	See **Appendix B**
--	Conversion factor (sec/day)	86,400

Table J-1-5. Liquid-Phase Transfer Coefficient – Streams (m/day) (Mercury Only)

$KL_{streams}$

$$KL_{streams} = \sqrt{\frac{D_w \times U \times 0.0001}{d_z}} \times 86400$$

Name	Description	Value
D_w	Diffusivity in water (cm^2/s)	2×10^{-5}
d_z	Depth of the water body (m)	See **Appendix B**
U	Current velocity of the water body (m/s)	See **Appendix B**
--	Conversion factor (sec/day)	86,400

Table J-1-6. Gas-Phase Transfer Coefficient – Lakes (m/day) (Mercury Only)

K_{gas}

$$K_{gas} = \sqrt{C_d} \times u_w \times \frac{k^{0.33}}{L_2} \times \left(\frac{\mu_a}{R_a \times D_a} \right)^{-0.67} \times 86400$$

Name	Description	Value
C_d	Drag coefficient (unitless)	0.0011
D_a	Diffusivity of chemical in air (cm^2/s)	0.05
k	von Karman's constant (unitless)	0.4
L_2	Viscous sublayer thickness (unitless)	4
μ_A	Viscosity of air (g/cm-s)	0.000181
R_a	Density of air (g/cm^3)	0.0012
u_w	Mean annual wind speed (m/sec)	See **Appendix B**
--	Conversion factor (sec/day)	86,400

Table J-1-7. Diffusion Transfer Rate (m/day) (Mercury Only)

K_v

$$Tempadjust = \theta_{water}^{(T_w - T_{hlc})}$$

$$K_v = \frac{1}{\frac{1}{K_L} + \frac{1}{K_g \times H'}} \times TempAdjust$$

$$H' = \frac{HLC}{R \times T_w}$$

Name	Description	Value
HLC	Henry's law constant (atm-m^3/mole)	7 x 10^{-10}
H’	Dimensionless Henry's law constant (unitless)	Calculated
K_g	Gas-phase transfer coefficient (m/d)	Calculated (**Table J-1-6**)
KL	Liquid-phase transfer coefficient (m/d)	Calculated (**Table J-1-4** [lakes], **Table J-1-5** [streams])
R	Ideal gas constant (atm-m^3/K-mole)	0.00008205
θ_{water}	Temperature correction (unitless)	1.026
T_{hlc}	Temperature of HLC (K)	298
T_w	Temperature of the water body (K)	See Appendix B

Note: Drawn from U.S. EPA, 1998 (EPA-530-D-98-001A and EPA-600/R-98/137).

Table J-1-8. Water Concentration Dissipation Rate Constant (1/day)

K_{wt}

$$K_{wt} = \left(f_{Water} \times f_d \times k_{vol}\right) + \left(f_{benth} \times K_b\right) + \left(f_{Water} \times k_{sw}\right) + \left(f_{benth} \times k_{sed}\right) + k_h$$

$$K_b = \frac{WB}{d_b}$$

$$k_{vol} = \frac{K_v}{d_w}$$

Name	Description	Value
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Calculated (**Table J-1-1**)
f_{benth}	Fraction of contaminant in benthic sediments (unitless)	Calculated (**Table J-1-2**)
f_d	Dissolved fraction (unitless)	Calculated (**Table J-1-3**)
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated (**Table J-1-1**)
K_b	Benthic burial rate constant (1/day)	Calculated (see above)
k_h	Hydrolysis rate (1/day)	0
k_{sed}	Degradation rate for sediment (1/day)	0
k_{sw}	Degradation rate for water column (1/day)	0
K_v	Diffusion transfer rate (m/day)	Calculated (mercury only)
k_{vol}	Water column volatilization rate constant (1/day)	Calculated (mercury only)
WB	Rate of burial (m/day)	0

Table J-1-9. Total Water Body Concentration from Loading (g/m³ or mg/L)

C_{wtot}

$$C_{wtot} = \frac{L_{total}}{\left(\left(V_{fx} \times f_{Water} \times \frac{d_z}{d_w}\right) + \left(K_{wt} \times V\right)\right)}$$

$$V = Area \times d_z$$

Name	Description	Value
V_{fx}	Water body annual flow mixing volume (m^3/day)	See **Appendix B**
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated (**Table J-1-1**)
d_z	Water body depth (m)	See Appendix B
d_w	Depth of water column (m)	Calculated (**Table J-1-1**)
K_{wt}	Water concentration dissipation rate constant (1/day)	Calculated (**Table J-1-8**)
V	Flow independent mixing volume (m^3)	Calculated (see above)
Area	Area of the water body (m^2)	See **Appendix B**

Table J-1-10. Total Water Column Concentration (g/m³ or mg/L)

C_{wcTot}

$$d_w = d_z - d_b$$

$$C_{wcTot} = C_{wTot} \times f_{water} \times \frac{d_z}{d_w}$$

Name	Description	Value
C_{wTot}	Total water body concentration from loading (g/m³ or mg/L)	Calculated (**Table J-1-9**)
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Calculated (**Table J-1-1**)
d_z	Depth of the water body (m)	See **Appendix B**
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated (**Table J-1-1**)

Table J-1-11. Dissolved Water Body Concentration (mg/L)

C_{dw}

$$d_w = d_z - d_b$$

$$C_{dw} = Cw_{Tot} \times f_{Water} \times f_d \times \frac{d_Z}{d_w}$$

Name	Description	Value
C_{wTot}	Total water body concentration from loading (g/m³ or mg/L)	Calculated (**Table J-1-9**)
d_b	Depth of upper benthic layer (m)	0.03
d_w	Depth of water column (m)	Calculated
d_z	Depth of the water body (m)	See **Appendix B**
f_d	Dissolved fraction (unitless)	Calculated (**Table J-1-3**)
f_{Water}	Fraction of contaminant in water column (unitless)	Calculated (**Table J-1-1**)

Table J-1-12. Total Concentration in Bed Sediment (g/m³ or mg/L)

C_{wbs}

$$C_{bs} = C_{wTot} \times f_{benth} \times \frac{d_z}{d_b}$$

Name	Description	Value
C_{wTot}	Total water body concentration from loading (g/m^3 or mg/L)	Calculated (**Table J-1-9**)_
f_{benth}	Fraction of contaminant in benthic sediments (unitless)	Calculated (**Table J-1-2**)_
d_b	Depth of upper benthic layer (m)	0.03
d_z	Depth of the water body (m)	See **Appendix B**

Appendix K.

Uncertainty Analyses

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K.1 Introduction

To confirm the results of the probabilistic analysis and to better understand whether any particular subset of disposal practices drives the risks identified, the U.S. Environmental Protection Agency (EPA or the Agency) retained each of the exposure pathways from the probabilistic analyses for additional uncertainty analyses. This appendix details the methodology used for some of the uncertainty analyses summarized in **Section 5** the document.

- **Attachment K-1** provides graphs of the times to peak concentration for select constituents.

K.2 Surface Impoundment Preclosure and Postclosure Releases

This section presents the approach used to evaluate uncertainties associated with the modeling of preclosure and postclosure releases for surface impoundments. EPA used the results of this analysis to draw conclusions, summarized in **Section 5**, about the potential for this uncertainty to affect the risk results of the probabilistic analysis.

K.2.1 Technical Approach

The lifetime of a surface impoundment is conceptualized in two phases: a 75-year operational period, during which a constant amount of wastewater is maintained, and a postclosure period, when all free liquid remaining in the impoundment is removed, leaving behind coal combustion residual (CCR) sludges and sediments that are capped with an appropriate final cover. The forces driving leaching from surface impoundments during operation and postclosure are different. During operation, free liquids that are ponded in the impoundment create a strong hydraulic head that acts to increase infiltration through the base of the impoundment. The removal of free liquids and capping during closure reduces the hydraulic head and the rate of contaminant migration. After closure is complete, infiltration through the impoundments is driven only by percolation of incident precipitation through the cap.

In the 2010 Risk Assessment, the postclosure period was not modeled because the hydraulic head reduction between the operational and postclosure periods is so great that the peak ground water exposures used in the HEI risk assessment are unlikely to be affected. However, based on a number of public and peer-review comments received, the revised risk assessment estimated the risks associated with postclosure to determine if any significant risks to ground water had been overlooked. The operational phase of an impoundment is modeled using the standard impoundment source term in EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP). Liquid wastes in the impoundment are assumed to be replenished over the operational life to maintain a constant level of liquid in the unit with constant constituent concentrations. At the end of the 75-year operational life, no additional contaminant mass is introduced into the system. Modeling the postclosure portion of the surface impoundment required a second run of EPACMTP where the surface impoundment was re-conceptualized as a closed landfill. This run was conducted using the database of impoundment and site characteristics supplemented with the additional inputs necessary to define the landfill source term as follows:

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- **Infiltration Rate**: The infiltration rate through the closed impoundment was determined using the following criteria:
  - If the impoundment is unlined, the postclosure infiltration rate is set equal to the regional recharge rate that corresponds to the regional soil type, which is assumed to also be the source for the native soil cap.
  - If the impoundment is lined with clay, the postclosure infiltration rate is set equal to the Hydrologic Evaluation Of Landfill Performance-modeled infiltration rate calculated based on the assigned climate center (see **Appendix C**) and the modeled clay liner hydraulic conductivity of 1×10^{-7} cm/sec.
  - If the impoundment has a geomembrane/composite liner, the infiltration rate from the preclosure period is used as the governing rate.

- **Depth:** The depth of waste in a landfill is one of the parameters used to determine how long constituents leach from the waste. The depth of waste in the landfill (i.e., the closed impoundment) is assumed to be the thickness of the sludge in the impoundment.

- **Total Leachable Concentration:** Following closure, the mass of constituents present in the impoundment are no longer replenished and become finite. This parameter was estimated by assuming that the concentrations in the interstitial pore water and in the sludge sediments are at equilibrium defined by the sorption coefficient (K_d) for the unsaturated zone from the preclosure period simulations. EPA developed K_d values for the unsaturated native soils immediately beneath the waste management units (WMUs), rather than the sludges within the WMUs. These sludges are expected to have a higher sorptive capacity than underlying soils because of the generally higher organic carbon contents of these sludges. A higher sorptive capacity would result in a slower release into the vadose zone. Therefore, the assumption that the K_d in the sludge is identical to that in the vadose zone is conservative for the purposes of these analyses.

For each constituent, peak concentrations are derived from the composite time series results using the following approach. Ground water concentrations resulting from preclosure and postclosure are estimated through the superposition (addition) of the modeled results for both phases. The time series of receptor well concentrations are modeled and saved for each simulation. We conducted preclosure and postclosure simulations separately. Results are interpolated from the model-specified time steps (chosen by EPACMTP in each simulation to maximize computing power) to whole years (e.g., 0, 1, 2, and 3). EPACMTP assumes that time zero corresponds to the time of first release of leachate from a waste management unit; however, postclosure releases are assumed to begin 75 years after the preclosure period begins. To properly combine the two results, the post closure releases must be translated forward in time by 75 years to account for relative perspective of time in EPACMTP simulation results. The two interpolated time series are superimposed by simply adding the simulation results together for each equivalent time step.

The approach was implemented using EPACMTP with non-linear sorption isotherms to investigate whether postclosure releases influence peak ground water concentrations. Trivalent arsenic (arsenic III) and hexavalent chromium (chromium VI) were selected for this uncertainty

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analysis because they are the only carcinogens modeled. Twelve Monte Carlo simulations were performed: both a preclosure and a postclosure simulation of the two metal species for the three waste types modeled in the full-scale analysis [combined ash, ash and coal refuse, and flue-gas desulfurization waste (FGD)]. Peak receptor well concentrations were calculated for the preclosure simulations alone, and in combination with the postclosure simulations. For each waste type / metal species combination, the peak concentrations from the two scenarios were compared to determine the likelihood that the combined peak concentration would exceeded the preclosure peak.

K.2.2 Results of Pre- and Postclosure Modeling

As shown in the following table, consideration of postclosure leaching resulted in higher peak concentrations for only about five percent of all modeled surface impoundments. However, the magnitude of these higher concentrations was typically small. The vast majority (99.3 percent) of the exceedances resulted in a difference of less than 0.000001 mg/L, or four orders of magnitude below the arsenic maximum concentration limit. Only 0.02 percent resulted in a difference greater than 0.01 mg/L, with a maximum difference of 0.017 mg/L. Because the frequency of higher concentrations is very small and the magnitude of the higher concentrations that do occur is typically small, the decision to neglect these postclosure releases is not a major source of uncertainty. **Table K-1** summarizes the frequency at which consideration of postclosure leaching resulted in higher peak concentrations. Percentages are calculated based on the total number of results for all model runs and for each liner type. Any increase in risks attributable to postclosure releases would not be sufficient to change the results presented in **Section 4**.

Table K-1. Summary of Frequencies and Percentages of Combined Peak Concentrations Exceeding Preclosure Peak Concentrations

Liner	Total Model Iterations	Number of Exceedances	All Liners		By Liner Type	
			Percent Exceed	Percent > 1×10^{-6} mg/L	Percent Exceed	Percent > 1×10^{-6} mg/L
All	17,424	866	5.0%	0.7%	—	—
Unlined	12,111	422	2.4%	0.6%	3.5%	0.9%
Clay	2,596	149	0.9%	0.1%	5.7%	1.0%
Composite	2,717	295	1.7%	< 0.1%	10.9%	0.2%

K.2.3 Verification of Pre- and Postclosure Results

EPACMTP is a composite of two modules: a one-dimensional variably saturated module for the vadose zone and a three-dimensional saturated module for the aquifer. A more robust ground water fate and transport model was necessary to verify the EPACMTP results that peak exposures associated with the ground water pathway are dominated by preclosure releases. The MODFLOW-based Hydrologic Modeling System (MODHMS) (HydroGeoLogic, Inc., 2011) was selected. MODHMS is an enhanced version of the U.S. Geological Survey Modular Three-Dimensional Finite-Difference Ground-Water Flow (MODFLOW) model (McDonald and Harbaugh, 1988) that

can simulate the same subsurface conditions as EPACMTP, but can account for a single, variably saturated domain.

MODHMS Model Design

To validate the combined pre- and postclosure EPACMTP results, a MODHMS conceptual model was developed to be as similar as possible to the conceptual model used by EPACMTP. **Figure K-1** depicts the settings of the verification scenario. A single, fixed set of inputs to characterize a surface impoundment was chosen at random from the set of As III releases from the combined ash waste type. Next, it was assumed that neither adsorption nor degradation occurred in the ground water. Finally, the regional ground water gradient in the MODHMS-based model was imposed by constant heads along the boundaries. A separate set of boundary conditions were applied to represent pre- and postclosure phases of the surface impoundment:

- **Complete clean closure:** constant leaching for a 75-year operational life, after which the infiltration rate is reduced to the regional recharge rate and leaching is discontinued.
- **Partial clean closure:** constant leaching for 75-year operational life, after which the infiltration rate is reduced to the regional recharge rate while the leachate concentration held at the same value.

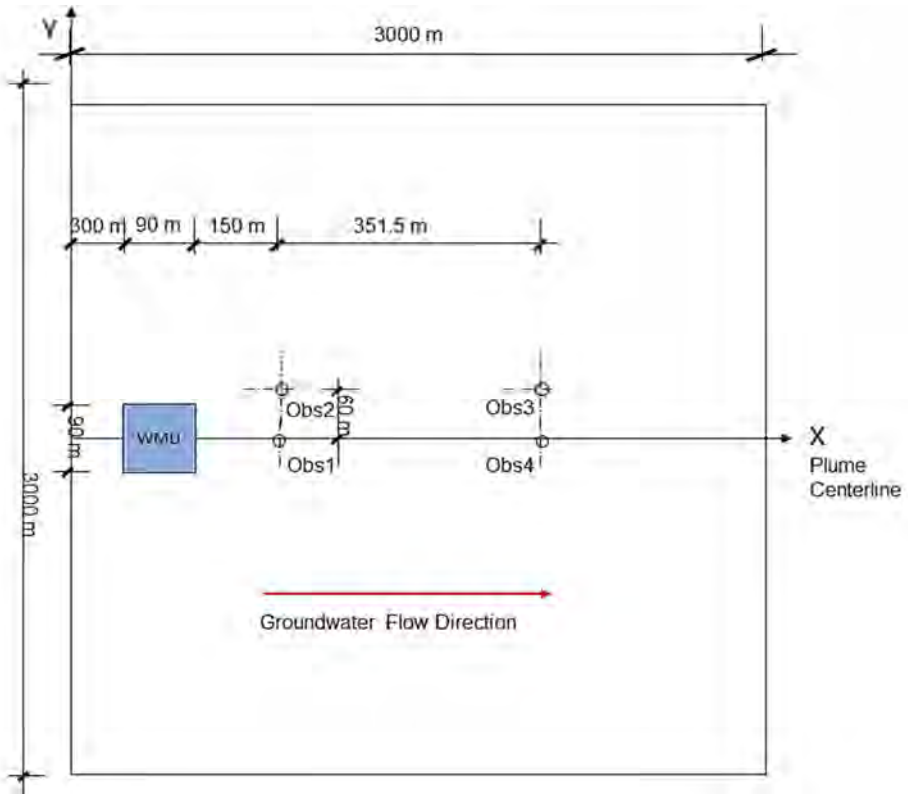

Figure K-1. Diagram of verification cases (not to scale).

The total size of the modeled domain is 3,000 m × 3,000 m. The depth from ground surface to water table is 6.1 m and the thickness of the saturated zone is a uniform 15.2 m. The domain is discretized into uniform grid cells with the horizontal dimensions of 30 m × 30 m. A 90 m × 90 m square impoundment is located 300 m from the upstream boundary and 500 m from the upper

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boundary. To allow comparison of receptor well concentrations at various locations in the flow path from the source, four receptor well cluster locations were chosen. A pair of well clusters is located at 150 m and another pair at 501.5 m downgradient from the impoundment. One well in each pair is located 0 m from the centerline of the plume and the other is offset by 60 m. Each well is screened at depths of 1.1 m, 5.4 m, and 9.8 m below the water table.

The vadose zone is discretized into six equally spaced layers, while the saturated zone is discretized into seven equally spaced layers. The model domain is homogeneous with a hydraulic conductivity of 21,800 m/year for the saturated layers and a saturated hydraulic conductivity of 78.7 m/year for the unsaturated layers with an effective porosity of 0.45. A hydraulic gradient of 0.004 is assigned across the model domain. The regional recharge rate is 0.0912 m/year and an infiltration rate of 3.547 m/year is imposed at the source. The longitudinal, transverse and vertical dispersivities are set at 10 m, 1 m and 0.1 m, respectively. The leachate concentration during operational life is 0.05212 mg/L. The postclosure leachate concentration is held at the same value.

MODHMS Results

As shown in **Figure K-2**, the arsenic concentrations at even the closest sample location quickly fell far below the peak levels following both complete and partial closure. This indicates that the contribution from postclosure impoundment releases to peak risks is minimal. These additional MODHMS model runs are consistent with and provide a high degree of confidence in the EPACMTP results discussed earlier. Based on these results, EPA elected to not include postclosure releases in the full-scale modeling. This decision is based on consideration of the time and resources saved by avoiding additional analyses that would have no appreciable effect on the full-scale characterization of peak risks.

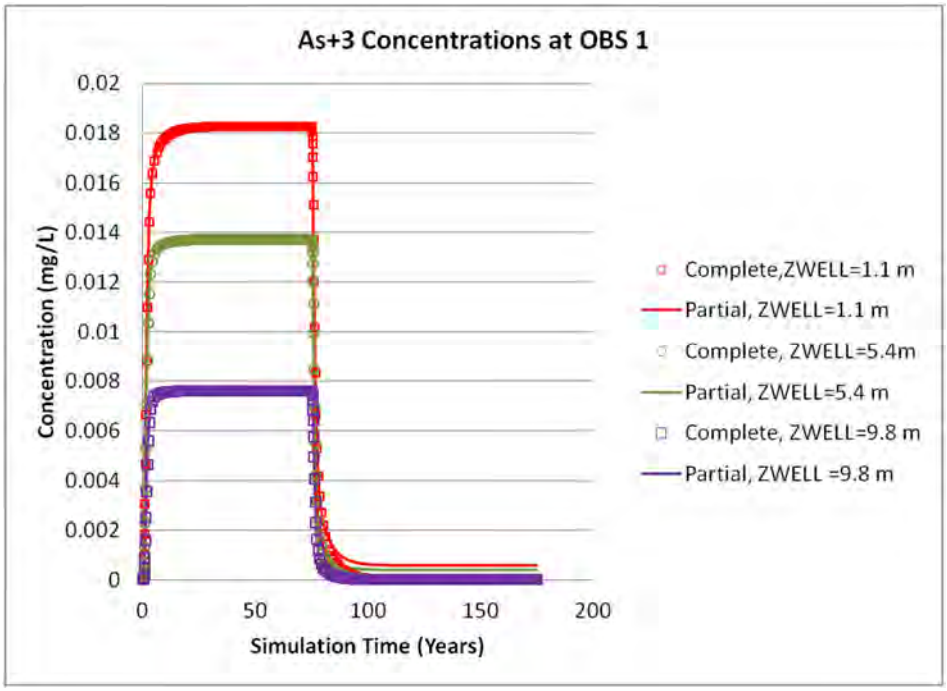

Figure K-2. Breakthrough curves with complete clean closure and partial clean closure at Observation Well 1 (OBS 1).

K.3 Evaluating Two-Pulse Source Term Modeling for Constituents in the Washout Phase

This section presents the approach used to evaluate uncertainties associated with the modeling of washout-controlled constituents in EPACMTP. EPA used the results of this analysis to draw conclusions, summarized in **Section 5**, about the potential for this uncertainty to affect the risk results of the probabilistic analysis.

K.3.1 Technical Approach

The empirical relationship between leachate concentration and cumulative liquid-to-solid (L/S) ratio for washout-controlled constituents is discussed in **Appendix I**. Due to the constraints of EPACMTP, EPA simplified this relationship into a single, constant concentration pulse for the probabilistic analysis. To understand the uncertainty introduced through this simplification, EPA considered the effects of modeling a two-step function. The original exponential liquid-solid partitioning curve (hatched) and the simplified two-step liquid-solid partitioning curve (red) are shown in **Figure K-3**.

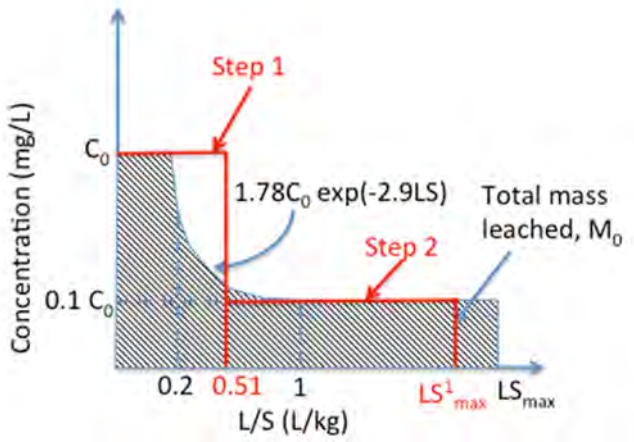

Figure K-3. Two-step idealization of L/S partitioning curve for washout-controlled species at simulation pH.

The first step is represented by a leachate concentration of C_0 that continues until a cumulative L/S ratio of 0.51 L/kg. The profile then immediately decreases to a second step represented by a leachate concentration of $0.1C_0$. Leaching continues at this level until the remaining leachable mass is depleted. **Equations K-1** and **K-2** provide the resulting, two-step equation for total mass and the adjusted L/S ratio where all available mass is leached, respectively.

(K-1) $$M_0 = C_0 \cdot LS_{0.51} + 0.1C_0(LS_{max} - LS_1)$$

(K-2) $$LS^1_{max} = LS_{max} - LS_{0.49}$$

Where:

M_0 = Total available mass (mg/kg);
C_0 = Initial leaching concentration (mg/L);
LS_X = Liquid-to-solid ratio of X (L/kg);
LS_{max} = Liquid-to-solid ratio at which total available mass is depleted (L/kg); and
LS^1_{max} = Adjusted liquid to solid ratio at which total available mass is depleted (L/kg).

To determine whether modeling only the first step of washout-controlled leaching sufficiently captures peak ground water concentrations, an uncertainty analysis was conducted. This analysis used boron and vanadium leachate data from fly ash sample AaFA. These two constituents provide a good bounding on potential washout-controlled leaching behavior. Vanadium is strongly sorbing, with concentrations that sometimes fall in the nonlinear range of the sorption isotherms. By contrast, boron is weakly sorbing, with concentrations that often fall in the linear range of the sorption isotherms.

A CCR landfill was selected from the New Johnsonville power plant in Tennessee to represent a landfill in the eastern half of the United States with fairly consistent monthly precipitation rates. All available and applicable site-specific data were used for the sensitivity simulations, supplemented by median default values for other required EPACMTP input parameters (e.g., depth to water table, soil material properties). To allow comparison of receptor well concentrations at various locations downgradient from the landfill, the three discrete receptor well locations presented below in **Figure K-4** were chosen with the following coordinates:

- **X-Distance:** 150 m from the landfill boundary. This was selected to represent the closest quartile of distances in the probabilistic assessment where risks are likely highest.
- **Y-Distance:** 0 m, 143 m, and 286 m from the centerline of the plume. The 0 m distance was selected to represent the centerline where dilution is minimized. The two non-zero distances correspond to locations that line up with the edge of the landfill (143 m) and the same distance beyond the edge of the landfill (286 m).
- **Z-Distance:** 5.2 m below the water table. The 5.2 m depth below the water table was selected to represent a central tendency depth.

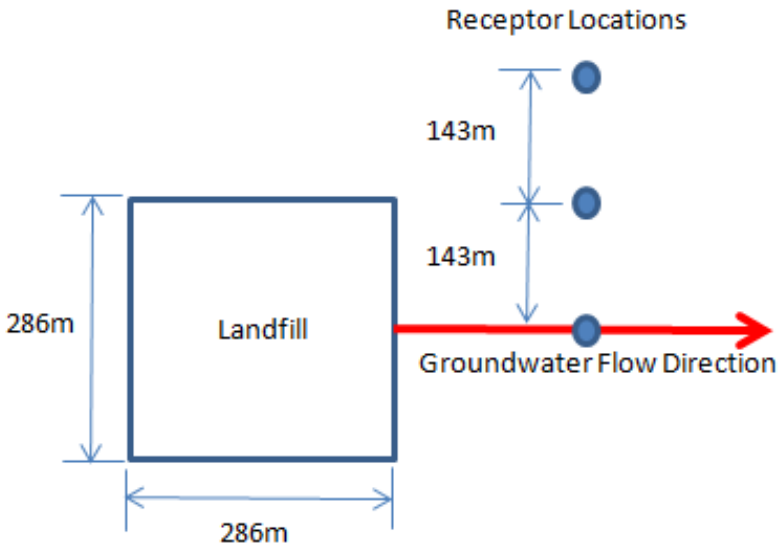

Figure K-4. Landfill and receptor locations for sensitivity analyses for washout-controlled leaching analyses.

The sensitivity analysis was conducted for each pH-specific, washout-controlled leachate concentration identified from available Method 1313 data. Vanadium in AaFA is washout-controlled over a pH range of 11.2 to 13 and represented by 10 leachate concentrations. Boron in

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AaFA is washout-controlled over the entire pH range of 2.8 to 13 and is represented by 52 leachate concentrations. For each of the locations in **Figure K-4** and washout leachate concentrations the sensitivity analysis involved two separate simulations:

- **Square Pulse Simulation:** Model the leachate concentration as C_0 until all available mass was depleted. This is the same approach used in the probabilistic analysis of **Section 4**. Due to the use of the higher leachate concentration for the entire leaching duration, this alternative likely overestimates risks.
- **Two-Step Simulation**: Simulate the first leaching step at C_0 until reaching an L/S of 0.51 L/kg. Separately simulate the second leaching step at $0.1C_0$ until the remaining available mass is depleted. These two simulations were superposed with the year one of the second step lining up with the time equivalent of an L/S of 0.51 L/kg. Superposition is an accurate assumption where a constituent concentration falls in the linear portion of the nonlinear isotherms. However, where a concentration falls in the nonlinear portion, superposition may underestimate the effect that the second pulse has on risk.

K. 3.2 Results of Two-Pulse Modeling

The results of the sensitivity analyses were compared by examining the difference in peak concentration at the three receptor wells between the square pulse simulation and the two-step simulation. As explained above, the time series of simulated ground water concentrations resulting from the combined steps more accurately approximates the ground water concentrations of the true release profile in the linear range of the isotherms, but it may underestimate true concentrations to some degree in the nonlinear range. Maximum average concentrations were calculated for a series of increasing exposure durations, in increments of 5 years, over the interval of 5 to 45 years. These averaging periods were chosen to cover the majority of averaging times considered in the probabilistic analysis. Plotting the change in average well concentration ($\Delta_{\mathrm{AveConc}}$) as a function of averaging period is defined by:

(K-3) $$\Delta_{\mathrm{AveConc}} = \frac{\left|\mathrm{Max}\left(\mathrm{C}_{\mathrm{Composite}}\right) - \mathrm{Max}\left(\mathrm{C}_{\mathrm{Single}}\right)\right|}{\mathrm{Max}\left(\mathrm{C}_{\mathrm{Composite}}\right)}$$

Where:

$\Delta_{\mathrm{AveConc}}$ = Change in average well concentration (%);
$C_{composite}$ = Average concentration for two-step results over an averaging period (mg/L);
C_{single} = Average concentration for single-step results over an averaging period (mg/L).

The peak concentration associated with the initial pulse is always an order of magnitude higher than the secondary pulse, which is proportional to the ratio of the leaching concentrations for the two pulses. **Figures K-5** and **K-6** compare the difference in maximum average concentrations of vanadium and boron, respectively, between the two simulations. Separate graphs are presented for each of the three well locations identified in Figure K-4.

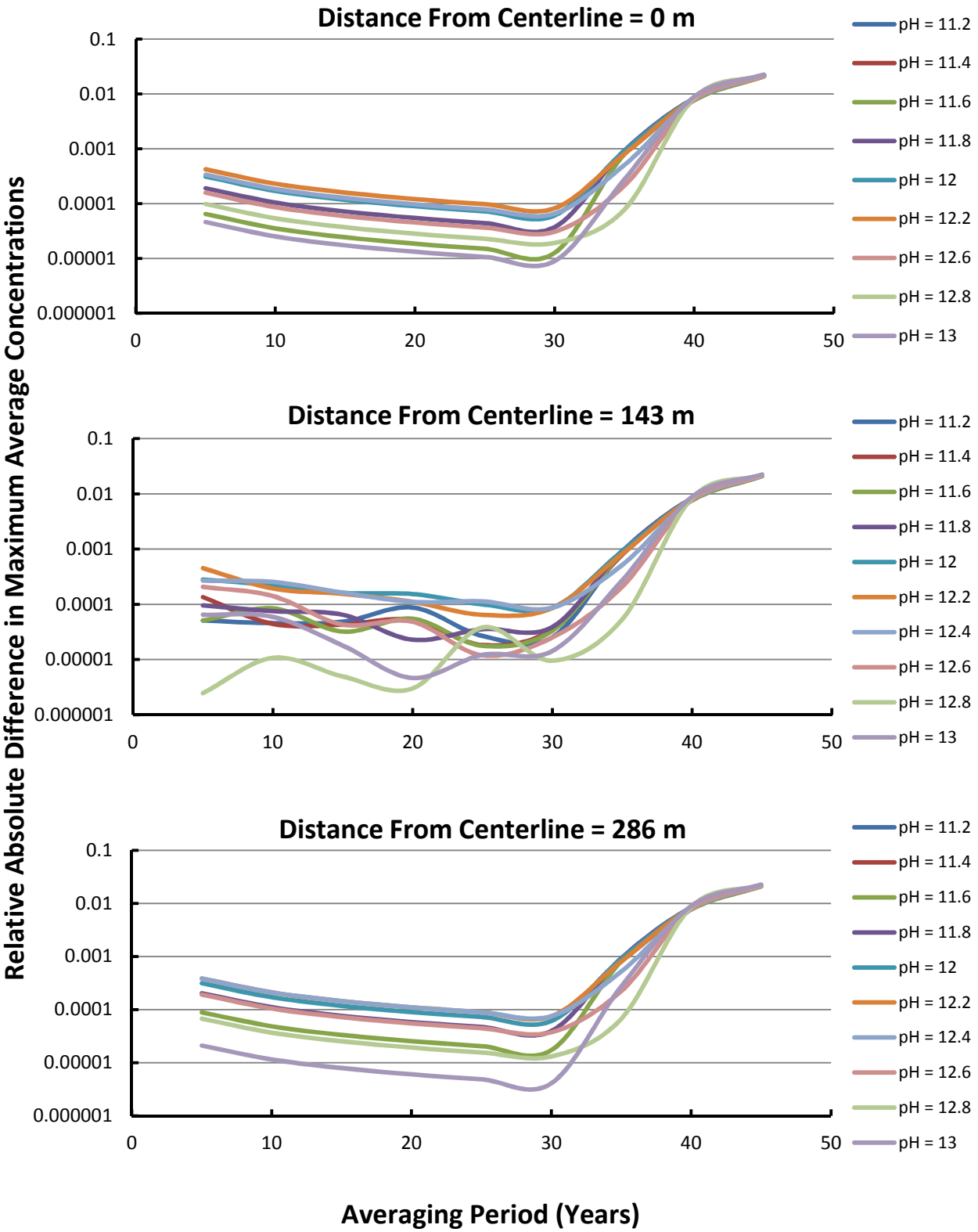

Figure K-5. Relative difference in average concentrations of vanadium based on composite releases and initial releases from the plume centerline.

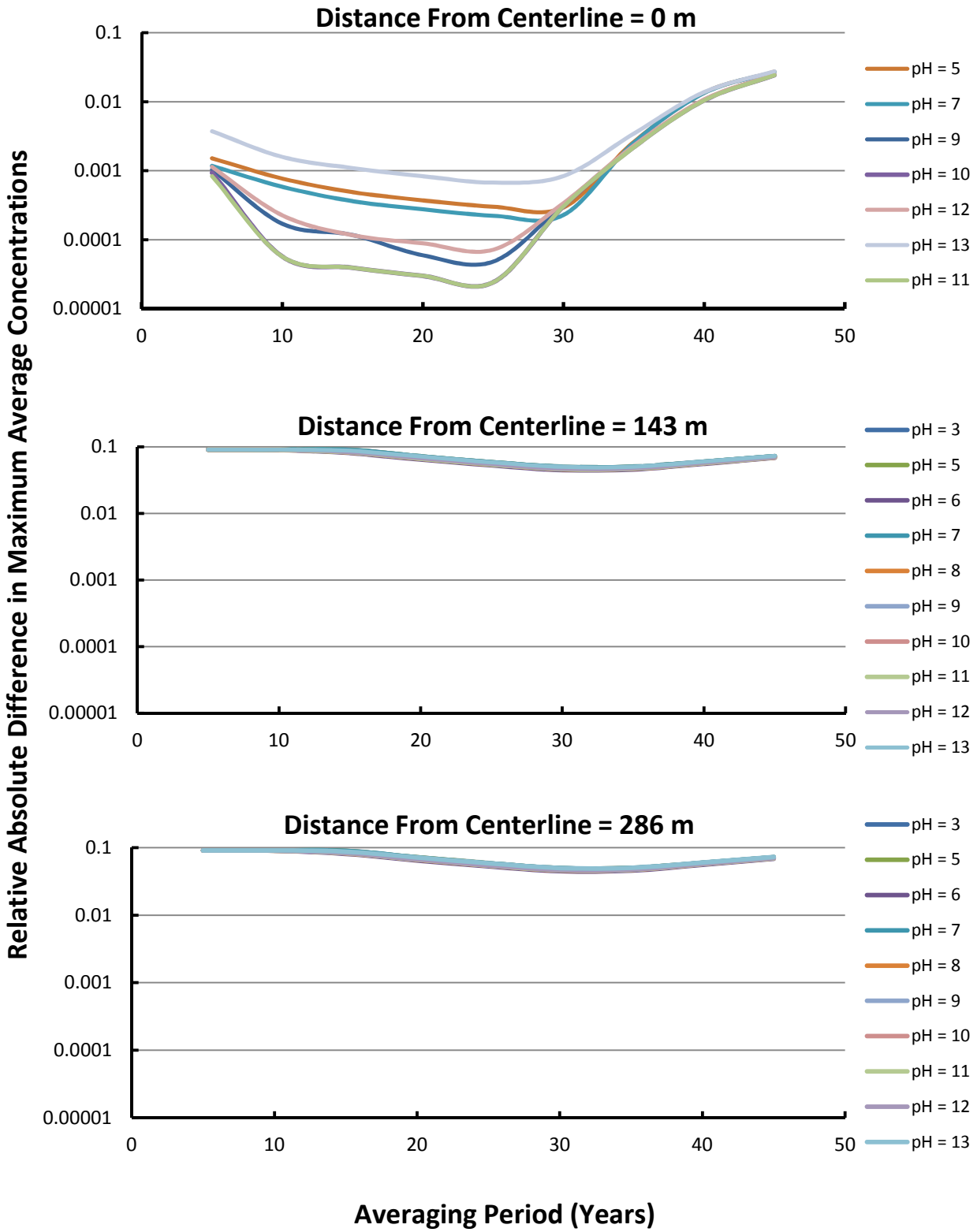

Figure K-6. Relative difference in average concentrations of boron based on composite releases and initial releases from the plume centerline.

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These figures show that average vanadium concentrations in the two simulations differ by less than 0.01 (1 percent) for all pH values at all but the longest averaging times. Boron behaves similar to vanadium along the centerline of the plume. However, as the distance from the centerline of the plume increases, the concentrations from the two simulations differ between 0.04 and 0.09 (4 and 9 percent, respectively) for the modeled range of pH values and averaging times. Thus, EPA concludes that the modeling of constituents in the washout-controlled phase by a single pulse is unlikely to have a significant effect on the results.

K.4 Time to Peak Concentration at Receptor Well for Selected CCR Constituents

This section presents the approach used to evaluate uncertainties associated with the timeframe over which fate and transport was modeled. EPA used the results of this analysis to draw conclusions, summarized in **Section 5**, about the potential for this uncertainty to affect the risk results of the probabilistic analysis.

To better understand the time frames over which risks associated with exposures to contaminated ground water may occur, the EPA performed an analysis to graphically represent distributions of arrival time of the peak ground water concentrations at the nearby drinking water well. The analysis was performed by WMU type and liner, across all waste types. A description is provided below of how the peak concentrations and their arrival times were treated to create the plots presented in this appendix, including the treatment of zero-value observations. These plots reflect the time to peak concentration used to calculate risks for the ground water to drinking water [Ground Water (GW)→Drinking Water (DW)] exposure pathway. Plots are presented for the following selected constituents from the 2010 risk assessment: arsenic III and V, boron, cobalt, selenium IV and VI, and thallium. While only the 2010 arrival times were presented in the document for comparison, the 2014 data were used here to confirm the continued appropriateness of relying on these 2010 data. From the revised risk assessment, the following constituents were selected: arsenic III, boron, and vanadium. These select constituents represent those with the highest modeled risks and span the range of mobility in the subsurface.

The outputs generated by the GW→DW pathway include the peak concentration observed at a receptor well and the number of years required to reach that concentration. For each scenario modeled (i.e., combination of waste management unit type and liner type), approximately 10,000 sets of inputs were probabilistically selected and modeled, resulting in the same number of well concentrations. For this analysis, the model results were segregated based on the different constituents of potential concern (COPCs) and WMU type. Some of the modeled well concentrations are zero because of negligible infiltration rates (which occur only for WMUs with composite liners) or subsurface conditions that inhibit the movement of a constituent to such an extent that it cannot reach the receptor well within the 10,000 year modeled time frame. Model runs that resulted in zero-value concentrations were treated in the following manner:

- Zero-value concentrations corresponding to negligible infiltration rates were assigned an arbitrary value of −1, effectively excluding those data from the graphs. Only composite liner scenarios produced zero-value infiltration rates.
- Zero-value concentrations corresponding to nonzero infiltration rates were assigned an arbitrarily high arrival time, greater than 10,000 years, the maximum simulation time frame (i.e., constituent did not reach the well during the simulation period).

Table K-2 shows the distribution of zero-value concentrations by WMU for all liners and for composite liners. The presented ranges for the zero well concentrations reflect the COPC-specific fate and transport variability. Note that for surface impoundments, there are fewer model runs (observations) for thallium because thallium data were not available for the ash and coal waste type due to limited data in the 2011 CCR constituent database. All of the percentage values are based on the total number of observations for each COPC.

Table K-2. Percentage of Zero Concentration Results by WMU Type

WMU Type	COPC	Number of Runs Per COPC	Range of Zero Observations (%)		
			Zero Well Concentration All Liners	Zero Well Concentration Composite Liners	Zero Infiltration All Liners
2010 Data					
Impoundments	As, B, Co, Se	19,825	3.1 – 8.8	2.9 – 6.5	2.5
	Tl	9,905	5.8	5.5	3.9
Landfills	As, B, Co, Se, Tl	29,717	28.6 – 46.3	15.3 – 16.1	11.9
2014 Data					
Impoundments	As, B, V	99,691	16.3 – 23.7	10.1 – 16.1	7.3
Landfills	As, B, V	45,699	56.3 – 63.5	25.6 – 27.2	20.4

After zero concentrations were addressed, the remaining time to peak concentrations were plotted as a series of cumulative distributions. These distributions are shown in **Attachments K-1** through **K-8**. Even with lined units, peak arrival times typically occur sooner for surface impoundments than landfills. This may be a result of the combination of the shorter, 75 year modeled operating life for surface impoundments. Landfills are modeled postclosure as a depleting source, requiring hundreds to tens of thousands of years to cease leaching. Thus, ground water plumes from landfills will take longer to plateau at a peak value, compared to surface impoundments. To provide a better resolution for this data, some surface impoundment plots are provided both the full 10,000 years and a second 1,000 year time frame to highlight the rapid changes that occur in the first several hundred years.

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Differences between liner types for different WMU types and constituents reflect the degree to which infiltration rates impact regional ground water flow. High infiltration rates associated with unlined units are more likely to increase local ground water flow velocities and reduce travel times to receptors. Low infiltration rates associated with lined units are less likely to change regional flow fields and ambient flow velocities. The shorter arrival times shown for some constituents for clay-lined landfills compared with unlined landfills are a result of the relatively small number of units modeled in 2010 and the site-based subsurface geology assigned to these units. The shorter arrival times mainly reflect more transmissive soils and aquifer materials at the clay-lined facility locations.

In general, differences in times to peak between the 2010 and 2014 results can be attributed to interception by surface water bodies. The 2010 Risk Assessment did not account for interception, resulting in an overestimation of ground water transport. The updated methodology used in the revised risk assessment requires that downstream receptor wells be moved farther downgradient by a distance that makes the travel time between the intercepting stream and the original receptor location (based on the reduced ground water velocity after baseflow removal) the same as the travel time between the stream and the relocated receptor well (based on the original ground water velocity before baseflow removal). Applying this requirement, the relocated receptor well is farther from the associated waste management unit than the original location. As a consequence, greater travel distances artificially increase the time for peak concentrations to arrive at downstream receptor locations.

K.5 References

HydroGeoLogic, Inc. 2011. MODHMS, A Comprehensive MODFLOW-Based Hydrologic Modeling System. HydroGeoLogic, Inc., Reston, VA.

McDonald, M.G., and A.W. Harbaugh. 1988. A modular three-dimensional finite-difference ground-water flow model. *Techniques of Water-Resources Investigations of the United States Geological Survey, Book 6*. U.S. Geological Survey. Available online at: pubs.usgs.gov/twri/twri6a1/pdf/TWRI_6-A1.pdf.

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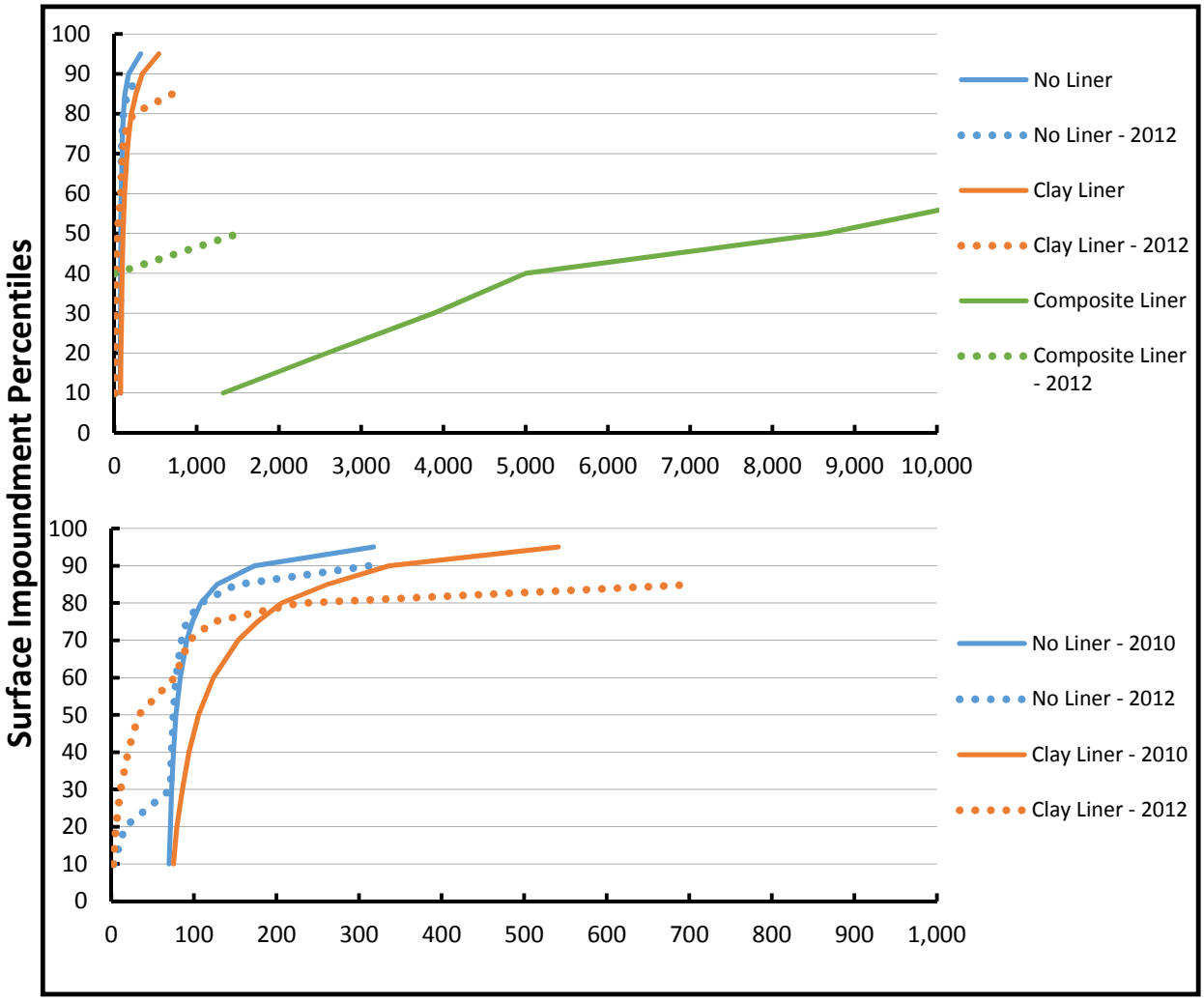
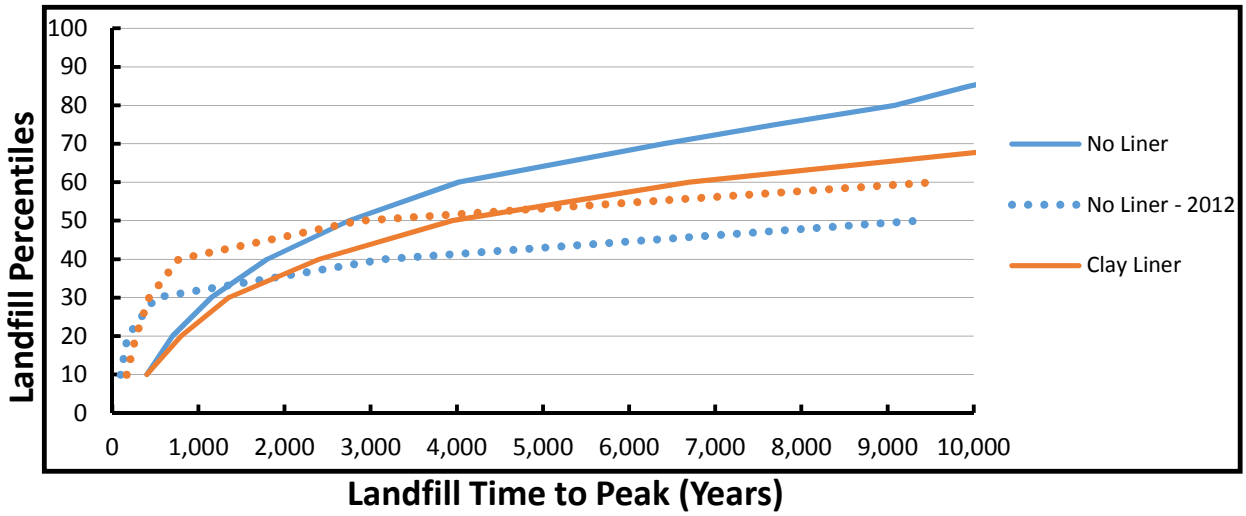
Attachment K-1.

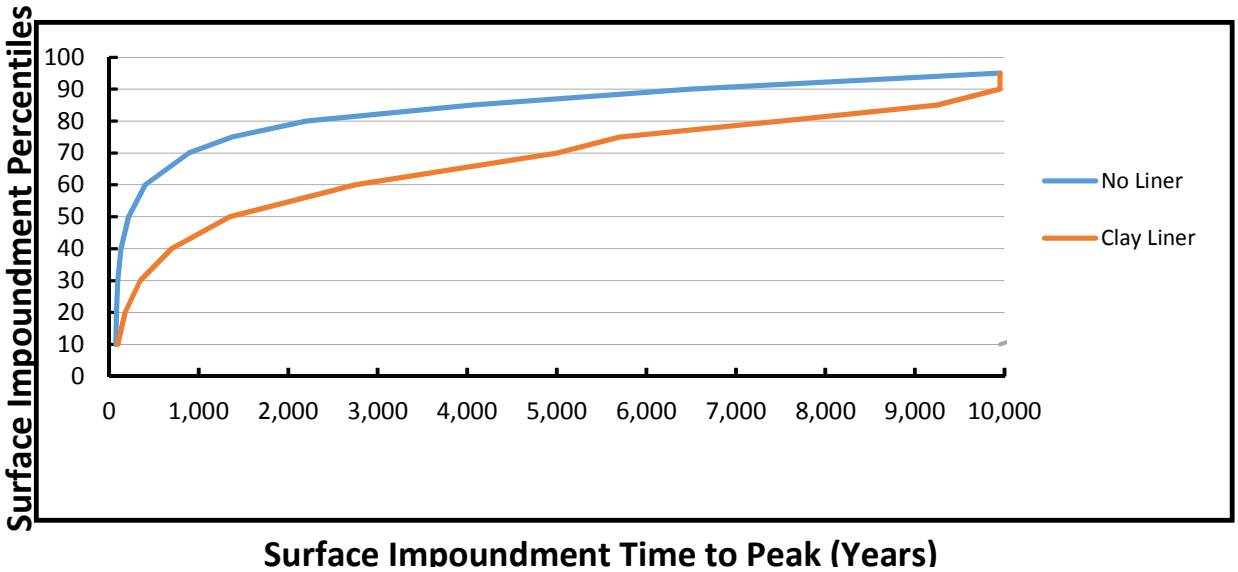
Surface Impoundment and Landfill Time to Peak Charts for Selected Constituents

2010/2014 Arsenic III Times to Peak for All Waste

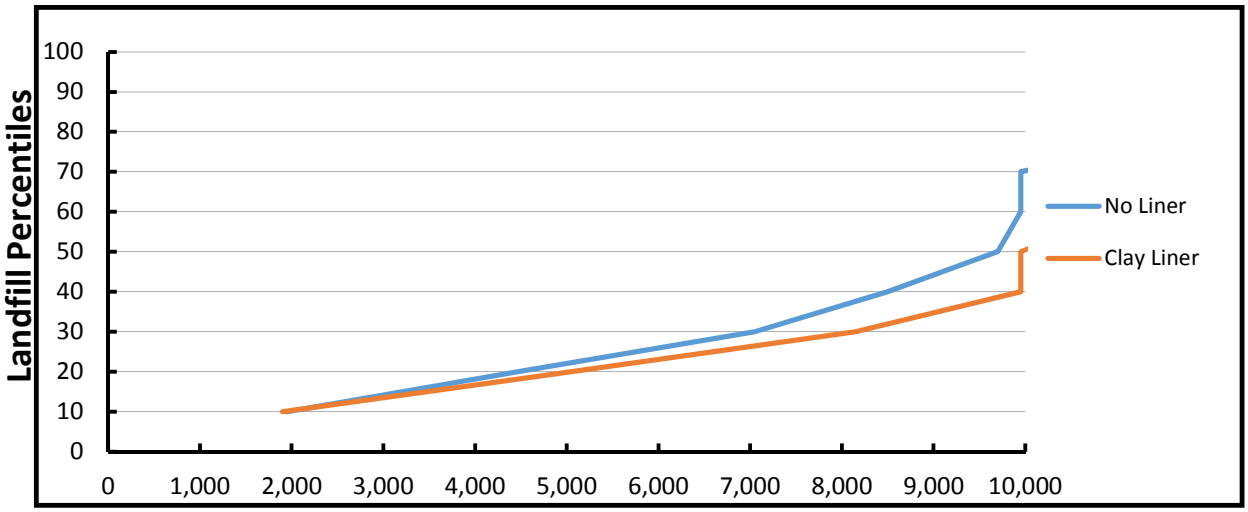




2010 Arsenic V Times to Peak for All Waste

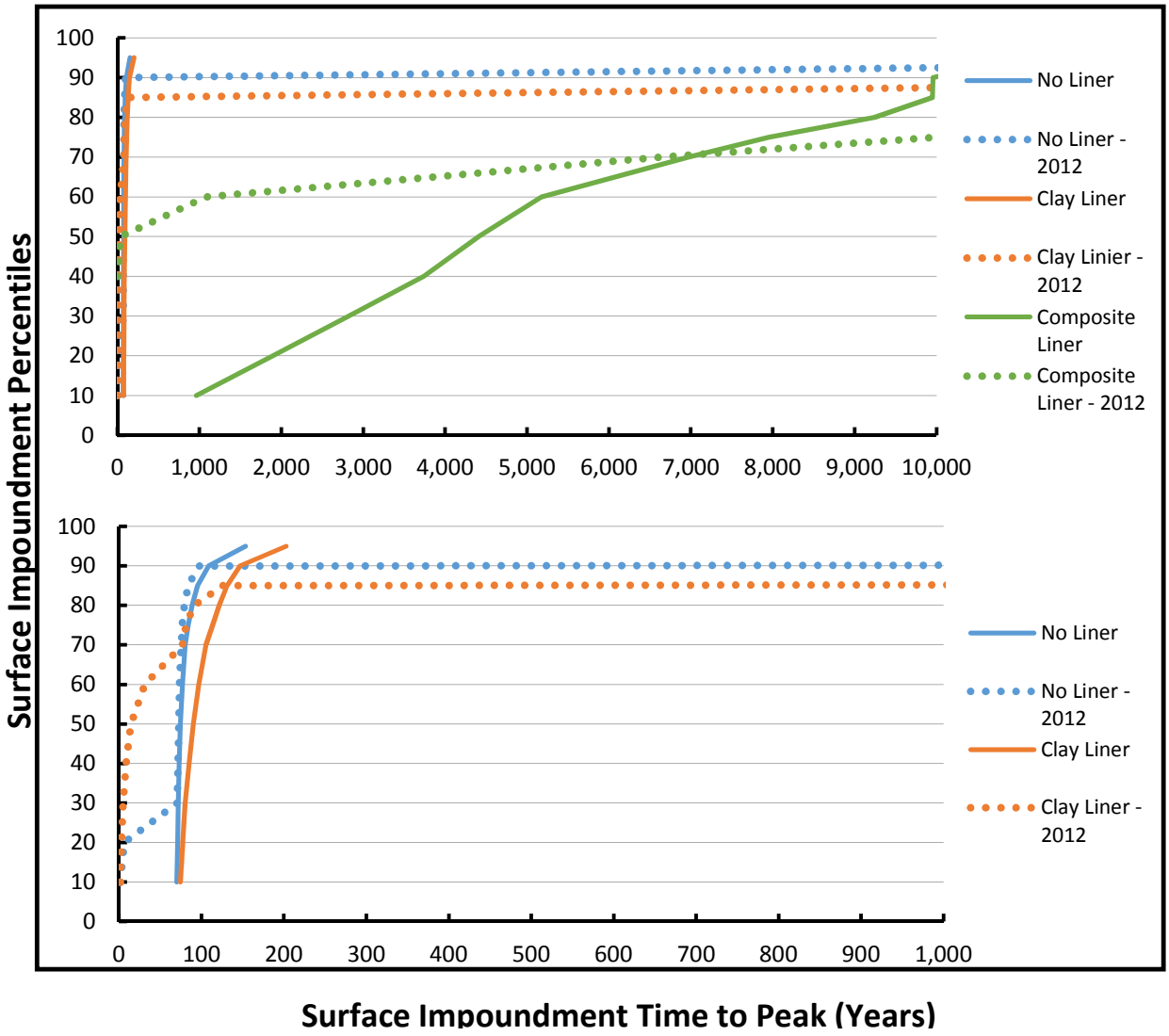


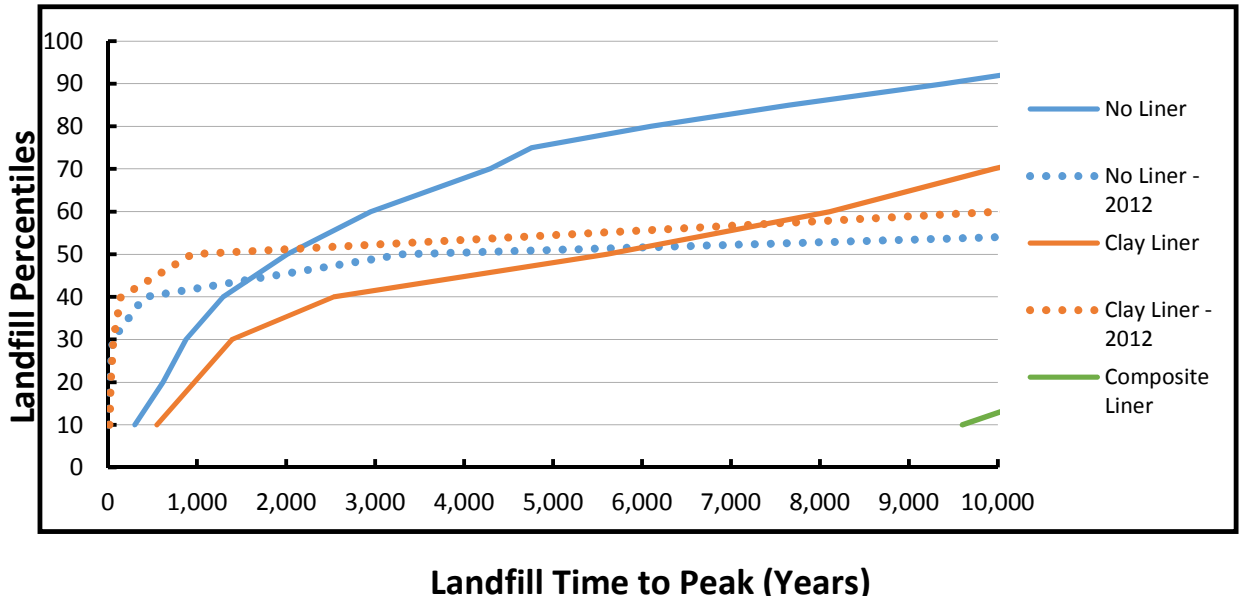
Surface Impoundment Time to Peak (Years)



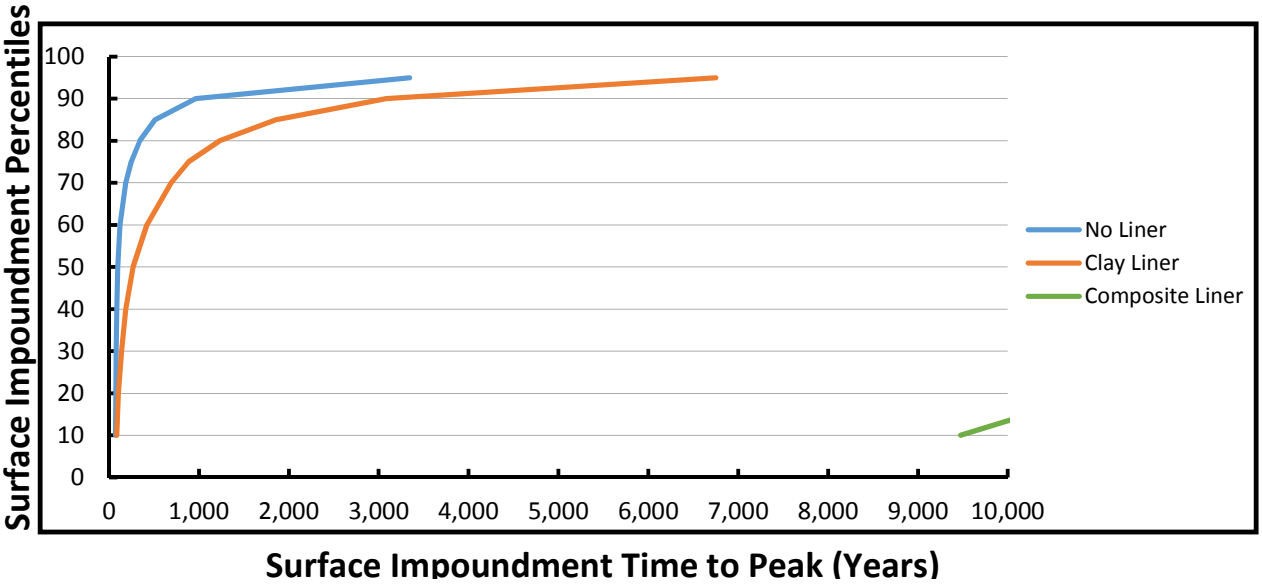
Landfill Time to Peak (Years)

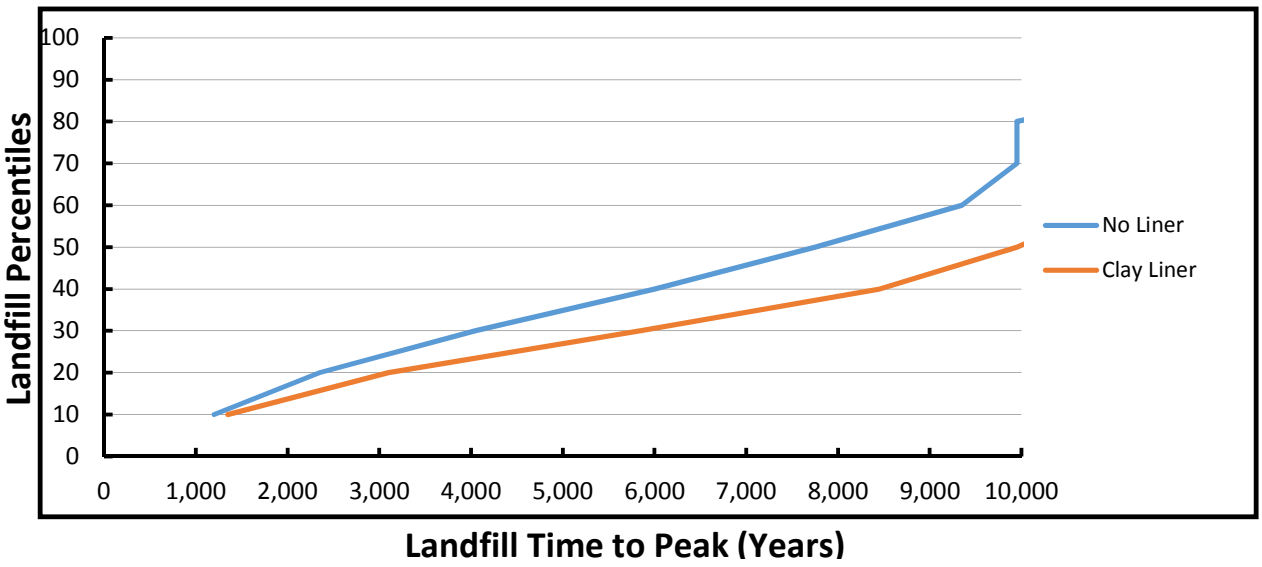
2010/2014 Boron Times to Peak for All Waste



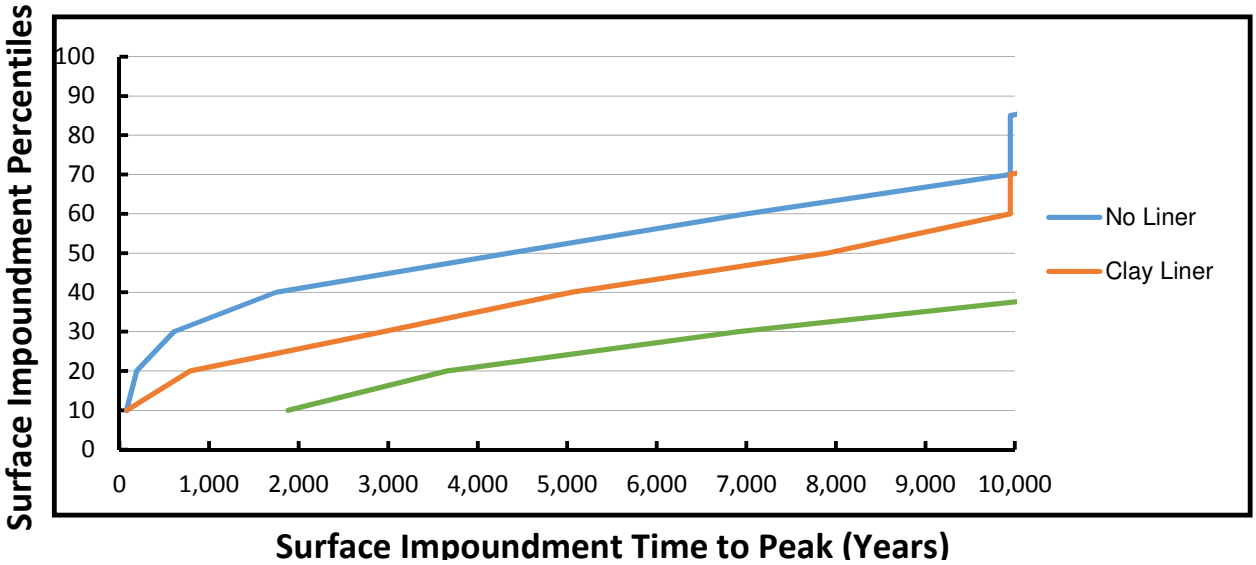


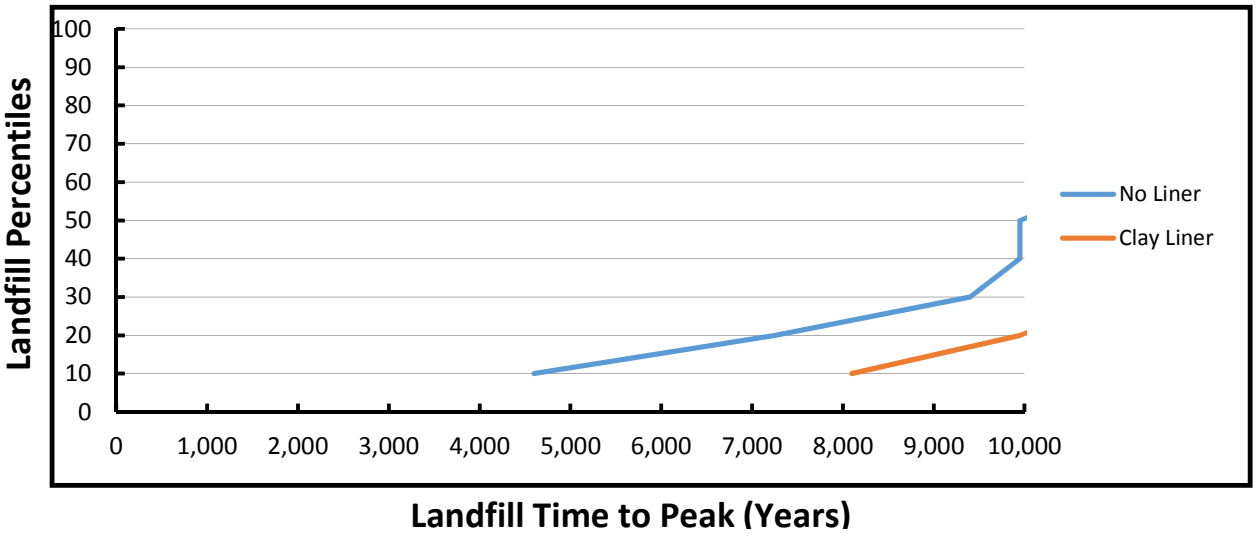
2010 Cobalt Times to Peak for All Waste



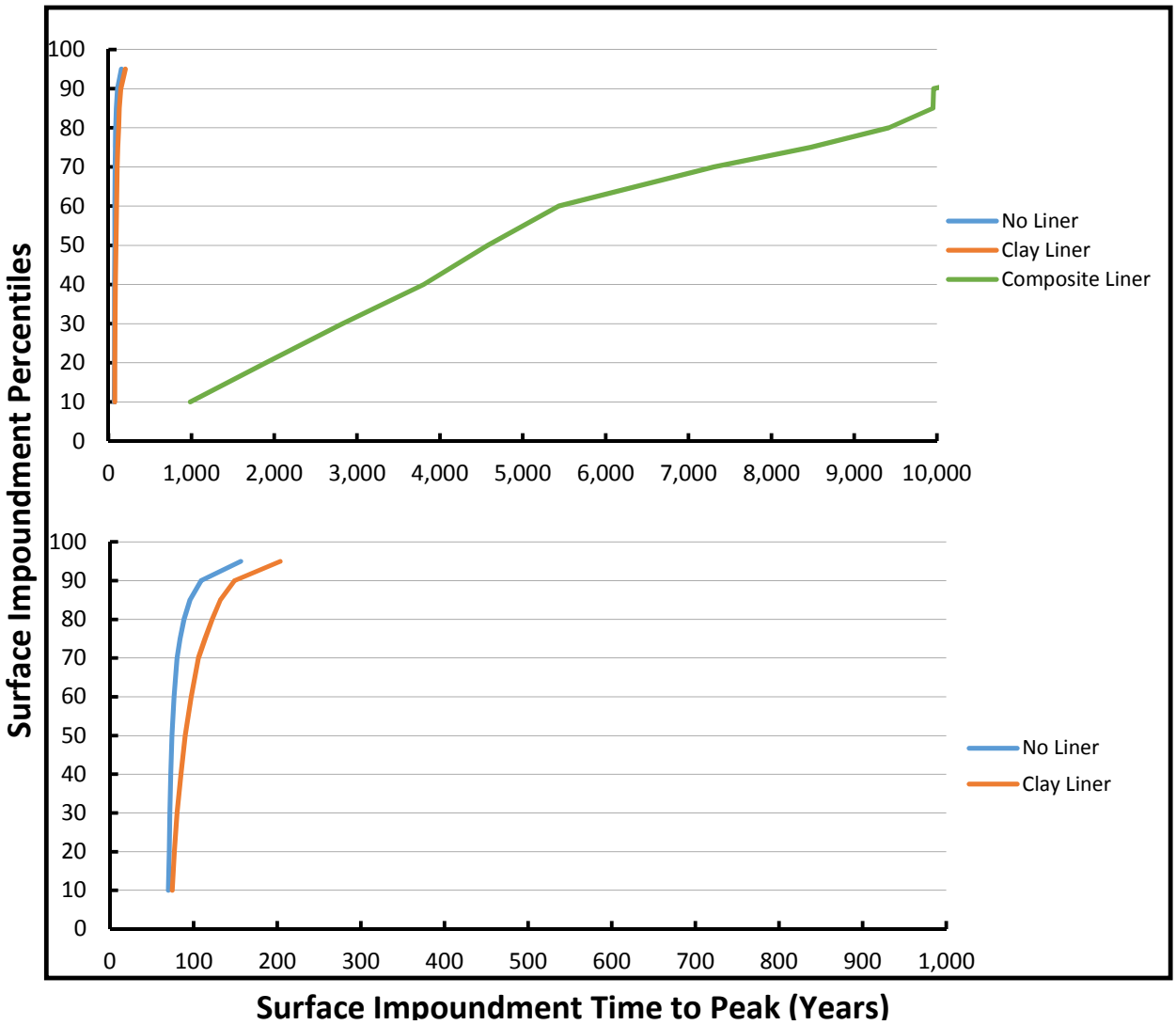


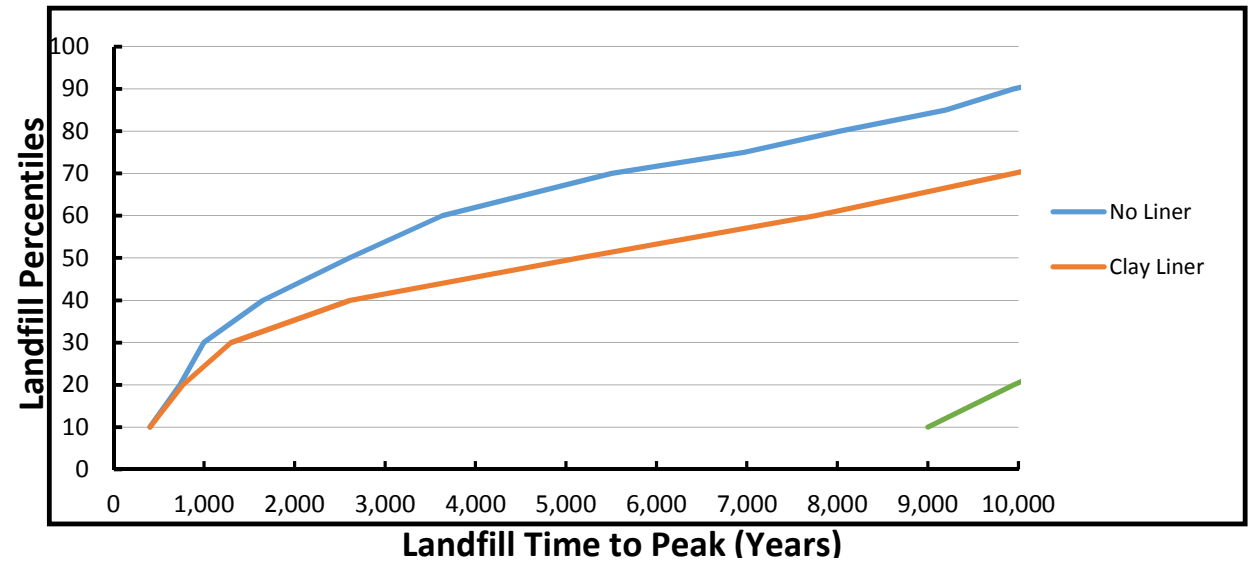
2010 Selenium IV Times to Peak for All Waste



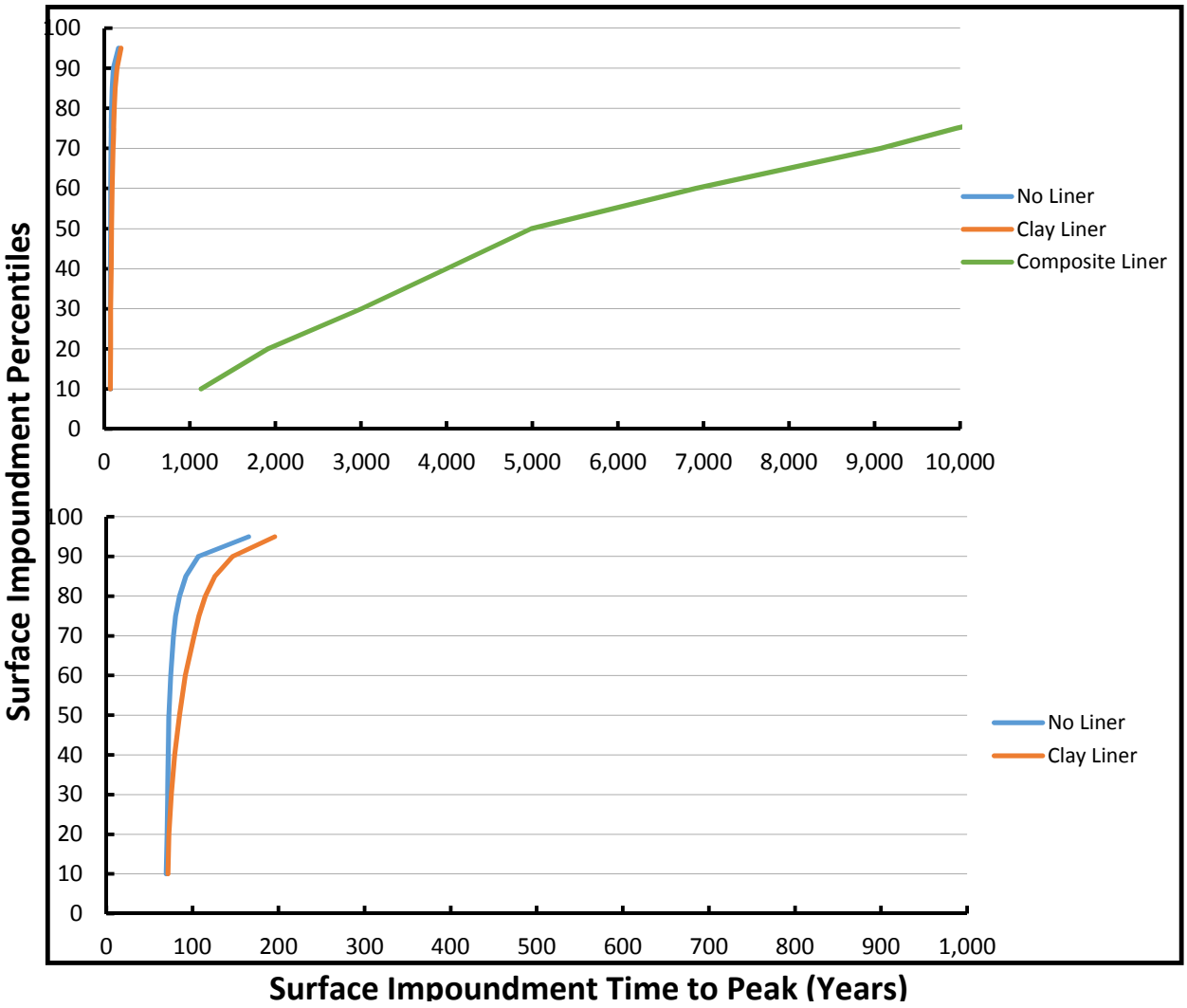


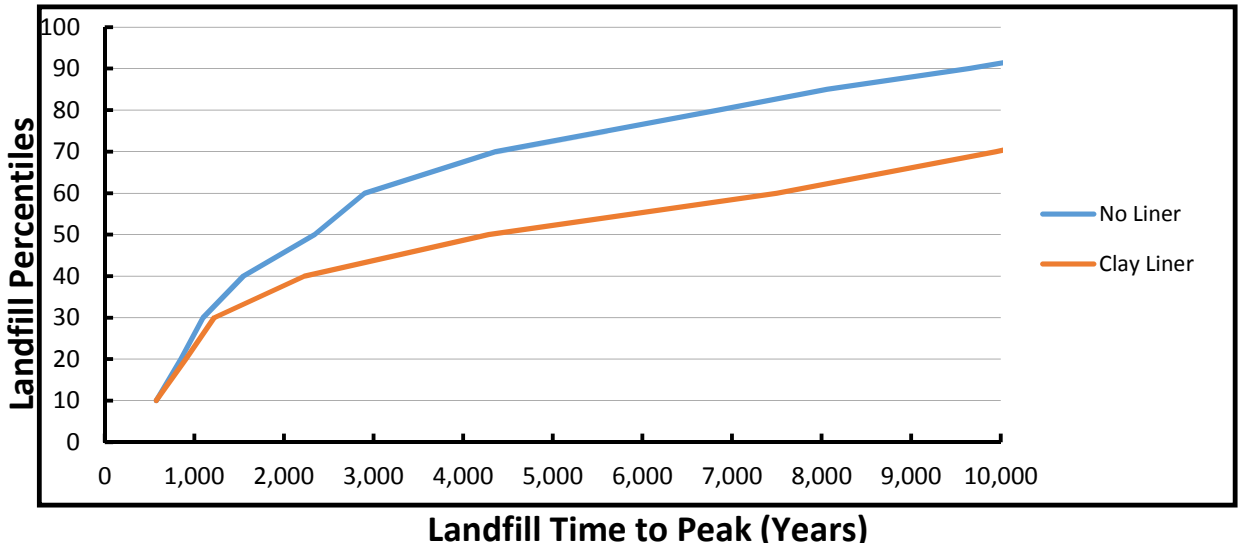
2010 Selenium VI Times to Peak for All Waste



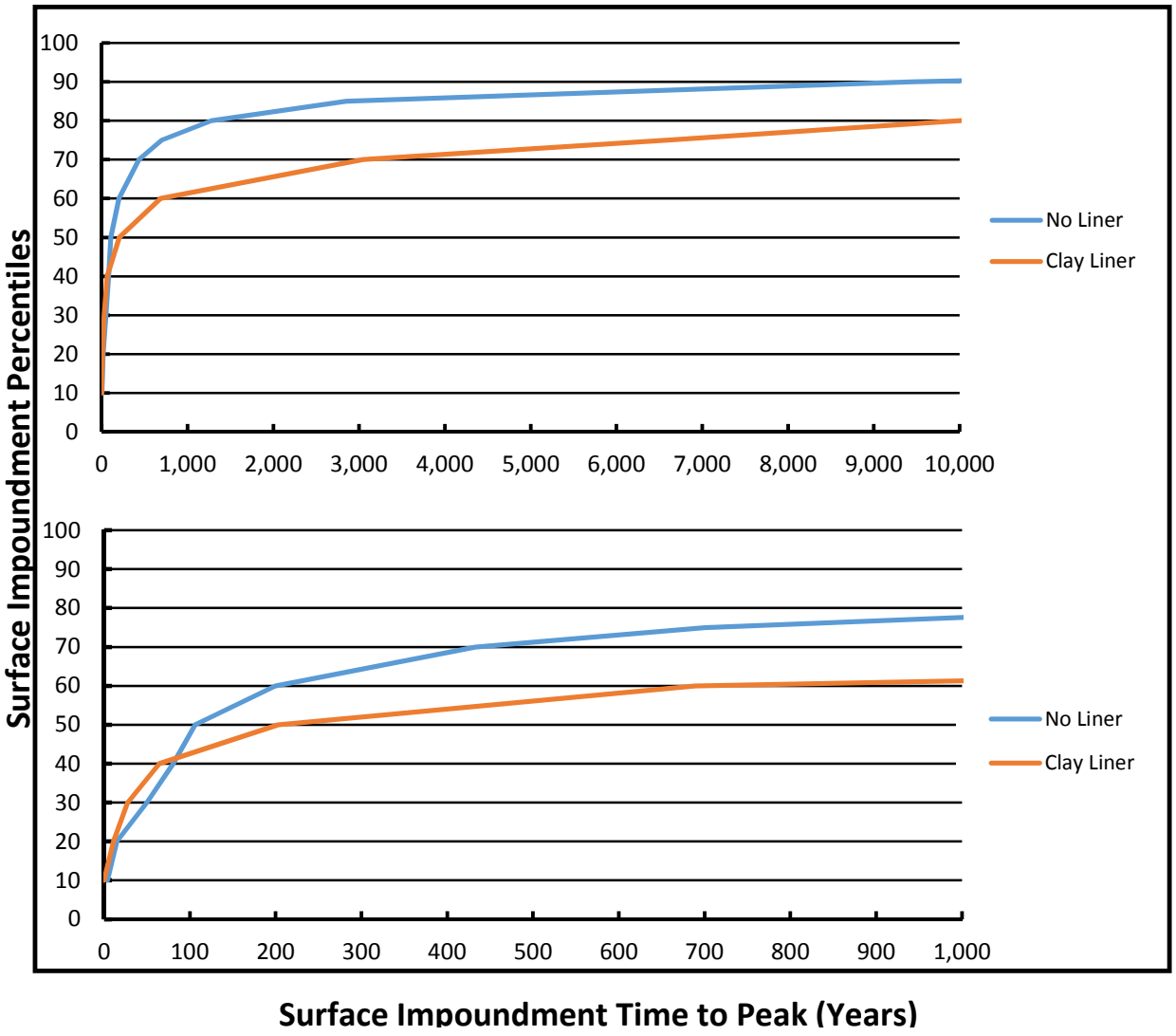


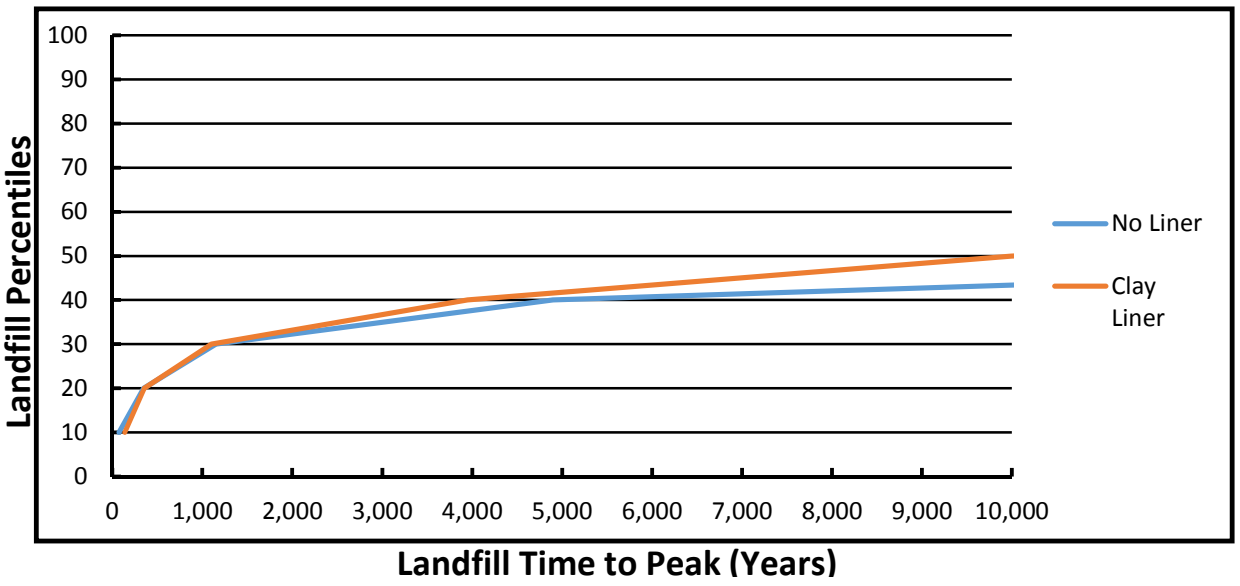
2010 Thallium Times to Peak for Combined Ash





2012 Vanadium Times to Peak for All Waste





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Appendix 26

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DISCLAIMER

The U.S. Environmental Protection Agency's Office of Solid Waste (EPA or the Agency) has compiled this methods manual in order to provide comprehensive guidance to analysts, data users, and other interested parties regarding test methods that may be employed for the evaluation of solid waste and other testing specified in regulations issued under the Resource Conservation and Recovery Act (RCRA). Except where explicitly specified in a regulation, the use of SW-846 methods is not mandatory in response to Federal testing requirements.

The Agency does not intend to restrict the use of new analytical techniques. Advances in technologies applicable to the sampling and analysis of environmental media and hazardous wastes outpace the ability of the Agency to promulgate revisions to this manual. In addition, given the large number of manufacturers and vendors of scientific equipment, glassware, reagents, and supplies, it is not feasible to cite all possible sources for these materials. Thus, the mention of trade names or commercial products in this manual is for illustrative purposes only, and does not constitute an endorsement or exclusive recommendation for use by EPA. The products and instrument settings cited in SW-846 methods represent those products and settings used during method development or subsequently evaluated by the Agency. Glassware, reagents, supplies, equipment, and settings other than those listed in this manual may be employed provided that method performance appropriate for the intended RCRA application has been documented as described in Chapter Two (see Sec. 2.1).

EPA generally does not intend these methods to be overly prescriptive. The words "shall," "must," or "require" are used to indicate aspects of the method that are considered essential to its performance, based on sound analytical practices (e.g., an instrument must be calibrated before use). In contrast, the words "should," "may," or "recommend" are used to provide guidance on aspects of the method that are useful but not essential. This flexibility does not apply to those method-defined parameters where the analytical result is wholly dependent on the process used to make the measurement.

EPA emphasizes that the ultimate responsibility for producing reliable analytical results lies with the entity subject to the Federal, State, or local regulation. Thus, members of the regulated community are advised to refer to the information in Chapter Two and to consult with knowledgeable laboratory personnel when choosing the most appropriate suite of analytical methods. The regulated community is further advised that the methods here or from other sources need only be used for those specific analytes of concern that are subject to regulation or other monitoring requirements.

Many of the methods include performance data that are intended as guidance on the performance that may be achieved in typical matrices and may be used by the analyst to select the appropriate method for the intended application. These performance data are not intended to be used as absolute QC acceptance criteria. Rather, each laboratory should develop performance criteria as described in Chapter Two and elsewhere in the manual.

In summary, the methods included here provide guidance to the analyst and the regulated community in making judgments necessary to generate data that meet the data quality objectives for the intended use of the results.

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Appendix 27

USEPA SW-846 Chapter 1, Project Quality Assurance and Quality Control, July 2014.

CHAPTER ONE
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Project Quality Assurance and Quality Control

For a summary of changes in this version from the previously published Chapter One, please see Appendix A at the end of this document.

1.0 INTRODUCTION

The goal of this chapter is to provide an understanding of environmental data and the need for quality. EPA has developed numerous guidance documents on quality assurance. This chapter is not intended to summarize the previously developed EPA guidance. Instead, this chapter will provide familiarity with regulations and guidance relating to QA and where to find them.

Regulations promulgated under the Resource Conservation and Recovery Act (RCRA) of 1976, as amended; require the collection and use of environmental data by regulated entities. In addition, organizations often collect and use environmental data for decision making. Given the significant decisions to be made based on environmental data, it is critical that the data are of sufficient quantity and quality for their intended use and can support decision-making based on sound science.

In response to the need for quality data, it is recommended that all parties follow a structured system of data quality assurance and quality control (QA/QC). In addition, some of the RCRA regulations include specific requirements for ensuring data quality.

This chapter provides general guidance intended to ensure data are of sufficient quality for their intended use. Its intended audience is any entity, government or private party that may be collecting environmental data. It is designed to support the efforts of those responsible for preparing and reviewing project planning documents such as Quality Assurance Project Plans (QAPPs), those involved in implementing and assessing data collection and generation activities in the field or laboratory, and those who use the data for decision-making.

Due to the diversity of data collection efforts, it is not possible to provide all details necessary to meet the needs of all members of the intended audience. However, EPA has developed a variety of detailed QA guidance documents that are incorporated into this Chapter by reference. This series of quality systems documents can be accessed on the EPA's Quality web site at: http://www.epa.gov/quality. These documents describe in detail EPA policies and procedures for planning, implementing and assessing the effectiveness of quality systems.

EPA's quality system comprises three structural levels: policy, organization/program, and project. This document addresses quality at the project level of the system, including technical aspects of analytical method quality assurance (QA) and quality control (QC). Entities which desire guidance on the other two structural levels (policy and organization/program levels) can access such guidance at the aforementioned EPA quality web site.

A project's life cycle under EPA's quality system has three phases: planning, implementation, and assessment. This chapter is organized into these three phases. Additionally, Figure 1 is provided, and illustrates this process.

Additionally, this chapter contains general project QC guidance to be used with the subsequent chapters and methods in this manual. It should be noted that several methods (e.g.,

Method 8000) also contain general QC criteria and guidance that pertain to the individual methods referenced therein (e.g., Methods 8081, 8082, 8260 and 8270). Individual methods may also contain QC criteria specific only to that method. The QC criteria in the general methods take precedence over chapter QC criteria. Method-specific QC criteria take precedence over general method QC criteria.

1.1 PLANNING

Planning, the first phase of a project's life cycle, involves the development of project objectives and acceptance or performance criteria using a systematic process. Data quality objectives (DQOs) and a sampling and analysis design are established to generate data of an appropriate type, quality and quantity to meet project objectives. The final output of this phase is a planning document, such as a QAPP, and/or a sampling and analysis plan (SAP) or a waste analysis plan (WAP).

This section provides guidance on activities and concepts that EPA recommends to be used or considered during the planning phase, when appropriate to a specific project.

1.1.1 Systematic Planning

Systematic planning is a process designed to ensure that the level of detail in planning is commensurate with the importance and intended use of the work and the availability of resources to accomplish it. The ultimate goal of systematic planning is to ensure collection of the appropriate type, quantity, and quality of data to support decisions with acceptable confidence. Following is a summary of EPA's Agency-wide guidance on systematic planning. More detail can be found in the *EPA Quality Manual for Environmental Programs (CIO-2105-P-01-0).*

The systematic planning process generally involves the following elements:

- Identification and involvement of data generators and users.
- Identification of project schedule, milestones, resources (including budget), and any applicable requirements.
- Description of the project goals and objectives (i.e., what is trying to be accomplished by performing this project)
- Identification of the type (e.g., individual data points to be used to estimate risk at a site, multi-point composites to be used to evaluate the average concentration in a decision unit), quantity and quality (e.g., screening for the presence/absence of an analyte, definitive data supported by all method specific QC results) of data needed. Be specific on what kind of analytical result will be needed to make a decision, whether the collected results need to be comprehensive and meet well defined DQOs or are merely for screening purposes to make a presence/absence decision?
- Specification of acceptance or performance criteria for ensuring the data collected meets the needs of the project.
- Description of how, when, and where the data will be obtained, and identification of any constraints on data collection.

- Specification of QA and QC activities needed to assess quality performance criteria (e.g., QC samples for the field and laboratory, audits, technical assessments, performance evaluations, etc.).

- Description of how acquired data will be analyzed (i.e., field and/or laboratory), evaluated, and assessed against performance criteria. If statistical assumptions are made as part of the planning process, the assessment must discuss how the assumptions will be verified as accurate, and what actions will be taken if the statistical assumptions are not supported by the data.

Planners should also recognize that existing data (i.e., secondary data) can be useful in supporting decision making. Secondary data can provide valuable information to help design a plan for collecting new data, while also lowering the cost of future data collection efforts. However, the limitations on using any secondary data must be clearly understood and documented. For example, secondary data must be examined to ensure that their quality is acceptable for a given application. Combining secondary data with current data can be a complex operation and should be undertaken with care. Sometimes, statistical expertise is necessary to evaluate both data sets before they can be combined. If combining data sets, make sure historical data use is appropriate in type and quality to the current project.

1.1.2 DQOs

The DQO process, discussed in detail in the *Guidance on Systematic Planning Using the Data Quality Objectives Process, EPA QA/G-4*, is designed to produce scientific and resource-effective data collection designs that will support decision making with a defined level of confidence.

The DQO process can be applied to any study, regardless of its size. While there is no regulatory obligation to use the DQO process, it is the recommended planning approach for most EPA data collection activities. The depth and detail of DQO development will depend on the study objectives. The DQO process is particularly applicable to a study in which multiple decisions must be reached. By using the DQO process, the planning team can clearly separate and delineate data requirements for each decision to be made or question to be answered. It consists of seven planning steps that are summarized below.

1.1.2.1 Step 1: State the Problem

The purpose of Step 1 is to clearly define the problem that has created the need for the study. In describing the problem, especially for more complex sites, it is often useful to include a conceptual site model (CSM). The CSM is a three-dimensional "picture" of site conditions at a discrete point in time that conveys what is known or suspected about the facility, including releases, release mechanisms, contaminant fate and transport, exposure pathways, potential receptors, and risks.

1.1.2.2 Step 2: Identify the Goals of the Study

The purpose of Step 2 of the DQO process is to identify the key questions that need to be answered in order to resolve the problem(s) identified in Step 1. Step 2 should also identify any actions that may be taken based on study results. The goals of the study and the alternative actions are then combined to form decision statement(s) that will resolve the problem. A decision statement defines which of the identified alternative actions will be pursued depending on the outcomes of the study.

1.1.2.3 Step 3: Identify the Information Inputs

The purpose of Step 3 of the DQO process is to identify the information needed to resolve the decision statement. This may include, but is not limited to:

- Primary data, including sampling and analysis methods
- Secondary data, including the necessary information to ensure the data is of known and documented quality (e.g., sampling and analysis methods used as well as sufficient information to evaluate the quality of the data)
- Action limits to be considered
- Background information about the site or process, including known or anticipated variability of the study parameters that may help the planning team identify critical sampling locations

1.1.2.4 Step 4: Define the Boundaries of the Study

The purpose of Step 4 of the DQO process is to define the spatial and temporal boundaries for the data collection design, including where samples will be collected. Spatial boundaries describe the physical area (i.e., horizontal and vertical boundaries) of the study. They can include geographic area or volume of material. Temporal boundaries include both the period of time the data collection effort will represent and the timeframe to which the decision will apply.

1.1.2.5 Step 5: Develop the Analytic Approach

The purpose of Step 5 of the DQO process is to consider the outputs from Steps 1-4 and develop “If..., then... else” decision rules that unambiguously state which of the alternative actions identified in Step 2 will be pursued. These if/then/else decisions should be formulated to be dependent on how the results of the study compare to an established action level.

1.1.2.6 Step 6: Specify Performance or Acceptance Criteria

The purpose of Step 6 of the DQO process is to set limits on decision errors, and to document those limits. For judgmental and random samples, Step 6 should examine consequences of making incorrect decisions, and place acceptable limits on the likelihood of making decision errors. For random samples, Step 6 should specify any statistical hypothesis to be considered and all applicable statistical tests that will be used to assess the data.

1.1.2.7 Step 7: Develop the Plan for Obtaining Data

The purpose of Step 7 of the DQO process is to develop the data collection plan that will satisfy the objectives presented in Steps 1 through 6. *RCRA Waste Sampling Draft Technical Guidance*, dated August 2002, provides guidance that may be used during sampling design development. EPA also developed a guidance document called *Guidance for Choosing a Sampling Design for Environmental Data Collection (QA/G-5S)*, to specifically provide the information needed to carry out step 7 and develop a sampling design.

The proposed plan should be the most resource-effective data collection design that meets the previously identified performance or acceptance criteria. The plan for obtaining data is documented in detail by developing a project QAPP as per *EPA Requirements for*

Quality Assurance Project Plans (QA/R-5), which presents the requirements for QAPPs, and its companion document, *EPA Guidance for Quality Assurance Project Plans (QA/G-5)*.

1.1.3 Development of QAPPs, Waste Analysis Plans (WAPs) and Sampling and Analysis Plans (SAPs)

Documentation of planning processes and outcomes are critical to the:

- effective communication of planned activities to all participants in the process,
- reconstruction of completed events, and
- reconciliation of the analytical data with the project plans.

Two types of planning documents are discussed in this section. Section 1.1.3.1 discusses QAPPs, which are a key output of the systematic planning process. Section 1.1.3.2 discusses WAPs and SAPs.

1.1.3.1 QAPPs

All environmental data collection efforts performed by or funded by EPA (e.g., through an EPA contractor) must be supported by an approved QAPP. EPA also recommends the use of QAPPs for environmental data collection efforts by other entities (e.g., by other regulated entities in compliance with the RCRA regulations). EPA has issued several documents to aid in preparing QAPPs, including the documents noted in Section 1.1.2.7. These documents provide suggestions for both EPA and non-EPA organizations on preparing, reviewing, and implementing QAPPs.

The primary purpose of the QAPP is to present the data collection activities to be implemented, including all necessary QA and QC, to ensure that all data produced are of known and documented quality, and that the data will satisfy the stated performance criteria.

QAPPs, and any accompanying WAPs or SAPs, should be accessible to all participants throughout the life of the project. They should provide understandable instructions to those who must implement the QAPP, such as the field sampling team, the analytical laboratory, modelers, and the data reviewers.

When preparing a QAPP, a graded approach should be used to determine the level of detail needed. This will ensure that the level of information presented is consistent with the intended use of the results and the degree of confidence needed in the quality of the results. The QAPP should be detailed enough to provide a clear description of every aspect of the project, from site history through assessment of the planned data collection. At a minimum, the QAPP should provide sufficient detail to demonstrate that:

- the project technical and quality objectives are identified and agreed upon;
- the intended measurements and data generation or data acquisition methods are appropriate for achieving project objectives;
- assessment procedures are sufficient for confirming that data of the type and quality needed and expected are obtained; and
- any limitations on the use of the data can be identified and documented.

As described in QA/R-5 and QA/G-5, the QAPP should be composed of standardized, recognizable elements covering the entire project from planning through assessment. These elements may be divided into the following four general groups:

- Project Management - The elements in this group address project organization and management; site background and history; and project objectives. These elements ensure that project goals are clearly defined, that the participants understand the goals and the approach to be used, and that the planning process is documented.

- Data Generation and Acquisition - The elements in this group address all aspects of project design and implementation, including the numbers, types, and locations of all samples to be collected; the rationale for why the proposed data collection effort will be sufficient to address the study objectives; all sampling, subsampling and analytical procedures to be followed (i.e., both sample preparation as well as determinative procedures); QC requirements for all applicable field and laboratory procedures including the data quality indicators (DQIs) discussed below in Section 1.1.4; instrument calibration and maintenance for both field and laboratory equipment; use of secondary data; and data management. Implementation of these elements ensures that appropriate methods for sampling, analysis, data handling, and QC activities are employed and properly documented.

- Assessment and Oversight - The elements in this group address the activities for assessing the effectiveness of project implementation and associated QA and QC activities. The purpose of assessment is to ensure that the QA Project Plan is properly implemented as prescribed.

- Data Validation and Usability - The elements in this group address the QA activities that occur after data collection or generation is completed. These elements address how data will be reviewed, verified and validated as well as how data will be assessed and reconciled with the project objectives.

While most QAPPs will describe project- or task- specific activities, there may be occasions when a *generic* QAPP may be more appropriate. A generic QAPP addresses the general, common activities of a program that are to be conducted at multiple locations or over a long period of time. For example, a generic QAPP may be useful for a large monitoring program that uses the same methodology at different locations. A generic QAPP describes, in a single document, the information that is not site or time-specific but applies throughout the program. Application-specific information is then added to the approved QAPP, either in the form of a site-specific QAPP, QAPP Addendum, or SAP.

1.1.3.2 WAPs and SAPs

In certain cases, WAPs or SAPs are required by a RCRA regulation. For example, WAPs are required as part of a permit application. Where WAPs or SAPs are required by regulation, the applicable regulations should be reviewed to ensure that the content and format requirements for the WAP or SAP are understood. Additionally, it should be noted that EPA has prepared various guidance documents to assist in preparing WAPs and SAPs that meet various regulatory requirements. Examples of these guidance documents include the following:

- EPA guidance on the preparation of WAPs can be found in the document entitled *Waste Analysis at Facilities that Generate, Treat, Store and Dispose of Hazardous Wastes* (ECDIC 2002-011), dated April 1994.
- EPA guidance on SAPs for delisting petitions can be found in the document entitled *EPA RCRA Delisting Program Guidance Manual for the Petitioner*, dated March 2000.
- General SAP guidance can be found in EPA's *RCRA Waste Sampling Draft Technical Guidance*, dated August 2002.
- Chapter 9 of this document (*Test Methods for Evaluating Solid Waste, Physical/Chemical Methods - SW-846*) presents additional discussion on sampling plans.

A QAPP may also be prepared, and required, as a supplement to any WAP or SAP. It should also be noted that if a WAP or SAP is not required by regulation, QAPPs can be prepared such that they present sufficient detail to cover both the QAPP and WAP or SAP in a single document. If a WAP or SAP is prepared along with a QAPP, it is common for these documents to reference one another for necessary information. To enhance the usability of QAPPs and WAPs/SAPs, references between the documents should be specific, providing the full document name, section number, subsection, and page number.

1.1.4 Data Quality Indicators

As part of systematic planning, measurement performance criteria for DQIs must be established and documented for each data collection effort. DQIs apply to both laboratory and field activities. At a minimum, DQIs should include precision, accuracy, representativeness, comparability, and completeness (PARCC). The following presents a discussion of PARCC and other DQIs.

1.1.4.1 Precision

Precision measures the agreement among a set of replicate measurements. Field precision is assessed through the collection and analysis of field duplicates. Analytical precision is estimated by duplicate/replicate analyses, usually on laboratory control samples, spiked samples and/or field samples. The most commonly used estimates of precision are the relative standard deviation (RSD) and, when only two samples are available, the relative percent difference (RPD).

1.1.4.2 Accuracy

Accuracy is the closeness of a measured result to an accepted reference value. Accuracy is usually measured as a percent recovery. QC analyses used to measure accuracy include standard recoveries, laboratory control samples, spiked samples, and surrogates.

1.1.4.3 Representativeness

Sample representativeness expresses the degree to which data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. It is dependent on the proper design of the sampling program and will be satisfied by ensuring the approved plans were followed during sampling and analysis.

1.1.4.4 Comparability

Comparability expresses the degree of confidence with which one data set can be compared to another. It is dependent upon the proper design of the sampling program and will be satisfied by ensuring that the approved plans are followed and that proper sampling and analysis techniques are applied. Further, when assessing comparability, data sets should be of known and documented quality.

1.1.4.5 Completeness

Completeness is a measure of the amount of valid data collected compared to the amount planned. Measurements are considered to be valid if they are unqualified or qualified as estimated data during validation. Field completeness is a measure of the number of samples collected versus the number of samples planned. Laboratory completeness is a measure of the number of valid measurements compared to the total number of measurements planned.

1.1.4.6 Bias

Bias is the systematic or persistent distortion of a measurement process that causes error in one direction (e.g., the sample measurement is consistently lower than the sample's true value). Bias can be introduced during sampling, analysis, and data evaluation. Sampling bias is best addressed through the proper selection and use of sampling tools, uses of correct sampling and subsampling procedures to limit preferential selection or loss of sample media, use of random sampling designs, and use of sample handling procedures that limit the loss or gain of constituents to the sample media. Analytical bias refers to deviation in one direction (i.e., high, low or unknown) of the measured value from a known spiked amount. Analytical bias can be assessed by comparing a measured value in a sample of known concentration to an accepted reference value or by determining the recovery of a known amount of contaminant spiked into a sample (matrix spike). The planning team should specify qualitative criteria for sampling bias and quantitative criteria for analytical bias, typically expressed as "percent recovery."

1.1.4.7 Reproducibility

Analytical reproducibility is a quantitative indicator that is used when referring to the uncertainty associated with the use of multiple laboratories for a specific study. The ability of multiple laboratories to generate the same result for splits of the same sample can be expressed as a measure of interlaboratory precision and bias. Specific indicators of precision and bias (such as range or variance) are generated using data from replicate samples sent to multiple laboratories.

1.1.4.8 Repeatability

Repeatability is a quantitative indicator that in used within a single laboratory (i.e., intralaboratory precision). It is determined when the laboratory, analyst, test method and equipment remain constant and random aliquots of the same sample are analyzed within a short period of time.

1.1.4.9 Sensitivity

Sensitivity is an instrument's or method's minimum concentration that can be reliably measured or reported (i.e., or lower limit of quantitation [LLOQ]).

Please note the glossary section to this chapter includes further discussion of the DQIs.

1.2 IMPLEMENTATION

Implementation is the second phase of the project life cycle. The implementation phase includes the following steps:

1.2.1 Standard Operating Procedures (SOPs)

SOPs are written documents that describe, in detail, the routine procedures to be followed for a specific operation, analysis, or action. Please note, in most cases, referencing a given method or method number is not sufficient, unless the method is performed exactly as written (e.g., a method-defined parameter). Laboratories must have an SOP to demonstrate that their procedure meets the conditions of the referenced method. Information on how to prepare SOPs can be found in EPA's *Guidance for the Preparation of Standard Operating Procedures (QA/G-6)*, dated April 2007.

SOPs enable tasks to be accomplished reproducibly, even if there are changes in the personnel performing them. Consistent use of an approved SOP ensures conformance with organizational practices, reduction in the frequency of errors, and improved data comparability and defensibility. SOPs also serve as resources for training and for ready reference and documentation of proper procedures.

The SOPs, and/or procedures described in the QAPP, must be followed for all project activities from sample collection to validation. If project-specific modifications to SOPs are needed, they must also be presented in the QAPP. Field and laboratory SOPs should be provided for the areas discussed below, as applicable:

- Sample Custody SOPs that describe sample receipt and handling; sample storage; sample security and tracking; and holding times
- Sample collection
- Analytical Method SOPs, including subsampling, sample preparation/clean-up, calibration, QC, and analysis
- Reagent/Standard Preparation and Traceability SOPs
- Equipment Calibration and Maintenance SOPs
- Corrective Action SOPs
- Data Reduction SOPs
- Data Reporting SOPs
- Records Management SOPs
- Waste Disposal SOPs

As indicated above, the QC associated with each method may be provided in appropriate SOPs. The types of QC parameters to include in the SOPs and QAPP are defined in the glossary of this chapter. Since the QC acceptance limits are frequently adjusted more often than SOPs are revised, it may be impractical to update SOPs as these limits change. Therefore, field and laboratory QC limits may need to be presented in QAPP tables rather than SOPs.

1.2.2 Conducting the Study/Experiment

The data collection effort is performed in accordance with approved plans (e.g., QAPP). The QAPP will present all proposed methods (i.e., including sampling, subsampling, preservation, preparation, clean-up and determinative methods), as well as a rationale for why the proposed methods are sufficient to meet the project DQOs.

The QAPP should also indicate whether the proposed analyses include method-defined parameters and/or whether the flexible approach to methods will be utilized. For the flexible approach, the QAPP must also demonstrate that the proposed methods are adequate to reach the study goals outlined in the DQOs.

1.2.2.1 Method-defined parameters

Method-defined parameters (MDP), such as the Toxicity Characteristic Leaching Procedure (TCLP), have been written into regulations, the methods should be followed without deviation, and should not to be modified on a project basis. For a list of method-defined parameters, see Vol 40 CFR 260.11 references or the Methods Innovation Rule (MIR), in Volume 70, Number 113 of the Federal Register (70 FR 34537 Table 3). Some method-defined parameters are discussed in Chapter 8 of this manual.

1.2.2.2 Flexible Approach to Environmental Measurements

The Flexible Approach to Environmental Measurement was finalized in 2008 as EPA's preferred approach for environmental monitoring except in cases where methods are required by regulation.

The goals of the flexible approach are to:

- Provide method users flexibility when choosing sampling and analytical approaches to meet regulatory requirements for measurements
- Develop processes for validation to confirm measurements meeting quality requirements
- Increase collaboration with stakeholders to develop validation processes for new measurement technology
- Ensure timely assessment of new or modified technologies, methods, and procedures.

Chapter Two of this manual entitled, "Choosing the Correct Procedure" provides additional guidance regarding the selection of appropriate methods and method flexibility.

1.2.3 Technical Assessments

Technical Assessments (otherwise known as audits) are systematic and objective examinations of a program or project to determine whether environmental data generation activities and related results comply with planning documents. Technical assessments can be performed to evaluate all phases of a project including field sampling, laboratory analysis, validation and data handling/management.

The QAPP should identify all personnel responsible for performing technical assessments, the authority of the auditor (e.g., do they have the authority to stop work if significant deviations from planning documents are found), and the planned audit frequency. Additionally, if technical assessments are planned or required as part of a project, the QAPP should provide the applicable

technical assessment checklists. These checklists establish and document the scope of all proposed technical assessments. The development of these technical assessment checklists should overseen by an independent party (i.e., someone not involved in the day to day operations of a project), such as the organization's QA personnel. Further, the QAPP should establish a process for correcting technical assessment findings and confirming implementation of any corrective actions taken as a result of the findings.

While most technical assessments will be scheduled in advance with an organization, there may be occasions when unannounced technical assessments are needed. However, an unannounced audit may not reveal a representative picture of project activities if it occurs when the project is not active, or activities that are not within the scope of the technical assessment are occurring.

Technical assessments may be planned as part of the pre-award activities, or throughout the life of a project. For example, pre-award audits, including performance evaluation (PE) samples, are useful tools in determining the ability of a laboratory to perform the proposed analytical work. Additionally, technical assessments may also be used as an investigative tool where problems may be suspected. The EPA document Guidance on Technical Audits and Related Assessments for Environmental Data Operations (QA/G-7), dated January 2000, provides detailed information on various types of technical audits and includes an example checklist for a technical systems audit of a laboratory measurement system.

1.3 ASSESSMENT

Following planning (Sec. 1.1) and implementation (Sec. 1.2), assessment is the third and final phase of the project data generation life cycle. The purpose of this phase is to evaluate whether the data are of the type, quantity and quality needed to meet project DQOs. Assessment can involve many different complex activities, including the use of statistical tools. This section provides an introduction and overview of these data assessment activities.

1.3.1 Data Verification and Validation

Data verification and/or validation is the first step in the assessment process. Validation and verification are defined in the EPA Guidance on Environmental Data Verification and Data Validation (QA/G-8), dated November 2002. According to QA/G-8, verification is the process of evaluating the completeness, correctness, and conformance/compliance of a data set against a specified set of requirements. QA/G-8 defines validation as an analyte and sample specific process that extends the evaluation of data beyond data verification to determine its analytical quality. For the purposes of this chapter, it should be noted that the meaning of verification and validation is often program, organization and/or system specific. Further, these terms are used interchangeably at times, and in other cases have very different meanings. Therefore, it is critical that the procedures for verification and/or validation be clearly documented in the approved QAPP.

In general, data verification/validation involves the examination and review of project data (e.g., field and laboratory data for all applicable QC measurements) to confirm that the sampling and analysis protocols specified in the QAPP (and any other planning or contractual documents) were followed. Data verification/validation also involves examining whether the data met the method performance and acceptance criteria established in the project QAPP. When these criteria are not met, data verification/validation procedures should include qualification of the data (e.g., the *J* qualifier is commonly used to indicate *estimated* data and the *R* qualifier is commonly used to indicate *rejected* data). The reasons for any failure to meet performance criteria also

need to be documented during this phase of assessment (e.g., in a data verification/validation report).

In addition to QA/G-8, EPA has published several references which provide more detailed information on what should be included in data verification and validation procedures. These include EPA regional and programmatic validation guidance documents that may apply to particular projects. It is also common for EPA guidance from one program or region to be modified for use in another area. While this may be acceptable, any modifications or changes to the established validation procedures should be included in the approved QAPP.

Data verification/validation may be performed at various phases throughout a project. As such, the procedures for verifying and/or validating data may need to be described in laboratory SOPs and/or QA Plans, in addition to the project documents like the QAPP. Corrective action based on verification/validation findings may also need to be described in these documents.

Data verification/validation activities may be performed internally (e.g., when the laboratory or data collector review their own data), or externally by an independent entity (i.e., a party that is not associated with the data collection effort). Internal and external data verification/validation procedures should be defined in the QAPP or other project documents.

A data verification/validation report should be generated to document the procedures followed as well as the findings and qualifications applied during data verification/validation. The report should include a list of the samples collected, field information about how the samples were collected, the analyses performed on the samples, the results of the analysis and the quality of the reported data, at a minimum. The usability of this report can be enhanced by listing the samples and analytes affected by each QC criteria exceedance, as well as the extent of the exceedance, and any qualifiers applied. Any other observations noted by the data reviewer that may impact the usability of the data should also be documented.

1.3.2 Data Quality Assessment

Data quality assessment (DQA) is the second step in the assessment process. DQA is often needed because data verification/validation alone is generally not sufficient to determine whether a data set can be used for its intended purpose. Typically, the DQA follows the data verification and/or validation step.

In general, the DQA should include an evaluation of overall trends or biases in the data and associated QC results, as well as how the data may be affected. For random data sets, the DQA should evaluate the validity of any statistical assumptions made during the planning phase. If the statistical assumptions made during the planning phase are not supported by the data, recommendations for corrective action should be presented. All DQA findings should be summarized in a report.

Guidance documents available from EPA that discuss the DQA process include *Data Quality Assessment: A Reviewer's Guide* (QA/G-9R), dated February 2006, and *Data Quality Assessment: Statistical Tools for Practitioners* (QA/G-9S), dated February 2006.

The DQA process described in this guidance is a five-step process.

Step 1: Review the Data Quality Objectives and Sampling Design
Step 2: Conduct a Preliminary Data Review
Step 3: Select the Statistical Method
Step 4: Verify the Assumptions of the Statistical Method

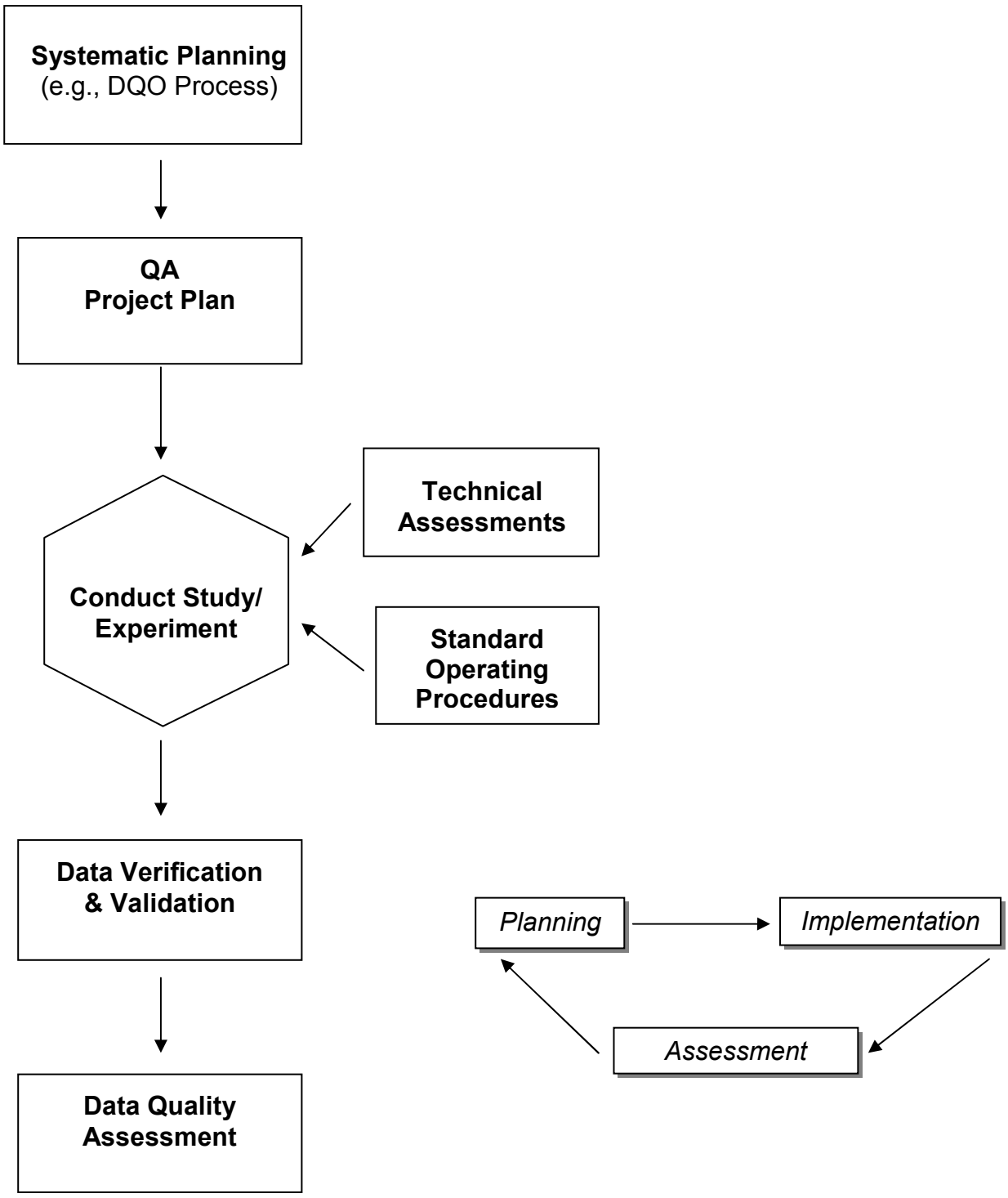
Step 5: Draw Conclusions from the Data

It is recommended that the data user refer to these guidance documents, because they provide extensive information about DQA and the statistical tools that can be employed.

Although the DQA process described in QA/G-9R and QA/G-9S includes a significant amount of statistical procedures, it should be noted that the DQA process is not only applicable to random data sets, where statistics can be used to assess the data. A DQA should also be performed on judgmental, or biased, data sets. The process for how any data set will be assessed should be determined during the planning phase, and documented in the QAPP or other site documents.

FIGURE 1-1

PROJECT LEVEL EPA QA SYSTEM



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1.5. GLOSSARY

Also see the following for a glossary of quality-related terms developed by EPA:

http://www.epa.gov/fem/pdfs/Env_Measurement_Glossary_Final_Jan_2010.pdf

ACCURACY — The degree of agreement between an observed value and an accepted reference value. When applied to a set of observed values, accuracy includes a combination of a random error (precision) and systematic error (bias) components.

ANALYTICAL BATCH — A group of samples, including quality control samples, which are processed together using the same method, the same lots of reagents, and at the same time or in continuous, sequential time periods. Samples in each batch should be of similar composition and share common internal quality control standards. For QC purposes, if the number of samples in a batch is limited to 20; laboratory QC samples are not included in the batch count.

Each batch should be uniquely identified within the laboratory for tracking purposes. Samples collected from the same site would normally be grouped together for batching purposes within the constraints imposed by the method holding times and batch size. Samples prepared in the same batch would normally be analyzed together on a single instrument. However, laboratories may find it necessary to group multiple clients' samples into a single batch. Under these circumstances, additional matrix QC samples (*i.e.*, duplicates, matrix spikes) may be needed to evaluate the effect of the matrix from each site on method performance.

BIAS — The constant or systematic distortion of a measurement process, different from random error, which manifests itself as a persistent positive or negative deviation from the known or true value. This can result from improper data collection, poorly calibrated analytical or sampling equipment, or limitations or errors in analytical methods and techniques.

Bias can be assessed by comparing a measured value to an accepted reference value in a sample of known concentration or by determining the recovery of a known amount of contaminant spiked into a sample (matrix spike). Thus, the bias (B) due to matrix effects based on a matrix spike is calculated as:

$$B = (x_s - x_u) - K$$

where:

x_s = measured value for spiked sample,
x_u = measured value for unspiked sample, and
K = known value of the spike in the sample.

Using the following equation yields the percent recovery (%R).

$$\%R = 100\ (x_s - x_u)/\ K$$

BLANK	Blanks are generally considered to be acceptable if target analyte concentrations are less than ½ the LLOQ or are less than project-specific requirements. Blanks may contain analyte concentrations greater than acceptance limits if the associated samples in the batch are unaffected (i.e. targets are not present in samples or sample concentrations are ≥10X the blank). Other criteria may be used depending on the needs of the project. For method specific details see methods 6010, 6020 for inorganics and Method 8000 for organics). See also Calibration Blank, Equipment Blank, Method Blank, Reagent Blank and Trip Blank.
CALIBRATION BLANK	A calibration blank is a sample of analyte-free media that can be used along with prepared standards to calibrate the instrument. A calibration blank may also be used to verify absence of instrument contamination (e.g., initial calibration blank and continuing calibration blank).
CALIBRATION CHECKS	Calibration check analyses are used to assess calibration drift and memory effects over time for each analytical system. These analyses may include zero, span (low and high) to cover the full calibration range, and mid-range checks, depending on the method.
CALIBRATION CURVE	A plot of instrument response to an analyte versus known concentrations or amounts of analyte standards. Calibration standards are prepared by successively diluting a standard solution to produce working standards which cover the working range of the instrument. Standards should be prepared at the frequency specified in the appropriate method. The calibration standards should be prepared using the same type of acid or solvent and at the same concentration as the samples following sample preparation. This is applicable to organic and inorganic chemical analyses.
CO-LOCATED SAMPLES	A type of field duplicate where independent samples are collected as close as possible to the same point in space and time. They are two separate samples taken from the same source, stored in separate containers, and analyzed independently by the same method and laboratory. These duplicates are useful in documenting the precision of the sampling process.
COMPARABILITY	The degree to which different methods or data agree or can be represented as similar. Comparability describes the confidence that two data sets can contribute to a common analysis and interpolation.
COMPLETENESS	A measure of the amount of valid data obtained from a measurement system compared with the amount that was expected to be obtained under correct, normal conditions. Percent completeness is calculated as: $$\% \text{ Completeness} = \frac{x}{y} \times 100$$ where:

x = amount of valid data obtained
y = amount of data expected to be obtained

DATA QUALITY INDICATORS (DQIs)	The quantitative statistics and qualitative descriptors that are used to interpret the degree of acceptability or utility of data to the user. The principal indicators of data quality are precision, bias, accuracy, representativeness, comparability, completeness, and sensitivity.
DATA QUALITY OBJECTIVES (DQOs)	Qualitative and quantitative statements derived from the DQO Planning Process that clarify the purpose of the study, define the most appropriate type of information to collect, determine the most appropriate conditions from which to collect that information, and specify tolerable levels of potential decision errors.
DATA VALIDATION	The process of evaluating the available data against the project DQOs to make sure that the objectives are met. Data validation may be very rigorous, or cursory, depending on project DQOs. The available data reviewed will include analytical results, field QC data, laboratory QC data, and may also include field records.
DUPLICATE	See Co-located Samples, Laboratory Duplicate, Field Duplicate, Field Split Samples, and Matrix Spike Duplicate.
EQUIPMENT BLANK	A sample of analyte-free media which has been used to rinse the sampling equipment. It is collected after completion of decontamination and prior to sampling at a location. This blank is useful in documenting adequate decontamination of sampling equipment.
EQUIPMENT RINSATE	See Equipment Blank.
FIELD BLANK	Field blanks include any sample submitted from the field that is identified as a blank. These include trip blanks, rinsates, equipment blanks, etc. Field blanks may also be obtained by the sampling organization to measure ambient contamination in the field. If this type of field blank is requested, a container of reagent water or a solid blank material is opened in the field for a predefined period of time. The sample is then sent to the laboratory for analysis.
FIELD DUPLICATES	Field duplicates are useful in documenting the precision of the sampling process. Field duplicates are used to assess improper homogenization of the samples in the field; reproducibility of sample preparation and analysis; and, heterogeneity of the matrix. See also Co-located Samples and Field Split Samples.
FIELD SPLIT SAMPLES	A type of field duplicate where the sample is homogenized and then divided into two or more aliquots so that variability can be evaluated, (i.e., often between laboratories or methods). Homogenization may have an impact on sample integrity for some sample types (e.g., VOCs

in soil), and in these cases co-located samples may be more appropriate.

INITIAL DEMONSTRATION of PROFICIENCY (IDP)

Prior to the analysis of samples an initial demonstration of method proficiency is accomplished through the successful calibration of method-specific instruments according to project requirements and criteria set forth in the applicable analytical methodology. This initial demonstration should be performed prior to independently running an analytical method, and should be repeated if other changes occur (e.g., instrument repair, significant change in procedure).

Please see individual methods for additional guidance on IDP.

INTERNAL STANDARD

Internal standards may be spiked into prepared field samples and QC samples (or sample extracts). Their recovery is generally used to demonstrate the lack of severe matrix effect in the instrumental analysis by setting criteria for the internal standard response in comparison to a response in a sample with a known lack of matrix effect (*i.e.*, a standard). Internal standards are also used to account for matrix effects and/or variability in instrument response by normalizing the response of the target analytes and surrogates, thereby decreasing measurement bias to the extent that their behavior mimics that of the target analytes.

LABORATORY CONTROL SAMPLE

The Laboratory Control Sample (LCS) is analyzed to assess general method performance based on the ability of the laboratory to successfully recover target analytes from a control matrix. The LCS is similar in composition to the method blank in that it is an aliquot of analyte-free water or analyte-free solid (e.g., Ottawa sand, anhydrous sodium sulfate, or other purified solid) to which known amounts of the method analytes are added. LCS analyses help determine if the system is running properly (i.e., within pre-defined limits). Although the frequency of LCS analysis should be determined by the needs of a project, typically one LCS is prepared and analyzed for every analytical batch. The LCS sample is prepared and analyzed in the same analytical batch and in exactly the same manner as the other routine samples. The recovery of the target analytes in the LCS analysis demonstrates whether the methodology is in control and the laboratory is capable of making unbiased measurements. The results of the LCS are evaluated in conjunction with other QC information to determine the acceptability of the data generated for that batch of samples. Acceptance criteria for LCS recovery are calculated based on statistical treatment of historical LCS recovery data through the use of control charts.

LABORATORY DUPLICATE

The analysis or measurements of the variable of interest performed identically on two sub-samples of the same sample, usually taken from the same container. The results from duplicate analyses are used to evaluate analytical or measurement precision and include variability associated with sub-sampling and the matrix, but not the precision of field sampling, preservation, or storage internal to the laboratory.

Laboratory duplicate analysis entails removing two aliquots from the

	same sample and taking them through the same preparative and analytical procedures to evaluate analytical precision. Laboratory duplicates are more commonly used to assess precision for inorganic and radiological constituents, while precision for organic analyses is usually assessed by determining the RPD between matrix spike and matrix spike duplicates. The frequency of laboratory duplicate analysis will depend on project requirements.
LOWER LIMIT OF QUANTITATION (LLOQ)	The lowest point of quantitation which, in most cases, is the lowest concentration in the calibration curve. The LLOQ is initially verified by spiking a clean control material (e.g., reagent water, method blanks, Ottawa sand, diatomaceous earth, etc.) at the LLOQ and processing through all preparation and determinative steps of the method. Laboratory-specific recovery limits should be established when sufficient data points exist. Individual methods may recommend procedures for verifying the LLOQ and acceptance limits for use until the laboratory has sufficient data to determine acceptance limits. LLOQs should be determined at a frequency established by the method, laboratory's quality system, or project. Please see individual methods for additional guidance on implementing LLOQ (e.g., 8000, 6020).
MATRIX	The material of which the sample is composed or the substrate containing the analyte of interest, such as waste water, storm water and biosolids. Also called medium or media.
MATRIX SPIKE	Matrix spikes are aliquots of environmental samples to which known concentrations of certain target analytes have been added before sample preparation, cleanup, and determinative procedures have been implemented. Matrix spike analysis would normally be included with each preparation batch of samples processed. Under ideal circumstances, the original, unspiked, field sample will be analyzed first, to determine the concentration in the unspiked sample. However, if this approach is not practical, the samples may be spiked at the midpoint of the calibration range or at the same level as the LCS. The matrix spike analysis is used to assess the performance of the method by measuring the effects of interferences caused by the sample matrix and reflects the bias of the method for the particular matrix in question.
MATRIX SPIKE DUPLICATES	Matrix spike duplicates are additional replicates of matrix spike samples that are subjected to the sample preparation and analytical scheme as the original sample. A matrix spike duplicate sample would normally be included with each preparation batch of samples processed. Analysis of spiked duplicate samples ensures a positive value, allowing for estimation of analytical precision. Matrix spike duplicates are used to document the precision as well as bias of a method in a given sample matrix. When critical decisions are based on the matrix spike and matrix spike duplicate recoveries, the laboratory should maintain control charts for these samples to monitor

precision and bias for each particular matrix.

METHOD BLANK

Method blanks are analyzed to assess background interference or contamination that exists in the analytical system that might lead to the reporting of elevated concentration levels or false positive data. The method blank is defined as an interference-free blank matrix, similar to the sample matrix, to which all reagents are added in the same volumes or proportions as used in sample preparation and carried through the complete sample preparation, cleanup, and determinative procedures. For aqueous analyses, analyte-free reagent water would typically be used. For soil analyses, a purified solid matrix (e.g., sand) would typically be used, except for metals analyses. Method blank results are evaluated in conjunction with other QC information to determine the acceptability of the data generated for that batch of samples. The method blank results should be below the LLOQ for the target analytes being tested; otherwise, corrective action should be taken. A method blank is included with the analysis of every analytical batch of 20 samples or less or as stated in the QAPP or method, whichever is more frequent.

ORGANIC-FREE REAGENT WATER

All references to water in the methods refer to water in which an interferant is not observed at the LLOQ for the compounds of interest. Preparation of organic-free reagent water may depend on the types of interferants of concern for the analysis and may include boiling, sparging with an inert gas, reverse osmosis purification, distillation, particle filtration, activated carbon filtration, ion exchange filtration, etc.

POST-DIGESTION SPIKES

Post-digestion spike samples are typically prepared for inorganic analyses when pre-digestion/pre-distillation matrix spike recoveries are outside the required control limits. They are prepared by spiking a known amount of standard to the sample digestate. The recovery data from the post digestion spike analyses are used to further assess if matrix effects may be a source of measurement bias in sample quantitation.

PRECISION

The agreement among a set of replicate measurements without assumption of knowledge of the true value. Precision is estimated by means of duplicate/replicate analyses of separate aliquots of the same sample (not multiple runs of a single digestion/extraction). These samples should contain concentrations of analyte at or above the LLOQ, and may involve the use of matrix spikes. The most commonly used estimates of precision are:

Relative standard deviation (RSD), also known as the coefficient of variation (CV):

$$RSD = CV = (100)*(S/\bar{x})$$

where:

$\bar{x}$ = the arithmetic mean of the i measurements, and
S = the square root of the variance of i measurements; and,

Relative percent difference (RPD) when only two results are compared:

$$RPD = \frac{|X_1 - X_2|}{\left(\frac{X_1 + X_2}{2}\right)} * 100$$

where: x_1 and x_2 are measurements of independently prepared aliquots of the same sample or replicate samples.

PROJECT	Single or multiple data collection activities that are related through the same planning sequence.
QUALITY CONTROL SAMPLE	A sample made from standards or matrix and used to verify acceptability of the results from preparation and/or analysis of a batch of samples. Examples of laboratory quality control samples are method blanks, laboratory duplicates, and laboratory control samples; field quality control samples are field blanks, trip blanks, field duplicates, and matrix spikes.
QUALITY ASSURANCE PROJECT PLAN (QAPP)	A formal document describing in comprehensive detail the necessary quality assurance, quality control, and other technical activities that should be implemented to ensure that the results of the work performed will satisfy the stated performance criteria.
REAGENT BLANK	Reagent blanks are analyzed to assess background interference or contamination that exists in the analytical system that might lead to the reporting of elevated concentration levels or false positive data. The reagent blank is defined as an interference-free blank matrix, to which all reagents are added in the same volumes or proportions as used in sample preparation but are NOT carried through the complete sample preparation, cleanup, and determinative procedures. The purpose of a reagent blank is to gauge contamination from chemical inputs and instrumental factors only. A reagent blank is NOT run as part of a digestion or preparation method.
REAGENT GRADE	Analytical reagent (AR) grade, ACS reagent grade, and reagent grade are synonymous terms for reagents which conform to the current specifications of the Committee on Analytical Reagents of the American Chemical Society.
REAGENT WATER	Water that has been generated by any method which would achieve the performance specifications for ASTM Type II water. For organic analyses, see the definition of organic-free reagent water.
REFERENCE MATERIAL	A material containing known quantities of target analytes in solution or in a homogeneous matrix. It is used to document the bias of the analytical process.
REPEATABILITY	The degree of agreement between mutually independent test results produced by the same analyst using the same test method and equipment on random aliquots of the same sample within a short

	period of time.
REPRESENTATIVE-NESS	A measure of the degree to which data accurately represent a characteristic of a population, a parameter variation at a sampling point, a process condition, or an environmental condition.
REPRODUCIBILITY	Reproducibility is defined as the closeness of the agreement between the results of measurements of the same analyte carried out under variable conditions of measurement.
STANDARD ADDITION	The addition of a known amount of analyte to the sample in order to determine the relative response of the detector to an analyte within the sample matrix. The relative response is then used to assess either an operative matrix effect or the sample analyte concentration.
SURROGATE	Surrogates are most commonly used to monitor the performance of organic analyses using methods such as high performance liquid chromatography (HPLC), gas chromatography (GC), and gas chromatography/mass spectrometry (GC/MS). Surrogate spikes are added to field samples and QC samples for organic analyses at known amounts, and their recoveries are used to assess matrix effects and, to some extent, verify proper processing and instrument performance for each sample. The analytes used as surrogates mimic the behavior of the target analyte(s) throughout sample preparation and instrument determination. Surrogates are organic compounds which are similar to the target analytes in chemical composition and behavior in the analytical process, but are not normally found in the environmental samples. Surrogates added to LCS samples and blanks are used to assess recovery in a matrix known to be free from interference. This information can be used to determine the magnitude of matrix interference effects on environmental sample results.
TRIP BLANK	A sample of analyte-free media taken from the laboratory to the sampling site and returned to the laboratory unopened. Trip blanks should be prepared at a frequency of one per day of sampling during which samples are collected for volatile organic constituents (VOCs). Trip blanks are prepared prior to the site visit at the time sample containers are shipped to the site. The trip blank should accompany the sampling kits throughout all the sample collection and transport operations. This blank will not be opened during the sampling activities and will be used to assess sample VOC contamination originating from sample transport, shipping, or site conditions. A trip blank is used to document contamination attributable to shipping and field handling procedures.

APPENDIX A

SUMMARY OF UPDATES/CHANGES IN CHAPTER 1

1. The entire Chapter has been rewritten and reorganized to reflect changes in the EPA data quality system approach.
2. The revision number was changed to two and the date published to July 2014.
3. This appendix was added to document changes made during the editorial process.
4. The document was updated to match the current SW-846 style guidelines.
5. Figure 1 was added based on information in EPA QA/G-8, November 2002, Figure 1.

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Appendix 28

USEPA SW-846 Chapter 2, Choosing the Correct Procedure, July 2014.

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CHAPTER TWO

CHOOSING THE CORRECT PROCEDURE

SW-846 is not intended to be an analytical training manual. Therefore, method procedures are written based on the assumption that they will be performed by analysts who are formally trained in at least the basic principles of chemical analysis and in the use of the subject technology.

In addition, SW-846 methods, with the exception of required method use for the analysis of method-defined parameters, are intended to be guidance methods containing general information on how to perform an analytical procedure or technique which a laboratory can use as a basic starting point for generating its own detailed Standard Operating Procedure (SOP), either for its own general use or for a specific project application. The performance data included in these methods are for guidance purposes only, and are not intended to be and must not be used as absolute quality control (QC) acceptance criteria for the purposes of laboratory accreditation.

2.0 INTRODUCTION

The purpose of this chapter is to aid the analyst in choosing the appropriate methods for sample analyses, based upon the sample matrix and the analytes to be determined. The ultimate responsibility for producing reliable analytical results lies with the entity subject to the regulation. Therefore, members of the regulated community are advised to refer to this chapter and to consult with knowledgeable laboratory personnel when choosing the most appropriate suite of analytical methods. In addition, analysts and data users are advised that, except where explicitly specified in a regulation, the use of SW-846 methods is not mandatory in response to Federal testing requirements.

SW-846 analytical methods are written as quantitative analytical methods, and specific methods may be used to demonstrate that a waste does not contain analytes of concern that cause it to be managed as a hazardous waste. SW-846 methods typically contain relatively stringent recommended QC criteria appropriate to many levels of analyses, including trace. However, if a particular application does not require data of this quality, less stringent QC criteria may and should be used.

The choice of the appropriate sequence of analytical methods depends on the information sought and on the experience of the analyst. Appropriate selection is confirmed by the usability of data (i.e., adequate for its intended use). The use of the recommended procedures, whether they are approved or mandatory, does not release the analyst from demonstrating the correct execution of the method.

Sec. 2.1 provides guidance regarding the analytical flexibility inherent to SW-846 methods and the precedence of various QC criteria. Sec. 2.2 reviews the information required to choose the correct combination of methods for an analytical procedure. Sec. 2.3 provides useful information on implementing the method selection guidance for organic analyses. Sec. 2.4 provides guidance on choosing procedures for characteristic analyses. Sec. 2.5 provides guidance on the determination of analytes in groundwater. Finally, Sec. 2.6 provides

information regarding choosing procedures for inorganic analyte analyses. Tables and figures referenced in this chapter are sequentially located after the last page of chapter text.

2.1 GUIDANCE REGARDING FLEXIBILITY INHERENT TO SW-846 METHODS AND THE PRECEDENCE OF SW-846 QUALITY CONTROL CRITERIA

The specific products and instrument settings cited in SW-846 methods represent those products and settings used during method development or subsequently evaluated by the Agency for use in the method. Glassware, reagents, supplies, equipment and settings other than those listed in this manual may be employed, provided that method performance appropriate for the intended application has been documented. Such performance includes consideration of precision, accuracy (or bias), recovery, representativeness, comparability, and sensitivity (quantitation or reporting limits, now referred to as lower limit of quantitation (LLOQ)) relative to the data quality objectives (DQOs) for the intended use of the analytical results. In response to this inherent flexibility, if an alternative analytical procedure is employed, then EPA expects the laboratory to demonstrate and document that the procedure is capable of providing appropriate performance for its intended application. This demonstration must not be performed after the fact, but as part of the laboratory's initial demonstration of proficiency with the method. The documentation should be in writing, maintained in the laboratory, and available for inspection upon request by authorized representatives of the appropriate regulatory authorities. The documentation should include the performance data as well as a detailed description of the procedural steps as performed (i.e., a written standard operating procedure).

Given this allowance for flexibility, EPA wishes to emphasize that this manual also contains procedures for "method-defined parameters," where the analytical result is wholly dependent on the process used to make the measurement. Examples include: the use of the toxicity characteristic leaching procedure (TCLP) to prepare a leachate, and the flash point, pH, paint filter liquids, and corrosivity tests. In these instances, changes to the specific methods may change the end result and incorrectly identify a waste as nonhazardous. Therefore, when the measurement of such method-defined parameters is required by regulation, those methods are <u>not</u> subject to the flexibility afforded in other methods.

Analysts and data users are advised that even for those analytes that are not method-defined, different procedures may produce some difference in results. Common examples include the differences in recoveries of phenolic compounds extracted from water by separatory funnel (Method 3510) and continuous liquid-liquid (Method 3520) extraction techniques, differences in recoveries of many compounds between Soxhlet (Method 3540) and ultrasonic (Method 3550) extraction techniques, and differences resulting from the choice of acid digestion of metals (Method 3050) or microwave digestion (Method 3051). Where practical, the Agency has included guidance in the individual methods regarding known potential problems, and analysts are advised to review this information carefully in choosing or modifying analytical procedures. Chapter One describes a variety of QC procedures that may be used to evaluate the quality of the analytical results. Additional QC procedures may be described in the individual methods. The results of these QC procedures should be used by the analyst to evaluate if the analytical procedures and/or any modifications are appropriate to generate data of the quality necessary to satisfy the data quality needs of the intended application.

The performance data included in the SW-846 methods are <u>not</u> intended to be used as absolute QC acceptance criteria for method performance. The data are intended to be guidance, by providing typical method performance in typical matrices, to assist the analyst in selection of the appropriate method for the intended application. In addition, it is the

responsibility of the laboratory to establish actual operating parameters and in-house QC acceptance criteria, based on its own laboratory SOPs and in-house QC program, to demonstrate appropriate performance of the methods used in that laboratory for the RCRA analytical applications for which they are intended.

The regulated community is further advised that the methods here or from other sources need only be used for those specific analytes of concern that are subject to regulation or other monitoring requirements. The fact that a method provides a long list of analytes does not mean that each of those analytes is subject to any or all regulations, or that all of those analytes must be analyzed each time the method is employed, or that all of the analytes can be analyzed using a single sample preparation procedure. It is EPA's intention that the target analyte list for any procedure includes those analytes necessary to meet the DQOs of the project (i.e., those analytes subject to monitoring requirements and set out in a RCRA permit or other applicable regulation, plus those analytes used in the methods for QC purposes, such as surrogates, internal standards, system performance check compounds, etc.). Additional analytes, not included on the analyte list of a particular method(s) but needed for a specific project, may be analyzed by that particular method(s), if appropriate performance can be demonstrated for those analytes in the matrices of concern at the levels of concern.

2.1.1 Trace analysis vs. macroanalysis

Through the choice of sample size and concentration procedures, the methods presented in SW-846 were designed to address the problem of "trace" analyses (<1000 ppm), and have been developed for an optimized working range. These methods are also applicable to "minor" (1000 ppm - 10,000 ppm) and "major" (>10,000 ppm) analyses, as well, through use of appropriate sample preparation techniques that result in analyte concentrations within that optimized range. Such sample preparation techniques include:

1. Adjustment of size of sample prepared for analysis (for homogeneous samples)
2. Adjustment of injection volumes
3. Dilution or concentration of sample
4. Eelimination of concentration steps prescribed for "trace" analyses
5. Direct injection (of samples to be analyzed for volatile constituents)

The performance data presented in each of these methods were generated from "trace" analyses, and may not be applicable to "minor" and "major" analyses. Generally, extraction efficiency improves as concentration increases.

CAUTION: Great care should be taken when performing trace analyses after the analysis of concentrated samples, given the possibility of contamination.

2.1.2 Choice of apparatus and preparation of reagents

Since many types and sizes of glassware and supplies are commercially available, and since it is possible to prepare reagents and standards in many different ways, the apparatus, reagents, and volumes included in these methods may be replaced by any similar types as long as this substitution does not affect the overall quality of the analyses.

2.1.3 Quality control criteria precedence

Chapter One contains general QC guidance for analyses using SW-846 methods. QC guidance specific to a given analytical technique (e.g., extraction, cleanup, sample introduction, or analysis) may be found in Methods 3500, 3600, 5000, 7000, and 8000. Method-specific QC criteria may be found in Sec. 8.0 of most older individual methods, in Sec. 9.0 of newer methods, or in Sec. 11.0 of some air sampling methods. When inconsistencies exist between the information in these locations, method-specific QC criteria take precedence over both technique-specific criteria and those criteria given in Chapter One, and technique-specific QC criteria take precedence over the criteria in Chapter One.

2.2 INFORMATION NECESSARY FOR CHOOSING THE CORRECT PROCEDURE

In order to choose the correct combination of methods to comprise the appropriate analytical procedure, some basic information is necessary. This includes information on:

1. The physical state of the sample
2. The analytes of interest
3. The analytical sensitivity needed
4. The analytical objective
5. Whether the purpose is quantitation or monitoring
6. What sample containers and preservation will be used and what holding times may apply

2.2.1 Physical state(s) of sample

The phase characteristics of the sample must be known. There are several general categories of phases into which the sample may be categorized, including:

Aqueous	Oil or other Organic Liquid
Sludge	Multiphase Sample
Solid	Groundwater
Stack Sampling –Volatile Organics Sampling Train (VOST) Condensate	
TCLP or Extraction Procedure (EP) Extract	

There may be a substantial degree of overlap between the phases listed above and it may be useful to further divide these phases in certain instances. A multiphase sample may be a combination of aqueous, organic liquid, sludge, and/or solid phases, and generally must undergo a phase separation as the first step in the analytical procedure.

2.2.2 Analytes of interest

Analytes may be divided into various classes, based on the determinative methods used to identify and quantify them. The most basic differentiation is between organic (e.g., carbon-containing) analytes and inorganic (e.g., metals and anions) analytes.

Table 2-1 is an alphabetical list of analytes cited within the SW-846 organic determinative methods (excludes immunoassay and other screening methods). These analytes have been evaluated by those methods. The methods may also be applicable to other analytes that are similar to those listed. Tables 2-2 through 2-38 list the analytes for each organic determinative method. Table 2-39 indicates which methods are applicable to inorganic analytes.

NOTE: Analysts should review the discussion in Sec. 2.1 of this chapter with regard to the presence of an analyte in a method versus the need for its analysis for a given project.

2.2.3 Sensitivity

Some regulations may require a specific sensitivity or quantitation limit (LLOQ) for an analysis, as in the determination of analytes for the Toxicity Characteristic (TC). Drinking water quantitation limits, for those specific organic and metallic analytes covered by the National Primary Drinking Water Regulations, are desired in the analysis of groundwater.

2.2.4 Analytical objective

Knowledge of the analytical objective is essential in the choice of sample preparation procedures and in the selection of a determinative method. This is especially true when the sample has more than one phase. Knowledge of the analytical objective may not be possible or desirable at all management levels, but that information should be included in the project planning document and transmitted to the analytical laboratory management to ensure that the correct techniques are used during the analytical effort. Screening methods or composite sampling may be highly beneficial for some applications in order to generate a broader view of contaminant distribution than may be possible with a more precise and more costly method. Table 2-46 identifies some screening methods appropriate for different classes of organic chemicals in certain matrices.

2.2.5 Quantitation or monitoring

The strategy for quantitation of compounds in environmental or process samples may be contrasted with the strategy for collecting monitoring data. When there is little information available about the composition of the sample source (e.g., a well or process stream), mass spectral identification of organic analytes leads to fewer false positive results. Thus, the most practical form of quantitation for organic analytes is often mass spectral identification. However, where the sensitivity requirements exceed those that can be achieved using mass spectral methods (e.g., gas chromatography/mass spectrometry (GC/MS) or high performance liquid chromatography (HPLC)/MS), it may be necessary to employ a more sensitive quantitation method (e.g., electron capture). In these instances, the risk of false positive results may be minimized by confirming the results through a second analysis with a dissimilar detector or chromatographic column. Thus, the choice of technique for organic analytes may be governed by the sensitivity requirements and potential interferants.

Similarly, the choice of technique for metals may be governed by the sensitivity requirements and potential interferants.

In contrast, monitoring samples are analyzed to confirm existing and ongoing conditions, tracking the presence or absence of known constituents in an environmental or process matrix. In well-defined matrices and under stable analytical conditions, less compound-specific quantitation modes may be used, as the risk of false positive results is less.

2.2.6 Sample preservation and holding times

Table 2-40 provides information regarding recommended sample preservation techniques, sample holding times, and other information. Similar information may be found in Table 3-1 of Chapter Three (inorganic analytes) and Table 4-1 of Chapter Four (organic analytes). Samples

need to be extracted and analyzed within the recommended holding times for the results to be considered reflective of native concentrations as collected. Analytical data generated outside of the recommended holding times should typically be considered as minimum values only. Such data may be used to demonstrate that a waste is hazardous where it shows the concentration of a constituent to be above the regulatory threshold, but cannot be used to demonstrate that a waste is not hazardous. However, regarding the information in Table 2-40, a longer holding time may be appropriate if it can be demonstrated that reported concentrations are not adversely affected from preservation, storage and analyses performed outside the recommended holding times.

2.3 CHOOSING PROCEDURES FOR ORGANIC ANALYSES

Table 2-1 summarizes the organic analysis options available in SW-846.

2.3.1 Extraction and sample preparation procedures for organic analytes

SW-846 methods for preparing samples for organic analytes are shown in Table 2-41. Method 3500 and associated methods should be consulted for further details on preparing the sample for analysis.

2.3.1.1 Aqueous samples

Methods 3510, 3520, and 3535 may be used for extraction of the semivolatile organic compounds (SVOCs) from aqueous samples. The choice of a preparative method depends on the sample. Method 3510, a separatory funnel liquid-liquid extraction technique, is appropriate for samples which will not form a persistent emulsion interface between the sample and the extraction solvent. The formation of an emulsion that cannot be broken up by mechanical techniques will prevent proper extraction of the sample. Method 3520, a continuous liquid-liquid extraction technique, may be used for any aqueous sample and will minimize emulsion formation.

Method 3535 is solid-phase extraction technique that has been tested for organochlorine pesticides, phthalate esters, polychlorinated biphenyls (PCBs), organophosphorus pesticides, nitroaromatics and nitramines, and some explosive compounds, and may be applicable to other semivolatile and extractable compounds as well. The aqueous sample is passed through a solid sorbent material which traps the analytes. They are then eluted from the solid-phase sorbent with a small volume of organic solvent. This technique may be used to minimize the volumes of organic solvents that are employed, but may not be appropriate for aqueous samples with high suspended solids contents.

2.3.1.1.1 Acidic extraction of phenols and acid analytes

The solvent extract obtained by performing Method 3510, 3520, or 3535 at a pH less than or equal to 2 will contain the phenols and acid/neutral extractable organics of interest, and may contain some mildly basic compounds. The particular pH extraction conditions needs to be defined during the project planning process based on the desired target analytes and performance goals.

2.3.1.1.2 Basic or neutral extraction of semivolatile analytes

The solvent extract obtained by performing Method 3510, 3520, or 3535 at a basic pH will contain the organic bases of interest, if acid extraction is performed first. It will also contain the neutral compounds of interest, if acid extraction is not performed. Refer to Table 1 in the extraction methods (3510 and/or 3520) for guidance on the requirements for pH adjustment prior to extraction and analysis.

2.3.1.2 Solid samples

Soxhlet extraction (Methods 3540, 3541 and 3542), pressurized fluid extraction (Method 3545), microwave extraction (Method 3546) and ultrasonic extraction (Method 3550) may be used with solid samples. Consolidated samples should be ground finely enough to pass through a 1-mm sieve. In limited applications, waste dilution (Methods 3580 and 3585) may be used if the entire sample is soluble in the specified solvent.

Methods 3540, 3541, 3542, 3545, 3546 and 3550 are neutral-pH extraction techniques and therefore, depending on the analysis requirements, acid-base partition cleanup (Method 3650) may be necessary. Method 3650 will only be needed if chromatographic interferences are severe enough to prevent quantitation of the analytes of interest. This separation will be most important if a gas chromatography (GC) method is chosen for analysis of the sample. If GC/MS is used, the ion selectivity of the technique may compensate for chromatographic interferences.

There are three extraction procedures for solid samples that employ supercritical fluid extraction (SFE). Method 3560 is a technique for the extraction of petroleum hydrocarbons from various solid matrices using carbon dioxide at elevated temperature and pressure. Method 3561 may be used to selectively extract polynuclear aromatic hydrocarbons (PAHs) from solid matrices using supercritical carbon dioxide and appropriate modifiers, based on the determinative procedure to be used. Method 3562 may be used to selectively extract organochlorine pesticides or PCBs from solid matrices using supercritical carbon dioxide.

2.3.1.3 Oils and organic liquids

Method 3580, waste dilution, may be used to prepare oils and organic liquid samples for analysis of semivolatile and extractable organic analytes by GC or GC/MS. Method 3585 may be employed for the preparation of these matrices for volatiles analysis by GC or GC/MS. To avoid overloading the analytical detection system, care must be exercised to ensure that proper dilutions are made. Methods 3580 and 3585 give guidance on performing waste dilutions.

To remove interferences for semivolatiles and extractables, Method 3611 (alumina cleanup) may be performed on an oil sample directly, without prior sample preparation.

Method 3650 is the only other preparative procedure for oils and other organic liquids. This procedure is a back extraction into an aqueous phase. It is generally introduced as a cleanup procedure for extracts rather than as a preparative procedure. Oils generally have a high concentration of semivolatile compounds and, therefore, preparation by Method 3650 should be done on a relatively small aliquot of the sample. Generally, extraction of 1 mL of oil will be sufficient to obtain a saturated aqueous phase and avoid emulsions.

NOTE: The use of traditional extraction techniques (i.e., 3510, 3520, 3535, 3540, 3541, 3545, 3546, and 3550), is neither suitable nor recommended for use in these matrices due to a high potential for hydrocarbon interferences and decreased determinative method sensitivity (i.e., poor analytical performance).

2.3.1.4 Sludge samples

Determining the appropriate methods for analysis of sludges is complicated because of the lack of precise definitions of sludges with respect to the relative percent of liquid and solid components. There is no set ratio of liquid to solid that enables the analyst to determine which of the three extraction methods cited is the most appropriate. Sludges may be classified into three categories: liquid sludges, solid sludges, and emulsions, but with appreciable overlap.

If the sample is an organic sludge (solid material and organic liquid, as opposed to an aqueous sludge), the sample should be handled as a multiphase sample.

2.3.1.4.1 Liquid sludges

Method 3510 or Method 3520 may be applicable to sludges that behave like, and have the consistency of, aqueous liquids. Ultrasonic extraction (Method 3550) and Soxhlet-type (Method 3540 series) procedures will, most likely, be ineffective because of the overwhelming presence of the liquid aqueous phase.

2.3.1.4.2 Solid sludges

Soxhlet extraction (Methods 3540 and 3541), pressurized fluid extraction (Method 3545), microwave extraction (Method 3546), and ultrasonic extraction (Method 3550) will be more effective when applied to sludge samples that resemble solids. Samples may be dried or centrifuged to form solid materials for subsequent determination of semivolatile compounds.

Using Method 3650, Acid-Base Partition Cleanup, on the extract may be necessary, depending on whether chromatographic interferences prevent determination of the analytes of interest.

2.3.1.4.3 Emulsions

Attempts should be made to break up and separate the phases of an emulsion. Several techniques are effective in breaking emulsions or separating the phases of emulsions, including:

1. Freezing/thawing -- Certain emulsions will separate if exposed to temperatures below 0 °C.

2. Salting out -- Addition of a salt to make the aqueous phase of an emulsion too polar to support a less polar phase promotes separation.

3. Centrifugation -- Centrifugal force may separate emulsion components by density.

4. Addition of water or ethanol -- Emulsion polymers may be destabilized when a preponderance of the aqueous phase is added.

5. Forced filtering through glass wool -- Many emulsions can be broken by forcing the emulsion through a pad of Pyrex glass wool in a drying column using a slight amount of air pressure (using a rubber bulb usually provides sufficient pressure).

If techniques for breaking emulsions fail, use Method 3520. If the emulsion can be broken, the different phases (aqueous, solid, or organic liquid) may then be analyzed separately.

2.3.1.5 Multiphase samples

Choice of the procedure for separating multiphase samples is highly dependent on the objective of the analysis. With a sample in which some of the phases tend to separate rapidly, the percent weight or volume of each phase should be calculated and each phase should be individually analyzed for the required analytes.

An alternate approach is to obtain a homogeneous sample and attempt a single analysis on the combination of phases. This approach will give no information on the abundance of the analytes in the individual phases other than what can be implied by solubility.

A third alternative is to select phases of interest and to analyze only those selected phases. This tactic must be consistent with the sampling/analysis objectives or it will yield insufficient information for the time and resources expended. The phases selected should be compared with Figure 2-1 and Table 2-41 for further guidance.

2.3.2 Cleanup procedures

Cleanup procedure selection is determined by the analytes of interest within the extract. Each analyte type in Table 2-42, Cleanup Methods for Organic Analyte Extracts, corresponds to one or more of the possible determinative methods available in the manual. However, the necessity of performing cleanup may also depend upon the matrix from which the extract was developed. Cleanup of a sample may be done exactly as instructed in the cleanup method for some of the analytes. There are some instances when cleanup using one of the methods may only proceed after the procedure is modified to optimize recovery and separation. Several cleanup techniques may be possible for each analyte category. The information provided is not meant to imply that any or all of these methods must be used for the analysis to be acceptable. Extracts with components which interfere with spectral or chromatographic determinations are expected to be subjected to cleanup procedures.

The analyst, in consultation with the regulator, customer, and other project planning participants as necessary, must determine the necessity for cleanup procedures, as there are no clear-cut criteria for indicating their use. Method 3600 and associated methods should be consulted for further details on extract cleanup.

2.3.3 Determinative procedures

In Table 2-43, the determinative methods for organic analytes are divided into four categories, specifically: GC/MS (this category includes single quadrupole MS, triple quadrupole (MS/MS), and time-of-flight instruments); GC with electromagnetic spectrometric (ES) detectors (i.e., Fourier Transform infrared (FT-IR) or atomic emission (AES)); specific quantitation methods (i.e., GC with specific non-MS detectors); and HPLC, including any HPLC-MS methods. This division is intended to help an analyst choose which determinative method will apply. Under each analyte column, SW-846 method numbers are indicated, if appropriate, for the determination of the analyte. A blank has been left if no chromatographic determinative method is available.

Generally, the MS procedures are more specific but less sensitive than the appropriate gas chromatographic/specific quantitation or ES method.

Method 8000 gives a general description of the techniques of GC and HPLC. Method 8000 should be consulted prior to application of any of the GC or HPLC methods.

Method 8081 (organochlorine pesticides), Method 8082 (PCBs), Method 8141 (organophosphorus pesticides), and Method 8151 (chlorinated herbicides), are preferred over GC/MS because of the combination of selectivity and sensitivity of the flame photometric, nitrogen-phosphorus, and electron capture detectors.

Method 8260 is a GC/MS method for volatile analytes. A variety of sample introduction techniques may be used with Method 8260, including Methods 5021, 5030, 5031, 5035, 5041, and 3585. A GC with a selective detector is also useful for the determination of volatile organic compounds in a monitoring scenario, as described in Sec. 2.2.5.

Method 8270 is a GC/MS method for semivolatile analytes. Method 8410 is another GC method for semivolatile analytes which uses a FT-IR detector. Method 8085 is a GC method for pesticides which uses an AES detector.

Table 2-43 lists several GC and HPLC methods that apply to only a small number of analytes. Methods 8031 and 8033 are GC methods for acrolein, acrylonitrile, and acetonitrile. Methods 8315 and 8316 are HPLC methods for these three analytes. Method 8316 also addresses acrylamide, which may be analyzed by Method 8032. Method 8325 is an HPLC coupled with particle beam MS for the determination of benzidines and nitrogen-containing pesticides in water and wastewater. Method 8520 measures formaldehyde in ambient air primarily for non-occupational exposure monitoring. Method 8540 is used for field-testing of soil samples for pentachlorophenol (PCP).

HPLC methods have been developed for other types of analytes, most notably N-methyl carbamates (Method 8318); azo dyes, phenoxy acid herbicides, carbamates, and organophosphorus pesticides (Method 8321); PAHs (Method 8310); explosives (Methods 8330, 8331, and 8332); and some volatile organics (Methods 8315 and 8316).

Method 8430 utilizes a FT-IR spectrometer coupled to a gas chromatograph to determine bis(2-chloroethyl) ether and its hydrolysis products. The sample is introduced by direct aqueous injection. Method 8440 may be employed for the determination of total recoverable petroleum hydrocarbons (TRPH) in solid samples by infrared (IR) spectrophotometry. The samples may be extracted with supercritical carbon dioxide, using Method 3560.

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2.4 CHOOSING PROCEDURES FOR CHARACTERISTIC ANALYSES

2.4.1 Figure 2-2 outlines a sequence for determining if a waste exhibits one or more of the characteristics of a hazardous waste.

2.4.2 SPLP, EP and TCLP extracts

The leachate obtained from using either the Synthentic Precipitation Leaching procedure (SPLP), EP (Figure 2-3A) or the TCLP (Figure 2-3B) is an aqueous sample, and therefore, requires further solvent extraction prior to the analysis of semivolatile compounds.

The SPLP or TCLP leachate is solvent extracted with methylene chloride at a pH <2 and at a pH >11 by either Method 3510 or 3520. The leachate may also be extracted as received for organochlorine pesticides and semivolatiles and at pH <1.0 for phenoxyacid herbicides using the solid phase extraction (SPE) disk option in Method 3535. The best recoveries are usually obtained using either Method 3520 or Method 3535.

The solvent extract obtained by performing either Method 3510 or 3520 at an acidic pH will contain the acid/neutral compounds of interest. Refer to the specific determinative method for guidance on the pH requirements for extraction prior to analysis. Method 5031 (azeotropic distillation) may be used as an effective preparative method for pyridine.

Due to the high concentration of acetate in the TCLP extract, it is recommended that purge-and-trap be used to introduce the volatile sample into the gas chromatograph.

The SPLP, EP and/or TCLP extracts can also be digested using acids (Method 3010, 3015, or 3020) and analyzed for metals using a 6000 or 7000 series method (Figures 2-3A and 2-3B).

2.5 CHOOSING PROCEDURES FOR GROUNDWATER ANALYSES

Appropriate analysis schemes for the determination of analytes in groundwater are presented in Figures 2-4A, 2-4B, and 2-4C. Quantitation limits (LLOQs) for the inorganic analytes should correspond to the drinking water limits, where such limits are available.

2.5.1 Special techniques for inorganic analytes

All atomic absorption (AA) analyses should employ appropriate background correction systems whenever spectral interferences could be present. Several background correction techniques are employed in modern AA spectrometers. Matrix modification can complement background correction in some cases. Since no approach to interference correction is completely effective in all cases, the analyst should attempt to verify the adequacy of correction. If the interferant is known (e.g., high concentrations of iron in the determination of selenium), accurate analyses of synthetic solutions of the interferant (with and without analyte) could establish the efficacy of the background correction. If the nature of the interferant is not established, good agreement of analytical results using two substantially different wavelengths could substantiate the adequacy of the background correction.

To reduce matrix interferences, all graphite furnace atomic absorption (GFAA) analyses should be performed using techniques which maximize an isothermal environment within the furnace cell. Data indicate that two such techniques, L'vov platform and the delayed atomization cuvette (DAC), are equivalent in this respect, and produce high quality results.

All GFAA analysis should be carried out using the best matrix modifier for the analysis. Some examples of modifiers are listed below. (See also the appropriate methods.)

Element(s)	Modifier(s)
As and Se	Nickel nitrate, palladium
Pb	Phosphoric acid, ammonium phosphate, palladium
Cd	Ammonium phosphate, palladium
Sb	Ammonium nitrate, palladium
Tl	Platinum, palladium

Inductively coupled plasma (ICP), AA, and GFAA calibration standards need to match the acid composition and strength of the acids contained in the samples. Acid strengths of the calibration standards should be stated in the raw data. When using a method which permits the use of internal standardization, and the internal standardization option is being used, matrix matching is not required.

2.6 CHOOSING PROCEDURES FOR INORGANIC ANALYSES

Methods for preparing different sample matrices for inorganic analyses are shown in Table 2-44. Guidance regarding the use of leaching and digestive methods for inorganic analysis is provided in Table 2-45.

2.7 REFERENCES

1. M. J. Barcelona, "TOC Determinations in Ground Water," Ground Water 1984, 22(1), 18-24.

2. R. Riggin, et al.; Development and Evaluation of Methods for Total Organic Halide and Purgeable Organic Halide in Wastewater; U.S. Environmental Protection Agency; Office of Research and Development; Environmental Monitoring and Support Laboratory; ORD Publication Offices of Center for Environmental Research Information; Cincinnati, OH, 1984; EPA-600/4-84-008.

3. G. McKee, et al.; Determination of Inorganic Anions in Water by Ion Chromatography (Technical addition to Methods for Chemical Analysis of Water and Wastewater, EPA 600/4-79-020); U.S. Environmental Protection Agency; Environmental Monitoring and Support Laboratory; ORD Publication Offices of Center for Environmental Research Information; Cincinnati, OH, 1984; EPA-600/4-84-017.

TABLE 2-1

DETERMINATIVE METHODS FOR ORGANIC ANALYTES

Analytes are listed in alphabetical order and alternative analyte names are in parenthesis. The applicable method listing does not include immunoassay or screening methods.

Analyte	Applicable Method
Abate (Temephos)	8085
Acenaphthene	8100, 8270, 8275, 8310, 8410
Acenaphthylene	8100, 8270, 8275, 8310, 8410
Acetaldehyde	8315
Acetone	8015, 8260, 8261, 8315
Acetonitrile	8015, 8033, 8260, 8261
Acetophenone	8261, 8270
2-Acetylaminofluorene	8270
1-Acetyl-2-thiourea	8270
Acifluorfen	8085, 8151
Acrolein (Propenal)	8015, 8260, 8261, 8315, 8316
Acrylamide	8032, 8316
Acrylonitrile	8015, 8031, 8260, 8261, 8316
Alachlor	8081, 8085
Aldicarb (Temik)	8318, 8321
Aldicarb sulfone	8318, 8321
Aldicarb sulfoxide	8321
Aldrin	8081, 8085, 8270
Allyl alcohol	8015, 8260
Allyl chloride	8021, 8260, 8261
Ametryn	8085
2-Aminoanthraquinone	8270
Aminoazobenzene	8270
4-Aminobiphenyl	8270
Aminocarb	8321
2-Amino-4,6-dinitrotoluene (2-Am-DNT)	8095, 8330
4-Amino-2,6-dinitrotoluene (4-Am-DNT)	8095, 8330
3-Amino-9-ethylcarbazole	8270
t-Amyl alcohol (TAA)	8015
t-Amyl ethyl ether (TAEE, 4,4-Dimethyl-3-oxahexane)	8015, 8260, 8261
t-Amyl methyl ether (TAME)	8015, 8260, 8261
Anilazine	8270
Aniline	8131, 8261, 8270
o-Anisidine	8270
Anthracene	8100, 8270, 8275, 8310, 8410
Aramite	8270
Aroclor-1016 (PCB-1016)	8082, 8270
Aroclor-1221 (PCB-1221)	8082, 8270
Aroclor-1232 (PCB-1232)	8082, 8270
Aroclor-1242 (PCB-1242)	8082, 8270
Aroclor-1248 (PCB-1248)	8082, 8270
Aroclor-1254 (PCB-1254)	8082, 8270

Aroclor-1260 (PCB-1260)..... 8082, 8270
Aspon 8141
Asulam..... 8321
Atraton 8085
Atrazine..... 8041, 8085, 8141
Azinphos-ethyl (Ethyl guthion)..... 8085, 8141
Azinphos-methyl (Guthion)..... 8085, 8141, 8270
Barban 8270, 8321
Baygon (Propoxur)..... 8318, 8321
Bendiocarb..... 8141, 8318, 8321
Benefin 8091
Benfluralin..... 8085
Benomyl..... 8321
Bentazon..... 8151
Benzal chloride 8121
Benzaldehyde 8315
Benz(a)anthracene 8100, 8270, 8275, 8310, 8410
Benzene..... 8015, 8021, 8260, 8261
Benzenethiol (Thiophenol) 8270
Benzidine..... 8270, 8325
Benzo(b)fluoranthene..... 8100, 8270, 8275, 8310
Benzo(j)fluoranthene..... 8100
Benzo(k)fluoranthene..... 8100, 8270, 8275, 8310
Benzoic acid 8270, 8410
Benzo(g,h,i)perylene..... 8100, 8270, 8275, 8310
Benzo(a)pyrene 8100, 8270, 8275, 8310, 8410
p-Benzoquinone..... 8270
Benzotrichloride 8121
Benzoylprop ethyl 8325
Benzyl alcohol..... 8270
Benzyl chloride..... 8021, 8121, 8260
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N-Nitrosomethylethylamine 8261, 8270
N-Nitrosomorpholine 8270
N-Nitrosopiperidine 8270
N-Nitrosopyrrolidine 8270
2-Nitrotoluene (*o*-Nitrotoluene, 2-NT) 8091, 8095, 8330
3-Nitrotoluene (*m*-Nitrotoluene, 3-NT) 8091, 8095, 8330
4-Nitrotoluene (*p*-Nitrotoluene, 4-NT) 8091, 8095, 8330
5-Nitro-*o*-toluidine 8270
trans-Nonachlor 8081
2,2'3,3'4,4'5,5'6-Nonachlorobiphenyl 8082, 8275
2,2,5,5,8,9,9,10,10-Nonachlorobornane (P62) 8276
2-endo,3-exo,5-endo,6-exo,8,8,9,10,10-Nonachlorobornane (P50) 8276
Nonanal 8315
Norflurazon 8085
2-NT (2-Nitrotoluene, *o*-Nitrotoluene) 8091, 8095, 8330
3-NT (3-Nitrotoluene, *m*-Nitrotoluene) 8091, 8095, 8330
4-NT (4-Nitrotoluene, *p*-Nitrotoluene) 8091, 8095, 8330
OCDD 8280, 8290
OCDF 8280, 8290
2,2',3,3',4,4'5,5'-Octachlorobiphenyl 8275
2-endo,3-exo,5-endo,6-exo,8,8,10,10-Octachlorobornane (P26) 8276
2-endo,3-exo,5-endo,6-exo,8,9,10,10-Octachlorobornane (P40) 8276
2-exo,3-endo,5-exo,8,9,9,10,10-Octachlorobornane (P41) 8276

2-exo,5,5,8,9,9,10,10-Octachlorobornane (P44) 8276
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) 8095, 8330
Octamethyl pyrophosphoramide 8270
Octanal 8315
Oxamyl 8318, 8321
4,4'-Oxydianiline 8270
Oxyfluorfen 8085
Paraldehyde 8015, 8260
Parathion 8085, 8270
Parathion, ethyl 8141
Parathion, methyl 8085, 8270, 8141, 8321
PCB-1016 (Aroclor-1016) 8082, 8270
PCB-1221 (Aroclor-1221) 8082, 8270
PCB-1232 (Aroclor-1232) 8082, 8270
PCB-1242 (Aroclor-1242) 8082, 8270
PCB-1248 (Aroclor-1248) 8082, 8270
PCB-1254 (Aroclor-1254) 8082, 8270
PCB-1260 (Aroclor-1260) 8082, 8270
PCBs, as congeners 8082
PCNB (Pentachloronitrobenzene) 8081, 8091, 8270
Pebulate 8085, 8141, 8321
1,2,3,7,8-PeCDD 8280, 8290
PeCDD, total 8280, 8290
1,2,3,7,8-PeCDF 8280, 8290
2,3,4,7,8-PeCDF 8280, 8290
PeCDF, total 8280, 8290
Pendimethaline (Penoxalin) 8085, 8091
Penoxalin (Pendimethaline) 8085, 8091
Pentachlorobenzene 8121, 8270
2,2',3,4,5'-Pentachlorobiphenyl 8082
2,3',4,4',5-Pentachlorobiphenyl 8275
2,2',4,5,5'-Pentachlorobiphenyl 8082, 8275
2,3,3',4',6-Pentachlorobiphenyl 8082
Pentachloroethane 8260, 8261
Pentachloronitrobenzene (PCNB) 8081, 8091, 8270
Pentachlorophenol 8041, 8085, 8151, 8270, 8410
Pentaerythritol tetranitrate (PETN) 8095, 8330
Pentafluorobenzene 8260
Pentanal (Valeraldehyde) 8315
2-Pentanone 8015, 8260
Perchloroethylene (Tetrachloroethene, Tetrachloroethylene) 8021, 8260, 8261
Permethrin (*cis* + *trans*) 8081
Perthane 8081
Phenacetin 8270
Phenanthrene 8100, 8270, 8275, 8310, 8410
Phenobarbital 8270
Phenol 8041, 8270, 8410
1,4-Phenylenediamine 8270
1,2-Phenylenediamine (*o*-Phenylenediamine) 8141, 8321
Phorate 8085, 8141, 8270, 8321
Phosalone 8270

Phosmet (Imidan) 8085, 8141, 8270
Phosphamidon 8085, 8141, 8270
Phthalic anhydride 8270
Physostigmine 8321
Physostigmine salicylate 8321
Picloram 8085, 8151
2-Picoline (2-Methylpyridine) 8015, 8260, 8261, 8270
Piperonyl sulfoxide 8270
Polychlorinated biphenyls (PCBs), as Aroclors or congeners 8082, 8270
Pramitol 5p (Prometon) 8085
Profluralin 8085, 8091
Promecarb 8318, 8321
Prometon (Pramitol 5p) 8085
Prometryn 8085
Pronamide (Kerb) 8085, 8270
Propachlor (Ramrod) 8081, 8085
Propanal (Propionaldehyde) 8315
1-Propanol (*n*-Propyl alcohol) 8015, 8260
2-Propanol (Isopropyl alcohol) 8015, 8260
Propargite (S-181) 8085
Propargyl alcohol 8260
Propazine 8085
Propenal (Acrolein) 8015, 8260, 8261, 8315, 8316
Propetamidophos 8085
Propham 8141, 8321
ß-Propiolactone 8260
Propionaldehyde (Propanal) 8315
Propionitrile (Ethyl cyanide) 8015, 8260, 8261
Propoxur (Baygon) 8318, 8321
n-Propyl alcohol (1-Propanol) 8015, 8260
n-Propylamine 8260
n-Propylbenzene 8021, 8260, 8261
Propylthiouracil 8270
Prosulfocarb 8141, 8321
Prothiophos (Tokuthion) 8141
Pyrene 8100, 8270, 8275, 8310, 8410
Pyridine 8015, 8260, 8261
Ramrod (Propachlor) 8085
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine) 8095, 8330
Resorcinol 8270
Ronnel 8085, 8141
Rotenone 8325
S-181 (Propargite) 8085
Safrole 8270
Sevin (Carbaryl) 8270, 8318, 8321, 8325
Siduron 8321, 8325
Simazine 8085, 8141
Silvex (2,4,5-TP) 8085, 8151, 8321
Solvent Red 3 8321
Solvent Red 23 8321
Sonalan (Ethalfluralin) 8085

Stirophos (Tetrachlorvinphos, Gardona)..... 8085, 8141, 8270
Strobane..... 8081
Strychnine..... 8270
Styrene..... 8021, 8260, 8261
Sulfallate..... 8270
Sulfotepp..... 8085, 8141
Sulprofos (Bolstar)..... 8085, 8141
2,4,5-T..... 8151, 8321
2,4,5-T (acid)..... 8085
TAA (t-Amyl alcohol)..... 8015
TAEE (t-Amyl ethyl ether, 4,4-Dimethyl-3-oxahexane)..... 8015, 8261
TAME (t-Amyl methyl ether)..... 8015, 8261
2,4,5-TB..... 8085
2,3,7,8-TCDD..... 8280, 8290
TCDD, total..... 8280, 8290
2,3,7,8-TCDF..... 8280, 8290
TCDF, total..... 8280, 8290
Tebuthiuron..... 8085, 8321
Temephos (Abate)..... 8085
Temik (Aldicarb)..... 8318, 8321
TEPP (Tetraethyl pyrophosphate)..... 8141, 8270
Terbacil..... 8085
Terbufos..... 8141, 8270
Terbutryn (Igran)..... 8085
1,2,3,4-Tetrachlorobenzene..... 8121
1,2,3,5-Tetrachlorobenzene..... 8121
1,2,4,5-Tetrachlorobenzene..... 8121, 8270
2,2',3,5'-Tetrachlorobiphenyl..... 8082, 8275
2,2',4,5'-Tetrachlorobiphenyl..... 8275
2,2',5,5'-Tetrachlorobiphenyl..... 8082, 8275
2,3',4,4'-Tetrachlorobiphenyl..... 8082, 8275
1,1,1,2-Tetrachloroethane..... 8021, 8260
1,1,2,2-Tetrachloroethane..... 8021, 8260, 8261
Tetrachloroethene (Perchloroethylene, Tetrachloroethylene)..... 8021, 8260, 8261
2,3,4,5-Tetrachloronitrobenzene..... 8091
2,3,5,6-Tetrachloronitrobenzene..... 8091
2,3,4,5-Tetrachlorophenol..... 8041, 8085
2,3,4,6-Tetrachlorophenol..... 8041, 8085, 8270
2,3,5,6-Tetrachlorophenol..... 8041
Tetrachlorvinphos (Stirophos, Gardona)..... 8085, 8141, 8270
Tetraethyl dithiopyrophosphate..... 8270
Tetraethyl pyrophosphate (TEPP)..... 8141, 8270
Tetrahydrofuran (THF)..... 8261
Tetrazene..... 8331
Tetryl (Methyl-2,4,6-trinitrophenylnitramine)..... 8330
THF (Tetrahydrofuran)..... 8261
Thiodicarb..... 8318, 8321
Thiofanox..... 8321
Thionazin (Zinophos)..... 8141, 8270
Thiophanate-methyl..... 8321
Thiophenol (Benzenethiol)..... 8270

1,3,5-TNB (1,3,5-Trinitrobenzene)..... 8095, 8270, 8330
2,4,6-TNT (2,4,6-Trinitrotoluene)..... 8095, 8330
TOCP (Tri-*o*-cresylphosphate)..... 8141
Tokuthion (Prothiofos)..... 8141
m-Tolualdehyde..... 8315
o-Tolualdehyde..... 8315
p-Tolualdehyde..... 8315
Toluene..... 8015, 8021, 8260, 8261
Toluene diisocyanate..... 8270
o-Toluidine..... 8015, 8260, 8261, 8270
Toxaphene..... 8081, 8270, 8272, 8276
2,4,5-TP (Silvex)..... 8085, 8151, 8321
Treflan (Trifluralin)..... 8081, 8085, 8091, 8270
Triademefon..... 8085
Triallate..... 8085, 8141, 8321
Tributyltin chloride..... 8323
Trichlorfon..... 8141, 8321
2,4,5-Trichloroaniline..... 8131
2,4,6-Trichloroaniline..... 8131
1,2,3-Trichlorobenzene..... 8021, 8121, 8260, 8261
1,2,4-Trichlorobenzene..... 8021, 8121, 8260, 8261, 8270, 8275, 8410
1,3,5-Trichlorobenzene..... 8121
2,2',5-Trichlorobiphenyl..... 8082, 8275
2,3',5-Trichlorobiphenyl..... 8275
2,4',5-Trichlorobiphenyl..... 8082, 8275
1,1,1-Trichloroethane..... 8021, 8260, 8261
1,1,2-Trichloroethane..... 8021, 8260, 8261
Trichloroethene (Trichloroethylene)..... 8021, 8260, 8261, 8535
Trichlorofluoromethane..... 8021, 8260, 8261
Trichloronate..... 8141
1,2,3-Trichloro-4-nitrobenzene..... 8091
1,2,4-Trichloro-5-nitrobenzene..... 8091
2,4,6-Trichloronitrobenzene..... 8091
2,3,4-Trichlorophenol..... 8041
2,3,5-Trichlorophenol..... 8041
2,3,6-Trichlorophenol..... 8041
2,4,5-Trichlorophenol..... 8041, 8085, 8270, 8410
2,4,6-Trichlorophenol..... 8041, 8085, 8270, 8410
2,3,4-Trichlorophenyl 4-nitrophenyl ether..... 8111
2,3,5-Trichlorophenyl 4-nitrophenyl ether..... 8111
2,3,6-Trichlorophenyl 4-nitrophenyl ether..... 8111
2,4,5-Trichlorophenyl 4-nitrophenyl ether..... 8111
2,4,6-Trichlorophenyl 4-nitrophenyl ether..... 8111
3,4,5-Trichlorophenyl 4-nitrophenyl ether..... 8111
1,2,3-Trichloropropane..... 8021, 8260, 8261
Triclopyr (Garlon)..... 8085
Tri-*o*-cresylphosphate (TOCP)..... 8141
O,O,O-Triethyl phosphorothioate..... 8270
Triethylamine..... 8015
Trifluralin (Treflan)..... 8081, 8085, 8091, 8270
Trihalomethanes..... 8535

Trimethyl phosphate 8270
2,4,5-Trimethylaniline 8270
1,2,4-Trimethylbenzene 8021, 8260, 8261
1,3,5-Trimethylbenzene 8021, 8260, 8261
1,3,5-Trinitrobenzene (1,3,5-TNB) 8095, 8270, 8330
2,4,6-Trinitrophenylmethylnitramine 8095
2,4,6-Trinitrotoluene (2,4,6-TNT) 8095, 8330
Triphenyltin chloride 8323
Tris-BP (Tris(2,3-dibromopropyl) phosphate) 8270, 8321
Tris(2,3-dibromopropyl) phosphate (Tris-BP) 8270, 8321
Tri-*p*-tolyl phosphate 8270
Valeraldehyde (Pentanal) 8315
Vernolate 8085
Vinyl acetate 8260
Vinyl chloride 8021, 8260, 8261
Vinylidene chloride (1,1-Dichloroethene) 8021, 8260, 8261
m-Xylene 8015, 8021, 8260, 8261
o-Xylene 8015, 8021, 8260, 8261
p-Xylene 8015, 8021, 8260, 8261
Zinophos (Thionazin) 8141, 8270

TABLE 2-2

METHOD 8011 (MICROEXTRACTION AND GAS CHROMATOGRAPHY)

1,2-Dibromo-3-chloropropane (DBCP)
1,2-Dibromoethane (EDB)

TABLE 2-3

METHOD 8015 (GC/FID) - NONHALOGENATED VOLATILES

Acetone	Ethylene oxide
Acetonitrile	Gasoline range organics (GRO)
Acrolein	Isopropyl alcohol
Acrylonitrile	Methanol
Allyl alcohol	Methyl ethyl ketone (MEK, 2-Butanone)
t-Amyl alcohol (TAA)	*N*-Nitroso-di-*n*-butylamine
t-Amyl ethyl ether (TAEE)	Paraldehyde
t-Amyl methyl ether (TAME)	2-Pentanone
Benzene	2-Picoline
t-Butyl alcohol	1-Propanol (*n*-Propyl alcohol)
Crotonaldehyde	Propionitrile
Diesel range organics (DRO)	Pyridine
Diethyl ether	Toluene
Diisopropyl ether (DIPE)	*o*-Toluidine
Ethanol	*m*-Xylene
Ethyl acetate	*o*-Xylene
Ethyl benzene	*p*-Xylene
Ethyl *tert*-butyl ether (ETBE)	Triethylamine

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TABLE 2-4

METHOD 8021 (GC, PHOTOIONIZATION AND ELECTROLYTIC CONDUCTIVITY DETECTORS) - AROMATIC AND HALOGENATED VOLATILES

Allyl chloride	*cis*-1,2-Dichloroethene
Benzene	*trans*-1,2-Dichloroethene
Benzyl chloride	1,2-Dichloropropane
Bis(2-chloro-1-methylethyl) ether	1,3-Dichloropropane
Bromoacetone	2,2-Dichloropropane
Bromobenzene	1,3-Dichloro-2-propanol
Bromochloromethane	1,1-Dichloropropene
Bromodichloromethane	*cis*-1,3-Dichloropropene
Bromoform	*trans*-1,3-Dichloropropene
Bromomethane	Epichlorhydrin
n-Butylbenzene	Ethylbenzene
sec-Butylbenzene	Hexachlorobutadiene
tert-Butylbenzene	Isopropylbenzene
Carbon tetrachloride	*p*-Isopropyltoluene
Chlorobenzene	Methylene chloride
Chlorodibromomethane	Naphthalene
Chloroethane	*n*-Propylbenzene
2-Chloroethanol	Styrene
2-Chloroethyl vinyl ether	1,1,1,2-Tetrachloroethane
Chloroform	1,1,2,2-Tetrachloroethane
Chloromethane	Tetrachloroethene
Chloromethyl methyl ether	Toluene
Chloroprene	1,2,3-Trichlorobenzene
2-Chlorotoluene	1,2,4-Trichlorobenzene
4-Chlorotoluene	1,1,1-Trichloroethane
1,2-Dibromo-3-chloropropane	1,1,2-Trichloroethane
1,2-Dibromoethane	Trichloroethene
Dibromomethane	Trichlorofluoromethane
1,2-Dichlorobenzene	1,2,3-Trichloropropane
1,3-Dichlorobenzene	1,2,4-Trimethylbenzene
1,4-Dichlorobenzene	1,3,5-Trimethylbenzene
Dichlorodifluoromethane	Vinyl chloride
1,1-Dichloroethane	*o*-Xylene
1,2-Dichloroethane	*m*-Xylene
1,1-Dichloroethene	*p*-Xylene

TABLE 2-5

METHODS 8031 AND 8033 (GC WITH NITROGEN-PHOSPHORUS DETECTION)
AND METHOD 8032 (GC WITH ELECTRON CAPTURE DETECTION)

Method 8031: Acrylonitrile
Method 8032: Acrylamide
Method 8033: Acetonitrile

TABLE 2-6

METHOD 8041 (GC) - PHENOLS

2-Chloro-5-methylphenol	2,5-Dinitrophenol
4-Chloro-2-methylphenol	Dinoseb (2-*sec*-butyl-4,6-dinitro phenol)
4-Chloro-3-methylphenol	2-Methyl-4,6-dinitrophenol
2-Chlorophenol	2-Methylphenol (*o*-Cresol)
3-Chlorophenol	3-Methylphenol (*m*-Cresol)
4-Chlorophenol	4-Methylphenol (*p*-Cresol)
2-Cyclohexyl-4,6-dinitrophenol	2-Nitrophenol
2,3-Dichlorophenol	3-Nitrophenol
2,4-Dichlorophenol	4-Nitrophenol
2,5-Dichlorophenol	Pentachlorophenol
2,6-Dichlorophenol	Phenol
3,4-Dichlorophenol	2,3,4,5-Tetrachlorophenol
3,5-Dichlorophenol	2,3,4,6-Tetrachlorophenol
2,3-Dimethylphenol	2,3,5,6-Tetrachlorophenol
2,4-Dimethylphenol	2,3,4-Trichlorophenol
2,5-Dimethylphenol	2,3,5-Trichlorophenol
2,6-Dimethylphenol	2,3,6-Trichlorophenol
3,4-Dimethylphenol	2,4,5-Trichlorophenol
2,4-Dinitrophenol	2,4,6-Trichlorophenol

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TABLE 2-7

METHOD 8061 (GC/ECD) - PHTHALATE ESTERS

Bis(2-*n*-butoxyethyl) phthalate	Diethyl phthalate
Bis(2-ethoxyethyl) phthalate	Dihexyl phthalate
Bis(2-ethylhexyl) phthalate	Diisobutyl phthalate
Bis(2-methoxyethyl) phthalate	Di-*n*-butyl phthalate
Bis(4-methyl-2-pentyl) phthalate	Dimethyl phthalate
Butyl benzyl phthalate	Di-*n*-octyl phthalate
Diamyl phthalate	Dinonyl phthalate
Dicyclohexyl phthalate	Hexyl 2-ethylhexyl phthalate

TABLE 2-8

METHOD 8070 (GC) - NITROSAMINES

N-Nitrosodimethylamine
N-Nitrosodiphenylamine
N-Nitrosodi-*n*-propylamine

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TABLE 2-9

METHOD 8081 (GC) - ORGANOCHLORINE PESTICIDES

Alachlor	4,4'-DDE	Halowax-1051
Aldrin	4,4'-DDT	Halowax-1099
α-BHC	Diallate	Heptachlor
β-BHC	Dichlone	Heptachlor epoxide
δ-BHC	Dichloran	Hexachlorobenzene
γ-BHC (Lindane)	Dicofol	Hexachlorocyclopentadiene
Captafol	Dieldrin	Isodrin
Carbophenothion	Endosulfan I	Methoxychlor
Chlordane (NOS)	Endosulfan II	Mirex
cis-Chlordane	Endosulfan sulfate	Nitrofen
trans-Chlordane	Endrin	*trans*-Nonachlor
Chlorobenzilate	Endrin aldehyde	Pentachloronitrobenzene (PCNB)
Chloroneb	Endrin ketone	Permethrin (*cis* + *trans*)
Chloropropylate	Etridiazole	Perthane
Chlorothalonil	Halowax-1000	Propachlor
Dacthal (DCPA)	Halowax-1001	Strobane
DBCP	Halowax-1013	Toxaphene
4,4'-DDD	Halowax-1014	Trifluralin

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TABLE 2-10

METHOD 8082 (GC) - POLYCHLORINATED BIPHENYLS

Aroclor 1016	2,2',3,4,5,5'-Hexachlorobiphenyl
Aroclor 1221	2,2',3,5,5',6-Hexachlorobiphenyl
Aroclor 1232	2,2',4,4',5,5'-Hexachlorobiphenyl
Aroclor 1242	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl
Aroclor 1248	2,2',3,4,5'-Pentachlorobiphenyl
Aroclor 1254	2,2',4,5,5'-Pentachlorobiphenyl
Aroclor 1260	2,3,3',4',6-Pentachlorobiphenyl
2-Chlorobiphenyl	2,2',3,5'-Tetrachlorobiphenyl
2,3-Dichlorobiphenyl	2,2',5,5'-Tetrachlorobiphenyl
,2',3,3',4,4',5-Heptachlorobiphenyl	2,3',4,4'-Tetrachlorobiphenyl
2,2',3,4,4',5,5'-Heptachlorobiphenyl	2,2',5-Trichlorobiphenyl
2,2',3,4,4',5',6-Heptachlorobiphenyl	2,4',5-Trichlorobiphenyl
2,2',3,4',5,5',6-Heptachlorobiphenyl	

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TABLE 2-11

METHOD 8085 (GC/AED) – PESTICIDES

Abate (Temephos)	Cycloate	Diphenamid
Acifluorfen	Coumaphos	Disulfoton (Disyston)
Alachlor	2,4-D acid	Diuron
Aldrin	2,4-DB acid	Endosulfan I
Ametryn	DCPA (Dacthal)	Endosulfan II
Atraton	2,4'-DDD	Endosulfan sulfate
Atrazine	4,4'-DDD	Endrin
Azinphos ethyl (Ethyl guthion)	2,4'-DDE	Endrin aldehyde
Azinphos methyl (Guthion)	4,4'-DDE	Endrin ketone
Benfluralin	2,4'-DDT	EPN
α-BHC	4,4'-DDT	Eptam (EPTC)
β-BHC	DEF (Butifos)	Ethalfluralin (Sonalan)
δ-BHC	Demeton-O	Ethion
γ-BHC (Lindane)	Demeton-S	Ethoprop
Bromacil	Diallate	Fenamiphos
Bromoxynil (Brominal)	Diazinon	Fenarimol
Butachlor	Dicamba	Fenitrothion
Butylate	Dichlobenil (Casoron)	Fensulfothion
Captafol	3,5-Dichlorobenzoic acid	Fenthion
Captan	Dichlorprop	Fluridone
Carbophenothion	Dichlorvos (DDVP)	Fonofos
Carboxin	Diclofol (Kelthane)	Gardona (Tetrachlovinphos)
trans-Chlordane	Diclofop-methyl	Heptachlor
Chlorpropham	Dieldrin	Heptachlor epoxide
Chlorpyrifos	Dimethoate	Hexachlorobenzene
Chlorthalonil (Daconil)	Dinoseb	Hexachlorocyclopentadiene
Cyanazine	Dioxathion	Hexazinone

TABLE 2-11 (continued)

Imidan (Phosmet)	Norflurazon	Sulfotepp
Ioxynil	Oxyfluorfen	Sulprofos (Bolstar)
Malathion	Parathion	Silvex
MCPA acid	Pebulate	2,4,5-T acid
MCPP acid	Pendimethalin	2,4,5-TB
Merphos	Pentachlorophenol (PCP)	Tebuthiuron
Metalaxyl	Phorate	Terbacil
Methoxychlor	Phosphamidon	Terbutryn (Igran)
Methyl chlorpyrifos	Picloram	2,3,4,5-Tetrachlorophenol
Methyl paraoxon	Profluralin	2,3,4,6-Tetrachlorophenol
Methyl parathion	Prometon (Pramitol 5p)	Triademefon
Metolachlor	Prometryn	Triallate
Metribuzin	Pronamide (Kerb)	2,4,5-Trichlorophenol
Mevinphos	Propachlor (Ramrod)	2,4,6-Trichlorophenol
MGK-264	Propargite (S-181)	Triclopyr (Garlon)
Mirex	Propazine	Trifluralin (Treflan)
Molinate	Propetamidophos	Vernolate
Napropamide	Ronnel	
4-Nitrophenol	Simazine	

TABLE 2-12

METHOD 8091 (GC) - NITROAROMATICS AND CYCLIC KETONES

Benefin	2,4-Dinitrotoluene
Butralin	2,6-Dinitrotoluene
1-Chloro-2,4-dinitrobenzene	Isopropalin
1-Chloro-3,4-dinitrobenzene	1,2-Naphthoquinone
1-Chloro-2-nitrobenzene	1,4-Naphthoquinone
1-Chloro-4-nitrobenzene	Nitrobenzene
2-Chloro-6-nitrotoluene	2-Nitrotoluene
4-Chloro-2-nitrotoluene	3-Nitrotoluene
4-Chloro-3-nitrotoluene	4-Nitrotoluene
2,3-Dichloronitrobenzene	Penoxalin [Pendimethalin]
2,4-Dichloronitrobenzene	Pentachloronitrobenzene
2,5-Dichloronitrobenzene	Profluralin
3,4-Dichloronitrobenzene	2,3,4,5-Tetrachloronitrobenzene
3,5-Dichloronitrobenzene	2,3,5,6-Tetrachloronitrobenzene
Dinitramine	1,2,3-Trichloro-4-nitrobenzene
1,2-Dinitrobenzene	1,2,4-Trichloro-5-nitrobenzene
1,3-Dinitrobenzene	2,4,6-Trichloronitrobenzene
1,4-Dinitrobenzene	Trifluralin

TABLE 2-13

METHOD 8095 (GC) - EXPLOSIVES

2-Amino-4,6-dinitrotoluene	2-Nitrotoluene
4-Amino-2,6-dinitrotoluene	3-Nitrotoluene
3,5-Dinitroaniline	4-Nitrotoluene
1,3-Dinitrobenzene	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
2,4-Dinitrotoluene	Pentaerythritoltetranitrate
2,6-Dinitrotoluene	1,3,5-Trinitrobenzene
Hexahydro-1,3,5-trinitro-1,3,5-triazine	2,4,6-Trinitrophenylmethylnitramine
Nitrobenzene	2,4,6-Trinitrotoluene
Nitroglycerine	

TABLE 2-14

METHOD 8100 - POLYNUCLEAR AROMATIC HYDROCARBONS

Acenaphthene	Dibenz(*a,h*)anthracene
Acenaphthylene	7H-Dibenzo(*c,g*)carbazole
Anthracene	Dibenzo(*a,e*)pyrene
Benz(*a*)anthracene	Dibenzo(*a,h*)pyrene
Benzo(*b*)fluoranthene	Dibenzo(*a,i*)pyrene
Benzo(*j*)fluoranthene	Fluoranthene
Benzo(*k*)fluoranthene	Fluorene
Benzo(*g,h,i*)perylene	Indeno(1,2,3-*cd*)pyrene
Benzo(*a*)pyrene	3-Methylcholanthrene
Chrysene	Naphthalene
Dibenz(*a,h*)acridine	Phenanthrene
Dibenz(*a,j*)acridine	Pyrene

TABLE 2-15

METHOD 8111 (GC) - HALOETHERS

Bis(2-chloroethoxy)methane	2,5-Dichlorophenyl 4-nitrophenyl ether
Bis(2-chloroethyl) ether	2,6-Dichlorophenyl 4-nitrophenyl ether
Bis(2-chloro-1-methylethyl) ether	3,4-Dichlorophenyl 4-nitrophenyl ether
4-Bromophenyl phenyl ether	3,5-Dichlorophenyl 4-nitrophenyl ether
4-Chlorophenyl phenyl ether	4-Nitrophenyl phenyl ether
2-Chlorophenyl 4-nitrophenyl ether	2,3,4-Trichlorophenyl 4-nitrophenyl ether
3-Chlorophenyl 4-nitrophenyl ether	2,3,5-Trichlorophenyl 4-nitrophenyl ether
4-Chlorophenyl 4-nitrophenyl ether	2,3,6-Trichlorophenyl 4-nitrophenyl ether
2,4-Dibromophenyl 4-nitrophenyl ether	2,4,5-Trichlorophenyl 4-nitrophenyl ether
2,4-Dichlorophenyl 3-methyl-4-nitrophenyl ether	2,4,6-Trichlorophenyl 4-nitrophenyl ether
2,3-Dichlorophenyl 4-nitrophenyl ether	3,4,5-Trichlorophenyl 4-nitrophenyl ether
2,4-Dichlorophenyl 4-nitrophenyl ether	

TABLE 2-16

METHOD 8121 (GC) - CHLORINATED HYDROCARBONS

Benzal chloride	δ-Hexachlorocyclohexane (δ-BHC)
Benzotrichloride	γ-Hexachlorocyclohexane (γ-BHC)
Benzyl chloride	Hexachlorocyclopentadiene
2-Chloronaphthalene	Hexachloroethane
1,2-Dichlorobenzene	Pentachlorobenzene
1,3-Dichlorobenzene	1,2,3,4-Tetrachlorobenzene
1,4-Dichlorobenzene	1,2,3,5-Tetrachlorobenzene
Hexachlorobenzene	1,2,4,5-Tetrachlorobenzene
Hexachlorobutadiene	1,2,3-Trichlorobenzene
α-Hexachlorocyclohexane (α-BHC)	1,2,4-Trichlorobenzene
β-Hexachlorocyclohexane (β-BHC)	1,3,5-Trichlorobenzene

TABLE 2-17

METHOD 8131 (GC) - ANILINE AND SELECTED DERIVATIVES

Aniline	2,6-Dibromo-4-nitroaniline
4-Bromoaniline	3,4-Dichloroaniline
2-Bromo-6-chloro-4-nitroanilne	2,6-Dichloro-4-nitroaniline
2-Bromo-4,6-dintroaniline	2,4-Dinitroaniline
2-Chloroaniline	2-Nitroaniline
3-Chloroaniline	3-Nitroaniline
4-Chloroaniline	4-Nitroaniline
2-Chloro-4,6-dinitroaniline	2,4,5-Trichloroaniline
2-Chloro-4-nitroaniline	2,4,6-Trichloroaniline
4-Chloro-2-nitroaniline	

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TABLE 2-18

METHOD 8141 (GC) - ORGANOPHOSPHORUS COMPOUNDS

Aspon	Disulfoton	Parathion, methyl
Atrazine	EPN	Pebulate
Azinphos-ethyl	EPTC	*o*-Phenylenediamine
Azinphos-methyl	Ethion	Phorate
Bendiocarb	Ethoprop	Phosmet
Bolstar (Sulprofos)	Famphur	Phosphamidon
Butylate	Fenitrothion	Propham
Carbophenothion	Fensulfothion	Prosulfocarb
Chlorfenvinphos	Fenthion	Ronnel
Chlorpyrifos	Fonophos	Simazine
Chlorpyrifos methyl	Hexamethyl phosphoramide (HMPA)	Stirophos (Tetrachlorvinphos, Gardona)
Coumaphos	Leptophos	Sulfotepp
Crotoxyphos	Malathion	Terbufos
Demeton-O, and -S	Merphos	Tetraethyl pyrophosphate (TEPP)
Diazinon	Methiocarb	Thionazin (Zinophos)
Dichlorofenthion	Mevinphos	Tokuthion (Prothiofos)
Dichlorvos (DDVP)	Molinate	Triallate
Dicrotophos	Monocrotophos	Trichlorfon
Dimethoate	Naled	Trichloronate
Dioxathion	Parathion, ethyl	Tri-*o*-cresyl phosphate (TOCP)

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TABLE 2-19

METHOD 8151 (GC USING METHYLATION OR PENTAFLUOROBENZYLATION DERIVATIZATION) - CHLORINATED HERBICIDES

Acifluorfen	Dicamba	MCPP
Bentazon	3,5-Dichlorobenzoic acid	4-Nitrophenol
Chloramben	Dichloroprop	Pentachlorophenol
2,4-D	Dinoseb	Picloram
Dalapon	5-Hydroxydicamba	2,4,5-T
2,4-DB	MCPA	2,4,5-TP (Silvex)
DCPA diacid		

TABLE 2-20

METHOD 8260 (GC/MS) - VOLATILE ORGANIC COMPOUNDS

Acetone	2-Chloroethyl vinyl ether	Diisopropyl ether (DIPE)
Acetonitrile	Chloroform	1,4-Dioxane
Acrolein (Propenal)	1-Chlorohexane	Epichlorohydrin
Acrylonitrile	Chloromethane	Ethanol
Allyl alcohol	Chloroprene	Ethyl acetate
Allyl chloride	2-Chlorotoluene	Ethyl t-butyl ether (ETBE)
t-Amyl ethyl ether (TAEE)	4-Chlorotoluene	Ethyl methacrylate
t-Amyl methyl ether (TAME)	Crotonaldehyde	Ethylbenzene
Benzene	Cyclohexane	Ethylene oxide
Benzyl chloride	1,2-Dibromo-3-chloropropane	Hexachlorobutadiene
Bis(2-chloroethyl)sulfide	1,2-Dibromoethane	Hexachloroethane
Bromoacetone	Dibromomethane	2-Hexanone
Bromobenzene	1,2-Dichlorobenzene	Iodomethane
Bromochloromethane	1,3-Dichlorobenzene	Isobutyl alcohol
Bromodichloromethane	1,4-Dichlorobenzene	Isopropylbenzene
Bromoform	cis-1,4-Dichloro-2-butene	p-Isopropyltoluene
Bromomethane	trans-1,4-Dichloro-2-butene	Malononitrile
n-Butanol	Dichlorodifluoromethane	Methacrylonitrile
2-Butanone (MEK)	1,1-Dichloroethane	Methanol
t-Butyl alcohol	1,2-Dichloroethane	Methyl acrylate
n-Butylbenzene	1,1-Dichloroethene	Methyl-t-butyl ether (MTBE)
sec-Butylbenzene	cis-1,2-Dichloroethene	Methyl methacrylate
tert-Butylbenzene	trans-1,2-Dichloroethene	Methylcyclohexane
Carbon disulfide	1,2-Dichloropropane	Methylene chloride
Carbon tetrachloride	1,3-Dichloropropane	4-Methyl-2-pentanone (MIBK)
Chloral hydrate	2,2-Dichloropropane	Naphthalene
Chloroacetonitrile	1,3-Dichloro-2-propanol	Nitrobenzene
Chlorobenzene	1,1-Dichloropropene	2-Nitropropane
1-Chlorobutane	cis-1,3-Dichloropropene	N-Nitroso-di-n-butylamine
Chlorodibromomethane	trans-1,3-Dichloropropene	Paraldehyde
Chloroethane	1,2,3,4-Diepoxybutane	Pentachloroethane
2-Chloroethanol	Diethyl ether	Pentafluorobenzene

TABLE 2-20 (continued)

2-Pentanone	Styrene	Trichloroethene
2-Picoline	1,1,1,2-Tetrachloroethane	Trichlorofluoromethane
1-Propanol	1,1,2,2-Tetrachloroethane	1,2,3-Trichloropropane
2-Propanol	Tetrachloroethene	1,2,4-Trimethylbenzene
Propargyl alcohol	Toluene	1,3,5-Trimethylbenzene
ß-Propiolactone	o-Toluidine	Vinyl acetate
Propionitrile (Ethyl cyanide)	1,2,3-Trichlorobenzene	Vinyl chloride
n-Propylamine	1,2,4-Trichlorobenzene	o-Xylene
n-Propylbenzene	1,1,1-Trichloroethane	m-Xylene
Pyridine	1,1,2-Trichloroethane	p-Xylene

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TABLE 2-21

METHOD 8261 (VD/GC/MS) - VOLATILE ORGANIC COMPOUNDS

Acetone	1,3-Dichlorobenzene	Methacrylonitrile
Acetonitrile	1,4-Dichlorobenzene	Methyl *t*-butyl ether (MTBE)
Acetophenone	*cis*-1,4-Dichloro-2-butene	Methyl methacrylate
Acrolein	*trans*-1,4-Dichloro-2-butene	Methylene chloride
Acrylonitrile	Dichlorodifluoromethane	1-Methylnaphthalene
Allyl Chloride	1,1-Dichloroethane	2-Methylnaphthalene
t-Amyl ethyl ether (TAEE) (4,4-Dimethyl-3-oxahexane)	1,2-Dichloroethane	4-Methyl-2-pentanone
t-Amyl methyl ether (TAME)	1,1-Dichloroethene	Naphthalene
Aniline	*cis*-1,2-Dichloroethene	*N*-Nitrosodibutylamine
Benzene	*trans*-1,2-Dichloroethene	*N*-Nitrosodiethylamine
Bromochloromethane	1,2-Dichloropropane	*N*-Nitrosodimethylamine
Bromodichloromethane	1,3-Dichloropropane	*N*-Nitrosodi-*n*-propylamine
Bromoform	2,2-Dichloropropane	*N*-Nitrosomethylethylamine
Bromomethane	1,1-Dichloropropene	Pentachloroethane
2-Butanone	*cis*-1,3-Dichloropropene	2-Picoline
n-Butylbenzene	*trans*-1,3-Dichloropropene	Propionitrile
sec-Butylbenzene	Diethyl ether	*n*-Propylbenzene
tert-Butylbenzene	Diisopropyl ether (DIPE)	Pyridine
Carbon disulfide	1,4-Dioxane	Styrene
Carbon tetrachloride	Ethanol	1,1,2,2-Tetrachloroethane
Chlorobenzene	Ethyl acetate	Tetrachloroethene
Chlorodibromomethane	Ethyl *t*-butyl ether (ETBE)	Tetrahydrofuran
Chloroethane	Ethyl methacrylate	Toluene
Chloroform	Ethylbenzene	*o*-Toluidine
Chloromethane	Hexachlorobutadiene	1,2,3-Trichlorobenzene
2-Chlorotoluene	2-Hexanone	1,2,4-Trichlorobenzene
4-Chlorotoluene	Iodomethane	1,1,1-Trichloroethane
1,2-Dibromo-3-chloropropane	Isobutyl alcohol	1,1,2-Trichloroethane
Dibromomethane	Isopropylbenzene	Trichloroethene
1,2-Dichlorobenzene	*p*-Isopropyltoluene	Trichlorofluoromethane

TABLE 2-21 (continued)

1,2,3-Trichloropropane	Vinyl chloride	*p*-Xylene
1,2,4-Trimethylbenzene	*o*-Xylene	
1,3,5-Trimethylbenzene	*m*-Xylene	

TABLE 2-22

METHOD 8270 (GC/MS) - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	Aroclor-1260
Acenaphthylene	Azinphos-methyl
Acetophenone	Barban
2-Acetylaminofluorene	Benz(a)anthracene
1-Acetyl-2-thiourea	Benzidine
Aldrin	Benzo(b)fluoranthene
2-Aminoanthraquinone	Benzo(k)fluoranthene
Aminoazobenzene	Benzoic acid
4-Aminobiphenyl	Benzo(g,h,i)perylene
3-Amino-9-ethylcarbazole	Benzo(a)pyrene
Anilazine	*p*-Benzoquinone
Aniline	Benzyl alcohol
o-Anisidine	α-BHC
Anthracene	β-BHC
Aramite	δ-BHC
Aroclor-1016	γ-BHC (Lindane)
Aroclor-1221	Bis(2-chloroethoxy)methane
Aroclor-1232	Bis(2-chloroethyl)ether
Aroclor-1242	Bis(2-chloro-1-methylethyl)ether
Aroclor-1248	Bis(2-ethylhexyl)phthalate
Aroclor-1254	4-Bromophenyl phenyl ether

Table 2-22 (continued)

Bromoxynil
Butyl benzyl phthalate
Captafol
Captan
Carbaryl
Carbofuran
Carbophenothion
Chlordane (NOS)
Chlorfenvinphos
4-Chloroaniline
Chlorobenzilate
5-Chloro-2-methylaniline
4-Chloro-3-methylphenol
3-(Chloromethyl)pyridine hydrochloride
1-Chloronaphthalene
2-Chloronaphthalene
2-Chlorophenol
4-Chloro-1,2-phenylenediamine
4-Chloro-1,3-phenylenediamine
4-Chlorophenyl phenyl ether
Chrysene
Coumaphos
p-Cresidine
Crotoxyphos
2-Cyclohexyl-4,6-dinitrophenol
4,4'-DDD
4,4'-DDE
4,4'-DDT
Demeton-O
Demeton-S
Diallate (*cis* or *trans*)
2,4-Diaminotoluene
Dibenz(*a,j*)acridine
Dibenz(*a,h*)anthracene
Dibenzofuran
Dibenzo(*a,e*)pyrene
1,2-Dibromo-3-chloropropane
Di-*n*-butyl phthalate
Dichlone
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3'-Dichlorobenzidine
2,4-Dichlorophenol
2,6-Dichlorophenol
Dichlorovos
Dicrotophos
Dieldrin
Diethyl phthalate
Diethyl sulfate
Diethylstilbestrol
Dimethoate
3,3'-Dimethoxybenzidine
Dimethyl phthalate
Dimethylaminoazobenzene
7,12-Dimethylbenz(*a*)anthracene
3,3'-Dimethylbenzidine
α,α-Dimethylphenethylamine

Table 2-22 (continued)

2,4-Dimethylphenol
1,2-Dinitrobenzene
1,3-Dinitrobenzene
1,4-Dinitrobenzene
4,6-Dinitro-2-methylphenol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Dinocap
Dinoseb
Di-*n*-octyl phthalate
Diphenylamine
5,5-Diphenylhydantoin
1,2-Diphenylhydrazine
Disulfoton
Endosulfan I
Endosulfan II
Endosulfan sulfate
Endrin
Endrin aldehyde
Endrin ketone
EPN
Ethion
Ethyl carbamate
Ethyl methanesulfonate
Famphur
Fensulfothion
Fenthion
Fluchloralin
Fluoranthene
Fluorene
Heptachlor
Heptachlor epoxide
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
Hexachlorophene
Hexachloropropene
Hexamethylphosphoramide
Hydroquinone
Indeno(1,2,3-cd)pyrene
Isodrin
Isophorone
Isosafrole
Kepone
Leptophos
Malathion
Maleic anhydride
Mestranol
Methapyrilene
Methoxychlor
Methyl methanesulfonate
Methyl parathion
3-Methylcholanthrene
4,4'-Methylenebis(2-chloroaniline)

Table 2-22 (continued)

4,4'-Methylenebis(N,N-dimethylaniline)	N-Nitrosodimethylamine
2-Methylnaphthalene	N-Nitrosodiphenylamine
2-Methylphenol	N-Nitrosodi-n-propylamine
3-Methylphenol	N-Nitrosomethylethylamine
4-Methylphenol	N-Nitrosomorpholine
Mevinphos	N-Nitrosopiperidine
Mexacarbate	N-Nitrosopyrrolidine
Mirex	5-Nitro-o-toluidine
Monocrotophos	Octamethyl pyrophosphoramide
Naled	4,4'-Oxydianiline
Naphthalene	Parathion
1,4-Naphthoquinone	Pentachlorobenzene
1-Naphthylamine	Pentachloronitrobenzene
2-Naphthylamine	Pentachlorophenol
Nicotine	Phenacetin
5-Nitroacenaphthene	Phenanthrene
2-Nitroaniline	Phenobarbital
3-Nitroaniline	Phenol
4-Nitroaniline	1,4-Phenylenediamine
5-Nitro-o-anisidine	Phorate
Nitrobenzene	Phosalone
4-Nitrobiphenyl	Phosmet
Nitrofen	Phosphamidion
2-Nitrophenol	Phthalic anhydride
4-Nitrophenol	2-Picoline (2-methylpyridine)
Nitroquinoline-1-oxide	Piperonyl sulfoxide
N-Nitrosodi-n-butylamine	Pronamide
N-Nitrosodiethylamine	Propylthiouracil

Table 2-22 (continued)

Pyrene	Toluene diisocyanate
Resorcinol	o-Toluidine
Safrole	Toxaphene
Strychnine	1,2,4-Trichlorobenzene
Sulfallate	2,4,5-Trichlorophenol
Terbufos	2,4,6-Trichlorophenol
1,2,4,5-Tetrachlorobenzene	O,O,O-Triethylphosphorothioate
2,3,4,6-Tetrachlorophenol	Trifluralin
Tetrachlorvinphos	Trimethyl phosphate
Tetraethyl dithiopyrophosphate	2,4,5-Trimethylaniline
Tetraethyl pyrophosphate	1,3,5-Trinitrobenzene
Thionazine	Tris(2,3-dibromopropyl)phosphate
Thiophenol (Benzenethiol)	Tri-p-tolyl phosphate

TABLE 2-23

METHOD 8275 (TE/GC/MS) - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	2,2',3,4',5,5',6- Heptachlorobiphenyl
Acenaphthylene	Hexachlorobenzene
Anthracene	2,2',3,3',4,4'- Hexachlorobiphenyl
Benz(*a*)anthracene	2,2',3,4,4',5'- Hexachlorobiphenyl
Benzo(*k*)fluoranthene	Indeno(1,2,3-*cd*)pyrene
Benzo(*b*)fluoranthene	Naphthalene
Benzo(*g,h,i*)perylene	2,2',3,3'4,4',5,5',6- Nonachlorobiphenyl
Benzo(*a*)pyrene	2,2',3,3',4,4',5,5'- Octachlorobiphenyl
4-Bromophenyl phenyl ether	2,2',4,5,5'-Pentachlorobiphenyl
2-Chlorobiphenyl	2,3',4,4',5-Pentachlorobiphenyl
1-Chloronaphthalene	Phenanthrene
Chrysene	Pyrene
2,2',3,3'4,4',5,5',6,6'- Decachlorobiphenyl	2,2'3,5'-Tetrachlorobiphenyl
Dibenz(*a,h*)anthracene	2,2'4,5'-Tetrachlorobiphenyl
Dibenzofuran	2,2',5,5'-Tetrachlorobiphenyl
Dibenzothiophene	2,3',4,4'-Tetrachlorobiphenyl
3,3'-Dichlorobiphenyl	1,2,4-Trichlorobenzene
Fluoranthene	2,2',5-Trichlorobiphenyl
Fluorene	2,3',5-Trichlorobiphenyl
2,2',3,3',4,4',5- Heptachlorobiphenyl	2,4',5-Trichlorobiphenyl
2,2',3,4,4',5,5'- Heptachlorobiphenyl	

TABLE 2-23A

METHOD 8276 (GC-NICI/MS) - TOXAPHENE AND TOXAPHENE CONGENERS

2-endo,3-exo,5-endo,6-exo,8,9,10-Heptachlorobornane (Hp-Sed)
2-exo,3-endo,6-exo,8,9,10-Hexachlorobornane (Hx-Sed)
2,2,5,5,8,9,9,10,10-Nonachlorobornane (P62)
2-endo,3-exo,5-endo,6-exo,8,8,9,10,10-Nonachlorobornane (P50)
2-endo,3-exo,5-endo,6-exo,8,8,10,10-Octachlorobornane (P26)
2-endo,3-exo,5-endo,6-exo,8,9,10,10-Octachlorobornane (P40)
2-exo,3-endo,5-exo,8,9,9,10,10-Octachlorobornane (P41)
2-exo,5,5,8,9,9,10,10-Octachlorobornane (P44)
Toxaphene

TABLE 2-24

METHODS 8280 (HRGC/LRMS) AND 8290 (HRGC/HRMS) - POLYCHLORINATED DIBENZO-*p*-DIOXINS (PCDDs) AND POLYCHLORINATED DIBENZOFURANS (PCDFs)

1,2,3,4,6,7,8-HpCDD	2,3,4,6,7,8-HxCDF
HpCDD, total	HxCDF, total
1,2,3,4,6,7,8-HpCDF	OCDD
1,2,3,4,7,8,9-HpCDF	OCDF TCDF, total
HpCDF, total	1,2,3,7,8-PeCDD
1,2,3,4,7,8-HxCDD	PeCDD, total
1,2,3,6,7,8-HxCDD	1,2,3,7,8-PeCDF
1,2,3,7,8,9-HxCDD	2,3,4,7,8-PeCDF
HxCDD, total	PeCDF, total
1,2,3,4,7,8-HxCDF	2,3,7,8-TCDD
1,2,3,6,7,8-HxCDF	TCDD, total
1,2,3,7,8,9-HxCDF	2,3,7,8-TCDF

TABLE 2-25

METHOD 8310 (HPLC) - POLYNUCLEAR AROMATIC HYDROCARBONS

Acenaphthene	Chrysene
Acenaphthylene	Dibenzo(*a,h*)anthracene
Anthracene	Fluoranthene
Benz(*a*)anthracene	Fluorene
Benzo(*b*)fluoranthene	Indeno(1,2,3-*cd*)pyrene
Benzo(*k*)fluoranthene	Naphthalene
Benzo(*g,h,i*)perylene	Phenanthrene
Benzo(*a*)pyrene	Pyrene

TABLE 2-26

METHOD 8315 - CARBONYL COMPOUNDS

Acetaldehyde	Decanal	Octanal
Acetone	2,5-Dimethylbenzaldehyde	Pentanal (Valeraldehyde)
Acrolein	Formaldehyde	Propanal (Propionaldehyde)
Benzaldehyde	Heptanal	*m*-Tolualdehyde
Butanal (Butyraldehyde)	Hexanal (Hexaldehyde)	*o*-Tolualdehyde
Crotonaldehyde	Isovaleraldehyde	*p*-Tolualdehyde
Cyclohexanone	Nonanal	

TABLE 2-27

METHOD 8316 (HPLC)

Acrolein
Acrylamide
Acrylonitrile

TABLE 2-28

METHOD 8318 (HPLC) - *N*-METHYLCARBAMATES

Aldicarb (Temik)	Dioxacarb	Mexacarbate
Aldicarb sulfone	Formetanate hydrochloride	Oxamyl
Bendiocarb	3-Hydroxycarbofuran	Promecarb
Carbaryl (Sevin)	Methiocarb (Mesurol)	Propoxur (Baygon)
Carbofuran (Furadan)	Methomyl (Lannate)	Thiodicarb
m-Cumenyl methylcarbamate	Metolcarb	

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TABLE 2-29

METHOD 8321 (HPLC/TS/MS) - NONVOLATILE ORGANIC COMPOUNDS

Azo Dyes	Organophosphorus Compounds
Disperse Brown 1	Asulam
Disperse Orange 3	Dichlorvos (DDVP)
Disperse Orange 30	Dimethoate
Disperse Red 1	Disulfoton
Disperse Red 5	Famphur
Disperse Red 13	Fensulfothion
Disperse Yellow 5	Merphos
Solvent Red 3	Methomyl
Solvent Red 23	Monocrotophos
	Naled
Anthraquinone Dyes	Parathion methyl
Disperse Blue 3	Phorate
Disperse Blue 14	Thiofanox
Disperse Red 60	Trichlorfon
	Tris(2,3-dibromopropyl) phosphate (Tris-BP)
Chlorinated Phenoxyacid Compounds	
2,4-D	Silvex (2,4,5-TP)
2,4-D, butoxyethanol ester	2,4,5-T
2,4-D, ethylhexyl ester	2,4,5-T, butyl ester
Dalapon	2,4,5-T, butoxyethanol ester
2,4-DB	
Dicamba	
Dichlorprop	
Dinoseb	
MCPA	
MCPP	

Table 2-29 (continued)

Carbamates	
Aldicarb	Linuron
Aldicarb sulfone	Methiocarb
Aldicarb sulfoxide	Methomyl
Aminocarb	Metolcarb
Barban	Mexacarbate
Bendiocarb	Molinate
Benomyl	Monuron
Bromacil	Neburon
Butylate	Oxamyl
Carbaryl	Pebulate
Carbendazim	*o*-Phenylenediamine
Carbofuran	Physostigmine
Carbofuran phenol	Physostigmine salicylate
Carbosulfan	Promecarb
Chloropropham	Propham
Chloroxuron	Propoxur
m-Cumenyl methyl carbamate	Prosulfocarb
Diuron	Siduron
EPTC	Tebuthiuron
Fenuron	Thiodicarb
Fluometuron	Thiophanate-methyl
Formetanate hydrochloride	Triallate
3-Hydroxycarbofuran	

TABLE 2-29A

METHOD 8323 (MS) - ORGANOTINS BY MICRO-LIQUID CHROMATOGRAPHY-ELECTROSPRAY ION TRAP MASS SPECTROMETRY

Dibutyltin dichloride	Monophenyltin trichloride
Diphenyltin dichloride	Tributyltin chloride
Monobutyltin trichloride	Triphenyltin chloride

TABLE 2-30

METHOD 8325 (HPLC/PB/MS) - NONVOLATILE ORGANIC COMPOUNDS

Benzidine	3,3'-Dimethylbenzidine
Benzoylprop ethyl	Diuron
Carbaryl	Linuron (Lorox)
o-Chlorophenyl thiourea	Monuron
3,3'-Dichlorobenzidine	Rotenone
3,3'-Dimethoxybenzidine	Siduron

TABLE 2-31

METHOD 8330 (HPLC) - NITROAROMATICS AND NITRAMINES

2-Amino-4,6-dinitrotoluene (2-Am-DNT)	2-Nitrotoluene (2-NT)
4-Amino-2,6-dinitrotoluene (4-Am-DNT)	3-Nitrotoluene (3-NT)
3,5-Dinitroanaline (3,5-DNA)	4-Nitrotoluene (4-NT)
1,3-Dinitrobenzene (1,3-DNB)	Nitroglycerin
2,4-Dinitrotoluene (2,4-DNT)	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)
2,6-Dinitrotoluene (2,6-DNT)	Pentaerythritol tetranitrate (PETN)
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	1,3,5-Trinitrobenzene (1,3,5-TNB)
Methyl-2,4,6-trinitrophenyl-nitramine (Tetryl)	2,4,6-Trinitrotoluene (2,4,6-TNT)
Nitrobenzene (NB)	

TABLE 2-32

METHOD 8331 (HPLC)

Tetrazene

TABLE 2-33

METHOD 8332 (HPLC)

Nitroglycerine

TABLE 2-34

METHOD 8410 - SEMIVOLATILE ORGANIC COMPOUNDS

Acenaphthene	1,2-Dichlorobenzene
Acenaphthylene	1,3-Dichlorobenzene
Anthracene	1,4-Dichlorobenzene
Benzo(*a*)anthracene	2,4-Dichlorophenol
Benzo(*a*)pyrene	Diethyl phthalate
Benzoic acid	Dimethyl phthalate
Bis(2-chloroethoxy)methane	4,6-Dinitro-2-methylphenol
Bis(2-chloroethyl)ether	2,4-Dinitrophenol
Bis(2-chloro-1-methylethyl)ether	2,4-Dinitrotoluene
Bis(2-ethylhexyl) phthalate	2,6-Dinitrotoluene
4-Bromophenyl phenyl ether	Di-*n*-octyl phthalate
Butyl benzyl phthalate	Di-*n*-propyl phthalate
4-Chloroaniline	Fluoranthene
4-Chloro-3-methylphenol	Fluorene
2-Chloronaphthalene	Hexachlorobenzene
2-Chlorophenol	1,3-Hexachlorobutadiene
4-Chlorophenol	Hexachlorocyclopentadiene
4-Chlorophenyl phenyl ether	Hexachloroethane
Chrysene	Isophorone
Dibenzofuran	2-Methylnaphthalene
Di-*n*-butyl phthalate	2-Methylphenol

Table 2-34 (continued)

4-Methylphenol	*N*-Nitrosodiphenylamine
Naphthalene	*N*-Nitroso-di-*n*-propylamine
2-Nitroaniline	Pentachlorophenol
3-Nitroaniline	Phenanthrene
4-Nitroaniline	Phenol
	Pyrene
2-Nitrophenol	1,2,4-Trichlorobenzene
4-Nitrophenol	2,4,5-Trichlorophenol
N-Nitrosodimethylamine	2,4,6-Trichlorophenol

TABLE 2-35

METHOD 8430 (GC/FT-IR) - BIS(2-CHLOROETHYL) ETHER AND ITS HYDROLYSIS PRODUCTS

Bis(2-chloroethyl) ether
2-Chloroethanol
2-(2-Chloroethoxy) ethanol
Diethylene glycol
Ethylene glycol

TABLE 2-35A

METHOD 8440 - TOTAL RECOVERABLE PETROLEUM HYDROCARBONS BY INFRARED SPECTROPHOTOMETRY

This method does not give a specific compound list but is applicable to total recoverable petroleum hydrocarbons.

TABLE 2-36

METHOD 8510 (COLORIMETRIC SCREENING) - RDX AND HMX

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)

TABLE 2-36A

METHOD 8520 (CONTINUOUS MEASUREMENT OF FORMALDEHYDE IN AMBIENT AIR)

Formaldehyde

TABLE 2-37

METHOD 8535 (COLORIMETRIC SCREENING) - VOLATILE ORGANIC HALIDES

Carbon tetrachloride
Perchloroethylene (Tetrachloroethene)
Trichloroethylene
Trihalomethanes

TABLE 2-38

METHOD 8540 (UV-INDUCED COLORIMETRY) - PENTACHLOROPHENOL

Pentachlorophenol

TABLE 2-39

DETERMINATIVE METHODS FOR INORGANIC ANALYTES

Analyte	Applicable Methods
Aluminum	6010, 6020, 7000, 7010
Antimony	6010, 6020, 6200, 6800, 7000, 7062
Arsenic	6010, 6020, 6200, 7010, 7061, 7062, 7063
Barium	6010, 6020, 6200, 6800, 7000, 7010
Beryllium	6010, 6020, 7000, 7010
Boron	6010, 6800
Bromide	6500, 9056, 9211
Cadmium	6010, 6020, 6200, 6800, 7000, 7010
Calcium	6010, 6020, 6200, 6800, 7000
Chloride	6500, 9056, 9057, 9212, 9250, 9251, 9253
Chromium	6010, 6020, 6200, 6800, 7000, 7010
Chromium, hexavalent	6800, 7195, 7196, 7197, 7198, 7199
Cobalt	6010, 6020, 6200, 7000, 7010
Copper	6010, 6020, 6200, 6800, 7000, 7010
Cyanide	9010, 9012, 9013, 9014, 9015, 9016, 9213
Fluoride	6500, 9056, 9214
Iron	6010, 6020, 6200, 6800, 7000, 7010
Lead	6010, 6020, 6200, 6800, 7000, 7010
Lithium	6010, 7000
Magnesium	6010, 6020, 6800, 7000
Manganese	6010, 6020, 6200, 7000, 7010
Mercury	6010, 6020, 6200, 6800, 7470, 7471, 7472, 7473, 7474
Molybdenum	6010, 6200, 6800, 7000, 7010
Nickel	6010, 6020, 6200, 6800, 7000, 7010
Nitrate	6500, 9056, 9210
Nitrite	6500, 9056, 9216
Osmium	7000
Perchlorate	6850, 6860
Phosphate	6500, 9056
Phosphorus	6010
Phosphorus, white	7580
Potassium	6010, 6020, 6200, 6800, 7000
Rubidium	6200
Selenium	6010, 6020, 6200, 6800, 7010, 7741, 7742
Silica	6010
Silver	6010, 6020, 6200, 6800, 7000, 7010
Sodium	6010, 6020, 7000
Strontium	6010, 6200, 6800, 7000
Sulfate	6500, 9035, 9036, 9038, 9056
Sulfide	9030, 9031, 9215
Thallium	6010, 6020, 6200, 6800, 7000, 7010
Thorium	6200
Tin	6010, 6200, 7000
Titanium	6010, 6200

TABLE 2-39 (cont)

Vanadium.....6010, 6020, 6200, 6800, 7000, 7010
Zinc.....6010, 6020, 6200, 6800, 7000, 7010
Zirconium.....6200

TABLE 2-40A

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

(Note: Footnotes are located on the last page of the table.)

VOLATILE ORGANICS

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Concentrated waste samples	Method 5035: See the method. Method 5021: See the method. Methods 5031 and 5032: See the methods. Use PTFE-lined lids for all procedures.	Cool to 0 - 6 °C.	14 days
Aqueous samples with no residual chlorine present	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Cool to 0 - 6 °C and adjust pH to less than 2 with H_2SO_4, HCl, or solid $NaHSO_4$	14 days
		If carbonaceous materials are present, or if MTBE and other fuel oxygenate ethers are present and a high temperature sample preparative method is to be used, do not acid preserve the samples.	*7 days*
		If the reactive compound 2-chloroethyl vinyl ether[b] is an analyte of interest, collect a second set of samples without acid preservatives and analyze immediately.	*7 days*

TABLE 2-40A (continued)

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

VOLATILE ORGANICS (continued)

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Aqueous samples WITH residual chlorine present	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Collect sample in a 125-mL container which has been pre-preserved with 4 drops of 10% sodium thiosulfate solution. Gently swirl to mix sample and transfer to a 40-mL VOA vial. Cool to 0 - 6 °C and adjust pH to less than 2 with H_2SO_4, HCl, or solid $NaHSO_4$.	14 days
		If carbonaceous materials are present, or if MTBE and other fuel oxygenate ethers are present and a high temperature sample preparative method is to be used, do not acid preserve the samples.	*7 days*
		If the reactive compound 2-chloroethyl vinyl ether[b] is an analyte of interest, collect a second set of samples without acid preservatives and analyze immediately.	*7 days*
Acrolein and acrylonitrile in aqueous samples	Methods 5030, 5031, and 5032: 3 x 40-mL vials with PTFE-lined septum caps	Adjust to pH 4-5. Cool to 0 - 6 °C. *These compounds are highly reactive and should be analyzed as soon as possible.*	7 days
Solid samples (e.g., soils, sediments, sludges, ash)	Method 5035: See the method. Method 5021: See the method. Methods 5031 and 5032: See the methods.	See the individual methods.	14 days
		If vinyl chloride, styrene, or 2-chloroethyl vinyl ether are analytes of interest, collect a second set of samples without acid preservatives and analyze as soon as possible.	7 days

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TABLE 2-40A (continued)

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

SEMIVOLATILE ORGANICS/ORGANOCHLORINE PESTICIDES AND HERBICIDES

Sample Matrix	Container	Preservative[1]	Holding Time[1]
Concentrated waste samples	125-mL wide-mouth glass with PTFE-lined lid	None	Samples extracted within 14 days and extracts analyzed within 40 days following extraction.
Aqueous samples with no residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Cool to 0 - 6 °C.	Samples extracted within 7 days and extracts analyzed within 40 days following extraction.
Aqueous samples WITH residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Add 3 mL 10% sodium thiosulfate solution per gallon (or 0.008%). Addition of sodium thiosulfate solution to sample container may be performed in the laboratory prior to field use. Cool to 0 - 6 °C.	Samples extracted within 7 days and extracts analyzed within 40 days following extraction.
Solid samples (e.g., soils, sediments, sludges, ash)	250-mL wide-mouth glass container with PTFE-lined lid	Cool to 0 - 6 °C.	Samples extracted within 14 days and extracts analyzed within 40 days following extraction.

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TABLE 2-40A (continued)

RECOMMENDED SAMPLE CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR ORGANIC CHEMICALS[a]

POLYCHLORINATED BIPHENYLS, POLYCHLORINATED DIBENZO-*p*-DIOXINS, AND POLYCHLORINATED DIBENZOFURANS

Sample Matrix	Container	Preservative[1]	Holding Time[2]
Concentrated waste samples	125-mL wide-mouth glass with PTFE-lined lid	None	None
Aqueous samples with no residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Cool to 0 - 6 °C.	None
Aqueous samples WITH residual chlorine present	4 x 1-L amber glass container with PTFE-lined lid, or other size, as appropriate, to allow use of entire sample for analysis.	Add 3 mL 10% sodium thiosulfate solution per gallon (or 0.008%). Addition of sodium thiosulfate solution to sample container may be performed in the laboratory prior to field use. Cool to 0 - 6 °C	None
Solid samples (e.g., soils, sediments, sludges, ash)	250-mL wide-mouth glass container with PTFE-lined lid.	Cool to 0 - 6 °C.	None

[a] The information presented in this table does not represent EPA requirements, but rather is intended solely as guidance. Selection of containers, preservation techniques, and applicable holding times should be based on the stated project-specific DQOs.

[1] The exact sample, extract, and standard storage temperature should be based on project-specific requirements and/or manufacturer's recommendations for commercially available standards. Furthermore, alternative storage temperatures may be appropriate based on demonstrated analyte stability in a given matrix, provided the stated DQOs for a project-specific application are still attainable.

[2] A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected from preservation, storage, and analyses performed outside the recommended holding times.

TABLE 2-40B

RECOMMENDED CONTAINERS, PRESERVATION TECHNIQUES, AND HOLDING TIMES FOR INORGANIC AND OTHER ANALYTES IN AQUEOUS MATRICES
(SEE CHAPTER THREE FOR MORE DETAILED GUIDANCE, INCLUDING REGARDING SOLID MATRICES)
(Footnotes are located on the next page.)

Name	Container[1]	Preservation[2]	Holding Time[3]
Inorganic Tests:			
Chloride	P, G	None required	28 days
Cyanide, total and amenable to chlorination	P, G	Cool to 0 - 6 ˚C; if oxidizing agents present add 5 mL 0.1N $NaAsO_2$ per L or 0.06 g of ascorbic acid per L; adjust pH>12 with 50% NaOH. See Method 9010 for other interferences.	14 days
Hydrogen ion (pH)	P, G	None required	As soon as possible
Nitrate	P, G	Cool to 0 - 6 ˚C.	48 hours
Sulfate	P, G	Cool to 0 - 6 ˚C.	28 days
Sulfide	P, G	Cool to 0 - 6 ˚C , add zinc acetate, NaOH to pH >9	7 days
Metals:			
Chromium VI	P, G	Cool to 0 - 6 ˚C.	24 hours
Mercury	P, G	HNO_3 to pH<2	28 days
Mercury (soil/sediment)	P, G	Cool to 0 - 6 ˚C.	28 days
Mercury Species in soil/sediment	P, G	Cool to 0 - 6 ˚C.	5 days
All Other Metals	P, G	HNO_3 to pH<2	6 months
Hexane Extractable Material (HEM; Oil and grease)	G	Cool to 0 - 6 ˚C,HCl or H_2SO_4 to pH<2	28 days
Organic carbon, total (TOC)	P, G	Cool to 0 - 6˚C, store in dark; HCl or H_2SO_4 to pH<2	28 days
Radiological Tests:			

Name	Container[1]	Preservation[2]	Holding Time[3]
Alpha, beta and radium	P, G	HNO_3 to pH<2	6 months

[a] The information presented in this table does not represent EPA requirements, but rather is intended solely as guidance. Selection of containers, preservation techniques and applicable holding times should be based on the stated project-specific DQOs. See Chapter Three, Chapter Four, or the individual methods for more information.

[1] Polyethylene (P) or glass (G)

[2] The exact sample, extract, and standard storage temperature should be based on project-specific requirements and/or manufacturer's recommendations for commercially available standards. Furthermore, alternative storage temperatures may be appropriate based on demonstrated analyte stability in a given matrix, provided the stated DQOs for a project-specific application are still attainable.

[3] A longer holding time may be appropriate if it can be demonstrated that the reported analyte concentrations are not adversely affected by preservation, storage, and analyses performed outside the recommended holding times.

TABLE 2-41
PREPARATION METHODS FOR ORGANIC ANALYTES
(Note: Footnotes are located on the last page of the table.)

	Matrix			
Analyte Type	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils
Acid Extractable	35103520 (pH ≤ 2)	3540 3541 3542[13] 3545 3546 3550	3520 (pH ≤ 2)	3650 3580[3]
Acrolein[12], Acrylonitrile[12], and Acetonitrile	5031 5032[12]	5031 5032[12]	5031 5032[12]	3585
Acrylamide	8032[4]			
Aniline and Selected Derivatives	3510 3520 (pH >11) 5031[11]	3540 3541 3545 3550	3520 (pH >11)	3580[3]
Aromatic Volatiles	5021 5030 5032	5021 5032 5035	5030 5032	3585
Base/Neutral Extractable	3510 3511 3520 (pH >11)	3540 3541 3542[13] 3545 3546 3550	3520 (pH >11)	3650 3580[3]
Carbamates	8318[5] 8321	8318[5] 8321	8318[5]	8318[5]
Chlorinated Herbicides	3535 (pH < 1) 8151[6] (pH ≤ 2) 8321	3545 3546 8151[6] 8321	8151[6] (pH ≤ 2)	3580[3]
Chlorinated Hydrocarbons	3510 3520 (pH as received)	3540 3541 3550	3520 (pH as received)	3580[3]
Dyes	3510 3520	3540 3541 3545 3550		

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TABLE 2-41 (continued)
PREPARATION METHODS FOR ORGANIC ANALYTES

Analyte Type	Matrix			
	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils
Explosives	3535 8330[7] 8331[8]	8330[7] 8331[8]		
Formaldehyde	8315[9]	8315[9]		
Haloethers			3510 3520	3540 3541 3545 3550
Halogenated Volatiles	5021 5030 5032	5021 5032 5035	5030	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Nitroaromatics and Cyclic Ketones	3510 3520 (pH 5-9) 3535	3540 3541 3545 3550	3520 (pH 5-9)	3580[3]
Nitrosamines	3510 3520	3540 3541 3545 3550		
Non-halogenated Volatiles	5021 5030 5031 5032	5021 5031 5032 5035	5021 5031 5032	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Organochlorine Pesticides	3510 3520 3535 (pH 5-9)	3540 3541 3545 3546 3550 3562	3520 (pH 5-9)	3580[3]
Organophosphorus Pesticides	3510 3520 (pH 5-8) 3535	3540 3541 3545 3546	3520 (pH 5-8)	3580[3]

TABLE 2-41 (continued)
PREPARATION METHODS FOR ORGANIC ANALYTES

	Matrix			
	Aqueous[1]	Solids	Sludges and Emulsions[1,2]	Organic Liquids, Tars, Oils 3650 3580[3]
Phenols	3510 3520 (pH ≤ 2) 3535	3540 3541 3545 3546 3550 3562	3520 (pH ≤ 2)	3650 3580[3]
Phthalate Esters	3510 3520 3535 (pH 5-7)	3540 3541 3545 3546 3550	3520 (pH 5- 7)	3580[3]
Polychlorinated Biphenyls	3510 3520 3535 (pH 5-9)	3540 3541 3545 3546 3562	3520 (pH 5-9)	3580[3]
PCDDs and PCDFs	8280[10] 8290[10]	3545 3546 8280[10] 8290[10]	8280[10] 8290[10]	8280[10] 8290[10]
Polynuclear Aromatic Hydrocarbons	3510 3511 3520 (pH as received)	3540 3541 3545 3546 3550 3561	3520 (pH as received)	3580[3]
Volatile Organics	5021 5030 5031 5032	5021 5031 5032 5035	5021 5030 5031 5032	5021 (methanol extr) 5035 / 5030 (methanol extr) 5032 3585
Wipes (Chemical Agents only)		3572		

[1] The pH at which extraction should be performed is shown in parentheses.
[2] If attempts to break an emulsion are unsuccessful, these methods may be used.
[3] Method 3580 is only appropriate if the sample is soluble in the specified solvent.
[4] Method 8032 contains the extraction, cleanup, and determinative procedures for this analyte.

[5] Method 8318 contains the extraction, cleanup, and determinative procedures for these analytes.
[6] Method 8151 contains the extraction, cleanup, and determinative procedures for these analytes.
[7] Method 8330 contains the extraction, cleanup, and determinative procedures for these analytes.
[8] Method 8331 is for Tetrazene only, and contains the extraction, cleanup, and determinative procedures for this analyte.
[9] Method 8315 contains the extraction, cleanup, and determinative procedures for this analyte.
[10] Methods 8280 and 8290 contain the extraction, cleanup, and determinative procedures for these analytes.
[11] Method 5031 may be used when only aniline is to be determined.
[12] Method 5032 may be used for acrolein and acrylonitrile.
[13] Method 3542 is used for extraction of semivolatiles from stack samples collected using Method 0010.

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TABLE 2-42

CLEANUP METHODS FOR ORGANIC ANALYTE EXTRACTS

Analyte Type	Method
Acid Extractable	3650, 3640
Base/Neutral Extractable	3650, 3640
Carbamates	8318[1]
Chlorinated Herbicides	8151[2]
Chlorinated Hydrocarbons	3620, 3640
Haloethers	3620, 3640
Nitroaromatics & Cyclic Ketones	3620, 3640
Nitrosamines	3610, 3620, 3640
Organochlorine Pesticides	3620, 3630, 3640 3660
Organophosphorus Pesticides	3620
Phenols	3630, 3640, 3650 8041[3]
Phthalate Esters	3610, 3611, 3620 3640
Polychlorinated Biphenyls	3620, 3630, 3640 3660, 3665
Polychlorinated Dibenzo-*p*-Dioxins and Polychlorinated Dibenzofurans	8280[4] 8290[4]
Polynuclear Aromatic Hydrocarbons	3610, 3611 3630, 3640, 3650

[1] Method 8318 contains the extraction, cleanup, and determinative procedures for these analytes.
[2] Method 8151 contains the extraction, cleanup, and determinative procedures for these analytes.
[3] Method 8041 includes a derivatization technique followed by GC/ECD analysis, if interferences are encountered using GC/FID.
[4] Methods 8280 and 8290 contain the extraction, cleanup, and determinative procedures for these analytes.

TABLE 2-43

DETERMINATIVE METHODS ORGANIC ANALYTES

Analyte Type	GC/MS Method	Specific GC Method[6]	HPLC Method
Acid Extractable	8270	8410[6]	
Acrolein, Acrylonitrile, Acetonitrile	8260, 8261	8015, 8031, 8033[1]	8315[2], 8316
Acrylamide	8260	8032	8316
Aniline and Selected Derivatives	8270	8131	
Aromatic Volatiles	8260, 8261	8021	
Base/Neutral Extractable	8270	8410[6]	8325[4]
Carbamates			8318, 8321
Chlorinated Herbicides	8270[3]	8151	8321
Chlorinated Hydrocarbons	8270	8121	
Diesel Range Organics (DRO)		8015, 8440[7]	
Dyes			8321
Explosives		8095	8330, 8331, 8332
Formaldehyde			8315
Gasoline Range Organics (GRO)		8015	
Haloethers	8270	8111, 8430	
Halogenated Volatiles	8260, 8261	8011, 8021	
Nitroaromatics and Cyclic Ketones	8270	8091	8330[5]
Nitrosoamines	8270	8070	
Non-halogenated Volatiles	8260	8015	8315
Organochlorine Pesticides	8270[3], 8276	8081, 8085[6]	
Organophosphorus Pesticides	8270[3]	8141, 8085[6]	8321
Phenols	8270	8041, 8410[6]	
Phthalate Esters	8270	8061, 8410[6]	
Polychlorinated Biphenyls	8270[3]	8082	
PCDDs and PCDFs	8280, 8290		
Polynuclear Aromatic Hydrocarbons	8270	8100, 8410[6]	8310
Volatile Organics	8260, 8261	8011, 8015, 8021, 8031, 8032, 8033	8315, 8316

[1] Of these analytes, Method 8033 is for acetonitrile only.
[2] Of these analytes, Method 8315 is for acrolein only.
[3] This method is an alternative confirmation method, not the method of choice.
[4] Benzidines and related compounds.
[5] Nitroaromatics (see "Explosives").
[6] Includes GC/ES methods, e.g., Methods 8085 and 8410.
[7] FT-IR determinative method only. Does not use GC.

TABLE 2-44

PREPARATION METHODS FOR INORGANIC ANALYSES [1]

Matrix	Method
Surface water	3005, 3010, 3015, 3020
Groundwater	3005, 3010, 3015, 3020
Extracts	3010, 3015, 3020
Aqueous samples containing suspended solids	3010, 3015, 3020
Oils	3031, 3040, 3051, 3052[2]
Oil sludges	3031, 3052[2]
Tars	3031, 3052[2]
Waxes	3031, 3040, 3052[2]
Paints	3031, 3052[2]
Paint sludges	3031, 3052[2]
Petroleum products	3031, 3040, 3052[2]
Sediments	3050, 3051, 3052[2], 3060[3], 3200[4]
Sludges	3050, 3051, 3052[2], 3060[3]
Soil samples	3050, 3051, 3052[2], 3060[3], 3200[4]
Ashes	3052[2]
Biological tissues	3052[2]

[1]It is the responsibility of the analyst to refer to each analytical method to determine applicability of the chosen method to a specific waste type and target analyte.

[2]For total decomposition analysis ONLY.

[3]For the analysis of samples for hexavalent chromium ONLY.

[4]For the analysis of samples for mercury or mercury species ONLY.

TABLE 2-45

USE OF LEACHING, EXTRACTION AND DIGESTION METHODS
FOR INORGANIC ANALYSIS (In order of increasing strength)

Method	Method Name	Reagents & Conditions	Use
1310	Extraction Procedure (EP) Toxicity Test Method and Structural Integrity Test	Dilute acetic acid	Simulate leaching that would result from codisposal of a solid waste and municipal waste in a sanitary landfill[1]
1311	Toxicity Characteristic Leaching Procedure	Extraction Fluid # 1 -- Dilute glacial acetic acid and NaOH, pH 4.93 ± 0.05 Extraction Fluid # 2 -- Dilute glacial acetic acid, pH 2.88 ± 0.05	Simulate leaching that would result from codisposal of a solid waste and municipal waste in a sanitary landfill[1]
1312	Synthetic Precipitation Leaching Procedure	Dilute H_2SO_4 and HNO_3 (synthetic acid rain)	Simulate acid rain leaching of a waste
1313	Liquid-Solid Partitioning as a Function of Extract pH Batch Extraction Procedure	Dilute HNO_3, KOH	Industrial wastes, soils, sludges, combustion residues, sediments, stabilized materials, construction materials, and mining wastes
1316	Liquid-Solid Partitioning as a Function of Liquid-to-Solid Ratio in Solid Materials Using a Parallel Batch Procedure	None	Industrial wastes, soils, sludges, combustion residues, sediments, stabilized materials, construction materials, and mining wastes
1320	Multiple Extraction Procedure	Dilute H_2SO_4 and HNO_3 (synthetic acid rain)	Simulate long-term acid rain leaching of a waste
3005	Acid Digestion of Waters for Total Recoverable or Dissolved Metals Analysis by FLAA or ICP Spectroscopy	HNO_3, heat	Surface water and groundwater
3010	Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by FLAA or ICP Spectroscopy	HNO_3, HCl, heat	Aqueous samples and extracts
3015	Microwave Assisted Acid Digestion of Aqueous Samples and Extracts	HNO_3 or alternatively HNO_3 and HCl, (pressure, heat)	Aqueous samples and extracts

TABLE 2-45 (continued)

USE OF LEACHING, EXTRACTION AND DIGESTION METHODS
FOR INORGANIC ANALYSIS (In order of increasing strength)

Method	Method Name	Reagents & Conditions	Use
3020	Acid Digestion of Aqueous Samples and Extracts for Total Metals for Analysis by GFAA Spectroscopy	HNO_3, heat	Aqueous samples and extracts for GFAA work only
3031	Acid Digestion of Oils for Metals Analysis by Atomic Absorption or ICP Spectrometry	Potassium permanganate, H_2SO_4, HNO_3, HCl, heat	Oils, oily sludges, tars, waxes, paint, paint sludge, and other viscous petroleum products
3040	Dissolution Procedure for Oils, Greases, or Waxes	Solvent (e.g., xylene, kerosene, or MIBK)	Dissolution of oils, oily wastes, greases and waxes
3050	Acid Digestion of Sediments, Sludges, and Soils	HNO_3 and H_2O_2, heat (for GFAA or ICPMS) HNO_3, H_2O_2, and HCl, heat (for ICP-AES or FLAA)	Sediments, soils, and sludges
3051	A Microwave Assisted Acid Digestion of Sediments Sludges, Soils, and Oils	HNO_3, or alternatively HNO_3 and HCl, microwave assisted (pressure, heat)	Sludges, sediments, soils and oils
3052	Microwave Assisted Acid Digestion of Siliceous and Organically Based Matrices	HNO_3, HF, HCl (optional) H_2O_2 (optional), heat, pressure	Siliceous, organic and other complex matrices for total sample decomposition
3060A	Alkaline Digestion for Hexavalent Chromium	Na_2CO_3/NaOH, heat	Soils, sludges, sediments and some industrial wastes for the analysis of hexavalent chromium only.

[1] As described in the respective background documents developed in support of the rulemakings, which added required use of these methods to the Toxicity Characteristic regulation (Method 1311 replaced Method 1310 for Toxicity Characteristic determinations on March 29, 1990, 55 FR 11862).

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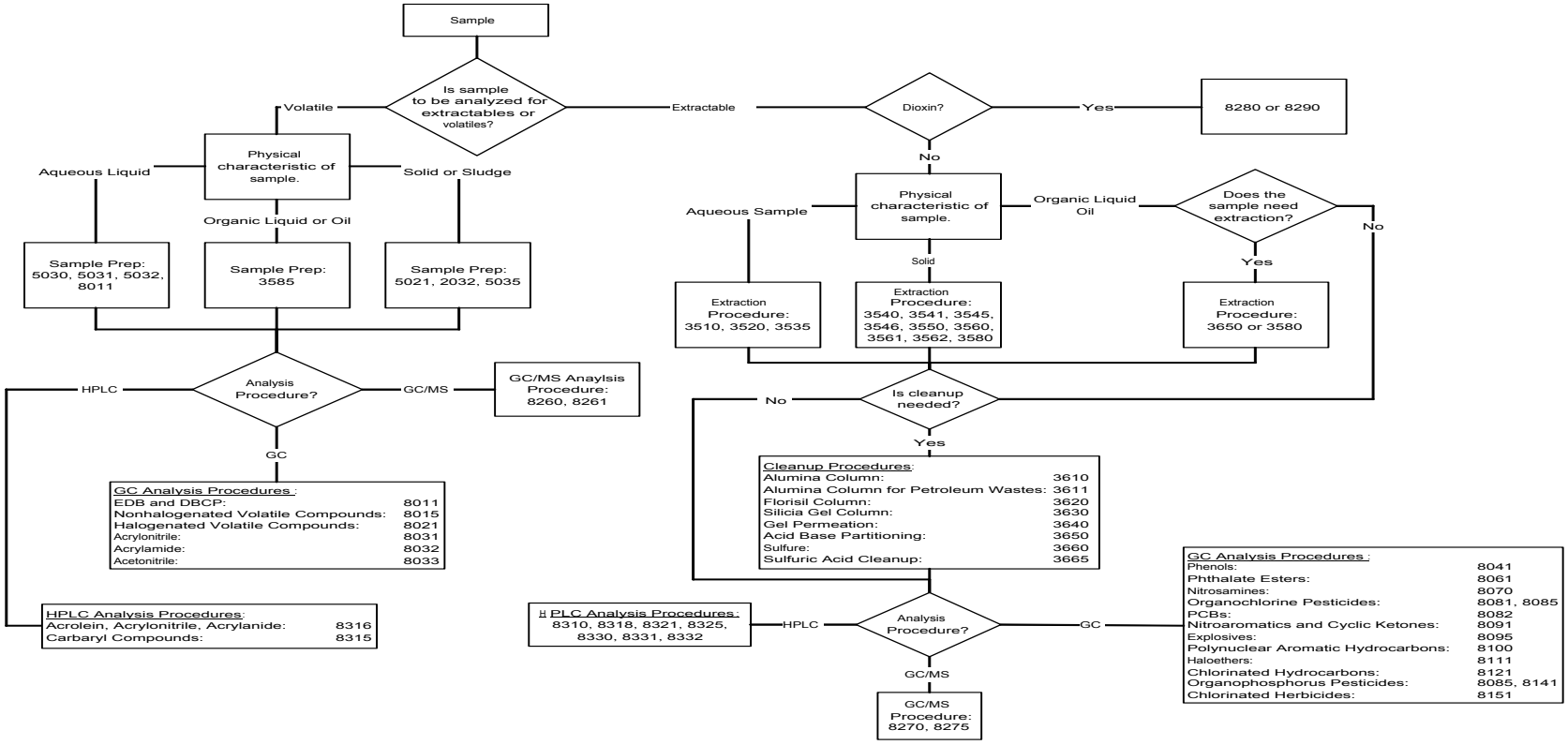
TABLE 2-46
SCREENING METHODS FOR ORGANIC ANALYTES

Analyte Type	Matrix			
	Aqueous	Solids	Sludges and Emulsions	Organic Liquids, Tars, Oils
Chlordane		4041		
2,4-Dichlorophenoxyacetic acid	4015	4015		
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)		4051 8510		
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)		8510		
Pentachlorophenol	4010	4010 8540	4010	
Petroleum Hydrocarbons		4030		
Poly-Chlorinated Biphenyls (PCBs)	4425 (coplanar)	4020 4425 (coplanar)		4020 (non-aqueous)
Polychlorinated Dibenzodioxins	4425	4425		
Polychlorinated Dibenzofurans	4425	4425		
Polynuclear Aromatic Hydrocarbons (PAHs)	4425	4035 4425		
Toxaphene		4040		
Triazine Pesticides	4670 (quantitative)			
1,1,1,-Trichloro-2,2-bis(chlorophenyl)ethane (DDT) and breakdown products		4042		
Trinitrotoluene (TNT)		4050 8515		

FIGURE 2-1
ORGANIC ANALYSIS OPTIONS FOR SOLID AND LIQUID MATRICES



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See the disclaimer and Sec. 2.1 for information on the flexibility inherent in SW-846 methods.

NOTE: Not all clean-up methods are applicable to all listed methods. Consult the individual methods for further information on what clean-up methods are applicable and appropriate.

FIGURE 2-2
SCHEMATIC OF SEQUENCE TO DETERMINE
IF A WASTE IS HAZARDOUS BY CHARACTERISTIC

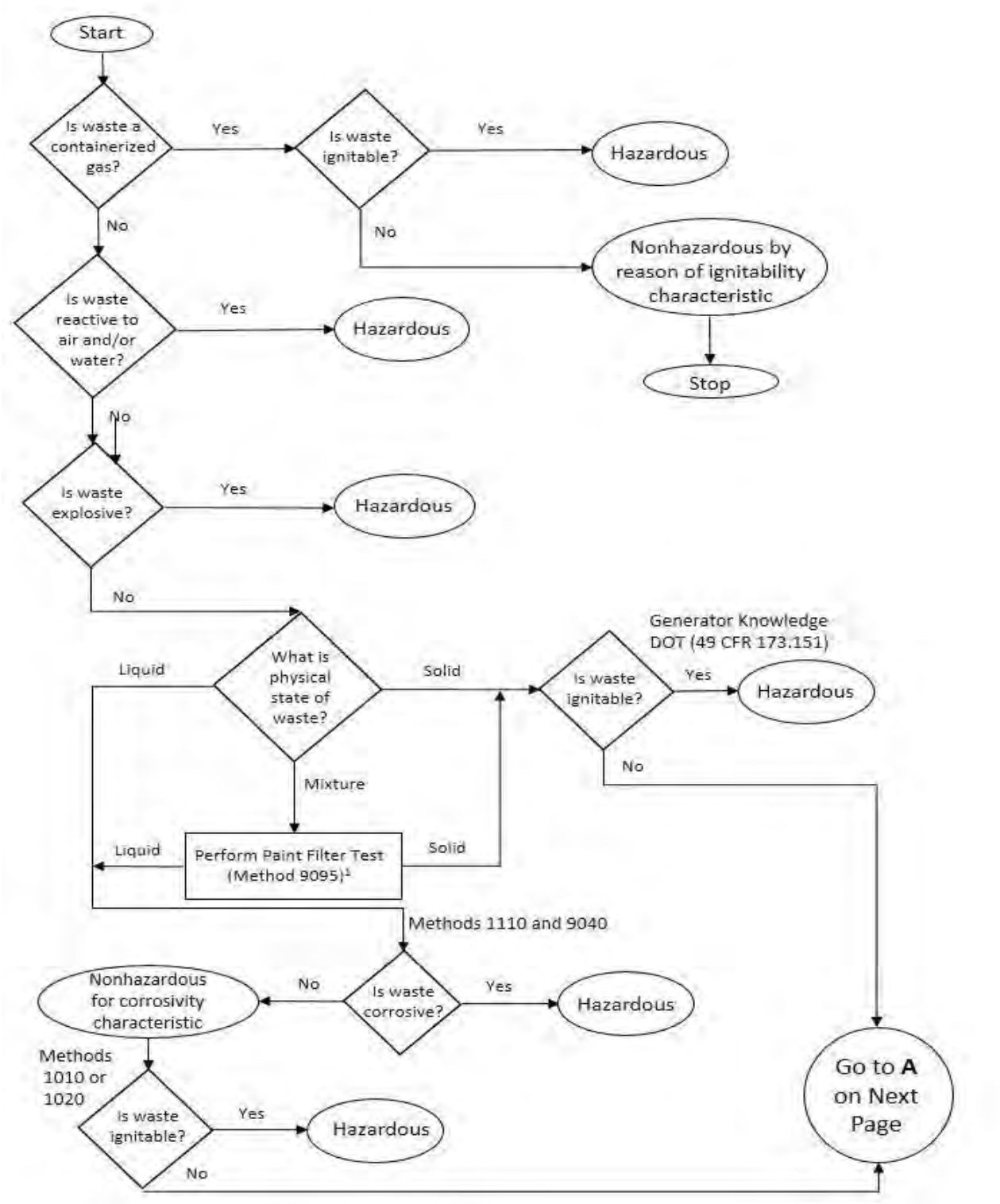
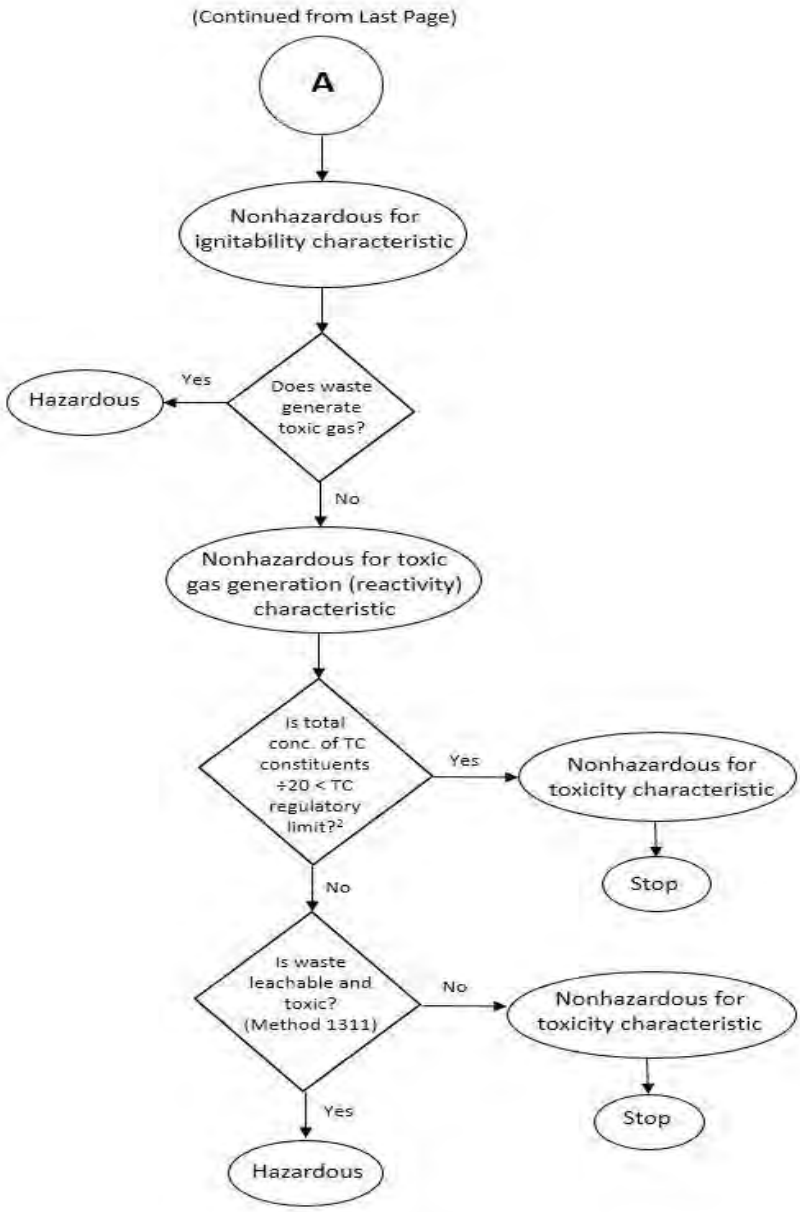


FIGURE 2-2 (continued)



1. Users can find information regarding the corrosivity characteristic for samples in a gel matrix at:http://yosemite.epa.gov/osw/rcra.nsf/0/7D573EA3E0F1576D8525670F006BEA5F/$file/11719.pdf.
2. Biphasic or multiphasic waste can present a unique challenge. More information can be found on this topic in the Federal Register (Dec 21, 1995 FR (page 66389). This can be found online at: http://nepis.epa.gov/Exe/ZyNET.exe/10001E3Y.txt?ZyActionD=ZyDocument&Client=EPA&Index=1995%20Thru%201999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&UseQField=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A\ZYFILES\INDEX%20DATA\95THRU99\TXT\00000000\10001E3Y.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h|-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p|f&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=48

FIGURE 2-3A
RECOMMENDED SW-846 METHODS FOR ANALYSIS OF EP LEACHATES

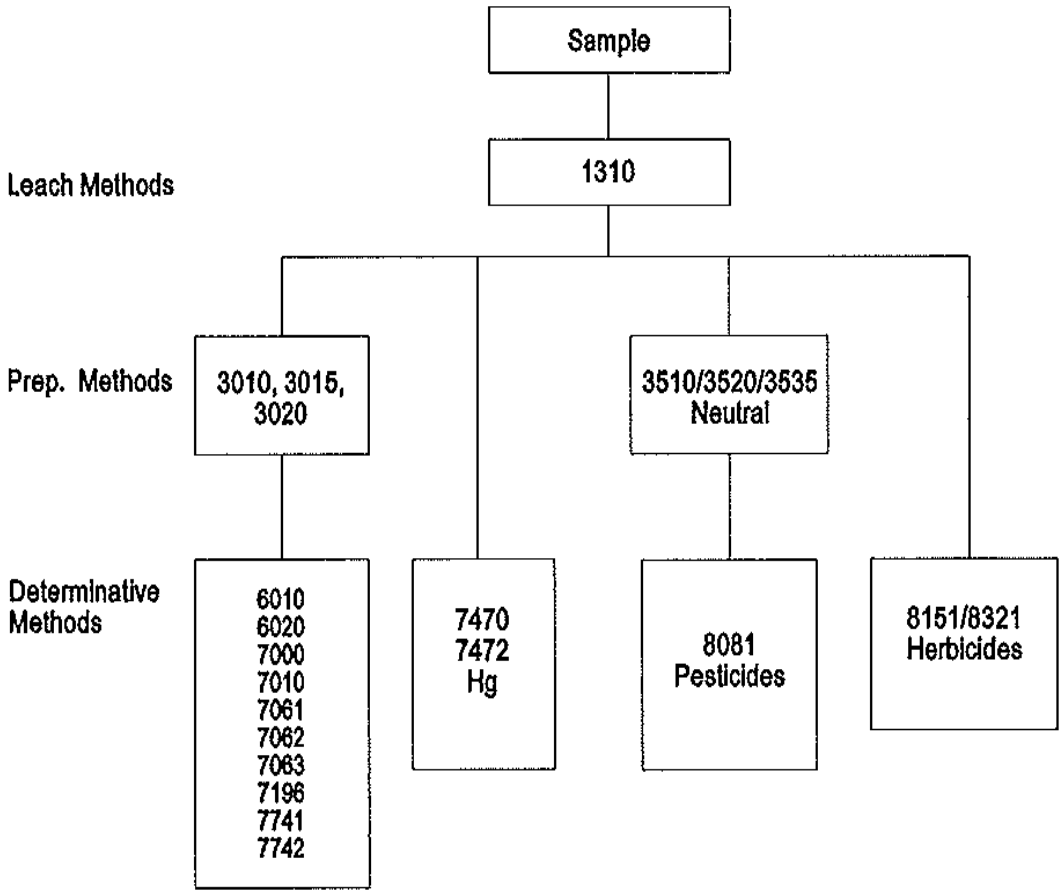


FIGURE 2-3B

RECOMMENDED SW-846 METHODS FOR ANALYSIS OF TCLP LEACHATES

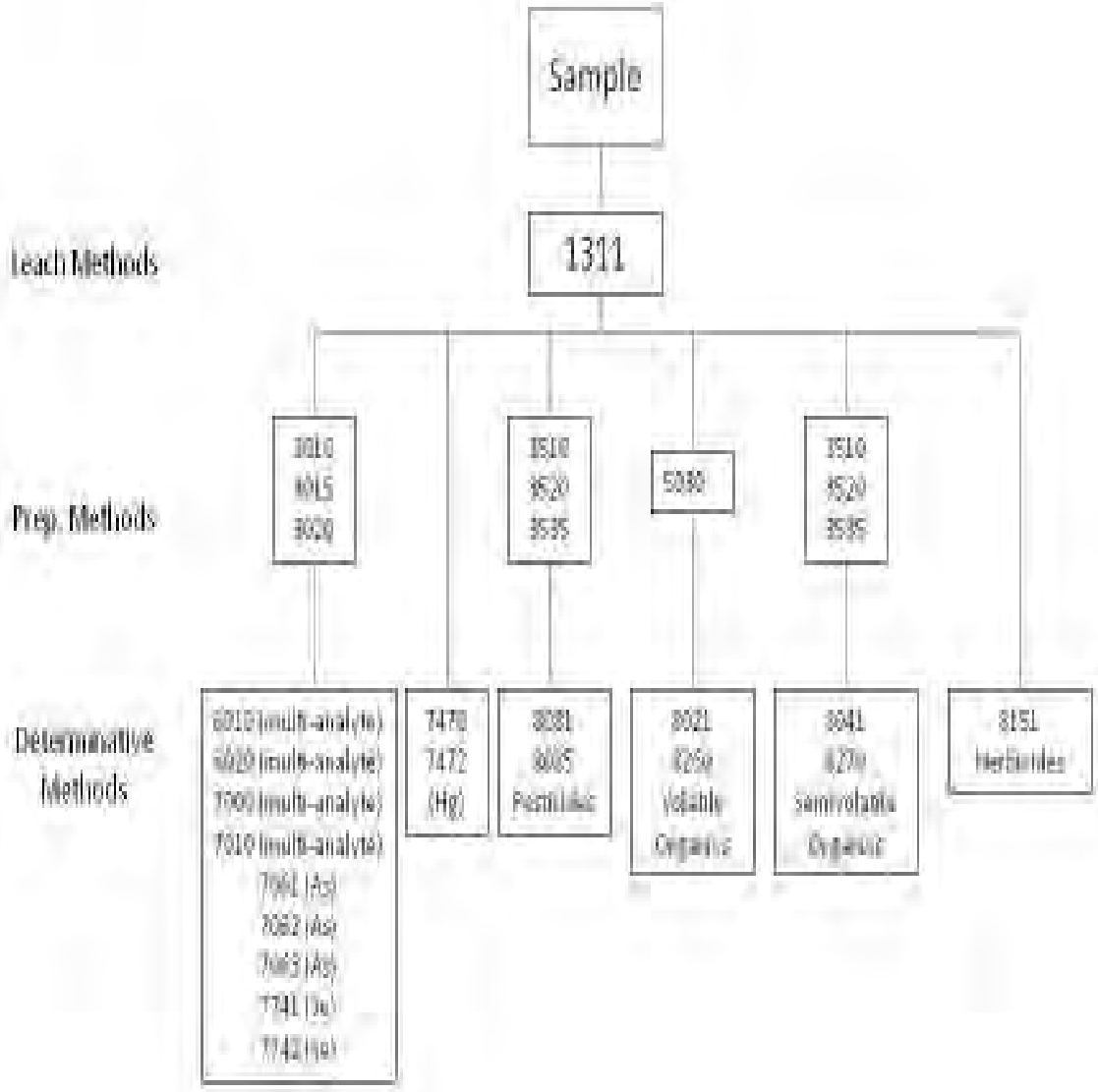


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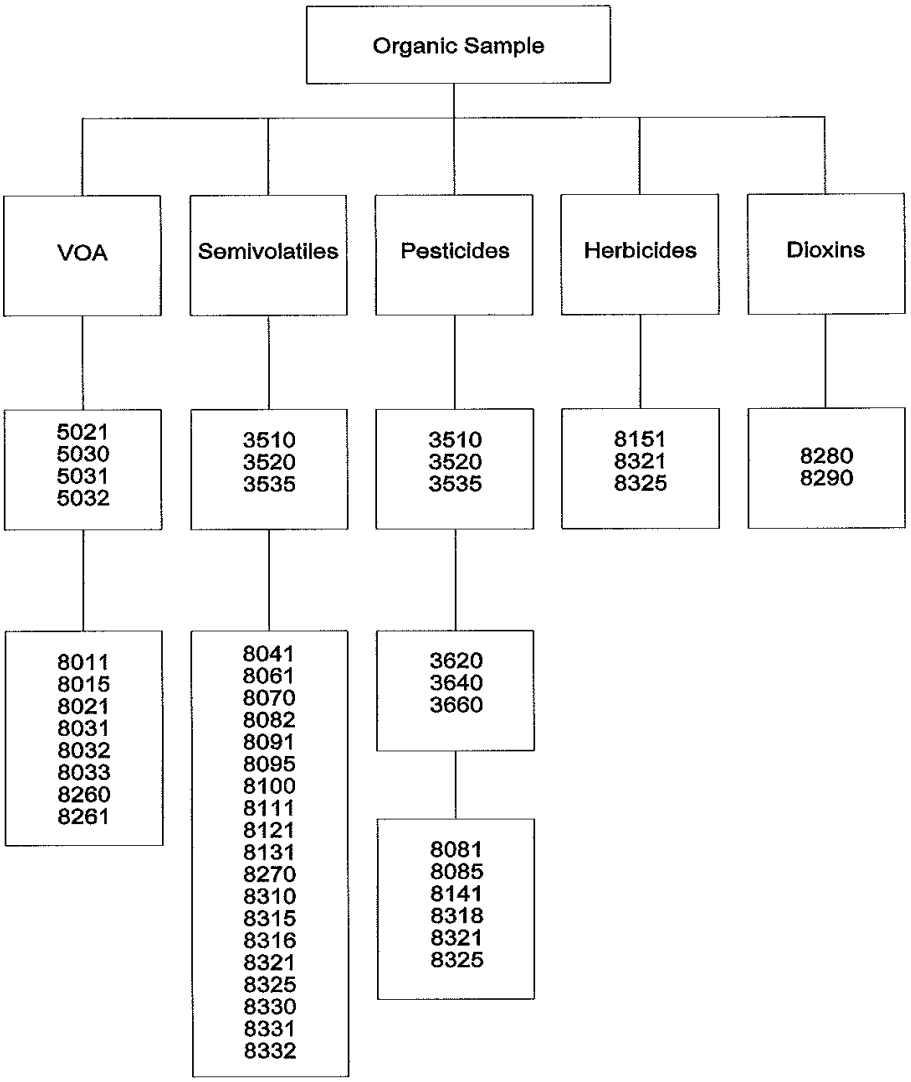
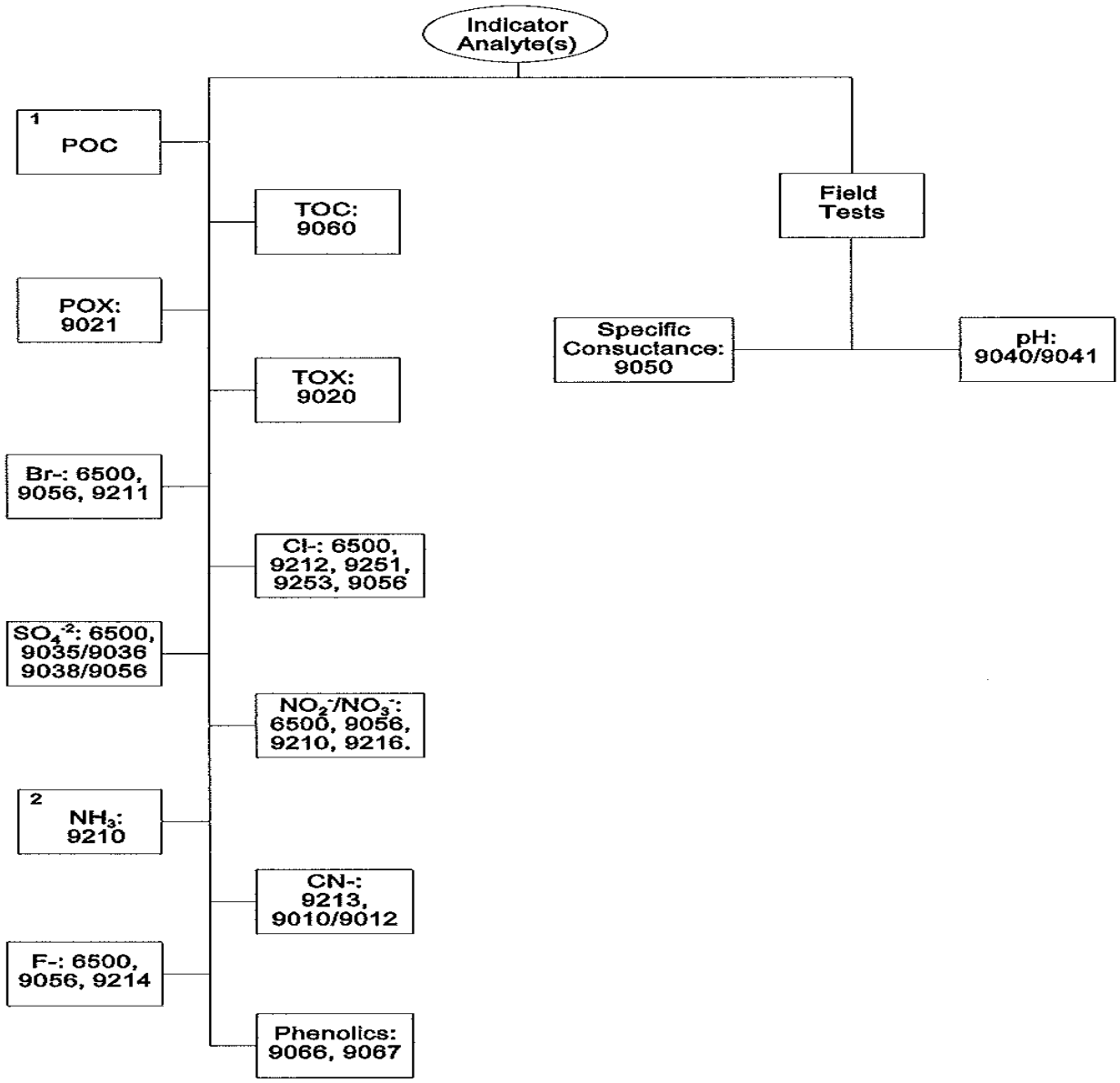
FIGURE 2-4A
GROUNDWATER ANALYSIS - ORGANIC ANALYTES



For illustrative purposes only.
See the disclaimer and Sec. 2.1 for information on the flexibility inherent in SW-846 methods.

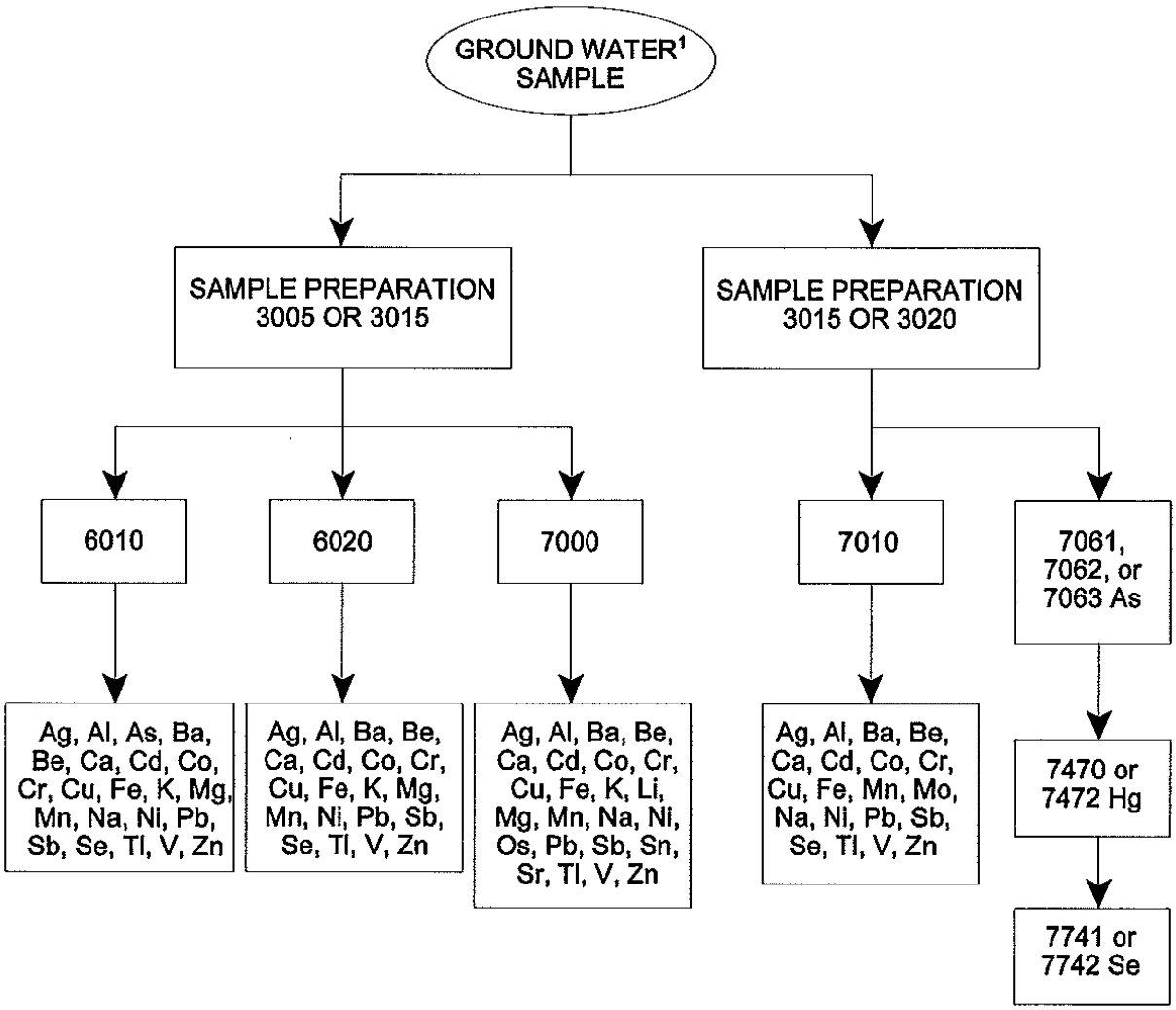
FIGURE 2-4B
GROUNDWATER ANALYSIS - INDICATOR ANALYTES



For illustrative purposes only. See the disclaimer and Sec. 2.1 regarding the flexibility inherent in SW-846 methods.

FIGURE 2-4C

GROUNDWATER ANALYSIS - INORGANIC ANALYTES



For illustrative purposes only. See the disclaimer and Sec. 2.1 regarding the flexibility inherent in SW-846 methods.

Appendix A: Summary of Updates/Changes in Chapter 2

1. Improved overall method formatting for consistency with new SW-846 methods style guidance. The entire document was reformatted in Microsoft Word.docx format from the original .WPD and .PDF files.
2. The revision number was changed to five and the published date to July 2014.
3. A Table of Contents was compiled and added to make finding information easier.
4. Minor editorial and grammatical changes (e.g., removing extra spaces between words, adding commas, etc.) were made throughout Sections 1.0 to 2.7. The disclaimer statement in Section 1.0 was numbered to keep the format consistent, as it started at Section 2.0 originally.
5. Graphics in the Figures Section were modified from Corel Drawing Objects V.10 to .jpg graphical images where needed to remove artifacts from the conversion process. The text titles of each figure was centered and formatted.
6. This appendix was added to document non-significant changes made during the editorial process.
7. Bis(2-chloroisopropyl) ether was corrected to Bis(2-chloro-1-methylethyl) ether in Tables 2-1, 2-4, 2-15, 2-22, and 2-34.
8. Revised Table 2-40A to reflect current sample preservation guidance for styrene and vinyl chloride in aqueous samples (i.e., deletion of previously recommended practice of collecting a second set of samples without acid preservatives and analyze immediately, if styrene and vinyl chloride are analytes of interest).
9. Revised Table 2-41.
10. Revised Table 2-45 to include Methods 1313 and 1316.
11. Added Table 2-46.
12. Added Figure(s) for new leaching procedure(s).
13. Revised Table 2-40B to include Mercury Speciation hold times in addition to totals.
14. All other tables were updated with the target compound list in the current published methods.